Meeting Summary
Meeting between NRC and Plastics Pipe Institute Representative

March 3, 2010
Rockville, MD

Purpose:

The purpose of the meeting was to facilitate communication between the NRC staff unable to attend the recent public ASME Code meeting and a representative of the plastic piping industry. Mr. Stephen Boros of the Plastics Pipe Institute (PPI) presented the same brief made at the recent public ASME Boiler and Pressure Vessel Code Week meeting entitled, "Long-Term Hydrostatic Strength and Design of Polyethylene Piping Compounds."

Meeting Summary:

NRC is reviewing Code Case N-755 on the use of high-density polyethylene (HDPE) piping in safety-related nuclear applications. NRC requested the meeting and presentation with Mr. Stephen Boros of PPI to clarify the methods used to establish the design stress values in N-755. Mr. Boros is the Technical Director of PPI and chairs the Hydrostatic Stress Board. The Hydrostatic Stress Board is responsible for providing pressure ratings (i.e. the hydrostatic design basis or HDB) for plastic pipe resins based on proprietary test data submitted by resin manufacturers. The HDB helps establish the allowable stress values for plastic pipe design.

Mr. Boros presented the attached brief, which was the same material as presented at the public February 2010 ASME Boiler and Pressure Vessel Code Meeting. He presented the methodology to establish the HDB based on standardized test methods. He further discussed the determination of the hydrostatic design stress (HDS) used to develop design stress values for HDPE resins. Mr. Boros also provided a status of PPI sponsored research to update generic fusion procedures. The ASME HDPE Fusion Task Group will provide updates of the results of the fusion research at future ASME Code meetings.

Meeting Attendees:

Attendees	Affiliation
Eric Focht	NRC/RES/DE/CIB
Tim Lupold	NRC/NRR/DCI/CPNB
Chakrapani Basavaraju	NRC/NRR/DE/EMCB
Don Naujock	NRC/NRR/DE/CPNB
Robert Hsu	NRC/NRO/DE/EMB
John Wu	NRC/NRO/DE/EMB
Eric Reichelt	NRC/NRO/DE/CIB1
David Terao	NRC/NRO/DE/CIB1
Aladar Csontos	NRC/RES/DE/CIB
Prabhat Krishnaswamy	Engineering Mechanics Corp. of Columbus
Steven Boros	Plastics Pipe Institute

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Long-Term Hydrostatic Strength and Design of Polyethylene Piping Compounds

Stephen J. Boros
Technical Director – Plastics Pipe Institute
Chairman, Hydrostatic Stress Board

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Overview

- Long-Term Hydrostatic Strength (LTHS)
- Regression Analysis
- Establishing a Hydrostatic Design Basis (HDB)
- Design Factor (i.e. Service Factor)
- Maximum Design Pressure – HDS
- New applications

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Long-Term Hydrostatic Strength

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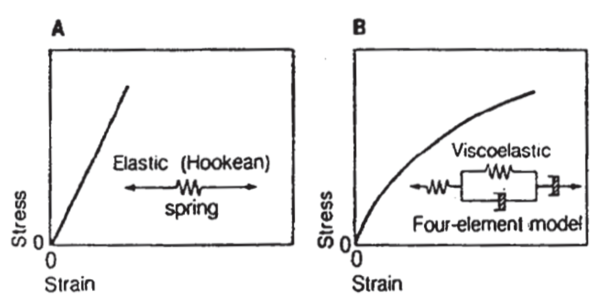
Long-Term Hydrostatic Strength

Viscoelastic Response to Stress

– Dependent on level and duration of stress
– Unlike metals, long-term strength cannot be determined from short-term tensile test.



