ASCE MOP NO. 145 – DESIGN OF CLOSE-FIT LINERS FOR REHABILITATION OF GRAVITY PIPES

Presented By
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ASCE Task Group Chairman

- Growing beyond the ASTM non-mandatory Design Appendix X1 for circular pipe shapes to designing for *all* shapes of gravity pipes

  - Circular
  - Egg Shapes
  - Elliptical
  - Pipe Arch Shapes
  - Arch Topped Box Shapes
  - Box Shaped Pipes

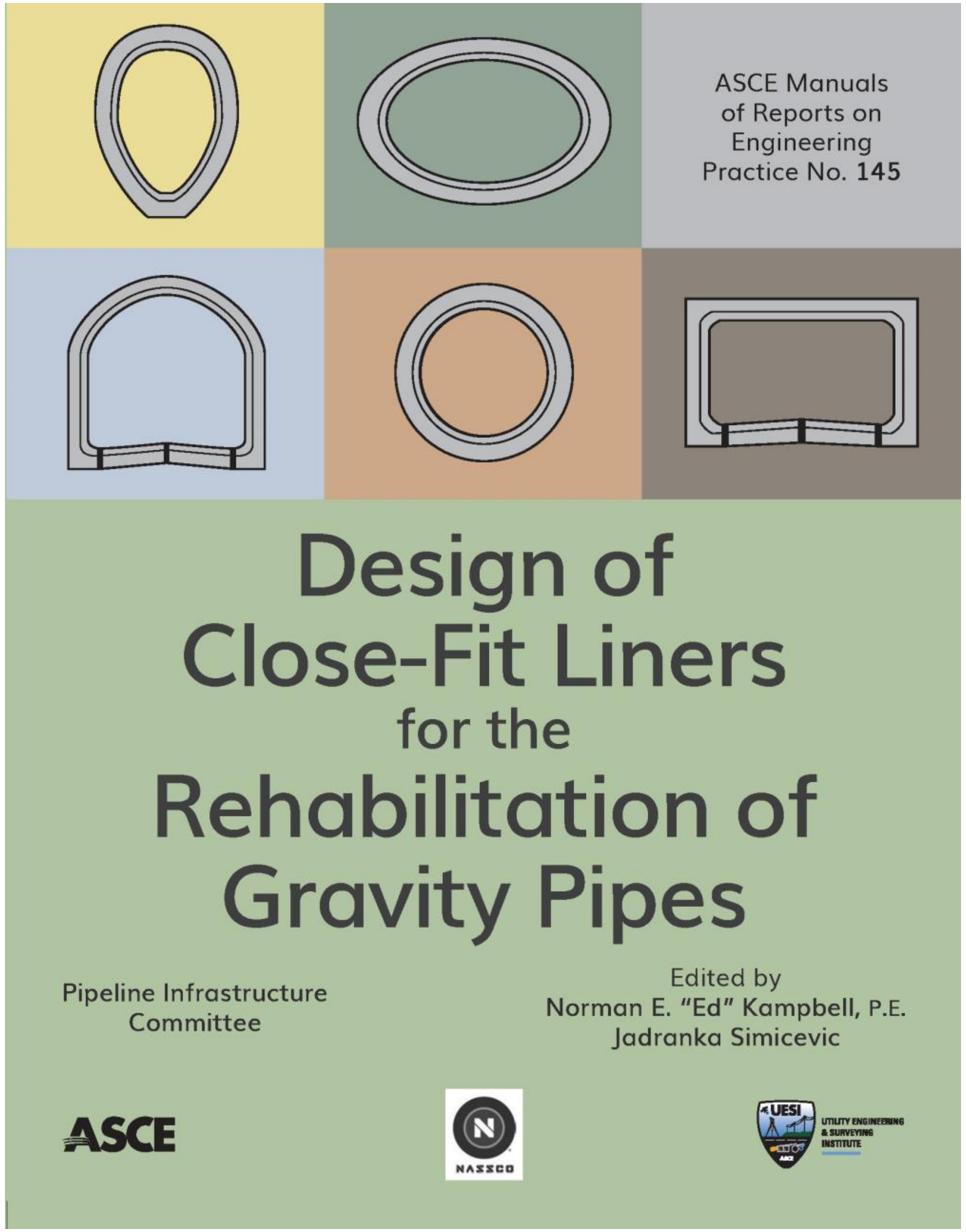


Table of Contents in the MOP No. 145

LRFD vs ASD – MOP uses Load Resistance Factor Design versus Allowable Stress Design

LRFD gives the designer the ability to address the variability of the loading on the liner as well as the liner's ability to provide resistance to that loading. It is more conservative as it allows the designer to place proper emphasis on the individual components of the uncertainty of the loading and the in situ achieved material strengths…

The Evolution of Liner Design

- Constrained vs Un-Constrained Buckling
  - Timoshenko’s solution
  - Glock’s solution
- Hoop Strength of Rigid Pipes after fracturing occurs
- Load Transfer in the Soil
  - In an Initial Burial Condition of the Pipe
  - In a Mature Burial Condition at Lining

