WORKSHOP

Penstocks, pressure shafts & pressure tunnels

Milano, 3 – 4 novembre 2022

Penstocks in ENEL: risk assessment system

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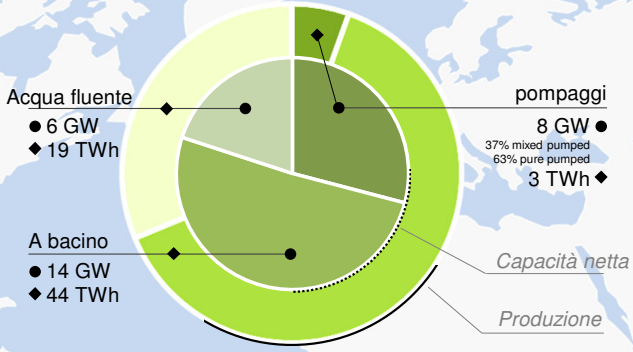
Green Power

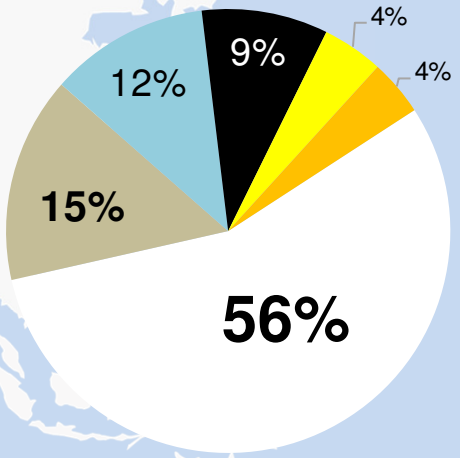
Our hydroelectric network

749 impianti

1428 unità



333 Grandi dighe

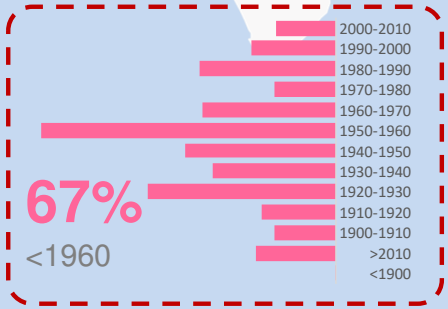


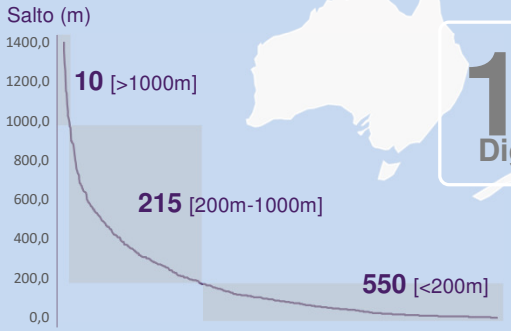
