WEST

Engineering Services, Inc.

www.westengineer.com

MINI SHEAR STUDY

For

U.S. Minerals Management Service

Requisition No. 2-1011-1003

December 2002

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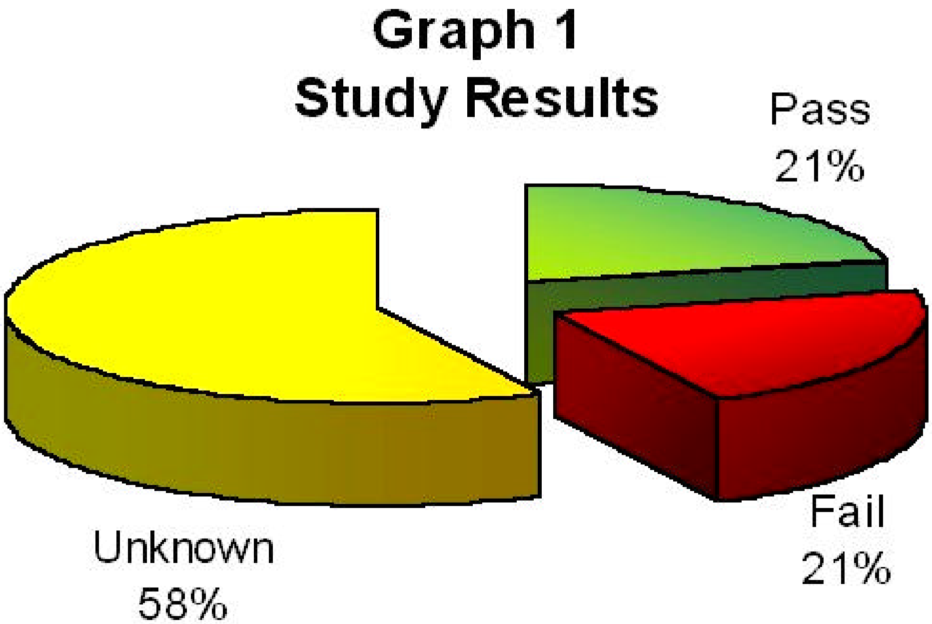
1 Executive Summary

This study was designed to answer the question "Can a given rig's BOP equipment shear the pipe to be used in a given drilling program at the most demanding condition to be expected?" Briefly, this can only be demonstrated conclusively by testing. Seven of the 14 cases above opted not to test to confirm capabilities; another had insufficient data to draw a definitive conclusion. This is presented below as Graph 1.



Of the seven tested, five successfully sheared and sealed (71%) based on shop testing only. If operational considerations of the initial drilling program were accounted for, shearing success dropped to three of six (50%). Based on the results obtained, two of the rigs modified their equipment to enable shearing and sealing on the drill pipe for their program.

The increase in drillpipe sizing as well as improved metallurgies, while benefiting the industry in many respects, detrimentally affects the ability to shear pipe should this last means of securing a well be necessary. Adding to the above concern is the hydrostatic effect of shearing at depth that must be taken into account. Knowledge of the findings herein should help prudent operators and drilling contractors provide a safer workplace while protecting the environment. Herein we briefly explore the data points available from recent shear tests and graphically compare their results.

API Specification 16A requirements and procedures used for shear testing are reviewed. Meeting Spec 16A requirements does not by any means guarantee that a rig is operating in a prudent or safe manner. The pipe referred to in the spec is not representative of that used on the 5th generation rigs operating at this time. Additional factors to be considered for more realistic operating conditions should be better understood before a final recommendation can be established.

This limited data set from the latest generation of rigs paints a grim picture of the probability of success when utilizing this final tool in securing a well after a well control event. While modifications, such as boosters or increased control system pressure, are available, demonstrative evidence that the installed shear rams will shear is often lacking.

2 Background

Many operators and drilling contractors have chosen not to perform actual shear testing when accepting new or rebuilt drilling rigs. Others have learned the importance of shear tests prior to accepting a rig as they have experienced occasions when normal control system pressure was not adequate to shear the pipe being used. Some rigs were able to add the necessary equipment modifications before initiation of drilling.

For the purposes of this study, when the term "successful shear test" is used, it is understood to mean both shear and seal with locks only as would happen in an actual disconnect sequence.