Committee Report

ASCE American Society of Civil Engineers

ASCE

Pipeline Division

Pipeline Infrastructure (PINS) Task Committee

American Society of Civil Engineers

Emerging Concepts for the Design of Pipeline Renewal Systems

June 2007

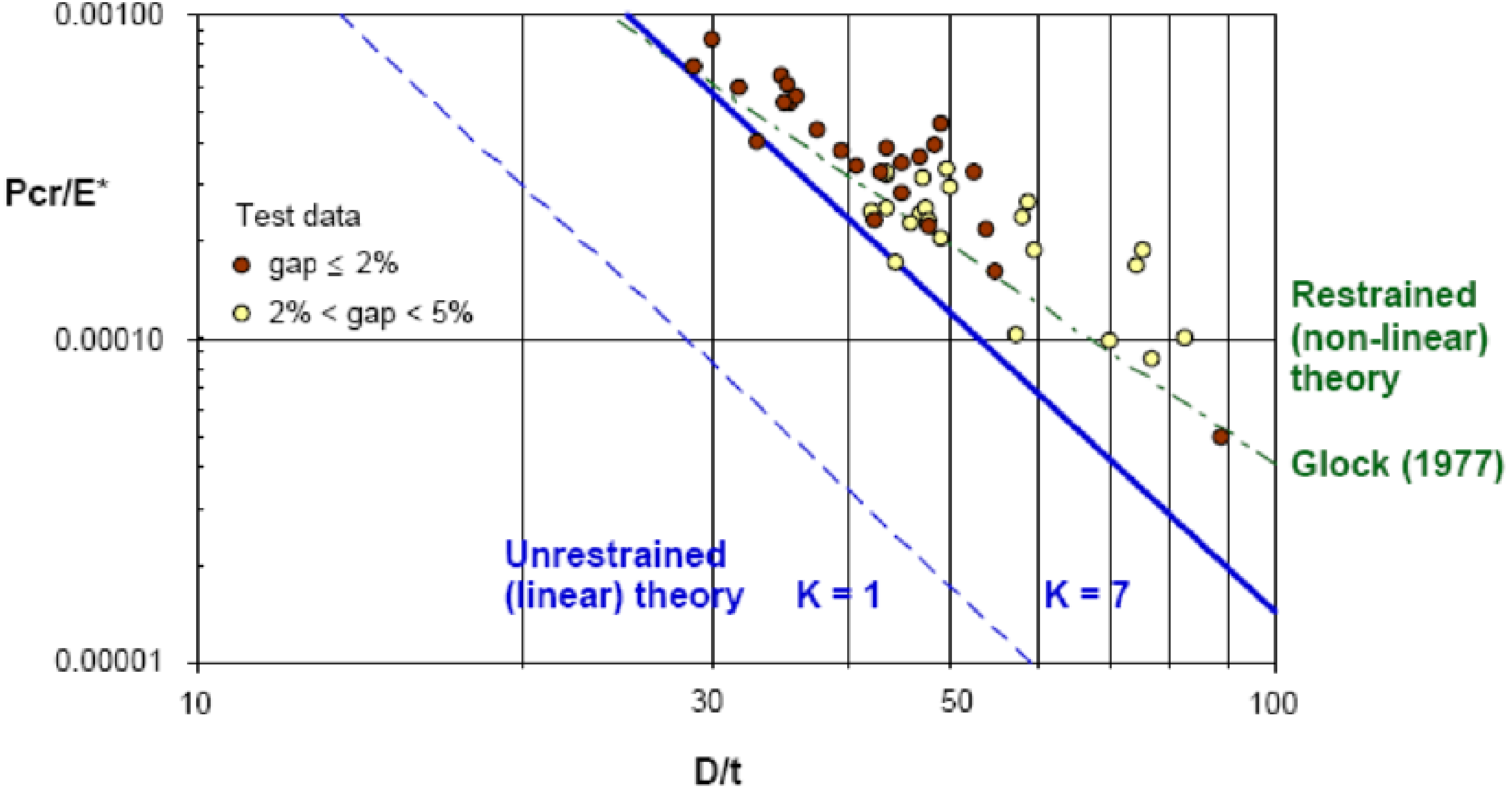


Figure 2 – Aggarwal's 1984 hydrostatic buckling data compared with contemporary theories

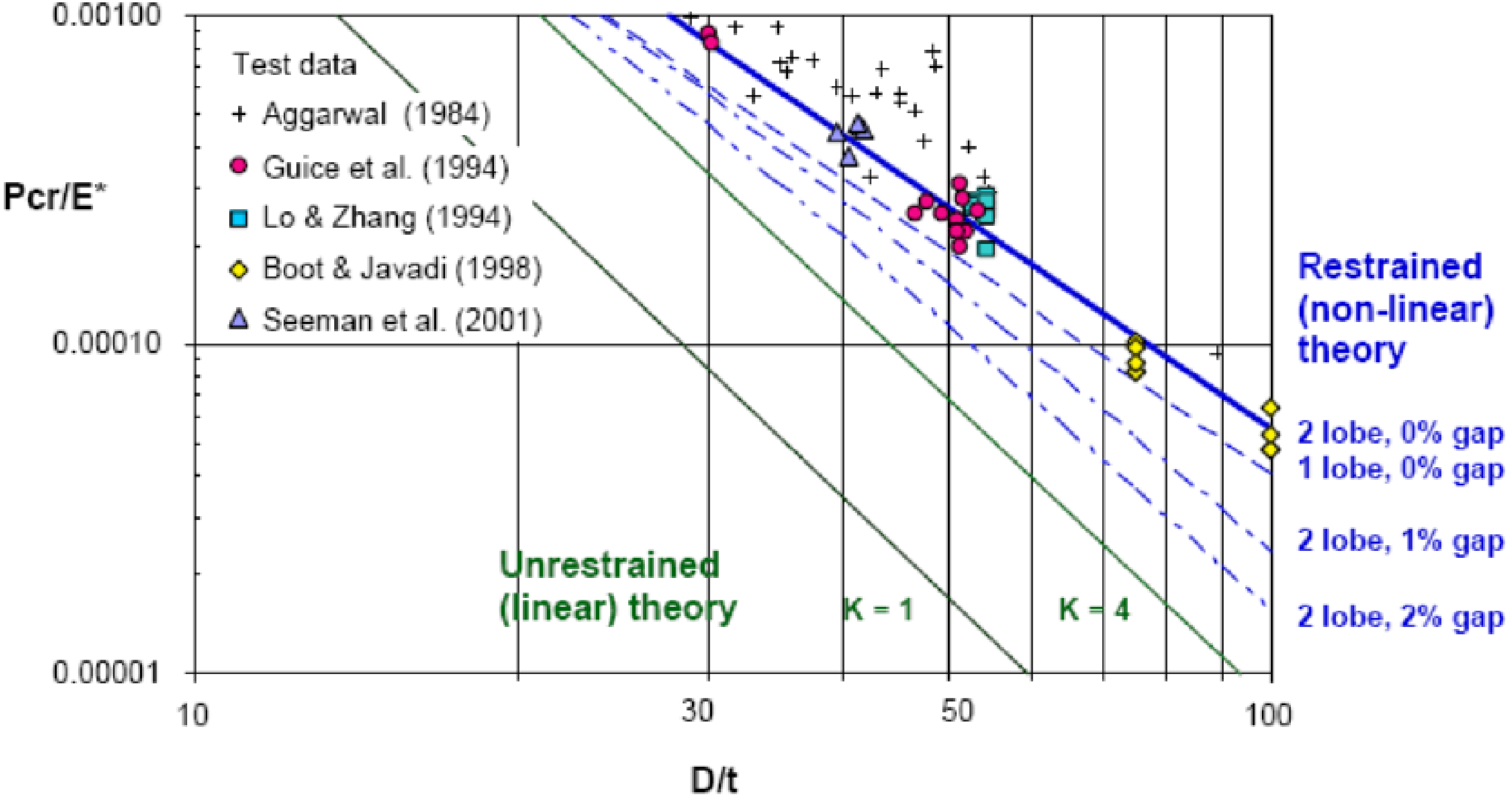


Figure 6 – Various gap-corrected hydrostatic buckling data compared with current theories for perfectly close-fitting, perfectly circular liners