12 paesi

2 continenti

28,3 GW

64 TWh @2018

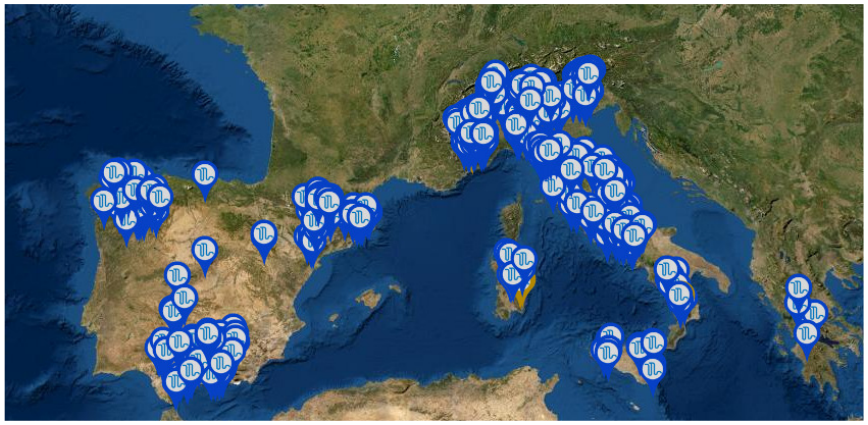




194 Dighe minori

~ 2700 persone sulla tecnologia idroelettrica

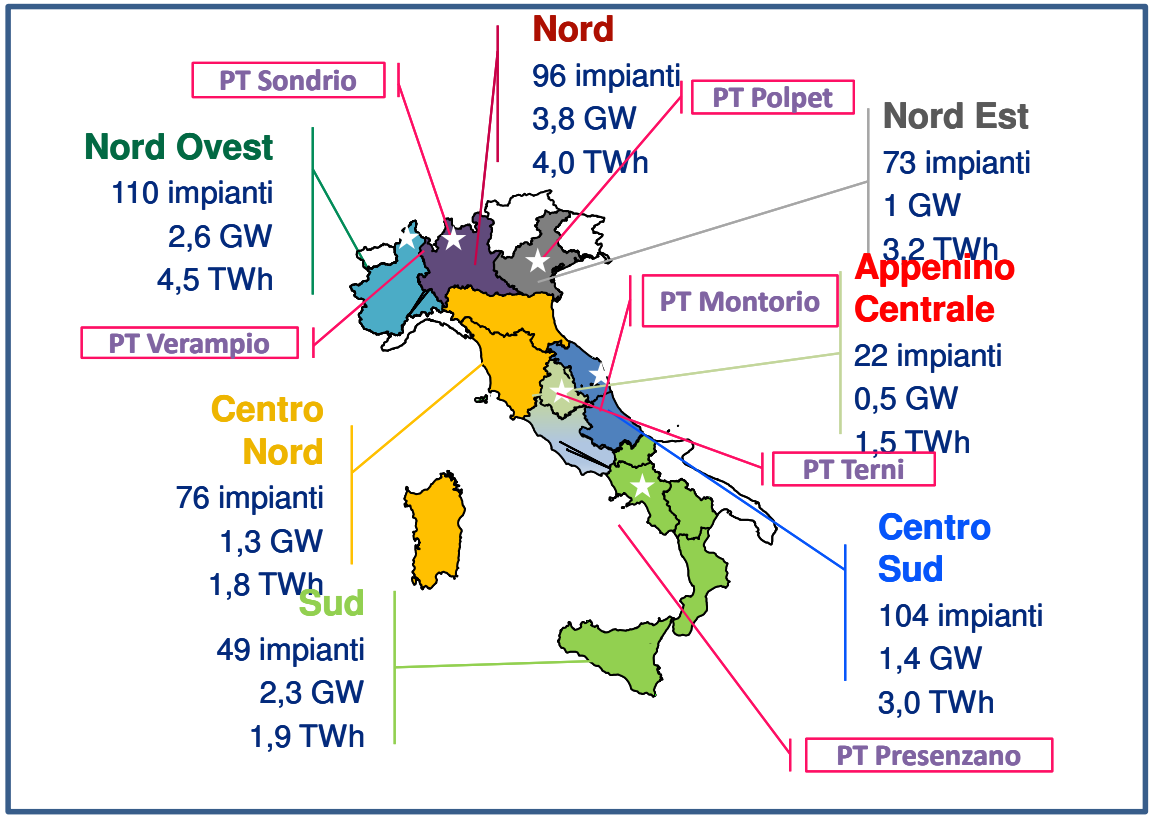
Our HPP in Europe



• ITALY	530
• SPAIN	145
• GREECE	5

ITALY

- ~1.750 people
- 12,9 GW (7 GW pumping + 5,9 GW conventional)
- ~ 17 TWh/anno production
- 530 centrals
- 430 dams
- > 2.500 km channels, tunnels & penstocks