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Long-Term Hydrostatic Strength

ASTM D 2837 - *"Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products"*

– First published in 1963
– Similar in function to ISO 9080

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Establishing a Maximum Design Stress

The relationship between stress and internal pressure is determined by application of the thin walled pressure vessel equation

– threat as a thin wall pressure vessel

$$S = \frac{P\left(D - t\right)}{2t}$$

where: S = Stress, psi
P = internal pressure, psig
D = average outside diameter, inches
t = minimum wall thickness, inches

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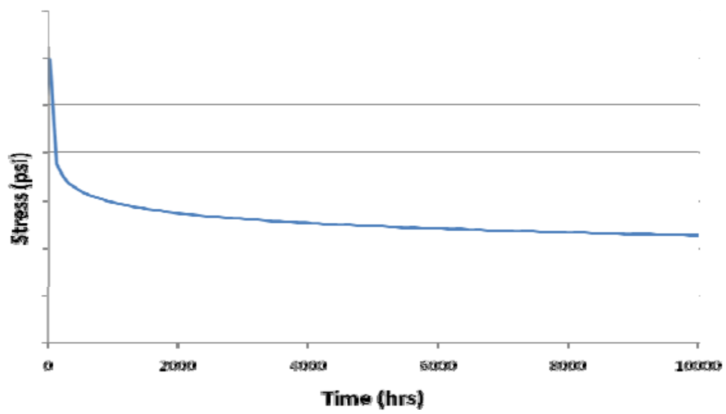
Long-Term Hydrostatic Strength



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Regression Analysis

Linear Least Squares Model – log/log.

$$h = a + bf$$

where: h = logarithm of failure time, hours
f = logarithm of failure stress, psi

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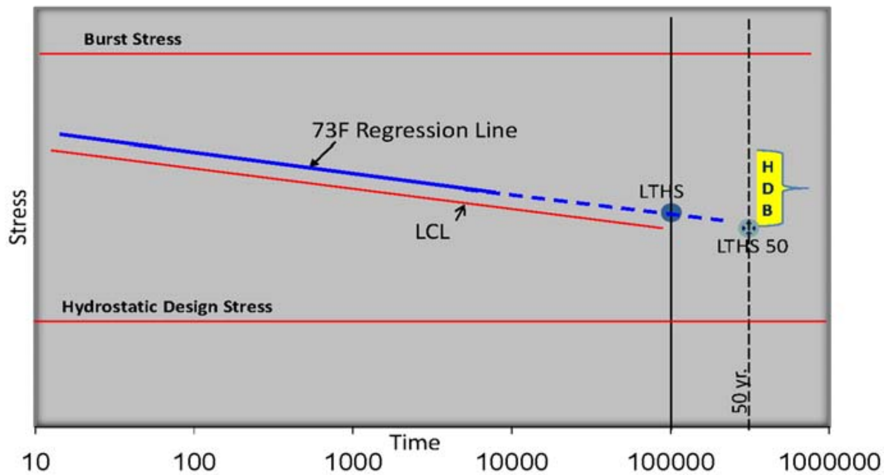
Regression Analysis



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Long-Term Hydrostatic Strength

Long-term strength is categorized, or standardized, within established ranges called a Hydrostatic Design Basis.

Range of Calculated LTHS Values		**Hydrostatic Design Basis**	
psi	(MPa)	psi	(MPA)
760 to < 960	(5.24 to < 6.62)	800	(5.52)
960 to < 1200	(6.62 to 8.274)	1000	(6.89)
1200 to < 1530	(8.27 to < 10.55)	1250	(8.62)
1530 to < 1920	(10.55 to < 13.24)	1600	(11.03)
1920 to < 2400	(13.24 to <16.55)	2000	(13.79)
2400 to < 3020	(16.55 to <20.82)	2500	(17.24)
3020 to < 3830	(20.82 to < 26.41)	3150	(21.72)
3830 to < 4800	(26.41 to < 33.09)	4000	(27.58)

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Regression Analysis

To assure linearity of extrapolation:

- **Validation** – assure linearity of extrapolation to 100,000 hours.
- **Substantiation** – assures linearity to 50 years.

