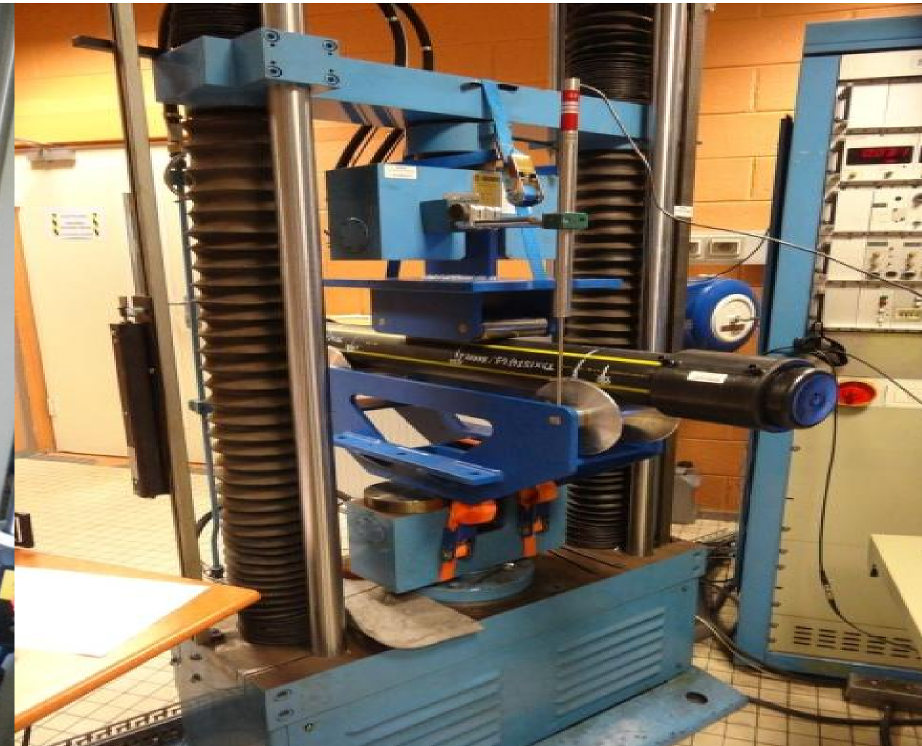


Mechanical Behavior of PE Pipes in Small-Scale Simulated Seismic Conditions in Laboratory

D. Gueugnaut; C. Fernandez; A. Boujlal; B. Sèvre; R. Bouaffre; G. Garneret; AFPS

PE100+ ASSOCIATION

afps

ENGIE

Advisory Meeting, Krakow, Poland, June 2015, 9th

CONTEXT OF THE STUDY

GENERIC LOADING INDUCED BY THE SEISMIC ACTIVITIES

SIMULATED SEISMIC LOADING IN LABORATORY

EXPERIMENTAL

RESULTS AND DISCUSSION

CONCLUSIONS

CONTEXT OF THE STUDY

CONTEXT OF THE STUDY

"crigen

- ✓ Although moderate in France, the seismic activity can have consequences on industrial infrastructures in some regions; Thus the the French Regulator has updated – by decrets - the legislation for buried gas pipelines regarding earthquakes
- ✓ The decrets contains the seismic zoning which divides France in 5 zones of increasing seismicity and introduce the notion of " normal not retroactive risk " as well as the notion of " special retroactive risk "
- ✓ For gas infrastructures, the new regulations concern the new domestic networks but also imposes to check the statutory conformity of existing ones with regards to their criticality (SEVESO)
- ✓ So, for any project of installation of pipes in zones of seismicity 3, 4 or 5 for the distribution, the operators will have to present in the administrative file of authorization a technical argument proving that the future pipe is sized to resist the seismic loads fixed in the order
- ✓ The new legislation imposes the establishment of a specific methodology adapted to the distribution networks, thus including PE

Task attributed to the French Association for Earthquake Engineering (AFPS in French) who helps the community by editing different guidelines regarding earthquakes aspects

The methodology held by the Working Group leans in particular on a test program on PE pipes in representative seismic loading conditions which could be met on the French territory

GENERIC LOADING INDUCED BY THE SEISMIC ACTIVITIES

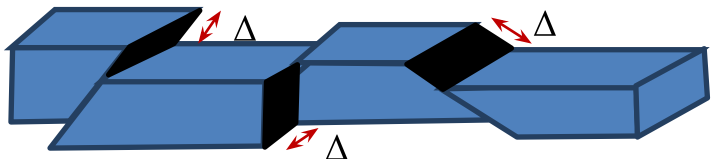
GENERIC LOADING INDUCED BY THE SEISMIC ACTIVITIES

"crigen

The earthquakes generate two types of movements:

Vibratory movements

- ✓ Such movements generate ground deformations
- ✓ The ground deformations transmit in turn some deformations to the buried piping system; Transmission is depending on the capability of the soil to slip or not
- ✓ The piping systems experience some rapid movements in short time durations (oligocyclic fatigue)

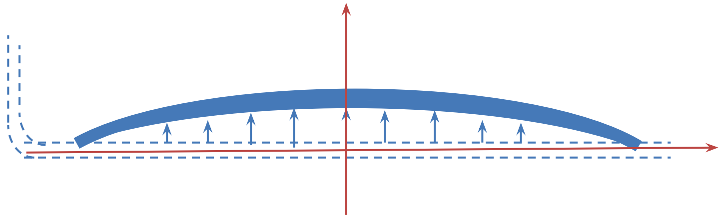


Reverse fault – Strike-slip faults – Normal fault

Permanent movements

Such movements result from:

- ✓ Fault movements
- ✓ Soil liquefaction which can generate significant lateral displacements
- ✓ Landslides
- ✓ Ground failures



The resistance criteria of the piping systems towards the earthquakes are known for steel pipes

But not known for PE pipes!