Zooming on penstocks in Italy

2019 completed database

2020 technical survey

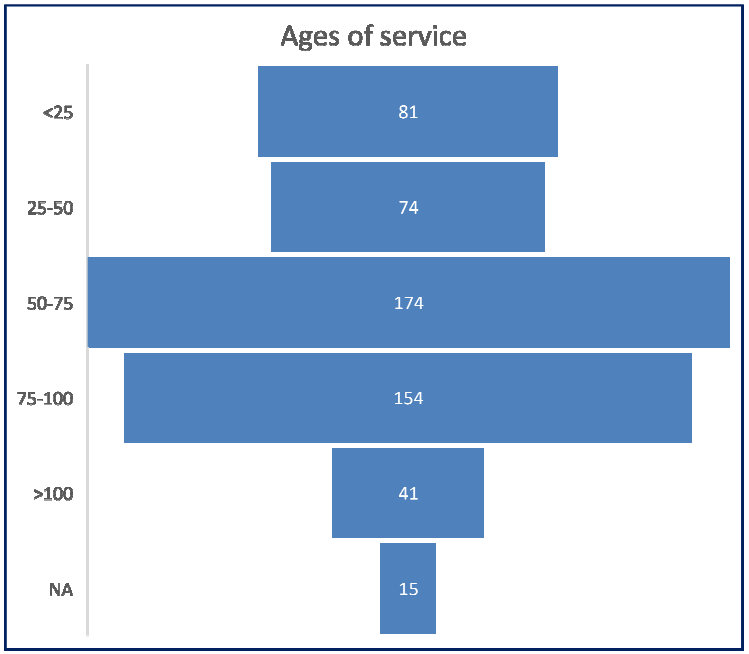
2021 implemented new wave of non destructive tests

Number of penstoks Surveyed: 525

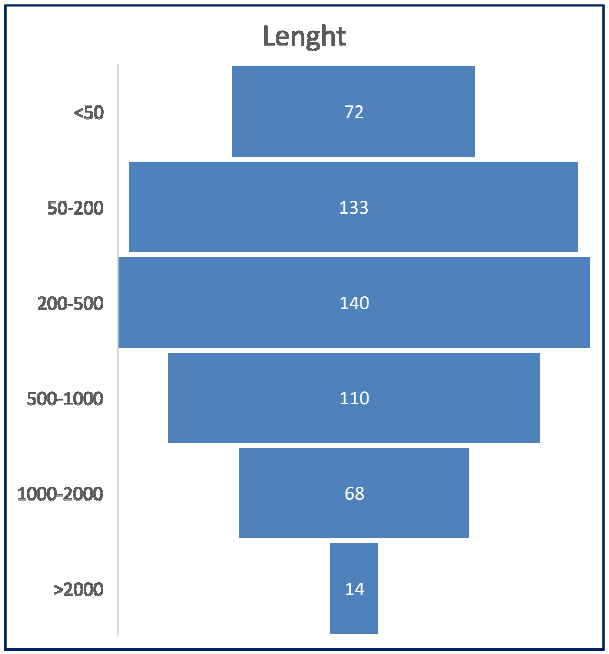
2021 digital multilayer cartografy

Some statistical data

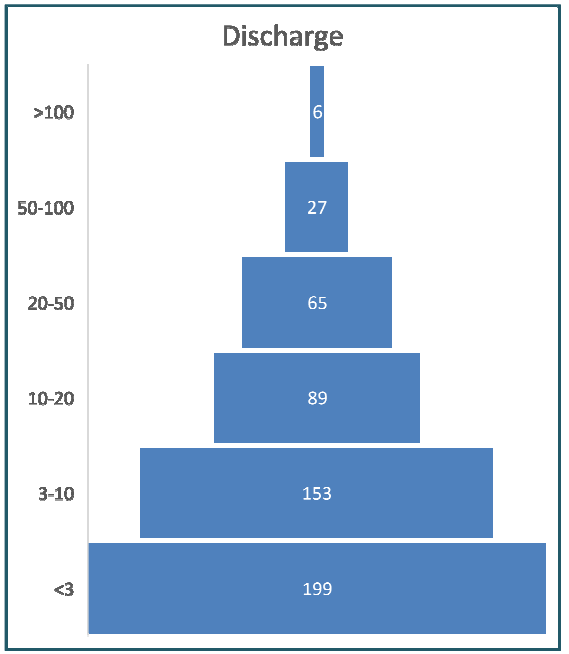
Average age 63
The oldest is 117 years old



