Assessment of BOP Stack Sequencing, Monitoring and Kick Detection Technology

Final Report 01 – BOP Stack Sequencing and Shear Ram Design

January 23rd, 2014

A Wood Group kenny business

Outline

- Introduction
- **Section 1: Stack Design and Sequencing**
  - Industry Practices and Requirements for Stacking and Sequencing
- **Section 2: Shear Ram Performance and Design**
  - Shop Test and Results
  - Development of FEA Simulation Model
  - Validation of FEA Model with Test Data
  - Shear Ram Performance Evaluation using Validated Simulation Model
  - Flowing Well Simulations
- **Conclusions**
- **Recommendations**

Introduction

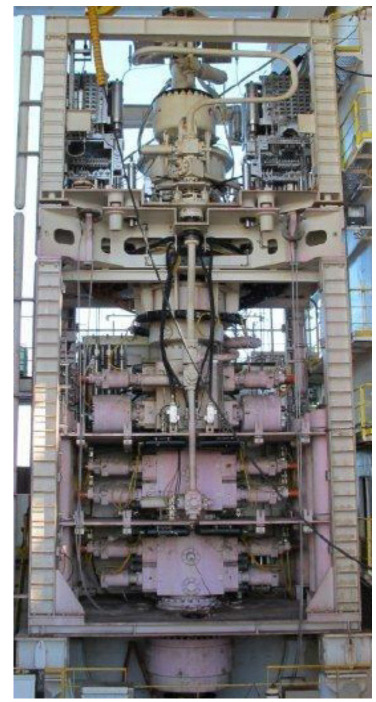
- This project is awarded in response to BSEE Broad Agency Announcement number **E12PS00004, TAP NO: 713.**
- The project assesses 3 key areas of a Blowout Preventer (BOP), including:
  - Topic 1: Ram Sequencing and Shearing Performance
  - Topic 2: BOP Monitoring and Acoustic Technology
  - Topic 3: Kick Detection and Associated Technologies

This presentation covers Topic 1.

Upper Shear Ram

Lower Shear Ram

Surface BOP



Subsea BOP

Section 1

Stack Design and Sequencing

Industry Practices and Requirements for Stacking and Sequencing

- Drilling contractors have BOP's built to rigorous design specifications with multiple redundant rams.
- One drilling contractor interviewed is building 6 new rigs with 7 ram stacks.
- Subsea Stacks of class 7 or 8 have many implications:
  - Older wells may not be designed to support the loads of new generation stack.
  - Larger stack has implications on rig design (6 ram BOP stack is 50ft compared to 8 ram BOP stack of ~63ft.
  - Size and weight of stacks impact deck design, handling and deployment.
  - Brings operational challenges associated with working at increased heights for maintenance and testing.

Industry Practices and Requirements for Stacking and Sequencing

- BOP system with larger stacks and increased number of rams
  - Can be more complex
  - Maintenance time goes up
  - BOP downtime could lead to significant expense to drilling contractor
  - For one drilling contractor, BOP down time cost is $80 million in 2012
  - New rigs with two BOP stacks to reduce maintenance delays and shorten drilling time
- BOP Standards [API 53]
  - Risk assessment should be performed by equipment user and owner
  - If single ram is incapable of shearing and sealing, 2 rams can be used
  - Subsea BOP shall include a minimum of:
    - One Annular Preventer
    - Two Pipe Rams
    - Two sets of shear rams (at least one capable of sealing)

Industry Practices and Requirements for Stacking and Sequencing

- Number of Rams installed in BOP determined by:
  - Drill Pipe and Casing Sizes
  - Operator and Regulatory Requirements
  - Moored or dynamically positioned rig
  - Rig limitations
  - Stripping and hang off capability of the rams
  - Shear capability of the rams
  - Sealing capability of the ram
- Blind Shear Rams (BSR)
  - Developed to allow rapid disconnect from well
  - Shortened time required to shear and seal
  - Dual function bring uncertainty around potential damage to seals
  - Requirements to fold over the lower drill pipe section

Industry Practices and Requirements for Stacking and Sequencing

- Casing Shear Rams (CSR)
  - These non-sealing rams should be used with BSR
  - Multiple scenarios to be considered when using CSR (stuck casing, black-out leading to draw works failure, locking and the sheared casing not picked up)
  - Some vessels adopted the practice of having a BSR both above and below the CSR
- Ram Sequencing
  - If BSR’s located above CSR’s – cut pipe must be lifted above the BSR’s prior to closing the BSR’s. If pipe is not moved, the risk is that the BSR’s will not close fully
  - If BSR’s located below CSR’s – cut pipe can fall away from BSR allowing closure of BSR, provided the cut pipe is not stuck or suspended on the pipe rams

- Any automatic sequencing involving BSR and CSR is problematic in nearly all cases.
- Sequencing must be influenced by condition and equipment besides the BOP control system.
- The correct response for sequencing differs with situation and pipe movement
- Incorrect operation or sequence may be worse than no sequence, particularly in a blow out scenario

Section 2

Shear Ram Performance and Design

Shear Ram Design Challenges

- Some of the present challenges being faced by BOP shear ram technology include:
  - Pipe centralization
  - Shearing of compressed/buckled pipe
  - Shearing of flowing well conditions
  - Non-shearables across the BOP
  - Combined shearing and sealing
  - Multiple rams needed to shear different grades of drill pipe and casing

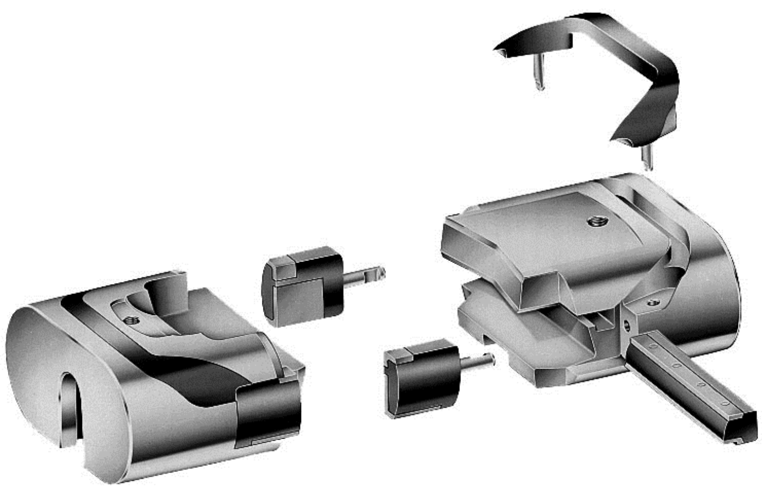
Objectives

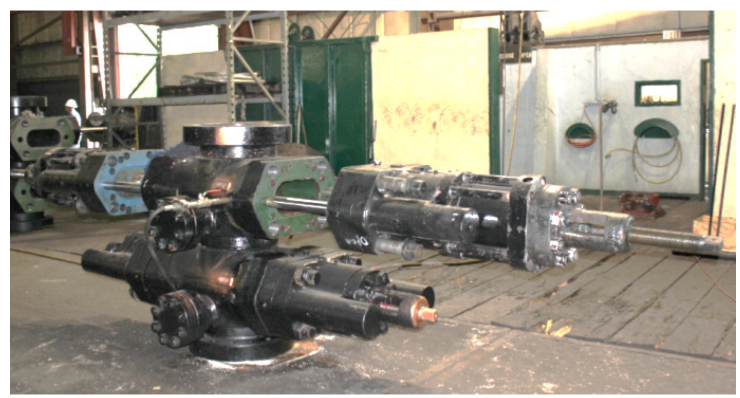
- Conduct a shop test to shear a drill pipe in non-flowing conditions
- Develop a methodology to model shearing process using FEA
- Validate the FEA Model with shop test data
- Test the scalability of validated model for higher drill pipe sizes and compare against OEM formulas
- Study the effect of various parameters on the shearing performance:
  - Non-centralization of Drill Pipe in Well bore
  - Pre-load on Drill Pipe
    - Tension
    - Compression
    - Buckling
  - Flowing well Simulations
- Evaluation of different shear ram design features

Shop Test

- Primary objective is to shear drill pipe and capture information such as:
  - Shearing Force
  - Shearing time
  - Deformed shape of sheared pipes
- Test conducted By Archer at Amelia facility on May 31st, 2013

Parameter	Value
BOP Type	Surface BOP
Shear Rams	Blind & V-Shear
BOP bore (inch)	13-5/8
Drill Pipe OD (inch)	3-1/2
Drill Pipe Material	S-135
No of tests	2

