Overview of penstock types with main components

Nicolas CROCHETON, 03 November 2022

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Presentation topics

1 INTRODUCTION

- Main considerations
- Configurations of installation

2 CONSTRUCTIVE TYPES OF PENSTOCKS

- Steel penstocks
- Ductile iron penstocks
- Non metallic penstocks

3 MAIN CONSTITUTIVE COMPOMENTS

- Supporting systems
- Inlet gate or valve
- Flow control systems

1 INTRODUCTION

INTRODUCTION
Main considerations

- What is a penstock?

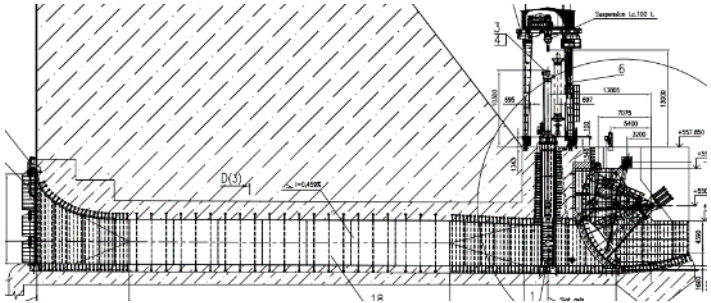
A penstock is made to bring water from an upstream intake structure to a downstream reservoir or water way.

Water is considered pressurized inside the penstock, generally by gravity load or by a pumping system.

- On which facilities are penstocks installed?

Hydro electric power plants, Water transfer facilities, bottom outlet of dams

SETIS water transfer (Algeria)



Dam bottom outlet

ABDELMOUMEN PSP (Morocco)

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INTRODUCTION
Main considerations

- What are the main design constrains ?

A penstock shall comply with 2 main requirements:

1. To provide a structure that is strong enough to ensure safety of people and of the facility > Tend to reduce pipe diameter in order to lower mechanical stress

$$\sigma_{radial} = \frac{Pressure * Radius}{Thickness}$$ (For elastic material)

2. To minimize the head loses on the transferred water (efficiency of the facility) >Tend to increase pipe diameter in order to lower flow speed

$$\Delta H_{linear} = \lambda \frac{L}{D} \frac{V^2}{2g}$$

Design of the penstock has to be developed with these 2 requirements and with the best economic compromise (with also the number of pipes).

INTRODUCTION
Configurations of installation

- Aerial: Outside configuration or in tunnel configuration
  - Cheaper installation if topography is compatible
  - Easier maintenance
  - Exposed to external environment (rock falls, avalanches, etc.)
  - Visual impact
  - Large temperature variations
  - No external pressure but vacuum effect to be managed

- Underground: In rolled fill trench, in concreted tunnel through dam body or natural terrain
  - Shortest route to go from a point A to a point B
  - No possible maintenance of external surface
  - Potential presence of high external pressure from water infiltrations

Concrete or rock can participate to the mechanical strength of the penstock (non self-resistant steel lining).

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2 CONSTRUCTIVE TYPES OF PENSTOCKS

CONSTRUCTIVE TYPES OF PENSTOCKS

Steel penstocks

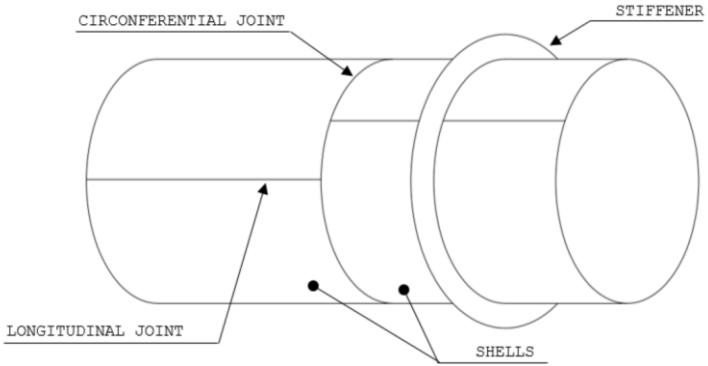
- General scheme

A steel penstock is composed of pipes to be assembled on site:

- Rigid assembly: Rivets, welding, bolted flanges
- Flexible assembly: sliding spool, dilatation joint

Each pipe is composed of several shells (cylindrical or conical).

