Underground Construction Technology
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UCT

SEWER
WATER
TELECOM
GAS
ELECTRIC

Selection of Water Main Materials

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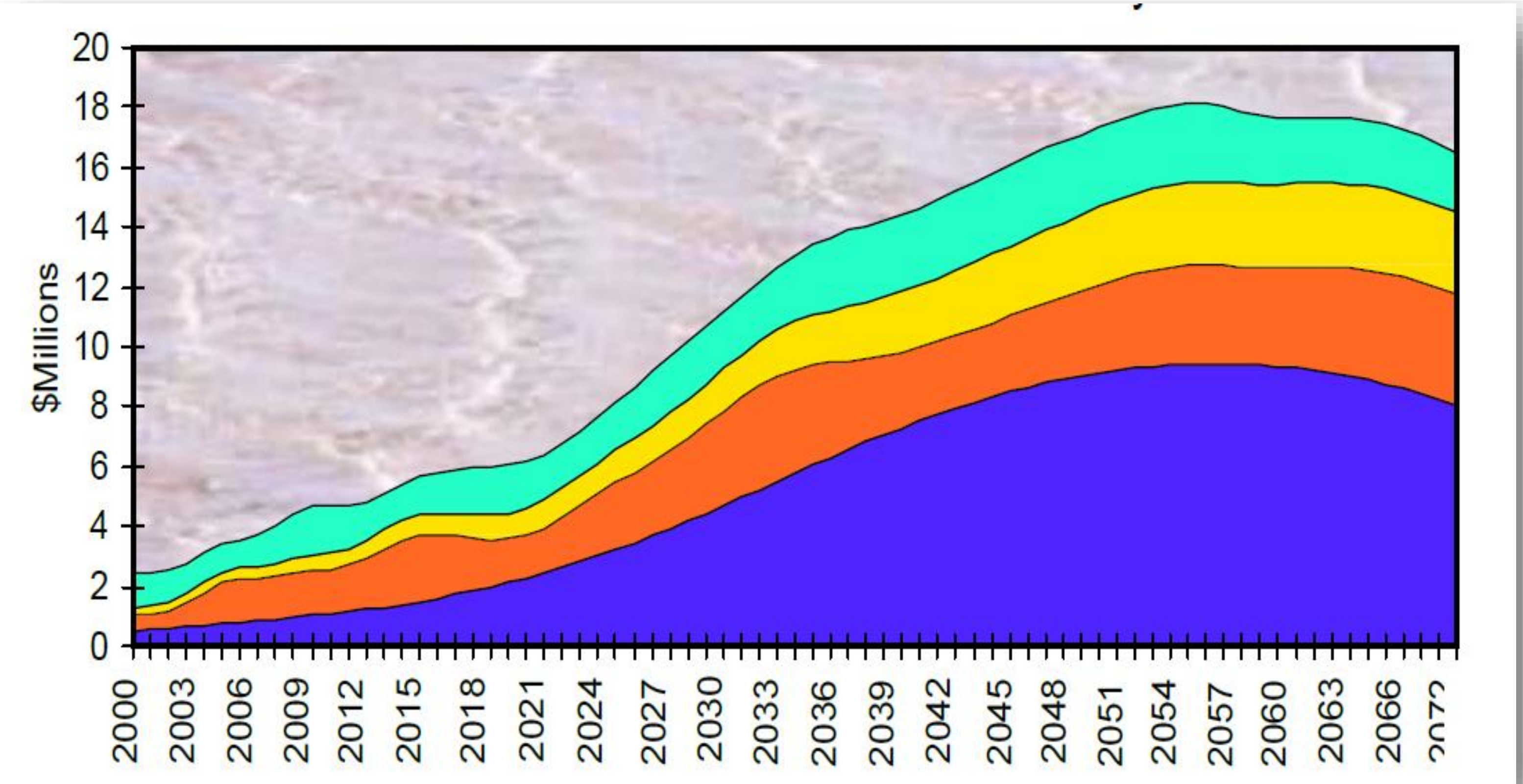
HDR

A Monster Lurks Around the Bend!



Graphic: AWWA – Buried No Longer

Polyvinyl Chloride (PVC) Pipe

- Used for 60% of new water mains in the U.S.
- 30+ years of good data
- Does not corrode, but does weaken with age
- Low failure rates, but brittle
- Failures can be significant events

High-Density Polyethylene (HDPE) Pipe

- Used for most new **gas** mains in the U.S.
- Choice for water mains in U.K. and elsewhere
- 40+ years of data
- Does not corrode
- Very ductile
- Very Low failure rates
- Fused joints

Ductile Iron Pipe

» Modern version of cast-iron pipe
  - Ductility
  - Corrosion Protection

» Lots of data
  - Historic cast iron data
  - Trade association tests

» Very strong! Typically much stronger than required for internal water pressure

» Low failure rates

Steel CML/CMC Pipe

- » Used for special applications and large diameter pipes
- » Welded joints resist ground movement and fully seal the pipe
- » Coating & lining plus cathodic protection
- » Lots of data
    - Historic cast iron data
    - Field tests
- » Low failure rates when well protected
- » Generally costly for small diameters

Cost Factors for Existing Streets

	Ductile Iron	PVC
Material Cost (6-inch)	$12/ft	$6/ft
Trenching	no difference	
Paving	no difference	
Permitting and traffic control	no difference	
Installation / handling	more rugged, but polywrap required	lighter easier to cut
Thrust restraint	field-lock gaskets	concrete thrust blocks
Service lateral installation	can be directly tapped	saddle needed & special drill bit
Backfill (slurry)	no difference	
TOTAL INSTALLED COST	$250/ft	$225/ft

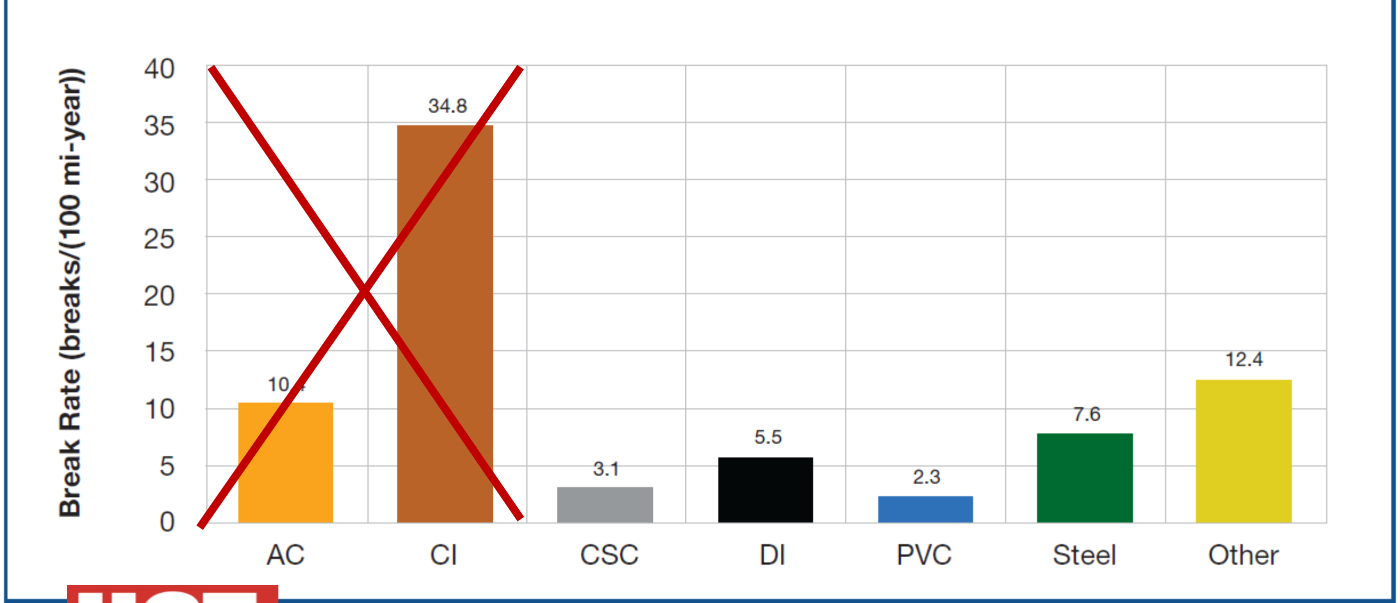
Break rates for modern materials are low…HDPE is lowest

UK Breaks/100 miles/year	1998	1999	2000	2001	Averages
~~Asbestos Cement~~	~~26.4~~	~~27.5~~	~~24.3~~	~~25.4~~	~~25.9~~
Ductile Iron	8.0	8.5	7.7	7.7	8.0
~~Cast Iron~~	~~38.1~~	~~38.1~~	~~30.7~~	~~34.9~~	~~35.5~~
Polyethylene (HDPE and MDPE)	5.6	4.7	5.3	5.0	5.1
PVC	15.4	14.6	11.6	11.9	13.4
Steel	8.0	9.8	9.3	9.2	9.1
~~Unknown~~	~~0.2~~	~~0.0~~	~~0.0~~	~~0.2~~	~~0.1~~
Source: MacKellar and Pearson, 2003					

Comparisons of Break Rates can be misleading

» These pipes have different average ages, different average sizes….