Conclusions of 2007 Committee Report

- WRc/ASTM hydrostatic buckling formula has shown to be too conservative for current needs and above all limited in predictive power by its lack of theoretical consistency
- Any new theory should include the influence of gap, ovality, and longitudinal imperfections on restrained hydrostatic buckling pressure (characteristics of product being designed)
- Any new theory must be capable of accounting for the host pipe system imperfections affecting buckling resistance

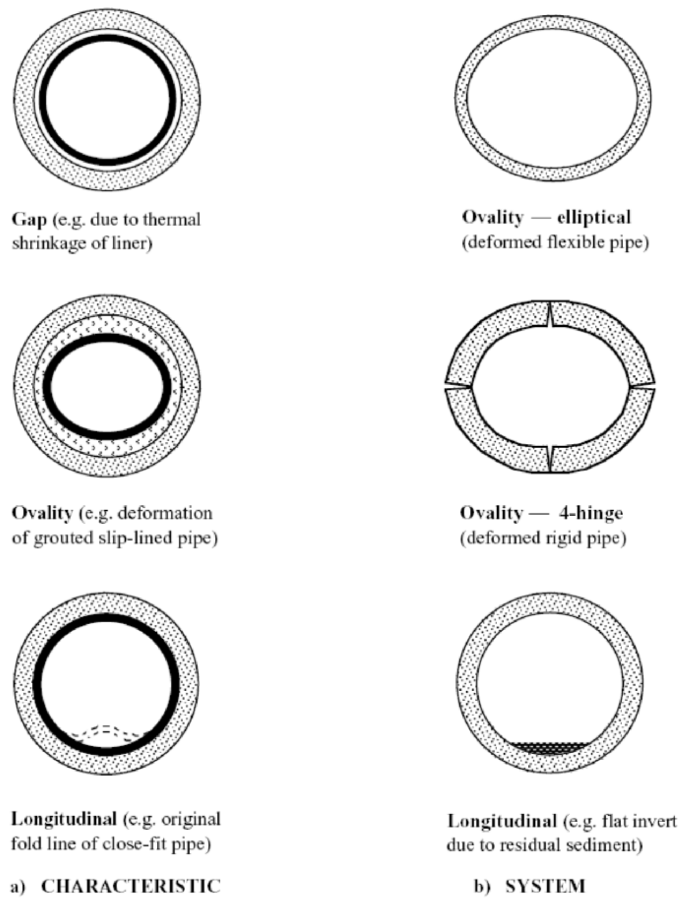
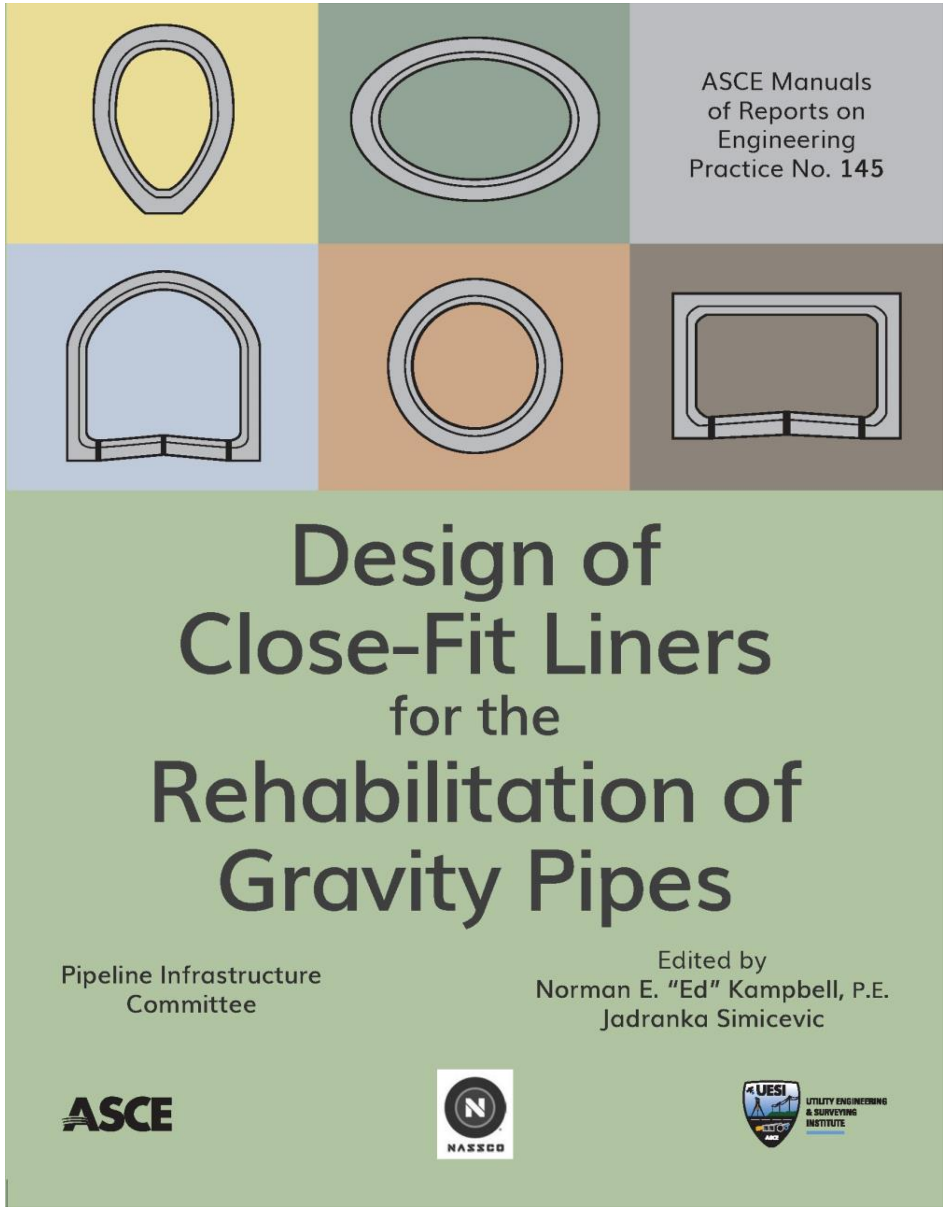


