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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 displacement, 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.

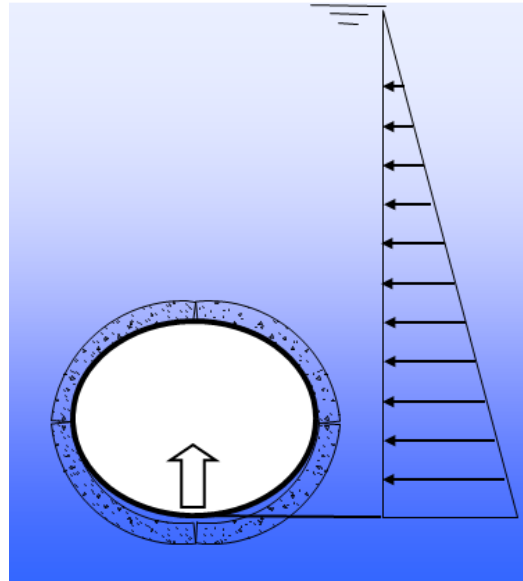
⇒ **Soil condition and water flow control displacements.**

# How close-fit liners really perform

- **Right conceptions:**
  - Groundwater pressure acts **directly** on the liner.
  - It is an imposed pressure  $\Rightarrow$  creep will increase deflection with time.
  - Groundwater pressure may lead to **buckling or unacceptable 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

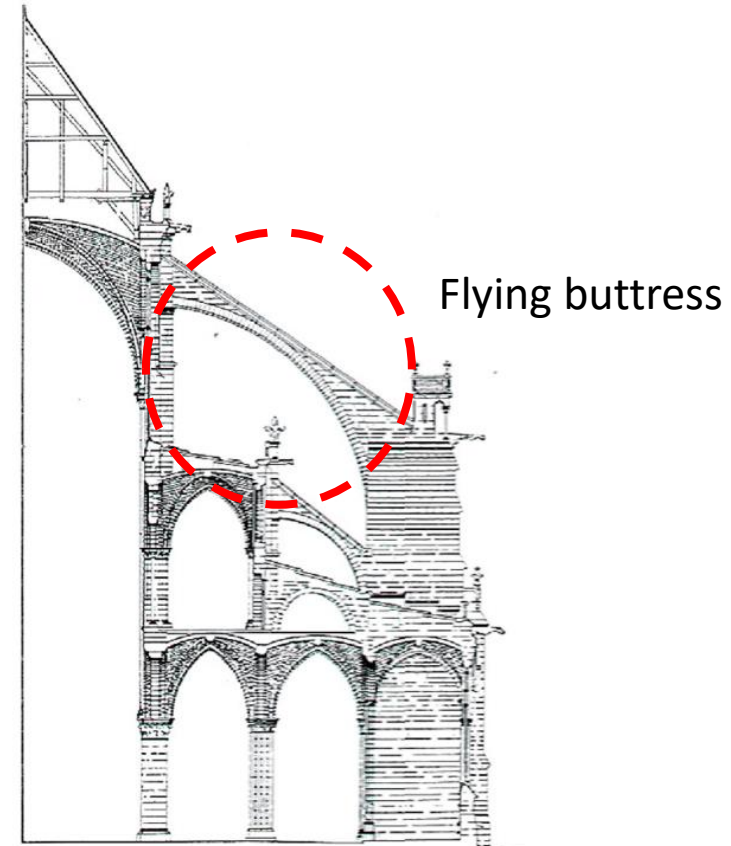
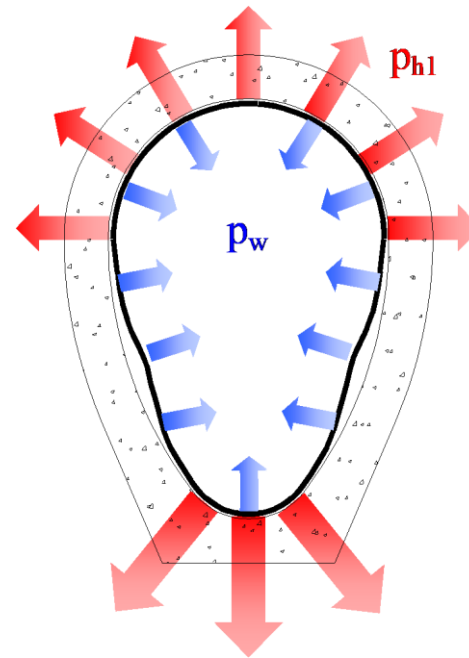
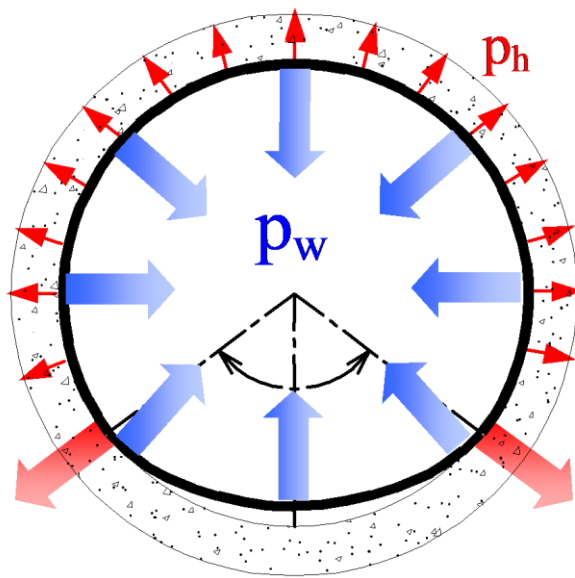
- Close-fit liners should be designed to resist only groundwater pressure, taking into account shapes, imperfections and imposed (deferred) deflections.