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Typical PE 4710 Regression Analysis

Follow PPI TR-3 Policies for establishing a hydrostatic Design Basis:

- One 73°F and 140°F full dataset to 10,000 hours meeting the full requirements of D 2837.
- Minimum 18 data points with proper distribution.
- LTHS minimum for HDB.
- LCL/LTHS ratio > 0.90
- LTHS50 > 80% LTHS.

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Typical PE 4710 Regression Analysis

Follow PPI TR-3 Policies for establishing a Hydrostatic Design Basis - HDB:

- Two additional 73°F and 140°Fdatasets to 2000 hours.
- 10 data points minimum with proper distribution.
- Distinct and separate lots of the compound to demonstrate consistency.
- The regression analysis must also meet the ASTM D 2837 requirements (HDB, LCL, etc…).

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Typical PE 4710 Regression Analysis

Follow PPI TR-3 Policies for establishing a Hydrostatic Design Basis – HDB:

- Validation of 73°F and 140°F HDB – two datasets at 80C or 90C.
- Substantiation of the 73°F HDB -
  - 80C – 6000 hrs
  - 90C – 2400 hrs

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Validation of the 140°F HDB

HDB to be Validated (psi)	Test Temperature			
	193°F (90°C)		176°F (80°C)	
	Stress (psi)	Time (h)	Stress (psi)	Time (h)
1250	860	3800	970	11300
1000	690	"	775	"
800	550	"	620	"
630	435	"	490	"
500	345	"	390	"

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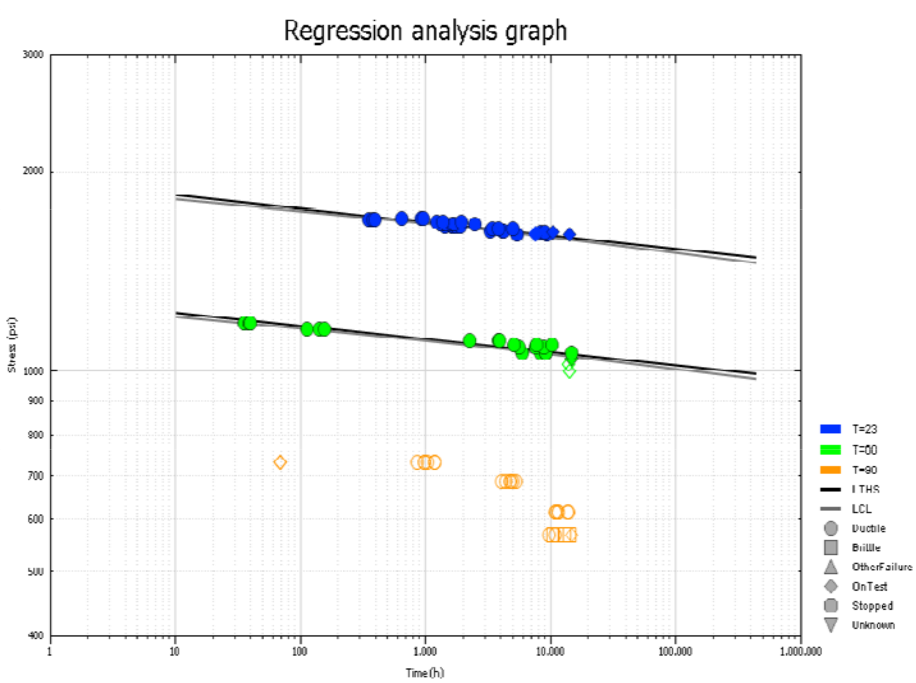

Establishing a Maximum Design Stress

Maximum design stress requires the application of a design factor (DF) - while similar, not the same as a safety factor, or margin of safety.

$$HDS = HDB \times DF \times DF_T$$

Where: HDS = hydrostatic design stress, psi
HDB = hydrostatic design basis, psi
DF = design factor, a number less than one.