Average lenght 504 m
The longest 3622 m



Max flow from 0,1 to 100 m3/s



ENEL Control catalogue

Within O&M Enel Hydro power plant control catalogue there are different periodical controls on penstock, including the «assessment» or penstock evaluation:

- The purpose of the assessment is to evaluate the condition of the penstock component and everything that falls within the operating and environmental perimeter, to establish whether or not it is suitable for operation

Throught:

- Set of controls relevant to the penstock, the construction characteristics of the penstock itself and the components that fall within the scope of verification;
- Assessment of the results of the controls of the individual parts and overall assessment of the condition of the penstock

Steel penstocks status evaluation

Evaluation Approach:

- **Structural integrity**
- **Boundary condition**
- **Protection**

Penstock system

Case study: penstock failure and checks

Some events

Riveted penstock:
failure due to local corrosion

No external damages

Riveted penstock:
failure due to local corrosion

High external damages

Welded penstock:
failure due to thickness reduction and corrosion

No external damages

Case study: penstock failure and checks

Some events

Riveted penstock:
damages due to air-venting failure and thickness reduction

No external damages

Riveted penstock:
damages due to air-venting failure

No external damages

Welded penstock:
Failure due thickness reduction (erosion and corrosion)

No external damages

Root cause analisys

Steel penstock failure

Exceeding of mechanical characteristics

Thickness reduction

- corrosion
- erosion

Local stress concentration factor

- Geometry modification (penstock roundness and straightness)
- Local strains (rock impact, support failure)
- Constraints (thermal, supports, blocks)
- Earthquake
- Geotechnical factors
- Climate factors

Joints failure

- Rivetings
- Weldings
- Expansion joints

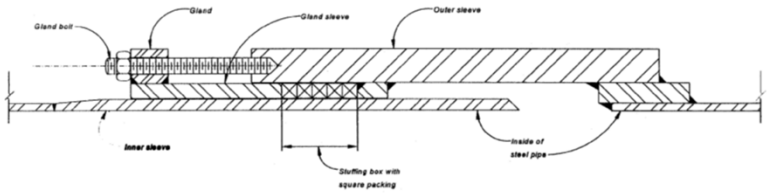
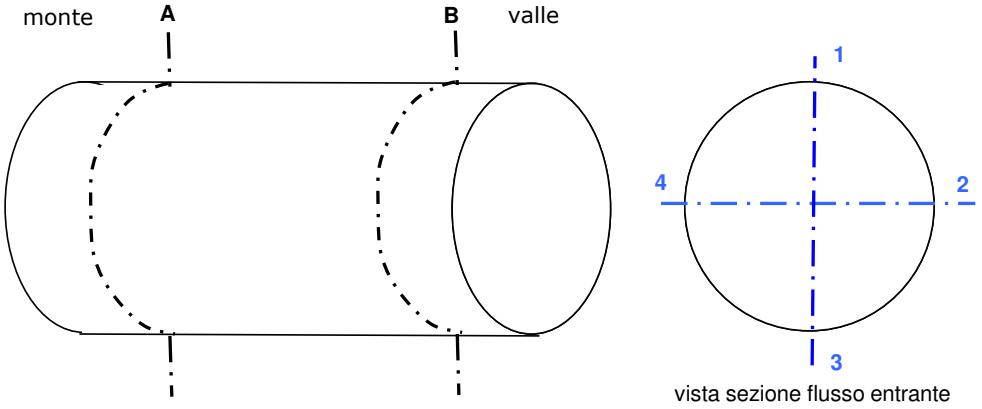


Figure 7. - Cross section of expansion joint.

