Evaluate Oil and Gas Industry's Ability to Perform BOP Shearing Tests Under Simulated Blowout Flow Conditions

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Limitations of the Report

The scope of this report is limited to the matters explicitly covered and is prepared for the sole benefit of Bureau of Safety and Environmental Enforcement (BSEE). In preparing this report, Wood Group Kenny (WGK) relied on information provided by BSEE and third parties. WGK made no independent investigation as to the accuracy or completeness of such information and assumed that such information was accurate and complete.

All recommendations, findings, and conclusions stated in this report are based on facts and circumstances as they existed at the time this report was prepared. A change in any fact or circumstance on which this report is based may adversely affect the recommendations, findings, and conclusions expressed in this report.

Executive Summary

After the 2010 Macondo well incident in the Gulf of Mexico, numerous research studies were conducted to assess the performance of Blind Shear Rams (hereafter referred to as shear rams) in a Blowout Preventer (BOP) stack. A combination of physical testing and numerical simulation has been used to evaluate the performance of shear rams. However, all studies conducted to date have been performed under non-flowing conditions. They do not account for the high pressure and high velocity fluid effects on the shearing process that are encountered during a blowout scenario.

The objectives of this study are to gather data on the flow rates and pressures observed during a subsea well blowout and to identify facilities that can perform BOP shearing tests under simulated flowing well conditions. This report catalogues the capabilities and cost information for each identified facility.

Literature Review and Industry Surveys

Wood Group Kenny (WGK) conducted a comprehensive literature review and industry surveys to identify typical flow rates and pressures observed during a subsea well control scenario. The U.S. Bureau of Ocean Energy Management (BOEM) defines Worst Case Discharge (WCD) as the single highest daily flow rate of liquid hydrocarbons during an uncontrolled wellbore flow event. The WCD should be taken into account when evaluating the ability of shear rams to perform under real world conditions. The WCD depends on various factors, including the wellbore configuration, zones capable of flow at each section of the wellbore, reservoir characteristics (i.e., rock properties), fluid properties (e.g., fluid type, pressure, volume, temperature), and casing roughness.

Because the interactions among the various parameters are very complex, accurately estimating the flow rate and pressure of a well in blowout conditions can be difficult. The industry surveys echo a similar response. As WGK has studied the Macondo well blowout conditions extensively, we have used these conditions as a basis for defining the physical test conditions in this study. During the Macondo incident, the average flow rate was estimated to be about 60,000 barrels of oil per day (BPD) at reservoir pressures of approximately 10,000 pounds per square inch (psi).

Feedback from the industry surveys indicates that the shear rams are not designed to operate under flowing well conditions. During a well control scenario, annular preventers and pipe rams are typically activated before the shear rams are activated. The shear rams are positioned between the annular preventers, and the pipe rams and are used to cut the drill pipe and seal the well, when necessary. The annular preventer or pipe rams (or both) are expected to isolate the annulus region containing the shear rams from the high velocity fluid flow. Therefore, when

the shear rams are activated, they are not expected to see the high velocity flow from the reservoir; they are only designed to withstand the high pressures from the well. However, if for any reason the annular preventers and pipe rams both fail to operate, the shear rams can be exposed to the high velocity fluid from the reservoir.

Test Facilities

WGK has identified several test facilities and has assessed their capabilities for shearing a drill pipe in a BOP under simulated flowing well conditions. WGK has found that the identified facilities require some form of modification and additional equipment to perform the tests. In addition, none of the facilities are capable of testing at the required flow rates and pressures (i.e., Macondo conditions). This report includes the capabilities of the five identified facilities and their cost information.

The facilities are:

- National Energy Technology Laboratory (NETL) – Ultra-deep Drilling Simulator (UDS)
- NETL – High Pressure High Temperature (HPHT) Lab
- Pennsylvania State University, Applied Research Lab (ARL) – Deep Ocean Test Facility (DOTF)
- Pennsylvania State University, ARL – Garfield Thomas Water Tunnel (GTWT)
- The University of Oklahoma – Well Construction Technology Center (WCTC)

The NETL UDS and HPHT labs cannot perform full-scale testing of BOPs. The tests can only be performed on scaled models. The Pennsylvania State University ARL DOTF has a pressure vessel and can provide a maximum flow up to 17,150 BPD. The Pennsylvania State University ARL GTWT can provide the required flow rates using a 6-inch water tunnel, but it has limitations on the maximum pressure. The University of Oklahoma WCTC can provide flow rates up to 8,640 BPD and pressure up to 5000 psi. All five facilities can perform the flowing well shearing tests, but none of them can meet both the flow rates and the pressures that occurred in the Macondo incident.

Findings

- BOP Original Equipment Manufacturers (OEMs) state that the shear rams are not designed for flowing well conditions. The shear rams are designed and tested to operate under high pressure conditions only.
- Extensive physical testing and numerical simulation work has been conducted to evaluate the performance of shear rams under non-flowing well conditions. In addition, BOP OEMs have provided empirical correlations to estimate the pressure required to shear the drill pipe and seal the wellbore.

- The industry has conducted no tests to evaluate the flowing fluid effect on the shearing process.
- One of the BOP OEMs surveyed is currently studying the erosion effects on the shear rams. No study is currently underway to shear under flowing well conditions.
- WGK has identified facilities to perform shearing tests under simulated flowing well conditions. The identified facilities do not have experience conducting shearing tests under actual flowing well conditions.
- The identified facilities are willing to perform the testing, but the testing requires modifications to the facilities and additional equipment such as a BOP, pumps, and BOP actuation equipment.
- The facilities may be unable to replicate the high flows and pressures observed during the Macondo incident. Some facilities can only perform scaled model tests because full-scale testing can be complicated and expensive.
- The cost information that the test facilities have provided may be inaccurate because the equipment to be procured and the testing conditions are unconfirmed.
- There is a safety concern for conducting these types of tests because of the high flow rates and pressures involved.
- One of the BOP OEMs surveyed stated that shearing a drill pipe under flowing conditions may not be helpful because several variables (such as the flow rate, pressure, temperature, fluid medium, drill pipe position, drill pipe loads) need to be considered. This may require several tests to evaluate the effect of each parameter on the shearing process during flowing conditions.

Recommendations

- The function of shear rams in a BOP stack is to shear the drill pipe and seal the wellbore. A clarification is required from BSEE and/or the American Petroleum Institute (API) if the function of the shear rams applies to both flowing and non-flowing well conditions. If the shear rams must function under flowing well conditions, their design must be verified and tested accordingly.
- Because the identified facilities may be unable to provide the high flow rates and pressures observed during the Macondo incident, BSEE should provide a new set of specifications with details, such as the type and size of BOP, the expected flow rate and pressure, and other test conditions.
- BSEE should select a test facility from the list of identified facilities that can perform the shearing test, work with the test facility to make the required modifications, and procure the necessary equipment.

- A computer simulation methodology can be developed to evaluate the effect of high pressure fluid on the shearing process. The methodology can be used to evaluate the effect of various flow parameters on the shearing process.
- Special consideration is required to ensure that the elastomers can withstand the high velocities of fluid under flowing well conditions. In accordance with API Standard 53, the response time to close the shear rams must be equal to or less than 45 seconds. This response time should be verified to ensure that there is no erosion of the elastomer and that the well can be sealed safely.