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Establishing a Maximum Design Stress

- Choice of DF is based on several factors
  - Method used to establish long-term strength
  - Failure mechanisms
  - Reaction to stress intensifications (fracture mechanics)
  - Installation practices
  - Range of “normal” operating conditions

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Establishing a Maximum Design Stress

In 1963 a design factor (DF) of 0.5 was "chosen" to provide an appropriately conservative design.

- Purposely chosen as a multiplier to be different from a safety factor.
- Excellent performance over last 40 years.
- Continuous development of newer materials has led to revisiting this factor.

Not equivalent to a 2.0 safety factor

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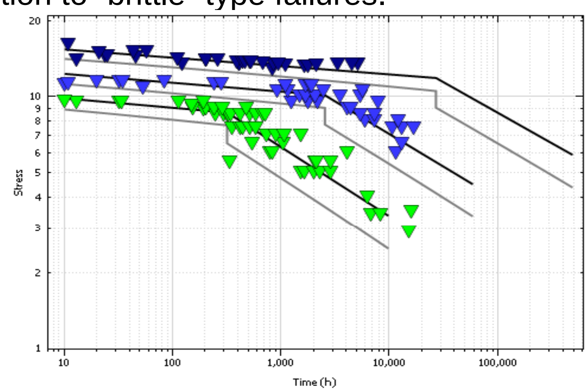
Establishing a Maximum Design Stress

Older PE materials had stress regression curves showing transition to "brittle" type failures.



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Establishing a Maximum Design Stress

The Hydrostatic Stress Board of PPI set additional performance criteria for PE materials

These materials could be operated at a higher bulk stress without sacrificing service life or safety.

1) 50 year substantiation
2) 90% LCL/LTHS ratio
3) 500 hours PENT SCG performance

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Establishing a Maximum Design Stress

1) 50 year Substantiation

- Ductile mode through at least the 50-year intercept.
- PE material continues to operate in the ductile state

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Establishing a Maximum Design Stress

2) 90% LCL/LTHS ratio

- Ratio of average LTHS to 95% LCL
- Ensures higher statistical reliability in strength forecast.

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Establishing a Maximum Design Stress

3) 500 hours PENT SCG performance

- ASTM F 1473 slow crack growth resistance indication
- Essential immunity to effects of localized stress intensifications.

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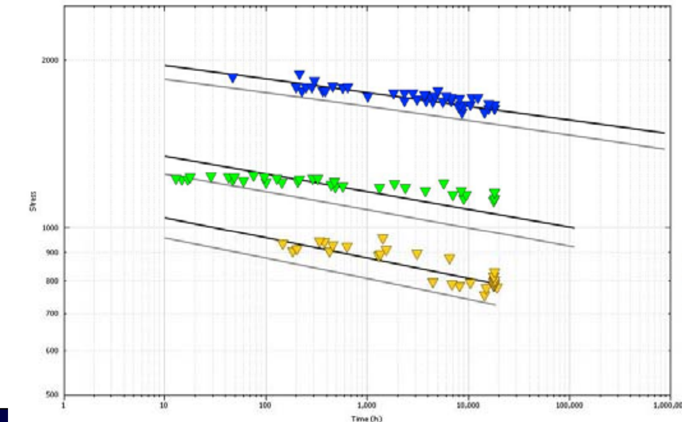
Establishing a Maximum Design Stress

