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**Lining procedures and limit states for
structural design**

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Summary

1. Stability of existing culverts
2. Lining procedures
3. Liner strength limits
 - External fluid pressure
 - External earth pressure and vehicle live loads
4. References

Stability of existing culverts : structure



Metal Culvert: Invert and waterline corrosion



Rigid pipe: Longitudinal fractures: excess moment

Deterioration characteristics are different for rigid & flexible culverts and so are the effects of the damage

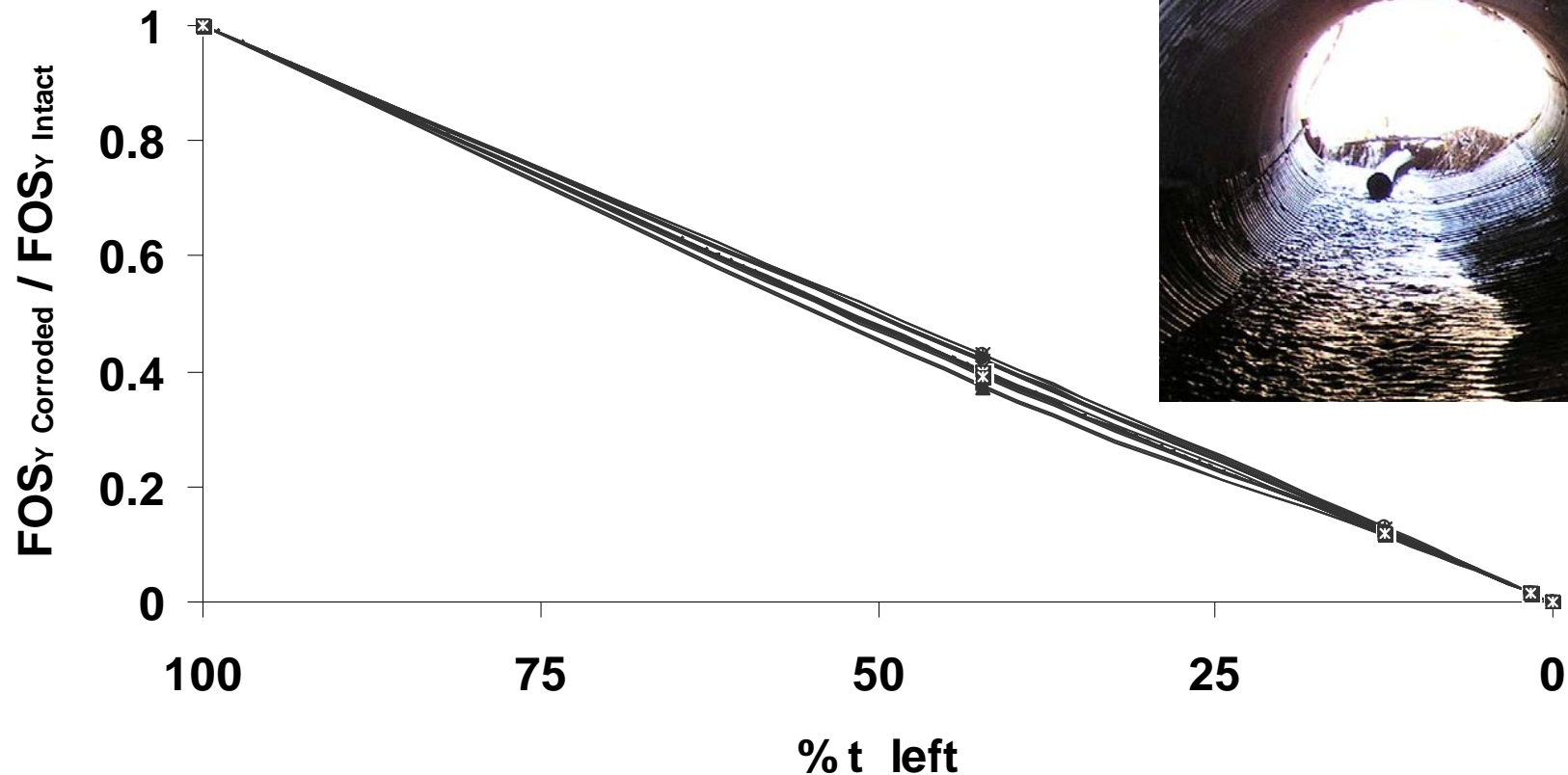
Stability of existing culverts : erosion



Perforations or fractures allow water ingress and this can lead to soil erosion.

Voids generally occur at the springline and they jeopardize both rigid and flexible culverts.

