API well 60-817-44169, Macondo well site, on Mississippi Canyon Block 252 blew out on April 20, 2010 in the Gulf of Mexico with resulting loss two days later of Transocean Ltd., Deepwater Horizon, drilling rig along with 11 workers on the rig killed and numerous others wounded and traumatized. It is clear the well has copious amounts of high pressure oil and gas that is being wasted in this prolific blowout!

The Macondo well is 65% owned by BP (British Petroleum PLC), 25% by Anadarko Petroleum, and 10% owned by Mitsui Oil Exploration Company, Ltd.

Blowout preventers (BOPs) are stacked devices sitting on the well head in almost 5,000 feet of water (1520 meters) to prevent a blowout on the BP well. Clearly the BOPs did not control the blowout as seen by video cameras attached to remote operated vehicles equipped with television cameras show at the crumpled riser lying at the bottom of the sea. TV coverage of the blowout is unprecedented.

This calamity may be the largest oil spill in USA waters. As of June 1, 2010 pollution and contamination of sea water is unprecedented. How could this have happened with protective BOPs on the well head at the bottom of the sea? Speculation is rampant. The root of the problem is unknown at the beginning of June 2010. The world awaits retrieval of the BOP stack and control system for determination of the root cause of the problem based on physical inspection.

Three types of BOPs are used as safety devices on the subsea stack to prevent tragedies such as this spill. These are massive devices with steel reinforced rubber goods which are required to severely deflect to maintain unbroken contact against surfaces so a seal can be obtained. The contacting sealing pressures must be greater than the pressures to be contained (in some cases, the pressures are 20,000 psi which is 1360 bar).

**Annular** BOPs are like giant sphincter muscles surrounding the pipe to, upon command, prevent leakage around pipe. Hydril Company (now General Electric Oil & Gas) is generally attributed as the inventor of the first successful annular BOPs.

**Ram** BOPs are like giant hands that, upon command, close around the pipe sealing against the pipe and the BOP body—the rams blocks can also be blind to seal the opening if nothing is in the hole. Fixed ram blocks require each size of pipe to have specific ram size for the application (although some limited size ranges are covered by use of variable rams) to seal the pressures. Cameron Iron is generally attributed as the first successful ram inventor.

**Shear ram** BOPs are the last line of defense for blowout protection and they are located at the top of the BOP stack. Their job is to, upon command, close on what ever is in the hole and shear it. Shearing whatever is in the hole will part the string. The bottom portion of the string is dropping to the bottom of the hole. The top part of the string
moves upward from release of the weight on the rig hook so the shear ram blocks can then seal the hole against release of oil/gas/drilling mud.

BOPs are brutish devices. They deliver herculean forces to prevent imminent calamities.

First, the calamity must be detected.

Second, the control systems must be initiated to transfer hydraulic energy to the BOPs to prevent blowouts.

Third, closing of BOPs does not take place in the twinkle of your eye and this saps energy from the accumulators!

Fourth, BOPs require massive hydraulic energy from control systems with energy stored in high pressure hydraulic accumulators nearby.

Fifth, when pressures within the drilling system become uncontrolled and wild, the shear ram is the last to close and blank off the hole. Closing of the shear ram occurs when hydraulic accumulators are nearing the end of their stored energy.

Sixth, the final act of closing the shear ram must have sufficient power and strength to shear what ever is in the hole.

Seventh, after the material in the hole has been sheared, the BOP must seal the high pressures from the blowout for long time periods.

To date, there is no evidence the Macondo well site shear ram performed its intended function—hence the blowout for reasons not yet determined.

Great force is required to close the shear ram. What follows is a case study published in The New Weibull Handbook, 4th edition. It is unintentionally missing from early editions of the 5th edition. The data is from actual shear ram BOP tests in 1992 for the Shell Troll platform shear ram BOPS. This case study is published with permission of The New Weibull Handbook author, Dr. Robert B. Abernethy and with knowledge of the contributor of the case study, Ken Young. The test data described below was acquired using a commercial Hydril 18-3/4 15,000 psi shear ram as the data acquisition device. The shearing task is based on the drill pipe and not the drill pipe tool joint whereas the 6-5/8” screen contains a packed well screen on a slotted 5” casing and inside the casing is a 4” blast joint.