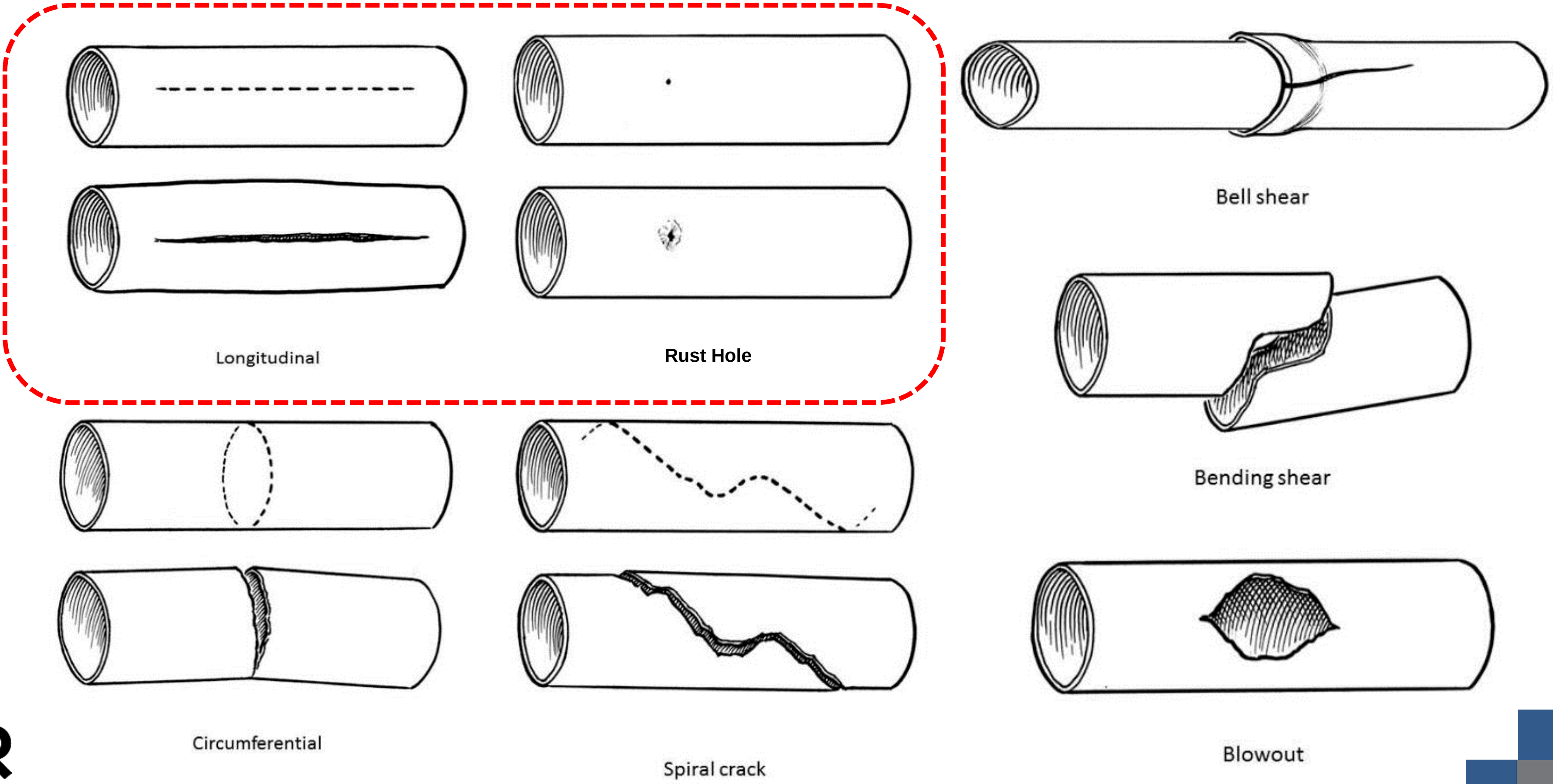
FIGURE 20: BREAK RATES OF EACH PIPE MATERIAL FROM THE BASIC SURVEY



Source: Steven Folkman, Utah State Univ., 2018

Survey of 281 Utilities, serving 27 million people

“Breaks” are failures of the pipe barrel



What is the life expectancy of a pipe?

» Unlike a person, the death of a pipe is not a definitive event

» Unlike a person, a pipe is not a definitive thing

» A pipe lasts until someone decides to replace it

» Decisions may be rational, objective, based on data

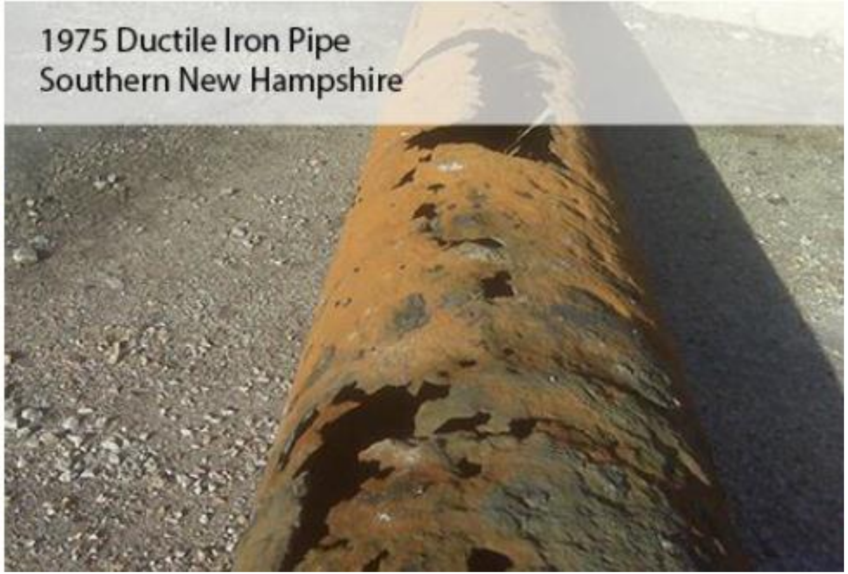
…or not

<u>Good Reasons to Replace a Pipe:</u>

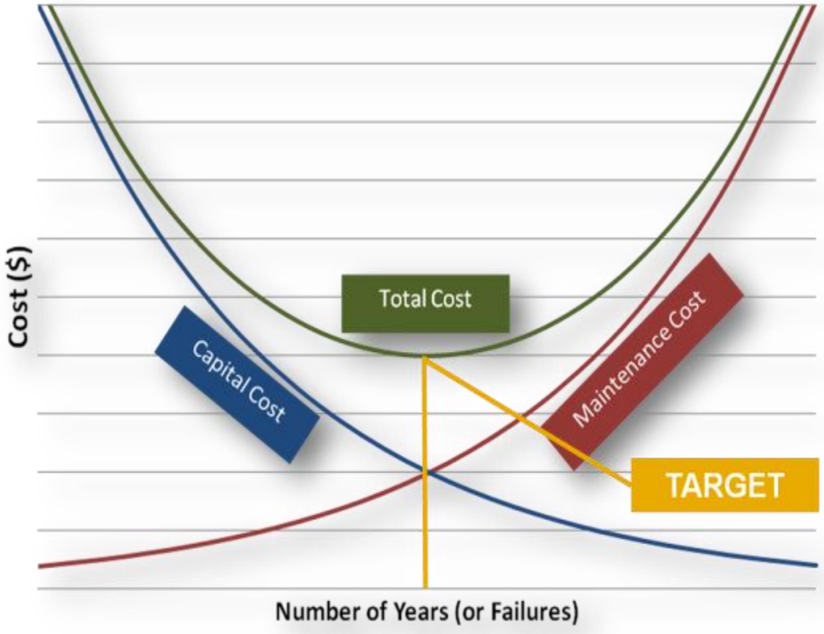
1. Repairs get too costly
2. Service is substandard
3. Infrastructure stewardship