Usually, the shells are made from cold-rolled plates, up to a limit of 5% deformation rate (CODAP).



ABDELMOUMEN rolling machine (Morocco)

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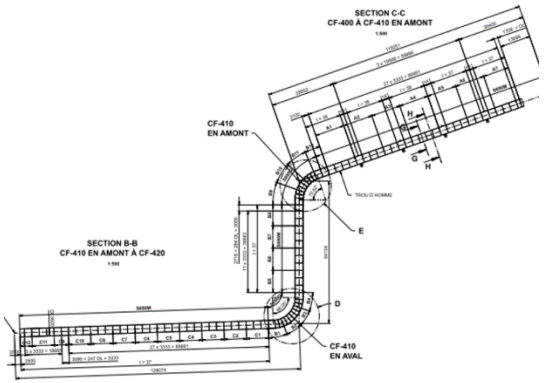
CONSTRUCTIVE TYPES OF PENSTOCKS

Steel penstocks

- Various possibilities

GERDP HPP – Ø8 m penstock – 146 mWC (Ethiopia)

Le Ternay Dam– Ø0,45 m penstock – 33 mWC (France)



Abdelmoumen PSP – Ø3,6 to 5 m penstock – Dynamic head up to 900 mWC (Morocco)

CONSTRUCTIVE TYPES OF PENSTOCKS

Steel penstocks

- Rivet assembly penstock – up to the 1950's

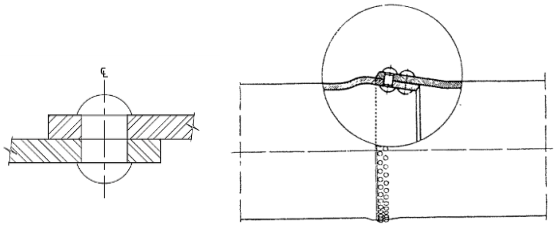
Oldest assembly process between metal sheets (19th century).

Risks of corrosion and erosion due to flow turbulences around them.

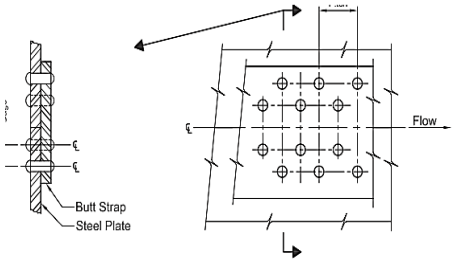
Stress concentration around rivet heads. When one rivet breaks, risk of propagation to the next one and so on.

COINDRE HPP (France)

Simple overlapping assembly:



Butt strap assembly :



CONSTRUCTIVE TYPES OF PENSTOCKS
Steel penstocks

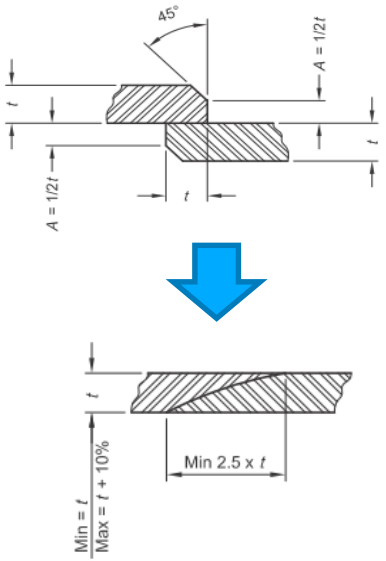
- Forge welding penstock – Up to the 1930's

Manufacturing process:

- Step 1: Two plates are assembled with overlapping
- Step 2: The area is heated up to about 1200°C (self welding). Heat provided by "water gas" to avoid corrosion
- Step 3: The heated edges are assembled by a press or hammering or rolling machine
- Step 4: Internal stress is released by post heating at about 900°C
- Step 5: The shell is fully rolled to get its final geometry, before that temperature drops below 500°C

Requires pressure test (1,5 to 2 times nom. pressure) due to lack of NDT tests at these times.

