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Suppression System Piping

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ALLOWABLE STRESSES FOR USE IN DYNAMIC ANALYSIS OF PF-4 FIRE SUPPRESSION SYSTEM PIPING

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1 INTRODUCTION

1.1 Purpose

The purpose of this paper is to present the results of a limited test program performed on samples of fittings removed from the PF-4 fire suppression system and to present recommendations for allowable stresses to be used in subsequent piping analysis.

1.2 Background

The SAFER project was initiated around 2009 after the Update of the Probabilistic Seismic Hazard Analysis³ (PSHA) of the Los Alamos National Laboratory was published as final. The results of the PSHA indicated that the seismic hazard at the laboratory was greater than previously thought. Soon after the PSHA was accepted, the laboratory began a focused and intensive study (SAFER) whose objective was to determine if engineered systems important to safety would continue to perform their safety functions at the higher seismic demand. The safety systems within PF-4 were naturally set at a high priority.

As part of the SAFER project ARES Corporation was contracted to perform walkdown evaluations and seismic calculations on the PF-4 fire suppression system (FSS). Results of the initial walkdowns indicated that the FSS required strengthening through the addition of braces to function at seismic Performance Category 3 (PC3) levels. ARES subsequently designed upgrades to the piping. The results of the design verification are documented in ARES Calculations 054801.09-31-S-001, R1, Piping Analysis for PC-3 Seismic Upgrades to PF-4 Mezzanine Fire Suppression, and 054801.09-31-S-002, Piping Analysis for PC-3 Seismic Upgrades to PF-4 Basement Fire Suppression System.

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³ Wong, I., Dober, M., Silva, W., Darragh, B., and Gregor, N., Update of the Probabilistic Seismic Hazard Analysis and Development of CMRR Design Ground Motions, Los Alamos National Laboratory, New Mexico, for Los Alamos National Laboratory, 4 December, 2009.

One of the assumptions made in the design verification analysis was that the fittings used in the piping systems were made of carbon steel (ASTM A120). This steel was allowed to be used in NFPA compliant fire suppression piping systems. However, the NFPA code also permits the use of both cast iron and malleable iron fittings. An investigation was initiated to determine the specific material used in the fittings primarily due to ongoing uncertainties. A submittal from 1976⁴ indicates Cast Iron Fittings from Kuhns or Equivalent were allowed to be used in the fire protection piping inside of the building. In addition, a previous metallographic analysis performed on an elbow used in the fire protection system indicates it was made of “grey cast iron”⁵

Because these data strongly indicate that the fittings in the PF-4 fire suppression system are composed of cast iron and not carbon steel (ASTM A120) we reviewed the subject ARES calculations to determine the percentage of fittings that would fail code acceptance stress criteria if the allowable material stresses were reduced to that of cast iron

The specific Autopipe models referenced in those calculations were obtained and are summarized below:

1. PF-4_Mezzanine Piping 1 Revised Rods Removed (054801.09.30-S-001, PF-4 FSS & Ceiling Seismic, Mezzanine Fire Protection Piping.
2. Fire_Protection Model Base-1, Rods Removed (054801.09.31-S-002 .1: Basement Fire Protection Piping Stress Analysis.
3. Fire_Protection Model Base-2, Rods Removed (054801.09.31-S-002 .2: Basement Fire Protection Piping Stress Analysis.
4. Fire_Protection Model Base-2, Rods Removed (054801.09.31-S-002 .3: Basement Fire Protection Piping Stress Analysis.

Three separate models were developed for the basement. Each model represented a different portion of the basement. ARES developed only one model for the laboratory space.