AGE IS A POOR PREDICTOR OF PIPE CONDITION

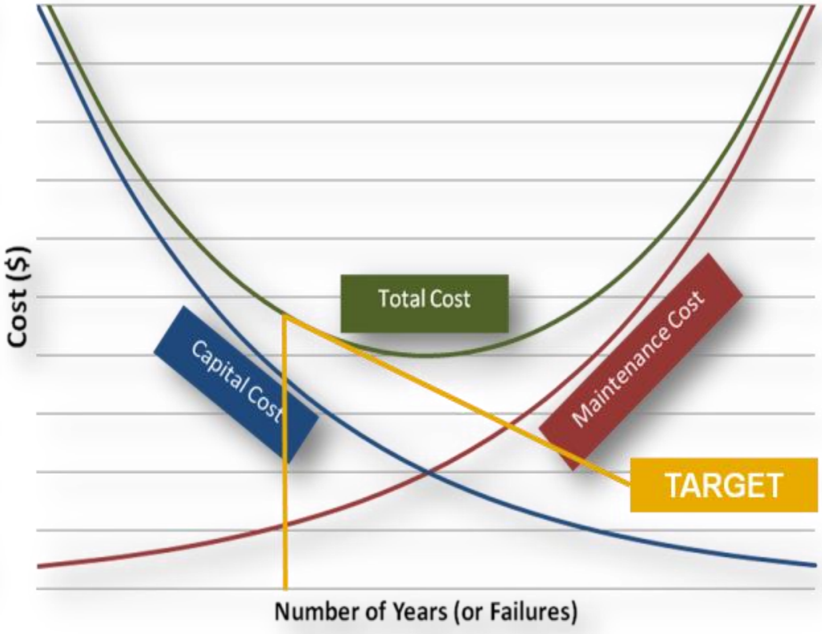
- » **Yes**, pipe failures increase with age
- » **No**, pipe lives are not found in a book…



Life Expectancies Depend on Economics and Levels of Service



theory



practice

Life expectancies are highly localized and highly variable – and MAY SURPRISE YOU

Pipe Type / Location	Mean Life Expectancies	
AC Pipe – Anchorage	*Based on Statistical Analyses*	125 to 170 years
Old Cast Iron – Anchorage		75 to 150 years
Cast Iron – Eugene		130 to 200 years
Cast Iron – Portland		> 200 years
All pipes – Boulder		150 to 200 years
Most pipes – Seattle		>200 years
Old AC – SF Bay Area		90 to 100 years
Newer AC – SF Bay Area		175 to 185 years
Cast Iron – Western US	60 to 100 years*	

** Per "Buried No Longer"*

Iron Pipe Aging and Failures

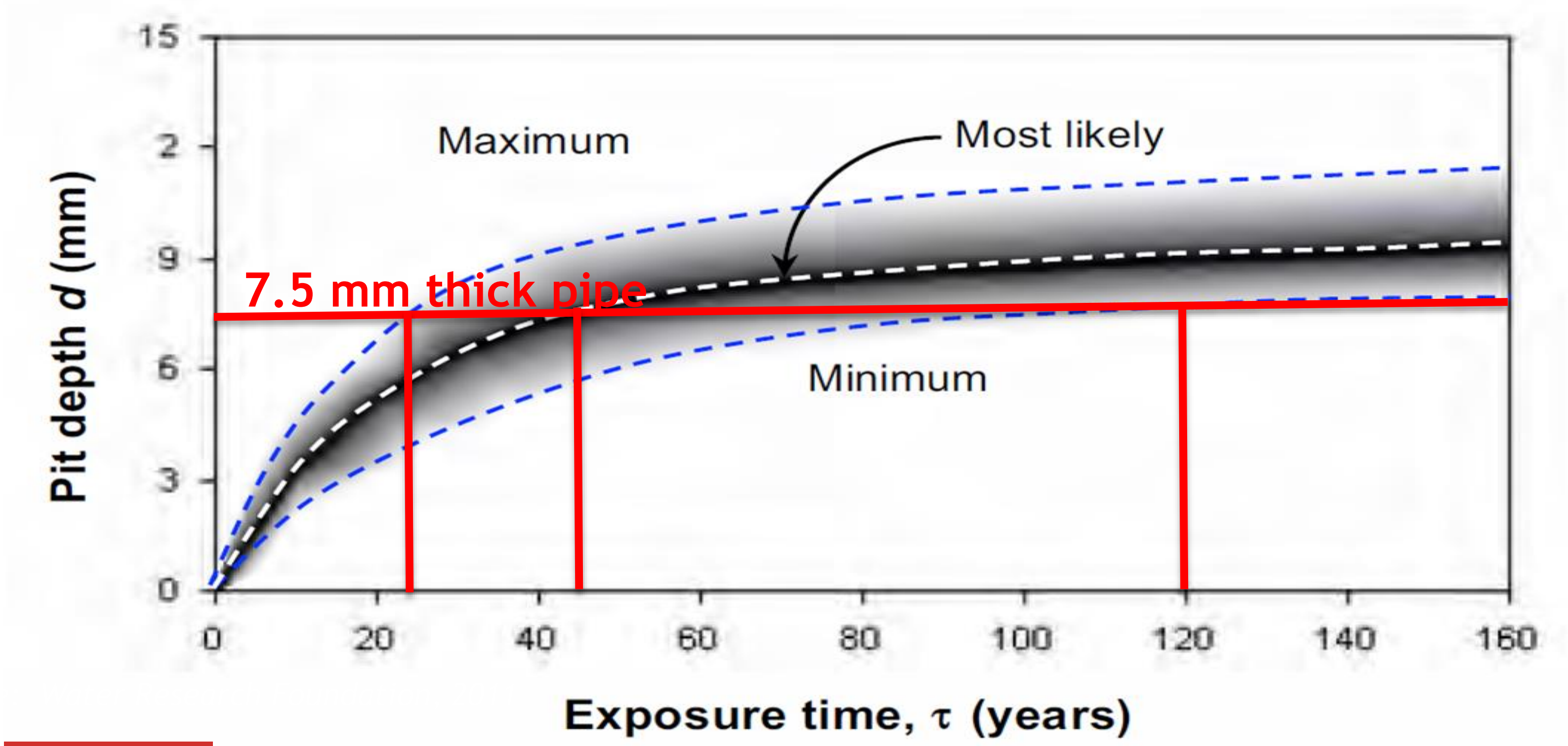
Pipe Material	Aging Processes	Failure Methods

Ductile iron	• Internal corrosion
	• External corrosion
	    • General
	    • Pitting
		• Rust holes or other leaks
		• Bursts (longitudinal)
		• Breaks (circumfrential)
		• Joint and service tap leaks

