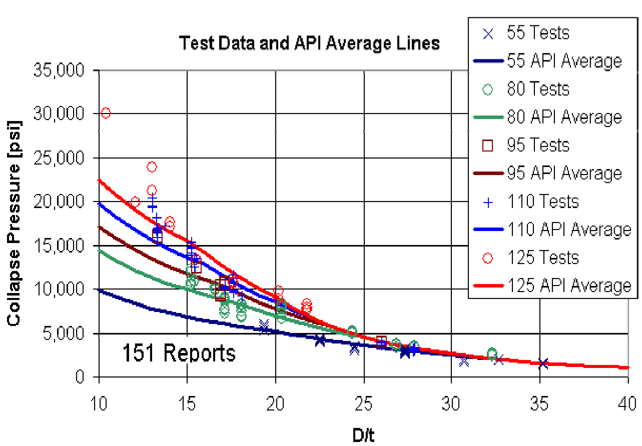
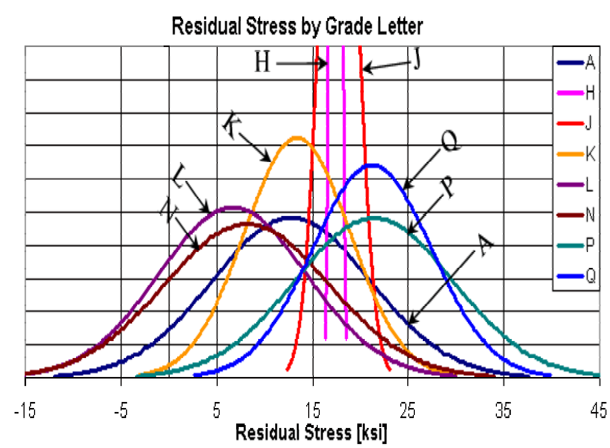
DEA-130
Modernization of Tubular Collapse Performance Properties

API/HSE/MMS
Participant Report

October 2002





DEA-130
MODERNIZATION OF TUBULAR COLLAPSE PERFORMANCE PROPERTIES

API/HSE/MMS PARTICIPANT REPORT

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APPENDICES

Due to the large amount of pages in each Appendix, the information is provided on CD only.

Appendix A - Southwest Research Institute Collapse Test Procedure

Appendix B
- Piper.xls (Tool for reading all data for each of the 151 test samples on a per sample basis; refers to WG2b database)
- Piper.hlp (Help file for Piper.xls)
- Delivery.xls (Summary Table of all test data and plots comparing Shell donated pipe to all other manufacturers)
- WG2b.mdb (Database with all test samples)

Appendix C - Material Test Plots of Stress vs Strain

1.0 EXECUTIVE SUMMARY

In recent years, some users of OCTG casing and tubing have realized the improved performance of today's pipe. This includes both internal or burst resistance and external or collapse resistance. This improvement is due to newer methods of making and finishing tubulars and the manufacturers are to be thanked for these improvements.

Pipe performance is primarily given by API bulletins and specifications and is based on data and engineering that was produced in the 1960s. These burst and collapse values were and are very important to the user and form the basis from which drilling engineers design their oil and gas wells. Currently the petroleum industry is aware of the somewhat outdated API pipe performance values and is actively working to improve pipe burst and collapse ratings. The main group doing this work is ISO/API TC67/SC5/WG2b, which has been meeting for the past three years. The group has been diligently seeking both burst and collapse test data from the industry to use in providing new equations and ratings for pipe performance. From the beginning, WG2b was aware of the lack of well documented collapse test data, particularly data on pipe made in the past 5,10 and 20 years.

The convener of WG2b is Dr. M. L. Payne. During the late1990s Dr. Payne was with ARCO and he investigated the collapse performance of several pipe mill products. Through testing and statistical analysis, Payne was able to take advantage of today's pipe collapse resistance and ARCO drilled and completed many wells with lighter pipe weights than traditionally had been used, providing ARCO a significant savings. From this work, Payne put together a joint industry proposal and presented this to the Drilling Engineering Association. The proposal was successful and became known as DEA-130. The purpose of DEA-130 was to perform collapse tests and carefully document the pipe samples and test data. This report was prepared for the operating companies participating in the program.

The participants of DEA-130 consisted of 12 end-users, three industry / government agencies and 11 pipe manufacturers. The program was performed by four engineering companies and was directed by a Steering Committee (SC), which was made up of representatives of the end-users and agencies. The pipe manufacturers were selected by the Steering Committee and invited to join the program. All current producers of OCTG pipe that were invited accepted the invitation. Stress Engineering Services was the primary contractor. Subcontractors were (1) Technical & Quality Solutions Inc. (TQSI) which made the mill visits and selected the pipe samples, (2) Southwest Research Institute (SWRI) which performed the collapse tests and (3) Hecate which provided special software and data reduction. The deliverables consisted of - all the data, software and reduction with manufacturers identified for the end-users; all of the data and some software without the manufacturers identified for the agencies; and all of the data but with only each manufacturer's own data identified and some software for the manufacturers.

During the first six months of the program, each manufacturing participant made a presentation to the Steering Committee to describe their products and manufacturing processes and the committee produced a “preferred” list of pipe to be tested. This list contained a total of 246 possible pipe samples. Thereafter, over a period of approximately nine months, TQSI made visits to all of the pipe mills and selected the pipe samples, which were then shipped to SWRI for testing. A condition of the selection was that TQSI had to accept pipe that was available in the manufacturer’s yard at the time of the visit.

The mill visits produced a total of 216 pipe samples. Each sample was carefully identified and additional pipe adjacent the sample was taken for material tensile testing, residual stress testing and extra pipe for possible other testing. Typically, four samples of a given size/weight/grade were selected with one serving as a spare. In addition to these samples, Shell Oil donated 17 samples of high chrome/high alloy pipe.

A total of 151 samples were tested. While the samples tested did not totally match the SC’s “preferred” pipes, overall the match was reasonably good. Figure 1-1 shows the preferred pipe, selected pipe, Shell donated pipe and samples tested.

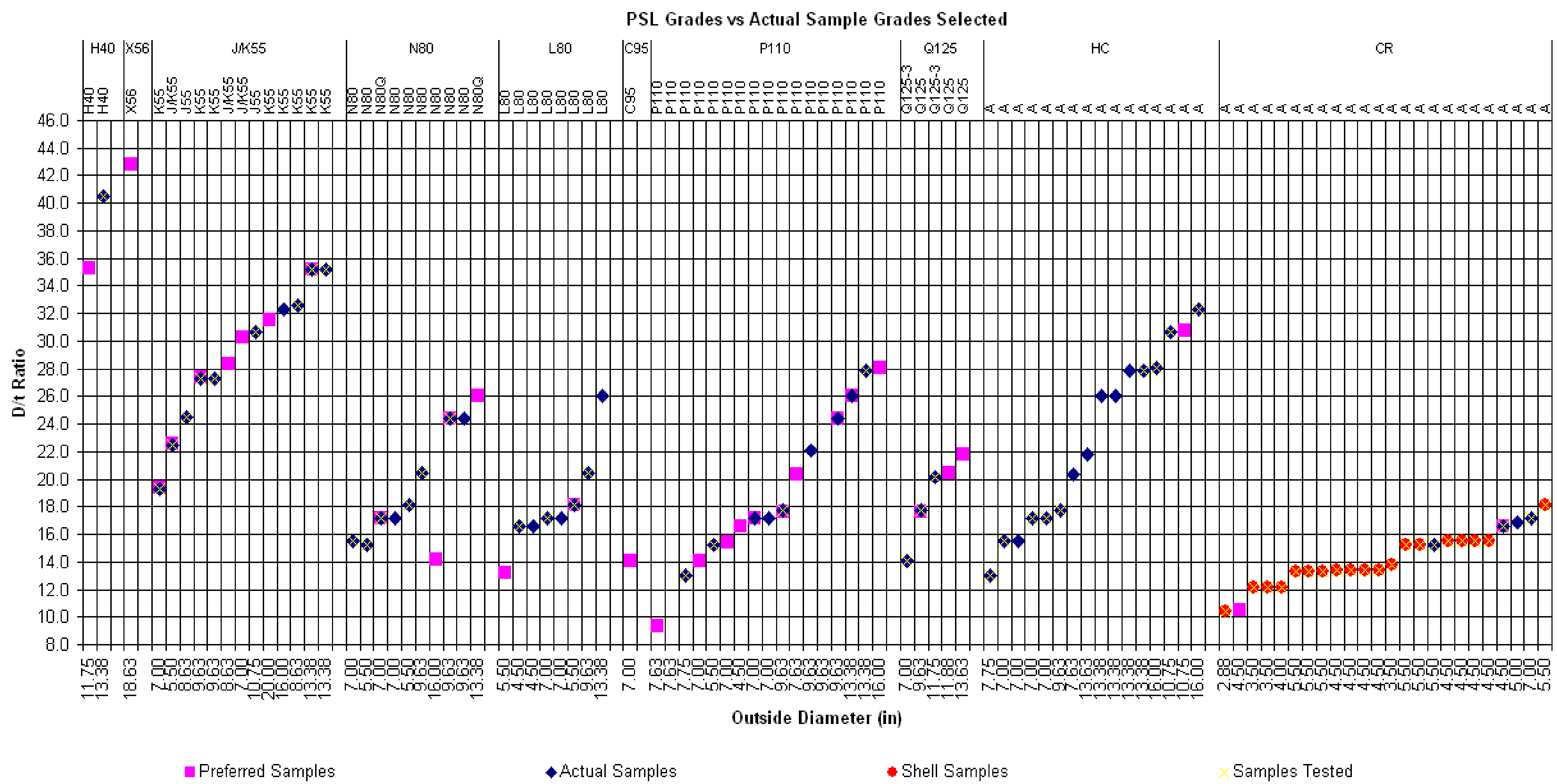
Each sample tested was measured for OD, wall and ovality in 1D increments (total of 9 planes of measurements). Residual stress tests were made from pipe directly adjacent the collapse sample. Prior to shipping, material tensile tests were made directly adjacent the collapse sample and several feet past the other end of the sample. The manufacturers made these tensile tests. The collapse pressure and location of the deformed failure were reported by SWRI.

Data reduction is given that compares the parameters that are significant to collapse, namely OD, wall thickness, ovality, eccentricity, yield strength, shape of the stress-strain curve and residual stress. Plots of the test data are given along with current API collapse rating and WG2b’s most recent proposed new equation for predicting collapse. Pipe performance by manufacturer is plotted for comparison purposes.

The data is provided in Microsoft Access so that the participants can perform further reduction as desired.

FIGURE 1-1

Preferred Samples Versus Actual Samples Collected



2.0 PROGRAM SCOPE

DEA-130 was structured to provide proprietary benefit to participating companies, while also providing public benefit to the industry through the acquisition of a collapse database on modern pipe for use by API and ISO. The objective was to collect as much collapse test data as possible and to formulate software that could reduce the collapse data and predict pipe collapse limits. The software would also allow comparisons between mill products to be made.

Operator participants received all of the results of the collapse tests, material tensile tests and residual stress tests, including identification of the pipe sample manufacturer. Industry standard and government agencies received all of the test data, however without identity of the test sample manufacturer. Manufacturing participants received the entire test data with only their pipe results identified (all other data was in anonymous form). All participants and API, MMS and HSE received the database that is a compilation of the test data.

3.0 PROGRAM PARTICIPANTS

The program was first presented as a Drilling Engineering Association (DEA) joint industry program in February of 1999. This was a quarterly meeting of the DEA at the ARCO facility in Plano TX. At that meeting, Dr. Mike Payne presented the background of the proposed project and the need for collapse pipe values for today's pipe. Additional presentations of the program were made at the API 1999 Winter Work Week and API 1999 Standardization Conference. The kick-off meeting of the DEA-130 program was held in October of 1999.

3.1 OPERATORS

Eleven operating companies joined the program, as follows:

1. ARCO (now a part of BP)
2. AMOCO (now a part of BP)
3. Burlington Resources
4. Chevron (now with Texaco)
5. Marathon Oil
6. PEMEX
7. REW-DEA
8. Shell E&P Technology
9. Texaco (now with Chevron)
10. Total Fina (now includes Elf)
11. Unocal
12. Phillips Petroleum Co. (acquired rights to DEA-130 with their purchase of ARCO Alaska, Inc., in 2000)

3.2 INDUSTRY AND GOVERNMENT AGENCIES

Three industry and/or government agencies joined as follows:

1. American Petroleum Institute (API)
2. Health and Safety Executive (HSE - UK)
3. Mineral Management Service (MMS)

3.3 PROGRAM STEERING COMMITTEE

A Steering Committee (SC) was formed to direct the activities of the program and to oversee the budget. The SC consisted of one representative from the above fourteen participants above plus one backup representative.

3.4 PIPE MANUFACTURERS

The SC selected the pipe manufacturers that they wanted to join the program and to test the manufacturers pipe. All of the pipe mills that were invited to join, did join the program, with the exception of one mill that had just announced that they were about to stop offering OCTG pipe. A total of 11 pipe mills joined the program.

3.5 CONTRACTOR AND SUBCONTRACTORS

Four companies were contracted to perform the program work as follows:

1. Contractor – Stress Engineering Services (SES)
2. Subcontractor for selecting the pipe samples – Technical and Quality Solutions Inc (TQSI)
3. Subcontractor for performing the collapse tests and residual stress tests – Southwest Research Institute (SWRI)
4. Subcontractor for software and data reduction – Hecate

The program was co-chaired by Dr. Mike Payne of BP and Mr. Tom Asbill of Stress Engineering Services.

4.0 PARTICIPATING MANUFACTURERS

In order to accumulate the required data points for the project, the steering committee solicited various manufacturers to participate in the project. The manufacturers solicited were randomly chosen by the steering committee, but with the intent of gaining the participation of manufacturers who produce a full range of products. The range of products required for this project is detailed in Section 5.0 of this report.

Through the efforts of the steering committee, 11 manufacturers elected to participate in this project. Although only 11 manufacturers participated, many of the manufacturers have multiple facilities, which enabled the collection of the desired tubular collapse samples.

4.1 SUMMARY OF MANUFACTURERS

After the manufacturers were selected and became approved participates in the project, the steering committee prepared, submitted and requested that the manufacturers complete the attached “Fact Sheet”. The “Fact Sheet” was prepared to gather specific information about the manufacturer’s operations and included topics covering the manufacturing processes used at the various facilities and the probable products available to select collapse samples from each of the facilities. A copy of the original “Fact Sheet” submitted to the manufacturers was provided to the operator participants only.

4.2 PRODUCTS

To identify the types of products each of the manufacturers provide, the Steering Committee prepared a table for the manufacturers to complete in conjunction with the aforementioned “Fact Sheet”. This table, when completed by the manufacturer, provided a Matrix for their products, i.e., sizes, grades and processes used to finish the products, which assisted in identifying the types of samples which might be available for selection at each of the various manufacturer’s facilities.

As was noted by the Steering Committee, the majority of the manufacturers produce similar sizes with the difference in the products being the type of processing performed, e.g., hot rotary straightened, gag straightened and stress relieved, etc. These varying processes significantly affect the performance properties of the finished product .

4.3 PROCESSES

There are numerous methods of processing tubulars to provide the finished product supplied to the end-user. In simplified terms, the major processing techniques most commonly used include the production of seamless and EW tubulars.

In order to reach this finished product stage, the manufacturing process begins with the making of steel to form these products. In just the steel making process there are multiple techniques, which involve various mixtures of metallurgical elements, e.g., nickel, chromium, carbon, etc., to produce the final product. The percentage of these elements in the mixture impacts the resultant performance properties of the tubular. In the steel making process there have been significant advancements. As an example, improved chemistry control during the casting stages- e.g. the use of argon steering and calcium injection to enhance the cleanliness of steel. Here “clean” steel refers to superior grain structure in the steel and absence of defects, voids, and impurities. These types of improvements have been implemented in many of the steel manufacturing facilities.

Following the steel making process, the steel is rolled in primary mills to a semi-finished shape of blooms, slabs or as is most common for seamless tubular mills, it is formed into billets through a continuous casting process.

From this stage the steel is processed through various piercing and sizing operations. Since the geometry/dimensions play an important role in the performance of the product, i.e., ovality, eccentricity, total wall thickness, etc., tight controls must be placed on these operations. This is especially critical when enhanced collapse performance is required.

Upon completing the sizing operations, the product is processed through final heat treating phases to accomplish the required strength. The heat treating operations have encountered significant advances. Improved furnaces provide manufacturers with the ability to obtain and track temperatures more accurately, and thus yield better material properties. The improved furnace designs use the “walking beam” or “conveyor driven” systems to ensure uniform heating of the tubes as they move through the furnace. New furnace types include computer controlled baffling systems to provide an even distribution of heat throughout the oven. These computerized enhancements ensure adequate soak times for austenitizing and tempering of steel. This is a significant improvement over batch type furnaces, which can suffer from poor temperature control and the lack of uniformity in heat distribution.

After heat treatment the product is normally processed through a straightening operation. This operation is completed in several different manners, which can consist of gag straightening or rotary straightening while the steel is either hot or cold. Unfortunately, this straightening operation can induce residual stress, which can reduce the overall performance of the finished product. These stresses can be mitigated by means of either stress relieving the product at temperatures around 900° F, or processing the product through the straightening operation after completing the heat treating process and before the steel has cooled below this temperature. Improvements in post heat treatment processes such as “hot rotary straightening” have contributed to reducing residual stresses in tubulars.

To assist in comparing the tubular collapse samples collected from the various manufacturers, a processing code was developed and used in the identification of the samples selected. This code identified the sample according to the type of processing that was used to finish the product. The code is outlined in the following table:

TABLE 4-1 List of Pipe Finishes

Finish ID	Heat Treatment	Straightening Process
1	As-Rolled	Cold Gag
2	As-Rolled	Cold Gag (Stress Relief)
3	As-Rolled	Cold Rotary
4	As-Rolled	Cold Rotary (Stress Relief)
5	As-Rolled	Hot Rotary
6	Seamannealed	Cold Gag
7	Seamannealed	Cold Gag (Stress Relief)
8	Seamannealed	Cold Rotary
9	Seamannealed	Cold Rotary (Stress Relief)
10	Seamannealed	Hot Rotary
11	Normalized	Cold Gag
12	Normalized	Cold Gag (Stress Relief)
13	Normalized	Cold Rotary
14	Normalized	Cold Rotary (Stress Relief)
15	Normalized	Hot Rotary
16	N&T	Cold Gag
17	N&T	Cold Gag (Stress Relief)
18	N&T	Cold Rotary
19	N&T	Cold Rotary (Stress Relief)
20	N&T	Hot Rotary
21	Q&T (Air)	Cold Gag
22	Q&T (Air)	Cold Gag (Stress Relief)
23	Q&T (Air)	Cold Rotary
24	Q&T (Air)	Cold Rotary (Stress Relief)
25	Q&T (Air)	Hot Rotary
26	Q&T (Water)	Cold Gag
27	Q&T (Water)	Cold Gag (Stress Relief)

Finish ID	Heat Treatment	Straightening Process
28	Q&T (Water)	Cold Rotary
29	Q&T (Water)	Cold Rotary (Stress Relief)
30	Q&T (Water)	Hot Rotary
31	Q&T (Oil)	Cold Gag
32	Q&T (Oil)	Cold Gag (Stress Relief)
33	Q&T (Oil)	Cold Rotary
34	Q&T (Oil)	Cold Rotary (Stress Relief)
35	Q&T (Oil)	Hot Rotary
36	Cold Drawn	No straightening

5.0 PRODUCTS SELECTED FOR COLLAPSE TESTING

After numerous meetings with the project steering committee and discussions with ISO/API Work Group 2b, a list of the preferred collapse samples was compiled, which was identified as the "Preferred Sample List". This list provided a mixture of the various processing techniques along with a substantial range of D/t's. The list of the Preferred Samples is detailed in Table 5-1 below:

TABLE 5-1

Preferred Sample List

TUBULAR DESCRIPTION					
NO.	**OD**	**WEIGHT**	**WALL**	**GRADE**	**D/T**
1	4.5	12.6	0.271	P110	16.61
2	4.5	12.6	0.271	L80 or L8013Cr	16.61
3	4.5	18.8	0.43	L80-13Cr	10.47
4	5.5	14	0.244	J55/K55	22.54
5	5.5	17	0.304	L80	18.09
6	5.5	23	0.415	L80	13.25
7	7	17	0.231	J55/K55	30.30
8	7	26	0.362	K55	19.34
9	7	29	0.408	N80Q	17.16
10	7	29	0.408	P110	17.16
11	7	32	0.453	P110	15.45
12	7	35	0.498	C95	14.06
13	7	35	0.498	P110	14.06
14	7.625	29.7	0.375	P110	20.33
15	7.625	59	0.812	P110	9.39
16	8.625	28	0.304	J55/K55	28.37
17	9.625	36	0.352	K55	27.34
18	9.625	40	0.395	N80	24.37
19	9.625	40	0.395	P110	24.37
20	9.625	53.5	0.545	P110	17.66
21	9.625	53.5	0.545	Q125	17.66
22	10.75	40.5	0.35	HCK55	30.71
23	11.75	42	0.333	H40	35.29
24	11.875	71.8	0.582	Q125	20.40
25	13.375	54.5	0.38	K55	35.20
26	13.375	68	0.48	P110	27.86
27	13.375	72 (12-1/4" drift)	0.514	N80Q	26.02
28	13.375	72 (12-1/4" drift)	0.514	P110	26.02
29	13.625	88.2	0.625	Q125	21.80
30	16	84	0.495	N80	32.32
31	16	97	0.57	P110	28.07
32	18.625	87.5	0.435	X56	42.82
33	20	133	0.635	K55	31.50

In preparation for the selection of these samples, a “Collapse Sample Selection and Identification Process” (CSSIP) was prepared. The CSSIP included specific steps for TQSI to follow during the selection process and included an identification process. After selecting the available samples, the identification process involved mapping the sample length to accommodate mechanical tests, residual stress tests and collapse tests samples (8D lengths). As a precautionary measure an additional 3D length was mapped on each sample to provide for additional mechanical tests if required. The mapping of each sample followed Figure 5-1 below.

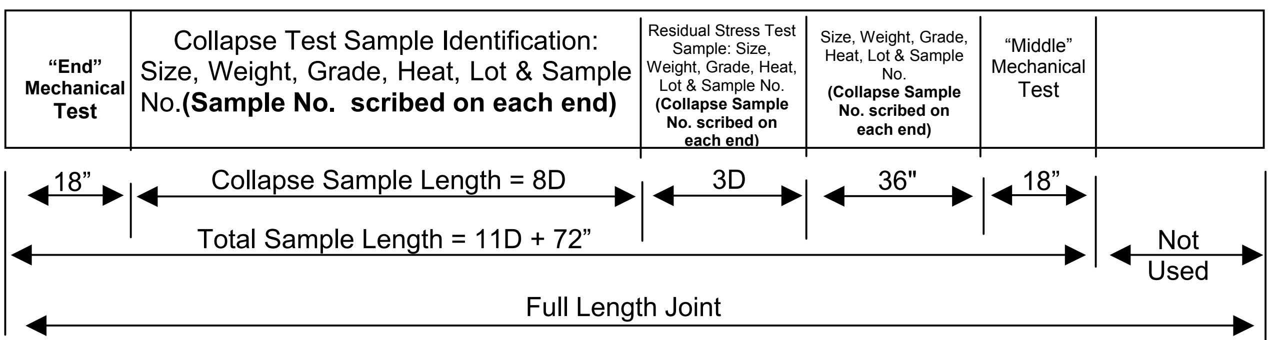


FIGURE 5-1

Collapse Sample Mapping

For ease of identification and in an effort to maintain trace ability of each sample, the sample serial numbers were scribed into each section of the sample and a DEA-130 Sticker was applied to each end of the sample, shown in Figure 5-2 below.

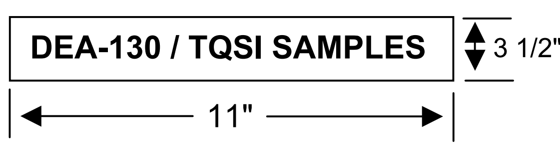


FIGURE 5-2

DEA-130 Sticker Format

Although the “Preferred Sample List” defines, as indicated in the title, the “Preferred Samples” the limiting factor in obtaining the exact “Preferred Samples” was dependent on the tubulars available at the manufacturer’s facility. Because of the budget constraints and the project objective, i.e., randomly selected samples representing a typical finished product manufactured by the participating manufacturer, the physical sample selection was limited by available tubulars with “Preferred Sample” similarities

(OD, Grade, D/t, etc.). Due to these constraints, the actual samples selected differed from the “Preferred Samples”. A comparison of the “Preferred Samples” versus the “Actual Samples” selected is detailed in Figure 5-3. The total number of samples selected was 216. All samples were sent to Southwest Research Institute in San Antonio, Texas, with shipping provided by the manufacturer. Overall, the obtained samples reasonably met the desired range of pipe OD, D/t and material. The main difference was fewer non-Q&T than desired and more Q&T and High Collapse, particularly the HC products. However, as stated earlier, pipe samples obtained had to be from the products that were at the manufacturer at the time when TQSI made the visit.

Note: Non-API grades have been identified as “A”.

In addition to the “Actual Samples” selected at the various participating manufacturer’s facilities, Shell Oil (a Participating Sponsor of the project) contributed seventeen (17) tubular collapse samples for testing. These samples are identified in Table 5-2, and were all high chrome/high alloy materials.

FIGURE 5-3

Preferred Samples Versus Actual Samples Collected By D/T

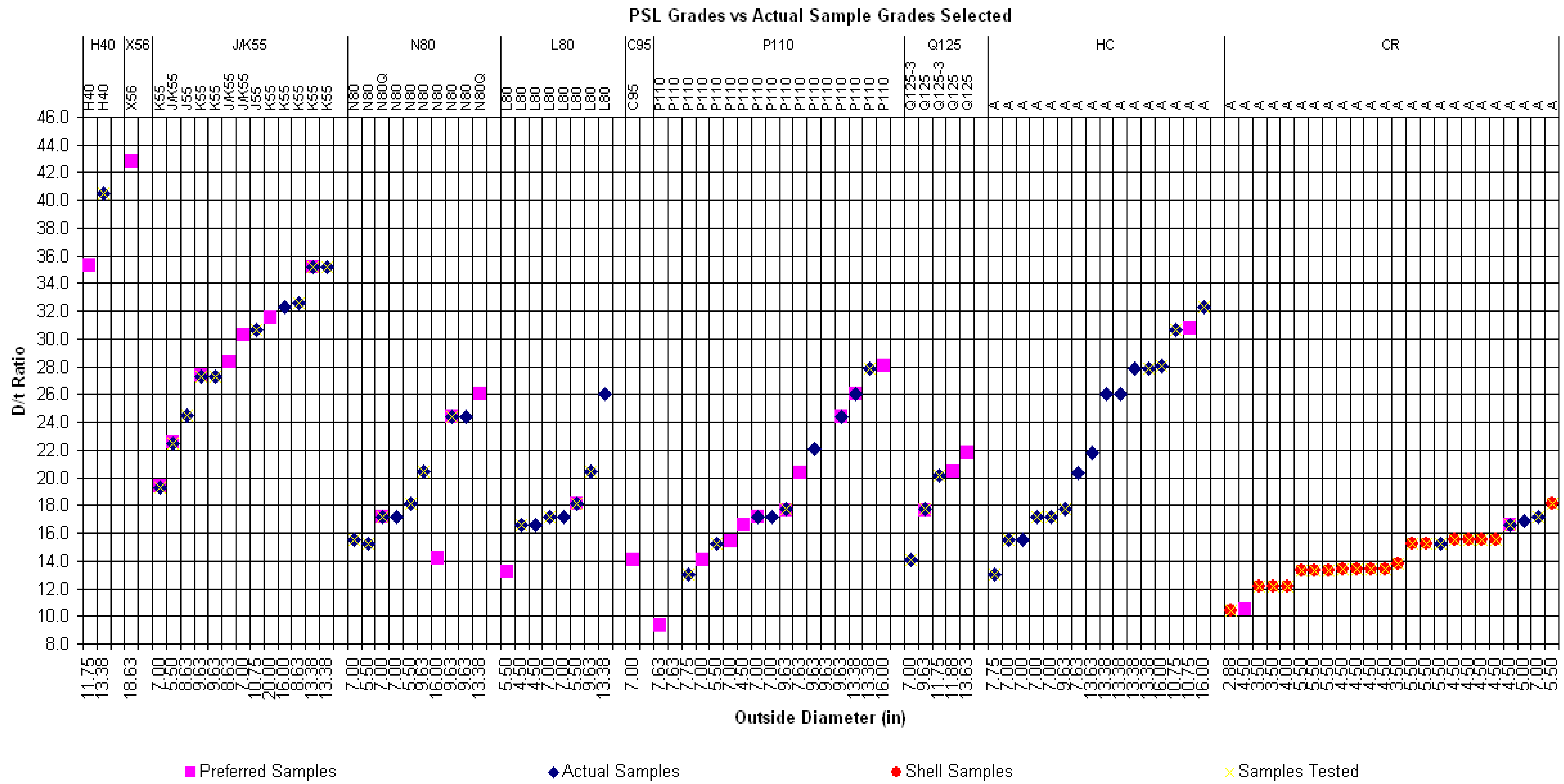


TABLE 5-2 Pipe Samples Donated By Shell Oil

Note: color coded according to notionally "same" materials

Grade	Finish	OD	Approx ID	Weight	Approx D/T	Mill	Heat No.
2550	36	2.88	2.32	7.7	10.4	Sumitomo	?
825	36	3.50	2.91	10.2	11.8	Special Metals	?
NK15Cr110	25	5.50	4.67	23	13.3	Nippon Kokan	46409
KOHP-1-13Cr110	25	5.50	4.67	23	13.3	Kawasaki	Used
13Cr110	25	5.50	4.67	23	13.3	Sumitomo	4F111347
NK15CR110	25	4.50	3.83	15.1	13.4	Nippon Kokan	46409
KOP1-13Cr110	25	4.50	3.83	15.1	13.4	Kawasaki	27288
SM13CrM110	25	4.50	3.83	15.1	13.4	Sumitomo	F818170 Used
SM13CrM110	25	3.50	2.99	9.2	13.8	Sumitomo	F51C102
Hyper 13Cr-110	25	4.50	3.90	13.5	15.0	Kawasaki	470892
13 Cr-85	25	4.50	3.90	13.5	15.0	Kawasaki	70889
825	36	4.50	3.90	13.5	15.0	Special Metals	?
KOHP-1-13Cr110	25	5.50	4.778	20	15.2	Kawasaki	Used
NK15Cr110	25	5.50	4.78	20	15.2	Nippon Kokan	Used
13 Cr-95	25	4.50	3.92	13.5	15.5	Nippon Kokan	2789
Hyper 13Cr-110	25	5.50	4.89	17	18.0	Kawasaki	70873
NK15Cr95	25	4.50	3.83	15.1	13.4	Nippon Kokan	?

6.0 DESCRIPTION OF TESTS PERFORMED

6.1 MATERIAL YIELD STRENGTH TESTS

Tension tests provide information on the strength and ductility of materials under uniaxial axial stresses. This information is useful in quality control, comparison of materials as well as static strength requirements. In its simplest form, the tension test is accomplished by gripping opposite ends of a test specimen. An axial force is then applied, resulting in gradual elongation and eventual fracture of the test specimen. During this process force extension data, a quantitative measure of how the test specimen deforms under the applied force, is monitored and recorded. The mechanical properties determined from the tension test include:

- Elastic Deformation properties
  - Modulus of elasticity (Young's Modulus)
  - Poisson's Ratio
- Ductility Properties
  - Elongation
  - Reduction of Area
- Strain-Hardening Characteristics
- Yield Strength
- Ultimate Tensile Strength

Each of the collapse samples selected from the manufacturers was material tested by the manufacturer. The test was conducted following the requirements outlined in ASTM E8. Test specimens were machined from each end of the collapse samples selected and labeled as "End" and "Middle". These test specimens were machined into round bar or strip specimens, shown in Figure 6-1, depending on the testing machine capacity and the collapse sample wall thickness.

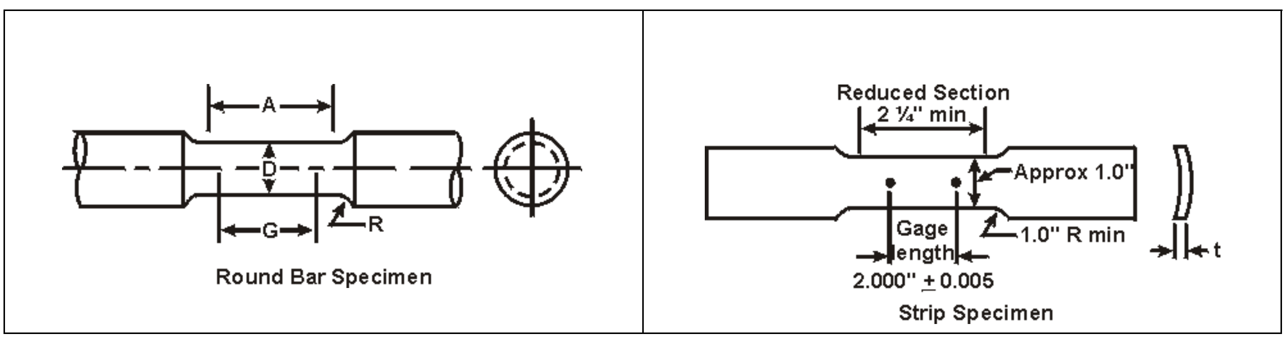


FIGURE 6-1

Tensile Test Specimen Types

In the pre-testing process various data points would be collected to determine the resultant elastic, ductility, yield and tensile strength in the post-testing phase of the operation. These data points are as follows:

Pre-Test Measurements:

- Overall Length
- Distance between Shoulders
- Gage Length
- Diameter or Width
- Width of Grip Section
- Radius of Fillet
- Cross Sectional Area

During the actual testing a comparison between stress and strain was recorded and provided on a diagram to provide accuracy in determining specific properties, i.e., modulus of elasticity, etc. As defined in the latest edition of API Specification 5CT, the actual yield point of each test specimen was determined at a specified Total Extension Under Load of Gauge Length. The extension point at which these strengths were measured, varied by grade (0.50% through 95 yield material, 0.60% for 110 yield material and 0.65% for 125 yield material).

Upon reaching the ultimate strength of the test specimen (fracture point), post test measurements were completed to compare against the pre-test measurements. The results for each specimen tested are detailed in Section 11.5 of this report.

6.2 COLLAPSE TESTS

The SWRI normal procedure for collapse tests is given in Appendix A. Their procedure includes making pre-test measurements of the pipe at the mid-length of the pipe, in accordance with API Bul 5C3. The measurements consist of the average outside diameter (OD) using a pi tape, maximum OD for ovality, minimum OD for ovality, and eight wall thickness readings spaced 45° apart.

The SC decided that more than one set of pre-test measurements would give more data and be beneficial for data reduction and predicting pipe collapse pressure. It was decided that pre-test pipe measurements would be made in 1D increments along the length. The pipe sample length was 8D and therefore nine sets of pre-test measurements were taken and recorded for each sample. The pipe sample length of 8D resulted from meetings of the ISO 10400 workgroup (WG2b) during which some members presented data that showed shorter sample lengths tended to give unrealistically high collapse pressures. The group had determined that an unrestrained sample length of 8D was sufficient to give true collapse pressure.

A list of instructions for handling and testing the pipe samples was prepared by SES and approved by the SC. On November 7, 2000, these instructions were provided to SWRI for testing the DEA – 130 samples, which were as follows:

1. Cut pipe sample length to L = 8D (or as required for testing) and square the ends as required.

2. Save the excess pipe with clear identification as to the manufacturer and pipe sample number. Some residual stress measurements may be performed at a later time.

3. Pre test measurements:
   - Record wall, average OD (pi tape) and ovality (max OD and min OD) in increments of 1D along the length (9 increments total) per API 5C3.
   - Record overall length and weight of each sample.

4. Perform collapse test and record collapse pressure.

5. Post test observations.

6. Record location/direction of the ovality relative to the eight wall thickness measurements.

7. Digital photographs of typical setup and samples (not all samples).

8. All data to be provided in Excel spreadsheet.

9. Material tensile tests? To be determined later. If done, will use excess material.

10. Store the test samples for at least 12 months before scrapping and notify SES before doing so.

Figure 6-2 is a spreadsheet that was written by SES, approved by the SC and provided to SWRI for recording the pre-test measurements, collapse pressure and post-test observation of where the collapse occurred. The spreadsheet also made several calculations such as average thickness and eccentricity. The length and weight of each pipe sample was measured and recorded on the sheet. All pipe sample data was given on this one page spreadsheet and the SWRI / API 5C3 reporting format was not used.

Figures 6-3 and 6-4 are photographs that show a typical test setup and test sample.

The collapse test results for all manufacturers are given in Appendix B.

FIGURE 6-2 SWRI Collapse Test Data

			SOUTHWEST RESEARCH INSTITUTE								
			DEA-130 PIPE COLLAPSE DATA SHEET								
	Filename :	Example									
	Pipe Sample:	**Example**				**Sample Collapse Pressure :**			**11,684**	**Psig**	
	Grade:	Example				**Failure Location (small axis)**			135/315 DEG		
	Nom.Weight(lb/ft.)	53.50	**Sample Weight:**	341.9	lbs.	**Test Date :**			Example		
	Pipe O.D.	9 5/8	**Pipe Length:**	77	inch						
	Actual Weight(lb/ft.)	53.33									
Longitude		End "A"	1 x O.D.	2 x O.D.	3 x O.D.	4 x O.D.	5 x O.D.	6 x O.D.	7 x O.D.	End "B"	AVG
Radial Axis						Wall Thickness	(inches)				
Degrees 0		0.565	0.570	0.570	0.565	0.568	0.572	0.558	0.555	0.550	0.564
45		0.537	0.539	0.542	0.547	0.549	0.548	0.536	0.535	0.530	0.540
90		0.550	0.553	0.556	0.556	0.560	0.560	0.559	0.560	0.559	0.557
135		0.538	0.535	0.536	0.538	0.543	0.537	0.542	0.546	0.550	0.541
180		0.555	0.552	0.552	0.553	0.559	0.558	0.560	0.565	0.568	0.558
225		0.533	0.529	0.526	0.526	0.531	0.528	0.535	0.528	0.536	0.530
270		0.543	0.539	0.535	0.538	0.529	0.532	0.524	0.525	0.531	0.533
315		0.540	0.541	0.539	0.540	0.532	0.533	0.517	0.521	0.527	0.532
Avg.Thickness		0.545	0.545	0.545	0.545	0.546	0.546	0.541	0.542	0.544	0.544
Avg O.D. (PI-Tape)		9.715	9.717	9.718	9.718	9.715	9.715	9.716	9.716	9.716	9.716
Actual O.D. @ 0/180		9.714	9.707	9.715	9.708	9.702	9.706	9.711	9.705	9.716	9.709
Ovality Gauge Max (+)		.003/270	.004/270	.000/270	.007/270	.015/270	.000/270	.000/270	.012/270	.005/270	
Ovality Gauge Min (-)		.005/135	.005/135	.006/135	.012/135	.000/135	.005/135	.015/135	.000/135	.005/135	
Ovality Max & Min indicated in inches. 2nd number represents location in degrees.											
Ovality, (Max-Min)/Avg		0.08%	0.09%	0.06%	0.20%	0.15%	0.05%	0.15%	0.12%	0.10%	0.11%
Eccentricity,	0-180	1.83%	3.30%	3.31%	2.20%	1.65%	2.56%	0.37%	1.85%	3.31%	2.26%
(tmax-tmin)/tavg	45-225	0.73%	1.84%	2.94%	3.85%	3.29%	3.66%	0.18%	1.29%	1.10%	2.10%
	90-270	1.28%	2.57%	3.86%	3.30%	5.67%	5.13%	6.47%	6.46%	5.15%	4.43%
	135-315	0.37%	1.10%	0.55%	0.37%	2.01%	0.73%	4.62%	4.61%	4.23%	2.07%
Actual Avg D/T		17.82	17.84	17.85	17.82	17.78	17.79	17.95	17.93	17.86	17.85
T-Max	0.572										
T-Min	0.517										
T-Avg.	0.544										
STDEV.	0.013791512										
Pipe Sample Failure Details:		SAMPLE FLATTENED 2D TO 6D W/SMALL AXIS AT 135 & 315 DEG									
			135 DEG		315 DEG						

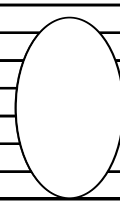


FIGURE 6-3

Typical Collapse Sample Being Installed Into Chamber

FIGURE 6-4

Typical Collapsed Samples

6.3 RESIDUAL STRESS TESTS

Finished pipe contains residual stresses that are a result of the manufacturing process. The ISO 10400 workgroup has determined that the amount of residual stress is a significant factor to the collapse resistance of pipe and one of the variables in the calculation of collapse pressure is the residual stress in the circumferential direction. Therefore, it was decided that residual stresses for the pipe samples tested in this program were required.

