37TH INTERNATIONAL NO-DIG FLORENCE 2019

Fortezza da Basso • FLORENCE (Italy)

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Design of close-fit liners for gravity pipes according to the French ASTEE 3R-2014

Influence of geometrical imperfections of host pipe & liner

How close-fit liners really perform

Misconceptions about close-fit liners and loads:

- Close-fit liners **bear soil** dead load.
- Vehicule loads **are "transferred"** to the liners through the soil.
- In fully deteriorated situation, the total pressure (vehicule loads +soil dead loads+groundwater pressure) will be « transferred » to the liner which will have to resist **« buckling ».**

How close-fit liners really perform

Right conceptions :

- **Liner stiffness is very low** in comparison of that of a rigid pipe or even some flexible pipe.
- Liner stiffness is **negligible** in comparison with soil stiffness.
- Loads transmitted by the soil-damaged host pipe to the liner are **imposed displacements** not imposed force or pressure.
- The liner has to deal **with** imposed deplacement, not resist.

How close-fit liners really perform

Right conceptions :

- Deflections of soil under **vehicule service loads** are very low. Fortunately for pavements!

  ⇒ Vehicule loads have virtually no effect on liners.

- Deflections of broken host pipe or flexible host pipe are mainly due to **soil erosion** **by water ingress/leakage**.

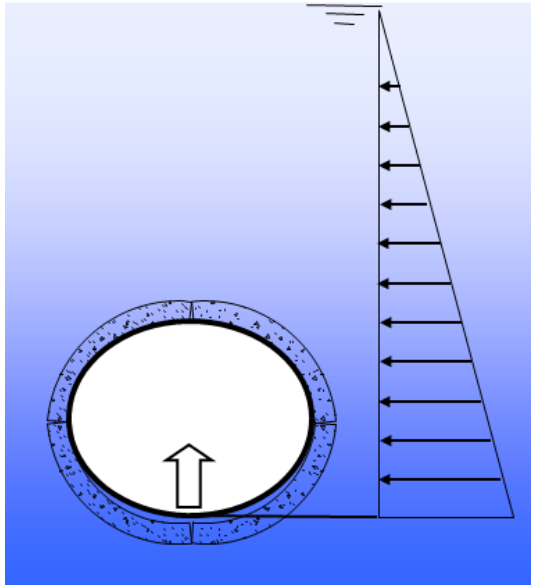
⇒Soil condition and water flow control displacements.

How close-fit liners really perform

- **Right conceptions:**
- Groundwater pressure acts **directly** on the liner.
- It is an imposed pressure ⇒ creep will increase deflection with time.
- Groundwater pressure may lead to **buckling or inacceptable deflections**.
- The liner must **resist** groundwater pressure.
- **Geometrical imperfections dramatically** decrease the resistance to groundwater.
- Imposed (deferred) deflections will also decrease the resistance to groundwater pressure.

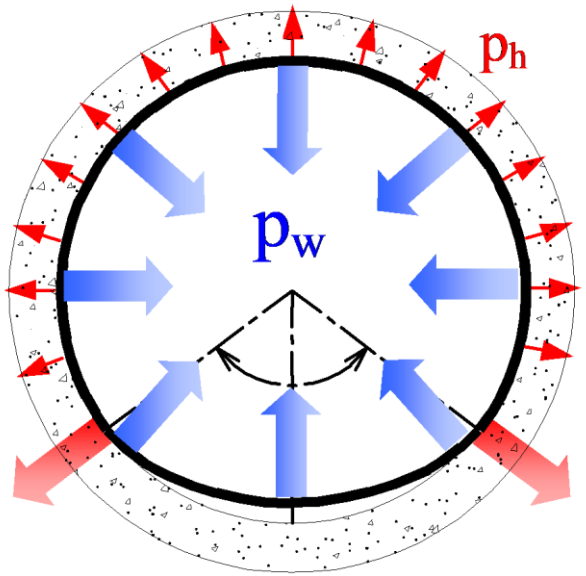
How close-fit liners really perform

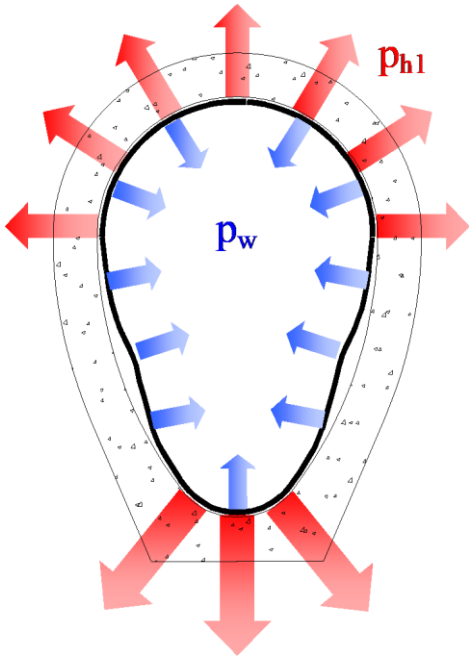
- Close-fit liners should be designed to resist only groundwater pressure, taking into account shapes, imperfections and imposed (deferred) deflections.