Pitting Corrosion

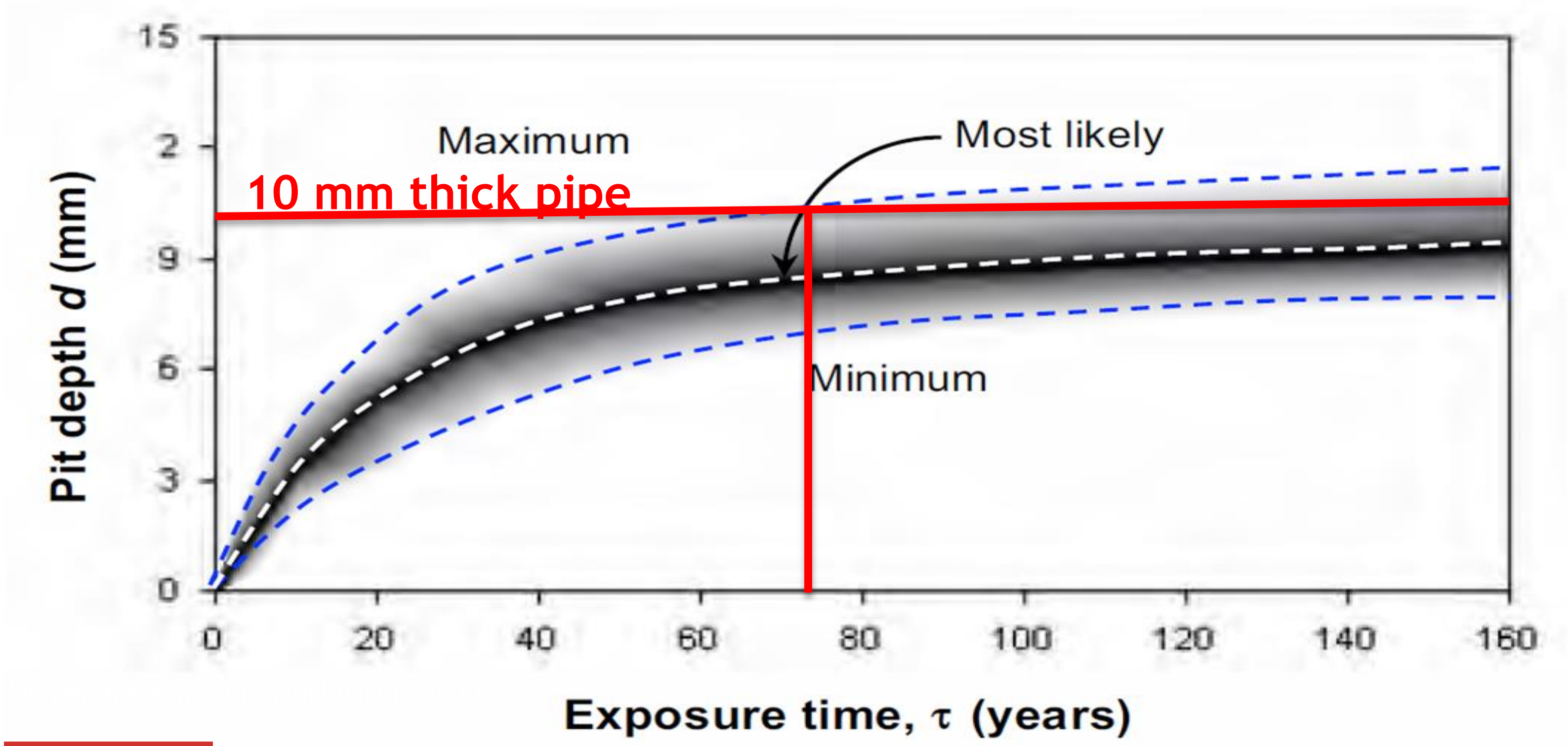
General Corrosion

Corrosion of Iron or Steel is NOT Linear



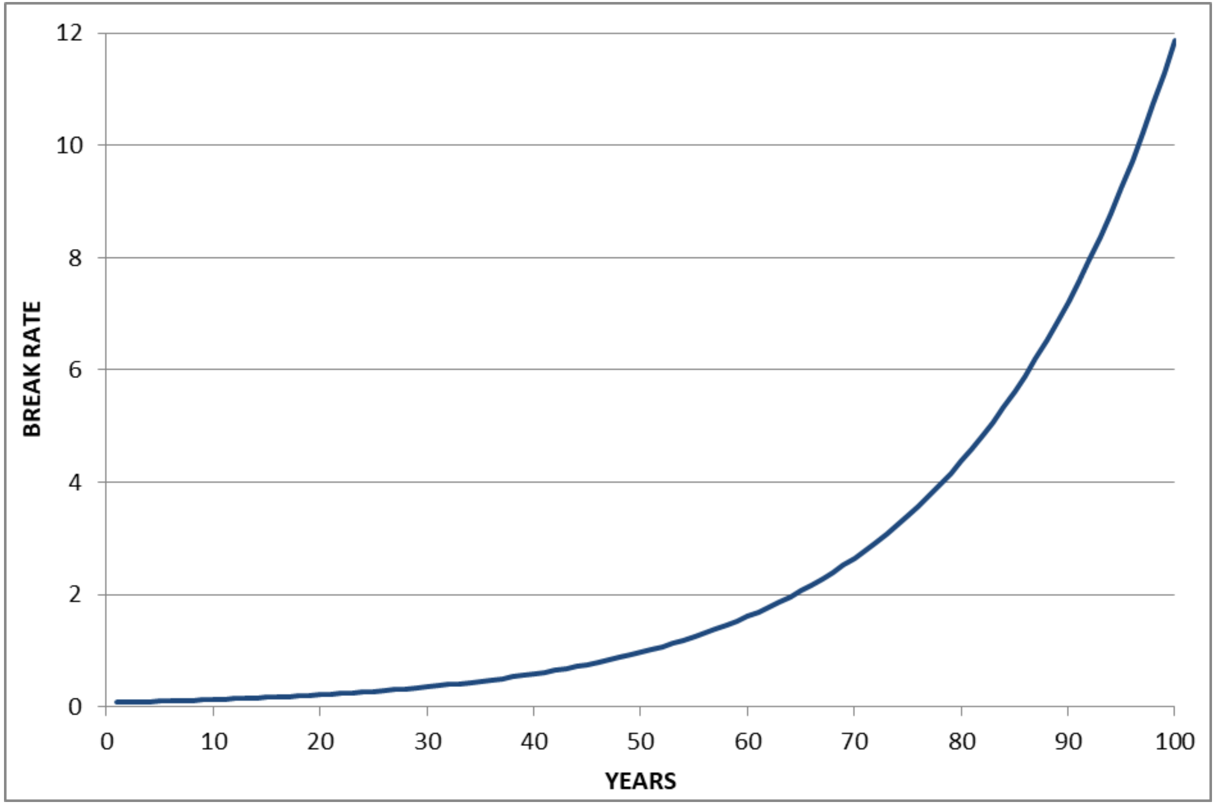
Source: *Water Research Fdtn*

Corrosion of Iron or Steel is NOT Linear



Source: Water Research Fdtn

New Pipes Should be Designed to Last 100 Years or More



CLASSIC METALLIC PIPE BREAK CURVE

PVC Aging and Failures

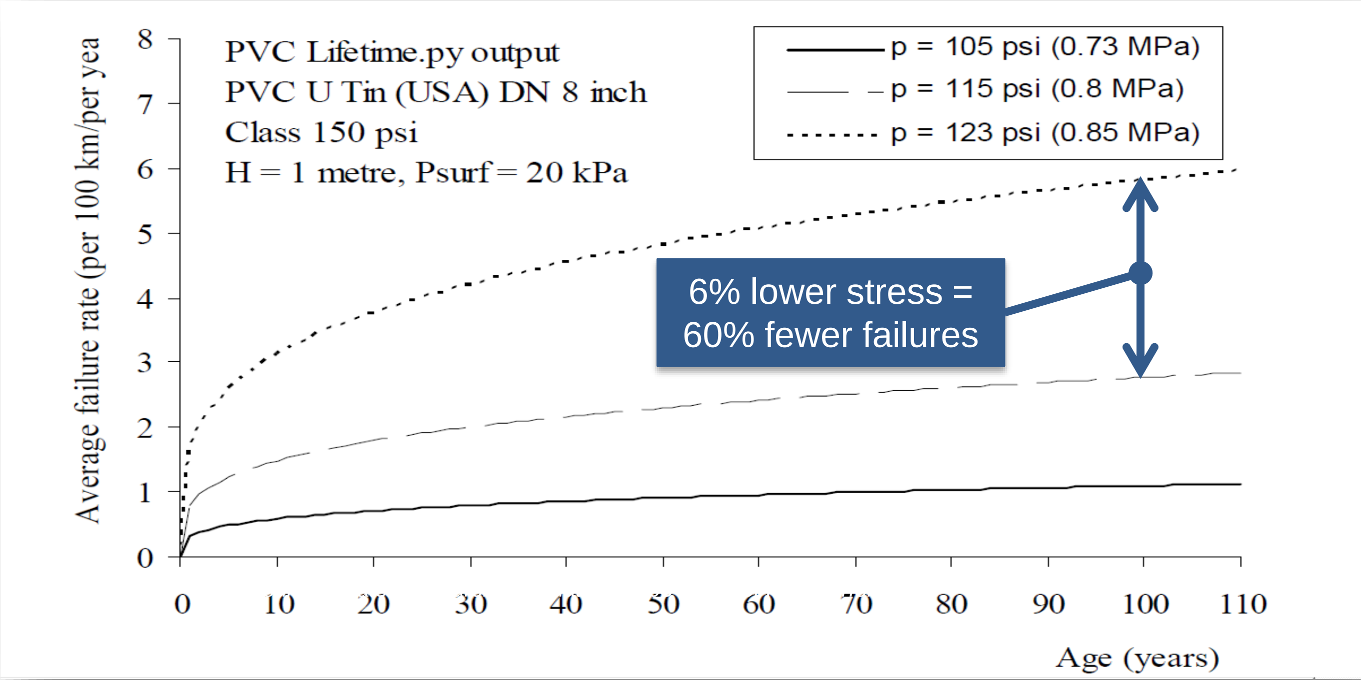
Pipe Material	Aging Processes	Failure Methods
Polyvinyl Chloride	• Slow crack growth • Long-term creep • Material degradation	• Brittle fractures • Ductile burst (very rare) • Joint and service tap leaks • Contractor damage