An investigation was made to learn more about pipe residual stress and how it was measured. The following information was found:

- Currently pipe mills do little to none measurements for residual stress. This was determined from a questionnaire that was sent by the ISO 10400 workgroup. What little work that has been done used the split ring method (discussed below).
- A popular method for circumferential residual stress in pipe is the split ring method. One of the first known methods was by D. K. Crampton in 1930 in his paper "Internal Stress and Cracking in Brass Tubes"[1]. Crampton gave an equation for calculating the residual stress that is based on pipe OD and wall thickness measurements. A ring is removed from the pipe, OD and walls measured, the ring is split longitudinally and the OD is measured again. A summary of Crampton's paper is given below:

    1. The majority of this paper deals with metallurgical aspects of season and corrosion cracking of brass tubes. A small part of the paper is concerned with residual stresses from manufacturing, and a summary of this is given below.

    2. Residual stresses by the method of Heyn and Bauer and Sachs is stated as being the proper ones to use for intensity and distribution of residual stresses. However, Crampton says these are too tedious and prohibitive to use.

    3. Crampton discusses both longitudinal strips in the tubes for measuring longitudinal residual stress and circumferential strips for measuring circumferential stress. For DEA-130, collapse of pipe is only concerned with circumferential stress.

    4. Crampton used the more general method for determining circumferential residual stress proposed by Hatfield and Thirkell. He simplified their method by using wider rings and he investigated the effect of the width of the ring.

    5. Circumferential residual stress measurements were made on 2-1/8" OD x 1/8" wall brass tubes using the split ring method.

    6. Residual circumferential stress was calculated from:

        S = ET/2((R1-R2)/(R1xR2), where
        E = modulus of elasticity
        T = wall thickness
        R1 = final mean radius of curvature

R2 = initial mean radius of curvature

7. The width of split rings varied from 0.080" to 18.0" (L/D = 0.04 to 8.47). A total of 13 rings was tested.

8. Several brass tubes of various sizes and degree of working were investigated and they had "much the same results". The apparent circumferential stress increased with the length of the ring up to a length of 2.5 to 3 times the diameter. Beyond this length, the apparent stress had no change.

9. The last two rings had basically the same stress (15 ksi), with ring widths of 5.5" (L/D = 2.6) and 18" (L/D = 8.5). Rings shorter than 5.5" had less stress.

10. Crampton adopted a ring width of L/D $\geq$ 3.

Another technical paper that addressed pipe residual stress was written by P. Mehdizadeh 's (Conoco) 1976 paper "Casing Collapse Performance"[2]. A summary of the paper is given below.

1. Total of 22 collapse tests performed on 7-5/8" 29.4# restricted yield N-80 pipe, 18 tests on 7-5/8" 26# N-80 and 12 tests on 7-5/8" 33.7# N-80 pipe.

2. L/D $\geq$ 7 required for valid collapse test.

3. Pressure acting on pipe closed ends gives higher collapse pressure than open end pipe test.

4. Residual stress by slit-ring method:
   - Tested ring widths of 2", 4", 8" and 16" (L/D = 0.29 to 2.3) on 7" 29# N-80 RY and found no difference due to ring length
   - Used 2" wide rings
   - Locate gage marks
   - Slit ring between gage marks
   - Measure amount of open or close, "a", where +a = ID compression stress and –a = ID tension stress
   - Stress, $S = atE/4.5R^2$, t = avg. wall, R = avg. middle radius, E = 30 E6 psi
   - Stress a function of D/T, yield strength, % quench and amount of straightening - 1 rotary pass = 27% reduction in collapse
2 rotary passes = additional 6% reduction
Also found some rotary straightening on second pass significantly increased collapse pressure, not sure why.

5. Slack quenching (slow cooling) causes -
   - thermal gradient through the pipe wall
   - different microstructure across the wall

- varying strength across the wall (higher on OD)
- and reduced collapse pressure (≅ 30%)

6. Rotary straightening significantly –
   - Increases residual stress (≅ 23%)
   - Reduces collapse pressure (≅ 10% - 40%)

7. Rotary straightening and slack quenching reduces collapse pressure approx. 33%.

8. Gag straightened pipe has much higher collapse resistance than severely rotary straightened pipe.

9. Estimate fully quenched pipe to have 20% - 30% higher collapse resistance than API ratings.

10. API ratings include severely slack quenched pipe but not both severely slack quenched <u>and</u> rotary straightened pipe.

Two other references, Frame[3] and ASTM[4], address the measuring of tubular circumferential residual stress and both use the split ring method.

A more recent method of measuring residual stress is by x-ray. The measurement of pipe residual stresses using the x-ray method was discussed with Mr. James Pineault of Proto manufacturing. Proto manufactures the equipment and also offers the service of using the equipment for measuring residual stresses. Mr. Pineault provided the following information:

1. Can readily measure pipe OD or ID residual stresses.
2. ID is limited to 4" and above in order to readily get to the surface.
3. Can measure both axial and hoop direction stress.
4. Once setup, the measurement and corresponding measured stress only takes a few minutes
5. One day can typically take 24 measurements or more.
6. Can measure from a depth of 0.0005" to 0.010" (and maybe more).
7. For steel, they usually measure over a 2 mm x 5 mm (0.08" x 0.20") area and the error is low.
8. Can measure at the surface or any depth below the surface.
9. I described the DEA-130 program and told him we wanted the average hoop stress at the ID. He recommended taking several measurements to achieve this.
10. The cost at their facility is $75 per measurement. Cost is more for field measurements.
11. Website is protoxrd.com

In the beginning, the number of samples to be collapse tested in this program was approximately 200. The budgeted funds for measuring residual stress was $22,000, which gave approximately $110 per sample. The x-ray method would require approximately 4 to 6 separate measurements to get the average hoop stress for a cost of $300 to $600 per sample. Since this method exceeded the budget amount, it was decided not to use x-ray measurements.

After reviewing the above technical papers, it was decided that the best method for obtaining pipe circumferential residual stress was the split ring method. The only uncertainty was the length of the ring. Crampton found that for 2-1/8" brass tubes a length of at least 2.5D was required, while Mehdizadeh determined that 2" was adequate for 7" pipe. More recently, Siderca performed a study of pipe collapse resistance and results were presented by Mr. Gustavo Lopen Turconi[5] at the 2001 Offshore Technical Conference. Turconi stated that they found that a length of 2D would give the same average residual hoop stress as a 3D length specimen. However, the scatter for the 2D length was more than that for a 3D length and they settled on 3D as their length for residual stress specimens. Therefore, it was decided to use a specimen length of 3D for this program.

A spreadsheet was written and used to record specimen measurements and calculate residual stress. It showed where to make the pipe OD and wall thickness measurements. The specimen OD was measured before and after splitting the ring at three locations along the length. The spreadsheet and typical test results are given in Figure 6-5. One sample of 8-5/8" pipe had a L/D=2. This was because at the very start of the program, L/D=2 was used and later changed to L/D=3. In the spreadsheet, the algebraic sign of the residual stress follows the direction of the change in measured OD (tension stress for OD increase and negative stress for OD decease). However, it should be noted that at the ID, the reverse is true, that is, tension residual stresses given in the spreadsheet are actually compression at the pipe ID. It is the pipe ID residual stress that affects collapse.

FIGURE 6-5 Example Residual Stress Data

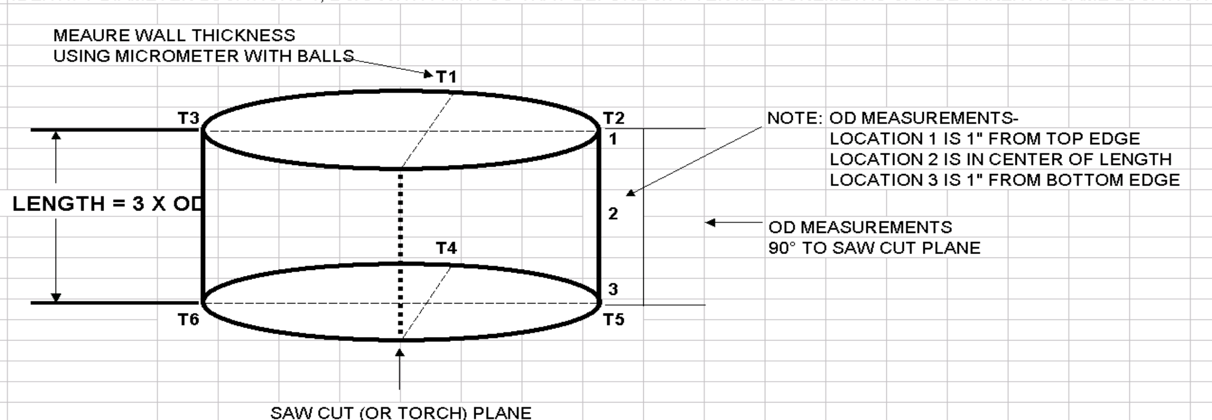
DEA-130 RESIDUAL STRESS
MEASUREMENT OF PIPE SAMPLES

PIPE DONATED BY SHELL OIL

SHELL NO.	PIPE DESCRIPTION OD	WEIGHT	GRADE	PIPE MILL	LENGTH INCH	L/D	THICKNESS, INCH (SEE NOTE BELOW) 1	2	3	4	5	6	AVG.
1	2.88	7.7	2550	Sumitomo	9 7/8	3.43	.286	.281	.284	.283	.282	.286	0.284
3	3.50	10.2	825	Special Metals	10 5/8	3.04	.287	.287	.281	.293	.287	.283	0.286
6	4.50	13.5	Hyper 13Cr-110	Kawasaki	15 1/4	3.39	.294	.298	.299	.296	.296	.311	0.299
7	4.50	13.5	13 Cr-85	Kawasaki	14 3/8	3.19	.294	.305	.295	.294	.297	.296	0.297
8	4.50	13.5	825	Special Metals	13 5/8	3.03	.307	.292	.301	.308	.291	.302	0.300
9	5.50	17	Hyper 13Cr-110	Kawasaki	17 1/4	3.14	.301	.312	.313	.302	.313	.312	0.309
10	3.50	9.2	SM13CrM110	Sumitomo	11 1/2	3.29	.265	.268	.272	.266	.271	.272	0.269
12	4.50	13.5	13 Cr-95	Nippon Kokan	15 1/4	3.39	.301	.318	.316	.300	.306	.318	0.310
13	4.50	15.1	NK15CR110	Nippon Kokan	14 1/5	3.15	.340	.363	.345	.332	.363	.345	0.348
14	4.50	15.1	KOP1-13Cr110	Kawasaki	14 7/8	3.31	.341	.339	.327	.341	.336	.332	0.336
15	4.50	15.1	SM13CrM110	Sumitomo	13 5/8	3.03	.358	.336	.334	.355	.337	.339	0.343
16	5.50	20	KOHP-1-13Cr110	Kawasaki	16 5/8	3.02	.359	.350	.361	.366	.351	.364	0.359
18	5.50	20	NK15Cr110	Nippon Kokan	17 1/2	3.18	.385	.383	.380	.390	.396	.384	0.386
19	5.50	23	NK15Cr110	Nippon Kokan	16 5/8	3.02	.412	.410	.421	.417	.426	.429	0.419
20	5.50	23	KOHP-1-13Cr110	Kawasaki	17 3/8	3.16	.413	.427	.422	.417	.430	.423	0.422
22	5.50	23	13Cr110	Sumitomo	16 1/8	2.93	.419	.424	.434	.414	.418	.439	0.425
23	4.50	15.1	NK15Cr95	Nippon Kokan	13 3/4	3.06	.345	.344	.346	.356	.359	.346	0.349

SHELL NO.	OUTSIDE DIAMETER, INCH (SEE NOTE BELOW) 1 BEFORE	1 AFTER	1 DIFF.	2 BEFORE	2 AFTER	2 DIFF.	3 BEFORE	3 AFTER	3 DIFF.	AVG. BEFORE	AVG. AFTER	AVG. DIFF.	RESIDUAL HOOP STRESS, PSI THIN WALL	CRAMPTON
1	2.897	2.893	0.00	2.891	2.900	0.01	2.890	2.900	0.01	2.893	2.898	0.00	5,578	5,076
3	3.510	3.552	0.04	3.507	3.558	0.05	3.509	3.559	0.05	3.509	3.556	0.05	36,060	32,814
6	4.516	4.552	0.04	4.516	4.543	0.03	4.513	4.556	0.04	4.515	4.550	0.04	16,953	15,427
7	4.513	4.523	0.01	4.511	4.524	0.01	4.516	4.532	0.02	4.513	4.526	0.01	6,227	5,667
8	4.508	4.583	0.08	4.511	4.579	0.07	4.508	4.570	0.06	4.509	4.577	0.07	32,763	29,814
9	5.520	5.570	0.05	5.521	5.571	0.05	5.522	5.572	0.05	5.521	5.571	0.05	16,551	15,061
10	3.523	3.532	0.01	3.522	3.534	0.01	3.524	3.539	0.02	3.523	3.535	0.01	8,545	7,776
12	4.545	4.555	0.01	4.551	4.545	-0.01	4.542	4.551	0.01	4.546	4.550	0.00	2,140	1,947
13	4.533	4.525	-0.01	4.526	4.528	0.00	4.528	4.538	0.01	4.529	4.530	0.00	746	678
14	4.512	4.542	0.03	4.511	4.543	0.03	4.511	4.555	0.04	4.511	4.547	0.04	19,081	17,364
15	4.523	4.537	0.01	4.520	4.537	0.02	4.536	4.541	0.01	4.526	4.538	0.01	6,609	6,014
16	5.526	5.571	0.04	5.526	5.577	0.05	5.530	5.589	0.06	5.527	5.579	0.05	19,802	18,020
18	5.530	5.529	0.00	5.529	5.534	0.00	5.527	5.532	0.00	5.529	5.532	0.00	1,249	1,137
19	5.540	5.538	0.00	5.529	5.538	0.01	5.536	5.539	0.00	5.535	5.538	0.00	1,503	1,367
20	5.538	5.549	0.01	5.526	5.551	0.03	5.523	5.544	0.02	5.529	5.548	0.02	8,617	7,842
22	5.526	5.539	0.01	5.534	5.534	0.00	5.530	5.522	-0.01	5.530	5.532	0.00	763	694
23	4.530	4.533	0.00	4.531	4.541	0.01	4.526	4.538	0.01	4.529	4.537	0.01	4,670	4,250

REMOVE ANY LOOSE SCALE AND EXCESS MILL VARNISH FROM OD & ID BEFORE MAKING MEASUREMENTS
IDENTIFY DIAMETER LOCATIONS 1, 2 & 3 WITH PAINT SO THAT BEFORE & AFTER MEASUREMETNS CAN BE TAKEN AT SAME LOCATIONS



7.0 SUMMARY OF COLLAPSE AND RESIDUAL STRESS TESTS

Table 7-1 lists all of the samples that were tested and their collapse pressure. It also gives additional information including OD, weight, grade, specified yield, grade, if it was a high collapse product, seamless vs welded, finish process, actual average OD, wall, ovality, eccentricity, yield and tensile strengths and Crampton residual stress. The first sample in the table was a high strength 2-7/8" tube donated by Shell. A collapse pressure of 30,000 psi was applied without failure of the pipe. All other samples did collapse.

Figure 7-1 shows the samples tested by pipe size. Almost 70% of the tests were performed by four popular diameters – 5-½", 7", 9-5/8" and 13-3/8". Testing by material grade is shown in Figure 7-2. With the exception of grade H, the samples were reasonably distributed over the grades.

Five samples were tested but did not collapse before reaching the pressure limit of the SWRI chamber, and were later retested. Three of the five samples were beyond the capacity of SWRI for L/D = 8 and pressure above 20,000 psi and were later tested at North Star Steel. In February of 2002, SWRI completed the installation of a new chamber and it was used to collapse thirteen of the samples, which was completed in April of 2002.

The collapse test results for all samples are given in Appendix B. Due to the large amount of collapse test data, a hard copy of the SWRI measurements and collapse results for all 151 samples is not given with this report. All of the SWRI test data is provided for each sample on a CD in Microsoft Access.

TABLE 7-1 Summary of DEA-130 Test Data (4 pages)

BLUE DATA IS SHELL DONATED PIPE

Sample Number	Nominal OD, Inch	Nominal Weight, Lb/Ft	Specified Yield, Ksi	Grade Letter	HighCollapse Pipe?	Process	Finish Code	Average OD, Inch	Average Wall, Inch	Average Ovality	Average Eccentricity	Actual Weight, Lb/Ft	Actual Weight, Lb	Sample Length, Inch	Collapse Pressure, Psi	Failure Location	Yield Stress, Ksi			Tensile Stress, Ksi			Residual Stress, Psi		Sample Number
																	End	Middle	Average	End	Middle	Average	Thin Shell	Crampton	
1	2.875	7.8	125	A	No	Smls	36	2.89	0.282	0.042%	1.113%	8.19	15.7	23	30,000	N/A			140.60			148.10	5,578	5,076	1
2	3.5	9.2	110	A	No	Smls	25	3.51	0.269	0.322%	1.900%	9.26	21.6	28	17,227	135/315 deg			115.80			126.10	8,545	7,776	2
3	3.5	10.2	125	A	No	Smls	36	3.51	0.285	0.060%	1.630%	10.11	23.6	28	19,903	135/270 deg			113.70			138.90	36,060	32,814	3
4	4.5	12.6	80	L	No	Smls	30	4.53	0.274	0.189%	1.521%	12.63	37.9	36	10,315	0/315-135/180deg	87.31	87.74	87.53	102.97	107.47	105.22	4,241	3,860	4
5	4.5	12.6	80	L	No	Smls	30	4.52	0.270	0.196%	2.337%	12.30	36.9	36	10,058	0/45-180/225deg	82.52	83.10	82.81	99.20	100.22	99.71	3,206	2,918	5
6	4.5	12.6	80	L	No	Smls	30	4.53	0.266	0.177%	1.882%	12.27	36.8	36	9,939	0/315-135/180deg	87.60	86.73	87.16	103.41	103.41	103.41	4,488	4,084	6
7	4.5	13.5	85	A	No	Smls	25	4.51	0.284	0.244%	1.901%	12.93	38.8	36	11,039	90/135-270/315			88.00			116.90	6,227	5,667	7
8	4.5	13.5	95	A	No	Smls	25	4.53	0.295	0.471%	3.145%	13.47	40.4	36	12,469	0/315-135/180			101.60			123.50	2,140	1,947	8
9	4.5	13.5	110	A	No	Smls	25	4.51	0.295	0.416%	2.356%	13.17	39.5	36	13,550	0/180 deg			118.50			126.20	16,953	15,427	9
10	4.5	13.5	125	A	No	Smls	36	4.51	0.297	0.074%	4.400%	13.83	41.5	36	13,416	90/290 deg			96.00			130.00	32,763	29,814	10
11	4.5	15.1	95	A	No	Smls	25	4.53	0.343	0.356%	3.933%	15.37	46.1	36	15,899	0/315-135/180			95.30			119.70	4,670	4,250	11
12	4.5	15.1	110	A	No	Smls	25	4.52	0.329	0.342%	2.969%	14.67	44	36	16,912	135/315 deg			116.60			140.40	746	678	12
13	4.5	15.1	110	A	No	Smls	25	4.51	0.333	0.261%	1.604%	14.80	44.4	36	16,368	135/315 deg			114.50			124.90	19,081	17,364	13
14	4.5	15.1	110	A	No	Smls	25	4.52	0.335	0.201%	2.708%	14.83	44.5	36	15,883	0/45-180/225			114.00			121.80	6,609	6,014	14
15	5	15	95	A	No	Smls	25	5.02	0.302	0.168%	1.910%	15.00	50	40	9,506	45/90-225/270	96.30	96.70	96.50	125.00	126.60	125.80	13,128	11,947	15
16	5	15	95	A	No	Smls	25	5.02	0.314	0.168%	2.203%	15.45	51.5	40	10,364	45/225 deg	96.30	98.20	97.25	125.70	127.00	126.35	10,967	9,980	16
17	5	15	95	A	No	Smls	25	5.02	0.304	0.139%	3.711%	14.85	49.5	40	9,229	0/315-135/180deg	94.60	95.40	95.00	121.70	123.10	122.40	15,239	13,868	17
18	5.5	14	55	J	No	EW	8	5.53	0.238	0.370%	0.643%	13.64	50	44	4,263	135/315	64.80	69.80	67.30	78.50	83.30	80.90	22,750	20,702	18
19	5.5	14	55	J	No	EW	8	5.53	0.238	0.428%	0.700%	13.58	49.8	44	4,160	135/315	67.20	65.70	66.45	79.50	78.00	78.75	21,069	19,173	19
20	5.5	14	55	J	No	EW	8	5.53	0.236	0.405%	0.376%	13.50	49.5	44	4,048	0/180	67.40	68.60	68.00	81.30	82.40	81.85	22,317	20,309	20
21	5.5	14	55	J	No	EW	8	5.54	0.243	0.385%	0.560%	13.94	51.1	44	4,355	0/180	69.20	67.20	68.20	82.70	81.70	82.20	18,192	16,555	21
22	5.5	17	80	N	No	EW	28	5.54	0.299	0.395%	0.697%	16.80	61.6	44	7,846	90/270	96.30	97.00	96.65	107.50	110.50	109.00	19,922	18,129	22
23	5.5	17	80	N	No	EW	28	5.54	0.299	0.431%	1.051%	16.80	61.6	44	8,084	90/270	98.20	101.20	99.70	109.70	113.20	111.45	19,334	17,594	23
24	5.5	17	80	N	No	EW	28	5.55	0.298	0.369%	0.997%	16.75	61.4	44	7,879	90/270	99.60	101.00	100.30	110.90	112.40	111.65	18,666	16,986	24
25	5.5	17	80	N	No	EW	28	5.55	0.298	0.507%	0.942%	16.80	61.6	44	8,226	90/270	103.20	101.90	102.55	114.70	113.30	114.00	13,199	12,011	25
26	5.5	17	80	L	No	EW	28	5.53	0.312	0.534%	0.937%	0.00	0	44	6,933	90-270	84.20	85.90	85.05	99.00	101.00	100.00	21,736	19,780	26
27	5.5	17	80	L	No	EW	28	5.53	0.307	0.508%	0.815%	16.91	62	44	7,439	90-270	85.00	85.10	85.05	98.90	101.40	100.15	23,564	21,443	27
28	5.5	17	80	L	No	EW	28	5.53	0.311	0.499%	1.109%	13.53	62	55	6,997	90-270	82.00	85.40	83.70	98.90	101.00	99.95	22,727	20,682	28
29	5.5	17	80	L	No	EW	28	5.53	0.308	0.701%	0.813%	16.83	61.7	44	6,793	90-270	91.90	87.50	89.70	104.60	101.30	102.95	22,109	20,119	29
30	5.5	17	110	A	No	Smls	24	5.51	0.301	0.354%	2.615%	16.64	61	44	9,153	0/45-225deg			116.30			129.60	16,551	15,061	30
31	5.5	20	80	N	No	Smls	30	5.51	0.363	0.145%	6.573%	19.91	73	44	11,968	0/315-135/180deg	92.53	95.72	94.12	108.05	110.37	109.21	9,462	8,611	31
32	5.5	20	80	N	No	Smls	30	5.52	0.372	0.149%	4.303%	20.43	74.9	44	12,258	0/180 deg	93.54	94.70	94.12	108.19	109.93	109.06	7,944	7,229	32
33	5.5	20	80	N	No	Smls	30	5.51	0.373	0.137%	3.666%	20.56	75.4	44	12,255	0/315-135/180deg	96.88	94.99	95.94	110.95	110.08	110.51	8,274	7,529	33
34	5.5	20	80	L	No	Smls	25	5.52	0.365	0.284%	2.022%	19.77	72.5	44	10,783	0/315-135/180deg	83.10	85.30	84.20	111.10	113.70	112.40	3,603	3,279	34
35	5.5	20	80	L	No	Smls	25	5.53	0.371	0.183%	1.909%	19.98	73.25	44	10,591	0/45-180/225deg	85.10	84.00	84.55	112.80	112.30	112.55	2,788	2,537	35
36	5.5	20	80	L	No	Smls	25	5.53	0.369	0.151%	4.216%	19.98	73.25	44	10,473	90/135-270/315deg	84.70	85.30	85.00	111.10	113.60	112.35	2,346	2,135	36
37	5.5	20	110	P	No	Smls	28	5.54	0.365	0.243%	2.290%	20.07	73.6	44	14,094	45/90-225/270	128.50	123.10	125.80	136.70	132.70	134.70	26,861	24,444	37
38	5.5	20	110	P	No	Smls	28	5.53	0.366	0.351%	4.241%	20.05	73.5	44	15,369	0-180	124.80	127.00	125.90	133.30	134.90	134.10	23,707	21,573	38
39	5.5	20	110	P	No	Smls	28	5.54	0.364	0.275%	3.217%	20.05	73.5	44	14,776	45/90-225/270	127.40	125.60	126.50	135.00	134.40	134.70	26,268	23,904	39
40	5.5	20	110	A	No	Smls	25	5.53	0.364	0.169%	3.227%	19.85	72.8	44	13,878	0/180 Deg			115.40			127.90	19,802	18,020	40

TABLE 7-1 Summary of DEA-130 Test Data (4 pages)

BLUE DATA IS SHELL DONATED PIPE

Sample Number	Nominal OD, Inch	Nominal Weight, Lb/Ft	Specified Yield, Ksi	Grade Letter	HighCollapse Pipe?	Process	Finish Code	Average OD, Inch	Average Wall, Inch	Average Ovality	Average Eccentricity	Actual Weight, Lb/Ft	Actual Weight, Lb	Sample Length, Inch	Collapse Pressure, Psi	Failure Location	Yield Stress, Ksi			Tensile Stress, Ksi			Residual Stress, Psi		Sample Number
																	End	Middle	Average	End	Middle	Average	Thin Shell	Crampton	
41	5.5	20	110	A	No	Smls	25	5.53	0.373	0.350%	2.335%	20.40	74.8	44	14,641	0/315-135/180			114.50			137.30	1,249	1,137	41
42	5.5	23	110	A	No	Smls	25	5.53	0.401	0.293%	2.103%	21.98	80.6	44	16,781	45/225 deg			121.80			137.90	1,503	1,367	42
43	5.5	23	110	A	No	Smls	25	5.52	0.427	0.201%	1.482%	22.91	84	44	18,162	90/270 deg			114.20			126.30	8,617	7,842	43
44	5.5	23	110	A	No	Smls	25	5.52	0.423	0.312%	2.281%	22.66	83.1	44	16,695	90/135-270/315			114.00			123.30	763	694	44
45	7	26	55	K	No	Smls	3	7.04	0.365	0.194%	2.872%	25.99	121.3	56	5,757	0/180 DEG	72.10	72.60	72.35	113.20	112.40	112.80	9,116	8,295	45
46	7	26	55	K	No	Smls	3	7.05	0.369	0.192%	2.304%	26.25	122.5	56	5,961	0/180 DEG	69.50	70.00	69.75	110.00	110.20	110.10	18,885	17,186	46
47	7	26	55	K	No	Smls	3	7.05	0.360	0.165%	6.662%	25.67	119.8	56	5,400	135/315 DEG	69.50	72.90	71.20	110.70	111.40	111.05	15,704	14,290	47
48	7	29	80	N	No	EW	28	7.06	0.402	0.675%	0.801%	28.44	132.7	56	7,799	0/180	100.70	96.30	98.50	115.10	111.10	113.10	33,687	30,655	48
49	7	29	80	N	No	EW	28	7.09	0.397	0.679%	1.126%	28.26	131.9	56	7,602	0/180	100.80	107.80	104.30	114.80	121.70	118.25	34,050	30,985	49
50	7	29	80	N	No	EW	28	7.07	0.404	0.603%	1.218%	28.69	133.9	56	8,484	135/315	93.00	94.00	93.50	107.60	107.70	107.65	-1,174	-1,068	50
51	7	29	80	N	No	EW	28	7.06	0.402	0.498%	0.897%	28.61	133.5	56	7,254	45/90-225/270	88.60	88.70	88.65	101.80	103.20	102.50	26,608	24,213	51
52	7	29	80	L	No	Smls	30	7.04	0.406	0.145%	2.189%	28.82	134.5	56	8,965	45/225 deg	86.58	86.58	86.58	106.89	107.32	107.10	6,064	5,518	52
53	7	29	80	L	No	Smls	30	7.05	0.402	0.169%	2.611%	28.76	134.2	56	8,912	45/225 deg	88.03	87.45	87.74	107.61	107.32	107.47	4,414	4,017	53
54	7	29	80	L	No	Smls	25	7.03	0.425	0.126%	0.843%	29.14	136	56	8,956	0/45-180/225deg	89.80	87.00	88.40	116.90	113.90	115.40	3,634	3,307	54
55	7	29	80	L	No	Smls	25	7.03	0.418	0.107%	1.961%	29.14	136	56	9,136	90/270 deg	86.60	87.30	86.95	113.60	114.00	113.80	2,960	2,694	55
56	7	29	80	L	No	Smls	25	7.03	0.421	0.125%	2.398%	29.25	136.5	56	8,770	90/135-270/315deg	86.90	88.20	87.55	113.60	113.70	113.65	3,173	2,887	56
57	7	29	95	A	No	EW	28	7.06	0.406	0.203%	0.554%	28.95	135.1	56	10,872	90/270	120.80	131.40	126.10	131.00	141.00	136.00	24,150	21,976	57
58	7	29	95	A	No	EW	28	7.07	0.406	0.225%	0.575%	28.95	135.1	56	10,370	90/270	120.40	121.70	121.05	130.60	132.00	131.30	24,400	22,204	58
59	7	29	95	A	No	EW	28	7.06	0.405	0.192%	0.891%	28.99	135.3	56	10,709	90/270	122.90	121.40	122.15	133.10	131.80	132.45	20,555	18,705	59
60	7	29	110	A	Yes	EW	28	7.07	0.405	0.146%	0.816%	28.76	134.2	56	10,323	0/45-180/225	114.90	113.60	114.25	129.60	127.00	128.30	6,853	6,236	60
61	7	29	110	A	Yes	EW	28	7.07	0.404	0.302%	0.612%	28.76	134.2	56	10,042	135/315	113.40	115.40	114.40	127.60	128.70	128.15	13,080	11,903	61
62	7	29	110	A	Yes	EW	28	7.08	0.403	0.325%	0.882%	28.67	133.8	56	10,211	135/315	114.30	113.30	113.80	127.90	127.20	127.55	13,815	12,572	62
63	7	29	110	A	Yes	EW	28	7.06	0.403	0.464%	0.819%	28.56	133.3	56	10,018	135/315	111.10	113.00	112.05	125.00	127.70	126.35	10,659	9,700	63
64	7	32	80	N	No	Smls	3	7.06	0.456	0.200%	2.958%	31.95	149.1	56	10,906	45/90-225/270	84.70	86.90	85.80	102.00	102.70	102.35	801	729	64
65	7	32	80	N	No	Smls	3	7.06	0.459	0.143%	1.436%	32.04	149.5	56	10,901	45/90-225/270	84.80	84.90	84.85	100.90	101.60	101.25	1,788	1,627	65
66	7	32	80	N	No	Smls	3	7.07	0.451	0.165%	1.157%	31.74	148.1	56	10,790	45/90-225/270	86.20	84.70	85.45	101.00	100.30	100.65	1,084	987	66
67	7	32	110	A	No	Smls	30	7.06	0.468	0.275%	3.694%	32.55	151.9	56	13,278	90/225 DEG	121.00	123.00	122.00	133.10	132.90	133.00	16,853	15,336	67
68	7	32	110	A	No	Smls	30	7.05	0.453	0.381%	2.818%	31.67	147.6	56	12,503	135/315 DEG	119.00	118.00	118.50	128.10	127.80	127.95	11,353	10,331	68
69	7	32	110	A	No	Smls	30	7.05	0.456	0.195%	1.807%	31.78	148.3	56	13,509	90/270 DEG	118.80	120.70	119.75	128.20	130.40	129.30	12,905	11,744	69
70	7	35	125	Q	No	Smls	30	7.04	0.506	0.295%	1.274%	35.25	164.5	56	17,601	135/180-0/315	136.60	139.60	138.10	148.30	154.30	151.30	24,034	21,871	70
71	7	35	125	Q	No	Smls	30	7.04	0.495	0.212%	2.315%	34.67	161.8	56	17,165	90/270 DEG	136.80	143.10	139.95	147.30	154.50	150.90	25,846	23,520	71
72	7	35	125	Q	No	Smls	30	7.03	0.499	0.234%	2.438%	34.82	162.5	56	17,674	90/135-270/315	135.00	139.00	137.00	148.90	154.80	151.85	26,993	24,564	72
73	7.75	46.1	110	P	No	Smls	28	7.81	0.588	0.232%	2.451%	45.33	234.2	62	20,468	22/202 Ddeg	129.30	139.90	134.60	153.90	153.80	153.85	32,388	29,473	73
74	7.75	46.1	110	P	No	Smls	28	7.80	0.608	0.285%	4.101%	46.80	241.8	62	19,474	90/270 DEG	133.70	125.20	129.45	146.70	151.00	148.85	24,744	22,517	74
75	7.75	46.1	110	P	No	Smls	28	7.81	0.588	0.247%	2.719%	45.31	234.1	62	19,413	135/315 DEG	134.20	130.80	132.50	145.40	152.30	148.85	32,567	29,636	75
76	7.75	46.1	125	Q	Yes	Smls	29	7.82	0.598	0.227%	1.905%	45.66	235.9	62	21,220	45/225 DEG	148.20	149.00	148.60	159.90	160.30	160.10	18,630	16,953	76
77	7.75	46.1	125	Q	Yes	Smls	29	7.82	0.600	0.226%	2.572%	45.89	237.1	62	23,956	45/225 DEG	145.10	142.20	143.65	157.70	155.50	156.60	19,234	17,503	77
78	8.625	24	55	K	No	Smls	3	8.68	0.274	0.330%	4.391%	24.52	141	69	2,022	0/315-135/180	65.20	66.10	65.65	105.30	107.00	106.15	19,002	17,292	78
79	8.625	24	55	K	No	Smls	3	8.68	0.274	0.215%	4.398%	24.43	140.5	69	1,959	45-225	67.60	68.90	68.25	108.70	109.90	109.30	13,844	12,598	79
80	8.625	24	55	K	No	Smls	3	8.68	0.273	0.287%	6.278%	24.33	139.9	69	1,989	0/45-180/225	66.80	66.40	66.60	107.10	107.00	107.05	16,157	14,703	80

TABLE 7-1 Summary of DEA-130 Test Data (4 pages)

BLUE DATA IS SHELL DONATED PIPE

Sample Number	Nominal OD, Inch	Nominal Weight, Lb/Ft	Specified Yield, Ksi	Grade Letter	HighCollapse Pipe?	Process	Finish Code	Average OD, Inch	Average Wall, Inch	Average Ovality	Average Eccentricity	Actual Weight, Lb/Ft	Actual Weight, Lb	Sample Length, Inch	Collapse Pressure, Psi	Failure Location	Yield Stress, Ksi			Tensile Stress, Ksi			Residual Stress, Psi		Sample Number
																	End	Middle	Average	End	Middle	Average	Thin Shell	Crampton	
81	8.625	32	55	J	No	EW	8	8.69	0.343	0.265%	0.510%	31.13	179	69	3,490	0/180	65.40	62.30	63.85	80.40	78.30	79.35	18,390	16,734	81
82	8.625	32	55	J	No	EW	8	8.69	0.342	0.142%	0.682%	30.56	175.7	69	3,329	0/180	62.20	63.30	62.75	78.80	78.30	78.55	17,660	16,071	82
83	8.625	32	55	J	No	EW	8	8.69	0.349	0.132%	0.470%	31.20	179.4	69	3,324	90/270	62.10	63.60	62.85	77.70	77.80	77.75	16,865	15,347	83
84	8.625	32	55	J	No	EW	8	8.69	0.343	0.277%	0.493%	30.75	176.8	69	3,091	90/135-270/315	64.90	65.10	65.00	79.90	80.40	80.15	17,737	16,141	84
85	9.625	36	55	K	No	EW	13	9.70	0.352	0.139%	1.278%	35.30	226.5	77	3,085	45/225	68.40	66.10	67.25	101.30	102.10	101.70	11,342	10,322	85
86	9.625	36	55	K	No	EW	13	9.70	0.353	0.215%	1.212%	35.53	228	77	3,144	0/180	70.30	70.10	70.20	100.00	99.20	99.60	11,635	10,588	86
87	9.625	36	55	K	No	EW	13	9.70	0.356	0.199%	0.725%	35.83	229.9	77	3,137	90/270	69.40	72.90	71.15	101.90	100.30	101.10	12,237	11,135	87
88	9.625	36	55	K	No	EW	13	9.71	0.353	0.151%	0.732%	35.59	228.4	77	2,988	0/180	70.30	67.10	68.70	102.60	101.30	101.95	12,193	11,096	88
89	9.625	36	55	K	No	Smls	3	9.69	0.358	0.211%	1.645%	35.44	227.4	77	2,814	90/135 - 270 DEG	68.20	70.00	69.10	106.80	107.00	106.90	13,138	11,956	89
90	9.625	36	55	K	No	Smls	3	9.69	0.355	0.287%	2.178%	35.50	227.8	77	2,777	45/225 DEG	67.50	67.50	67.50	106.50	106.70	106.60	15,128	13,767	90
91	9.625	36	55	K	No	Smls	3	9.70	0.359	0.307%	3.678%	35.74	229.3	77	2,689	90/270 DEG	66.20	65.10	65.65	102.60	103.10	102.85	15,294	13,918	91
92	9.625	40	80	N	No	Smls	3	9.71	0.402	0.143%	1.985%	39.72	254.9	77	5,032	45/90-225/270	94.00	93.20	93.60	108.20	107.80	108.00	5,120	4,659	92
93	9.625	40	80	N	No	Smls	3	9.71	0.401	0.232%	2.781%	39.71	254.8	77	4,975	135-315	94.80	93.60	94.20	109.40	107.80	108.60	5,050	4,595	93
94	9.625	40	80	N	No	Smls	3	9.70	0.406	0.219%	3.820%	40.07	257.1	77	5,231	135-315	91.20	94.00	92.60	106.40	108.60	107.50	3,163	2,878	94
95	9.625	47	80	L	No	Smls	30	9.69	0.470	0.213%	3.640%	46.15	296.1	77	7,405	45-225	84.70	81.80	83.25	102.10	101.23	101.67	-2,936	-2,672	95
96	9.625	47	80	L	No	Smls	30	9.69	0.463	0.147%	2.202%	45.49	291.9	77	7,163	90-270	80.49	85.28	82.88	97.75	101.38	99.56	2,572	2,340	96
97	9.625	47	80	L	No	Smls	30	9.68	0.471	0.283%	2.798%	45.19	290	77	6,622	45-225	86.15	85.13	85.64	103.12	101.67	102.39	2,023	1,841	97
98	9.625	47	80	N	No	Smls	30	9.70	0.478	0.223%	3.001%	47.00	301.6	77	7,779	90-270	99.93	95.43	97.68	116.31	113.41	114.86	3,961	3,604	98
99	9.625	47	80	N	No	Smls	30	9.69	0.491	0.265%	4.487%	48.22	309.4	77	8,226	45/90-225/270	99.35	97.75	98.55	112.54	115.15	113.85	1,150	1,047	99
100	9.625	47	80	N	No	Smls	30	9.69	0.490	0.285%	4.179%	48.36	310.3	77	8,021	135-315	99.20	99.06	99.13	113.41	114.43	113.92	2,933	2,669	100
101	9.625	53.5	110	A	No	Smls	30	9.71	0.543	0.097%	1.985%	53.01	339.8	77	11,287	135/315 DEG	119.20	123.10	121.15	132.30	134.30	133.30	20,262	18,438	101
102	9.625	53.5	110	A	No	Smls	30	9.71	0.544	0.113%	2.715%	53.33	341.9	77	11,684	135/315 DEG	122.80	122.90	122.85	133.50	134.10	133.80	19,102	17,383	102
103	9.625	53.5	110	A	No	Smls	30	9.72	0.548	0.128%	3.406%	53.63	343.8	77	11,640	45/225 DEG	122.20	123.90	123.05	133.20	135.20	134.20	19,663	17,894	103
104	9.625	53.5	110	P	No	Smls	30	9.69	0.534	0.632%	1.260%	52.18	334.8	77	9,879	0/180 DEG	134.70	131.50	133.10	145.30	143.90	144.60	19,051	17,337	104
105	9.625	53.5	110	P	No	Smls	30	9.69	0.546	0.531%	2.652%	53.14	341	77	10,728	0/180 DEG	123.80	127.20	125.50	137.70	139.30	138.50	191	174	105
106	9.625	53.5	110	P	No	Smls	30	9.72	0.551	0.347%	4.034%	52.83	339	77	9,629	90/135-270/315	123.60	119.30	121.45	137.90	137.30	137.60	19,543	17,784	106
107	9.625	53.5	125	Q	No	Smls	29	9.69	0.547	0.281%	1.617%	52.99	340	77	10,832	45/90-225/270	134.00	132.80	133.40	147.90	147.90	147.90	28,568	25,997	107
108	9.625	53.5	125	Q	No	Smls	29	9.69	0.543	0.154%	2.845%	52.85	339.1	77	10,836	135-315	125.80	126.70	126.25	143.00	143.00	143.00	32,321	29,412	108
109	9.625	53.5	125	Q	No	Smls	29	9.69	0.547	0.159%	2.017%	52.97	339.9	77	10,695	90/270	131.50	131.70	131.60	146.10	146.70	146.40	32,226	29,325	109
110	10.75	40.5	55	J	No	EW	8	10.82	0.343	0.280%	0.624%	38.40	275.2	86	1,783	0/45-180/225DEG	62.54	61.07	61.80	80.33	79.15	79.74	20,407	18,571	110
111	10.75	40.5	55	J	No	EW	8	10.81	0.342	0.275%	1.536%	38.19	273.7	86	2,062	45/225DEG	77.70	64.20	70.95	90.10	81.48	85.79	19,080	17,363	111
112	10.75	40.5	55	J	No	EW	8	10.82	0.344	0.292%	0.751%	38.25	274.1	86	1,738	45/225DEG	63.14	63.59	63.36	83.34	82.23	82.79	20,011	18,210	112
113	10.75	45.5	80	N	Yes	Smls	30	10.84	0.398	0.180%	2.071%	44.43	318.4	86	3,363	0/180 DEG	94.10	92.80	93.45	106.00	106.00	106.00	4,706	4,282	113
114	10.75	45.5	80	N	Yes	Smls	30	10.83	0.401	0.249%	1.614%	44.61	319.7	86	3,698	135/315	92.30	94.40	93.35	104.30	107.50	105.90	5,338	4,857	114
115	10.75	45.5	80	N	Yes	Smls	30	10.83	0.400	0.220%	1.562%	44.44	318.5	86	3,542	90/270 DEG	89.50	94.20	91.85	103.60	106.70	105.15	4,802	4,370	115
116	11.75	71	125	Q	No	Smls	30	11.84	0.589	0.268%	3.850%	69.70	546	94	8,865	0/180 DEG	141.30	141.80	141.55	147.60	147.60	147.60	13,723	12,488	116
117	11.75	71	125	Q	No	Smls	30	11.84	0.602	0.214%	2.333%	72.00	564	94	9,814	0/315-135/180	144.20	140.30	142.25	152.90	147.50	150.20	22,186	20,189	117
118	11.75	71	125	Q	No	Smls	30	11.84	0.588	0.289%	2.488%	70.25	550.3	94	8,860	45/90-225/270	142.60	143.90	143.25	147.80	148.80	148.30	12,468	11,346	118
119	13.375	48	40	H	No	EW	8	13.44	0.322	0.229%	0.638%	45.43	405.1	107	937	45/225 DEG	64.68	64.01	64.34	82.47	84.09	83.28	18,963	17,256	119
120	13.375	48	40	H	No	EW	8	13.44	0.323	0.208%	0.825%	45.40	404.8	107	936	45/225 DEG	61.85	62.35	62.10	82.48	83.26	82.87	18,896	17,196	120

