eZETA engineering

Penstocks, pressure shafts & pressure tunnels *workshop*

Rehabilitation of penstock: untraditional solutions

Emanuele Zaniboni

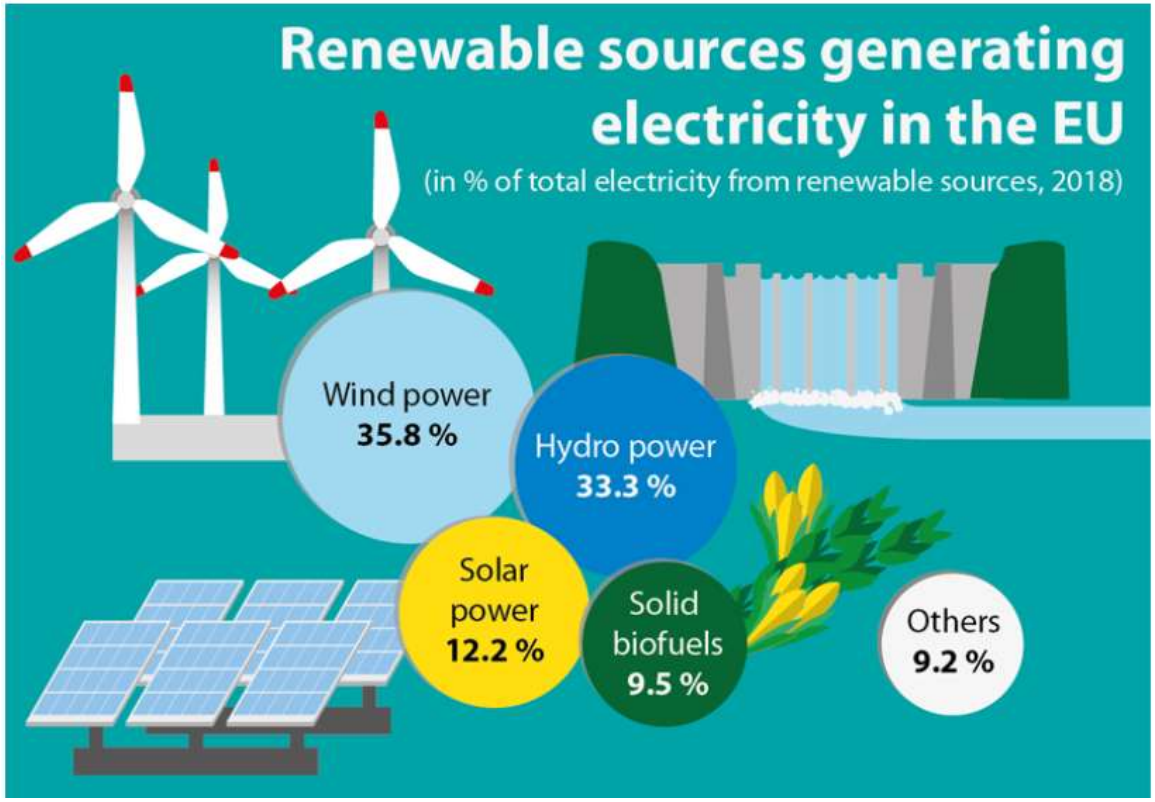
Milan, 4th November 2022

eZETA engineering

Hydropower is a significant component of renewables

Advantages:

- energy production "*demand-driven*"
- bridging the gap of discontinuous wind and solar energy production
- lower energy cost than other renewables sources



source: ec.europa.eu/eurostat

OUR APPROACH ON HYDROPOWER REHABILITATION ACTIVITIES

Ageing plants should needs **rehabilitation & maintenance** focused on:

SAFETY

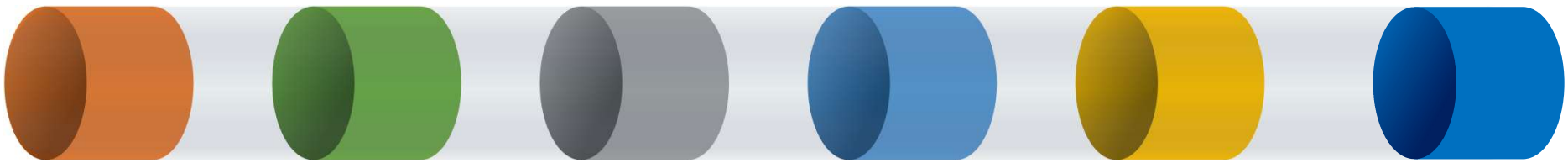
referred to the single item of the plant also application safety during rehabilitations works.

EFFICIENCY

Improve and/or maintening the performance level of the plant items and right level of energy production.

ABRASION MITIGATION

Mitigate issues related to the wet abrasion due to sediments transportation in the water



HEAD-LOSS REDUCTION

To include during activities of relining or recoating trought certified solutions able to ensure a smoother substrate

SUBSTRATE PREPARATION

Substrate must get a properly preparation in order to be suitable for the updated coatings technologies and automatic applications.

AVOID SHUTDOWN

Exploit solutions able to avoid plant shutdown during maintenance activities

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TRADITIONAL REHABILITATION TECHNOLOGIES

Patches over the affected area

Fully welded circumferential reinforcement

External circumferential ring reinforcement

Replacement penstock shell

INNOVATIVE/LIMITED REFERENCED SOLUTIONS

Pre-Formed composites
in autoclave

Epoxy resin application
for bonding

CFRP Preformed set-up

COMPOSITE POSSIBLE USES

- to compensate thickness reduction
- to improve the strength of forge welded connections
- to repair leakages on rivets connections
- to repair holes
- to install between penstock and his support to avoid corrosion
- possible application on damped surfaces

Rivets leakages repair

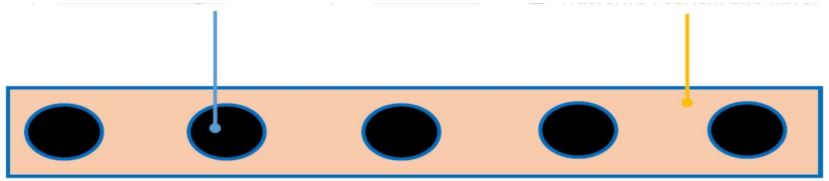
FRP: FIBER REINFORCED POLYMERS

Fibers

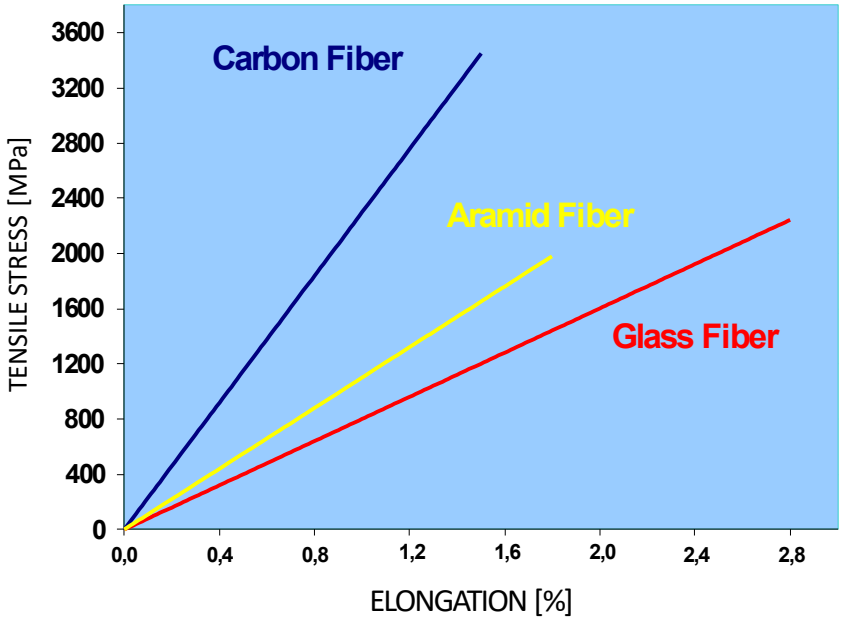
- high tensile stress value
- resistance to loads