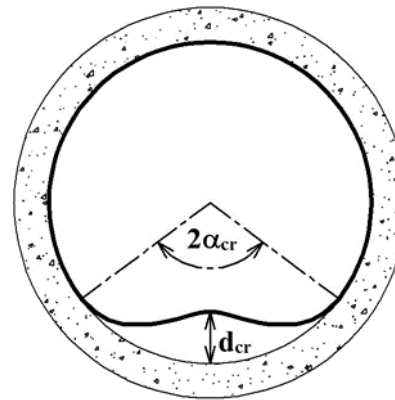
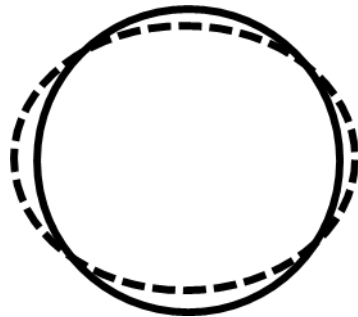
# Resistance to groundwater pressure

- 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.



Annular gap.



Flattening.



Intrusion.



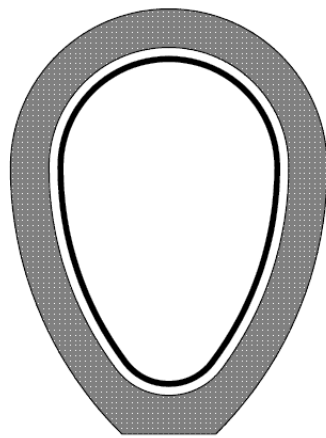
Ovality (4—hinge).



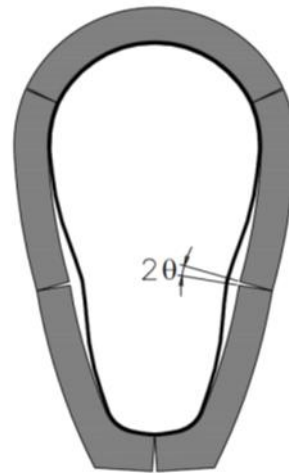
Ovality (elliptical).

# Imperfections

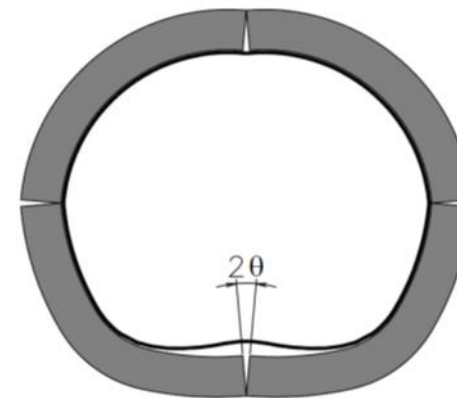
- Incidence of local imperfections on liner behavior may depend on their position, in contrast to global imperfections.
- ⇒ Open cracks in the arc where the lobe develops will have maximum effect.



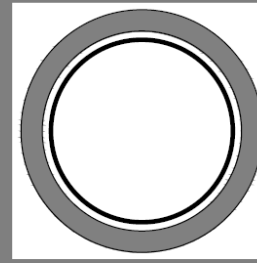
Annular gap



Hinge (fracture)



