Pipeline fatigue management

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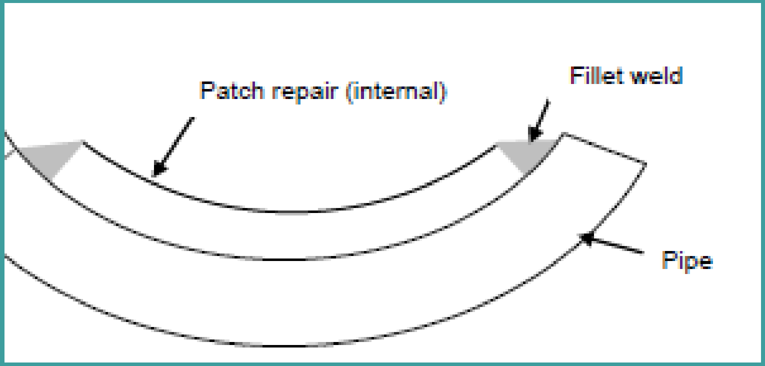
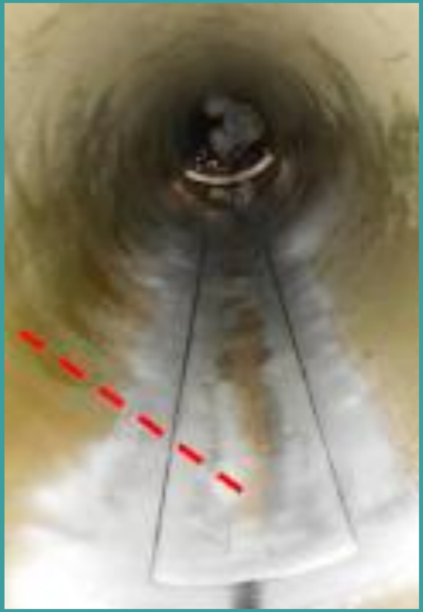
1. When is a fatigue assessment required?

A fatigue assessment should be required every time the roundness / continuity of the pipe shell is not satisfactory.

