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88th U.S. OPEN CHAMPIONSHIP
START
LEADERS
HOLE
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Phil Sheldon/Popperfoto
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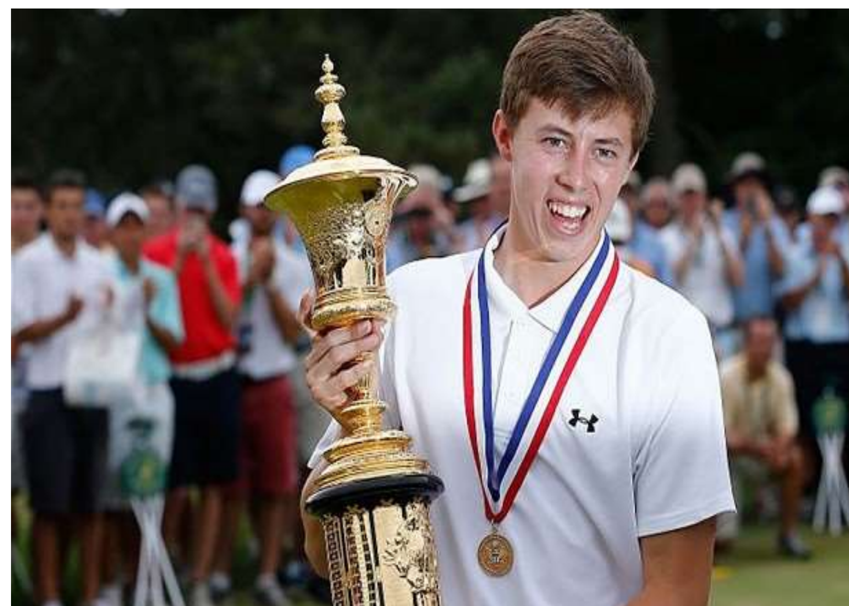
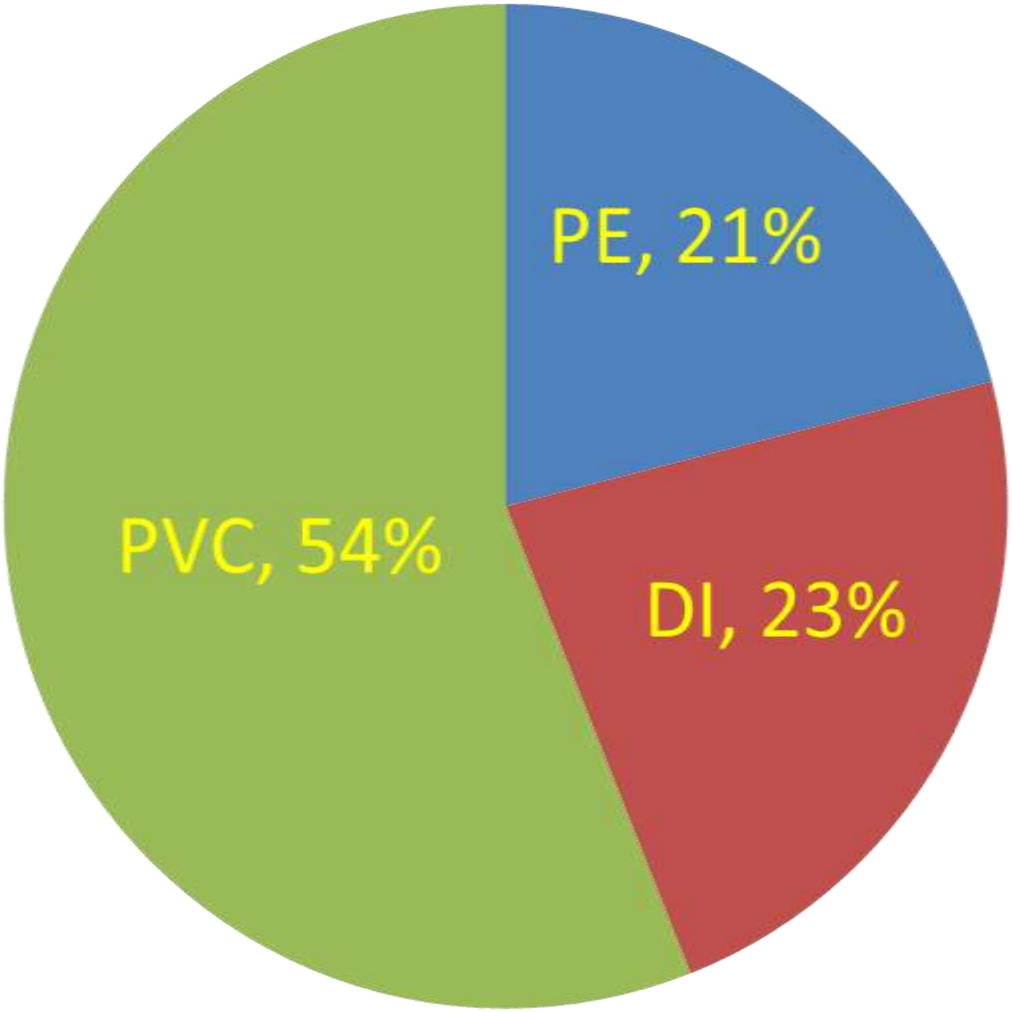


PIPE TECHNOLOGY	60's	70's	80's	90's	00's	10's
Asbestos Cement	X	X	X	X		
PVC IPS	X	X	X	X	X	X
Cast & Ductile Iron		X	X		X	X
PVC Sewer		X	X	X	X	X
PVC DIPS (C900)			X	X	X	X
Steel				X	X	X
PE Pressure					X	X
PE Corrugated						X
Copper						X
Lead						X


PE, 21%
DI, 23%
PVC, 54%

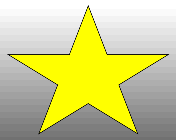
- **D**uctile **I**ron **P**ipe **R**esearch **A**ssociation
- **Unibell** PVC Pipe Association
- **P**lastic **P**ipe **I**nstitute

- **AWWA** Standards

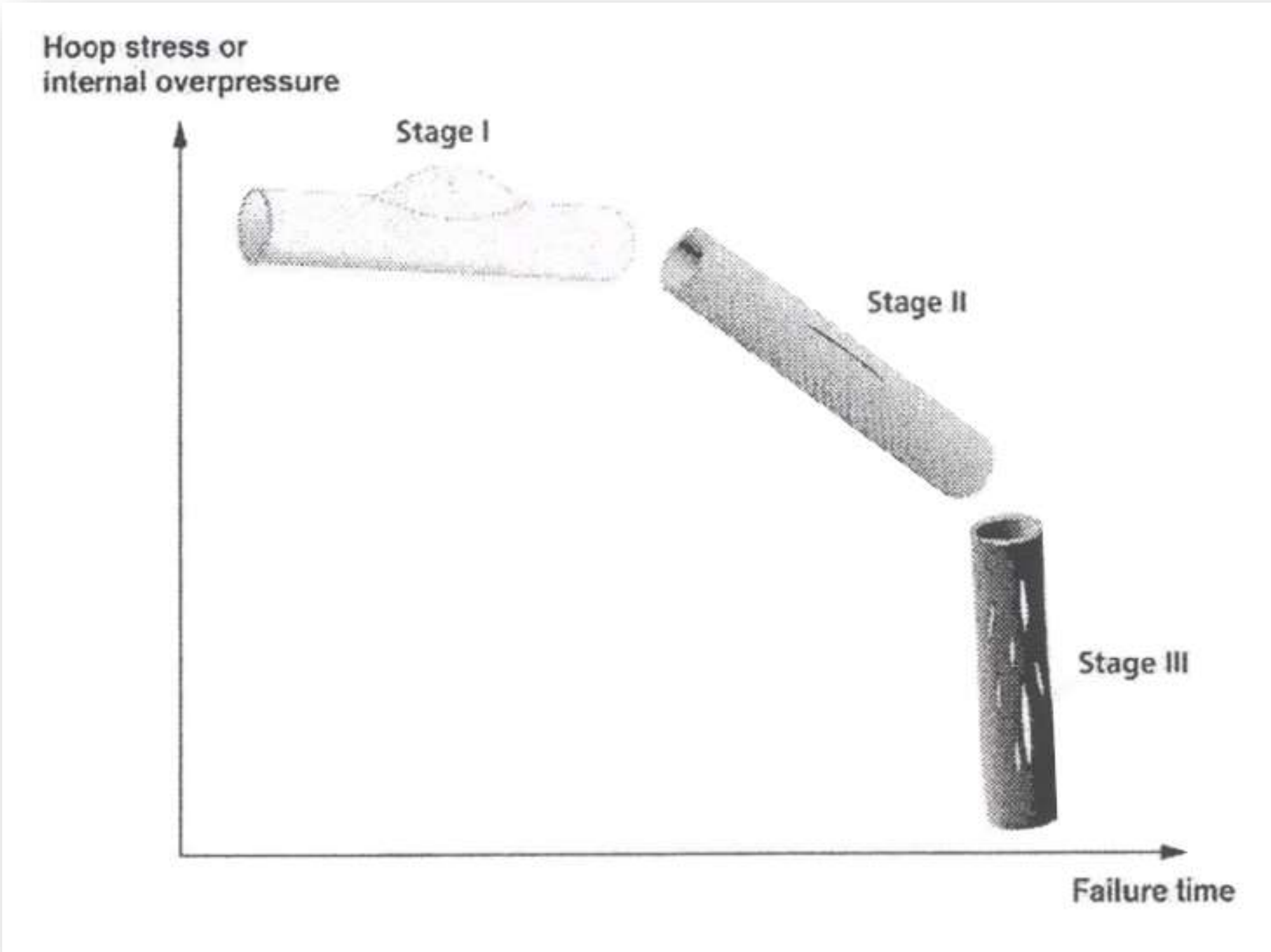
- **ASTM** Standards

Time/Life!