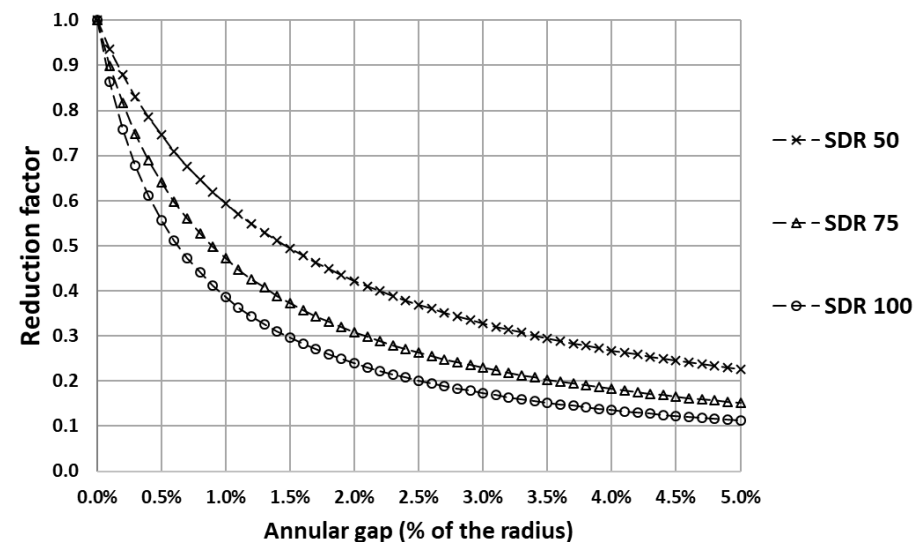
# Annular gap imperfection



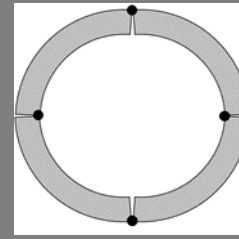
- Close-fit liners are designed to make full contact with the host pipe when installed and cured.
- The fit tolerance is typically 1 mm.
- Gap decreases dramatically the resistance to external groundwater.
- Minimum value for design:  $g = 0.5\%$  of the radius limited to 1 to 2 mm (may also cover gap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



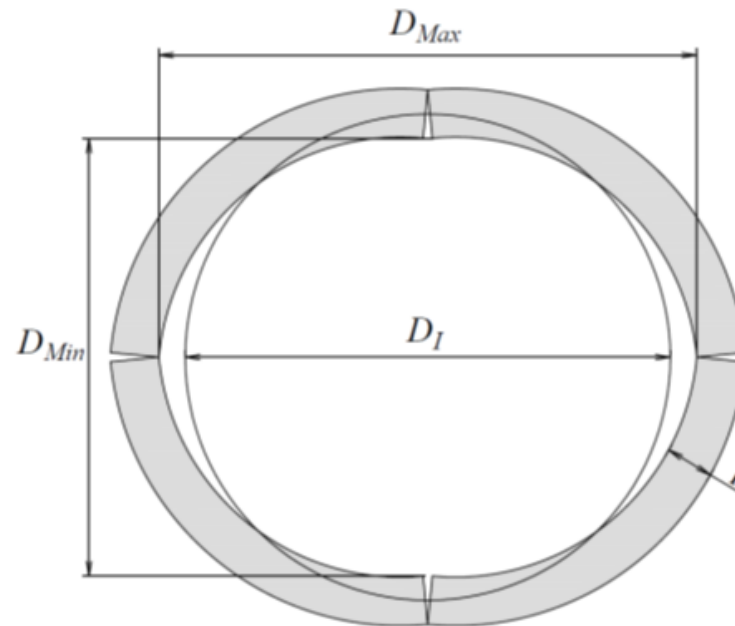
Credit: U.S. Environmental Protection Agency



# 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!

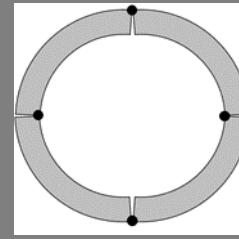


$$Ov1 = \frac{(D_{Max} - D_{Min})}{(D_{Max} + D_{Min})}$$

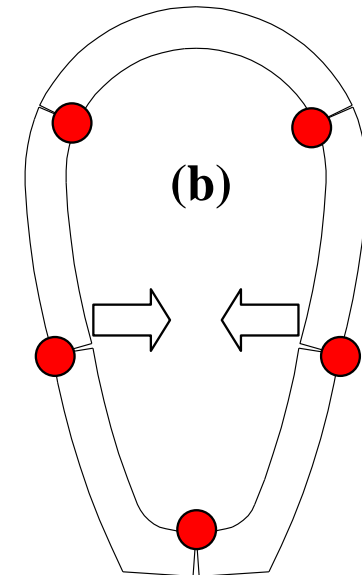
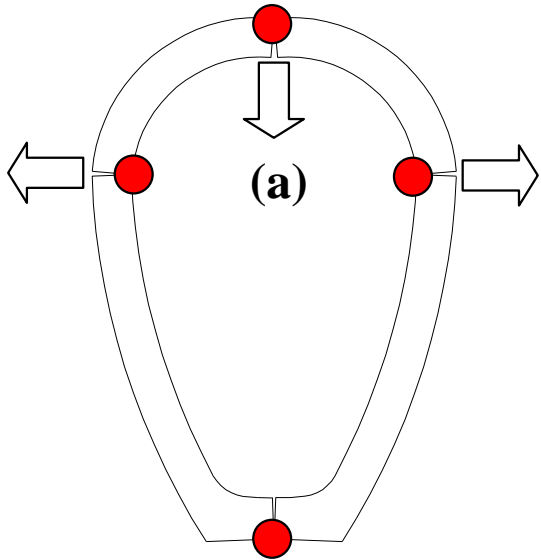
$$Ov2 = \frac{(D_{Max} - D_I)}{D_I}$$

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

# 4-hinge ovality imperfection

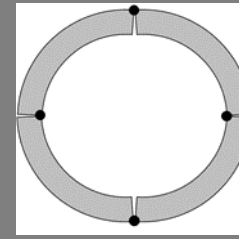


- 4-hinge ovality does exist for non-circular pipes.
- Ovality is replaced by **hinge rotation**.