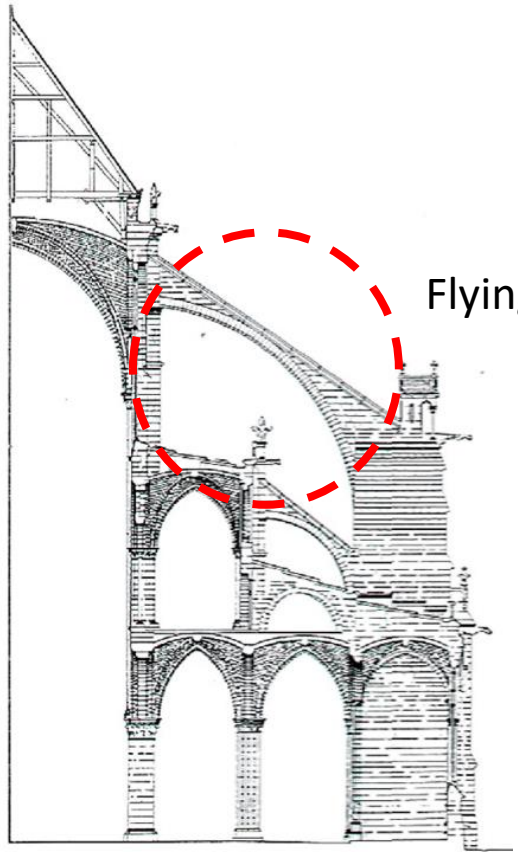


Resistance to groundwater pressure

- Resistance of close-fit liners to external groundwater pressure relies on the support of the host pipe.

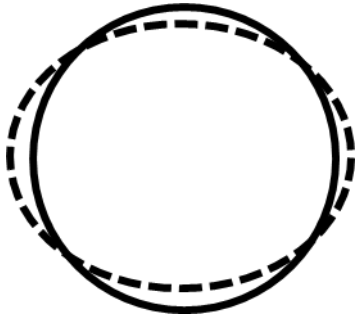


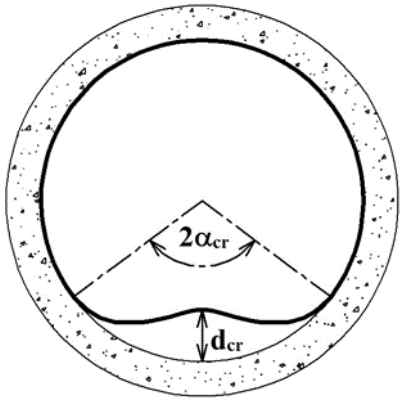




Resistance to groundwater pressure

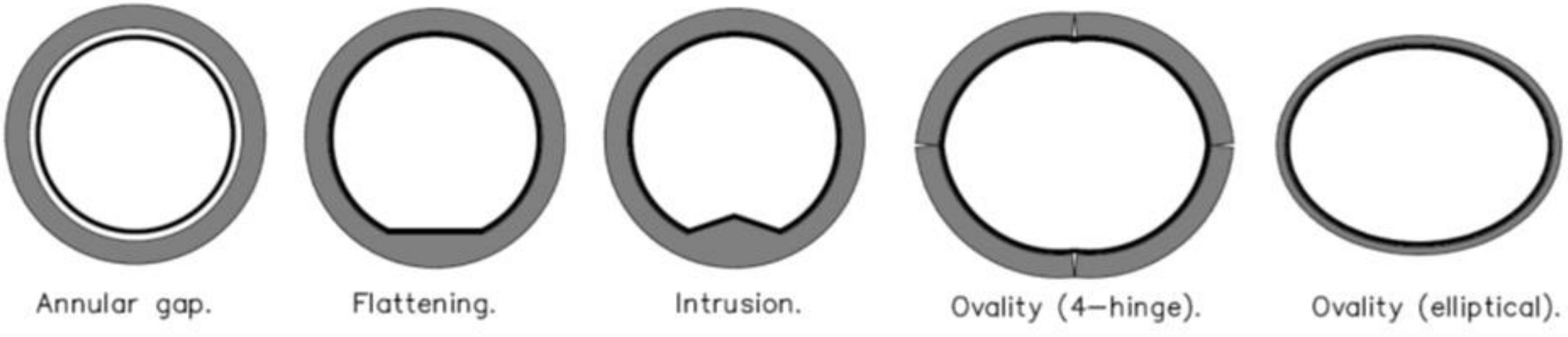
- The buckling pressure of unsupported circular liner (free ring) is typically **10 to 20 times lower** than a close-fit liner.
- Unsupported non-circular liner has almost **no resistance** to groundwater pressure.
- Geometrical imperfections can dramatically reduce the resistance to groundwater pressure.





Imperfections

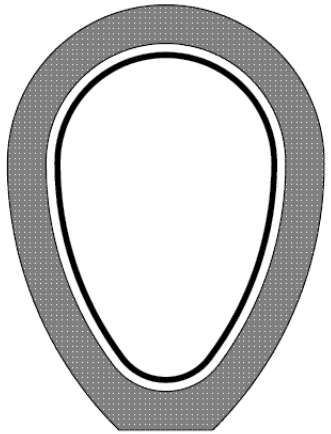
- Imperfections are deviations from the “perfect” profile.
- May be caused by defects in the host pipe or liner installation
- They are classified in two types: global or local.
  - Global are distributed around the perimeter like annular gap or ovality.
  - local imperfections are distributed on a limited angular sector like flattening or intrusion.