Failure Mechanisms	PVC	PE
Creep	√	√
Slow Crack Growth		√
Fatigue	√	√
Oxidative Degradation		√
Corrosion	√	√
Burst	√	√



PE Pipe Regression Curve



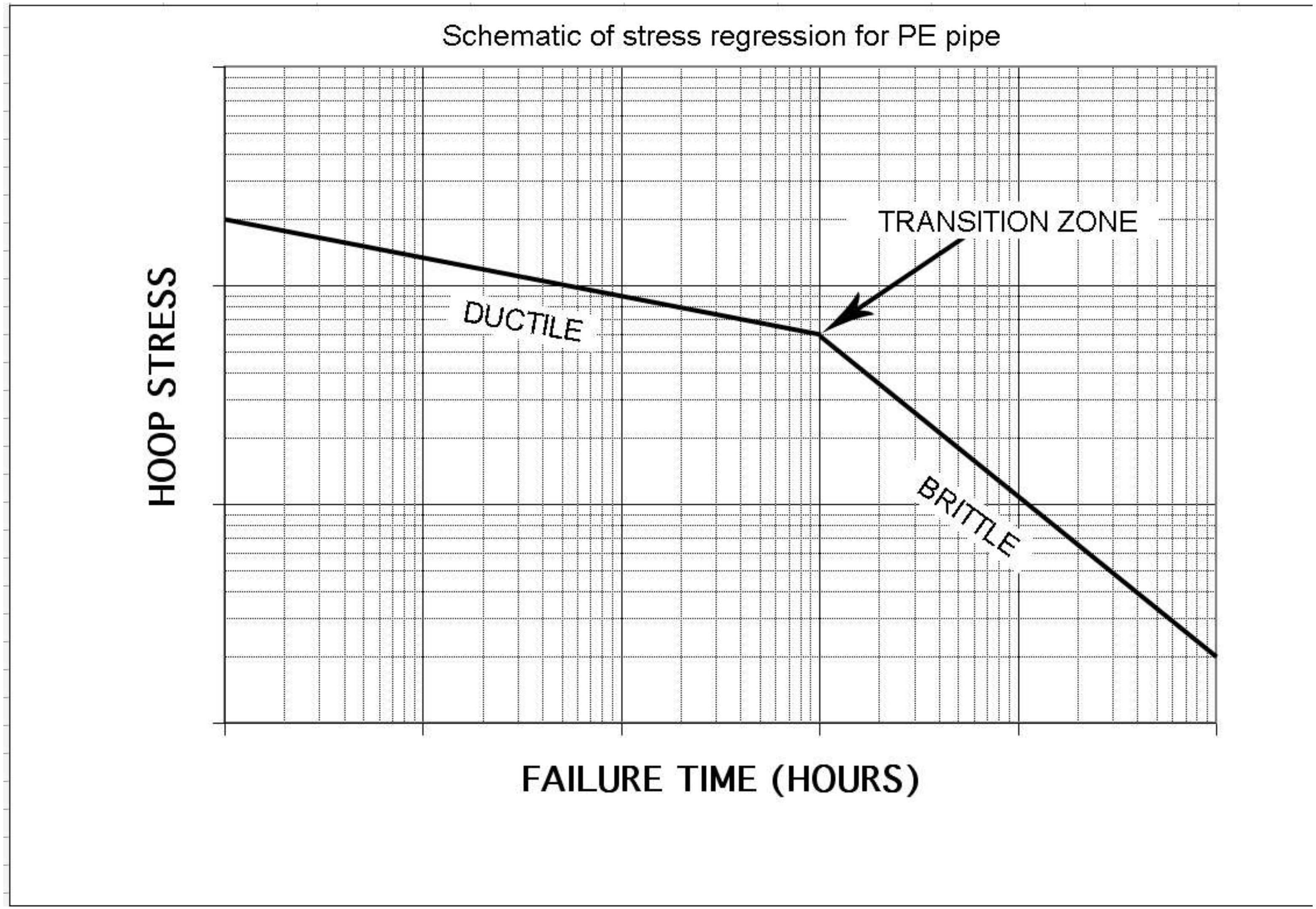
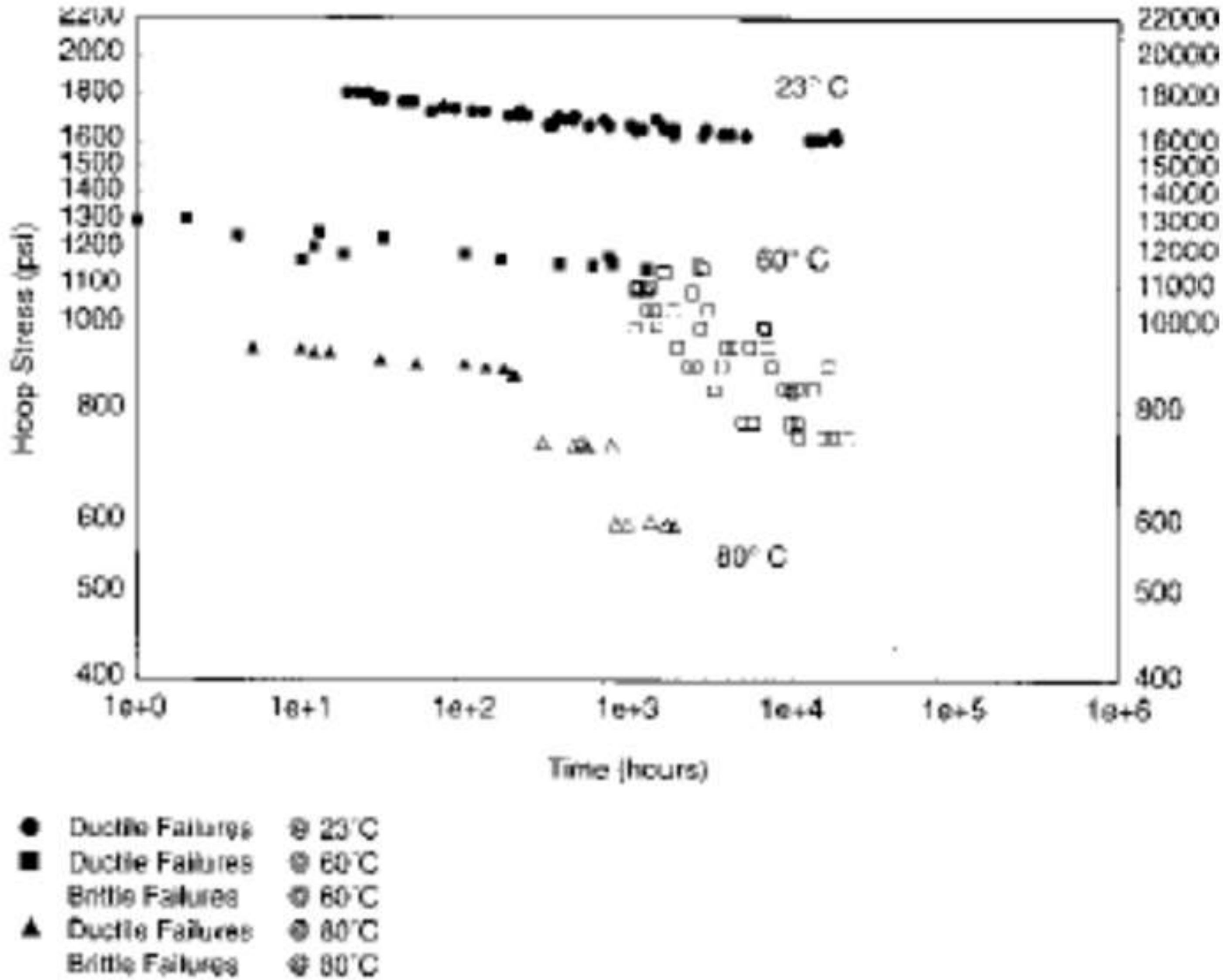
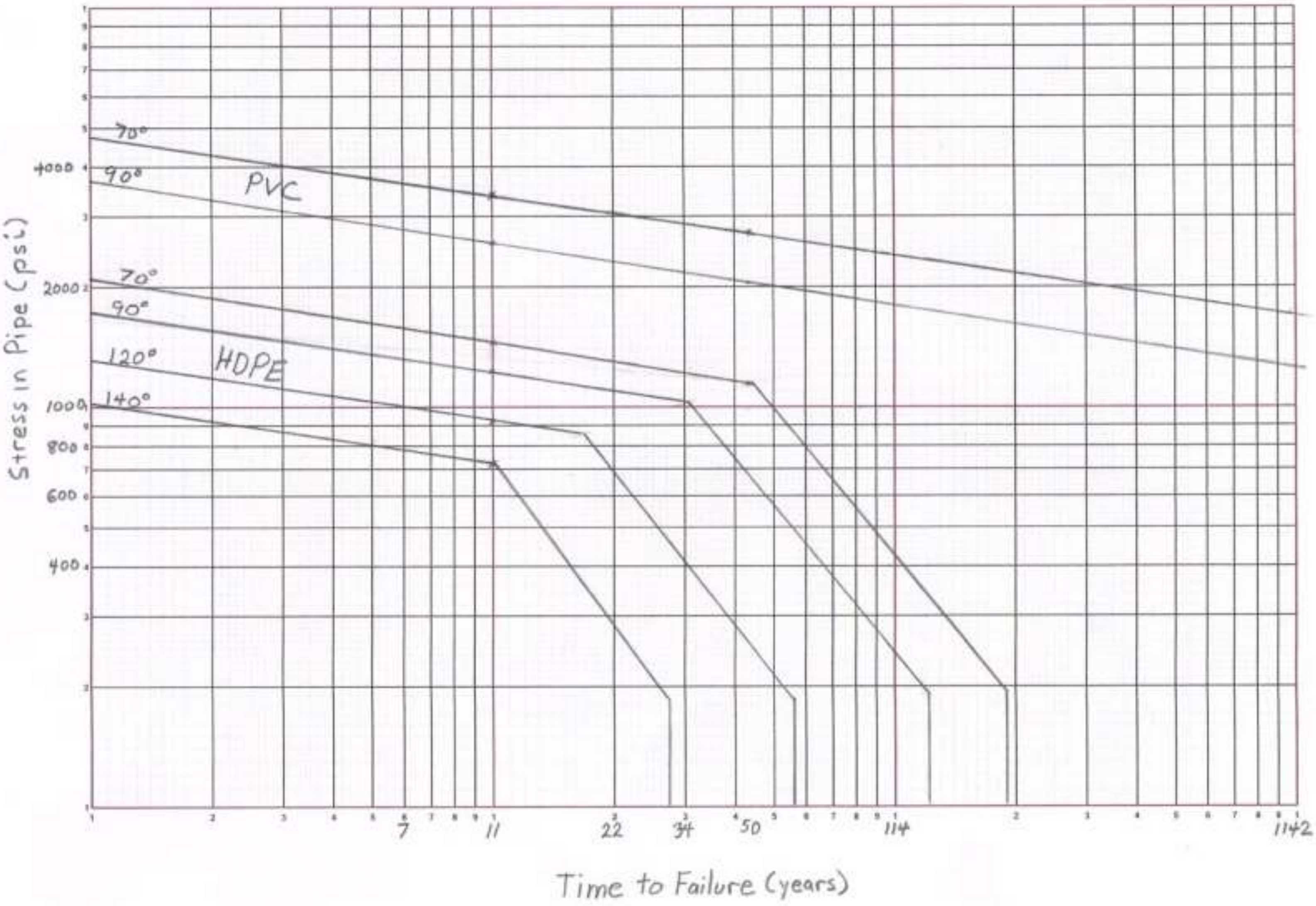