Consistent testing methodologies along with standard considerations for operational parameters will improve the accuracy of the shear tests and thus the improved probability of success when a shear operation is required. Currently, manufacturers, operators, and contractors use various means to determine if drillpipe will shear.

When shear tests are conducted, the increased pressure required to shear at water depth are rarely considered. With increasing water depths, higher hydrostatic pressure due to mud weight also must be allowed for. In the tests referenced in this report, operating pressure corrections of up to 500 psi were required to account for the operating environment.

Drill pipe technology has improved over the years. The latest generation of high specification pipe, known as SQAIR (Shell's Quality And Inspection Requirements), have increased ductility, which almost doubles the shearing pressure required for older pipe of the same weight, diameter, and tensile strength. Differences between the various generations of drill pipe cannot be visually discerned, although this data may be available on a case by case basis. Short of physical testing, only careful record keeping on a rig can determine which pipe is of what specification. WEST has learned recently that, in at least one case, those records were not adequately kept. Thus, in this case, the ability of the shear ram to shear and seal on the drillpipe in the bore was left to chance because of mixing drill pipe from various sources. Inconsistency in drillpipe lengths and internal/external upsets also increases the possibility of an ineffective shear.

Shear test on old pipe (left) and new pipe (right). The new pipe required almost 2,000 psi more to shear than the old pipe even though the specifications on both pipes were the same.

Historical test data, because of not having recorded critical physical properties, makes application to today's drill pipe suspect in some cases. Currently, equations used to estimate pressure required to shear also do not include all pertinent variables, reducing accuracy and mandating a physical shear test to establish shear requirements. Additional research is needed to confirm methods of estimating shear pressure for the full range of pipe available today. Incorporating ductility and other variables can be expected to improve the accuracy of these equations and lessen the reliance on actual shear tests.

There is not an established requirement for tool joint length. In fact, it is advantageous for the tool joint to be longer in length so that it may be reworked a number of times. However, this decreases the length of the drillpipe that can be sheared with standard blind shear rams. With variable lengths of tool joints, hang off to shear offsets must be checked to ensure the shear ram does not attempt to shear at the tool joint. This also does not consider the situations of automatically actuated shear sequences where the operator does not have the opportunity to ensure no tool joint is in the shear path.

Other variables also affect the ability to shear drillpipe. The internal upset varies and is not clear without measuring each joint of drillpipe. Work hardening can affect the ability of the pipe to shear. Low temperatures will negatively affect the ability of the ram to seal after a shear.

WEST is unaware of any regulatory requirements that state the obvious: that the BOP must be capable of shearing pipe planned for use in the current drilling program.

Education of those involved should result in higher safety of drilling operations. It appears that at least some of the rigs currently in operation have not considered critical issues necessary to ensure that their shear rams will shear the drillpipe and seal the wellbore.

3 API Spec 16A References

Only API Specification 16A Specification for Drill Through Equipment, 2nd Edition, December 1997 makes specific reference as to how to test blind shear rams. The references from the specification are listed below.

7.5.8.7.4 Shear-Blind Ram Test Procedure

Each preventer equipped with shear-blind rams shall be subjected to a shearing test. As a minimum, this test requires shearing of drill pipe as follows: 3 1/2-inch 13.3 lb/ft Grade E for 7 1/16-inch BOPs, 5-inch 19.5 lb/ft Grade E for 11-inch BOPs and 5-inch 19.5 lb/ft Grade G for 13 5/8-inch and larger BOPs. These tests shall be performed without tension in the pipe and with zero wellbore pressure. Shearing and sealing shall be achieved in a single operation. The piston closing pressure shall not exceed the manufacturer's rated working pressure for the operating system.

4.7.2.4 Shear Ram Test

This test shall determine the shearing and sealing capabilities for selected drill pipe samples. As a minimum, the pipe used shall be: 3 1/2-inch 13.3 lb/ft Grade E for 7 1/16-inch BOPs, 5-inch 19.5 lb/ft Grade E for 11-inch BOPs and 5-inch 19.5 lb/ft Grade G for 13 5/8-inch and larger BOPs. These tests shall be performed without tension in the pipe and with zero well-bore pressure. Documentation shall include the manufacturer's shear ram and BOP configuration, the actual pressure and force to shear, and actual yield strength, elongation, and weight per foot of the drill pipe samples, as specified in API Specification 5D.