Resins

- Ensure adhesion on substrate
- Transfer loads to fiber
- Protect and bind the fibers

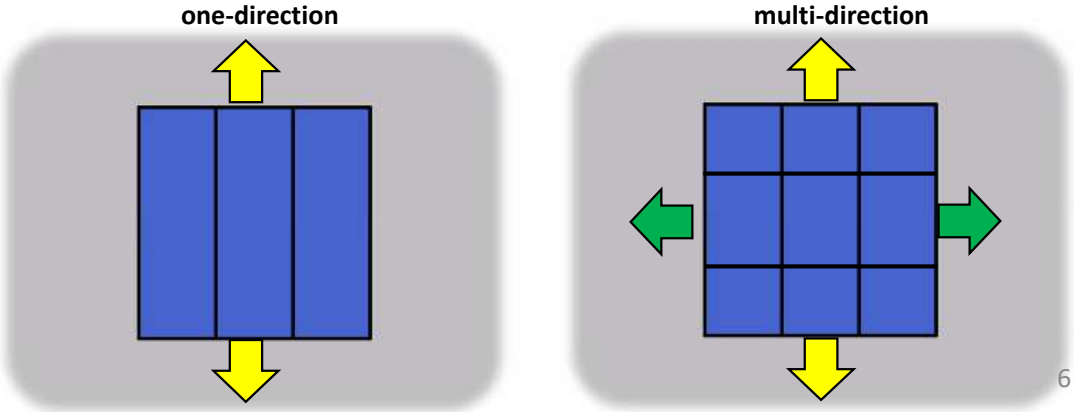


Composite : union of two or more different materials that retain theirs proper performance properties when joined together.

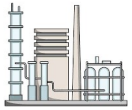


ORIENTATIONS

- **One-Direction**: For single stress reinforcement (i.e:Circumferential reinforcement)
- **Multi-Direction:** More distribuited strengths for more even reinforcement (i.e: Circumferential and Axials reinforcements)



STANDARD REGULATORY FRAMEWORK
FRP APPLICATION

	 Oil & Gas	 Infrastructure
STEEL SUBSTRATE USES	**ASME PPC-2-2022**: Repair of pressure equipment and piping **EN ISO 24817:2017:** Composite repair for pipework Qualification and design, installation, testing and inspection	**CNR DT 202/2005** (Italian standard) Guidelines for design and construction of externally bonded FRP for strengthening existing metallic structures **ASCE PENSTOCKS MANUAL Nr. 79 - 2012** CFRP uses for penstock rehabilitation
CONCRETE SUBSTRATE USES	**ANSI/AWWA C305-18** CFRP Renewal and strengthening of prestressed concrete cylinder pipe (PCCP) **ACI 440.2R-08** Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures	

Decrease in shell thickness is usually due to:

- SCOUR AND ABRASION FROM SEDIMENT TRANSPORTATION
- CAVITATION AT SHARP BOUNDARY EDGES
- LOCALIZED CORROSION OR PITS
- GENERAL CORROSION

ASCE PENSTOCKS MANUAL Nr. 79 - 2012

REPAIR/IMPROVE

- Patches installed over the affected area or fully welded on circumferential direction
- Corners or sharp edges must be rounded to reduce local stress or head-loss (internal installation)
- Full concrete encasement is used to transfer internal pressure
- CFRP wrapping as circumferential/axial shell rehabilitation reinforcement

REPLACE

- Replaced items must be properly designed;
- Plants shutdown is mandatory
- New and old items compatibility must be very close examined.

RELINING / RECOATING

RELINING

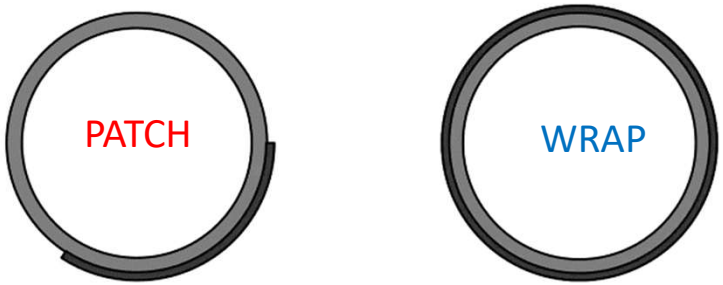
- Usually intended to prevent internal wall thinning and/or pitting and not to act as structural replacement systems
- Considered only when the current stress levels are within an acceptable limit
- Properly surface preparation must respect environmental application regulations

RECOATING

- Usually intended as external corrosion protection system against environmental condition. To be considered after understanding reasons of thickness reduction

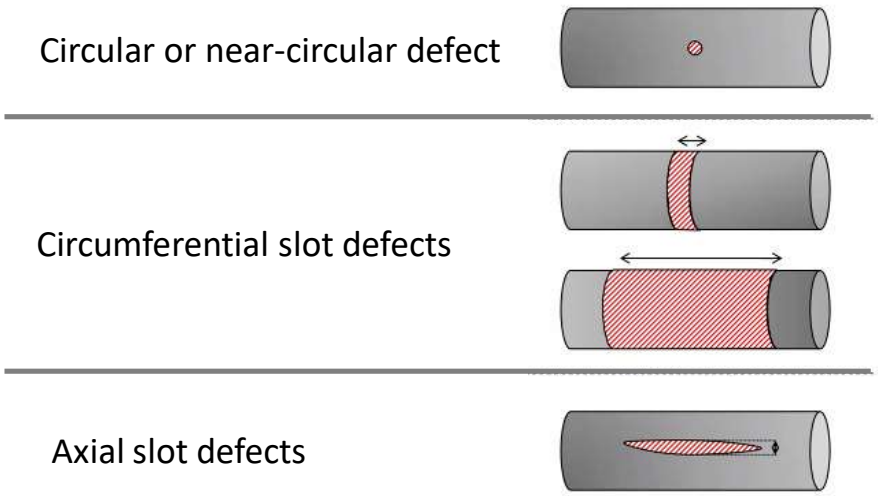
CFRP DESIGN - MAIN KEY CONCEPTS

WRAP vs. PATCH

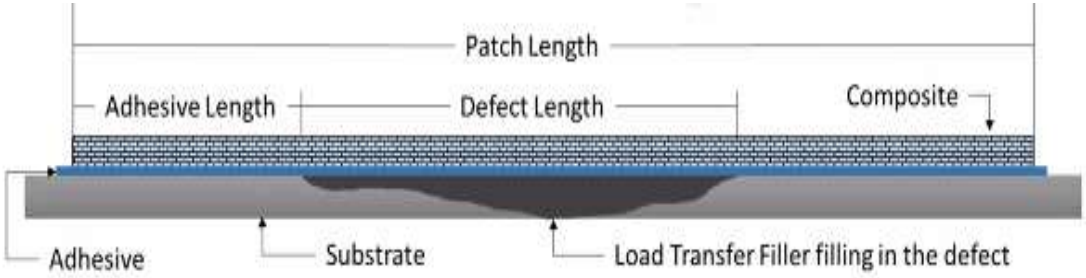


- **Wrap**: Covers the entire circumferential extent of the pressure vessel
- **Patch**: Provides only partial coverage over target area

