COMITÉ EUROPÉEN DE LA CHAUDRONNERIE ET DE LA TOLERIE

(EUROPEAN COMMITTEE FOR BOILERMAKING AND KINDRED STEEL STRUCTURES)

C. E. C. T.

RECOMMENDATIONS

FOR

THE DESIGN, MANUFACTURE AND ERECTION

OF STEEL PENSTOCKS OF WELDED CONSTRUCTION

FOR HYDRO ELECTRIC INSTALLATIONS

(prepared by the " Penstock " Section)

Édition, Janvier 1979.

These Recommendations have been drawn up by the Section V « Penstock Pipes » of the C.E.C.T. which groups the following National Trade Associations :

AUSTRIA	Fachverband der Maschinen - u.Stahl- u. Eisenbauindustrie Österreichs.
BELGIUM	Fabrimétal.
FRANCE	Syndicat National de la Chaudronnerie, de la Tôlerie et de la Tuyauterie Industrielle Syndicat des Constructeurs de Turbines Hydrauliques, Conduites Forcées et Vannes.
WESTERN GERMANY	Fachverband Dampfkessel-, Behälter- und Rohrleitungsbau.
ITALY	A.N.I.M.A. - Unione Costruttori di Caldareria.
NETHERLANDS	Vereniging van Nederlandse Fabrieken van Ketels, Drukhouders en Tanks.
PORTUGAL	Sorefame.
SPAIN	Sercometal.
SWITZERLAND	Société Suisse des Constructeurs de Machines.
UNITED KINGDOM	Water-Tube Boilermakers'Association, Tank and Industrial Plant Association, Association of Shell Boilermakers.

The Manufacturers will welcome any remarks or suggestions which may be submitted to C.E.C.T. Secretariat.

GENERAL TABLE OF CONTENTS

1980 Edition
This page annuls and replaces page 3 of the 1979 Edition.

RECOMMENDATIONS

Table of Contents

1 - GENERAL

1.1. - Purpose

The calculation, design and building of penstocks require very special knowledge and experience in the field of development of water schemes. The magnitude of the excavations, the lie of the land, the local conditions, the properties of the materials used, the manufacturing methods play a deciding part in the selection of the lay out and of the method of constructing the penstock. The client is sometimes at a loss to estimate the importance of each factor and to make a selection among all the technical solutions and tenders which are submitted to him. A summary of the points to be considered, when designing a penstock, must draw the client's and the manufacturer's attention to the extent of the tasks for which each is responsible.

The technical instructions set out hereafter are intended to be used as an outline in the drawing up by the client of the invitations to tenders for a hydroelectric project; furthermore, they will enable him, to a great extent, to judge and criticize the tenders received. These instructions are only recommendations and not strict requirements. The texte has been drawn up so that it does not hamper technological advances which is an advantage for the client and an incentive to the manufacturer.

1.2. - Scope

The general instructions apply to all types of penstocks and to their accessories, namely :

- exposed penstocks
- buried penstocks
- free penstocks laid in a tunnel
- lined shafts or tunnel, lining of surge chambers
- bifurcation pieces, distributors, manifolds
- accessories : anchors, supports, man holes, expansion joints . . .

These instructions do not apply to the sealing or regulating equipment installed on the penstocks.

2 - STUDIES AND PROJECTS

2.1. - Basic data

It is impossible to over-emphasize the advantages of a preliminary meeting between the client and the manufacturer. A part from the geological and topographical conditions, the technical considerations relative to the manufacture, transport and erection can play a decisive part in the choice of the economical solution.

The preparation of a project must be conducted according to the rules of the art and by taking the latest technical advances into account. The enquiry shall define the site and the type of penstock. Furthermore, the client shall give all the indications necessary for preparing the tender, in accordance with Annex I.

Should he deem it advisable, the manufacturer may submit to the client alternative proposals warranted and supported by his knowledge and experience in the field.

2.2. - Dimensioning of penstock sections

After establishing the basic data, the calculation of the various penstock sections and more particularly of the thicknesses will take the following points into account :

- external forces
- stresses resulting from the shape and the system
- permissible stress and/or design factors adopted.

3 - CLASSIFICATION AND DESIGN OF THE STRUCTURE

The main classification criteria are as follows :

- power or specific head
- location and type of the structure
- direct and indirect consequences of failure of the structure.

These criteria make it possible to define the class into which the construction is to be put (see Appendix 0).

3.1. - Power or specific head

The conventional definitions are :

- power PD^2 (proportional to the thrust against a head)
- Specific head PD (proportional to the circumferential load on the wall).

Units selected

P calculation pressure in meters of water column (m.w.c.)

D internal diameter in meters.

3.2. - Location and type

Location means the topography of the sites, and the type of the structure means the method of installation above the ground, buried, or braced against the rock, etc . . .

3.3. - Consequences of failure

The consequences of failure imply certain loss of human life, damage to heavy plant, to urban installations or to the structure itself, as well as stoppage of operation.

3.4. - Design factors

Factor of safety is defined as the ratio of the yield point of the steel used to the stress calculated according to the requirements of the Annex II. In some cases, the manufacturer will be permitted to make a case for a factor in relation to the ultimate tensile strength of the material.

As regards external pressures, the factor is calculated as for internal pressures, and in the case of buckling, it is equal to the ratio of the maximum external pressure to the critical pressure calculated.

4 - MATERIALS

The choice of steels for plates and fittings and of the filler materials for welding is determined by the following factors :

- characteristics of the structure and stresses to which it is subjected
- characteristics of the materials
- conditions of fabrication.

These data are detailed in Annexes II - III - IV.

5 - MANUFACTURE, TESTS AND INSPECTION

5.1. - Manufacturing processes

The type of penstock being stated by the manufacturer, he shall fix the manufacturing and inspection specifications.

5.2. - Tests and Inspection

All the tests and inspections aim at assuring the final quality of the installation to be carried out.

They include :

- inspection of plates and other materials before fabrication as specified in Annex III
- inspection of the materials for welding purposes in accordance with the requirements of Annex IV
- inspection of the supplies detailed in Annexes IV and V.

The extent of inspection depends upon the size of the section of penstock as regards its mode of loading and the value of the stresses. Special instructions shall be laid down in each particular case.

The results of the inspections shall be recorded in a report. If the characteristics comply with the requirements, the report can be considered as an acceptance certificate.

5.3. - Relationship between the weight and the price adjustment clauses

The weight tolerance depends upon the plus or minus tolerances of the products used and on the accurary of manufacture : the theoretical weight calculated from the approved shop drawings is accepted as the reference weight.

The price adjustment clauses with respect to this tolerance on this reference weight as well as to the difference between the weight estimated at the time of submitting the tender and the reference weight are specifically detailed in the commercial clauses of the Contract.

6 - TRANSPORT AND ERECTION

6.1. - General

Problems of transport and erection must necessarily be studied in conjunction with the design problems, whether technical or economical.

The erection operations are only the continuation of the shop work under more difficult conditions. Though the facilities and the working conditions are less favourable than in the workshop, the quality of the work must comply with the same requirements.

First of all, for such works, the safety of staff and equipment must be secured. The client and the manufacturer are responsible for taking all necessary steps in this connection. Special attention shall be paid to staff welfare, to housing and subsistence questions and to social and health services.

Sound and reliable work implies the employment of skilled staff and the provision of adequate installations, tools and auxiliary equipment.

6.2. - Transport

The client and the manufacturer agree, by common consent, upon the problem of the transport of penstock sections from the workshop to the site, whether this transport is by rail, by ship or by road. An adequate area must be arranged at the Site for storing the various parts; it will be provided with the necessary lifting apparatus and means of transport. The pipes will be laid by suitable safe means of transport (funicular or telpher). The transport equipment may be used for the Civil Engineering work, but the manufacturer must be given the priority during erection working hours.

6.3. - Erection

The erection proper includes first the laying down of the penstock sections, then their assembly by welding. The welds are mainly carried out by hand; in some cases, other processes can be used. The staff responsible for this work must be highly qualified.

All the Civil Engineering work (emplacement, earthwork, excavations etc . . .) carried out along the lay out, in tunnels or in shafts, and all that carried out at the time of erection (foundations, pedestal supports, anchor blocks, concreting works, grouting etc . . .) are not, as a general rule, included in the manufacturer's service. The manufacturer will only indicate the values of the forces acting on the anchor blocks and supports.

The choice of a rational erection procedure as well as the extent of the material involved depend upon the details of the penstock and upon the local site conditions.

6.4. - Tests and Inspection

The erection works, and more particularly the welds, are subjected to inspections similar to those carried out in the workshop and detailed in Annex IV.

Accessibility of the ground and the tunnels determines the process to be employed which will take into account the restricted possibilities of the erection.

The extent of inspection depends upon the characteristics of the structure and of the design factor; it will be defined in Tender Specifications. The results must comply with the requirements and are to be recorded in a report.

6.5. - Acceptance of the penstock

On completion of erection, the hydraulic pressure test and a final inspection take place, which makes it possible to have the provisional acceptance pronounced by the client. This acceptance will be the subject of a report signed by both parties. The agreed guarantee period starts from this date or, in case this test cannot take place at the proper time, from a date fixed previously with regard to the completion of erection. The client then takes responsibility for making use of the penstock. At the end of the guarantee period and if the penstock has proved satisfactory, the final acceptance will take place and will be the subject of a report.

7 - PROTECTION OF SURFACES

There are many kinds of anti-corrosive processes and products.

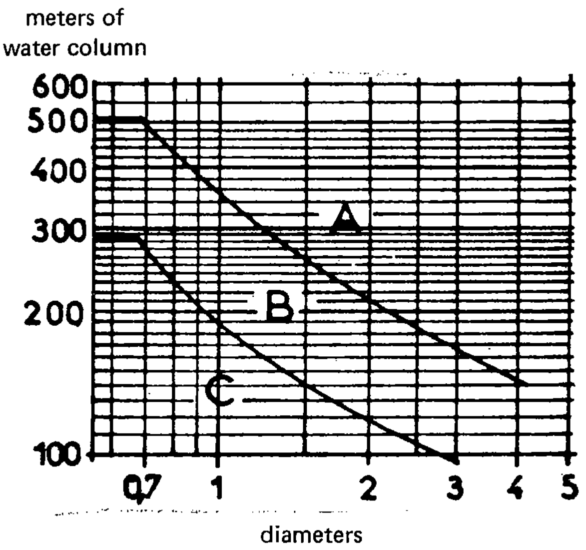
The carrying out of the protection depends more especially upon the erection conditions.

The selection of the protection process depends upon many factors which are described in Annex V.

APPENDIX 0

Classification of the structures according to their capacity or their specific head

As a general rule, the penstocks can be divided into three classes A, B, C according to the curves applicable to straight and smooth pipes (without stiffeners) as shown on the opposite drawing.



The classification is carried out according to the diameter expressed in meters and the design head expressed in meters of water column (m.w.c.)

The inspection classes I, II, III as mentioned in Annexures III and IV to the « Recommendations » are assigned to the penstock classes A, B, C according to the following table:

	A	B	C
1) Items whose failure leads to the distribution of the work as per Para. 3.3 of Annexure II			
Pipes, bends, flanges, inspection holes	I	II	III
Bifurcations, branches, watertight doors	I	I	–
External stiffeners other than hoops	II	III	III
Pipe-sections for connection with valves, gates and turbines	I	I	I
Items subjected to high bi-or triaxial stresses that are not easy to evaluate	I	I	–
Low pressure tunnels and surge tanks	–	II or III	II or III
2) Items whose failure does not lead to the destruction of the work			
Gussets, associated structures, ventilating-holes (air-vents)	III	III	III

ANNEX I

DATA AND BASIC DOCUMENTS

The preparation by the manufacturer of a complete proposal including possibly the erection of the penstock, requires the whole or part of the following data which the client can attach to any enquiry. For any special case, the client may have to choose, with the manufacturer's advice, among the data listed, those which are useful to the project under consideration.

Table of Contents

1 - GENERAL INDICATIONS

1.1. - Scheme

1 - Client's name

2 - Address of the head office

3 - Address of the Site

4 - Name of the nearest town
Distance from the Site to this town in kilometres

5 - Name of the development scheme

6 - Name of the stream or river to be harnessed

7 - Name of the lake to be harnessed

1.2. - Location (to be detailed, if necessary, by penstock lengths)

1 - Latitude and longitude

2 - Upstream and downstream height of the penstock

3 - Orientation of the penstock - Exposure

4 - Number of hours of sun

	Winter	Summer
Area I		
Area II		
Area III		

1.3. - Climatic and geological information (to be detailed, if required, by penstock lengths)

1 - Wind conditions
General direction
Maximum speed

2 - Snow conditions
Average depth
Period during which there is snow at the Site : from .... to ....

3 - Various remarks
Rock falls
Avalanches
Earthquakes

- nature
- intensity
- direction

4 - External temperatures

By day (*)	In Summer	Maximum temperature in the sun ....
		Mean ....
		In the shade ....
	In Winter	Maximum temperature in the sun ....
		Mean ....
		In the shade ....
By night		Normal minimum temperatures
		Abnormal minimum temperatures

5 - Geological details

- Nature of the ground
- Schistosity and important cleavage planes
- Bedding, orientation and dip of the seams
- Orientation of thalwegs and of rocky spurs
- Cultivated and wooded areas etc . . .
- Risks of land-slide

6 - Various information to be given (gauges and structures)

- Across the area of the Site
- Across railway tracks
- Across streams or canals

1.4. - Characteristics of water

1 - Characteristics of the water flowing in the penstock

- Chemical Composition
- Density
- PH
- Bacteriological details
- Minimum, maximum, mean temperature

2 - Characteristics of surface waters

As much information as possible must be given in this connection.

2 - DATA FOR DESIGN AND MANUFACTURING STUDIES

2.1. - Details of the location

1 - General drawing of the installation

2 - Complete longitudinal profile : possibly to be decided with the manufacturer if several solutions are feasible.

The several types of penstocks which are considered at the beginning of the project are to be detailed on this drawing:

- exposed penstock or free penstock laid in a tunnel
- buried penstock
- penstock laid in a tunnel supported from the rock
- lined shaft and tunnel
- steel lining of the surge chamber.

(*) a) If a similar penstock is in operation :
- maximum and minimum temperature of the empty penstock
- operating temperature
- temperature of still water (off load with filled penstock)

b) To estimate the maximum temperature of the empty penstock in the sun, it is necessary to know the temperature of a 1 sq.m plate (10 to 12 mm thick) exposed to full sun from ten a.m. to one p.m., sheltered from air currents. This test must be carried out on a bare plate and on another one having, if possible, the same lining as that provided on the penstock.

2.2. - Additional details concerning the Civil Engineering (to be detailed, if required, by penstock section)

1 - Above ground penstock

1. Quality and bearing capacity of the ground utilized: hardness - permeability - load bearing capacity
2. Permissible loads for supports and anchor blocks
3. Results of the borings and excavations carried out
4. Results of the soil tests (load tests, tests by seismic processes etc . . .)

2 - Buried penstocks

3 - Steel tunnel linings

1. Quality and strength of the rock
2. Modulus of elasticity
3. Faults and strata encountered
4. Covering thickness
5. Permeability
6. Pressures of possible infiltrations
7. Contemplated concreting process
8. Known data regarding the characteristics of the grouting, grouting holes and distribution of same
   - Grouting to consolidate the ground
   - Grouting for filling between the penstock and the rock
   - Grouting for bonding together the penstock and the concrete.

2.3. - Technical Data

1 - Data regarding the penstock ends

a) Upstream connection
- connection to the conduction tunnel or to the water intake
- surge tower (position - size)
- intake or sectional gates

b) Downstream connection
- connection of the penstock to the manifold and to the protecting or connecting apparatus of turbines or pumps
- type and arrangment of the turbines and of the connecting flanges
- setting of the turbine shafts (elevations and altitudes)
- type of manifold (free, concreted or buried); anchoring possibility, building joints
- reactive force of gates, turbines or pumps if they affect the connecting-up of the penstock.

2 - Hydraulic data

a) Main characteristics
- Maximum and minimum turbine flow
- Normal and exceptional overpressure due to water hammer effects at both ends of the penstock
- Maximum rise in the surge tower

(Il the last two points above 2 and 3 are not defined, the data given in paragraph b) are absolutely necessary for designing the penstock).

b) Characteristics used as a basis for the determination of the surge tower and the overpressures due to water hammer
- Maximum and minimum turbine flow
- Length of the various tunnel sections, size of intermediate reservoirs or basins
- Characteristics of the tunnel sections and head losses
- Characteristics of the surge tower
- Elevations of the maximum and minimum reserves
- Number and type of turbines and pumps installed in the power-station with description of their main characteristics
- Closing devices provided: closing time and if possible, closing diagram
- Operating conditions of the work: alternation of filling and emptying - Working schedule
- Other requirements imposed by regulation.

3 - Data required for calculating economical diameters of penstocks

a) Maximum head loss for a given flow rate.

b) Capitalized cost per meter head lost

c) Parameters determining the cost per meter head lost (these data are absolutely necessary if the cost has not been previously determined)
- Efficiency of the installation: ratio of the power at the Plant outlet terminals to the power available at the inlet of the turbines
- Cost of the kw/hour - p = ... at the Plant outlet terminals
- Capitalization index - c = ... (that is to say the reciprocal of the rate of interest)
- Table of operating factors :

Number of hours annually during which the installation is used at power Po

Po being the nominal power corresponding to the nominal flow rate Qo, with Qo in cu.meters.

from	Number of hours per year
0 to 0,05	
0,05 to 0,15	
0,15 to 0,25	
0,25 to 0,35	
0,35 to 0,45	
0,45 to 0,55	
0,55 to 0,65	
0,65 to 0,75	
0,75 to 0,85	
0,85 to 0,95	
0,95 to 1	
	8 760 hours

d) Additionally, if necessary:
- cost per cubic meter of tunnel excavation
- cost per cubic meter of filling concrete lining.

4 - Additional information on all the numerical data regarding the following details of the present annex:
- Number of hours of sun (1.2.4)
- Wind conditions (1.3.1)
- Snow conditions (1.3.2)
- Various remarks: rock falls, avalanches, earthquakes (1.3.3)
- External temperatures (1.3.4)
- Characteristics of the water flowing in the penstocks (1.4.1).

3 - SPECIAL DATA ON TRANSPORT AND ERECTION

3.1. - Data concerning more especially the transport

1 - Nearest railway station or harbour.

2 - Distance for transport by road from the above railway station or harbour to the site.

3 - Road, track or way leading to the site.
In case the penstock profile is crossed by carriage roads, the time when they can be used shall be specified.

4 - Existing telphers and funiculars - give full particulars.

5 - Are there in-situ handling or unloading equipment with hoisting apparatus ?
- Size: permissible maximum loads, available heights and widths
- Power
- Area served by the hoisting apparatus.

6 - Possibilities of transit for heavy and bulky parts
- Rail-gauge
- Permissible maximum loads on waggon
- Length of waggons

- Handling facilities available in railway stations, features and size of handling equipment
- If a telpher exists, what is its maximum load, speed and the loading gauge at the pylons ?
- In the case of a funicular, the capacity of the hoist must be specified. The track (width and weight of rails per meter) should be designed for, the maximum weight of the parts to be carried.
- Maximum load on bridges on roads
- All the special places where the roads can be blocked by the traffic shall be specified
  narrow roads through villages
  curves for passage of trailers
  tunnels, cuttings and other special places
- Passage under electric or telephone lines shall be provided for.

3.2. - Data concerning more especially erection

1 - Erection season (Summer or Winter)

2 - Time available for erection

3 - Preparatory works on lay out

4 - a) Planning for the Civil Engineering works: all the Civil Engineering work for the first stage of anchor blocks and supporting masonry must normally be finished before erection, and at the second stage it will proceed in step with the erection as soon as the sections are aligned and finally welded in position.
   b) Delivery schedule for the head and foot valves and for all parts to be secured to the penstock.

5 - Storage area and premises
   a) Area available
   b) Premises available for stores and offices
   c) General workshops which can be used, including machine tolls, carpenter's shop, forges etc . . . (the features of the main machines shall be given, if possible)
   d) In case of large diameter pipes delivered in strakes, is the installation of a site workshop and the supply of automatic or semi-automatic welding machines to be provided for.

6 - Client's or manufacturer's services regarding the following materials and supplies :
   a) Handling equipment
   b) Hoists for ramps or telphers
   c) Telpher
   d) Tracks of ramps
   e) Welding machines and electrodes
   f) Power required for the erection works
   g) The following services are usually supplied by the client :
      - The execution of the earthwork for the foundation of the ramp and all the Civil Engineering works concerning the erection installations: blocks for anchoring of hoists and other lifting gears, earthwork for the construction of quarters, general preparation of the land and access ways etc . . .
      - The supply of timber for chocking and scaffolding purposes
      - The supply of perishable and consumable goods: oil, grease, petrol, oils, fuel oil, acetylene, oxygen, rags, etc . . .
      - The supply of compressed air along the lay-out of the installation at the pressure of some 70 N/sq.cm at points marked by the manufacturer. The power shall be stated in the Tender.
      - The supply of electric current at all points of the installation indicated by the manufacturer who shall mention the power, the voltage and the frequency.
      - On the completion of the erection works, the adequate supply of water to ensure the filling and the possible hydraulic test of the penstock within 24 hours'time at most. It must be possible to use this water by gravity.