Appendix B.4.3 SHEAR RAM TEST (Non mandatory)

The following procedure is used for conducting a shear ram test on ram BOPs:

a. Install the preventer on test stump. Connect opening and closing lines to BOP. Connect line from the high-pressure test pump to the stump or BOP side outlet.
b. The opening, closing, and wellbore pressure line each shall be equipped with, as a minimum, a pressure transducer. All transducers shall be connected to a data acquisition system to provide a permanent record.
c. Install a new set of ram packers onto the blocks. Durometer measurements on the ram rubber seal shall have been made and recorded.
d. Suspend a section (approximately four feet in length) of drill pipe as specified in 4.7.2.4 for the preventer size vertically above the preventer and lower it into the wellbore. It is permitted to loosely guide the portion of the pipe below the ram to prevent excessive bending of the pipe section during shearing.
e. Set closing unit manifold pressure to manufacturer's recommended pressure for shearing. Close the rams and shear the pipe in a single operation. The pressure at which the pipe is sheared will be obvious from the rapid pressure change at the instant of shearing.
f. Raise the wellbore pressure to 200 to 300 psi and hold for three minutes examining for leaks.
g. Raise wellbore pressure to maximum rated working pressure of preventer and again examine for leaks for three minutes.
h. Reduce wellbore pressure to zero, open rams, inspect, and document any wear on the preventer.

i. Repeat Items d through h for two additional samples of drill pipe. Ram packers may be replaced as necessary.

Critical items from the above API references are as follows:

- 7.5.8.7.4 – The spec requires that the specified pipe can be sheared and the wellbore sealed in one operation (within the BOP manufacturer's recommended operating range) for pipe that was common at the time the spec was drafted. The drill pipe size and metallurgies have been enhanced since this time making this standard low and negating the intent.
- 4.7.2.4 -- Once again the minimum specified pipe was for pipe in use when the spec was drafted; since that time, larger pipe with stronger Charpy impact material has become common. The actual pressure and force to shear is recorded.
- B 4.3 – A procedure for performing a shear test is outlined. It includes a recommended method for examining for leaks and the recommendation that at least three shear tests be performed.

The pipe required in Section 4.7.2.4 is a low standard since many drilling programs use much heavier and thicker pipe. The 5-inch 19.5 lb/ft Grade G for 13 5/8-inch and larger BOPs is minimal and really does not address modern drillpipe. Drillpipe such as 6 5/8-inch 40.9 lb/ft S-135 and heavier have been seen in deepwater drilling programs and require much greater shear pressures than the lighter weight test drillpipe in API Specification 16A. The shearing/sealing of pipe more resembling that to be used in a program would offer a much better assurance that shearing would work when needed.

Modifications to the procedure described in Section B.4.3 can further enhance the utility of shear info for other conditions. Specific guidelines ensure more uniform testing and results that are closer to actual shear values. For example, Section B.4.3 requires three shears for pipe. This does not establish enough data for statistical analysis of the shear rams' capabilities, but instead establishes three points of a graph that includes the shear population for a given pipe. Not stated is which shear pressure should govern—we would recommend that it should be greater than the average; the largest measured result (worst case) would be more reasonable.

4 Test Procedures Used

The tests included in this study were for BOP rams manufactured by two major manufacturers. The test procedures used complied with the requirements of API Specification 16A.

Correlations among the test procedures. The test procedures specify the basic equipment involved in the test and have the same acceptance criteria. All three rigs for which WEST have test procedures chose to test 5 ½-inch 24.7 lb/ft S-135 drillpipe. The test procedure developed for Rig C included a greater number of shears, which was requested by the operator.

Differences among test procedures. The primary difference between the procedures is the detail. The procedures developed by the manufacturer for Rigs C and D contained more definition that those developed by the operator (Rig E). The procedures for Rig C and D also include inspection of the shear ram assemblies and body cavity for damage between each test while those for Rig E included only pressure tests following the shears.

Rigs A and B

No test procedures are available.

Rig C

SCOPE:

SHEAR RAM TEST from major manufacturer of rams.

1.0 Pressure Test Records

1.0.1 Strip Chart Recorders (with pens set at 0 – 1,000 psi, 0 – 5,000 psi, and 0 – 20,000 psi) shall be used to record low pressure, closing/shearing pressure, and high pressure tests respectively. The records shall identify the recording device and shall be dated and signed.

1.1 Shear rams shall be subjected to a minimum of nine shearing tests. The shear ram shall shear and seal in a single operation.