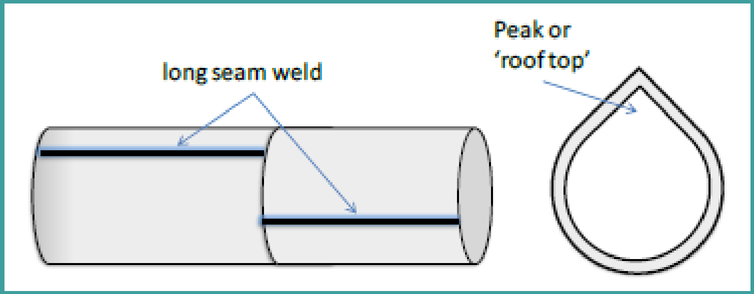
Examples

1. When is a fatigue assessment required?



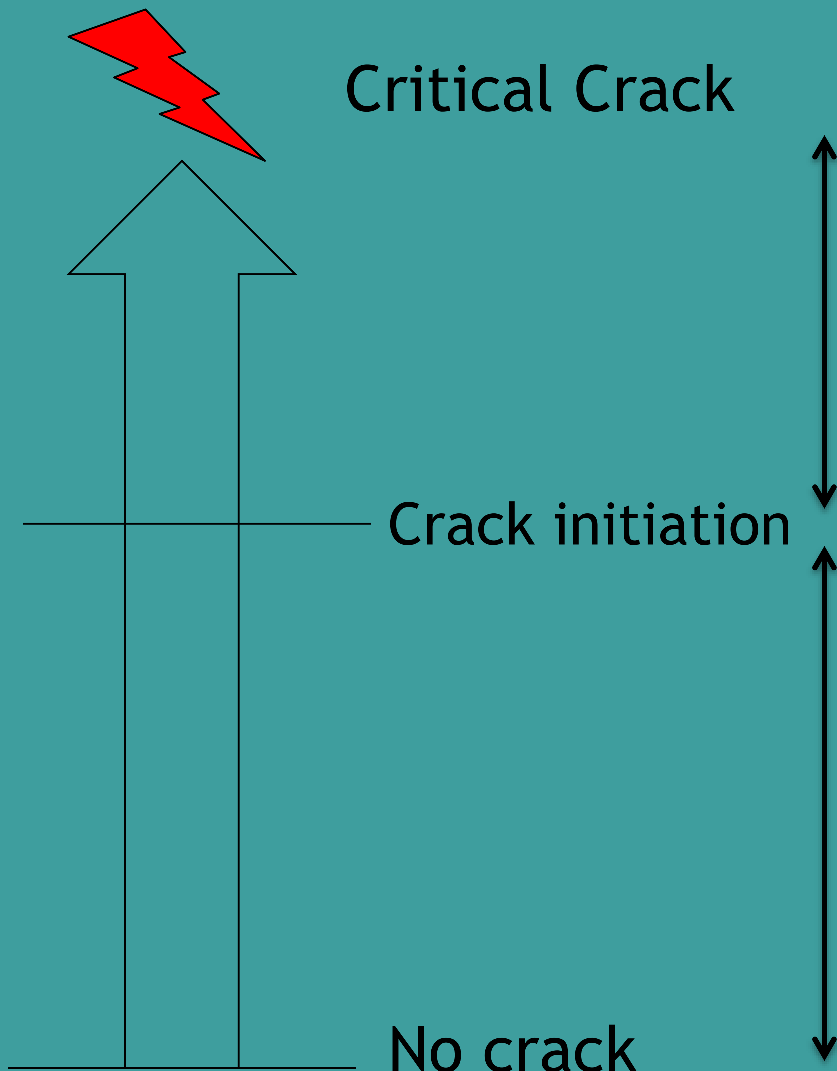


Welded patch



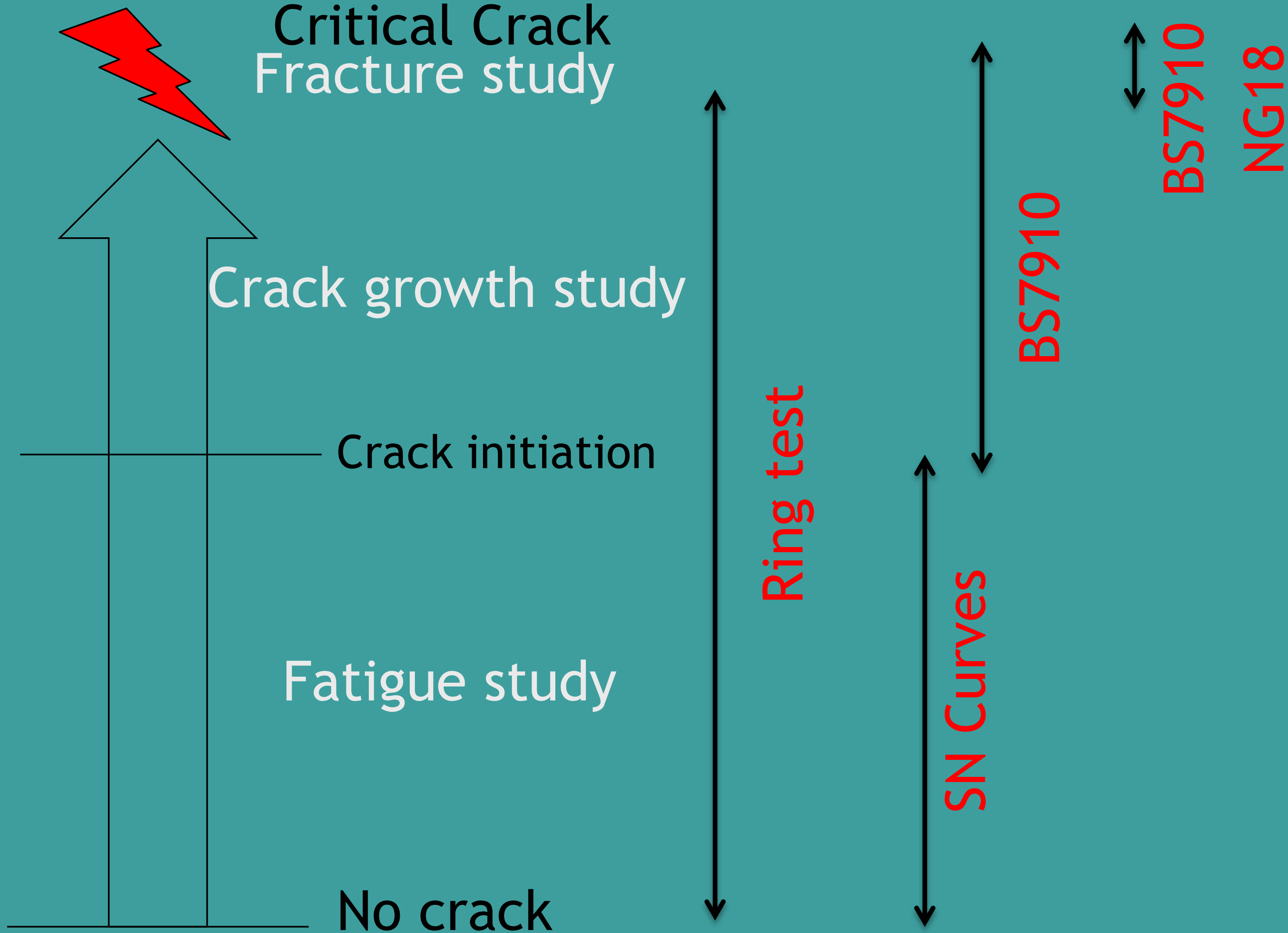
Roof topping etc…

2. Definitions



- Fracture study
- Crack growth study
- Fatigue study

2. Definitions



3. DATA collection

Step 1: IN LINE INSPECTION

- SPSE performed an ILI of all pipelines. Thus we know exactly the maximal size (depth + length) of the biggest indication. Defect may be a crack, roof topping, a dent...
- If no indication is detected, the detection threshold of the tool will be taken into account (1mm in our case)