7 - Client's or manufacturer's services regarding labour
   a) Specialized staff
   b) Labourers
   c) Drivers
   d) Supervisor, site and team foremen

e) Local skilled labour: its kind, specialities, grade of qualification, more especially for the welders.

f) Transport charges for staff and material from workshop to site and vice versa.

g) Food and lodging for staff: canteens, dining-rooms, co-operative stores, towns in the neighbourhood.

h) Indications about the cost of living, fiscal taxes and all kinds of duties. If possible, official schedule of salaries and indications of the actual local rates (bonuses, various allowances, etc ...)

i) Means of transport between quarters and side - existing telphers and funiculars available for the staff.

j) Social organization
- health service
- drinking water.

8 - Special questions

a) Provision of the laboratory equipment to the staff for welding inspection.

b) In case of hydraulic test, details on the heads to be provided, on their location and possibly on the tightness of the foot valves.
Provision and operation of the test pump.

c) Shop painting to be provided for
Painting during or after erection
Nature of internal protection
Nature of external protection (special factors of corrosion and recommended tints).

A N N E X I I

CALCULATION DATA FOR PENSTOCKS

Technical Supplement

The preparation of a complete proposal by the manufacturer and the evaluation by the client of the different proposals require the statement of the permissible stress and/ or the design factors adopted.

The statement of a design factor or of the permissible stress is of value only when the forces or stresses considered, the bases and computation methods adopted are specified.

Table of Contents

1 - SAFETY

Safety is a precaution against the risk of failure of the structure.

The conventional notion of design factor to express the safety of the structure namely the ratio of the stress causing failure of the structure to an operating stress must be enlarged upon.

If all the causes and the relationships between cause and effect were fully known, the materials could be used to the ultimate possible limit, which is assumed to be well known. Now, this is not the case, due to some uncertainties or ignorance relating to:

- loads: some of these loads are known with almost absolute accuracy, for instance the pressure due to a static height; other loads are numerically approximated, for example an overpressure; others must be considered as accidental or random e.g. a fall of stones or a landslide
- the material and its mechanical characteristics
- the actual geometry of the manufactured product and the consequence of the various workshop processes undergone to obtain the finished product
- the calculation methods.

All these uncertainties compel the adoption of an allowance by increasing the relation between the stress liable to cause the failure of the structure and the permissible maximum stress in operation, which leads to the notion of a safety factor.

As the uncertainties which make it necessary are diminished, so this allowance can be reduced in proportion.

1) By considering the various loads: permanent, intermittent, exceptional.
2) By inspection of the materials and by guaranteeing that they are perfectly suitable for their intended use.
3) By the conditions governing the working of the materials, the welding methods, the heat treatment, and the manufacturing controls.
4) By appropriate design methods or the evaluation of the overall working conditions of the material under multi-axial stress.
5) By previous experience, by model tests or by tests carried out on the construction itself.

2 - NATURE OF LOADING

The determination of the stress condition in each calculation is made by taking into consideration the total effect of the forces of which the most important are :

- the pressure
- the weight
- the temperature.

Moreover, it is necessary to take into account deformations which can introduce stresses due to Poisson's effect.

This determination of the stress condition is carried out by taking into consideration at every point studied, the most unfavourable stresses due to the forces mentioned below.

2.1. - Permanent Loads

The loads of permanent nature are the forces which act upon the penstock in normal operation :

- the maximum operating pressure which includes the maximum static pressure increased by the overpressure due to water hammer arising from the sudden flow variations resulting from a normal closing or opening,

taking into account the oscillations in the surge tower (*)
- the actual weight of the penstock and that of the water
- the spacing and type of supports used
- the anchors
- the difference between the temperatures which can exist in the penstock in normal operation and the temperature existing when coupling up the sections during erection
- the effect of the rock in case of concrete lined tunnel penstock.

In each special case, all the other causes of forces of permanent nature must be also taken into account (sliding joint, friction at the supports, overload by backfill . . .).

2.2. - Intermittent loads

The loads of intermittent nature are all the forces which, though not exceptional, do not often arise :

Penstock during filling, or emptying or empty penstock when the upper penstock valve is closed under normal flow conditions (the penstock can be fitted with a ventiduct or an air vent).

The penstock shall therefore be, calculated in two main cases :
- penstock during filling or emptying
- empty penstock under partial vacuum

by taking into account, in each case,
- the weight of the penstock and that of the water
- the type and spacing between the supports
- the anchors
- possibly the overloads due to wind or snow and to the backfill
- the difference between the temperatures which may occur in the penstock and the temperature existing when coupling up the sections during erection
- the effect of the rock in case of concrete lined tunnel penstock
- the constant external pressures
- the causes of any other nature which can arise in each particular case (sliding joint, friction at the supports etc . . .).

2.3. - Exceptional loads

The loads of exceptional nature can act upon the penstock in very rare cases: they can be combined with the normal stresses (weight of the penstock and of the water, etc . . .)

1 - Shop or site test

2 - Erection, concreting or grouting at the time of erection

3 - Bad operation of the safety devices, for instance blocked ventiduct which would create vacuum inside an emptying penstock (taking possibly the external pressures into account). The value of the maximum theoretical depression usually accepted in an atmosphere or, for convenience's sake, 10 N/Sq.cm.

4 - Unforeseen operation of regulating equipment or turbine or pump distributors which can produce instantaneous changes in the flow rate resulting in an accidental water hammer. In case of instantaneous shutting off of the flow, unless specially required by the client, the overpressure due to the sudden closing of a single feed valve is to be considered : this overpressure is then evenly applied above the maximum static level.

5 - Possibly, earthquake effects.

3 - STRESSES TO BE CONSIDERED

As a general rule, the stresses can be divided into :

1) Primary stresses

The primary stresses are those which are necessary for balancing the imposed loads.

The resulting diformation increase with the loads even after the yield point of the materials used is exceeded.

(*) : See appendix II A

2) Secondary stresses

The secondary stresses are local stresses which, as they are not necessary for balancing the loads, stop increasing with the forces when they reach the elastic limit of the material used.

Except in bifurcation pieces, as the radial and shearing stresses are usually small, the stress condition becomes a plane condition defined by the circumferential and longitudinal stresses.

The stresses encountered are listed hereunder :

3.1. - Circumferential stresses

1 - Primary circumferential stresses

- stresses due to the internal or external pressure in the bare pipe-section, the possible hoops and the stiffening rings
- stress in the pipe-section due to the internal or external pressures caused by the reinforcements
- stress due to ovalization at the supports for penstocks and concreted linings
- stress due to the internal pressure, taking the initial clearance between plate and concrete and the resistance of the rock into consideration.

2 - Secondary circumferential stresses

- local stresses in the vicinity of nozzles, reinforced openings etc . . .
- stress due to Poinsson's effect of local bending caused by the pressure and the longitudinal forces arising from stiffener rings
- stress due to ovalization on filling.

3.2. - Longitudinal stresses

1 - Primary longitudinal stresses

- stress due to Poisson's effect of the circumferential pressure stresses
- stress due to the thermal effects (*)
- longitudinal bending stress between supports
- stress due to the head effect
- bending stress due to the elbows or branches
- stress due to friction at the supports
- stress due to the weight of the pipes themselves according to the gradient of the installation
- possibly, stress due to pressure and to gripping at the rings of the sliding joints.

2 - Secondary longitudinal stresses

- stress due to local bending caused by the pressure and the longitudinal forces stiffener rings and possible hoops
- local stresses in the vicinity of the nozzles, reinforced openings etc . . .

4 - EVALUATION OF WORKING CONDITIONS

Stress criterion

For the primary stresses at least, all the calculations are made in the elastic range.

For each point considered, the stress conditions must be defined by the value of the equivalent stress determined (for instance) by HENCKY-VON MISES's criterion

$$\sigma_{eq} = \sqrt{\frac{1}{2}(\sigma_1 - \sigma_2)^2 + \frac{1}{2}(\sigma_2 - \sigma_3)^2 + \frac{1}{2}(\sigma_3 - \sigma_1)^2}$$

5 - PERMISSIBLE STRESSES

These must be laid down by taking into consideration the data listed in Chapter 1 and more particularly :

(*) See Appendix II B

1) the material
2) the nature of the load (permanent, intermittent, exceptional)
3) the stresses considered (only the primary ones or the primary and the secondary ones together)
4) the stress criterion.

For example, the permissible stress will be higher for non-permanent loads or when the secondary stresses are taken into account.

When estimating the permissible stress, one must take into account the actual properties of the material defined in Annex III of the Recommendations and more particularly its ability to undergo plastic adaptation without risk of failure of the structure.

Under the effect of secondary stresses, a certain elongation beyond the elastic limit may be permitted in so far as it is consistent with the conditions under which the part is used and taking into account possible changes that it could cause in the properties of the materials.

6 - STABILITY OF THE STRUCTURE

In addition to the determination of the stresses, it is advisable to consider the stability of the structures, taking into account, as may be necessary, the following points :

- installation method : free penstock out of ground or in tunnel, penstock in concreted lining, penstock in backfilled trench etc . . .
- axial force due to the weigh of the filled or empty penstock, according to the slope of the installation
- effect of the contraction due to Poisson's effect
- thermal effect (expansion or contraction)
- hydrostatic thrust on the heads, elbows or on the converging and divergent sections
- possible dynamic effect due to the elbows
- friction forces at sliding or rolling supports and at expansion joints
- pressure on the rings of the sliding joints
- possible effect of earth tremors, of the transverse force due to wind, of accidental overloads.

There shall be considered one after the other :

6.1. - Buckling of the walls

- resistance to buckling of bare pipe-sections
- resistance to buckling of pipe-sections provided with stiffener rings (stability of wall between stiffeners and stability of stiffeners).

6.2. - Elastic stability

- resistance to longitudinal buckling of the free penstock
- location of anchor blocks and supports.

6.3. - Anchor blocks and supports

The manufacturer usually supplies the connections of the penstock to anchor blocks and supports.

Furthermore, he must state the forces acting on the anchor blocks and on the supports; the client, knowing them, can determine their importance and arrange for them to be taken by the soil in accordance with its bearing capacity.

7 - THICKNESS ALLOWANCE FOR CORROSION

APPENDIX II A

Static pressure and overpressure

Static Pressure

The static pressure is the difference in level between the maximum static level and that of the point considered, without taking into account the maximum rise in the surge chamber.

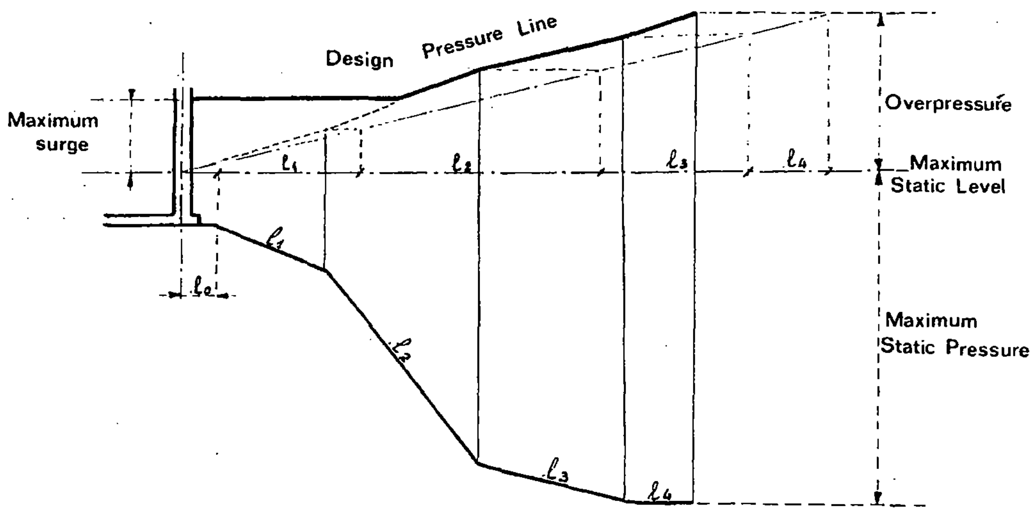
Overpressure

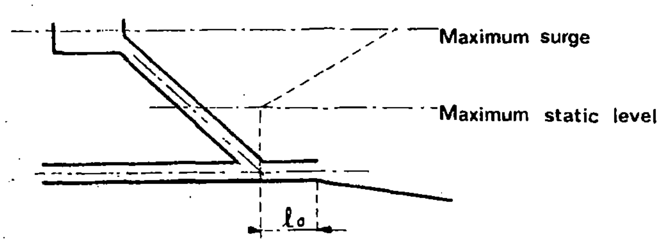
Unless otherwise especially required by the client, the overpressure due to the simultaneous closing of the emergency gears for turbines, in a given time, is considered as being linearly distributed along the developed lenght of the penstock, between the connecting point of the surge tower or in its absence the water intake and the nearest downstream closing gear.

Distribution line of the maximum pressure in normal operation (see sketch . . .).

The distribution line of the maximum pressure in normal operation (design pressure) is therefore the highest of the two following lines at each of the points considered :

— inclined straight line linearly distributed over the developed length of the penstock between a static level point plumb with the nozzle of the surge chamber on the pressure tunnel or, should there exist no surge chamber, with the water intake — and the closing device of the nearest downstream machine .
The case of a bottom necked surge chamber is to be specially considered with regard to the over-and underpressures that may occur below the neck.
Horizontal straight line drawn at the maximum uprise of the surge tank.





1984 Édition
This page annuls and replaces page 22 of the 1979 Édition.

APPENDIX II B

1 - THERMAL EFFECTS

If there is no sliding joint the maximum variations in temperature are determined in relation to the temperature prevailing at the time of connecting up the sections or clamping of the penstock.

Variations in temperature between the different points of the same section are not usually taken into consideration (upper or lower generatrix, for example).

Unless otherwise specified by the client, the variation in temperature justifying the safety factor shall be ± 10° C for the filled and empty concreted or buried penstocks and ± 30° C for the empty out of ground penstocks in relation to the temperature prevailing at the time of connecting up the sections.

2 - FRICTION AND ROLLING FACTORS AT SUPPORTS – FRICTION FACTOR AT SLIDING JOINTS

In the absence of particular specification by the client or relevant documents from the manufacturer, the following values are assumed :

- lubricated sliding supports	f = 0,3
- non-lubricated sliding supports	f = 0,4
- rolling supports	f = 0,15
- rocker supports	f = 0,1
- sliding joints	f = 0,3

Joint tightening pressure
Ps = twice the maximum pressure

APPENDIX II C

HEAD LOSSES

When the head loss is the subject of a special study, the manufacturer shall state the formulae applied in the relevant documents and for special parts, the results from model tests or previous experience.

It is advisable to mention the factors taken into account as regards the roughness of the walls or of the internal protection of the penstock.

APPENDIX II D

Dimensioning factors

1 - DEFINITION

A dimensioning factor is defined either as the ratio of a reference stress - in general Re - to the actual stress or as the ratio of a reference pressure ti the actual pressure to which the structure is subjected :

$$C' = Re / \sigma_{éq} \qquad C'' = P_{crit} / P_{design}$$

Table 1 below gives the dimensioning factors C that are applicable under the following conditions :

2 - FACTORS OF C′ AND C″ TYPES

2.1. - The C′ and C″ types are minimum factors that are applicable when all the working conditions of the section of the work under consideration have been carefully estimated (See Para. 1 of Annexure II) and the tolerances as per Annexures IV and V have been adhered to in compliance with Paragraphs 7 and 8.3.1 of Appendix E of Annexure II.

2.2. - Such factors apply to the three classes of work.

2.3. - The factors of columns 5, 6, 7 and 11 take any corrosion allowance into account. This allowance is not considered in the other columns.

3 - FACTORS OF C′ TYPE

3.1. - The C′ type factors apply to the equivalent stresses calculated with the primary stresses using the formula as indicated in Paragraph 4 of Annexure II.

3.2. - The reference stress is the apparent elastic limit guaranteed for the material and not its effective value.

3.3. - If both the primary and secondary stresses due to exceptional forces are considered, the equivalent stress shall generally be lower than the guaranteed elastic limit of the steel.

4 - FACTORS OF C″ TYPE

4.1. - The C″ type factors apply to the external overpressure on the penstock (atmospheric pressure for empty exposed penstock - overpressure in a power shaft).

4.2. - The reference pressure is the critical pressure that induces the failure of the structure due to instability or subsidence.

TABLE 1
Indicative table of minimum dimensioning factors C

Loading case : (as per para. 2 of Annexure II)	Permanent forces		Intermittent forces		Exceptional or accidental forces						
Factors C′ : σ perm. $= \frac{Re}{C'}$ Factors C″ : p critical $=$ C″. p max.	1 Cylindrical pipes	2 Distributors or special parts	3 Filling or Emptying	4 External overpressure (a)	5 Pressure Test after erection	6 Concreting (b)	7 Grouting (b)	8 Waterhammer effect due to a « sudden » cut-off of the flow	9 Penstock subjected to absolute vacuum (a)	10 Seisms	11 Shop tests Transport
Penstock condition	full	full	half-full section	P int. <P ext	full	empty	empty	full	total vacuum	full	full
Types of factors / Types of work	′	′	′	″	′	′	″	′	″	′	′
a : Exposed or free in tunnel	1.7	2	1.5	–	1.3	–	–	1.2	1.6	1.2	1.2
b : Buried	1.7	2	1.5	–	1.3	–	–	1.2	1.6	1.2	1.2
c : Buried and concreted	1.5	1.8	1.3	1.6	1.3	1.5	2	1.2	–	1.2	1.2
d : In concreted tunnel without collaboration of the rock	1.5	1.8	1.3	1.6	1.3	1.5	2	1	–	1	1.2
In concreted tunnel with collaboration of the rock — e : steel lining only considered	1.1	1.5	1	1.6	1	1.5	2	–	–	–	–
In concreted tunnel with collaboration of the rock — f : plate + concrete + rock assembly	2	2.5	–	1.6	1.8	–	2	–	–	–	–

(a) Such factors are to be used with the formulas indicated in Paragraphs 7 and 8 of Appendix II E
(b) Temporary reinforcements may be necessary to adhere to such factors

APPENDIX II E

STABILITY
OF EXPOSED PENSTOCKS AND CIRCULAR STEEL LINERS SUBJECTED TO A UNIFORM EXTERNAL PRESSURE

The external pressure is in most cases a determining factor for the dimensioning of an exposed penstock or of a tunnel steel liner or of a pressure shaft.

This supplement presents some important comments regarding the design and execution of such structures and the calculation bases for the checking of the stability of the work.