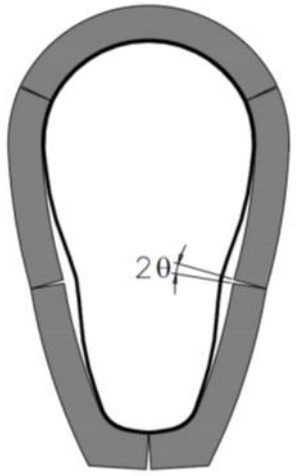
Imperfections

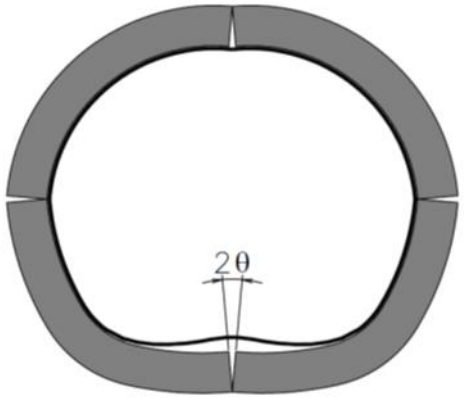
- Incidence of local imperfections on liner behavior may depend on their position, in contrast to global imperfections.

⇒Open cracks in the arc where the lobe develops will have maximum effect.



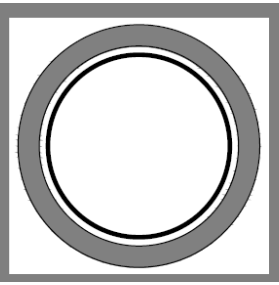
Annular gap





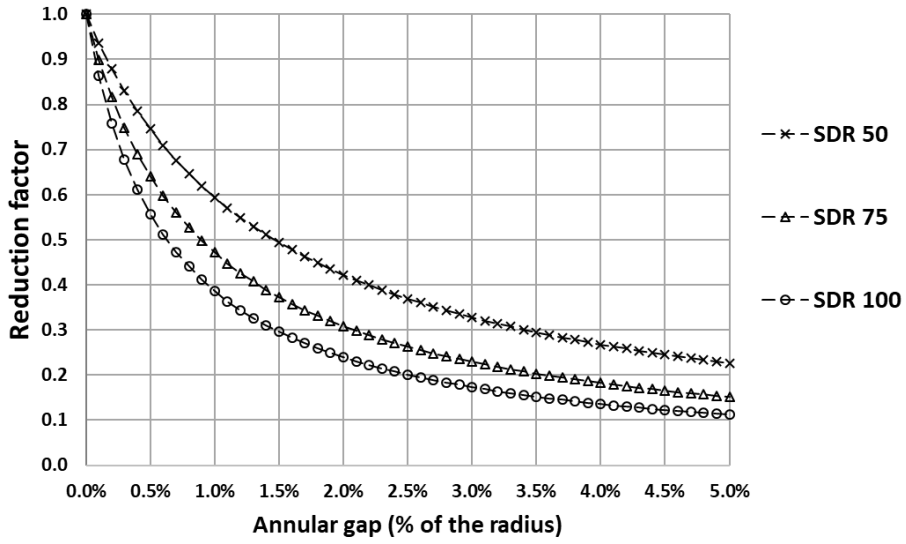
Hinge (fracture)

Annular gap imperfection

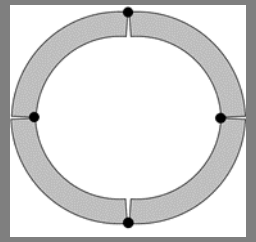


- Close-fit liners are designed to make full contact with the host pipe when installed and cured.
- The fit tolerance is typically 1 mm.
- Gap decreases dramatically the resistance to external groundwater.
- Minimum value for design: g = **0.5%** of the radius limited to 1 to 2 mm (may also cover gap due to deferred deflections).

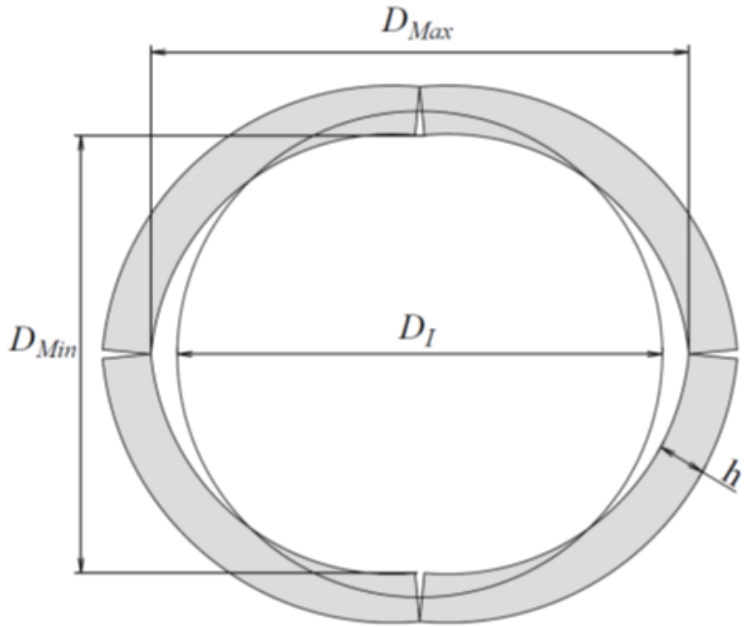
Credit: U.S. Environmental Protection Agency



4-hinge ovality imperfection



- 4-hinge ovality is a typical failure mode of overloaded rigid pipes.
- 3 definitions of ovality based on internal max, min and mean diameters!