Figure 8 – Examples of characteristic (renovation technique) and system (host pipe) imperfections affecting liner buckling resistance

Liner Thickness Design in MOP 145

- Step 1 – Calculate the imperfections parameters
- Step 2 – Design Resistance. Calculate the critical buckling pressure, and design strength of the liner based on its material properties
- Step 3 – Factored Load Effects. Calculate the factored loading on the liner (factored groundwater pressure) and load effects (maximum factored bending moment, factored hoop force, and stresses and strains on the liner)
- Step 4 – Limit States. Check the limit states (buckling stability, material strength)



Design States in MOP 145 are three…

Rigid Pipes

Table 5-1. Host Pipe Deterioration Level in Design States - Rigid Pipe.

State I	deflection 0%		AND/OR Minor surface corrosion	AND/OR Minor abrasion
State II	deflection 0 - 10%		AND/OR Minor surface corrosion	AND/OR Minor abrasion
State III	deflection ≤ 20%	AND/OR Steel reinforcement corrosion	AND/OR Major surface corrosion	AND/OR Major abrasion

Flexible Pipes

Table 5-2. Host Pipe Deterioration Level in Design States - Flexible Pipe.

State I	deflection 0 - 10%	AND/OR Minor surface corrosion	AND/OR Minor abrasion
State III	deflection ≤ 20%	AND/OR major corrosion	AND/OR major abrasion

NOTE: The deflection limit in State I is the serviceability limit; it is typically 10% but can be lower for some pipe materials (e.g., 6% for GRP pipes). The deflection limit in State III is due to the model limitation (applicability of used formulas).

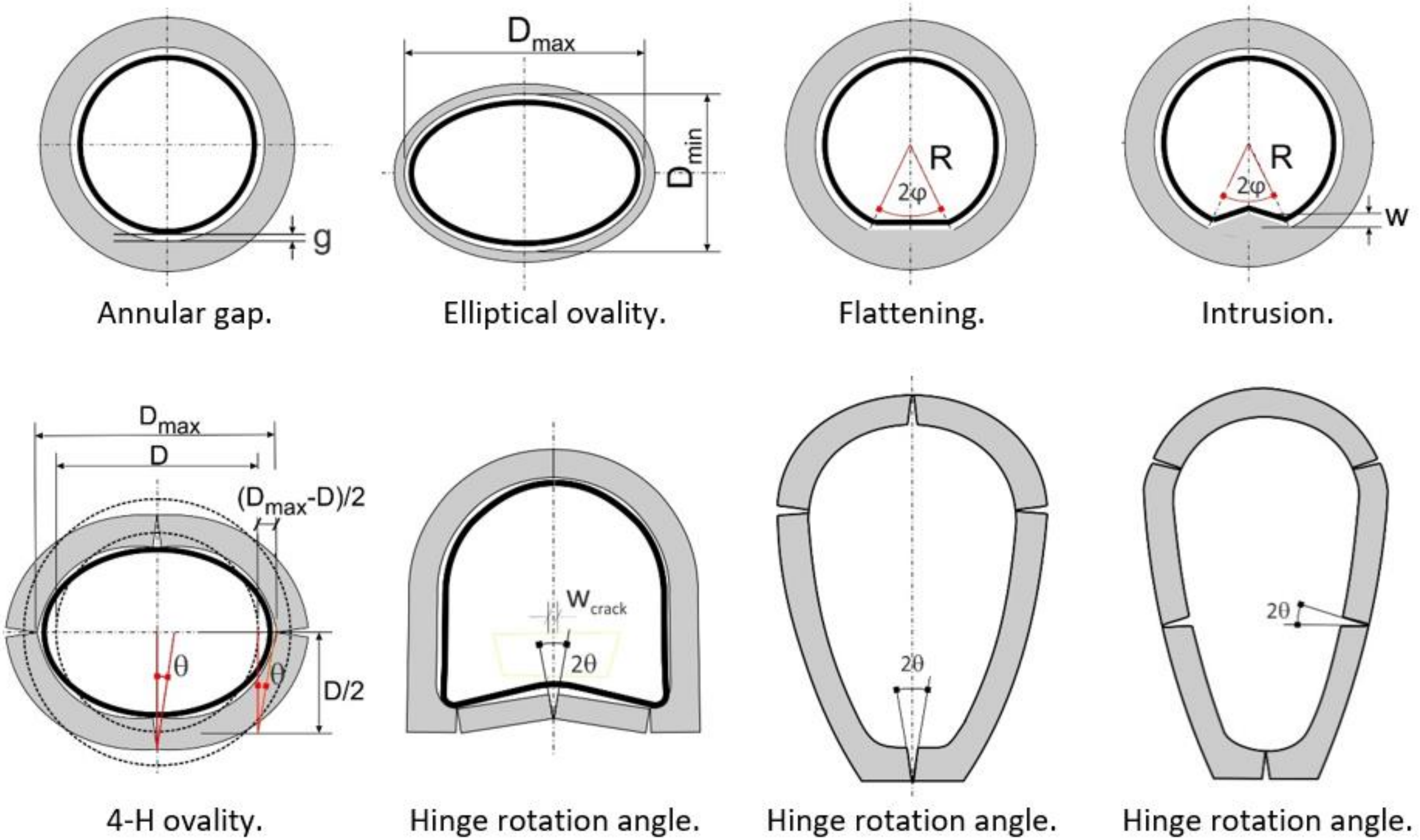
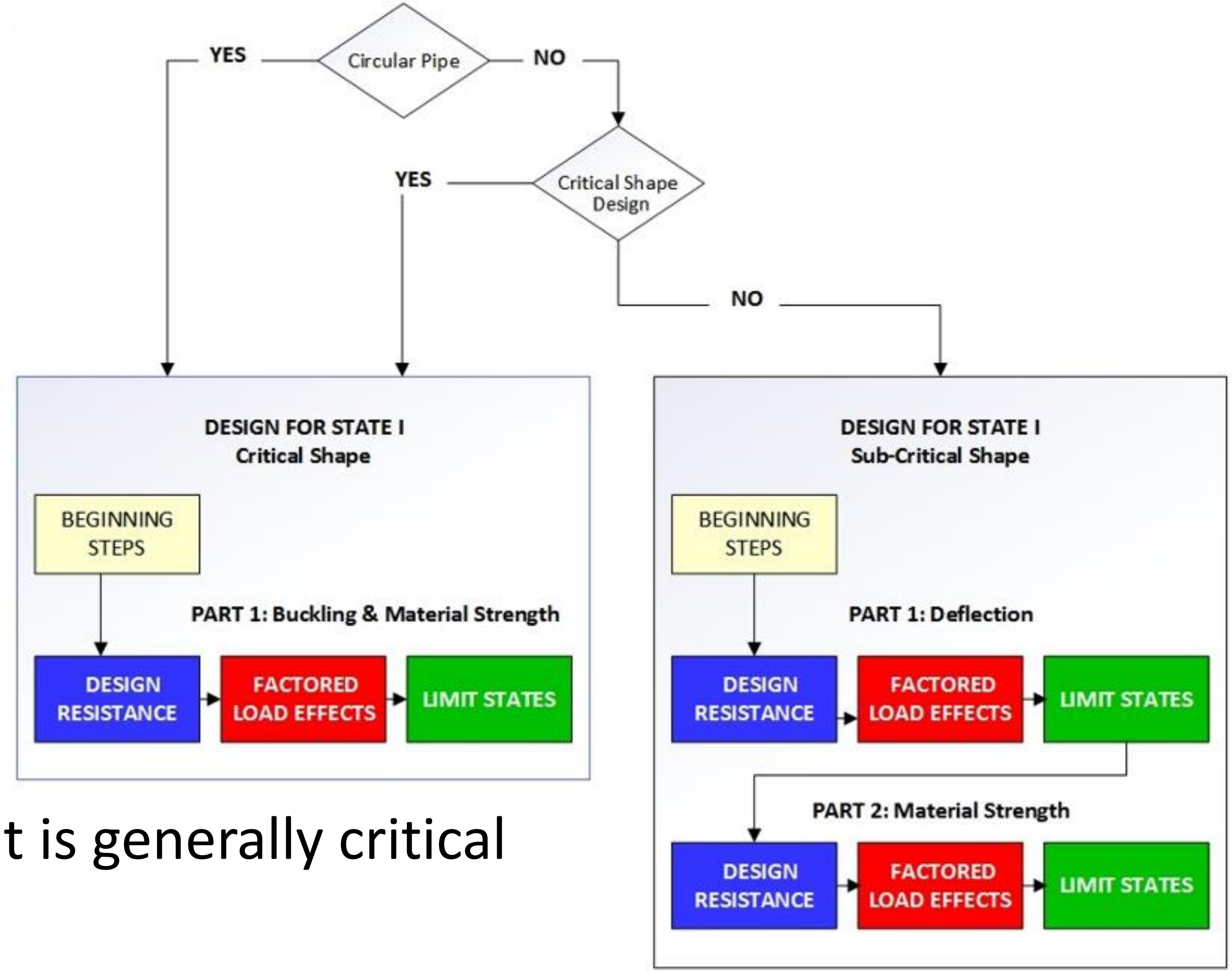