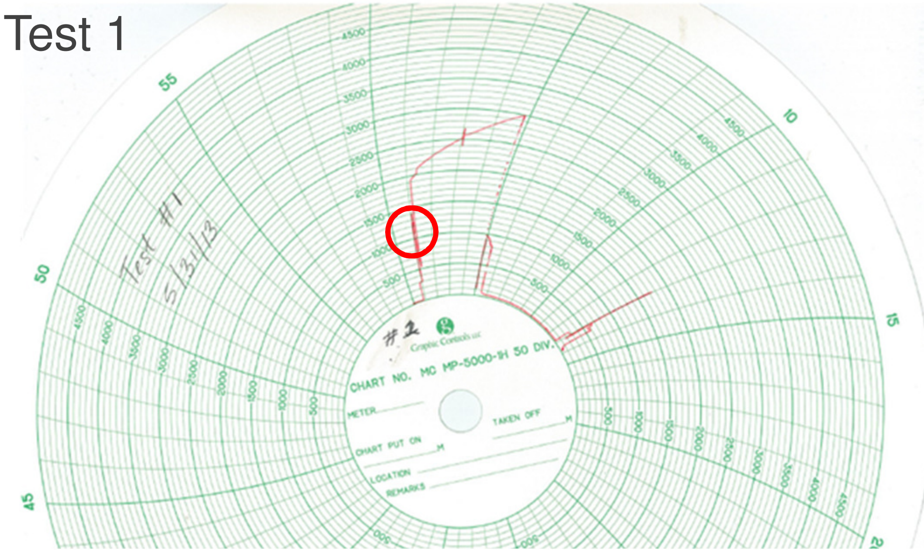




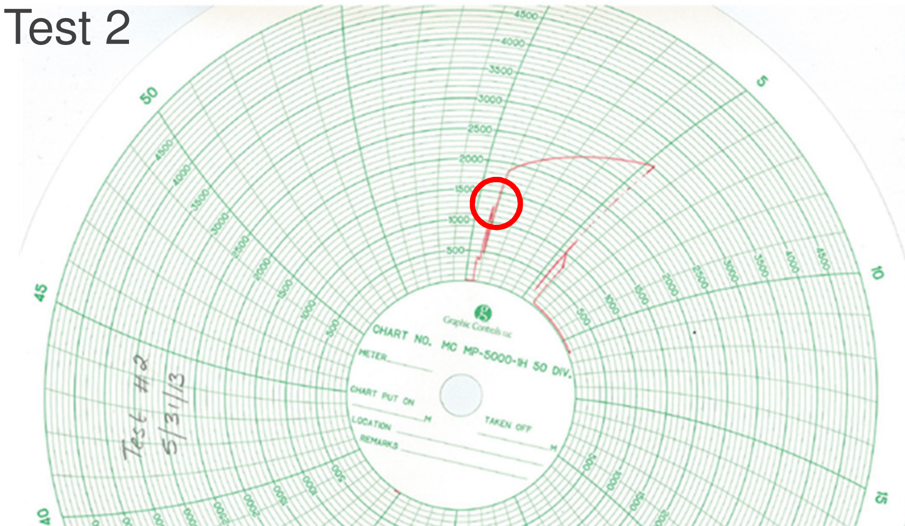
Surface BOP

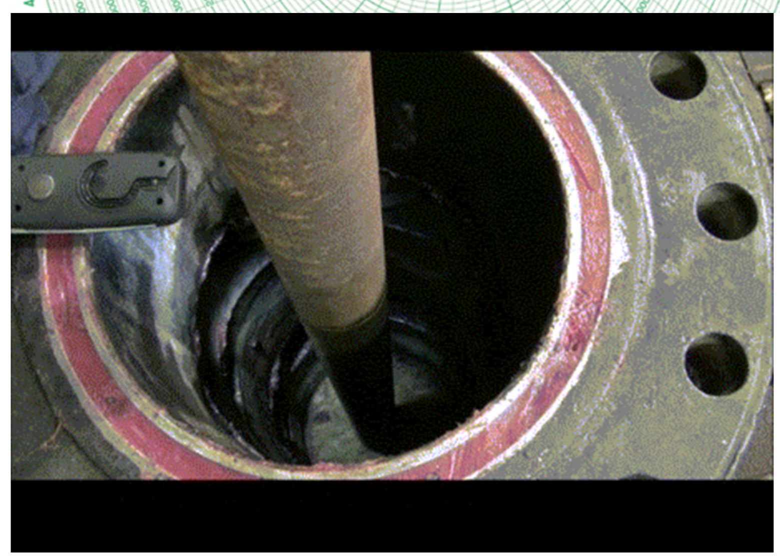
Shop Test

Test 1



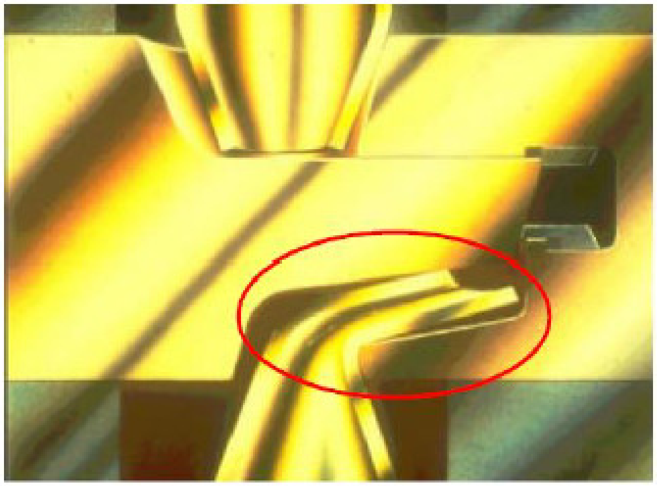
Test 2



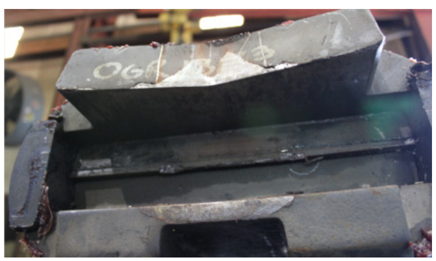


Test	Shearing force (lbf)
1	313,600
2	280,000

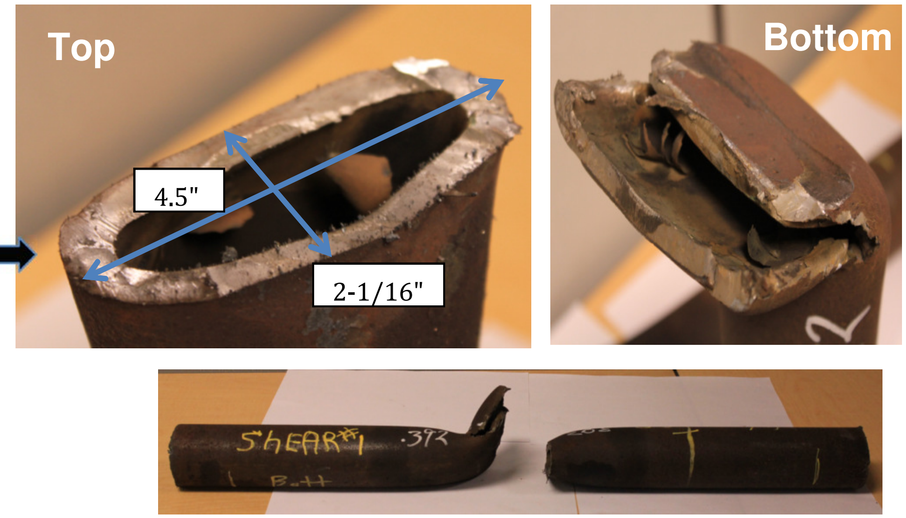
Shop Test



Schematic



Test 1



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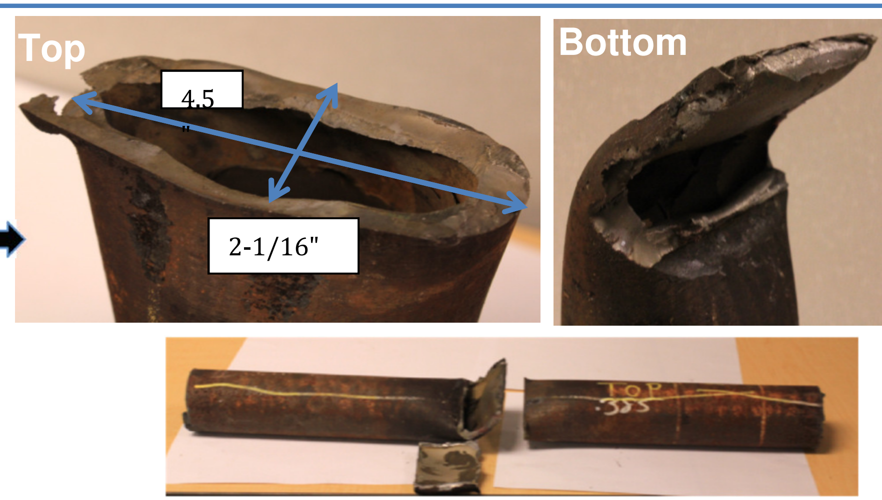
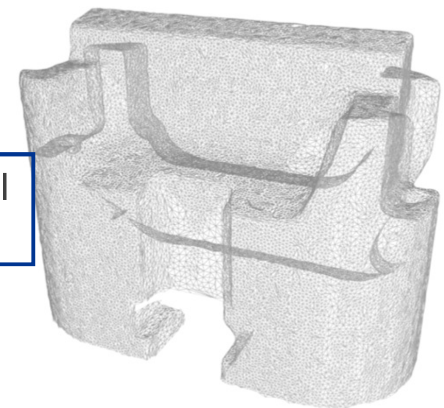
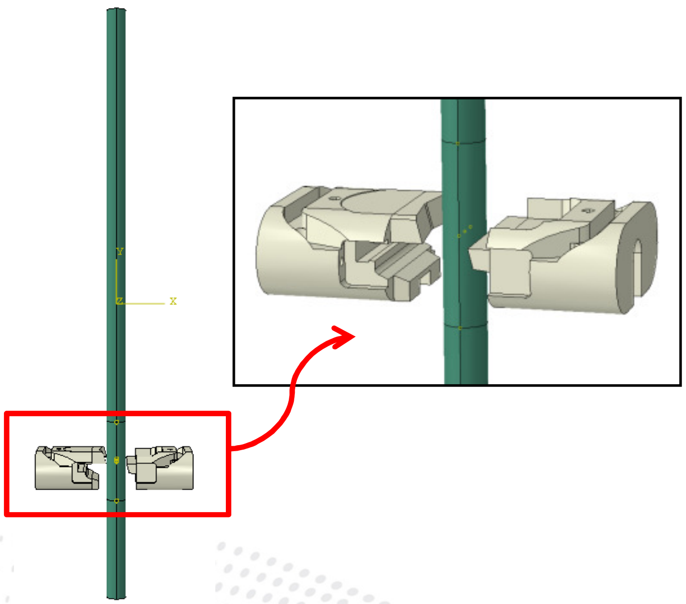


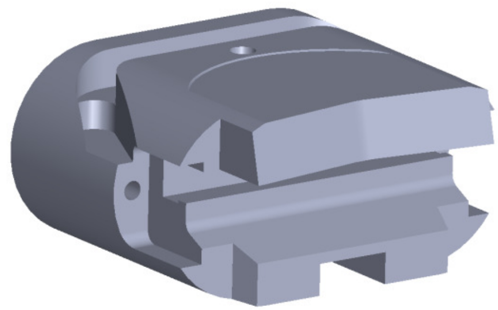
FEA Model

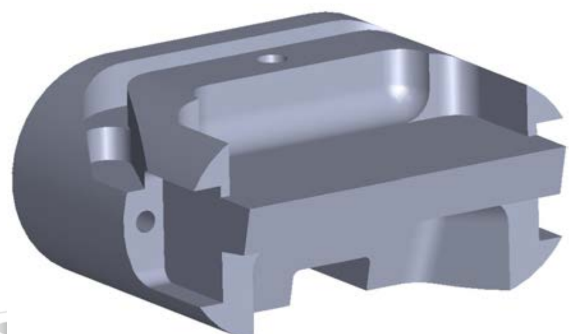
- Geometry obtained by laser scanning actual model
- Sealing is not considered in this study
- FEA software used: Abaqus Explicit
- Boundary Conditions