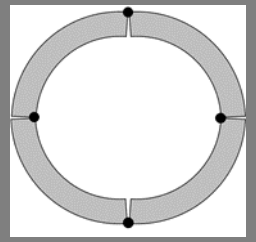


$$Ov1 = \frac{(D_{Max} - D_{Min})}{(D_{Max} + D_{Min})}$$

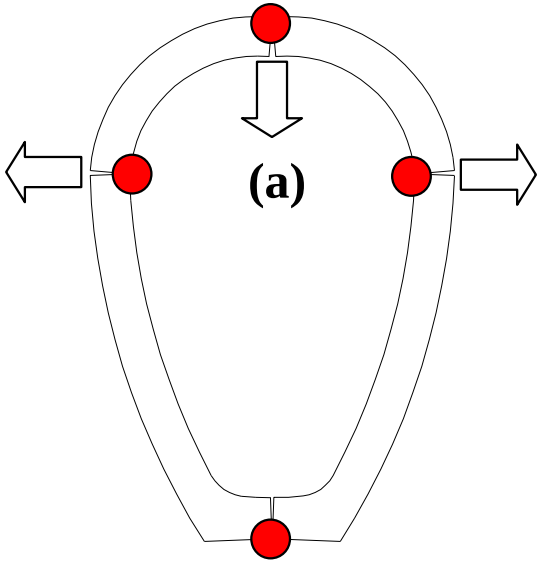
$$Ov2 = \frac{(D_{Max} - D_I)}{D_I}$$

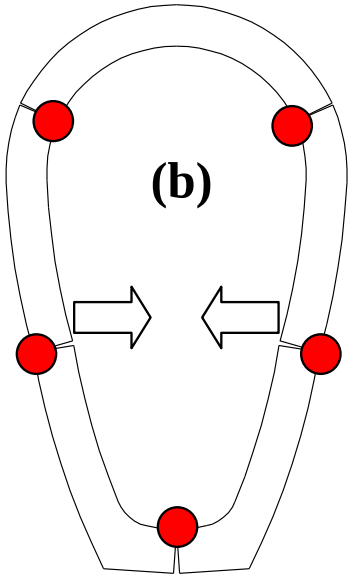
$$Ov3 = \frac{(D_I - D_{Min})}{D_I}$$

4-hinge ovality imperfection

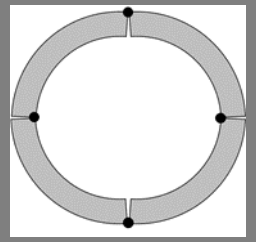


- 4-hinge ovality does exist for non-circular pipes.
- Ovality is replaced by **hinge rotation**.