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	Checked	Rhonda Cavender (RC)
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1.0 Introduction

1.1 General

Wood Group Kenny (WGK) has written this report in compliance with the Bureau of Safety and Environmental Enforcement (BSEE), Contract Number E14PC00041, to evaluate the oil and gas industry's ability to perform Blowout Preventer (BOP) shearing tests under simulated blowout fluid flow conditions.

The results from this study will help BSEE identify available facilities in the United States (U.S.) and the capabilities of each facility to perform BOP shearing tests under flowing well conditions. BSEE can use the gathered information for conducting future BOP shearing tests.

1.2 Background

After the high profile well control incident and loss of the *Deepwater Horizon*, the oil and gas industry realized that not only did the people and processes ultimately fail (i.e., based on the typical human factor analysis), but the potential sequencing and timing of the rig's equipment functions also failed.

The industry has concerns about the ability of the Blind Shear Rams (referred to in this report as shear rams) in the BOP stack to shear a drill pipe during a blowout scenario, which results in the formation fluid moving at high velocities and pressures toward the rig. Since the Macondo oil spill, there has been extensive research to assess the shearing capability of the shear rams, including physical tests in facilities for shearing drill pipe under non-flowing conditions [1]. These tests do not account for the effect of flowing fluid on the shearing process.

Therefore, BOP shear testing must be conducted under simulated flowing well conditions for surface and subsea BOP stacks to:

- Replicate the actual scenario of a well control event.
- Study the various flow parameter effects on the shearing process.

Original Equipment Manufacturer (OEM) formulations compute the maximum shearing force required to shear the drill pipe. However, these formulations have not considered the fluid flow effect on the shearing process, and they are generic in nature. There is no available information in the published literature about the validation of these formulas under flowing well conditions that can estimate the conservatism involved. Conducting the physical testing under actual blowout conditions can provide more information on the effects of fluid force on the shearing process. The output from the tests can be compared to that of OEM formulations used in the industry and for developing computer simulation methodologies. The developed computer model can also be used for conducting additional studies, such as the effect of drill pipe under axial loads, buckled drill pipe, and drill pipe in a non-centralized position.

1.3 Report Objectives

The objectives of this study are to:

1. Gather information related to typical flow rates and pressures observed during a well control scenario in subsea drilling operations.
2. Identify facilities that can perform shearing tests under flowing well conditions.
3. Contact each identified test facility and obtain information about the list of capabilities, maximum flow rate, and pressure that can be tested.
4. Obtain cost information for each identified shearing test from every facility.

1.4 Abbreviations

Below is a list of abbreviations used throughout this report.

API	American Petroleum Institute
ARL	Applied Research Lab
BOEM	Bureau of Ocean Energy Management
BOP	Blowout Preventer
BPD	Barrels Per Day
BSEE	Bureau of Safety and Environmental Enforcement
DOCD	Development Operations Coordination Document
DOE	Department of Energy
DOTF	Deep Ocean Test Facility
EP	Exploration Plan
FEED	Front-end Engineering Design
FRTG	Flow Rate Technical Group
GTWT	Garfield Thomas Water Tunnel

HP	High Pressure
HPHT	High Pressure, High Temperature
kPa	Kilo Pascal
kW	Kilowatt
m/s	Meters Per Second
MoC	Memorandum of Collaboration
MoU	Memorandum of Understanding
NETL	National Energy Technology Laboratory
NIC	National Incident Command
OEM	Original Equipment Manufacturer
psi	Pounds Per Square Inch
RDT&E	Research Development Test & Evaluation
SPE	Society of Petroleum Engineers
UDS	Ultra-deep Drilling Simulator
U.S.	United States
USGS	United States Geological Survey
WCD	Worst Case Discharge
WCTC	Well Construction Technology Center
WGK	Wood Group Kenny

2.0 Review of Available Literature and Industry Surveys

2.1 Introduction

This section provides a detailed literature review and comprehensive industry surveys to identify the flow rates and pressures at which BOP shear tests can be performed under flowing well conditions.

2.2 Literature Review

Several studies were conducted to evaluate shear ram designs by performing physical shear tests and calibrated finite element analysis. Under non-flowing conditions, the BOP OEMs performed the shear tests on each of their new designs to assess the performance of shear rams and the pressure required to shear the drill pipe.

MCS Kenny (now known as Wood Group Kenny [WGK]) collaborated with Archer to conduct physical shear tests and develop a calibrated finite element model [1]. The finite element model was further used to study various parameters such as the position of the drill pipe in the wellbore, tensile and compressive loads on the drill pipe, and shearing of a buckled drill pipe. All work was performed under non-flowing conditions. Figure 2.1 shows the shop test and the computer simulation model.

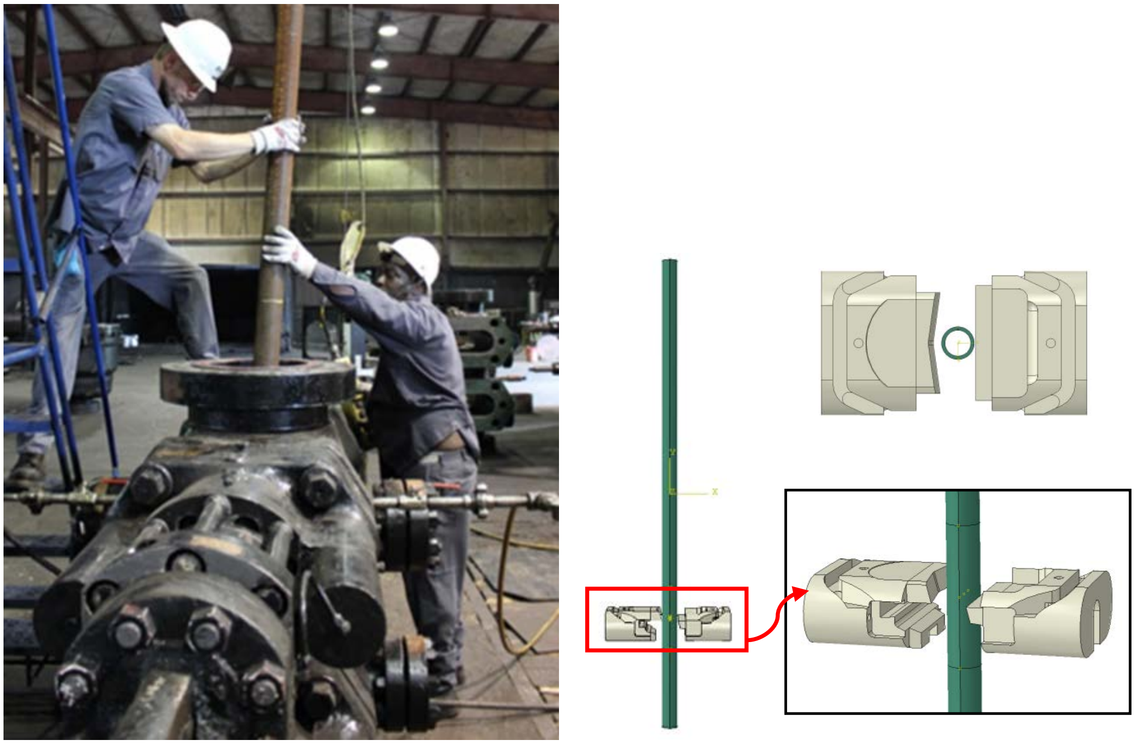

Figure 2.1: Shop Test and Computer Simulation Model under Non-flowing Conditions [1]

WGK has found no studies that evaluate shearing a drill pipe under flowing well conditions, probably because BOP OEMs claim that shear rams are not designed to operate under these conditions. In addition, it is difficult to obtain the actual flow rates and pressures during a blowout scenario. Because of the high pressure and flow rates necessary when shearing drill pipe in a test facility, safety is also a concern.

