Leakage from Drill Pipe Casing Subject to Shear Deformation

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Abstract

The possibility of fluids leaking from a pressurized drill pipe casing subject to shear deformation caused by various events, including geological activity (such as seismic activity or deformations associated with subsidence related to excavation and construction and/or subsurface mineral, thermal, or water resource exploitation) in the vicinity of the bore hole, is investigated. Such situations may occur in association with a variety of conditions, including oil and gas resource exploration, development and production procedures commonly known as "fracking", and other drilling-related activities. An experimental laboratory scoping investigation has been conducted to determine the potential for leakage from a pressurized drill pipe casing. The laboratory tests show that leakage from sheared casings is much more likely to occur in the neighborhood of the threaded couplers than at locations far from couplers. With the caveat that the effects of surrounding rock and internal cement between concentric casings may not have been accurately simulated or characterized, the tests show that if a threaded coupler is located within a band of tectonic shear deformation, development of a leak at the location of the coupler is predictable.

Keywords:

Drill Pipe Casing, Joint, Gas, Leakage, Shear, Deformation

1. Introduction

Leakage of fluids from pressurized drill-pipe casings is of practical interest, with increased levels and new techniques of gas-and-oil drilling and production underway and planned for the foreseeable future.

The experimental investigation reported here was prompted by issues related to a conflict between parties involved with gas and oil extraction and those involved with underground potash mining in the same area of southeastern New Mexico. There is concern that ground subsidence and strike-slip faults related to subsidence caused by potash mining will cause leakage of the well casings, resulting in oil and gas leaks which may interfere with potash mining operations. Minimum acceptable distances between mining areas and proposed oil and gas wells, as well as other safeguards and conditions necessary to avoid adverse interactions between potash mining and oil and gas development, must be determined.

Many of the issues in the situation described above are of concern in large areas of the United States and elsewhere, because of the increasing use of drilling, mining and hydraulic fracturing ("fracking") procedures for oil and gas resource exploitation. Techniques and procedures which will prevent the contamination of air and groundwater from harmful gases and fluids associated with oil and gas development are needed, but have not yet been identified. If even a small fraction of oil and gas exploration, development, and production wells were to leak, consequences are likely to be unacceptable. It is therefore important to understand the mechanisms by which leaks can occur.

Because drilling and fracking may, under certain conditions, cause earthquakes [Ellsworth et al., 2012], and because earthquakes are often associated with fault slippage, it is reasonable to assume that some boreholes will cross active faults, resulting in shear deformation of the bore hole. This paper seeks to provide some of the information necessary to determine how much shear deformation can take place before a drill pipe casing begins to leak.

The tests, (laboratory testing of a drill pipe casing under shear deformation), described in this paper were undertaken to obtain preliminary information for this purpose.

It is important to note that current gas and oil well-drilling practices usually involve multiple concentric drill pipes/casings with cement injected between casings as well as between the outermost casing and the surrounding rock. The deepest drill casing is not cemented to the surrounding rock. Thus, even though a threaded connection in a drill pipe casing may provide a potential path for leakage of gas and fluids, the multiple concentric pipes and layers of cement may provide, to some extent, resistance to leakage. Because the cements used in drilling are to some extent brittle and permeable, their resistance to fracture, and fluid flow, is limited. The properties of these materials should therefore be characterized to determine their suitability for these uses.

According to unpublished data from National Oilwell Varco (a major producer and supplier of oil and gas drilling and production equipment), approximately one out of every 57 drill pipe connections will leak under pressure [http://www.nov.com]. While there have been a number of papers on the mechanical behavior of drill pipe casing [Fleckenstein et al. 2005], to our knowledge, there is no literature explicitly describing the leakage behavior of internally pressurized drill pipe casing subject to shear deformation. Due to the complexities of threaded couplers and their interaction with sealants, and the variable characteristics of drilling and geological conditions, computer modeling and/or numerical simulation techniques are not adequate for investigation of these issues of concern. An initial laboratory testing program was therefore undertaken to obtain relevant information and results.