CONTENTS

1. DEFINITIONS AND SYMBOLS USED

1.1. General Definitions

External pressure Δp_e	Difference between the pressures simultaneously applied on the outside and inside surfaces of a pipe when $p_e > p_i$ ($\Delta p_e = p_e - p_i$)
Δp_e max	Max. external pressure to be considered in the calculation of stability
p_{cr}	External pressure showing instability (buckling) called « critical pressure ». p_{cr} means both p_{cr}^{-} and p_{cr}^{L}
p_{cr}^{-}	Critical pressure in the actual pipe without stiffener.
p_{cr}^{-i}	p_{cr} for a pipe without stiffener and having an ideal shape.
p_{cr}^{L}	p_{cr} for a pipe with stiffener rings and not having an ideal shape (centre distance = L)
p_{cr}^{Li}	p_{cr} for an ideal pipe with stiffener rings
N	Unit theoretical circumferential force = $\sigma_N . e$
$C_{ep} = p_{cr}/\Delta p_e$ max	Dimensioning factor relative to external pressures
$C_e\sigma = R_e/\sigma$ max	Dimensioning factor relative to stresses
σ_H	0.8 R_e allowable proportional limit (Hooke)
R_e	Apparent elastic limit or 0.2 % proof stress. The value of R_e is always positive, whether the calculation is in tension or in compression
R_e^U	Reduced fictive yield point due to a radial run-out expressed by $U > 0.1 . e$
$\sigma_{éq}$	Equivalent stress according to Hencky-Von Mises
σ_{max}	Highest $\sigma_{éq}$ in the penstock section considered
E, E*	Modulus of elasticity in the presence and in the absence of free lateral contraction. $E = 2.1 . 10^5$ N/mm² $E^* = E. (1-\nu^2)^{-1} = 2{,}3 . 10^5$ N/mm²
ν	0.3 allowable Poisson factor
e	Theoretical wall thickness i.e. actual « e » decreased by the corrosion allowance, if any
J	Moment of inertia of the smooth pipe wall of unit length
R	Theoretical inner radius (ideal pipe)
r	Local curvature radius
d_{max}, d_{min}	Large and small axis of the straight section of a pipe having a radial run-out
$\eta = \dfrac{d_{max} - d_{min}}{4}$	Maximum deviation between the circle of R radius and the pipe with a radial run-out (fig. 1)
U	Maximum inward deviation between the arc of circle (R radius) and the effective inner contour of the pipe with a radial run-out along an arc of a circle having a chord = R/2 but not exceeding 400 mm (fig. 2)

φ	Coefficient defining the highest normal stress for which the structure still meets the requirements of the Hooke law. In the absence of bending, we have : $\varphi = \sigma_H / R_e = 0.8$ On the contrary, should any bending occur for $p_e < p_{cr}$, as it is the case when the steel liner is supported against a concrete cover that collaborates in stabilization, the expression $\varphi = 0.7$ must be adopted. For penstocks and penstock sections whose R_e yield point has been increased by a plastic expansion, the yield point in compression has decreased correspondingly (Bauschinger effect). In this case, φ must also be subjected to an additional proportional decrease.
α	Stiffening factor in terms of L/R
β	Weakening coefficient of the smooth pipe due to a general ovality expressed by $\eta = 0.01$ R
γ	Weakening coefficient of the smooth pipe due a radial run-out expressed by $U > 0.1$ e
λ	Stiffening factor due to a variation of R_e

1.2. Stiffener rings (fig. 3)

Stiffener ring	Constant section ring connected to the penstock by a continuous weld seam including a penstock section of a L_o length
L_o	Penstock section length associated with the ring
$L_c = 0.78 \sqrt{R.e}$	Supporting length of the pipe, measured from the farthest welded joint between ring and pipe
a_o	Clear distance between ring webs in the case of a multi-web ring
e_o	Thickness of each ring web
A_o	Cross-sectional area of the ring with the penstock section L_o
J_o	Moment of inertia of the straight section A_o about its axis of gravity parallel to the penstock axis
R_o	Radius of the gravity line of section A_o
Y_o	Maximum distance of the marginal fiber - inner or outer - of the straight section A_o from its gravity line
L	Centre to centre of the rings
L_f	Ficticious centre distance by a nearly ideal encasement (zero rotation)
N_o	Circumferential load on the ring $= \sigma_{N_o} . A_o$

1.3. Steel Liners (see fig. 4)

j_o	Interstitial clearance between plate and concrete prior to grouting
j	Interstitial clearance immediately after draining
$\varrho \varrho_o$	Radius of curvature of the supporting arc of the weakening wave of the pipe or of the stiffener ring
σ_N, σ_{N_o}	Normal circumferential stresses associated with the radii p and p_o in the plate and in the ring respectively

2. NATURE OF EXTERNAL PRESSURES ON A PIPE

2.1. Concrete

2.1.1. Any steel liner is already subjected to an external pressure during the placement of the cover concrete. This pressure can result in an unallowable deformation of the steel liner if the latter has not been held in the required position during this operation.

The manufacturer shall determine the number of temporary and/or final stiffeners required.

2.1.2. The manufacturer shall be informed, as early as the start of the design work, of the anticipated concreting procedure and rate so that he can make any comments, should he so wish.

2.2. Grouting

2.2.1. After concreting, the Employer may ask a Civil Contractor to carry out grouting work of the types mentioned below :

a. **rock consolidation,** in depth (*)
b. **rock sealing,** in depth (*)
c. **filling** between concrete and rock at a moderate pressure
d. **bonding** between plate and concrete at a small pressure

(*) The grouting of type a and b shall be preferably carried out prior to the placement of steel liners.

2.2.2. As the steel liner can be directly stressed by the grouting work, the Manufacturer shall be informed, at the start of design work, of the anticipated grouting types and of the grouting pressures so that he can consider their influence on the stability of the steel liner.

2.3. Seepage water

2.3.1. It is admitted that seepage water in the rock acts outside the steel liners.

2.3.2. As a general rule, there is much uncertainty as to the overpressure that may be produced by seepage water.

2.3.3. The steel liner can already be stressed by the pressure of seepage water during concreting but it is particularly stressed when the water supply system is partly or fully emptied.

2.4. Internal vacuum

2.4.1. A partial or total internal vacuum may occur accidentally if during an emptying operation the ventilation cannot be effected normally.

2.4.2. The case of a bottom neck surge chamber must be particularly considered with due regard to the occurence of an underpressure below the diaphragm in the tunnel or in the most exposed sections of the penstock.

2.5. Case of an exposed penstock

Only the partial or total internal vacuum as mentioned under para. 2.4. above is to be considered here. The non-uniform external loads such as wind, snow, etc . . . are not considered here.

3. DETERMINATION OF THE VALUE OF THE EXTERNAL PRESSURE

3.1. As the Employer is the best qualified to define and modify, in case of need, the possible pressure of rock water p_e, he shall advise the Manufacturer of the maximum allowable value p_e max to be used in the calculation at any point of the profile.

3.1.1. An internal vacuum shall be considered in the calculation only if requested by the Employer.

4. DETERMINATION OF DIMENSIONING FACTORS C_e

4.1. The values of C_{ep} and $C_{e\sigma}$ shall be rather high to take two facts into consideration :
First, the external pressure can really cause damage to the structure (it is not the same with the internal pressure).
Second, the assumptions and methods of calculating the stability against the external overpressure are less reliable.

4.2. It is recommended to admit the same value both for $C_{e\sigma}$ and C_{ep}.

4.3. In accordance with the table of dimensioning factors (*) the value of the factors $C_{e\sigma}$ and C_{ep} should be 1.6. **A highest value** shall be taken when the definition of p_e max is very uncertain.

5. DIFFERENT WAYS OF WITHSTANDING THE EXTERNAL PRESSURE

5.1. Exposed penstock

The self-stability and the stiffener rings of an exposed penstock enable it to withstand any external pressure (internal vacuum).

5.1.1. The self-stability is improved by the prestressing due to flexible or rigid hoops.

5.2. Circular steel liner

5.2.1. The circular steel liner withstands any external pressure for the reasons mentioned under 5.1.

5.2.2. The self-stability of the circular steel liner is increased by the presence of concrete that limits deformation outwards.

5.2.3. A temporary prestress can be applied by high pressure grouting behind the plate or the concrete.

5.2.4. An adequate system for anchoring the steel liner to concrete can assist the steel liner in withstanding any external pressure.

5.2.5. Draining interstitial water can decrease their pressure.

5.2.6. Depth grouting in the rock may decrease or even shut off the pressure of seepage water.

(*) Appendix D to Annexure II

5.3. Prestressing a steel liner by grouting

5.3.1. The expected favourable action of a grouting prestress can be profitable only if the rock has not crept under the combined effect of such grouting, of the cooling water and of the water pressure. All measurements that have been made show the creep exists.

5.3.2. The calculation of the stability of a steel liner against any external pressure cannot therefore state a high pressure grouting prestress. On the contrary, it must consider an existing interstitial clearance « j » as mentioned under para. 6.

5.4. Depth grouting for rock sealing

5.4.1. In a creviced rock, the water does not create any damaging pressure in so far as its path towards the resurgence point is not obstructed.

5.4.2. Depth grouting in a creviced rock shall sometimes be carried out to make a working area drier or to consolidate the rock: in order to increase its apparent modulus E so that the rock can resist better the pressure thrust of the steel liner or in order to prevent any landslide.

5.4.3. As such grouting is likely to prevent seepage water from running out, the instability of the steel liner is considerably increased due to a rise in the water pressure.

The Civil Contractor shall also consider this aspect of the problem.

5.5. Drain efficiency

5.5.1. There is probably no fautless drain system **fit for flawless duty during a period equivalent to the use of the steel liner.**

5.5.2. Care shall be taken that the drain pipelines do not facilitate in any way the transport of pressure rock under water pressure from one location to another.

Should such preventive measures not be taken, the following results could be noted:
- excessive overload of the steel liner on the downstream side due to the overpressure so created
- slow obstruction of drain holes increasing upstream overpressure
- formation of scale in the pipelines due to the transport of rock water, which results in the progressive inefficiency of the draining operation in the case of the emptying of the shaft.

5.5.3. Any draining operation should at any rate be interrupted as soon as the steel liner is filled with water and operated again before emptying the shaft. This operation is not easily carried out in the case of accidental draining or emptying.

6. ORIGINS AND IMPORTANCE OF THE INTERSTITIAL CLEARANCE BETWEEN PLATE AND CONCRETE

6.1. Initial Clearance j_o

6.1.1. Any external pressure and in particular, the bonding grout pressure by which the steel liner is loaded is all the more critical as the ratio of the critical clearance j_o between plate and concrete versus the mean radius R of the steel liner is large.

6.1.2. The Civil Contractor shall therefore take all necessary measures to attain an initial clearance j_o as small as possible, before grouting.

6.1.3. This interstitial clearance is the main consequence of concrete shrinkage and of thermal shrinkage of the steel liner from the maximum temperature attained during concrete setting.

6.1.4. The initial clearance j_o shall in no way exceed 1‰ of the radius. It should decrease to not more than one fifth of this value if the conditions for the placement of high quality concrete are satisfactory.

6.2. Clearance j in service

6.2.1. The setting to work of a pressure shaft produces the cooling of the rock and consequently, a divergent shrinkage.

6.2.2. Even if the emptying of a pressure shaft or of a steel lined tunnel is carried out slowly i.e. in several days, the steel liner expands more rapidly than the rock does and becomes hot. Consequently, an interstitial gap j is formed momentarily and unavoidably on either face of the concrete which, in general, is already cracked in the radial direction.

6.2.3. The calculation assumes that the gap j exists over the whole periphery of the pipe between plate and concrete only.

6.2.4. The value of j depends on the elasticity, compacity and radial cracking of the rock as well as on the thickness and cracking of concrete etc . . .

6.2.5. Indicative values of j

In the absence of accurate data, the values below can be taken :

6.2.5.1. Very compact rock, due to its nature or to consolidation grouting, or in case of limited contribution of the rock to the resistance to internal pressure :

$$j/R \geqslant 0{,}2\,‰\,,\ 0.5\,‰ \text{ approx.}$$

6.2.5.2. Creviced rock without any grouting or with a low modulus of elasticity or of the slow expanding type :

$$j/R \approx 1.0\,‰$$

6.2.5.3. Steel liner highly loaded by the internal pressure (high yield point of the material, low modulus of elasticity of the rock)

$$j/R \geqslant 0.7\,‰$$

7. ALLOWABLE SHAPE ERRORS IN THE PENSTOCK AFTER ERECTION

7.0. Table I of Annexure V of the « Recommendations » gives a formula showing the allowable radial run-out. This formula applies to pipes loaded by the internal pressure only. The radial run-out produces an additional bending stress that does not endanger the structure. On the other hand, any radial run-out or ovality increases the subsidence hazards of a pipe subjected to an external overpressure. In this case, the shape tolerances shall therefore be much more severe.

7.1. Ovality (fig. 1)

7.1.1. An ovality changes the local radius of curvature « r » and consequently the loading of the pipe by the external pressure.

7.1.2. After erection, the pipe shall be checked for ovality. As an average, a section of steel lined shafts shall be scanned about every 30 m.

7.1.3. The largest radius of curvature of an ellipse (fig. 1) is given with an adequate accuracy by :

$$r = R + 3.\eta$$

where : $R = \frac{1}{4}(d_{max} + d_{min}) = R_{theoretical}$

and : $\eta = \frac{1}{4}(d_{max} - d_{min})$

7.1.4. Ovality tolerance of erected pipe

The ovality η shall not exceed 0.01 R or

$$d_{max} - d_{min} \leqslant 0.04\ R$$

(This requires the diameters d_{max} and d_{min} to be measured).

$$\text{or : } R \leqslant r \leqslant 1.03\ R$$

(to be checked with the template « 1.03 R », figure 1a).

7.2. Out of roundness (fig. 2)

7.2.1. Any radial run-out (out of roundness) can upset the equilibrium owing to the occurence of an additional bending moment U.N.

7.2.2. Roundness is checked by means of a template in accordance with figure 2 having a length not less than 0.5.R but not more than 400 mm.

7.2.3. Out of roundness tolerances

7.2.3.1. The expressions of p_{cr} are applicable as long as the radial run-out U does not exceed 0.1 e.

7.2.3.2. In the case of any deviation above this value – not more than 0.2 e – para. 8.3.1.3 shall be taken into consideration.

7.3. Within the tolerances mentioned under 7.2.3.1, the additional stresses due to shape errors are generally smaller than 30 % of $\sigma_N = p_e \cdot R/e$.

8. CHECKING OF THE STABILITY OF A CYLINDRICAL PIPE SUBJECTED TO A UNIFORM EXTERNAL PRESSURE

8.0. Criterion of pipe stability

The critical external pressure of the penstock calculated in accordance with 8.3 or 8.4 shall be greater than the expected maximum external pressure :

$$p_{cr} \geqslant C_{ep} \cdot \Delta p_{e\ max}$$

8.1. Cases under consideration

Stiffeners / Type of penstock	None ($L \Longrightarrow \infty$)	Rings (Spacing L)
Exposed	8.3.1.	8.3.2.
Braced against the rock	8.4.1.	8.4.2.
All cases above	with and without shape flaws	

8.2. Main Calculation Assumptions

8.2.1. The value of the external pressure is constant over the whole surface of the penstock section considered.

8.2.2. The pipe and its content have no weight.

8.2.3. The shape flaws are within the limits as specified in para. 7.

8.2.4. There is neither adhesion nor friction between penstock and concrete.

8.2.5. The gap between the penstock and concrete is constant as well as the elasto-plastic behaviour of the concrete/rock assembly.

8.2.6. All stiffener-rings that may be used are plane and not bonded to the cover concrete.

8.2.7. The behaviour of the material is purely elastic (Hooke). The following formula :

$$\sigma_N \leqslant \varphi . Re$$

is generally applicable even under the action of the critical external pressure.

8.3. Equations of the stability of an exposed pipe

8.3.0. The stability of an exposed pipe, stiffened or not with rings, with an ovality expressed by η (fig. 1) not exceeding 0.01.R for four steel grades can be readily checked by using the diagram (fig. 5 - 2).

8.3.1. Smooth pipe

8.3.1.1. Pipe without any shape error.

The critical external pressure is given by the following formula :

$$p_{cr}^{-i} = \frac{3E^* . I}{(R+e)^3} = \frac{E^*}{4} \cdot \left(\frac{e}{R+e}\right)^3$$

This is the curve 1 of diagram fig. 5 and the curve 4 of diagram fig. 6.

8.3.1.2. Pipe with ovality

The influence of any ovality characterized by $\eta = 0.01.R$ is given by the weakening factor β (curves 2 of Diagram fig. 5) :

$$p_{cr}^{-} \text{ (oval pipe)} = \beta . p_{cr}^{-i} \text{ (ideal pipe)}$$

8.3.1.3. Pipe with a radial run-out greater than 0.1.e but smaller than 0.2.e

If the amplitude U of the radial run-out (fig. 2) is greater than 0.1.e but yet smaller than 0.2.e, it is advisable to replace R_e by R_e^u :

$$R_e^u = R_e - 3.p_{cr} \cdot \frac{R}{e} \left(\frac{U}{e} - 0.1\right) = \gamma \cdot R_e$$

It is however assumed that $\gamma = 1$ for $U \leqslant 0.1.e$.

8.3.1.4. Checking of the elastic behaviour of the material

The diagram fig. 5 allows for the application limits of the dimensioning method for materials whose value R_e is between 22 and 40 hbar.

For materials whose yield point is not within this range, it is necessary to prove that

$$p_{cr}^{-} \frac{R+e}{e} \leqslant \varphi \cdot \gamma R_e$$

Where the yield point of the material in tension is increased by a manufacturing process, it is decreased in compression. The latter yield point shall be considered in a compressed area.

8.3.2. Pipe with stiffener rings

8.3.2.1. Stability of the pipe between two stiffener rings (Shape tolerances as per para. 7)

The curve family (3) of Diagram fig. 5 gives a value of the stabilization coefficient α and consequently, the critical pressure :

$$p_{cr}^{L\,i} \text{ (ideal stiffened pipe)} = \alpha \,.\, p_{cr}^{-i} \text{ (ideal pipe without stiffener)}$$

The factor β (curves (2)) gives the weakening degree in the case of out of roundness expressed by $\eta = 0.01.R$:

$$p_{cr}^{L} \text{ (oval stiffened pipe)} = \alpha \,.\, \beta \,.\, p_{cr}^{-i} \text{ (ideal pipe without stiffener)}$$

8.3.2.2. Stability of stiffener rings

The moment of inertia of stiffener rings shall be not less than J_o so that the rings can ensure a stabilizing efficiency :

$$J_o \geqslant \frac{p_{cr}^{L} \,.\, L \,.\, R_o^3}{3\,E} - \frac{(L - L_o) \,.\, e^3}{12}$$

The second term of this expression represents the contribution of the penstock between the rings to the rigidity of the assembly. This contribution is, in general, negligible.

In the calculation of the moment of inertia J_o of the ring, the penstock sections integral with the ring shall be included up to a length of L_c. The penstock length designated by L_o in fig. 3 shall therefore be considered as a part of the ring :

$$L_o = 2\,(L_c + e_o) + a_o \quad \text{with} \quad L_c = 0.78 \,.\, \sqrt{R.e}$$

8.3.2.3. Checking of the elastic behaviour of the material

Para. 8.3.1.4. also applies to the penstock shell. For the rings, it is also necessary to prove that :

$$p_{cr}^{L} \,.\, \frac{R_o \,.\, L_o}{A_o} \leqslant \varphi \,.\, R_e$$

8.4. Equations of the stability of a circular steel liner

8.4.1. Smooth steel liner

The steel liner will be stable if both equations A and B below are simultaneously fulfilled by a certain value of σ_N with the condition : $\sigma_N \leqslant \varphi \,.\, R_e$

$$\text{A.}\quad 12 \cdot \left(\frac{R+e}{e}\right)^2 \cdot \left(\sigma_N + E^* \cdot \frac{j}{R}\right) \cdot \left(\frac{\sigma_N}{E^*}\right)^{3/2} \leqslant R_e - \sigma_N$$

$$\text{B.}\quad p_{cr}^{-i} = \sigma_N \cdot \frac{e}{R+e} \cdot \left(1 + 0{,}35 \cdot \frac{R+e}{e} \cdot \frac{Re - \sigma_N}{E^*}\right)^{-1}$$

(The formulas A and B are derived from the E. Amstutz formulas (51) and (52) that are simplified to allow for the usual limits of R/e and j).

The system of equations A and B shall be resolved by iteration or using the diagram fig. 6. The curve (4) of the diagram gives p_{cr}^{-i} according to 8.3.1.1. and the family of curves (5) gives p_{cr}^{-} according to the formulas A and B for $R_e = 220$ cr N/mm^2 and for various relative clearances j/R and an ovality $\eta \leqslant 0.01.R$. The family of curves (6) gives the value of the stiffening factor λ for various relative clearances j/R and four values of R_e for the relation :

$$p_{cr} \; (R_e = 260, 300, 400, 500 \; N/mm^2) = \lambda \,.\, p_{cr} \; (R_e = 220 \; N/mm^2)$$

8.4.2. Steel liner with stiffener rings

8.4.2.0. Usefulness of stiffener rings

If the critical external pressure as specified in 8.4.1. is inadequate, the steel liner can be stiffened with rings.

8.4.2.1. Steel liner between two stiffener rings :

Because of the stiffening action of the rings, the steel liner cannot subside and it forms one or more waves of small amplitude. Assuming this form of instability is not appreciably affected by concrete owing to the interstitial clearance, the checking of the stability of the pipe shall be carried out in accordance with para. 8.3.2.1. as follows :

a. When the penstock can be considered rigidly encased and the rings are capable of resisting twisting, the distance between rings « L » as indicated in fig. 5 can be replaced by the fictious distance between rings « L_f » where :

$$L_f = 0.8 .(L - a_o)$$

b. When the pipe cannot be considered as encased (possible rotation of the stiffener ring section), the expression $0.8 \leqslant L_f/L \leqslant 1$ can be adopted depending on the encasement degree.

8.4.2.2. Stability of stiffener rings

It is assumed that there is neither adhesion nor friction between stiffener rings and concrete. The stiffener rings remain stable when both equations C) and D) are simultaneously fulfilled by a value of $\sigma_{N_o} \leqslant \varphi$. Re :

$$\text{C.}\quad 0.58 \cdot \frac{y_o}{R} \cdot (\sigma_{N_o} + E \cdot \frac{j}{R_o}) \cdot (1 + \frac{\sigma_{N_o}}{E} \cdot \frac{L}{L_o} \cdot \frac{A_o \cdot R_o^2}{J_o + \frac{L - L_o}{12} \cdot e^3})^{3/2}$$

$$\leqslant (Re - \sigma_{N_o}) \cdot (1 - 0.23 \cdot \frac{R_o}{y_o} \cdot \frac{Re - \sigma_{N_o}}{E})$$

$$\text{D.}\quad p_{cr}^L = \sigma_{N_o} \cdot \frac{A_o}{L_o R_o} \cdot (1 + 0.175 \cdot \frac{R_o}{y_o} \cdot \frac{Re - \sigma_{N_o}}{E})^{-1}$$

Note : Such formulas correspond to the G. Feder formulas (38), (39), (40) and (36 a) with the same simplifications as in 8.4.1.