Schematic of stress regression for PE pipe
HOOP STRESS
TRANSITION ZONE
DUCTILE
BRITTLE
FAILURE TIME (HOURS)

Figure 4 – Typical Hydrostatic Curves for PE at Various Temperatures

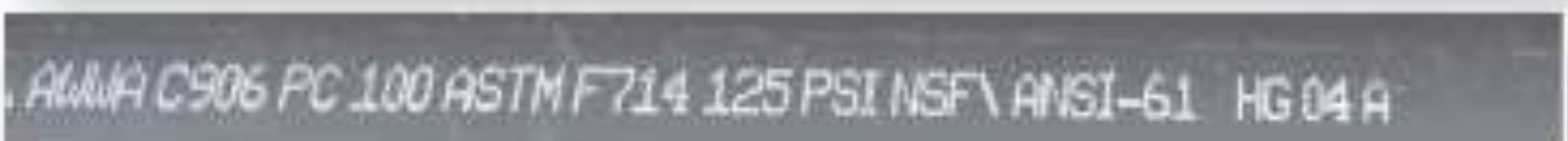


Pipe Life Curves



From PPI TR4

PE Compound	3608	4710
Hydrostatic Design Basis	1600 psi	1600 psi
Substantiation to Brittle Transition	50 years	50 years


4" IPS DR 17 DRISCOPLEX® PW 4100 PE3408\ 4710 ANSI\

AWWA C906 PC 100 ASTM F714 125 PSI NSF\ ANSI-61 HG 04 A

Las Vegas, NV; HDPE Service Line Failures:

Las Vegas Valley Water District (LVVWD) delivers water to over 1 million people in the Las Vegas Valley. Beginning in the early 1970's LVVWD began using polyethylene (HDPE) service laterals to deliver water from the mains to homes. In 1980, large numbers of HDPE service lines began to fail. Of the 80,000 HDPE service lines originally installed, about 56,000 are still in service, but the District is experiencing about 1500 failures per year.[1] One of the key causes of the failures as determined by LVVWD is oxidation of the HDPE service line which leads to brittle failure and cracking.[2]

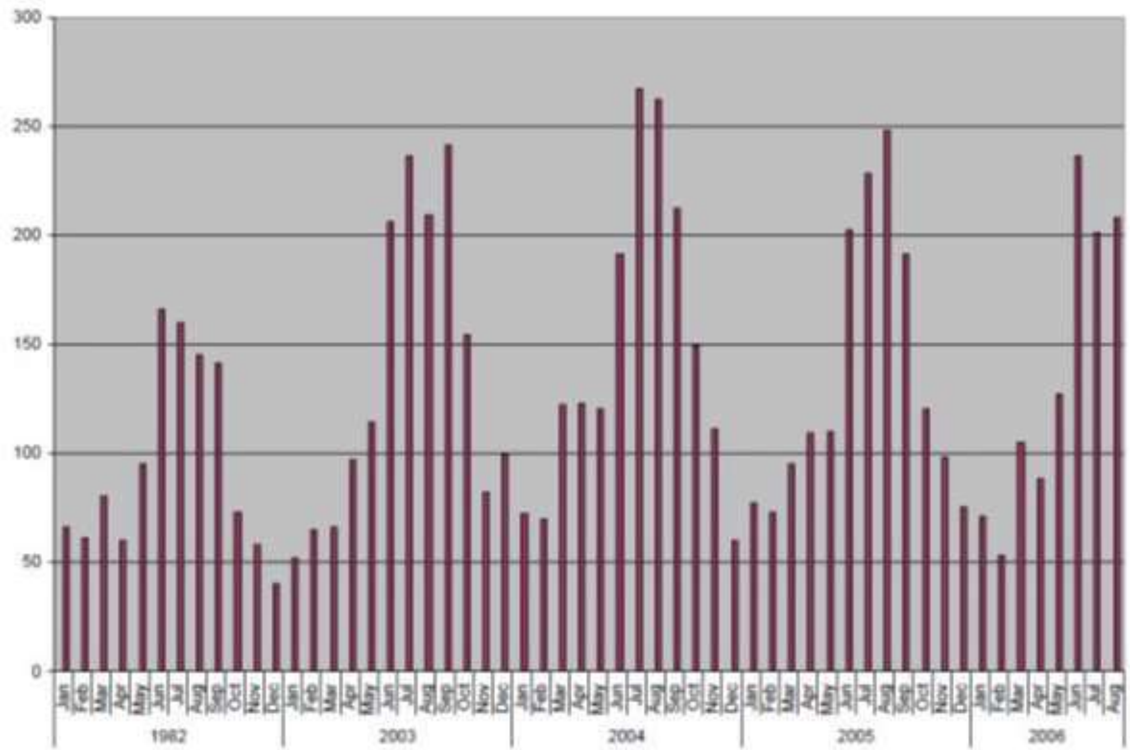


Figure # 1
PESL Failures by Month
Note Significant Increase in Failures During Summer Months

Failed HDPE Water Line, France– *Suez Environnement 2009*

Duvall, et al. *Oxidative Degradation of High Density Polyethylene Pipes from Exposure to Drinking Water Disinfectants*, 2009.