1.2 Pipe configuration to be sheared shall be 5 ½" S-135 24.7 lb/ft pipe.

2.0 Shear Ram Test Procedure

2.0.1 Hook up BOP as per Figure 1.

2.0.2 Fill BOP cavity with water.

2.0.3 Close and open rams two times with 1500 psi hydraulic pressure to expel trapped air.

2.0.3.1 The rams are equipped with operators and will have the number of turns and pressure to lock recorded as to locking position.

2.0.4 Suspend test sample in BOP wellbore on safety chain from bridge crane. Sample should extend approximately 18" - 25" below shear blade. Position the stabilization collar as close to the bottom of the bore as possible.

2.0.5 Set regulator to maintain 500 psi. Close the rams until the blades just contact the OD of the shear sample.

2.0.6 Place the operators in block mode and bleed hydraulic pressure to zero psi. With data acquisition and chart recorders running, place the shear rams in close position and slowly increase the operator pressure until pipe is sheared. DO NOT EXCEED 4500 psi. Bleed hydraulic pressure to zero psi.

2.0.7 Apply 300 ± 50 psi wellbore pressure under rams. Hold for a minimum of five minutes and check for leaks.

ACCEPTANCE CRITERIA

The low-pressure test will be considered satisfactory if there is less than 10 psi pressure drop in five minutes after an initial stabilization period and no visible leakage.

2.0.8 Apply 15,000 +100/-0 psi wellbore pressure under rams and hold for a minimum of ten minutes and check for leaks. Bleed to zero psi (0 bar).

The high pressure test (15,000 psi) will be considered satisfactory if there is less than 100 psi pressure drop in ten minutes after an initial stabilization period and no visible leakage.

2.0.9 Open shear rams.

2.0.10 Open BOP doors and inspect shear ram assemblies and body cavity for any damage from shear test. Dress shear blades and replace damaged seals if necessary. Take digital photos of rams and sheared sample.

2.0.11 Repeat steps 2.0.2 through 2.0.10 for a minimum of nine shear and seal tests on three separate test samples.

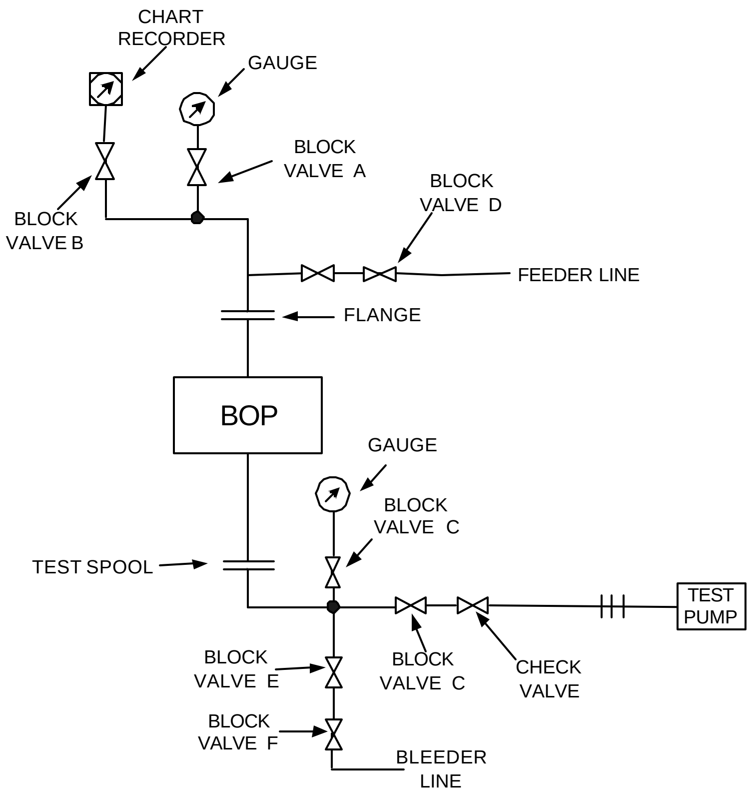


Figure 1 – Test Apparatus

Rig D

The shear tests for Rig D followed those for Rig C by approximately two months. The procedures were essential the same.

Rig E

This shear test procedure was developed by the operator during the rig acceptance phase. This procedure was not as specific as those for Rigs C and D. There are not parameters for acceptable leakage rate during pressure testing.