Risks of corrosion around the joint due to high temperature heating



CONSTRUCTIVE TYPES OF PENSTOCKS
Steel penstocks

- Hooping assembly penstock – Up to 1950's

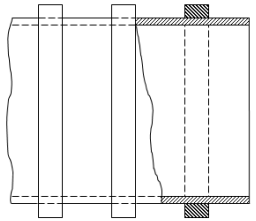
The aim of this technic is to limit the thickness of the pipe wall.

The pipe is initially pre-stress (compression) by high-strength external rings.

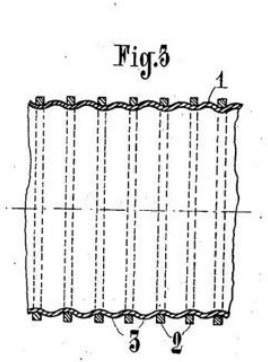
2 main methods:

- Hot hooping (rigid): heated rinks are inserted on the pipe. They then retract during cooling.
- Self-hooping (flexible): The pipe is pressed against the rinks by application of internal water pressure (at least 2 times nom. pressure).

Not possible to handle external pressure.



MALGOVERT HPP in initial configuration (France)



PASSY HPP in initial configuration (France)

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CONSTRUCTIVE TYPES OF PENSTOCKS

Steel penstocks

- Welded penstock – From the 1900's up to now

The only remaining steel penstock technic nowadays

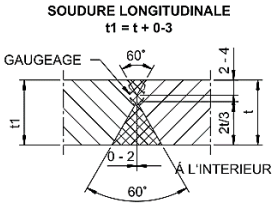
- Allows use of modern steel, with higher thickness.
- Almost no limit of geometry and working pressure.
- Adapted for on-site workshops.
- Limited head losses for flow

Tack welds for positioning

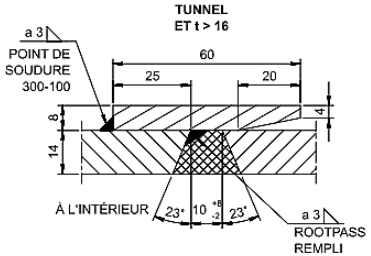
Final weld before grinding

Still weaknesses to be aware of:

- Welding execution requires high care with extensive controls and welds are sensitive to cycling loads
- Steel material remains sensitive to corrosion



X-type weld



V-type weld with backing stripe

CONSTRUCTIVE TYPES OF PENSTOCKS

Ductile iron penstocks

Modern ductile iron pipes started in the 1950's

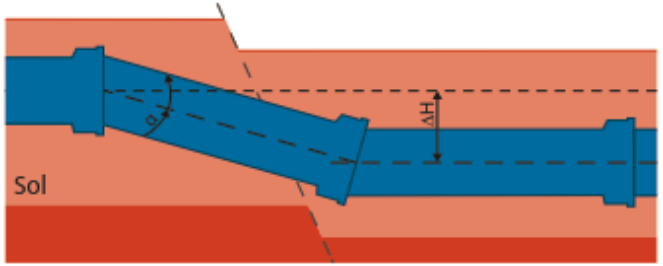
Typical properties: Re = 300 Mpa, Rm = 420 Mpa, E = 170 000 Mpa

Specific advantages:

- Product ranges with limited on site works
- Can be installed in rough trenches

Limitations:

- Lines of products only from specific manufacturers
- Limited to diameters up to 2000 mm
- Above 1 m diameter, service pressure limited to 20-30 bars
- On aerial configuration, requires 1 support on each pipe (usual every 6-8 m)
- Head losses at each junction



Source: PAM

CONSTRUCTIVE TYPES OF PENSTOCKS

Non metallic penstocks – Reinforced concrete

- Aerial reinforced concrete penstock

Concreting technologies allow nowadays to make penstocks of 1,5 to 3 m diameter for water head at about 50 m maximum.

- Aerial reinforced concrete penstock with non self-resistant steel lining

Concrete and steel lining both contribute to mechanical strength

The purpose of the concrete shell is mainly to minimize thermal effects: Reduction of thermal dilatation stress (lower temperature variations) and better insulation in very cold climates.