TABLE 7-1 Summary of DEA-130 Test Data (4 pages)

BLUE DATA IS SHELL DONATED PIPE

Sample Number	Nominal OD, Inch	Nominal Weight, Lb/Ft	Specified Yield, Ksi	Grade Letter	HighCollapse Pipe?	Process	Finish Code	Average OD, Inch	Average Wall, Inch	Average Ovality	Average Eccentricity	Actual Weight, Lb/Ft	Actual Weight, Lb	Sample Length, Inch	Collapse Pressure, Psi	Failure Location	Yield Stress, Ksi			Tensile Stress, Ksi			Residual Stress, Psi		Sample Number
																	End	Middle	Average	End	Middle	Average	Thin Shell	Crampton	
121	13.375	48	40	H	No	EW	8	13.44	0.323	0.220%	0.387%	45.31	404	107	950	135/315 DEG	64.70	61.56	63.13	84.19	83.92	84.05	19,634	17,866	121
122	13.375	54.5	55	K	No	Smls	3	13.44	0.386	0.212%	3.573%	53.47	476.8	107	1,543	135/315 DEG	72.00	69.10	70.55	110.80	109.10	109.95	15,112	13,752	122
123	13.375	54.5	55	K	No	Smls	3	13.47	0.386	0.364%	1.628%	53.57	477.7	107	1,552	0/45-180/225 DEG	65.50	65.80	65.65	105.10	105.10	105.10	1,970	1,793	123
124	13.375	54.5	55	K	No	Smls	3	13.46	0.391	0.170%	1.884%	54.24	483.6	107	1,462	135/315 DEG	66.70	66.70	66.70	105.70	107.10	106.40	16,927	15,403	124
125	13.375	54.5	55	K	No	EW	13	13.46	0.383	0.191%	0.522%	53.43	476.4	107	1,535	90/270	71.80	66.30	69.05	105.20	102.60	103.90	31,257	28,444	125
126	13.375	54.5	55	K	No	EW	13	13.48	0.383	0.210%	0.334%	53.56	477.6	107	1,455	45/225	69.90	68.90	69.40	102.80	100.10	101.45	9,992	9,092	126
127	13.375	54.5	55	K	No	EW	13	13.45	0.386	0.276%	0.533%	53.63	478.2	107	1,561	45/225	68.80	73.50	71.15	100.80	101.90	101.35	25,255	22,982	127
128	13.375	54.5	55	K	No	EW	13	13.47	0.383	0.169%	0.494%	53.62	478.1	107	1,468	0/180	71.50	69.80	70.65	103.90	103.00	103.45	10,836	9,861	128
129	13.375	68	80	N	Yes	Smls	28	13.45	0.482	0.170%	4.300%	66.76	595.3	107	3,402	0/180 DEG	102.20	103.00	102.60	114.20	114.10	114.15	4,751	4,323	129
130	13.375	68	80	N	Yes	Smls	28	13.44	0.485	0.166%	6.290%	66.82	595.8	107	3,521	45/225 DEG	99.50	98.20	98.85	110.70	110.00	110.35	5,477	4,984	130
131	13.375	68	80	N	Yes	Smls	28	13.45	0.486	0.302%	8.119%	66.93	596.8	107	3,437	135/315 DEG	100.70	102.40	101.55	112.30	114.10	113.20	6,638	6,041	131
132	13.375	68	110	P	No	Smls	30	13.47	0.479	0.225%	3.037%	65.83	587	107	3,278	90-270 DEG	131.11	131.25	131.18	145.76	149.67	147.71	39,310	35,772	132
133	13.375	68	110	P	No	Smls	30	13.47	0.482	0.368%	1.987%	66.13	589.7	107	3,342	135/315 DEG	129.51	131.54	130.53	139.52	143.58	141.55	30,937	28,152	133
134	13.375	68	110	P	No	Smls	30	13.47	0.479	0.184%	1.643%	65.92	587.8	107	3,316	90-270 DEG	128.35	129.95	129.15	142.71	146.34	144.52	36,961	33,635	134
135	13.375	68	110	P	Yes	Smls	28	13.44	0.480	0.212%	1.603%	65.94	588	107	3,208	45/225 Deg	127.00	130.10	128.55	135.80	137.80	136.80	25,011	22,760	135
136	13.375	68	110	P	Yes	Smls	28	13.44	0.473	0.271%	1.537%	65.21	581.5	107	3,080	135/315 Deg	124.70	127.10	125.90	135.40	136.90	136.15	22,688	20,646	136
137	13.375	68	110	P	Yes	Smls	28	13.43	0.481	0.196%	3.223%	66.28	591	107	3,352	90/270 Deg	121.70	125.50	123.60	132.20	135.60	133.90	23,847	21,701	137
138	13.375	72	95	A	Yes	Smls	30	13.47	0.523	0.647%	2.365%	70.04	624.5	107	3,813	45/225 deg	120.96	118.49	119.72	138.50	137.05	137.78	24,710	22,486	138
139	13.375	72	95	A	Yes	Smls	30	13.46	0.528	0.618%	2.458%	73.01	651	107	4,010	45/225 deg	119.50	122.41	120.96	140.39	139.95	140.17	27,825	25,321	139
140	13.375	72	110	P	Yes	Smls	28	13.46	0.502	0.396%	3.065%	69.14	616.5	107	3,637	90/270 Deg	125.50	127.00	126.25	135.60	137.30	136.45	12,227	11,127	140
141	13.375	72	110	P	Yes	Smls	28	13.45	0.505	0.269%	4.037%	69.53	620	107	3,809	45/225 Deg.	124.10	124.00	124.05	134.50	135.00	134.75	13,025	11,853	141
142	13.375	72	110	P	Yes	Smls	28	13.45	0.514	0.303%	4.757%	70.65	630	107	4,056	135/315 DEG	126.30	126.30	126.30	136.60	136.50	136.55	10,858	9,880	142
143	13.625	88.2	125	Q	Yes	Smls	29	13.73	0.642	0.218%	1.775%	89.94	817	109	8,317	90/135-270/315deg	149.60	151.70	150.65	160.50	162.90	161.70	25,745	23,428	143
144	13.625	88.2	125	Q	Yes	Smls	29	13.72	0.647	0.289%	1.537%	90.66	823.5	109	7,620	0/180 Deg	148.30	153.60	150.95	162.30	165.20	163.75	14,097	12,829	144
145	13.625	88.2	125	Q	Yes	Smls	29	13.73	0.647	0.200%	1.987%	90.28	820	109	7,849	90/270 Deg.	143.20	142.20	142.70	155.20	154.30	154.75	30,859	28,082	145
146	16	84	80	N	Yes	Smls	28	16.09	0.531	0.231%	2.329%	87.85	937.1	128	2,669	135/315 DEG	106.10	103.20	104.65	117.30	115.00	116.15	4,547	4,138	146
147	16	84	80	N	Yes	Smls	28	16.08	0.520	0.291%	4.723%	86.23	919.8	128	2,550	0/180 DEG	105.80	102.60	104.20	117.50	115.00	116.25	5,481	4,987	147
148	16	84	80	N	Yes	Smls	28	16.08	0.512	0.234%	4.682%	85.08	907.5	128	2,413	135/180-0/315	103.20	103.50	103.35	115.10	115.20	115.15	4,313	3,925	148
149	16	97	110	P	Yes	EW	26	16.07	0.574	0.274%	1.071%	94.08	1003.5	128	3,100	0/180 DEG	118.70	120.80	119.75	155.40	134.00	144.70	24,705	22,481	149
150	16	97	110	P	Yes	EW	26	16.09	0.572	0.334%	0.626%	90.35	963.7	128	2,903	0/45-180/225	112.40	123.70	118.05	136.30	136.10	136.20	26,747	24,340	150
151	16	97	110	P	Yes	EW	26	16.08	0.574	0.310%	0.532%	92.11	982.5	128	3,150	0/45-180/225	133.80	128.00	130.90	149.30	139.40	144.35	23,596	21,473	151

Note: Grade A = Proprietary
LC = 13% Chrome –80
All others are API

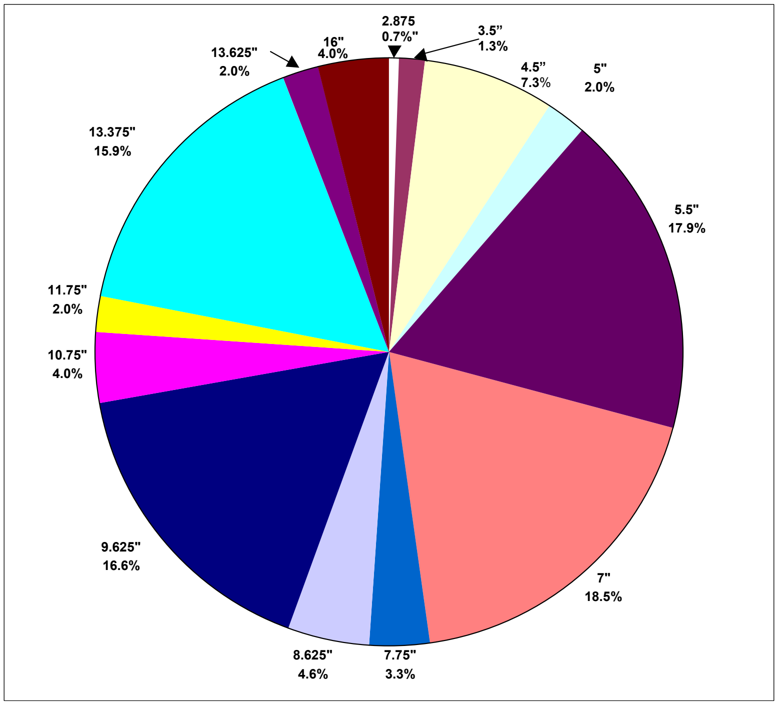


FIGURE 7-1

DEA-130 Pipe Tested By Diameter

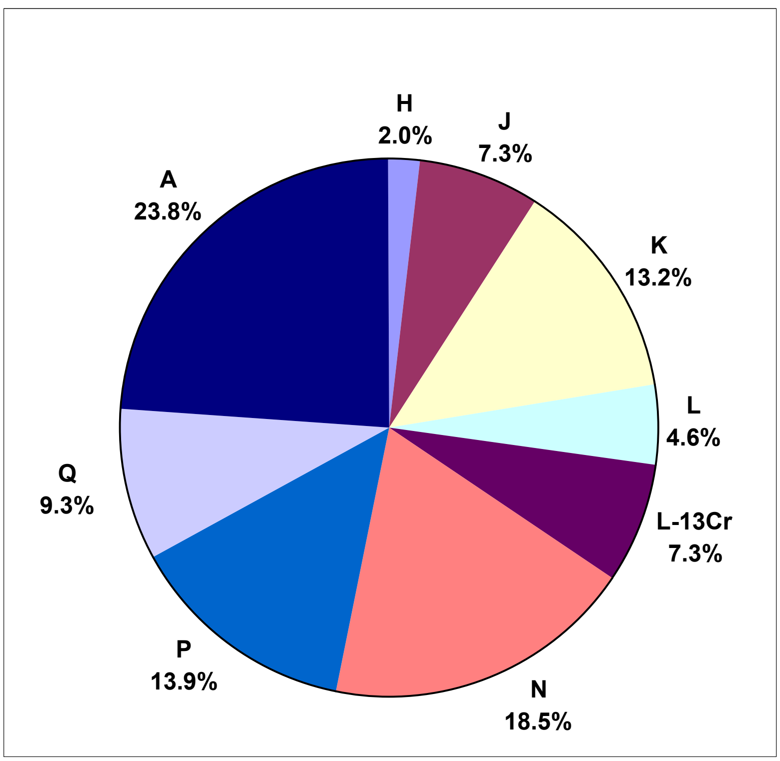
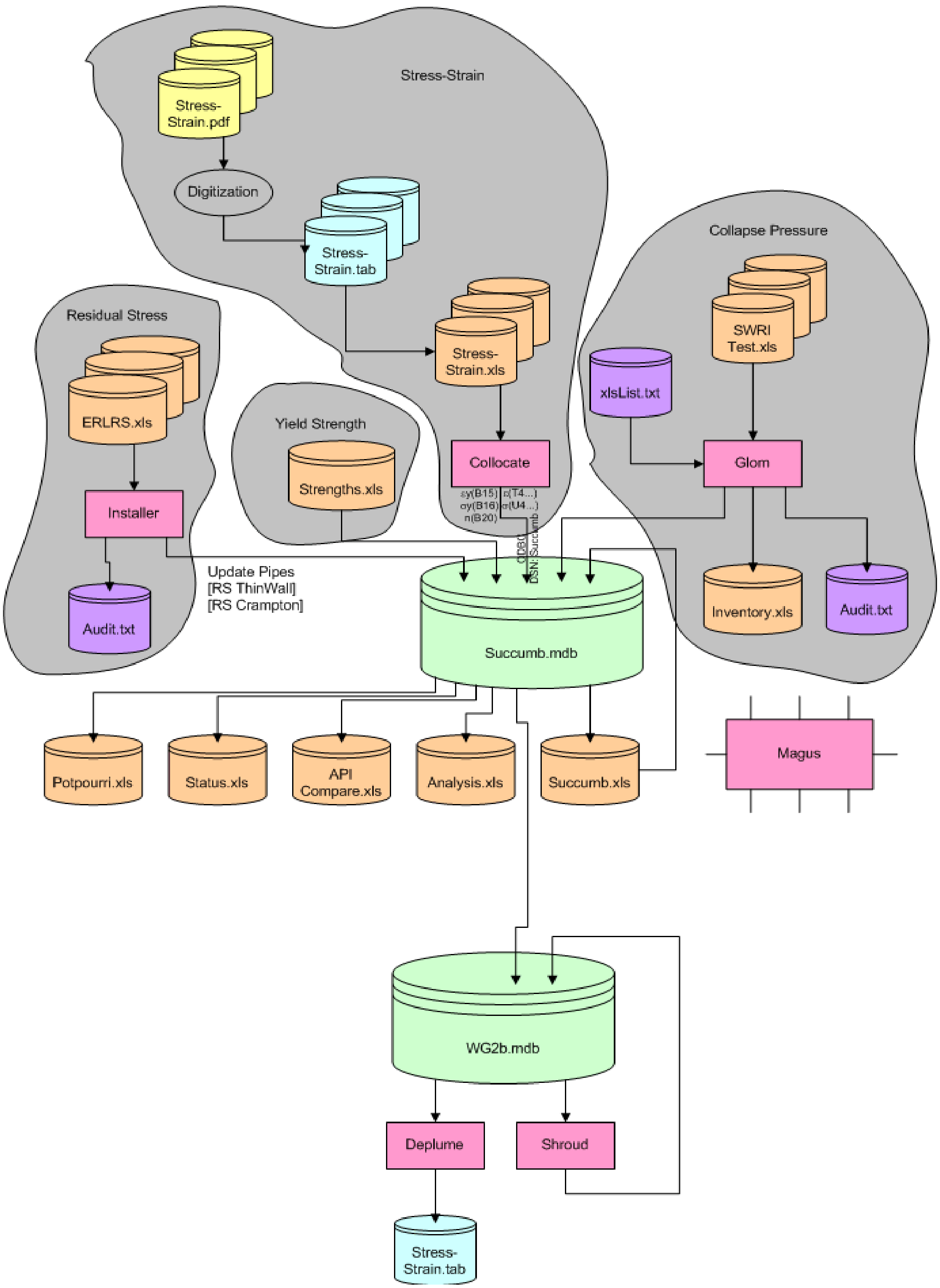


FIGURE 7-2

DEA-130 Pipe Tested By Grade

8.0 SPECIAL SOFTWARE

During acquisition and combing of the acquired data for DEA-130 a number of tools and data repositories were developed.



By design, a central repository of the entire effort is an Access database named Succumb.mdb.

suc·cumb (se-kùm¹) *verb*, *intransitive*

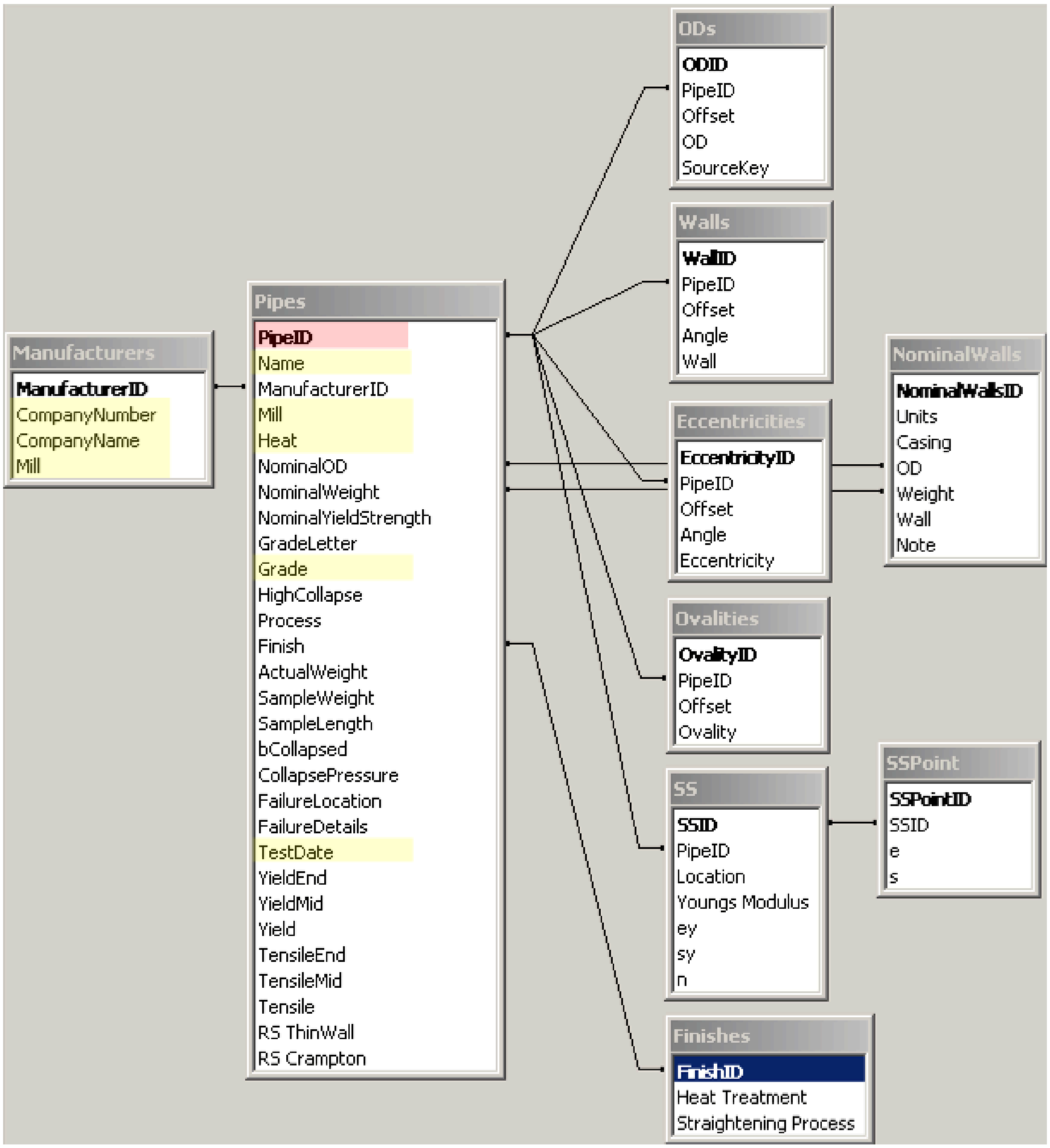
1. To submit to an overpowering force or yield to an overwhelming desire; give up or give in. See synonyms at yield.

Data in Succumb.mdb is quite raw and assumes that downstream tools will be used to examine the data. Making a copy of Succumb.mdb and shrouding all manufacturer-specifying information accomplished publication of the data in Succumb.mdb. This public version of the database is referred to as the WG2b version. This was a result of making the first public version available to API/ISO TC67/SC5/WG2b.

This section discusses some of the downstream tools.

8.1 THE DATABASE

Residing on your delivery CD is an Access Database. The schema for that database is shown below.



Relationships are shown with the connecting lines. Depending on the delivery, the name of the database can be Succumb.mdb, WG2b.mdb or YourName.mdb.

8.1.1 Table Manufactures

There is one record in this table for each manufacture that participated in DEA-130. Manufacturers contributed by providing pipe for testing.

Manufacturer ID is a unique number for each manufacturer. Generally these are useless numbers and exist only to establish the relationship with Table Pipes.

Company Number identifies the manufacturer in a standard way. These numbers were used as prefixes on physical pipes and in all reporting.

Company Name is the text string name.

Mill was initially intended to specify the source of the particular pipe but was never fully implemented. In the DEA-130 internal database, it is used to indicate manufacturer for the Shell donated pipes.

> ***Note: In all public releases of the database, all manufacturer-revealing information in this table has been obfuscated. In manufacturer specific versions of the database, the identified manufacturer's information has been restored.

8.1.2 Table Pipes

There is one record in this table for each pipe that had **any** testing done on it. There are 216 records in this table.

Pipe ID is a unique number that only exists to allow relationships with pipes. It is often used for brevity (e.g. Pipe 3). Pipe ID is not the same in all databases for security purposes.

Name is the long, text name of the pipe. In the public versions of the database, this is a random number.

Manufacturer ID is just a relationship link back to the table of that name.

Mill was never used.

Heat reflects the manufacturers report. This value is always blank in public versions of the database.

Nominal OD, **Nominal Weight**, **Nominal Yield Strength** and **Grade Letter** are self explanatory. **Grade Letter** is one character representing the API grade where possible. The letter 'A' is used to indicate a proprietary grade.

Grade is a character string assigned by the manufacturer and oft times contains information about manufacturer specific yields and/or processes. For this reason, the public version is either blank or contains the characters ‘Cr’ when those letters were included by the manufacturer to indicate that chromium was used in the pipe.

High Collapse is a Boolean (Yes/No) that indicates if the manufacturer reported that with the pipe.

Process is either ‘Smls’ indicating seamless or ‘EW’ indicating some kind of electric weld process.

Finish is a number {1…36} indicating the finishing process. Refer to the table in Section 8.2.7 for details.

Actual Weight, **Sample Weight** and **Sample Length** are self-explanatory.

bCollapsed is a Boolean (Yes/No) that indicates if the pipe actually collapsed. There was one instance where the attempt to collapse the pipe failed. The **Collapse Pressure** reported for that pipe indicated the maximum pressure reached in the failed attempt. With that one exception, **Collapse Pressure** is the actual failed (collapse) pressure.

Failure Location and **Failure Details** were reports by SWRI from observations on the collapsed pipe. In the SWRI reports, **Failure Location** is “Failure Location (small axis)” and typically is given like “90-270 DEG”. **Failure Details** oft times includes the Failure Location information as well as some indication at to the length of the collapsed region. For example, “SAMPLE FLATTENED AT 90/270 DEG FROM END A TO 7D”. The angular reference was arbitrary per sample but was used consistently throughout the reporting. Thus, the angular information in wall thickness and eccentricity are directly related to the collapse angle information.

Test Date is the date of the test. This is not included in public versions of the database.

Yield End, **Yield Mid** and **Yield** represent at most yield strength values from two tensile tests. In some cases only one value was reported. It was stored in Yield while the other two Yield fields were left blank. If two Yield reports were made (i.e. Yield End and Yield Mid), then Yield was the simple average of those two.

Tensile End, **Tensile Mid** and **Tensile** were treated the same as **Yield** above.

RS Thin Wall and **RS Crampton** are the two common methods of residual stress calculations.

8.1.3 Tables ODs, Walls, Eccentricities, Ovalities

These represent the results of the sample measurements made by SWRI. Refer to Sections 8.2.3 to 8.2.6 for details.

8.1.4 Tables SS and SS Point

These two tables hold the full results of the tensile tests. There is one or two records in SS for each pipe and any number of records in SSPoint for each record in SS. In all cases, SSPoint data give stress in [psi] and strain in [%]. Refer to Section 8.2.8 for details.

8.1.5 Table Nominal Walls

This is an unrelated but handy table that lists Nominal information for about 245 tubes and pipes. Each record presents:

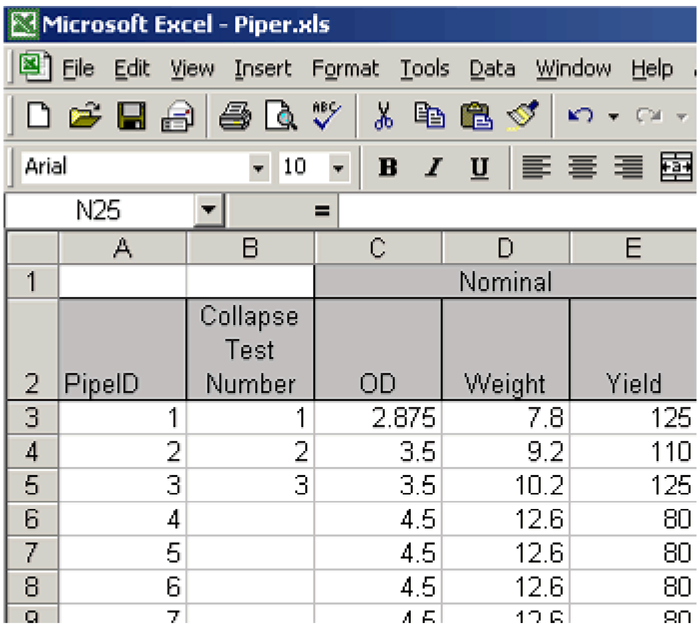
Casing	Yes/No Is this pipe considered casing rather than tubing?
OD	In inches.
Weight	In pounds per foot.
Wall	In inches.

It is typically used is queries to attach a nominal wall thickness to a pipe in Table Pipes.

8.2 PIPER.XLS

Piper.xls is an Excel spreadsheet that will extract **all** existing data on one pipe from your database and present that data in several tabbed sheets.

8.2.1 Sheet Pipes



	A	B	C	D	E
1			Nominal		
2	PipeID	Collapse Test Number	OD	Weight	Yield
3	1	1	2.875	7.8	125
4	2	2	3.5	9.2	110
5	3	3	3.5	10.2	125
6	4		4.5	12.6	80
7	5		4.5	12.6	80
8	6		4.5	12.6	80
9	7		4.5	12.6	80

You select the pipe you wish to investigate on **Sheet Pipes** by double-clicking on the row containing the pipe you wish to investigate. For example, double-clicking on Cell C5 will select the pipe with PipeID 3.

Pipes without a **Collapse Test Number** were not collapse-tested and thus have no collections of OD, wall, ovality or eccentricity data in the database. Selecting these pipes will result in data on the **Details** and perhaps on the **SS** sheet but nothing on the other sheets.

Of the 216 pipes shown on the Pipes sheet, 151 have collapse data. The second column gives the collapse test number and is the same test number as Table 7.1.

Just as a quick reference, the nominal OD, weight and Yield Strength are included on the line identifying the pipe. This information is also included on Sheet Details.

8.2.2 Sheet Details

	A	B	C
1	PipeID	3	Collapse Test #3
2	Name	6228	
3	ManufacturerID	1	
4	Mill		
5	Heat		
6	NominalOD	3.5	
7	NominalWeight	10.2	
8	NominalYieldStrength	125	
9	GradeLetter	A	
10	Grade		
11	HighCollapse	FALSE	
12	Process	Smls	
13	Finish		
14	ActualWeight	10.1	
15	SampleWeight	23.6	
16	SampleLength	28	
17	bCollapsed	TRUE	
18	CollapsePressure	19,903	
19	FailureLocation	135/270 deg	
20	FailureDetails	SAMPLE FLATTENED AT 135 AND	
21	TestDate		
22	YieldEnd	0	
23	YieldMid	0	
24	Yield	113.7	
25	TensileEnd	0	
26	TensileMid	0	
27	Tensile	138.9	
28	RS ThinWall	36,060	
29	RS Crampton	32,814	

All names in Column A are exactly as they appear in Table Pipes of your database.

All units are standard USC/OCTG oil-field units.

In the WG2b and Manufacturer's databases, the obvious fields have been obfuscated:

Name
Manufacturer ID
Mill
Heat
Grade
Test Date

Field **Process** is either **EW** indicating some kind of electric welding, or **Smls** indicating seamless.

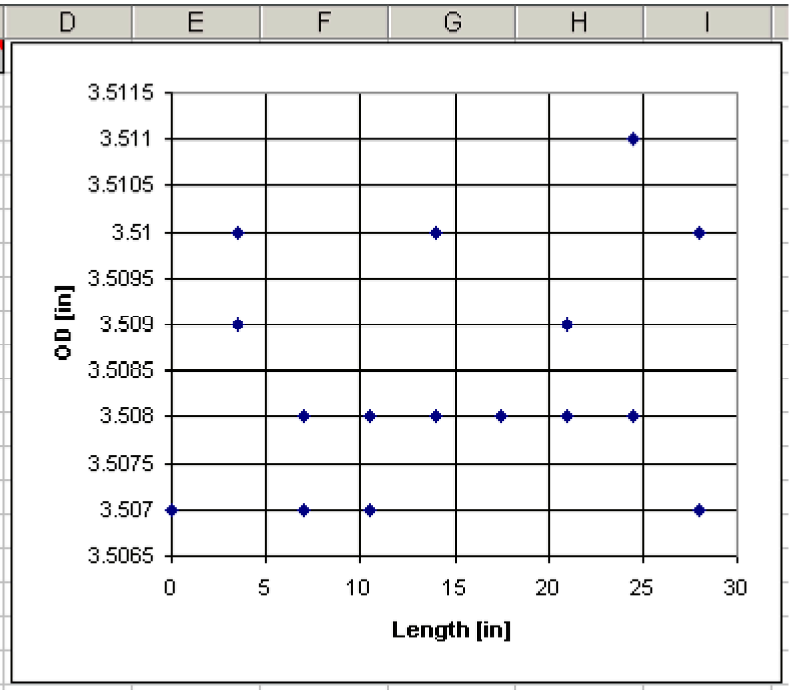
Field **Finish** (when not missing) is a number {1…36}. An explanation of these values can be found elsewhere.

Fields **Failure Location** and **Failure Details** were taken directly from the SWRI report.

For the **Yield** fields, if **Yield End** and **Yield Mid** both exist (i.e. are not blank), then **Yield** is the simple average of the two. The same is true for the **Tensile** fields.

8.2.3 Sheet ODs

	A	B	C
1	Offset	OD	Source
2	0	3.507	1
3	0	3.507	2
4	3.5	3.51	1
5	3.5	3.509	2
6	7	3.507	1
7	7	3.508	2
8	10.5	3.507	1
9	10.5	3.508	2
10	14	3.508	1
11	14	3.51	2
12	17.5	3.508	1
13	17.5	3.508	2
14	21	3.508	1
15	21	3.509	2
16	24.5	3.508	1
17	24.5	3.511	2
18	28	3.507	1
19	28	3.51	2



Assuming OD data exists for the selected pipe, **Sheet ODs** will present the 18 measures values.

Offset is reported in inches from the reference (arbitrarily selected) “End” and is the length along the sample in 1D increments.

OD is the outside diameter reported in inches at the specified Offset.

Source is:

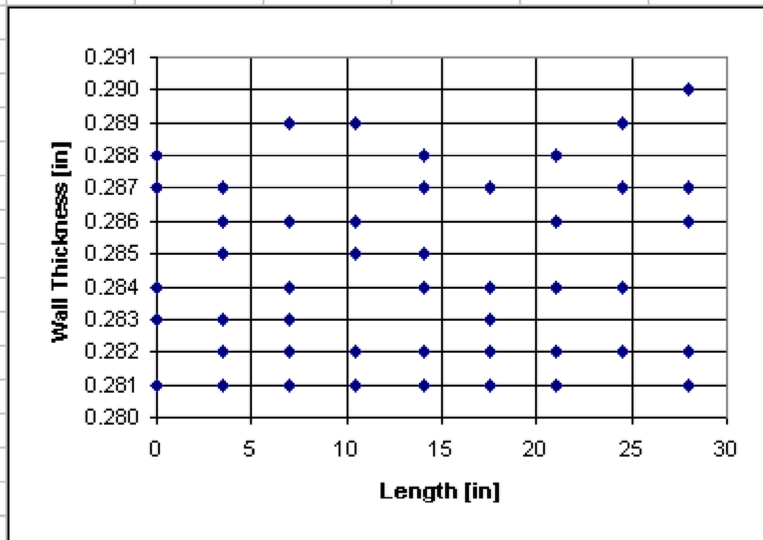
- 0 -> Unknown
- 1 -> Pi Tape
- 2 -> OD Micrometer at 0°-180° position

There are 18 reports because both a Pi Tape and an OD Micrometer measurement were made at the end and then at eight offsets of 1D (i.e. one pipe diameter). Thus, in this example, it is clear that the Nominal OD of the pipe is 3½ inches.

All known OD data is reported in the plot.

8.2.4 Sheet Wall Thickness

	A	B	C	D	E	F
1	Offset	Angle	Wall			
2	0	0	0.288		Average =	0.285
3	0	45	0.281		StDev =	0.00265
4	0	90	0.283			
5	0	135	0.283			
6	0	180	0.284			
7	0	225	0.287			
8	0	270	0.287			
9	0	315	0.288			
10	3.5	0	0.283			
11	3.5	45	0.281			
12	3.5	90	0.282			
13	3.5	135	0.282			
14	3.5	180	0.285			
15	3.5	225	0.286			
16	3.5	270	0.286			
17	3.5	315	0.287			
18	7	0	0.283			
19	7	45	0.282			
20	7	90	0.281			



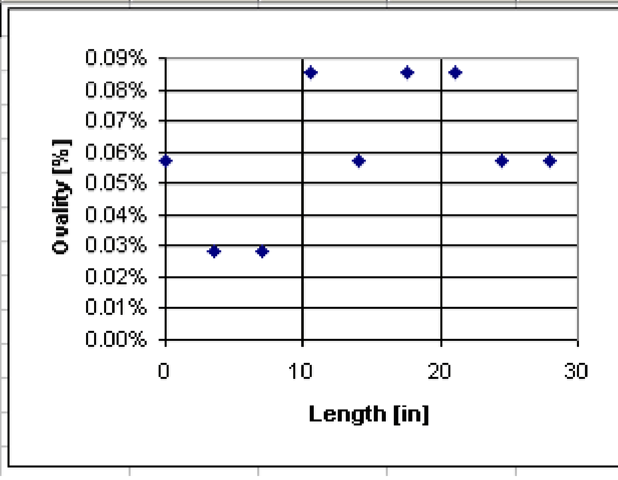
At each of the nine measurement stations along the pipe (spaced one diameter apart on a pipe that was eight diameters long), eight wall-thickness reading were taken. For pipes that had wall thickness readings, there should be 8*9=72 reports.

Each wall thickness report (**Wall** [inches]) included the **Offset** from the end of the pipe [inches] and the **Angle** [degrees] around the pipe where the measurement was made. The **Angle** refers to some arbitrary reference point but, importantly, it is the same reference that was used to report where the collapse occurred (c.f. Field **Failure Location** in Section **Sheet Details** above). It would thus be possible to study the relation of wall thickness to collapse axis.

For the 72 reports, an **Average** and **StDev** are given. It is generally accepted that wall thickness values are Normally distributed.

8.2.5 Sheet Ovalities

	A	B
1	Offset	Ovality
2	0	0.06%
3	3.5	0.03%
4	7	0.03%
5	10.5	0.09%
6	14	0.06%
7	17.5	0.09%
8	21	0.09%
9	24.5	0.06%
10	28	0.06%
11		
12		
13		
14		



One **Ovality** report was made for each of the nine measurement stations along the pipe. Measurement stations were separated by one pipe diameter and pipes were cut to be eight diameters long.