Figure 5-20. Imperfections parameters in Thépot analytical model.

Designing for State I



- Liner installed in a circular host pipe is always critical
- Liner design in non-circular host pipe with at least one flat segment is never critical
- Liner design in a non-circular host pipe with no flat segment is generally critical

Critical versus Non-Critical Shapes

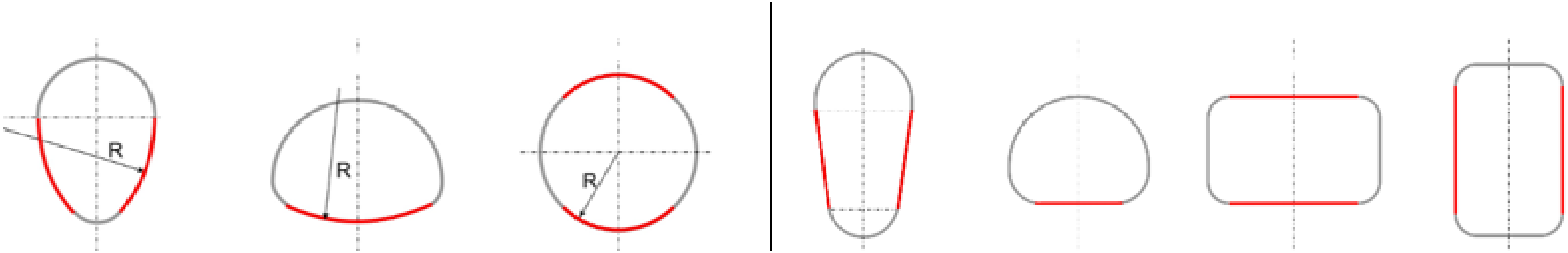


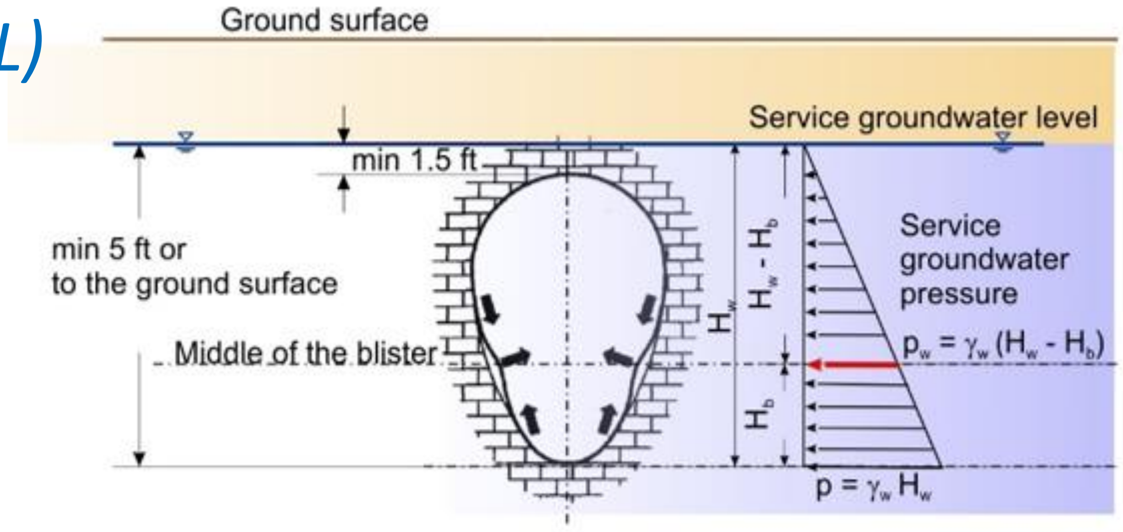
Figure 5-4. Critical shapes (left) and sub-critical shapes (right). Arcs and flat sections where blisters can develop are marked red. Note: In shapes with two marked sections, either one or two blisters may develop (k=1 or 2).