Metal culvert deterioration

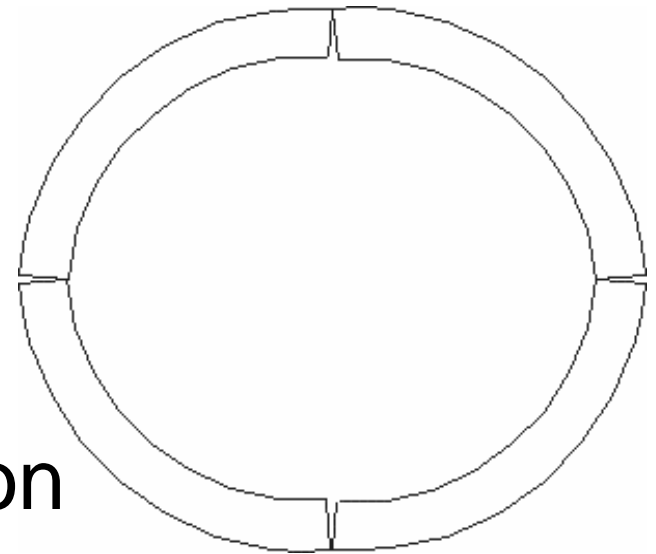


El Taher and Moore (2008) : stability against yield (wall crushing) - decreases in proportion to loss of wall thickness (if zero soil erosion)

Rigid culvert deterioration

e.g. Concrete Pipe Culvert

- i Joint leakage – ingress of groundwater
- ii Erosion of backfill
- iii Less uniform soil support
- iv Increased moments :
fracture accelerates erosion



Tan and Moore (2007) and Moore (2008) indicate that deformations infer the level of soil erosion

2. Lining procedures

- **Slip-lining** (insert preformed pipe & grout)
- **Cast in place pipe liner** (resin-impregnated tube pulled into place, inflated and cured)
- **Strip-winding** (form tube in-place by helically winding a strip, & grout)
- **Tunnel lining** (assemble from plates etc)
- **Sprayed linings** (concrete or polymers) and others (sewer processes) : fold and form (a.k.a. deform-reform), swage-lining etc.

Lining procedures : Slip lining



Use any preformed pipe (metal, polymer, ...)

Lining procedures : Cast-in-place lining

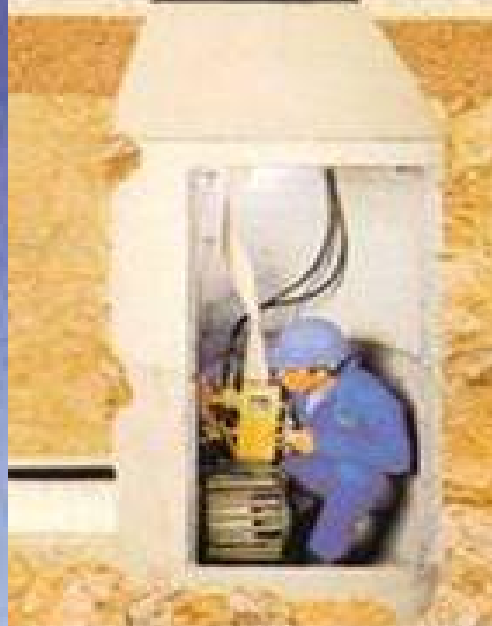
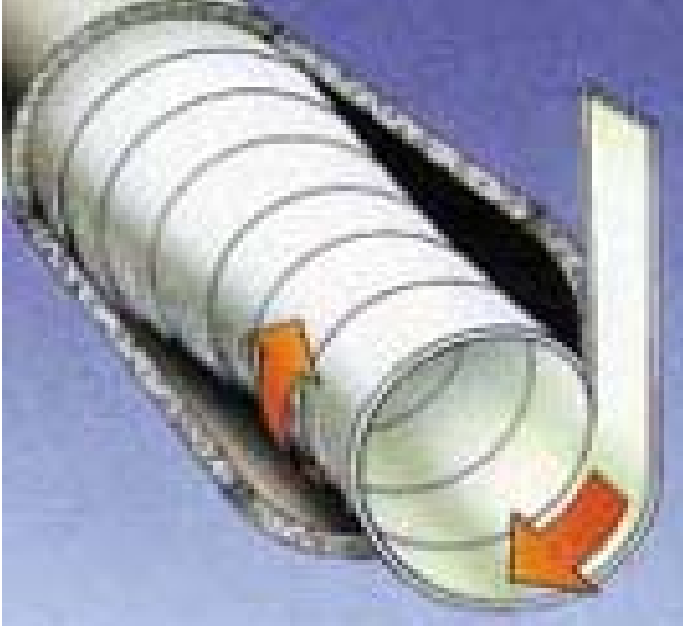