Shear RAM Blowout Preventer Tests

Contributed by: Kenneth D. Young, Hydril Company, Houston, TX.
[Ken is now with Mohr Engineering, a division of Stress Engineering Services in Houston, Texas]

Key Words: Pipe Shear Data, Log-normal, Judgment.

Blowout preventers (BOPs) are safety valves used during oil and gas drilling operations. During drilling operations, high pressure fluids and gases in the earth are controlled by drilling muds. Density and volume of drilling mud in the hole balances and controls pressures at the surface where the drilling rig is located. When sudden pressure changes occur within the well, a pressure "kick" occurs. A very small gas bubble in the
drilling mud at 25,000 feet depth becomes a huge gas pocket as the bubble rises. Rising bubbles blow mud out of the well causing blowouts. Wild well control requires BOP closures for preservation of life, limb, expensive drilling equipment assets, and avoidance of pollution while sealing pressures up to 20,000 psi.

Ram BOPs are specialized types of drill-through, hydraulically operated valves used to seal-off wellbore pressures by means of special reinforced elastomer sealing devices. Ram BOPs are stacked one above the other for acting as the last line of defense for preventing a blowout. Some ram BOPs seal around the pipe, others seal across the open hole, and the final safety device is a shear ram which cuts the pipe and seals the open hole. For offshore operations, ram BOPs play a vital role in controlling blowouts as sand in the wellbore quickly cuts through steel casing sinking drill ships into a "seltzer" mix of sea water and natural gas as they lose buoyancy. Shear ram BOPs cut through tubular goods in the open hole and then seal wellbore pressures as a last act of desperation in wild well control.

In offshore Norwegian waters, long, prolific, horizontal, gas wells are anticipated which cannot be killed by drilling offset wells and pumping mud into the formation if a blowout occurs. The ram BOP must reliably perform its assigned task. Norwegian customers expect 99.99% reliability for potential catastrophic equipment events. New technology for these wells will use prepacked slotted liners in 10,000 meter horizontal wells at 5000 psi. Shear tests were conducted on a Hydril® 18 ¾ - 15,000 psi ram BOP for determining ram BOP shear loads; this in turn determines size of the hydraulically operated pistons and volume of high pressure fluids which must be stored for drilling emergencies.

Figure 9-18 shows the sequence of events for shearing pipe. The shear samples supplied by the customer included 6 5/8-inch prepacked slotted liners, 5 ½-inch 21.9 lb/ft S-135 drill pipe, and 5-inch 19.5 lb/ft S-135 drill pipe. This provided enough material for making 14 shears on the prepacked liner and 12 shears on each drill pipe. More data was preferred but shear tests are costly. The issue was to make the most of the information available for safe designs. High speed digital equipment searched for the peak shearing forces during the shear.
The maximum force, F, is the ordinate in Figure 9-19. The object is to find the minimum shear force that will provide 99.99% reliability regardless of the type of pipe. If the equipment is sized too small (low force capability), it will not provide the protection desired by the customer. If the equipment is sized too large (high force capability), it will provide very low risk to the customer, but will not be cost or size competitive.

Table 9-7 shows shear forces found by experiment using customer supplied materials. An uncertainty analysis was not made for identifying allowable significant...
digits using 1/2% accuracy instruments, thus data rounding will occur at the design stage. From this data, design modifications will be made for upgrading equipment in the North Sea waters.

Table 9-7. Shear Forces (lbs)