3. DATA collection

- **Step 2: PRESSURE DATA**
  - Ideally, we need to work on “real time” data (sampling 1hz).
  - When data is not available, it is possible to generate pressure data based on recent records providing that pumping conditions are similar.

3. DATA collection

- Raw pressure data cannot be used directly for a fatigue analysis.
- It has to be converted from temporal to elementary cycles of pressure. This method is called *RAINBOW method*. (AFNOR A03 406)

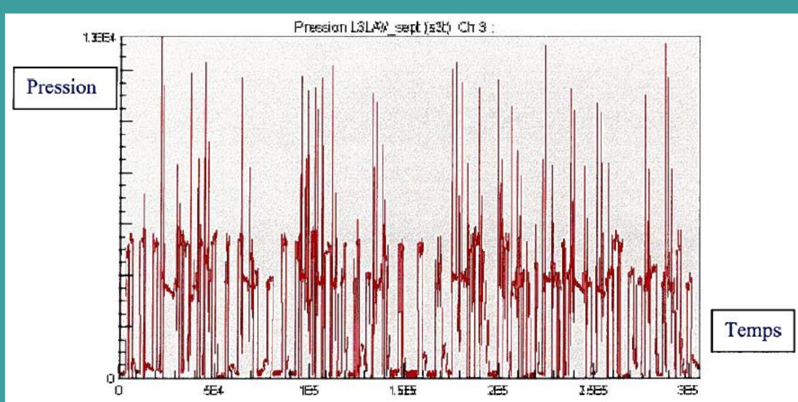
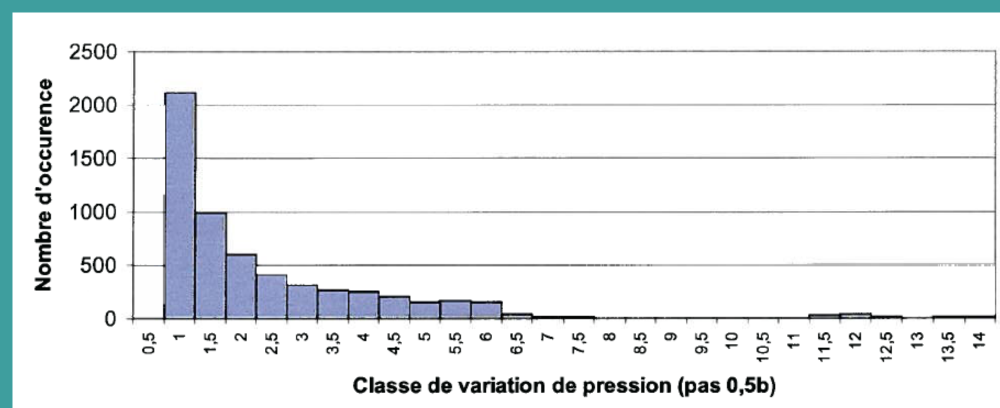