Felt impregnated with epoxy or other resin

Hot water, steam, or UV light cured

Circular prismatic shapes easy; new techniques permit non-circular and variable diameter liners

Lining procedures : Strip-wound lining



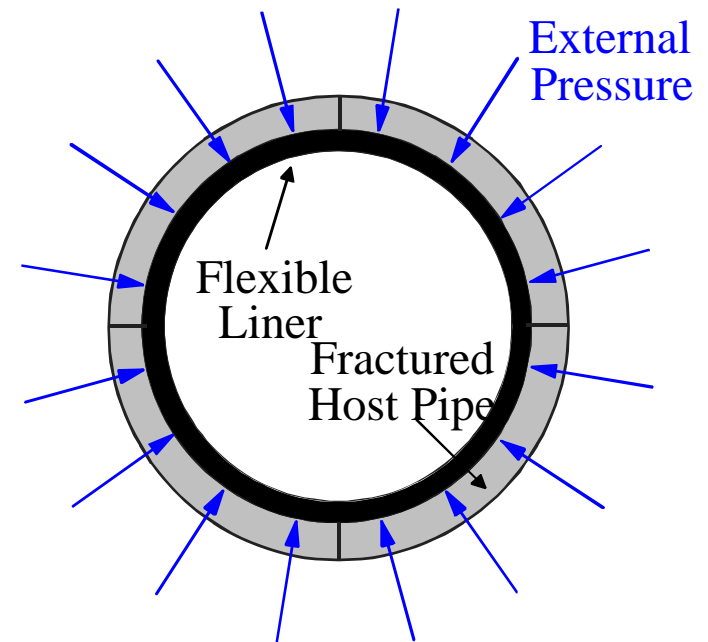
Polymer strips
welded, glued or
locked together
Grout or reverse
wind to treat gap

3. Liner strength limits

Two dominant loads (“demands”)

1. External fluid loads

- water in embankment after high-water event
- grout during construction

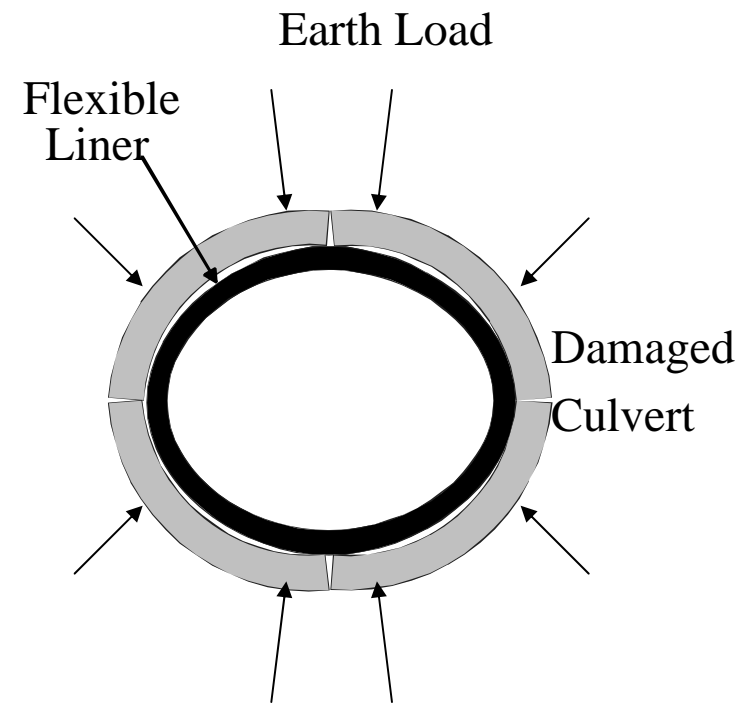


3. Liner strength limits

Two dominant loads (“demands”)