The U.S. Bureau of Ocean Energy Management (BOEM) defines Worst Case Discharge (WCD) as the single highest daily flow rate of liquid hydrocarbons during an uncontrolled wellbore flow event. The WCD should be taken into account when evaluating the ability of shear rams to perform under real world conditions. The WCD depends on various factors, such as the wellbore configuration, zones capable of flow at each section of the wellbore, reservoir characteristics (i.e., rock properties), fluid properties (e.g., fluid type, pressure, volume, and temperature), casing roughness, etc. The Society of Petroleum Engineers (SPE) Technical Report, "Calculation of Worst-Case Discharge (WCD)," [2] provides a detailed review of various parameters that can affect the calculation of WCD.

Considering these factors, accurately estimating the flow and pressure of a well in blowout condition may be difficult. Since the Macondo well incident in 2010, blowout conditions have been studied extensively. WGK used these conditions as a basis for defining the physical test conditions in this study.

After the Macondo incident, the regulations for drilling in U.S. waters became more stringent. Now, operators are required to submit an Exploration Plan (EP) or Development Operations Coordination Document (DOCD) with details of the potential blowout scenario, an estimate of flow rate, the total discharge, and the maximum duration of a potential blowout. NTL 2010-N06 [4] (superseded by BOEM NTL No. 2015-N01), 30 CFR 550.213(g) [3], and 30 CFR 550.243(h) [3] provide details of the necessary documentation required to be submitted to BSEE for drilling in U.S. waters.

Studies were conducted to obtain an accurate estimate of the rate of release of hydrocarbons from the Macondo well during the blowout. National Incident Command (NIC) and Interagency Solutions Group established Flow Rate Technical Group (FRTG) to estimate the flow rate from the Macondo well [5]. FRTG used different methodologies to estimate the flow rate (defined in this report as BPD, which is stock tank barrels of oil at sea level) and provided a range of 35,000 to 60,000 barrels per day (BPD).

After installing the capping stack on the Macondo well, the Department of Energy (DOE) lab team recorded pressure measurements at the choke valve to yield the most precise and accurate estimation of 53,000 BPD. The teams assigned an uncertainty of ±10% based on collective experience and judgement. Conservatively, the flow rate can be estimated to have been about 60,000 BPD.

The United States Geological Survey (USGS) [6] developed a computer model to simulate oil flow and reservoir depletion from the Macondo well. In the 86-day simulation (i.e., from the start of the blowout to the shut-in), the simulated reservoir pressure at the well face declined from the initial reservoir pressure of 11,850 pounds per square inch (psi) to 9,400 psi. After shut-in, the simulated reservoir pressure recovered to a final value of 10,300 psi, as shown in Figure 2.2. The simulated flow rate declined from 63,600 BPD immediately after the blowout to 52,600 BPD during shut-in of the well, as shown in Figure 2.3. The overall estimated uncertainty in the simulated flow rates and total volume of oil discharged was ±10%.

From the previously mentioned studies, the flow rate and pressures from the Macondo well blowout are estimated to be about 60,000 BPD and 10,000 psi, respectively.

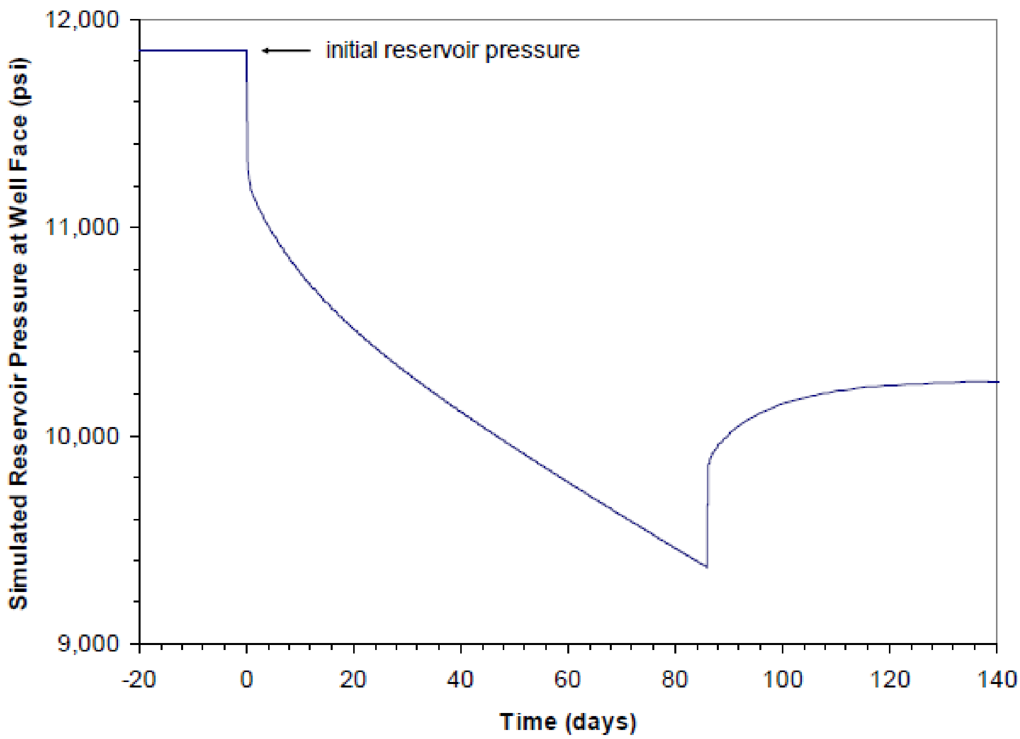

Figure 2.2: Simulated Reservoir Pressure at the Macondo Well Face [6]