Table 5-16. Quantifying Imperfections.

Imperfection Type	Symbol	Unit	Formula	Note:
Annular gap	g	inch	$g = s \cdot P/2\pi \leq g_{max}$	Recommended Limit for State I: $g_{max} = 0.04$ in.
4-Hinge ovality	Ov_{4H}	-	$Ov_{4H} = \frac{D_{max} - D}{D}$	In circular rigid pipe: $Ov_{4H} = \theta$
Hinge rotation angle	θ	radians	$\theta = \frac{w_{crack}/2}{t_p}$	In non-circular rigid pipe.
Elliptical ovality	Ov_E	-	$Ov_E = \frac{D_{max} - D_{min}}{D_{max} + D_{min}}$	In flexible circular pipe.
Flattening	φ	radians	$2\varphi \leq 0.785$ (45°) $2\varphi = 0.262$ (15°) intr.	The angle 2φ is limited to 45°. For intrusions, 2φ=15°.
Intrusion (amplitude)	w	inch	$2\% \leq w/R \leq 5\%$	The ratio w/R is between 2% and 5%.

Selecting Service Groundwater Level (SGWL)

- Use an estimate of the seasonal high GW level at the site based on local well info
- Use hydrologic frequency curves for GW
- Use a SGWL of at least 1.5 ft above the pipe crown and at least 5 ft above the pipe invert
- The SGWL is limited by the ground surface
- The load factor will be applied to the SGWL in the wall thickness design calculations



Load Factors

Table 5-12. Load Factors (Unitless).

Applies To	Symbol	Recommended Value
Groundwater pressure	γ_{GW}	1.6 (ASCE)
Dead load	γ_{DL}	1.2 (ASCE)
Live load	γ_{LL}	1.6 (ASCE)

Dead load: soil overburden pressure, surface static load

Live load: highway traffic, railway traffic, aircraft

Load factors account for the variability of loads acting on a host pipe and liner, and reflect the uncertainty in estimating magnitudes of different load types.

Resistance Factors

Applies To	Symbol	Recommended Value	
Long-term flexural strength, $\sigma_{50,F}$	Φ_{LF}	0.8	for CIP liners impregnated and cured on site.
		0.85	for CIP liners resin impregnated off-site and cured on site.
		1.0	for factory manufactured thermoplastics (PVC, PE), installed fold-and-form
Long-term flexural modulus, E_{50}	Φ_{LM}	0.8	
Long-term buckling stability	Φ_{LM}	0.8	
Corrosion strain, ε_L	$\Phi_{L\varepsilon}$	0.9	For in-situ manufactured GRP liners.
		1.0	For factory manufactured GRP liners.
Constrained modulus of the backfill soil	Φ_S	0.8	

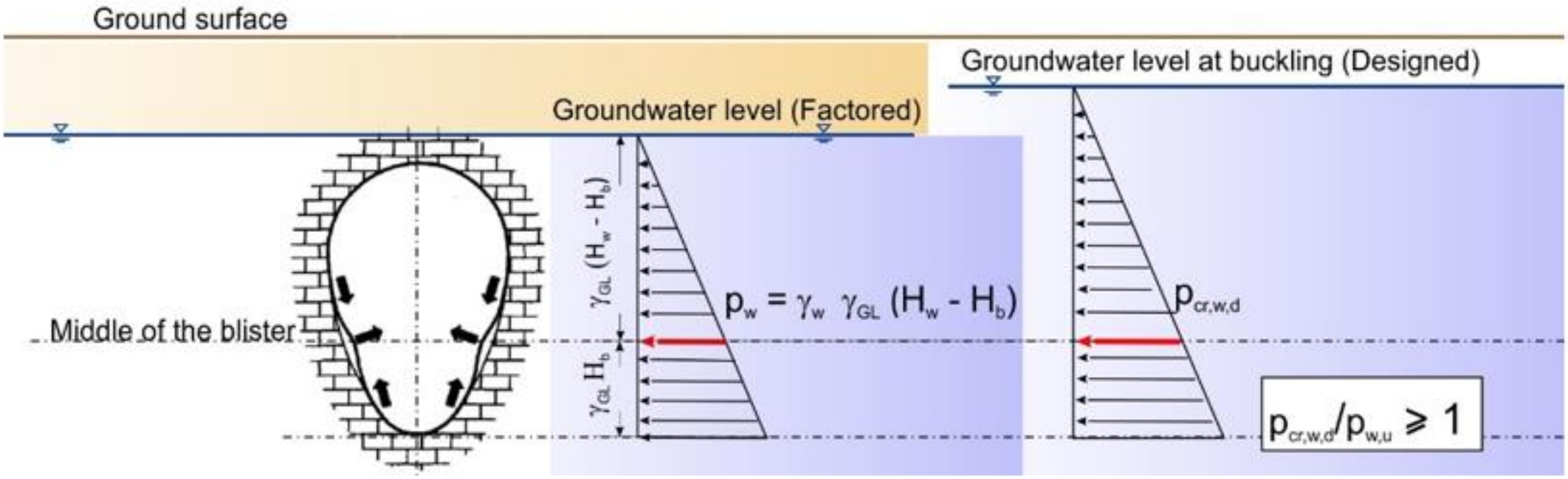
These factors account for the probability of obtaining lower values of materials properties in the field compared to published values from laboratory tests under controlled conditions and vary widely by product and process of installation.