Raw hexagonal file format









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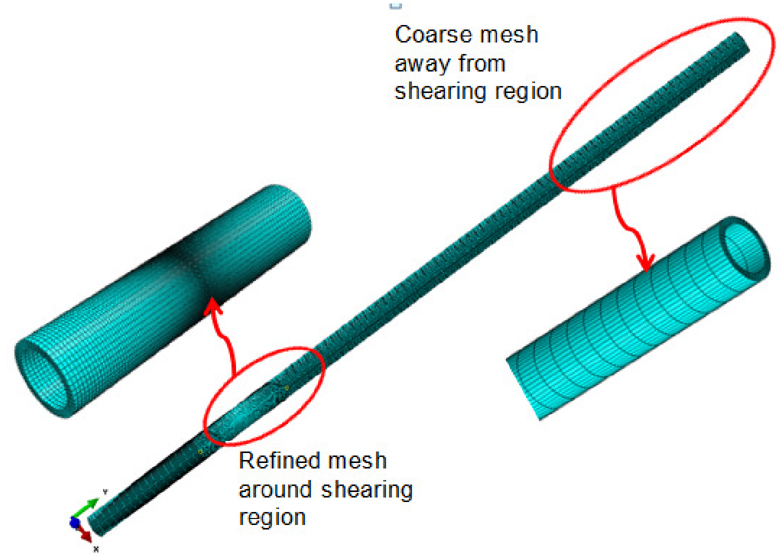
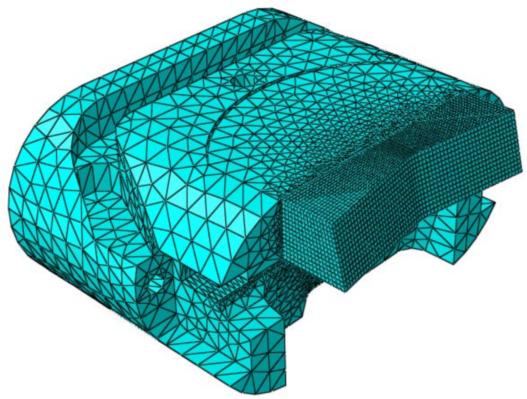
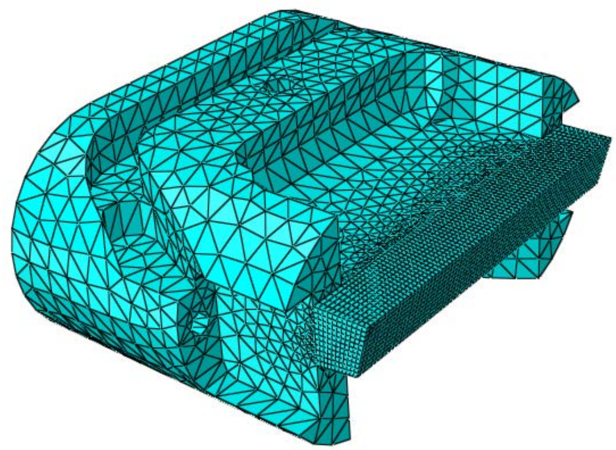
Computer Model (Continued)

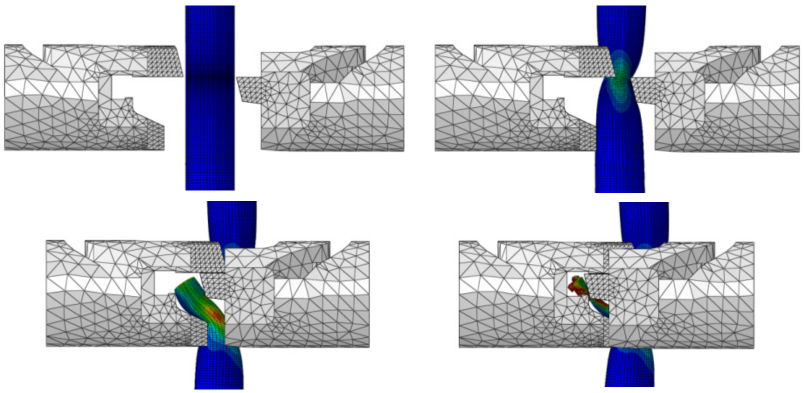
- Mesh
- Elastic-Plastic Material Model
- Damage Model
- General Contact
- Sensitivity of Simulation Parameters