TYPES OF DEFECTS



REPAIR LENGHT



Repair Lenght key concern are:

- Defect Lenght;
- Defect Size / Type
- Adhesive lenght

AXIAL COMPOSITE REPAIR ASSUMPTIONS

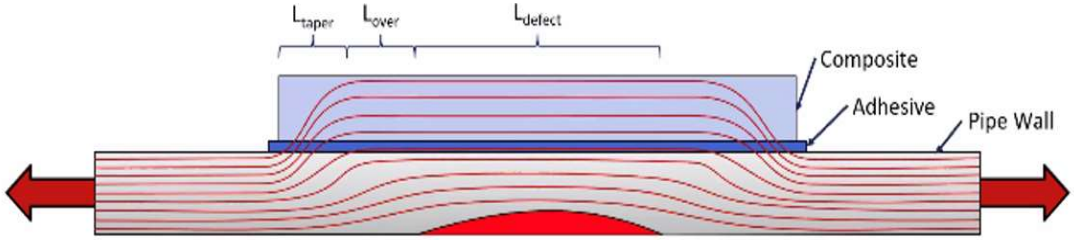
Simplified design assumptions:

- Perfect adhesion
- Both Systems strain at same rate ($\Delta\varepsilon_{a,p} = \Delta\varepsilon_{a,c} = \Delta\varepsilon_a$)
- Both Systems behalve in elastic region ($\sigma = E \times \varepsilon$)

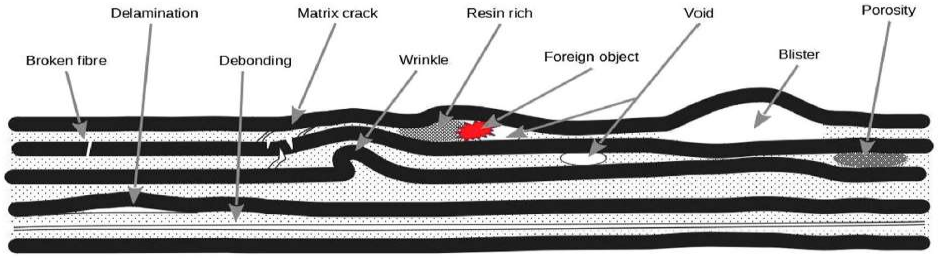
AXIAL STRESS OVERVIEW

When Installed correctly:

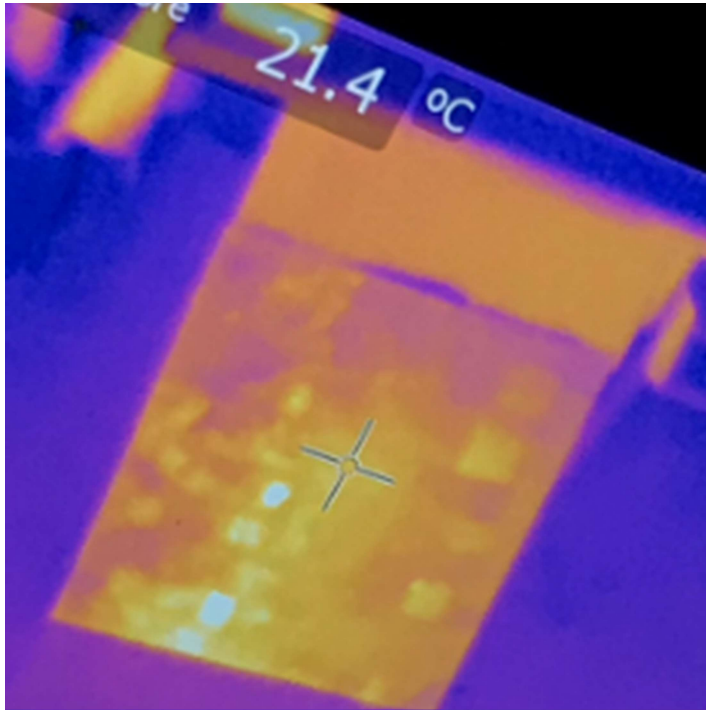
- Axial stress is transferred to the load bearing composite
- Localized stress is small enought to prevent adhesive/cohesive failure

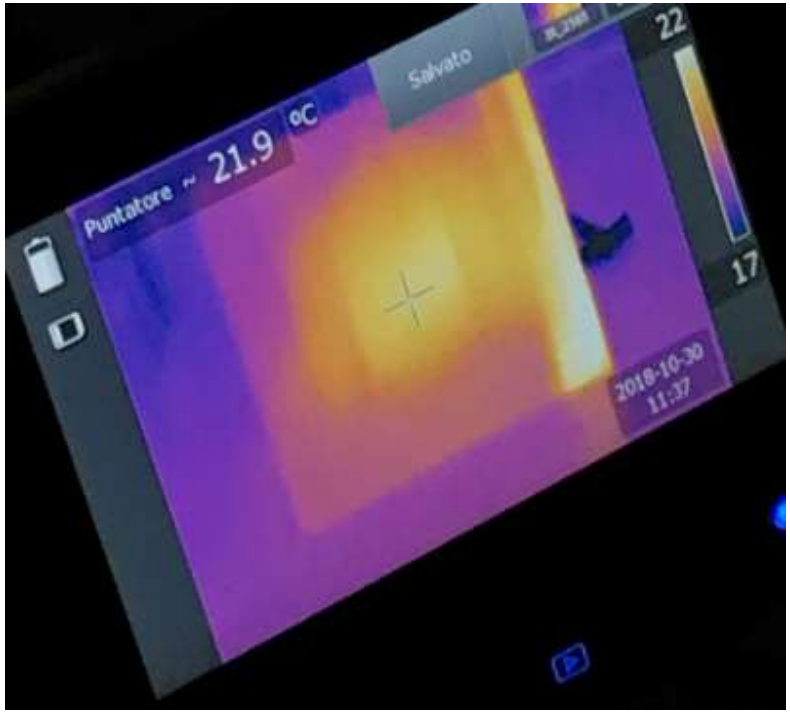


CFRP – QUALITY CONTROL PLAN



ID	Check*
1	Thixotropic resin application on surfaces irregularities
2	Fabric fiber saturation
3	Visual control defects absence
4	Overall dry fabric film thickness
5	Sound check of voids (gavel)
6	**Vacuum control by thermography**
7	Adhesion Control