Risks of external pressures between concrete and steel may require to include efficient drainage systems

- Reinforced concrete penstock in tunnel

Memve'le hydropower scheme (Cameroun)

Waneta hydropower scheme (Canada)
Source: Redpath/FKCI Waneta Tunnelers

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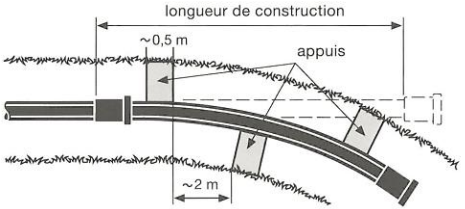
CONSTRUCTIVE TYPES OF PENSTOCKS

Non metallic penstocks – Polymer materials

- PE (Polyethylene)
  - Mostly for small applications – Diameter up to 500 mm, pressure up to 16 bars.
  - Good roughness, sensitive to abrasion.
  - High thermal expansion.



- PRV (Fiber glass reinforced polyester)
  - Diameter up to 4 000 mm, pressure up to 32 bars.
  - For a pressure of 10 bars and diameter about 1 m, mass is 1,4 to 2,3 times lighter than steel: Interesting for projects with difficult access.
  - Good roughness, sensitive to abrasion.
  - Sensitive to shocks.
  - High thermal expansion.

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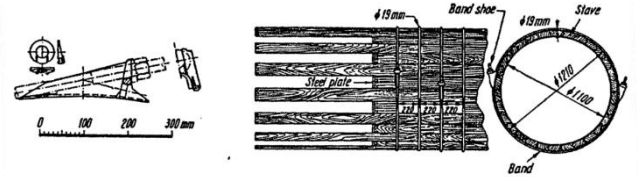
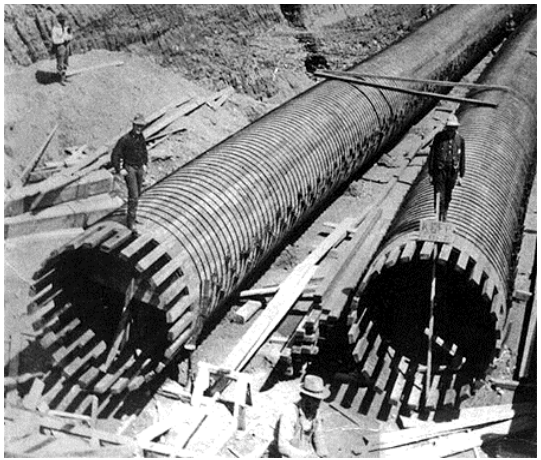
CONSTRUCTIVE TYPES OF PENSTOCKS

Non metallic penstocks – Wood

- A rare and old technology
  - Used in the past in areas with high quality wood easily available (North America, Scandinavia).
  - Suitable to low pressure applications.
  - Mechanical strength is ensured by external steel straps.
  - Require to be constantly full of water to avoid leaks.





Sequoia penstock from THOMSON company (USA)

3 MAIN CONSTITUTIVE COMPOMENTS

MAIN CONSTITUTIVE COMPONENTS
Supporting system

- Fully blocked penstock

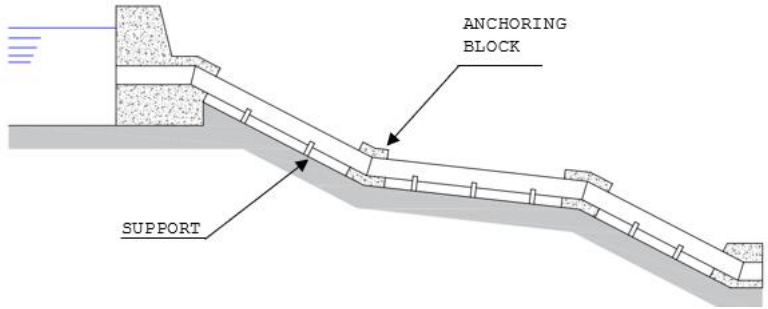
1 anchoring concrete block at each direction change (elbow):