SIMULATED SEISMIC LOADING IN LABORATORY

SIMULATED SEISMIC LOADING IN LABORATORY

"crigen

A classical mean to tackle the difficulty to represent the ground motion in the simple way is to use the sinusoidal relationship

$$u(\omega, t) = D \sin(\omega(t - \frac{x}{C}))$$

Two movements are defined:

✓ "Low frequency" movement which verifies the maximum imposed displacement and velocity
✓ "High frequency" movement which verifies the maximum imposed velocity and acceleration

These conditions (two for each case) allows defining the two parameters of the input signal D et ω and to derive the maximum strain and maximum strain rate needed for testing

Low frequencies	High frequencies
$\varepsilon_{max} = \frac{V_0}{C}$	$\varepsilon_{\max} = \frac{V_0}{C}$
$\dot{\varepsilon}_{max} = \frac{V_0^2}{D_0 C}$	$\dot{\varepsilon}_{\max} = \frac{A_0}{C}$

V_0 = Speed of the soil
C = Celerity of the incident wave (≈ 1,000 m/s)
A_0 = Maximum acceleration
D_0 = Displacement (particules)

SIMULATED SEISMIC LOADING IN LABORATORY

"crigen

Cyclic Loading

✓ The values used for the cyclic tests cover reasonably the variations of the different parameters up to the Zone 5, which concern mainly the French West Indies Islands, Guadeloupe and Martinique.

✓ A margin of about 2 on the amplitude will be applied

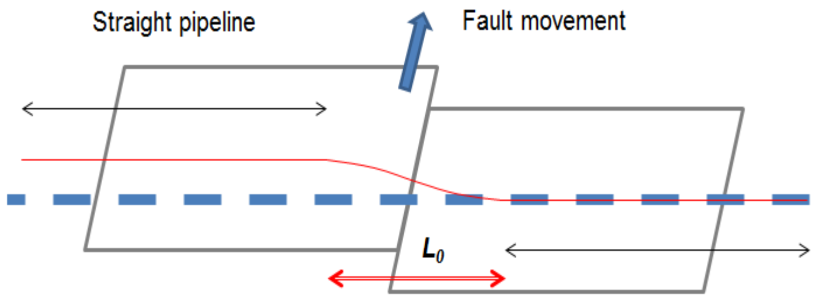
Seismic area	Low frequencies		High frequencies	
	ε_{max}	f_{LF} (Hz)	ε_{max}	f_{HF} (Hz)
4	0.01 to 0.05 %	0.4 to 0.8 Hz	0.01 to 0.05 %	1.7 to 5.0 Hz
5	0.04 to 0.10 %	0.5 Hz	0.04 to 0.10 %	1.3 to 2.5 Hz

SIMULATED SEISMIC LOADING IN LABORATORY

crigen

Imposed deformation

The test carried out with an imposed deformation aim at simulating a relative displacement of the crossing fault, referred to as δ, applied on a section L_0 of the pipe



Seismic area	Magnitude (M_w)	L_0 (cm)	δ (cm)	ε_{axial}
3	5	10	5	12 %
4	6		25	169 %
5	6,5		50	410 %
3	5	50	5	0 %
4	6		25	12 %
5	6,5		50	41 %

EXPERIMENTAL

EXPERIMENTAL

Studied samples

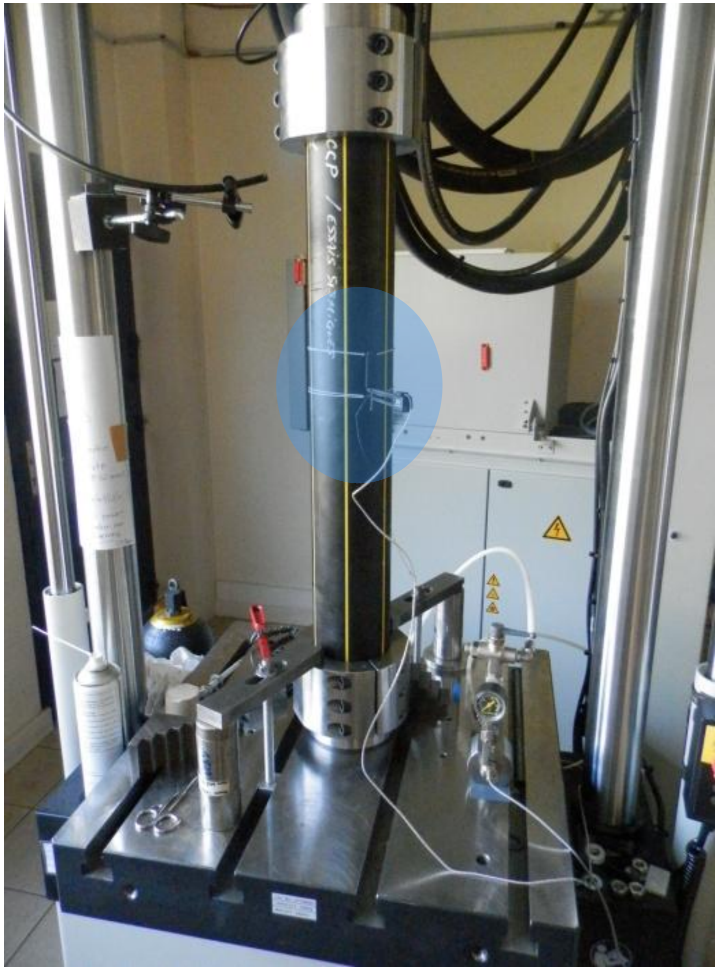
The samples have been chosen among more than 30 PE resins on the following criteria:

- PE50/63 and PE63/80 widespread on the gas networks
- One PE resin representative of each class: PE50/63, PE63/80 and PE100
- One PE extracted from the french network after a significant operational life
- Existence of reference data (CRIGEN) for comparison purpose

Pipe ID (CRIGEN)	Test specimen	PE type	Pipe outer diameter (SDR*)	Pipe fabrication
# 6581 / 12727	16-17 - AB 16-17 - BC 12-13 14-15	PE50/63	110 (11)	August 1977
# 574 (TSX) / 8819	1 / G1 - XY 1 / G1 - YZ 2-AB 2-BC	PE63/80	110 (11)	August 1991
13432	1 / AB 2 / BC 3 / AB 3 / BC	PE100	110 (11)	January 2014

EXPERIMENTAL

Cyclic loading



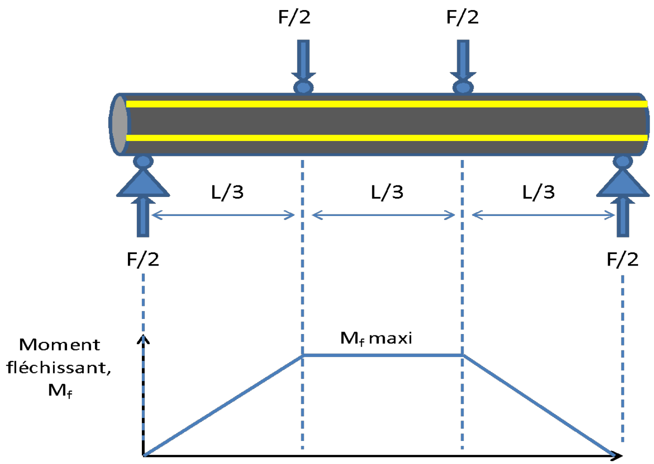
Cyclic Tensile-Compression tests aimed at fixing a behavior law of the pressurized pipes (axial direction) for a high deformation rate

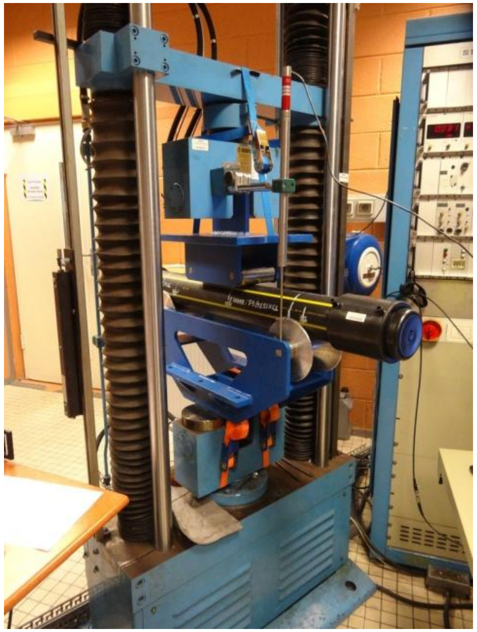
✓ After the pressurization step (4 bar in air) the pipe specimen is sumitted to a cyclic loading with a sine wave up to a defomation of ± 0.05% with a 5 Hz frequency during 15 s

✓ All along the test, the axial deformation is measured by means of a mechanical extensometer or indirectly from the displacement of the machine cylinder

EXPERIMENTAL

4-point Bending Test





✓4-point bending test: Constant flexural moment

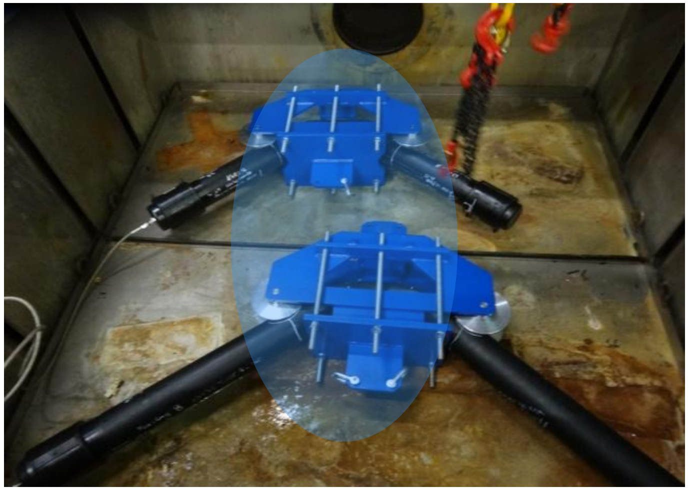
✓ Radius of curvature ≈ 3 times lower than the coiling ratio on drums or coils during storage thus the 4-point Bending test conditions are far more severe

✓ Tests carried out at the laboratory temperature 23°C ± 2°C, with a compression rate of 20 mm/min

✓4-point Bending tests carried out on non pressurized pipes (for safety concerns)

EXPERIMENTAL

Hydrostatic Pressure Testing (HPT)



- ✓ HPT are carried out on the pipes after cyclic loading and after 4-point Bending tests
- ✓ For the 4-point bent pipes, HPT were carried out directly on the imprisoned bent pipes

The test conditions and the requirements correspond either to the NF EN 1555-2 for the PE63/80 and PE100 pipes, or to technical file requirements for the 35-year old PE50/63 pipe

PE50/63 (#6581 / 12727)		PE63/80 (#574 (TSX) / 8819)		PE100 (13432)	
2 MPa / 80°C 600 h without failure	4 MPa / 80°C 50 h without failure	4 MPa / 80°C 1,000 h without failure	4.5 MPa / 80°C 165 h without failure	5 MPa / 80°C 1,000 h without failure	5.4 MPa / 80°C 165 h without failure