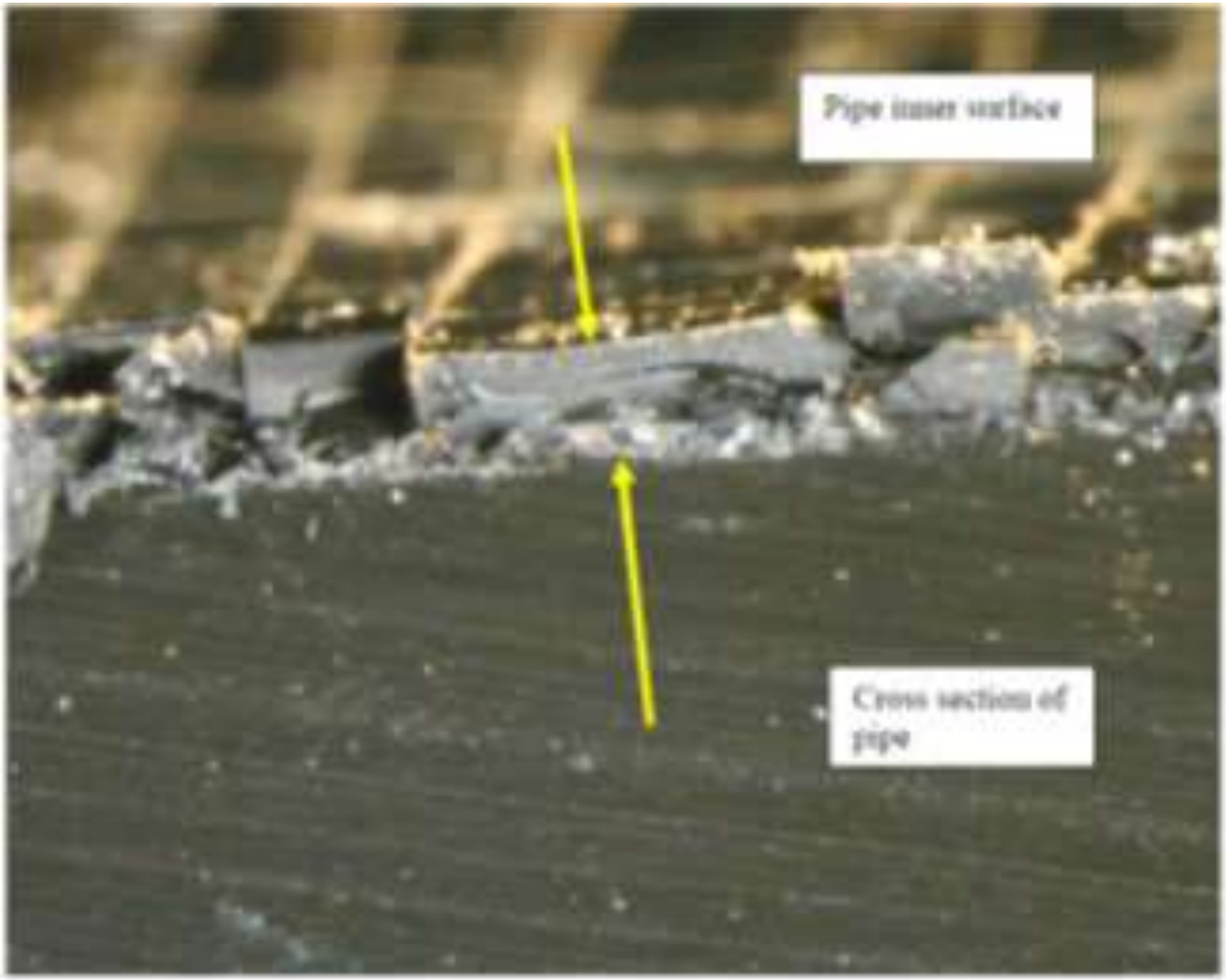


Figure 7. Thick degraded layer on inner surface of failed pipe.

Charter Plastics

Polyethylene. Pipe. Partners.

50 YEAR LIMITED WARRANTY
CHARTER PLASTICS
PE 3408, PE 3608 and PE 4710
POTABLE WATER PIPE

All CHARTER PLASTICS PE 3408, PE 3608 and PE 4710 POTABLE WATER PIPE is covered by this 50 Year Limited Warranty, against defects in materials and workmanship that result in failures in service. This warranty is valid when Charter Plastics PE 3408, PE 3608 and PE 4710 Potable Water Pipe is installed in a potable water well, potable water service or potable water distribution system in accordance with accepted and approved industry guidelines and practices. This warranty applies only to Charter Plastics PE 3408, PE 3608 and PE 4710 Potable water Pipe ("Potable Water Pipe")

Failures resulting from misuse, improper installation, improper disinfections, mechanical damage or chemically induced degradation or consumption of the pipe's anti-oxidants are not covered by this warranty, nor are failures resulting from fitting failures or improper fusions. This warranty does not apply to the design or installation of the potable water well, the potable water service or the potable water distribution system or any other component of the potable water well, the potable water service or the potable water distribution system.

Failures resulting from misuse, improper installation, improper disinfections, mechanical damage or chemically induced degradation or consumption of the pipe's anti-oxidants are not covered by this warranty,

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

2012 TECHNICAL REPORT

Long Term Performance of PE4710 Materials in Disinfectant Treated Nuclear Raw Water Systems

Table 4-11
Performance Projections of Cases for A Conservative End-Use Application (Heat Exchanger Outlet) For A Generic Category 3 PE Compound

Sub-case #[1]	Operating Stresses at End-Use Temperatures (psi)	ORP (mV)	Projected Lifetime (years)[2]			
			4" DR 11	12" DR 11[3]	24" DR 11[3]	36" DR 11[3]
C	604/648/670[4]	768	8	13	15	16
D		828/500	41	60	72	79
C	544/583/603[5]	768	12	18	22	24
D		828/500	59	87	100	110
C	483/518/536[6]	768	18	27	33	36
D		828/500	89	130	160	170

Notes: 1: See Table 2 for Case details. 2: Based on modeling approach detailed in Appendix A. 3: Based on application of size shift to 4" data (Appendix A). 4: 100% of design allowable stress. 5: 90% of design allowable stress. 6: 80% of design allowable stress.

From EPRI Report 1025296

PE Compound Categorization for Potable Water Applications

TN-43/2014

PLASTICS · PIPE · INSTITUTE®

THE VOICE OF AN INDUSTRY

Table 1: PE Compound Categorization Requirements

	Test Stress, psi		
	360	400	450
Categorization	**Minimum Log Average Test Time, h**		
Category 1 (CC1)	2,700	1,900	1,200
Category 2 (CC2)	7,400	5,100	3,400
Category 3 (CC3)	16,200	11,100	7,400

From PPI TN-43

Critical Flaw Size in Butt-Fusion Joints for Service Life Prediction of HDPE Pipes

Drs. Prabhat Krishnaswamy, S. Kalyanam, D.-J. Shim, Y. Hioe
Engineering Mechanics Corporation of Columbus (Emc^2)
and
E. Focht
US Nuclear Regulatory Commission

September 22, 2014
Session 3A
Plastics Pipes XVII
Chicago, IL

Summary Observations

- ***Brown, Popelar, GTF (Emc^2), and other models are VERY similar….service life is a***
  - ***Power law function of SIF K_I***
  - ***Exponential function of Temperature***
  - ***Function of other Geometric / Constraint Factors***

- ***Calibrate Brown model with Slope (n), PENT Value, and Q, the Temperature Shift Function; Other geometric factors needed?***

- ***Based on limited data available – PE butt joints may have MUCH LOWER RESISTANCE to SCG than Parent material***

- ***Need Additional SCG data on Coupons, Notched Pipes - Joints vs Parent Material……Joint SCG resistance may be independent of resin PENT Value???***

A Fracture Mechanics Approach to Service Life Prediction of HDPE Fusion Joints in Nuclear Applications

By S. Kalyanam[1], P. Krishnaswamy[1], Y. Hioe[1], D.J. Shim[1], and E. Focht[2]
[1]Engineering Mechanics Corp. of Columbus (Emc[2]), Columbus, Ohio, USA
[2]United States Nuclear Regulatory Commission, Rockville, Maryland, USA

Note: This is an abridged version of the authors' original ANTEC® Orlando 2015 paper, which won SPE's Plastic Pipe and Fittings Special Interest Group's Best Paper Award (this year sponsored by Chevron Phillips Chemical Company LP). To see the complete paper and the full ANTEC proceedings, contact SPE customer relations at +1 203-775-0471.

High-density polyethylene (HDPE) pipes are considered by the nuclear industry as a potential replacement option to currently employed metallic piping for service-water applications. The nuclear industry is motivated in using HDPE in service water piping due to inherent advantages such as resistance to corrosion, abrasion resistance, much lower weight compared to steel, high flexibility, ductility and resistance to soil movement, and superior flow characteristics due to hydraulic friction.

More recently, higher-grade HDPE materials (such as PE100 in Europe and Asia and PE4710 which meets the cell class 445574C as per ASTM D3350[1]) have become candidate materials for safety-related nuclear service water applications, high-pressure gas transmission, and other hydraulic/water distribution applications. HDPE piping has been installed in the Callaway and Catawba plants with relief requests.[2,3] HDPE piping and fusion-joints are being evaluated from the perspective of design, operation, and service life before their routine installation in nuclear power plants.

Past data on safety-related applications for PE piping in the gas distribution industry were developed for smaller diameter pipes (203.2 mm (8 in.) or less) that are buried and operate at temperatures that are around 22.8°C, which is much lower than service water application temperatures (60°C). It is well known that the major failure mode of concern in HDPE piping is slow crack growth (SCG) that occurs from flaws under sustained stresses.[4]

SCG rates in PE materials vary exponentially with temperature, specified by:

$$da/dt = AK^n \exp(Q/RT) \qquad \text{Equation 1}$$

where da/dt is the SCG rate, K is the stress intensity factor, T is the temperature, R is the universal gas constant, and A, n, and Q are material constants. *Equation 1* depicts the SCG

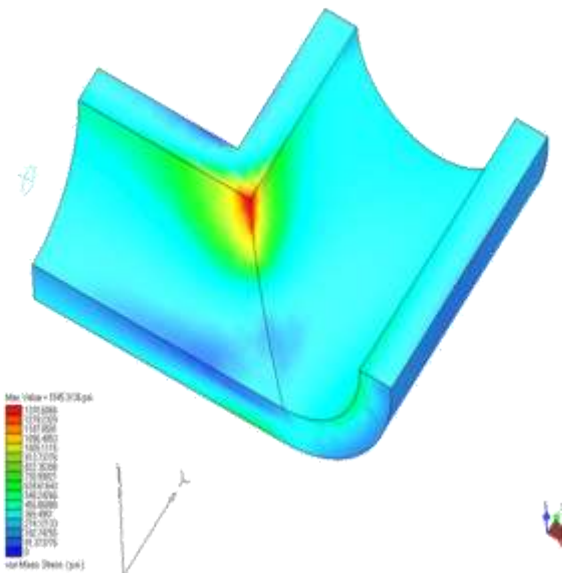
Ashish M. Sukhadia of Chevron Phillips Chemical Company LP (left) presented an ANTEC 2015 Best Paper Award to Prabhat Krishnaswamy of Emc[2].

The test indicates the small time required for damage development in the butt fusion joint material. Markedly lower joint material SCG failure times were also observed in work by other researchers on PE resins, PE resins used in gas pipelines, and our earlier study on unimodal HDPE resins.