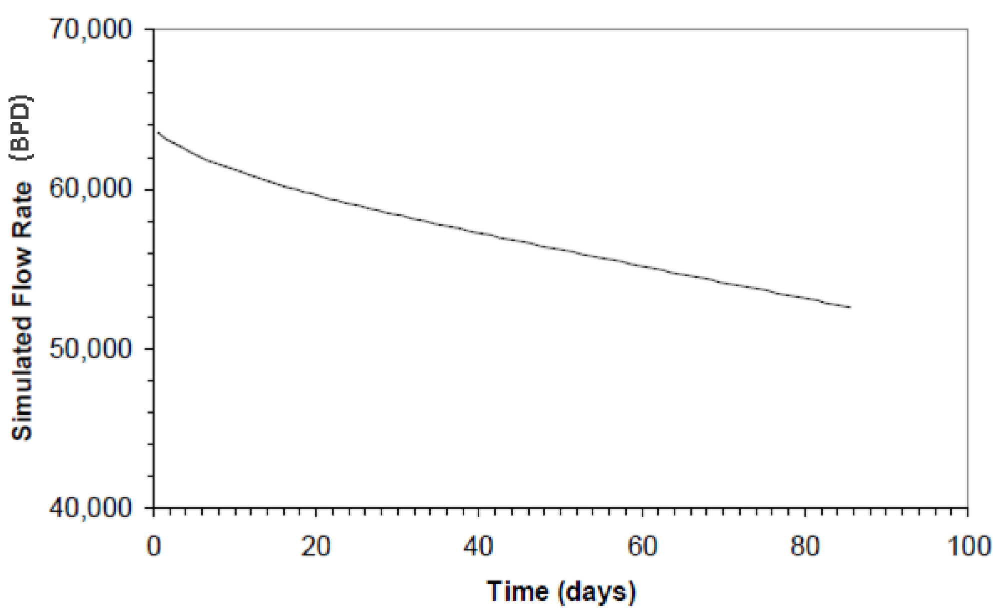

Figure 2.3: Simulated Volumetric Flow Rate of Oil from Macondo Well [6]

2.3 Industry Surveys

Surveys of relevant industry personnel (such as BOP OEMs with previous BOP testing experience) were conducted to address the shear ram requirements and limitations and to find any relevant test data. The findings from the surveys are discussed in this sub-section.

BOP OEMs emphasize that the name 'Blowout Preventer' indicates that BOPs are designed to prevent a blowout from occurring, but they are not responsible for stopping a blowout. Therefore, shear rams are not designed to withstand the high velocity fluid from the reservoir.

Shear rams are used to shear the drill pipe and seal the wellbore. They are the last line of defense and are rarely used. The shear ram design can withstand pressures of up to 10,000 psi or 15,000 psi under non-flowing conditions.

The typical steps used to activate a shear ram after identifying a kick are:

1. Pump drilling mud into the wellbore.
2. Close the upper annular preventer to regulate the flow.
3. If there is pipe across the BOP:
    a. Space it out to close the BOP pipe ram and hang off the drill string on the closed pipe ram.
    b. Close another pipe ram if the well is flowing beyond the closed pipe ram (and the annular).
4. Close the shear ram to cut the pipe (i.e., no flow), and seal the well.

In a typical subsea BOP stack, shear rams are placed between the annular preventers and the pipe rams. When the upper annulars are closed, the velocity of the fluid below could be negligible. The next step is to activate the pipe rams to handle the high pressure fluid. Finally, the shear rams are activated. During this step, there is no high velocity fluid passing through the wellbore.

If the annular preventer and the pipe rams fail to close for any reason, the shear ram can come into contact with the high velocity fluid. The chance of this occurring is low because there are multiple pipe rams and annular preventers in a typical BOP stack. BOP OEMs state this as a reason for shear rams not being designed for flowing well conditions.

One of the BOP OEMs surveyed stated that performing the shearing test under flowing well conditions is not helpful because:

- Blowout condition flow rates, pressures, and temperatures can vary drastically from one well to another.

- The formation fluid medium can vary from well to well, making it difficult to accurately conduct a shear test. Fluids can be liquid, gas, a mixture of liquid and gas, a mixture of hydrocarbons with mud, etc.
- The position of the drill pipe and the loads acting on the drill pipe can vary, depending on the blowout conditions and the well.
- The size and material of the drill pipe can have an effect on the shearing process during flowing conditions because the shearing force changes, depending on the material and size of the drill pipe in the BOP.

These parameters can greatly affect the shearing process. Several tests must be conducted to maintain a database for different scenarios. In addition, predicting the situation for each well blowout is difficult, and performing additional tests can be costly and time-consuming.

One of the BOP OEMs surveyed is currently performing reliability and erosion studies. This OEM stated that no studies for shearing a drill pipe under flowing well conditions have been conducted because of the following reasons:

1. In a blowout scenario, the high velocity fluid does not come into contact with the shear rams.
2. Shear rams are not designed to withstand high velocities.

No reliable data is available on the exact pressure and velocities that occur during a blowout scenario. The test facility would require large-sized pumps, and human safety is a concern during testing. Therefore, performing scaled tests in a test facility can be an option. The test data can be used to create and validate a computer model. The validated computer model can be used to study various flow parameters that can affect the shearing process.

3.0 Test Facilities

3.1 Introduction

This section identifies and discusses the facilities that can perform BOP shearing tests under flowing conditions. This section also provides the technical capabilities, cost information, and a point of contact for each facility.

The following laboratories/universities are willing to perform the shearing test under flowing well conditions:

- National Energy Technology Laboratory (NETL)
  - Ultra-deep Drilling Simulator (UDS)
  - High Pressure, High Temperature (HPHT) Lab
- Pennsylvania State University – Applied Research Lab (ARL)
  - Deep Ocean Test Facility (DOTF)
  - Garfield Thomas Water Tunnel (GTWT)
- The University of Oklahoma – Well Construction Technology Center (WCTC)

3.2 National Energy Technology Laboratory

NETL cannot perform full-scale tests because of space limitations in the laboratory, but they can perform scaled model tests. A 3-1/16-inch bore BOP with a pressure rating of 20,000 psi can fit the NETL facility.

NETL has two modifiable facilities to perform the scaled BOP shearing test under flowing well conditions. They are:

1. Ultra-deep Drilling Simulator (UDS)
2. High Pressure, High Temperature (HPHT) Lab/High Pressure (HP) Test Room

The UDS can be modified to set up the BOP, flow loop, and related equipment as shown in Figure 3.1. The UDS can be used to test the model up to 20,000 psi using real drilling mud in a realistic, scaled operating condition. The maximum flow rate that can be provided through the UDS is 2 gallons per minute (gpm). This is the main test cell that can handle high pressures [9]. Table 3.1 provides a comparison of the UDS and HP test room capabilities with the Macondo conditions.