<table>
<thead>
<tr>
<th>5&quot; Drill Pipe</th>
<th>5 1/2&quot; Drill Pipe</th>
<th>6 5/8&quot; Screen</th>
</tr>
</thead>
<tbody>
<tr>
<td>245,111</td>
<td>366,628</td>
<td>479,844</td>
</tr>
<tr>
<td>251,772</td>
<td>380,780</td>
<td>484,183</td>
</tr>
<tr>
<td>251,904</td>
<td>387,951</td>
<td>501,920</td>
</tr>
<tr>
<td>251,904</td>
<td>393,800</td>
<td>503,807</td>
</tr>
<tr>
<td>252,847</td>
<td>399,272</td>
<td>512,110</td>
</tr>
<tr>
<td>254,357</td>
<td>414,367</td>
<td>515,129</td>
</tr>
<tr>
<td>254,923</td>
<td>445,502</td>
<td>527,583</td>
</tr>
<tr>
<td>257,376</td>
<td>458,521</td>
<td>528,715</td>
</tr>
<tr>
<td>259,640</td>
<td>460,031</td>
<td>528,903</td>
</tr>
<tr>
<td>260,206</td>
<td>485,882</td>
<td>528,903</td>
</tr>
<tr>
<td>263,225</td>
<td>499,467</td>
<td>533,809</td>
</tr>
<tr>
<td>266,433</td>
<td>511,732</td>
<td>538,527</td>
</tr>
<tr>
<td></td>
<td></td>
<td>562,113</td>
</tr>
</tbody>
</table>

Figure 9-19 shows a log-normal plot of the data which has small variations as expected from material shear failure tests. The data trend lines were expected to show a family of curves. Trend lines which cross, particularly in the high load areas significantly influencing the design, violate a sense of propriety for this carefully acquired data. Crossing indicates a potential problem with either the log-normal model, which has previously been used successfully for modeling shear data, or with the data. The actual pve% goodness of fit suggests good curve fits.

A nagging question arises concerning steep curves and potential outliers. On one hand, the lowest data point in each file may have resulted from missing the peak shear loads because the digital data scan rates may have been too low for capturing the peak. Higher value shear loads occur over a longer time interval and thus the likelihood of capturing peak shear loads is greater.

The 5 ½-inch drill pipe data in Figure 9-19 is troublesome because data scatter occurs from mixed log-normal shear modes. Mixed modes were discovered by a critical examination of test procedures which were found slightly different from other tests. The amount of over-pressure supplied to the pistons driving the shear was lower and the 5 ½-inch drill pipe shear blade stalled on the largest six data points. This is analogous to chopping wood with an ax by pushing the ax blade through the wood without any inertial effects. Inertial effects existed in all other data acquired thus the largest six data points for the 5 ½-inch drill pipe result in overstated forces.

Data for the 5 ½-inch drill pipe is presented two ways in Figure 9-20 using all of the data. The worst case operating condition is represented by using the largest six data points and suspending the smallest six data points. Using the smallest six data points
while suspending the six largest points provides for a more realistic design criteria based on engineering judgment.

Even with the pve% goodness of fit above above the 10% critical values, mixed distributions of data are detectable when plotted on probability paper. This raises flags to search for assignable causes in the scatter even with very tightly grouped data as shown in Table 9-7. The suspension technique in Figure 9-20 identifies a bias in the data and permits plotting the resulting family of curves without inducing a larger slope in the curve. Knowing assignable causes for mixed distributions with bias provides clues for better utilization of data for designs. Judgment is always required for making design decisions even with high technology data processing tools!

Quality in engineering designs is achieved through sound judgment and proper use of engineering tools. This analysis resulted in the design being optimized for high reliability for safety and minimum size for cost.

Figure 9-20. Suspended Points For 5 ½ Drill Pipe Data

The conclusion is that the shear ram should be designed with a shear force capability of slightly over 600,000 pounds to provide the customer with assurance of 99.99% reliability.

**Author's [Dr. Abernethy] Comments:** There is much to commend here. Prior knowledge was used to select the log normal model even though a normal model fits slightly better. (Steep log normal distributions approach the normal.) There was a thorough analysis of the anomalies in the data and this lead to physical understanding. Not included herein were comparisons with other models, particularly t zero and extreme value models, which led nowhere. The final analysis is clear and provides a specific,
quantitative design requirement which will meet the customer's requirement based on the tests conducted. Excellent case study!

Some other details arise from the case study as noted below.

All shear tests were performed on the pipe body and not in the drill pipe tool joint section (the heavy section on the drill pipe containing the threaded connections) and not in the threaded connections for the 6-5/8” screen section—this may require repositioning the drill pipe in case the connection is not sheared on first attempt.