Figure 1 : Relevé des variations de pression mesurées durant le mois de septembre 2009 (valeurs non écrêtées)



4. Experimental: Ring test method

Pipe selection

- For this method, samples of pipes will be tested in fatigue. A determined variation of pressure is applied until pipe failure.
- SPSE selected the ring test method. The advantage is that this method requires only a small sample of pipe (a ring) and thus, with only one pipe a large number of tests is made possible.
- It is important that the pipe used for the tests contains defects representative of the pipeline (i.e.: biggest crack, roof topping…)

4. Experimental: Ring test method

- In order to simulate cracks, SPSE used EDM notches.
- If the sample is taken on the pipeline, then the test is more accurate.

4. Experimental: Ring test method

SPSE feedback:

This method was used for the crude oil 40"-pipeline.

- The Ring test method gave exactly the right prediction for the accident of 2009 (it is the best method).
- But doing this required to have a sample with exactly the same characteristics (not always easy)
- Tests are long (months) and expensive.
- No problem of past pressure data collection

4. Experimental: Ring test method

Some figures

- Life time for a 40”pipeline, pipe with **no defect**: between 2000 to 10 000 years
- Life time for a 40”pipeline, pipe with **roof topping**: 400 years
- Life time for a 40”pipeline, pipe with **roof topping + crack + lamination**:

  <50 years

5. Fatigue assessment: SN curves

The stress variations in a perfect pipe are given by the Barlow law :