Ovality is calculated as:

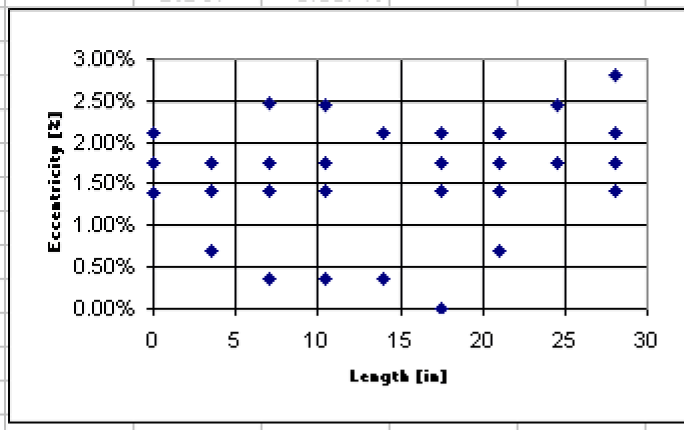
$$o = \frac{Gauge_{max} - Gauge_{min}}{Pi\ Tape(avg)} * 100$$

In the original reports from SWRI, some (but not all) of the OD gauge reports had angles reported with the gauge reports. These angles were not recorded in the database.

OD gauge reports (also not recorded per se in the database) were made as variations from the 0°-180° measured and reported OD.

8.2.6 Sheet Eccentricities

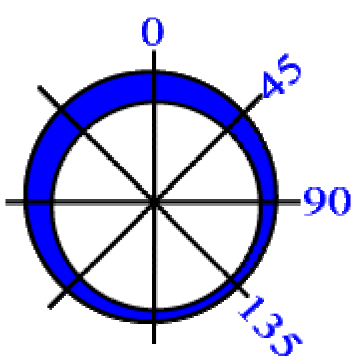
	A	B	C	D	E	F
1	Offset	Angle	Eccentricity			
2	0	0	1.40%		Average =	1.63%
3	0	45	2.10%		StDev =	0.667%
4	0	90	1.40%			
5	0	135	1.75%			
6	3.5	0	0.70%			
7	3.5	45	1.76%			
8	3.5	90	1.41%			
9	3.5	135	1.76%			
10	7	0	0.35%			
11	7	45	1.41%			
12	7	90	1.76%			
13	7	135	2.46%			
14	10.5	0	0.35%			
15	10.5	45	1.76%			



Eccentricity is calculated as:

$$e = \frac{t_{\max} - t_{\min}}{t_{avg}} * 100$$

where t is wall thickness.



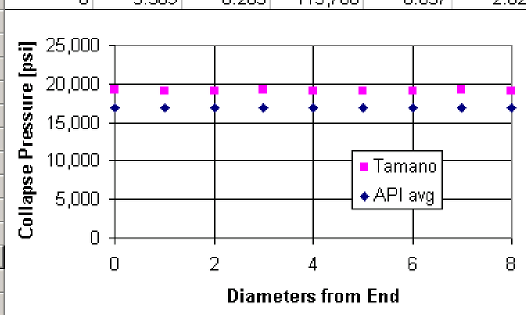
Four eccentricity calculations are included for pipes that were tested. Using the eight wall thickness readings described in Sheet Wall above, four eccentricity calculations were possible. They are reported as an **Offset** from the end of the pipe [inches] and the **Angle** [degrees] where the calculation was done.

There is some presumption about the nature of pipe eccentricity in using this approach (concentric circles), but they seem reasonable and appropriate. Since the wall readings are available, variations on this approach are certainly possible.

An **Average** and **StDev** for all 36 values are provided as a quick reference. In general, the industry assumes eccentricity is Lognormally, not Normally distributed but, since those values are a bit awkward to work with, a Normal population was assumed.

8.2.7 Sheet Compare

PipeID	3	Collapse Test # 3									
3.5"	10.2#	A-125									
								API			Tamano/
Diameters	OD	Wall	YS	Ovality	Ecc	RS	Q&T	min	avg	Tamano	API
0	3.507	0.285	113,700	0.057	1.666	32,814	FALSE	16,985	16,985	19,194	1.130
1	3.510	0.284	113,700	0.028	1.408	32,814	FALSE	16,908	16,913	19,102	1.129
2	3.508	0.284	113,700	0.029	1.496	32,814	FALSE	16,928	16,928	19,122	1.130
3	3.508	0.285	113,700	0.086	1.493	32,814	FALSE	16,956	16,956	19,157	1.130
4	3.509	0.284	113,700	0.057	1.670	32,814	FALSE	16,935	16,935	19,131	1.130
5	3.508	0.284	113,700	0.086	1.319	32,814	FALSE	16,940	16,940	19,136	1.130
6	3.509	0.284	113,700	0.086	1.495	32,814	FALSE	16,938	16,938	19,134	1.130
7	3.510	0.286	113,700	0.057	2.102	32,814	FALSE	16,994	16,994	19,206	1.130
8	3.509	0.285	113,700	0.057	2.020	32,814	FALSE	16,951	16,951	19,151	1.130



This sheet demonstrates one possible use of the data extracted from the database. This sheet is constructed entirely from information found elsewhere in the workbook and some “User Defined” functions described below. Knowing that there are always nine measurement stations along the pipe allows construction of nine sets of Tamano input parameters. These parameters also provide all information necessary to API (5C3) estimates of collapse pressure.

Here is a brief description of the Tamano parameters (Tamano equations described in report Section 9.2.7.4) and how they were obtained on Sheet Compare:

OD	Average of 2 values at station found on Sheet ODs.
Wall	Average of 8 values at station found on Sheet Walls.
YS	Single value for pipe (Cell B24) on Sheet Details.
Ovality	Single value at station found on Sheet Ovalities.
Ecc	Average of 4 values at station found on Sheet Eccentricities.
RS	Single value for pipe (Cell B29) on Sheet Details.
Q&T	Single value for pipe (Cell B13) on Sheet Details.

FinishID	Heat Treatment	Straightening Process
1	As-Rolled	Cold Gag
2	As-Rolled	Cold Gag (Stress Relief)
3	As-Rolled	Cold Rotary
4	As-Rolled	Cold Rotary (Stress Relief)
5	As-Rolled	Hot Rotary
6	Seamannealed	Cold Gag
7	Seamannealed	Cold Gag (Stress Relief)
8	Seamannealed	Cold Rotary
9	Seamannealed	Cold Rotary (Stress Relief)
10	Seamannealed	Hot Rotary
11	Normalized	Cold Gag
12	Normalized	Cold Gag (Stress Relief)
13	Normalized	Cold Rotary
14	Normalized	Cold Rotary (Stress Relief)
15	Normalized	Hot Rotary
16	N&T	Cold Gag
17	N&T	Cold Gag (Stress Relief)
18	N&T	Cold Rotary
19	N&T	Cold Rotary (Stress Relief)
20	N&T	Hot Rotary
21	Q&T (Air)	Cold Gag
22	Q&T (Air)	Cold Gag (Stress Relief)
23	Q&T (Air)	Cold Rotary
24	Q&T (Air)	Cold Rotary (Stress Relief)
25	Q&T (Air)	Hot Rotary
26	Q&T (Water)	Cold Gag
27	Q&T (Water)	Cold Gag (Stress Relief)
28	Q&T (Water)	Cold Rotary
29	Q&T (Water)	Cold Rotary (Stress Relief)
30	Q&T (Water)	Hot Rotary
31	Q&T (Oil)	Cold Gag
32	Q&T (Oil)	Cold Gag (Stress Relief)
33	Q&T (Oil)	Cold Rotary
34	Q&T (Oil)	Cold Rotary (Stress Relief)
35	Q&T (Oil)	Hot Rotary
36	Cold Drawn	No Straightening

Whether a pipe has been quenched and tempered can be determined from Cell B13 on Sheet Details. That field (Finish) is a numeric value that can assume one of 36 values as shown in this table.

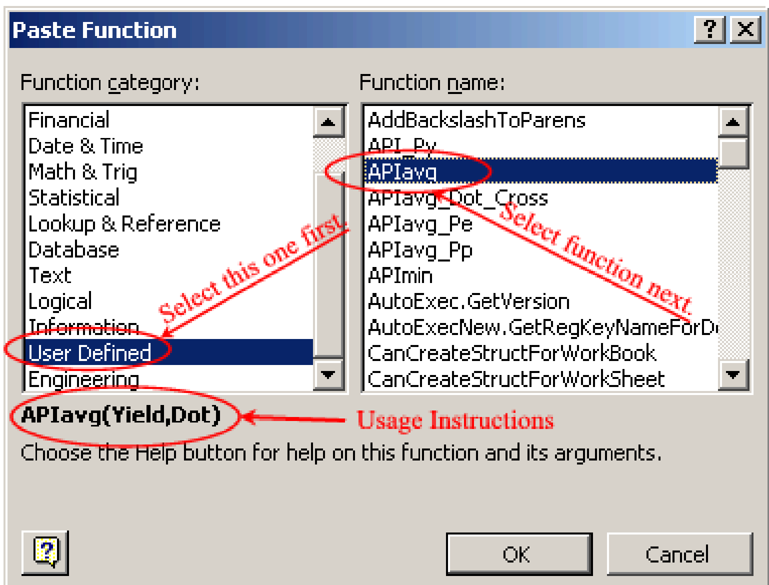
Q&T pipe have a Finish number between 21 and 35, inclusive.

This table exists in the database as Table Finishes and has a relationship to Field Finish in Table Pipe. This allows easy construction of queries that identify the Finish as verbiage rather than a single numeric value.

“User Defined” functions for calculation of API (5C3) and Tamano estimates of collapse pressure are provided.

8.2.7.1 Use of "User Defined" Functions

Perhaps the easiest way to invoke a "User Defined" function is with the fx button in Excel.

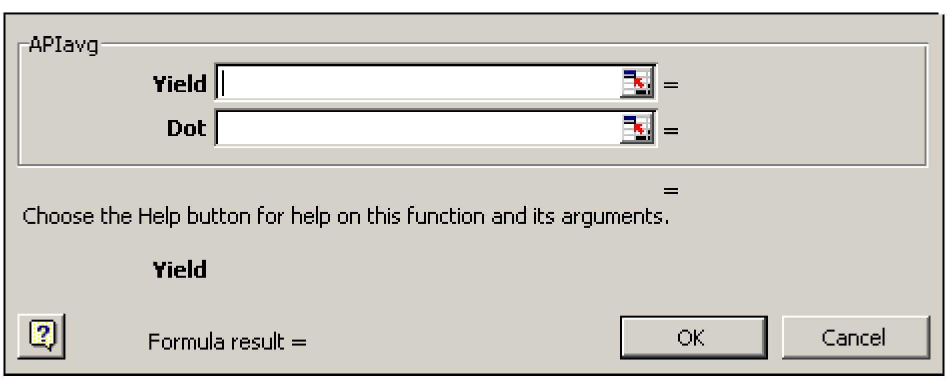


First select a cell and then press fx. You will be presented with something like the dialog shown here. In the **Function category**, find and select **User Defined**.

Next, in the **Function name** list box, find and select the function of interest. Function usage will immediately be provided.

Press OK.

You will be presented with a dialog prompting you for the various input data. Just click on the cell that contains the input data (Dot=D/t ratio).



8.2.7.2 Handling "User Defined" Functions

"User Defined" functions in Excel are just routines written in a Microsoft version of Basic called Visual Basic for Applications (VBA). VBA differs from regular Basic in a few peculiar ways but for the functions described here, there is essentially no difference.

The best way to have access to the "User Defined" functions in other Excel workbooks is to export them to some place as VBA files (*.bas) and subsequently load them in to new Excel workbooks. You should find two such files already unloaded and on your distribution CD. They are named modAPI.bas and modTamano.bas and contain the functions discussed below as well as other related functions.

8.2.7.3 API Formulae

There are two important, "User Defined" functions associated with API collapse pressure: APIavg and APImin. They can be found in file modAPI.bas on your distribution CD but are already included in Piper.xls.

APImin will provide the API Bulletin 5C3[6] predictions of collapse pressure. This function is implemented exactly as described in that API document.

APIavg presents the average values used by API when developing the formulae found in places like "Bulletin on Formulas and Calculations for Casing, Tubing, Drill Pipe, and Line Pipe Properties"[6], aka API Bulletin 5C3, Sixth Edition, October 1, 1994. The difference between APIavg and APImin is (compliments of Paul Cernocky):

- No difference in the Yield Strength Collapse region.
- In the Plastic Collapse region, the (-C) term is missing. Or rather, it is present in APImin.
- There is no Transition Collapse region.
- Elastic Collapse values are un-reduced by the 71.25% safety factor apparently in the 46.95E6 coefficient.

APIavg should be comparable to actual collapse and Tamano estimates.

From API Bulletin 5C3, Sixth Edition, October 1, 1994 -

Yield Strength Collapse Pressure Formula

$$P_{Y_P} = 2Y_P\left[\frac{(D/t)-1}{(D/t)^2}\right] \qquad \text{Eq. (1) (per 5C3)}$$

Plastic Collapse Pressure Formula

$$P_P = Y_P\left[\frac{A}{D/t} - B\right] - C$$ Eq. (3)

Transition Collapse Pressure Formula

$$P_T = Y_P\left[\frac{F}{D/t} - G\right]$$ Eq. (5)

Elastic Collapse Pressure Formula

$$P_E = \frac{46.95x10^6}{(D/t)((D/t)-1)^2}$$ Eq. (7)

Collapse Pressure Under Axial Tension Stress

$$Y_{pa} = \left[\sqrt{1-0.75(S_a/Y_p)^2} - 0.5S_a/Y_p\right]Y_p$$ Eq. (8)

$$A = 2.8762 + 0.10679x10^{-5}Y_p + 0.21301x10^{-10}Y_p^{\ 2} - 0.53132x10^{-16}Y_p^{\ 3}$$ Eq. (21)

$$B = 0.026233 + 0.50609x10^{-6}Y_p$$ Eq. (22)

$$C = -465.93 + 0.030867Y_p - 0.10483x10^{-7}Y_p^{\ 2} + 0.36989x10^{-13}Y_p^{\ 3}$$ Eq. (23)

$$F = \frac{46.95x10^6\left[\frac{3B/A}{2+B/A}\right]^3}{Y_p\left[\frac{3B/A}{2+(B/A)} - (B/A)\right]\left[1-\frac{3B/A}{2+B/A}\right]^2}$$ Eq. (26)

$$G = FB/A$$ Eq. (27)

8.2.7.4 Tamano Formulae

What is referred to here as The Tamano Equation refers to the algorithm published in a 1985 Nippon report.[7] Both functions described below are included in Piper.xls and in the external file modTamano.bas available on your distribution CD.

In its initial form, the Tamano formula is:

$$P_{est} = \frac{1}{2}(P_{EO} + P_{GO}) - \sqrt{\frac{1}{4}(P_{EO} - P_{GO})^2 + P_{EO}P_{GO}H} \ldots(17)$$ Estimated Collapse Pressure

where

$$P_{EO} = 2\frac{E}{1-\nu^2}\frac{1}{\frac{D}{t}\left(\frac{D}{t}-1\right)^2} \quad (2)$$ Elastic Collapse Pressure

$$P_{GO} = 2\sigma_Y \frac{\frac{D}{t}-1}{\left(\frac{D}{t}\right)^2}\left(1+\frac{1.47}{\frac{D}{t}-1}\right) \ldots(7)$$ General Yield Pressure

$$H = 0.0808u(\%) + 0.00114e(\%) - 0.1412\frac{\sigma_R}{\sigma_Y} \ldots(16)$$ Correction Factor

μ is ovality,
e is eccentricity,
σ_R is the circumferential residual stress in the inside surface of the test pipe, and
σ_Y is the yield strength of the ideal pipe.

API/ISO TC67/SC5/WB2b has proposed two substantial changes.

First is an updating of some of the coefficients. A new form of the Correction Factor as:

$$H = 0.071u(\%) + 0.0022e(\%) - 0.18\frac{\sigma_R}{\sigma_Y}$$ New Correction Factor[8]

A multiplicative 1.08 factor to the Elastic Collapse was also developed by WG2b so that:

$$P_{EO} = (1.08)2\frac{E}{1-\nu^2}\frac{1}{\frac{D}{t}\left(\frac{D}{t}-1\right)^2}$$ New Elastic Collapse Pressure

This formulation is available as **Tamano40**. The function input parameters are:

- Dot D/t [unit less]
- Y Yield Stress [psi or ksi]
- O Ovality [%]
- Ec Eccentricity [%]
- XS Axial Stress [psi]
- RS Residual Stress [psi]
- E (Optional) Young's Modulus (defaults to 30x10^6)
- nu (Optional) Poisson's Ratio (defaults to 0.28)

Second and in the same WG2b document[9], (Section 4.6 Suggested ULS equation for non-Q&T pipe), a "bolt-on" term to accommodate the character of pipe with soft stress-strain curves is described. Quoting from that report:

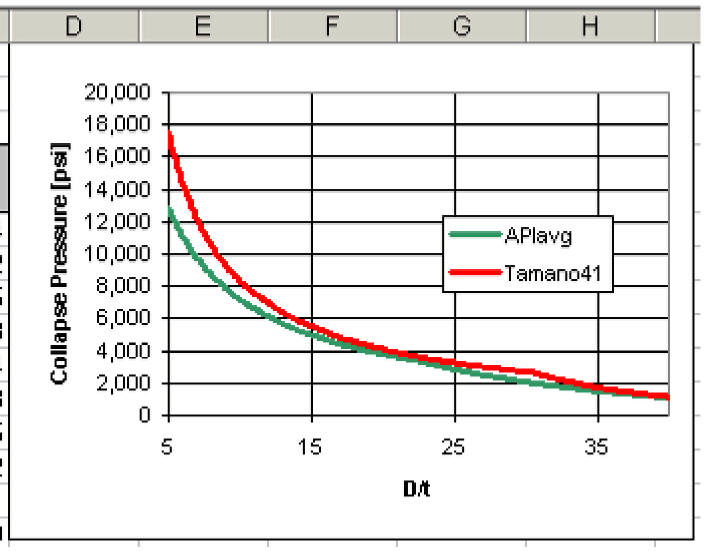
"The proposed decrement is a $\sin^2$ half-wave, with the center of the dip located at predicted/transitional strength = 1.0, in accordance with earlier analysis of non-Q&T collapse tests [14][9]."

This formulation is available as **Tamano41**. The function input parameters are:

- Dot D/t [unit less]
- Y Yield Stress [psi or ksi]
- O Ovality [%]
- Ec Eccentricity [%]
- XS Axial Stress [psi]
- RS Residual Stress [psi]
- QaT Was the pipe Quenched and Tempered (True/False)
- E (Optional) Young's Modulus (defaults to 30×10^6)
- nu (Optional) Poisson's Ratio (defaults to 0.28)

8.2.7.5 Using API and Tamano Functions

	A	B	C
1			
2	Yield	40,000	
3			
4	D/t	API avg	Tamano 41
5	5	12,800	17,504
6	5.1	12,611	17,132
7	5.2	12,426	16,775
8	5.3	12,246	16,433
9	5.4	12,071	16,104
10	5.5	11,901	15,788
11	5.6	11,735	15,485
12	5.7	11,573	15,192
13	5.8	11,415	14,911
14	5.9	11,261	14,639



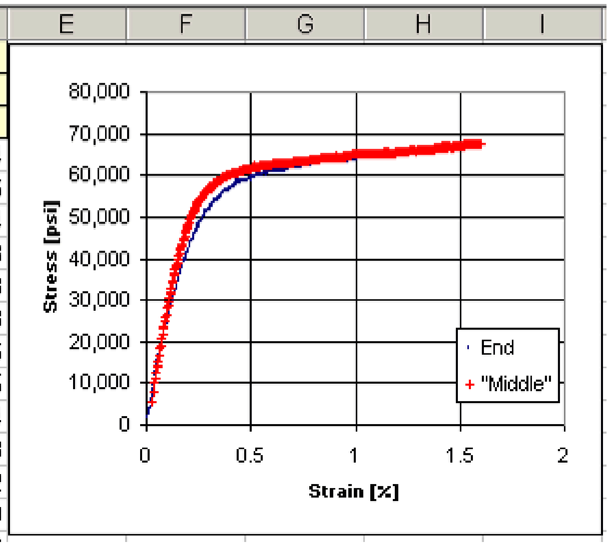
As an exercise of how to use the API and Tamano "User Defined" functions, Insert a new worksheet in Piper.xls. Fill in the Yield in B2 and a range of D/t values {5,5.1,5.2…40} as show above.

Column B values should come from "User Defined" function APIavg where the yield is from B2 and the D/t value from Column A. An entry in Column B should look something like: =APIavg(B2,A5).

To compare Tamano to API, some assumption must be made about the other input parameters to the Tamano model. For simplicity, set all other Tamano input values equal to zero and answer the "Has this pipe been through Q&T?" question (input field QaT) as "True". An entry for Column C should look something like:
=Tamano41(A5,B2,0,0,0,0,TRUE)

8.2.8 Sheet SS

	A	B	C	D
1	End		Middle	
2	Strain	Stress	Strain	Stress
3	[%]	[psi]	[%]	[psi]
4	0.012623	1938.22	0.024419	5353.54
5	0.017623	2713.508	0.029419	5735.936
6	0.017623	3488.796	0.034419	7647.914
7	0.022623	4264.083	0.034419	10324.68
8	0.022623	4264.083	0.039419	10324.68
9	0.027623	5427.015	0.044419	11089.48
10	0.027623	6202.303	0.044419	12619.06
11	0.032623	6977.591	0.049419	13766.25
12	0.032623	7752.879	0.054419	14148.64
13	0.037623	9691.099	0.054419	15295.83
14	0.037623	8528.167	0.059419	16443.02
15	0.042623	10466.39	0.064419	18354.99



This sheet presents the stress-strain data for the pipe. In all cases, the units are [psi] for the stress and [%] for the strain.

End and Middle refer to the place where the sample was taken. There were two samples taken per pipe.

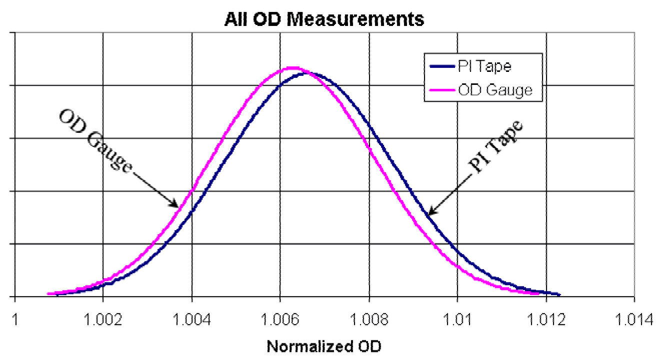
9.0 COMPARISON OF PIPE GEOMETRY AND YIELD STRENGTH

This section discusses the measured metrics: OD, wall thickness, yield strength, residual stress, ovality and eccentricity.

9.1 OD

9.1.1 Measurement Method

Two OD measurements were usually taken at each of the nine measurement stations, one Pi-tape and one gauge/micrometer at 0/180°. There were 1,359 Pi tape and 1,251 micrometer OD reports. The difference in OD reports was because the very first samples did not require the micrometer measurements.



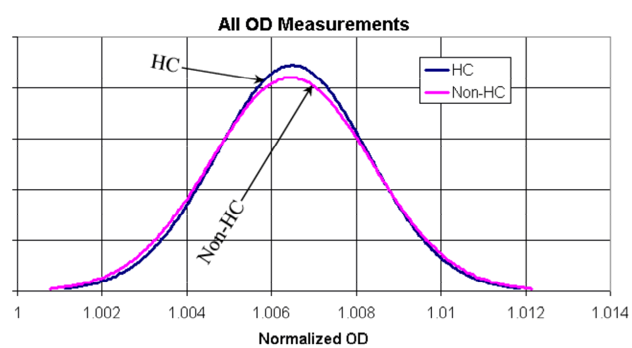
Comparison of the two methods can be accomplished by pooling the reports into two populations and then assuming both are Normally distributed.

	PI Tape	OD Gauge
Mean	1.006632	1.006288
SD	0.00189	0.001847

Although the Pi-Tape method gave slightly higher results, the difference between the two (0.000344) is only 0.034% of the average.

9.1.2 High Collapse

Of the 151 pipes that were collapse tested (thus had OD measurements), 29 were reported by the manufacture to be “High Collapse”.



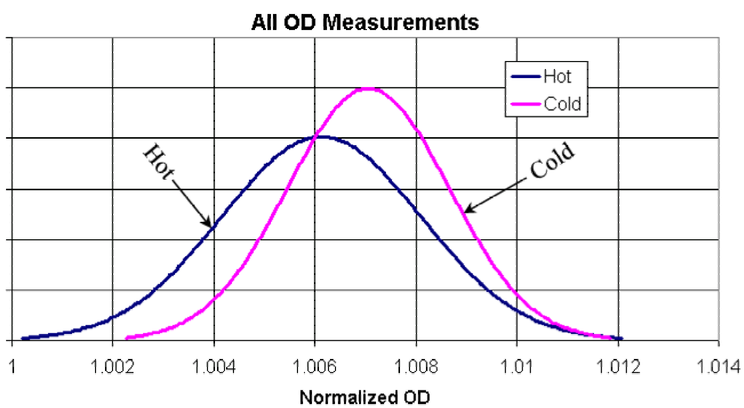
There is virtually no difference between “High Collapse” and other pipe regarding their OD distributions.

	PI Tape	OD Gauge
Mean	1.006497	1.00646
SD	0.001795	0.001896
Count	486	2,124

The difference between the two means is 3.61×10^{-5}, which is 0.004% of their average value.

9.1.3 Straightening Method

Of the 151 pipes with OD data, 11 did not report straightening, 51 were hot rotary straightened and 89 were cold straightened. Of the cold straightened, 3 were cold gag, 77 were cold rotary and 9 were cold rotary with stress relief.



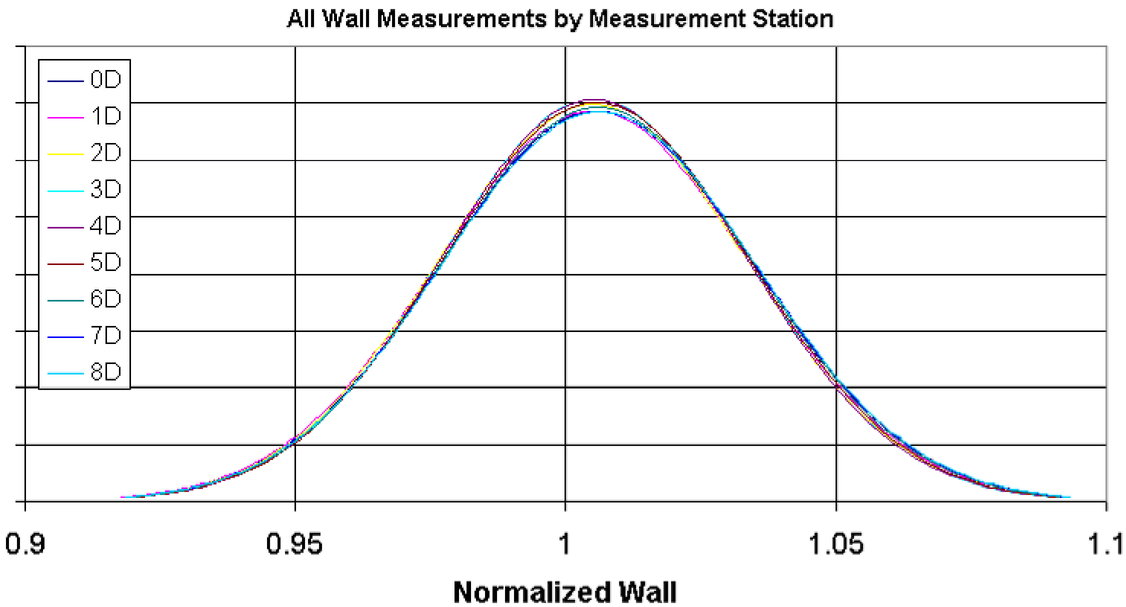
	PI Tape	OD Gauge
Mean	1.006132	1.007058
SD	0.001978	0.0016
Count	918	1,494

The difference between the two means is 0.000925, which is 0.092% of their average value.

9.2 WALL THICKNESS

All 151 pipes that were collapse tested report 72 wall measurements each: 10,872 wall thickness reports. This population has been examined in four approaches.

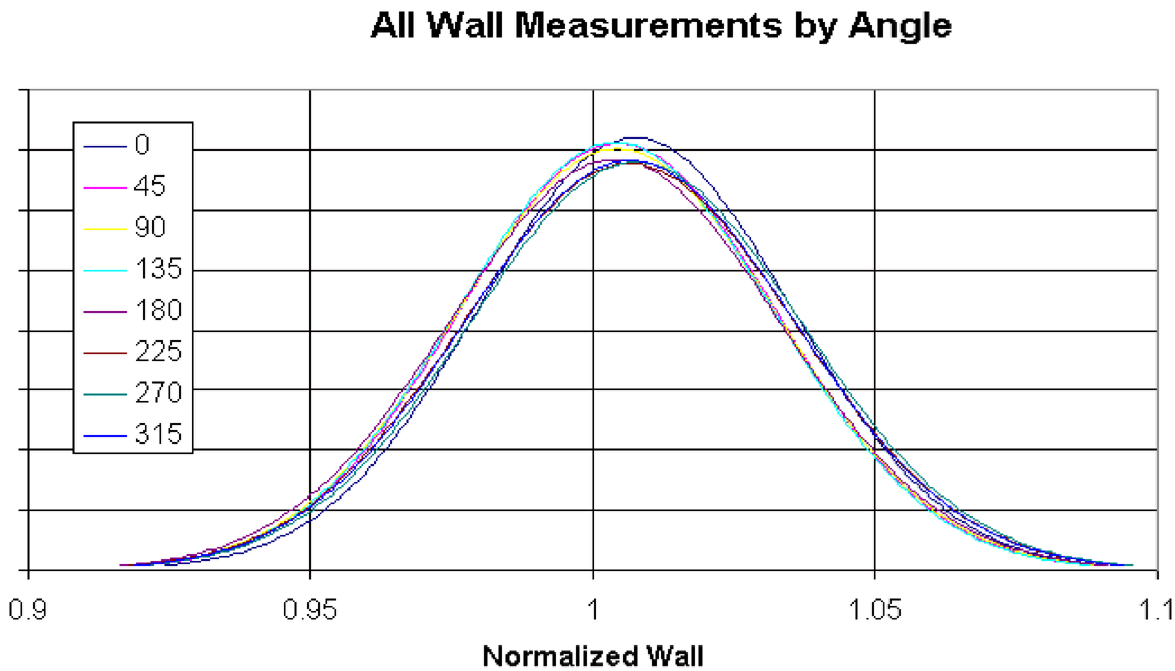
9.2.1 Measurement Station (Offset)



For each pipe, eight wall thickness measurements (ever 45°) were taken at the end of the pipe and then every one diameter down the pipe. Since all pipe were eight diameters long, that was nine measurement stations.

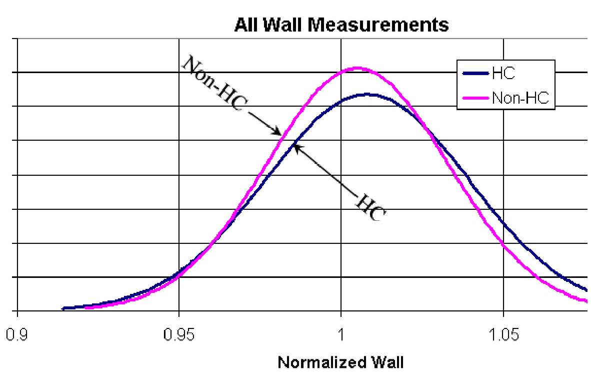
Presenting the data as nine populations, one at each measurement station, suggests there is no dependence on measurement station, or length along the sample.

9.2.2 Angle



The angular origin on each pipe was arbitrarily assigned. It is thus not unexpected that a presentation of the eight populations created by selection on angle is particularly informative.

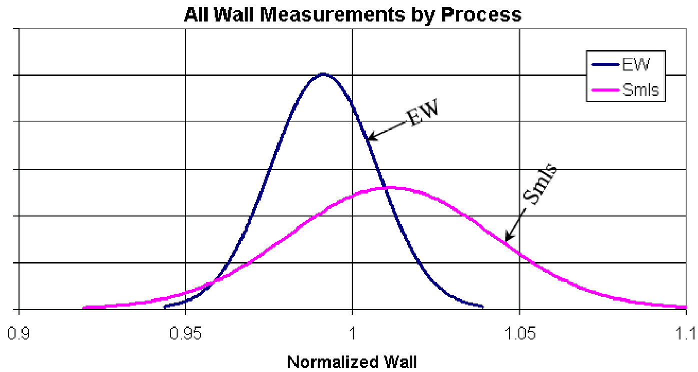
9.2.3 High Collapse



	HC	Non-HC
Count	2,088	8,784
Mean	1.008041	1.004981
StDev	0.031386	0.028032
COV	3.11%	2.79%

It appears there is a noticeable difference between wall thicknesses with High Collapse pipe being slightly thicker. The difference between means is 0.00306" which is 0.304% of their average value.

9.2.4 Process



Not surprisingly, there is a significant difference of wall thickness data when segregated by manufacturing process.

Here the two populations were seamless (Smls) and electrically welded (EW).

	EW	Smls
Count	3,168	7,704
Mean	0.991351	1.011415
StDev	0.015882	0.030722
COV	1.602%	3.038%

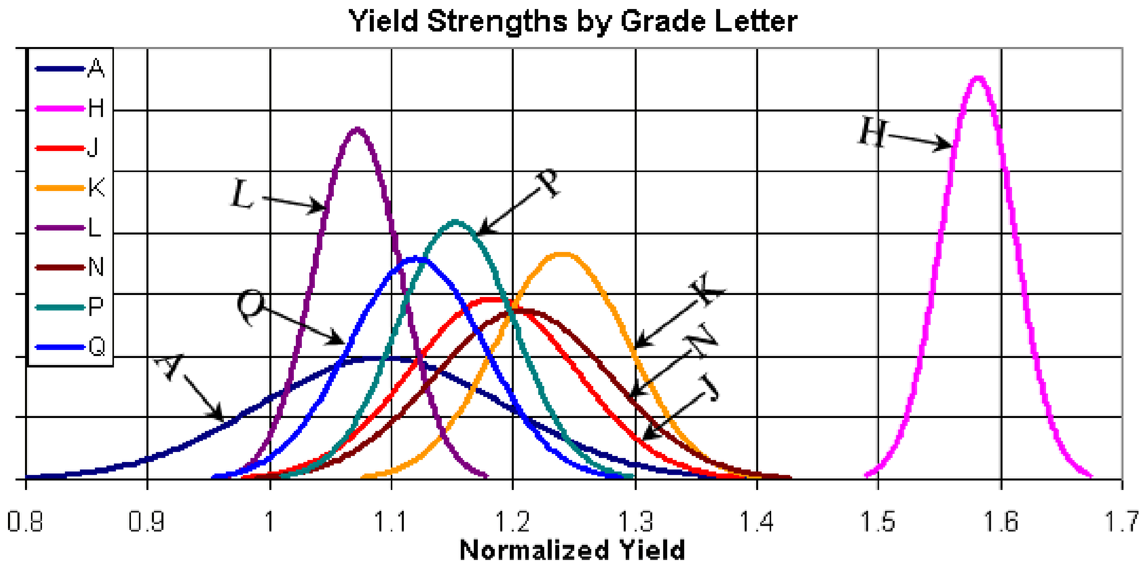
Mean values differ by 0.020064” which is 2.004% of the average of the two means.

Since there is less control on the thickness of seamless pipe, it is reasonable to find that is mean value is higher.

9.3 YIELD STRENGTH

Of the 216 pipes that were tensile tested, 17 had a single test while the remaining 199 had two tests. A total of 17 + 2*199 = 415 yield stress constitutes the population of tests.

9.3.1 Grade

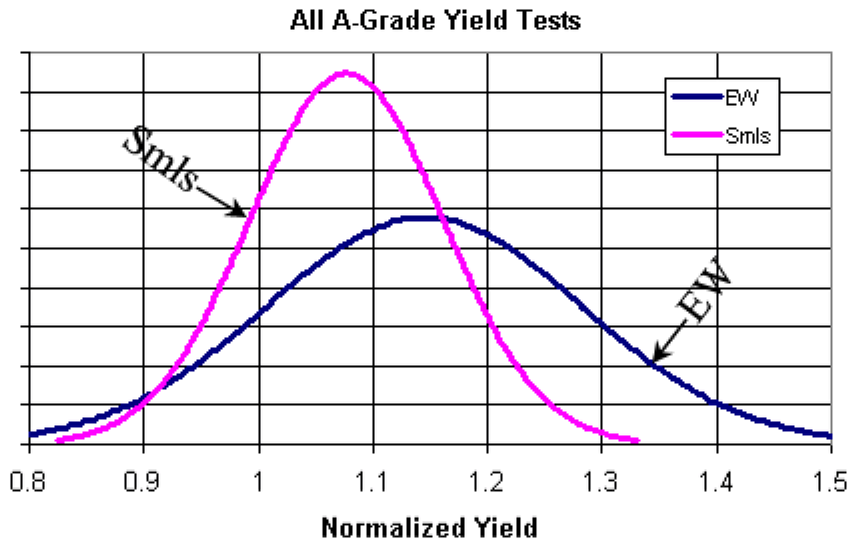


	A	H	J	K	L	N	P	Q
count	63	8	24	50	68	76	90	36
mean	1.092221	1.581703	1.183668	1.240364	1.071946	1.207891	1.153136	1.120649
SD	0.10158	0.030599	0.068224	0.054501	0.03519	0.072949	0.047892	0.055759
COV	9.30%	1.93%	5.76%	4.39%	3.28%	6.04%	4.15%	4.98%

It became apparent after an examination of the data when segregated by grade that all subsequent discriminations must be done within grade.

Recall that the fictitious Grade A designates those pipes where the grade reported by the manufacturer was proprietary and could not be mapped to an API grade.

9.3.2 Process Grade A

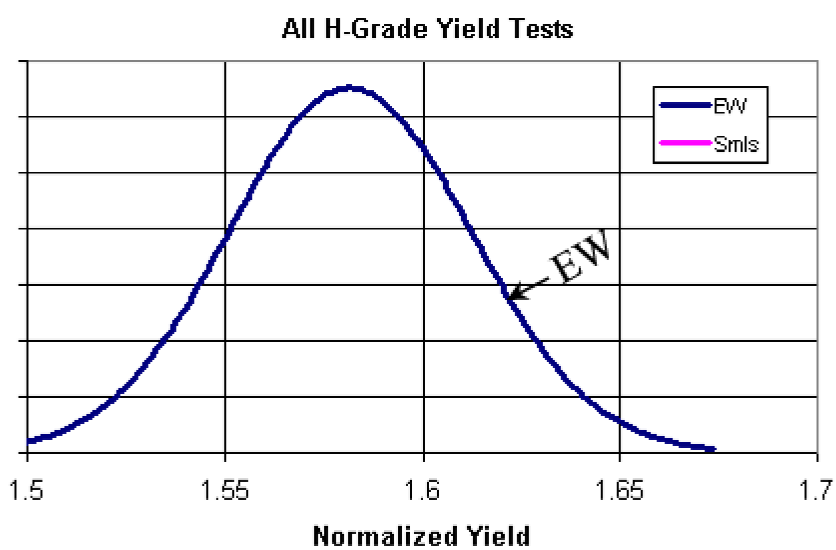


	EW	Smls
count	14	49
mean	1.145598	1.076971
SD	0.13796	0.084291
COV	12.04%	7.83%

The difference between the means is 0.069.