PE materials meeting the high performance criteria



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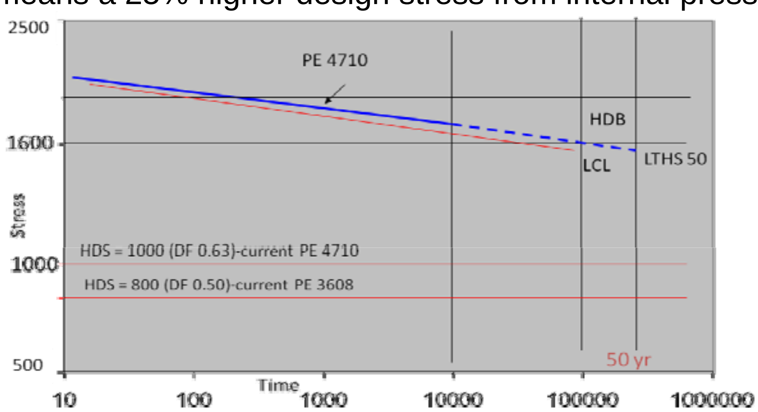
Establishing a Maximum Design Stress

This means a 25% higher design stress from internal pressure



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Establishing a Maximum Design Stress

This leads to the question, "Is this simply a reduction in the safety factor?"

Answer: No!!

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Establishing a Maximum Design Stress

The stress regression curve **does not** represent a "basket" or reserve of strength.

- The material does not get "weaker" over time.
- Short-term burst strength is the same as the original pipe.

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Formulation	Applied Long-Term Stress (psi)	Time on LT test (hours)	Avg. Burst Press. (psig)	Burst Quality
A (R398)	Control	NA	945	Ductile
B (R398)	700	115751	935	Ductile
C (R443)	Control	NA	1144	Ductile
D (R443)	719	112840	1112	Ductile
E (R834)	Control	NA	1327	Ductile
F (R834)	826	52896	1202	Ductile
G (R761)	Control	NA	1292	Ductile
H (R761)	997	61488	NA	Ductile
I (R853)	Control	NA	1287	Ductile
J (R853)	853	46153	1205	Ductile
K (R833)	Control	NA	1397	Ductile
L (R833)	829	52940	1267	Ductile
M (R881)	Control	NA	1299	Ductile
N (R881)	798	42196	1249	Ductile

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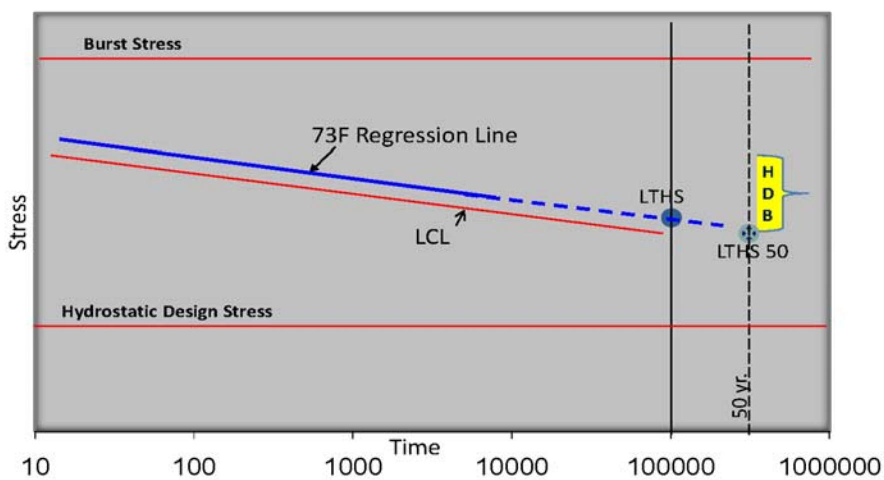

Establishing a Maximum Design Stress

This means the margin of safety against burst from over pressurization continues to be nearly 4:1.

– The additional requirements assure against failure due to localized stress intensifications.

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Conclusion

- The viscoelastic response is conservatively used to determine LTHS.
- Many factors go into determining the LTHS and HDB which will affect the choice of the appropriate DF.
- The design engineer needs to have an understanding of these factors to derive the maximum design stress and working pressure.
- The HSB has been giving these recommendations for 50 years.

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Plastics Pipes XV

Vancouver, Canada 2010

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