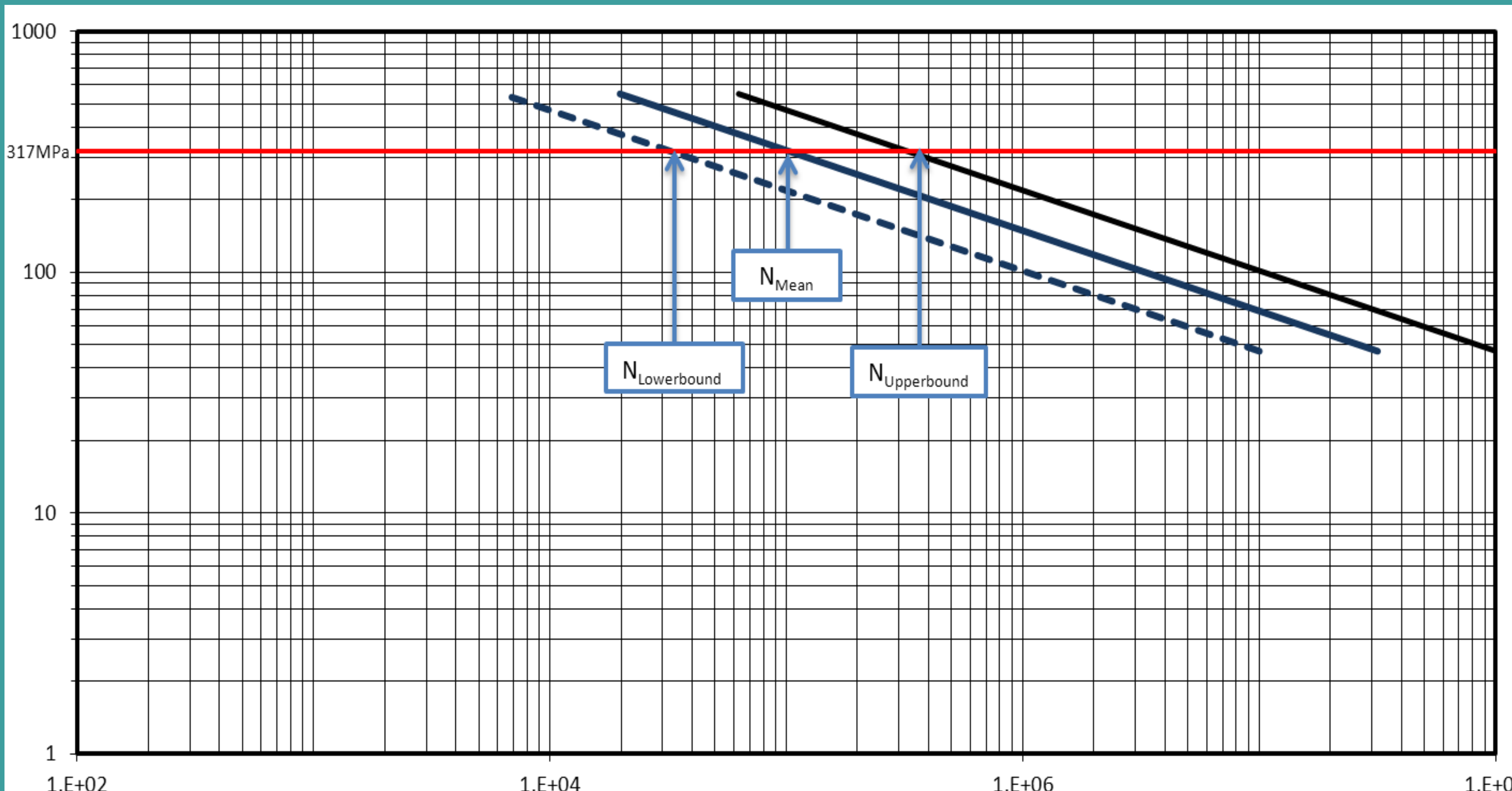
$$\Delta\sigma_{nom} = \frac{\Delta P.D}{2.e}$$

Where D is the diameter and e the wall thickness of the pipe

In most cases the pipe is not perfect. Pipes may be affected by roof topping for instance. This leads SPSE to use a Stress Concentration Factor. In BS7910, a very detailed formula for SCF of roof topping is given. For a dent, a SCF can also be calculated.

The number of cycles to rupture of a pipe is given by BS 7608. These curves are called S/N curves (stress vs. number of cycles). These curves give the number of cycles needed to failure with a probability of 95%.

5. Fatigue assessment: SN curves



5. Fatigue assessment: SN curves

SPSE feedback:

- For a pipe with no defect, or only affected by roof topping, this method works well.
- The study is easy to perform (data collection is the most time-consuming part)
- This method does not take into account a pre-existing crack since manufacture in the pipe mill.
  - **Problem**: the ILI inspection can only guarantee that the crack depth is <1mm.
  - This problem can be fixed by periodically launching a crack detection tool into the line (every 6 years for example)

5. Fatigue assessment: SN curves

Some figures:

- Life time for a pipeline 34” transfer line, pipe with **roof topping 6mm**: 80 years
- Life time for a pipeline 34” transfer line, pipe with **roof topping 6.3mm**: 626 years (this show the importance of pumping conditions)
- Life time for a pipeline 34” transfer line, pipe with **roof topping 3.7mm**: 252 years

6. BS7910 method

- Determine the depth of the critical crack

Several methods are available to establish the failure pressure of pipes containing crack