The stress results for the elbows and tees in each of the computer runs above were extracted from the code compliance section of the computer output. The code compliance section of Autopipe lists the controlling load combination, and the code stress and code allowable. We then computed the code demand to capacity ratio using the following:

⁴ Descriptive Submittal Review and Transmittal, J1-0130 Package, from Wallace/Brown-Olds/Howard J.V., “Sprinkler Drawings, Generator Building, Control Room, Vaults, and PU Building Basement. Hydraulic Calculations, Materials List and Certification (See p. 47 of 230)

⁵ LANL Memorandum from Dr. James C. Foley to Stuart McKernan, MST-6: 12-032, “Examination of Failed Cast Elbow,” February 14, 2012.

$$D/C = \frac{D}{2.4S_h}$$

Where:

D is the reported stress at temperature for the controlling load case given in the Autopipe Analysis, S_h is the allowable stress for the material at temperature (ASME B31E, eqn. 3.4). The factor 2.4 is allowed in ASME B31E. S_h is 10% of ultimate stress for cast iron materials per ASME B31. Note that EPRI 1019199 suggests the use of 20% allowable stress in resolving outlier resolutions, which is consistent with the ASME allowable of $2.4 \times (0.10 \times S_u)$ for cast iron material. The allowable stresses for grey cast iron are given in either Table of A-5 ASME B31.1, or Table A-1 of ASME B31.3. It was never confirmed what grade of materials were used for the fittings in the Fire Suppression System. Because of the uncertainty regarding the material used for the fittings, a limited sampling program was done on fittings from the Fire Suppression System. This report presents the results of that program.

1.3 Scope

This report summarizes the uniaxial tensile tests that were done on a number of fittings removed from the TA-55 PF-4 fire suppression piping system (See reference pictures A-C). The results of this report may be applied to fittings within that system, that were installed at about the same time, and for which no more recent data exist. This report is not applicable to other fittings at TA-55 or at other locations within the Los Alamos National Laboratory.

1.4 Plan of Development

This report is divided in to four (4) main sections. Section 1 is the introduction, and provides a purpose, background and scope. Section 2 presents the methodology. Section 3 presents results, and Section 4 presents recommendations and conclusions. The allowable stress to be used in the dynamic analysis of the fittings is given in Section 4.

2 Methodology

The tensile strength methodology presented in ASTM E-8⁶ was followed in determining the ultimate strength and stress-strain properties of the material found in fittings in PF-4. Samples were machined from fittings that had been removed from service. The samples were machined to the specimen size shown in Figure 1.

⁶ ASTM E 8-04, "Standard Test Methods for Tension Testing of Metallic Materials," Current Edition approved April 1, 2004, ASTM International, West Conshohocken, PA

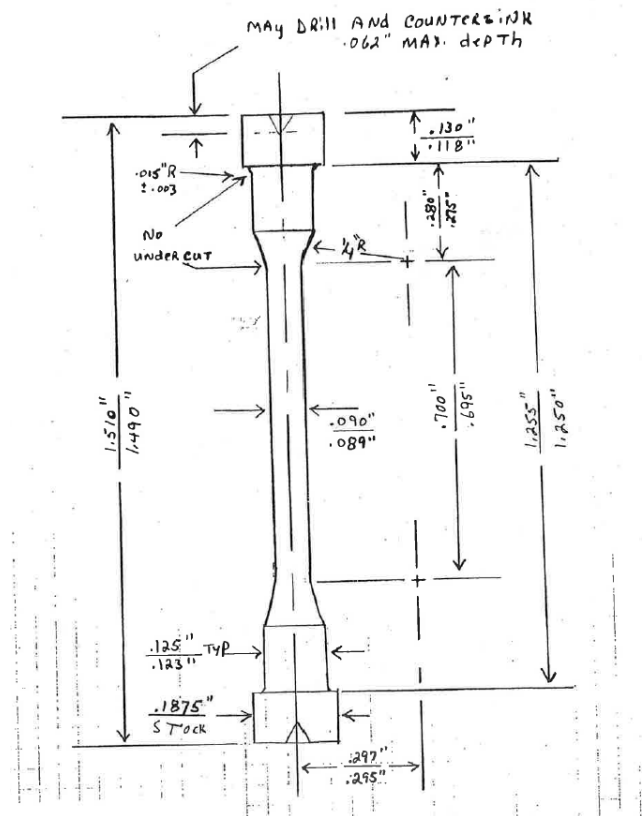


Figure 1 - Round Tensile Specimen
(Tolerances as Indicated)