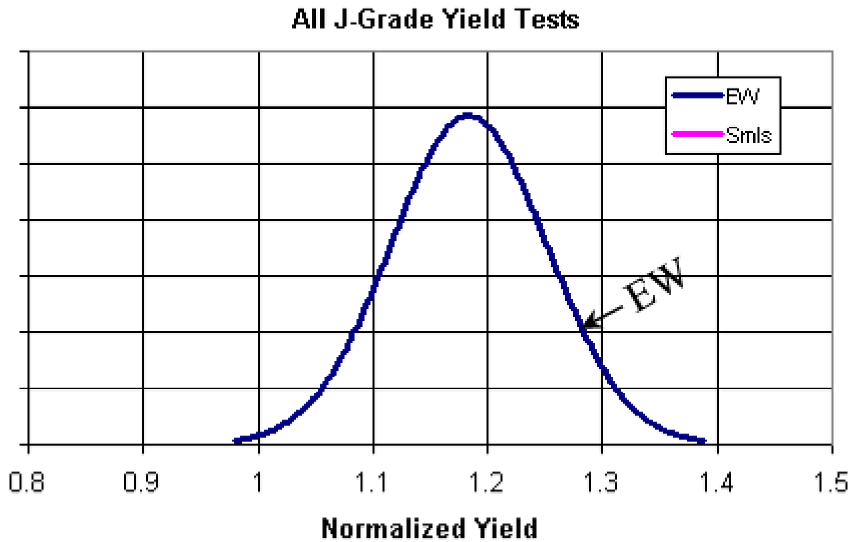
This is 0.618 times the average of the two standard deviations.

9.3.3 Process Grade H



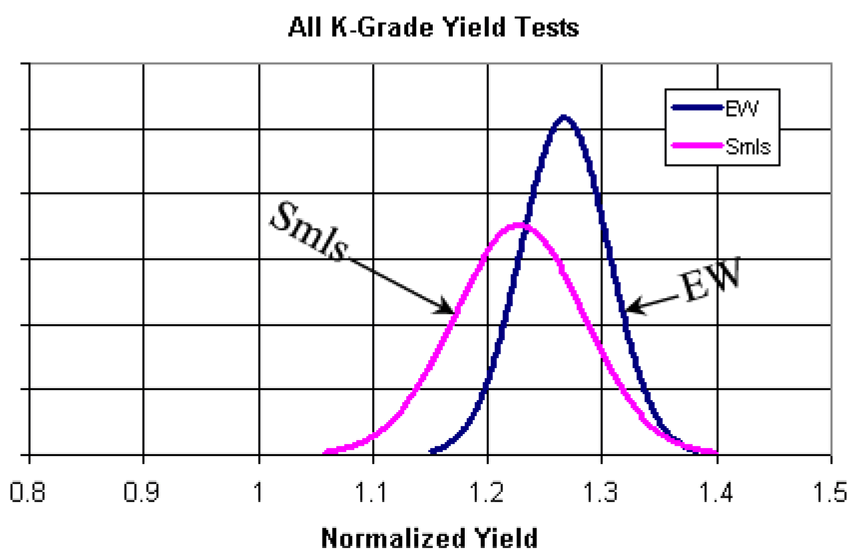
There are eight reports with an average of 1.58, a standard deviation of 0.031 producing a COV of 1.93%.

9.3.4 Process Grade J



There are 24 reports with an average of 1.18, a standard deviation of 0.068 producing a COV of 5.76%.

9.3.5 Process Grade K

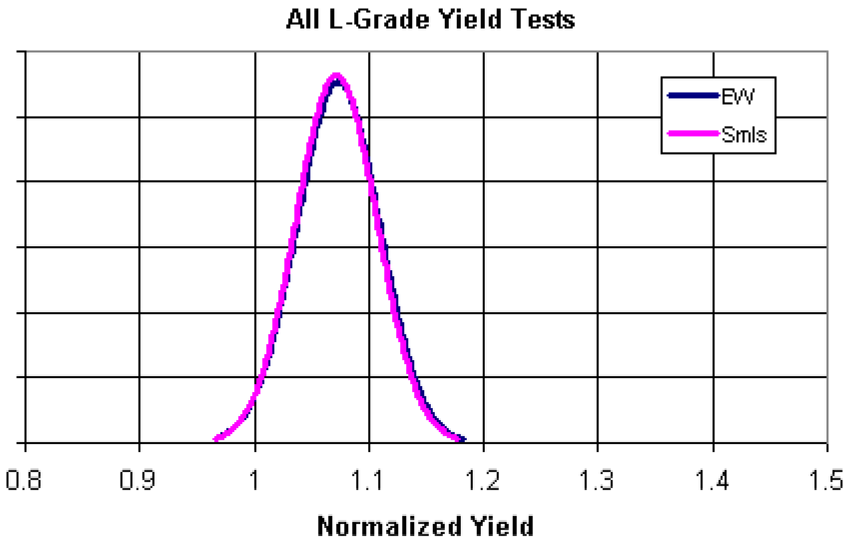


count	16	34
mean	1.267159	1.227754
SD	0.038646	0.056742
COV	3.05%	4.62%

The difference between the means is 0.039.

This is 0.826 times the average of the two standard deviations.

9.3.6 Process Grade L

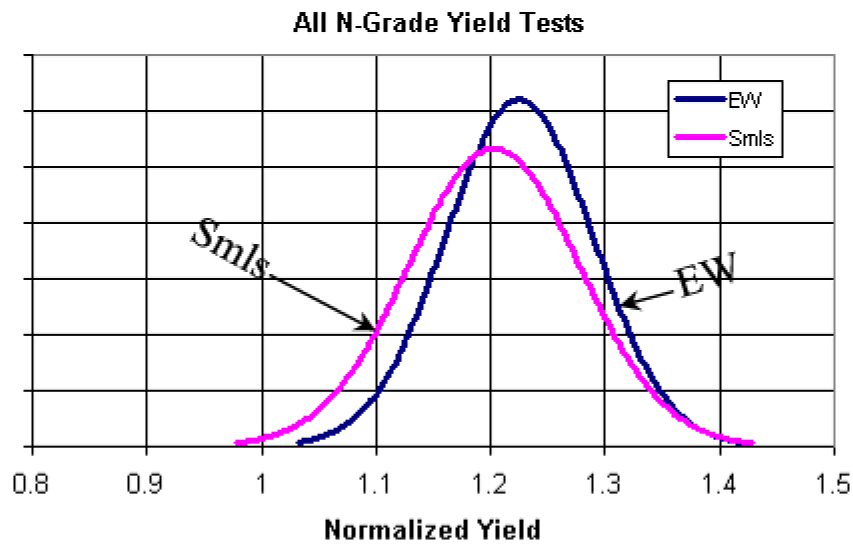


	EW	Smls
count	8	60
mean	1.073438	1.071747
SD	0.036091	0.035375
COV	3.36%	3.30%

The difference between the means is 0.002.

This is 0.047 times the average of the two standard deviations.

9.3.7 Process Grade N

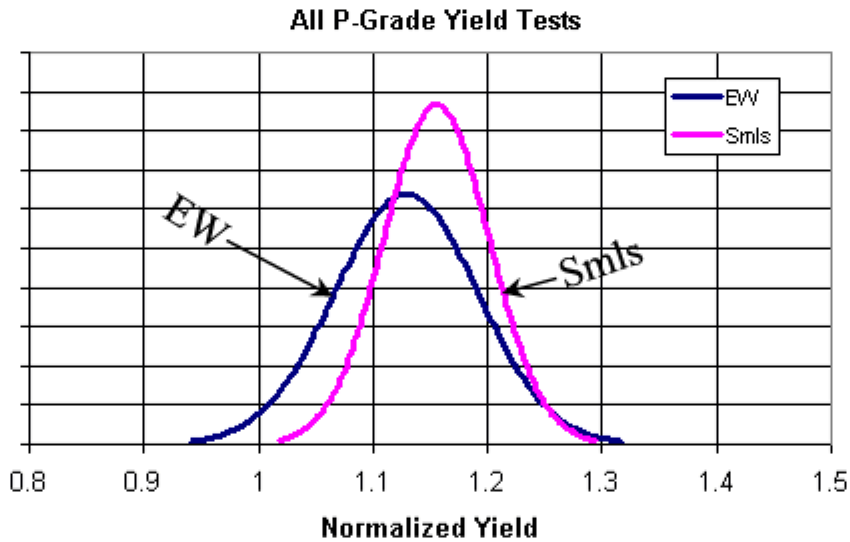


	EW	Smls
count	16	60
mean	1.225234	1.203266
SD	0.064379	0.074884
COV	5.25%	6.22%

The difference between the means is 0.022.

This is 0.315 times the average of the two standard deviations.

9.3.8 Process Grade P

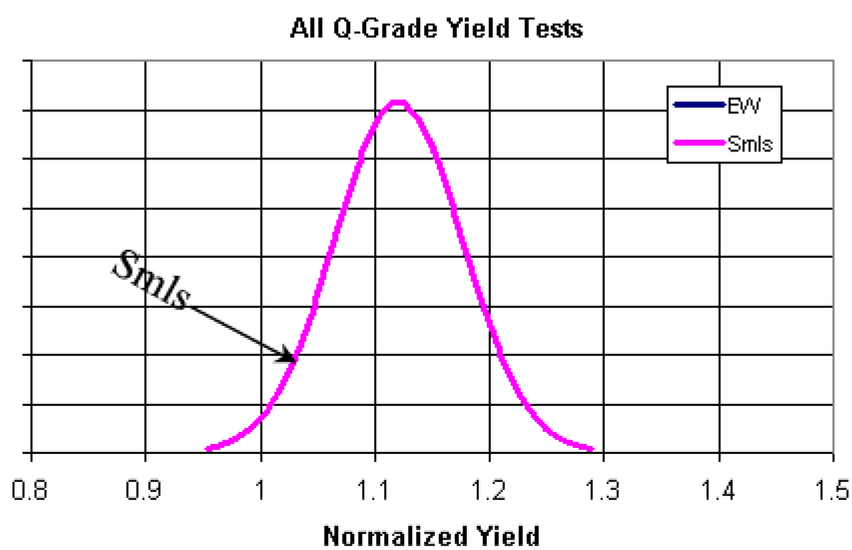


	EW	Smls
count	8	82
mean	1.129205	1.155471
SD	0.062524	0.046046
COV	5.54%	3.99%

The difference between the means is 0.026.

This is 0.484 times the average of the two standard deviations

9.3.9 Process Grade Q

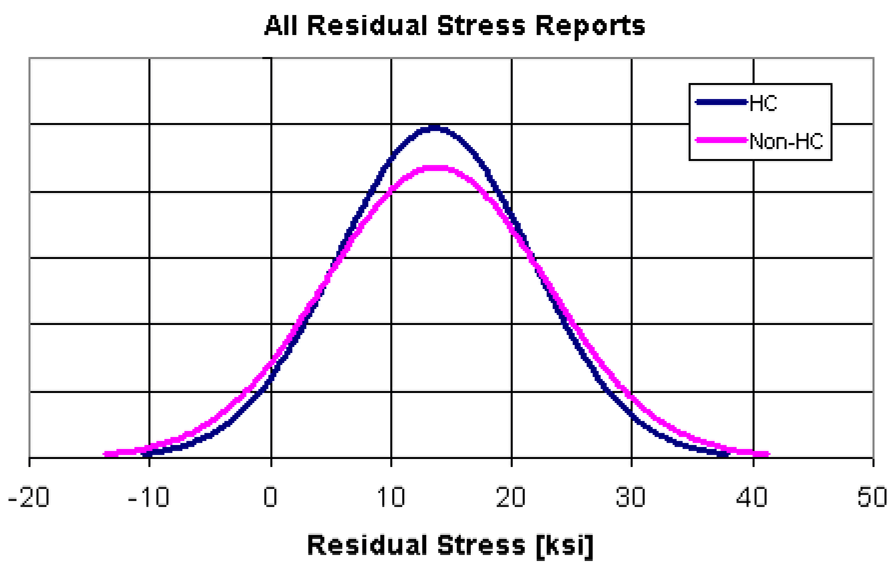


There are 36 reports with an average of 1.12, a standard deviation of 0.056 producing a COV of 4.98%.

9.4 RESIDUAL STRESS

All 151 pipes that were collapse tested reported a Residual Stress. All but two of the 151 reports were below zero. There were none that were identically zero.

9.4.1 High Collapse

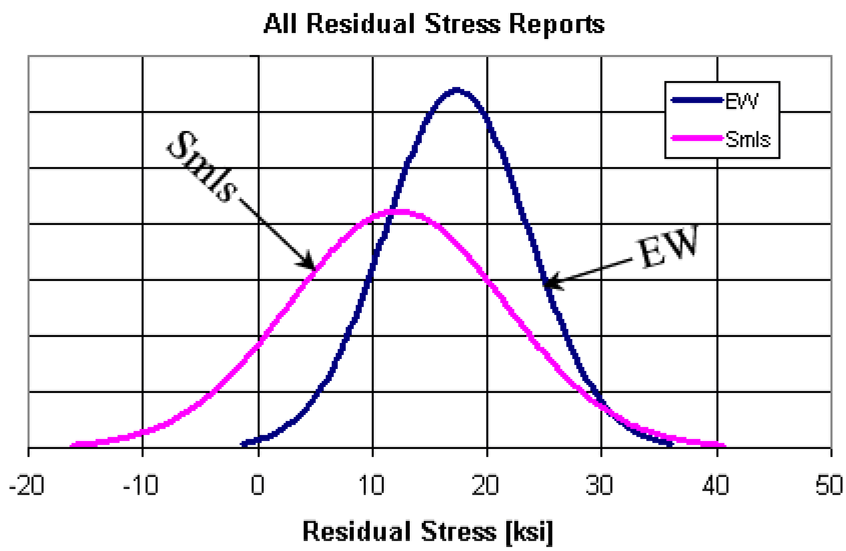


	HC	Non-HC
count	29	122
mean	13.62695	13.73995
SD	8.07256	9.157549
COV	59.24%	66.65%

The difference between the means is (13.73995=13.62695) = 0.113.

That is 0.013 times the average standard deviation.

9.4.2 Process

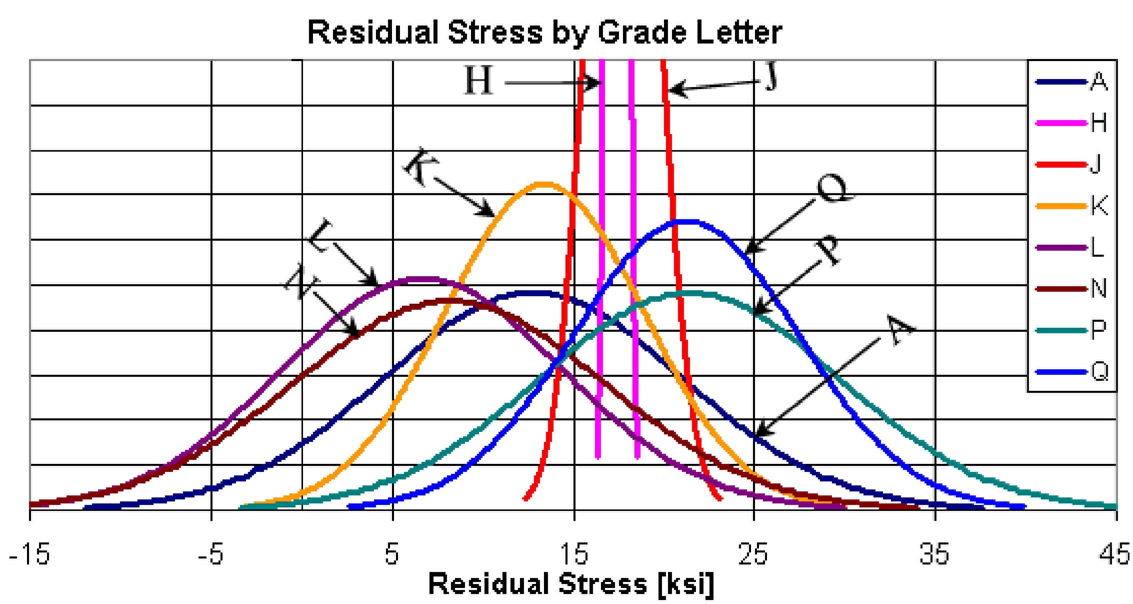


	EW	Smls
count	44	107
mean	17.3667	12.21795
SD	6.249502	9.450038
COV	35.99%	77.35%

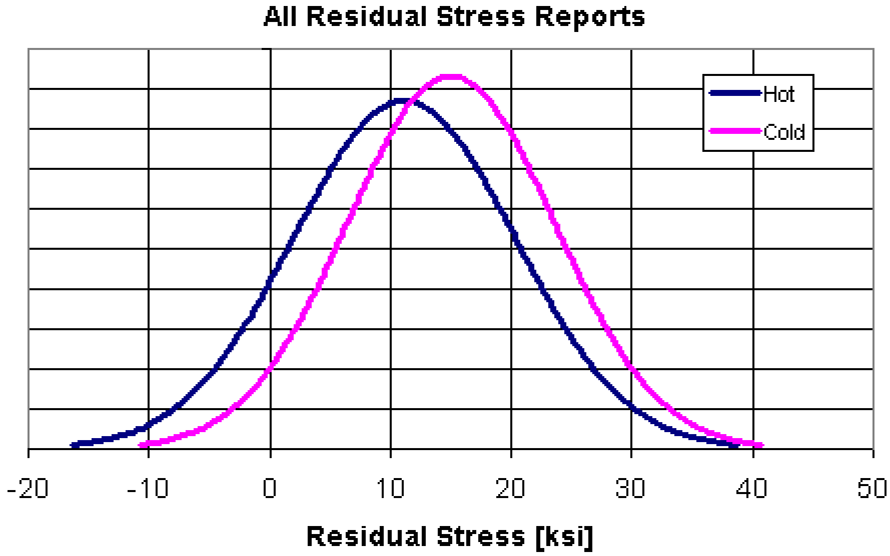
The difference between the means is (17.3667-12.21795) = 5.149.

That is 0.656 times the average standard deviation.

9.4.3 Grade



9.4.4 Straightening Process



	Hot	Cold	Total
count	51	100	151
mean	11.15336	15.02635	13.71825
SD	9.166233	8.566132	8.933867
COV	82.18%	57.01%	65.12%

The difference between the means is (15.02635-11.15336) = 3.873.

That is 0.437 times the average standard deviation.

9.5 OVALITY

All 151 pipes that were collapse tested reported one ovality at each of the nine measurement stations: a total of 1,359 ovality reports. Ovality reports were created from values obtained from calibrated OD gauge readings. SWRI recorded the readings as differential from Nominal. Although, in some cases, SWRI reported the angle the readings were taken, those readings are not in the database. This author has no sense about the angular separation between minimum and maximum OD readings.

It is industry standard wisdom that collections of ovalities constitute a population that is Lognormally distributed. A little discussion of Lognormal distributions is followed by a couple of views of the ovality data.

9.5.1 Lognormal Distributions

Ovality is said to be Lognormally distributed because it is the logarithm of ovality that is presumed to be Normally distributed.

Let x represent ovality. Then

$$y = \ln(x)$$

is Normally distributed. Borrowing from a tome[10] on the subject,

$$C_x = \frac{\sigma_x}{\mu_x}$$

$$e^{\sigma_y^2} = 1 + C_x^2 = 1 + \frac{\sigma_x^2}{\mu_x^2}$$

$$e^{\mu_y} = \frac{\mu_x}{\sqrt{1 + \frac{\sigma_y^2}{\mu_y^2}}}$$

$$\frac{\sigma_x^2}{\mu_x^2} = e^{\sigma_y^2} - 1$$

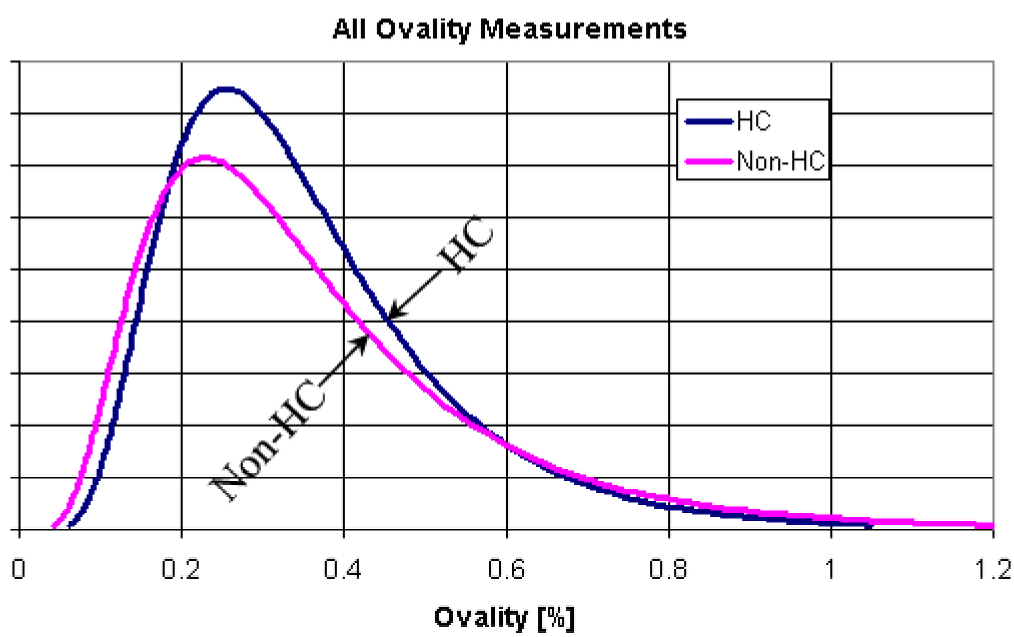
$$\mu_x = \sqrt{e^{\sigma_y^2}}\, e^{\mu_y}$$

$$\sigma_x = \sqrt{\mu_x^2\left(e^{\sigma_y^2} - 1\right)}$$

$$\sigma_x = \mu_x\sqrt{\left(e^{\sigma_y^2} - 1\right)}$$

9.5.2 High Collapse

From the data, it would seem that High Collapse pipe have a more controlled but higher average ovality than non High Collapse pipe.

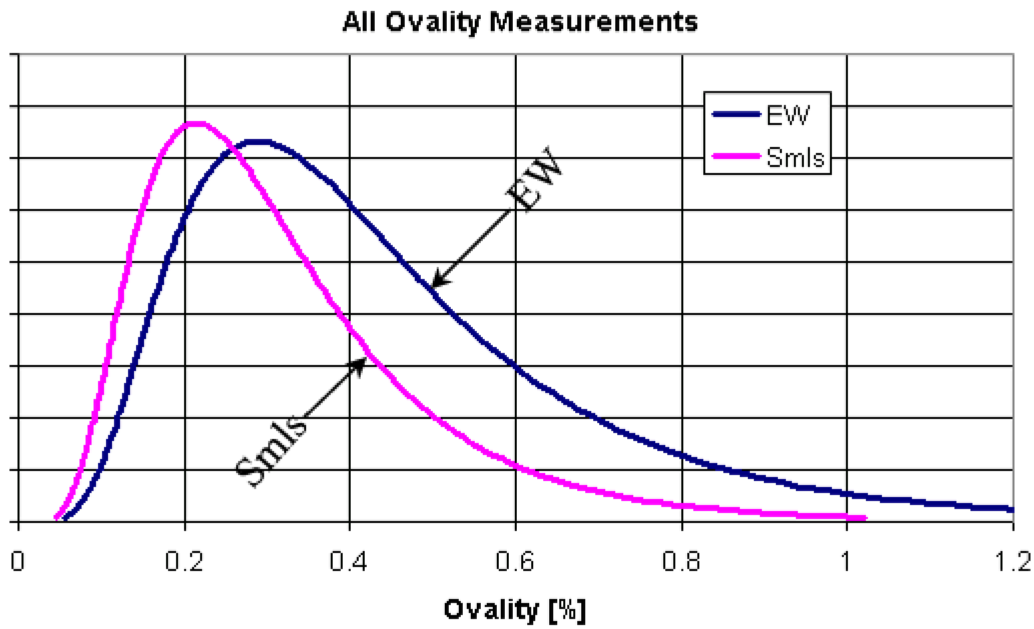


	HC	Non-HC
μ_y	-1.36589	-1.47413
σ_y	0.471256	0.558672
μ_x	0.285119	0.228977
σ_y	0.142181	0.138585

In logarithm space, the differences of the means is (1.47413-1.36589)=0.108.

That is 0.21 average standard deviations.

9.5.3 Process

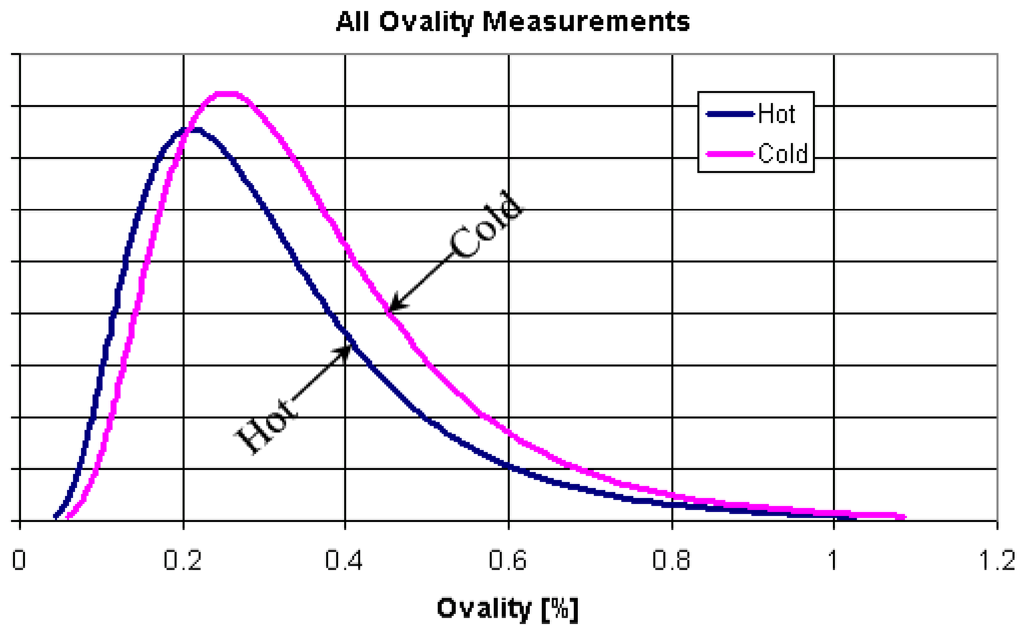


	HC	Non-HC
μ_y	-1.24239	-1.54009
σ_y	0.544966	0.520298
μ_x	0.334908	0.214362
σ_y	0.196941	0.119524

In logarithm space, the differences of the means is (1.54009-1.24239)=0.298.

That is 0.56 average standard deviations.

9.5.4 Straightening



	HC	Non-HC
μ_y	-1.55864	-1.37049
σ_y	0.528121	0.483855
μ_x	0.24191	0.253982
σ_y	0.137206	0.130447

In logarithm space, the differences of the means is (1.55864-1.37049)=0.188.

That is 0.37 average standard deviations.

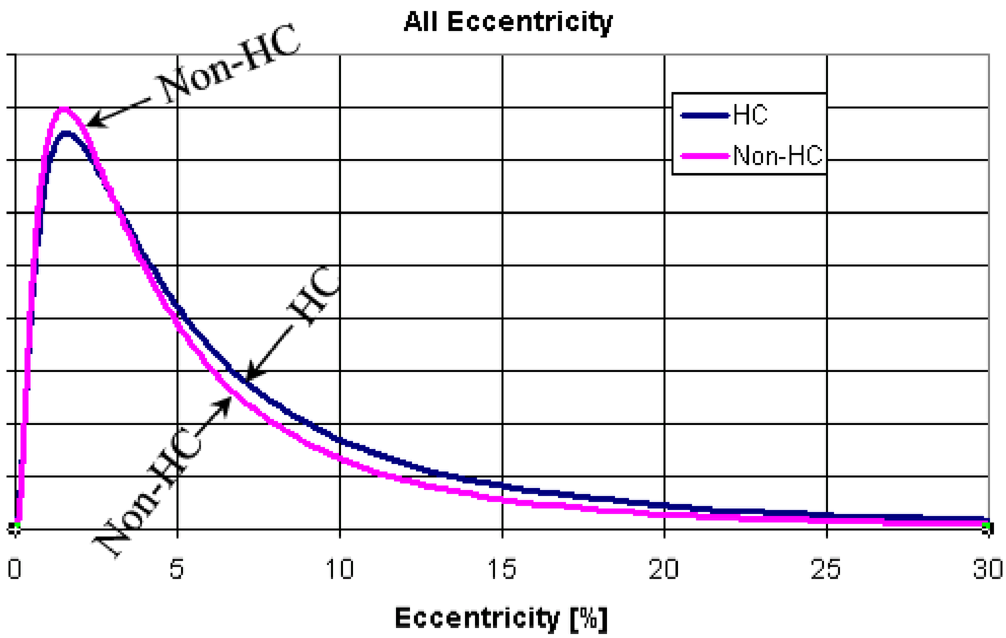
9.6 ECCENTRICITY

All 151 pipes that were collapse tested reported four eccentricity values at each of the nine measurement stations on each pipe: a total of 5,436 eccentricity reports. Eccentricity was calculated by SWRI using opposing wall thickness values as:

$$e = \frac{t_{\max} - t_{\min}}{t_{avg}}$$

where t is wall thickness. Wall thickness pairings were {0-180°, 45-225°, 90-270°, 135-315°}.

9.6.1 High Collapse

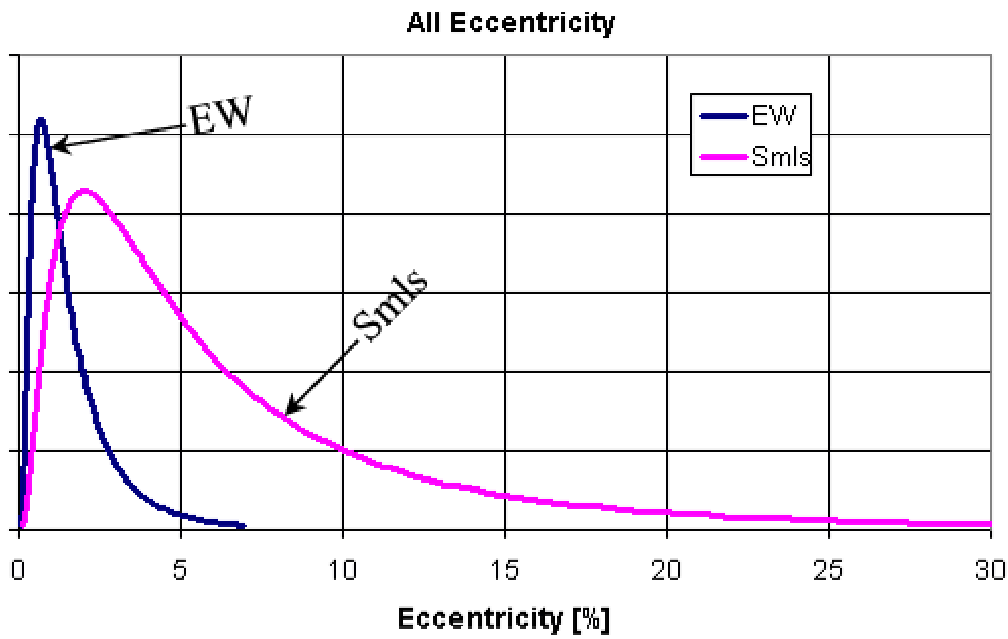


	HC	Non-HC
μ_y	0.46803	0.411559
σ_y	1.063128	1.001068
μ_x	2.809906	1.509169
σ_y	4.068453	1.981611

In logarithm space, the differences of the means is (0.46803-0.411559)=0.056.

That is 0.05 average standard deviations.

9.6.2 Process

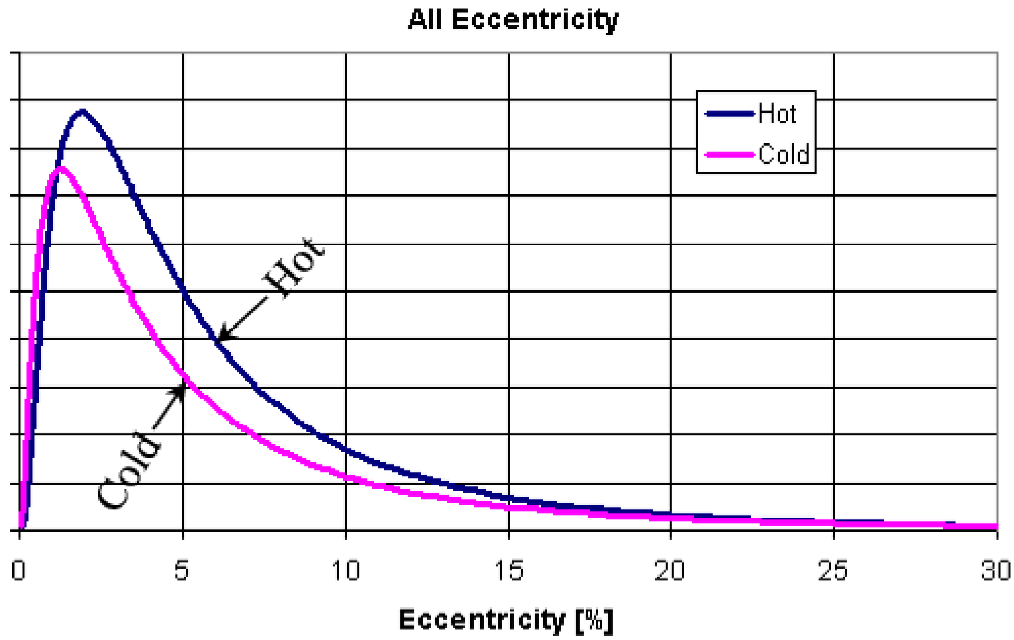


	HC	Non-HC
μ_y	-0.37025	0.714796
σ_y	0.769571	0.933428
μ_x	0.92855	2.043769
σ_y	0.83468	2.409557

In logarithm space, the differences of the means is (0.37025+0.714796)=1.085.

That is 1.27 average standard deviations.

9.6.3 Straightening



	HC	Non-HC
μ_y	0.653547	0.246315
σ_y	0.912924	1.056776
μ_x	2.916143	1.279302
σ_y	3.326447	1.833909

In logarithm space, the differences of the means is (0.653547+0.246315)=0.407.

That is 0.41 average standard deviations.

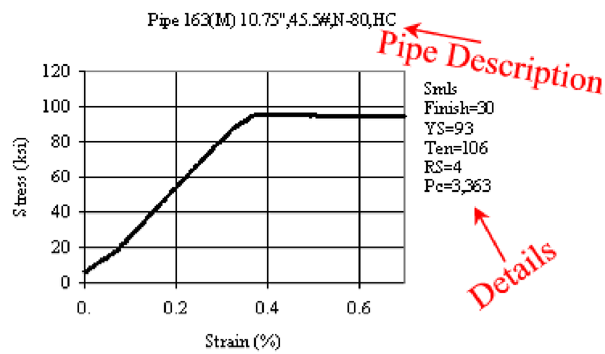
9.7 STRESS-STRAIN

Of the 216 pipes, 1 had no stress-strain data, 17 had only one set of stress-strain data and the remaining 198 pipes have two stress-strain data sets, one for each end.

A point consists of a {strain, stress} doublet. Strain always has units of [%], stress [psi].

Hecate digitized the stress-strain plots provided by the manufacturers. There are a total of 227,422 stress-strain data points. The maximum number of data points in a data set is 1,294, the minimum is 83 and on average, there are 551 data points.

All plots look very much the same. A Pipe Description is given that always contains the PipeID (e.g. 163) and whether the data set is for the end (E) or middle (M). This is followed by the nominal OD (e.g. 10.75"), weight [ppf] (e.g. 45.5) and some attempt at the grade (e.g. N-80).



If the manufacturer reported the pipe as High Collapse, then "HC" will also appear.

On the right side of each plot is the process {"Smls", "EW"}, the Finish when it is known. When known, the test yield strength (YS), test tensile strength (Ten), residual stress (RS) are reported in units of [ksi]. And finally, if known, the collapse pressure (Pc) in units of [psi].

Refer to Appendix C for a complete presentation of the known stress-strain data.

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10.0 DISCUSSION OF COLLAPSE PRESSURES

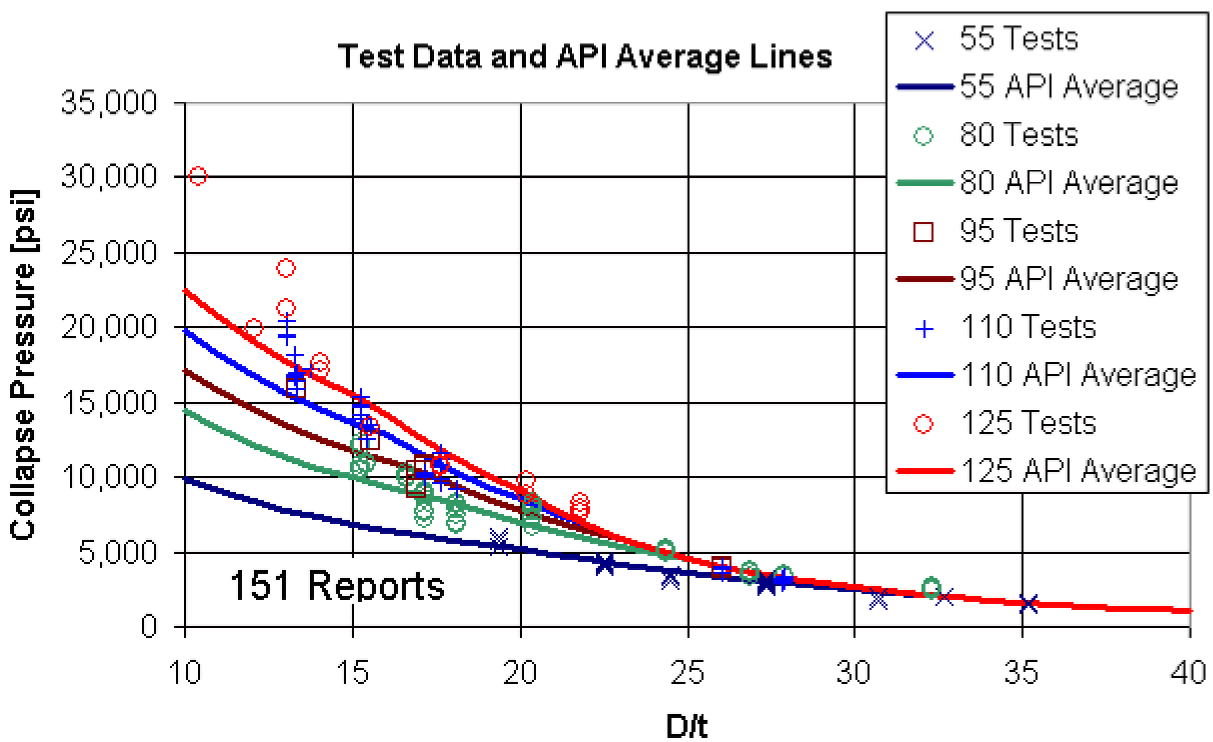
There were 151 pipes that underwent collapse pressure testing. All but one actually collapsed.