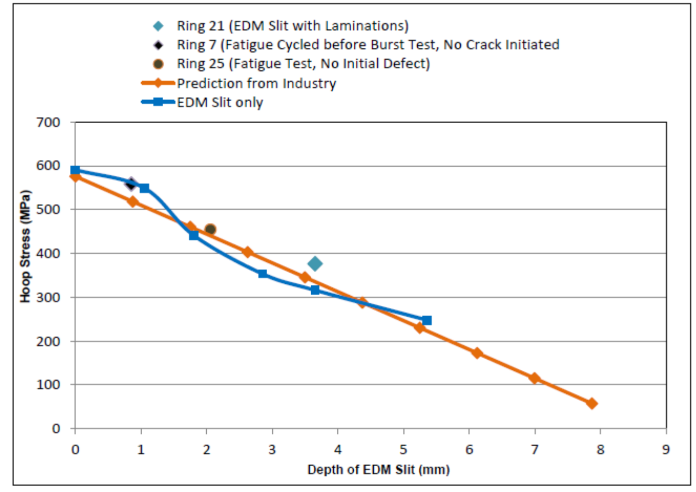
- BS 7910
- NG-18 (Battele model)
- FEA

The results of burst tests led SPSE to use the NG-18 model.

This model is used :

- to determine the biggest crack that can resist to an hydro-test
- To determine the depth of the critical crack at MAOP.

The other way to obtain the initial crack size is to use ILI results



6. BS7910 method

- The BS7910 allows calculating the number of cycles required to grow a crack from actual depth to a critical depth **at the loading stress conditions**. (*Penspen* used a software TWI Crackwise®) API 579 can also be used.
- Use a safety factor on this number of cycles. In the case of SPSE 's pipelines, it appears that a safety factor of 3.6 is conservative (compared to ring test)

6. BS7910 method

Ring No.	EDM Slit + Pre-Crack Depth[32] (mm)	Crack Depth after Fatigue Growth (mm)[33]	Crack Growth (mm)	Pressure Range (barg)	Hoop Stress Range (MPa)	Bending Stress Range (MPa)	No. Of Cycles from BS 7910	No. of Cycles from Test	Safety Factor[34]
10	3.2	5.23	2.03	18 to 32	80	126.8	1,524	12,024	7.9
12	3.05	5.25	2.20	10 to 29	108.10	200.3	623	5,305	8.5
13	3.10	5.20	2.10	10 to 29	109.10	187.8	616	3,800	> 6
	5.20	5.20	0[35]	18 to 32	80.42	121.3	0	12,460	
15	2.50	4.09	1.59	10 to 29	107.99	203.9	1000	1,000	> 11
	4.09	5.26	1.17	17 to 29	68.2	117.4	633	7,000	
	5.26	5.26	0[35]	10 to 29	107.99	203.9	0	3,500	
	5.26	5.26	0[35]	17 to 29	68.20	117.4	0	7,000	
	5.26	5.26	0[35]	10 to 29	107.99	203.9	0	1,810	
18	1.85	2.88	1.03	17 to 29	67.97	117.1	7,000	7,000	3.6
	2.88	5.28	2.40	10 to 29	107.61	202.3	766	2,735	
24	3.30	3.81	0.51	21 to 29	45.72	63.4	4,000	4,000	4.3
	3.81	5.22	1.41	10 to 29	108.57	172.6	1,176	275	

Table 5-6: Retrospective Studies on Fatigue Crack Growth.

The above results show that the fatigue life from ring testing is conservatively predicted using BS 7910 (with a minimum safety factor of 3.6).