2. Laboratory Test Apparatus

A schematic of the testing apparatus designed for this investigation is shown in Fig. 1. The sample drill pipe casing is subjected to four-point loading, in what is known as the "Iosipescu shear test" configuration. The loads, P, are applied by a 400,000-pound capacity universal testing machine, shown in Figure 2. Fabrication drawings of the strong-backs and loading blocks are shown in Figures 3 and 4. A finite element analysis of the strong-back showed that four inch-thick ASTM A36 steel plates bolted together would be capable of transmitting an applied load P of at least 200,000 LBS without yielding.

3. Sample Preparation

Eight test samples were fabricated and loaded, as shown in Table I. They were all fabricated using 4.5" OD K55 drill pipe casings, six with couplers, and capped with half-inch-thick ASTM A36 end plates welded onto each end. The casings had an outer diameter of 4.5 inches and an inner diameter of 4.09 inches. Each test sample, after assembly, was approximately 60 inches in length with the exception of Casing F, which was 48 inches long. Each casing was labeled with a letter, A through H. Casings A, B, C, E, G and H had a 6.5 inch-long threaded coupler with an outer diameter of 5 inches at the middle the center of the test sample. Casings D and F had no couplers. The couplers and the casings were all screwed together with a 1000 foot-pounds of torque. A casing and coupler are shown in Figures 5(a) and 5(b), respectively.

A K55 drill pipe casing, a standard in the petroleum industry, was tested. The American Petroleum Institute standards state that a K55 casing has yield strength between 55 to 80 KSI along with a maximum tensile strength of 95 KSI. These casings are attached using a 5" OD by 6.5"-long female threaded coupler. The threaded surfaces were coated with a sealant and lubricant called Cural [Jet Lube, 2004], applied to the threads, before being torqued to 1000 ft-lbs.

The casing projecting from each side of the coupler was approximately 26.75 inches long including the end caps. Test samples F, G and H are shown in Fig. 6. Two holes were drilled and tapped near one end of each casing to allow for a pressure gauge and Schrader-type air valve to be attached, as shown in Figure 6.

4. Experimental Program

Each drill pipe casing was pressurized with air at 40 PSI and then the shear deformation was applied until the casing was no longer able to hold pressure or until the casing could not be further deformed due to testing setup constraints. A removable reference beam, shown in Figure 7, was strapped on to each casing with pipe clamps, as a reference to measure displacements. Two dial-type displacement gauges were positioned along each side of the casing. The gauges were placed 23 inches from the reference beam supports, as shown in Figure 7(a). Each gauge was assigned a number for reading purposes, shown in Figure 7(b). The readings of

relative displacements were averaged to determine the displacement on each side of the applied shear load, as shown in Figure 8. A photograph of the test set-up including the reference beam is shown in Figure 9. Sketches of the loading configurations of the specimens are shown in Figure 10.

5. Test Results

At least one week prior to mechanical testing, all specimens were pressurized with air to gauge pressure of 40 PSI. The mechanical testing of each specimen was conducted within one-hour duration. In all cases, once shear deformation was sufficient to cause leakage, the leaking air produced an immediate and obvious loud hissing sound, and the pressure gauge indicated that the pressure was lost within approximately one minute. Once a leak commenced due to shear deformation, it provided very little resistance to air flow.

The results (load and pressure versus deformation) of the tests are summarized in Figure 11. Photographs of the specimens after testing, with obvious residual deformation, are shown in Figure 12.

Specimens A, G, and H, (with the end of the coupler within the 1”-long shear span) which were fabricated and tested under apparently identical conditions, showed very similar behavior: in all three specimens, the leaks formed at a shear deformation of between 0.03” and 0.06” and a shear load of between 40 kips and 60 kips. Once leakage commenced, these specimens de-pressurized within one to two minutes.

Specimen B (with the end of the coupler within the 5”-long shear span) de-pressurized at a shear deformation of 0.14”, at a shear force of 75 kips, and lost pressure within one minute after leakage commenced.