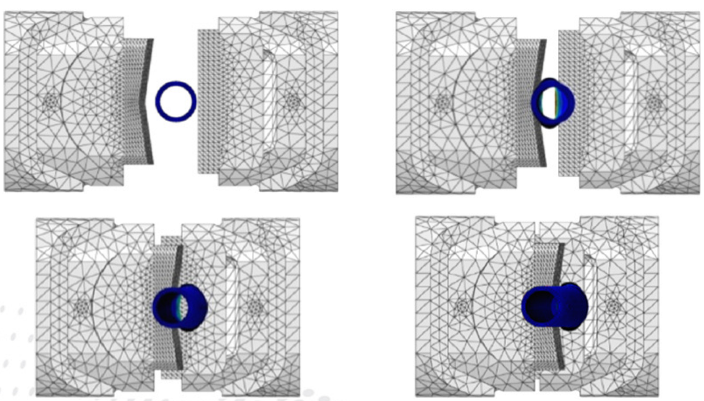


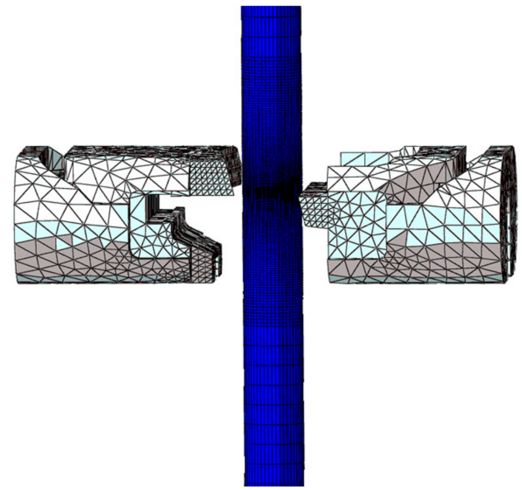


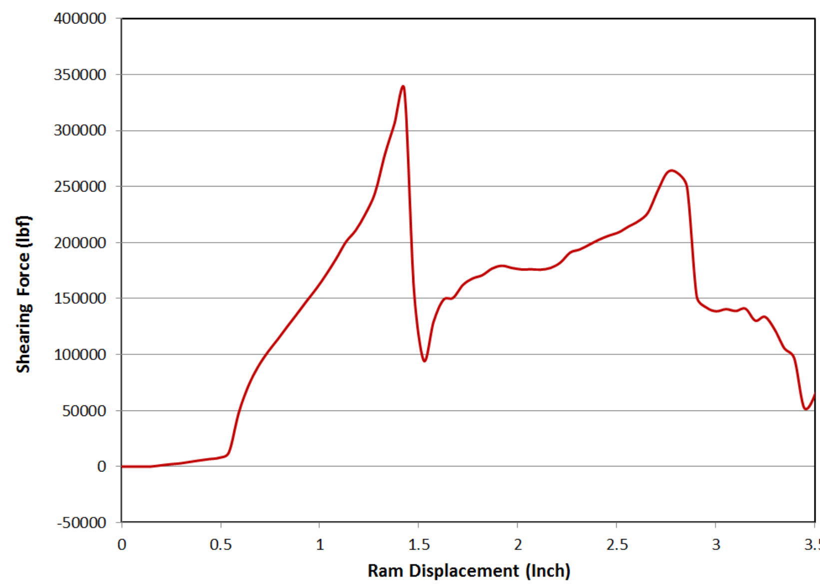


Simulation Results

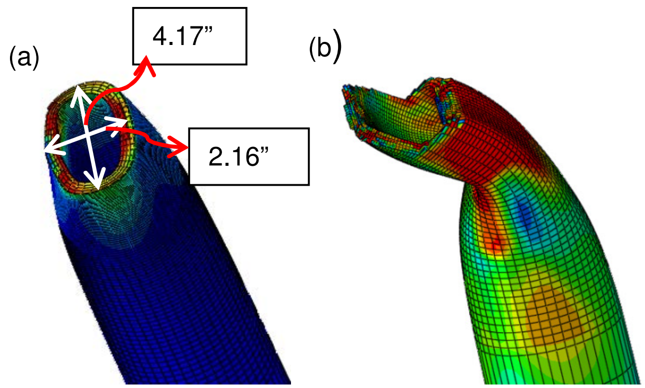




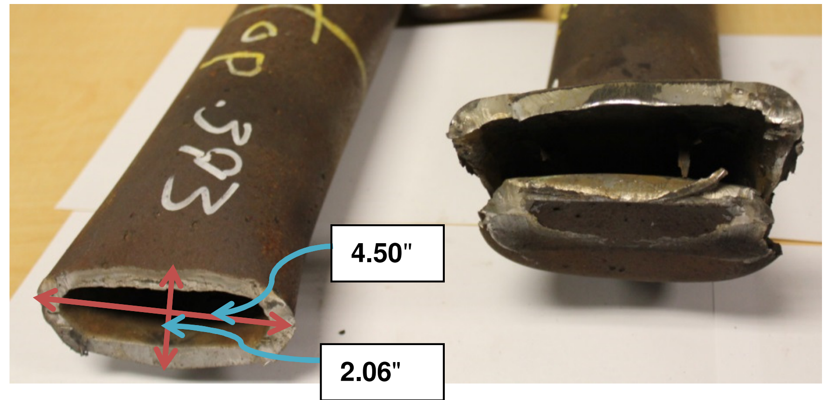




Validation



Sheared Drill Pipes, (a) Top, (b) Bottom

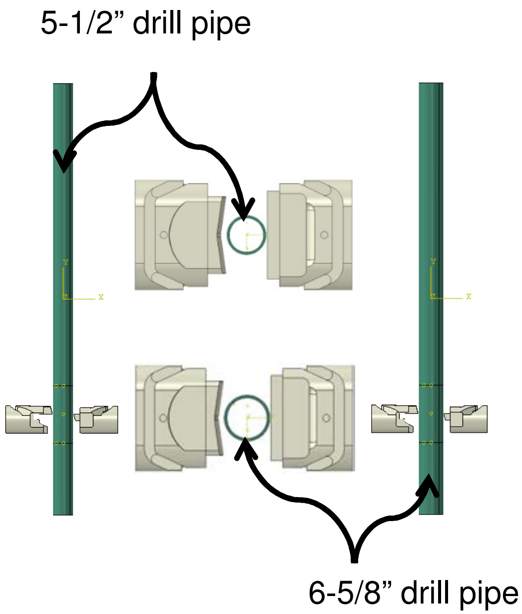


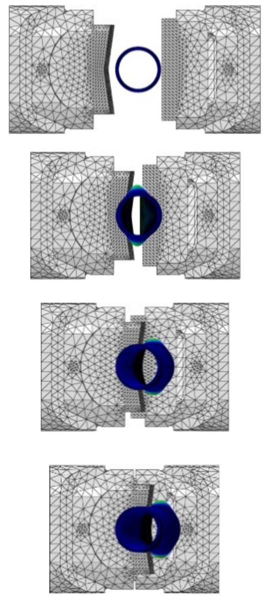
Shop Test 1

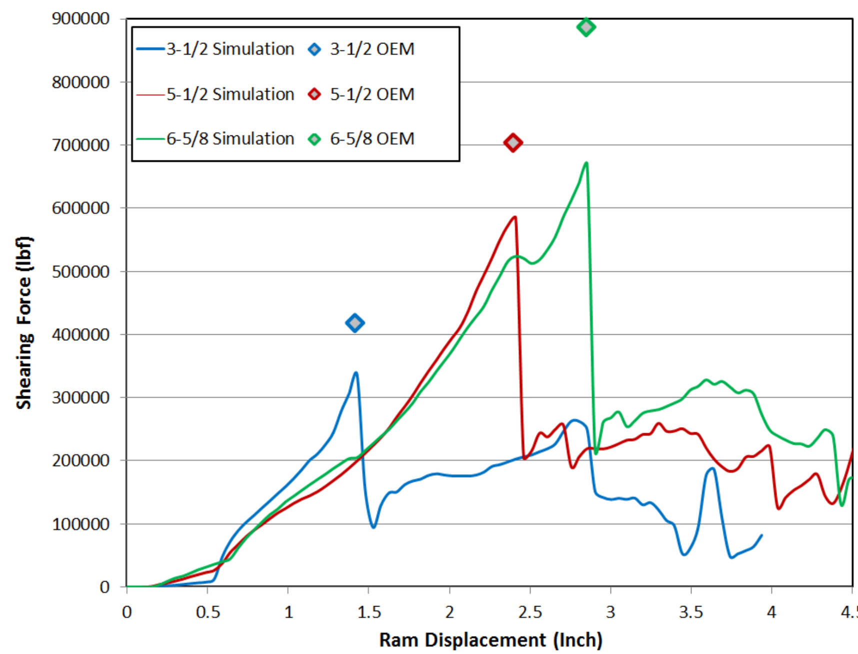
3.5	296,800	336,160	13.26%

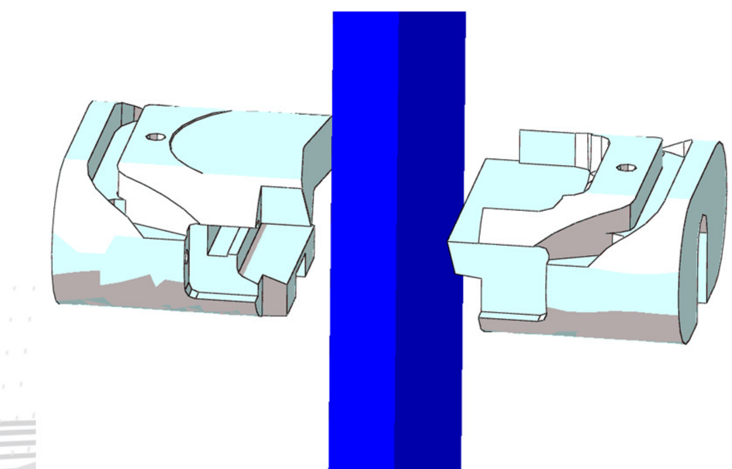
Shop Test 2

Scaled Model 5-1/2” and 6-5/8” Drill Pipes







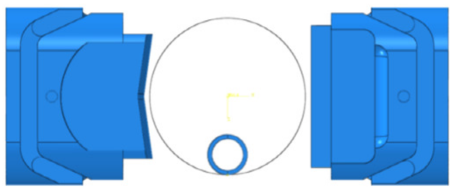


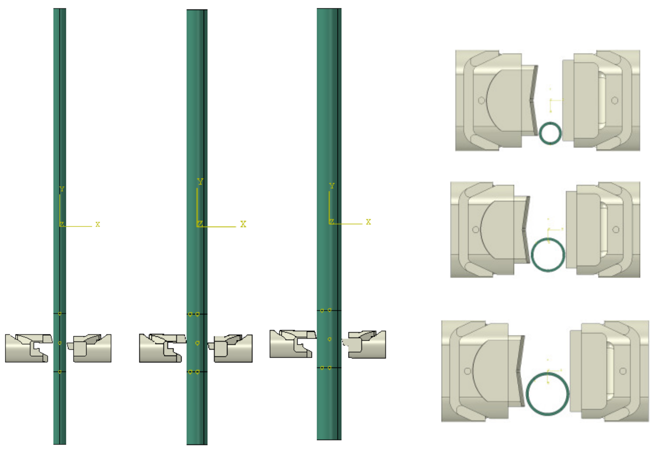
Drill Pipe Diameter OD (Inch)	FEA Analysis Max. Shearing Force (lbf)	OEM Formula Max. Shearing Force (lbf)	% Difference
3-1/2	336,160	417,984	24.34
5-1/2	584,255	702,338	20.21
6-5/8	668,842	886,016	32.47

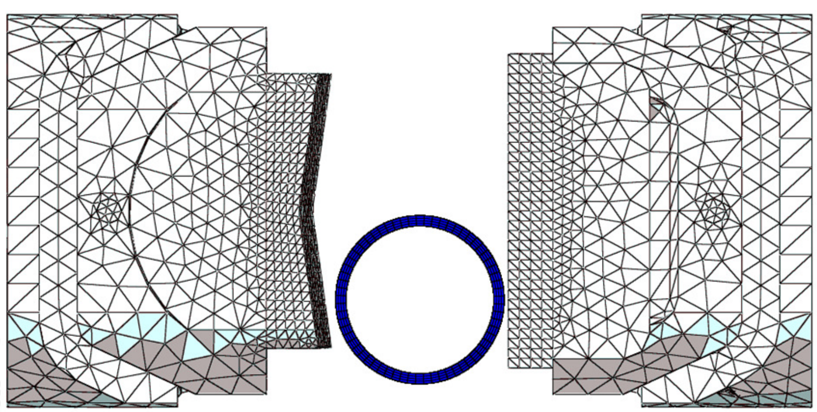
Methodology is scalable for other drill pipe sizes

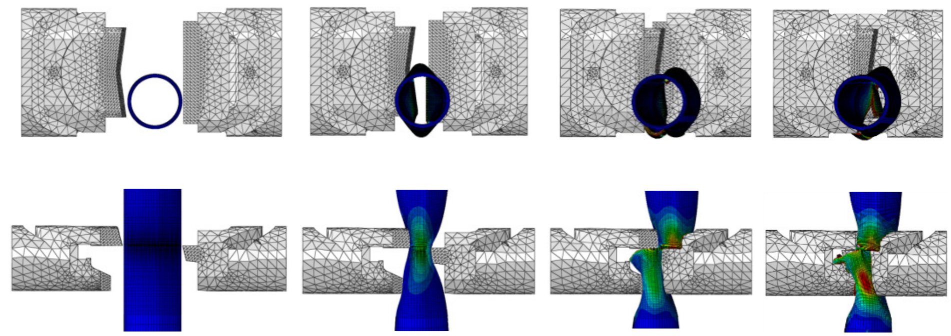
Non-centralized 3-1/2”, 5-1/2” & 6-5/8” OD

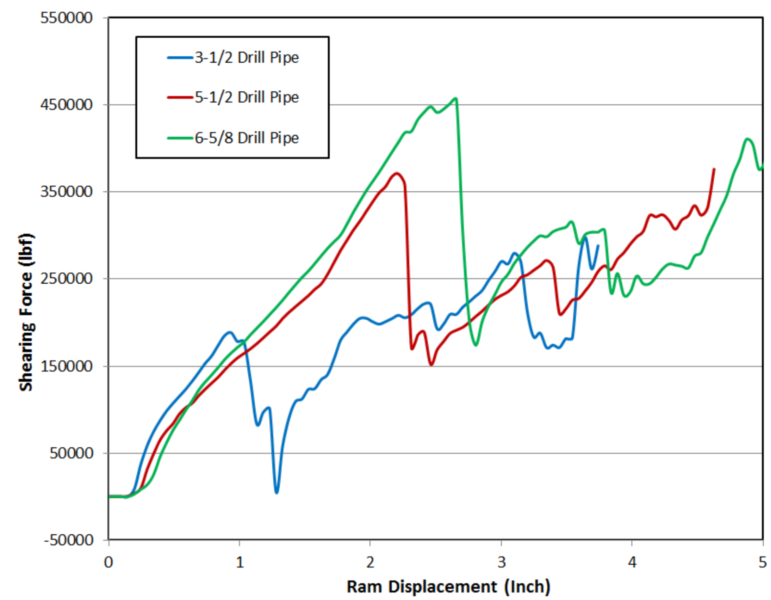
Schematic





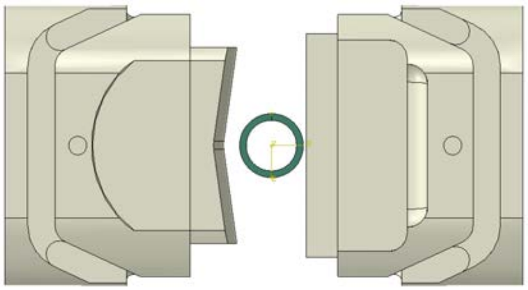




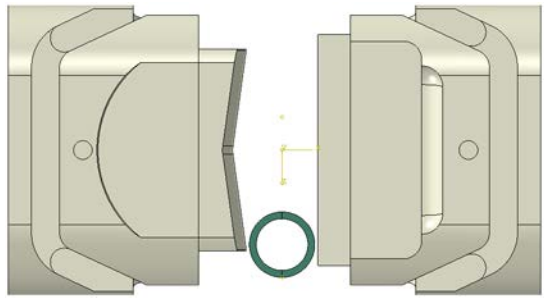


Non-Centralization Not Preferred

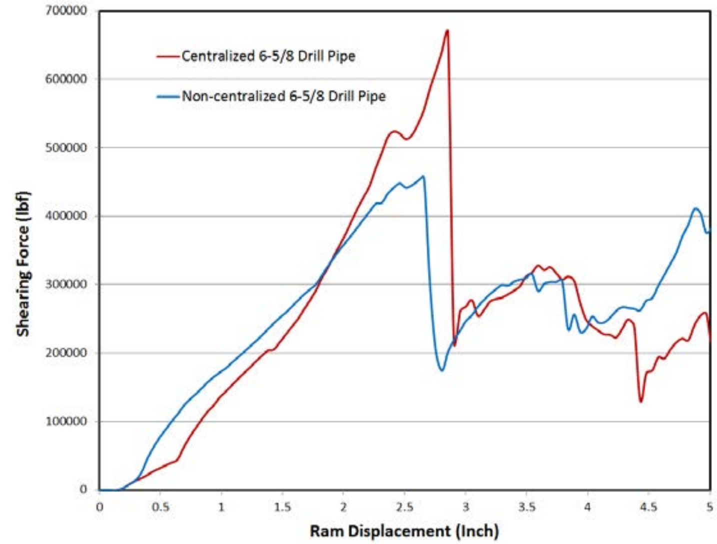
Centralized vs. Non-Centralized Drill Pipe