Both equations shall be resolved by iteration using preferably the value of p_{cr} as specified in 8.4.1. and 8.4.2.4.

8.4.2.3. Checking of the elastic behaviour of the material

Not only shall σ_{N_o} be lower than or equal to φ . Re but σ_N shall also be equal to

$$= \frac{p_{cr}^L \cdot L.R. - \sigma_{N_o} . A_o}{(L - L_o) \cdot e} \leqslant \varphi \cdot \gamma \cdot Re$$

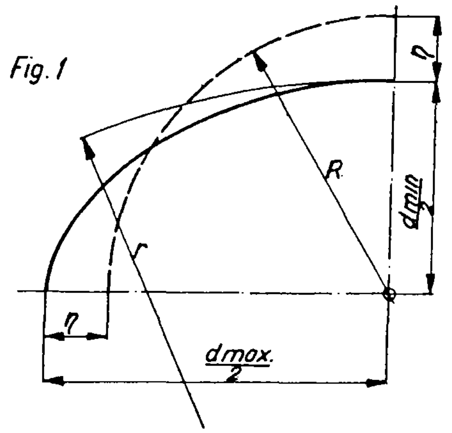
8.4.2.4. Determining critical external pressure

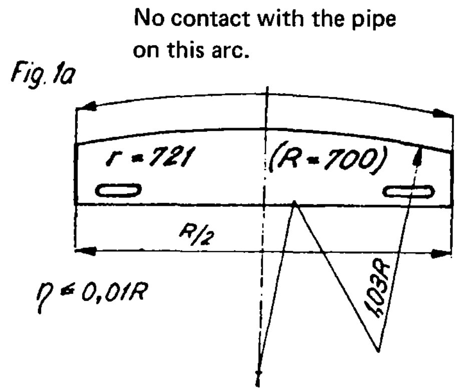
8.4.2.4.1. The determining value of p_{cr} is the smallest of the values obtained according to 8.4.2.1. and 8.4.2.2. These values shall comply with the requirements of para. 8.4.2.3.

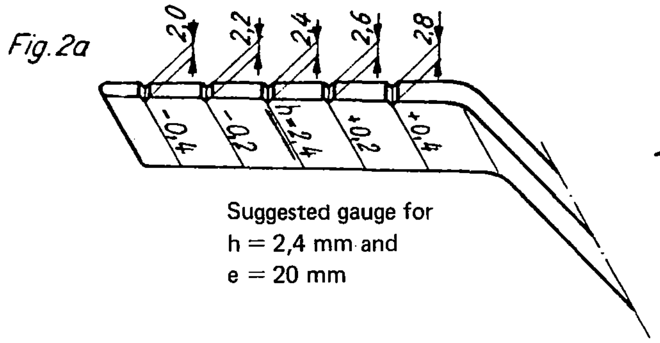
8.4.2.4.2. If the value obtained according to 8.4.2.4.1. is lower than that calculated in accordance with para. 8.4.1, the latter shall be retained. The stability of the steel liner is not therefore appreciably improved by stiffener rings.

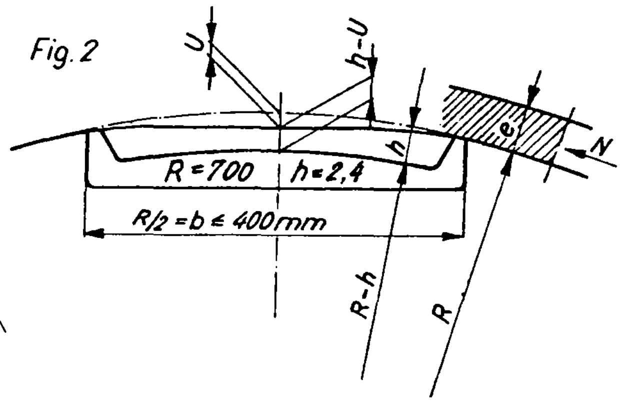
STABILITY OF EXPOSED PENSTOCKS AND CIRCULAR STEEL LINERS

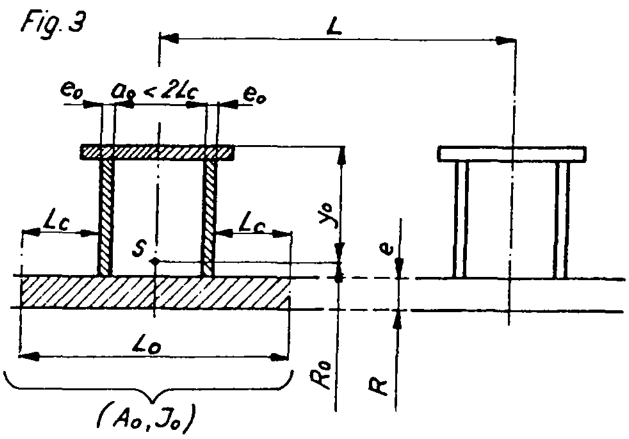
A – Shape checking : Fig. 1 : Ovality ; Fig. 2 : Radial runt-out Suggested gauges and templates.



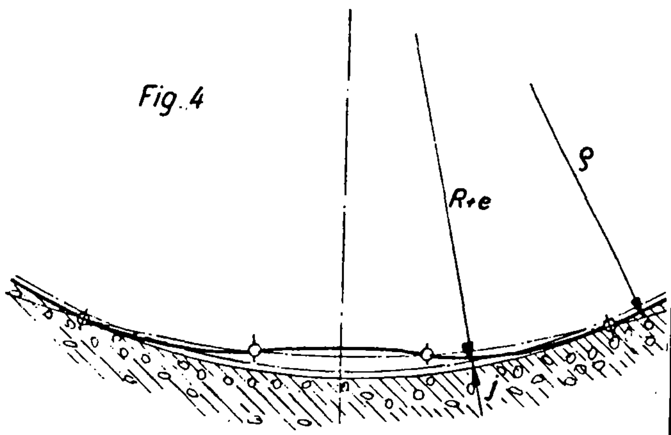








B – Definition of sizes relative to the rings.



C – Kinematics of subsidence for a steel liner Calculation bases.

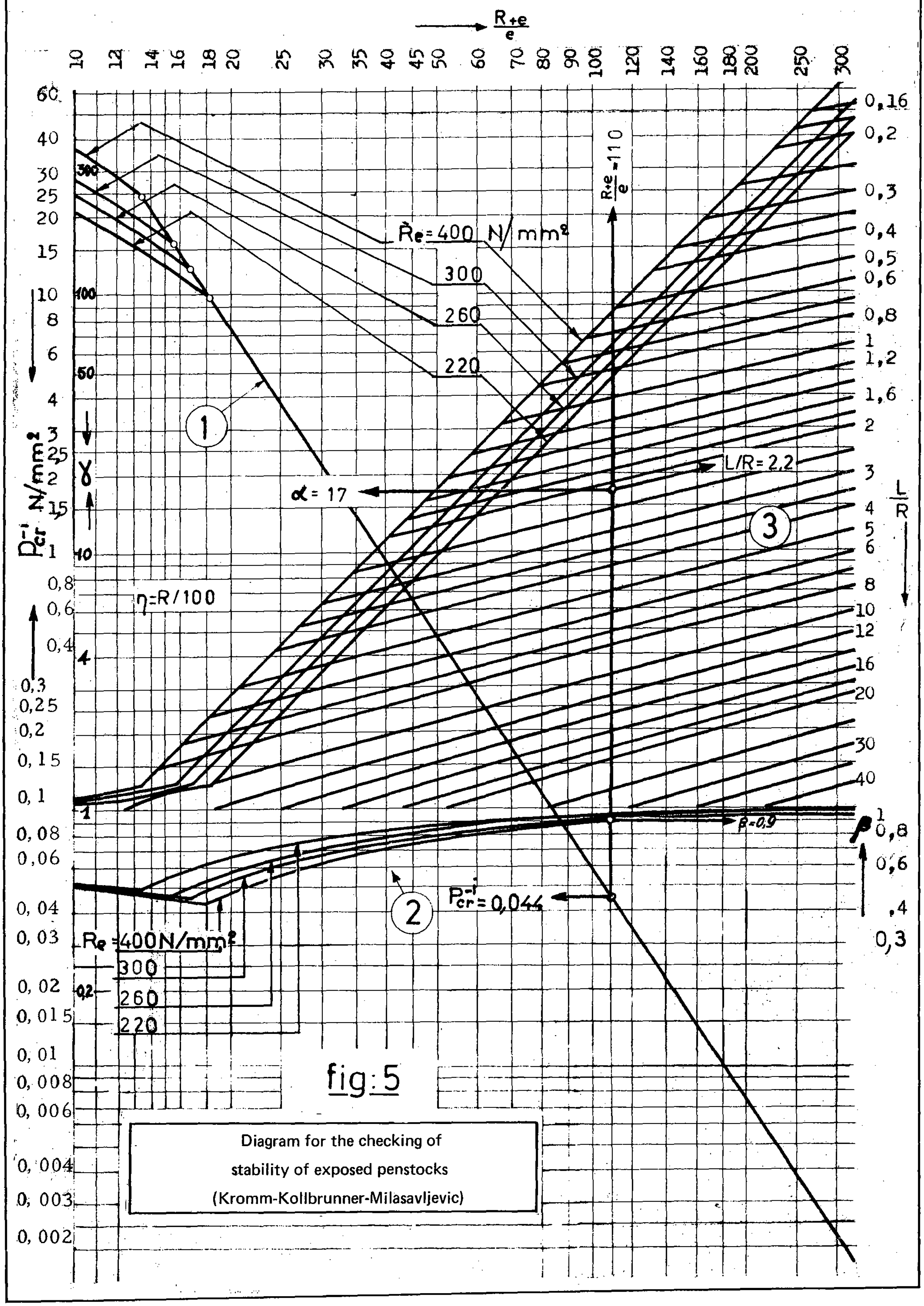


fig: 5

Diagram for the checking of
stability of exposed penstocks
(Kromm-Kollbrunner-Milasavljevic)

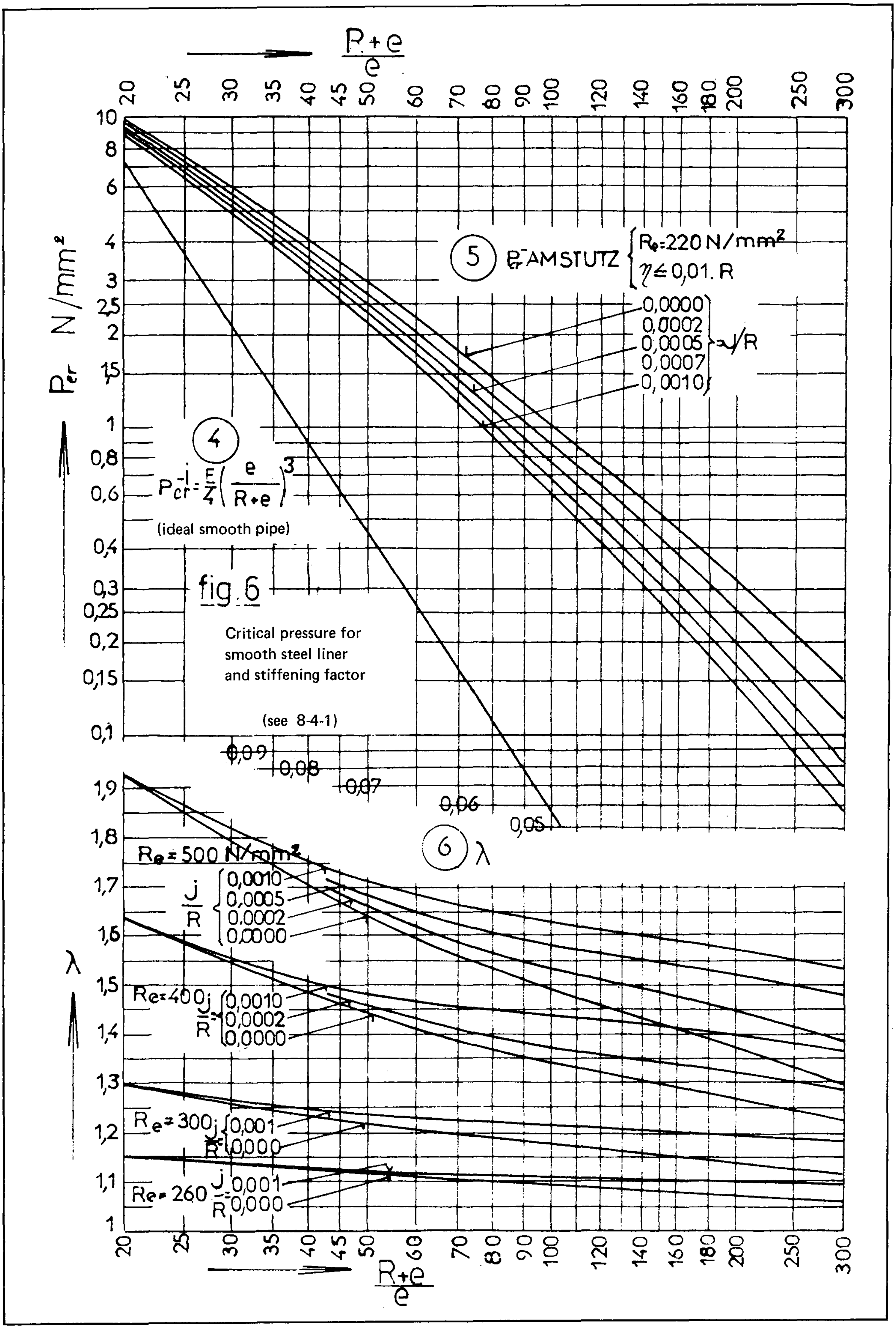


fig.6

Critical pressure for smooth steel liner and stiffening factor

(see 8-4-1)

ANNEX III

TECHNICAL SPECIFICATION OF STEEL PLATES AND FORGED PARTS FOR WELDED PENSTOCKS

Table of Contents

1980 Edition
This page annuls and replaces page 40 of the 1979 Edition.

ANNEX III A
TECHNICAL SPECIFICATION OF STEEL PLATES

1 - GENERAL

1.1. - Scope

This technical specification sets out the properties of steel plates used in the manufacture of penstocks or of certain connected parts in welded construction.

It also defines the extent of inspection and the acceptance conditions.

1.2. - Definition of plates

Plates are flat rolled products with edges cropped either by shearing or by flame cutting. The unit of rolling is the plate producing one or several plates after cutting.

2 - TYPE AND GRADE OF STEEL

The type and the grade of steel are defined by its chemical composition, its production, its heat treatment and its mechanical and technological properties.

2.1. - Chemical composition

The chemical composition must be such that the mechanical and technological properties are guaranteed and that the working of the plates is not influenced unfavourably.

2.2. - Manufacture

The method of manufacturing and casting as well as the rolling operations are left to the steel works provided that the requirements of 2.1. and 2.4. are complied with.

2.3. - Heat Treatment

Steel plates can be supplied according to their grade and their class in one of the three following conditions :

1 - Rolled at a controlled temperature
In this case, checking of the final rolling temperature is required.

2 - Normalized
Normalization consists of heating above the point AC3 followed by cooling in still air.

3 - Heat treated
Heat treatment involves hardening and tempering.
The process is left to the steel maker but it must be known by the manufacturer.

2.4. - Mechanical and technological properties

Yield Point
Tensile strength
Elongation at rupture
Bending properties
Breaking strength for brittle fracture before and/or after ageing
Weldability

The values of yield point and tensile strength lie within a certain scattered range. The lower limit of the yield point range and both the lower and upper limits of the tensile strength range are fixed. The properties must be guaranteed in the final manufactured condition of the conduit sections.

2.5. - Recommendations for working

If, during manufacture, the penstock parts undergo important strains and/or heat treatments, the manufacturer shall agree with the steel manufacturer upon the working conditions and the final treatment.

3 - FEATURES OF PLATES

3.1. - Dimensions and tolerances

The dimensions, the accuracy of the angles and the weight of the plates must meet the requirements specified in the order, taking into account the permissible tolerances determined by common consent.

3.2. - Appearance

The surfaces of the plates shall be smooth and flat. Small surface defects can be rectified by grinding or filing provided that the resulting depression is smoothly connected to the rest of the surface and that the remaining thickness is not smaller than the minimum thickness allowed for the nominal thickness considered. Repairs by hammering or by filler welding are not permitted except by agreement with the manufacturer.

3.3. - Homogeneity

Flaws and segregations affecting the normal conditions of use are not permitted.

4 - TEST AND INSPECTIONS

The features enumerated under 2.1 and 2.2 shall be checked by suitable tests and inspections.

In every case, the standards and specifications will define the choice, the sampling and the machining of the necessary test pieces, the number of tests and their possible repetition, as well as the carrying out of the tests.

The tests done in the condition mentioned under 2.3 shall apply, by agreement between the manufacturer and the steel maker, to each separate plate, to the rolled sheets or by lot.

4.1. - Systematic tests and inspection

1 - Tensile Test

The tensile test determines the breaking strength, the yield point and the elongation.

2 - Bending test

The bending test carried out according to one of the corresponding standards aims at determining the capacity of deformation in terms of the bending angle.

3 - Impact test

The breaking strength and energy at various conditions and temperatures of the steel is determined by the impact tests which constitute a check on the tendency to ageing and to brittle failure. The values to be guaranteed shall be separately agreed with the steel works.

4 - Ultrasonic examination

In order to confirm the absence of serious internal defects in the plates, they must be subjected, according to the purpose which they are intended for, to ultrasonic examinations. The procedure as well as the extent of the controls must be laid down.

5 - Control of chemical composition

A chemical analysis, carried out for each cast, is used to determine the contents of carbon, silicon, manganese, sulphur and phosphorus as well as of possible alloy elements. A control analysis can be required by the manufacturer; in this case, it must be specified at the time of the order.

4.2. - Optional tests and controls

The plates can be subjected to additional tests whose particulars have been specified for each order, having regards to the special conditions of use.

These tests are to check the susceptibility to cracking in the vicinity of a weld. They can include:
– either bending tests with filler welding (Kommerell test)
– or measures of hardness measurements under a weld bead etc . . .

The tests shall essentially apply to the metal of the plates; tests which would mainly involve the deposited metal (for example, crack tests of a weld bead) are not admitted for the testing of plates (see Annex IV).

5 - JUDGING OF RESULTS

5.1. - Acceptance of plates

In order that a batch of rolled plates or a single plate may be accepted, the results of the different tests enumerated in article 4 must conform to the guaranteed values.

5.2. - Cancellation of tests

Test results which are unreliable owing to faulty execution shall be cancelled.

5.3. - Rejection of plates

If the results of the quality tests for the plates examined do not meet the requirements, the tests shall be done again under the same conditions. If the results of these new tests are still unsatisfactory, the batch or the plate shall be rejected.

A rejected rolled sheet or plate can be subjected to another heat treatment with a view to a new series of tests which, in this case, will be just the same as the first. If these new tests are also unsatisfactory, the plates shall be finally rejected.

6 - ACCEPTANCE AND DELIVERY OF PLATES

6.1. - Acceptance

Plates can be ordered with a certificate of acceptance or for acceptance in the workshop.

When required, this acceptance shall take place at the steel works and before the plates are despatched. By special agreement, it shall be effected in the presence of an acceptance inspector appointed by the manufacturer or by the user.

6.2. - Presentation

The plates ready to be delivered shall be presented in lots to the Inspectors, in the steel works. The presentation is done as agreed and must be announced in due time to the principal or this representative, with all necessary information.

6.3. - Acceptance certificate

The results of the acceptance tests are recorded in a certificate in which each plate subjected to the tests is mentioned separately. The certificates only signed by the inspector and by a representative of the steel works shall be sent to the manufacturer with the required number of copies.

6.4. Marking

The following indications shall be marked on each plate by the steel works:

- Heat number
- Plate number
- Type and grade of steel
- Stamp of the steel works if required to identify the supplier
- Dimensions.

Each plate inspected shall be provided with the punch-mark of the inspector.

6.5. - Delivery

Once the plates are accepted and marked, they shall be delivered in accordance with the manufacturer's instructions.

6.6. - Replacement

If, during an additional inspection or during manufacture, defects are detected in a plate which prevent it from being used, the steel works shall be informed. If the complaint is substantiated, the steel works shall be compelled to replace the faulty plate as soon as possible.