Specimen C (with the entire coupler within the 4.5”-long shear span) did not leak until unloading from a maximum shear deformation of 0.47”.

Specimen D, with no coupler and a 5”-long shear span, did not leak even after being sheared up to 1.3” (at which time the test was stopped due to interference between the coupler and the loading machine).

Specimen E (with the entire coupler within the 1”-long shear span) leaked at a shear deformation of 0.35” and a shear force of 180 kips.

Specimen F (with no coupler and a 1”-long shear span) did not develop a leak, even with a shear deformation of 1.3” and a shear force of 165 kips.

6. Discussion and Conclusions

These tests have helped to illuminate under which conditions gas leaks are likely to develop due to shear deformations across drill pipes.

When the strike-slip deformations are less than 0.03”, leaks are unlikely to develop, even if the coupler is within the shear band.

When the shear band is not in the neighborhood of a coupler, shear deformations well above an inch are likely not to cause gas leaks in the drill pipe casing.

The most critical case of leakage is when one end of the coupler is within the shear band. In such a case, pressure loss is likely to occur at the small slip of only 0.03”.

In all cases, when the width of the shear band is larger, leakage would be expected to be less likely, while when the width of the shear band is small (the limiting case being a perfectly narrow shear crack), leakage is much more likely.

The width of the shear band will depend upon the characteristics of the rock. In the case of a competent hard rock like granite, it is probable that the width of the shear band may approach zero. However, in a soft sedimentary rock like halite or potash, with the ability to creep and deform under relatively low stresses, the width of the shear band is likely be much longer. In either case, a critical dimensionless parameter would appear to be the ratio of the width of the shear band to the diameter of the drill pipe casing. Additional testing and detailed computational analyses, employing the properties of the rock and the drill piper casing is recommended to determine this dimensionless parameter. However, such computational simulations of rock/pipe interaction are nonlinear, difficult and probably well beyond the state-of-the-practice.

It is difficult to generalize these test results, as only one size of casing was tested. However, these results are still useful in providing anecdotal evidence of leakage due to shear deformation.

It is important to note that there are many other mechanisms allowing leakage that have not been considered in this paper. Aging, chemical, and biological degradation of the sealant/lubricant Cural, as well as corrosion of the drill pipe could be other mechanisms by which leakage could occur.

These results demonstrate the need to test, evaluate, and understand the materials, techniques and procedures used for oil and gas drilling, exploration, production and well closure. With present practices, the potential for leakage of undesirable and potentially damaging substances into important water and air resources is significant, with potentially major adverse consequences that have not been fully addressed.

7. References

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Highlights

- Tests show under which conditions gas leaks are likely to develop due to shear deformations.
- When the strike-slip deformations are less than 0.03”, leaks are unlikely to develop at couplers in the type of casing tested.
- When the strike-slip deformations are more than 0.03”, leaks are likely to develop at couplers in the type of casing tested.
- Away from a coupler, shear deformations up to an inch are likely not to cause gas leaks.

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Table I – Test Sample Specifications

Label	5” OD Coupler	Overall Length	Type of Loading Block on Each Side of Shear Span	Left Loading Block Bearing on:	Right Loading Block Bearing on:	Clear Distance Between Loading Blocks
A	yes	60”	fully-enclosed	coupler	casing	1”
B	yes	60”	partially-enclosed	coupler	casing	5”
C	yes	60”	partially-enclosed	coupler	coupler	4.5”
D	no	60”	partially-enclosed	casing	casing	5”
E	yes	60”	fully-enclosed	coupler	coupler	1”
F	no	48”	fully-enclosed	casing	casing	1”
G	yes	60”	fully-enclosed	coupler	casing	1”
H	yes	60”	fully-enclosed	coupler	casing	1”