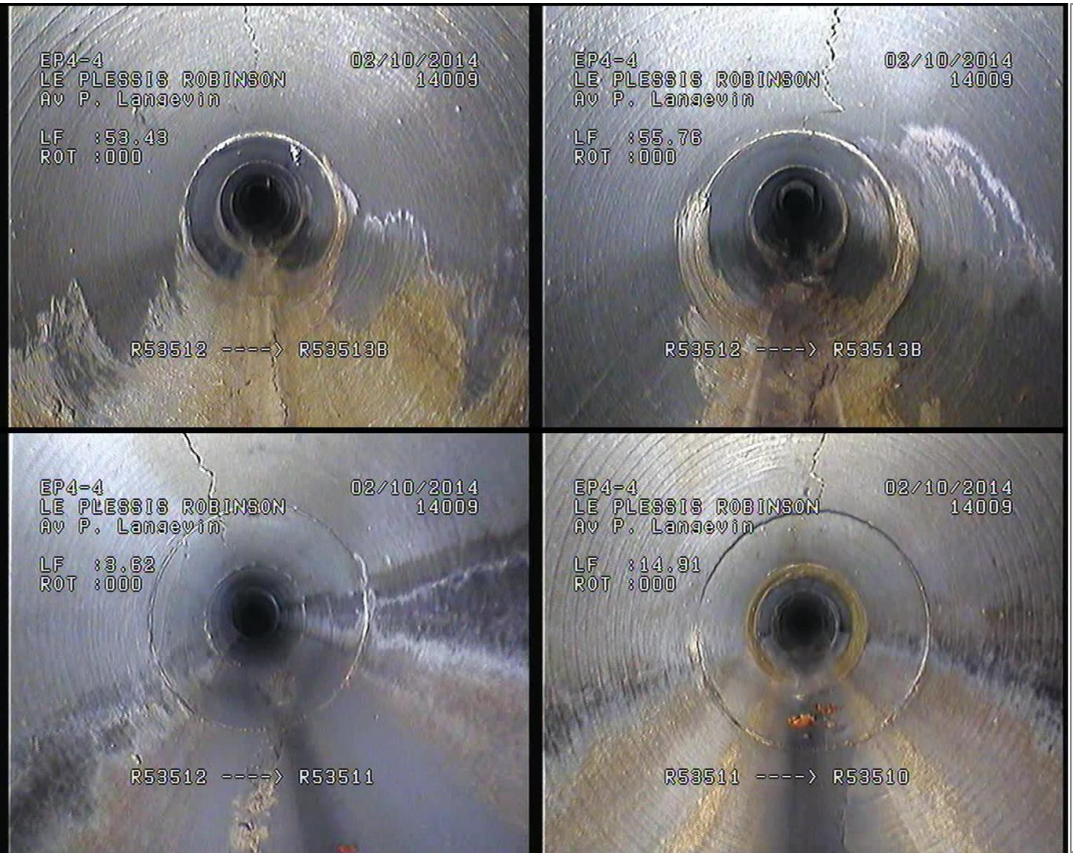


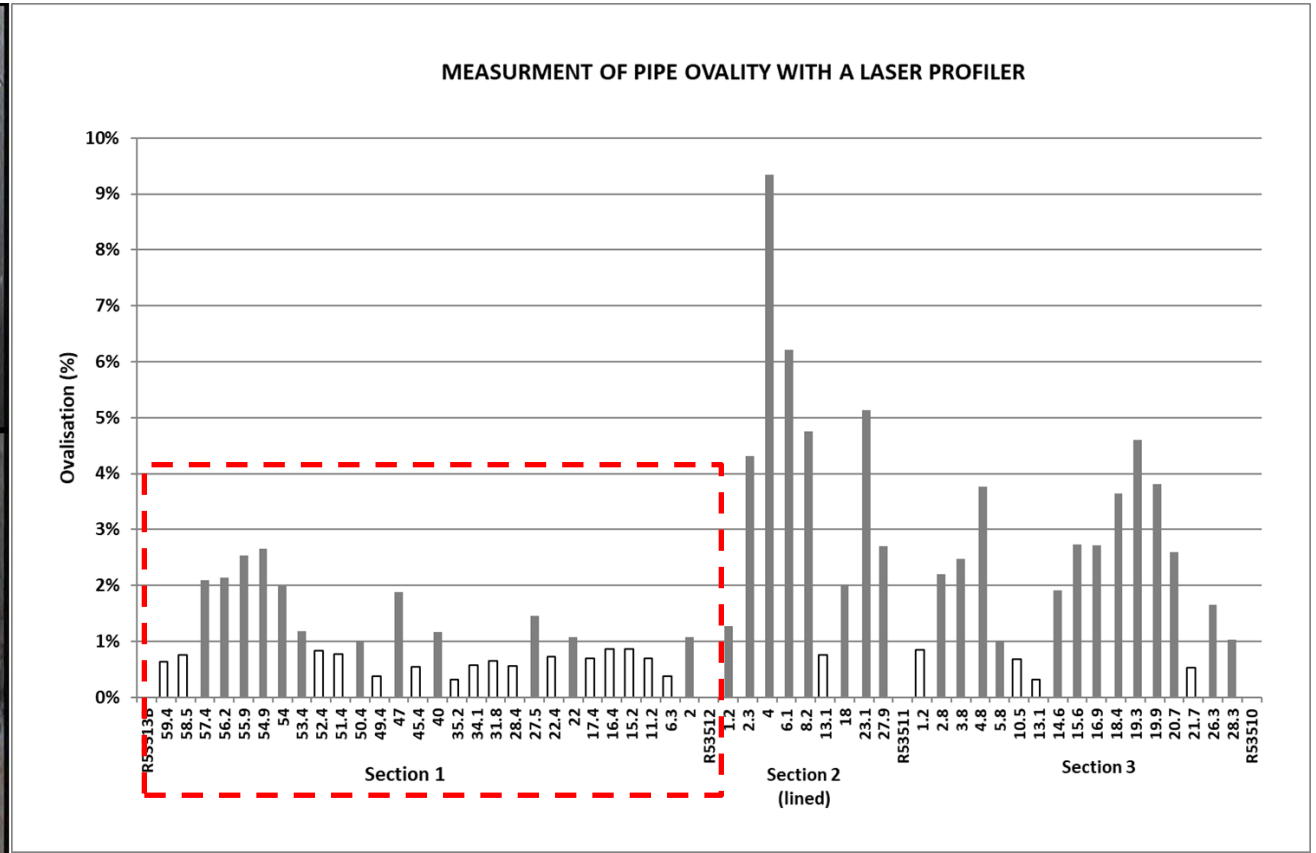


4-hinge ovality imperfection

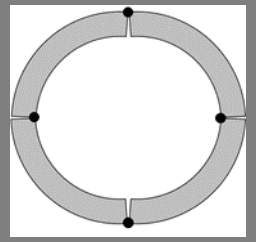


- At the beginning of the process ovality is often rather weak, less than 2%.