1. The test setup is to include monitoring equipment capable of permanently recording operating pressure (e.g., chart recorder), time and volume required to shear pipe with the BOP stack shear blind rams. Accurate data must be collected during testing.
2. Connect a test hose to the BOP stack to be able to pressure test under the blind shear rams.

Note: Precautions should be made to prevent damage to the test stump by the bottom-sheared section of the drillpipe.

3. Fill the BOP stack with water to above the blind shear rams.
4. Assign yellow pod and use high-pressure shear circuit (3,000 psi operating pressure).

5. Suspend a section of 5 1/2" - 24.70 lb/ft - S135 drillpipe in the bore of the BOP and close the shear rams on the pipe. The pressure to shear should be evident on the chart recorder. **Record pressure, time, and volume.**
6. Pressure test the blind shear rams: 200 psi/10 minutes - 15,000 psi/15 minutes.
7. Open the shear rams and remove the sheared off section of drillpipe.
8. Fill the BOP stack with water to above the blind shear rams.
9. Assign blue pod and adjust the manifold regulator to 3,000 psi operating pressure.
10. Suspend a section of 5 1/2" - 24.70 lb/ft - S135 drillpipe in the bore of the BOP and close the shear rams on the pipe. The pressure to shear should be evident on the chart recorder. **Record pressure, time, and volume.**
11. Pressure test the blind shear rams: 200 psi/10 minutes - 15,000 psi/15 minutes.
12. Open the shear rams and remove the sheared off section of drillpipe.
13. Fill the BOP stack with water to above the blind shear rams.
14. Suspend a section of 5 1/2" - 24.70 lb/ft - S135 drillpipe in the bore of the BOP and close the shear rams on the pipe. The pressure to shear should be evident on the chart recorder. **Record pressure, time, and volume.**

Rig F

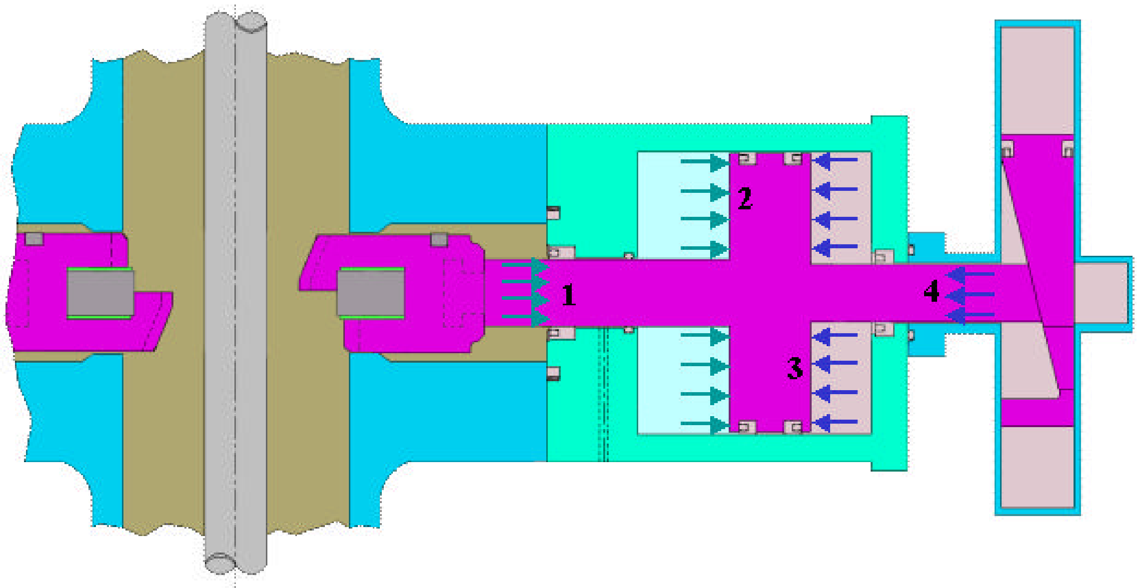
No test procedures are available.

Rig G

No test procedures are available.

5 Additional Shearing Pressure Required

Additional pressures must be considered when shearing pipe, but are generally ignored. These include two major categories: net hydrostatic pressure at water depth and closing the rams against a wellbore kick. Hydrostatic pressure includes the net effect of the BOP hydraulic fluid, seawater, and mud weight.