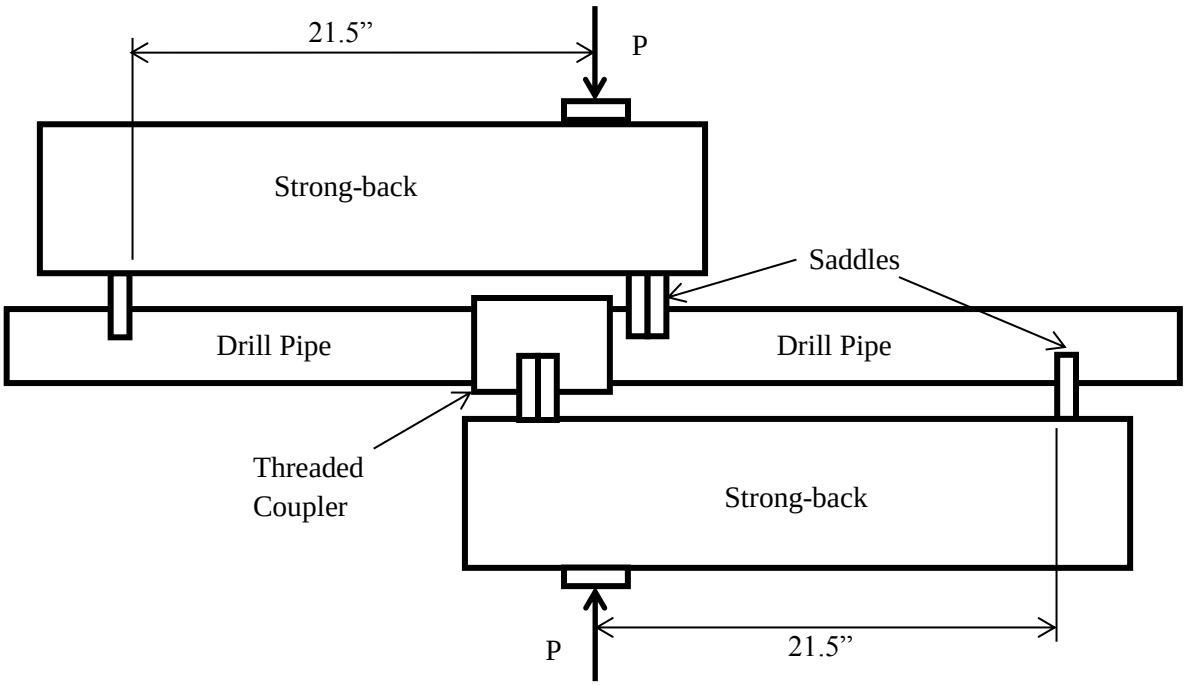


Figure 1 – Schematic of Iosipescu Shear Test

Figure 2 -Photograph of Iosipescu Shear Beam Test Apparatus

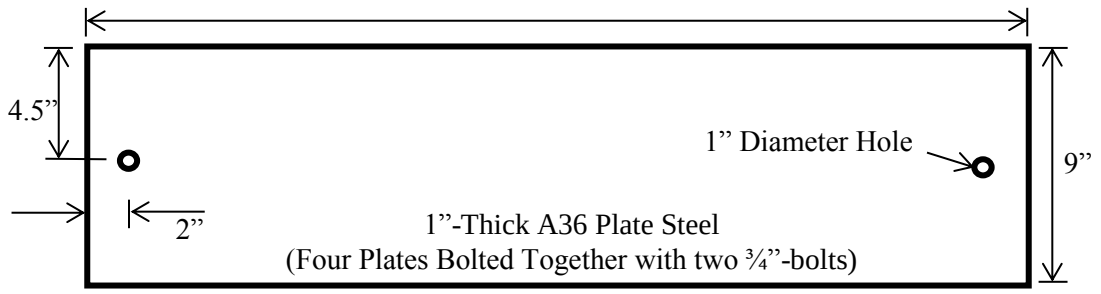