*Not referred to surface preparation

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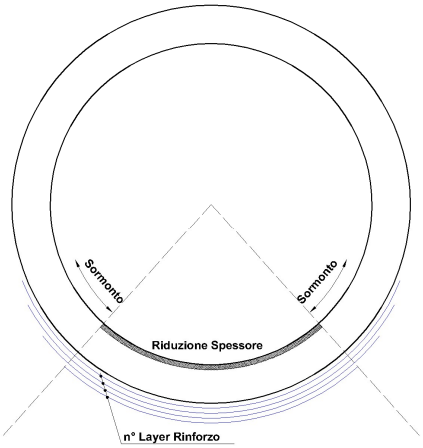
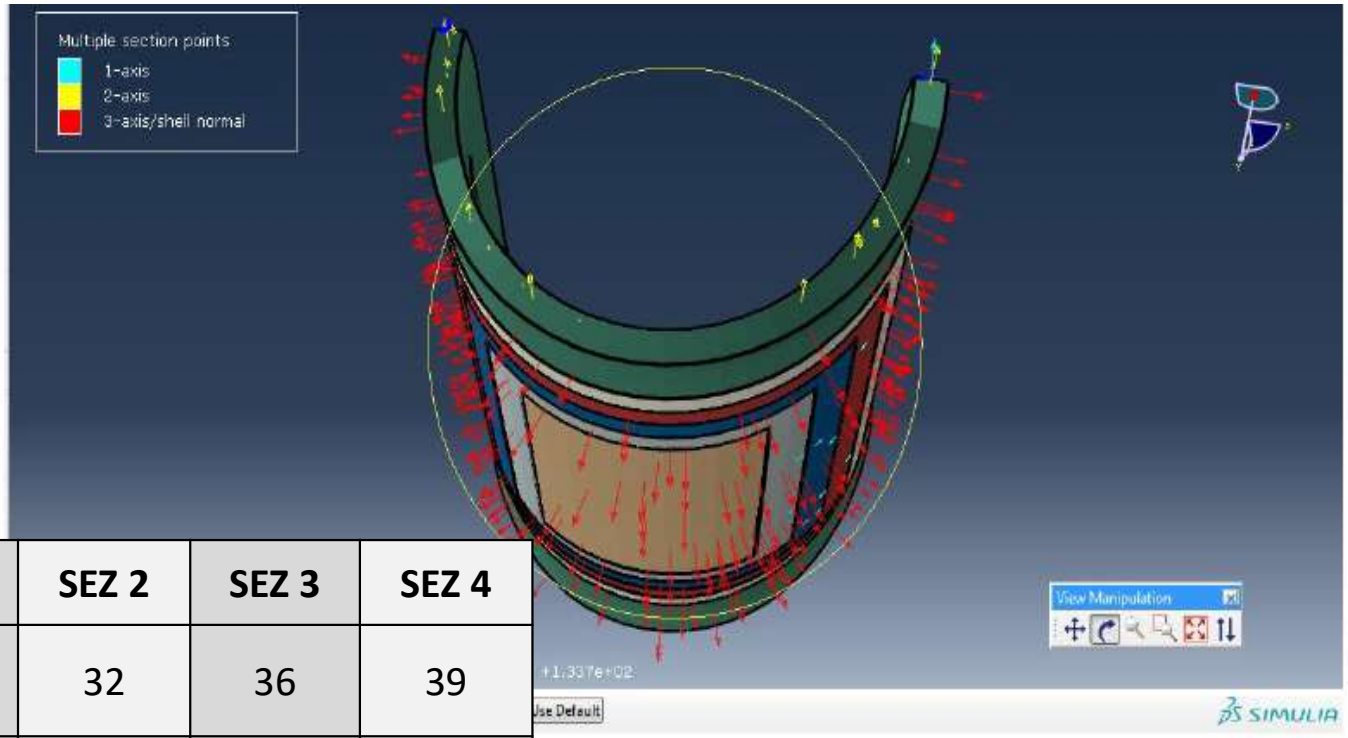
CASE HISTORY n.1 – *EXTERNAL PATCH PENSTOCK MAINTENANCE*

Target: Increase safety factor (become <1) in the lower part of the penstock
Design according to ISO 24817



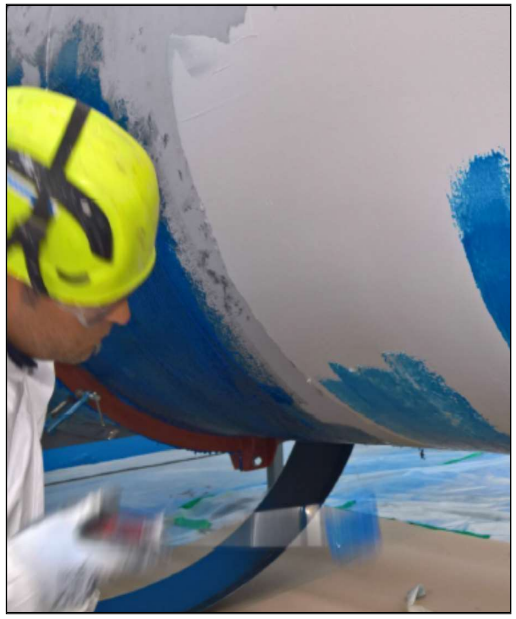


	SEZ 1	SEZ 2	SEZ 3	SEZ 4
Nominal Thickness [mm]:	28	32	36	39
Residual Thickness [mm]	24	31	32	35

CASE HISTORY n.1 – *EXTERNAL PATCH PENSTOCK MAINTENANCE*

PRE-MOLDED SHELL APPLICATION

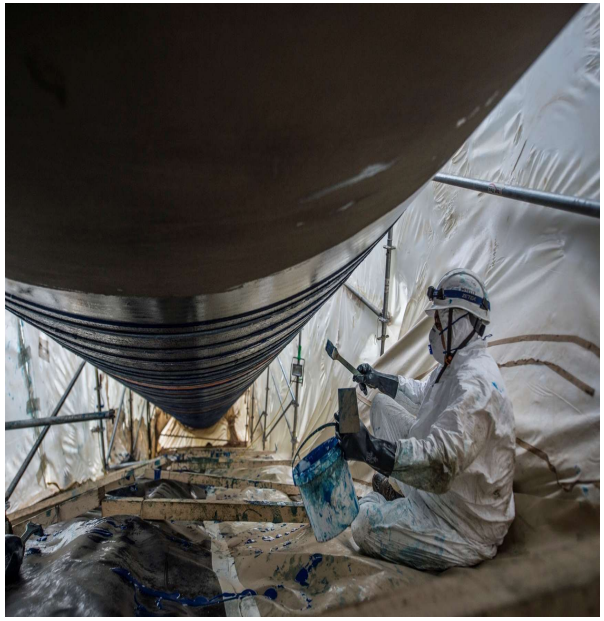
Preliminary activity: re-profiling of the corrosion pits and filleting of weld