Areas where mud, seawater, and BOP fluid pressures act on a Cameron ST Lock:1 – Mud Pressure
2 – Seawater Pressure
3 – BOP Fluid Pressure plus hydrostatic head
4 – Seawater Pressure.

Closing against a wellbore kick can increase the pressure required to close the rams by amount equal to the wellbore pressure divided by the closing ratio of the ram. This variable should be included since closing of the shear rams should be prepared for the worst case when there is wellbore pressure under the annular.

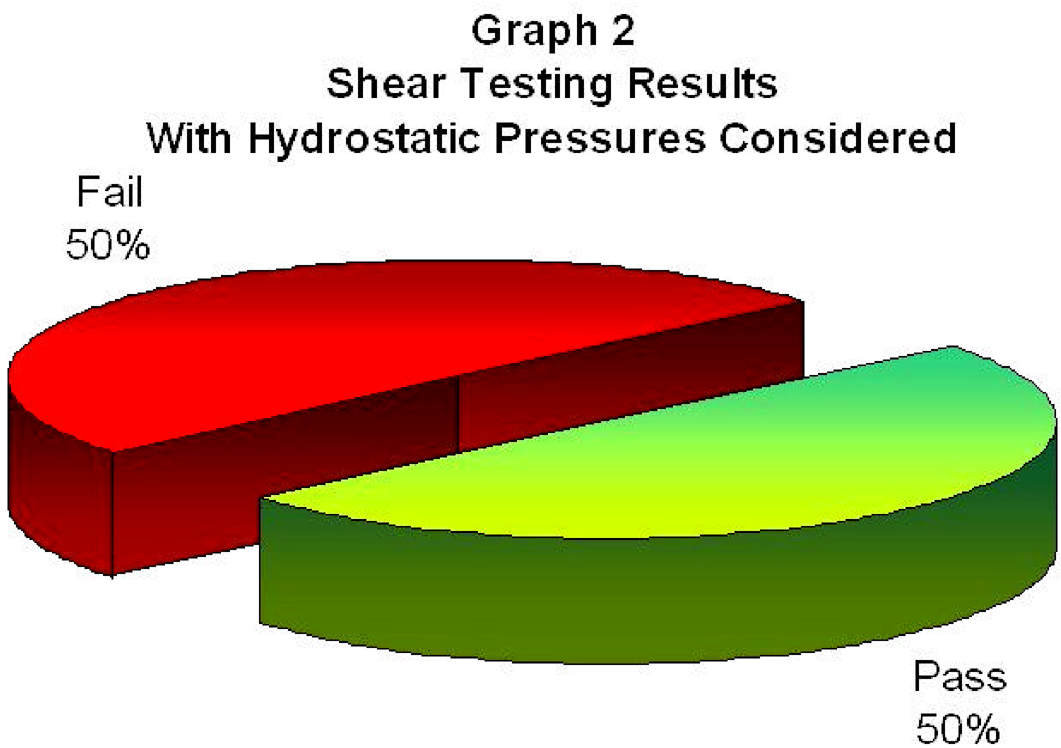
Hydrostatic pressure includes those effects caused by BOP hydraulic fluid, seawater, and mud weight. The BOP hydraulic fluid pressure acts to close the ram while the mud acts to open the ram. The net effect is an increase in the pressure required to close the shear rams in order to overcome the opening forces of the mud. However, when the shear rams are closed and sealed and the pressure trapped between the shear ram and the annular vented, this wellbore pressure assists in maintain the seal.

The total effect of these additive pressures can result in an increase of 20% or more to the shearing pressure established at the surface (using a 500 psi wellbore kick and mud weight of 16 ppg). These issues are rarely considered when reviewing the capability of the control system to operate the shear rams and to shear the drillpipe.

While outside the scope of this study, lubricity and cleanliness of the control fluid affects the ability of a shear ram to properly function. Rig procedures should ensure that these items are within manufacturer's recommended guidelines.