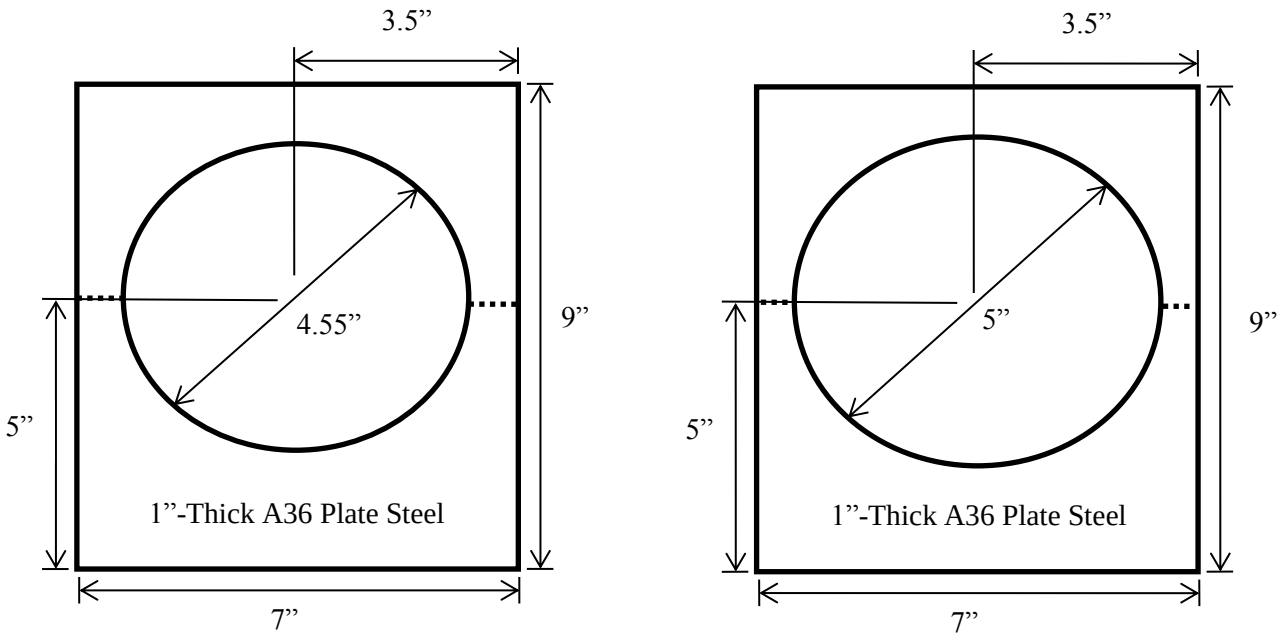


Figure 3 – Strongback Fabrication Drawing



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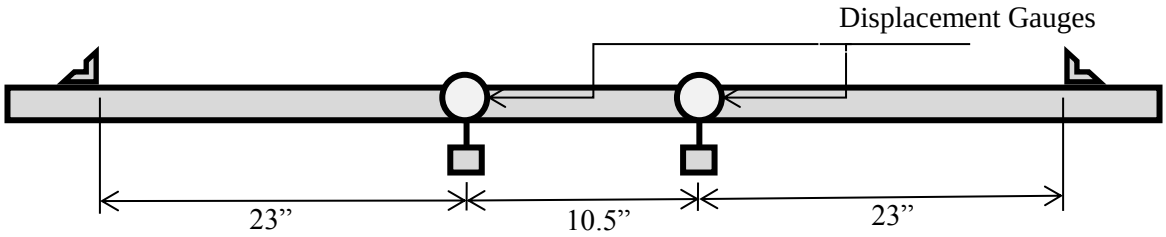
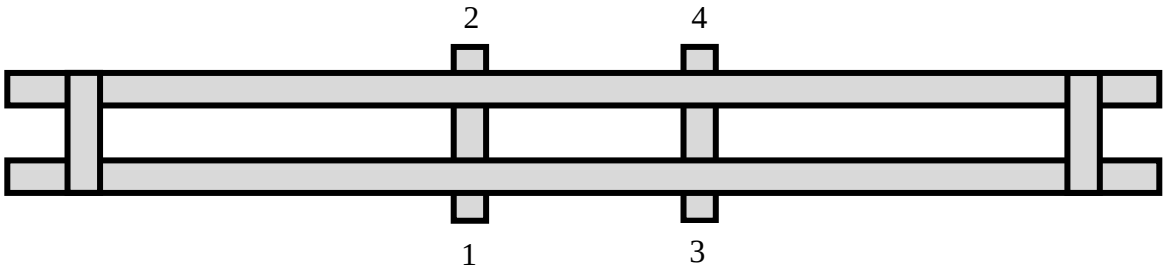
(a) (b)