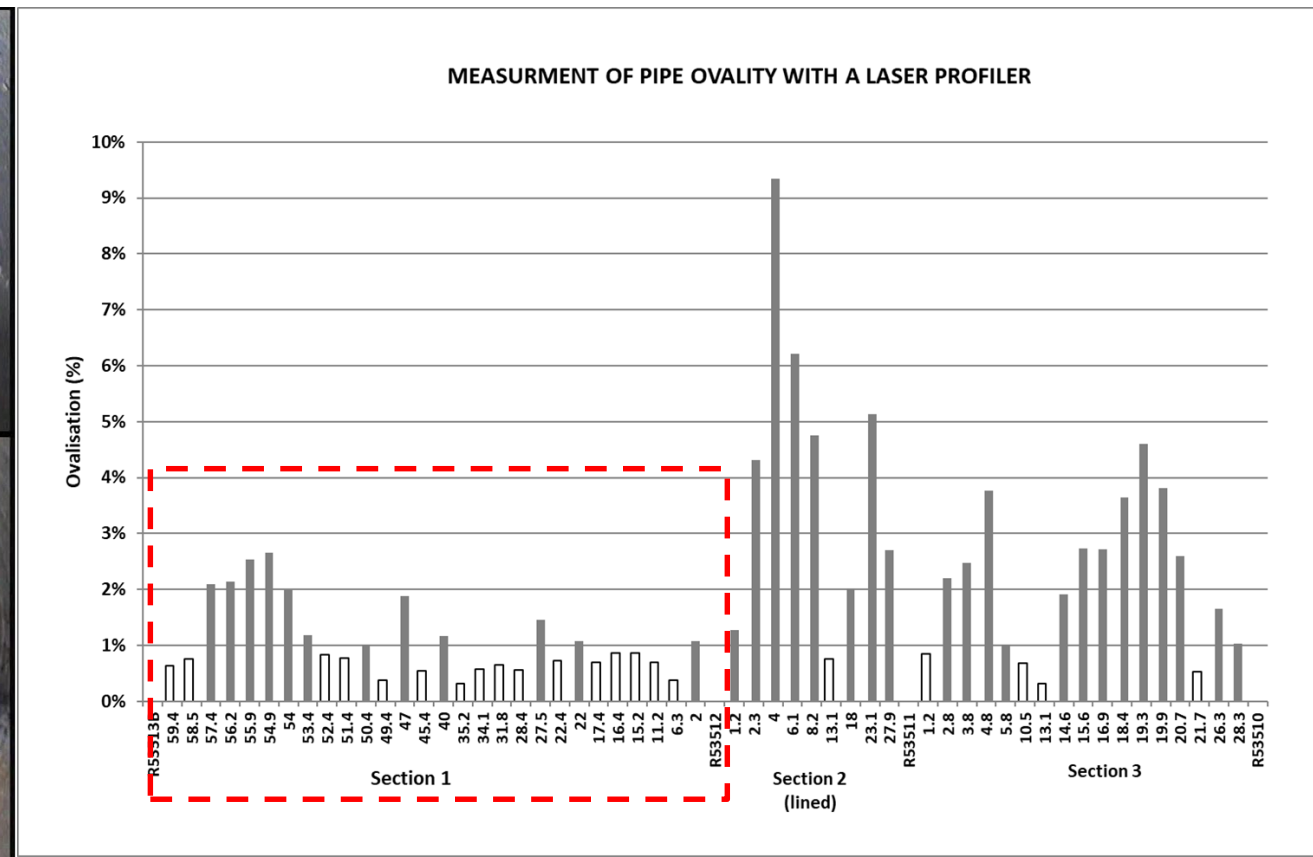
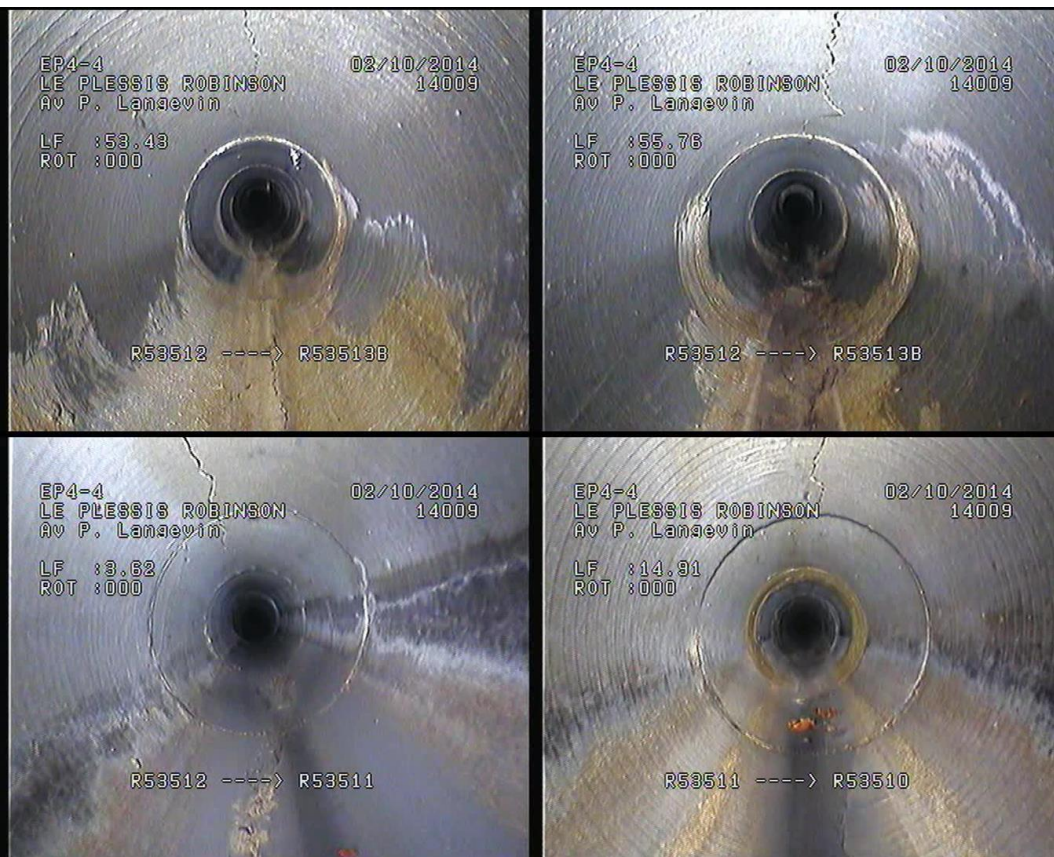




