Penstocks, pressure shafts & pressure tunnels

Milano 3 novembre 2022

Non-Destructive Testing for steel penstocks

Roberto Felicetti, Politecnico di Milano & **Ezio Tuberosa**, IREN ENERGIA - AIPnD, CICPND

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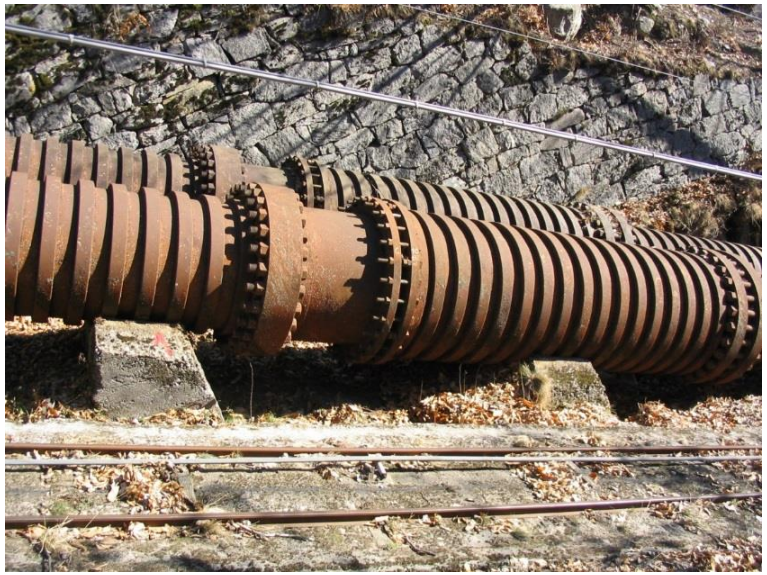
Definition of penstock:

part of the plant connecting
the surge tank or the forebay to the turbines.

It generally consists of one or more metal pipes,
and the foundation and accessory Civil works.

Penstocks are mostly made of metallic materials.

The classification of penstocks
can be organized according to various criteria,
depending on the peculiarities of the plant and the pipe itself
and, in the end , on the design choices.



- **design**
  1. free bends (deformation absorbed by the bends themselves)
  2. anchored bends (deformation absorbed by specific joints)

- **materials**
  1. reinforced concrete (plain, prestressed, fibre reinforced)
  2. cast iron
  3. steel
  4. high density polyethylene (HDPE)
  5. fibre reinforced polymers (FRP)

• Construction types

a) RC pipes

- sleeve joints (concrete or steel)
- cup joints
- flanged joints

b) cast iron pipes

- sleeve joints
- flanged joints

c) steel pipes

- forge welded pipes
- riveted pipes (longitudinal and transversal joints)
- stiffened (longitudinal weld and hoop stiffeners)
- calendered and electrically welded
- helical welded pipes

d) HDPE pipes

- mechanical jonts
- flanged joints
- melted joints.

e) FRP pipes

- cup joints
- flanged joints
- sleeve joints

- **Installation**

a) exposed
b) in accessible tunnels
c) pipeline bridge
d) buried

- **Internal lining**

a) uncoated
b) epoxy resin
c) bituminous
d) concrete (cast iron)

- **External lining**

a) uncoated
b) epoxy resin
c) bituminous

- **Diameter**

a) not accessible (< 1.0 m)
b) accessible (>1.0 m)

- **Saddles types**

a) different sliding mechanism (sliding, roller, ball and other bearings, etc.)

MAIN CAUSES OF WEAR AND / OR DAMAGE

Wear and/or damage during operation of pressure penstocks
ensue from various types of causes.
They may depend on the way the system is operated, the characteristics of the fluid, the surrounding environmental conditions and problems of other nature and origin.

- **Hydraulic causes**
  - water hammer overpressure
  - overpressure due to plant repowering
  - Overpressure due to modifications / variations in the operation of the plant
  - Underpressure due to pipeline emptying, failures, etc.
  - Overpressures / underpressures due to the failure of hydraulic components.

- **Construction material**
  - Weakening or strength loss of the material
  - Corrosion (general atmospheric; localized; by galvanic contact; pitting; intergranular; fatigue; etc..);
  - Erosion.

- **Design - Constructive type**
  - Weakening and loss or strength loss of welded and/or riveted connections;
  - Failure of the support elements and/or anchoring blocks;
  - Sliding of the support saddles (especially for the cradle type);
  - Joints and/or joint slip.

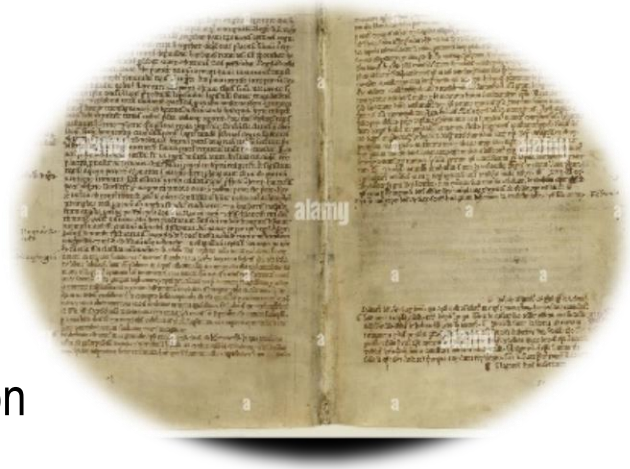
- **Exceptional events**
  - Earthquakes
  - Lanslides.

As a rule, penstocks are subject to systematic checks.

The procedures of the most important concessionaires provide for external visual inspections (penstock in operation) and internal visual inspection (empty penstock)

These inspections are scheduled to detect the presence of leaks, damages or an incipient failure condition.

Listed below are the destructive and non-destructive tests and controls which may be useful and applicable for carrying out investigations on penstocks conditions



1. Historical anamnesis - SH (System History)

starts from the direct check (inspection and visual verification) of the conformity to the project documentation.This is followed by the collection of all available documents pertaining to maintenance, renewal and replacement interventions; including documentation of any extraordinary events (landslides; seismic events; etc ..).

2. Visual Test - VT (Visual Test)

a) external (diretto e/o indiretto per zone difficilmente raggiungibili);

b) internal by way of direct inspection;

c) internal by way of instruments (endoscopes) or specific robots.

Not limited to the pipeline, including all accessory elements which can directly affect its behavior (hydraulic guard and safety organs; expansion joints; supports and saddles; anchor blocks; etc ..) .

3. Dimensional Tests - DT

They are designed to verify:

a) the compliance with the design documentation

b) any abnormal movement of the pipe and its supports (misalignments, detachment from the supports, sliding, settlements, rotation, etc.)

c) any functional anomalies of the expansion joints (misalignments, slipping or jamming, etc ...)

4. Ultrasonic Tests – UT

a) Digital thickness control by ultrasound

b) Digital thickness control with ultrasonic A-scan visualization (defectoscopic investigation of the detected anomalies)

c) Digital thickness control by the ultrasonic Phased-Array technique

d) Ultrasonic defectoscopic examination of welded and riveted joints

e) Ultrasonic defectoscopic examination (TOFD; Phased-Array) for defect sizeing

f) Ultrasonic check of concrete homogeneity

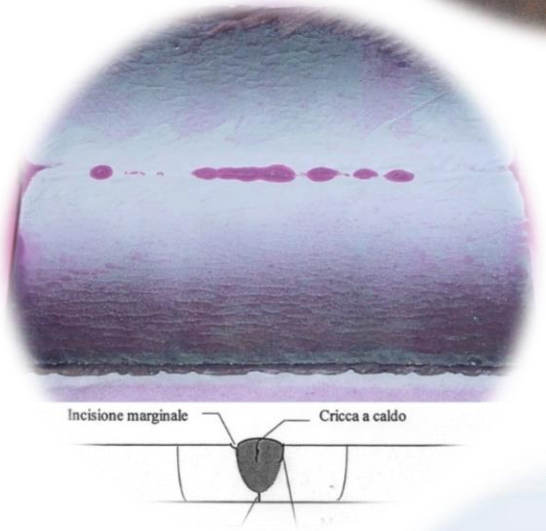
5. Magnetoscopic Tests - MT

a) Defectoscopic examination by magnetoscopy of welded joints, of surfaces in general and of other elements (rivets, stiffeners, etc);

b) Detection of rebars by magnetoscopy (covermeter).

6. Dye Penetrant Testing - PT

a) Defectoscopic examination of welded joints and surfaces using penetrating liquids



7. Radiographic Test - RT

a) Defectoscopic examination by radioscopy of the welded joints.

8. Site Non-Destructive Tests - SNdT

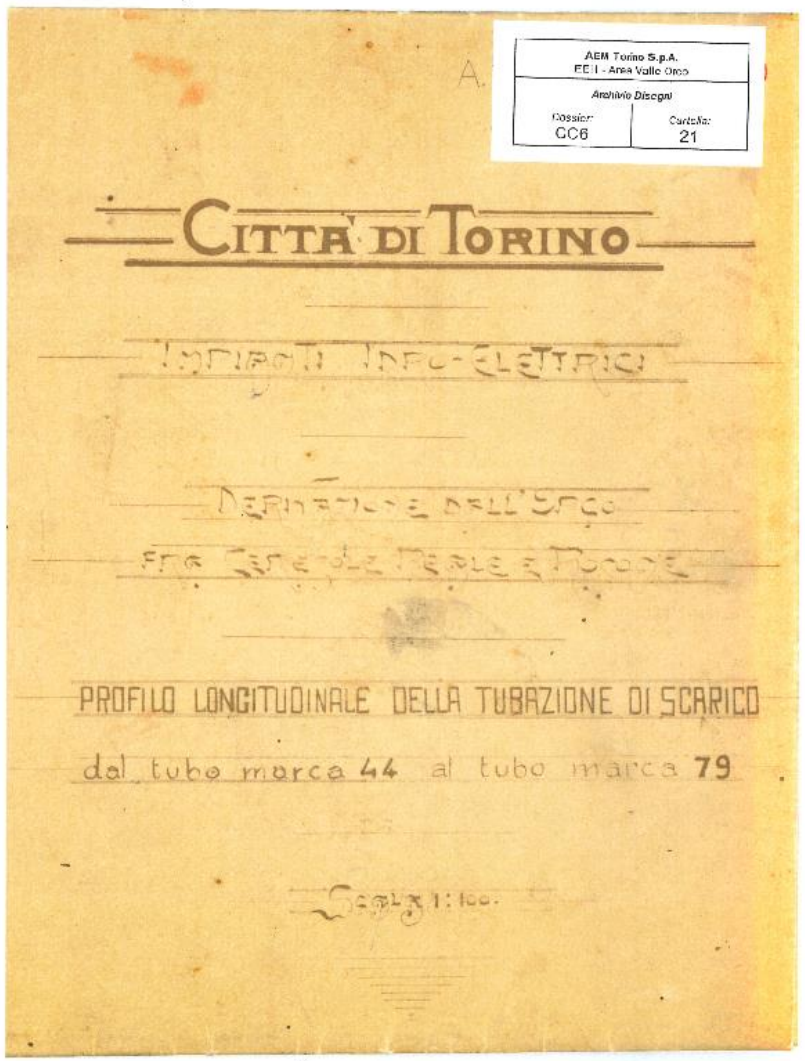
a) Metallographic field replica
b) Chemical analysis, Positive Material Identification
c) Hardness tests
d) Roughness checks
e) Surface stress measurement
f) Verification of the transition temperature at zero ductility (NDTT - Nil Ductility Transit. Temp.)
g) Surface hardness tests on concrete structures
h) Pull-out tests on concrete
i) Measurement of the depth of carbonation of concrete
j) Investigation of concrete walls using flat jacks.

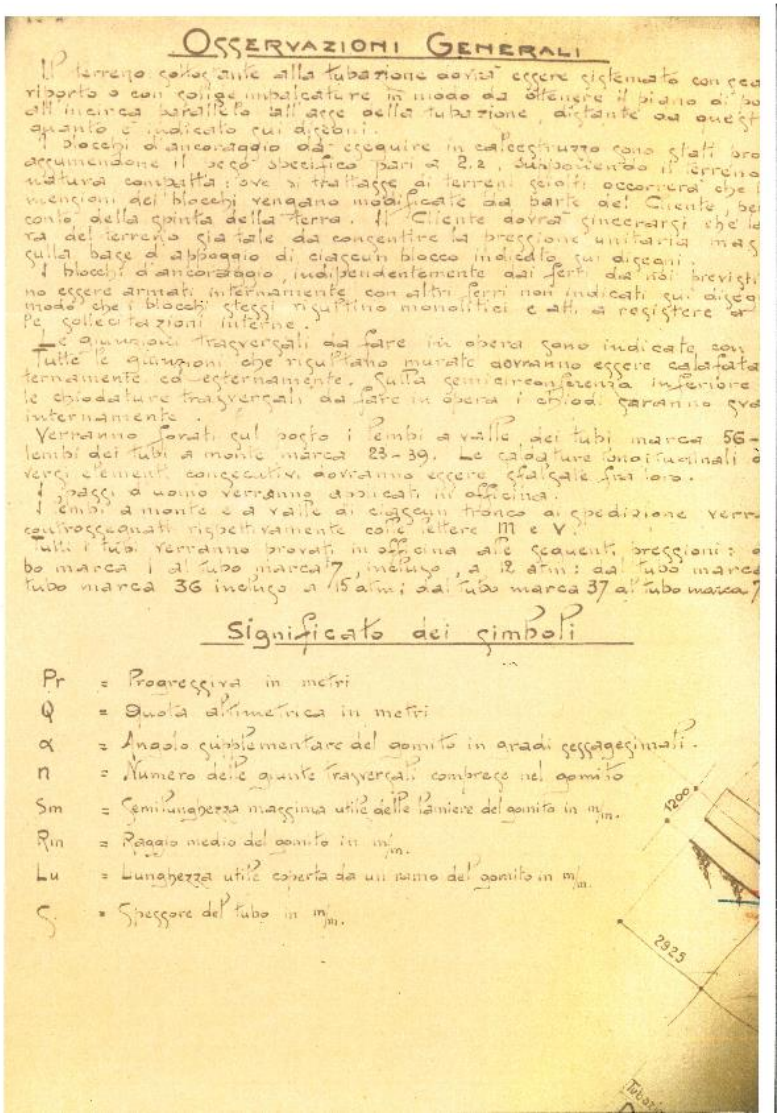
9. Laboratory Tests - LT

a) Tension, resilience, bend, chemical analysis, etc on pipeline samples and/or other accessory elements of penstocks made of steel, cast iron, HDPE and fiberglass
b) Core drilling on concrete structures for compression tests