2.1 Samples

Eight fittings were removed from service from the existing fire suppression system on Monday June 23⁷. Samples for tensile testing were machined from the fittings. The fittings consisted of four 1 inch diameter tee fittings and four 1 inch to ½ inch reducing elbows. Small diameter tensile specimens were extracted for subsequent tensile testing from each of the tees (See reference pictures A-C). Table 1 below shows the number of samples extracted from each tee.

Table 1 - Number of Samples for Tensile Testing

Tee	Number of Samples	Sample Id's
A	5	CIA1-CIA5
B	5	CIB1 – CIB5
C	4	CIC1-CIC-4
D	1	CID-1

⁷ Email from Chuck Tesch to Michael Salmon, Su: Re: elbows for testing?, 5/24/2015.

Tests were run on selected samples that were chosen to represent different lots of cast components. All samples were tested at room temperature. Each sample was loaded into the test fixture and a small preload of 25-50 N was applied to seat the sample and take out any slack in the system.

Because the material was considered to be brittle in nature it was assumed that there would be little ductile deformation and data acquisition was conducted at a rate of 20 points per second generating around 600 points for the typical test.

2.2 Mechanical Test Configuration

All tests were conducted in a low-strain-rate tensile configuration at a true strain rate of $0.001s^{-1}$. The tensile tests were conducted with an MTS model 880 test frame. In addition to the installed load cell an LVDT transducer additional load measuring device was used. A 1000 lb capacity load cell was used to make sure the most accurate measure of the load was made. Additionally, a $\frac{1}{2}$ " clip on extensometer was attached to the sample to measure the local strain on the sample. The control channel of these tests used the LVDT signal. The samples were loaded up to failure and the data was analyzed in True Stress/True Strain as well as Engineering Stress/Engineering Strain. In general the samples had a gage length of about 15.3 mm and a gage diameter of 2.15 mm. The data was analyzed from the 1000 lb load cell and the LVDT signal to capture the deformation across the entire gage length and to account for any deformation that occurred outside the extensometer gage length. It has been determined from previous work that the 100kN load cell can drift during this type of testing so all analysis was done using the 1000 lb data. The benefit to using this extensometer is that it eliminates system compliance and hysteresis determined to be small because of the low loads involved in the testing. Tests were conducted at room temperature (22°C).

The diameter of the sample was measured in three places along its length and the diameter closest to the failure point was used as the gage diameter for the data analysis. Stress and strain were calculated using the common equations. Data files were generated that collected time (s), LVDT displacement (mm), extensometer displacement (mm), Load (100 kN), and load (4.5kN). Each file was given a unique name that tied it back to the parent part that it was taken

from as well as the test temperature and strain rate of the test. Appendix 1 is a table of the file names with associated information about test conditions and special notes including the location of failure and sample dimensions as measured. In addition to the “raw” data files were generated that analyzed the stress strain response of each sample. Summary plots of the test results are presented later in this report.

2.3 Data Analysis

2.3.1 Stress-Strain Behavior

The stress strain behavior and the stress at ultimate strength were measured for each of the samples tested. The following equations were used to calculate the stress/strain response of each sample using the measured values for gage length and gage diameter. The gage diameter was measured prior to test at the top, bottom, and center of each sample. The gage diameter closes to the failure plane was used in determining the engineering stress at rupture.