2. External earth loads

- overburden pressure changes after lining
- vehicle loads

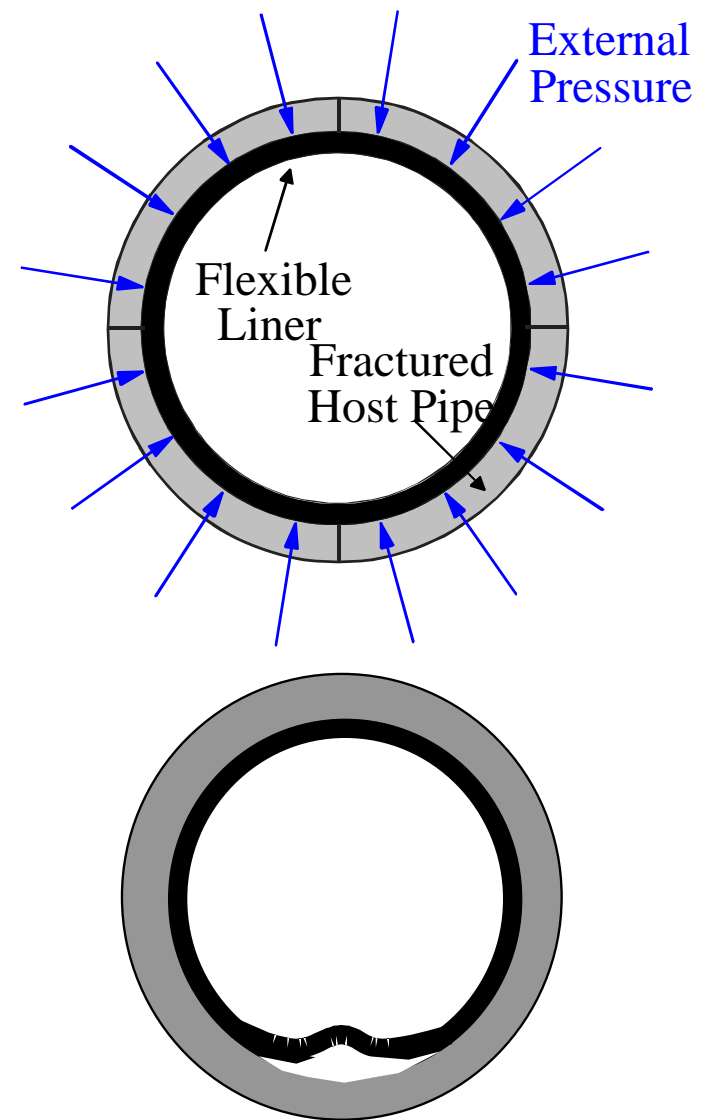


3. Liner strength limits

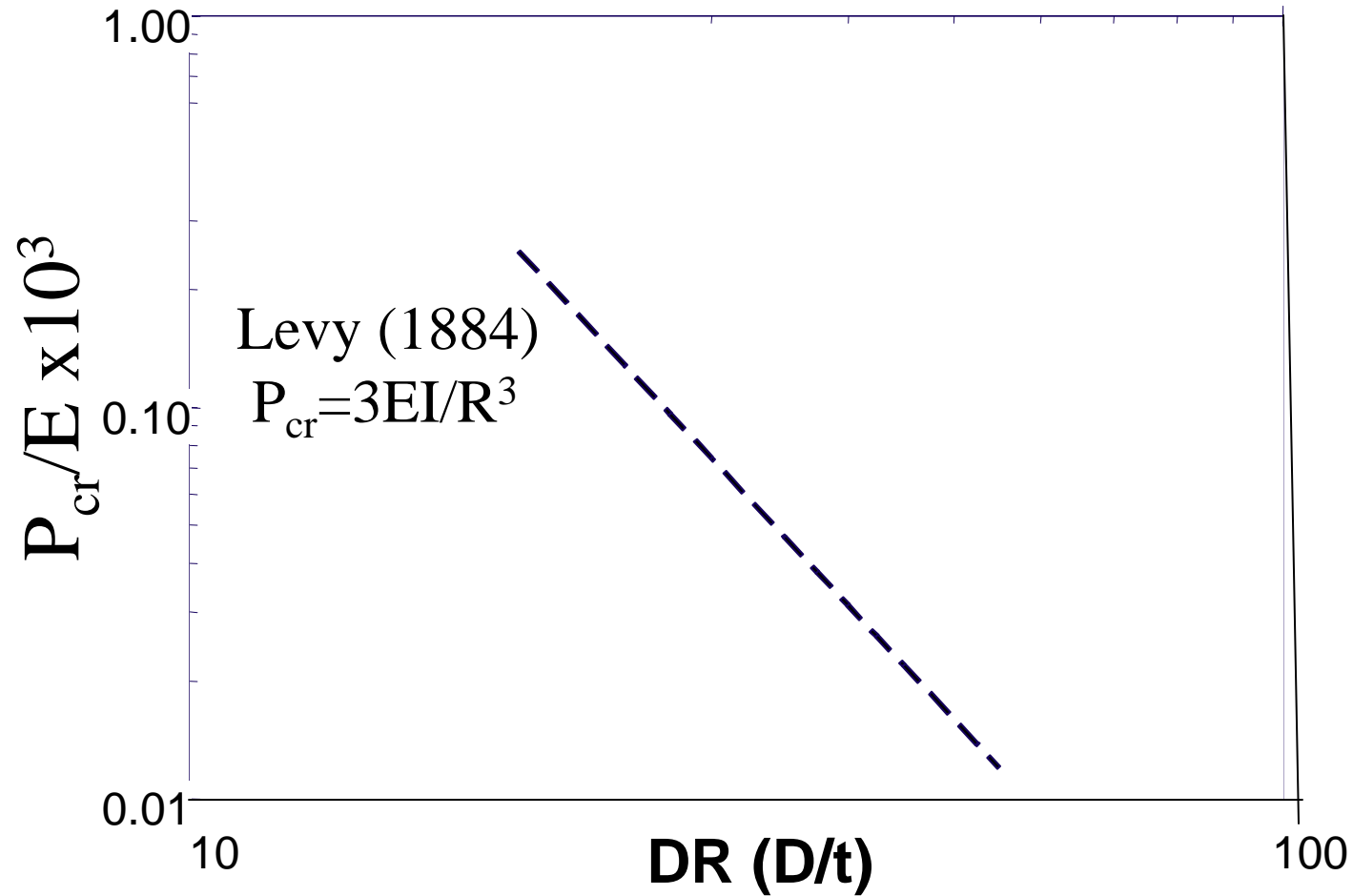
Resistance