Historical anamnesis - SH (System History)

Historical anamnesis - SH (System History)





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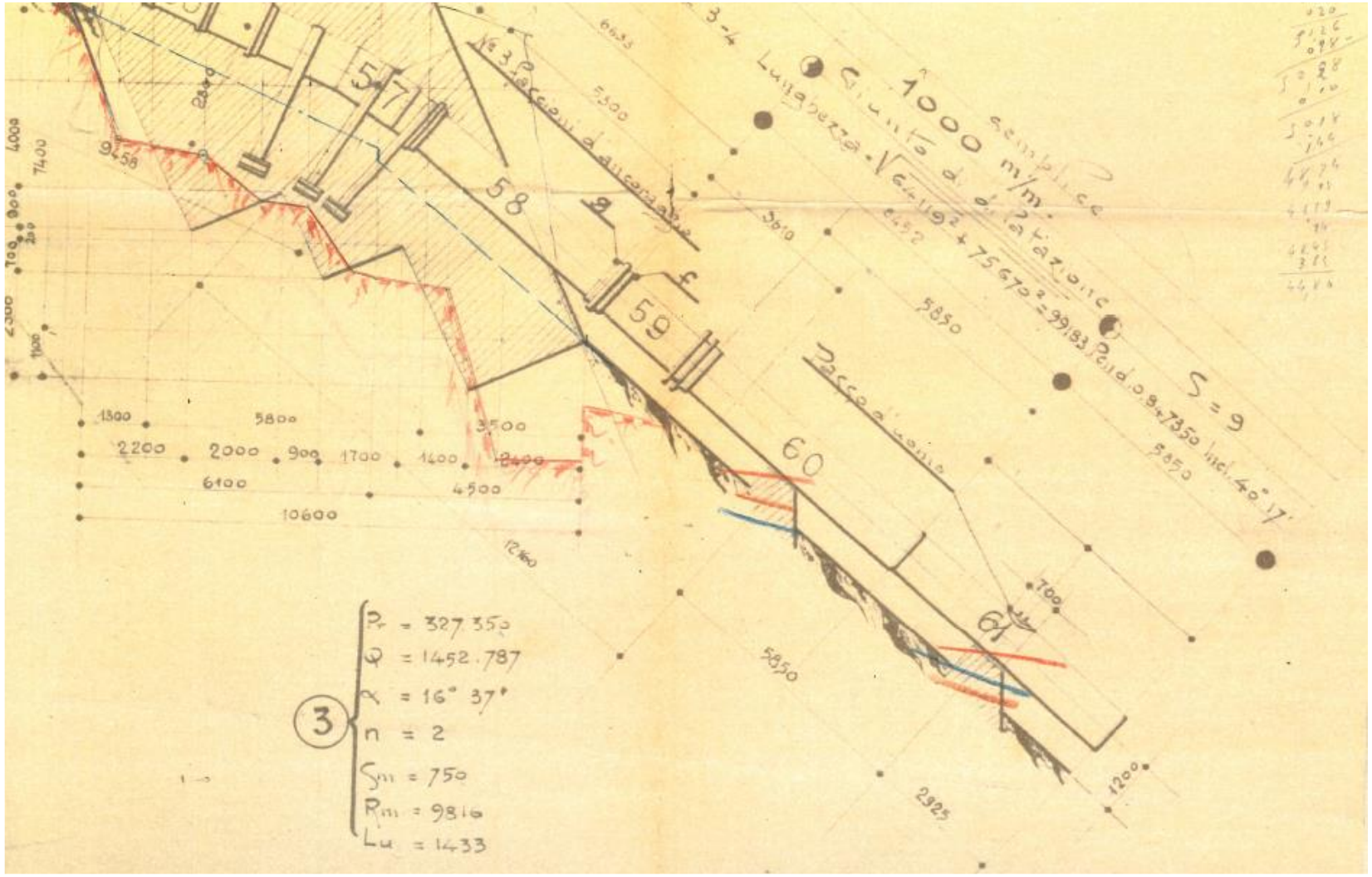

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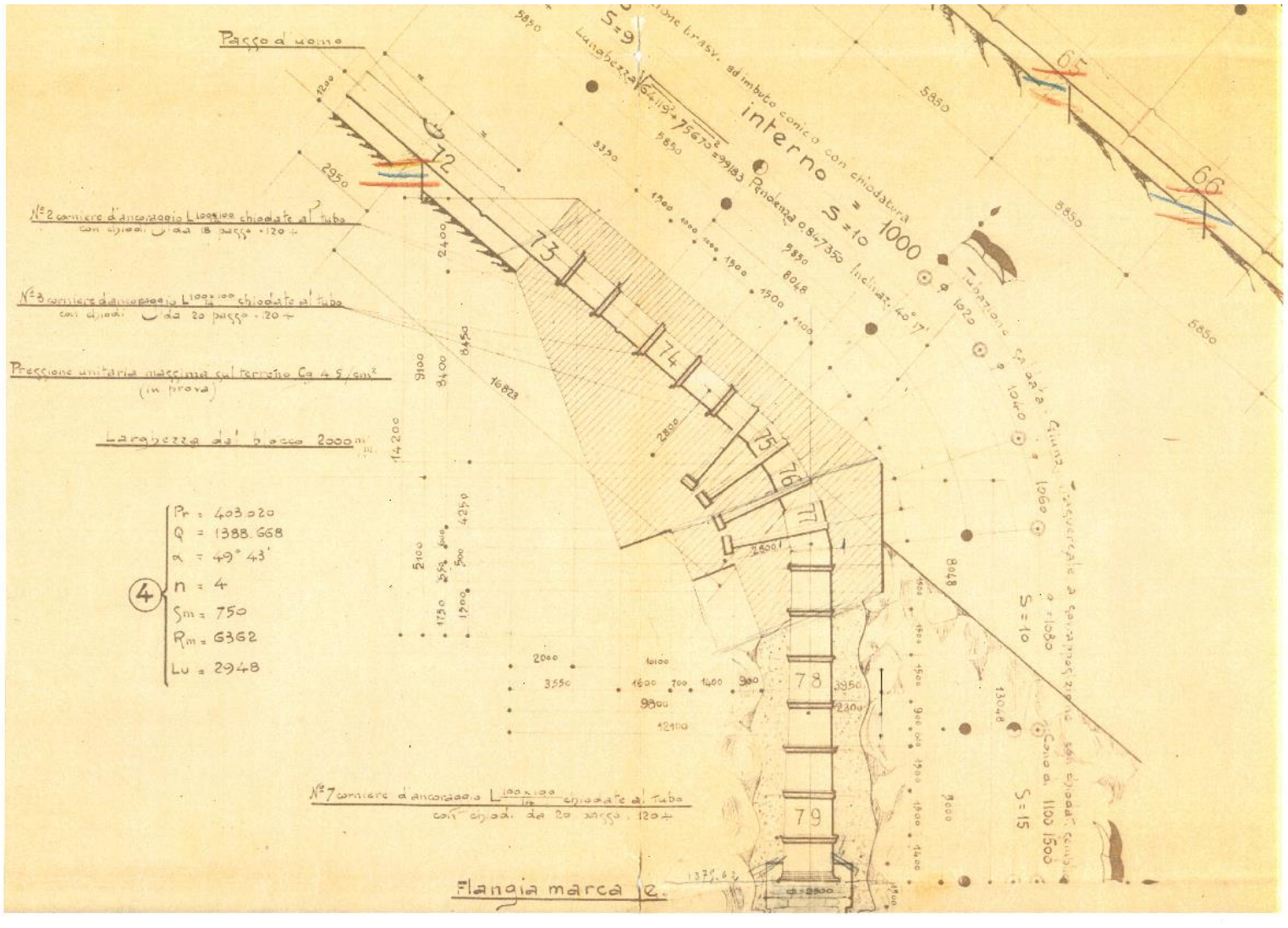


Visual Tests - VT

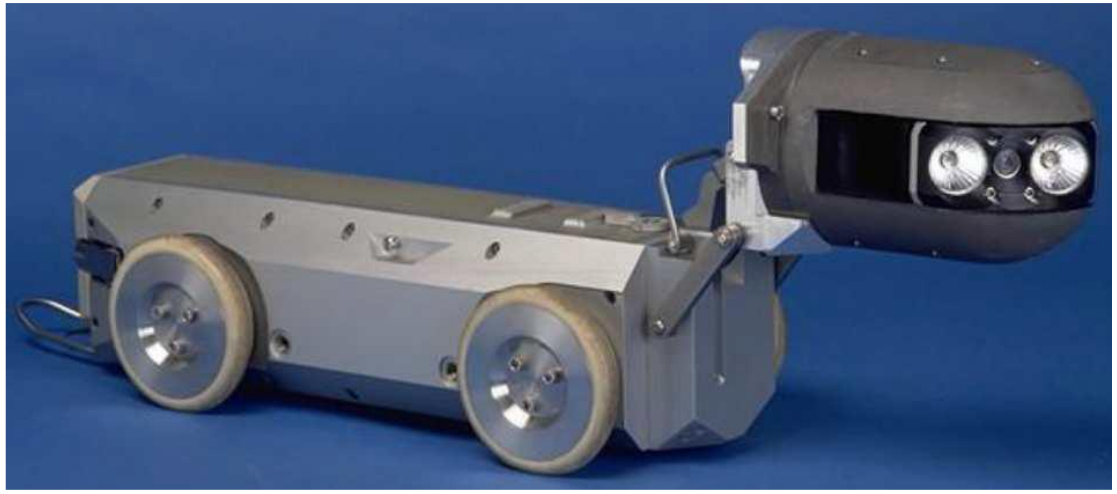
For pipelines built before the '50s there are problems related to particular construction features such as:

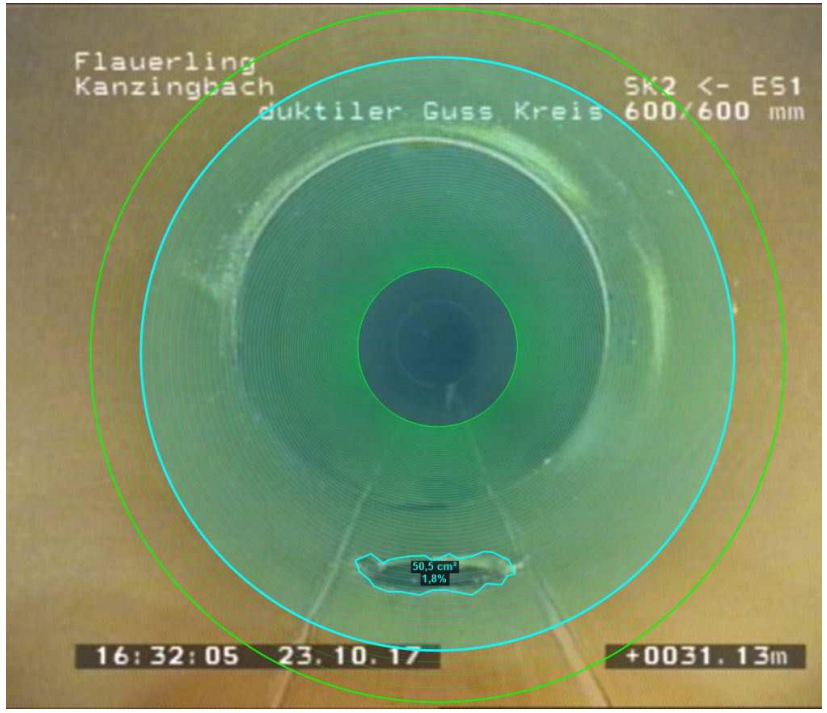
- The use of rimmed steels
- Presence of forged welds (bolliture)
- Presence of riveted joints
- Special pieces in cast steel

Visual Tests - VT

Visual examinations must not be limited to the pipeline only,
but must be extended to all accessory elements (hydraulic guard and safety devices; expansion joints; supports and saddles; anchor blocks; etc.) which can directly affect the behavior of the pipeline

1. External visual examination (direct and / or indirect for areas that are difficult to reach);
2. Internal visual inspection through direct inspections;
3. Internal visual examination using instruments (endoscopes) or specific robotic systems.