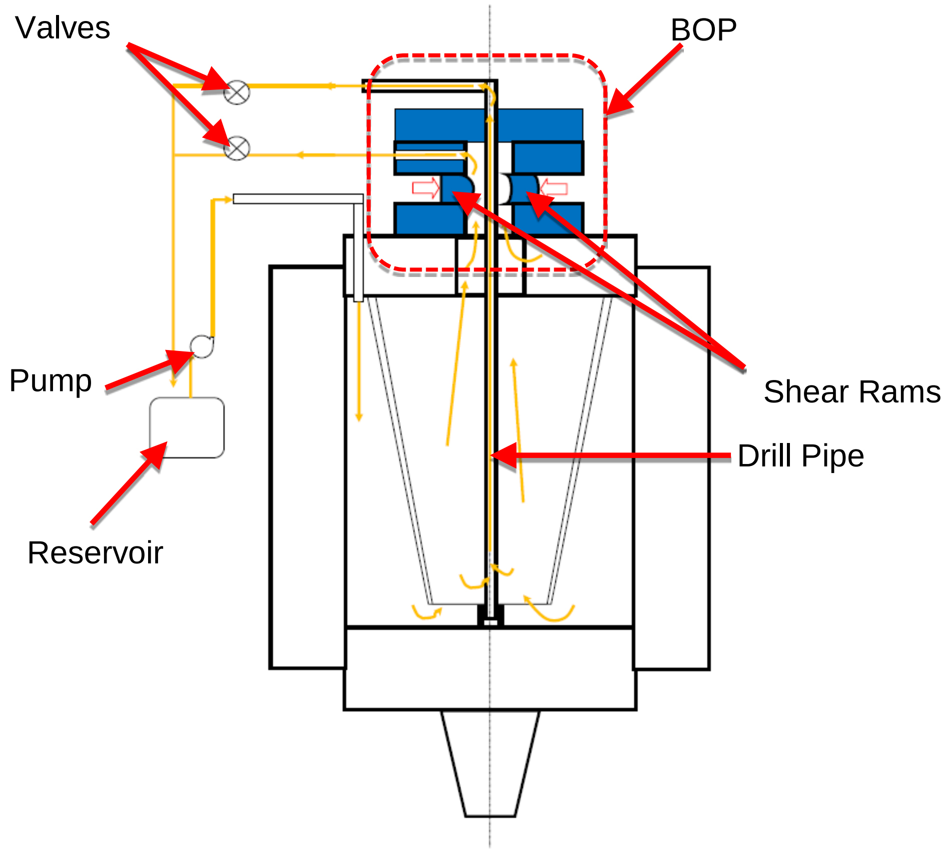

Figure 3.1: Conceptual BOP Shearing Test Design of UDS

The HP test room is also modifiable to perform the shearing test, and it too can use drilling mud because a separate mud lab is included with the test facility. This facility can be used to perform tests up to 10,000 psi. A flow rate higher than UDS can be achieved, and the maximum flow rate depends on the pumps to be procured.

Table 3.1: Capabilities of NETL Facilities Compared to Macondo Conditions

Parameter	Macondo Conditions	UDS	HP Test Room
BOP bore size	18-3/4 inch	3-1/16 inch	3-1/16 inch
Drill pipe size	5-1/2 inches	TBD	TBD
Maximum flow rate	60,000 BPD	~70 BPD	>70 BPD
Maximum pressure	10,000 psi	20,000 psi	10,000 psi
Fluid Medium	Oil and gas mixture	Water or mud	Water or mud

The cost to modify the UDS is expensive, ranging between $778,838 and $1,668,938. However, the advantage is that the test pressures can reach 20,000 psi, despite the flow rates being lower when compared to the HP test room. A breakdown of the total cost is provided in Table 3.2.

The costs shown in Table 3.2 cover the modification of the facility but not the cost of each individual test. The cost of each test depends on the number of days required to set up and perform the test (i.e., the labor cost is a function of time). Additional costs may accrue, such as replacement of any expendables (e.g., damaged rams, ram pistons, and labor for rebuilding the BOP if it is rented versus purchased, mud/fluid used).

Appendix A provides two pre-Front-end Engineering Design (FEED) estimates.

Table 3.2: Cost Information for the Two NETL Facilities

Parameter	Estimate to modify UDS	Estimate to modify HP Test Room
Time to start	2 weeks' notice	2 weeks' notice
Time to complete modification and test	Approximately 14 months	Approximately 10 months
Materials Cost	$126,000 – $270,000	$168,000 – $360,000
Labor/Miscellaneous Cost	$652,838 – $1,398,938	$383,250 – $821,250
Total Cost*	$778,838 – $1,668,938	$551,250 – $1,181,250
*Cost includes hydraulic system for BOP operation – cost of BOP not included		

3.3 Applied Research Lab at Pennsylvania State University

The Pennsylvania State University ARL is primarily a science, systems, and technology-based laboratory with several facilities to perform various tests.

The two facilities that can perform the BOP shear testing under flowing well conditions are:

1. Deep Ocean Test Facility (DOTF)
2. Garfield Thomas Water Tunnel (GTWT) facilities

Deep Ocean Test Facility

DOTF supports the U.S. Navy, the marine equipment industry, and the undersea oil and gas community with expert Research Development Test & Evaluation (RDT&E) consulting design, analysis, and test services.

The facility contains horizontal pressure tanks, which use salt water or freshwater as the pressurization fluid. Tank A, which is the largest tank, is 27 ft. long with a diameter of 10 ft., and it accommodates full-scale deep ocean vehicles down to 27,000-ft. water depths. The tank is widely used to evaluate underwater mining equipment, deep ocean arrays and cabling systems, diver transfer capsules, buoyancy devices, cabling, fuel cells, and manipulators. Small tanks aid in economically evaluating equipment such as submersible motors, piping and fittings, electrical connectors and enclosures, and pressure-compensated electrical and electronic equipment. Table 3.3 provides the technical specifications of various tanks in the DOTF.

In the past, DOTF tested BOPs in a pressure vessel under 10,000 ft. of water for Stewart and Stevenson and Cameron Research. DOTF operated the BOPs under pressure using through-tank signals and power connections. Figure 3.2 shows a subsea BOP being taken into a tank for pressure testing.

Table 3.3: Technical Specification of DOTF Pressure Tanks [7]

Tank Designation	A	B	H	V	Gun Shells
Tank Axial Center line	Horizontal			Vertical	
Inside diameter	10 ft.	4 ft.	30 inches	18 inches	9 inches
Inside length	27 ft.	12 ft.	6 ft.	6 ft.	2 ft.
Static pressure (maximum psi)	12,000	12,000	7,000	10,000	20,000
Pressurizing Fluid	Salt or Fresh Water	Salt or Fresh Water	Fresh Water	Fresh Water	Salt or Fresh Water
Heat removal capability (btu/hr)	1,500,000		None	Temperature Control	Temperature Control

Currently, DOTF cannot provide a large flow rate through the BOP, but the internal cavity of the BOP can be pressurized up to 12,000 psi. With some modification to the pressure vessel and the installation of a pump, DOTF can provide a flow rate of up to 17,150 BPD.

Figure 3.2: Pressure Test of Subsea BOP Section at DOTF Facility [7]

Pump installation costs approximately $40,000, and the purchase of additional equipment to allow for the flow costs is approximately $75,000. This does not include the cost of the BOP.

Tank A costs $12,000 per day. The total cost depends on the setup time required and the time required to perform the actual testing. For example, a one-week test, including set-up and tear down at 8 hours per day, costs roughly $75,000.

Garfield Thomas Water Tunnel

The GTWT has different diameter water tunnel facilities that are capable of performing a variety of tests, such as cavitation performance, noise and vibration measurements, and flow visualization.

The different facilities available are:

- Water Tunnel: 48-inch diameter
- Water Tunnel: 12-inch diameter

- Water Tunnel: 6-inch diameter
- Ultra High Speed Water Tunnel: 1.5-inch diameter
- Quiet Pump Loop
- Boundary-layer Research Tunnel
- Acoustic Reverberant Tank
- Flow-through Anechoic Chamber

The 6-inch diameter facility can provide a 60,000 BPD flow rate through an 18-3/4-inch BOP bore, which is calculated to be a velocity of 2 ft./sec. To perform the test, a knowledgeable party (which can be BSEE or a BOP OEM) must specify the type of BOP, the drill pipe size, and the BOP actuation mechanism. The equipment must be procured with additional funding. Table 3.4 provides the technical specifications of the GTWT 6-inch water tunnel.