1) Re-profiling corrosion pit and weld filleting

2) Pre-molded CFRP shell designed

3) Onsite shell saturation by epoxy resin



4) Onsite shell installation

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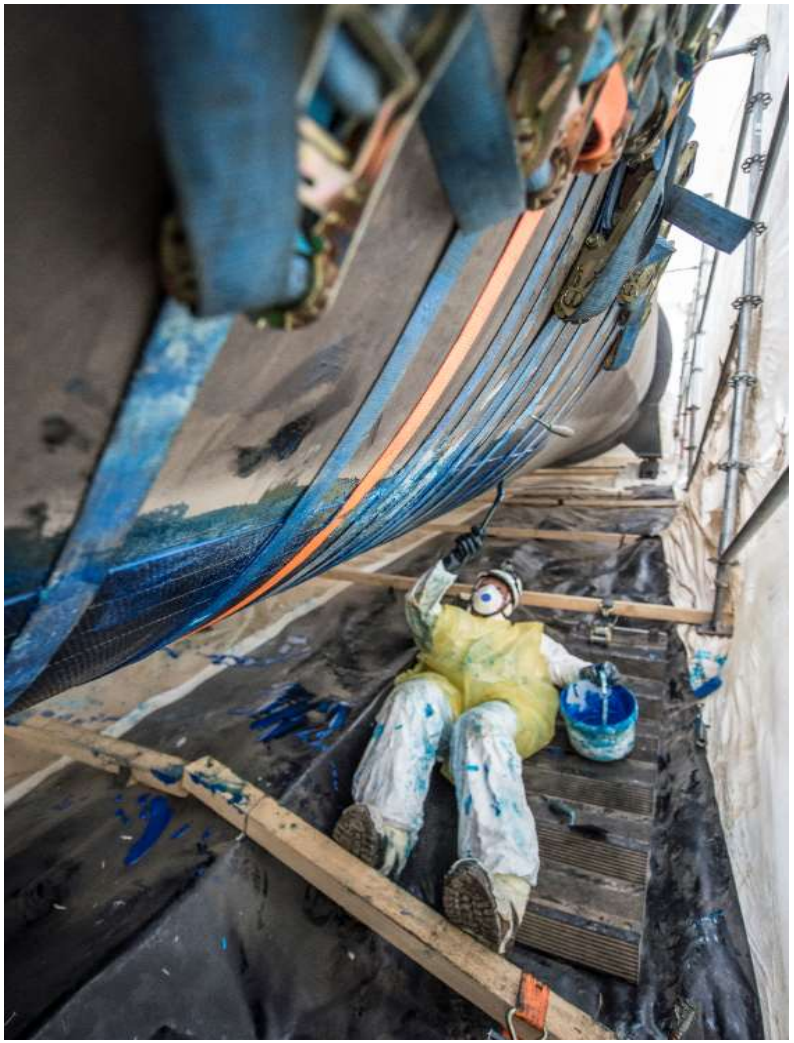
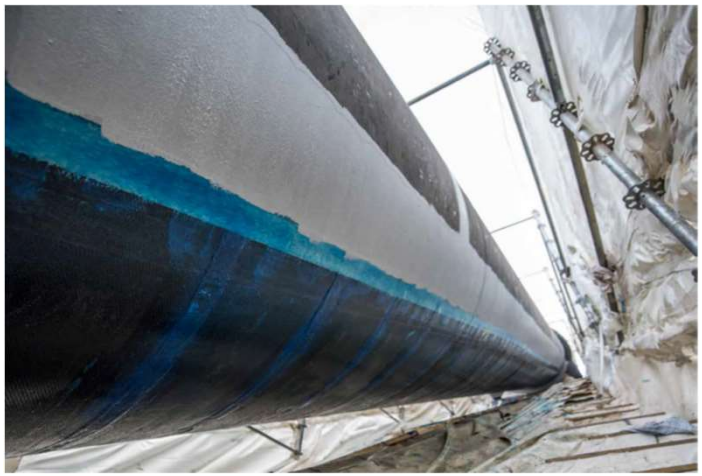
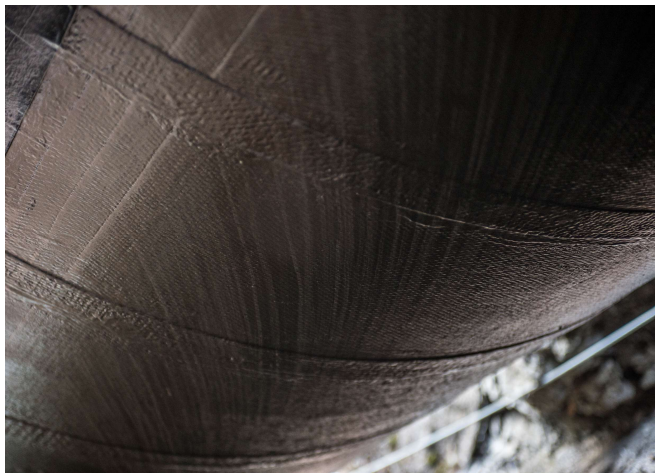
CASE HISTORY n.1 – *EXTERNAL PATCH PENSTOCK MAINTENANCE*







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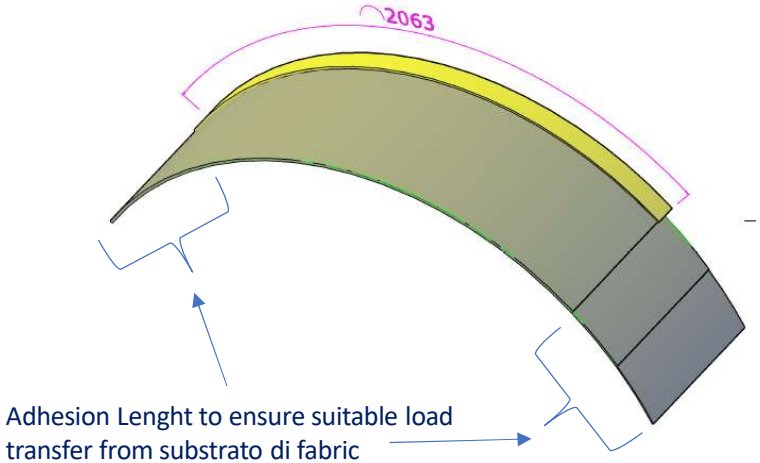
CASE HISTORY n.2 – *EXTERNAL WRAPPED PENSTOCK MAINTENANCE*

Design according to ISO 24817



Pre-Molded Shell

Diameter: 2.000 mm ÷ 1920mm

Surface Reinforced ~ 100 m^2

Reinforcement: n°3 pre-molded shell CFRP wrapped

SPECIFIC FEATURES:

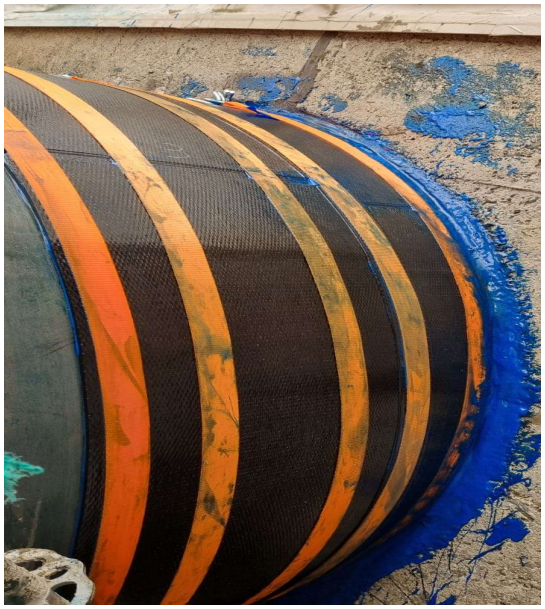
- Ensure the right size of pre-molded shell on variable diameter over penstock lenght
- Handling and keep in place pre-molded shell during epoxy resin curing-time
- Ensure suitable environmental conditions during installation

CASE HISTORY n.2 – *EXTERNAL WRAPPED PENSTOCK MAINTENANCE*

Design according to ISO 24817

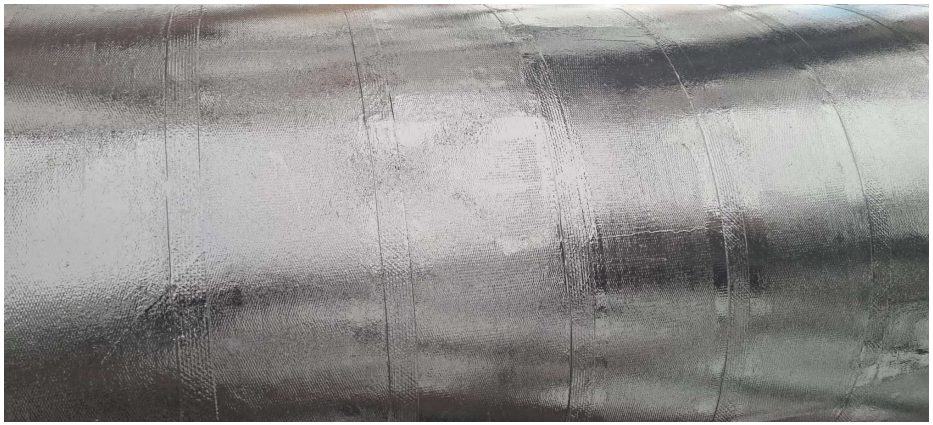
Pre-molded shell joints

Manhole detail



Belts holder durinig curing

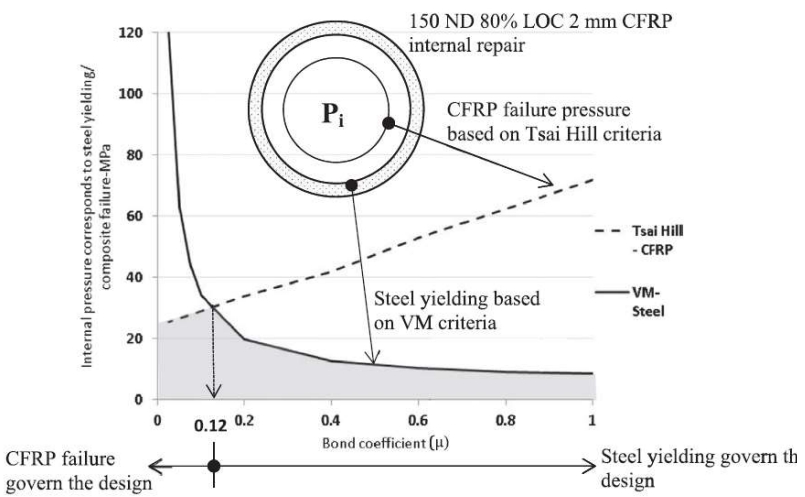
Penstock Anchor Block – after topcoat

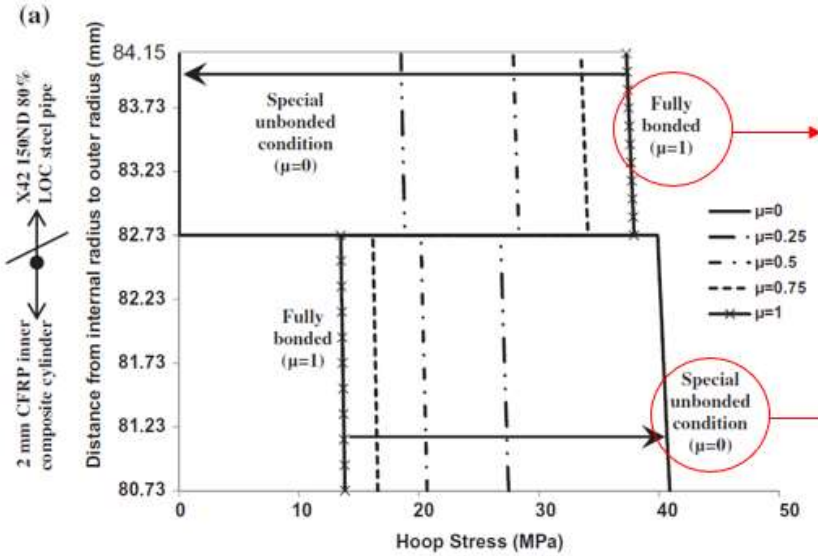


Penstock Current section – after topcoat

CASE HISTORY n.3 – *INNER PATCH PENSTOCK MAINTENANCE*

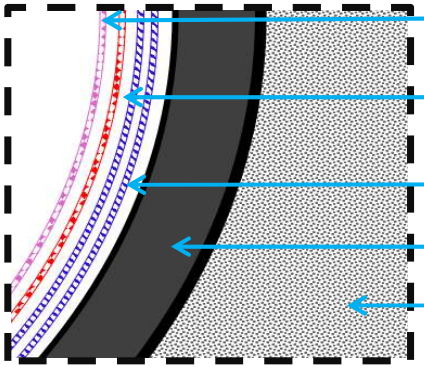
Design according to «Tsai-Hill» + «Von Mises» Criteria





μ=1 Fully Bonded Condition:
CFRP and Host steel pipe fully share hoop, radial, axial stresses

μ=0 Unbonded Condition:
No contribution from steel side to withstand internal pressure, all stresses addressed to composite



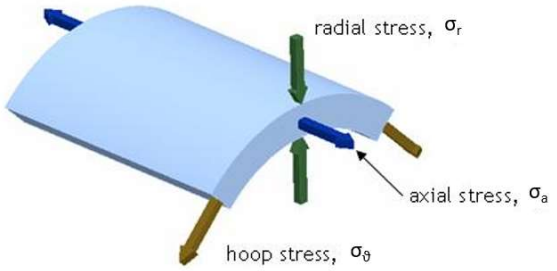
Corrosion protection top-coat

CFRP Layer (hoop)

GFRP (electrical insulation)