6.7. - Orders

In accordance with the instructions of the Comité Européen de la Chaudronnerie et de la Tôlerie (European Committee for Boilermaking and Kindred Steel Structures), orders for plates must include the following technical indications:

1 - List of plates with number, size, tolerances and weight of each position

2 - Type and grade of steel, delivery condition

3 - Properties to be guaranteed

4 - Instructions for acceptance tests and inspections

5 - Indications as regards the manufacture and destination of plates

6 - Special requirements (marking . . .).

ANNEX III B

TECHNICAL SPECIFICATION OF STEEL FORGED PARTS

The Recommendations of Annexure III relative to steel plates for penstocks fully apply to steel forgings to be welded after a few paragraphs 1.2, 2.3.1 and 4.1.2 as well as bending tests (para. 2.4) and Kommerell (para. 4.2) have been deleted and the following substitutions have been made:

Annexure III A	becomes	**Annex III B**
steel plate	becomes	forged parts
rolling sheet	becomes	forged parts
rolling	becomes	forging
ultrasonic examination	becomes	ultrasonic, Gamma or X-Ray examinations

(*) The paragraphs whose number is followed by « B » **replace** the same ones in Annexure III A. The numbers below **not followed by B** are **supplements.**

3.2. bis* - Appearance of forgings

Forgings shall be sound and free from scales, cracks, crevices or any other flaws that can be detrimental to their use.

During the various manufacturing stages, the surfaces shall be carefully checked for soundness of metal.

Surface inspection shall be carried out after pickling for all non-machined surfaces and both during roughing and finishing for all machined surfaces.

3.4. - Remedial work

Shape errors can be corrected by welding subject to previous agreement with the Constructor.

4 - TESTING AND INSPECTIONS

(Second paragraph). The mechanical tests shall be carried out in the condition stipulated in 2.3., with the agreement between the Constructor and the steel manufacturer, on separate items or by lots; if they are carried out on a test-piece, the same shall have been subjected to the same heat treatments and puddling processes as the actual part.

4.1.4. B - Non-destructive Tests

It may be requested that forgings be subjected, depending on their intended use, to non-destructive tests so that the absence of any major internal defects can be checked. The type, extent and acceptance criteria may be established, for instance, in accordance with the requirements of Appendix III B, para. C5.

4.1.6 - When the inspectors are carried out by lots, the quality of the lots shall be checked for homogeneity by measuring the hardness of each part of the lot and that of the sample.

4.3. - Dimensional Checking

The sizes of each part shall be checked at the steel manufacturer's on the basis of the drawings attached to the Order. For surfaces to be machined, the machining overthicknesses shall be adhered to.

5 - EVALUATION OF RESULTS

6 - ACCEPTANCE AND DELIVERY

In these two paragraphs replace **steel plates** by **forged parts**

APPENDIX III A

STEEL PLATES FOR WELDED PENSTOCKS

TABLE A – Specification of penstock steels and inspections according to their classes.

		Class I	Class II	Class III
A.1	Steel processing (para. 2.2.)	Open hearth or electric furnace or equivalent (LD process . . . .) (to be stated by the steel producer)		The same as for Classes I and II or, according to the cases air-enriched blown steel (total 30 % O_2)
A.2	Delivery condition (para. 2.3.)	Killed and normalized or treated (quenched and tempered)	The same or with controlled temperature at the end of rolling, then killed	Normalized or with controlled temperature at the end of rolling, then killed or, possibly semi-killed
A.3	Chemical characteristics checked on melts (para. 2.1. and 4.1.5)	Carbon, manganese, silicon, sulphur, phosphorus and any alloy elements		Carbon, sulphur, phosphorus and possibly, silicon
A.4	Guaranteed mechanical characteristics (para. 2.4. and 4.1.)	4.1.1. Tension: yield point and tensile strength elongation 4.1.2. Bending 4.1.3. Impact test, possibly in the aged condition (**)		4.1.1. Tension 4.1.2. Bending 4.1.3. Possibly, impact test (on special request)
A.5	Acceptance unit (*)	Per sample (= plate)	Per plate asrolled or, for treated steels, per sample	Per lot, melt or fraction of melt
A.6	Ultrasonic examination (*) (para. 4.1.4.)	Edges over 50 mm wide and screen pattern	Scanning inspection	No required

(*) at the steel manufacturer or the Constructor's Plant

(**) the impact value may be checked in the aged condition (round notch) whenever the plate is subject, during manufacture, to an apparent deformation over 3 % without later stress-relieving heat treatment.

TABLE B — Minimum characteristics of penstock steels

(The requirements 1 to 4 are shown in the following diagram)

B.1 **CF Grade :** (penstock steel)

This CF figure corresponds to a tenth of the minimum apparent elastic limit Re expressed in N/mm^2, as guaranteed for a plate thickness $\leqslant$ 30 mm.

B.2. **Guaranteed minimum apparent elastic limit Re**

For $t \leqslant 30$ mm Re = (CF figure) in N/mm^2.

When $t > 30$ mm, the elastic limit Re can be lower than 10 N/mm^2 (CF figure) by ten or thirty points (to be stated in the Order).

B.3. **Tensile Strength Rm**

The value of the tensile strength is independent of the plate thickness

Grades up to 650	:	Rm = (CF + 120) to (CF + 280) N/mm^2
Grades equal to 650 and over	:	Rm = (CF + 100) to (CF + 250) N/mm^2
Common exceptions	:	grades lower than CF 250 : Rm max = (2.CF + 20) N/mm^2

B.4. **Elongation (A5)**

Length of the bar to be considered : 5d or $5.65.S^{1/2}$
Normalized steels : $A5_{min}$ = 12 000/Rm_{eff} (%), but $\leqslant$ 24 %
Treated steels : $A5_{min}$ = 10 500/Rm_{eff} (%), but $\leqslant$ 13 %
Rm_{eff} is the effective tensile strength.

B.5. **Impact value (K)**

For all grades and temperatures and shapes of test specimens
K average of 3 specimens $\geqslant$3,5 daJ/cm^2
No individual values lower than 2,5 daJ/cm^2

Normal test temperature :

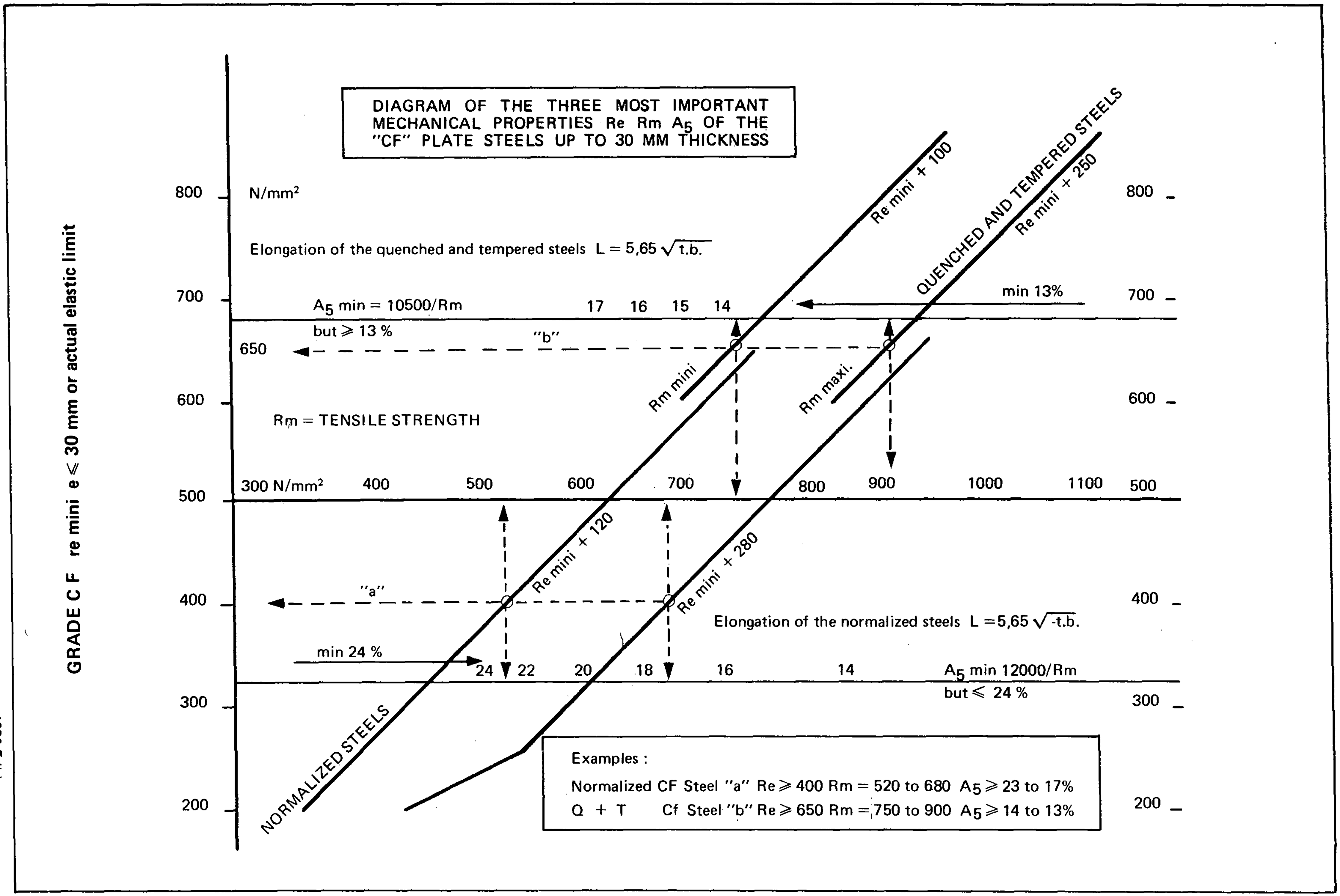
Classes I and II : KCV test specimens at − 20°C or 20°C below the minimum working temperature.

Class III : KCV test specimens at 0°C or at the minimum working temperature.

With aged specimen (10 %, 30 mm at 250°C) ISO (KCU), DVM, Mesnager or VSM : 20°C greater than the above.

B.6. **Direction of specimens**

In the transverse or longitudinal direction but preferably parallel to the loadest plate axis or in the direction of the last rolling operation.



1980 Edition
This page annuls and replaces page 47 of the 1979 Edition.

APPENDIX III B

TABLE C — Specification of CFf forged steels and inspections according to their classes.

		Class I	Class II	Class III
C.1	Manufacturing process	Open hearth or electric furnace or equivalent such as LD process (to be stated by the steel manufacturer)		
C.2	Delivery condition	Normalized or quenched and tempered	Normalized or quenched and tempered	Normalized or stress-relieved only (small parts)
C.3	Grades	All	Grades ⩽ 450	Grades ⩽ 320
C.4	Chemical characteristics	Carbon, manganese, silicon, sulphur, phosphorus and any alloy elements (the steel manufacturer shall issue a certificate on cast analysis)		Carbon, sulphur, phosphorus and silicon, if any
C.5	Testing of mechanical characteristics	Tensile test (1 to 2 specimens) Impact test (3 specimens) Hardness test, if any (on piece and tests specimens)		The steel manufacturer issues a certificate guaranteeing the characteristics of the part
C.6	Acceptance unit	Bars taken from the part before final machining or from a sample of the same melt that has been subjected to the same puddling processes and heat treatments as the part and having sections comparable to those of the part		None required
C.7	Non-destructive tests	Ultrasonic and/or radiographic examinations in the areas — to be determined in the order — where any homogeneity defect can be dangerous. Welds shall be in any way inspected.		Non required

TABLE D — Minimum characteristics of CFf forged steels

D.1 CFf Grade

The CFf figure corresponds to the Re minimum apparent elastic limit expressed in N/mm^2, guaranteed for a 50 mm thick. completed part that may have been subjected to a stress-relieving heat treatment after welding.

D.2 Guaranteed minimum apparent elastic limit Re

Thickness up to 50 mm : Re = CFf figure, in N/mm^2

Thickness above 50 mm : possibly Re = CFf grade minus ten to thirty points according to the grade and thickness (to be stated).

D.3 Tensile Strength Rm

Grades up to 450 : Rm = (CFf + 120) to (CFf + 280) N/mm^2
Grades above 450 : Rm = (CFf + 100) to (CFf + 250) N/mm^2

D.4 Elongation (A5)

Basic length on cylindrical bar : $L_o = 5.65.S_o{}^{1/2}$

Grade Rm	: 230	260	320	380	450	(520)	(600)	
Minimum elongation A5	: 20	19	18	17	15	13	11	%

D.5 Impact value (K)

For all grades, temperatures and K average of 3 specimens ⩾ 3.5 daJ/cm^2
No individual values lower than 2.5 daJ/cm^2

Test temperature in Classes I and II :
KCV specimens : – 20°C – Other specimens in the aged condition : 0°C
No impact test in Class III

D.6 Direction of specimens

In the case of rings, the direction of specimens is tangential.
In other cases, the direction of bars is specially agreed upon.

ANNEX IV

TECHNICAL SPECIFICATION FOR WELDING

Table of Contents

1984 Édition
This page annuls and replaces page 50 of the 1979 Édition.

1 - GENERAL

This specification covers the welded joints to be mostly found in penstocks as well as the most usual welding processes. It shall be applied in the absence or inadequacy of special specifications. It should enable the client to form accurate opinions on welded joints and to agree upon certain conditions with the manufacturer.

2 - RESPONSIBILITY

2.1. - In his design, the manufacturer shall be responsible for the position of the welds and for the conception of a structure adapted to the technics of welding. Knowing the tension conditions and the level of stresses, he determines the type and characteristics of welded joints.

2.2. - As regards manufacture and erection, the manufacturer considers the quality requirements and selects the suitable welding process, the shape of the bevels and the filler metal. If necessary, and especially in case of new processes and materials, he makes preliminary tests. He lays down the required instructions or regulations in order to obtain the guaranteed quality and takes care that they are complied with by proper inspections during the manufacture.

2.3. - The firm entrusted with the erection is responsible for the welds carried out at the site in accordance with the manufacturer's instructions. If necessary, the welding process and the filler metal shall be checked by means of preliminary tests to make sure that all the manufacturer's requirements are properly met.

2.4. - As a general rule, the client agrees with the manufacturer upon the specifications relative to the quality of welds and upon the examinations or preliminary tests. He receives the certificates of agreed quality and institues inspection procedures either directly or through an expert.

3 - QUALITY

3.1. - The selection of the quality of the welds depends upon the class adopted for the construction :

- calculation method : Annex II
- basic materials : Annex III
- welding : Enclosed tables 1 to 3

3.2. - Welds for penstocks and more especially the longitudinal and circular welds of the pipes require great care because they undergo the same forces as the basic element. With respect to ductility and resistance to brittle fracture under the action of a multiaxial stress condition, the properties of the filler metal have to be adapted to those of the basic material.

The mechanical properties of the metal desposited in longitudinal welds must generally conform at least to those of the basic material. For the circular joints in which the principal stress is exerted in the axis of the weld fillet, a filler metal can be selected whose elongation is greater than that of the basic material, with a somewhat smaller breaking strength and yield point. The impact values in the top pass and in the weld core must be adapted to those of the basic material.

Extra stress concentrations caused by a sudden change of cross-section, deep grooves, lack of fusion and cracks must be avoided.

4 - CLASSIFICATION

Butt welds are divided into 3 classes : I, II, III and defined in table 2. Welds with double bevel groove can be regarded as butt welds.

Fillet and butt welds not comprised in the above-mentioned classes do not enter into the classification.

5 - MANUFACTURE

5.1. - The groove shape depends on the workings conditions of the part, on the workshop facilities available and on the welding process to be used. Table 2 gives the more current groove configurations for butt or filled welds.

Assembly of elements with different thicknesses will preferably be carried out in workshop. Transitions must be gradually achieved and if possible, slope must not exceed 25%.

5.2. - Weld grooves are generally prepared by flame-cutting, shearing, planing or milling. Weld grooves in the flame-cut condition which are found non-satisfactory as concerns their shape or metallurgical properties will be ground.

5.3. - Welds can be performed by any proven method. Type of electrodes, filler metal, current and welding machine setting conditions must be defined under specifications or instructions specific to the Manufacturer. Requirement for preheating and the temperature thereof depend on the material to be welded, the wall thickness and the welding process used. A sealing run must be carried out, if possible, after weld cleaning.

Welding sequences will previously be determined when important shrinkage may occur due to the shape of the parts or when complex structures are involved. Utmost care will be given to the weld performing sequence.

5.4. - Welded joints must be performed according to the best modern practice and complying in particular with the following requirements :

- Except when impossible, crossing of main welds together or of main welds and welds of accessories is to be avoided as well as drilling of holes in the close vicinity or into the welds.
- Areas to be welded must be free from scale or oxide adhering particles : arc-air gougings must be ground before welding.
- Qualification of welding procedure and welders must have been carried out.
- Except when otherwise permitted, manual welding must be performed using low hydrogen electrodes.
- Prior to welding, electrodes must be appropriately stoved and placed, before use, in heating pots, in particular for field welding.
- Welding is prohibited when the ambient temperature is lower than —5 °C.
- The fusion faces must be free from dampness : heating can be carried out to take off the chill.
- Welding parameters are selected according to steel grade and thickness so that cracking is avoided : welding parameters can be determined on stud welds.
- Welding of accessories (such as lifting rings, struts, clamps, deck support, etc.) must be carried out with the same precautions (mainly as concerns preheating) as for performance of main welds : in case some of these accessories would subsequently be omitted, a dye penetrant test will be made on the surface previously ground in order to ensure the absence of cracks.

5.5. - Surface condition :

The surface of welds to be inspected must be free from irregularities exceeding the specified tolerances (streaks, undercuts, etc.) from which rupture may originate and which hinder the correct interpretation of non-destructive testing.

5.6. - The usual tolerances on the shape and aspect of longitudinal and girth welded joints are defined on Tables 1 E and 3.

6 - WELDING PROCEDURE QUALITIFICATION

The aim of this qualification is to confirm the choice of the filler metal and of the welding process for a well defined base material (steel plate) and to make sure that the final features of the welded joint reach the guaranteed values.

6.1. - Qualification of the welding procedure is not necessary when the manufacturer enjoys a long experience and can furnish adequate supporting evidence of same. For new base materials and filler metal and for new or modified welding processes, the qualification of the latter shall be carried out.

6.2. - Qualification of the welding procedure shall take place before manufacture and erection begin. It shall relate to every quality of steel and every welding process provided for. It shall be done under the same conditions as those prevailing during manufacture, such as, for instance : shape of chamfers, work preliminary to welding, number of runs, position, pre-heating, annealing, etc...

6.3. - As a generale rule, a test plate will consist of two strips (about 200 mm x 800 to 1000 mm) welded edge to edge in the longitudinal direction.

Its thickness shall be approximately equal to the greatest typical wall thickness for the steel or the welding process provided for. This test plate shall be treated in the same manner as the shop or erection welds.

6.4. - In the absence of any specifications or special agreements, inspection shall be carried out according to table 4 : welds of class I as per CT (complete test) and welds of classes II and III as per NT (normal test). For new base materials and filler metal, it is recommended to carry out additional tests, according to the circumstances.

6.5. - Table 1 gives instructions about the required tests.
Possible inspection methodes for fillet welds are to be laid down in each particular case.

7 - WELDER AND OPERATOR PERFORMANCE QUALIFICATION

For welding penstocks, the welders generally employed are those who have undergone qualification tests possibly confirmed by a certificate issued by an official organization. They must have the practical experience and the knowledge required for this job.

Failing this, the welder's record sheets normally kept by the manufacturer can act as the certificates. They shall mention the type and the position of the welds, the quality of the material, the length of the welds and the results of the inspections carried out.

8 - MANUFACTURING REQUIREMENTS

The manufacturing requirements lay down all the details necessary for obtaining the required qualities according to the welding process. They will generally be laid down for welds of class I and sometimes for those of class II. They may be made known by the client to the inspecting organisation.

9 - QUALITY CONTROL

The manufacturer and his inspection organization are responsible for current quality control. He makes proper arrangements for the general inspection of the welders' work and for compliance with requirements. More particularly, at the beginning of production, he checks the homogeneity of the welds by radiographic or ultrasonic examinations. The performances of each welder are shown on the control sheets.

The client or his representative is entitled, at any time, to make sure of the quality of the welds in the manufacturer's or in any sub-contractor's workshops by non-destructive examinations of the materials and of the mechanical features of the welds. If he deems it necessary, he can call in an expert for these inspections.

During production, the manufacturer or his sub-contractor draws up a report relative to the welds with all useful details such as for instance :

- the marked location of radiographs
- the results of tests
- the assessment of the radiographic and/or ultrasonic examinations

For class I and possibly for class II, this report will be sent to the surveyor.

10 - MECHANICAL AND CHEMICAL EXAMINATIONS OF THE WELDS

10.1. - The complete test (CT) according to table 4 gives the information necessary on the weldability of the steel plate and the qualities of the filler material as well as the quality of the welding and the process used.

The normal test (NT) is essentiallly a check on the maintenance of the required mechanical features.