Dimensional Tests - DT

general and/or specific dimensional checks

are designed to verify:

a) compliance with the design documentation
b) any anomalous movements of the pipes and of the relative supports (misalignments, ovalizations, detachment from the supports, sliding on the supports, lowering / rotation of the supports, etc.);
c) any functional anomalies of the expansion joints (misalignments, slipping or jamming, etc)

Thickness checks

by Ultrasonic testing - UT

the pulse-echo principle

Ultrasonic Testing - UT

a) Digital thickness control by ultrasound

b) Digital thickness control with ultrasonic A-scan visualization (defectoscopic investigation of the detected anomalies)

c) Digital thickness control by the ultrasonic Phased-Array technique

d) Ultrasonic defectoscopic examination of welded and riveted joints

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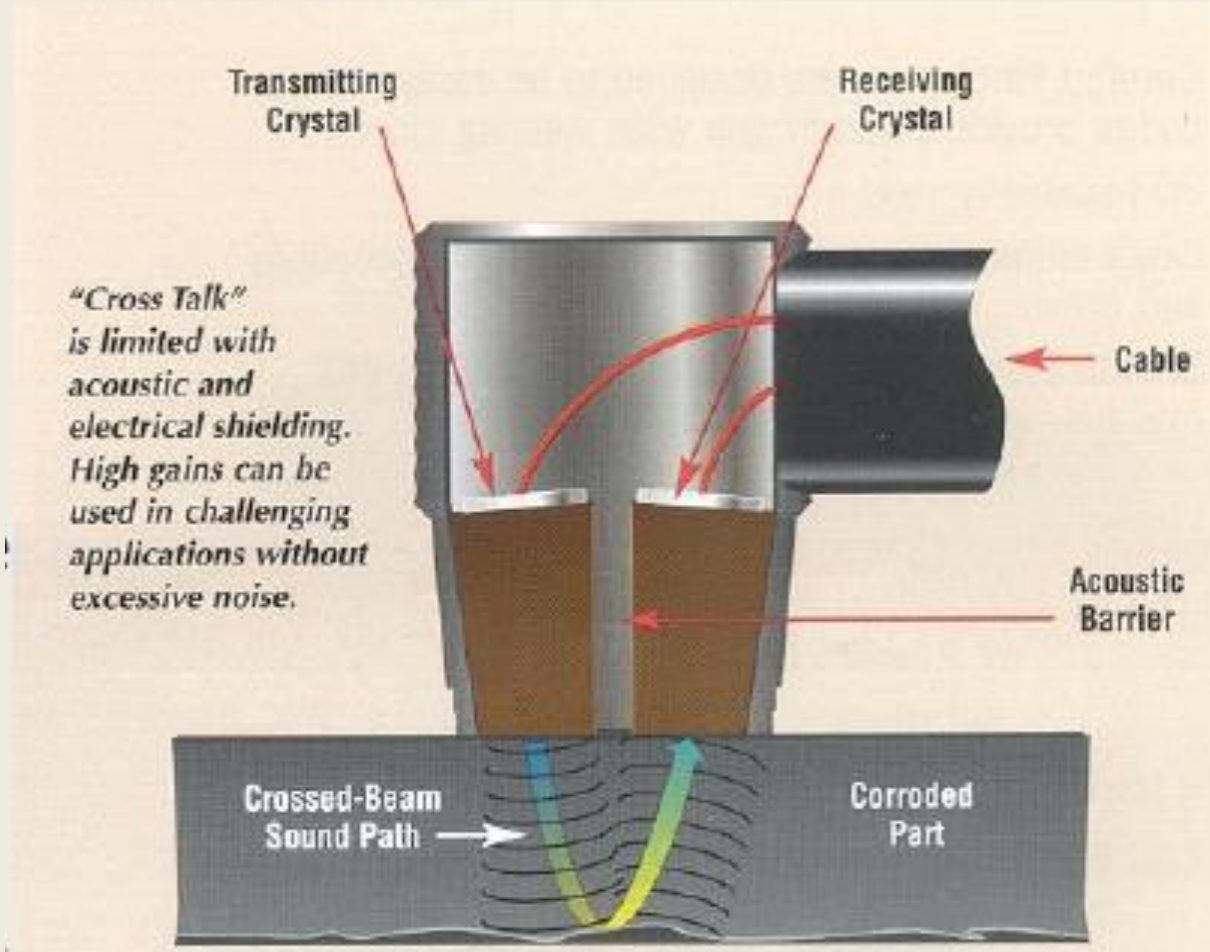
f) Ultrasonic check of concrete homogeneity

Contact probes
can have multiple transducers,
some of which work as transmitters
and others as receivers.

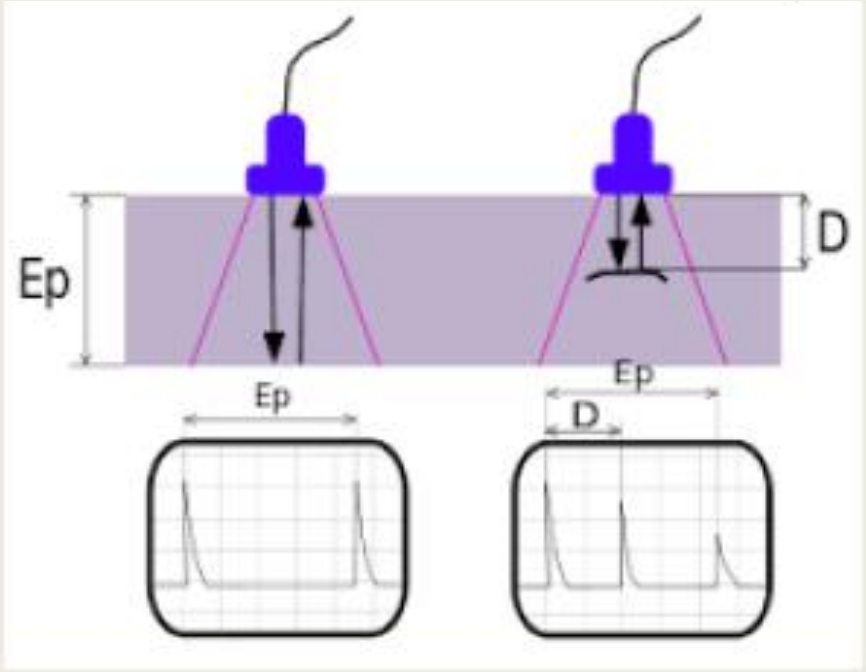
The most common probes
are those with converging beam
(T / R probes), i.e. one transmitting
and one receiving transducer

They can generate normal
or angled beam



Two angled elements create a crossed-beam sound path in the test material. This "Pseudo-Focus" enhances resolution in the focal zone.

internal defect detection via the A-scan



device with
digital measurement + A-scan

This control is used as a first screening. In case of positive results, no further special investigation is carried out.

It is performed from outside while the conduct is in service, with no influence on the results.

If the external surface of the pipe is not corroded and the protective coating is adherent and undamaged,
there are transducers suitable for detecting only the steel thickness, with no need to remove the paint.

Measurements are normally performed
on 4 orthogonal generatrices (top, right, bottom, left)

For each single element making up the pipe (shell), several measurement sections must be identified, depending on the element length

The section interval is normally about 1 meter.

Control procedure

The pipeline is divided into batches
of homogeneous thickness
A sample equal to 10% with a minimum of two shells
will be examined for each batch

The measurements must be statistically processed
for each homogeneous batch
in order to obtain the average thickness
and the probable minimum average thickness.

Finally, the minimum probable thickness
is compared against the nominal thickness

The main operational difficulty in thickness measurement is the possible presence of segregations in the sheets, which can mislead the operator.

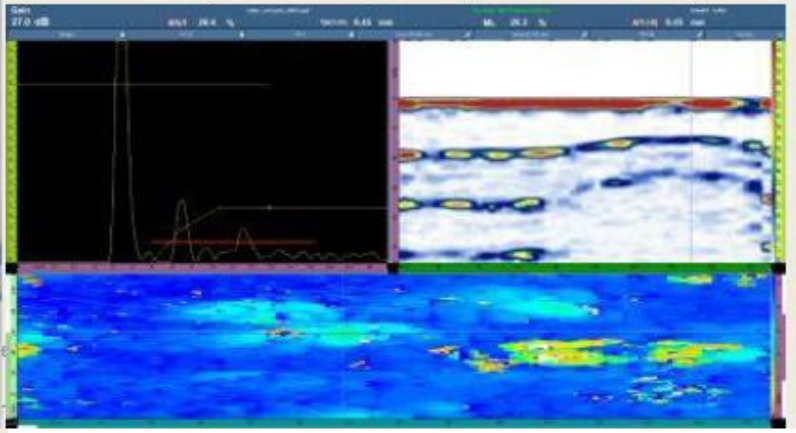
The phenomenon of segregation is more likely in old pipelines characterized by rimmed steels.

The risk is to confuse the presence of such defect in the pipe thickness with the presence of a deep corrosion

Surface preparation is also important
Remains of damaged paint have to be removed
and in presence of corrosion this must be removed by grinding

Carrying out the measurement:
placing the probe is not sufficient to take a measurement
A test area of at least 4 cm^2
should be inspected
at each test point
taking the minimum
value of thickness

Corrosion mapping

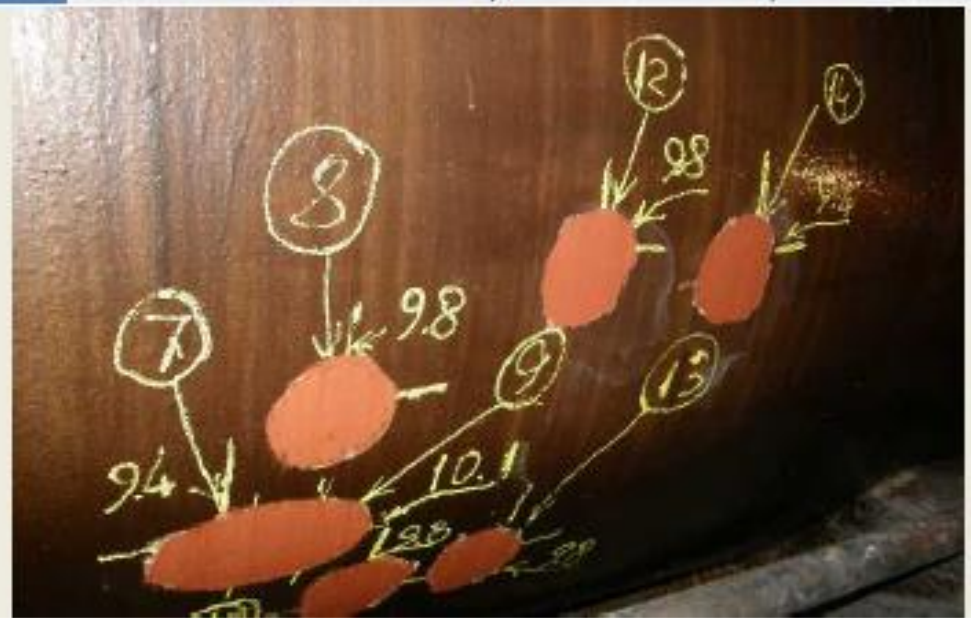


Corrosion mapping

- In case of high corrosion rates, advanced ultrasounic technologies allow to potray the condition of the interior surface by way of the phased array technique
- Phased Array techniques allow adjusting the beam angle and focal distance to create an image of the area to be monitored, improving the defect detection and the speed of the tests.

Corrosion mapping

Virola n°	Posizione (rif. Relazione 1995	Spess. 1995 (mm)	Spess. 2009 (mm)	Sp. Nom. (mm)
176	1	11,2	11,0	11
	3	10,4	10,0	11
	5	10,4	8,8	11
	7	9,4	8,3	11
	10	9,8	7,6	11
207	1	8,5	8,3	10
	3	9,3	8,9	10
	9	8,7	8,0	10
	15	8,9	7,8	10
	16	9,0	8,1	10



Thickness in the saddle area

This control
requires disrupting
the plant service

The thickness
is checked
from inside

Thickness in the saddle area

From the inside,
after surface preparation
the check is performed
to detect corrosion at the interface
between metal and saddles.

The procedure is adopted
also in the case of anchor blocks

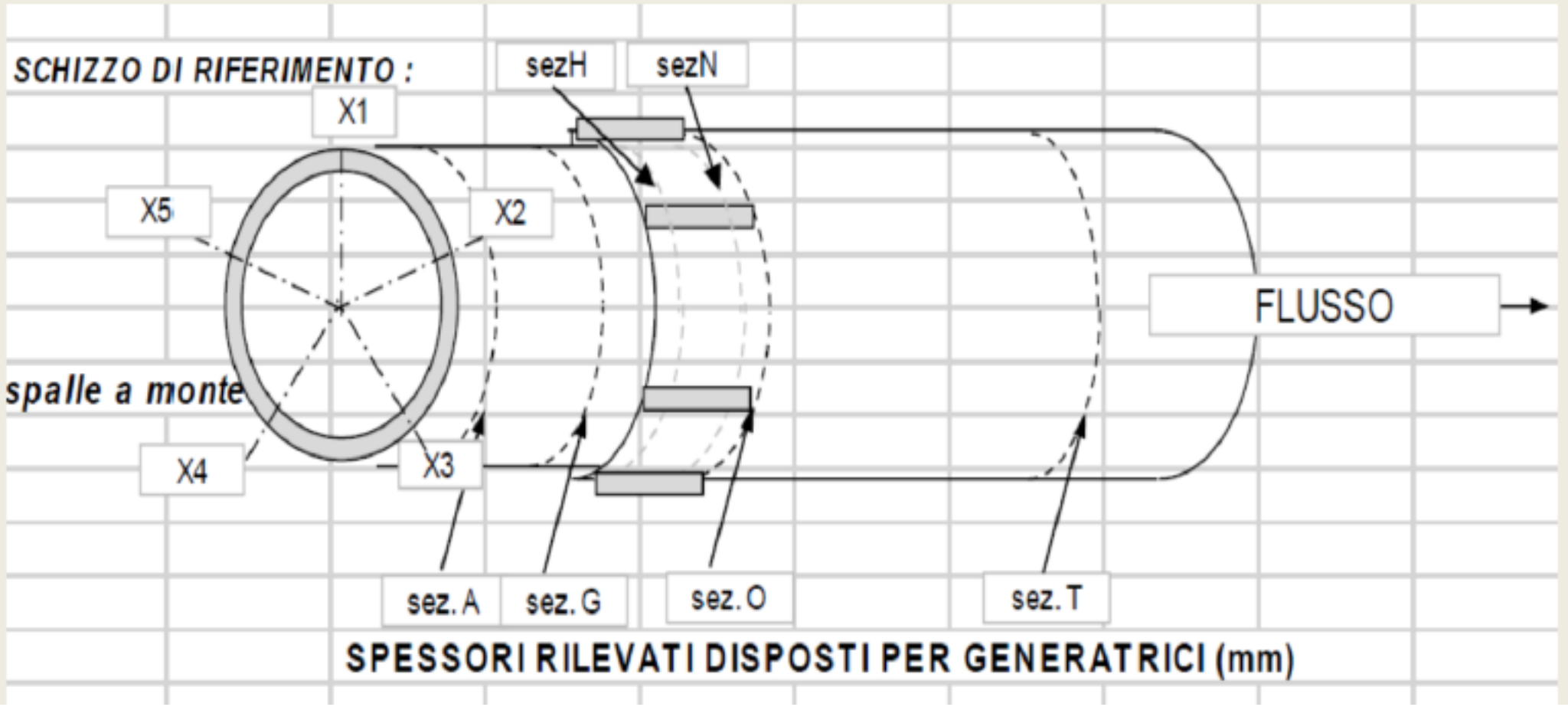
Thickness checks at telescopic expansion joints