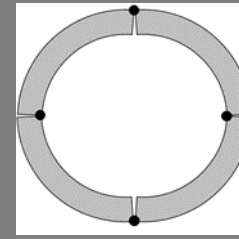
# 4-hinge ovality imperfection



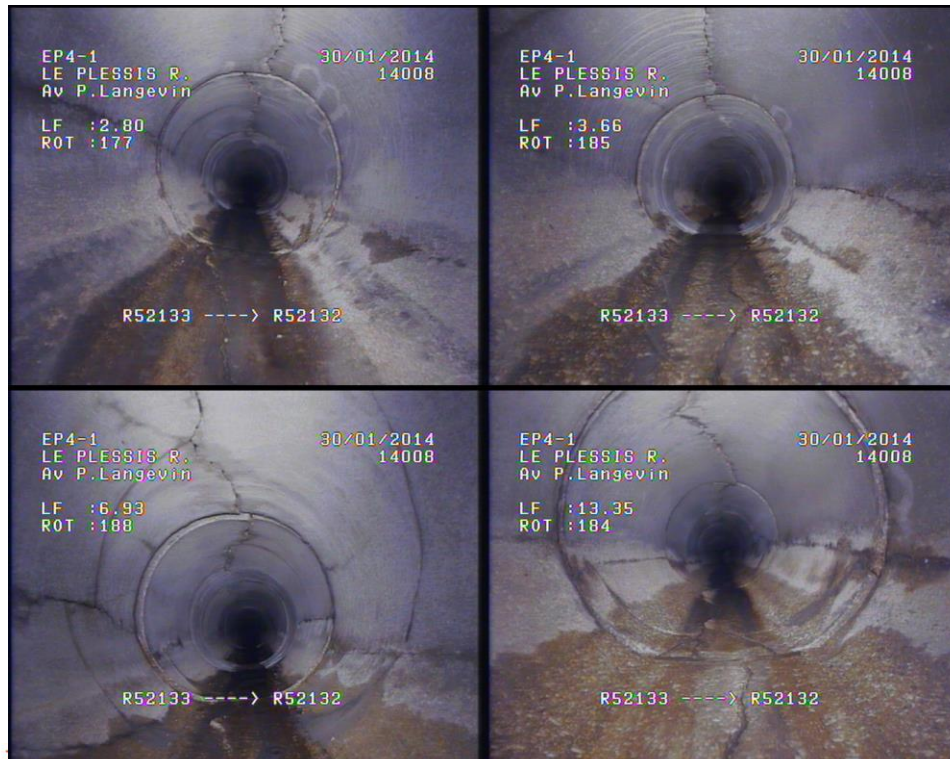
- At the beginning of the process ovality is often rather weak, less than 2%.