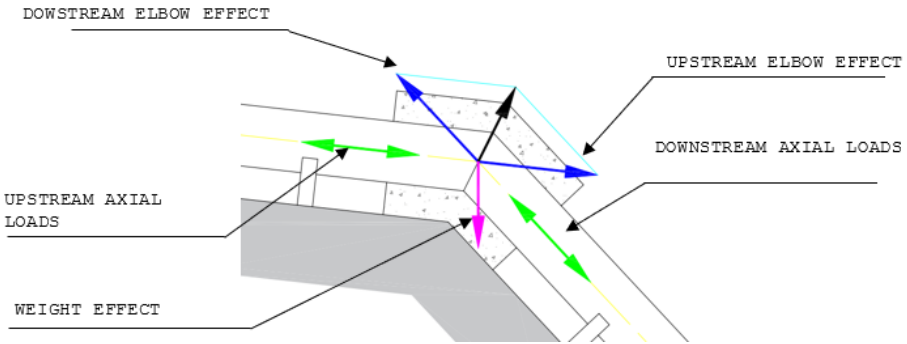
- All longitudinal displacements are blocked.
- Handling of: Poisson effect, Thermal effect, Weigh effect Elbow effect from water pressure
- High reacting efforts occur on the anchoring blocks, mainly due to thermal dilatation effect:

$$\sigma = E\alpha\Delta T$$

Leading to axial stress of 2.5 MPa per degree (steel)

- High care is required to achieve the last circumferential weld: To be done at the median value of the temperature variation range.

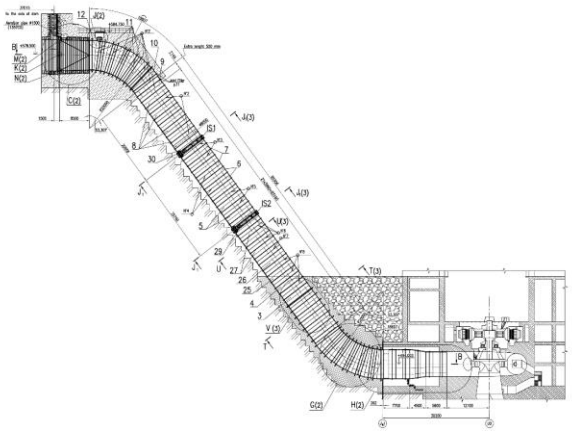




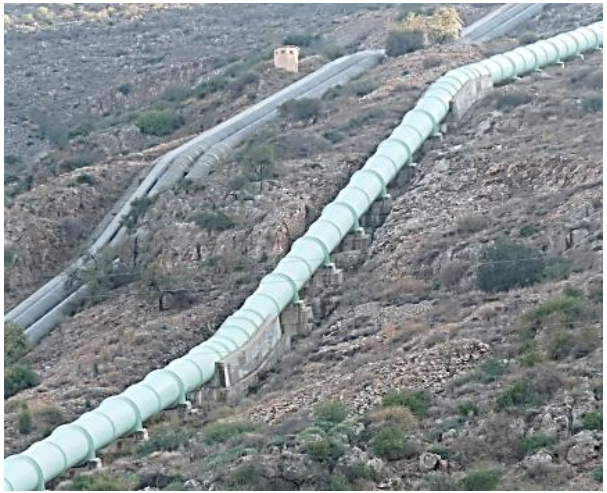
MAIN CONSTITUTIVE COMPONENTS
Supporting system

- Fully blocked penstock

Such configuration can be seen on penstocks with large diameter where dilatation joints are complex to install or on penstocks with numerous elbows.



Ø8 m penstock



AFOURER PSP (Morocco)

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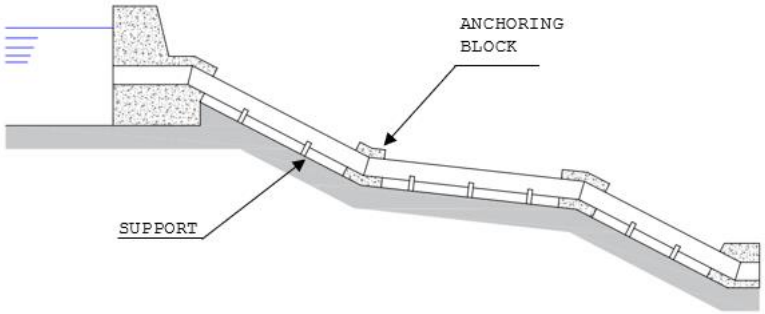
MAIN CONSTITUTIVE COMPONENTS
Supporting system