Steel penstock thickness measurements

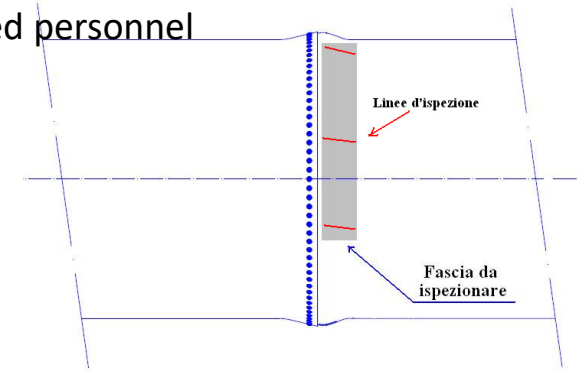
Definition of the measurements areas

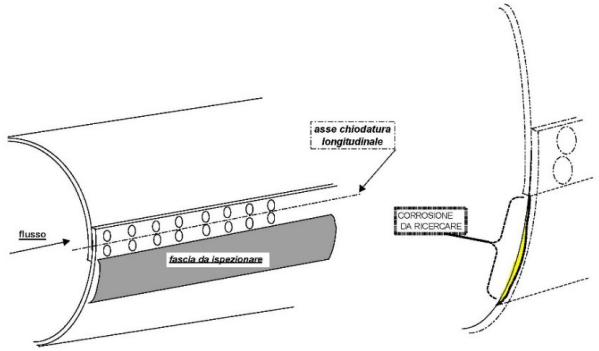


Definition of the numbers of measurements areas

Spessore del lotto (mm)	%i virole da controllare	n° minimo di sezioni da controllare	n° massimo di sezioni da controllare
sn ≤ 10	20 % (1 virola ogni 5)	6	40
sn > 10	12,5 % (1 virola ogni 8)	6	20
Tratti blindati	10 % (1 virola ogni 10)	6	20

Riveted Penstocks: local thickness measurements by double ultrasound gauge made by certified personnel





Measurement data evaluation

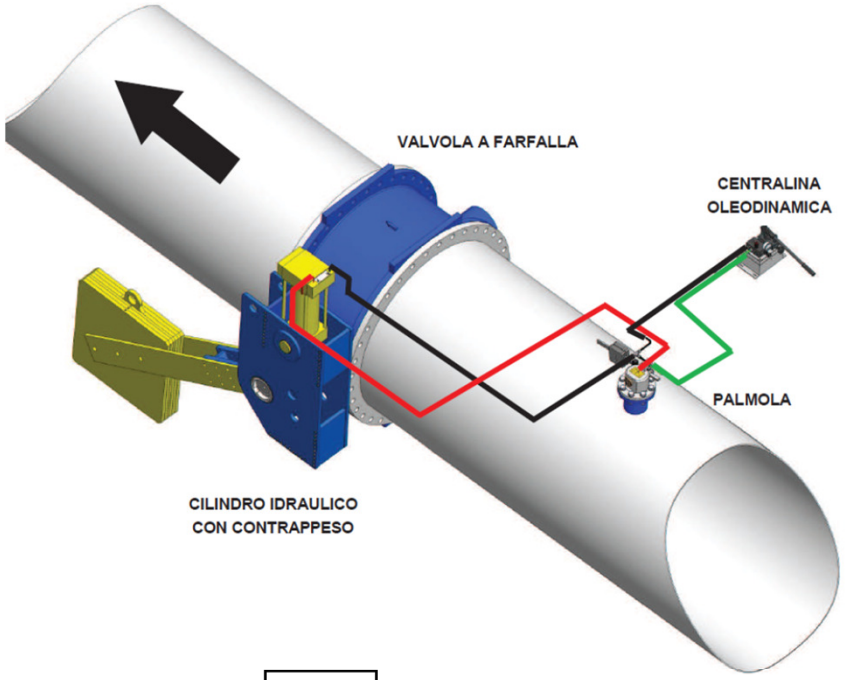
Survey on Safety factor k, comparing equivalent stress vs tensile stress of the penstock material, typical σsn >210 N/mm^2

k ≥ 1,9	→	Penstock status as original design **level 2**
1,6 ≥ k > 1,9	→	Plan of checks with frequency increased and/or specialized tests added **level 3**
k < 1,6	→	Structural stability evaluation needing **level 4**