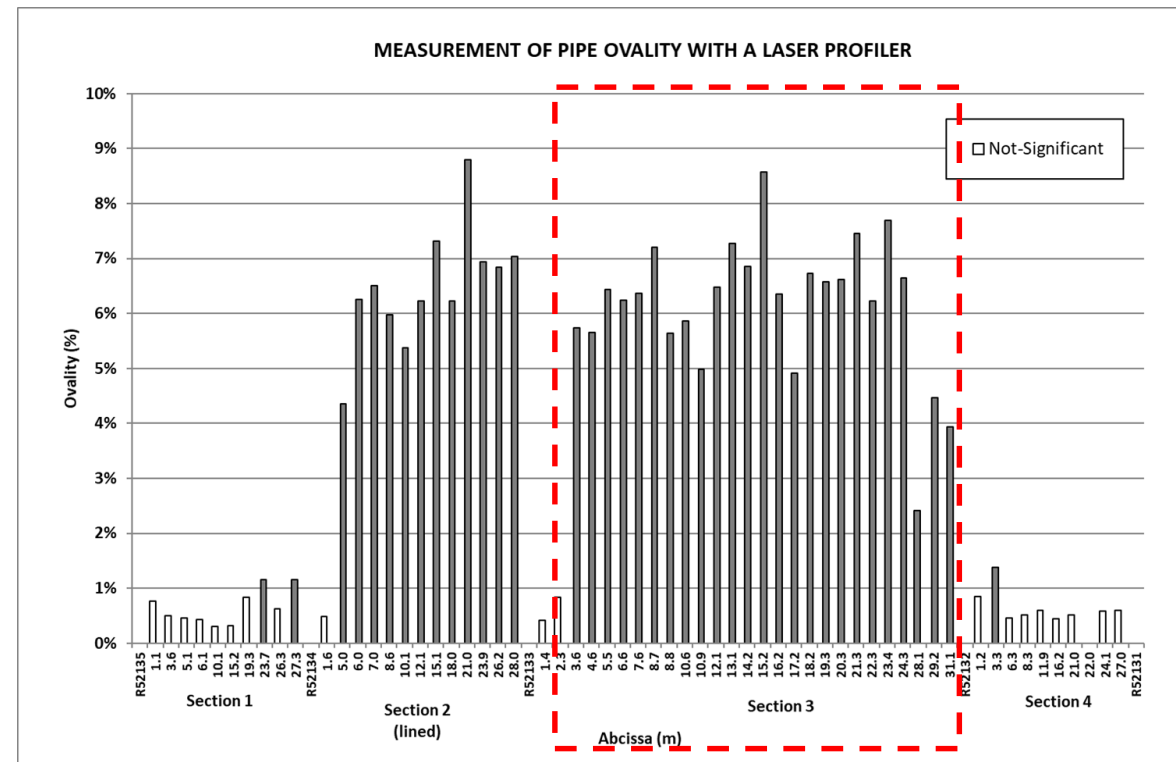
# 4-hinge ovality imperfection



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



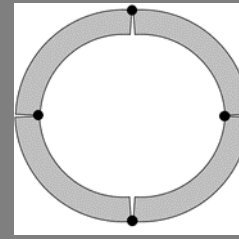
Video pictures of a DN 400 concrete pipe encountering four-point cracking failures



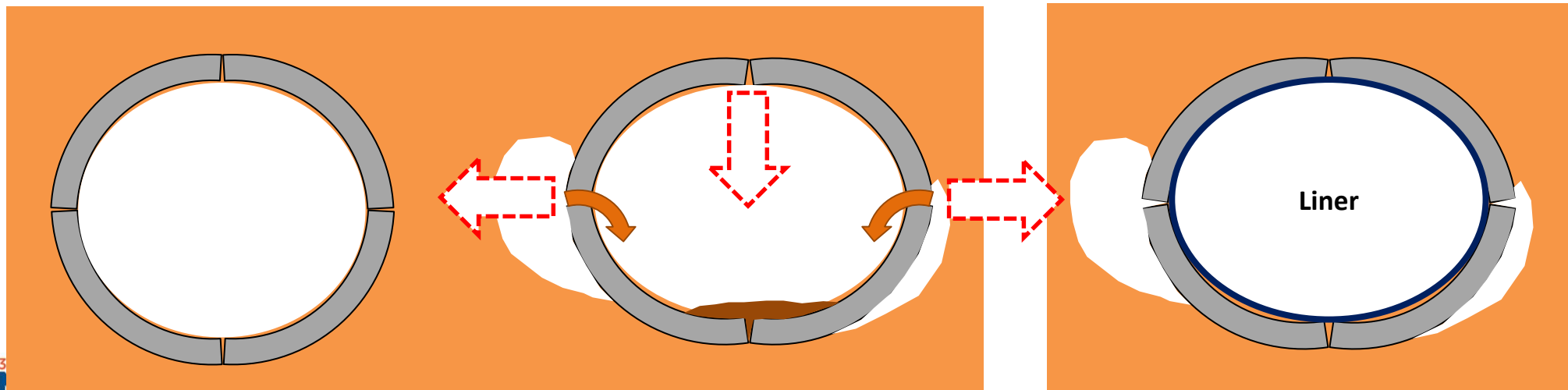
Ovality measurements made with a laser profiler in a concrete pipe DN 400.