1. External fluid loads
(water or grout)

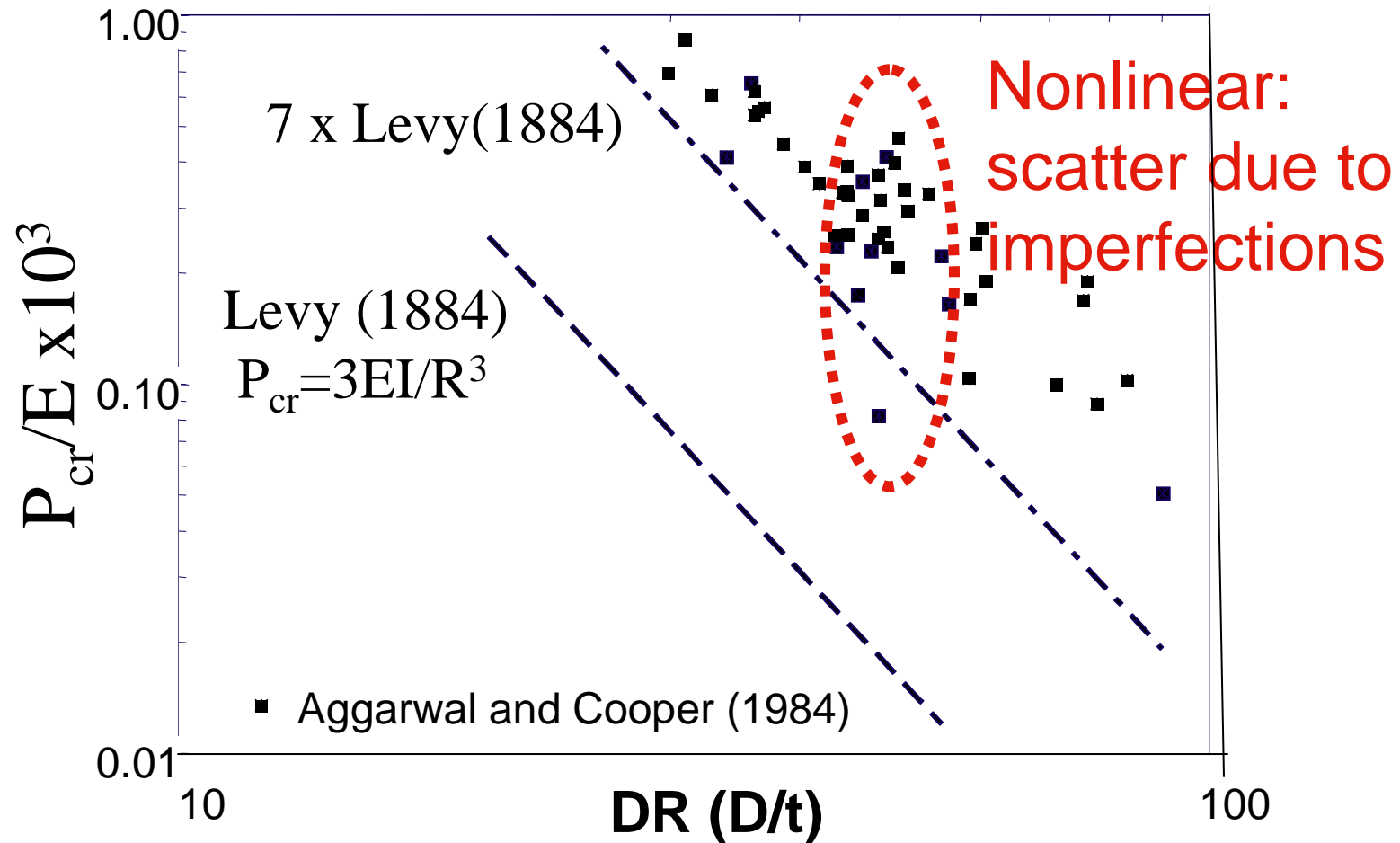
> Controlled by
buckling strength



Buckling of cylinder under external pressure



Comparison with experiments