Level = Steel Penstock Evaluation

\+ Visual inspection analisys – Operational history analisys

Failure effect mitigation

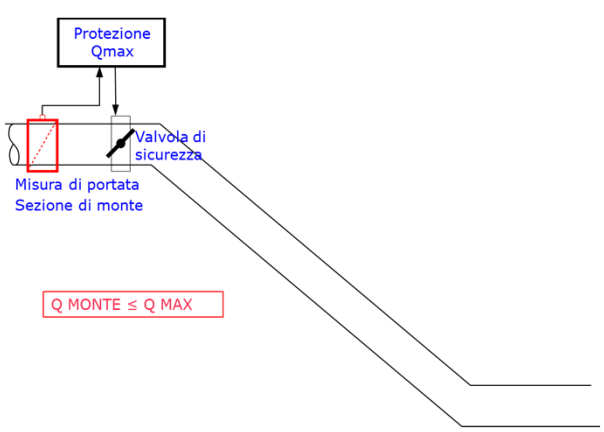


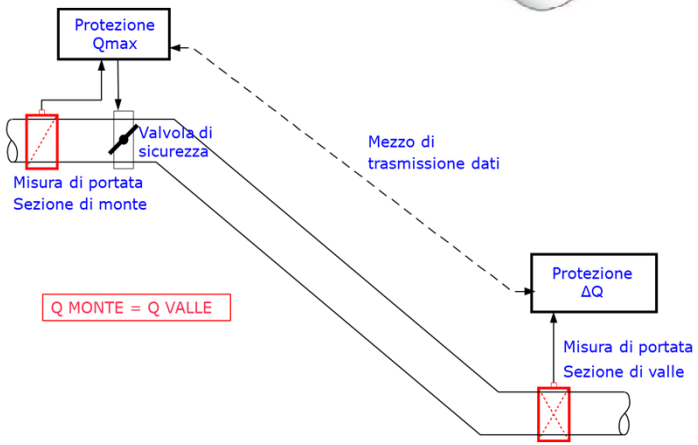
Emergency device verification

- functional tests
- internal and external inspection
- NDT on critical areas

Protection device verification

- functional tests
- periodical calibration





Risk evaluation of the penstock system

Probability

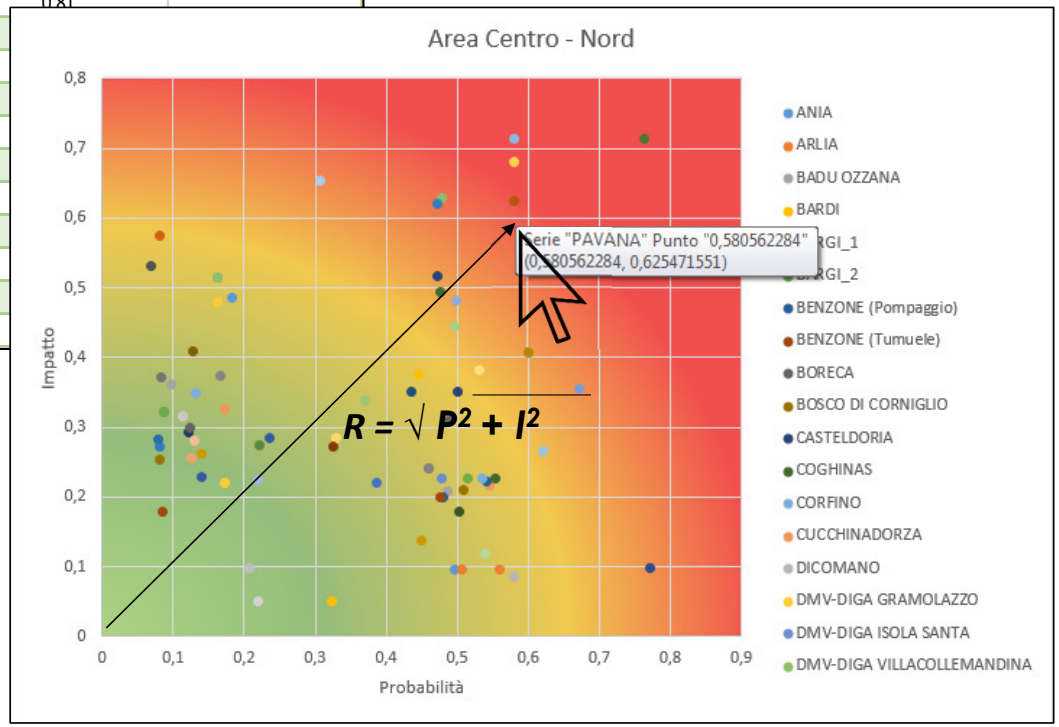
- Sismic level
- Geotechnical risk
- Installation year
- Assembly type
- Expansion joint presence
- Penstock length
- Support status
- Steel Penstock Evaluation
- Year of last NDT check