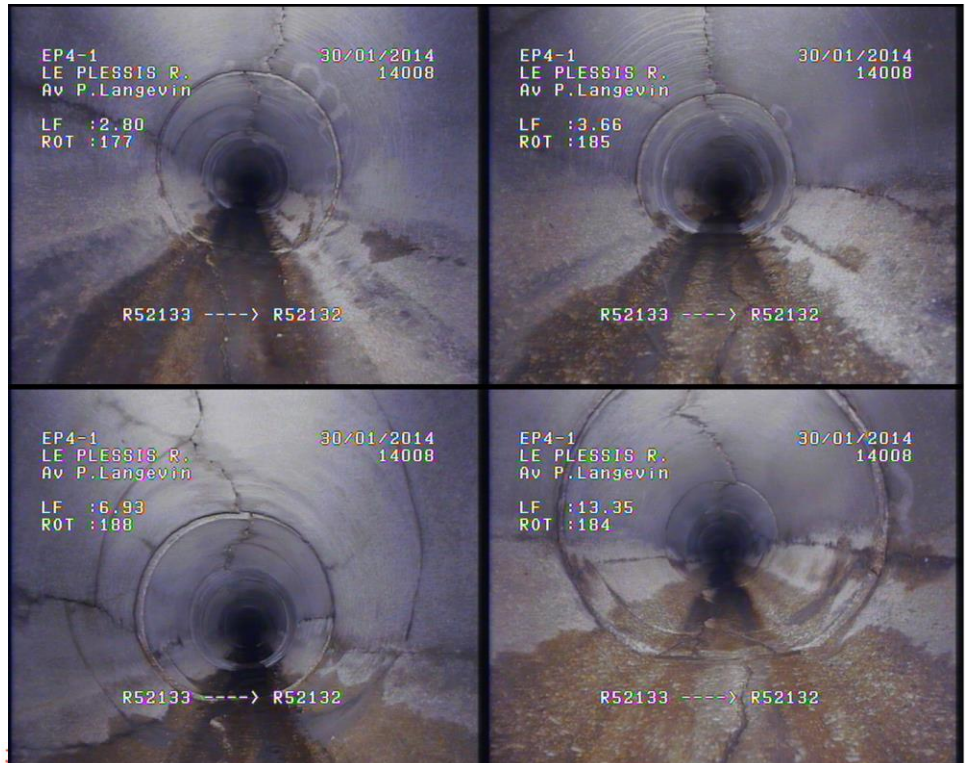




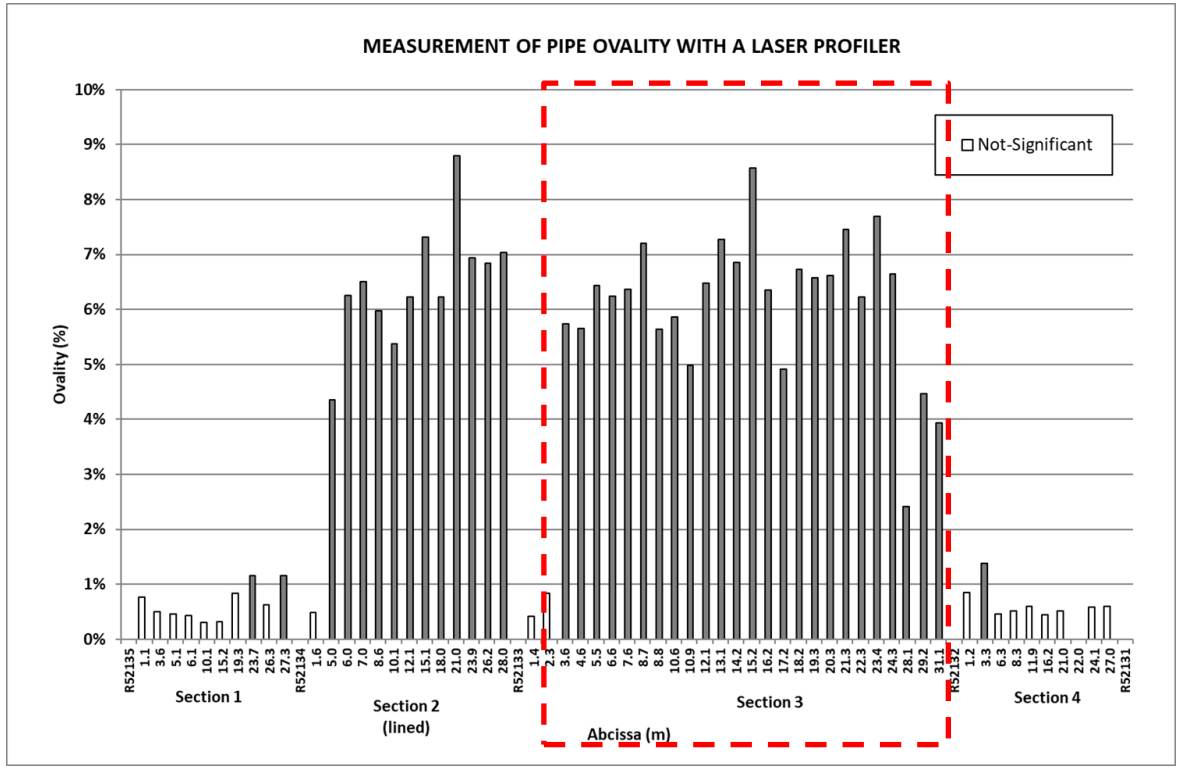
4-hinge ovality imperfection



- Ovality should not be “estimated” on video pictures, laser profiler should be used.

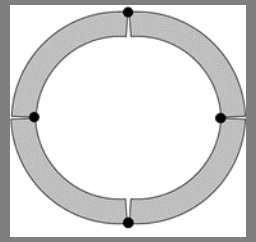


Video pictures of a DN 400 concrete pipe encountering four-point cracking failures