Table 3.4: Technical Specification of GTWT Pressure Tank [8]

Parameter	Value
Description of Facility	Closed circuit, closed jet
Type of drive system	Axial-flow pump
Total motor power	25 horse power
Working section maximum velocity	70 ft/sec
Max and Min absolute pressures	125 to 3 psi
Cavitation number range	>0.1 dependent on velocity and pressure
Instrumentation	Pressure transducers, lasers
Temperature	Ambient

3.3.1 University of Oklahoma – Well Construction Technology Center

The WCTC facility can be modified to perform BOP shearing tests under flowing well conditions. Currently, WCTC has the triplex pump and mixing tanks required to provide the required flow rate and pressures. However, WCTC must procure the BOP and the BOP activation equipment. This facility can provide flow rates up to 8,640 BPD and pressures up to 5,000 psi only (because of tubular capability limitations [10]).

3.4 Summary Chart

Table 3.5 shows information gathered from each of the facilities, such as the possible flow rates and pressures, location, cost information, and the point of contact.

Table 3.5: Capabilities and Cost Information of Identified Facilities

Name of the Lab	Facility	Location	Description	Technical Specifications	Shear Test Specification	Cost of test (including modification needed to conduct the test)	Point of Contact
Pennsylvania State University Applied Research Laboratory	Deep Ocean Test Facility	Annapolis, Maryland	Facility contains horizontal pressure tanks that use salt water or fresh water as the pressurizing fluid. Largest tank is 27 ft. long with diameter of 10 ft. that accommodates full-scale deep ocean vehicles down to 27,000 ft. depths.	Tank A: Inside length: 27 ft., inside diameter: 10 ft., Static pressure: 12,000 psi Tank B: Inside length: 12 ft., inside diameter: 4 ft., static pressure: 12,000 psi Tank H: Inside length: 6 ft., inside diameter: 30 inches, static pressure: 7,000 psi Tank V: (Vertical tank axial center line), Inside length: 6 ft., inside diameter: 18 inches	Max pressure: 12,000 psi Max flow: up to 8,000 BPD (with additional pump up to 16,500 BPD) Size of BOP to be determined case by case basis	Cost of Tank A is $12,000/day. Actual cost depends on the set-up time and actual testing. Hypothetical Case: One-week test, including set-up and tear down at 8 hours equals $75,000. If flow-through BOP is required, then $75,000 plus the cost to purchase pump ($40,000) and the cost to set it up.	Alan L. Hartman, Chief Engineer 2005 Agiro Drive, Annapolis, MD 21402 443-758-4032 (Cell) 410-349-3074 (Office)
Pennsylvania State University Applied Research Laboratory	Garfield Thomas Water Tunnel	North Atherton Street, University Park, Pennsylvania, 16801	GTWT Facilities: 48-inch diameter Water Tunnel 12-inch diameter Water Tunnel 1.5-inch diameter Ultra High Speed Water Tunnel Quiet Pump Loop 6-inch diameter Water Tunnel Boundary Layer Research Tunnel	48-Inch Diameter Water Tunnel: Closed-jet tunnel Motor power: 2000 horse power Working section size: 48 inches x 168 inches Velocity range: 3 ft./sec to 55 ft./sec Max /Min Absolute Pressure: 3 psi to 60 psi http://www.arl.psu.edu/facil_gtwt_facilities.php	Max. Pressure: This information is not available Max Flow: up to 60,000 BPD	Not provided by the facility	Jon Eaton, Applied Research Laboratory The Pennsylvania State University 1800 Alexander Bell Drive Suite 256, Reston, VA 20191-5465 Phone: 703-939-8670 Fax: 703-939-8672
National Energy Technology Laboratory (NETL)	Ultra-deep Drilling Simulator (UDS) and HPHT Lab	Morgantown, West Virginia	UDS is used to perform experiments that enable understanding of drilling dynamics as a function of key parameters. The facility can be modified to conduct the shearing tests under flowing conditions.	The BOP shear test can be performed by modifying any of the below two facilities at NETL. 1. Ultra-deep Drilling Simulator (UDS) modification 2. HP Test Room Modification (by building test fixture)	Max Pressure: 10,000 to 15,000 psi Max Flow Rate: 70 BPD	NETL Cost Summary: $551,250 to $1,668,938 Refer Appendix A for additional details. [A Memorandum of Collaboration/Understanding (MoC/MoU) is required between BSEE and NETL for sharing any further information]	Roy Long, Ultra-Deepwater Technology Manager, Strategic Center for Natural Gas & Oil DOE/NETL Houston Granite Towers, Suite 225 13131 Dairy Ashford Road, Sugar Land, Texas 77048 Phone: 281-494-2520

Name of the Lab	Facility	Location	Description	Technical Specifications	Shear Test Specification	Cost of test (including modification needed to conduct the test)	Point of Contact
University of Oklahoma (OU)	Well Construction Technology Center	Norman, Oklahoma	This information is not available at this time	This information is not available at this time	Max Pressure: 5000 psi Max Flow rate: 8640 BPD	Cost estimate not provided by facility.	Ramadan Ahmed, Room 1180 Sarkeys Energy Center, 100 E. Boyd St., Norman, OK 73019-1003 Phone: 405-325-0745 Email: r.ahmed@ou.edu Subhash Shah, Stephenson Chair Professor, Mewbourne School of Petroleum and Geological Engineering, University of Oklahoma Room 1158, Sarkeys Energy Center, 100 E. Boyd St., Norman, OK 73019-1003 Email: subhash@ou.edu Phone: 405-325-2921

4.0 Findings and Recommendations

4.1 Findings

The following are the findings from this study:

- BOP Original Equipment Manufacturers (OEMs) state that the shear rams are not designed to operate under flowing well conditions. The shear rams are designed and tested to operate under high pressure conditions only.
- Extensive physical testing and numerical simulation work have been conducted to evaluate the performance of shear rams under non-flowing well conditions. In addition, BOP OEMs provide empirical correlations to estimate the pressure required to shear the drill pipe and seal the wellbore.
- The industry has conducted no tests to evaluate the flowing fluid effect on the shearing process during flowing conditions.
- One of the BOP OEMs surveyed is currently studying the erosion effects on the shear rams. No study is currently underway to shear under flowing well conditions.
- WGK has identified facilities to perform shearing tests under simulated flowing well conditions. The facilities identified in Section 3.0 do not have experience conducting shearing tests under flowing well conditions.
- The identified facilities are willing to perform the testing, but it will require modifications to the facility and procurement of additional equipment, such as the BOP, pumps, and BOP actuation equipment.
- The facilities may be unable to replicate the high flows and pressures observed during the Macondo incident. Some facilities can only perform scaled model tests because full-scale testing can be complicated and expensive.
- The cost information provided by the test facilities may be inaccurate because the equipment to be procured and the testing conditions are unconfirmed.
- There is a safety concern for conducting these types of tests because of the high flow rates and pressures involved.
- One of the BOP OEMs surveyed stated that shearing a section of drill pipe under flowing conditions may not be helpful because several variables (such as the flow rate, pressure, temperature, fluid medium, pipe position, drill pipe loads) need to be considered. This may require several tests to evaluate the effect of each parameter on the shearing process during flowing conditions.