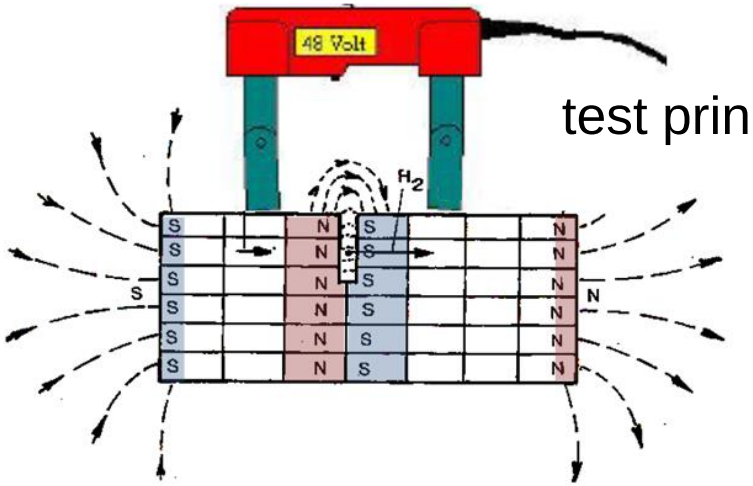
The females of the expansion joints
are more prone to internal corrosion
compared to other areas of the pipeline

This in particular in the male insertion section

More accurate inspections are required
for prevention (see diagram below)

Thickness checks at telescopic expansion joints





test principle

Magnetoscopic Tests - MT

Magnetoscopic Tests - MT

a) Defectoscopic examination by magnetoscopy of the welded joints, of surfaces in general and of other elements (rivets, stiffeners, etc. ..);

b) Detection of the rebars by magnetoscopy (covermeter).

Magnetic particle examination of joints
is usually required for forge welded pipes
when conditions of particular attention arise,
such as in the following special cases:

- the results of the thickness checks have shown significantly lower values than the nominal;
- presence of evident deformations
  or discontinuities
  observed during visual examination;
- losses, etc.

the check is generally also performed on:

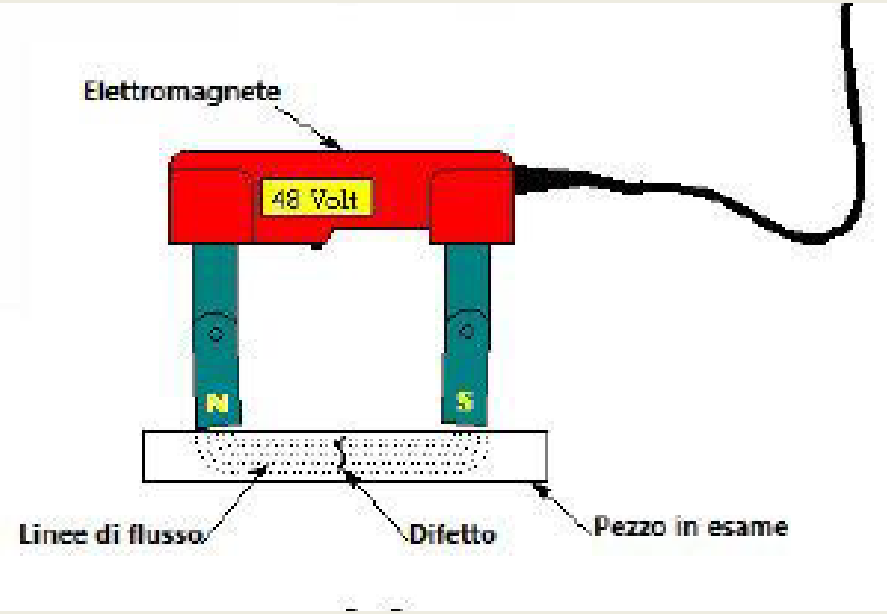
- riveted joints
- during repairs
- electric arc welding, for pipelines of particular importance or at visually detectable defects

Extension of controls

The sample of shells to be checked can vary from 2 to 10%, depending on the number of element which makes up the conduct

The image shows
the equipment
generally used this controls,
namely the 48 V powered
magnetic yoke.

An electrical power supply
is therefore required
which in field applications
is supplied by a generator



Electromagnetic yoke with articulated poles.

Generally works both on DC and AC

AC is recommended to take advantage of the skin effect, that facilitates the detection of emerging indications

There are also permanent magnets yokes, however, their sensitivity is lower.

In order to verify the reliability of the check there are field indicators which are easily used onsite.

Magnetic particle inspection

The surface preparation is important and demanding since it is necessary to remove the paint and oxides along the entire direction where the weld is located.

The check is normally performed with the following modality:

- Application of contrasting lacquer
- An AC current powered magnetic yoke is used
- Black powders in wet suspension (water or kerosene).

Control of a forged weld

Surface preparation example.

After removing the paint,
a coat of fast-drying
white lacquer is applied
to increase the contrast
against black
magnetic powders.

Magnetoscopic examination of forged weld joints

entails mostly linear defects ascribable to the manufacturing process, such as laps, laminations, tears, folds and necking along the melting-line, fostered by the presence of porosity and oxides.

Example of indication mapping

In most cases,
only linear indications
longer than 5 mm
are mapped

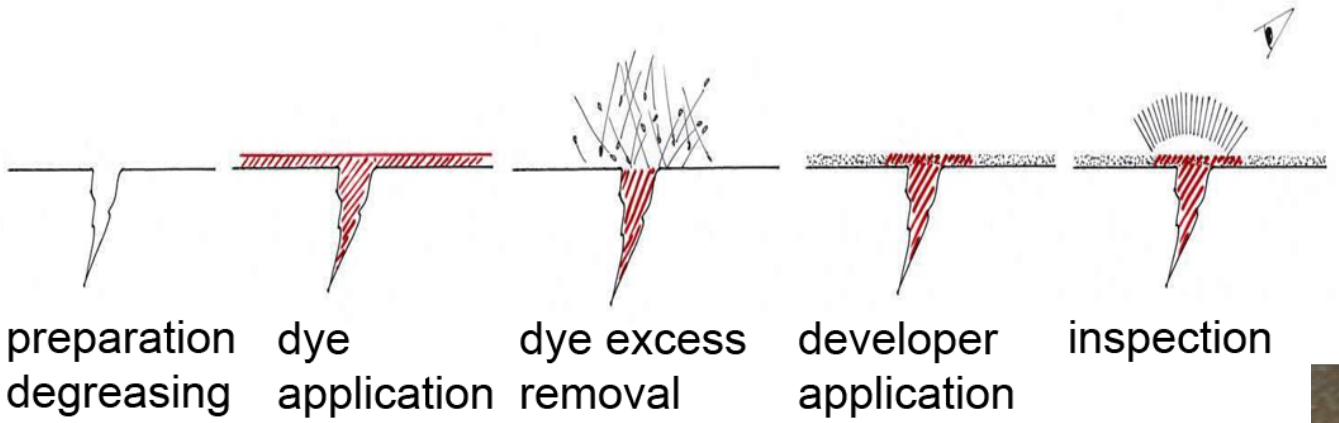

11 bis Dx


11 bis Dx
AEND

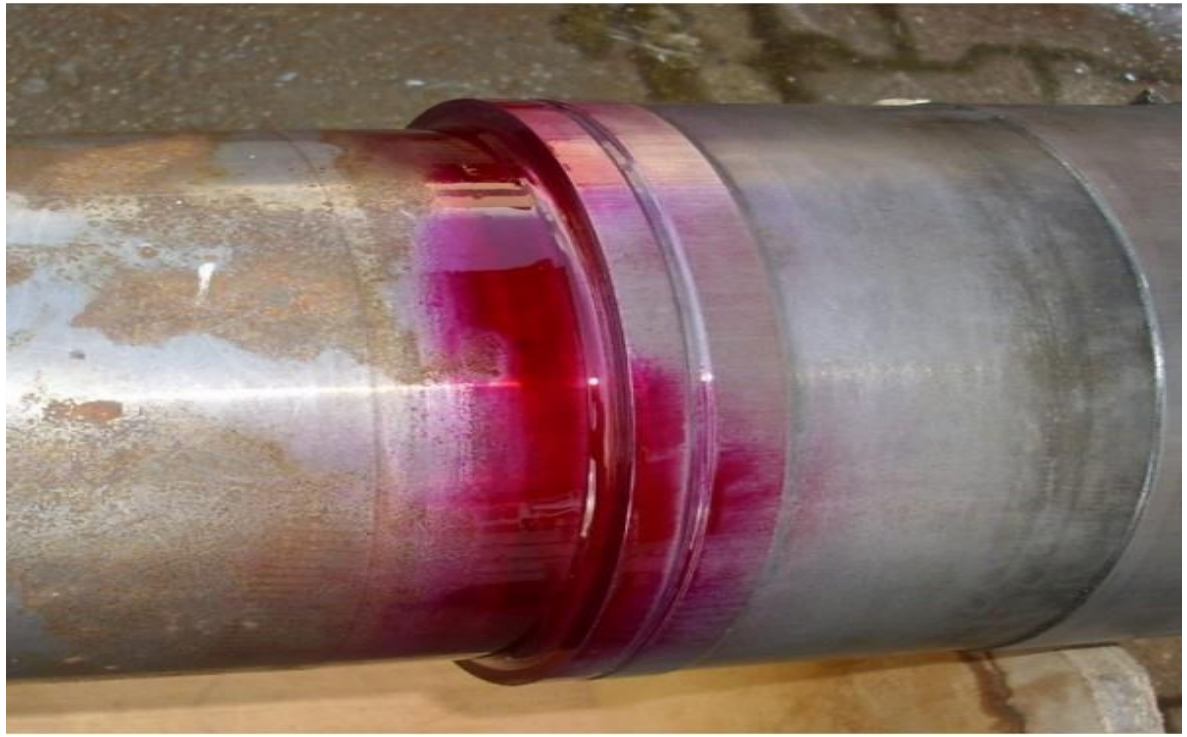

11bisDx


11bisDx
AEND

Dye Penetrant Testing - PT



Defectoscopic examination
of welded joints and surfaces
using penetrating liquids