EXPERIMENTAL

Non destructive evaluation of the pipes before and after seismic loading + HPT

- ✓ Non Destructive Evaluation of the pipes – as received and after seismic loading – has been carried out by means of the Phased Array Ultrasonic Technique (PA UT), implemented by the french Body Institut de Soudure Industrie

- ✓ The inspection was made from the outside of the pipes

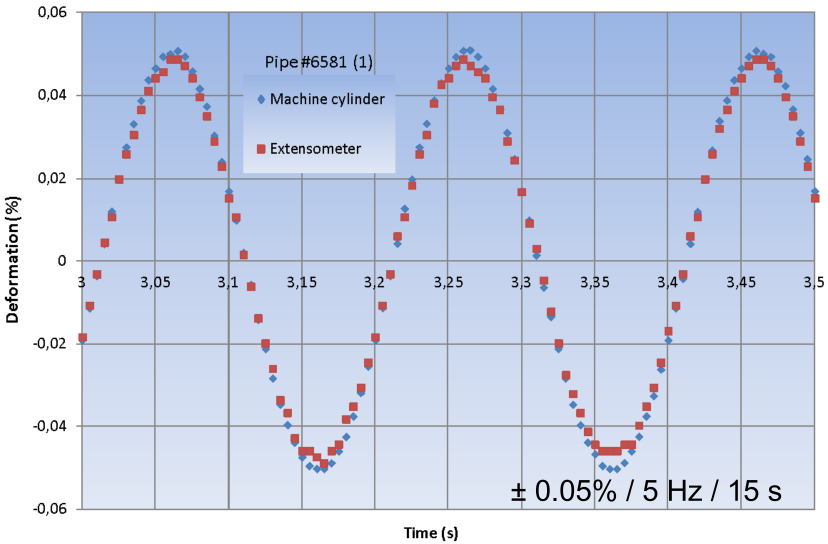
- ✓ The ultrasonic mapping of the faults – C-Scan and S-Scan – has been made on the accessible zones of the pipe, then excluding the imprisoned parts in the calibrated zone of the 4-point device

Step 0	NDE_0	
Step 1	Cyclic Tensile-Compression	4-point Bending Test
Step 2	NDE_1	Imprisoned zones of the pipe non accessible to NDE
Step 3	HPT on straight pipes	HPT on bent pipes
Step 4	NDE_2	

RESULTS AND DISCUSSION

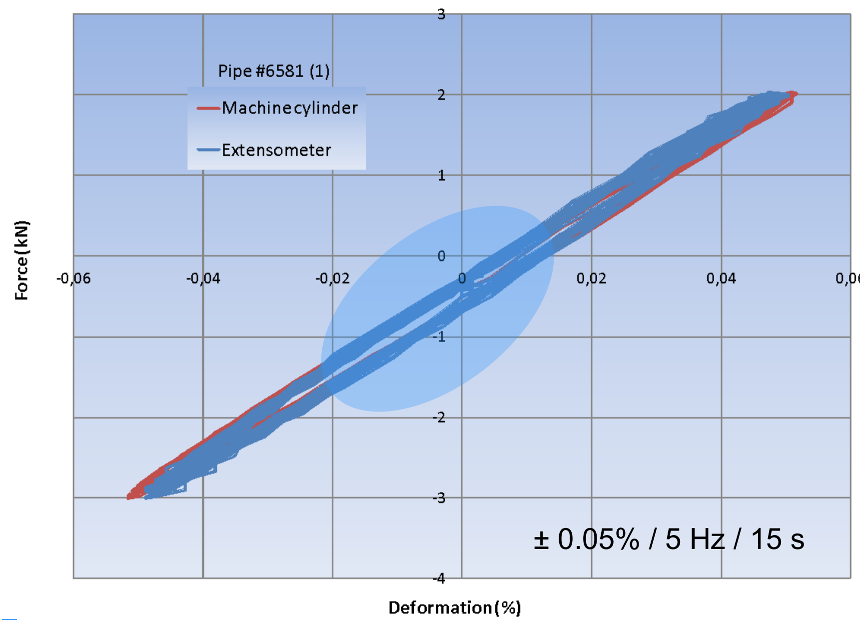
RESULTS AND DISCUSSION

Cyclic Compression-Tensile test



✓ Application of a sine wave compression-tensile deformation: Good agreement between the extensometer and the machine cylinder proving that deformation is homogeneous all along the pipe

✓ The results show a linear behavior of the materials in this range of deformation with a slight hysteresis between loading and unloading of the test specimens

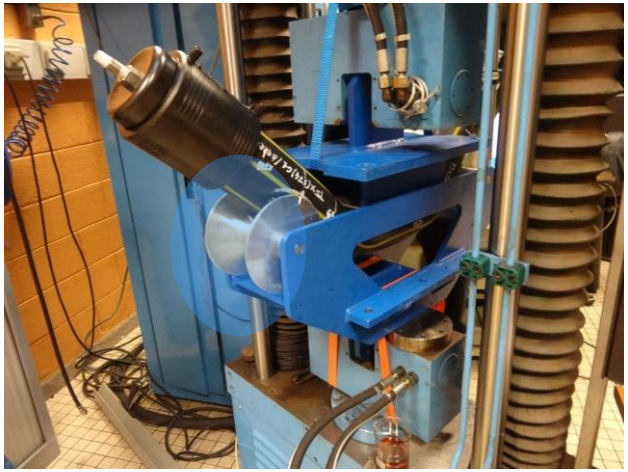


✓ The three PE materials behave in a similar way under such loading conditions

✓ No damage can be observed on the pipes after such tests

RESULTS AND DISCUSSION

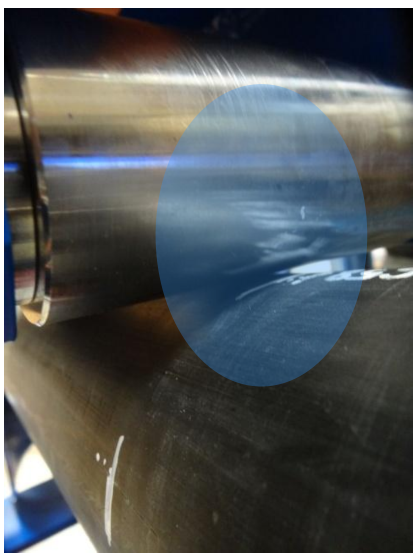
4-point Bending Test



A « target » deflection of 165 mm (1.5 times the pipe OD) could be achieved thanks to the good behavior of the experimental setup