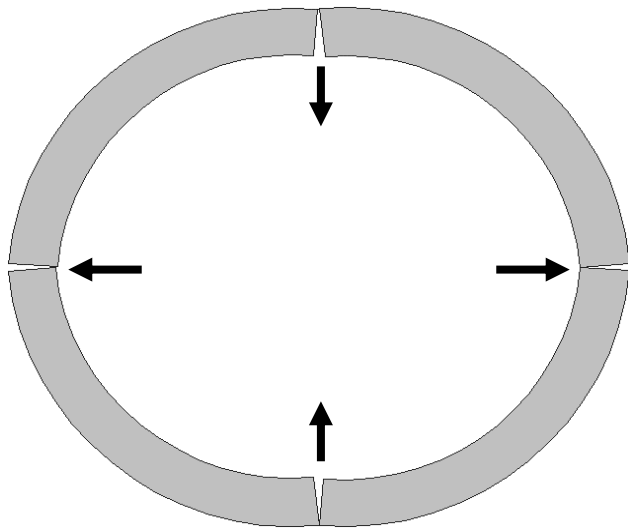


Old pipe increases stability – CIPP: ASTM F1216

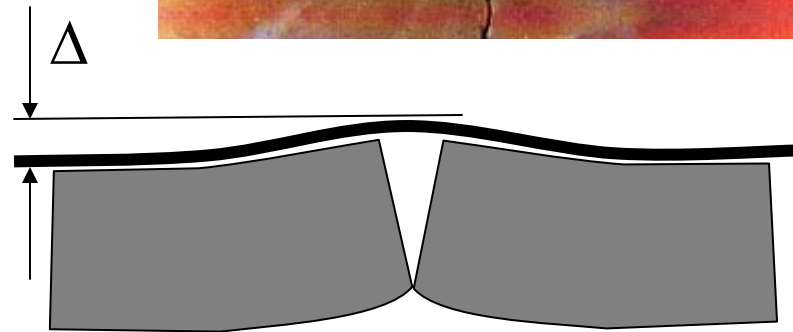
Effect of fractured pipe imperfections

ASTM F1216 proposal
Moore (2005,2008)