Engineering strain was computed using the displacement data and the following equation:

$$\varepsilon^{eng} = \frac{l_f - l_0}{l_0} = \frac{\delta}{l_0} \quad (\text{eqn. 1})$$

True strain using the following:

$$\varepsilon^{true} = \ln\left(\frac{l_f}{l_0}\right) = \ln\left(\frac{\delta + l_0}{l_0}\right) \quad (\text{eqn. 2})$$

Engineering stress, assuming conservation of volume:

$$\sigma^{eng} = \frac{\text{Axial Load}}{\text{Area}} = \frac{\text{Axial Load}}{\pi d^2 / 4} \quad (\text{eqn. 3})$$

True stress:

$$\sigma^{true} = \sigma^{eng} \cdot (1 + \varepsilon^{eng}) \quad (\text{eqn. 4})$$

2.3.2 Ultimate Strength

The ultimate strength for each of the tests was measured as the computed engineering stress at the time of rupture.

3 Results

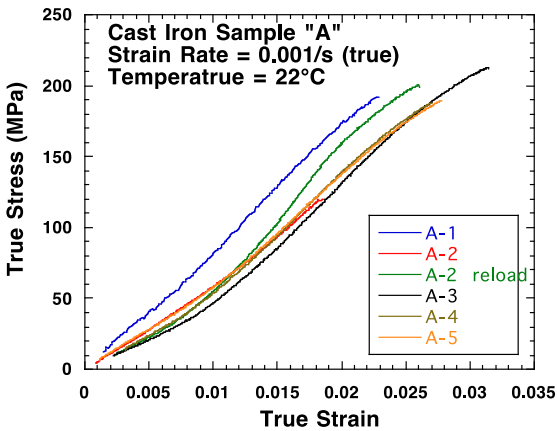
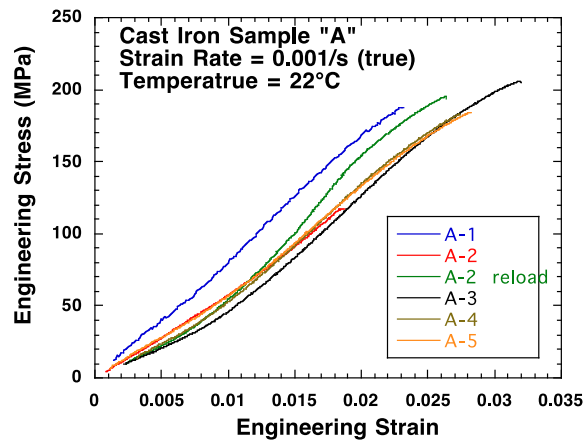
3.1 Stress-Strain Results

The initial test data was analyzed to calculate the Stress-Strain Response for each test. The test information that was used in the data analysis was the time, LVDT displacement, and load from the small load cell. The first step in the analysis was to shift the data such that the “visually” determined modulus goes through the zero-zero axis for load and displacement. Then the above equations were used to calculate the necessary parameters. The plots below are a summary of the calculated stress and strain. There were two additional files that were generated during the analysis. A file that calculates the engineering stress-engineering strain and a file for true stress-true strain. The attached appendix is a list of all the files that were stored during the testing or generated during the analysis. The file that has an “_eng.txt” will be the engineering stress-engineering strain calculation and the file that has an ending of “_S.txt” will be the calculations of true stress-true strain for each material. Again note that the calculations involves a data shift for all cases and recalculates the time assuming that time zero is the beginning of the test.