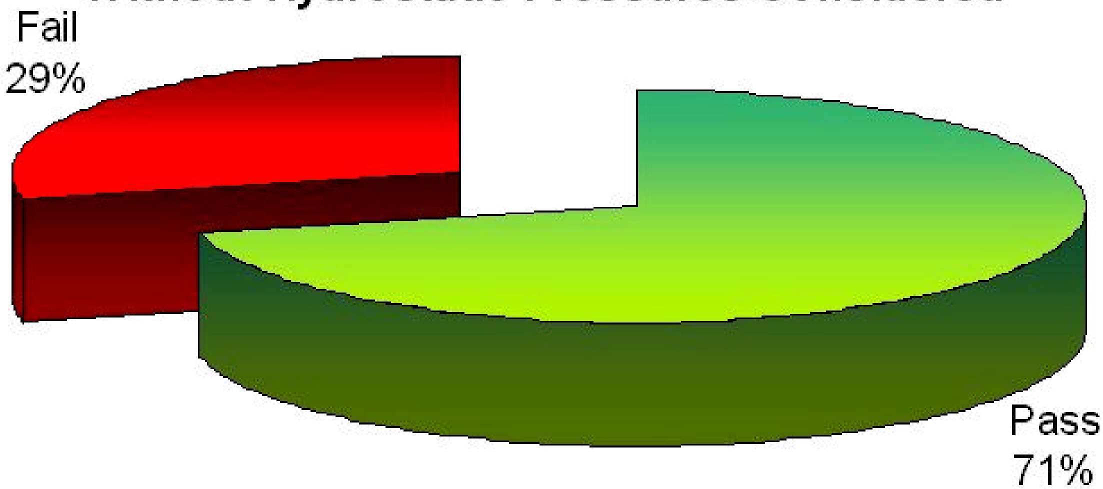
6 Findings

WEST had experience with 14 rigs during the recent round of upgrades. Shearing data is included in Table 1 – Shear Data. As can be seen of the 14 rigs, only seven conducted shear testing. One rig did shear testing on new SQAIR 5", 24.7 PPF, S-135 pipe. Included in the attachment is the Actual Shear Value (psi) that was necessary to shear the pipe. Thus, if the operating system pressure available has been exceeded, the pipe would not shear on the rig. As can be seen in the column "W/O Hyd Pass/Fail", five rigs passed and two failed to shear the pipe on the surface (71% success) upon simple analysis of the testing data. This is shown below in Graph 2.



When the supplementary affect of hydrostatic pressure at maximum rated water depth is added to the surface shearing pressure, one rig should no longer be able to shear the pipe. Another rig drops out, as the actual shearing pressure was not in the WEST files. Thus, three of six rigs pass in this case (50%). This is graphically presented in Graph 3.

Graph 3
Shear Testing Results
Without Hydrostatic Pressures Considered



For additional details, Graph 4 entitled “Percentage of Shearing Pressure Required to Available Control System Pressure” has been included. On the graph, shearing pressures requiring over 100% of available control pressure will most likely be unable to shear.

Graph 4
Percentage of Shearing Pressure Required to Available Control System Pressure