$$P_{cr} = E (t/D)^{2.2} R_q R_{\Delta}$$

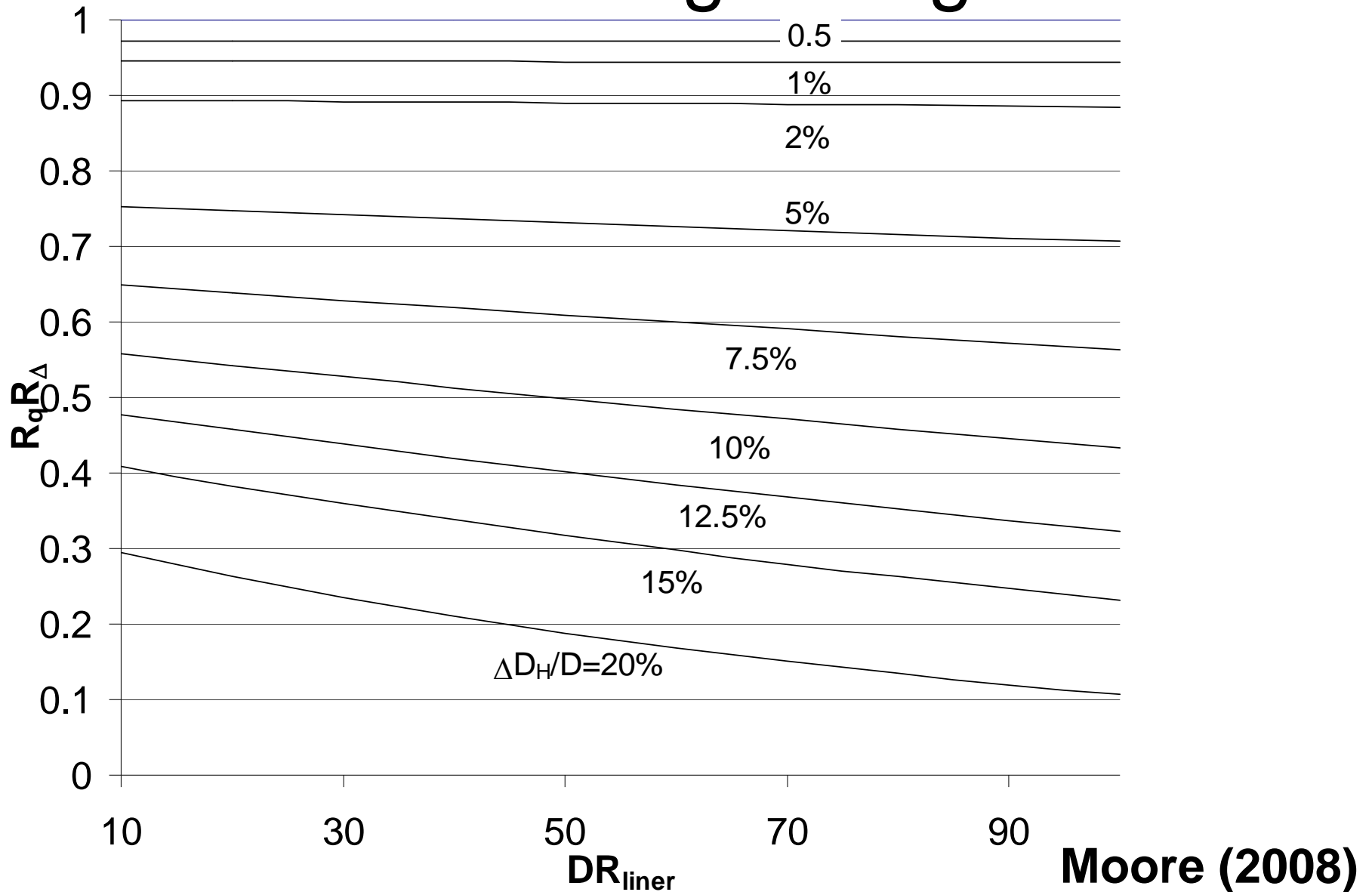


OVALITY R_q : *noncircular shape of fractured pipe*



WAVINESS R_{Δ} : *liner waviness over invert*

Effect of rigid pipe deformation on liner buckling strength



3. Liner strength limits

Resistance

2. External earth loads

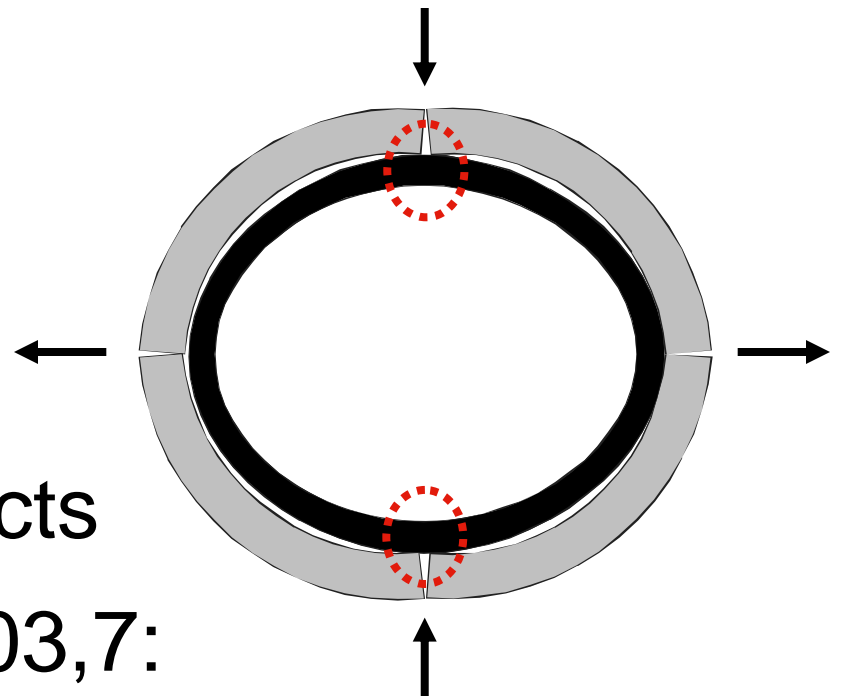
> Controlled by local effects

(e.g. Law and Moore, 2003,7:

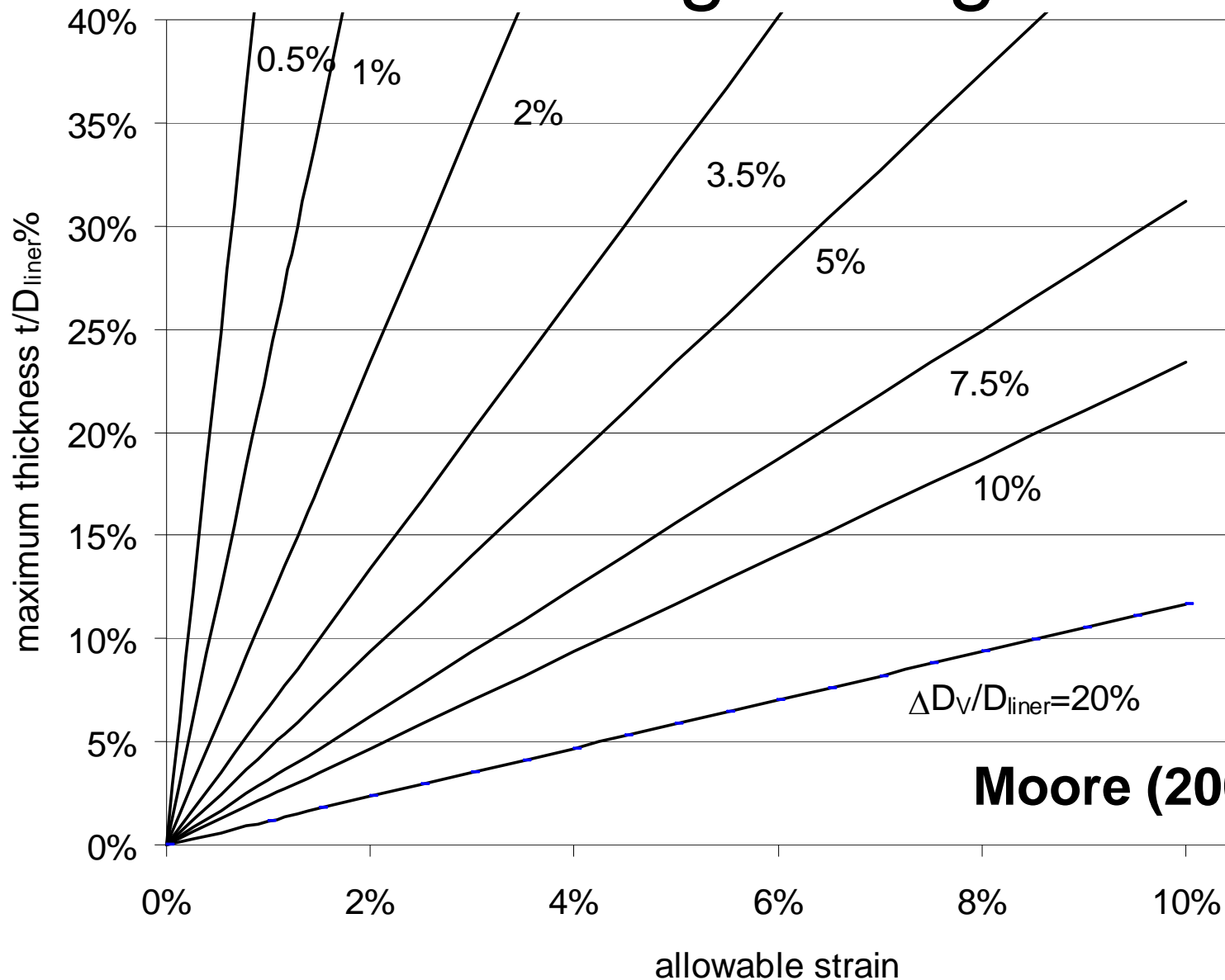
bending in liner deforming within rigid pipe:

vertical diameter decrease after repair) – not

conservative designing liner as ‘new pipe’



Effect of rigid pipe deformation: liner bending strength



Moore (2008)

3. Liner strength limits

Resistance – rigid pipe culverts

Choice of liner thickness

t_{\min} to resist buckling <

t selected <

t_{\max} to resist bending after installation

NCHRP 14-19

“Culvert Rehabilitation to Maximize Service Life
While Minimizing Direct Costs and Traffic Disruption”

Relevant tasks

- Verify strength of deteriorated culverts
- Develop culvert assessment guide
- Establish earth load effects on liners in metal culverts and concrete boxes
- Develop culvert repair guide

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