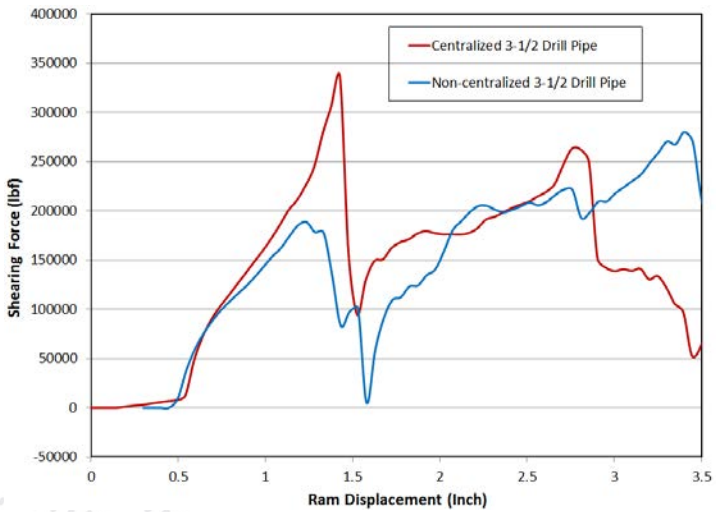


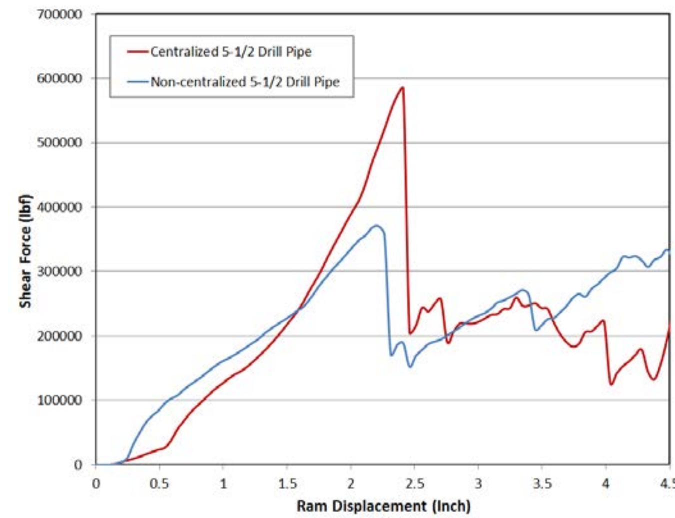
Centralized Drill Pipe



Non-Centralized Drill Pipe

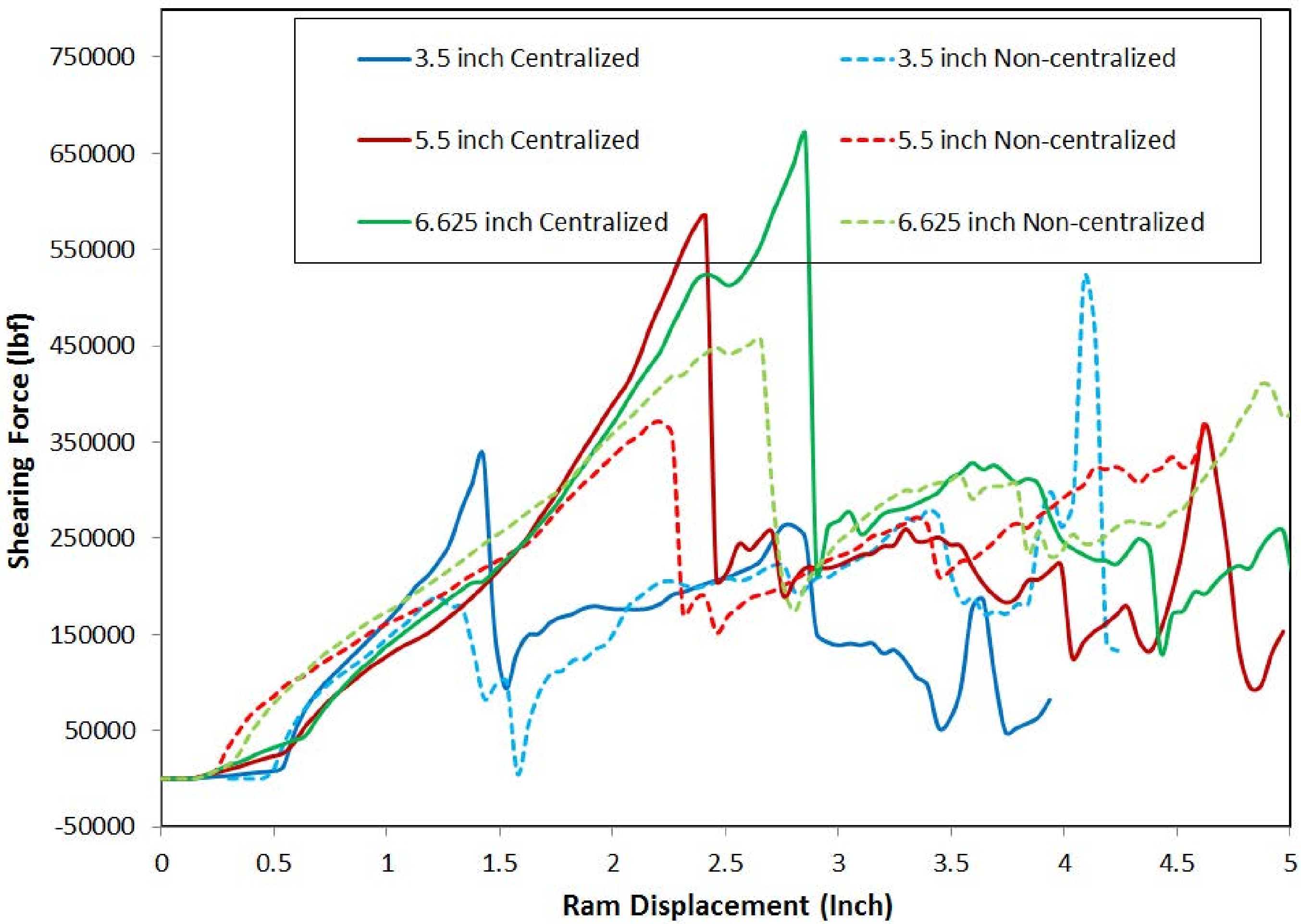




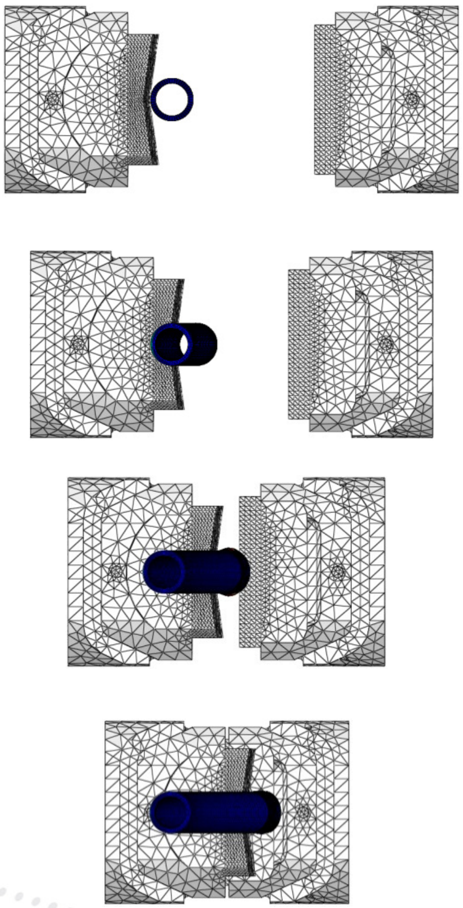


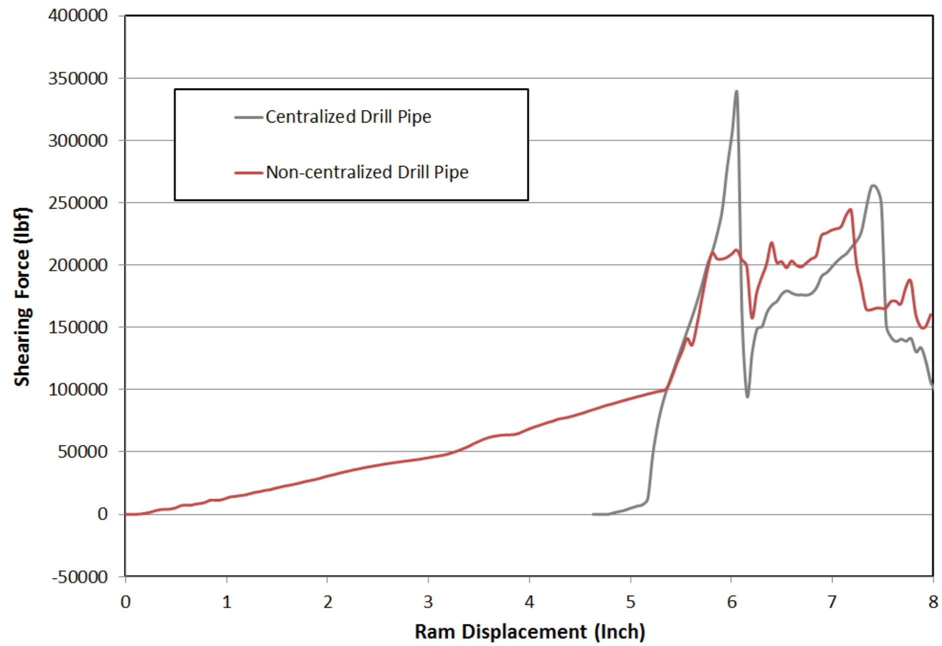
Non-Centralization Not Preferred

Shearing Force for Different Drill Pipe Sizes and Positions in Well Bore



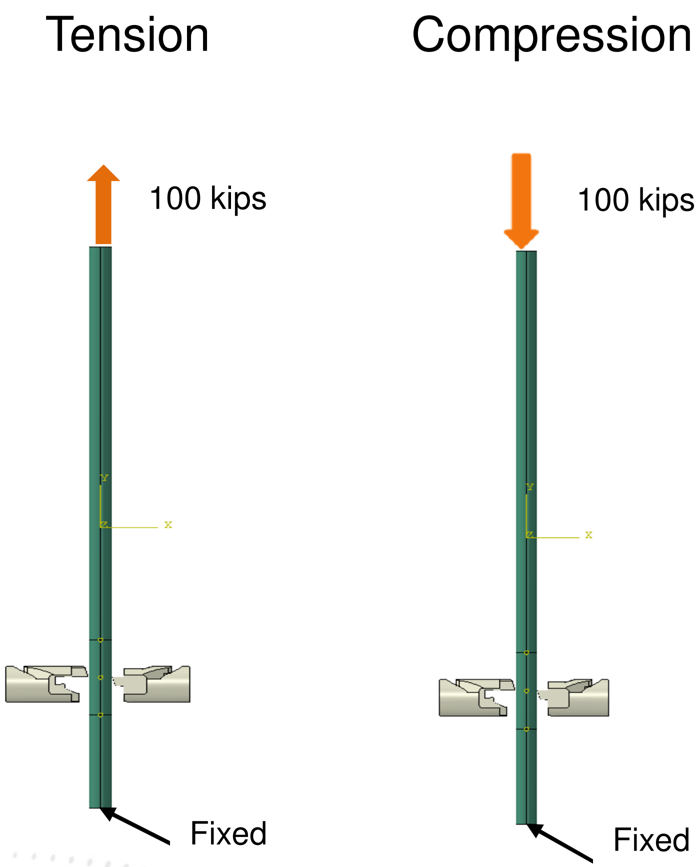
Non-Centralized 3.5” Drill Pipe

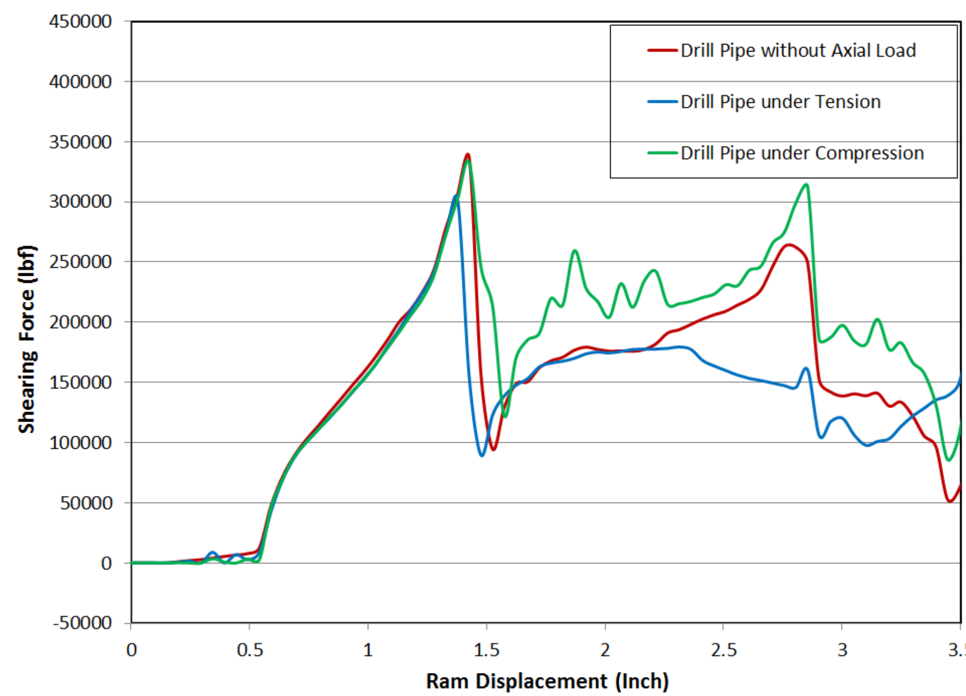




Non-Centralization Not Preferred

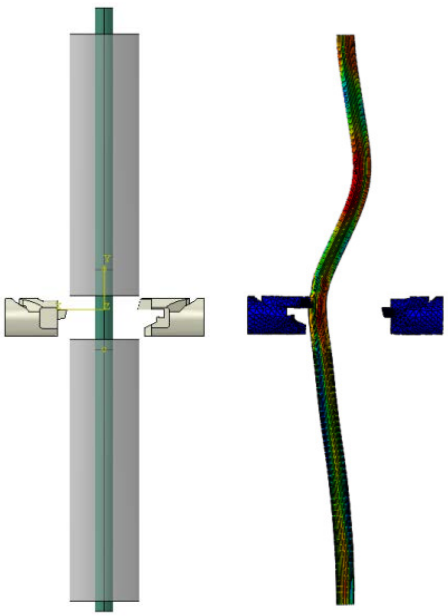
Effect of Pre-Load on Shearing of Drill Pipe (Tension & Compression)

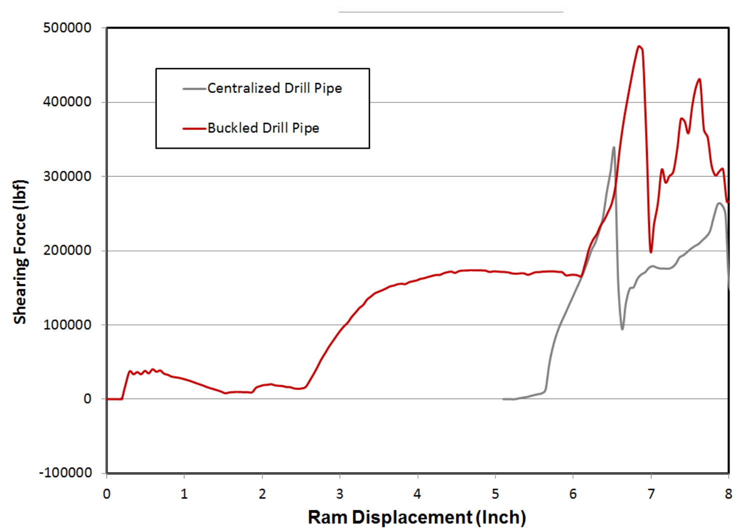


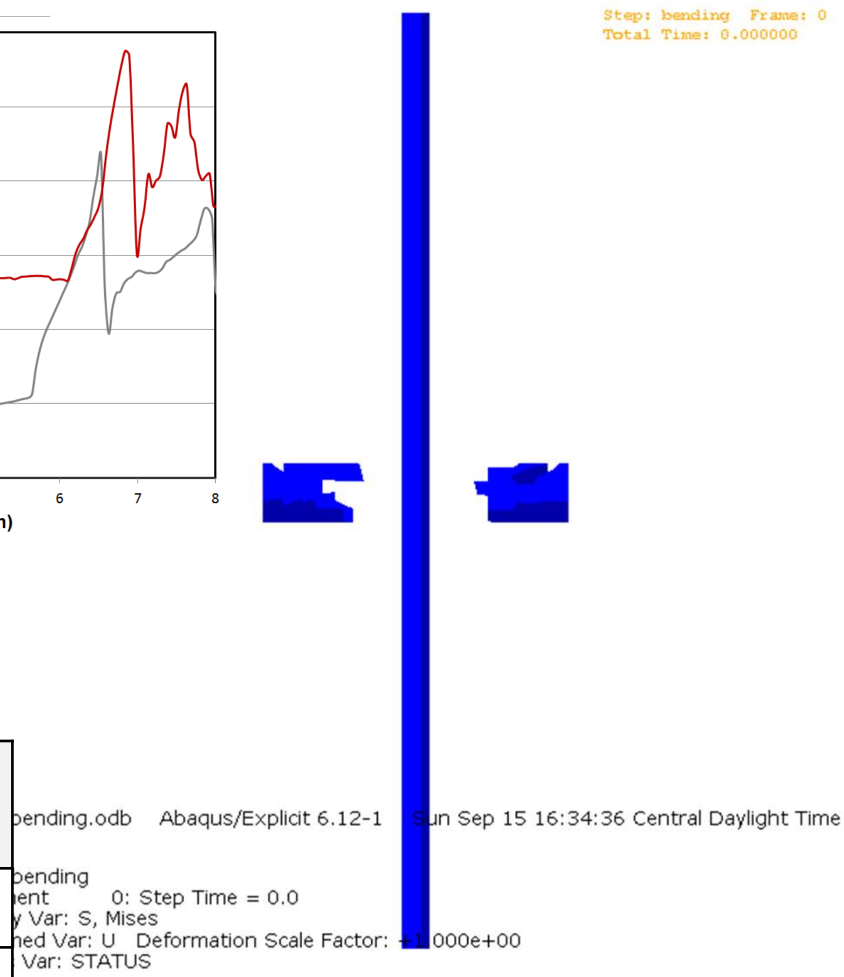