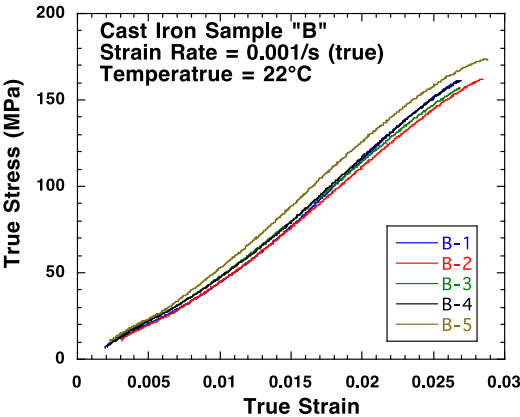
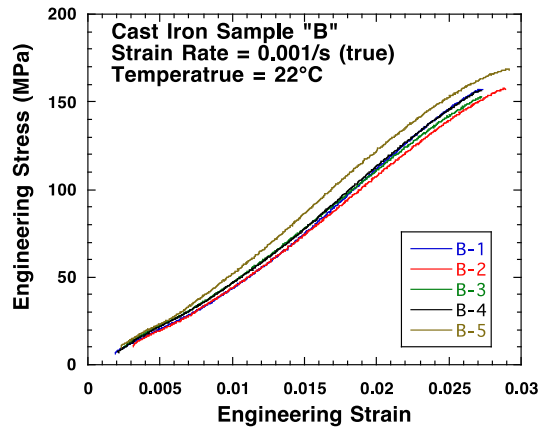
The resulting stress-strain curves are shown in the following figures. Each figure shows the stress strain curve, followed by photographs of the tees and the failed specimens from each of the tees.

Plots:

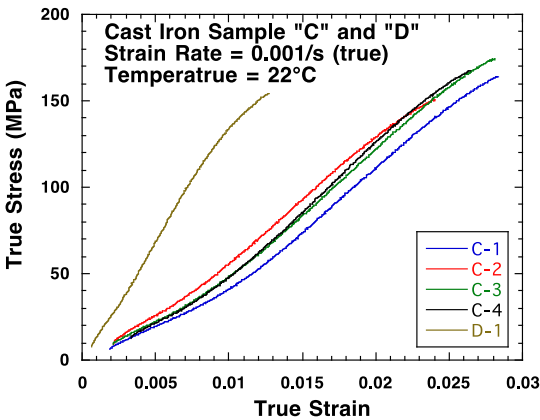
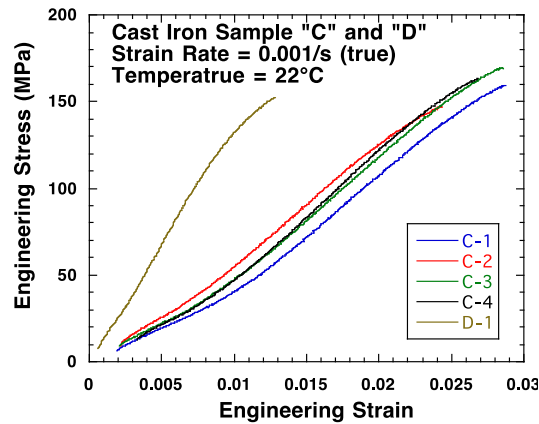
Coupons taken from sample A:



Coupons taken from sample B:



Coupons taken from sample C and D:



3.2 Ultimate Strength

Table 2 shows the results of the tests in terms of ultimate stress at rupture. :

Sample No.	Sample ID	Failure Stress (ksi)	Statistical Plotting Position ¹	$P(X \leq x)$ ²	Reference Data File Name
1	CIC-2	21.3	0.063	0.101	CIC-2_2951e-3e_295K_0.001s_S_eng.txt
2	CID-1	22.1	0.125	0.176	CID-1_2951e-3e_295K_0.001s_S_eng.txt
3	CIB-3	22.2	0.188	0.187	CIC-2_2951e-3e_295K_0.001s_S_eng.txt
4	CIB-4	22.7	0.250	0.257	CIC-2_2951e-3e_295K_0.001s_S_eng.txt
5	CIB-1	22.8	0.313	0.262	CIC-2_2951e-3e_295K_0.001s_S_eng.txt
6	CIB-2	22.8	0.375	0.266	CIC-2_2951e-3e_295K_0.001s_S_eng.txt
7	CIC-1	23.1	0.438	0.313	CIC-2_2951e-3e_295K_0.001s_S_eng.txt
8	CIC-4	23.7	0.500	0.392	CIC-2_2951e-3e_295K_0.001s_S_eng.txt
9	CIB-5	24.4	0.563	0.503	CIC-2_2951e-3e_295K_0.001s_S_eng.txt
10	CIC-3	24.4	0.625	0.512	CIC-2_2951e-3e_295K_0.001s_S_eng.txt
11	CIA-4	26.5	0.688	0.779	CIC-2_2951e-3e_295K_0.001s_S_eng.txt
12	CIA-5	26.7	0.750	0.804	CIC-2_2951e-3e_295K_0.001s_S_eng.txt
13	CIA-1	27.2	0.813	0.850	CIC-2_2951e-3e_295K_0.001s_S_eng.txt
14	CIA-2	28.1	0.875	0.908	CIC-2_2951e-3e_295K_0.001s_S_eng.txt
15	CIA-3	29.8	0.938	0.969	CIC-2_2951e-3e_295K_0.001s_S_eng.txt