Figure 5 – (a) 4.5” OD K55 Threaded Casing; (b) Threaded 5” OD by 6.5”-Long Coupler

Figure 6 – Casings F, G and H, showing Pressure Gauges and Valves



(a)



(b)

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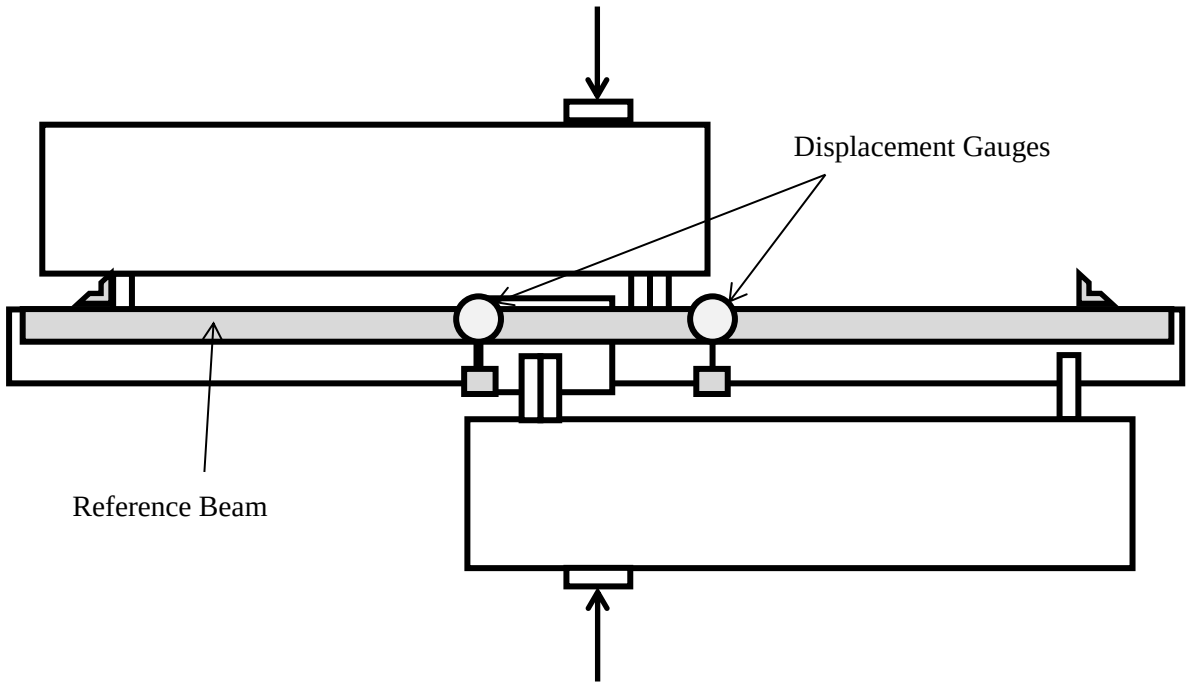