BUT

✓ Given the importance of the loads (1,000 to 1,500 kg) the expected rotation of the rolls was prevented during the tests

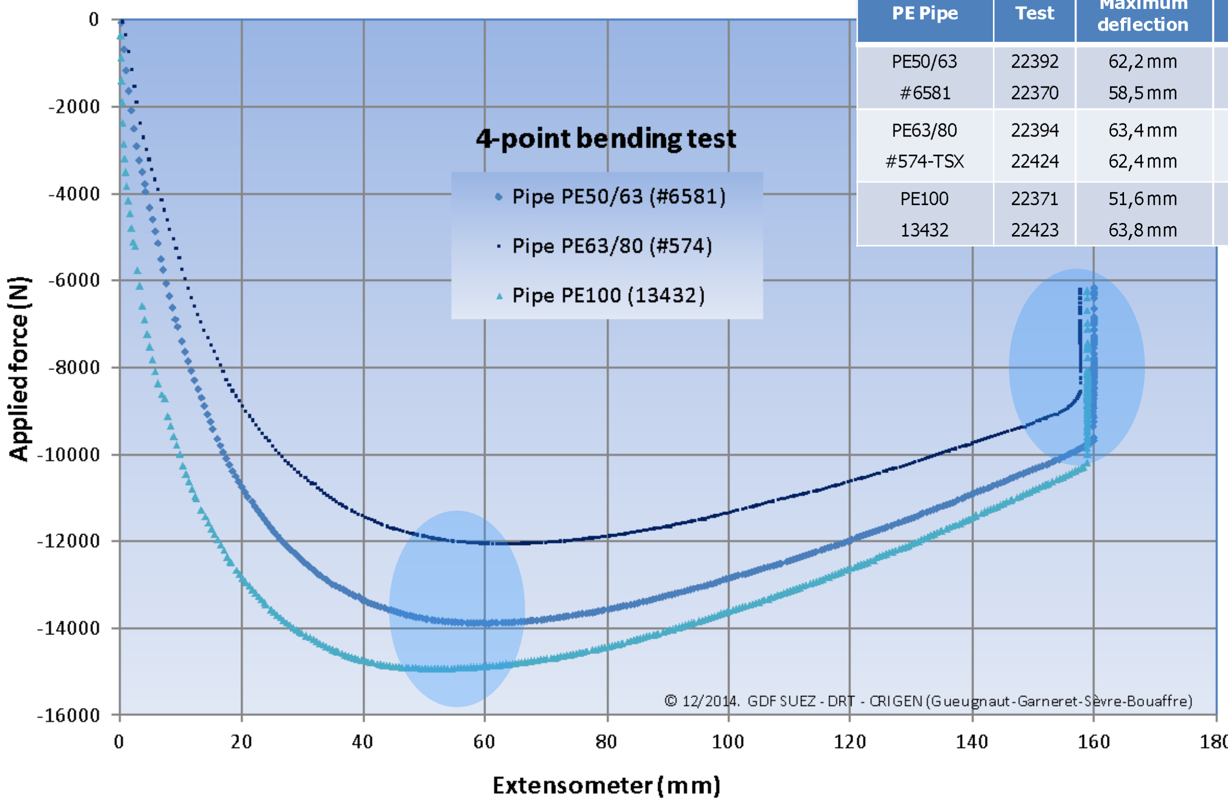


✓ Moreover pipe « crushing » occured in the calibrated zone of the setup during the test

✓ A blank test shows that any geometrical recovery of the pipe is quite impossible after the test

RESULTS AND DISCUSSION

PE Pipe	Test	Maximum deflection	Maximum Force at maximum Deflection	Bending Energy at maximum Force
PE50/63	22392	62,2 mm	14,3 kN	673 J
#6581	22370	58,5 mm	13,9 kN	635 J
PE63/80	22394	63,4 mm	12,0 kN	590 J
#574-TSX	22424	62,4 mm	12,0 kN	578 J
PE100	22371	51,6 mm	14,9 kN	640 J
13432	22423	63,8 mm	14,9 kN	747 J



✓ The shapes of the curves are very similar for the three PE materials

✓ The maximum values of the force are observed for a displacement of the order of 50 to 60 mm (0.5 times the pipe OD)

✓ Maximum values of the force are 14 kN (PE50/63), 12 kN (PE63/80) and 15 kN (PE100) "crigen

RESULTS AND DISCUSSION

Hydrostatic pressure resistance after Cyclic Tensile-Compression Tests

PE50/63 (#6581 / 12727)		PE63/80 (#574 (TSX) / 8819)		PE100 (13432)	
2 MPa / 80°C	4 MPa / 80°C	4 MPa / 80°C	4.5 MPa / 80°C	5 MPa / 80°C	5.4 MPa / 80°C
Stopped without failure at 1,034 h	Brittle failure at ≈ 72 h	Stopped without failure at 1,034 h	Stopped without failure at 233 h	Stopped without failure at 1,034 h	Stopped without failure at 301 h