Dye Penetrant Testing - PT

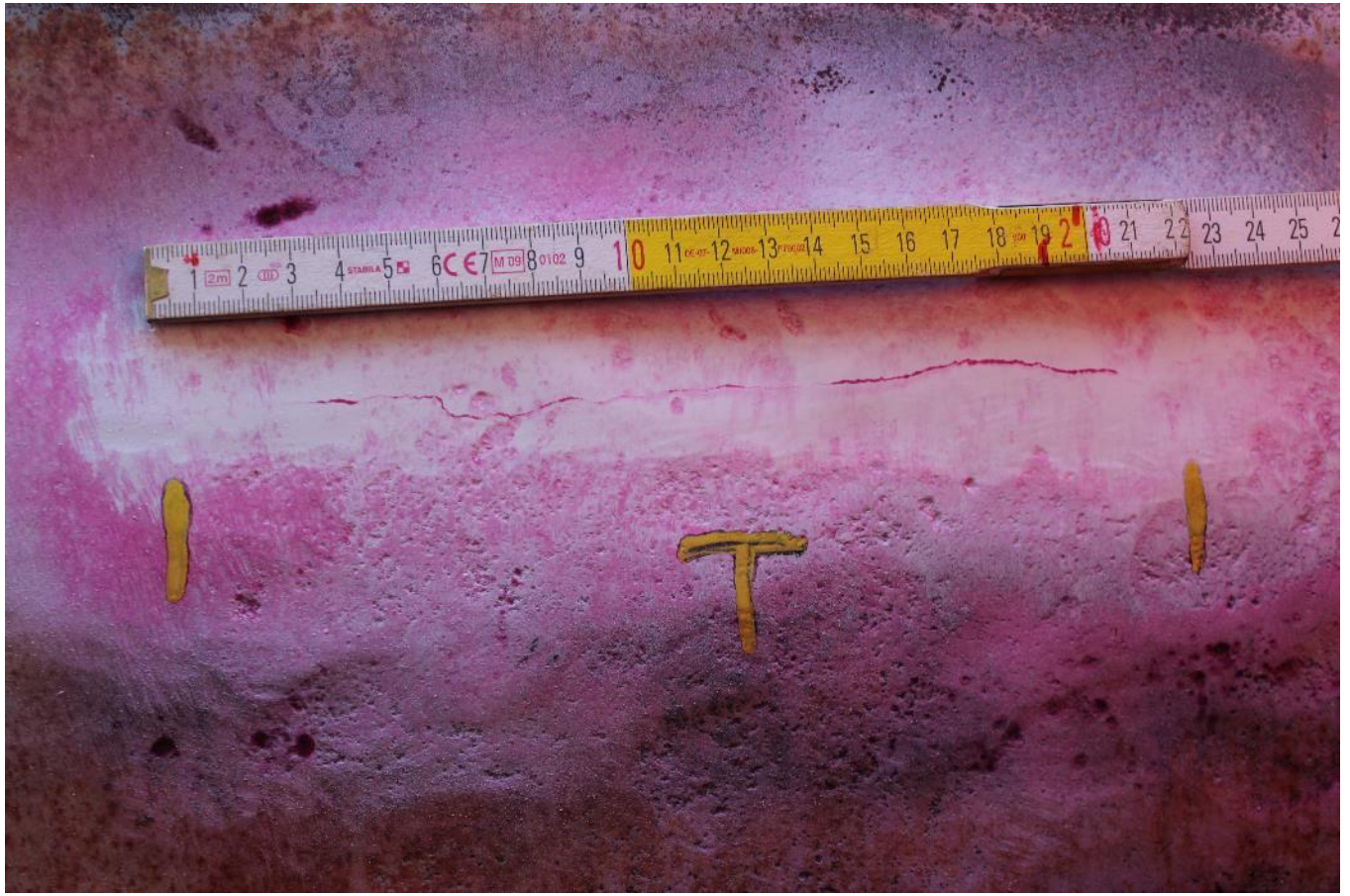
surface preparation

penetrant application

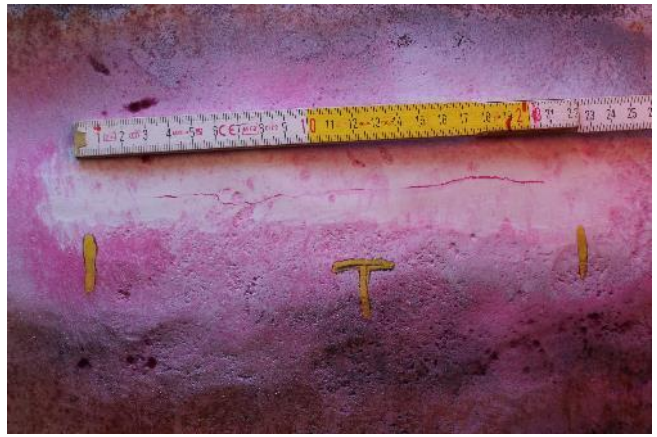
developer application

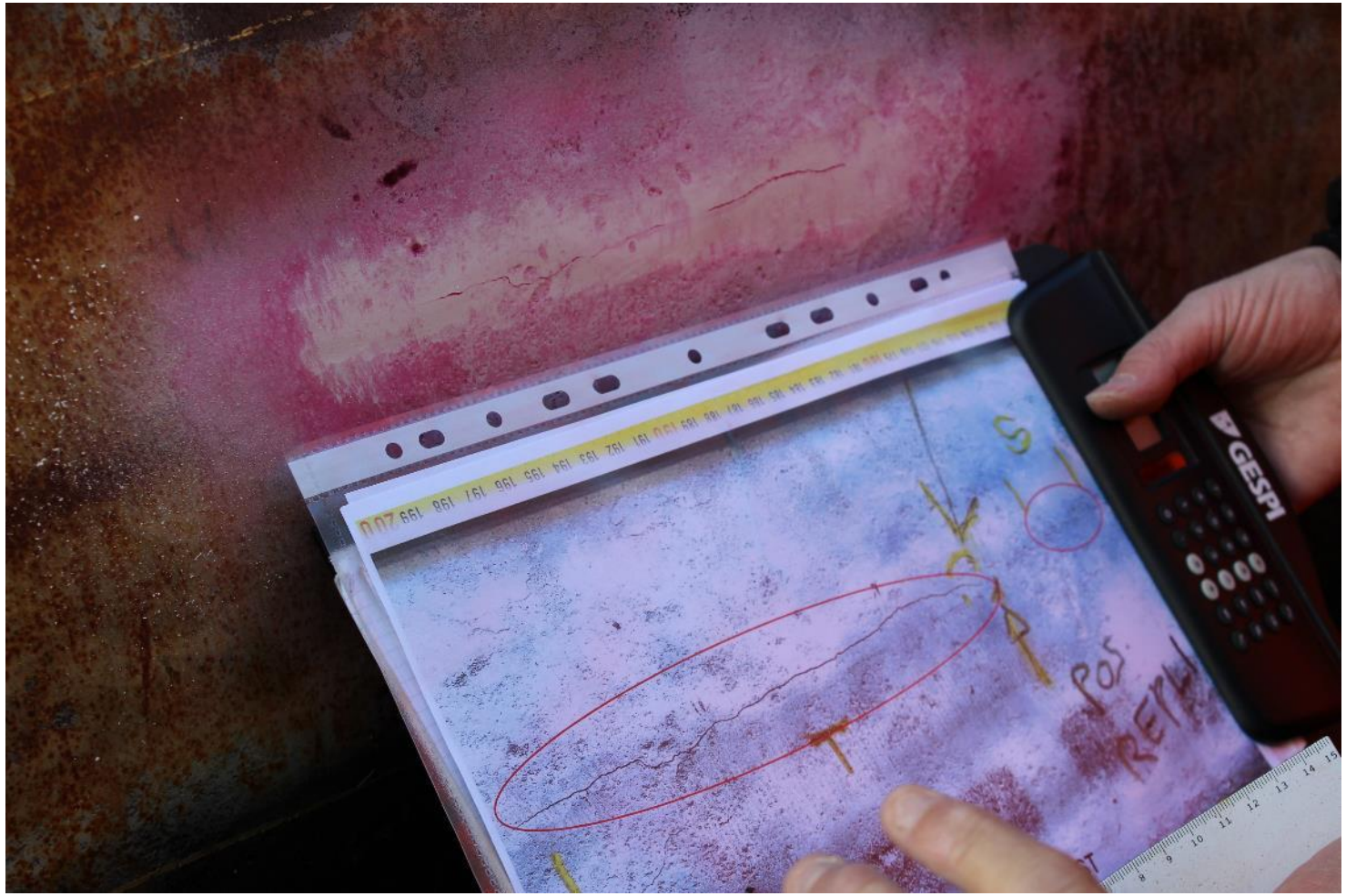
Dye Penetrant Testing - PT

inspection



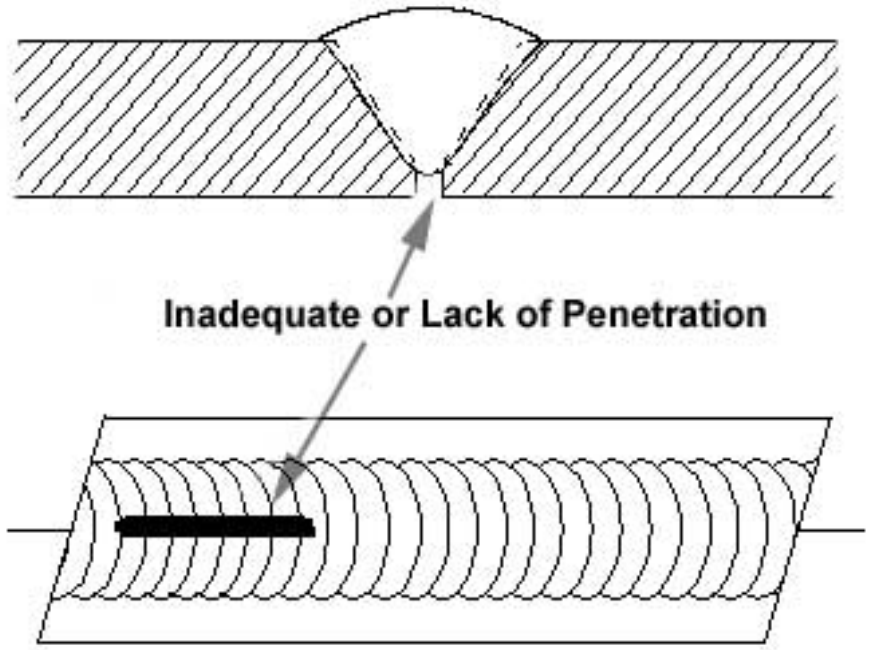
Dye Penetrant Testing - PT

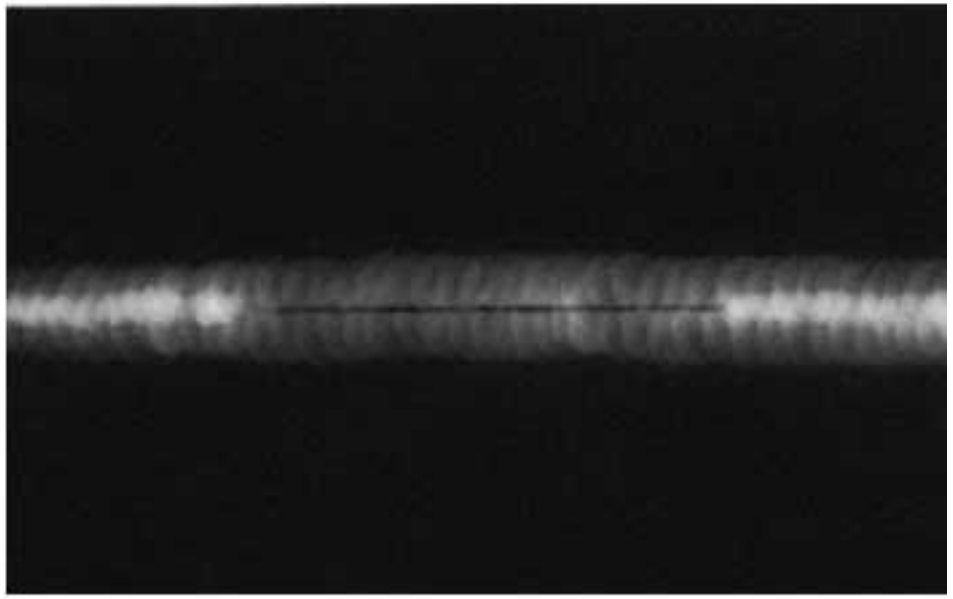




Radiographic Test - RT

Defectoscopic examination of welded joints by radioscopy





Site Non-Destructive Tests - SNdT

a) Metallographic field replica
b) Chemical analysis, Positive Material Identification (PMI)
c) Hardness tests
d) Roughness checks
e) Surface stress measurement
f) Verification of the transition temperature at zero ductility (NDTT - Nil Ductility Transit. Temp.)
g) Surface hardness tests on concrete structures
h) Pull-out tests on concrete
i) Measurement of the depth of carbonation of concrete
j) Investigation of concrete walls using flat jacks.

Longitudinal forged welds in penstocks

The construction of the first segments with longitudinal forged welds dates back to around 1910.

Pre-heating to about 1100°C was performed with a water gas flame or other means

The overlapping edge of the folded sheet was then pressed

The tubes thus obtained were subsequently annealed.

This was the methodology required by the 1922 AEI Standards for welded penstocks

Figura 3 - Sezione di una saldatura al gas d'acqua

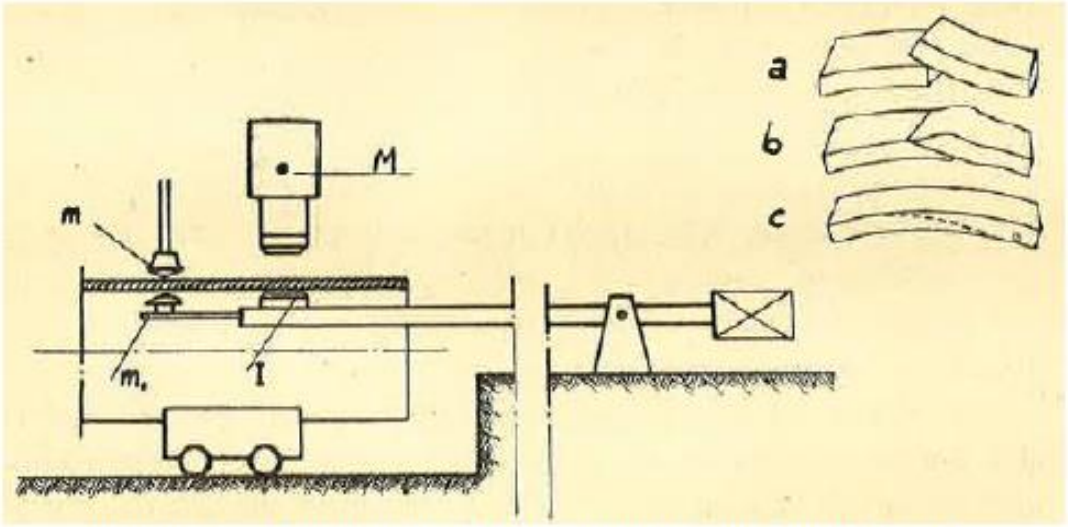


Figura 4 – Esecuzione di una saldatura per bollitura [1]

Identification of longitudinal forged welds

It is necessary to proceed with a careful surface preparation on a circumference sector

By design, welds are usually not placed at the botton (for inspectability)

Surface finishing must be done by sandpapering
Then perform an acid attack
(ammonium persulfate or Nital)