Penstock

Concrete Anchor



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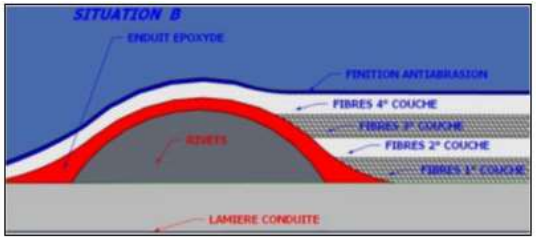
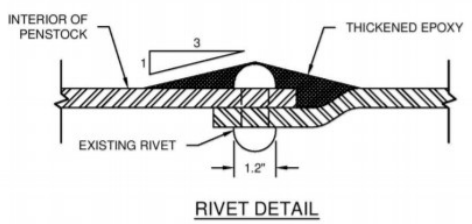
CASE HISTORY n.3 – *INNER PATCH PENSTOCK MAINTENANCE*
ONSITE INSTALLATION PHASES

1) Fill pitting, get smooth steel surfaces

2) Fabric and epoxy resins application





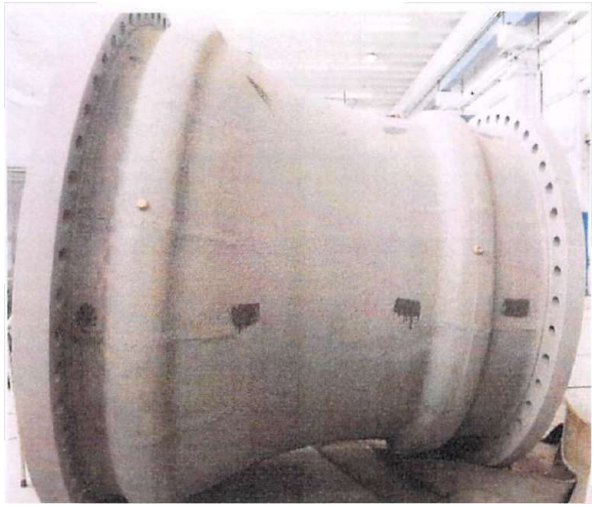
RIVET DETAIL

3) Keep in place fabric during curing time

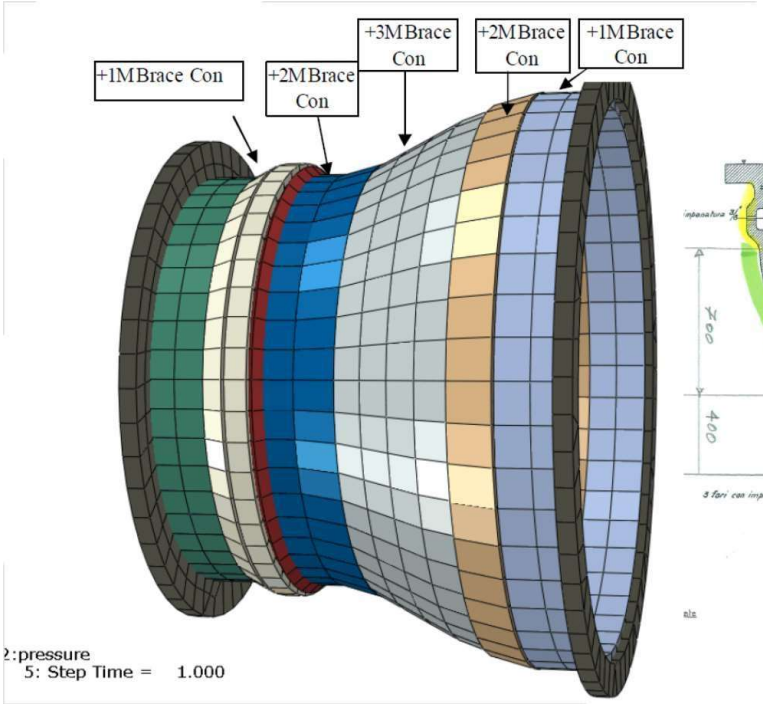
4) CFRP fabric after polymerization

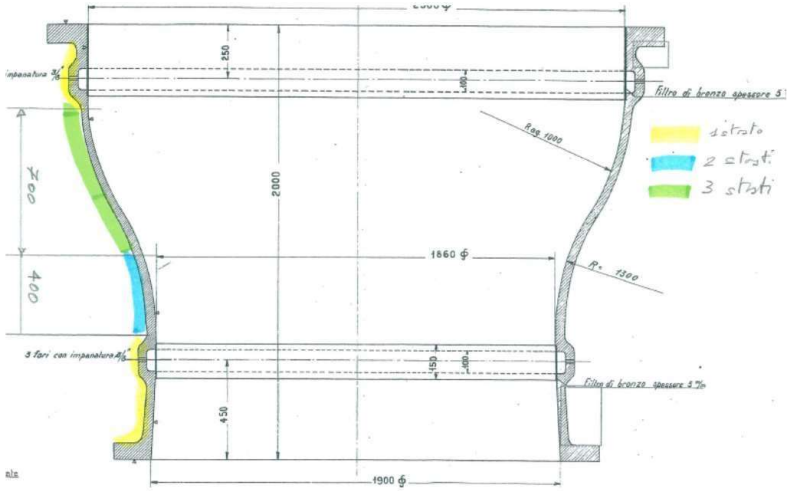
5) Wet abrasion resistant top-coat

CASE HISTORY n.4 – *"VENTURI" CAST IRON REINFORCEMENT*



Due to the complex geometry of the item, with various shape and different residual thickness, design has been done with the finite elements approach, using carbon fiber yarn rope (no fabric) as reinforcement.