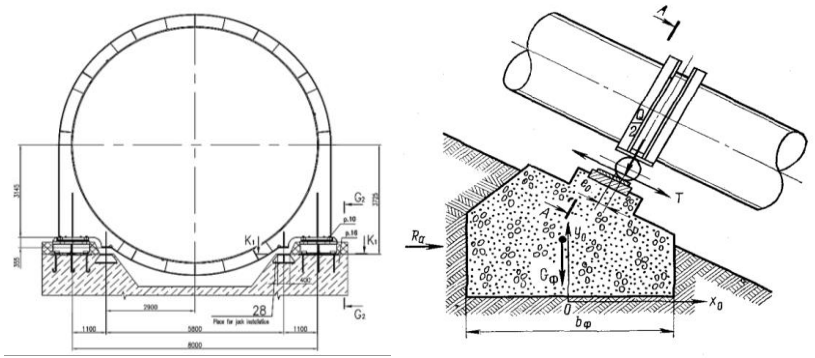
- Fully blocked penstock

Several intermediate sliding supports:

- Handling of weight and seism effects, in radial + transversal directions



Sliding support being assembled



Supports can be sliding or rolling types

MAIN CONSTITUTIVE COMPONENTS
Supporting system

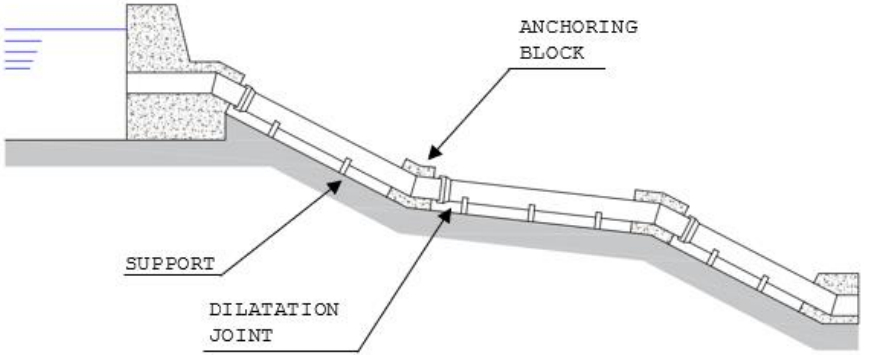
- Penstock with blocked elbows and dilatation joints

1 anchoring concrete block at each direction change (elbow) + 1 dilatation joint on each section (general configuration)

- Handling of: Weigh effect, Friction from dilatation joint, Elbow effect from water pressure

Several intermediate sliding supports:

- Handling of weight and seism effects, in radial + transversal directions.
- Sliding needs to be effective and resistance-free.



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MAIN CONSTITUTIVE COMPONENTS
Supporting system

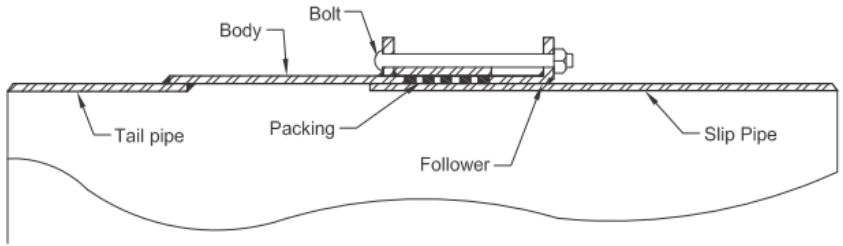
- Penstock with blocked elbows and dilatation joints

2 main options for displacement handling:

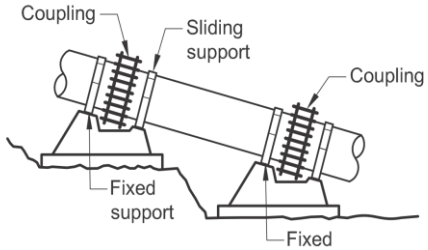
- 1 sliding joint with large displacement
- Several flexible couplings with small displacement

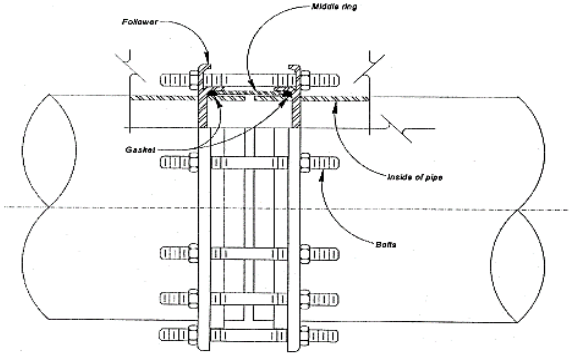
Limitations:

- The dilatation joints can be expensive devices and they require maintenance.
- Risks are water leaks and corrosion development.
- Axial loads are not fully removed due to friction in the joint (depending on water pressure and diameter).