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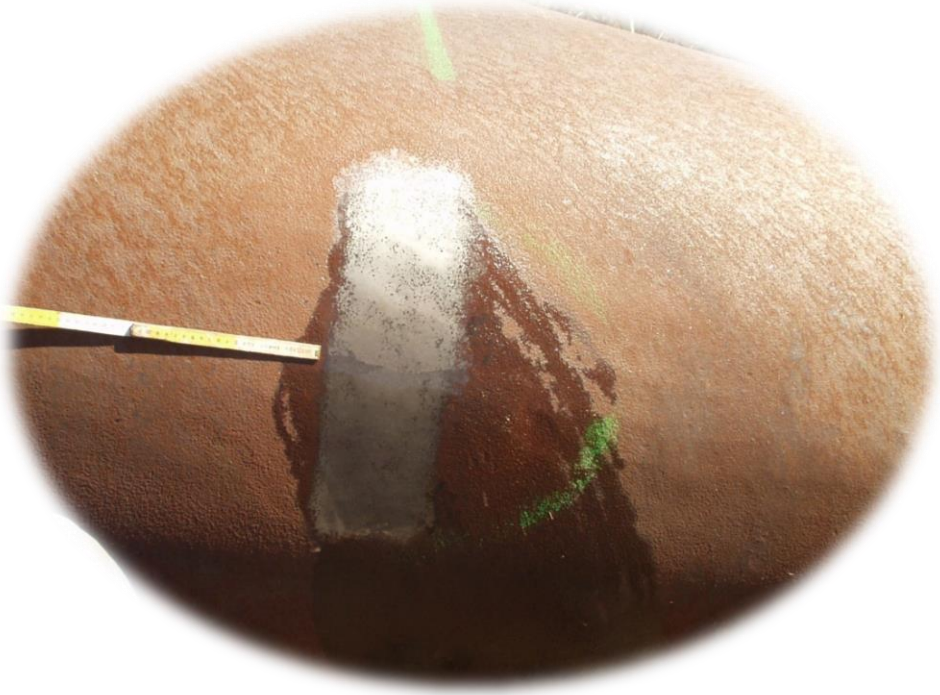


Non-Destructive Testing for steel penstocks

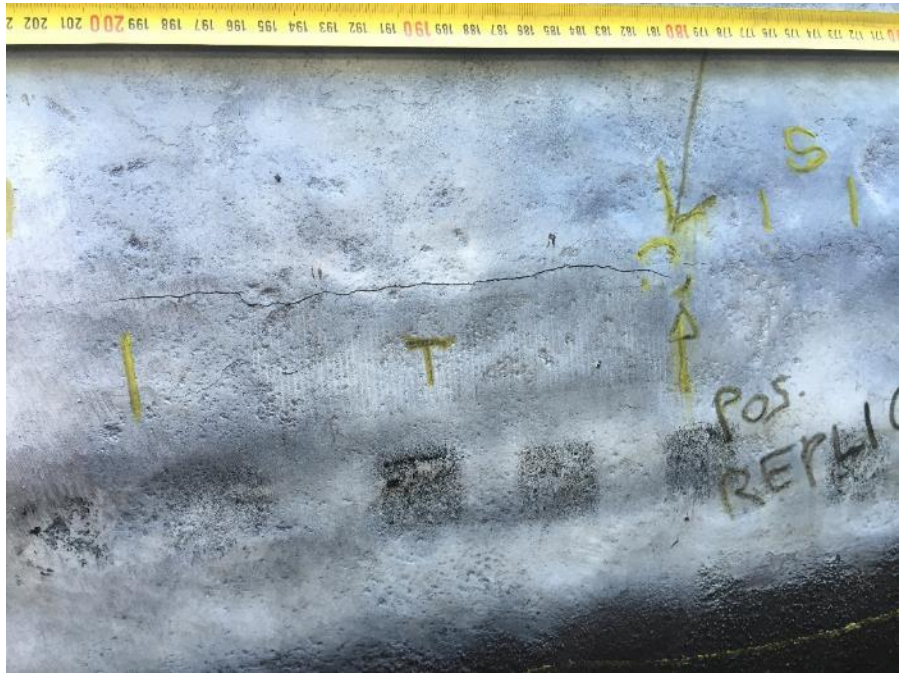
Field metallographic replica

Microscopic observation of constituents of a metal sample, highlighted by smoothing and polishing the surface, then etching with appropriate reagents (often followed by photographic documentation).

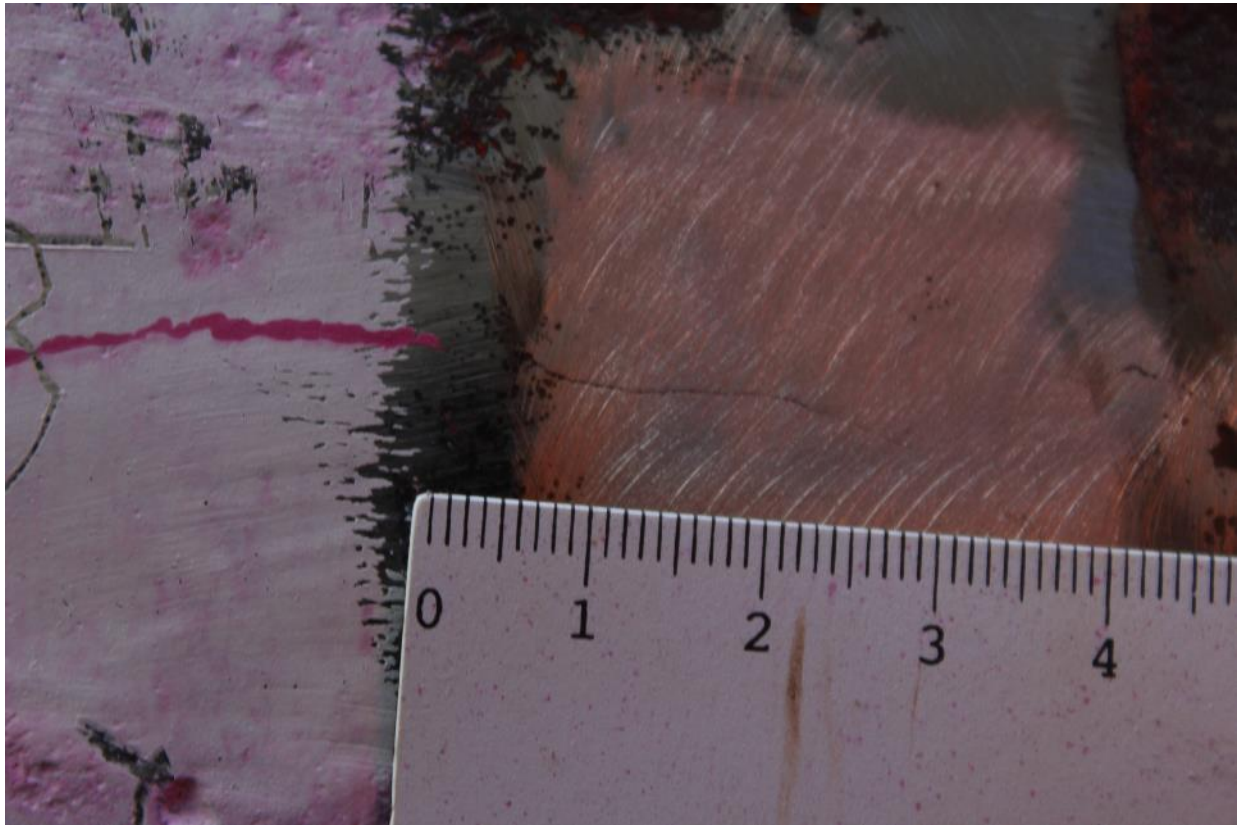
Metallographic replicais a non-destructive method that allows the metallographic structure of an object or sample to be imprinted and preserved on a cellulose acetate support or a plastic film.

Through an appropriate cleaning process (manual, mechanical or electrolytic), the surface to be examined is prepared and then a moistened plastic film is made to adhere to it by means of a suitable solvent (acetone or methyl acetate). After the film has dried, it is removed and inserted into a slide, so as to be protected from any damage due to transport and storage and to facilitate its inspection under the microscope.