The cyclic tensile-compression tests do not create any permanent damage in the pipes with regards to the standard and/or specification requirements both for the newest pipes and for the excavated oldest pipe

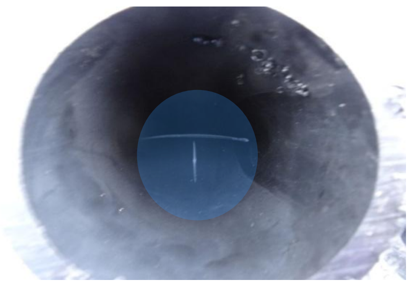
RESULTS AND DISCUSSION

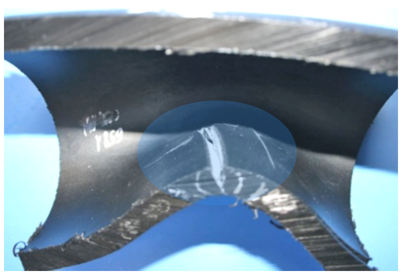
Hydrostatic pressure resistance on 4-point bent pipes

PE50/63 (#6581 / 12727)		PE63/80 (#574 (TSX) / 8819)		PE100 (13432)	
2 MPa / 80°C	4 MPa / 80°C	4 MPa / 80°C	4.5 MPa / 80°C	5 MPa / 80°C	5.4 MPa / 80°C
Brittle failure at ≈ 206 h	Brittle failure at ≈ 14 h	Stopped without failure at ≈1,050 h	Stopped without failure at 316 h	Stopped without failure at ≈1,050 h	Stopped without failure at 264 h

RESULTS AND DISCUSSION

Hydrostatic pressure resistance on 4-point bent pipes





- ✓ The three pipes # 6581 # 574 and 13432 do not reveal any crushing-induced wrinkles in the so-called « squeezed/crushed ears » where the damage should be the most severe
- ✓ The pipes # 574 (PE63/80) and 13432 (PE100) do not show any crack initiation sites
- ✓ The excavated oldest pipe # 6581 shows some faults in the most bent zones; The faults consist in axial and transverse cracks which initiate just below and in the vicinity of the upper rolls
- ✓ The transverse cracks correspond approximately to the contact line of the upper roll on the pipe
- ✓ The longitudinal cracks seem to develop in the ovalized part around the roll where the pipe is in tension (at the contrary of the “squeezed-off “zones where compression is dominating)

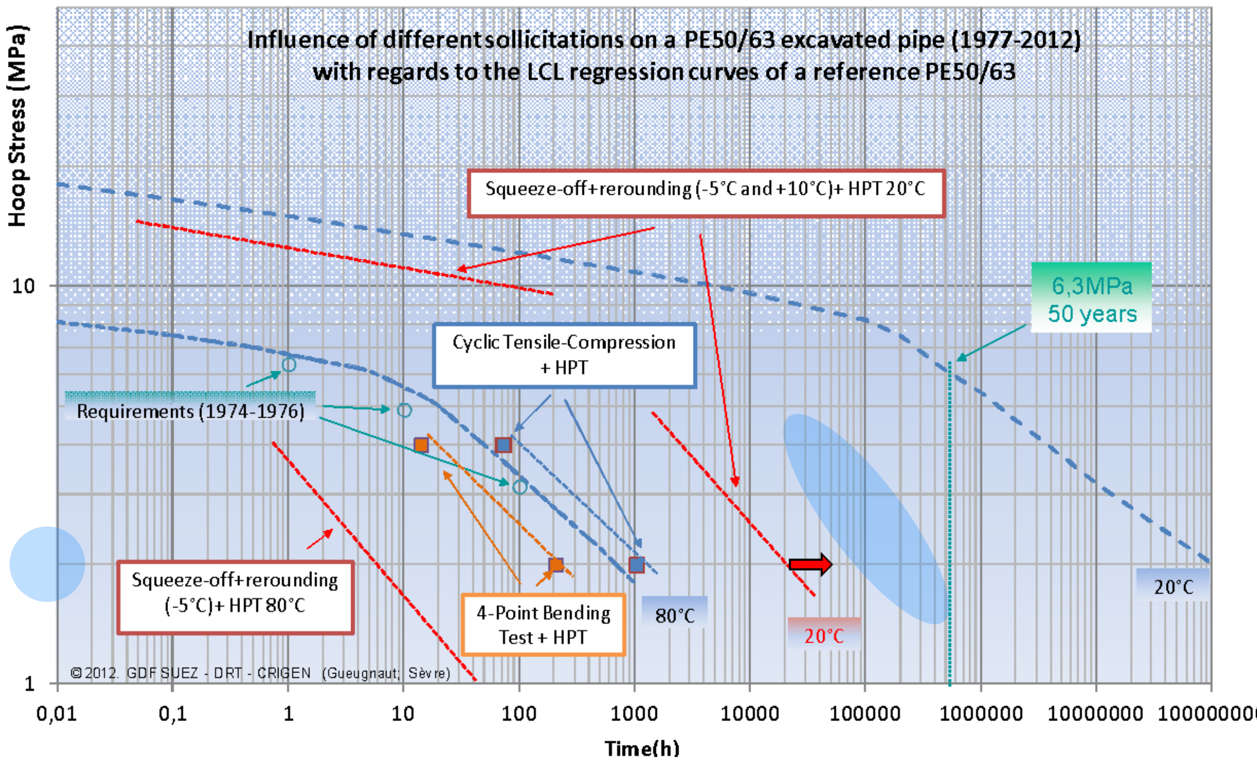
⬇

The 80°C HPT on the 4-point bent pipe # 6581 lead to premature failure times with regards to those required in the technical file of the resin

⬇

Residual performances at 20°C ?