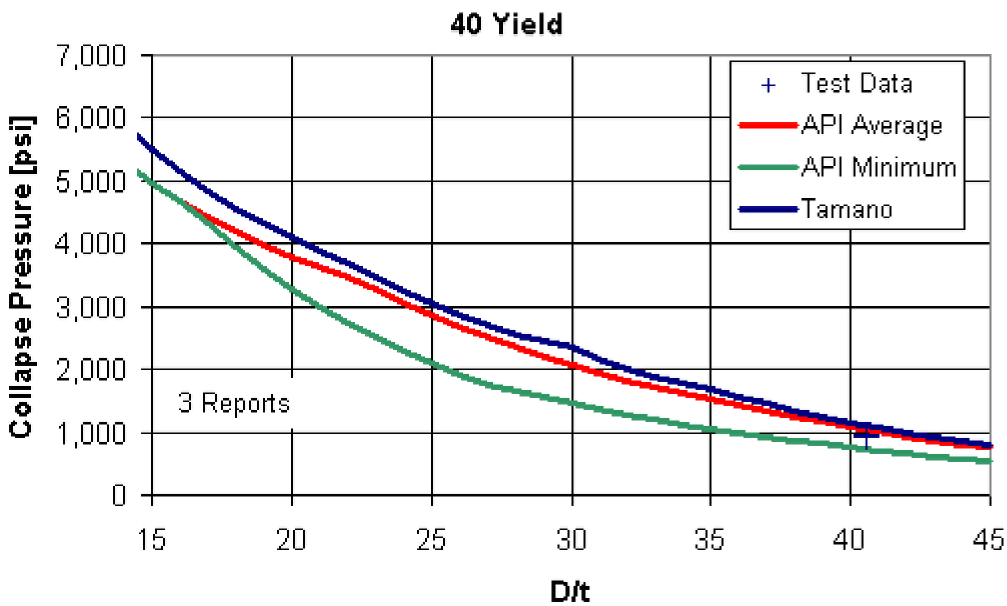
10.1 ACTUAL VERSUS API AND TAMANO COLLAPSE PRESSURES

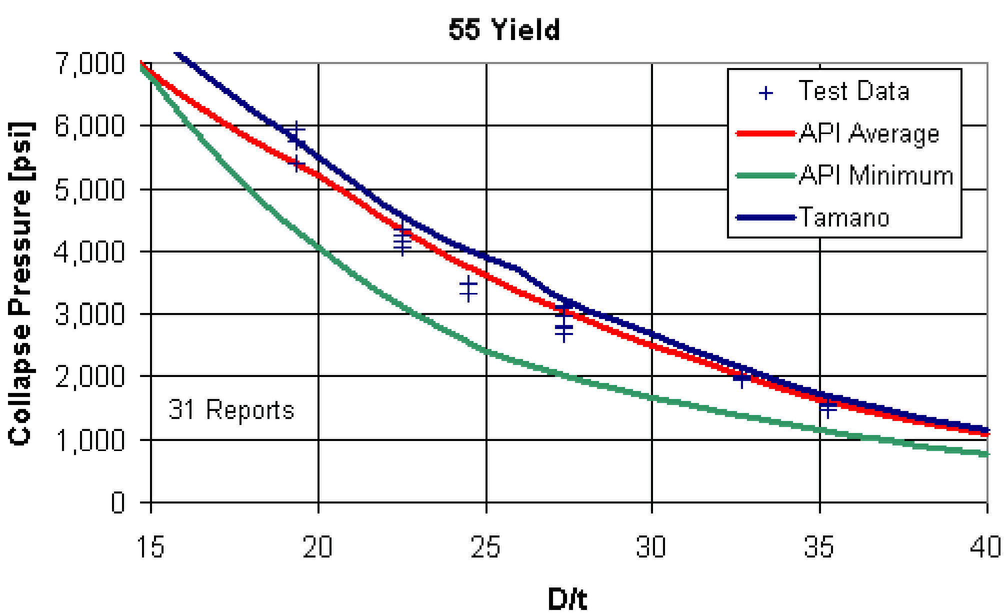
Yield [ksi]	Count
40	3
55	31
80	47
85	1
95	10
110	42
125	17
Total	**151**

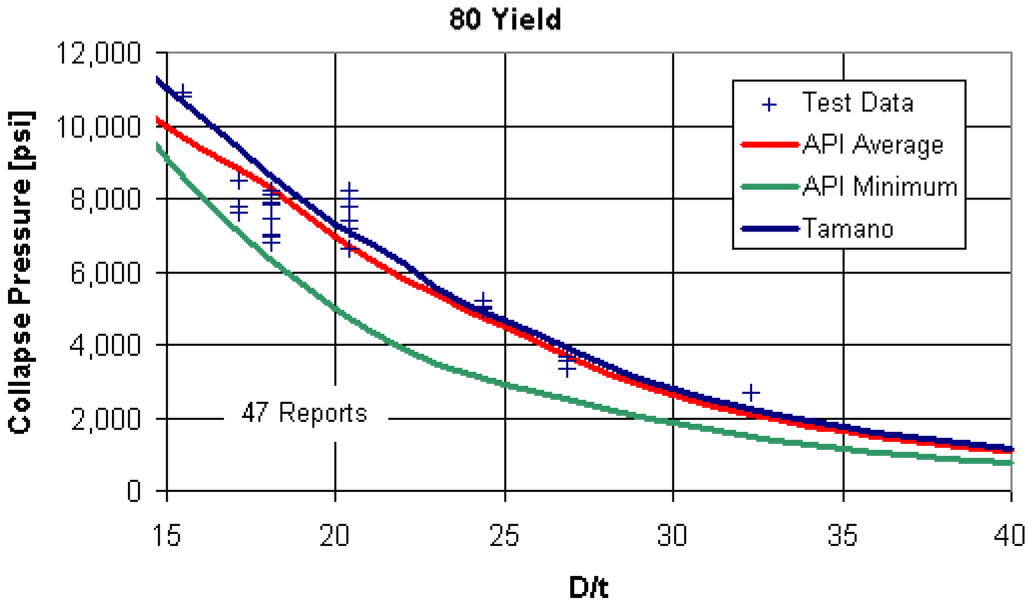
This is the breakdown of the 151 pipes that were subject to collapse testing by Nominal Yield Strength.

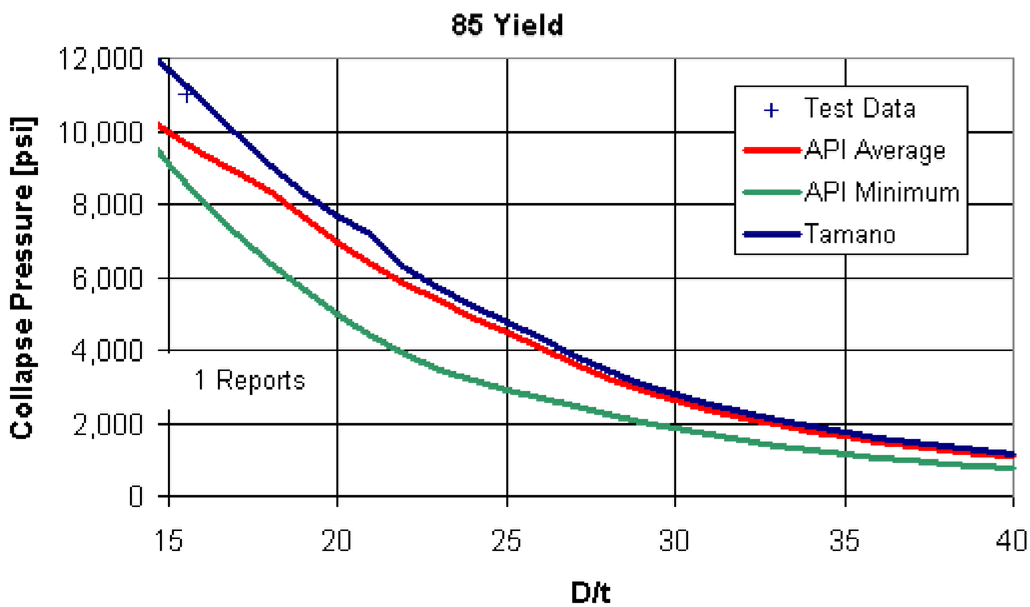
The following plots give the collapse test data by material grade. They also contain the API Average and API Minimum collapse curves and the Tamano curve. It should be noted that the Tamano curve is for a "perfect" pipe; that is, the curve assumes zero ovality, eccentricity and residual stress.

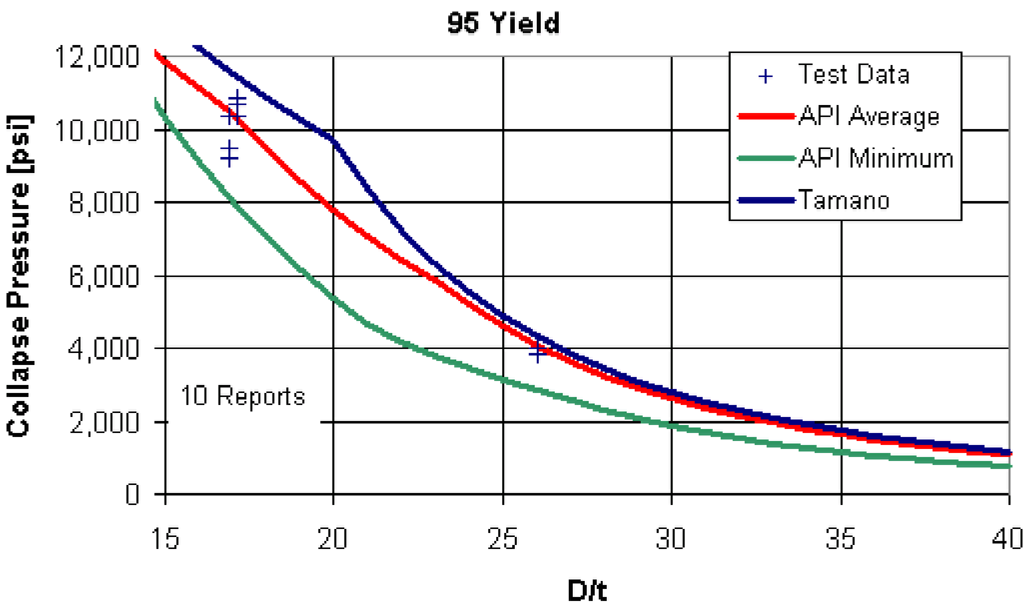


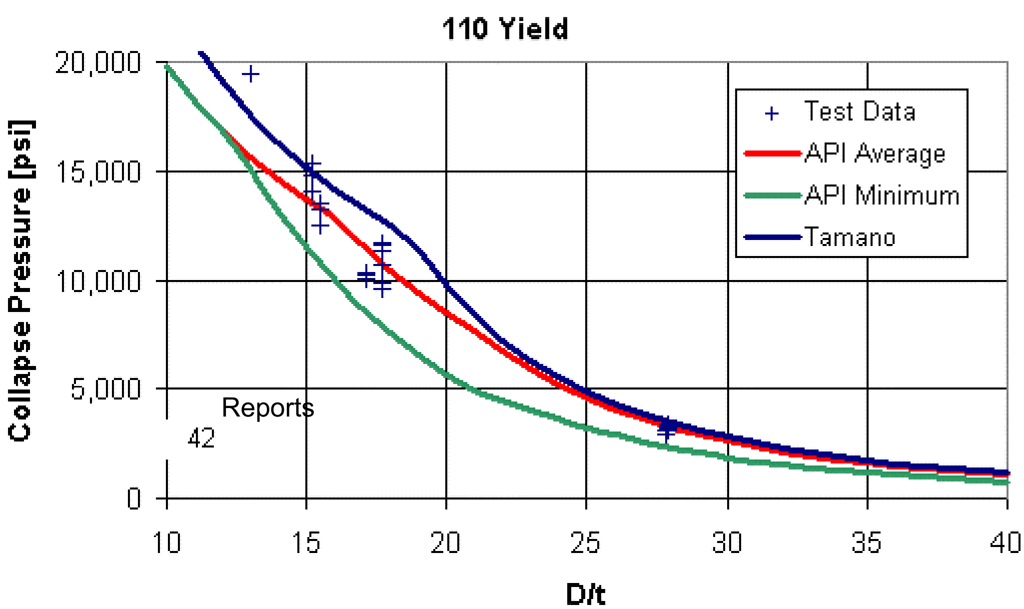

40 Yield
Collapse Pressure [psi]
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
15
20
25
30
35
40
45
D/t
Test Data
API Average
API Minimum
Tamano
3 Reports

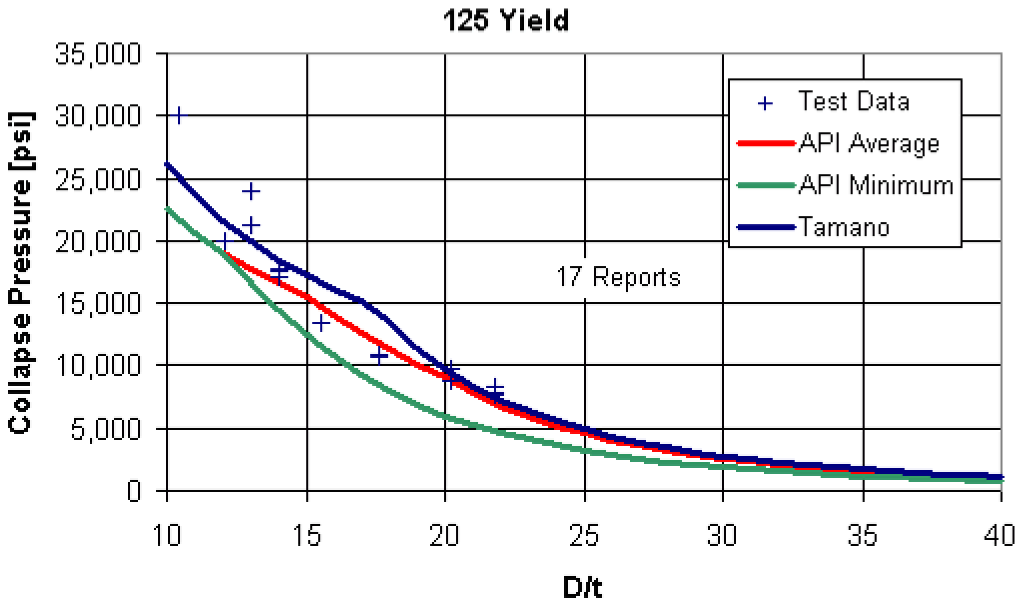

55 Yield
Collapse Pressure [psi]
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
15
20
25
30
35
40
D/t
Test Data
API Average
API Minimum
Tamano
31 Reports


80 Yield
Collapse Pressure [psi]
12,000
10,000
8,000
6,000
4,000
2,000
0
15
20
25
30
35
40
D/t
Test Data
API Average
API Minimum
Tamano
47 Reports


85 Yield
Collapse Pressure [psi]
12,000
10,000
8,000
6,000
4,000
2,000
0
15
20
25
30
35
40
D/t
Test Data
API Average
API Minimum
Tamano
1 Reports


95 Yield
Collapse Pressure [psi]
12,000
10,000
8,000
6,000
4,000
2,000
0
15
20
25
30
35
40
D/t
Test Data
API Average
API Minimum
Tamano
10 Reports


110 Yield
Collapse Pressure [psi]
20,000
15,000
10,000
5,000
0
10
15
20
25
30
35
40
D/t
Test Data
API Average
API Minimum
Tamano
Reports
42



All of the collapse values were above the API Minimum curve. As a whole, the values were evenly scattered both above and below the API Average curve. Most of the values are below the Tamano curve, with the main reason being that no ovality, eccentricity or residual stress was included.

11.0 COMPARISON OF MANUFACTURERS

Delivery.xls is an Excel workbook that contains information about all pipes excluding manufacturer-specific information, and is given in Appendix B.

This workbook is stand-alone. That is, there is no connection to any database.

There are 12 worksheets as indicated above. Each will be discussed in the order they appear.

Except for Pipes, each sheet contains one graphic of the named data with all applicable manufacturers represented. For ovality, eccentricity and residual stress, the data is presented both as Normal and Lognormal distributions. There is some uncertainty as to the true, underlying distributions of the various metrics but these two distribution assumptions are used as a means of showing relations between the manufacturers. Care should be taken in interpreting the data since manufacturers did not all produce the same kind of pipe nor the same quantity of pipe. This is obvious with eccentricity where the seamless and EW pipes have very different character.

There are two plot formats: Normal and Lognormal. Normal is provided for all metrics, Lognormal only for ovality, eccentricity and residual stress. There is no presumption that either adequately represents the underlying distribution. They are used merely for presentation convenience.

For **Normal plots**, the ordinate represents the frequency distribution:

$$f(x, \mu, \sigma) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\left(\frac{(\mu - x)^2}{2\sigma^2}\right)}$$

Variable x is the abscissa value (i.e. the independent variable), μ is the mean and σ the standard deviation. Importantly,

$\int f = 1$, i.e., the area under each plot equals 1.

The legend of the normal plots gives the mean and standard deviation for the Shell donated pipe vs all others parenthetically as ($\mu;\sigma$). In all cases, the range of x is limited to $-3\sigma \le x \le 3\sigma$. This plot is useful in an examination of the relative locations of the means (μ) and standard deviations (σ) for each population.

For **Lognormal plots**, the metric under scrutiny is u = ln(x) where ln(x) is the natural log of the metric x. For example, if x is eccentricity, then u = ln(eccentricity). Similar to the normal plots, the legend contains the mean, standard deviation and count for each manufacturer. However, means (μ) and standard deviations (σ) are reported for u, not x. Note that it is **not** legitimate to assume that

$$mean(x) = e^{mean(u)}$$

11.1 Sheet Pipes

All 151 pipes that were collapse tested are represented. This is all of the data from Table Pipes in the database (WG2b.mdb) for those pipes that collapsed.

In all cases, the Shell donated pipe is presented in blue.

Merged columns A3, B3 and C3 give the date of construction of the workbook. This will allow identification of revisions, updates, etc.

11.2 All Sheets Other than Pipes

Columns A:L represent the metric data for each of the manufacturers. Row 1 is the mean value of the metric for that manufacturer; row 2 is the standard deviation. Row 3 is always blank. Row 4 and below contain values of the metric in no particular order. In general, the number of rows for each manufacture is not equal.

No formulas appear in these columns. All calculations (e.g. normalization) were done in the program that created the workbook.

Column N presents 200 equally-spaced intervals between -3 and 3 inclusive (201 rows). These are the basis for the abscissa values as discussed below.

Columns O:AL are pairs of columns that contain exactly 201 rows. Each pair of columns (e.g. Columns O:P, Q:R, etc.) represent one manufacturer. The **left** column in each pair is the abscissa presented as

$$x = \mu + \sigma\phi$$

for the Normal distribution assumption, and

$$x = \exp^{\mu+\sigma\phi}$$

for the Lognormal distribution assumption. ϕ is a variable from the assumed standard deviation range {-3,3}.

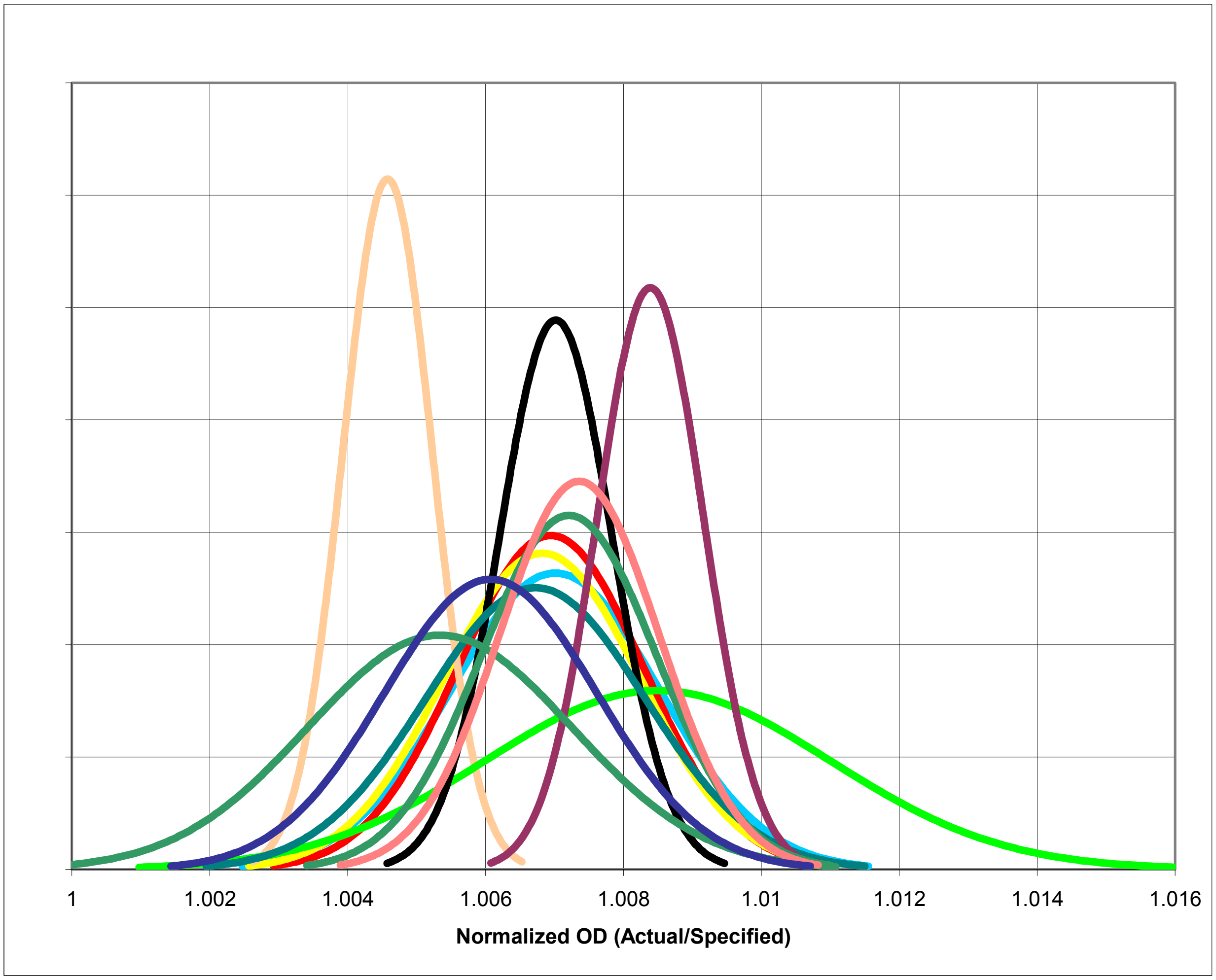
Right column values are Excel's NormDist(x, μ, σ, false). NormDist "returns the normal distribution for the specified mean and standard distribution." The *false* requests the density function rather than a cumulative value.

One thing to keep in mind when comparing some of the data/plots and manufacturers is the two processes for making the pipe. These are the welded pipe and seamless pipe

11.3 Sheet OD

Data was generated by dividing the measured OD by the specified (nominal) OD.

There are 2,610 OD reports.



The middle of the group had a value of approximately 1.007 and the light green plot at the right most side had a value of 1.0085, which is 0.70% and 0.85% over the specified OD, respectively. The smallest mean normalized OD was the brown plot at 1.0045.

API Specification 5CT[11] requires the OD of pipe equal to or above 4-1/2" to be between +1.0% and –0.5%. All mean values were between 1.0045 and 1.0085 and satisfy this requirement. Only three samples were below 4-1/2" OD. Of the 2,610 OD readings, 50 readings were above 1.0% of API specified. Forty-four of these were on 7" samples and six were on 9-5/8" pipe. The 50 readings were scattered over four different pipe grades- N-80, P-110, A95 and A110. Approximately half were on API pipe and half on HC pipe.

It is important to note that manufacturers frequently bias their OD tolerances to address other issues such as threading compliance (minimize black crested threads) or to facilitate special drifts that are larger than standard drifts.

11.4 Sheet Wall

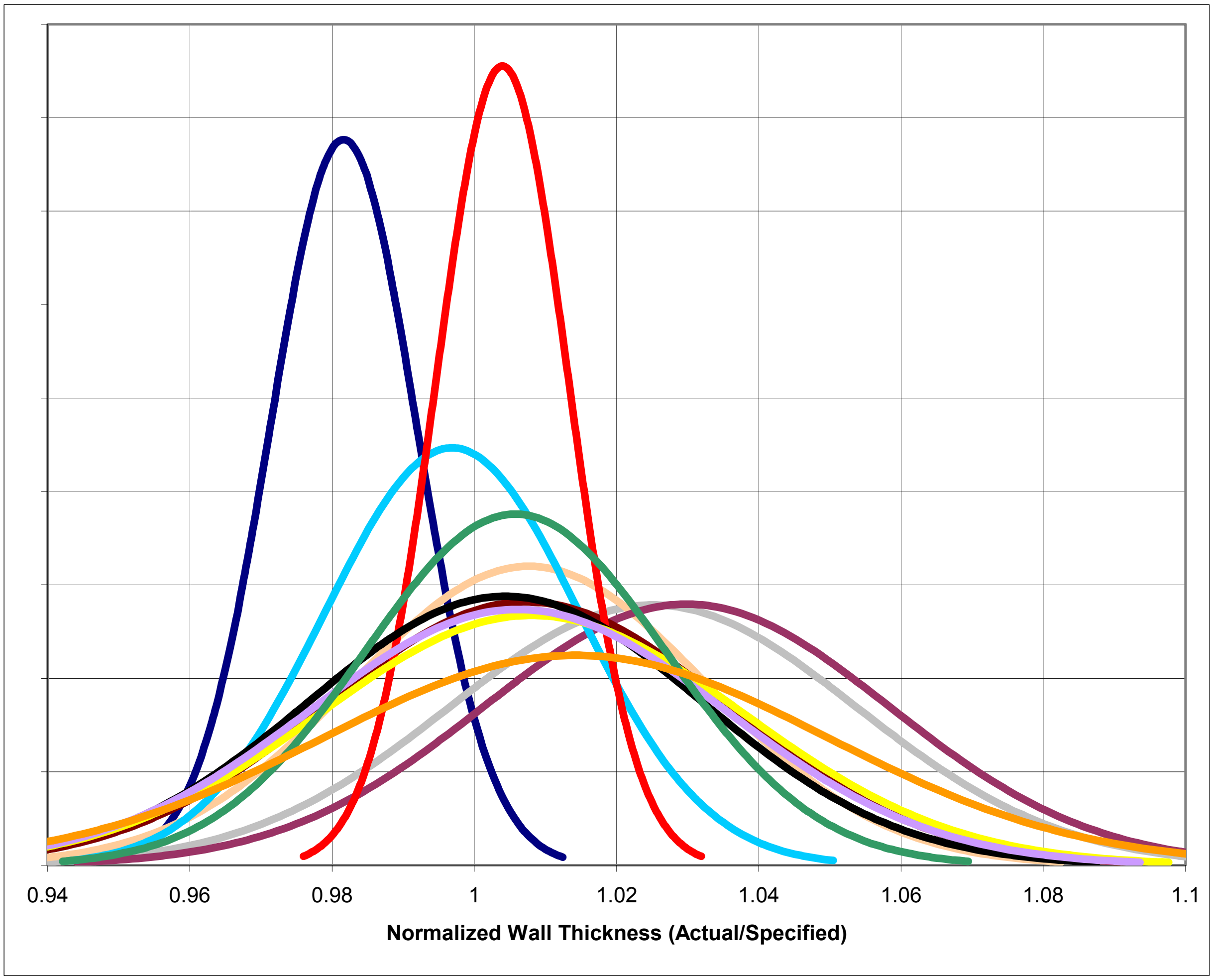
Data was generated by dividing the measured wall thickness by the specified (nominal) wall thickness. Specified (nominal) wall thicknesses can be found in the database in Table NominalWalls. This table was created to assist in queries where the wall thickness was not explicitly provided.

For example, given a 7”, 32# pipe, no information is provided about wall thickness. A query that includes wall thickness can be constructed using an Inner-Join on NominalOD and NominalWeight in Table Pipes with OD and Weight in Table NominalWalls. The Weight from NominalWalls will then be available.

For example, this query contains the pipe ID, pipe name, OD, weight and associated wall thickness.

```
SELECT Pipes.PipeID, Pipes.Name, Pipes.NominalOD, Pipes.NominalWeight, NominalWalls.Wall
FROM Pipes INNER JOIN NominalWalls ON
(Pipes.NominalWeight = NominalWalls.Weight) AND
(Pipes.NominalOD = NominalWalls.OD);
```

There are 10,872 wall thickness reports.



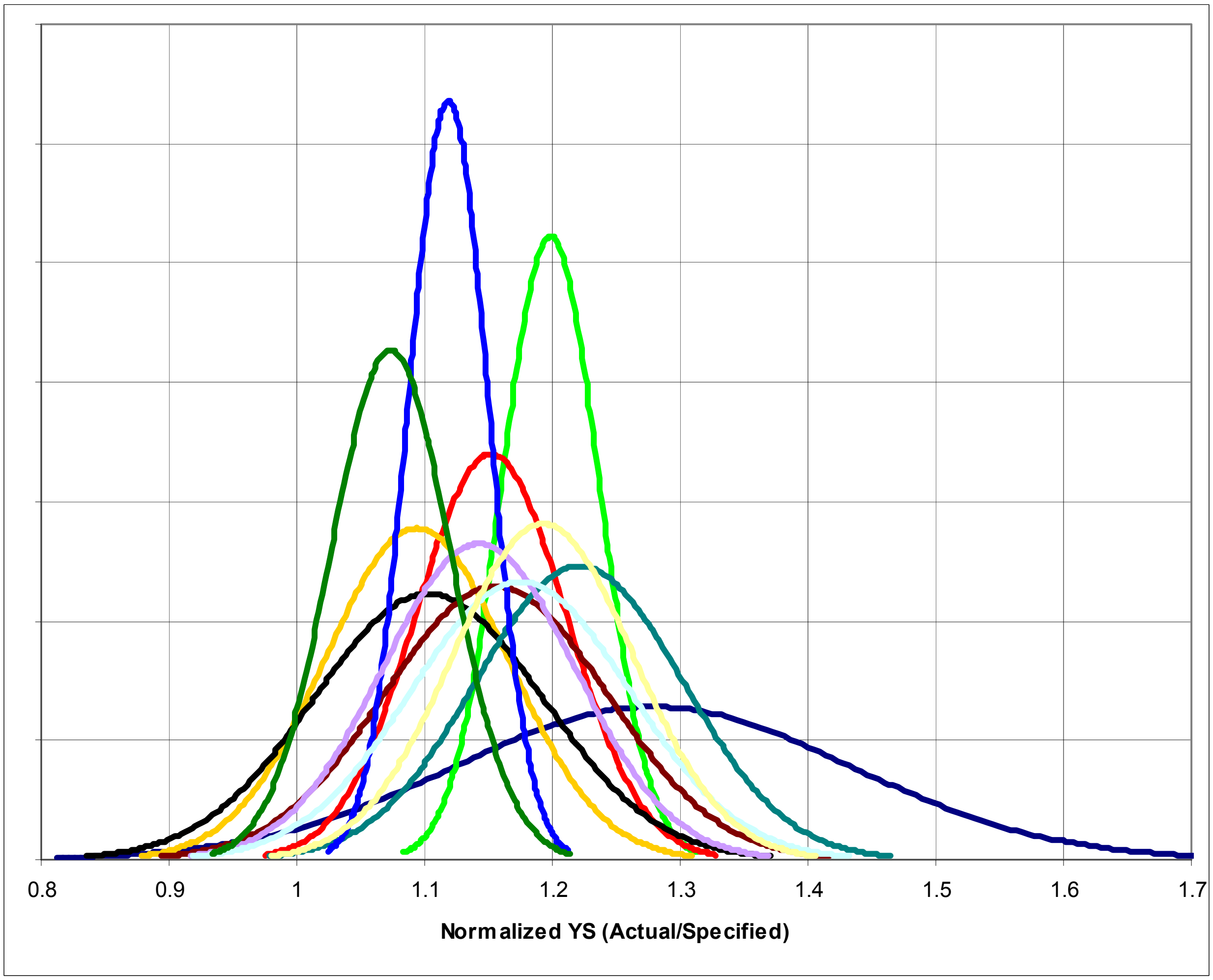
The manufacturer with the smallest mean wall was the dark blue plot and the largest was the maroon plot. The welded pipe manufacturers had the least wall thickness as well as the narrowest range, which is to be expected for welded pipe versus seamless pipe (see Section 9.2.4, page 56).

Only one wall value was below 87.5%. This was 0.873 (amount short basically negligible) on a 11-3/4" Q-125 sample.

11.5 Sheet YS and Yield Plots by Grade

11.5.1 Sheet YS

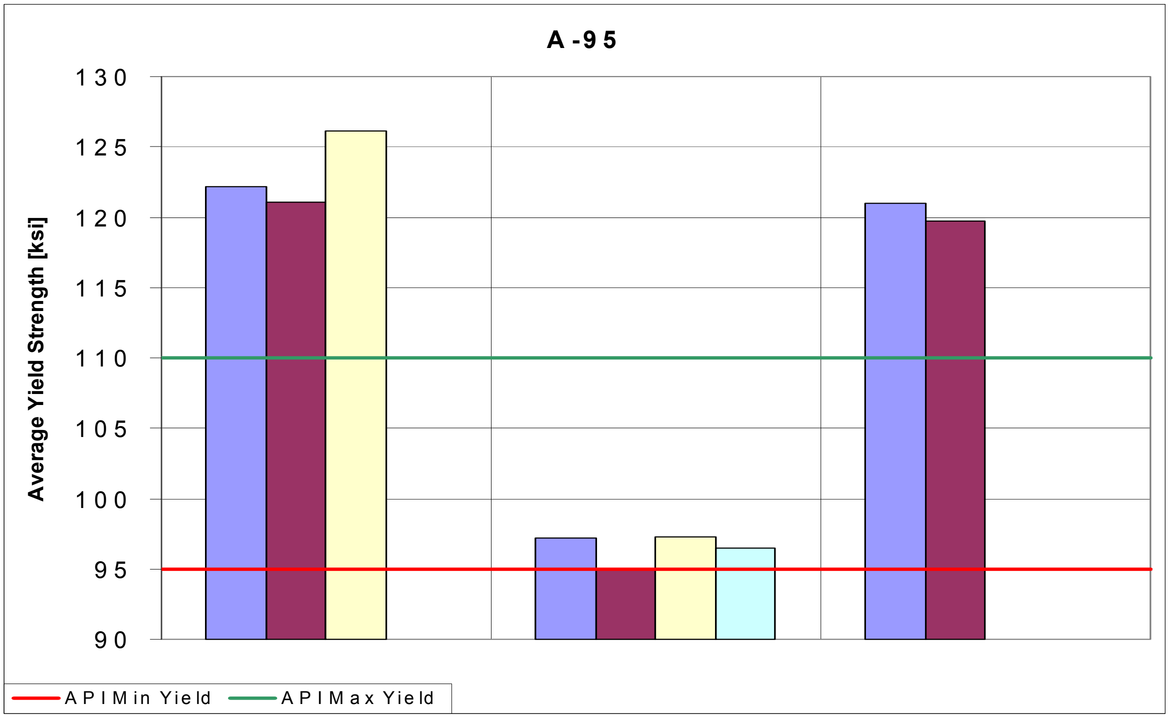
Data was generated by dividing the calculated (reported) yield strength by the specified (minimum) yield strength. All manufacturers are plotted together below.

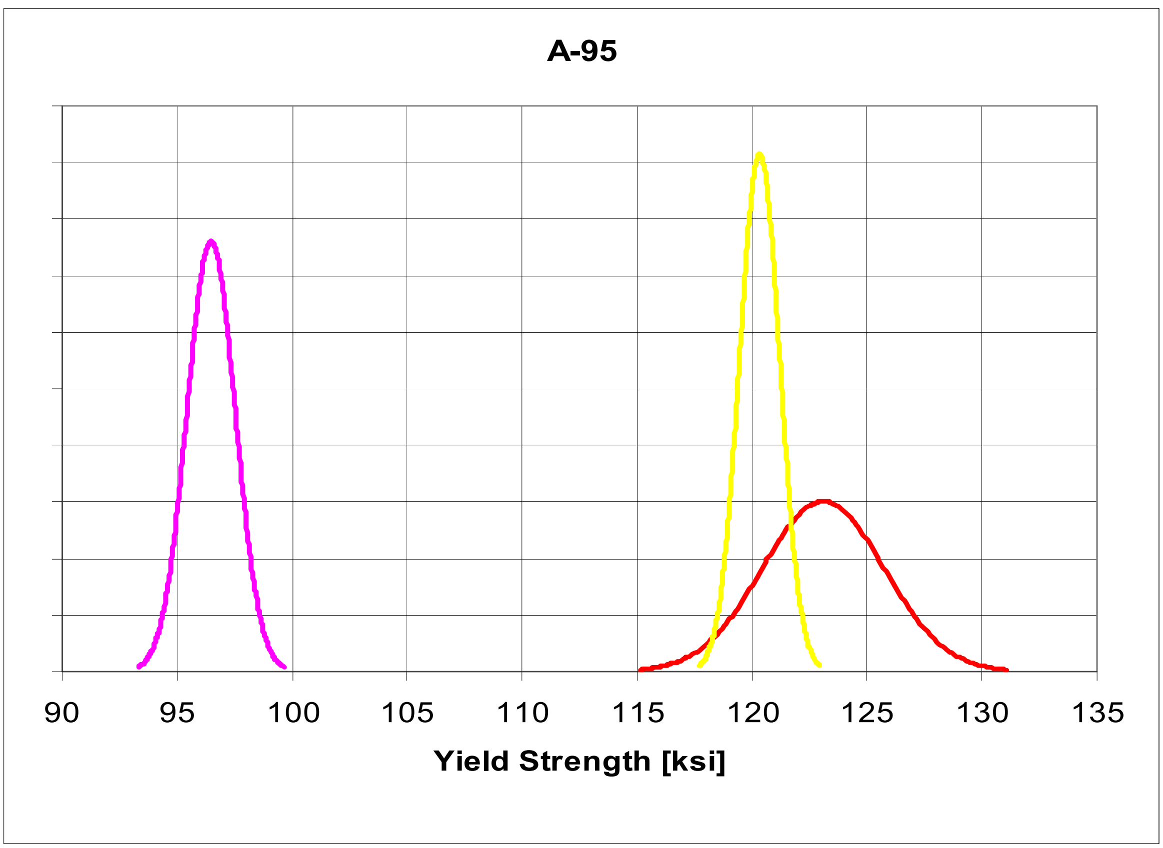


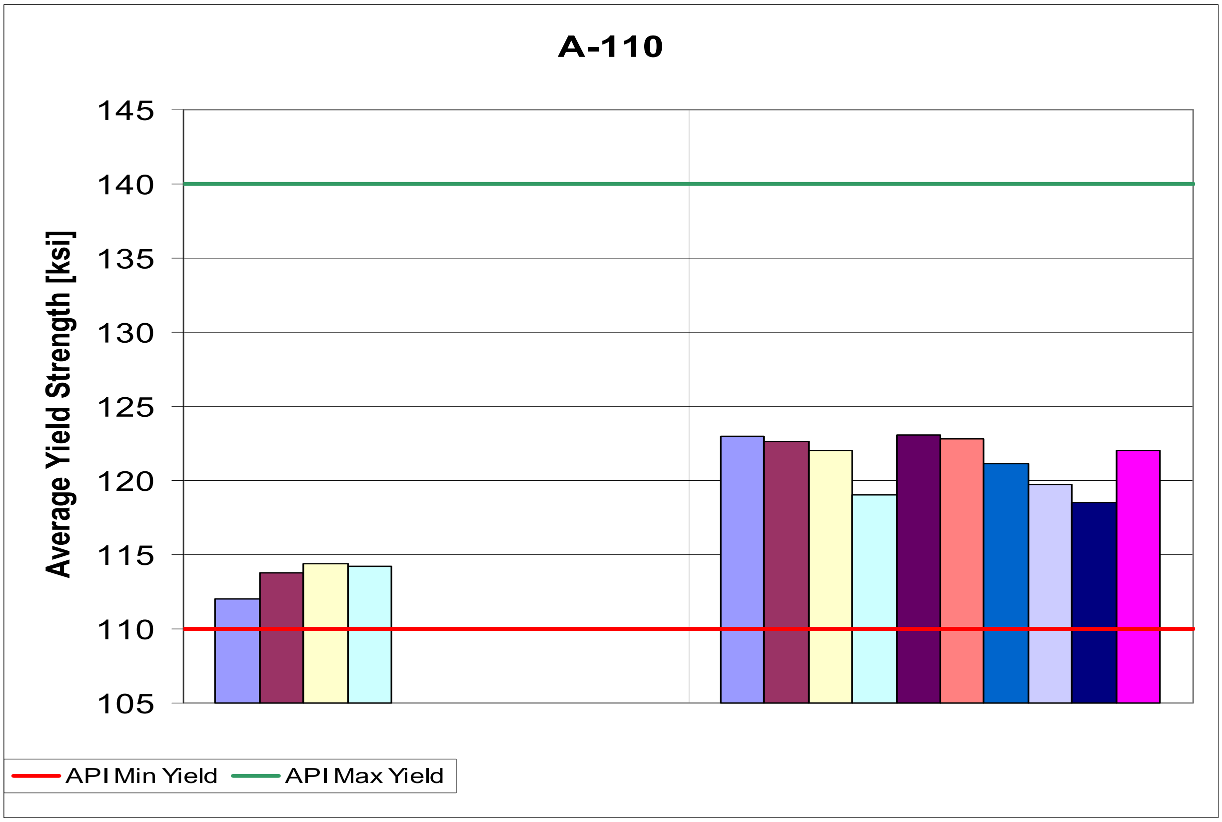
11.5.2 Yield Plots by Grade

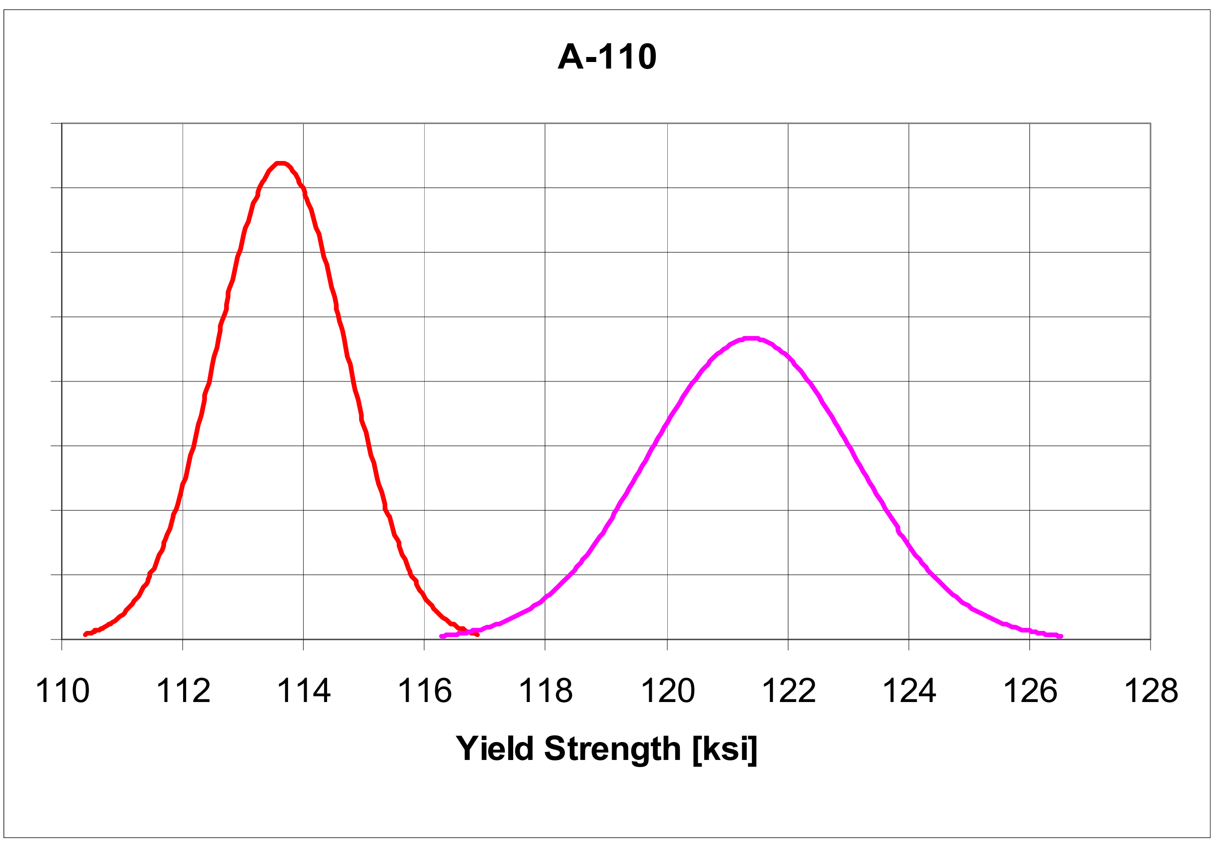
Yield strength results are displayed in the following figures by grade. These are created in separate workbooks named **Yields A-95.xls**, **Yields A-110.xls**, **Yields H-40.xls**, **Yields J-55.xls**, **Yields K-55.xls**, **Yields L-80.xls**, **Yields N-80.xls**, **Yields P-110.xls** and **Yields Q-125.xls**. In an effort to present the results in a useable format, the values of samples tested are compared against API Specification 5CT[11] strength requirements defined for the specific grade of material.