Sliding joint with large potential displacement





Configuration with 1 flexible coupling for each pipe

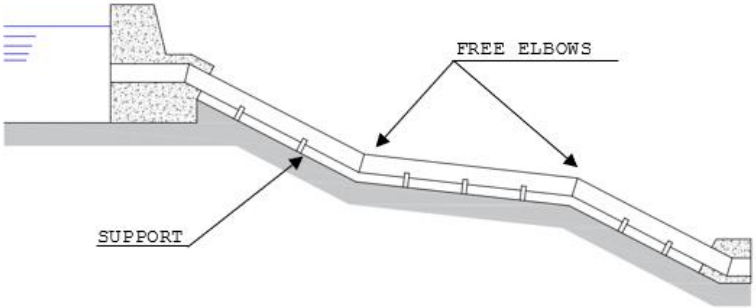
MAIN CONSTITUTIVE COMPONENTS
Supporting system

- Penstock with free elbows

Only sliding supports:

- No need of dilatation joints.
- Flexibility at elbows allows large deformations = no high loads on the elbows.
- Thermal effects are handled by the pipes them-self, they have to be designed for it.

Usually seen for diameters lower than 2 m. Calculation of stress and displacement effects in the penstock is more complex.



Bourg de Sirod HPP (France)

MAIN CONSTITUTIVE COMPONENTS

Inlet gate or valve

- A mandatory safety and maintenance equipment

Should be installed upstream of the penstock, at least upstream of the aerial sections.

Must be able to cut flow in case of full failure the penstock.

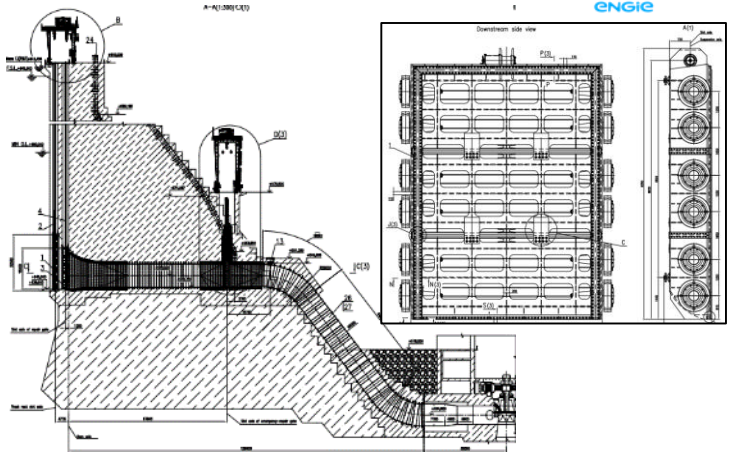
Must be able to cut flow without external energy.

2 main types depending mainly on dimensions:

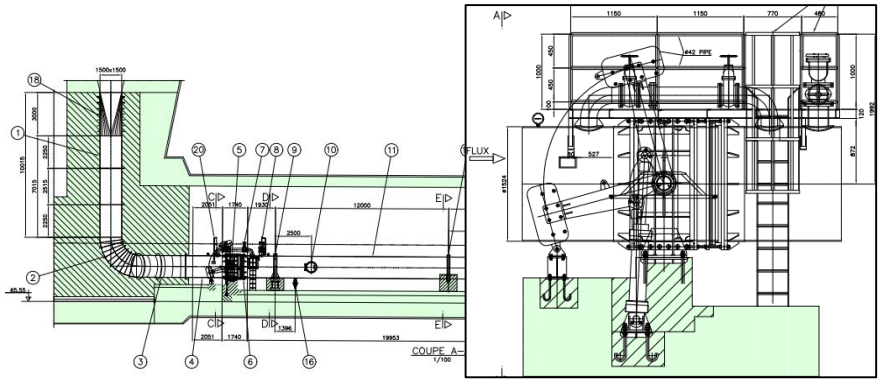
- Circular valve – butterfly or spherical valve
- Fixed wheel gate