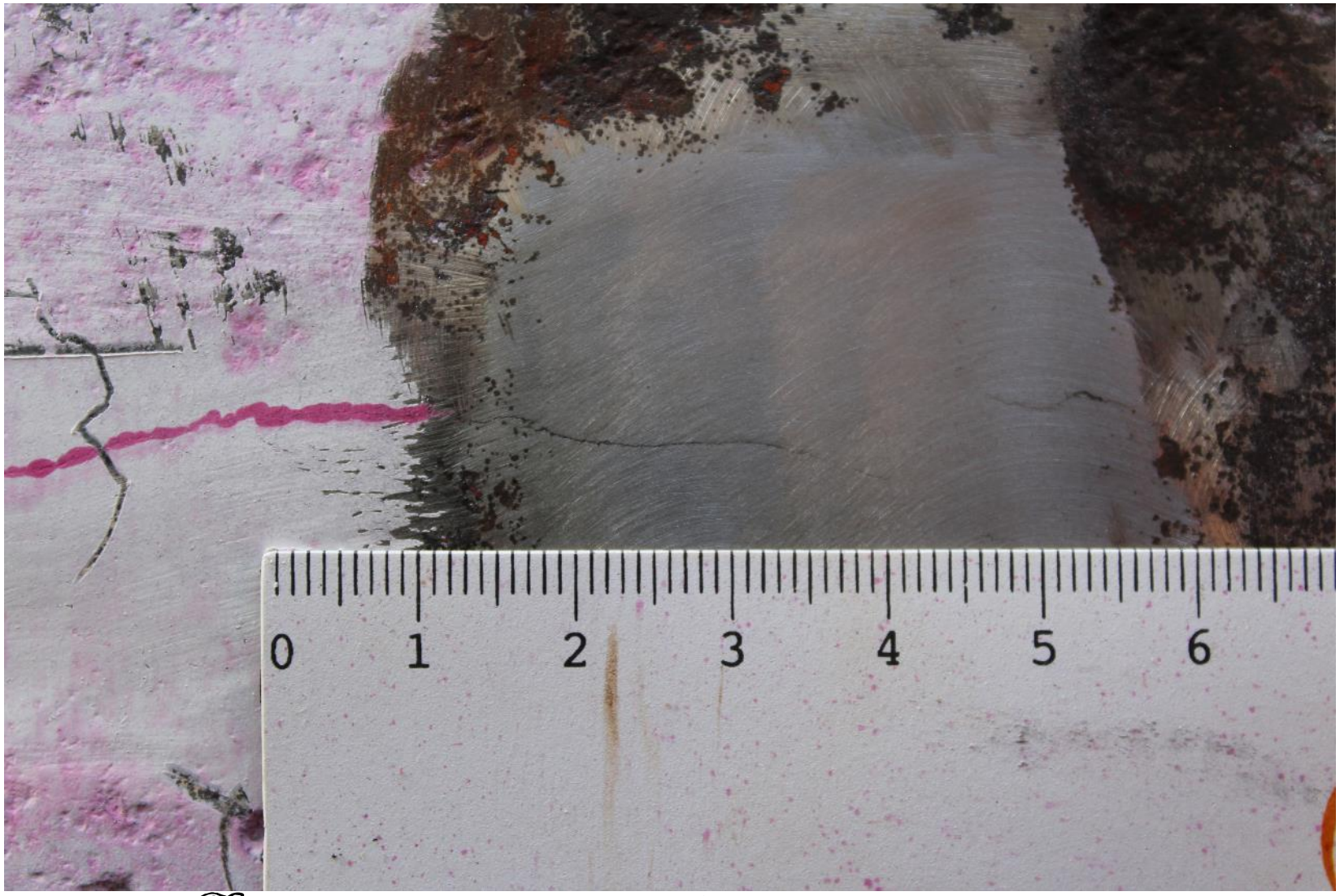
Field metallographic replica



Field metallographic replica

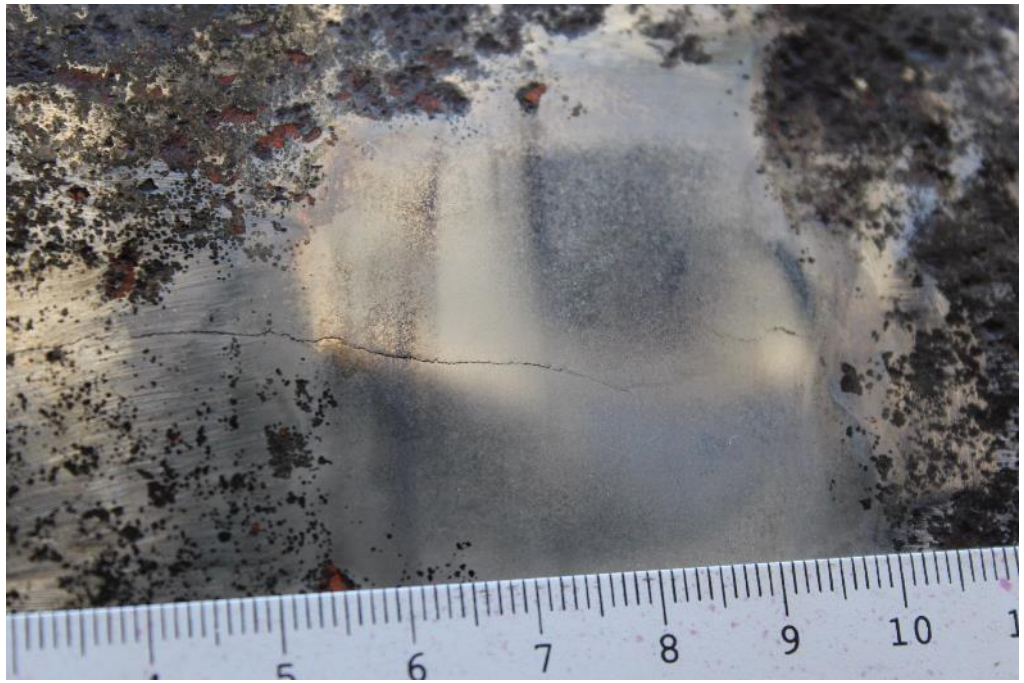


Field metallographic replica



Field metallographic replica

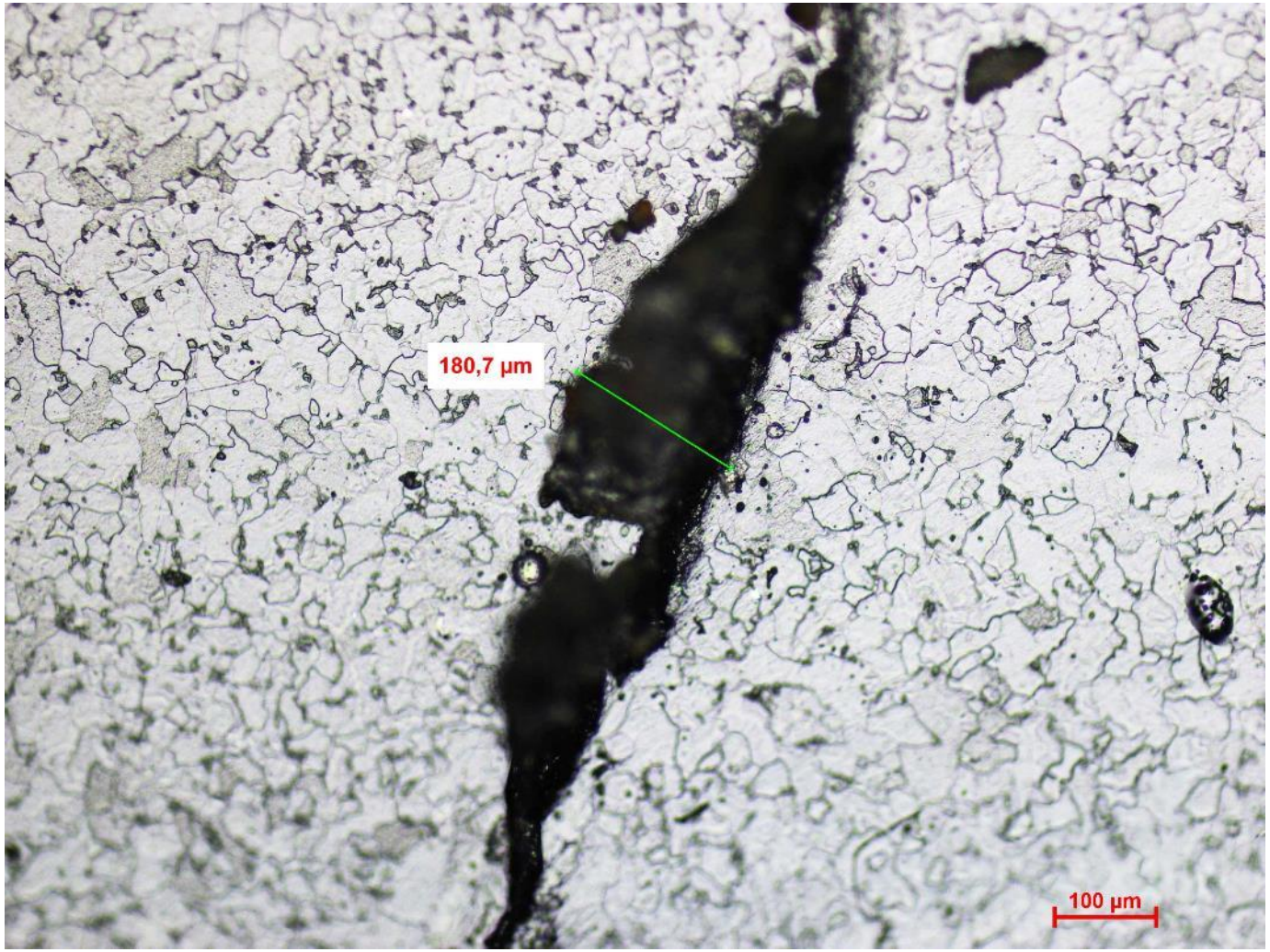
Field metallographic replica



Field metallographic replica

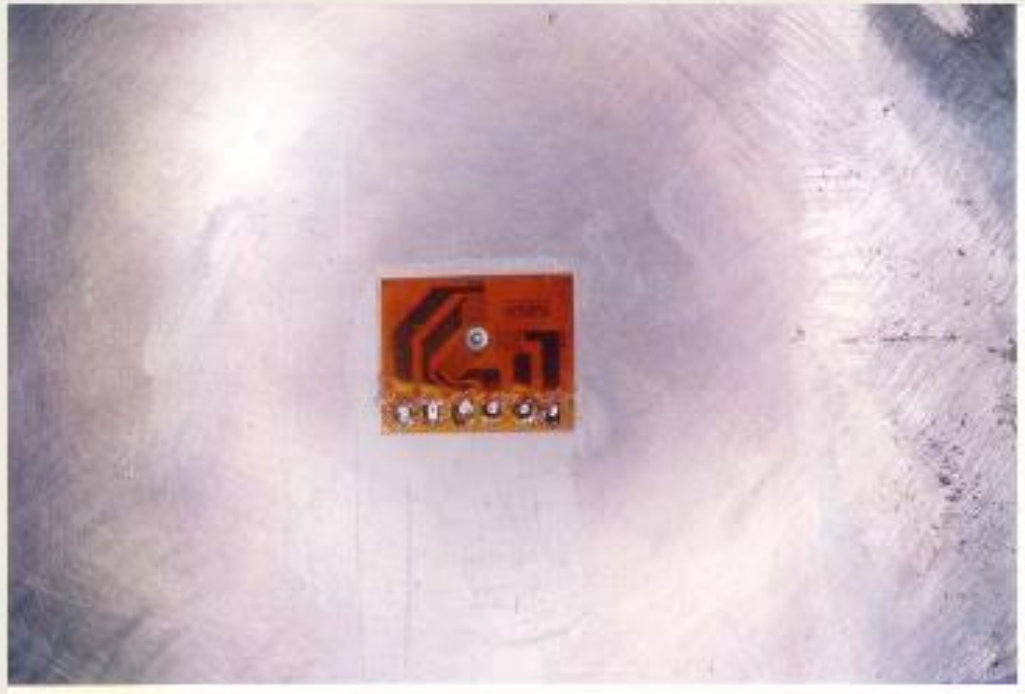
Field metallographic replica

Field metallographic replica



Residual stress measurement

residual stress measurement with the drilled strain gauge rosette method



residual stress measurement with the X-ray diffractometer

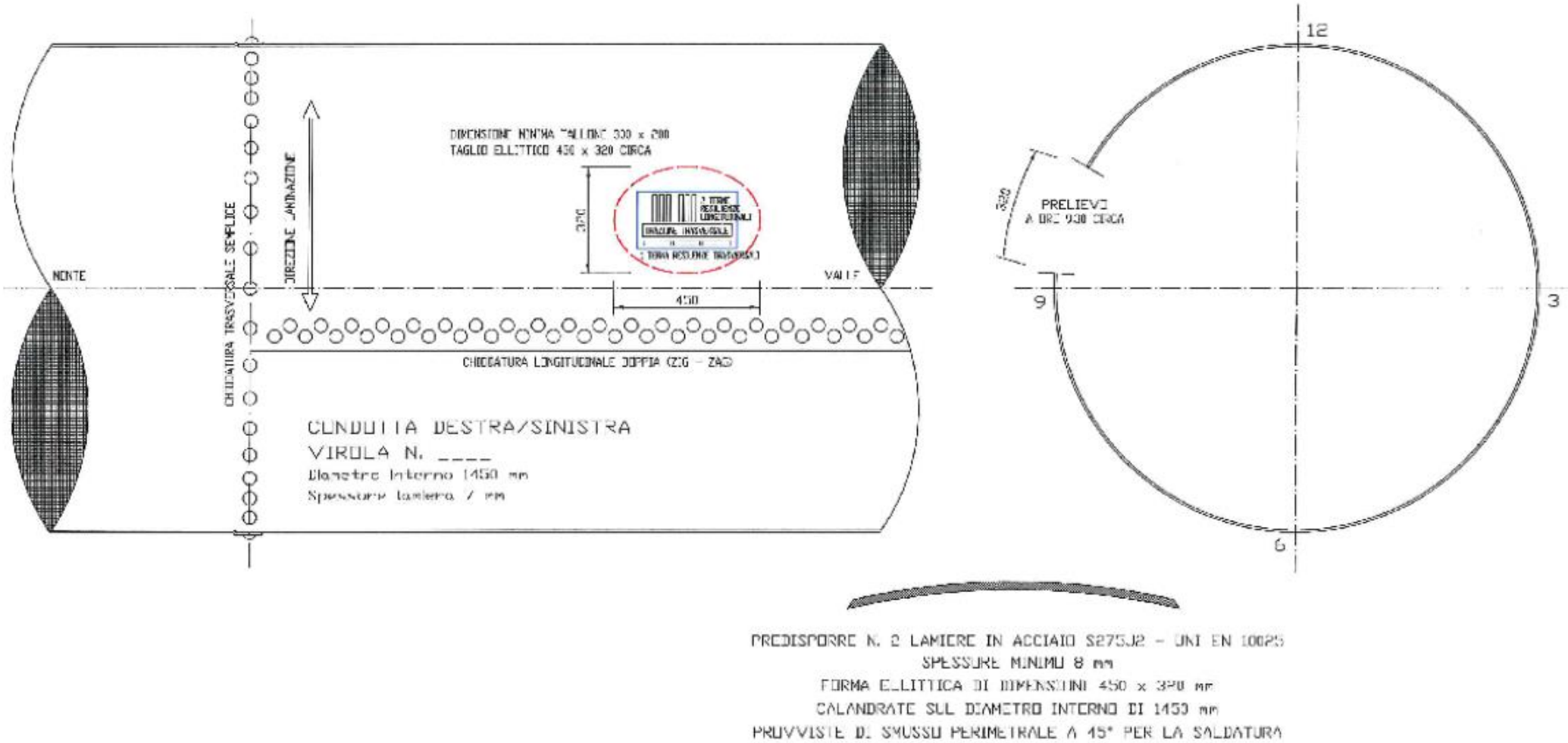
Destructive tests

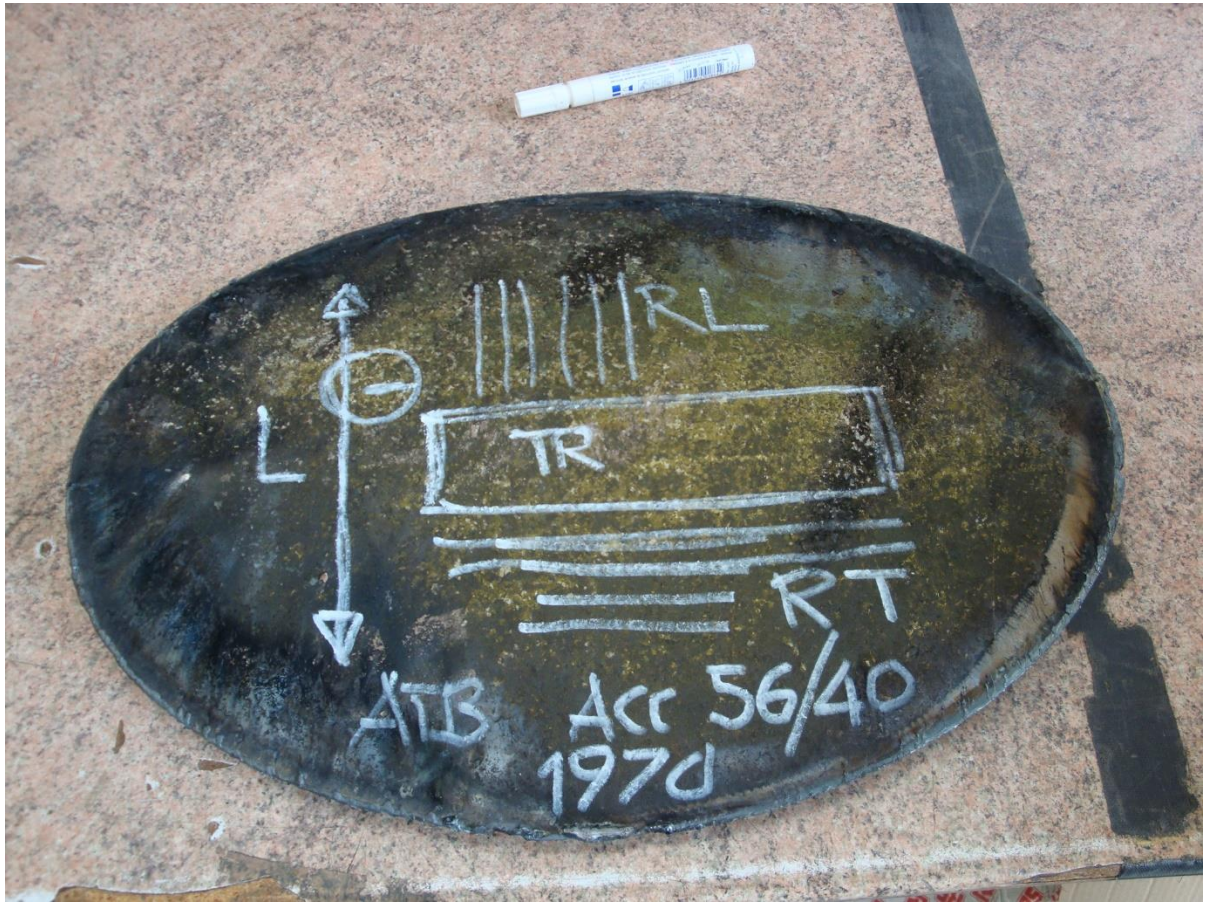
Laboratory Tests - LT on taken samples

a) Tension, resilience, bend, chemical analysis, etc on pipeline samples and/or other accessory elements of penstocks made of steel, cast iron, HDPE and fiberglass

b) Core drilling on concrete structures for compression tests


VIROLA 10
150
9,2


DIMENSIONE MINIMA TAGLIO 330 x 200
TAGLIO ELLITTICO 430 x 320 CIRCA
320
450
DIREZIONE MONTAGGIO
CHIODATURA TRASVERSALE SEMPLICE
MONTE
VALLE
CHIODATURA LONGITUDINALE DOPPIA (ZIG - ZAG)
CONDOTTA DESTRA/SINISTRA
VIROLA N. ____
Diametro interno 1450 mm
Spessore lamiera 7 mm
12
3
6
9
PRELIEVI
A ORE 9:30 CIRCA
325
PREDISPORRE N. 2 LAMIERE IN ACCIAIO S275J2 - UNI EN 10025
SPESSORE MINIMO 8 mm
FORMA ELLITTICA DI DIMENSIONI 450 x 320 mm
CALANDRATE SUL DIAMETRO INTERNO DI 1450 mm
PROVVISTE DI SMUSSO PERIMETRALE A 45° PER LA SALDATURA


RL
L
TR
RT
ATB
Acc 56/40
1970

bending samples

resilience samples

testing machine
and broken samples

Example of certificate reporting the results of the tension and bending tests

Norme di prova: UNI EN 895:1997 - UNI EN 875:1997 - UNI EN 910:1997

Apparecchiature: Macchine universali identificate SPT-0007 - SPT-0010
Pendolo da 300 J identificato SPT-0006

Risultati ottenuti:

Identif. N.	PROVA DI TRAZIONE TRASVERSALE ALLA SALDATURA					
	Dimensioni Provetta (mm)	Area Sezione (mm^2)	Temp. Prova (°C)	Carico massimo Totale (N)	Carico massimo Unitario (N/mm^2)	Posizione Rottura
					≥ 500	
PQS CP	4.0 x 24.9	99.6	+20	60610	609	Z.F.
PQS CP	4.0 x 24.9	99.6	+20	59680	599	Z.F.

