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Test-Free Simulation Method for Blowout Preventer Pipe Shearing Powered by Data

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Abstract. A Blowout Preventer (BOP) serves as a safety valve in the drilling process in the oil and gas industry. It will be closed if an influx of formation fluids occurs and threatens the rig. A Ram BOP is one type of widely used BOP. It is composed of two ram blades, which will move toward each other to shear the drilling pipe and to close the valve. To ensure the shearing process is completed on the rig, lab tests are often run to evaluate the BOP's capability and the required shearing pressure. Over the last decade, Finite element analysis (FEA) based simulation method has been set up to predict the shearing process. The simulation method still requires pipe damage parameters and requires lab test. This paper presents a test-free simulation method enabled by analyzing the ram BOP pipe shearing data, which significantly reduces the lead time and test costs.

Introduction

A BOP serves as a safety valve in the drilling process in the oil and gas industry [1]. It will be closed if an influx of formation fluids occurs [2]. This event, commonly referred to as a kick, threatens the rig. A Ram BOP, as shown in Fig. 1, is one type of widely used BOP, and acts as the last safety guard in the BOP stack. It is composed of two ram blades that will move toward each other to shear the drilling pipe and to close the valve.

Although the structure is known, the pipe shearing process is invisible since it is covered by the 'Black Box' – the BOP body. To ensure the shearing process can be completed on the rig, multiple lab test runs are required to evaluate the BOP's capability and the shearing pressure for the drill pipes given by the operators.

Efforts have been taken from around 10 years ago to develop a method to predict the shear pressure of Ram BOP. According to the report prepared for the US Minerals Management Services [3], analytical models were first presented, and then developments made to improve the accuracy of the analytical methods [4,5].

When developing accurate prediction methods, computer-aided numerical methods come into view, and the feasibility of computer-aided engineering (CAE) methods is checked. In 2014 [6] and 2015 [7], finite element analysis (FEA) was reported to model the Ram BOP shearing process. The Johnson-Cook damage model [8] was used to predict the pipe damage during the shearing process. For the application of the damage model, the prerequisite is the pipe material damage parameters. The damage parameters are not generic material property and require additional lab tests.

Recently, based on the big data accumulated through Cameron BOP shearing tests over the last decades, a test-free simulation method was developed. The method has been used to model the shearing process of Cameron Ram BOPs and displayed high accuracy. This paper presents this simulation method, which makes the simulation test free and significantly reduces the lead time and test costs.

Ram BOP Pipe Shearing Lab Test

Lab testing is the conventional and required method to check the capability of a BOP to ensure that the shearing process can be completed on the rig. For a given rig, operators will provide all types of pipes that will be used on the rig. Lab tests will then be run to evaluate the BOP's capability for each of the given drill pipes. Fig. 2 shows an example of the lab test setup. During the test, the curve of shear pressure vs. time is collected and the pipe shearing cross section is examined. The max shear pressure is used as the key output to check BOP capability. If the shearing test fails or the max shear pressure exceeds the allowed magnitude, the ram BOP design needs to be modified and then all tests must be rerun. The process will be repeated until the proposed BOP design can pass all the tests, and the BOP is qualified for field use.

The test method is very costly. Shearing tests of each BOP design usually take several months' lead time and cost thousands of dollars. The costs will double if a failure occurs and replacement of the BOP design is required.

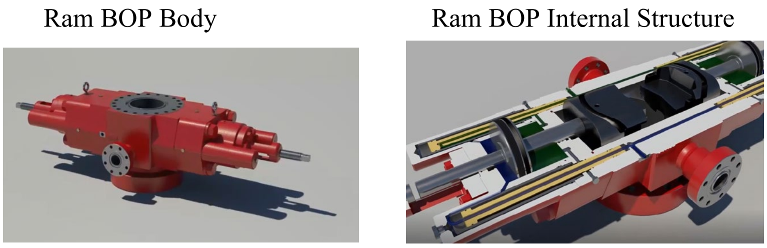


Figure 1. Ram BOP design.