An air inlet is required just downstream of the device:

- Air vent pipe
- Automatic air valve (requires maintenance)



Waterway with inlet wheel gate

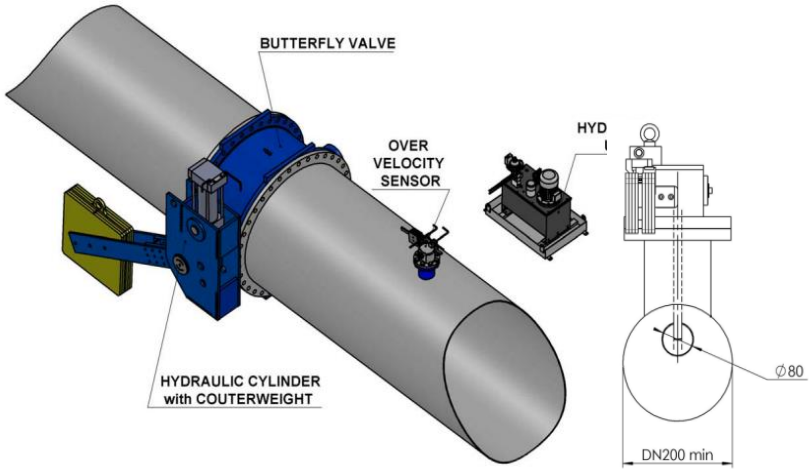


Waterway with inlet butterfly gate

MAIN CONSTITUTIVE COMPONENTS
Flow control systems

- Main safety functions:
  - To detect any potential incident in the waterway (overflow in turbines, failure on the penstock, etc.) by monitoring the flow rate.
  - To trigger closure of the inlet gate/valve.

- First main type of flow control: Mechanical system
  - A tilting device in the penstock is directly moved by the flow pressure.
  - The motion of the tilting device can then trigger an hydraulic valve or hard-wired sensors to start emergency closure of the inlet valve.
  - Can fully work without electricity but no information of the flow rate.



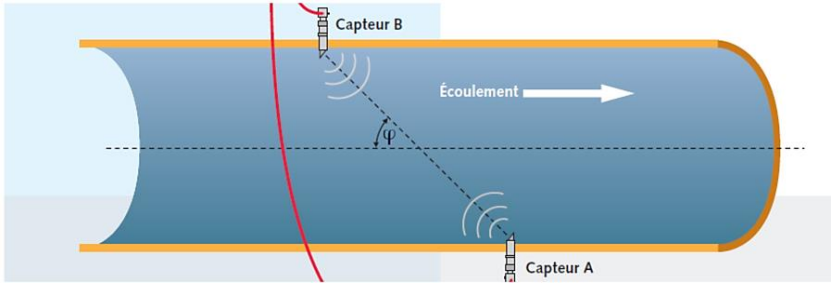
Overspeed mechanical detector (Source: TECH VALVES HYDRO, France)

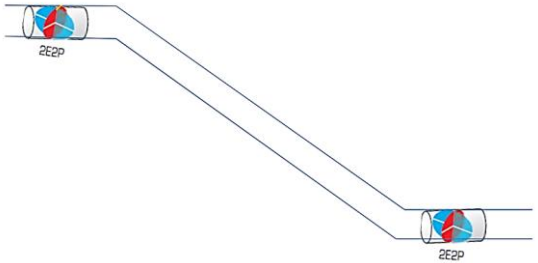
MAIN CONSTITUTIVE COMPONENTS

Flow control systems

- Second main type of flow control: Ultrasonic system

  - A set of 2 sensors (transmitter + receptor) measures flow speed that can be then converted to flow rate value. Several sets of sensors are generally used to provide redundancy and better accuracy.
  - The sensors are inside or outside the pipe, depending on context of installation.
  - Dedicated systems can provide differential measures to monitor any leakages along a penstock.
  - Relies on an electric power supply (normal, batteries, generator, etc.) but provides flow rate information.





Installation of US sensors on Etables HPP (France)

THANK YOU