Small Defects => Crack Initiation

Slow Crack Growth & Rapid Propagation

Predicted Failure Rates - PVC

» PVC failure rates tends to level off



8-inch PVC, Class 150

Source: Water Research Fdtn

Predicted Failure Rates - PVC

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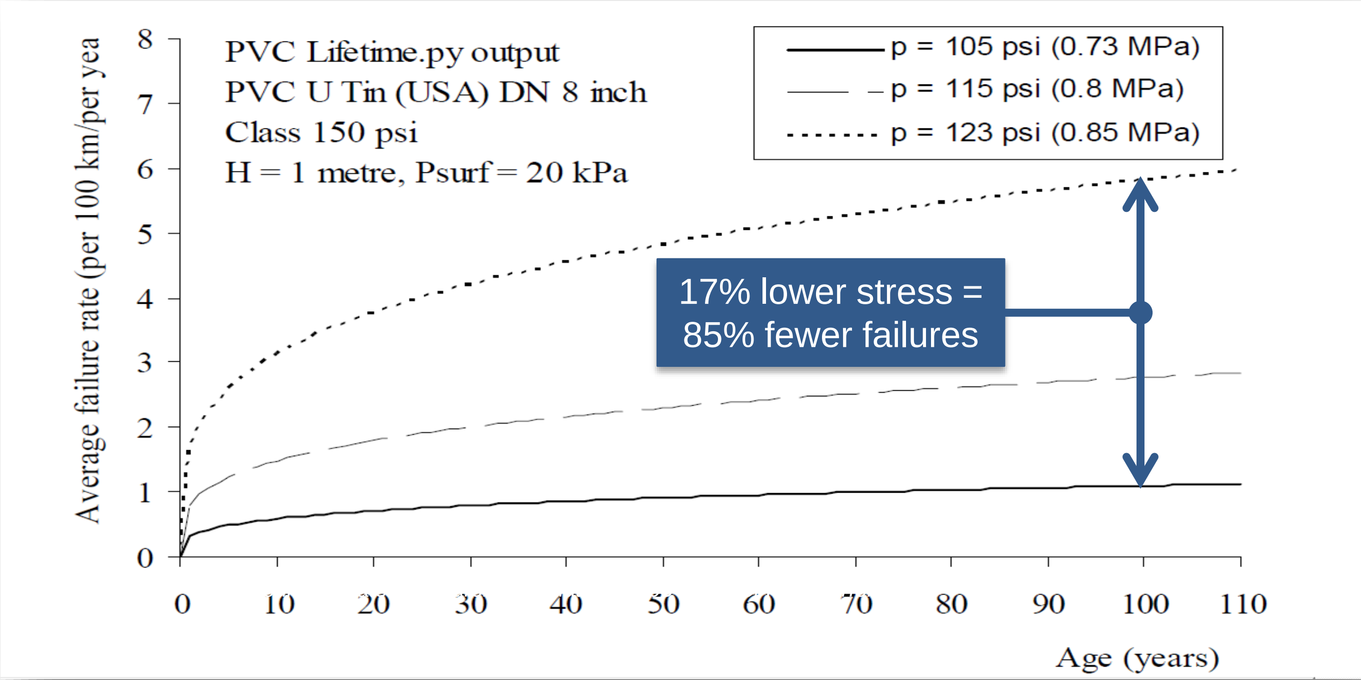


8-inch PVC, Class 150

Source: Water Research Fdtn

Failure analysis

» Design replication
» Laboratory testing
» Operational data

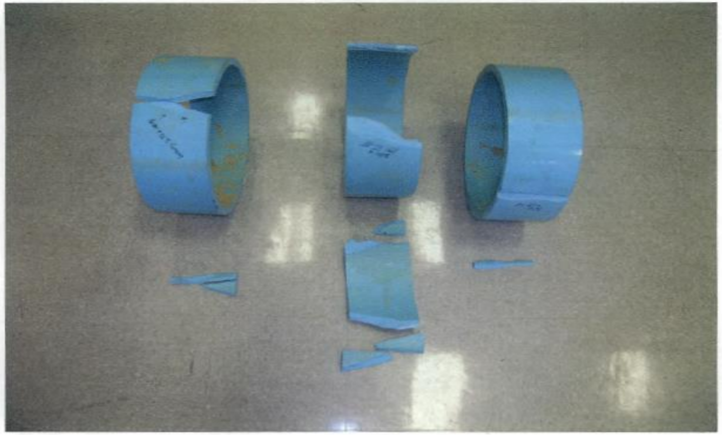


Photo 7: All 3 of the Sample #3 ring specimens from the flattening test failed prior to reaching the required 40% deflection.

Flattening Tests

The acetone test reveals very poorly fused material…it is no longer used in international standards

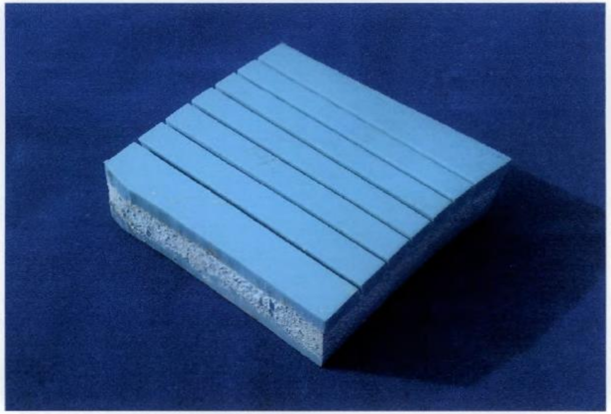
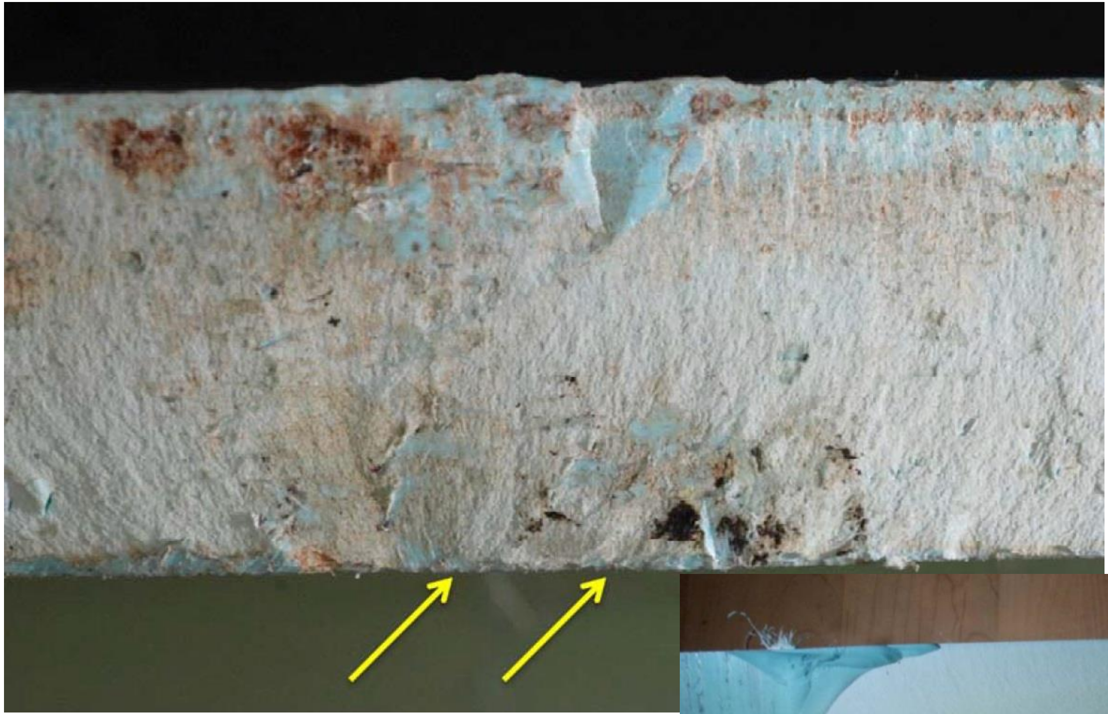


Photo 9: The acetone immersion sample shows inadequate fusion mid-wall. The combination of inadequate fusion and the presence of foreign material that will initiate cracking was the cause of the failure.