Critical Buckling Pressure

Formula 'Name'	Formula	
Glock (1977)	$p_{GL} = \frac{1}{1-\nu^2} \cdot E \cdot \left(\frac{t}{D}\right)^{2.2}$	
Glock-Thépot	$p_{cr} = 2.02 \cdot k^{0.4} \cdot \kappa_p \cdot \frac{(EI_L)^{0.6} \cdot (EA_L)^{0.4}}{P^{0.4} \cdot R^{1.8}}$	(general form)
	$p_{cr} = 2.02 \cdot k^{0.4} \cdot \kappa_p \cdot \frac{1}{1-\nu^2} \cdot E_L \cdot \frac{I^{0.6} \cdot A^{0.4}}{P^{0.4} \cdot R^{1.8}}$	(homogeneous material)

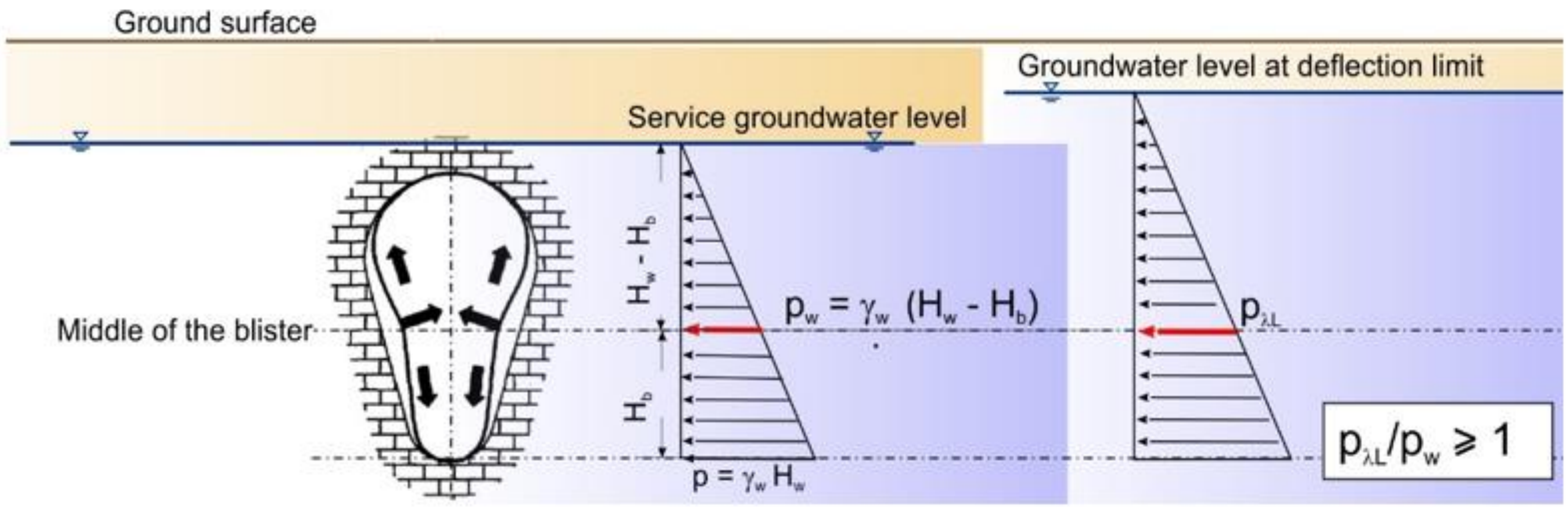
The critical buckling pressure is the pressure that will cause a liner of a given thickness to buckle.

Limit State: Buckling Stability



The buckling stability limit state is the state when the groundwater pressure acting on the liner (load) is equal to the critical buckling pressure (resistance).

Serviceability Limit State: Deflection



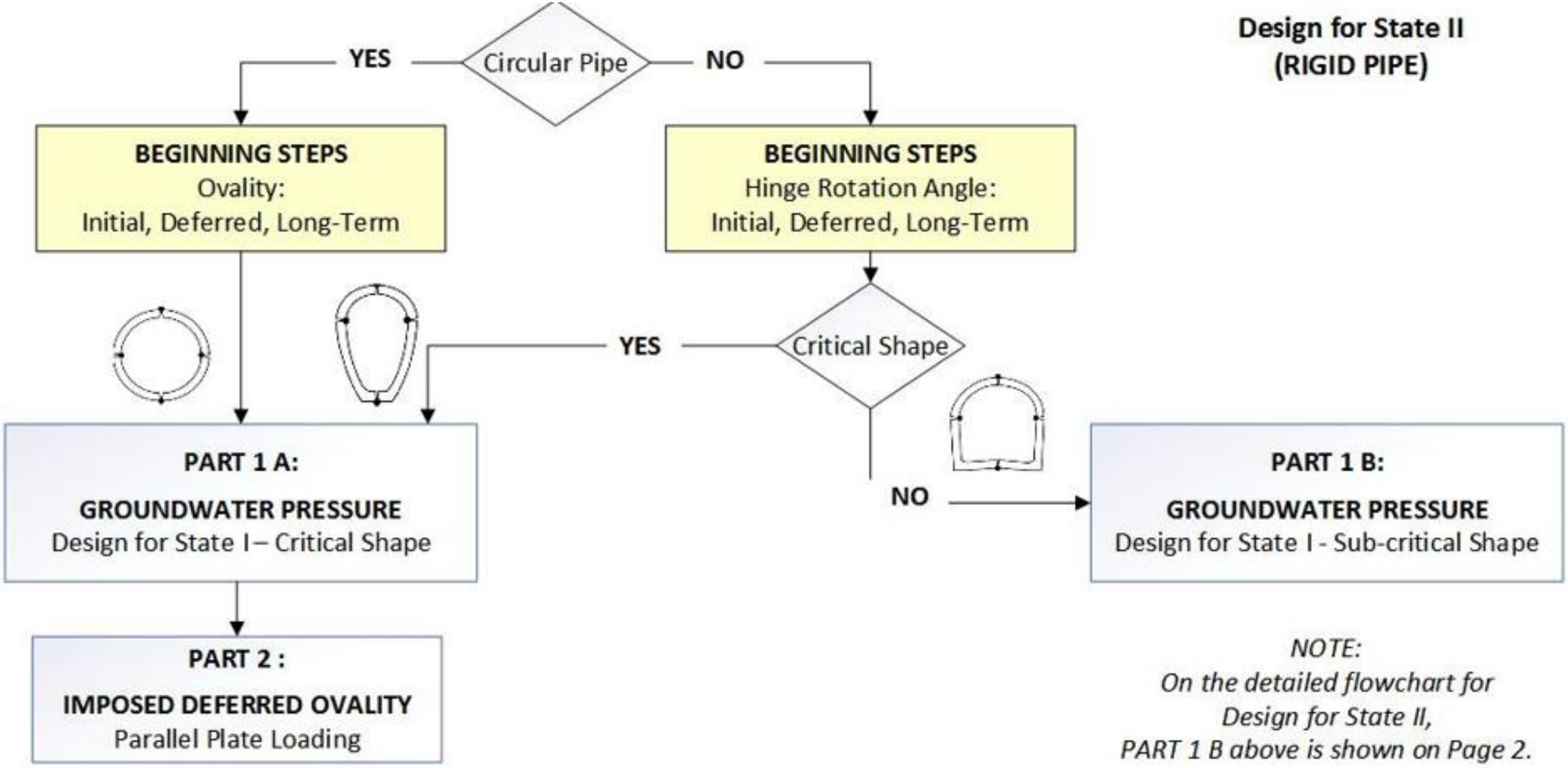
Parameter	Symbol	Unit	Formula
Pressure at deflection limit	p_λ	psi	$p_\lambda = \frac{4\pi^4 \cdot m}{\eta^4} \cdot \left[\lambda + \frac{1}{144\beta \cdot \eta}(6\lambda\eta - 4\gamma)(12G\eta^2 + 3\lambda^2\eta - 4\lambda\gamma)\right]$