From earlier investigations it was found that the SCG test failure time using SENT tests on parent material could be correlated to the 10k or 2k PENT failures on the compounded resin materials. However, from *Figure 4* (or *Table 1*) it was observed that the butt-fusion joint failure times are similar, irrespective of the parent material.

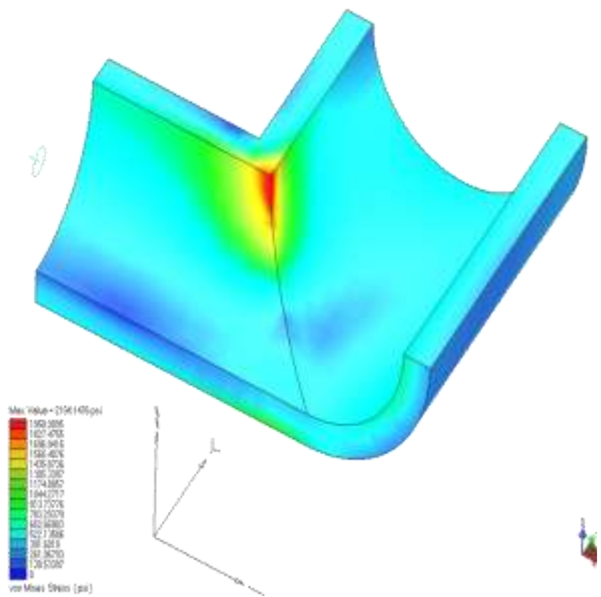
Stress in PE Tee

DR 7 - 12” Tee



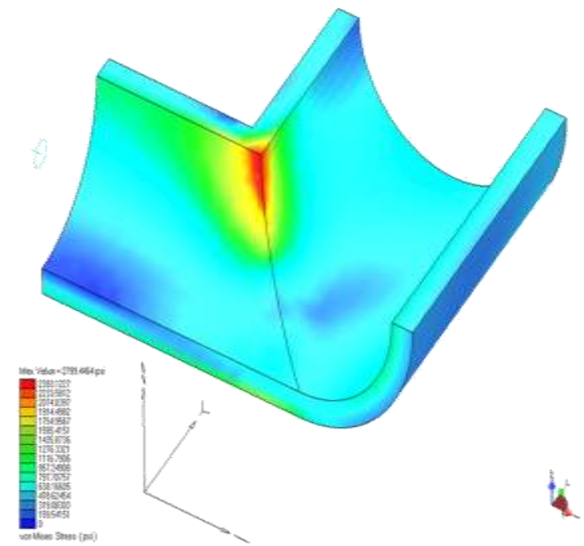
Max = 1370.6 psi

DR 9 - 12” Tee



Max = 1958.0 psi

DR 11 - 12” Tee



Max = 2391.1 psi

Information provided courtesy of Harrington Corporati

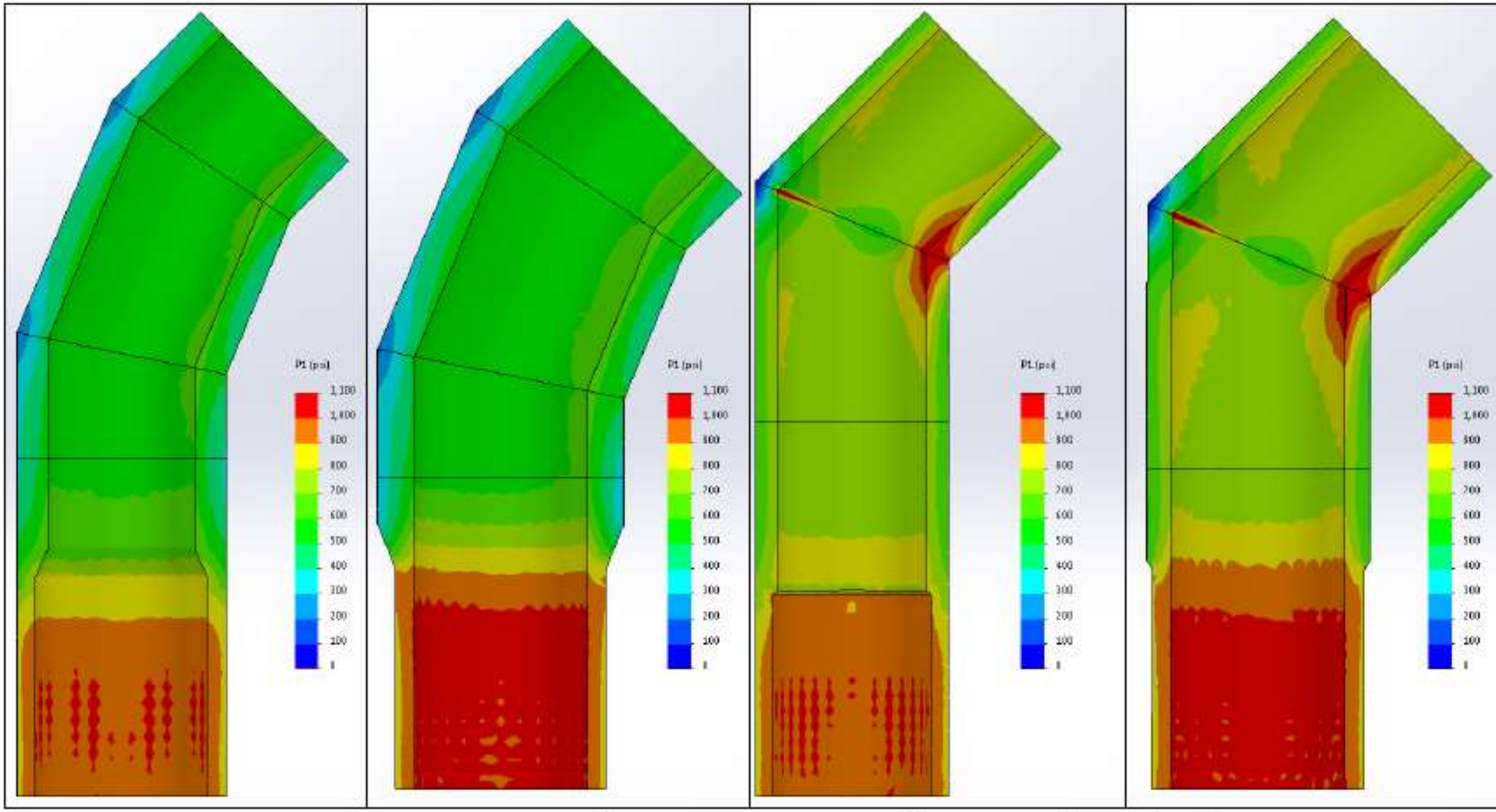
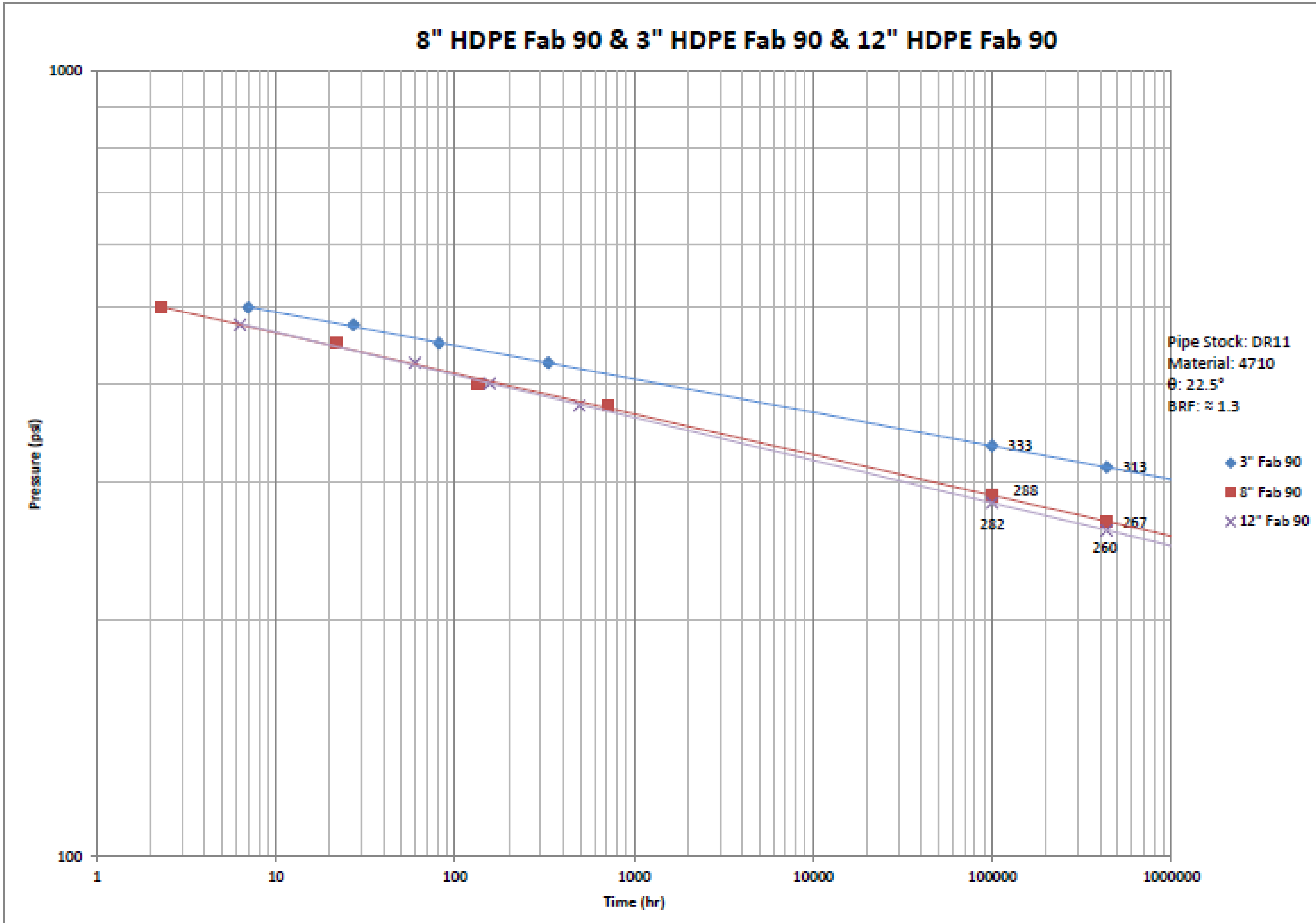