Acetone Emersion



Infant Mortality Example - Over-Stabbing and Deflecting of Joints

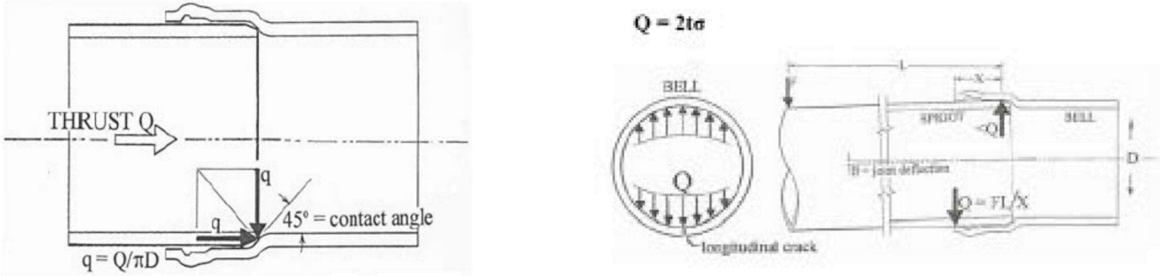


Figure 2a, b: An Over-Belled Joint; Excessive Axial Offset

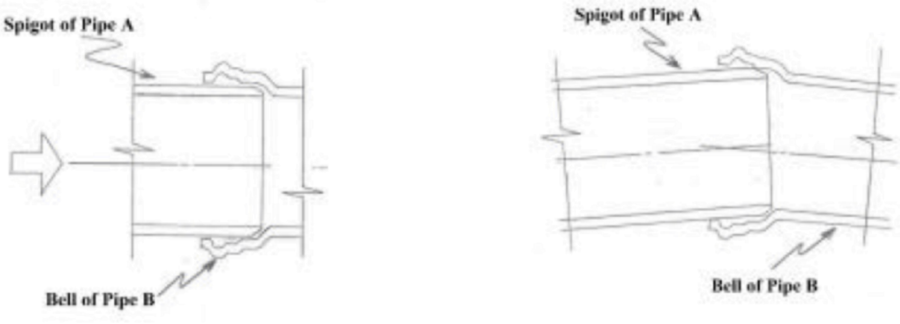


Figure 7a, b: Over Assembled Joint; Axially Offset Joint

Infant Mortality Example - Over-Stabbing and Deflecting of Joints

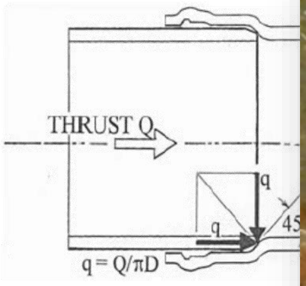
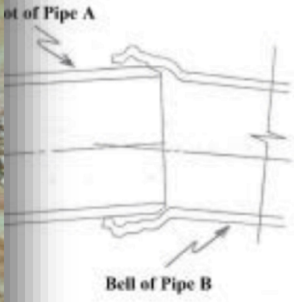


Figure 2a,



xially Offset Joint

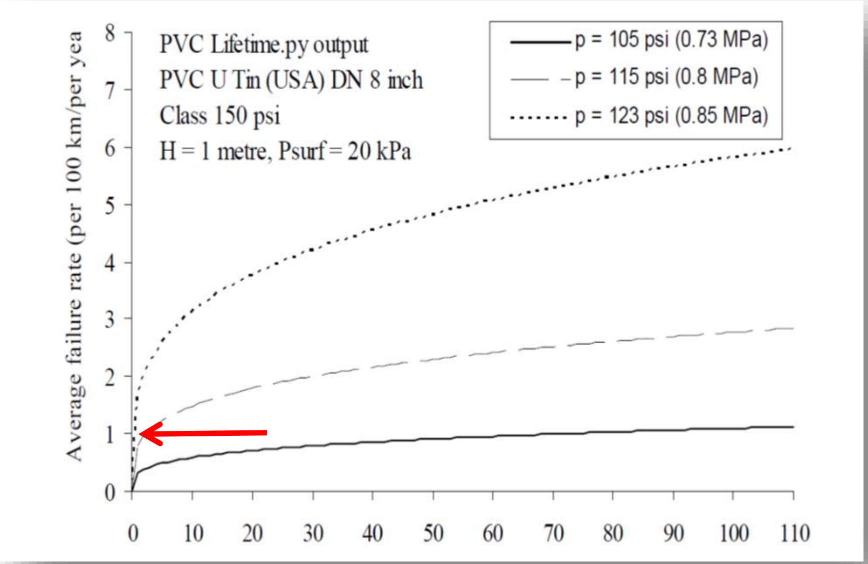
HDPE Aging and Failures

Pipe Material	Aging Processes	Failure Methods
HDPE	• Slow crack growth • Long-term creep • Material degradation	• Brittle fractures (rare) • Ductile burst (very rare) • Joint and service tap leaks • Contractor damage • Bad welds

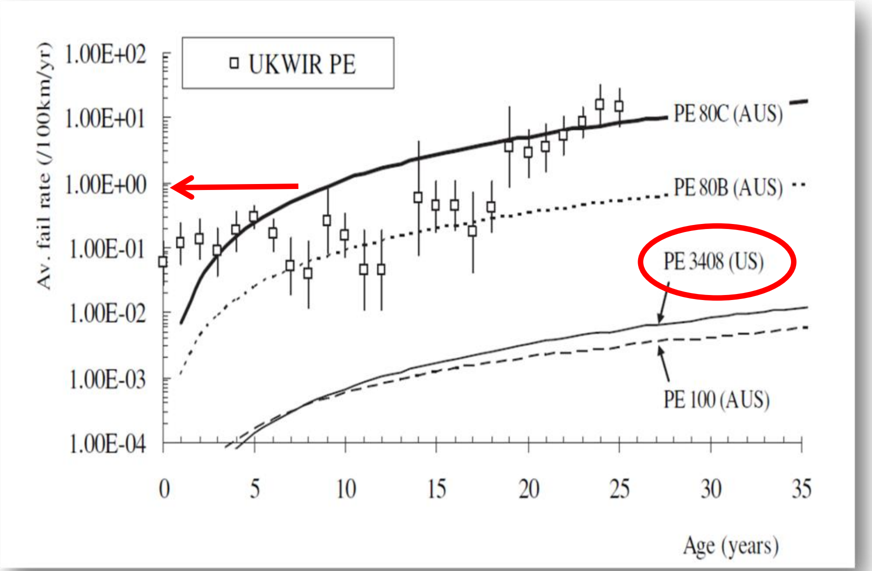
Premature aging can also occur with high temperatures, high chlorine, and inadequate stabilizers