Typical API drill pipe sizes and grades frequently used in the oil patch are covered by API-5D and API-7-1:

<table>
<thead>
<tr>
<th>Drill Pipe OD (inches)</th>
<th>Nominal Weight (lbs/ft)</th>
<th>Pipe Wall Thickness (inches)</th>
<th>Tool Joint OD (inches)</th>
<th>Tool Joint ID (inches)</th>
<th>API Material Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-3/8</td>
<td>6.65</td>
<td>0.280</td>
<td>3-3/8</td>
<td>1-3/4</td>
<td>E-75, X-95, G-105, S-135</td>
</tr>
<tr>
<td>2-7/8</td>
<td>10.40</td>
<td>0.362</td>
<td>4-1/8</td>
<td>1-5/8, 2, 2-1/8</td>
<td>E-75, X-95, G-105, S-135</td>
</tr>
<tr>
<td>3-1/2</td>
<td>13.3, 15.50</td>
<td>0.368, 0.449</td>
<td>4-3/4, 5, 5-1/2</td>
<td>2-1/8, 2-1/4, 2-7/16, 2-9/16, 2-11/16</td>
<td>E-75, X-95, G-105, S-135</td>
</tr>
<tr>
<td>4</td>
<td>14, 15.70</td>
<td>0.330, 0.380</td>
<td>5-1/4, 5-1/2, 6</td>
<td>2-7/16, 2-11/16, 2-13/16, 3, 3-1/4, 3-1/2</td>
<td>E-75, X-95, G-105, S-135</td>
</tr>
<tr>
<td>4-1/2</td>
<td>16.60, 20.00</td>
<td>0.337, 0.430</td>
<td>6-1/4, 6-5/8</td>
<td>2-1/4, 2-1/2, 2-3/4, 3, 3-1/4, 3-1/2, 3-5/8, 3-3/4, 3-3/4,</td>
<td>E-75, X-95, G-105, S-135</td>
</tr>
<tr>
<td>5</td>
<td>19.50, 25.60</td>
<td>0.362, 0.500</td>
<td>6-5/8, 7, 7-1/4</td>
<td>2-3/4, 3, 3-1/4, 3-1/2, 3-3/4,</td>
<td>E-75, X-95, G-105, S-135</td>
</tr>
<tr>
<td>5-1/2</td>
<td>21.90, 24.70</td>
<td>0.361, 0.415</td>
<td>7, 7-1/4, 7-1/2</td>
<td>3-1/2, 3-3/4, 4</td>
<td>E-75, X-95, G-105, S-135</td>
</tr>
<tr>
<td>6-5/8</td>
<td>25.20, 27.70</td>
<td>0.330, 0.362</td>
<td>8, 8-1/4, 8-1/2</td>
<td>4-1/4, 4-3/4, 5</td>
<td>E-75, X-95, G-105, S-135</td>
</tr>
</tbody>
</table>

The tool joint can be hard-banded or internally coated for longer life. Grade E-75 is the lower grade drill pipe with 75,000 psi yield strength where as Grades X-95, G-105, and S-135 refer to high strength drill pipe. S-135 is the strongest drill pipe. Over the years, drill pipe has gotten stronger, more ductile, and less notch sensitive.

Probability Plots Of Experimental Data

Three typical distributions for modeling shear ram tests are shown below for comparison using all data from the table shown above in Table 9-7. You can download a demonstration version of SuperSMITH Weibull at
The demo version will run the authentic files with hyperlinks below to replicate the data and use the precise reading from plot icon to replicate the expected forces at 99.999% occurrence where the results are obtained by extrapolation. The files you can download for the demonstration software are:

- Weibull shear ram test data
- Lognormal shear ram test data
- Gumbel upper shear ram test data
- Weibull shear ram test data with suspensions
- Lognormal shear ram test data with suspensions
- Gumbel upper shear ram test data with suspensions

DO NOT save the data files while in the demonstration software as this will void the authenticity of the files and the data will be slightly randomized.