Table 2 - Summary of Strength Data

Table Notes

1. The Statistical plotting position is the estimate of the cumulative probability and is estimated

as $PlottingPosition = \frac{i}{n+1}$, where i is the “ith” value out of n samples.

2. The cumulative probability is taken from the lognormal fit and is estimated as

$$P(x \leq X) = \phi \left(\frac{\ln \left(\frac{X}{X_{med}} \right)}{\beta} \right), \text{ where } X_{med} \text{ is the median value and } \beta \text{ is the lognormal standard}$$

deviation.

A lognormal probability distribution was fit to the data, assuming that all of the data are from the same population of cast iron. This may not be a particularly good assumption. If the 15 sets of data are from the same population the resulting median value and lognormal standard deviation are computed to be:

$$X_{med} = 24.4 \text{ ksi}$$

$$\beta = 0.11$$

Assuming that the sample variance is a reasonable estimator of the population variance the 90% confidence limits on the median strength may be computed as lying between 23.4 ksi and 24.6 ksi. The data themselves show very little inherent uncertainty. A plot of this distribution, with 90% confidence limits is given in Figure 2 and shows that the data fit the lognormal parameters fairly well.

Using these estimates the 95% non-exceedance ultimate strength value may be estimated as:

$$X_{0.05} = X_{med} \exp(-1.65\beta)$$

Or

$$X_{0.05} = 24.4 \text{ ksi} \cdot \exp(-1.65 \cdot (0.11)) = 20.35 \text{ ksi}, \text{ with a lower bound estimate of 19.5 ksi.}$$

So report the ultimate strength of the cast iron material as 20 ksi.

4 Conclusions and Recommendations

A test program was conducted on a number of small sized specimens of cast iron fittings in order to determine the grade of material. The material sampled was from fittings in the existing PF-4 fire suppression system. Fifteen samples were available (See reference pictures A-C). Based on the test data it is concluded that the material has a nominal tensile strength of 20 ksi. This corresponds to ASTM A 48 Grade 20 gray cast iron per ASME B31.1. ASME B31.1 limits the allowable stress in cast iron materials to be 1/10 of the published nominal ultimate strength. In this case the allowable

stress for the material is limited to 1/10 of 20 ksi, or 2 ksi. ASME B31E allows an increase in the basic allowable stress for piping systems to be the minimum of 2.4S, 1.5 Sy or 60 ksi. For this material there is not a well-defined yield point, so ASME B31E seismic stresses (

$$\frac{PD}{4t} + 0.75i \frac{M_{sustained} + M_{seismic}}{Z}$$

) should be checked against 2.4x2 or 4.8 ksi. It is recommended that seismic stresses in the FSS system be checked against a limit of 4.8 ksi in accordance with ASME B31.1 and ASME B31E.