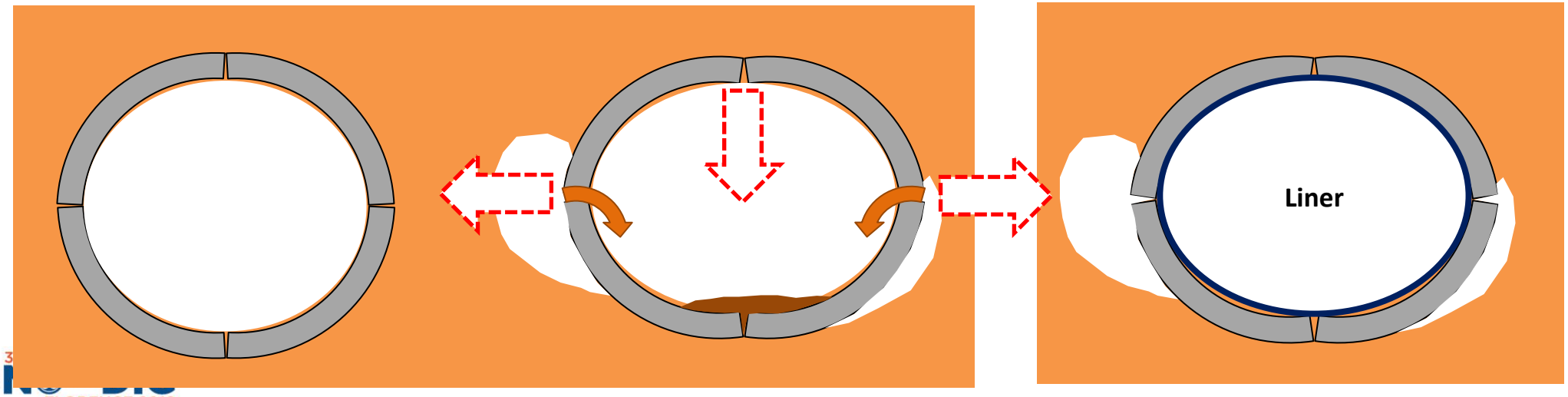


Ovality measurements made with a laser profiler in a concrete pipe DN 400.

4-hinge ovality imperfection

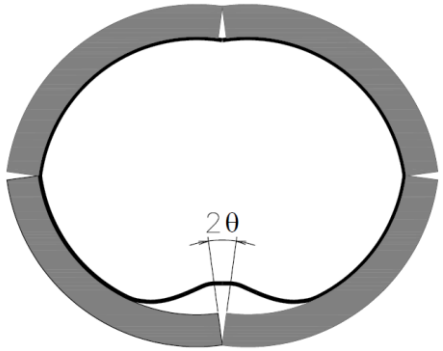


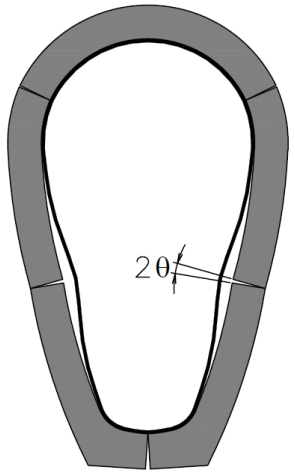
- **Soil erosion due to** water leakage or ingress is the main factor of ovality development.
- Erosion is generally stopped by installation of a liner.

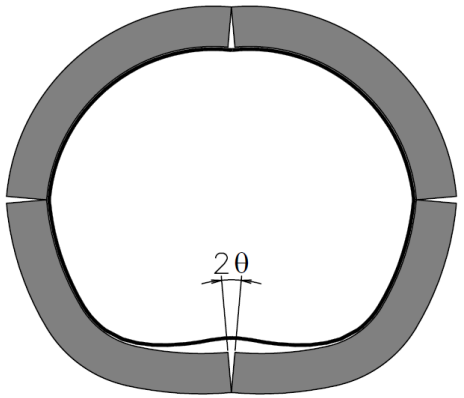


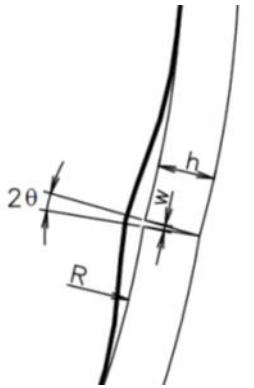
4-hinge ovality imperfection

- ASTEE 3R2014 design method deals with 4-hinge ovality by mean of a closed-form analytical solution.
- For non-circular linings, ovality is replaced by the rotation angle of the hinge formed by the fracture/crack.
- Analytical solution valid until 20% ovality / hinge rotation.