PROVA DI PIEGA					
Identif. N.	Dimensione Provino mm	Mandrino mm	Angolo α °	Senso di piegamento	Esito della prova
PQS CP	20 x sp	20	180	DIRITTO	CONFORME
PQS CP	20 x sp	20	180	DIRITTO	CONFORME
PQS CP	20 x sp	20	180	ROVESCIO	CONFORME
PQS CP	20 x sp	20	180	ROVESCIO	CONFORME

Example of certificate reporting the results of resilience tests (at -20°C and +20°C)

Identif. N.	PROVA DI RESILIENZA SU PROVETTA CHARPY		
	VWT Dim.10x2.5x55 mm Temp. -20°C*	VHT Dim.10x2.5x55 mm Temp. -20°C*	VHT Dim.10x2.5x55 mm Temp. -20°C*
	≥ 10 J ▲	≥ 10 J ▲	≥ 10 J ▲
PQS CP	16 - 16 - 18	24 - 26 - 16	26 - 24 - 22

Identif. N.	PROVA DI RESILIENZA SU PROVETTA CHARPY		
	VWT Dim.10x2.5x55 mm Temp. +20°C*	VHT Dim.10x2.5x55 mm Temp. +20°C*	VHT Dim.10x2.5x55 mm Temp. +20°C*
	≥ 10 J ▲	≥ 10 J ▲	≥ 10 J ▲
PQS CP	18 - 18 - 22	24 - 26 - 26	24 - 22 - 26

* Temperatura di prova indicata dalla Richiedente.

▲ Valore minimo richiesto dalla Direttiva PED 97/23/CE ; valori equivalenti per provette a spessore ridotto, ricavati secondo Raccolta S Rev. '95 Ed. '99.

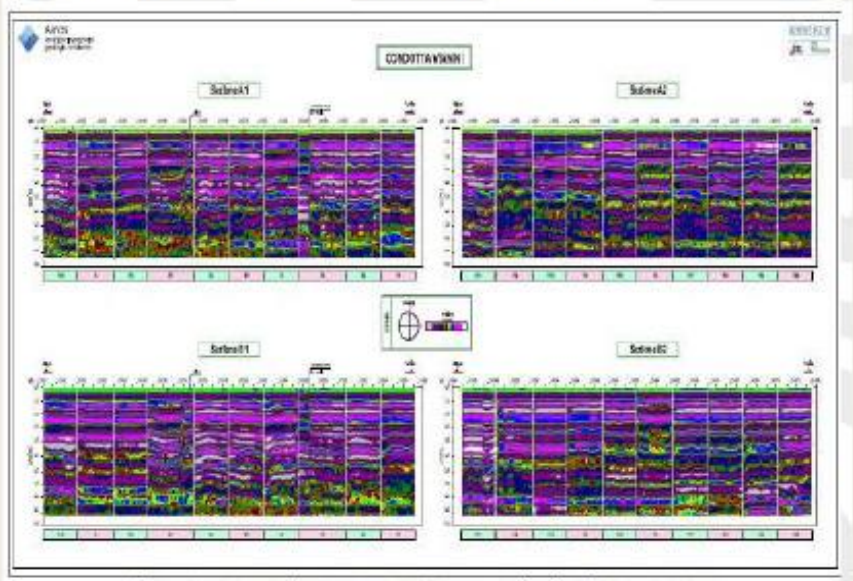
Other tests

a) Laser scanner survey of the duct surface (internal and external) to determine the degree of corrosion, abrasion etc. and the extent of the individual damages

b) Bond tests on coatings (“Pull Off” - EN ISO 4624)

Ground Penetrating Radar (GPR)

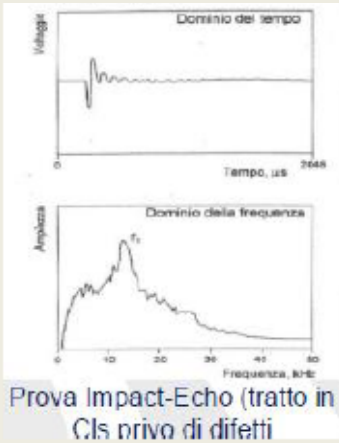
is a geophysical survey method
based on the propagation of
high frequency electromagnetic waves



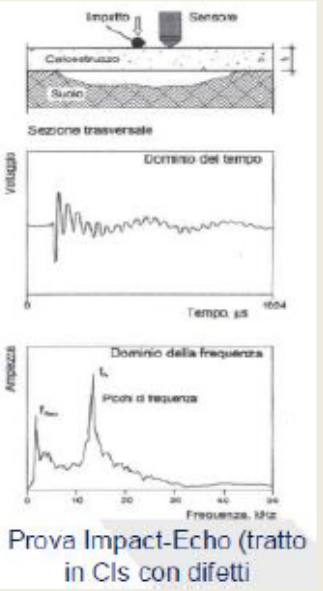
Prova georadar con antenna ad alta frequenza

Impact-echo

it is based on the analysis of elastic waves
generated by an impactor (steel ball or hammer)
on the surface of the tested structure
These low frequency waves propagate and
are possibly back-reflected by any defects.



Prova Impact-Echo (tratto in
Cls privo di difetti



Prova Impact-Echo (tratto
in Cls con difetti

REQUIREMENTS OF THE CONTROL AND INVESTIGATION METHODS

Nel seguito è illustrata una tabella che riassume le proprietà e le peculiarità delle singole metodologie di controllo, in funzione delle finalità cui è destinato il controllo e dell'applicabilità alle varie tipologie di condotte.

METODO	*CARATTERISTICHE*	*VANTAGGI*	*LIMITI*	*ESEMPI DI IMPIEGO*	*CAMPI DI APPLICAZIONE*
ANAMNESI STORICA	Consiste nella raccolta di tutti i dati e le documentazioni storiche di progetto ed esercizio	Consente di avere un preciso quadro storico dell'impianto e degli interventi/eventi che possano aver modificato lo stato iniziale	Il limite è solo nella difficoltà di reperimento e nella mancanza di tale documentazione	Tutte le parti componenti	Tutte le tipologie di condotte
ESAMI VISIVI	È il metodo di base per ogni tipo di esame e controllo e dev'essere utilizzato a monte di ogni altro controllo. Consente di avere un quadro dello stato superficiale	Economico	Consente unicamente di verificare lo stato superficiale dell'elemento e la rilevazione di difettosità macroscopiche Per le condotte interrate è possibile solo internamente	Qualunque tipo di materiale Trattamenti protettivi anticorrosione Finiture superficiali	Tutte le tipologie di condotte
CONTROLLI DIMENSIONALI	Il controllo dimensionale può succedere o essere simultaneo al controllo visivo. Consente di verificare la conformità dei manufatti al progetto ed eventuali anomalie o deformazioni successive all'installazione in opera	Economico Facilmente ripetibile	Consente di identificare e misurare eventuali non conformità rispetto al progetto senza individuarne le cause Per le condotte interrate è limitato solo all'interno (ove possibile)	Condotte ed accessori (organi di intercettazione, giunti di dilatazione, elementi di appoggio, ecc..)	Tutte le tipologie di condotte
ESAMI CON LIQUIDI PENETRANTI	È un controllo superficiale Si basa sul contrasto cromatico tra il penetrante per capillarità (rosso) e lo sfondo rivelatore (bianco)	Poco costoso Portatile e facile da applicare Rileva anche indicazioni non vivibili ad occhio nudo	I difetti devono essere aperti in superficie Non è applicabile su materiali molto porosi o ad elevata rugosità	Saldature Elementi di organi di intercettazione Chiodature	Quasi tutti i tipi di condotte Non è applicabile su condotte in calcestruzzo
CONTROLLI MAGNETICI	Si basa sulla variazione dei campi magnetici causate da difetti superficiali o sub-superficiali	Costo medio-basso Si possono rilevare difetti superficiali e fino a circa 2 mm di profondità	Può essere impiegato solo su materiali ferro-magnetici Preparazione delle superfici abbastanza laboriosa Può richiedere smagnetizzazione	Saldature Giunti Elementi di organi di intercettazione	Solo per le condotte realizzate con materiale ferro-magnetico Per le condotte in c.a. può essere impiegato per rilevare le armature
ESAMI AD ULTRASUONI	È un controllo volumetrico che sfrutta le variazioni di impedenza acustica causate dalla presenza di difettosità	Può sondare elementi di elevato spessore Eccellente per l'individuazione di cricche	Richiede una buona preparazione delle superfici Richiede l'uso di un mezzo accoppiante Le superfici devono avere una rugosità contenuta	Può essere impiegato per rilevare difetti in quasi tutti i tipi di materiali Esame delle saldature	Tutte le tipologie di condotte
PROVE NON DISTRUTTIVE IN SITO	Prove che possono essere effettuate in sito, senza prelievo di campioni, per conoscere le caratteristiche chimiche, fisiche e di resistenza dei materiali componenti	Non richiedono il prelievo di campioni Hanno carattere non distruttivo	Hanno un margine di attendibilità leggermente inferiore rispetto alle prove eseguite in laboratorio Possono essere onerose	Tutte le parti componenti	Tutte le tipologie di condotte
ESAME RADIOGRAFICO	Si basa sulle variazioni di densità di un corpo, originate dalla presenza di vuoti, cricche, inclusioni, ecc..	Può essere applicato su qualunque materiale, anche a spessori elevati Fornisce una pellicola su cui l'esame è registrato in modo permanente	Severe misure precauzionali a causa delle radiazioni Non facilmente trasportabile e applicabile Cricche orientate con il fascio possono sfuggire al controllo	Saldature Giunti Chiodature	Tutte le tipologie di condotte escluse quelle in calcestruzzo
PROVE MECCANICHE SU CAMPIONI PRELEVATI	Prove di laboratorio atte a caratterizzare, chimicamente e fisicamente, il campione di materiale prelevato	Precisione dei risultati	Necessitano del prelievo di un campione Sono prove generalmente distruttive	Tutti i tipi di materiali, compresi elementi accessori e giunzioni saldate	Tutte le tipologie di condotte

CONTROL AND INVESTIGATION METHODS APPLICABLE TO EACH PENSTOCK TYPE

	CONDOTTE FORZATE IN ACCIAIO SALDATE	CONDOTTE FORZATE IN ACCIAIO CHIODATE	CONDOTTE FORZATE IN GHISA	CONDOTTE FORZATE IN CALCESTRUZZO	CONDOTTE FORZATE IN PEAD	CONDOTTE FORZATE IN VETRORESINA	CONDOTTE FORZATE INTERRATE
ANAMNESI STORICA SH (Sistem History)	SI - Indispensabile per qualsiasi tipologia di condotta						
ESAMI VISIVI VT (Visual Test)	SI	SI	SI	SI	SI	SI	SI Possibile solo internamente
CONTROLLI DIMENSIONALI DT (Dimensional Test)	SI	SI	SI	SI	SI	SI	SI Possibile solo internamente
ESAMI CON LIQUIDI PENETRANTI PT (Penetrant Test)	SI	SI	SI	NO	SI	SI	SI Possibile solo internamente
CONTROLLI MAGNETICI MT (Magnetoscopic Test)	SI	SI	SI	SI (Rilevazione armature mediante pacometro)	NO	NO	SI Possibile solo internamente
ESAMI AD ULTRASUONI UT (Ultrasonic Test)	SI	SI	SI	SI (Verifica omogeinità calcestruzzo)	SI	SI	SI Possibile solo internamente
PROVE NON DISTRUTTIVE IN SITO SNdT (Site NdT)	SI	SI	SI	SI	SI	SI	SI Possibile solo internamente
ESAMI RADIOGRAFICI RT (Radiographic Test)	SI	SI	SI	NO	SI	SI	SI Possibile solo internamente
PROVE MECCANICHE SU CAMPIONI PRELEVATI LT (Lab Test)	SI	SI	SI	SI	SI	SI	SI

CONCLUDING REMARKS

Well established techniques are available for local penstock inspection

Due to the remarkable size, difficult access, demanding preparation of test areas
a coordinated strategy has to be devised to tackle the problem
(e.g. by combining different test methods at different scales

Training of personnel is a crucial aspect for planning the campaign,
implementating the measurements and evaluating the observed indications

AIPnD

Associazione Italiana Prove non Distruttive
Italian Society for Non-Destructive Testing
promoting the culture of NDTs in Industry and Civil Engineering