Most failures are attributed to weld problems or third-party damage

Comparison of Stage II (slow crack growth) failure rates



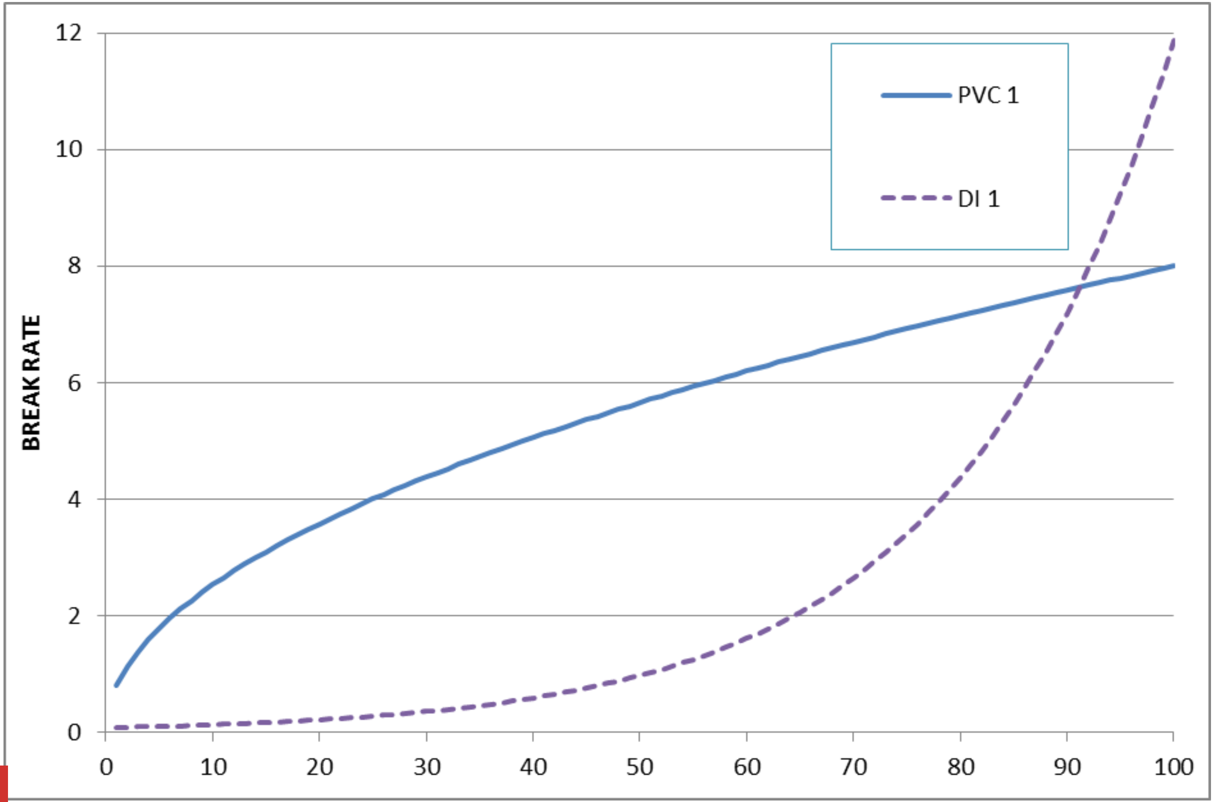
PVC



HDPE

Source: Water Research Fdtn

New Pipes Should be Designed to Last 100 Years or More



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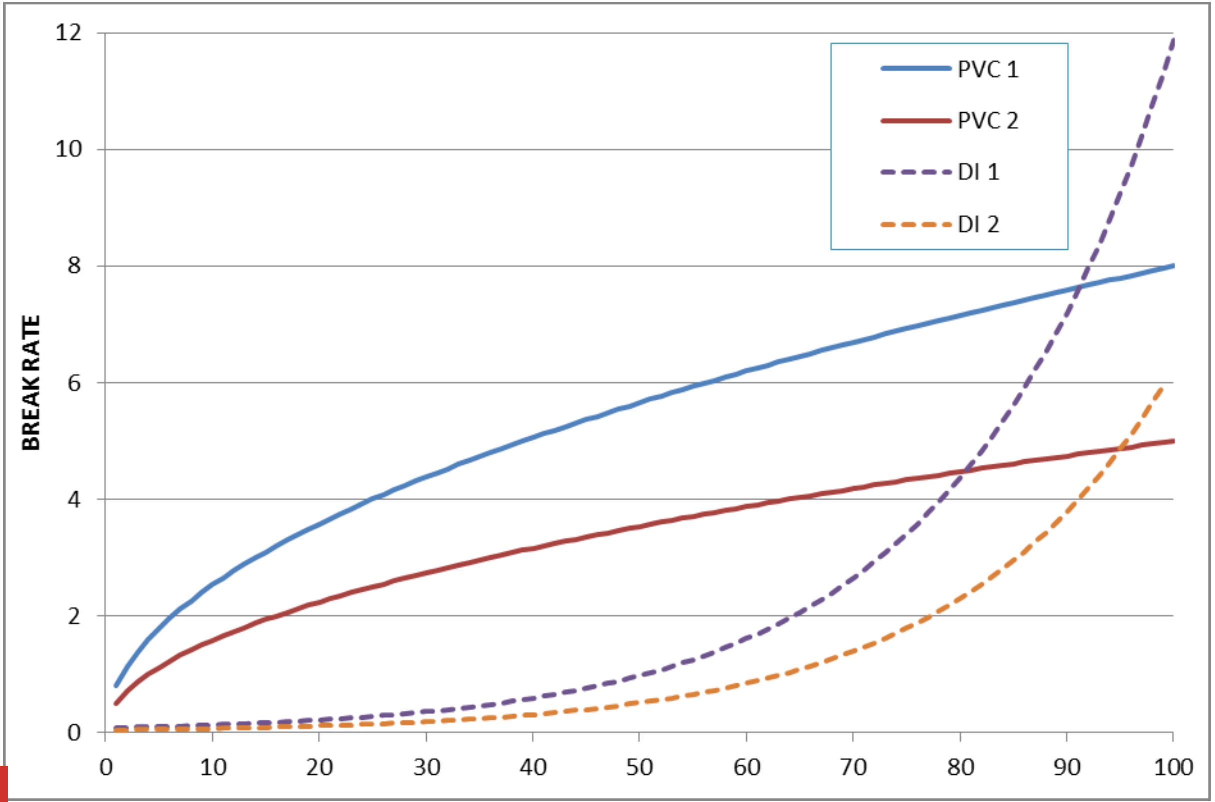