For the different classes, the welding tests given in table 1 must be carried out. The extent of the tests in accordance with CT or NIT is dealt with in table 4.

10.2. - Welds tests are generally carried out on test-pieces taken from plates welded simultaneously with the pipes and under similar conditions preferably in the prolongation of the longitudinal welds. The test plates undergo the same heat treatment as the pipes.

10.3. - The marking of the welds to be inspected is carried out by the manufacturer, taking into account the client's or his representative's wishes.

10.4. - Erection welds are not generally subjected to mechanical tests.

11 - NON DESTRUCTIVE TESTS

Non destructive tests give information about weld soundness and quality of the work performed by the welders and welding machines. Inspection can be carried out by the radiographic or ultrasonic method or by a combination of the two processes.

11.1. - The radiographic examination permits to disclose weld defects such as porosities, slag inclusions, lack of fusion, cracks, etc... Generally, the radiographs are submitted to the Owner or his Representative for review. Acceptance criteria of welds are to be previously determined. The inspection Records will indicate the type of radiographic facilities, the isotopes and intensity thereof as well as the type of radiographic films and penetrameters used.

The radiographs are kept by the Manufacturers while copies are delivered to the Owner, upon request.

Requirements concerning the extent of radiographic inspections are indicated on Table 1. It is recommended to radiograph the junctions of longitudinal and girth welds.

11.2. - The ultrasonic examination permits to localize weld defects and to appraise the necessity for carrying out repairs or not. The Operator must be highly qualified. The base metal on either side of the weld must be free from segregations, laminations and other defects. Tolerances will be mutually agreed upon. All defects remaining after possible repair will be marked up and described in a written Report. The latter will also indicate the characteristics of the test equipment, search units and calibration blocks along with the frequencies used. This Report will be submitted to the Inspection Agent who may direct spot examinations if required. Table 1 gives instructions concerning the extent of inspections. It is recommended to complete the ultrasonic inspection by a radiographic examination of a weld junction.

11.3. - Apart from radiographic and ultrasonic inspections, other non-destructive tests can be performed. Soundness examination can be carried out to detect weld surface defects or cracks.

The soundness inspection method is selected in order to obtain the best inspection quality and depending on the test facilities available. It must be reminded that the ultrasonic inspection permits a better detection of fine defects such as cracks and is thus recommended first ; however efficiency of this method is questionable for non-ground welds under 12 mm thick for which a radiographic examination should preferably be used.

Vee welds over 20 mm thick, without sealing runs (with or without backing strips) will be inspected for soundness after complete filling of the weld groove. Absence of cracks in the first welding run may be checked by magnetic particle or dye penetrant examination ; in such a case spot inspections will be made on some weld seams.

The presence of a root face in partial penetration fillet welds does not permit a good interpretation of soundness examinations. Fillet welds Classes 1 and 2 will preferably be fully penetrated.

For welds Class 2 under 8 mm thick, soundness inspection may be limited to a magnetic particle or dye penetrant examination of the two faces after grinding to obtain clean surfaces ; the magnetic particle or dye penetrant examination can also be used to ascertain that surface defects have been removed after repairs.

11.4. - Acceptance criteria for defects - Repairs

The maximum permissible sizes of defects are given for the various weld classes on table 3 as concerns surface and shape defects and on the Tables dealing with soundness defects. (See Table 5 for radiographic inspection and Table 6 for ultrasonic inspection).

Defects beyond the acceptance limits are to be repaired.

However, if in view of the difficulties involved in the repair work the Manufacturer would think that performance of such repair-work may affect more seriously the final quality of the part than the non-removal of the defect, he will be entitled to submit to the Owner a proposal for waiving the repair work, giving fully details justifying his proposal.

Removal of surface defects (streaks, undercuts...) will preferably be carried out by mere grinding (provided underflushing is avoided) and to avoid building up by welding which often leads to risks of cracking during a quenching treatment.

12 - ACCEPTANCE

The client's representative generally confirms the acceptance of welds, more especially those of class 1 by approving the reports which have been prepared.

13 - TABLES

1 - Classes and inspection of welds
2 - Typical shapes of chamfers
3 - Tolerances on shape
4 - Mechanical tests of welds
5 - Radiographic weld inspection
6 - Ultrasonic weld inspection

TABLE 1 — Classes and Inspection of Welds

N.B. - The extent of testing will take into account the various thicknesses, base and welding materials and the processes used.

	Class I	Class II	Class III
A. Controls of the base material	According to the same classification as ANNEX III		
B. Control of welding (table 4)			
B1. Control of the procedure : number of tests (para. 9)	1 CT or documentary evidence	1 NT or documentary evidence	1 NT or documentary evidence
B2. Control of manufacture : number of tests (para. 9)			
CT	1 per lot of over 100T but at least 1 per 1000T	nil	nil
NT	1 per 250T or per 250m of weld length	1 per 500T or per 500m of weld length	1 per 1000T or per 1000m of weld length
C. Radiography and/or ultrasonic examination of welds (para.10)			
C1. Minimum extent of examination of welded lengths (when possible)	100 % (1)	10 to 20 % (1)	Spot check
In case of ultrasonic examination, the radiography of X % of the welded lengths will be added	5 to 20 %	5 %	
C2. Results			
- cracks or lack of fusion	not permissible	not permissible	not permissible
- lack of penetration	not permissible	not permissible	
- other defects	to be agreed upon, for instance, for the radiographs according to the IIS/IIW groups		
inclusions			
porosities	black or blue	blue	green
D. Examination of the mechanical properties of the welds			
D1. Yield point and tensile strength	adapted to those guaranteed for the base material (Annex III)		
D2. Elongation	Product RA equal to the minimum guaranteed for the base material (Annex III)		
D3. Impact Value	Average of outer surface and core on the one hand, and in the transition zone on the other, to be equal, for the same type of test piece, to the minimum value laid down by the manufacturer for a temperature 20°C lower for the base material as delivered (Annex III).		
E. Surface inspection of the welds			
Type of weld	with multipasses	with several passes	not prescribed
Sealing run	with sealing run	with sealing run	not prescribed
Surface condition	smooth without projection, upset or indercut	smooth	not prescribed

(1) These figures do not allow for the repetition of examination after repair of the non-permissible defects. If these defects occur often, the extent of examination will be increased. On the other hand, in case of complete absence of defects the extent of examination may be reduced to a suitable proportion according to the experience of the manufacturer and by agreement with the inspector.

TABLE 2

Typical shapes of chamfers

CHAMFERS
(butt-welding)

Classes I, II, III

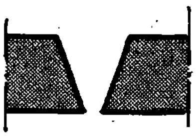


Fig. 1

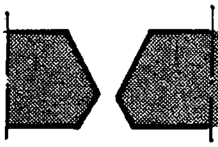


Fig. 2

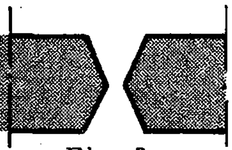


Fig. 3

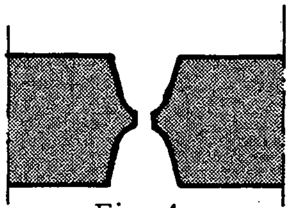


Fig. 4

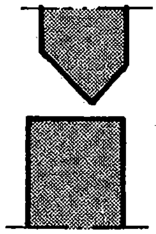


Fig. 9

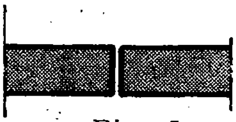


Fig. 5

Fig. 6

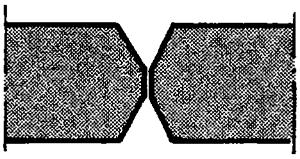


Fig. 7

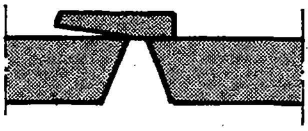


Fig. 8

GRADIENTS

1/4 or 15°

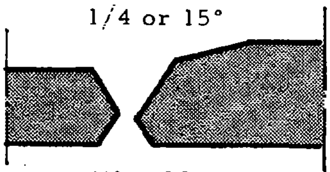


Fig. 10

1/4 or 15°

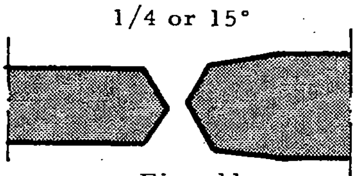


Fig. 11

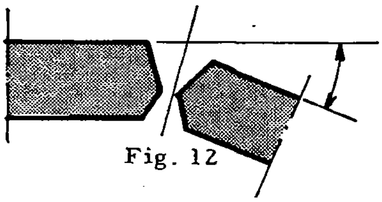


Fig. 12

I 15°
II 20°
III 30°

FLANGES
Classes I, II
1/4 or 15°

Corner Welds

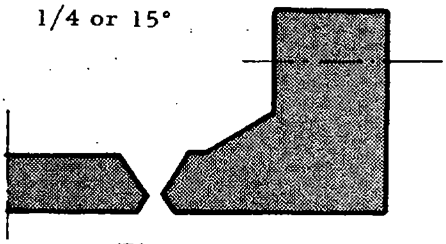


Fig. 13

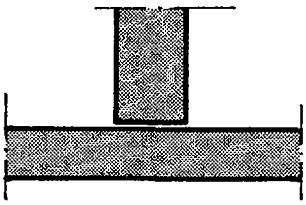


Fig. 14

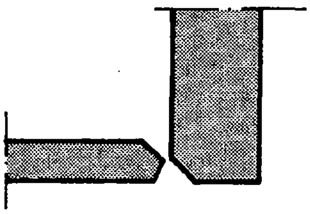


Fig. 15

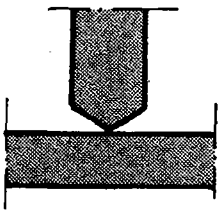


Fig. 16

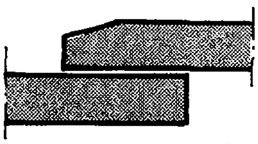


Fig. 17

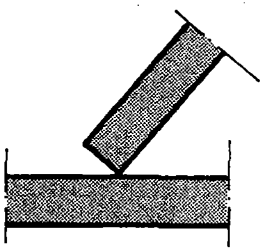
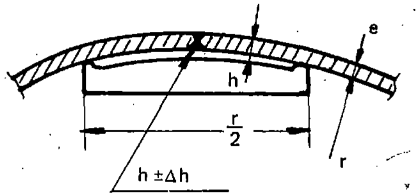


Fig. 18

TABLE 3 — Tolerance on shape (all dimensions in mm)

1 - Projection of flattening adjacent to the welds as for the pipe-section i.e

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



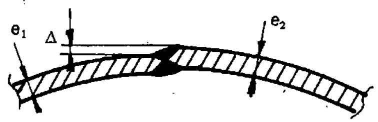
2 - Displacement of the longitudinal joint

Classes :

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

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

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



Δe Difference between the actual thicknesses of the edges involved

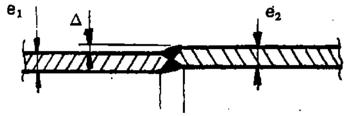
3 - Displacement ot the circumferential joint

Classes :

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

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

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



Δp Tolerance on the circumference according to the formula of Annex V (page 65)

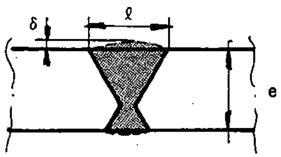
4 - Reinforcement of welds

Classes :

I $\quad \delta \leqslant 1 + \frac{3}{100}(e + \ell)$ mm

II $\quad \delta \leqslant 2 + \frac{e + \ell}{20}$

III tolerance not subject to control



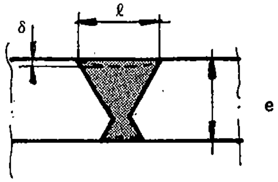
ℓ theoretical width between the edges of the chamfer

5 - Concavity due to grinding of welds

I $\quad \delta \leqslant \frac{e + \ell}{100}$

II $\quad \delta \leqslant \frac{e + \ell}{50}$

III tolerance not subject to control



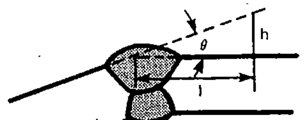
6 - Misalignment

Classes :

I $\quad tg\,\theta < \frac{1}{20}$

II $\quad tg\,\theta < \frac{1}{10}$

III $\quad tg\,\theta < \frac{1}{10}$



$tg\,\theta = \frac{h}{l}$

7 - Undercut

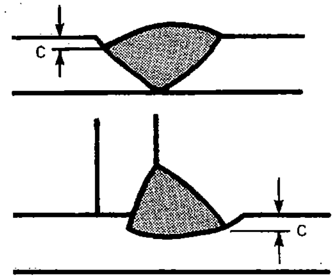
Classes :

I $\quad C < 0{,}5$ mm $\quad l_{max}$ 10 mm

II $\quad C < 0{,}5$ mm $\quad l_{max}$ 20 mm

III $\quad 0{,}5 < C < 1$ mm $\quad l_{max}$ 40 mm

$C < 0{,}5$ without length limitation



8 - Effective throat thickness

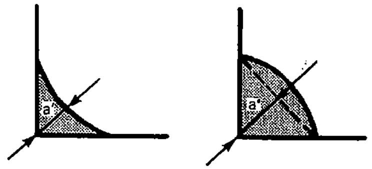
If a = theoretical throat thickness required by calculation :

Classes :

I $\quad a' \geqslant a$

II $\quad a' \geqslant a$

III $\quad a' \geqslant a$



9 - Connecting angle

Classes :

I $\quad \gamma 1 > 160°$
$\quad \gamma 2 > 120°$

II $\quad \gamma 1 > 145°$
$\quad \gamma 2 > 120°$

III $\quad \gamma 1 > 135°$
$\quad \gamma 2 > 120°$

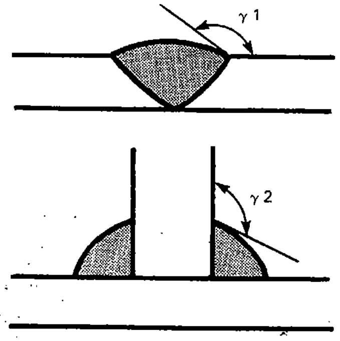


TABLE 4 — Mechanical Tests of Welds

CT **Complete test :**
(Test-piece about 400 x 900 mm)

- 100 % radiography or/and ultrasonic test
- 1 tensile test, test-specimen with parallel faces
- 1 bending test - weld ground flush - direct bending
- 1 bending test - weld ground flush - reverse bending
- 1 tensile test of the filler metal (cylindrical test specimen)
- 1 series of test specimens to determine the fall of impact value on the outer fibres and in the core
- 1 impact test in the transition zone (3 test-pieces)
- 1 test to determine the differences of hardness (base metal - outer fibres - transition)
- 1 chemical analysis of the deposited metal
- 1 macroscopic examination
- 1 micrographic examination (plate, transition, weld)

NT **Normal test :**
(Sample : about 400 x 500 mm)

- 100 % radiographic and ultrasonic test
- 1 tensile test - test specimen with parallel faces
- 2 bending tests - weld ground flush (as in CT)
- 1 impact test (3 test-specimens in the outer surface
  3 test-specimens in the core if the thickness of the plate makes it possible — only in classes I and II
  3 test-specimens in the transition zone
- 1 macroscopic examination

Dimensions of the test-pieces in compliance with standards to be agreed upon. Impact tests, notch perpendicular to the surface of the plate, sampling as per fig.:

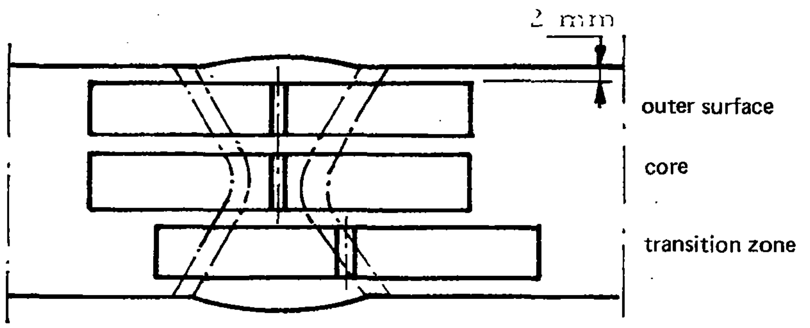


TABLE 5 — Radiographic weld inspection

MAXIMUM SIZE, L, OF SOUNDNESS DEFECTS (1)				
	CLASS 1		CLASSES 2 AND 3	
Nature of defects	within middle third of thickness	within external thirds of thickness (2)	within middle third of thickness	within external thirds of thickness (2)
Crack, flaw	permissible if $L < e$; max 10 mm	permissible if $L < \frac{e}{2}$; max 5 mm	permissible if $L < e$; max 10 mm	permissible if $L < \frac{e}{2}$; max 5 mm
Incomplete fusion or penetration	permissible if $L < e$; max 20 mm	permissible if $L < e$; max 10 mm	permissible if $L < 2e$; max 40 mm	permissible if $L < e$; max 20 mm
linear porosities or inclusions	permissible if $L < 2e$; max 60 mm	permissible if $L < e$; max 40 mm	permissible if $L < 2e$; max 80 mm	permissible if $L < 2e$; max 60 mm
Isolated gas cavity or blowholes	permissible if $\varnothing < \frac{e}{3}$; max 6 mm	permissible if $\varnothing < \frac{e}{4}$; max 4 mm	permissible if $\varnothing < \frac{e}{3}$; max 8 mm	permissible if $\varnothing < \frac{e}{4}$; max 6 mm

(1) L is the aggregate length of defects of same nature ; e is the thickness of the assembled plate ; these two defects are considered as a single one if spaced by a distance smaller than 6 times the length of the smaller defect.
(2) Defects of any length, open to the surface, must be removed.

TABLE 6 — Ultrasonic weld inspection

1 - GENERAL

The ultrasonic inspection must be performed by qualified operators, using an ultrasonic test equipment in perfect working order and of a modern design.

The plate surface, on either side of the weld seam (over a width of 150 mm) must be free from rust, scale, weld spatters, paint of uneven thickness, etc.) to permit a good contact with the search unit ; the weld seam surface must be free from irregularities.

Scanning is carried out on either side of the weld seam, using anglebeam searchs units (frequency : 2 or 3 MHz) and an inclination to the entry surface (normally of 70°) permitting complete coverage of the weld volume.

2 - SETTING OF ULTRASONIC EQUIPMENT

Detection of weld defects must be carried out with the maximum penetration and gain control giving an easy reading of the oscillogram ; this precaution permits to improve detection of non-volumic defects which may be badly orientated in relation to the ultrasonic beam direction.

Evaluation of a discontinuity is made after setting of the sensitivity level by adjusting the instrument gain control by means of a reference block on which defects are featured by a series of cylindrical holes located a gradual deeper distances from the contact face, the axis of these holes being parallel to the contact face and perpendicular to the ultrasonic beam direction.

The reference block must be manufactured from a steel similar to that of the part to be inspected. The absorption and the effect of the surface condition of the scanned part must be compared with those of the reference block : the attenuation variation must normally not exceed 4 dB for a path corresponding to one time the thickness.

Thickness of the reference block must correspond to the thickness of the part to be inspected :

— within ± 20% : for thicknesses under 50 mm

— within ± 10% : for thicknesses over 50 mm.

Diameter of holes is at most :

— 1.5 mm for thicknesses up to 100 mm

— 2 mm for thicknesses over 100 mm

and are located at the following depths :

— for thicknesses under 60 mm : one hole located at e/3

— for thicknesses over 60 mm : a series of holes every 20 mm of depth.

3 - EVALUATION OF DISCONTINUITIES

3.1. - Discontinuity reflection

Evaluation of a discontinuity is made by comparing its maximum reflection amplitude (Hd) to the amplitude (Hr) of the reference block hole located at the nearest depth, after due consideration, if required, of the correction to allow for attenuation variation between the reference block and the part to be inspected at the discontinuity.

3.2. - Differentiation between volumic and non-volumic discontinuities

Starting from the search unit location (position on the surface and orientation) for which maximum reflection amplitude (Hd) is obtained, the search unit is rotated around the discontinuity, the latter being kept in the symmetry plane of the search unit.

If the reflection decrease is smaller than 6dB $\left(\frac{Hd}{2}\right)$ for a total rotation angle of about 10°, the discontinuity is considered as volumic otherwise, it is considered as non-volumic.

Generally, non-volumic discontinuities such as cracks give high amplitude reflections. However, in some special cases such as for instance when the inclination of the ultrasonic beam to the discontinuity plane is too important, non-volumic defects may give low amplitude reflections.

3.3. - Length of discontinuities

The length L of a discontinuity is determined by measuring the distance between the two extreme positions of the search unit axis for which there is an attenuation of 6 dB $\left(\frac{Hd}{2}\right)$ in relation to the position giving the maximum reflection Hd.