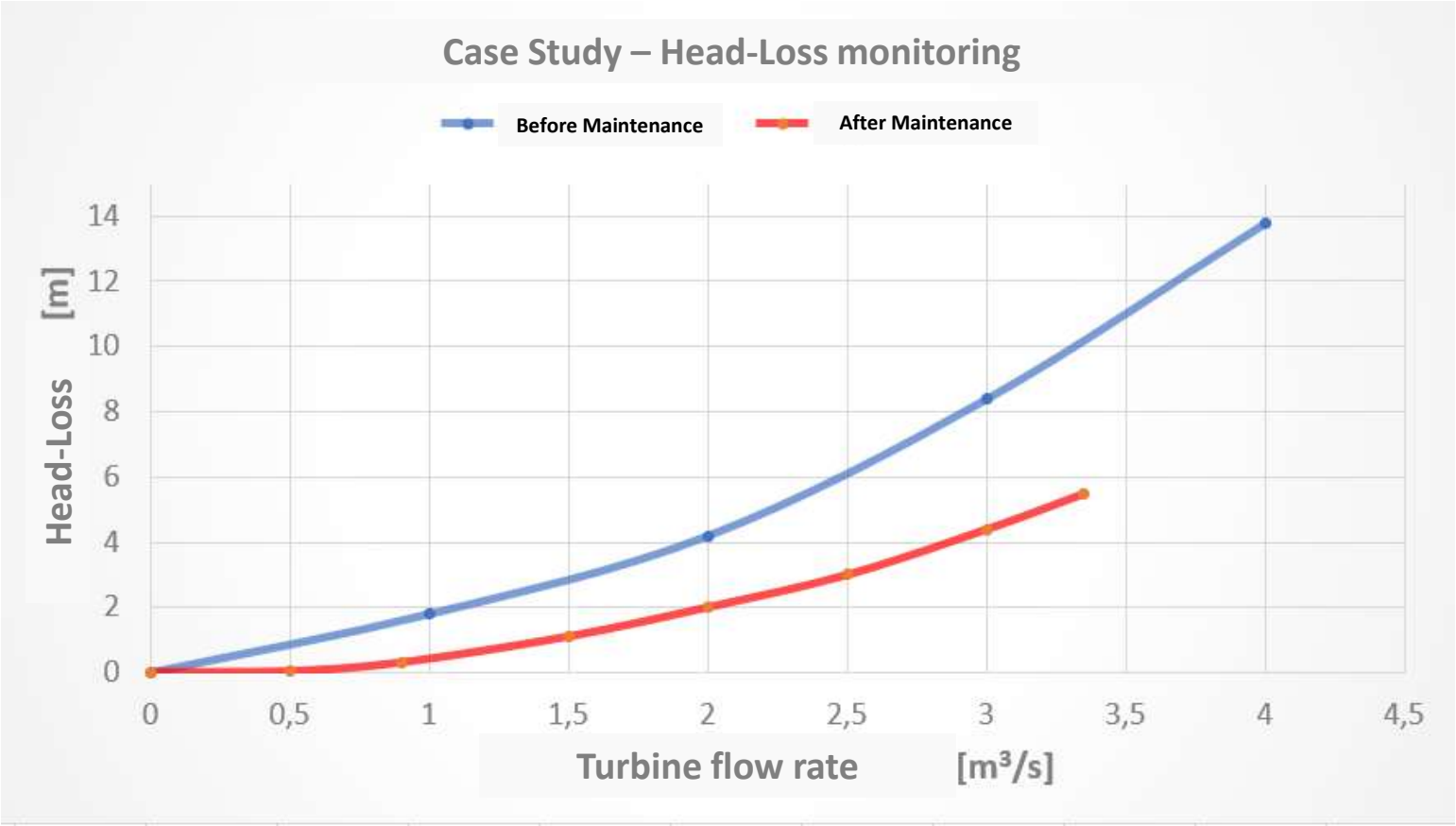


CASE HISTORY n.4 – *"VENTURI" CAST IRON REINFORCEMENT*

Reinforcement application using high-strength carbon yarn ropes

CASE HISTORY n.5 – *COATING PAINTING INNER RELING – Without CFRP*

Penstock efficiencies mean try to **keep the same head-loss** during the time.
Uses of **certified** surfaces roughness protective coating can ensure a low Strickler (85÷90) coefficient in order to get a smoother substrate



Sediment trasportation cause scale on substrate

Not flattened weld increase head-loss

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CASE HISTORY n.5 – *COATING PAINTING INNER RELING – Without CFRP*

PRELIMINARY PREPARATION

Blasting

1

Get a flat welding

Primer

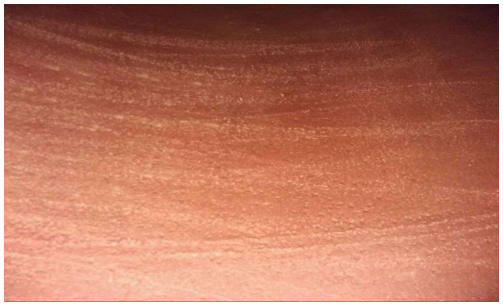
2

Fill/Grout deeper pittings

COATING APPLICATION

3

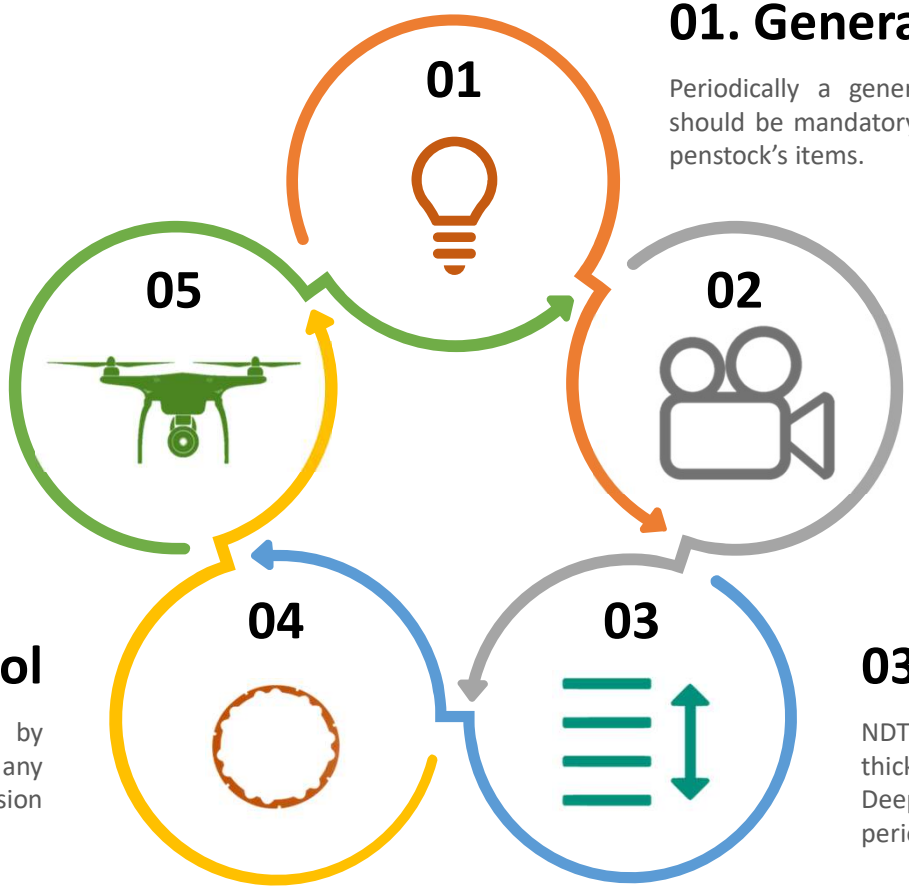
Apply certified protective coatings preferring hot robotic/automatic systems in order to reduce of humans in confined spaces and ensure a standard thickness on surfaces.



Penstock substrate after 4 years in-service

MAINTENANCE PROGRAM

STATUS OF PENSTOCK SHOULD BE MONITORED AT LEAST BY:



01. General Assesment

Periodically a general assessment based on schedule specifications should be mandatory in order to check the status and features of main penstock's items.

02. Video Inspection

Internal video inspection should be periodically scheduled. Robotic video systems can be a safe, replicable for collaborator and more accurated alternative to human on-site survey

03. Shell Thickness Control

NDT (Non Desctructive Testing) can provide a quick thickness check of steel items avoiding plant shutdown. Deeper investigation should be planned during periodically plant shutdown

04. Lining/Coating Control

Lining and coating durability should be checked by periodically scheduled survey in order to control any local damages and residual thickness due to abrasion affect

05. Topographic Movement Control

Ground and penstock's items movement can generate serious damages. Monitoring and check the respective stability could be a right way to prevent very expensive restoration.

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Thanks

Ing. Emanuele Zaniboni
Mail: info@ezetaengineering.com