Cumulate Distribution of Cast Iron Strengths (PF-4 FSS Fittings)

Sheet1

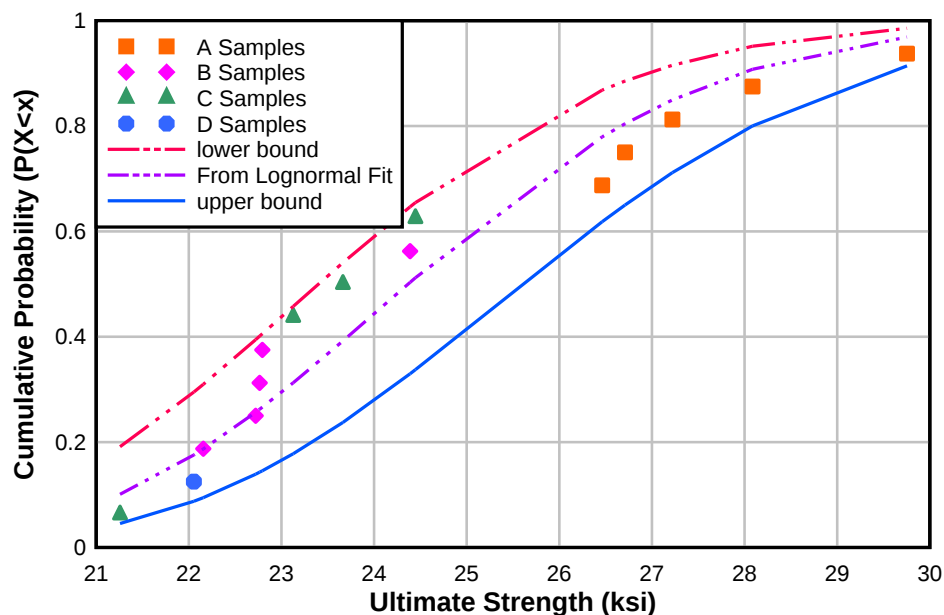
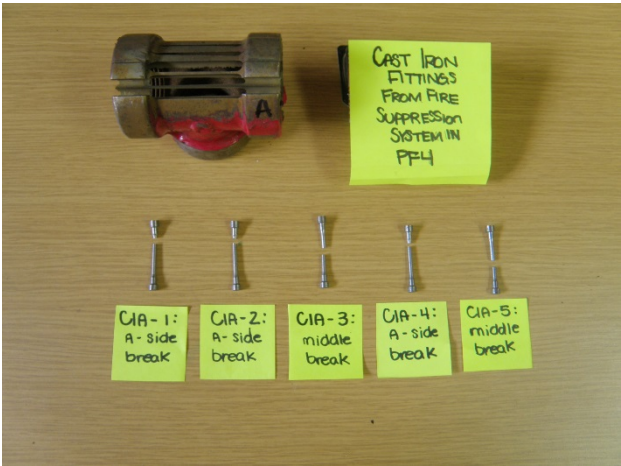


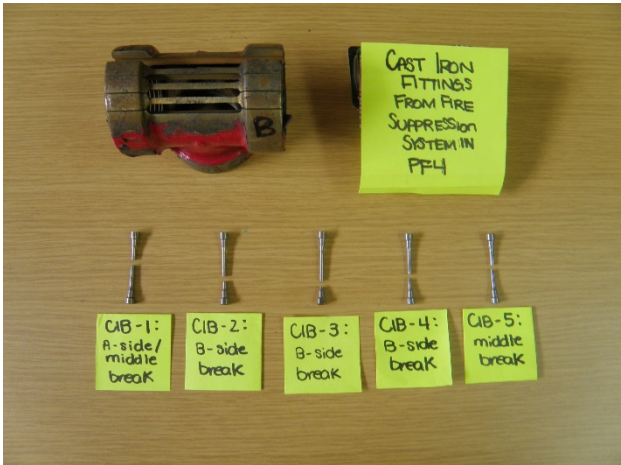
Figure 2 - Cumulate Distribution of Ultimate Strength

Reference Pictures:

A)



B)



C)