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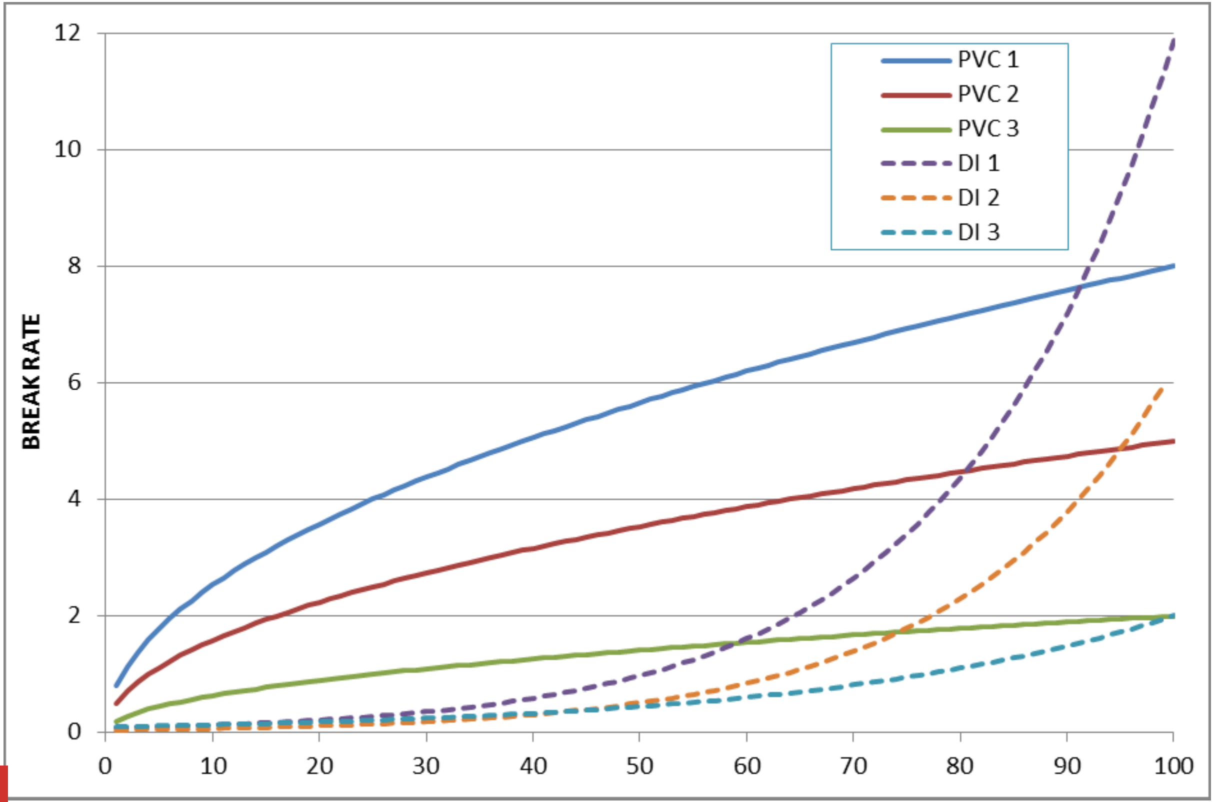
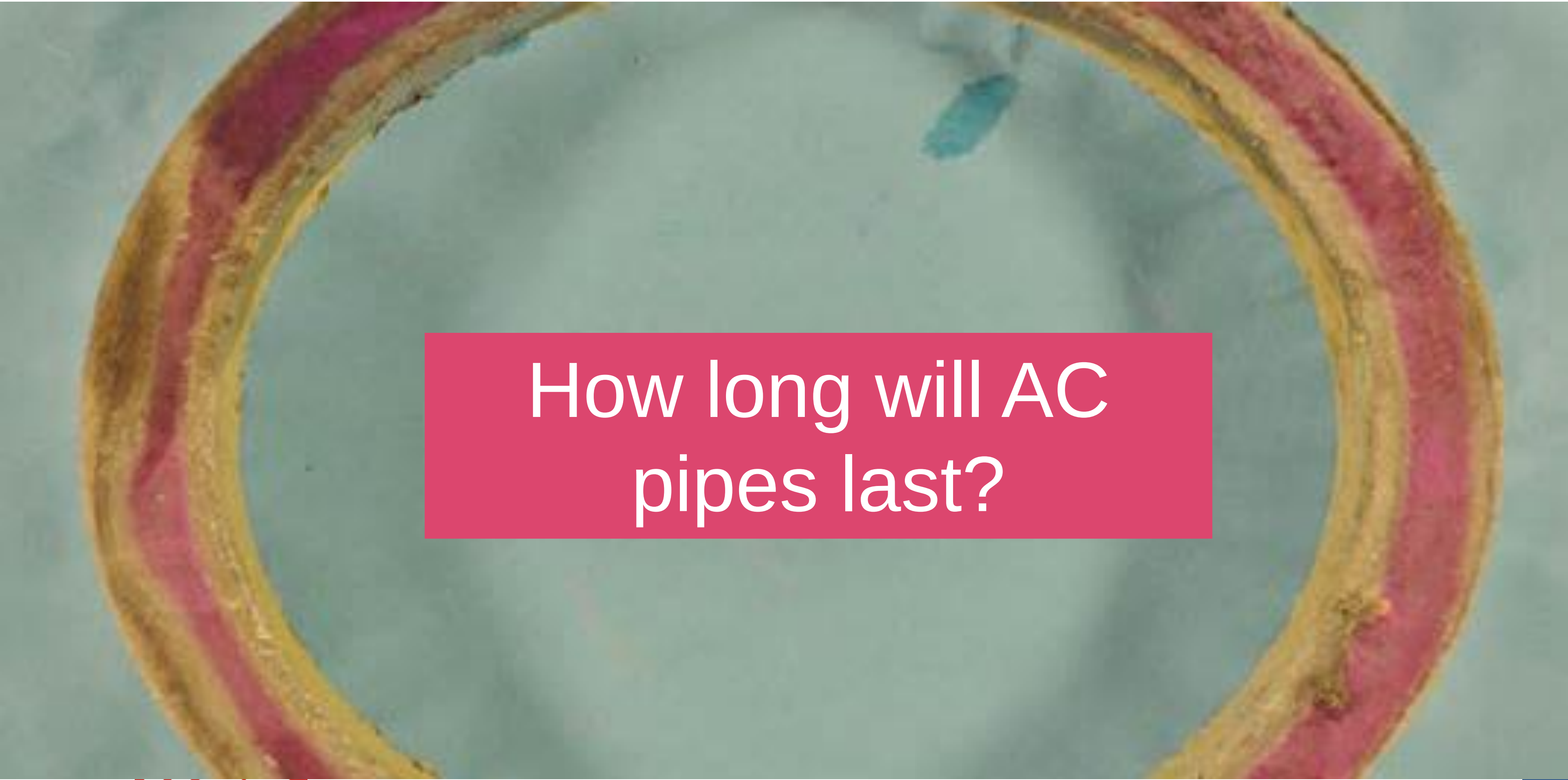
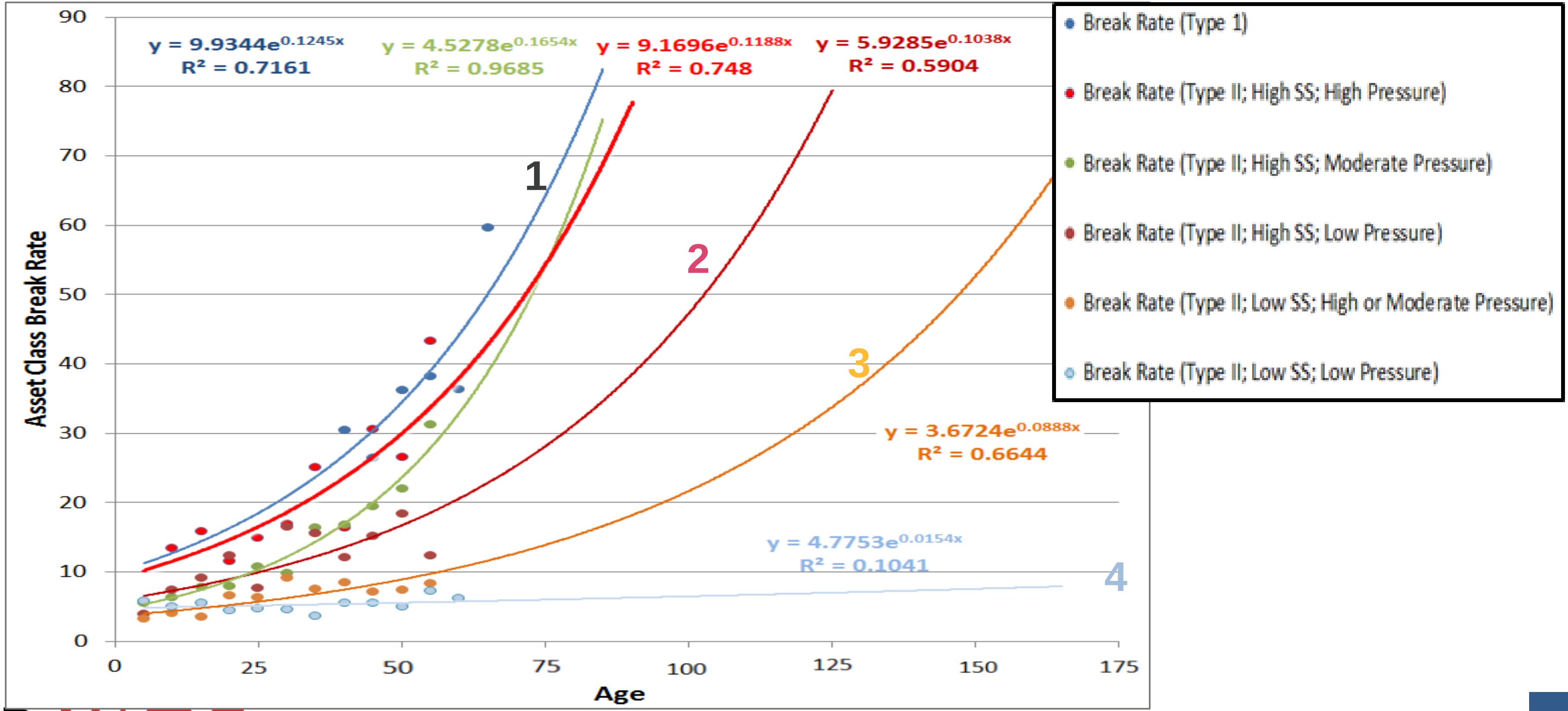




How long will AC pipes last?

Different "Asset Classes" Exhibited Different Performance



Life expectancy depends on pipe type, shrink/swell, pressure

	Asset Classes	Median Life Expectancy	Portion of EBMUD System
1	Type I or Type II with High SS, High or Moderate Pressure	98 years	27%
2	Type II with High SS, Low Pressure	90 years	12%
3	Type II with Low SS, High or Moderate Pressure	166 years	29%
4	Type II with Low SS, Low Pressure	255 years	32%

Weibull Modeling Results

Failure = 3 breaks in 500 feet or less, or 4 Breaks in > 500 feet

Earthquake Hazards Affecting Pipe

- » **Shaking**
  - Wave propagation acting straining the pipe
  - Surge/transients
- » **Permanent Ground Deformation (PGD)**
  - Fault movement
  - Liquefaction
  - Lateral spread
  - Landslide
  - Differential settlement

Pipe Characteristics Affecting Seismic Performance

- **Ruggedness** – material strength or ductility to resist shear and compression failures.
- **Bending** – beam strength or material ductility to resist barrel bending failures.
- **Joint flexibility** – joint and gasket design to allow elongation, compression, and rotation.
- **Joint restraint** – a system that keeps joints from separating.

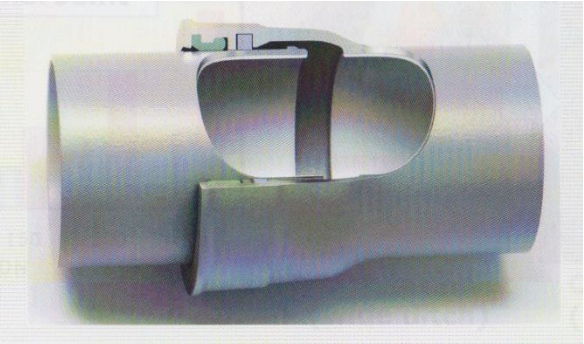
Pipe Failure Rates - Kobe, Japan, 1995

» DIP (unrestrained joint) failed from joint pull-out

» PVC pipe suffered barrel, fitting, and joint failures in addition to joint pull-out

Failure Mode	Failure Rates/km - Number of Failures									
	DIP		CIP		PVC		Steel		AC	
PipeLength (km)	1874		405		232		30		24	
Barrel	0	9	0.63	257	0.38	88	0.33	10	1.24	30
Fitting	0	1	0.31	124	0.17	40	0.03	1	0.04	1
Pulled Joint	0.47	880	0.49	199	0.33	76	0	0	0.37	9
Joint Failure	0	2	0.06	25	0.50	115	0.07	2	0.08	2
Joint Intrusion	0	5	0	1	0.01	3	0	0	0	0

Emerging Opportunities



Japanese Seismic Joint for DI Pipe

QUESTIONS?

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