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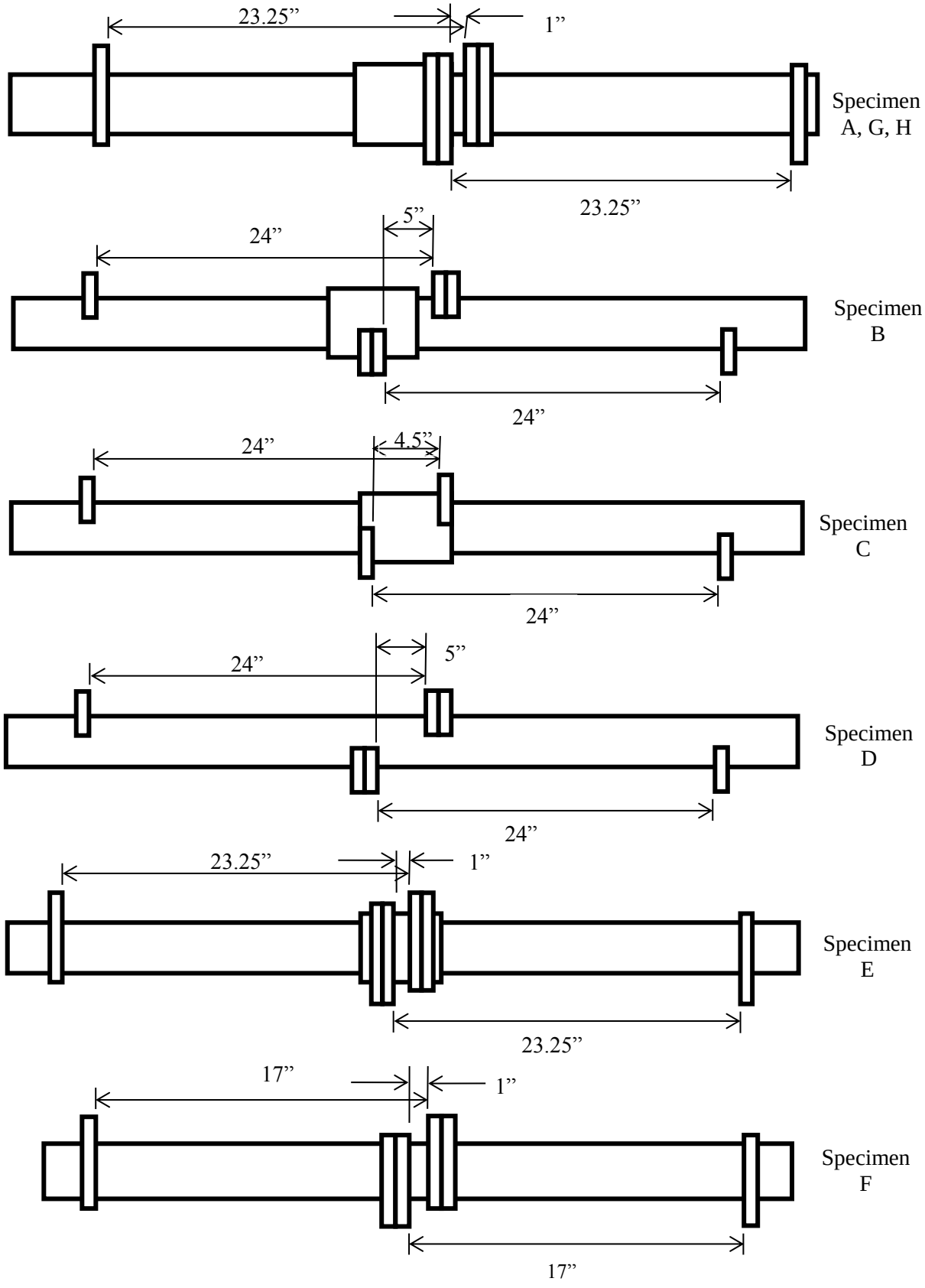