Weibull distributions model failure of the weakest link in the system show by use of all data-

![Hydril 18-3/4 - 15,000psi Shear Ram Test](image)

At 99.999% value the forecasted forces by the Weibull distribution are:

- 5” Drill Pipe = 270,893 pounds force
- 5-1/2” Drill Pipe = 573,252 pounds force
- 6-5/8” Drill Pipe = 579,549 pounds force

Note all three curves have p-value estimates (pve%) greater than the minimum requirement of 10% thus they display a good curve fit.

Lognormal distributions model accelerating failures in the system shown by use of all data (notice the magnification in the upper regions of the lognormal probability plot)-
At 99.999% value the forecasted forces by the lognormal distribution are:

- 5” Drill Pipe = 283,589 pounds force
- 5-1/2” Drill Pipe = 720,644 pounds force
- 6-5/8” Screen = 630,808 pounds force

Note all three curves have p-value estimates (pve%) greater than the minimum requirement of 10% thus we have a good curve fit.

Gumbel upper distribution (the Gumbel upper statistical distribution was not available in the software when the BOP shear ram tests were conducted) which models the largest values recorded in the system shown by use of all data.
At 99.999% value the forecasted forces by the Gumbel distribution are:

- 5” Drill Pipe = 311,389 pounds force
- 5-1/2” Drill Pipe = 902,083 pounds force
- 6-5/8” Drill Pipe = 727,453 pounds force

Note all three curves have p-value estimates (pve%) greater than the minimum requirement of 10% thus we have a good curve fit.

Next, following the method proposed by Ken Young of suspending (not eliminating the data) for the 6 smallest data points and 6 largest data points for the 5-1/2 drill pipe we see the following plots (note the designation of n/s in the statistics portion of the plot where n=the total number of data points and s=the number of suspensions (i.e., censored data). The suspensions occurred because of the physically identified different modes of failure.

Weibull distribution with 5-1/2 drill pipe smallest 6 data points suspended for a different mode of failure and corresponding 6 largest data points suspended for 5-1/2 drill pipe:

At 99.999% value the forecasted forces by the Weibull distribution with suspensions are:

- 5” Drill Pipe = 270,893 pounds force
- 5-1/2” Drill Pipe = 467,331 pounds force suspending top 6 data vs 573,252 pounds force w/o suspensions
- 5-1/2” Drill Pipe = 556,276 pounds force suspending bottom 6 data vs 573,252 pounds force w/o suspensions
- 6-5/8” Drill Pipe = 579,549 pounds force

Note all four curves have p-value estimates (pve%) greater than the minimum requirement of 10% thus we have a good curve fit.

Lognormal distribution with the 5-1/2” drill pipe smallest 6 data points suspended for a different mode of failure and corresponding 5-1/2” drill pipe 6 largest data points suspended:
At 99.999% value the forecasted forces by the lognormal distribution are:

- 5” Drill Pipe = 283,589 pounds force
- 5-1/2” Drill Pipe = 569,159 pounds force for suspended top 6 data vs 720,644 pounds force
- 5-1/2” Drill Pipe = 627,070 pounds force for suspended bottom 6 data vs 720,644 pounds force
- 6-5/8” Drill Pipe = 588,166 pounds force vs 630,808 pounds force

Note four curves have p-value estimates (pve%) greater than the minimum requirement of 10% thus we have a good curve fit.

Gumbel upper distribution with the 5-1/2” drill pipe smallest 6 data points suspended for a different mode of failure and corresponding 5-1/2” drill pipe 6 largest data points suspended:
The Gumbel upper distribution projects very large values and it also looses the family of curves property which seems irrational although the Gumbel upper distribution is frequently used when the largest data values are reported as is the case with flood data. Notice the Gumbel upper distributions magnification is such that ~3/4 of the Y-axis covers the range from 90% to 99.999%.

At 99.999% value the forecasted forces by the Gumbel distribution are:

- 5” Drill Pipe = 311,389 pounds force
- 5-1/2” Drill Pipe = 761,270 with the bottom 6 suspension vs 902,083 pounds force with no suspensions
- 5-1/2” Drill Pipe = 788,132 pounds force with top 6 suspensions and this is the largest forecasted force vs 902,083 pounds force with no suspensions which is biased by the lack of suspensions detected in the physical evaluation of failures.
- 6-5/8” Drill Pipe = 727,453 pounds force

Note all four curves have p-value estimates (pve%) greater than the minimum requirement of 10% thus we have a good curve fit even though the disturbing situation of loss of family of curves is displayed and thus the use of the Gumbel upper distribution is ruled out on the basis of engineering judgment.