RESULTS AND DISCUSSION



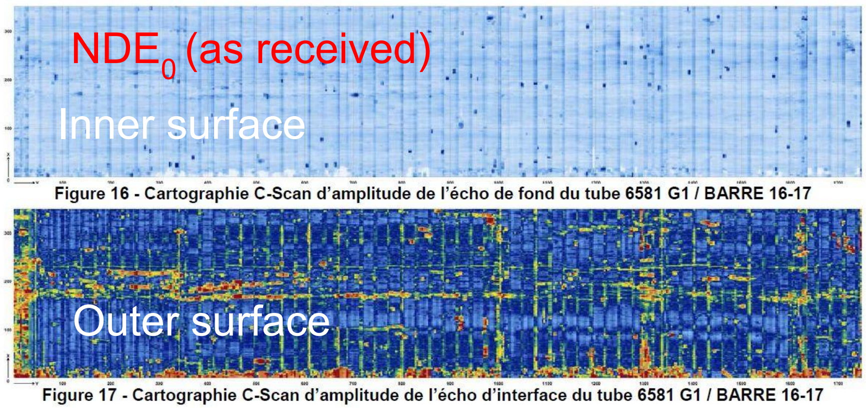
For a 2 MPa Hoop stress (4 bar pressure for a SDR11 pipe) the old pipe # 6581 shouldn't fail before around 100,000 h (~10 years)

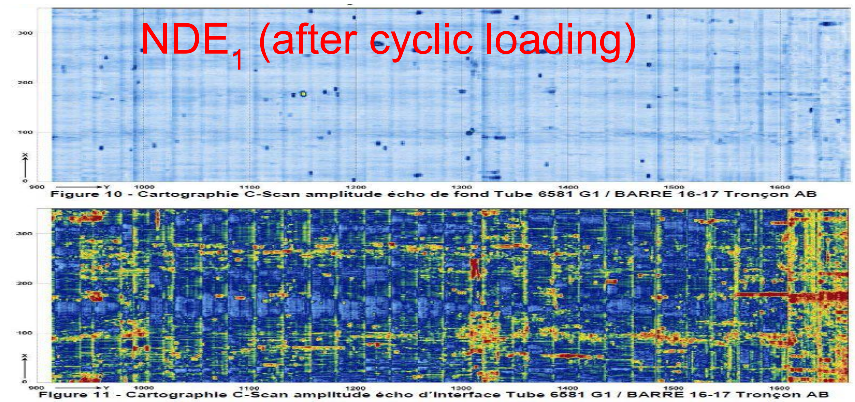
Such a (conservative) estimate is based on the hypothesis of :

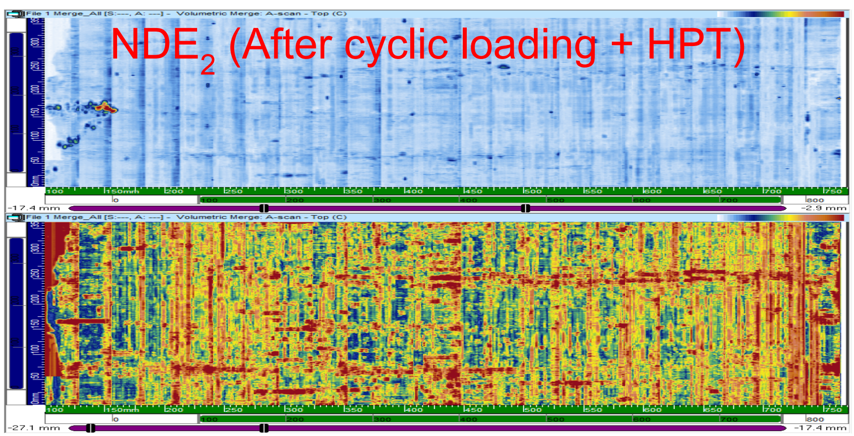
- ✓ *The similarity of Slow Crack Growth with regards to the Standard curves*
- ✓ *The conservation of the distances between the 20°C and the 80°C-curves in both configurations (squeeze-off and 4-point Bending)*