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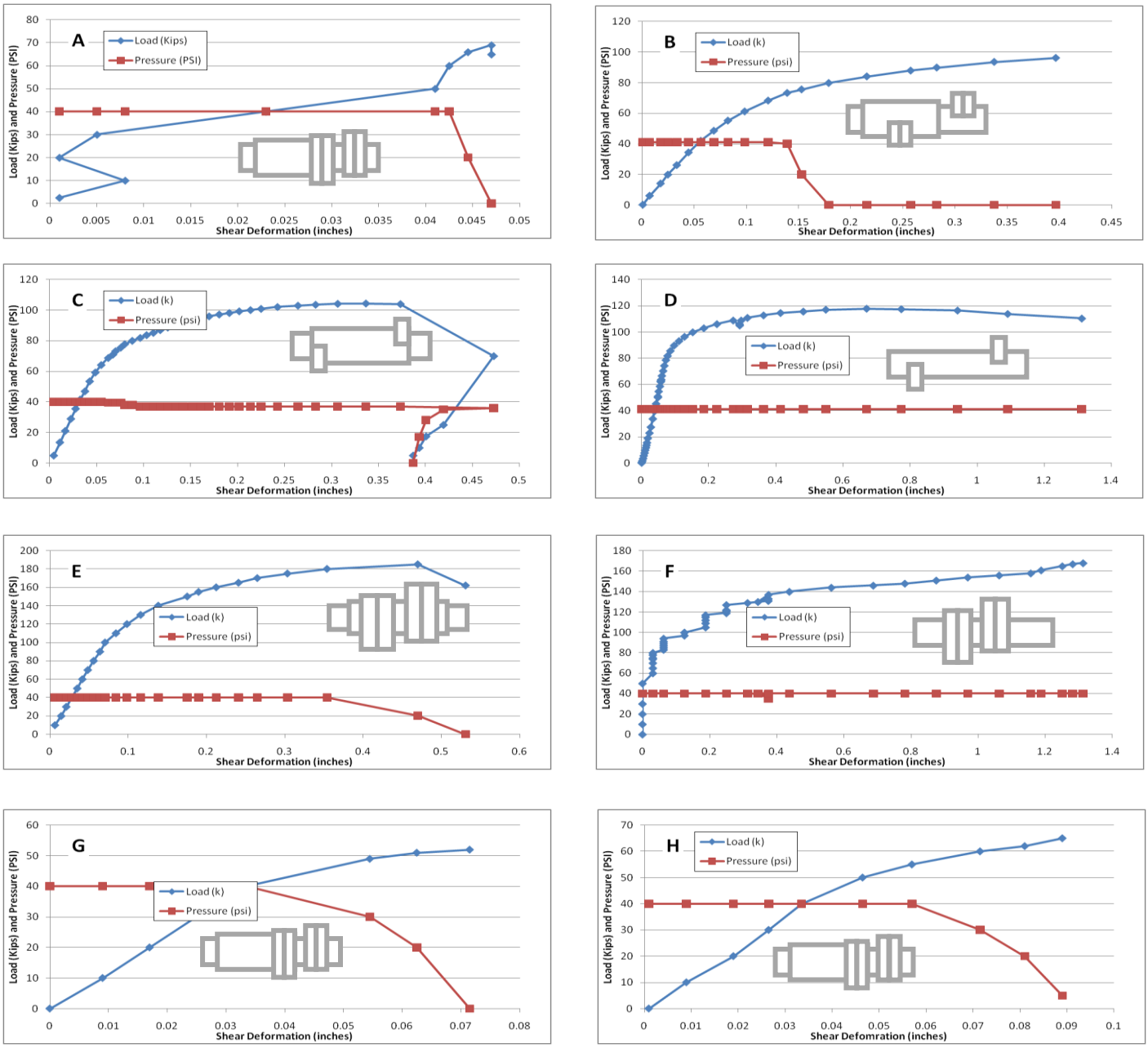


Figure 11 – Load and Pressure versus Shear Deformation. Time between Data Points is Approximately 30 Seconds

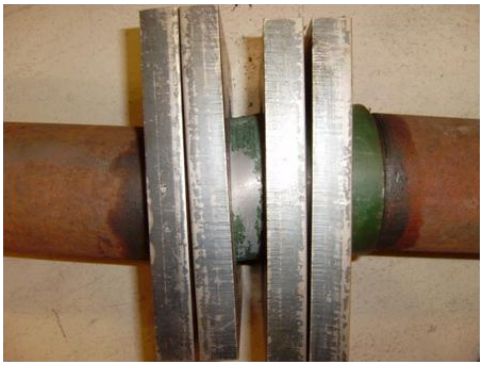
A

B

C

D

E



F

G

H

Figure 12 – Photographs of Casings after Shear Deformation