The design safety factor covers the highest and realistic failure load with 600,000 force based on 2700 psi control system pressure would provide 666,600 force at 3,000 psi rated capability of the control system. Did you also note the customer expectations were for 99.99% reliability and the design criteria was for 99.999% reliability for an extra safety factor. All probability plots used the engineering method of rank regression for curve fits.
Why were no three-parameter probability plots used as you would expect no shear failures before a specified force level? Dr. Abernethy in The New Weibull Handbook gives four specific rules which must be followed prior to making a three-parameter plot:

1. The two-parameter plots must show concavity (either upward or downward). The two-parameter curves above do not show obvious curvature.
2. You must have at least 21 data points. (Maybe ~100 data if curvature is gentle). We only have 12 and 13 data points.
3. You must have a physical reason for an offset of the axis. We have a threshold load that must be reached prior to shearing of the pipe. (By the way, simply making a better curve fit is not a physical reason for use of a 3-parameter plot.)
4. The three-parameter goodness of fit must be substantially better than the two-parameter curve fit. (The three-parameter curve fit is not appropriate for the Gumbel distribution.)

Two parameter concave upward plots indicate a certain percentage of the population arrive prefailed. Whereas two parameter concave downward plots indicate a specific load value must be exceed before any failure can occur—in short, this indicates a failure free zone. For a shear ram BOP it is reasonable to expect no shearing action would occur until a threshold force has been reached but more data is required to validate this expectation.

The data sets shown above fail to meet the four specific rules for use of a three-parameter distribution. Only one rule (physical reason for curvature) is met out of the four requirements. If more data was available, then perhaps the four criteria would be met for a three parameter probability plot.

Recent USA Federal Requirements-
The Department Of Interior’s May 27, 2010 publication of Increased Safety Measures For Energy Development On The Outer Continental Shelf sets new requirements of safety features on BOPs and related backup and safety equipment on page 3 including:

“…a requirement that BOPs have two sets of blind shear rams spaced at least four feet apart to prevent BOP failure in a drill pipe or drill tool is across on[e] set of rams during an emergency;…”

The dual shear ram thinking is that if the thicker drill pipe tool joint blocks one set of rams from shearing the material in the hole, the second set of rams will land on only the smaller diameter drill pipe. Note the shear rams are physically in series. However, you must consider how they function as the functional results can be either in series (lower reliability) or in parallel (higher reliability) for the shearing operation.

A series reliability equation for each element in the system is:

\[ R_{\text{series system}} = R_1 \times R_2 \times R_3 \times R_4 \ldots \]

A parallel reliability equation for each element in the system is

\[ R_{\text{parallel system}} = 1 - (1-R_1) \times (1-R_2) \times (1-R_3) \times (1-R_4) \ldots \]

Special note for a parallel system, each element in the parallel system must be capable of carrying the full load.
For example, if the dual shear rams can cut through drill pipe tool joints with say 50% reliability and say 99.99% reliability for shearing the drill pipe, then functionally this system is in parallel and the system reliability would be $R_{system} = 1-(1-0.5)*(1-0.9999) = 0.99995$ which means the unreliability of the system is 0.00005. This is less than the reliability of commercial aircraft wings.

However, if the dual shear ram will not part the string at a tool joint and it will part the string at the drill pipe with a reliability of say 99.99%, then the system reliability would be $R_{system} = 1-(1-0)*(1-0.9999) = 0.9999$ which then functionally, the system is in series as the unreliability of the system is 0.0001. This is roughly the allowed reliability required for exposure of one human to a potential fatality. Remember the shear rams are only a portion of the entire safety system, so don’t be misled by the reliability of one block in the block diagram system as being adequate.

Since the dual ram requirement is for safety, health, and environment which should then requires the shear ram to part the tool joint for more reliable operations. The % change in unreliability based on the functionally dual shear system compared to the series functioning system will show as % change in unreliability = $(0.000,05-0.000,01)/0.000,05 = -0.000,05/0.000,05 = -100\%$. This is a huge deterioration in unreliability if the shear rams cannot cut the tool joint in a dual ram arrangement.