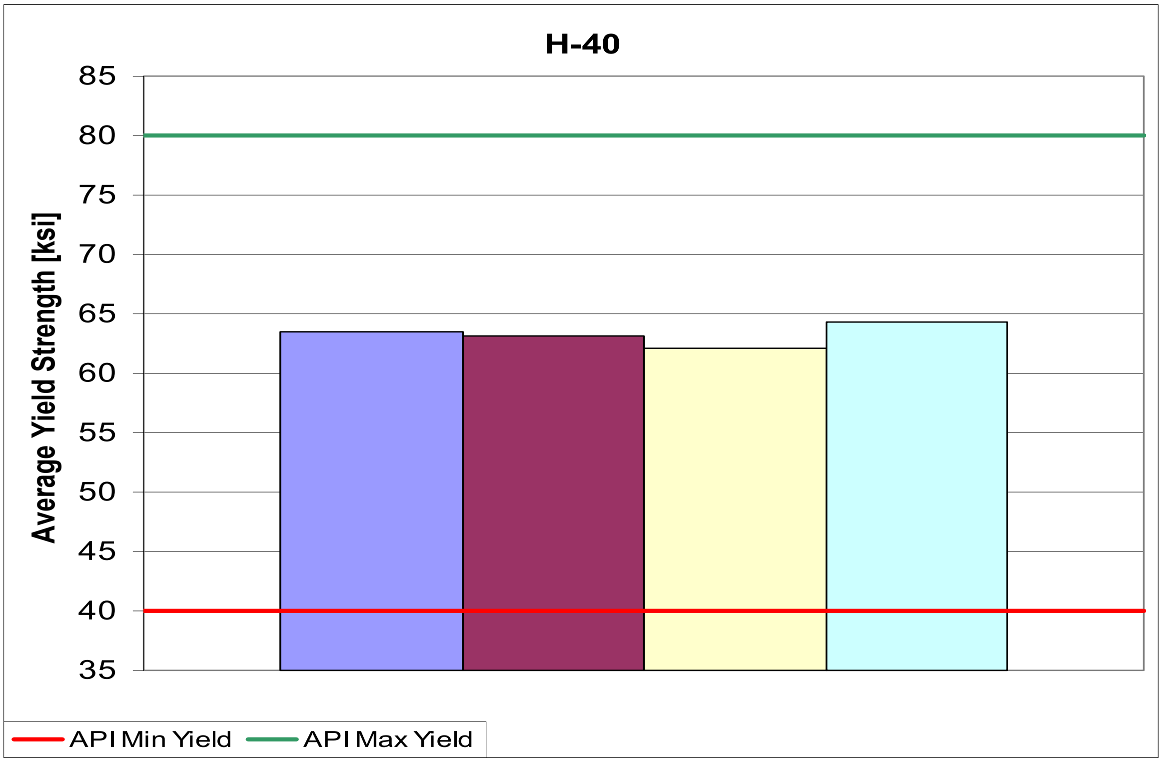
Two plots are presented. First is a bar chart where each bar represents one pipe. Pipes are segregated by manufacturer. Next is a bell-curve plot of the same data. The letter "A" represents all proprietary grades and is not any API grade.

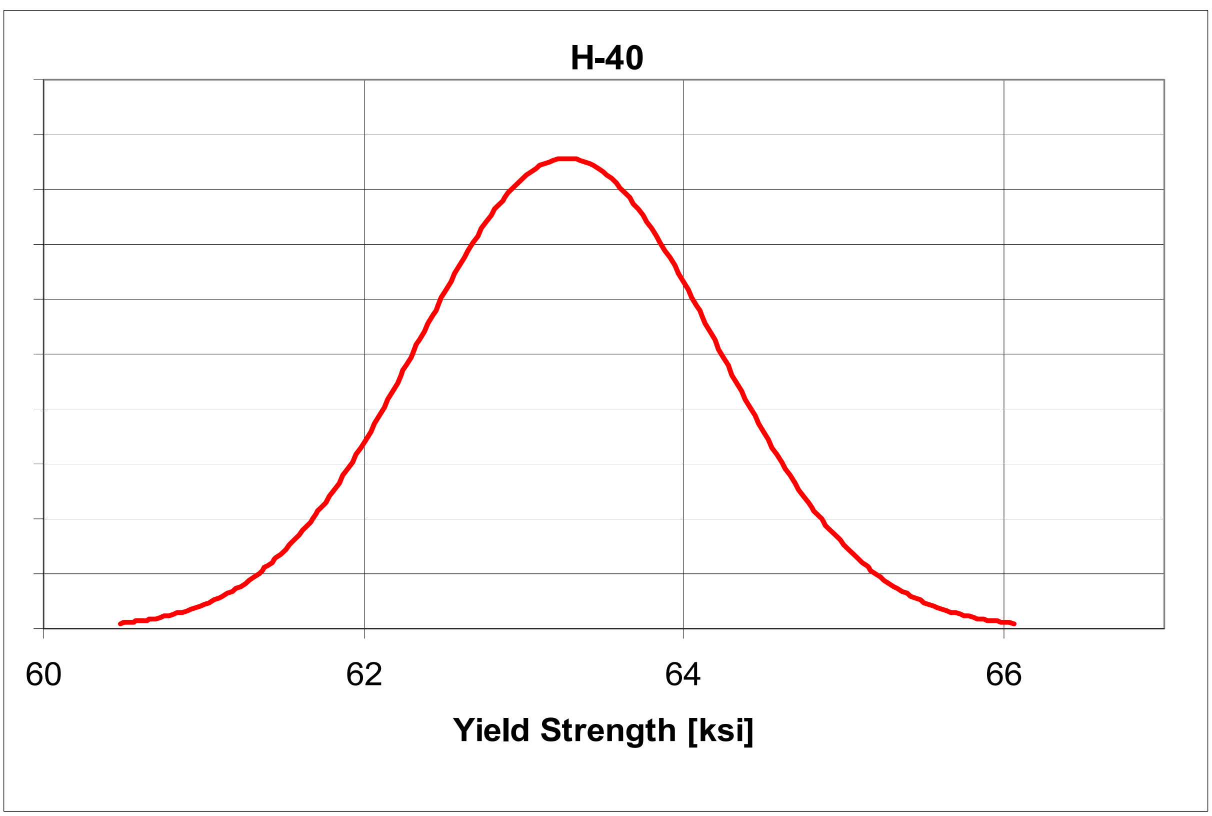


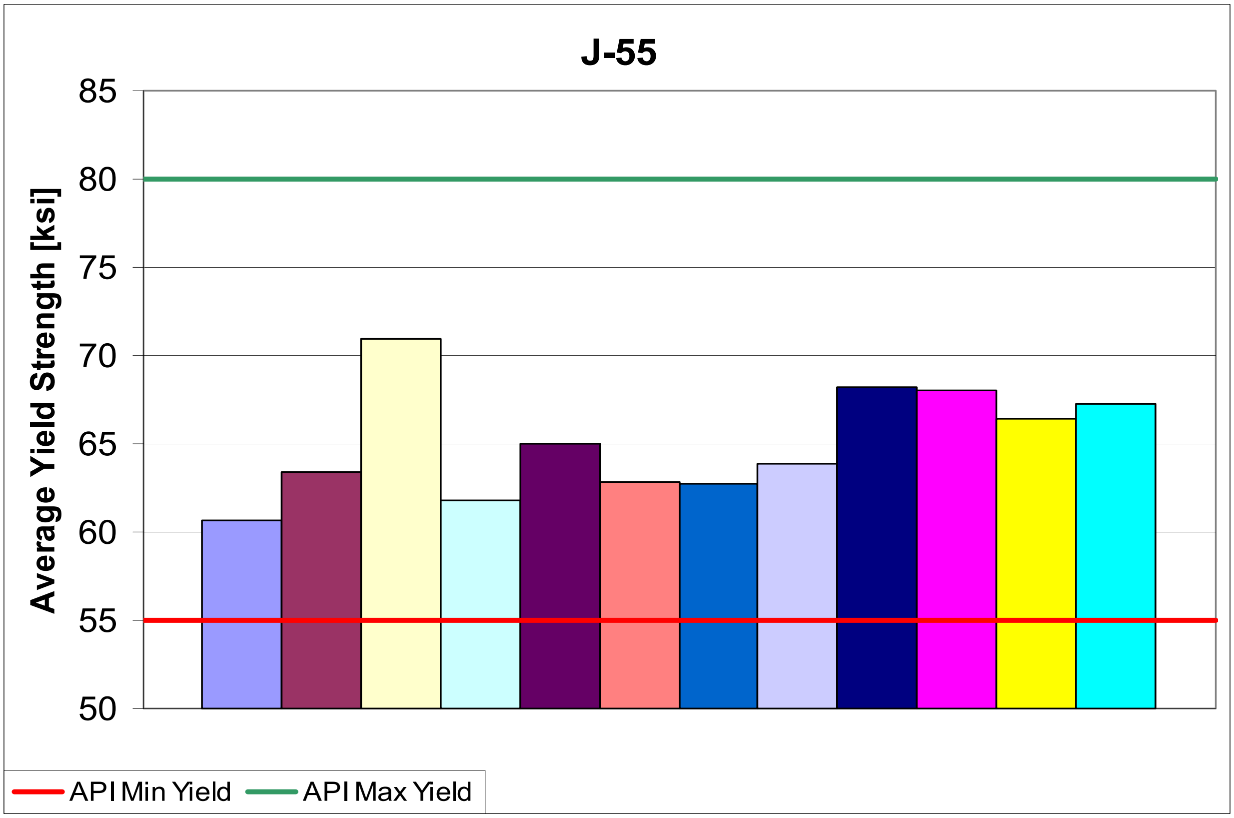


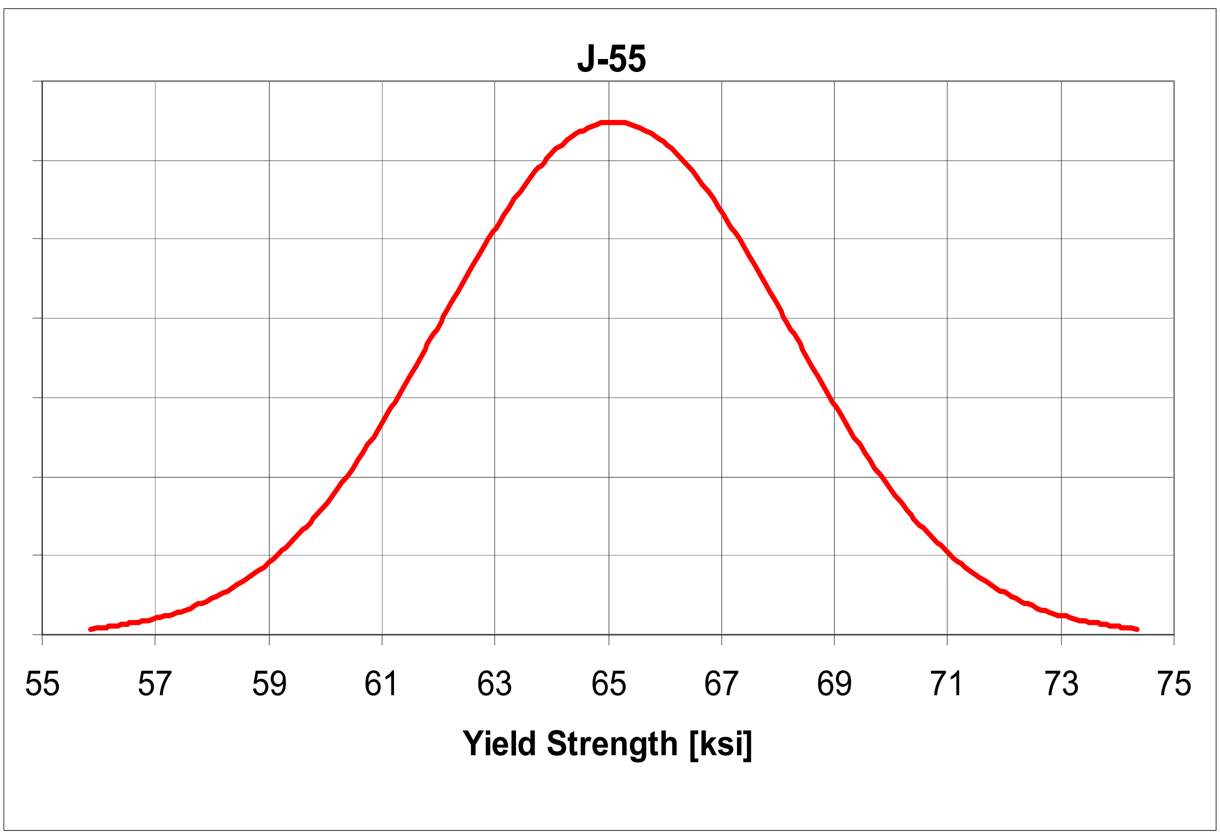

A-110
Average Yield Strength [ksi]
145
140
135
130
125
120
115
110
105
API Min Yield
API Max Yield

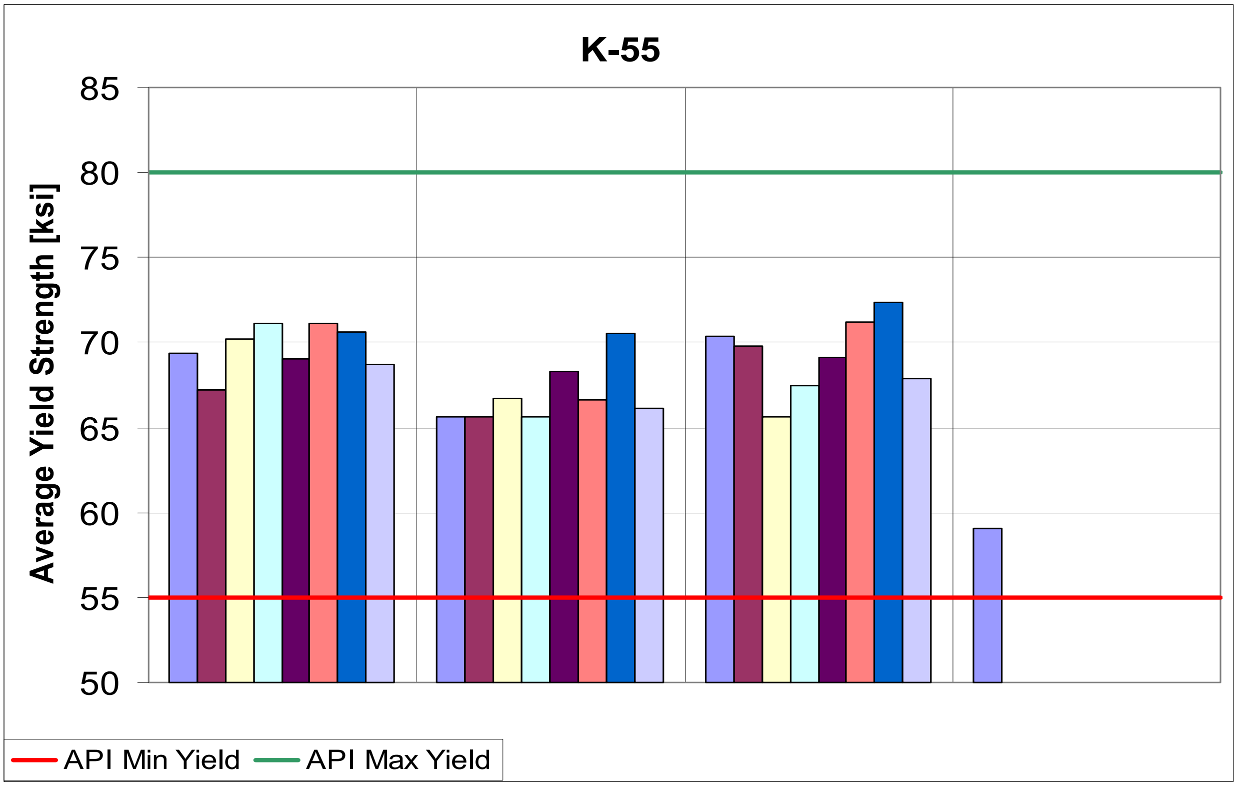

A-110
110
112
114
116
118
120
122
124
126
128
Yield Strength [ksi]

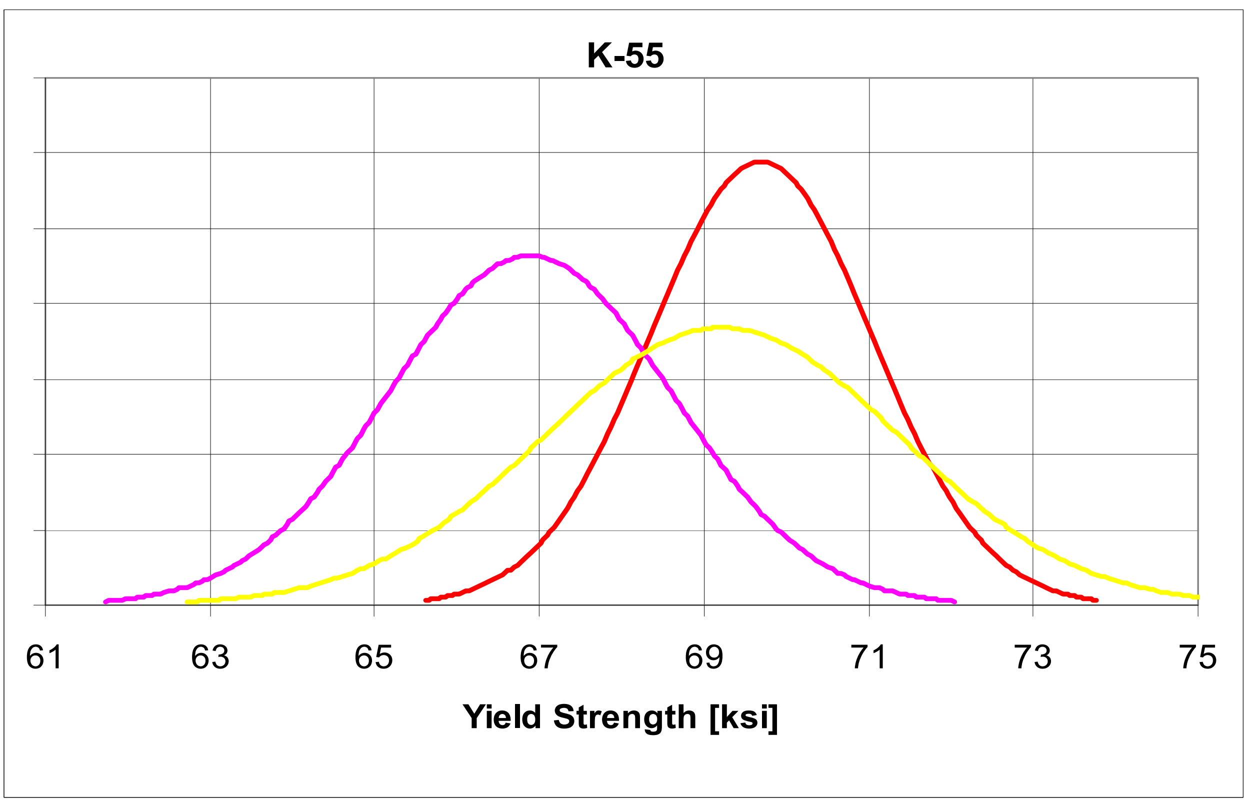

H-40
Average Yield Strength [ksi]
85
80
75
70
65
60
55
50
45
40
35
API Min Yield
API Max Yield

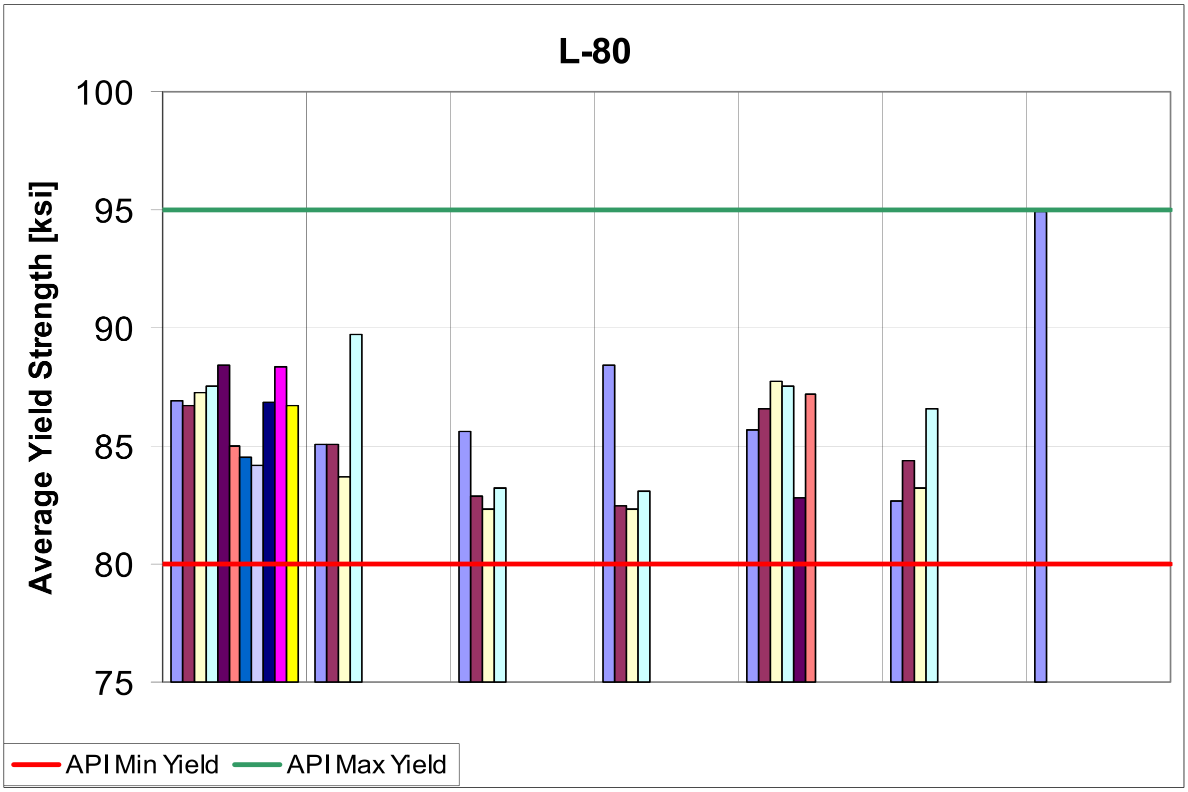

H-40
60
62
64
66
Yield Strength [ksi]

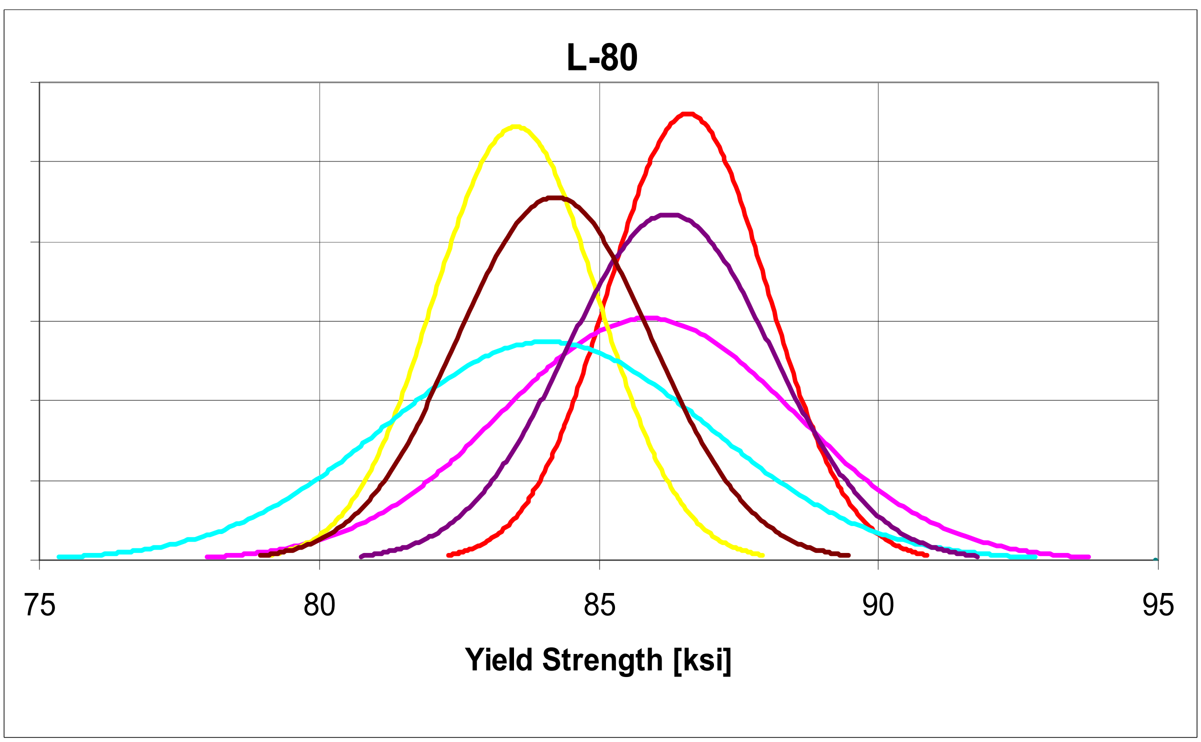

J-55
Average Yield Strength [ksi]
85
80
75
70
65
60
55
50
API Min Yield
API Max Yield

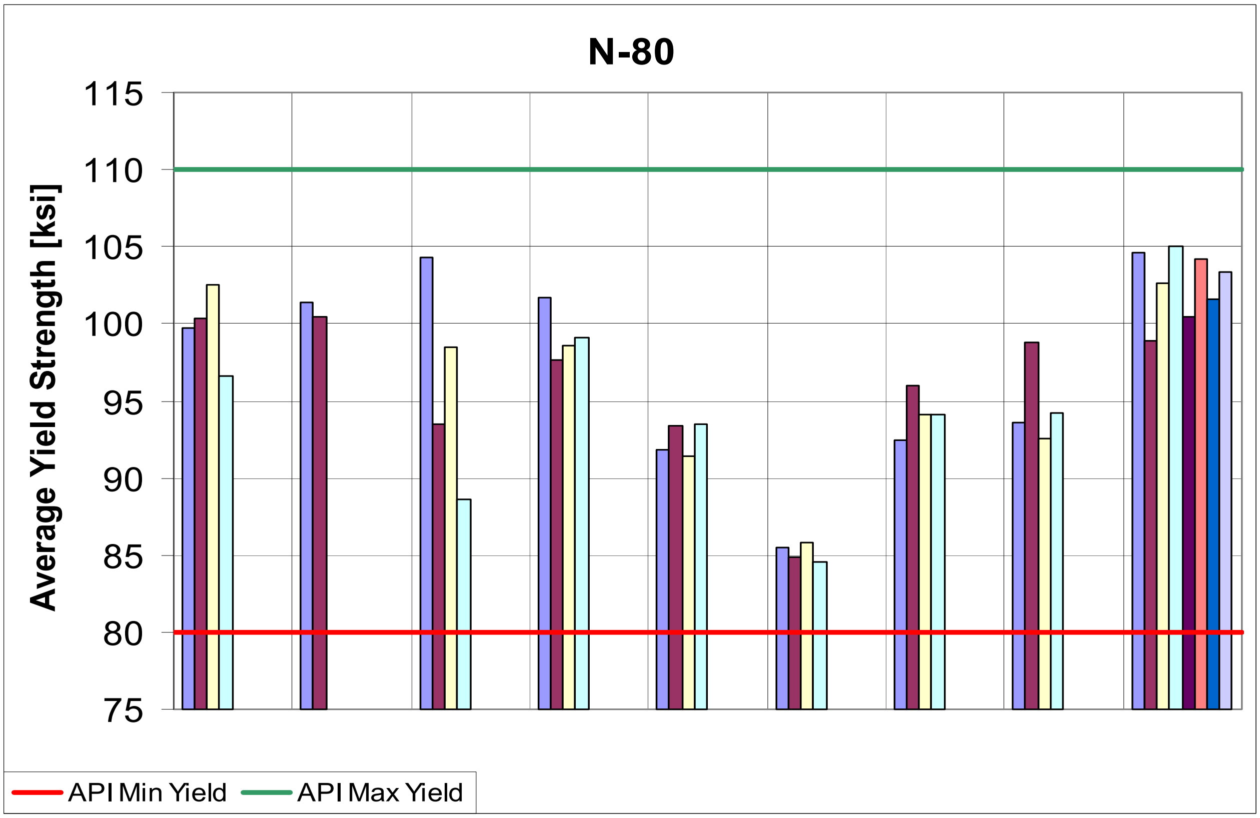

J-55
55
57
59
61
63
65
67
69
71
73
75
Yield Strength [ksi]

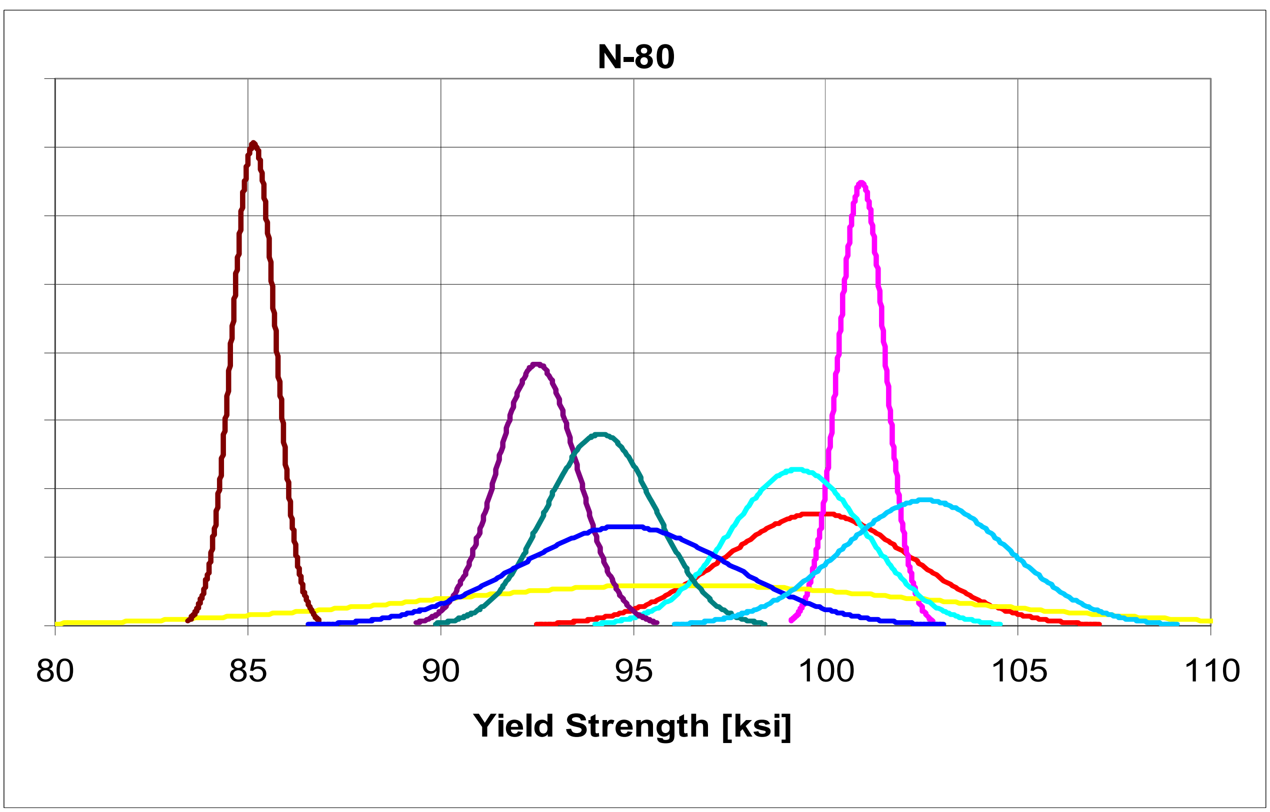

K-55
85
80
75
70
65
60
55
50
Average Yield Strength [ksi]
API Min Yield
API Max Yield

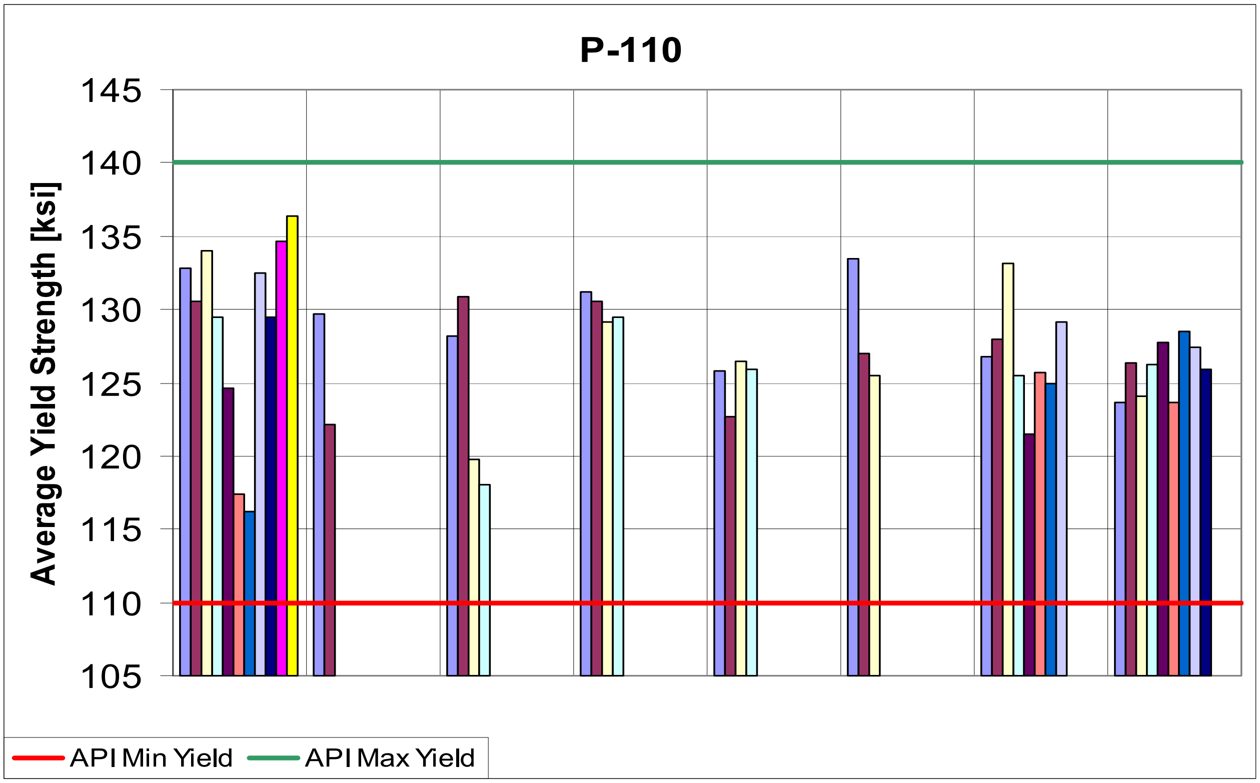

K-55
61
63
65
67
69
71
73
75
Yield Strength [ksi]