The deflection limit state happens when the SGW pressure acting on the liner (load) exceeds the pressure at deflection limit (resistance)

Limit States – Material Strength

Two limit states related to material strength are possible for a liner under GW pressure: one is the liner wall crushing which is controlled by the material's flexural strength, and the other is the liner interior wall cracking due to Stress Corrosion Cracking (SCC) which is controlled by the material's corrosion strain property

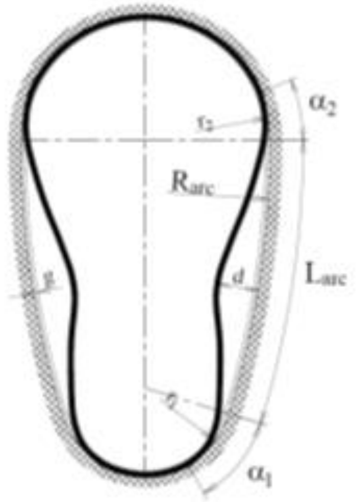
Design State II: Liner's Flexural Stiffness is Neglected

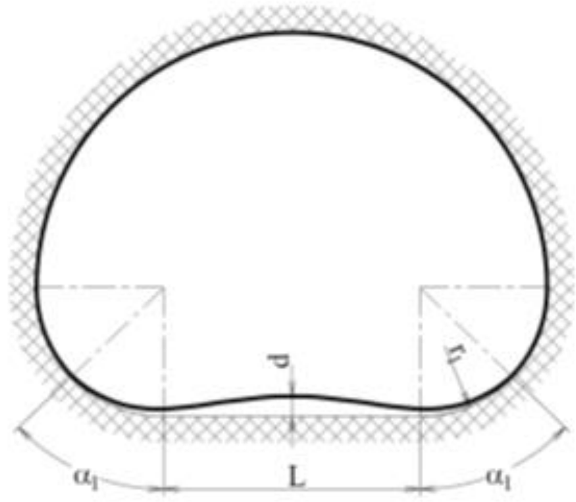


The main parts of the Design State II procedure are:

- If the host is circular, calculate the ovalities: initial, deferred, and long-term. If the host pipe is non-circular, the hinge rotation angles are calculated. The non-circular shape is then check-ed to see if it is critical or not.
- The minimally required thickness is determined for (1) the factored groundwater pressure at long-term ovality (circular pipe), or (2) the long-term hinge rotation angle (non-circular pipe)
- Design for State I Sub-Critical Shape. Eleven model non-dimensional parameters are calculated for long-term rotation angle. The minimally required thickness is determined for the factored groundwater pressure.
- Imposed Deferred Ovality. Material strength is checked for the loading imposed on the liner by the host pipe fragments at the factored deferred ovality (parallel plate loading condition)

Sub-Critical Shaped Pipes





Step 1 – Verify the geometry condition
Step 2 – Specify the Deflection Limit
:
Step 9 – Calculate external pressure at the specified deflection limit
Step 10 – Calculate Load: Groundwater pressure (service, factored)
Step 11 – Check Limit State: Deflection.
:
Step 14 – Calculate Material design stiffness, strength, and elongation.
Step 15 – Determine Factored Relative Deflection
Step 16 – Calculate Load Effects
Step 17 – Check Limit State: Material Strength and Corrosion Strain (if applicable)

Design State III: Liner's Flexural Stiffness is Not Neglected

- The existence of the host pipe or its fragments in the soil is ignored; it is assumed that the liner is in full contact with the ground, and there are no voids at the interface or around pipe fragments
- It is assumed that the ovality of the liner will continue to increase under the soil over-burden weight and surface loading over the years. The deferred ovalization depends on both the soil condition (constrained soil modulus immediately next to the host pipe) and the liner's flexural stiffness. The deferred ovality at the end of the design period is added to the initial ovality which gives the designer the long-term ovality of the liner
  There is continuous soil support to the outside of the liner
- Groundwater pressure is acting on the liner as in Design State I and II. In addition, the soil overburden weight and the surface loads are fully transferred onto the liner

The liner is designed for limit states in three loading conditions:

(1) Groundwater pressure acting on a liner; the liner has long-term ovality. The limit states for buckling and wall crushing from bending moments and hoop force in the liner are checked.
(2) All loads acting on a liner; the liner ovality is not considered. The limit states for buckling and wall crushing from the maximum hoop force in the liner are checked.
(3) Deferred ovalization imposed on the liner. Parallel plate loading is considered for a liner in a rigid 4-hinge fractured pipe; bending of a ring in elastic continuum for a liner in a flexible pipe.

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