6. BS7910 method

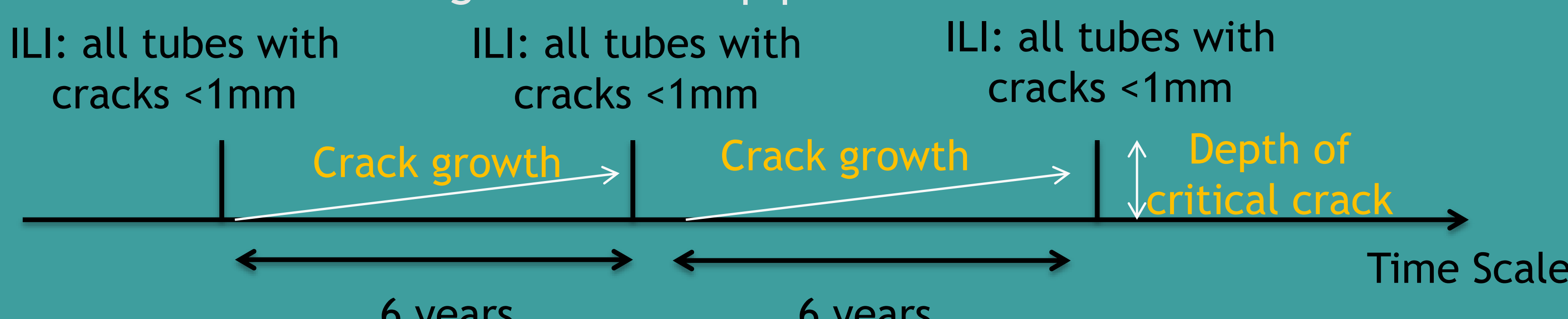
No.	Dist (m)	Spool No.	RT (mm)	Wall Thickness (mm)	Hoop stress range (MPa)	Max bending stress range (MPa)	No of Cycles from CrackWise	No of Cycles per year [39]	Fatigue life [40] (Years)	Date of Re-inspection/ Repair
1	7848	43440	4.1	8.8	167.18	405.60	1115	72.05	5.57	Oct-2015
2	35938	44066	4.5	9.6	167.18	414.83	1139	72.05	5.69	Nov-2015
3	6891	43692	4.0	9.0	167.18	392.44	1205	72.05	6.02	Mar-2016
4	9872	44407	4.0	9.0	167.18	392.44	1205	72.05	6.02	Mar-2016
5	36376	44221	4.0	9.0	167.18	392.44	1205	72.05	6.02	Mar-2016
6	6760	43604	4.3	9.6	167.18	399.88	1220	72.05	6.10	Apr-2016
7	6111	44234	4.0	9.2	167.18	387.21	1256	72.05	6.28	Jun-2016
8	6831	43703	4.0	9.2	167.18	387.21	1256	72.05	6.28	Jun-2016
9	36532	44233	4.0	9.2	167.18	387.21	1256	72.05	6.28	Jun-2016
10	43206	43727	4.0	9.2	167.18	387.21	1256	72.05	6.28	Jun-2016
11	48550	43680	4.0	9.2	167.18	387.21	1256	72.05	6.28	Jun-2016
12	57222	42961	4.0	9.2	167.18	387.21	1256	72.05	6.28	Jun-2016
13	44676	43731	4.0	9.4	167.18	382.05	1307	72.05	6.53	Sep-2016
14	48727	43449	4.0	9.4	167.18	382.05	1307	72.05	6.53	Sep-2016
15	70444	41442	4.0	9.4	167.18	382.05	1307	72.05	6.53	Sep-2016

Predicted Fatigue lives

6. BS 7910 method

SPSE feedback:

- The key criteria is to be sure of the size of the critical defect.
- This method requires a conservative safety factor. The adjustment of the safety factor is easier with some prior ring tests.
- This method is fully adapted to an integrity manager because each pipe can be specifically monitored. The target is to have an interval for ILI < life of each tube. Then it is possible to re-assess the pipe with the new crack depth.
- Data on the toughness of the pipe has to be available



6. BS 7910 method

Some figures

- Life time for pipeline 40", **with crack 1mm** (detection threshold of ILI) and **roof topping 3.5mm**: 5.6 years
- Due to the position of the spool in the line (altitude) *Penspen* was able to deliver an excavation program (1st spool: rupture after 5.6 years, 2nd spool: 5.7 years, 3rd spool: 6 years etc.)
- Life time of an **internal patch with a crack of 1mm** 570 years

Based on a ILI run every 5 years to check absence of indication, life time is infinite.

7. Conclusion

- To conclude, these 3 methods give an answer to the regulation standard EN 14161, 6.4.2.4 Fatigue, which is mandatory in Europe.
- The most important is to have a good knowledge of the pipeline: pressure data, material data. Otherwise, the results of the study might be far from reality.
- The study is not finished when the inspection company delivers the report. Then, you start to monitor the pipeline operational pressure data to check year per year that the conditions of the study are fulfilled.