Figure 10. Comparison of stresses in ID and OD reinforced elbows


54 min
400 psi
2hrs 48min
450psi
2hrs.
18mins
500psi


8" HDPE Fab 90 & 3" HDPE Fab 90 & 12" HDPE Fab 90
Pressure (psi)
Time (hr)
1000
100
1
10
100
1000
10000
100000
1000000
333
313
288
282
267
260
Pipe Stock: DR11
Material: 4710
θ: 22.5°
BRF: ≈ 1.3
3" Fab 90
8" Fab 90
12" Fab 90

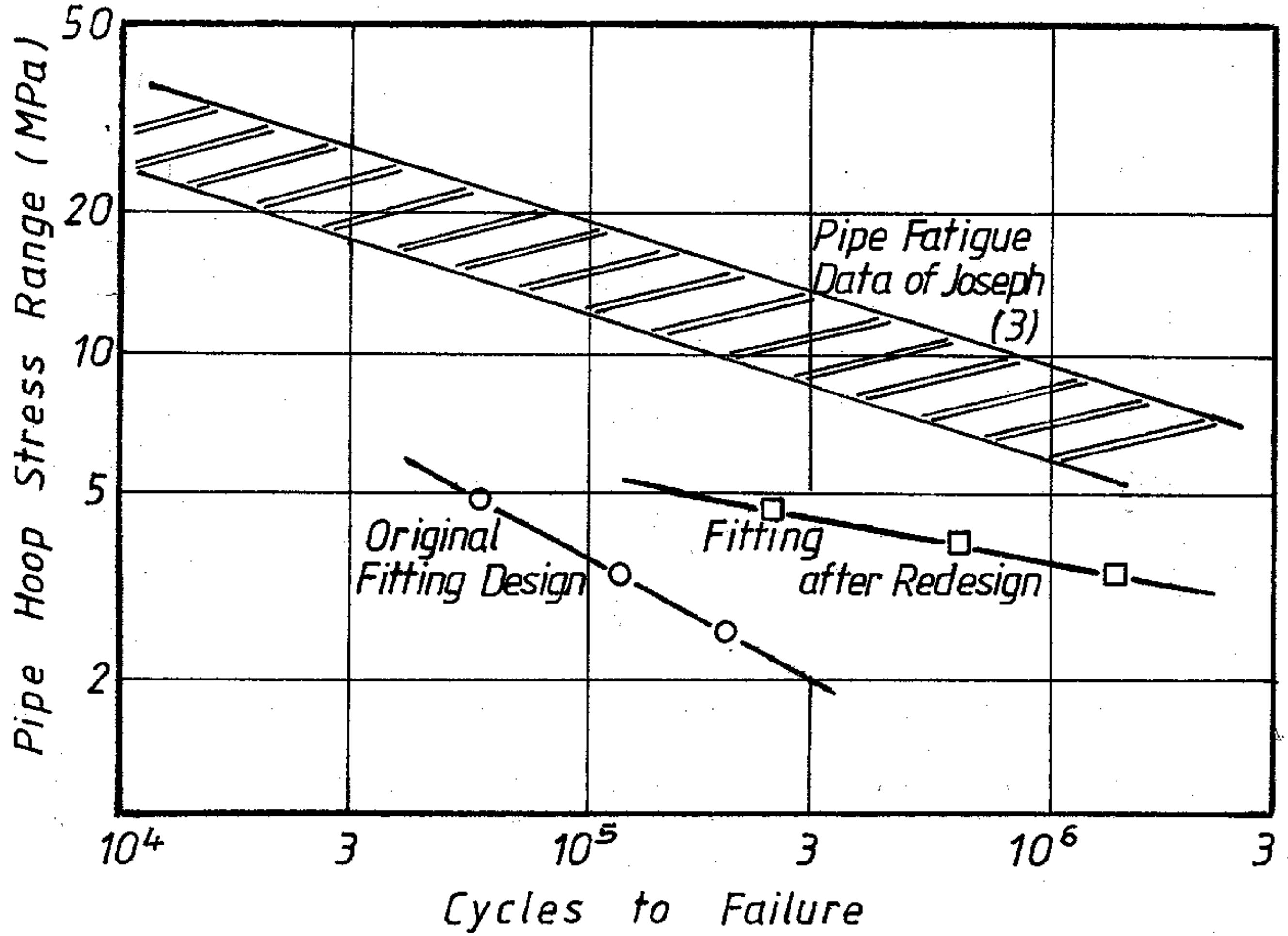


Figure 8. The fatigue response of a UPVC equal tee. Note first that the design was important in determining response, and that the fitting failed before the pipe.

AWWA M55, Chapter 4

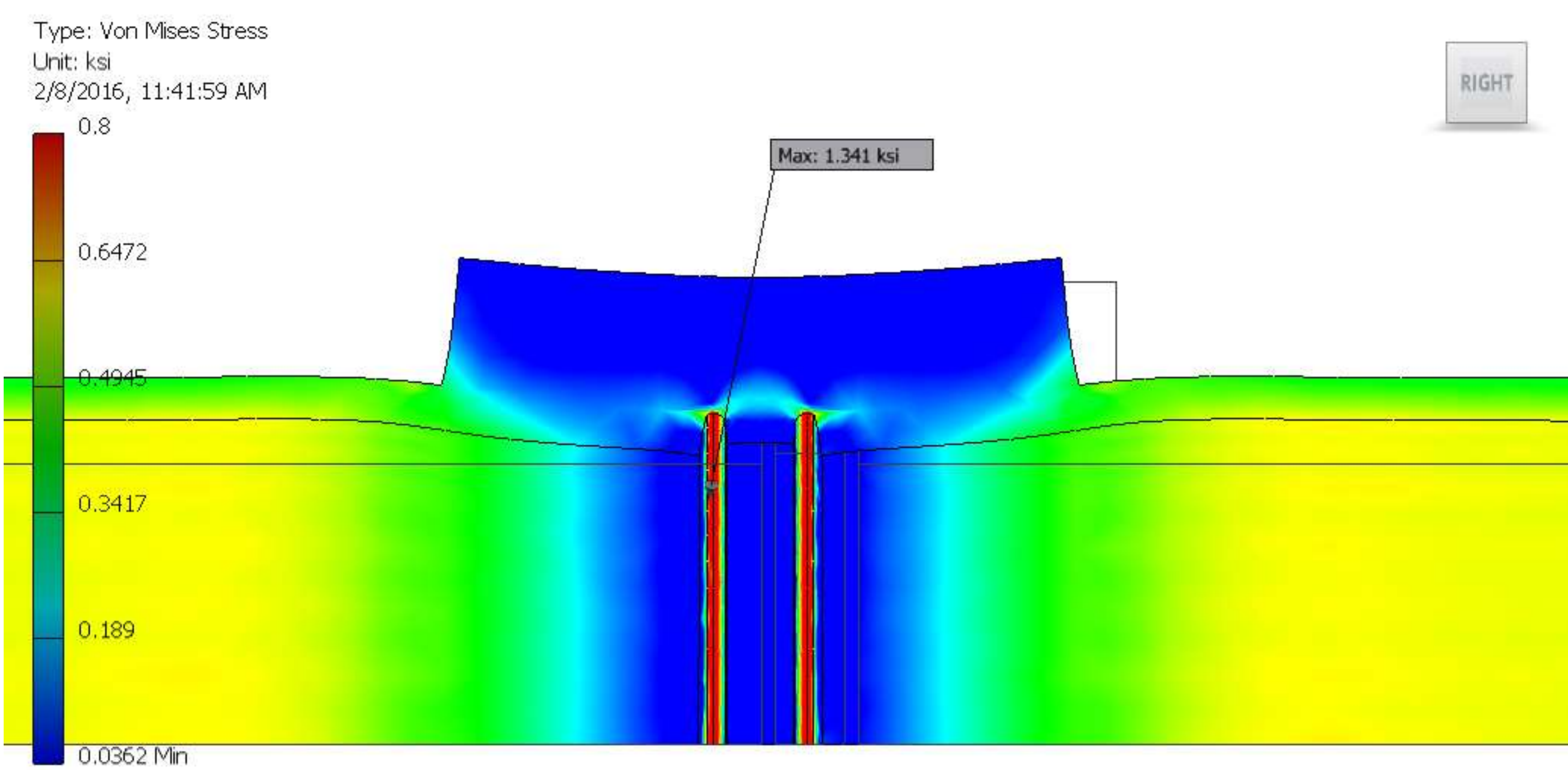
Table 4-7 PE 3408 working pressure rating for recurring surge events as a result of instantaneous change in water column velocity