Of course cutting material in the hole is the first task of a shear ram. The shearing must be followed by equal ability of the shear ram to seal very high pressures during the blowout. Likewise it is imperative that the system meet the seven requirements noted above.

F. R. Farmer’s risk charts can help determine how much unreliability society says can be tolerated as shown below and available as Figure 1-1 and Figure 6-1 from NUREG-74/014.
Following the publication of the May 27, 2010 regulations mentioned above other requirements have followed the Deepwater Horizon tragedy on Regulations to Strengthen Drilling Safety, Reduce Risk of Human Error on Offshore Oil and Gas Operations of September 30, 2010:

1. A fact sheet on The Drilling Safety Rule,
   A few of the key provisions are:
   Mandatory requirement of API PR 65—Part 2 for isolating potential flow zones during well construction.
   Requirement of certification by a professional engineer that the casing and cementing program is fit for use.
Requirement of two independent test barriers across each flow path during completion activities.

Requirement of ensuring proper installation, sealing, and locking of casing liners.

Requirement of approval from the BOEM [Bureau of Ocean Energy Management] District Manager before replacing heavy drilling fluid with lighter fluid

Requirement of enhanced deepwater well control training for rig personnel.

Requirement of independent third party verification that shear rams are capable of cutting drill pipe under maximum anticipated pressures

Requirement of subsea BOP stacks capable of ROV intervention.

Requirement of maintaining a ROV [Remote Operated Vehicle, i.e., a submarine] with trained crew on each floating drilling rig on a continuous basis.

Requirement of a auto shear and deadman system for dynamically positioned rigs

2. A fact sheet on Workplace Safety Rule, and
   A few of the key provisions are:
   - Mandatory requirement of API RP-75 on use of the 13 elements of Workplace Safety Rules which includes:
     - General provision for a Safety and Environmental Management Systems [SEMS].
     - Safety and environmental information
     - Hazards analysis
     - Management of change
     - Operating procedures
     - Safe work practices
     - Training
     - Mechanical integrity
     - Pre-startup review
     - Emergency response and control
     - Investigation of incidents
     - Audits
     - Records and documentation

3. A fact sheet on recent offshore oil and gas reforms.
   A few of the key provisions are:
   - BOEM has increased the bar for:
     - safety,
     - oversight, and
     - environmental protection
     - at every stage of review, permitting, drilling, and development process for offshore oil and gas operations.
   - New provisions exist at the environmental review stage
   - New provisions exist at the permitting stage with independent certification by a professional engineer
New provisions exist at the drilling and production stage for testing and CEOs of drilling companies must document by their signature that certify rigs comply with all requirements. All of these new requirements (plus other published details) are intended to reduce the risk of offshore failures and the consequent imperilment of life, equipment, and environment.

What About Confidence Limits?
The trend lines shown in the probability plots are 50% confidence lines. If you add 90% confidence limits to the plots, the confidence limits are very wide because of the few test data. The right hand confidence intervals at higher loads requiring greater capability for inherent shearing loads so the left hand limits are the important values for how much more capability you need. How much more money would you like to spend to narrow the limits?—the usual answer from people financing the tests is no more testing. Thus you have what you have from the limited test data. Most people financing further testing are reluctant to spend the testing cash. One way around the confusing issues of confidence intervals is to simply set the standard to a higher reliability standard and thus avoid arguments about what the confidence intervals really mean.

In Summary-
Multiple sheared test results are required to establish the reliability of the shear ram preventer on a statistical basis. The probability density function of the shearing forces is lognormal distribution with longer tails to the right which means higher shearing forces. Most shear ram preventers expect to shear only the drill pipe which means about 3 feet of every 32 foot long joint of drill pipe (3'/32' = 9.4% of the pipe) cannot be sheared. Substantial improvements in system reliability can be achieved if dual shear rams are used as compared to existing shear rams that cannot cut tool joints. Further large gains in system reliability can be achieved provided both shear rams can cut the tool joints on drill pipe.

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