Magnitude

- Nominal flow rate
- Head
- Penstock location
- External infrastructure presence
- Emergency device type
- Protection device type
- Emergency device status
- Protection device status
- Protection device calibration
- Plant average production

Steel penstock failure risk

Area	UT	Impianto alimentato	SOMMATORIA PROBABILI	SOMMATORIA IMPAT	VALUTAZIONE DEL RISCH	NOTE
Centro-Nord	Lucca	SILLANO 0	0,67	0,22	0,71	
Centro-Sud	Ascoli	CASTELLANO (gruppo)	0,71	0,64	0,96	
Centro-Sud	Ascoli	CARASSAI (gruppo)	0,70	0,64	0,95	
Centro-Sud	Ascoli	PIORACO_1	0,64	0,67	0,93	
Centro-Sud	Ascoli	PIORACO_2	0,64	0,67	0,93	
Centro-Sud	Montorio	PESCARA I_2	0,75	0,31	0,81	
Centro-Sud	Ascoli	VILLA POTENZA 1	0,65	0,36		
Centro-Sud	Ascoli	S.ELENA 1	0,64	0,33		
Centro-Sud	Ascoli	VENAMARTELLO	0,66	0,15		
Nord	Sondrio	FORNETTO	0,88	0,20		
Nord	Sondrio	MONTESPINO	0,75	0,40		
Nord	Bergamo	BRASA	0,69	0,28		
Nord	Cedegolo	LOZIO-LANICO I	0,71	0,10		
Nord	Bergamo	CLANEZZO BREMBO	0,64	0,22		
Nord-Est	Feltre	PREVALDESCA	0,72	0,54		
Nord-Est	Vittorio Veneto	S.GIOVANNI	0,70	0,21		



Risk evaluation of the penstock system

Hydro Italy – first results

Penstocks: total	525
Steel penstocks: total	494

Type	Number
DMV	18
Syphon	5
Discharge	4
Not in operation	2

Not included in the survey

	min	max
Diameter (m)	0,5	5
Lenght (m)	9	3.622
Total lenght (m)	263.000	
Mass flow (m3/s)	0,1	125
Age (years)	1	112