4.2 Recommendations

WGK makes the following recommendations as a result of this study:

- The function of shear rams in a BOP stack is to shear the drill pipe and seal the wellbore. A clarification is required from the American Petroleum Institute (API) and/or BSEE if the function of the shear rams applies to both flowing and non-flowing well conditions. If the shear rams must function under flowing well conditions, their design must be verified and tested accordingly.
- Because the identified facilities may be unable to provide the high flow rates and pressures observed during the Macondo incident, BSEE should provide a new set of specifications with details, such as the type and size of BOP, the expected flow rate and pressure, and other test conditions.
- BSEE should select a test facility from the list of identified facilities that can perform the shearing test, work with the test facility to make the required modifications, and procure the necessary equipment.
- A computer simulation methodology can be developed to evaluate the effect of high pressure fluid on the shearing process. The methodology can be used to evaluate the effect of various flow parameters on the shearing process.
- Special consideration should be given to ensure that the elastomers can withstand the high velocities of fluid under flowing well conditions. In accordance with API Standard 53, the response time to close the shear rams must be equal to or less than 45 seconds. The response time should be verified to ensure that there is no erosion of the elastomer and the well can be sealed safely.

5.0 References

1. MCS Kenny/Archer, Assessment of BOP Stack Sequencing, Monitoring and Kick Detection Technology,http://www.bsee.gov/uploadedFiles/BSEE/Technology_and_Research/Technology_Assessment_Programs/Reports/700-799/713AA.pdf [Accessed March 20, 2015].
2. SPE Technical Report, "Calculation of Worst-Case Discharge (WCD)," March 2015.
3. BSEE, Electronic Code of Federal Regulation, http://www.ecfr.gov/cgi-bin/text-idx?SID=49441f57c00a622782a6877899297b68&mc=true&node=pt30.2.550&rgn=div5 [Accessed April 6, 2015].
4. BSEE, NTL 2010-N06, http://www.bsee.gov/Regulations-and-Guidance/Notices-to-Lessees-and-Operators/ [Accessed April 6, 2015].
5. National Incident Command, Interagency Solutions Group, Flow Rate Technical Group, *Assessment of Flow Rate Estimates for the Deepwater Horizon/Macondo Well Oil Spill*, U.S. Department of Interior, March 10, 2011.
6. Hsieh, P., Computer Simulation of Reservoir Depletion and Oil Flow from the Macondo Well Following the Deepwater Horizon Blowout, US Department of Interior, USGS, Open-File Report 2010-1266.
7. PennState Applied Research Lab (ARL), Deep Ocean Test Facility, https://www.arl.psu.edu/facil_dotf.php [Accessed March 15, 2015].
8. PennState Applied Research Lab (ARL), Garfield Thomas Water Tunnel, https://www.arl.psu.edu/facil_gtwt_facilities.php [Accessed March 15, 2015].
9. National Energy Technology Laboratory, http://www.netl.doe.gov/ [Accessed March 12, 2015].
10. University of Oklahoma, Well Construction Technology Center, http://www.ou.edu/mcee/mpge/research.html [Accessed March 20, 2015].

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Appendix A : NETL Pre-FEED Cost Estimates

NETL Summary Sheet for Facility Mods for BOP Testing			
	Estimate for Building test fixture in HP test room		**Estimate for Mod to UDS Cell****
Time to Start	2 weeks from NPT		2 weeks from NPT
Time to complete mods and test	Approx 10 months		Approx. 14 Mos.
Total Cost*	$551,250 - $1,181,250		$778,838 - $1,668,938
Materials Cost	$168,000 - $360,000		$126,000 - $270,000
Labor/Msc. Cost	$383,250 - $821,250		$652,838 - $1,398,938
Planned test presure capabililty	10,000 psi		Up to 20,000 psi
* Cost Includes Hydraulic System for BOP operation - cost of BOP not included			
** Note: Advantage to modifying UDS cell is that test pressures can go beyond 10 KSI, easily to 20 KSI			

Form No. RIS-1001.1

RIS
ESTIMATING WORKSHEET

Reference RES-EG-00-001 for Estimating Worksheet Guidelines

DATE: **2/9/2015**

WORK ORDER : **NA**

NETL DCN: **NA**

PROJECT: **BOP Testing**

PREPARED BY: S.FIKE/T.THEWLIS

LOCATION: **B-12**

REVIEWED BY:

LABOR ACCOUNT CODE: **NA**

APPROVED BY:

WORK DESCRIPTION: Modify UDS to accept/test BOP

Task Description	Quantity (User)	Estimated Hours / Task	Average Cost / hr	Total Hours	Extended Cost	Remarks (User)
AECOM Project Manager	1	2080	$100	2,080	$208,000	One full-time AECOM project manager over the period of 1 year
ME to analyze current UDS legs and B-12 concrete floor for additional 4000 lbs of weight added by BOP. Provide report.	1	400	$125	400	$50,000	This assumes no major redesign of the legs or modifications to the floor is needed
ME to specify and purchase new hydraulic system to operate BOP ram, modify drawings, perform construction support and operational checkout	1	350	$125	350	$43,750	Ram Hydraulic System and controls
ME redesign of UDS Upper Plug and hydraulic removal mechanism to accept BOP. This is to include mounting requirements of BOP and impact of BOP actuation	1	700	$125	700	$87,500	
CE Design modification of building wall to accept BOP, incorporate new sliding door.	1	65	$125	65	$8,125	
Design team participate in Haz Op/SARS process	1	80	$125	80	$10,000	This is NOT performing SARS, just participating
Design team participating in modification to Standard Operating Procedures	1	60	$125	60	$7,500	
EE Modification of control I/O and electrical drawings for additional equipment	1	120	$125	120	$15,000	
			Totals From Continuation Sheet: (if needed)	5,170	$502,750	
			Total:	**9,025**	**$932,625**	

Estimate Type (Place an X in the block below to select the type of estimate)		NOTES
X	Order of Magnitude (-30% to +50%)	
	Preliminary (-15% to +30%)	
	Definitive (-5% to +15%)	

Estimate Summary

Total Estimated Hours: **6318 - 13538**

Total Material Cost: **$126,000 - $270,000**

Total Estimated Cost: **$778,838 - $1,668,938**

Estimated Start Date: **Two (2) weeks after NTP**
Dependent on approval of estimate

Estimated Completion Date **Approx 14 months**
Dependent on approval of estimate

Estimate Qualification Statement

Please note that the estimates provided herein are dependent upon the basis of quantities, execution approach, pricing techniques and the underlying assumptions, inclusions and exclusions. Actual project costs will differ and can be significantly affected by changes in the scope, sequence and external environment, the manner in which the project is implemented and other factors which impact the basis upon which the initial estimate was prepared. Estimate accuracy ranges are projections of the most likely potential range of variance and are in accordance with typical industry accepted practice. The accuracy range is based on the level of scope definition, level of project execution development and the cost estimating methods and practices utilized in preparing the estimate. The range is not a guarantee of actual project costs.

The estimated start and completion dates stated above are dependent on receiving estimate approval before the noted estimated start date. In the event the estimate approval is received after the estimated start date, the Work Control Lead shall provide a realistic start and completion date based on the current schedule.