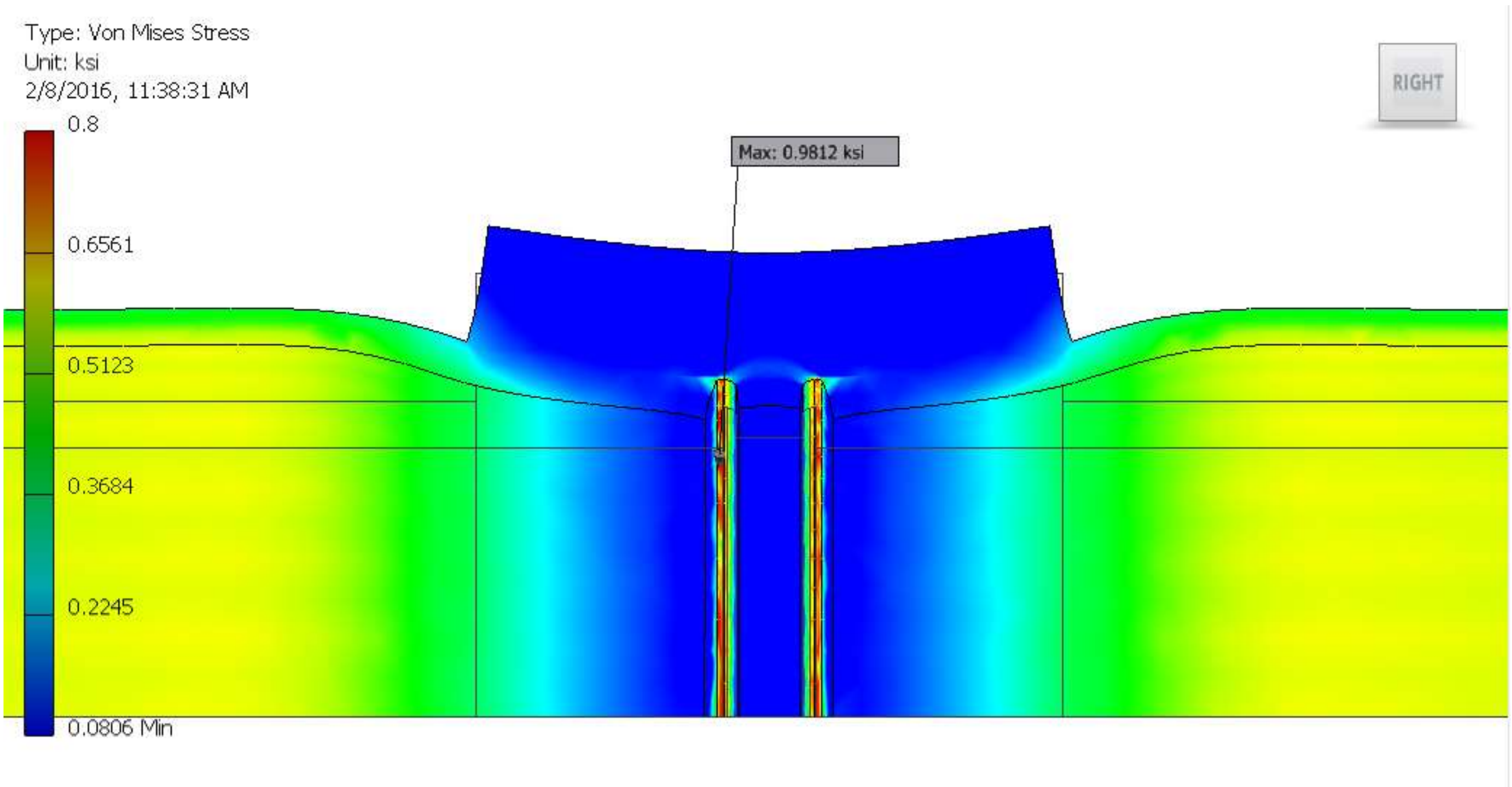
	WPR (*psi*) vs. Recurring Instantaneous Change in Water Column Velocity (*fps*)						
Pipe DR	0-2 *fps*	3 *fps*	4 *fps*	5 *fps*	6 *fps*	7 *fps*	8 *fps*
7.3	254	254	254	254	254	252	234
9	200	200	200	200	200	187	171
9.3	193	193	193	193	193	178	162
11	160	160	160	160	154	139	125
13.5	128	128	128	128	115	102	90
15.5	110	110	110	106	94	83	71
17	100	100	100	94	82	71	60
21	80	80	80	70	60	50	40
26	64	64	60	51	42	33	24
32.5	51	51	44	36	28	20	13

NOTE: While the pipe is adequate to resist the positive pressure shown in the shaded areas of the table, negative pressure must be prevented from exceeding 1.0 atmosphere to prevent water column separation.

TABLE I. THE MEASURED 80°C AND ESTIMATED 20°C FATIGUE STRENGTH OF BUTT, SOCKET AND ELECTROFUSION JOINED MDPE PIPE SYSTEMS

	JOINTING METHOD		
	BUTT	SOCKET	ELECTROFUSED
Failure Site	in the pipe	socket fitting	electrofusion fitting
Nominal (N) or Actual (A) $\Delta\sigma_H$	4.38 MPa(A)	4.65 MPa (N)	4.65 MPa (N)
Mean Measured 80°C Fatigue Life	82,300 Cycles	39,300 Cycles	39,800 Cycles
Estimated 20°C Fatigue Life	271×10^6 Cycles	21.1×10^6 Cycles	19.0×10^6 Cycles


Type: Von Mises Stress
Unit: ksi
2/8/2016, 11:41:59 AM
0.8
0.6472
0.4945
0.3417
0.189
0.0362 Min
Max: 1.341 ksi
RIGHT



Type: Von Mises Stress
Unit: ksi
2/8/2016, 11:38:31 AM
0.8
0.6561
0.5123
0.3684
0.2245
0.0806 Min
Max: 0.9812 ksi
RIGHT

Polyethylene Encasement

Pipe	60 Second Burst Pressure
DR 17 PE	363 psi
DR 15.5 PE	400 psi
DR 13.5 PE	464 psi
DR 11 PE	580 psi
SDR 21 PVC	630 psi

From ASTM standards.

Who is John Riordan

- I am a product manager and product engineer for harco.
- The designs of most of the products used in irrigation were overseen by me
- I sent in various industry councils including AWWA, ASTM, Unibell, and Plastic Pipe Institute

What changes has the use of more PE in Golf Irrigation brought at Harco?

- We anticipated uptake of PE over 20 years ago
- From that time we executed a research of the PE technology and industry in general and particularly as it applies to pipe fittings both in North America and the rest of the world.
- In addition to gaining facility with the technology we developed relationships with participants including manufacturers and industry associations.
- We started then developing

PE vs PVC share in golf irrigation installation

Harco has introduced a full line of fittings and valves for PE systems

Golf irrigation distributors have had to adapt

Where is PE not a good choice?

- The Country Club has had a good experience with PE to date
- If might have been interesting to contrast that with a panel member who has not had a good experience.

“50-100 Year Life Expectancy”

Fusion vs Gaskets, Glued Fittings

Environmentally Sensible

Less Surge Related Fatigue

Deteriorating Metal Fittings

Great Installation in Rock

Maximized Life of Installed Pipe

No Thrust Blocks

Minimized Metal Components

Easy Add-Ons

3-4 Hour Water Window

No Leaks !!!

No Leaks !!!

Self Restrained and Thus No Thrust Blocks

TEMPERATURE

AWWA M55, Chapter 4

Table 4-4 Pressure class, surge allowance, and corresponding sudden velocity change for PE 3408 pipe operating at service temperatures through 80°F (27°C)

		Recurring Surge Events		Occasional Surge Events	
DR	PC (*psi*)	P_{RS} (*psi*)	Corresponding Sudden Velocity Change (*fps*)	P_{OS} (*psi*)	Corresponding Sudden Velocity Change (*fps*)
7.3	254	127	6.9	254	13.8
9	200	100	6.2	200	12.4
9.3	193	96	6.1	193	12.2
11	160	80	5.6	160	11.1
13.5	128	64	5.0	128	10.0
15.5	110	55	4.7	110	9.3
17	100	50	4.4	100	8.9
21	80	40	4.0	80	8.0
26	64	32	3.6	64	7.2
32.5	51	25	3.2	51	6.4

AWWA M55, Chapter 4

Table 4-6 Temperature compensation multipliers, F_T

Maximum Operating Temperature		Temperature Compensation Multiplier, F_T
°F	°C	
Below 81°F	Below 28°C	1.0
From 81°F to 90°F	From 28°C to 32°C	0.9
From 91°F to 100°F	From 33°C to 38°C	0.8
Above 100°F	Above 38°C	—

NOTE: The upper operating temperature limit, as well as the temperature compensation multiplier for temperatures above 100°F (38°C), can vary depending on the pipe material. The pipe manufacturer should be consulted for this information.

PE Handbook, Chapter 3

TABLE A.2

Temperature Compensating Multipliers for Converting a Base Temperature HDS or PR to HDS or PR for Another Temperature Between 40 and 100°F (4 and 38°C)

Maximum Sustained Temperature, °F (°C) [1]	Multiplier [2,3]
40 (4)	1.25
50 (10)	1.17
60 (15)	1.10
73 (23)	1.00
80 (27)	0.94
90 (32)	0.86
100 (38)	0.78

PE Handbook, Chapter 3

Examples of the Application of the Interpolation Equation

Example – A PE pipe is made from a PE4710 material that has an established HDB of 1600psi for 73°F (533°R) and, an HDB of 1,000psi for 140°F (600°R). What is the temperature compensating multiplier for a sustained operating temperature of 120°F (580°R)?