Relevant to the 465 penstocks under investigation

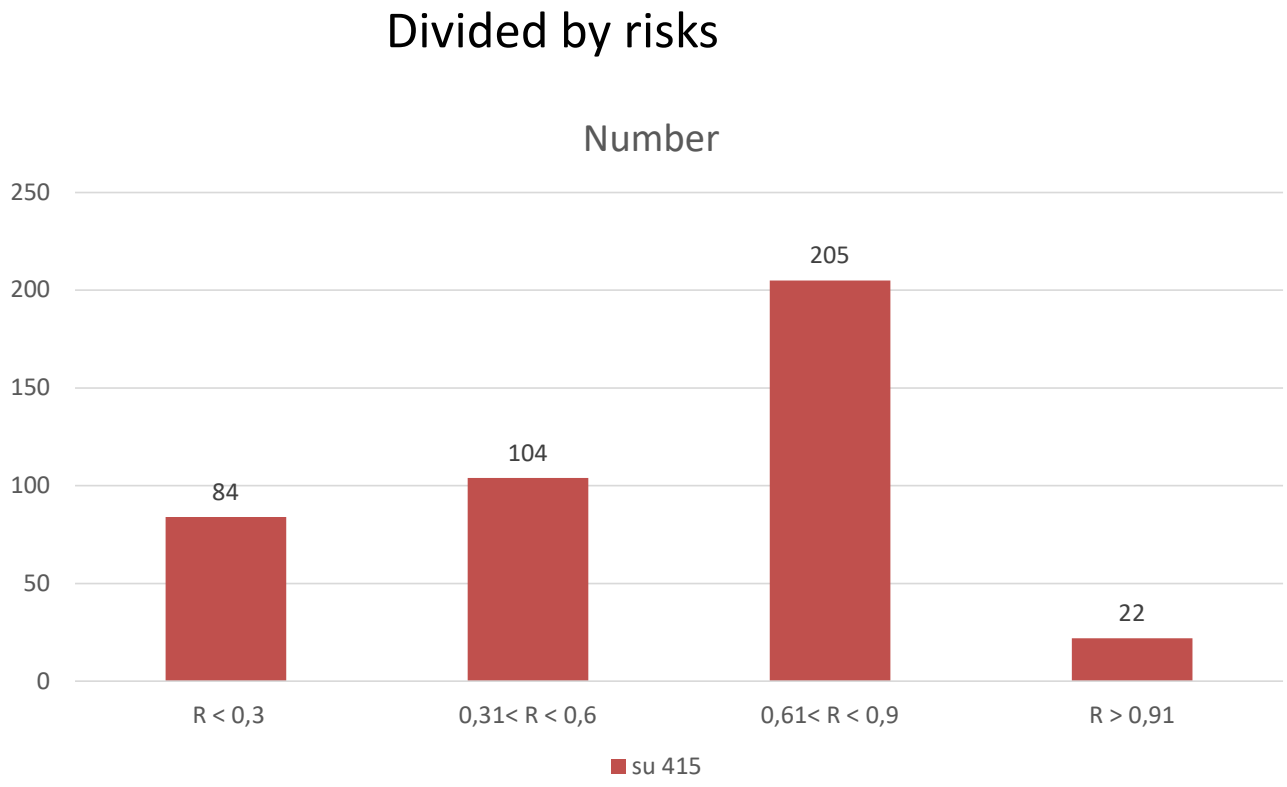
Penstock lay out	Number
Above ground (totally or partially)	324
In Trench (totally or partially)	18
Within a tunnel (totally or partially)	23
Within concrete	33
Within rocks	17
Buried (totally or partially)	50

Penstock main features	Number
Bollitura (autogenous welding)	50
Riveted	121
Welded	288
Others	6

Steel penstocks observed: 415

Risk evaluation of the penstock system

Hydro Italy – first results



Risk evaluation of the penstock system

Hydro Italy – first results

Actions

Taking into consideration the penstock system status:

- 3 substitution on going (one to be approved)
- 3 substitution already done
- 2 substitution to be approved

Steel Penstock Evaluation: **Level 4**

Risk values: from 0,69 to 0,95 age: from 56 to 80 years

- 15 penstocks 7 riveted
  6 welded

Steel Penstock Evaluation: **Level 3** - Increasing NDT frequency and new evaluation

Risk values: from 0,4 to 0,77 age: from 56 to 101 years

Back up

Risk evaluation of the penstock system

Hydro Italy – first results

Divided by external infrastructures