Form No. RIS-1001.1

RIS
ESTIMATING WORKSHEET
(Labor Continuation Sheet)

WORK ORDER : **NA**
PROJECT: **BOP Testing**

DATE: **2/9/2015**
NETL DCN: **NA**

Task Description	Quantity (User)	Estimated Hours / Task	Average Cost / hr	Total Hours	Extended Cost	Remarks (User)
Subcontract for modifying wall					$35,000	South concrete wall of existing door
Subcontract for installing larger door					$35,000	
Subcontract for Conrol system modification					$20,000	modify HMI accordinly for new testing
Subcontract for installing BOP					$25,000	Hoisting/rigging BOP into position
AECOM modification/fabrication of new Upper Plug	1	350	$75	350	$26,250	major UP mods and/or new
AECOM fabrication & installation of new reaction column/spacer and bracket	1	120	$75	120	$9,000	
AECOM install of hydraulic system for BOP ram	1	500	$75	500	$37,500	
AECOM inspect current system, re-connect utilities, make necessary repairs	2	40	$75	80	$6,000	
AECOM Shakedown/start-up activtiies	1	120	$75	120	$9,000	
Operator training	2	2000	$75	4000	$300,000	
		Continuation Totals:		5170	$502,750	

Form No. RIS-1001.1

RIS
MATERIAL ESTIMATE WORKSHEET

WORK ORDER : **NA**
PROJECT: **BOP Testing**
MATERIAL ACCOUNT CODE:

DATE: **2/9/2015**
NETL DCN: **NA**

MATERIALS

Product Description	Quantity	Unit	Unit Price	Extended Cost	Remarks (User)
Hydraulic pump for BOP ram	1		$40,000	$40,000.00	
Circulating pump & associated equipment for internal pipe flow	1		$40,000	$40,000.00	
New large door for cell	1		$50,000	$50,000.00	
Upper plug material	1		$10,000	$10,000.00	
Reaction column materials	1		$5,000	$5,000.00	
Hydraulic tubing, hoses, valves, supports, etc	1		$20,000	$20,000.00	
Electrical & Control System components for modiciation	1		$15,000	$15,000.00	
				$0.00	
				$0.00	
				$0.00	
				$0.00	
				$0.00	
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				$0.00	
				$0.00	
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				$0.00	
				$0.00	
		Material Totals:		$180,000.00	

Form No. RIS-1001.1

RIS
ESTIMATING WORKSHEET

Reference RES-EG-00-001 for Estimating Worksheet Guidelines

DATE: **2/9/2015**

WORK ORDER : **NA**

NETL DCN: **NA**

PROJECT: **BOP Testing**

PREPARED BY: S.FIKE/T.THEWLIS

LOCATION: **B-12 - East Test Cell**

REVIEWED BY:

LABOR ACCOUNT CODE: **NA**

APPROVED BY:

WORK DESCRIPTION: Design, Fabrication, and Installation of new system for BOP testing in East Test Cell.

Task Description	Quantity (User)	Estimated Hours / Task	Average Cost / hr	Total Hours	Extended Cost	Remarks (User)
AECOM Project Manager	1	1720	$100	1,720	$172,000	One full-time AECOM project manager over the period of 10 months
ME to specify and purchase new hydraulic system to operate BOP ram, create drawings, perform construction support and operational checkout	1	350	$125	350	$43,750	Ram Hydraulic System and controls
ME to design custom rig to mount BOP and hydraulic removal mechanism. This is to include mounting requirements of BOP and impact of BOP actuation	1	600	$125	600	$75,000	Spool piece design, support structure design, calculations, analysis, PFD and P&ID creation
EE creation of control I/O and electrical drawings for additional equipment	1	300	$125	300	$37,500	
Design team participate in Haz Op/SARS process	1	80	$125	80	$10,000	This is NOT performing SARS, just participating
Design team participating in modification to Standard Operating Procedures	1	60	$125	60	$7,500	
		Totals From Continuation Sheet: (if needed)		2,690	$201,750	
		Total:		**5,800**	**$547,500**	

Estimate Type (Place an X in the block below to select the type of estimate)		NOTES
X	Order of Magnitude (-30% to +50%)	
	Preliminary (-15% to +30%)	
	Definitive (-5% to +15%)	

Estimate Summary

Total Estimated Hours: **4060 - 8700**

Total Material Cost: **$168,000 - $360,000**

Total Estimated Cost: **$551,250 - $1,181,250**

Estimated Start Date: **Two (2) weeks after NTP**
Dependent on approval of estimate

Estimated Completion Date **Approx 10 months**
Dependent on approval of estimate

Estimate Qualification Statement

Please note that the estimates provided herein are dependent upon the basis of quantities, execution approach, pricing techniques and the underlying assumptions, inclusions and exclusions. Actual project costs will differ and can be significantly affected by changes in the scope, sequence and external environment, the manner in which the project is implemented and other factors which impact the basis upon which the initial estimate was prepared. Estimate accuracy ranges are projections of the most likely potential range of variance and are in accordance with typical industry accepted practice. The accuracy range is based on the level of scope definition, level of project execution development and the cost estimating methods and practices utilized in preparing the estimate. The range is not a guarantee of actual project costs.

The estimated start and completion dates stated above are dependent on receiving estimate approval before the noted estimated start date. In the event the estimate approval is received after the estimated start date, the Work Control Lead shall provide a realistic start and completion date based on the current schedule.

Form No. RIS-1001.1

AECOM

RIS
ESTIMATING WORKSHEET
(Labor Continuation Sheet)

WORK ORDER : **NA**
PROJECT: **BOP Testing**

DATE: **2/9/2015**
NETL DCN: **NA**

Task Description	Quantity (User)	Estimated Hours / Task	Average Cost / hr	Total Hours	Extended Cost	Remarks (User)
AECOM fabrication of components for new testing rig	1	350	$75	350	$26,250	spool piece fabrication
AECOM fabrication & installation of support system for testing rig	1	120	$75	120	$9,000	assemle spool pieces, install support structure and BOP mounting
AECOM install of hydraulic system for BOP ram	1	500	$75	500	$37,500	
Installation of Electrical components	1	300	$75	300	$22,500	
AECOM Shakedown/start-up activtiies	1	120	$75	120	$9,000	
Controls System Configuration	1	300	$75	300	$22,500	
Operator Training	1	1000	$75	1000	$75,000	
		Continuation Totals:		2690	$201,750	

Form No. RIS-1001.1

RIS
MATERIAL ESTIMATE WORKSHEET

WORK ORDER : **NA**
PROJECT: **BOP Testing**
MATERIAL ACCOUNT CODE:

DATE: **2/9/2015**
NETL DCN: **NA**

MATERIALS

Product Description	Quantity	Unit	Unit Price	Extended Cost	Remarks (User)
Hydraulic pump for BOP ram	1		$60,000	$60,000.00	
Circulating pump & associated equipment for internal pipe flow	1		$55,000	$55,000.00	
Control System software	1		$10,000	$10,000.00	
Hydraulic tubing, hoses, valves, supports, etc	1		$50,000	$50,000.00	
Electrical & Control System components for new system	1		$20,000	$20,000.00	
Material for spool sections	1		$30,000	$30,000.00	
Material for support structure	1		$15,000	$15,000.00	
				$0.00	
				$0.00	
				$0.00	
				$0.00	
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				$0.00	
		Material Totals:		$240,000.00	