For this case, $F_{120°F} = 1 - \frac{(1600-1000)}{1600} \frac{\left[\frac{1}{533}-\frac{1}{580}\right]}{\left[\frac{1}{533}-\frac{1}{600}\right]} = 0.73$

PE Handbook, Chapter 4

TABLE 1-3A

Allowances for Momentary Surge Pressures Above PR or PC for Pipes Made From PE4710 and PE3710 Materials[1].

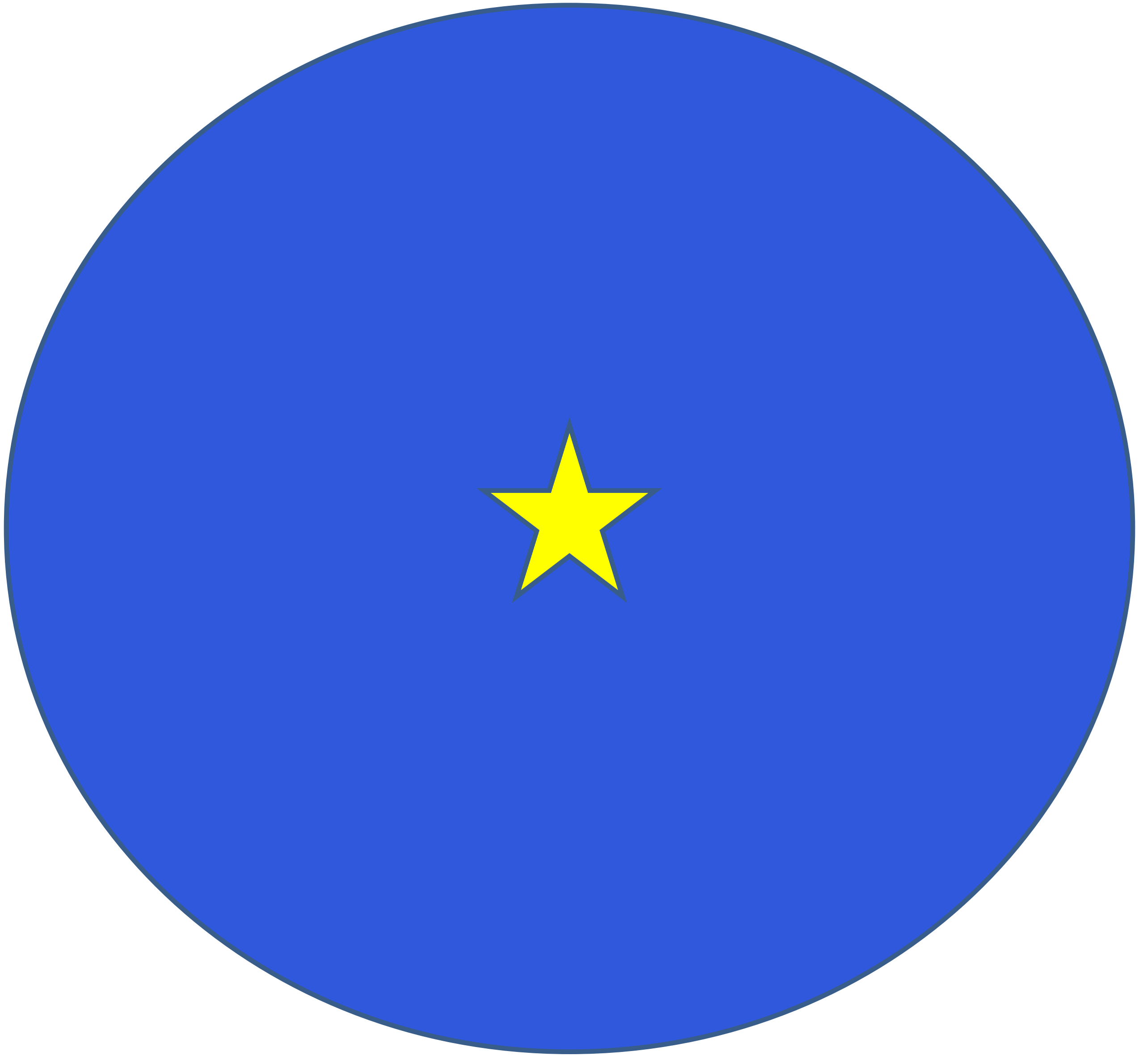
Pipe Standard Diameter Ratio (SDR)	Standard Static Pressure Rating (PR) or, Standard Pressure Class (PC) for water @ 73°F, psig	Standard Allowance for Momentary Surge Pressure Above the Pipe's PR or PC			
		Allowance for Recurring Surge		Allowance for Occasional Surge	
		Allowable Surge Pressure, psig	Resultant Allowable Sudden Change in Velocity, fps	Allowable Surge Pressure, psig	Resultant Allowable Sudden Change in Velocity, fps
32.5	63	32	4.0	63	8.0
26	80	40	4.5	80	9.0
21	100	50	5.0	100	10.0
17	125	63	5.6	125	11.2
13.5	160	80	6.2	160	12.4
11	200	100	7.0	200	14.0
9	250	125	7.7	250	15.4
7.3	320	160	8.7	320	17.4

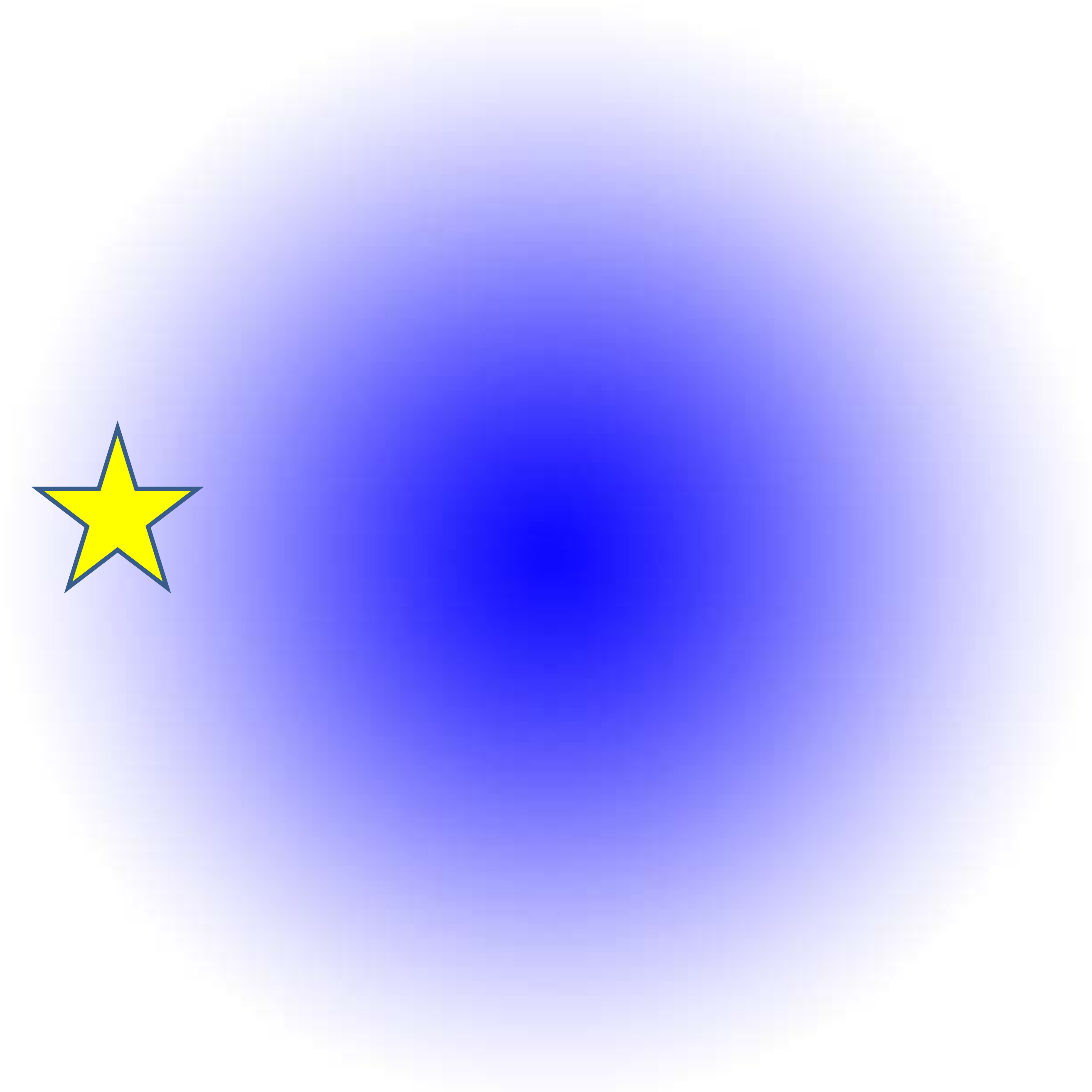
1. AWWA C906-07 limits the maximum Pressure Class of PE pipe to the values shown in Table B. At the time of this printing C906 is being revised to allow PC values in Table A to be used for PE3710 and PE4710 materials. Check the latest version of C906

Does resin type matter?

What are Fitting & Valve considerations?

Limits!





Who is Harco?

- Harco is a maker and supplier of pipe fittings and valves used in water, sewer, irrigation, and drainage applications/markets
- We are not a “you fill the material type” company.
- Harco has been doing this since 1966.
- In the course of the decades we have developed and supplied fittings for all major pipe technologies used in underground water conveyance in North America.