Drill Pipe under Tension requires less shearing force

Shearing of a Buckled Drill Pipe





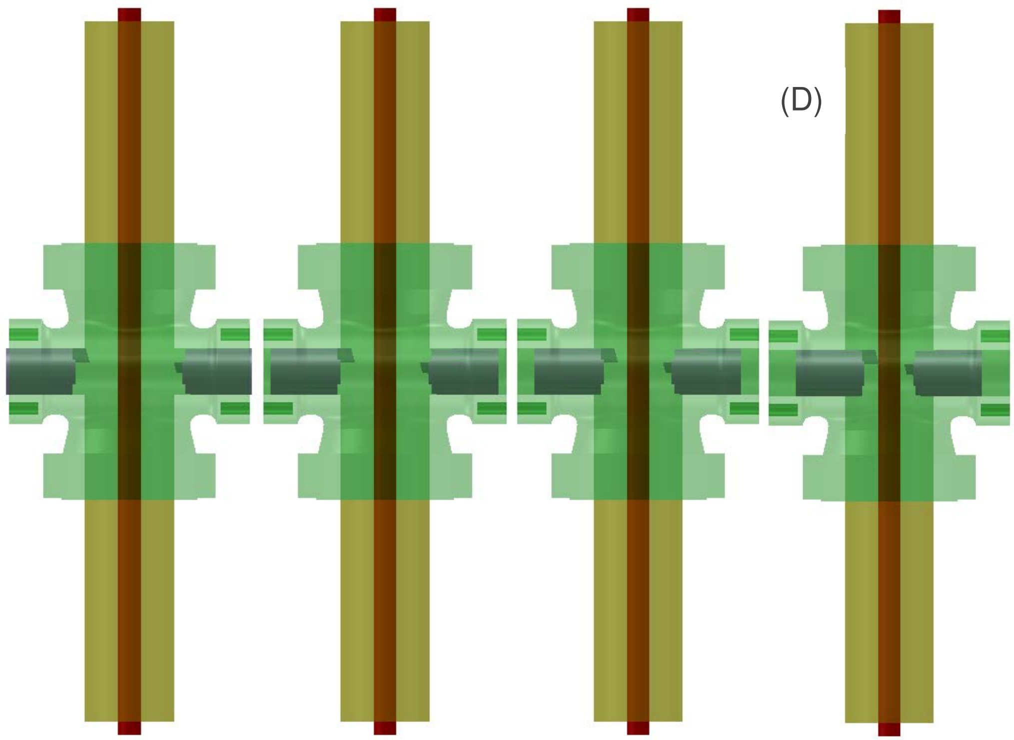


3-1/2 Drill Pipe Diameter OD (inch)	FE Analysis Max. Shearing Force (lbf)	OEM Formula Max. Shearing Force (lbf)	% Difference
Centralized – No Pre-load	336,160	417,984	- 24.34 %
Buckled Pipe	475,619	417,984**	+ 13.7 %

Flowing Well Condition

- A series of flowing well cases are analyzed
- Steady state simulations are performed for 4 positions of shear rams in well bore

- (A) Rams 13.5” apart
- (B) Rams 10.5” apart
- (C) Rams 7.5” apart
- (D) Rams 4.5” apart



Flowing Well Condition

Simulation Cases

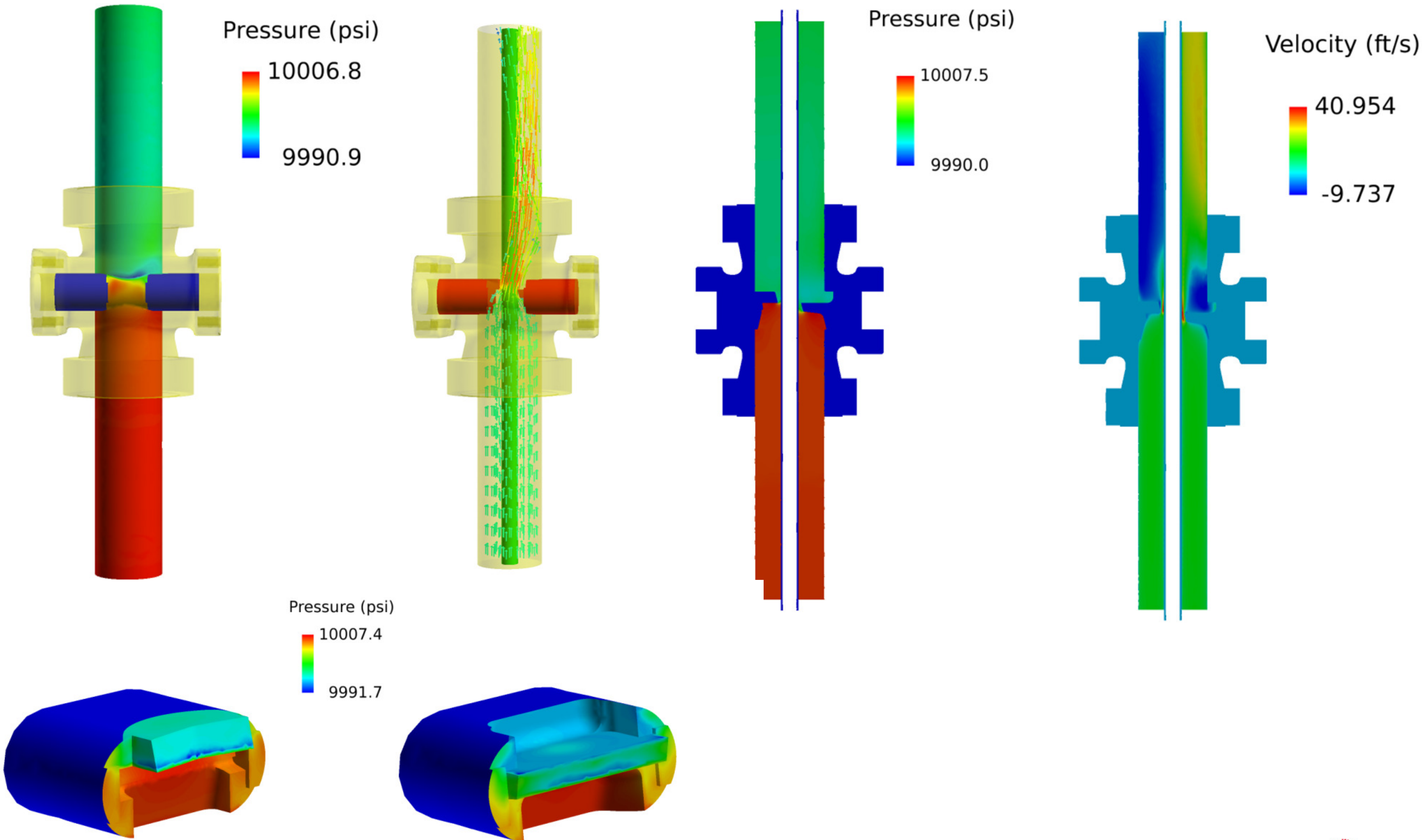
A series of CFD simulations are performed for