3.4 - Case of two discontinuities forming a single discontinuity

Two discontinuities are considered as a single one if the distance between them is smaller than or equal to 6 times the length of the smaller discontinuity or to 20 mm when one of the discontinuity is a punctual defect. This condition only applies to discontinuities located within a metal volume limited by planes parallel to the surface of the part, each spaced by less than 20 mm.

MAXIMUM SIZE, L, OF SOUNDNESS DEFECTS (1)					
		CLASS 1		CLASSES 2 AND 3	
Nature of defects	Reflection amplitude (3)	within middle third of thickness	within external thirds of thickness (2)	within middle third of thickness	within external thirds of thickness (2)
Volumic defects	$Hd > \frac{Hr}{2}$	permissible if L < 2e ; max 60 mm	permissible if L < 2e ; max 40 mm	permissible if L < 2e ; max 80 mm	permissible if L < 2e ; max 60 mm
	$Hd < \frac{Hr}{2}$	permissible	See (4)	permissible	See (4)
Non-Volumic Defects	$Hd > \frac{Hr}{3}$	permissible if L< e ; max 10 mm	permissible if $L<\frac{e}{2}$; max 5 mm	permissible if L< e ; max 10 mm	permissible if $L<\frac{e}{2}$; max 5 mm
	$\frac{Hr}{3}>Hd>\frac{Hr}{10}$	permissible if L< e ; max 20 mm	permissible if $L<\frac{e}{2}$; max 10 mm	permissible if L < 2e; max 40 mm	permissible if L < e ; max 20 mm
	$Hd<\frac{Hr}{10}$	permissible	permissible L < 100 mm	permissible	permissible if L < 200 mm

(1) L is the aggregated length of defects of same nature ; e is the thickness of the assembled plate ; two defects are considered as a single one when spaced by a distance smaller than 6 times the length of the smallest defect.
(2) Defects of any length, open to the surface, must be removed.
(3) Hd = discontinuity reflection amplitude ; Hr = reference reflection amplitude.
(4) Continuous defects will be subjected to additional scanning if L > 50 mm (class 1) or 100 m (Class 2).

ANNEX V

CODE OF GOOD CONSTRUCTION AND ERECTION

Table of Contents

1 - GENERAL

1.1. - Lay out and siting of penstocks and steel linings

The general siting of the structures is laid down by the client under his full responsibility the manufacturer possibly intervening as an advisor for the laying out of the penstock profile.

The drawings required for the design of the penstock, site drawings, ground longitudinal profiles, cross-sections, drawings of the structures are supplied to the manufacturer ; in line with these drawings, marks are set on the ground by the client, at suitable distances, in a durable way to be used for the setting out of the structures and the erection on the penstock. If, during the preliminary works, the marks disappear, they shall be replaced by the client.

The manufacturer can make an additional pegging out of the longitudinal profile according to the survey-poles set up by the customer and himself mark the particular points necessary for the erection of the penstock. In this case, this pegging out which must be protected must not be used by the civil engineers for whose setting out of the structures the penstock manufacturer cannot be responsible.

It is advisable to adopt a minimum gradient for the penstock greater than the gradient arising from the deflection permitted by the maximum construction tolerances or from bending between supports.

1.2. - Design and Dimensioning of the Civil Engineering Works

The penstock manufacturer is not responsible for the load bearing capacity of the ground, nor the maintenance and execution of the anchor blocks but only for the value of the forces defined by the features of the penstock. The manufacturer shall be advised, where necessary, of the movements of the ground to be taken into account in the calculation of the penstock.

The manufacturer's drawings set out the maximum forces which must be taken into account for calculating the stability of the structures. They detail the connections between his supply and the civil engineering structures and the different phases of concreting.

The dimensions of the structures subjected to these forces are so determined as to ensure a distribution of the permissible loads according to the nature of the ground as well as the resistance of the structure to sliding, overturning and upheaval.

If the manufacturer himself makes the drawings of the anchor blocks, the client will transmit to him the permissible pressures on the ground, determined, if necessary, by previous borings. These drawings shall detail the dimensions and the various phases of execution of the blocks necessary for the erection of the penstock excluding any other detail concerning the civil engineering.

The firm entrusted with the civil engineering works draws up its working drawings and carries out all the topographic operations necessary for the sitting of the structures as well as for the checking, preservation and maintenance of any initial pegging out which may have been done by the penstock manufacturer.

The drawings of the civil engineering firm must be sent to the manufacturer for checking the parts of the structures which are connected with his supply.

2 - CONSTRUCTION

2.1. - Openings in penstocks

Inspection openings shall be allowed for and shall make it possible to maintain the inside of the penstock. If possible, they shall not be more than 300 m apart.

At the lowest point, one or more draining-holes shall be provided ; one of these holes must be large enough to discharge under full load.

Air intake and discharge holes shall be placed at the upper points.

2.2. - Connection between supplies from different manufacturers

Unless otherwise agreed, the bolts, nuts and washers for connections by flanges on the penstock head valves or on the turbine emergency valves are not supplied by the penstock manufacturer. Also, the templates which may be required for drilling the flanges are not provided by the manufacturer. This provision applies to the other valves and fittings excluded from the supply of the penstock.

In case of welded connection, the part to be connected shall only be made after the manufacturer has agreed upon its lay-out and dimensions as well as upon the quality of the steel used and the weld preparation.

ANNEX V

CODE OF GOOD CONSTRUCTION AND ERECTION

Table of Contents

1 - GENERAL

1.1. - Lay out and siting of penstocks and steel linings

The general siting of the structures is laid down by the client under his full responsibility the manufacturer possibly intervening as an advisor for the laying out of the penstock profile.

The drawings required for the design of the penstock, site drawings, ground longitudinal profiles, cross-sections, drawings of the structures are supplied to the manufacturer ; in line with these drawings, marks are set on the ground by the client, at suitable distances, in a durable way to be used for the setting out of the structures and the erection on the penstock. If, during the preliminary works, the marks disappear, they shall be replaced by the client.

The manufacturer can make an additional pegging out of the longitudinal profile according to the survey-poles set up by the customer and himself mark the particular points necessary for the erection of the penstock. In this case, this pegging out which must be protected must not be used by the civil engineers for whose setting out of the structures the penstock manufacturer cannot be responsible.

It is advisable to adopt a minimum gradient for the penstock greater than the gradient arising from the deflection permitted by the maximum construction tolerances or from bending between supports.

1.2. - Design and Dimensioning of the Civil Engineering Works

The penstock manufacturer is not responsible for the load bearing capacity of the ground, nor the maintenance and execution of the anchor blocks but only for the value of the forces defined by the features of the penstock. The manufacturer shall be advised, where necessary, of the movements of the ground to be taken into account in the calculation of the penstock.

The manufacturer's drawings set out the maximum forces which must be taken into account for calculating the stability of the structures. They detail the connections between his supply and the civil engineering structures and the different phases of concreting.

The dimensions of the structures subjected to these forces are so determined as to ensure a distribution of the permissible loads according to the nature of the ground as well as the resistance of the structure to sliding, overturning and upheaval.

If the manufacturer himself makes the drawings of the anchor blocks, the client will transmit to him the permissible pressures on the ground, determined, if necessary, by previous borings. These drawings shall detail the dimensions and the various phases of execution of the blocks necessary for the erection of the penstock excluding any other detail concerning the civil engineering.

The firm entrusted with the civil engineering works draws up its working drawings and carries out all the topographic operations necessary for the sitting of the structures as well as for the checking, preservation and maintenance of any initial pegging out which may have been done by the penstock manufacturer.

The drawings of the civil engineering firm must be sent to the manufacturer for checking the parts of the structures which are connected with his supply.

2 - CONSTRUCTION

2.1. - Openings in penstocks

Inspection openings shall be allowed for and shall make it possible to maintain the inside of the penstock. If possible, they shall not be more than 300 m apart.

At the lowest point, one or more draining-holes shall be provided ; one of these holes must be large enough to discharge under full load.

Air intake and discharge holes shall be placed at the upper points.

2.2. - Connection between supplies from different manufacturers

Unless otherwise agreed, the bolts, nuts and washers for connections by flanges on the penstock head valves or on the turbine emergency valves are not supplied by the penstock manufacturer. Also, the templates which may be required for drilling the flanges are not provided by the manufacturer. This provision applies to the other valves and fittings excluded from the supply of the penstock.

In case of welded connection, the part to be connected shall only be made after the manufacturer has agreed upon its lay-out and dimensions as well as upon the quality of the steel used and the weld preparation.

2.3. - Flange-joints

Flanges are preferably shop welded rather than site welded.

When flange joints are not absolutely necessary for erection or connection reasons etc... all joints are preferably made by butt-welding.

The bolts, nuts and washers for joining the flanges shall be of proper quality. All the bolts of the same joint shall be uniformly tightened to the stress called for.

When the shape and the magnitude of the structure, the steel and the welding process used require it, the joints must undergo a stress-relieving heat treatment either locally or on the whole part. The temperature and duration of the possible heat treatment shall be laid down according to the type of steel employed.

2.4. - Inspection

2.4.1 - Dimensional controls as per attached Table I
2.4.2 - Steel controls as per Annex III
2.4.3 - Weld inspection as per Annex IV
2.4.4 - Supervision of manufacture
The client's representative may be sent to attend these inspections.

2.5. - Shop hydraulic test

When a hydraulic test is called for, it can be carried out either between the plates of a test press or between heads.

In some cases, for special parts, strain-gauges measurements or model test can be requested by the client. If the test conditions entail, on account of the test pressure, stresses different from those resulting from the normal working conditions of the installation, supporting calculations can be supplied.

Elbows can be tested as straight members before being finished (tests of longitudinal welds only).

If the test discloses unacceptable faults such as leakages and local strains, the repairing process shall be agreed by the parties concerned and will include a new hydraulic test.

2.6. - Anti-corrosion protection

The anti-corrosion protection can be a part of the manufacturer's supply.

The surfaces to be coated shall be prepared with regard to the protection called for. Weld burrs and roughness of the seame which would be detrimental to ther performance and to the appearance of the coating shall be removed.

Pipe-ends to be field welded can be protected by a coat of a product which can be easily removed before welding and/or which does not interfere with welding or inspection or the application of the final coating.

2.7. - Delivered weights

The difference between the total or partial delivered weight and the theoritical corresponding weight derived from the approved working drawings of the penstock sections arises from the total of the variations due to the dimensional tolerances of the materials supplied by the iron-works and by the rolling-mills and the fabrication tolerances.

3 - ERECTION

Penstocks consist of sections anchored at their ends, with or without an expansion joint.

3.1. - Determination of the temperature on connecting up to penstocks or adjustment of expansion joints

The information required for this determination as follows :

- the data used for the calculation of the penstock
- the extreme temperatures of the penstock in operation or extreme temperatures of the turbine water (forecast or observations effected on a parallel installation)

- the extreme temperatures of the empty penstock
- the extreme temperatures of the penstock filled still water (off load with filled penstock)
- the taking of the elongation and contraction measurements in the erected penstock before the connections are made.

These measurements are taken between two marks placed at each joint for the extreme temperatures which it is possible to establish during the operation.

3.2. - Cleaning and internal inspection of the penstock

Before putting into service, the penstock must be cleaned and freed from any foreign bodies which may be found in it (wood, rags, electrode waste, cement, etc...) because these bodies can damage or choke the turbine distribution. The client will lay down the cleaining methods with the firms concerned.

A general inspection shall be carried out inside and outside the penstock by the manufacturer's or erector's representative in the presence of the client's representative and possibly the turbine-manufacturer's delegate (should he so request).

This inspection shall be mentioned on the test and acceptance report of the works.

3.3. - Inspections

The manufacturer shall make sure by suitable inspection that the erection meets the requirements.

- Inspection of welds as per Annex IV
- Inspection of the siting of the works and of the position of the assembled elements (compliance with the drawings)
- External inspection of the erected supply (among other things it will be checked that the filled or empty penstock bears properly on its supports.

A representative may be sent by the client to attend these inspections.

When the parts are despatched in sections and assembled before they are put in place, the manufacturing controls are the same as those carried out in the manufacturer's workshop.

In case of penstocks or linings concreted in tunnel, shaft or dam, the manufacturer may determine the wedging and the internal reinforcements necessary during the concreting process of during any cement groutings according to the means of concreting and the pressure of grouting which will be stated to him by the client.

In the case of a free penstock laid in a tunnel or a trench, there shall be adequate room between the penstock and the walls to make possible the inspection of the welds, and the inspection and subsequent maintenance of the penstock.

In the of a backfilled trench, the backfill must be deposited by successive compacted layers, the manufacturer not being responsible for the proprer carrying out of this work.

As soon as erection is completed, the unpainted parts (welded joints) shall be prepared and touching up and couplings carried out. The finishing off of protective measures shall be done in accordance with planning requirements.

The final protection is then applied according to the selected process.

4 - TESTS AND ACCEPTANCE

4.1. - Filling tests

On completion of erection, the penstock is filled : its stability and tightness are then checked.

For filling the penstock, the under-mentioned operations shall be carried out :

- Check the closing and tightness of emergency valves, heads, inspection openings, emptying valve and all the accessories.
- Open the air-cocks (air release valves at the top of the penstock, waste cocks at the high points such as spherical distributors, ventiducts, etc...).
- Fill slowly and a most with a flow rate equal to 1/10 normal flow so that the air can be more easily removed more especially in the horizontal or near horizontal sections.
- Maintain constant communication between the supervising staff at the distributor (watching the control and recording pressure ganges) and the staff at the penstock head (supervising filling and air discharge).

Filling must only be carried out after making sure of :

- the complete state of readiness of the penstock
- the proper operation of the valves and accessories and the possibility of emptying the volume of water very quickly.
- the cleaning of the tailrace, the tunnel gutters and any place liable to be used for the discharge of water
- the safety of staff working on the test and of staff working in the neighbourhood who could be hurt by the accidental bursting of the penstock.

Carrying out of the test :

The test includes putting under pressure either up to the normal static pressure or preferably a higher pressure. The ends of the penstock can be sealed either by heads or by turbine head or emergency valves made water-tight.

Static tests :

Pressure is raised to test pressure and maintained sufficiently long to check the tightness of all welds and inspect the penstock completely, at least 30 minutes. A pressure gauge, preferably of recording type, enables these operations to be controlled.

Dynamic Tests :

If specified in the contact, systematic water hammer tests corresponding to shut-off of the total flow rate or to a partial instantaneous variation can be carried out by the client. In this case, very accurate recording instruments must be provided and strain-gauge measurements can be made at particular points.

Emptying of the penstock after testing :

The penstock can be tested only if there are means of rapidly emptying the volume of water contained in the penstock.

Emptying is generally carried out through a turbine as long as the water level remains adequate : the emptying of the lower point is completed by the drain-valve designed for this purpose.

In default of emptying through a turbine, a drain-opening operating under full load can be used and fitted with the necessary energy destruction device ; the diameter of the opening must be so dimensioned as to discharge the volume of water very quickly.

4.2. - Head losses

The head losses in penstocks are determined by mathematical formulae and factors defined by the client in agreement with the manufacturer. Generally, the mathematical formulae used make possible the determination of the linear head loss and particular losses in known parts such as converging and diverging sections, elbows, valves, etc...

The linear head loss factors are defined according to the surface roughness of the anti-corrosive protection provided for the inside of the penstock. In special parts such as bifurcations, distributors, etc... the head losses can be determined by mathematical calculation or by model tests.

The estimate of the efficiency of the installation in service should take into account unavoidable inaccuracies in the calculations for evaluating the head loss, and possible errors in the measuring instruments.

If the results of the tests are found to be deficient, a new test shall be made after a working period at least equal to the guarantee period of the installation.

4.3. - Acceptance of the work

After carrying out the filling and possibly the overpressure and flow tests, a report detailing these operations and the observations made shall be prepared by the client and the manufacturer.

If the result of the tests is satisfactory, the provisional acceptance of the installation shall be pronounced. If these tests cannot take place at the time desired, provisional acceptance will be automatically pronounced after a time stated in advance related to the erection completion time.

At the end of the guarantee period called for, the final acceptance shall be pronounced without any other formality.

Acceptance as regards the protection of surfaces shall be covered by a special clause.

TABLE I

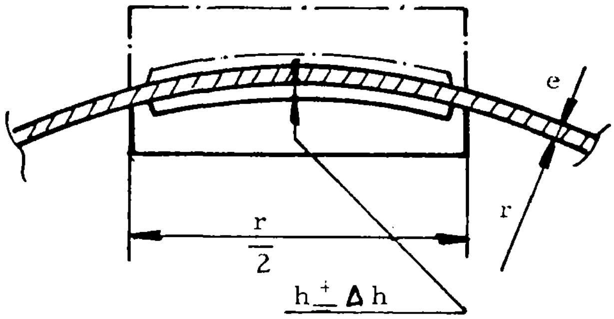
The following tolerances can be applied to constructions requiring welds belonging to classes I and II.

— Tolerances on dimensions

— Roundness

To control the roundness, pipes with large diameters and small thicknesses can be suspended or internally stiffened.

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

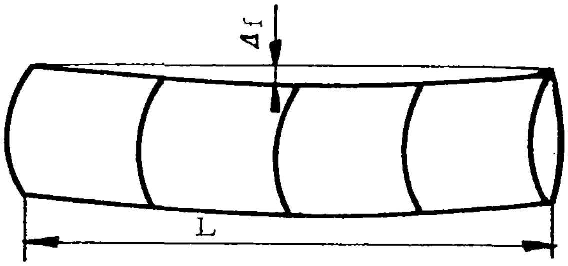


— Variation from theoretical periphery

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

— Straightness of generating lines

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



Application of the formulae	r = internal radius of pipe e = thickness of wall L = length of pipe	all the measurements are in mm

Thickness of walls : e according to the tolerances permitted by the iron-works.

Tolerances on diameters resulting from the tolerances on roundness and circumference.

— Supervision of construction

Inspections can be carried out by the client's representatives in agreement with the manufacturer, including :

— inspection of the welds as per Annex IV

— surface inspection and checking of dimensions.

IMP. L. HARDY - PARIS
Imprimé en France

ANNEX VI

PROTECTION OF SURFACES

Table of Contents

1 - GENERAL

The protection of penstock surfaces by coating is characterized by the extent of the surfaces to be protected and the characteristics of water and environment. The characteristics must the refore be shown on the Invitation to Tender Documents (see Appendix B hereafter). The various operations of construction and installation often require to separate the successive coating stages.

The cathodic protection of the surfaces is not considered here.

1.1. - Properties required of internal coatings

An internal coating must meet the following major requirements :

- metal protection against corrosion
- impermeability
- adhesion to metal
- resistance to abrasion
- resistance to shocks
- resistance to temperature variations
- low rugosity to reduce head losses to a minimum

1.2. - Properties required of external coatings

The main properties required of an external coating are defined according to the lay-out of the Work (above ground and exposed to bad weather conditions, free in tunnel, buried, etc...) and include :

- protection of metal against corrosion
- resistance to chemical reactions, more particularly those due to organic products such as pollens, etc,...,
- resistance to temperature variations, sun conditions, humidity and condensations ;
- resistance to shocks during transportation, erection and backfilling of penstocks and to stone-falls on exposed penstocks ;
- final shade of colour determined by aesthetic factors or to promote resistance to sun conditions;
- adhesion to metal
- impermeability.

2 - PROTECTING OF SURFACES

2.1. - Nature of protection

The penstock protection by coating will include the following operations :

a) Preparation of the surfaces to be protected by means of a mechanical cleaning process;

b) Surface treatment using passivation, metal-spraying or any other process or application of some primary (or primer) coats consistent with the nature of the metallic surface;

c) Application of the coating products themselves in one or a number of coats constituting the protective system;

Since the protection work may be partially or completely carried out at the Manufacturer's workshops, on a yard, under shelter or upon completion of the erection, the manufacturer or applicator will have to indicate the scheduled method and application programme, with due consideration to the Employer's requirements.

2.2. - Preparation of surfaces

All welds inside the penstock to be particularly smooth in order to avoid an accelerated abrasion on the asperities or through whirling behind them.

The surfaces to be free of any contamination and made suitable for the coating application. In particular, they will be thoroughly scaled and free of any grease mark.

All interstices between parts welded together such as stiffening ribs, bearing rings, etc... to be, in so far as possible, sealed off by a continuous weld.

2.2.1. Cleaning processes

The penstock wall surfaces will be cleaned by spraying corundum or other material or, exceptionally, by mechanical brushing, depending upon the surface condition required and the penstock diameter. In addition, the dust will be removed from those surfaces by means of a dry oil-free air jet.

Hand cleaning and de-rusting will be used only when the spraying process is impossible and solely for surfaces that are not in contact with either running or condensation water.

The grade of spray cleaning is specified by the standard blocks of Swedish scale SIS 05.5900. The SA 3 grade of this Standard Specification will be required for the acceptance of the metal spraying or of the products the adhesion of which necessitates the same precautions.

The cleaning grade will be controlled by way of a 8 to 10 times luminous magnifying-glass. The surface will be fully scaled, whatever the required cleaning grade may be.