# 4-hinge ovality imperfection

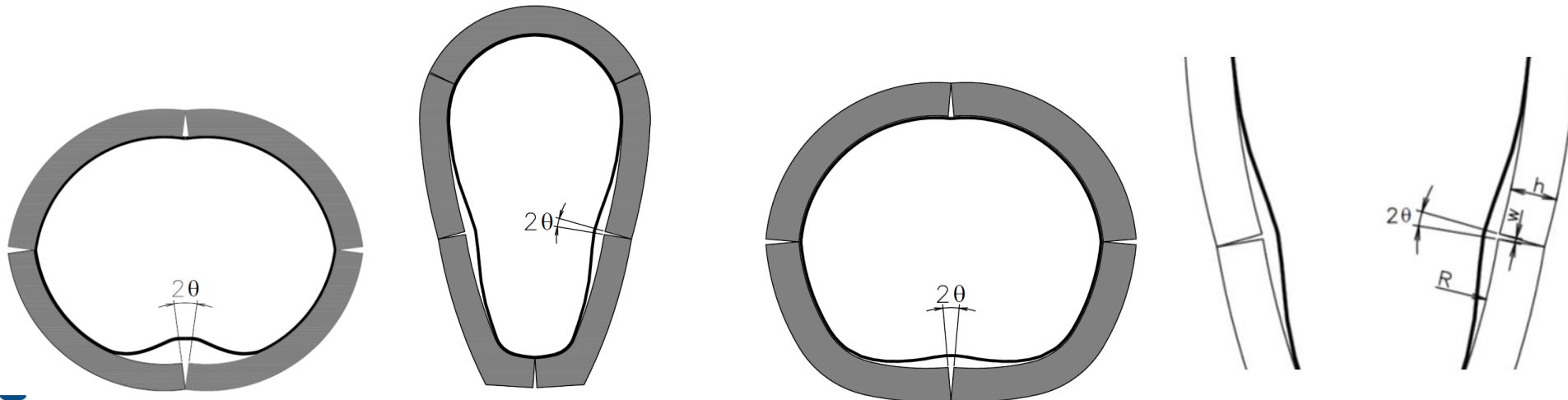


- **Soil erosion due to** water leakage or ingress is the main factor of ovality development.
- Erosion is generally stopped by installation of a liner.



# 4-hinge ovality imperfection

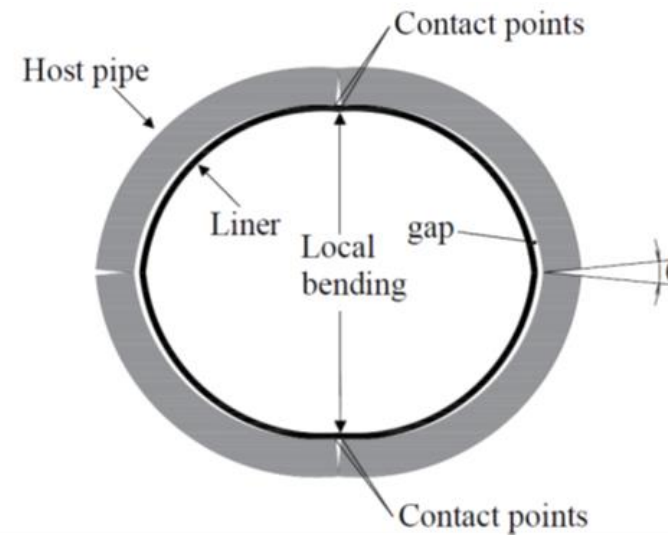
- ASTEE 3R2014 design method deals with 4-hinge ovality by mean of a closed-form analytical solution.
- For non-circular linings, ovality is replaced by the rotation angle of the hinge formed by the fracture/crack.
- Analytical solution valid until 20% ovality / hinge rotation.



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

# 4-hinge ovality imperfection

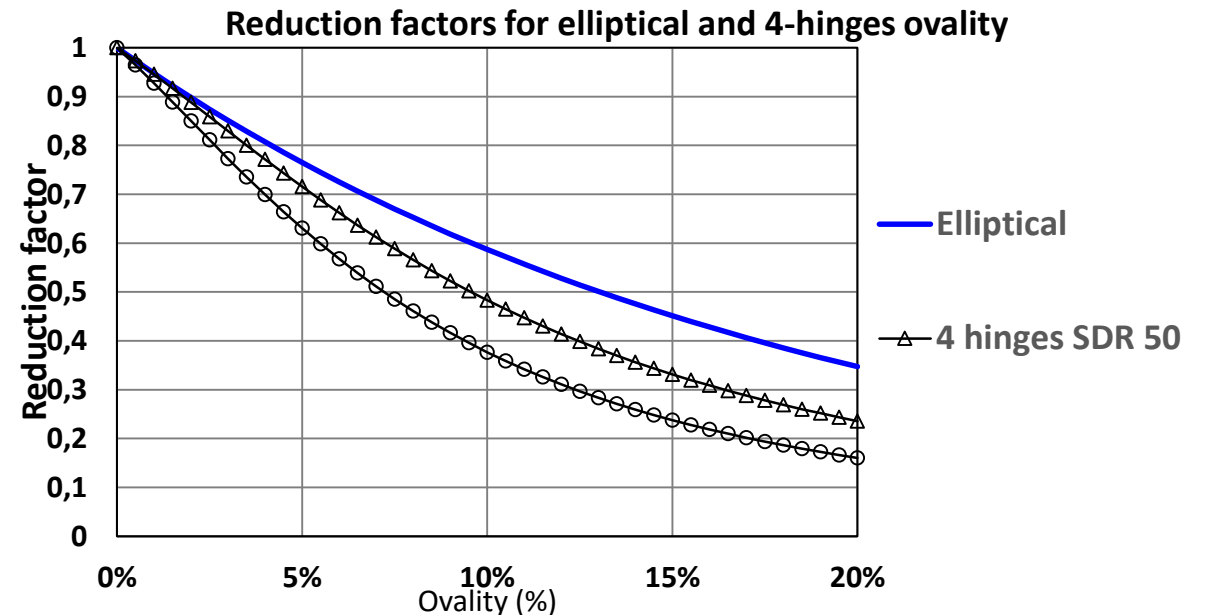
- Fractures can still develop after linings  $\Rightarrow$  **deferred ovality**
- Deferred ovality may have 3 effects on a liner (Law and I.D. Moore) :
  1. Bending strain/stress at contact points  $\Rightarrow$  could be a problem for thick liners
  2. Gap at the interface  $\Rightarrow$  **decrease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