1. Various ram positions
2. Range of inlet volume flow rates (50,000 BPD to 200,000 BPD)
3. Range of pressure outflow boundary conditions (1000 psi to 20,000 psi)

Config	Volume Flow Rate (BPD)	Inlet Velocity (ft/s)	Max Velocity (ft/s)[3]	P_{inlet} (psi)	P_{outlet} (psi)	Max Pressure At Ram (psi)[1]	Pressure increase (psi)	Force Increase on Ram (lbf)[2]	% Force Increase on Ram (lbf)[4]
D1	50,000	3.89	10.5	1000.3	1000	1000.4	0.1	10.32	0.003%
D2	100,000	7.73	20.3	1002	1000	1002.25	0.25	25.8	0.008%
D3	200,000	15.4	42.1	1008.7	1000	1009.8	1.1	113.52	0.034%
D4	200,000	15.4	42.1	10006.4	10,000	10007.5	1.1	113.52	0.034%
D5	200,000	15.4	40.6	20003.8	20,000	20004.8	1	103.2	0.031%
B5	200,000	15.4	19.4	19995.7	20,000	19996.9	1.2	123.84	0.037%
C5	200,000	15.4	26	19997	20,000	19998.2	1.2	123.84	0.037%

Flowing Well Condition

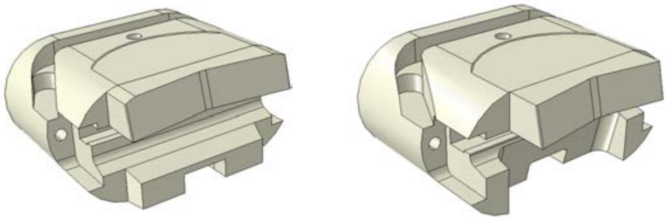
Configuration D4

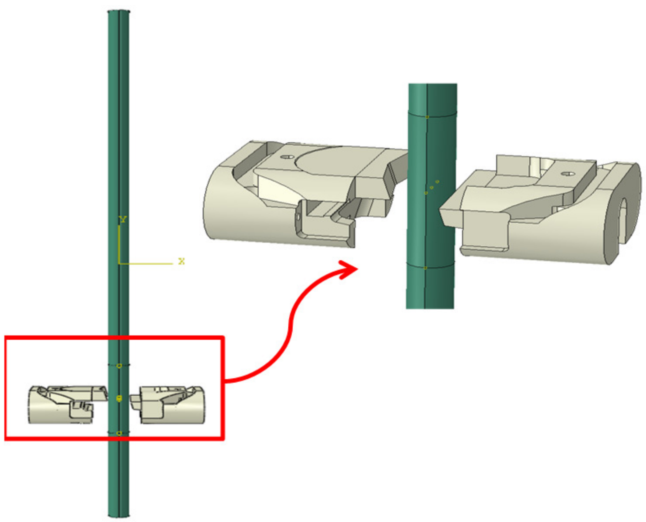


Flowing Well Condition

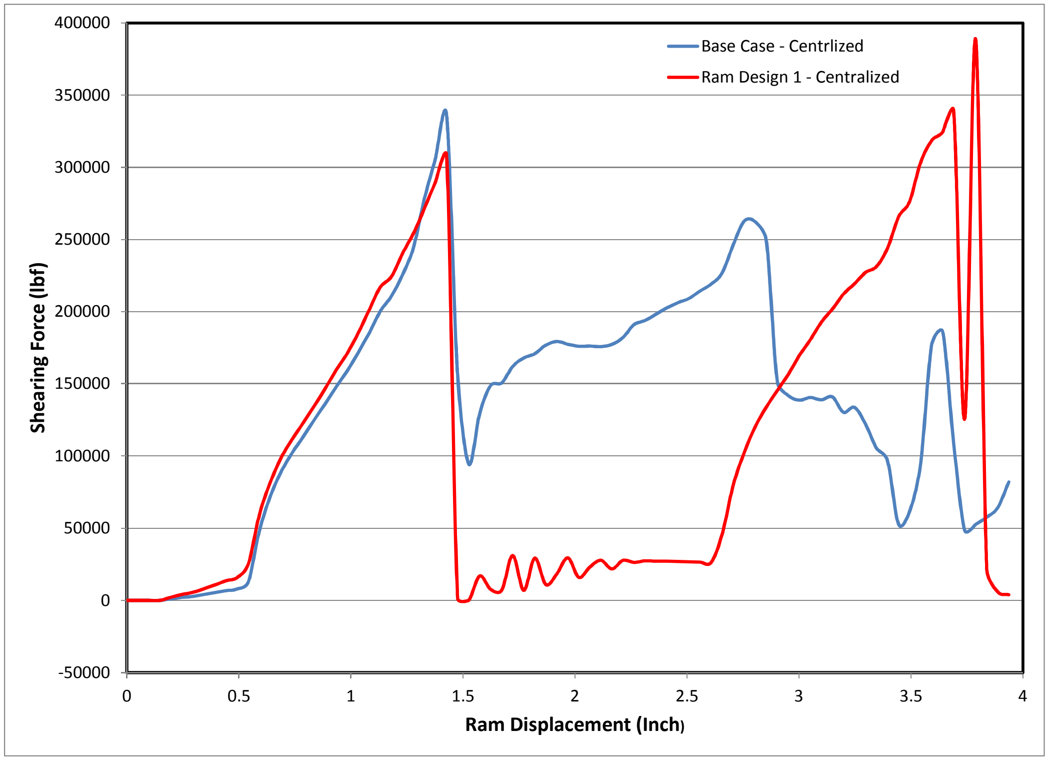
- Dynamic fluid conditions, such as water hammer are not considered
- Any abrupt pressure drop above the BOP rams is not considered
- Such a drop can result in steep pressure gradient across the rams during their shearing action
- Well bore pressure included in standard OEM shear calculations
- For 10,000 psi bore pressure, required shear pressure increased by 32% (equivalent to 130,000 lbf of additional shear force)
- The force exerted by the well bore on the ram face would be much larger than this.
- It is believed that shear ram design minimizes the pressure differential between front and back of rams and hence a smaller increase in shear pressure is required.
- Due to a large number of variables in the design of BOP shear ram system, it is recommended that a thorough review of different designs and how they compensate for wellbore pressure be performed.
- The results of flow simulations should be seen as a precursor to further investigation on the effects of these flow uncertainties on the shearing process.

Ram Design 1 – Reduced Width of Upper V-Blade and no Lower Lip





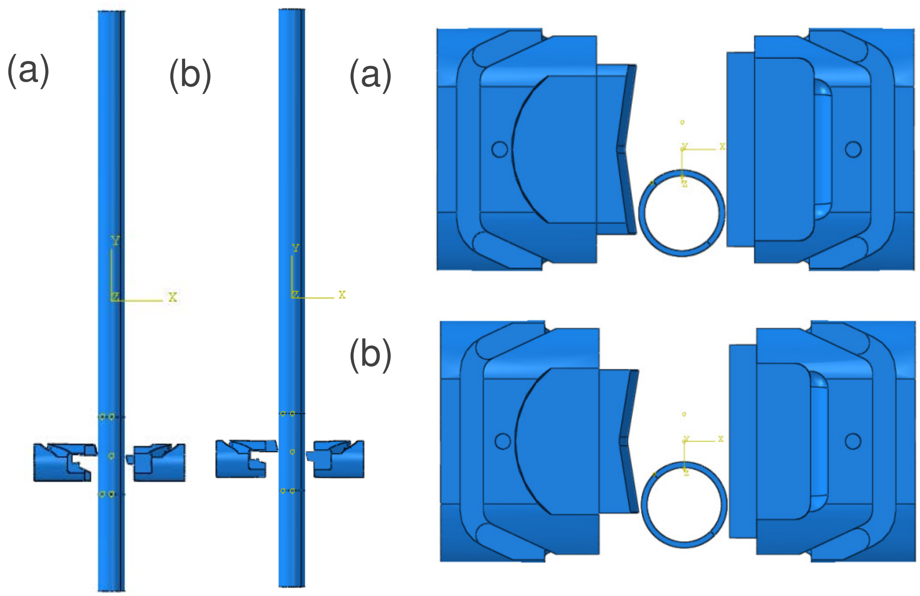
Drill Pipe – Shear Ram Assembly



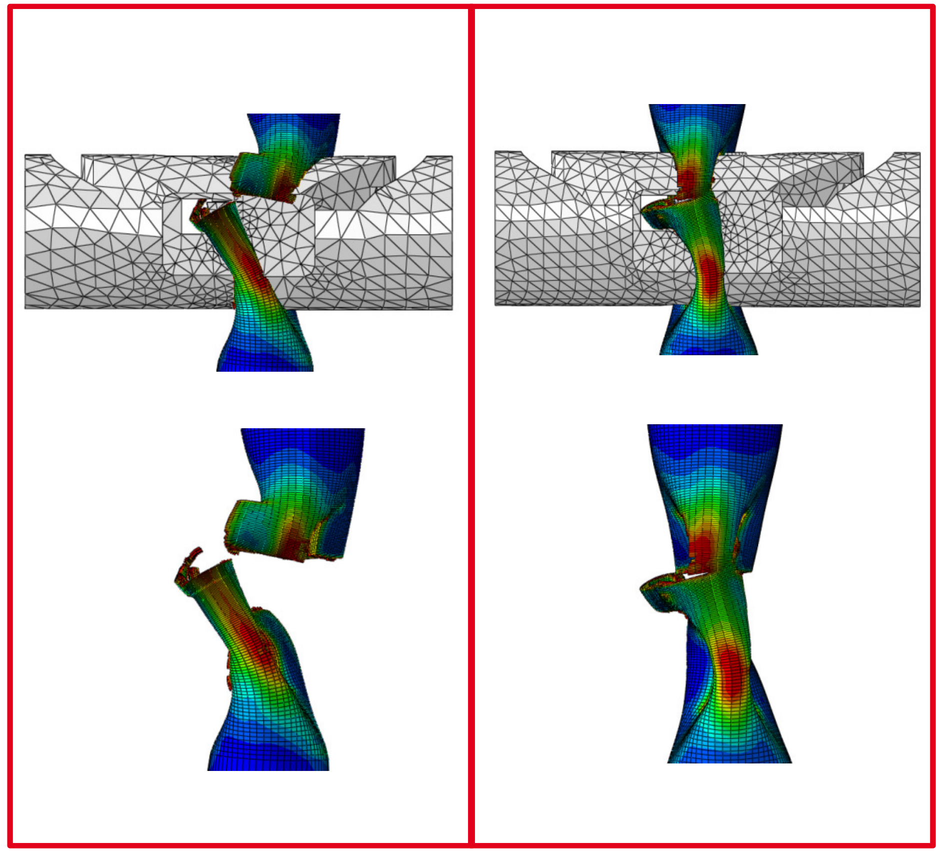
Requires Less Force than benchmarked model