The rugosity required for a good adhesion, or about 50 μm, can be visually checked against a sample corresponding to Rugotest n° 3 LCA-CEA.

The spraying process will not be used when the relative humidity of the air exceeds 80 %, when its temperature is less than 10°C higher than the condensation temperature or if the surface has become wet by rain or fog.

Since the cleaned surfaces are particularly sensitive to oxidation, it will be necessary to envisage the application of the metal-spray or the first coat of the protective system immediately after cleaning is completed.

2.2.2. Materials used for spray cleaning

Corundum (electrically molten and crushed alumina) or any other equivalent material; or else, if this is accepted, quartz sand, will be used for spray cleaning.

The size (diameter) of the grains depends on the work to be carried out. It varies from 0.6 to 1.6 mm for corundum and from 0.7 to 2 mm for sand.

Corundum and quartz grains finer than 0.5 mm are ineffective and reduce the adhesion of the coating. Large grains, from 1.5 to 2 mm, may be kept for a first cleaning of old paints and/or a heavy rust.

The sand will be perfectly washed and free of dust so as to exclude any impurities such as, for instance, traces of clay, non-ferrous metals, electrolytes and on the other hand, would corrode the steel plate even under an impervious cover.

2.3 - Metal spraying

Metal spraying is needed to protect metallic surfaces against the corrosion caused by an electro-chemical couple.

Metal spraying with a spray-gun (Shoopisation system) of internal surfaces is not recommended for waters with a pH higher than 8.5 or smaller than 5.0 as well as for service pressures higher than 40 bars, unless a pore sealing paint (zinc powder base paint, for instance) is used. Metal spraying will not be applied when pressure exceeds 60 bars or for diameters of less than 700 mm.

Preferably, zinc protection will be selected for penstocks. The wire used will have à 99,95 % purity and the required thickness will correspond to the ZP 120 symbol.

	Minimum thickness (μm)	Zinc weight (Kg/m2)	
		theoretical	to be sprayed
ZP 120	120	0.8	1.2 to 1.3

Upon completion of metal-spraying, the possible droplets adhering to the treated surface will be scraped off with a grindstone. Furthermore, the surface will be carefully freed from dust by way of compressed air before being filled in by the primer paints. The first of the should preferably be a zinc powder and epoxy resin base paints.

Protection by zinc rich paint is considered as an anti-corrosion coating, like the other products specified under "coatings".

2.4. - Coatings

The first coat, called "bonding layer", will be manually applied, crossing several times the working direction. It will be applied with a wire-brush or with a roller or preferably with a paint brush. Using the spray gun is not recommended, because it cannot eliminate a possible film of water, often invisible (2 to 5 m)

The intermediate and finalcoats will be applied by any means accepted by the manufacturers and the drying times corresponding to the temperature of the moment will have to be met.

Touching up and any additional work will be carried out in accordance with the selected protective system, including all the different phases provided for.

2.4.1. - Data sheets for the products used

The following data concerning the products used for the protection wil be shown on a sheet :

- Commercial names
- Types
- Covering power per coat (Kg/m2)
- Number of coats
- Thickness of coating
- Shades of successive coats
- Application methods
- Application temperatures
- Drying time between coats (minimum and maximum if necessary) at 10 and 20°C.
- Setting time
- Origin of pigments
- Delivery state
- Packaging
- Duration and permissible storage conditions
- Specific weights (masses) of delivered product and dried product.
- Preparations recommended for the support
- Thinners and solvents to be used.
- Proportion of solid components of the products ready for use
- Chemiccal and organic resistance
- Accepted range of service temperature
- Resistance to water and bad weather conditions
- etc...

2.4.2. - Types of protective systems

The following protective systems are recommended for the penstock coatings :

2.4.2.1. - Internal coating for diameters enabling spray cleaning

- Surface preparation : cleaning to white metal (SA 3)
- Protective systems :
  a) Multi-layer of bituminous paint or other
  b) Multi-layer of paint requiring a particularly careful processing, such as epoxy and polyurethane paint with or without solvent.
  c) ZP 120 metal-spraying followed by a sealing off operation with bituminous paint or other
  d) Zinc powder epoxy paint covered by several layers of bitumen or coal tar The successive layers will be differentiated by their shades of colour.

2.4.2.2. - External coatings

- Surface preparation : Cleaning to white metal (SA 2. 1/2 or 3). Wirebrushing will be exceptionally permitted for the bituminous paints.
- Protective systems :
  e) Multi-layer with bituminous paint or other, depending if a black, metallic or colour finish is required.
  f) Multi-layer with bituminous paint receiving a hot-applied enamel (penstocks in free tunnel).
  g) Multi-layer as in f) byt with insertion of linen cloth of fiberglass between two layers of appropriate paint (buried penstocks).
  h) ZP 120 metal spraying followed by a sealing off with bituminous paint or other.
  i) Multi-layer with paint requiring a particularly careful processing (equal to b) above).

2.4.3. - Concreted-in areas :

Surfaces to be in contact with the concrete will be free of pipings, scale and rust, using appropriate means. They could receive a thin primer coat of chlorinated rubber base paint, for instance, when a long storage or marine transport is anticipated. In all the other cases, the surfaces in contact with the concrete will be left in rough condition and without protection. However, the protection adopted for the parts not in contact with the concrete will be extended by 20 cms inside the concrete.

2.5. - Comparative tests of coatings

It may be worth comparing various alternatives for coatings relative to their resistance under service conditions.

2.5.1. - Comparison of resistance

The comparison of mechanical and chemical behaviour of the various possible coatings can be effected only by comparison of their resistance to corrosion, ageing and abrasion, when these coatings are placed in identical test conditions, for instance, on a similar structure already in service.

It is to be noted that any accelerated ageing can only provide information on the behaviour of a coating under those test conditions, which differ from service conditions. Any transposition of results would be very doubtful.

2.5.2. - Comparison of rugosity

Il a comparison of the rugosity of the various coatings is required, it could be made by compared measurement of the head loss in identical penstock sections onto which these various coatings would have been applied.

3 - CONDITIONS FOR CARRYING OUT PROTECTION

3.1. - Protection carried out at the manufacturer's workshop

The protection work can be entrusted to the manufacturer. It could be carried out by him, if the has a paint-shop; otherwise, he may sub-contract the work, under his responsibility, to a paint applicator of his choice.

If, upon special agreement, a paint applicator selected by the Employer is to carry out the protective work at the Manufacturer's shops, the latter will make available to him, on a charge basis, the shelters, workshops, areas for storage or working purposes together with the required power and he will ensure the handling of the parts to be treated.

Apart from any paint protection which the Manufacturer could be led to carry out, he will have to perform the temporary protective work necessitated by the construction and erection operations such as :

- Lubrication of mechanical parts (more especially studs, bolts, threaded plugs, etc...) unless they are of stainless steel;
- Easily removable varnishes or coatings, protecting if necessary the machined surfaces, the faces of joints of flanges and bosses, etc...

The weld chamfers could be protected by a primer not liable to impede welding operations, or by an easily removable coating.

3.2. - Protection of pipe ends and adjusting sleeves

To ensure satisfactory welding operations during erection or on site and to avoid any destruction or modification of a coating carried out at the workshop, this coating will be stopped as follows (fig. 1).

a) For a conventional pipe of wall thickness t : inside and outside, at a distance equal to (6t + 100 mm) on each side.

b) For hooped pipes : inside, at a distance (6t + 100 mm) and outside, at a "half pitch distance between hoops + lateral face and external face of the first hoop".

c) For a pipe with an adjusting sleeve : at a distance (6t + 100 mm) from the non-covered edges and, on the covering side, at a distance (6t + 100 mm + A) where A is the greatest expected covering length.

d) The distance of the coating end will be increased and defined by the Manufacturer when a local stress-relief heat treatment of the field welds will have to be carried out.

Depending upon the extent of these areas, it might be preferable to perform all this protective work upon completion of this heat treatment.

e) Certain products could be applied to the whole surface including the weld chamfers and are then evaporated or burnt during the welding operations without impairing the weld. This is, for instance, the case with zinc powder rich paints provided their thickness does not exceed 20 μm. In case of doubt, two normal weld tests (Appendix IV, Table 4) will be conducted with the proposed product. The discharge of toxic or merely troublesome vapours should be correctly ensured.

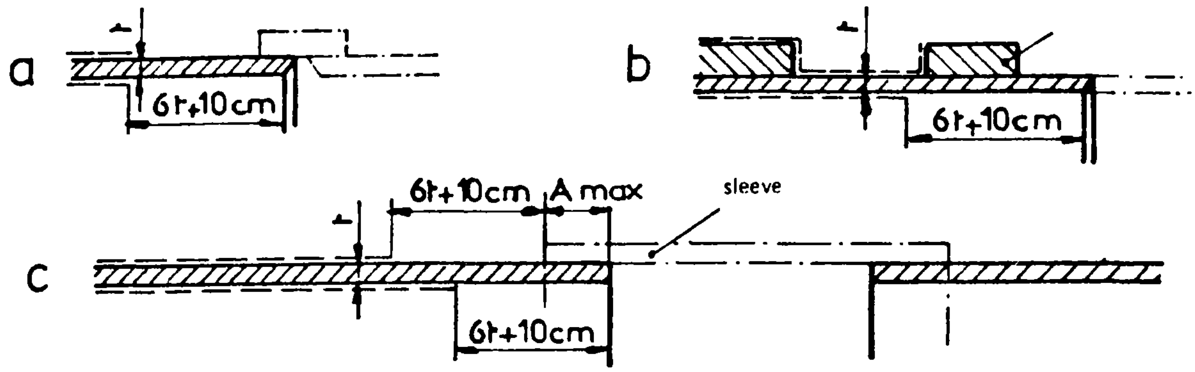


Fig. 1 – Protection of pipe ends

3.3. - Protection carried out on site and/or after erection :

When a partial or complete protection has been carried out at the workshop, the protective work to be carried out on Site includes three parts :

- Touch-up of the coatings carried out at the workshop and damaged during handling operations, transports storage and erection.
- Completion of coating on the areas left bare for welding and inspection of welded joints or certain pipe jointings.
- Application of additional finish layers to the whole penstock.

When no protection (except the temporary protections defined in para. 3.1.) has been carried out at the workshop, the work to be performed at Site will include all the operations stated for the protection : Preparation of surfaces and application of the coating (s).

This work could be done on the storage Yard, or in parallel with the erection progress or preferably upon completion of the erection work.

The spray cleaning will be carried out under the conditions set forth in Article 2.2.1. This will possibly necessitate the insulation and air-conditioning of the paint application Site. Laying of the initial coat of the system, which could be metal-sprayed, will be done in the shortest possible time and under the same atmospheric conditions. For subsequent coats, the requirements of the products's suppliers will be strictly adhered to.

According to terms to be defined with the erection Contractor, the Applicators may use the Contractor's facilities or be required to supply and install their own equipment for the achievement of the protective work.

The erection programme must foresee the execution of those operations through a joint agreement between the main Contractor, the penstock erector and the coating paint applicator.

The erection Contractor and, if the case arises, the Civil Contractor (grountings) must proceed with the cleaning of the penstock before making it available to the applicator. The surfaces must be free of foreign matters and defects such as weld droplets, erection accessories, residual cement, traces of oil and grease, etc... liable to necessitate subsequent touch-up work.

These firms are generally responsible for damage, which could have been avoided and are due, for instance, to : lack of care in stowing of pipes on the erection trolleys, moving of equipment by sliding on the coatings, frictions of hoist ropes, mooring of welding or erection platforms, jets of hot welding rods, etc...

The Contracts passed with the Firms will make clear their respective responsibilities. They will in particular indicate the maximum surface percentage which should be repaired at the applicator's expenses.

It results from the above that it will be almost always preferable to achieve the full coating system once the erection is completed. The superior quality of the protection so performed generally permits a longer guarantee period.

4 - INSPECTIONS AND ACCEPTANCE TESTS

4.1. - Inspection of products

Samples of the products for check of compliance or for analysis can be taken by the Employer from the manufacturer's plant or from the applicator's shop. The replacement of the products and the expenses incurred by this replacement, if the analyses disclose anomalies, will be borne by the applicator or the manufacturer.

Fabrication of the products used and their labelling will comply with the rules applicable to paints. The safety rules required during their application will be strictly observed.

The use of products as well as the work force and the recording of the stock required for the implementation of the programme, will be placed under the applicator's entire responsibility.

Before starting on work, the applicator will submit referenced metallic test plates, of sizes 150 x 210 x 2 mm (A5), the latter having to be increased (A4) when the product is less easy to apply. These test plates will be prepared according to the specification and will receive the specified products with the exact utilization shades selected and specified number of layers applied in compliance with the methods described in the offer or the order (fig. 2).

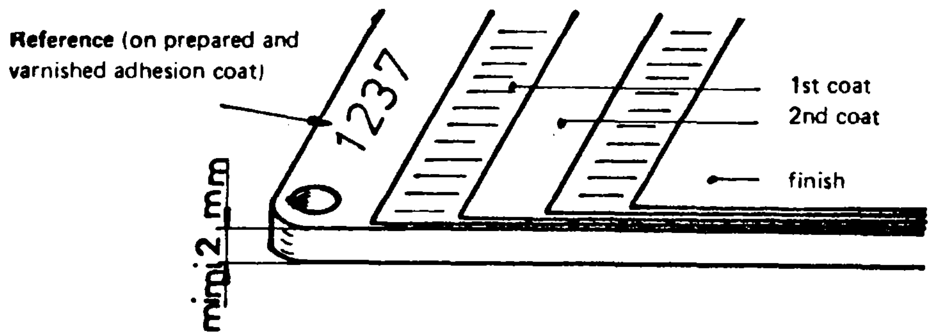


Fig. 2 – Example of sample plate

4.2. - Inspection of coatings

Upon completion, the coating appearance must be in accordance with the requirements and the test plates supplied.

Checking the thickness during the work is often useful. A final inspection of the thickness is recommended.

If the coating thickness is subject to a guarantee, it will be checked after its drying time in a number of areas of 1 m2 representing together a percentage of the total surface of the coating that will be specified in the Invitation to Tender documents. Within each area of 1 m2, one will select for instance 8 elementary surfaces of 1 dm2 for a paint application and 16 for a metal-spraying when 10 punctual measurements of the thickness will be effected. The average of the measurements over 1 dm2 must not be smaller by more than 10 % of the contractual value and no single measurement must show a thickness smaller by more than 30 % of the guaranteed thickness. If, over 1 dm2, these tolerances are not met, the coating thickness will be measured on two more adjacent elementary surfaces.

The applicator will have to bring up the thickness of the coating wherever it is recognised to be insufficient.

The thickness measuring unit will have been preferably calibrated and crosschecked by both the Employer and Applicator.

When, for internal coatings, a checking of the impermeability is specified, this will be done to an extent to be specified in the order, for instance on a number of elementary surfaces from 20 to 30 dm2 totalling at least 5 % of the total surface, with the elementary surfaces distributed over the perimeter and length of the structure.

4.3. - Acceptance of Protection - Guarantees

Upon completion of the work and sometimes independently of the penstock filling tests, an inspection of the protective work will be carried out for acceptance purposes and a report drawn up.

This acceptance will be based on the examination of the coatings for aspect and continuity and possibly, the checking of impermeability and thickness.

This acceptance will be considered provisional if the duration of the protection is subject to a guarantee clause.

The guarantee period will be calculated from the day the protection is provisionally accepted and at the latest, however, one month after completion of the work if the inspection for acceptance purposes cannot take place at an earlier date.

Any touch up or partial repair of a coating recognized to be defective after cross-checking should not delay the acceptance of the protection if the surface to be touched-up does not exceed 5 % of the totality of the protected areas and if the repair work is carried out immediately.

The guarantees given may concern the thickness, impermeability, aspect, rugosity, rusting degree and adhesion of the coating. In the interest of all concerned, they will be given jointly by the supplier of the products and by the applicator, the costs incurred by making good on a coating having to be fairly evenly shared between those Firms.

These guarantees will be defined knowing the quality of the coating, the conditions in which the application will be made and also the operating characteristics of the structure.

The guarantee will only cover the reconditioning costs, in accordance with the protective system specified in the order. The following will therefore be excluded from such guarantee :

- All costs and consequential damages and, in addition :
- Mechanical damage (by pressure, shearing, etc...)
- Damage due to a chemical, thermal, bacteriological or electrolytic unexpected action.
- A slight variation in colour.

The maximum duration of guarantee periods that can be contemplated, save for a particular request from the Employer, are defined in Appendix VI.A.

The behaviour of a coating is generally assessed by comparing its aspect with the reference blocks put forward by :

- "L'Echelle Européenne de degrés d'enrouillement pour peinture anti-rouille", called "Echelle européenne" by the European Committee of Paint and Painting Ink Manufacturers Association
- The Swedish Standard Specification SIS 05 5900 - 1967 "Pictorial Surface Preparation Standard for Painting Steel Surfaces" (1) which corresponds to the American Standard Specification "SSPC Visual Standard Vis 1 of the Steel Structures Painting Council".

4.4. - Periodical inspections

Cross-inspections between the applicator and the manufacturer will be provided for. The date of the first visit as well as the periodicity of these inspections will be specified. Normally, four visits spread over the guarantee period will have to be provided for.

---

1) This standard Specification relates, on the one hand, to the degree of preparation of the steel plates before any protection and, on the other hand, to the rusting degree of a first protection.

The Employer will report, during the whole guarantee period, on any damage or corrosion that he might notice.

The applicator will be responsible for repairing, at his own expenses, the coatings in the parts which do not favourably meet the comparison with the scales defined above.

If, for reasons of Plant operation imposed by the Employer, the applicator would have been prevented from carrying out the required repair work, a statement of the surfaces to be repaired will be drawn up and any worsening in the condition of those surfaces would be borne by the Employer until he hands over the structure to the applicator for repair and making goods of same.

It is generally accepted that a protection can be judged from a technical viewpoint only after one year of industrial operation. The applicator will then be permitted to make good the surfaces showing defects with no extension of the total period of guarantee.

APPENDIX VI. A

INDICATORY TABLE OF GUARANTEES RECOMMENDED FOR PROTECTIVE COATINGS

For each coating the following table gives, for information only, the guarantees generally accepted by the applicators under good coating conditions.

Designation of coating	Total thickness of coating	Guarantee Period	Reference block	Absolute Rugosity
	µm	Years (1)	(2)	µm
A - Internal Coatings (para. 2.4.2)				
a) (multi-layer/bituminous paint)	400	5 (3+2)	6	60
b) (multi-layer/epoxy and polyurethane)	150	8 (5+3)	7	4
c) (met. spray + bituminous paint)	400	8 (5+3)	7	60
d) (zinc epoxy + bituminous paint)	400	5 (3+2)	7	60
B - External coatings (para. 2.4.3.)				
f) (3 layers)	400	5 (3+2)	6	
g) (1 c. + 2 c. enamel)	1800	6 (4+2)	6	
h) (1 c. + 2 c. enamel and inserted linen)	2000	5 (3+2)	6	
i) (met. spray + 2 layers)	400	7 (4+3)	7	
k) (5 layers or more)	150	7 (4+3)	7	

1) The values between brackets have the following meaning :
   - The first figure represents the number of years of full guarantee of the protection.
   - The second figure represents the years of decreasing guarantee of protection resistance.

   For instance, (4 + 3) means that the reconditioning costs will be borne by the applicator in the proportion of :

   100 % up to the end of the 4 th year

   75 % up to the end of the 5 th year (25 % taken over by the Employer)

   50 % up to the end of the 6 th year (50 % taken over by the Employer)

   25 % up to the end of the 7 th year (75 % taken over by the Employer)

   0 % after the 7 th year.

2) The figures in this column represent the "Efficiency Degree of the rust inhibiting protection" of the European Scale. 6 and 7 correspond to the rusting degrees RE4 (3 % of rusting) and RE3 (1 %) respectively, of the same Standard Specification.

APPENDIX VI B

WATER ANALYSES

An analysis in the Spring and another one late Autumn will at least inform on the following points :

- Date and place (also, altitude) of the sampling
- Temperature of water and air at that time
- Appearance
- Free carbonic gas, in mg CO_2 per litre
- CO_2 liable to attack the anticipated protection, in mg CO_2 per litre
- CO_2 attacking lime, in mg CO_2 per litre
- Dissolved oxygen in mg O_2 per litre
- Saturation point in O_2
- pH (acidity)
- Electronical potential rH_2 (oxiding - reducing power)
- Resistivity (osmotic pressure due to electrolytes)
- Contents of Fe, chlorides, sulphates, etc. . .
- Contents of organic matters, bacteria, etc. . . and their origin
- Contents of solid particles and characteristics thereof.

The analyses will be done, if possible, in situ, as storage and transport can modify some of the characteristics.

The analyst will also try to estimate the modifications that could be entailed by the formation of the reservoir possibly anticipated in the project.