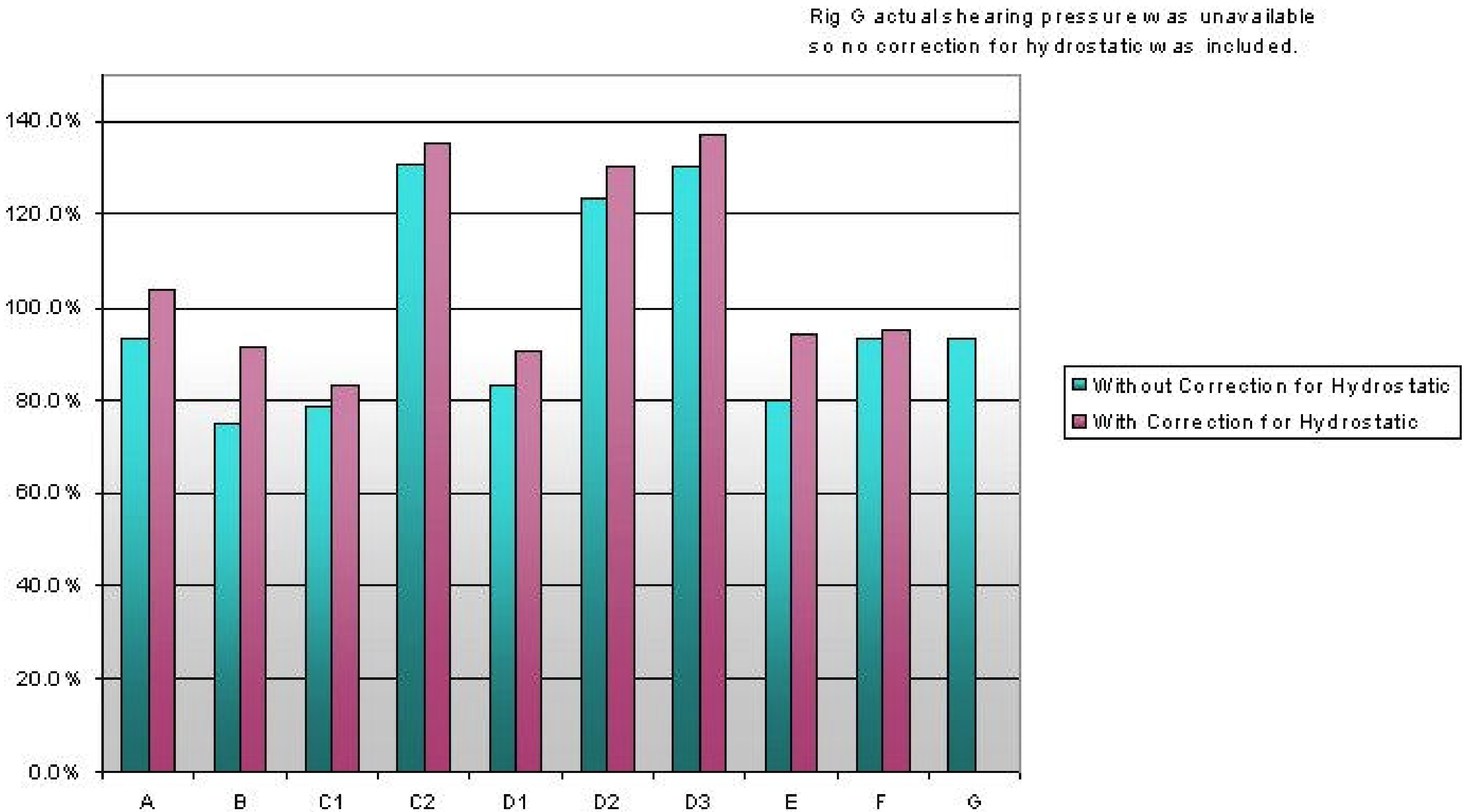


Table 1
Study Data

Rig Code Letter	Actual Shear Value (psi)	Pipe Sheared	W/O Hyd Pass/Fail	Max Rated Water Depth (ft)	Total Pressure at Max Depth	% of Control System W/O Hydrostatic	W/Hyd Pass/Fail	% of Control System W/ Hydrostatic
A	2800	New 5.5", 24.7 PPF, S-135	**Pass**	5000	3104	93.3%	**Fail**	103.5%
B	2250	5.5", 21.9 PPF, S-135	**Pass**	10000	2751	75.0%	**Pass**	91.7%
C1	2360	Used 5", 24.7 PPF, S-135	Pass	3281	2499	78.7%	Pass	83.3%
C2	3930	New SQAIR 5", 24.7 PPF, S-135	**Fail**	3281	4069	131.0%	**Fail**	135.6%
D1	2500	5", 19.5 PPF, S-135	Pass	6000	2715	83.3%	Pass	90.5%
D2	3700	5.5", 24.7 PPF, S-135, H-series, Range 2	**Fail**	6000	3915	123.3%	**Fail**	130.5%
D3	3900	5.5", 24.7 PPF, S-135, H-series, Range 2	Fail	6000	4115	130.0%	Fail	137.2%
E	2400	5.5", 25.89 PPF, S-135	**Pass**	8200	2824	80.0%	**Pass**	94.1%
F	2800	6 5/8", 27.7 PPF, S-135	**Pass**	450	2859	93.3%	**Pass**	95.3%
G	Under 3000	5", 19.5 PPF, Grade G	**Pass**	7500	3194		Not Incl	
H		None		10000				
I		None		7500				
J		None		8000				
K		None		6600				
L		None		6000				
M		None		6000				
N		None		6000				

Notes:

1 On Rig G, less than 3,000 psi was recorded as shearing pressure, thus it could not be included with hydrostatic calculations.
2 When several shears were performed on a job, the highest shear pressure is recorded.
3 Hydrostatic increase due to mud and seawater
Mud weight = 14.5 PPG (gradient=0.753 psi/ft)
4 Control system shear pressure = 3,000.
5 Rig passing/failing shear test is in **bold**.