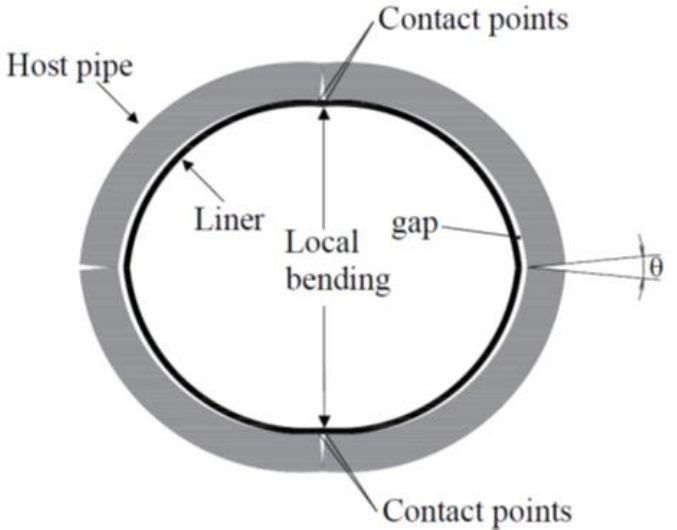




$$\theta = 0.5\frac{w}{h}$$

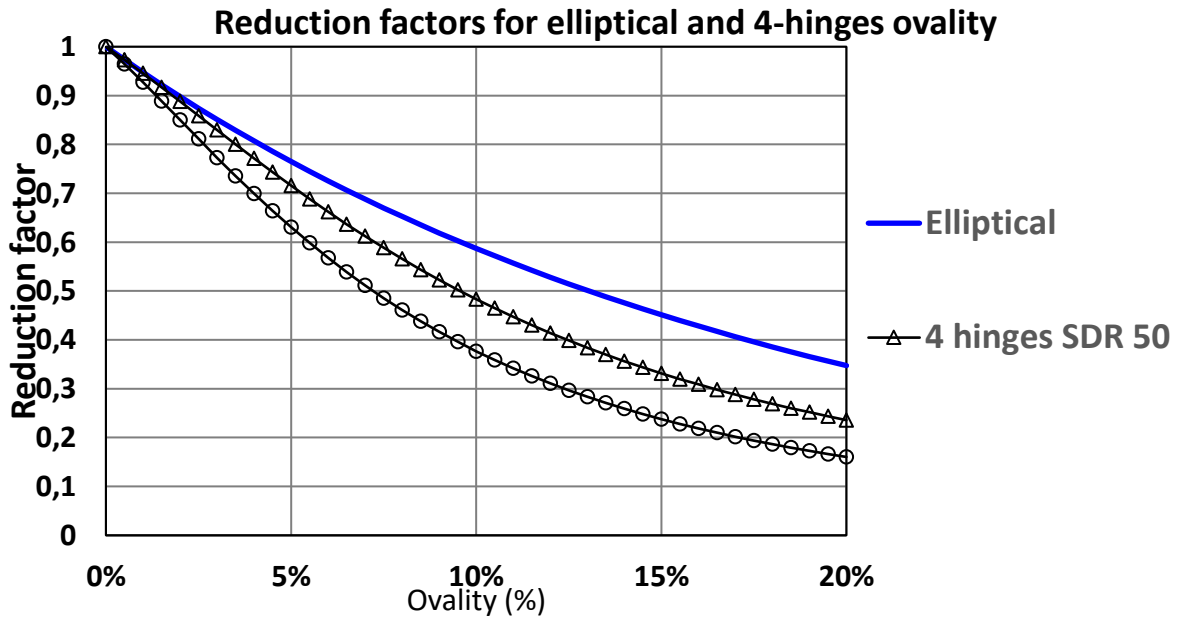
4-hinge ovality imperfection

- Fractures can still develop after linings ⇒ **deferred ovality**
- Deferred ovality may have 3 effects on a liner (Law and I.D. Moore) :
    1. Bending strain/stress at contact points ⇒ could be a problem for thick liners
    2. Gap at the interface ⇒ **decrease resistance to groundwater**
    3. Increase of total ovality ⇒ **decrease resistance to groundwater**
- Deffered ovality can be estimated or calculated.

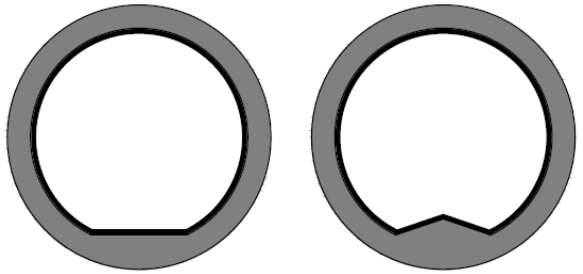


Elliptical ovality

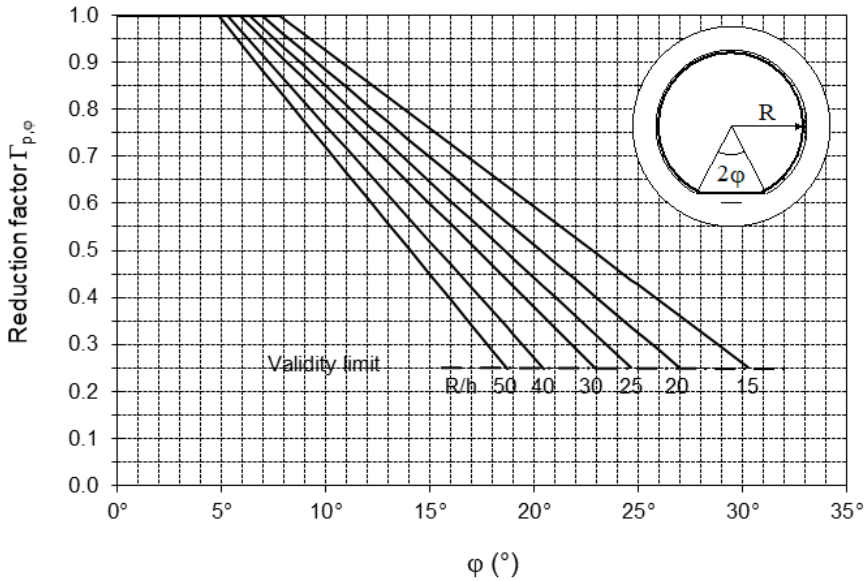
- Elliptical ovality ⇒ Flexible pipe
- Elliptical ovality ≠ 4-hinge ovality
- ASTM F1216: ovality = elliptical
- ASTEE 3R2014 : Elliptical and 4-hinge ovality are clearly distinguised.



Flattening and intrusions



- Protruding defects when these defects cannot be or will not be removed prior to lining.
- Example: Flattening due to hard deposit.
- ASTEE 3R2014 method deals with the effects of these defects.



Conclusions

- Close-fit liners restore hydraulic integrity and stop soil erosion, main cause of pipes failure.
- Close-fit liners do not carry soil or vehicule loads.
- Close-fit liners should be designed to resist groundwater pressure taking into account shapes, imperfections and deferred deflections.