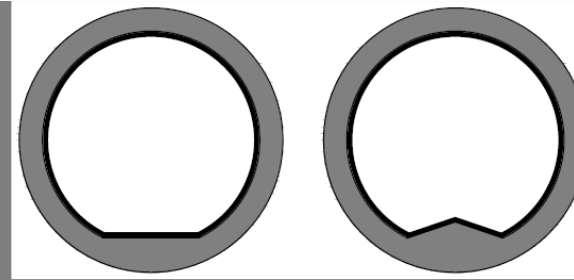
# Elliptical ovality



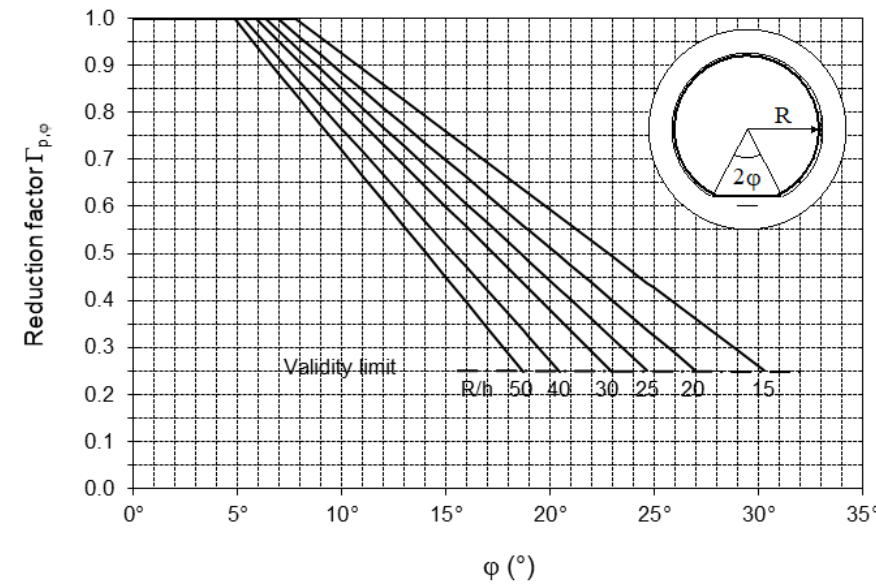
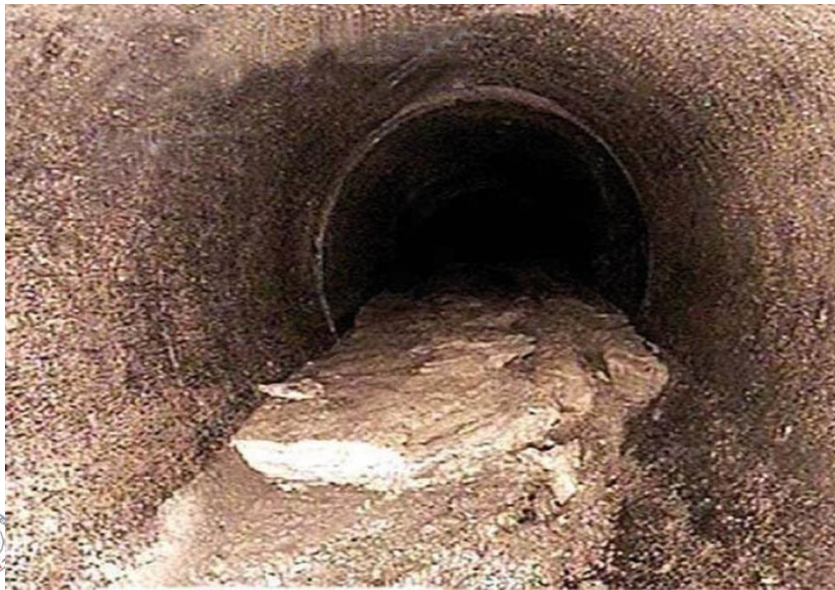
- Elliptical ovality  $\Rightarrow$  Flexible pipe
- Elliptical ovality  $\neq$  4-hinge ovality
- ASTM F1216: ovality = elliptical
- ASTEE 3R2014 : Elliptical and 4-hinge ovality are clearly distinguished.



# 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.