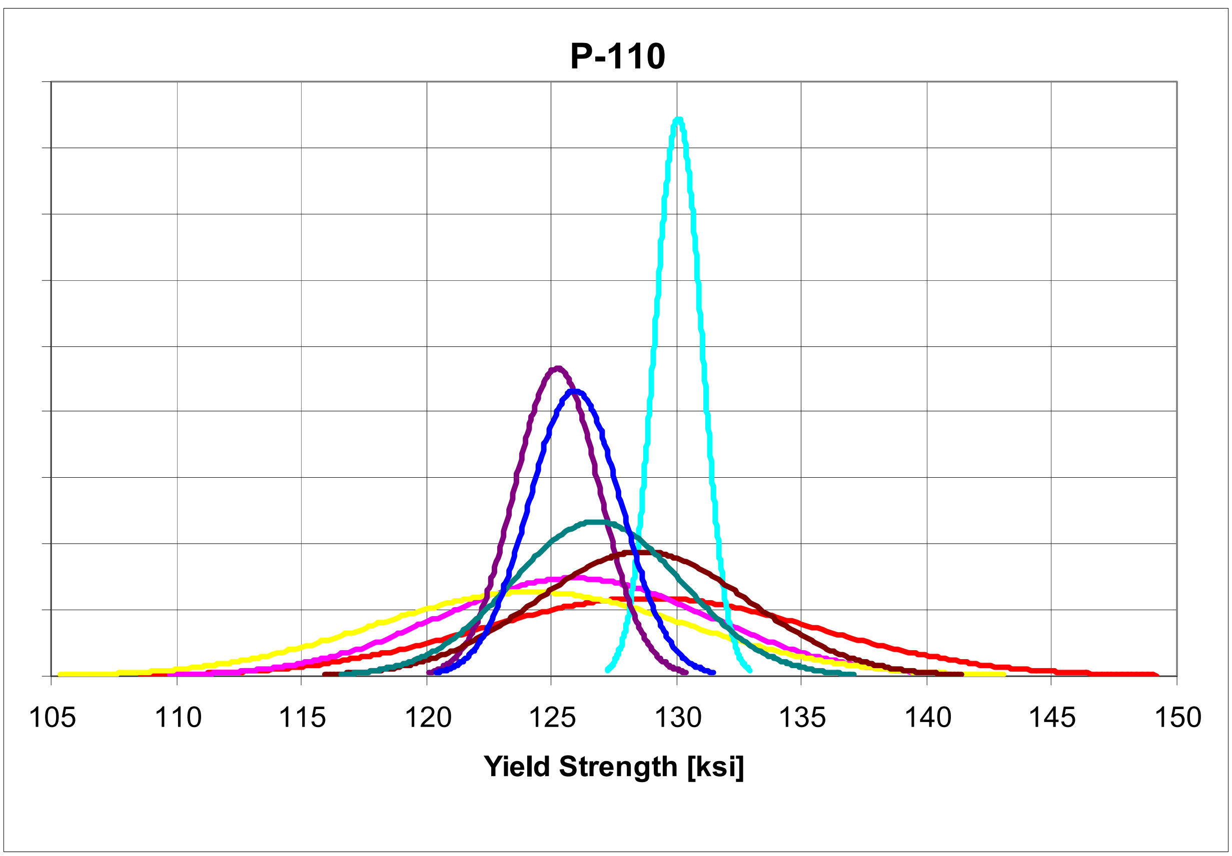

L-80
Average Yield Strength [ksi]
100
95
90
85
80
75
API Min Yield
API Max Yield

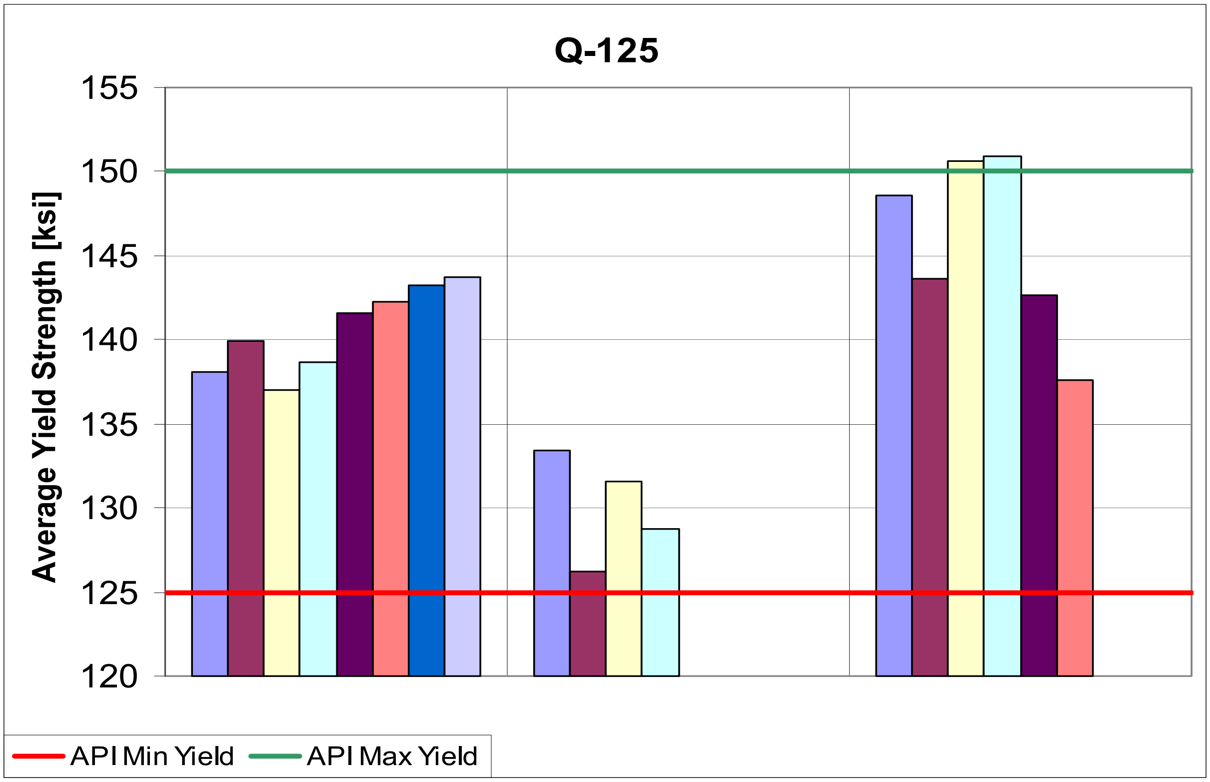

L-80
75
80
85
90
95
Yield Strength [ksi]

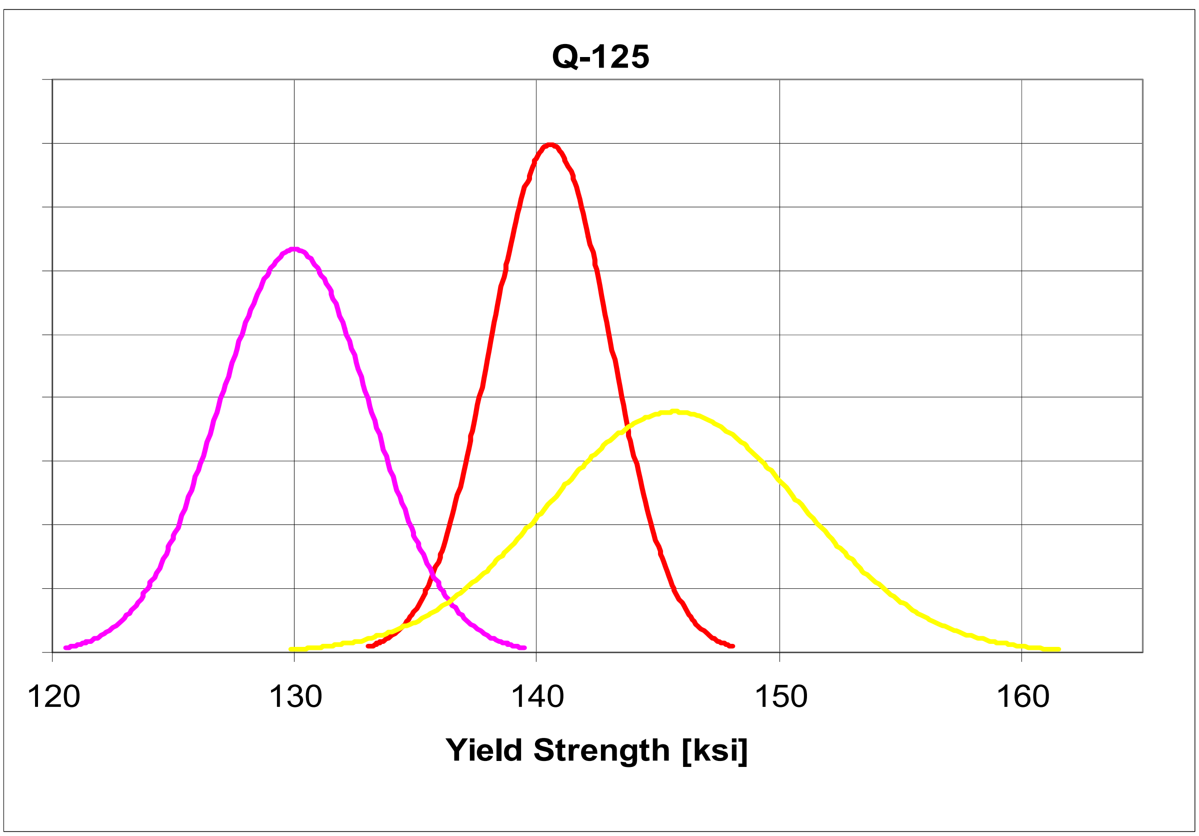

N-80
115
110
105
100
95
90
85
80
75
Average Yield Strength [ksi]
API Min Yield
API Max Yield


N-80
80
85
90
95
100
105
110
Yield Strength [ksi]


P-110
145
140
135
130
125
120
115
110
105
Average Yield Strength [ksi]
API Min Yield
API Max Yield


P-110
105
110
115
120
125
130
135
140
145
150
Yield Strength [ksi]


Q-125
155
150
145
140
135
130
125
120
Average Yield Strength [ksi]
API Min Yield
API Max Yield


Q-125
120
130
140
150
160
Yield Strength [ksi]

No average sample yield strength values were below the specified minimum value. One manufacturer had several average sample yield strengths that were above the API limit and these were for Q-125 grade. One L-80 average yield strength was at the maximum API limit of 95 ksi.

11.6 Sheet Ovality

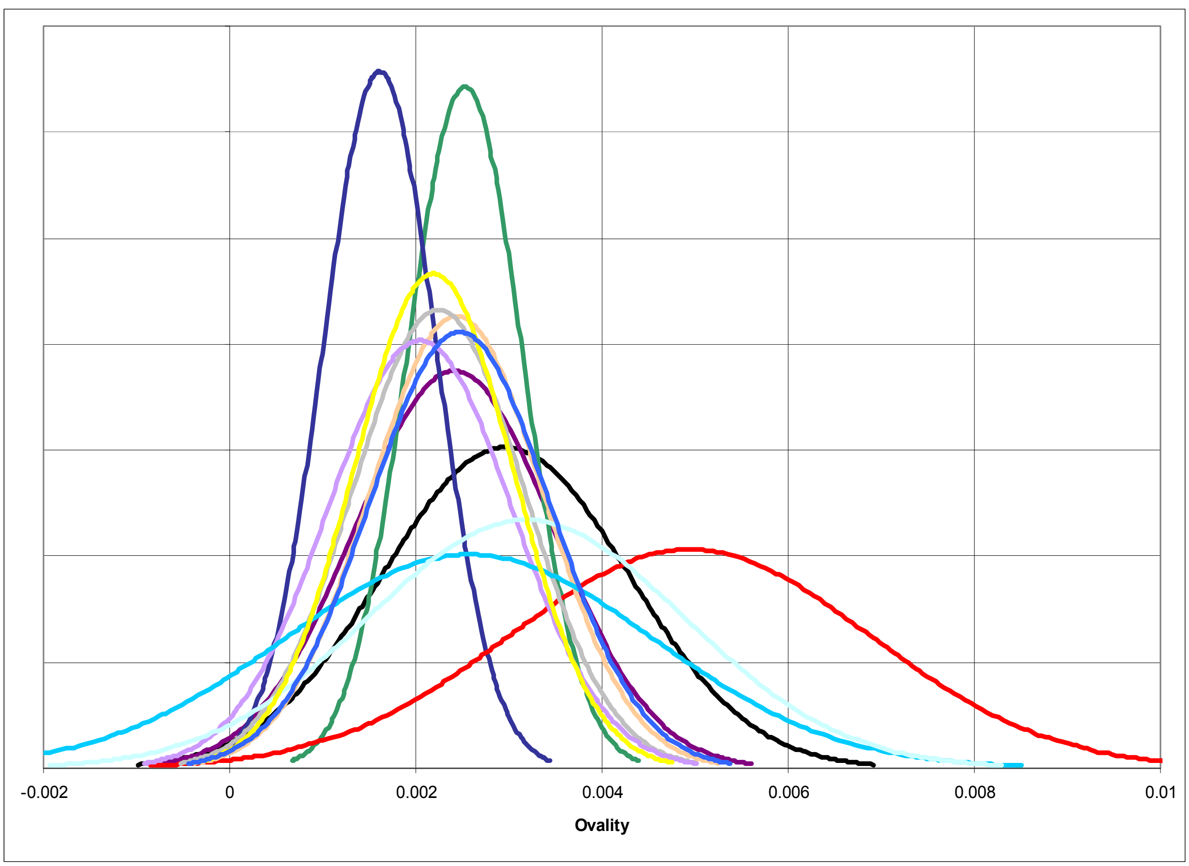
Ovality is not measured directly but rather calculated as:

$$o = \frac{\max OD - \min OD}{avgOD}$$

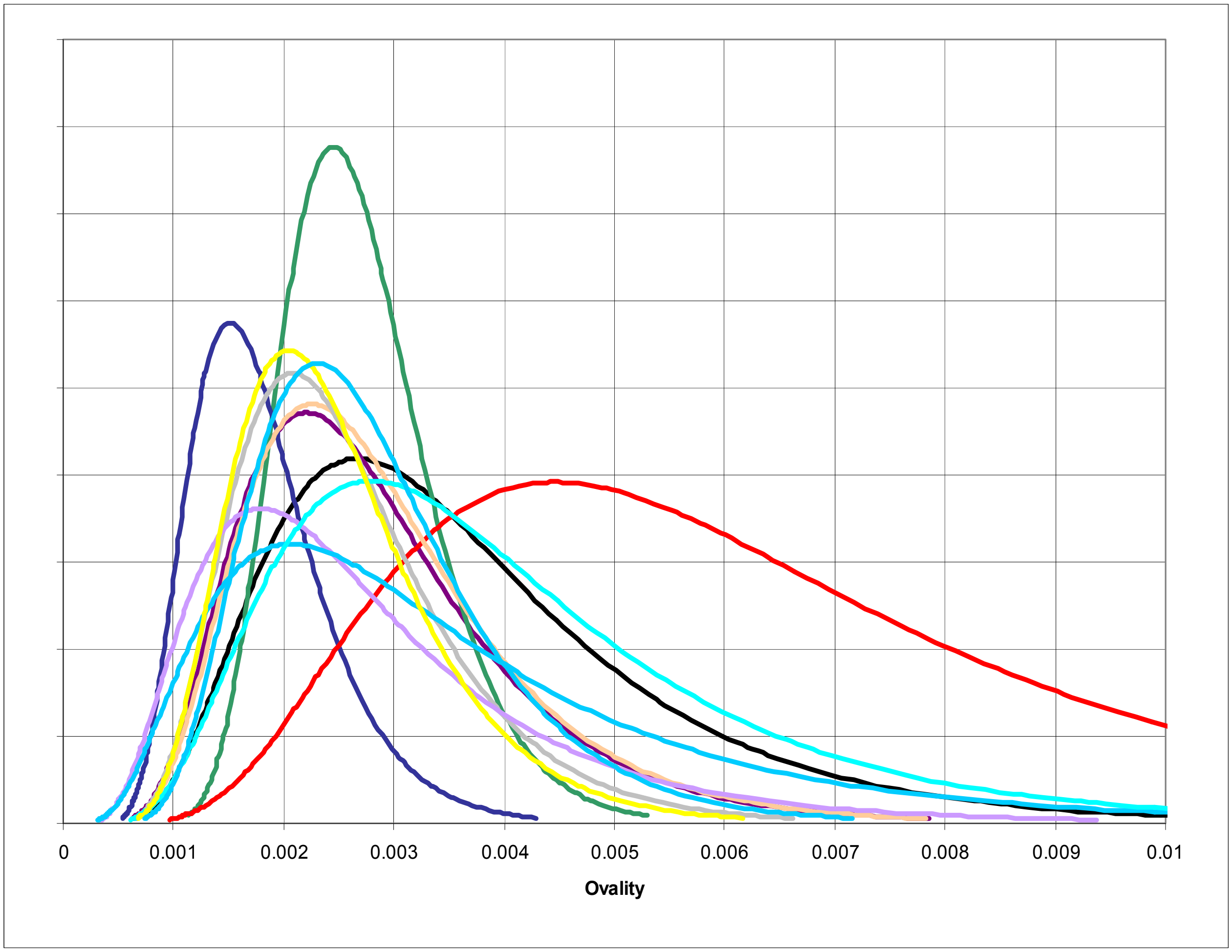
Ovality data is reported on Sheet Ovality this way. Often it is reported as percent, i.e.

$$o = \frac{\max OD - \min OD}{avgOD} * 100$$

There are 1,359 ovality values in the database.



Below is the same data presented assuming a Lognormal distribution.



The significance of these curves is that the peak represents the most probable occurrence of ovality. This data indicates that the manufacturer with the least amount of ovality is the dark blue plot and the manufacture with the greatest is the red plot (somewhat affected by the product, all red samples were cold sized). Of all the manufacturers, the green plot had the smallest standard deviation of ovality.

11.7 Sheet Ecc

Eccentricity is not measured directly but rather calculated as:

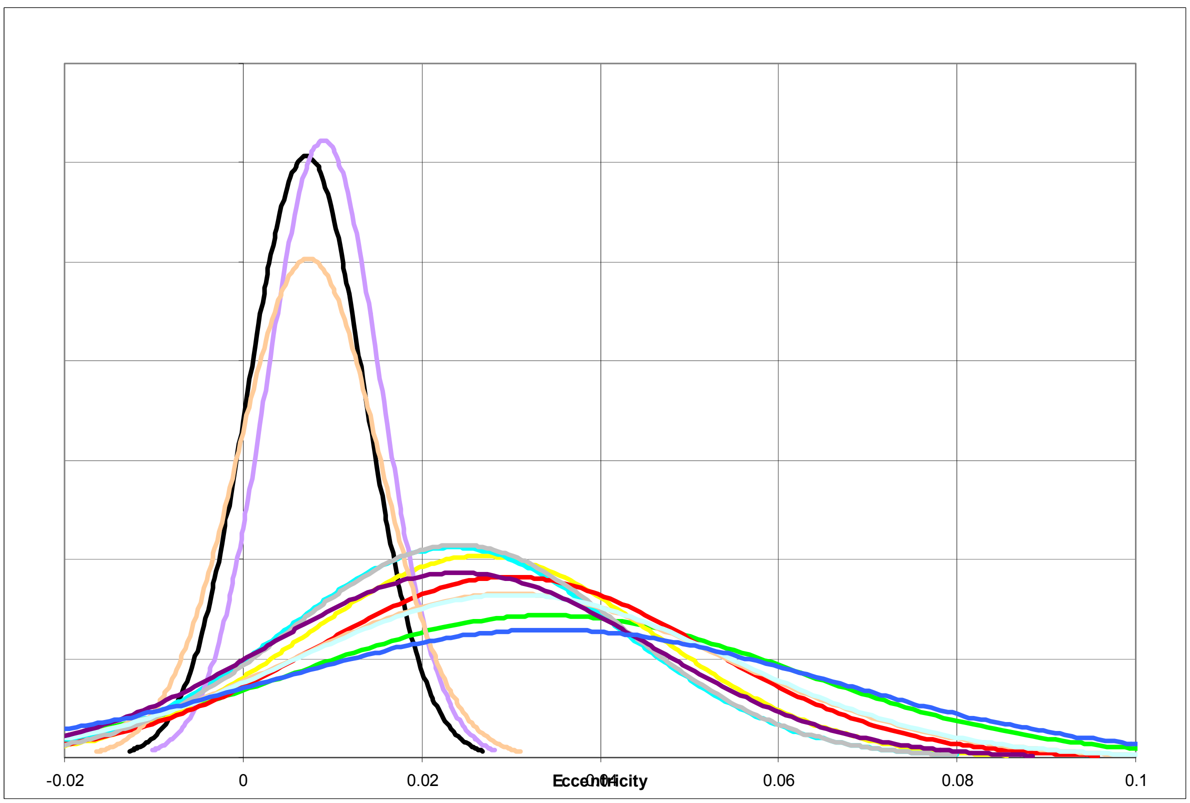
$$e = \frac{t\max - t\min}{tavg}$$

where t is wall thickness.

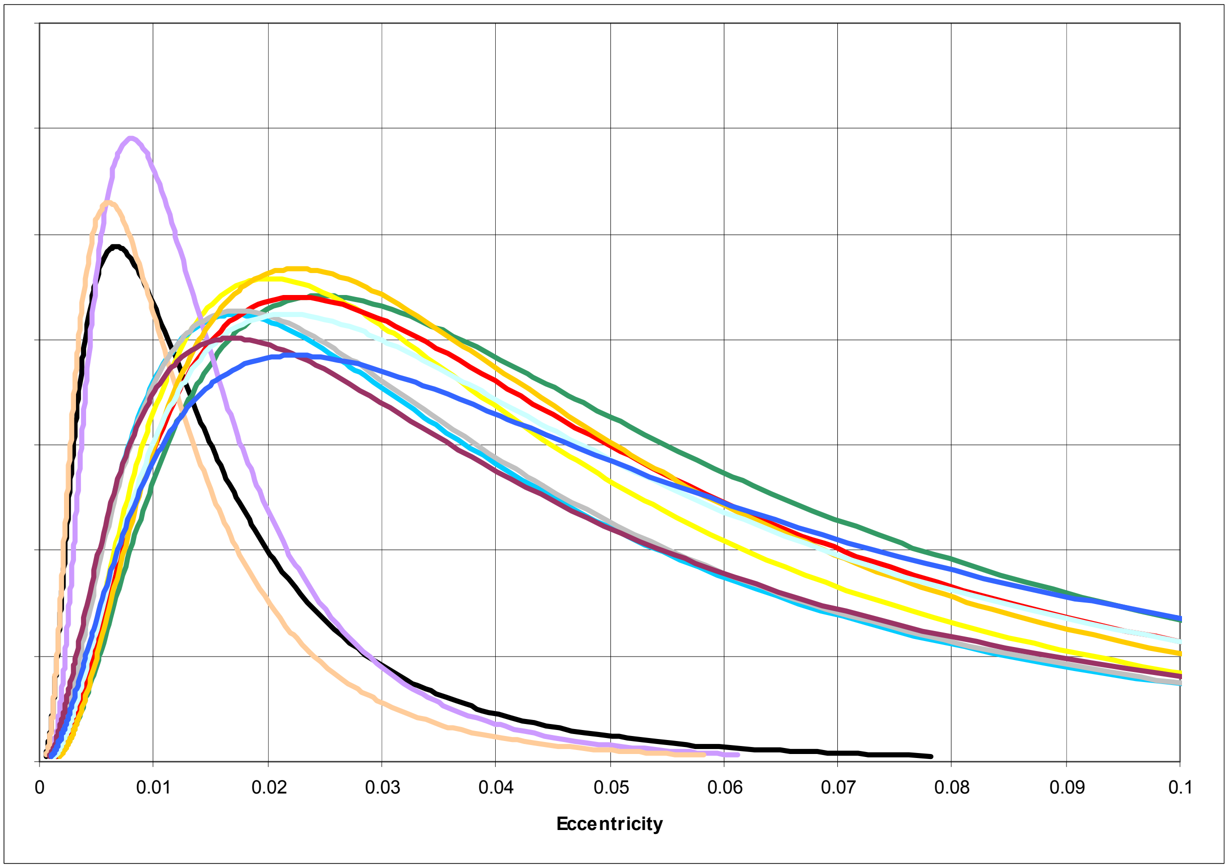
It is reported on Sheet Ecc this way. Often it is reported as percent, i.e.

$$e = \frac{t\max - t\min}{tavg} * 100$$

There are 5,436 eccentricity values in the database.



Below is the same data presented assuming a Lognormal distribution.



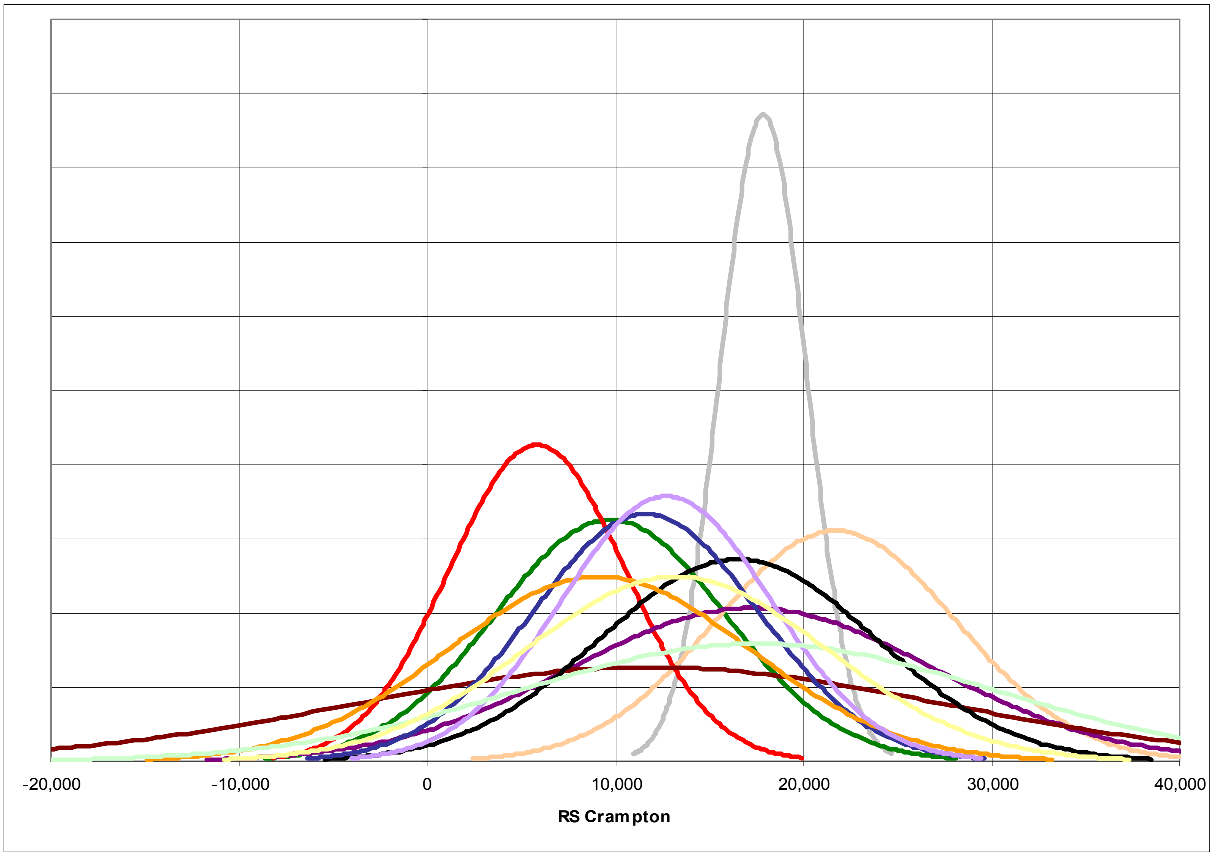
The welded pipe manufacturers had the smallest amount of eccentricity, plots brown, black and purple.

The seamless manufacturers all had about the same amount of eccentricity and about the same variance.

11.8 Sheet RS

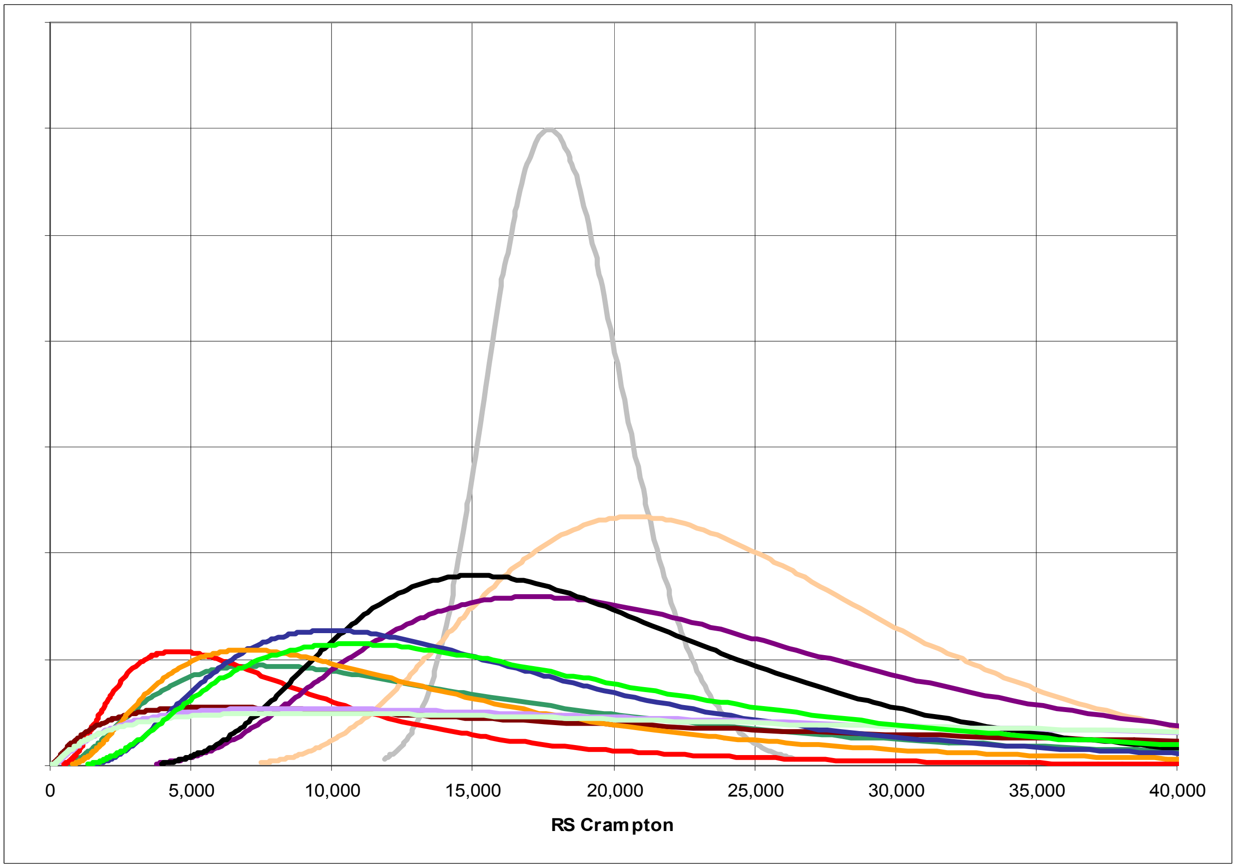
Two methods of residual stress were calculated as part of DEA-130. One was the Crampton method while the other was based on thin shell theory. The Crampton method was deemed most familiar and is the only one presented. It is reported in units of [psi].

Each of the 151 pipes that were collapse tested had a Crampton residual stress report.



Residual Stress can be either positive or negative, depending upon the process, heat treat and straightening. In this study, only two pipe samples had a negative residual stress (and both were small values). Therefore there could be an argument made for the case that Residual Stress is usually positive. This suggests using the assumption that the underlying population is Lognormally distributed.

All positive Residual Stress were used to create this presentation:



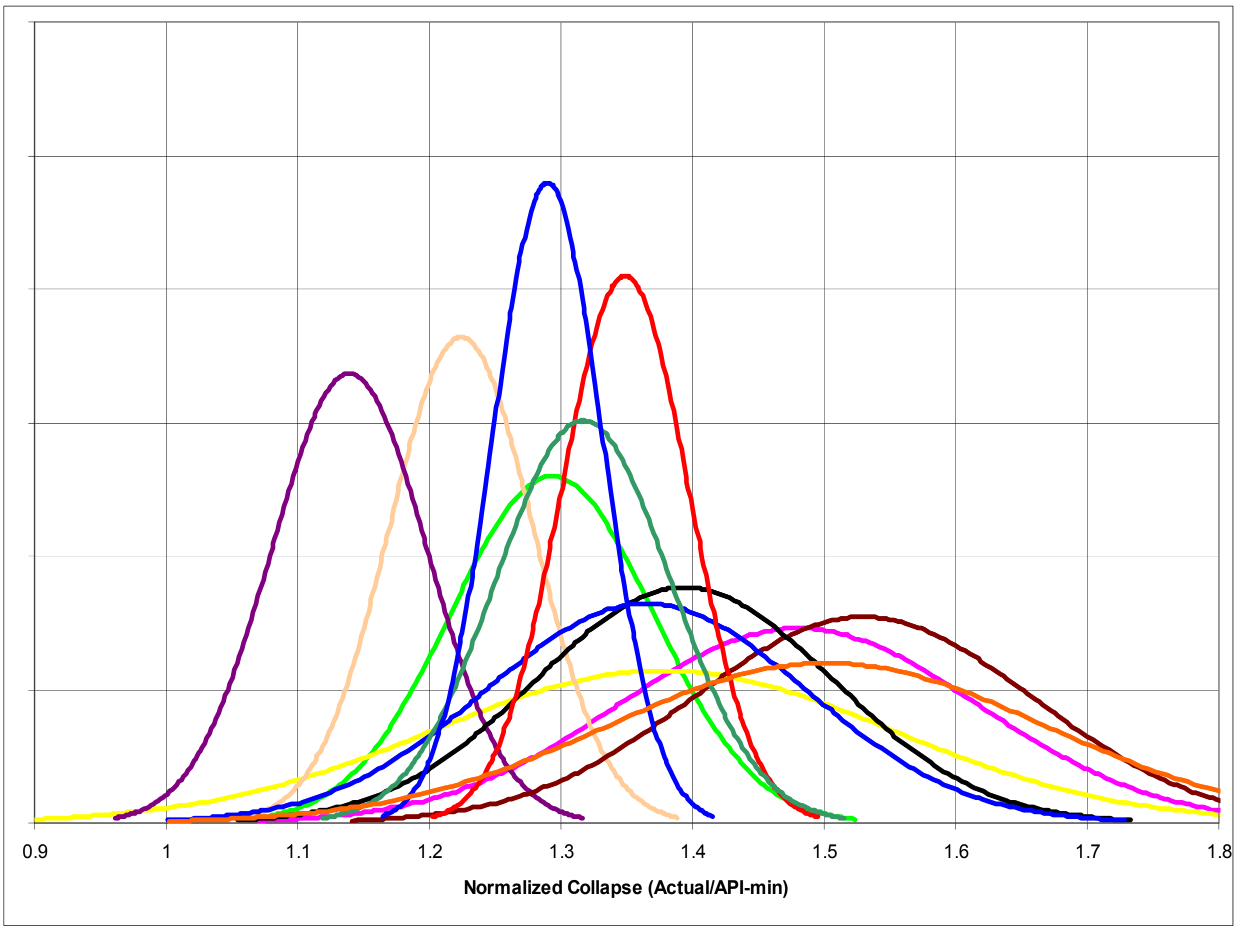
The brown plot had the largest average residual stress at approximately 22 ksi and also one of the largest variances of stress. The manufacturer with the smallest residual stress was the red plot. The light purple plot had the largest variance of residual stress. Residual stress is also dependent on hot vs cold straightening as shown in Section 9.4.4, page 65.

It is interesting to note that the gray plot clearly had the most consistent residual stress with an average of 17.5 ksi and a very small variance.

11.9 Sheet Collapse

Collapse values were normalized first against API "minimum" and then to API "average" values. Refer to API Bulletin 5C3 and section 8.2.7.3 of this report for details of the API minimum and average values.

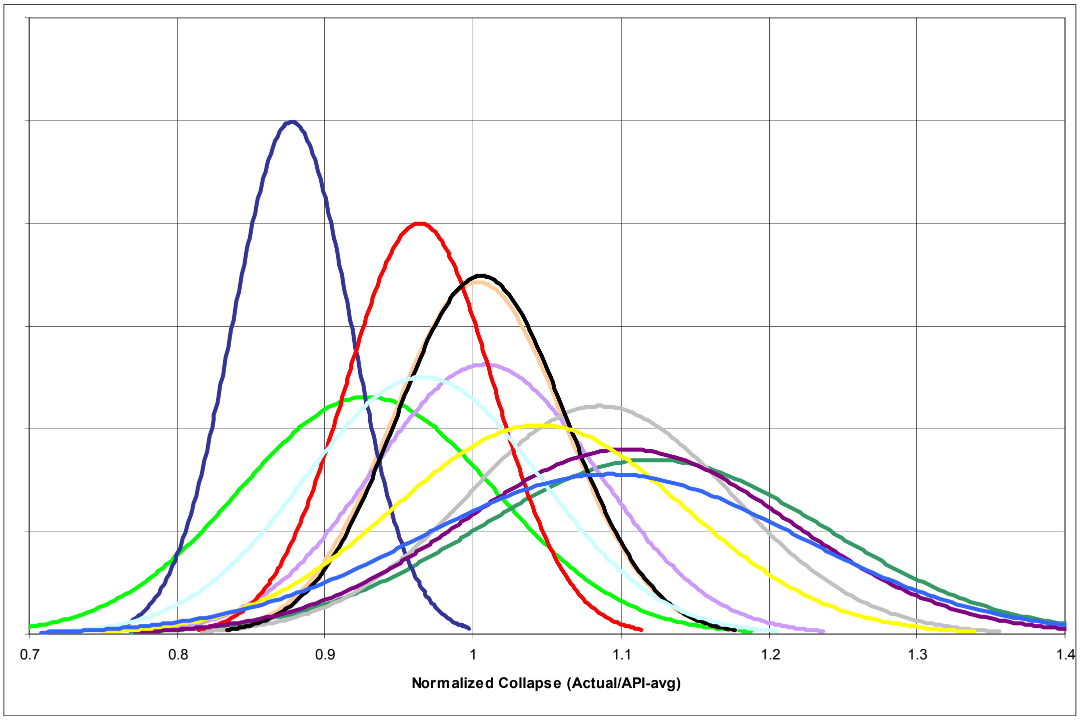
There was some pipe that did not fit nicely into API categories. For example there are some pipes reported with proprietary yield strength of 95/110. Every effort was made to find an appropriate yield strength value to use in the API calculations used for normalization.



API Minimum Collapse Pressure is the pressure listed in API Bulletin 5C2[12] and is the value typically used in the design of tubing and casing strings. Any collapse test pressure results below this API value would have serious problems. Fortunately, no test results were below this value.

The highest mean collapse resistance was the dark brown plot with the orange plot being the second highest. The purple plot had the lowest mean collapse pressures with the light brown having the second lowest.

In terms of range of collapse pressure, the yellow plot had the largest variance followed with the orange plot. The blue plot had the smallest variance with the red plot the second smallest.



API Average Collapse Pressure is the statistically average collapse pressure from the tests that the API Bulletin 5C2 pressures are based on. The values are not listed in any API documents but can be calculated from the equations given in API Bulletin 5C3. The API Average Collapse Pressure is basically the collapse pressure without a safety factor applied. The ratio between API Average and API Minimum is not constant with D/t.

On the high end, four manufacturers were in close agreement. The highest mean collapse resistance was the dark green plot with the dark purple plot being the second highest. The dark blue plot had the lowest mean collapse pressures with the light green plot having the second lowest.

In terms of variance of collapse pressure, the green, dark purple and blue plots had the largest variance and dark blue the smallest variance with the red plot having the next smallest.

Because of relatively small sampling, these observations may be indicative of more general behaviors but should be confirmed when necessary for important design decisions.

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3. **Casing Setting Depths Are Not Assured by Physical Properties of the Steel**, W.M. Frame, Drilling and Production Practice API, 1939

4. **Standard Practice for Estimating the Approximate Residual Circumferential Stress in Straight Thin-Walled Tubing**, ASTM, E 1928-98

5. **Effect of Measurement Procedures on Estimating Geometrical Parameters of Pipes,** Andrea P. Assanelli, SPE, FUDETEC; and Gustavo Lopez Turconi, SIDERCA

6. **Bulletin on Formulas and Calculations for Casing, Tubing, Drill Pipe, and Line Pipe Properties**, API Bulletin 5C3

7. **A New Empirical Formula for Collapse Resistance of Commercial Casing,** Toshitaka Tamano, Toshitaro Mimaki, Samon Yanagimoto, Nippon Steel Technical Report No. 26 July 1985, UDC 622.276: 621.643: 620.173

8. **Collapse: Trial Calibration (3)**, report prepared by Amerada Hess for API/ISO TC67/SC5/WG2b, October 2000

9. **Collapse: Effect of Stress-Strain Curve Shape**, report prepared by Amerada Hess for API/ISO TC67/SC5/WG2b, September 1999

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12. **Bulletin on Performance Properties of Casing, Tubing and Drill Pipe**, API Bulletin 5C2