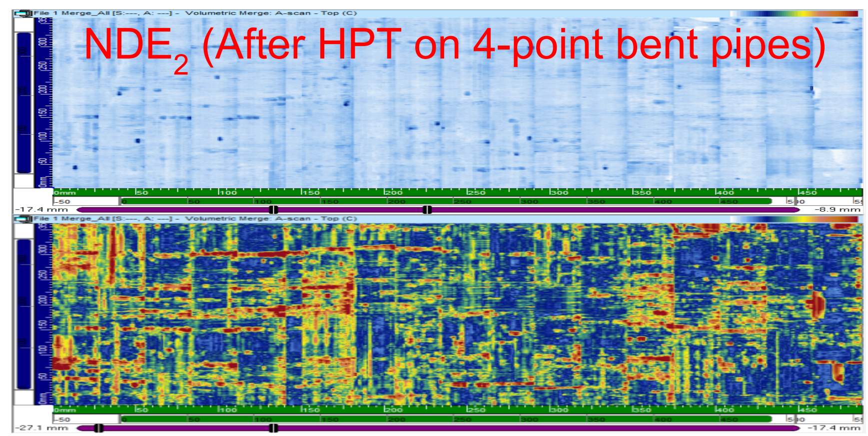
RESULTS AND DISCUSSION

Non destructive evaluation of the pipes before and after seismic loading +HPT





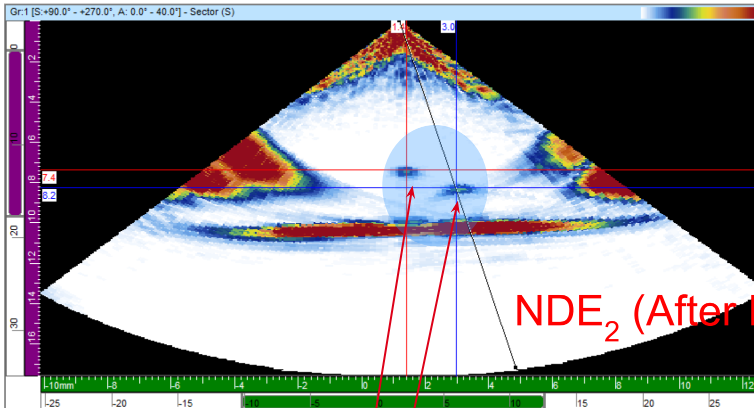


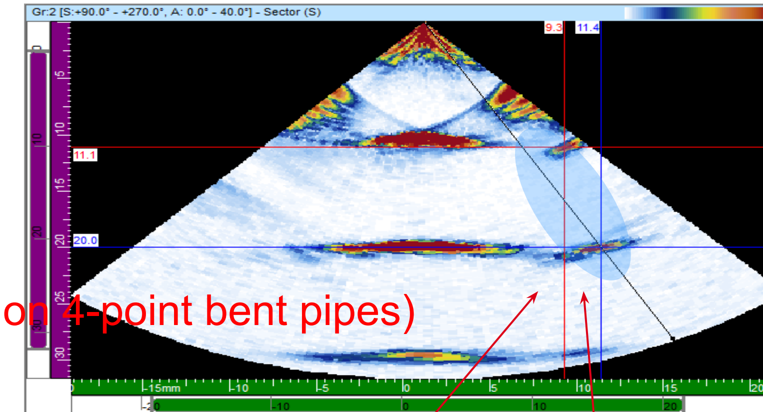


- ✓ Small scratches on the outer surfaces, as expected
- ✓ No faults on the inner surfaces and in the wall thickness of every pipes

RESULTS AND DISCUSSION

Non destructive evaluation of the pipes before and after seismic loading + HPT

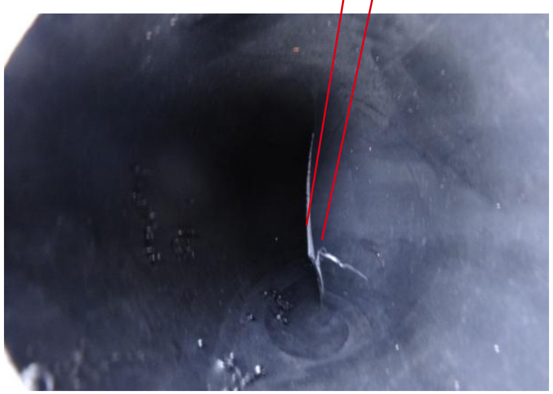


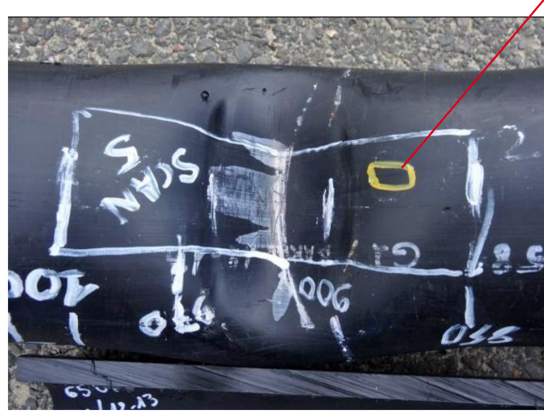


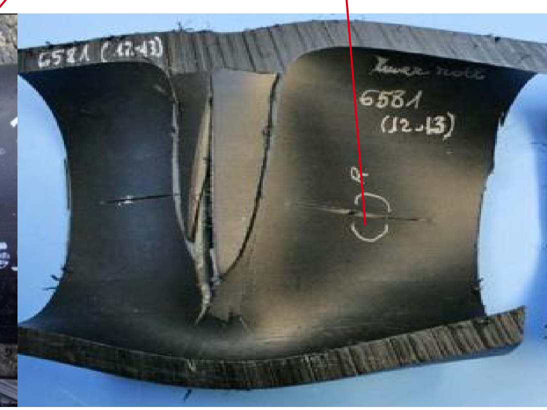
NDE$_2$ (After HPT on 4-point bent pipes)

Close to the cracks in the bent zones of the pipe
Height of the cracks ≈ 2.6 et 1.8 mm (from the inner)

Crack responsible for the leak after HPT (10 mm)







CONCLUSIONS

CONCLUSIONS

✓ The Cyclic Tensile-Compression loading doesn't alter the pipe residual performances for the three PE families tested, as shown by both the hydrostatic pressure tests and the Phased Array Ultrasonic Technique evaluation (Non Destructive Testing).

✓ Bending tests do not alter the performances of the PE63/80 and PE100 families, which comply with the standard requirements as shown by both the hydrostatic pressure tests and the Phased Array Ultrasonic Technique evaluation (Non Destructive Testing).

✓ After 4-Point Bending + HPT, the excavated 35 years old PE50/63 pipe doesn't meet the requirements anymore although no immediate failure occurred; Nevertheless, on the basis of data regarding a severe squeeze-off of the similar pipes, the reduced failure times obtained under accelerated pressure tests suggest a remaining life of 10 years or more

In conclusion, the tests carried out in laboratory confirm the outstanding mechanical behavior of these three PE families

What about welds?

THANK YOU FOR YOUR ATTENTION

Charles.fernandez@gdfusez.com
Dominique.gueugnaut@gdfsuez.com