Ram Design 1 – Reduced Width of Upper V-Blade and no Lower Lip

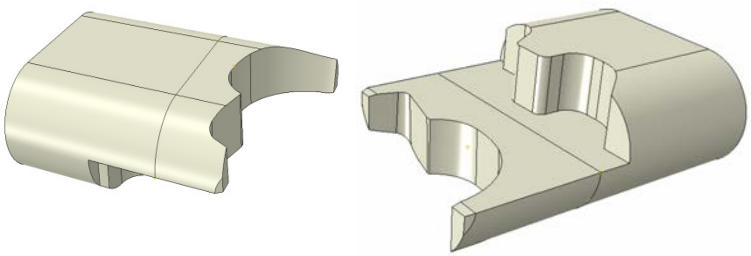
Non-Centralized 5.5” Drill Pipe

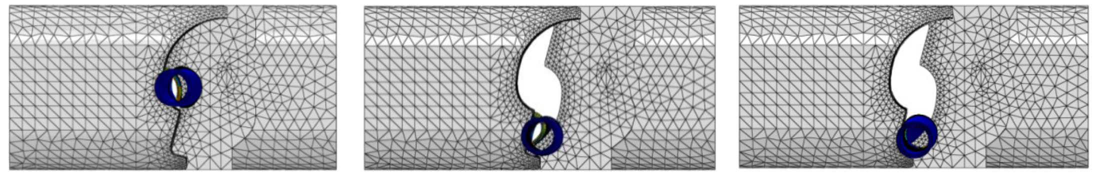


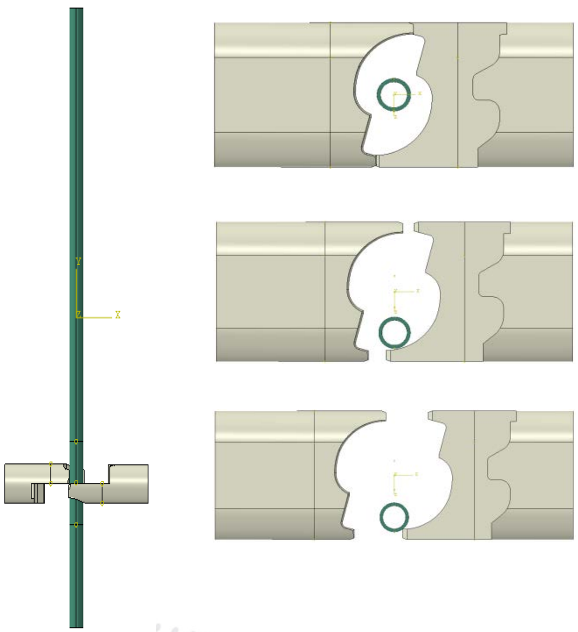
Drill Pipe – Shear Ram Assembly



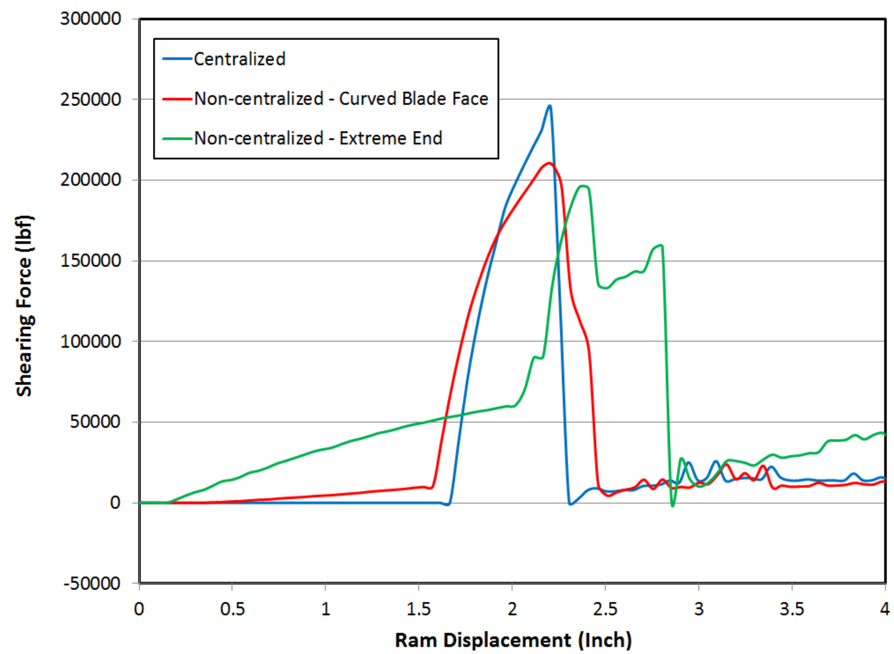
Ram Design 2 – Curved Blade Shear Ram







Drill Pipe – Shear Ram Assembly



Requires Less Force than benchmarked model

Conclusions

- There are many ways to configure a BOP stack. As per API 53 the subsea BOP shall be class 5 or greater and shall include a minimum of one annular preventer, two pipe rams (excluding test rams) and two sets of shear rams for shearing the pipe of which at least one shall be capable of sealing
- Many drilling contractors are having BOPs built to rigorous design specifications, with multiple redundant rams in an attempt to stay ahead of the regulatory and industry requirements. One drilling contractor interviewed is building 6 new rigs with 7 ram stacks
- The BOP standards are not specific about the placement of rams. However per API 53 [10], a documented risk assessment shall be performed by the equipment user and the equipment owner for all classes of BOP arrangements to identify ram placements and configurations
- For dynamically positioned vessels two BSR could be used, the first to shear the drill pipe and the second to seal the well in an emergency disconnect. This may be favorable with the risk of loss of station keeping and the narrow drilling margin when working in deepwater

Conclusions

- Robust FE methodology developed for shearing a drill pipe
- Validated with FE model with physical shearing tests
- Methodology has been applied to different drill pipe sizes and different shear ram designs
- Some variation in physical test results is observed due to the variation in dimensional differences and toughness (charpy) of the drill pipe
- Good consistency with OEM calculated shear force values are observed for drill pipe sizes of 3-1/2", 5-1/2" and 6-5/8"
- Benchmark ram lower lip helps to fold the lower drill pipe section (fish) and a large increase in shearing force is required.
- Upper Ram does not cover the full width of the BOP bore
- Shearing of a non-centralized pipe results in ram slicing through the drill pipe

Conclusions

- In the non-centralized position (pipe positioned against wall of BOP), corner of upper ram punctured the pipe resulting in lower shearing force
- On the other hand, large force is required to crush the uncut drill pipe and close the rams
- Tensioned drill pipe is easier to shear
- Compressive force in drill pipe increases the force required to shear
- Shearing of a buckled pipe is the most critical compressive case
  - Load required to shear is more than 40% of the base case
  - Maximum shearing force also exceeded OEM calculated force by 13.7%
- Flowing well conditions simulated
  - Flow simulations assume the pressure on either side of the ram is the same
  - A small pressure rise (~1.5 psi) was found when the annulus flow was constricted, when the shear rams are close to the drill pipe
  - Effect of fluid on the shearing process is very small

Conclusions

- Ram Design 1:
  - Had similar shearing performance to the benchmark for the centralized case
  - Difficult to shear non-centralized pipe due to lower width of the blade
  - Due to no fold over lip, energy required is much higher than benchmark (390,000 lbf)
- Ram Design 2:
  - Has some of the features of T3 shear all ram
  - Performed well for both centralized and non-centralized cases
  - For centralized pipe, the required maximum shearing force reduced by 27% compared to base design
  - Reduction is believed to be a result of higher contact area between the shear ram and drill pipe due to curved blade profile.
  - Shearing force for non-centralized case is lower than centralized case due to the initial bending of the pipe and the knife like action of the curved blades help in shearing process

Recommendations

- No published standards to cover BOP equipment rated above 15ksi. API RP 6HP developed in 2005, addresses the design verification methodology for HPHT drilling and completion equipment but has not yet published. Releasing API RP 6HP would help the industry in standardizing the design methodology for HPHT BOP equipment
- Full bore coverage with the shearing rams is recommended to guarantee successful shearing and sealing. If full bore coverage is not achievable then some method of centralization to move the pipe within shearing zone and protect sealing elements is essential
- OEM calculation considers the buckled pipe case in its shear force calculation and shear ram design
- It has been suggested that V-shape shear rams are particularly sensitive to variations in toughness in contrast to other ram designs. A more detailed evaluation of the mechanics of shearing and its sensitivity to toughness is recommended.

Recommendations

- Shearing process of different ram designs result in many fish profiles. Some fold the pipe, others leave clean open sections. It is recommended that a study of a desired fish profile be performed taking into account requirements of sealing, re-access, and intervention via the sheared pipe
- Ram sealing performance is outside the scope of this study. A detailed evaluation of BOP ram sealing performance is recommended
- Dynamic fluid flow conditions, such as fluid hammer effect, are not considered in this study. Moreover, any abrupt pressure drop above the BOP rams is not considered. Such a drop would result in a steep pressure gradient across the rams during their shearing action. Additionally, it is assumed that an equalization of pressure on either side of the rams has occurred. The results of the flow simulations should be seen as a precursor to further investigation on the effects of these flow uncertainties on the shearing process. The feasibility of occurrence of these uncertainties during shearing ram activation should also be taken into account during this investigation.

Recommendations

- Due to the large number of variables in the design of BOP shear ram systems, it is recommended that a thorough review of different designs and how they compensate for wellbore pressure be performed. This could be due to significant pressure in the bore during the shearing operation, especially if the annular(s) have been closed.
- The erosional effects of the increased fluid velocity as the rams are closed should be evaluated in more detail. This has the potential to impact the shear ram sealing performance.

Reference

- Final Report 01 – BOP Stack Sequencing and Shear Ram Design

Questions