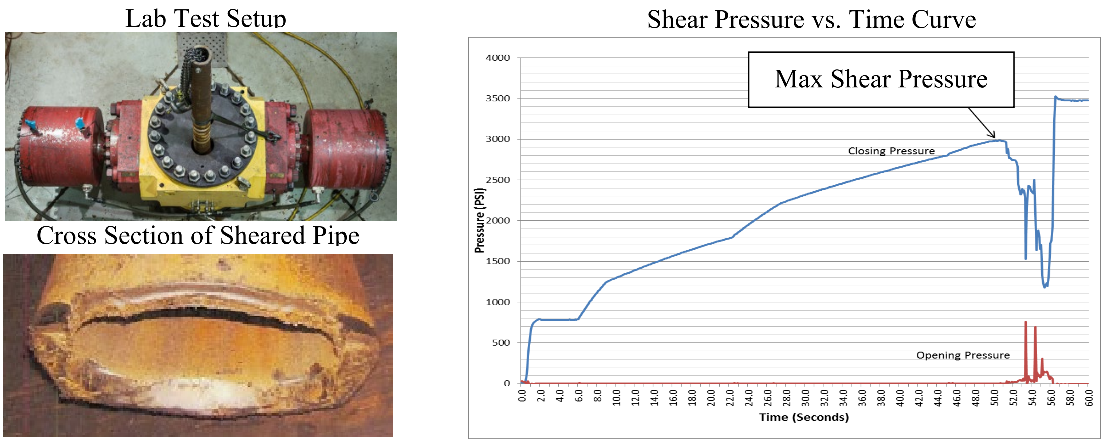


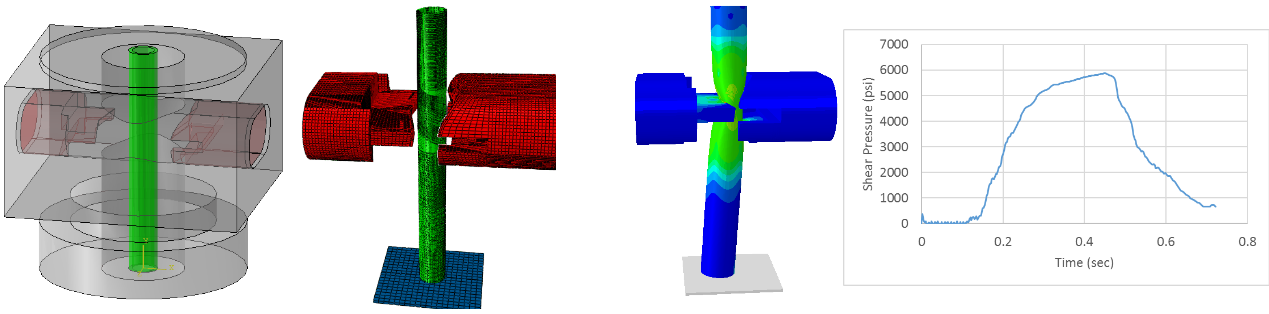
Figure 2. Figures of Ram BOP lab test setup, sheared pipe cross-section, and shearing pressure.

FEA Simulation

FEA-based simulation method has been developed in recent years to simulate the BOP shearing process. It provides designers with a 3D virtual shearing process tool that helps predict the shearing pressure.

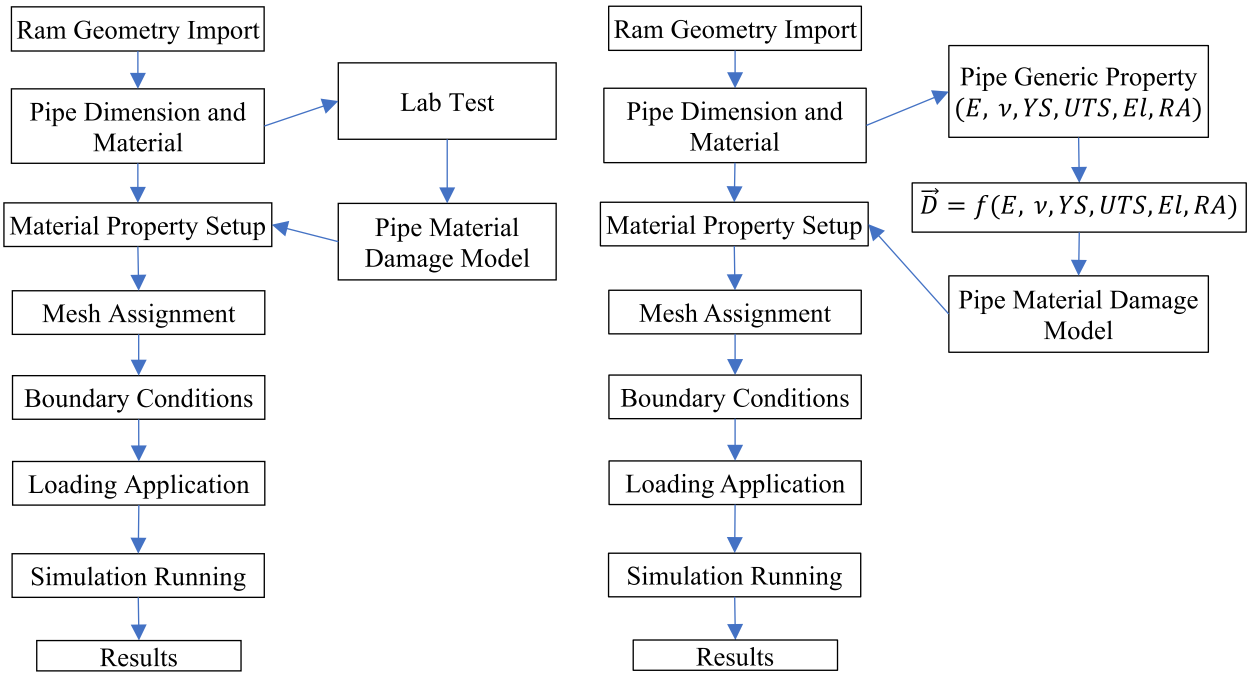
Fig. 3(a) shows an example of the FEA model setup from a BOP computer-aided design (CAD), where the model consists of the BOP rams (blades) and a pipe. The pipe is supported on the bottom, and two rams (blades) will move toward each other to shear the pipe. When the pipe breaks, the highly deformed element will be deleted. The model records and outputs the pipe deformation, ram deformation, and shearing pressure during the whole shearing process, as illustrated in Fig. 3(b).

The traditional FEA simulation workflow is shown in Fig. 4(a). The engineer collects the information on the BOP design, pipe dimension, and material properties. The engineer then sets up the model by importing the geometry, meshing, assigning material properties, implementing a pipe damage model, applying boundary and loading conditions, running the simulation, and generating results.



(a). Ram BOP CAD design and FEA model setup (b). FEA output of pipe deformation and shear pressure curve

Figure 3. Illustration of Ram BOP FEA model setup and simulation output.



(a). Traditional simulation method. (b). Test-free simulation method.

Figure 4. Workflow for FEA simulation.

Damage Model

The pipe material damage model is used to characterize the damage growth behavior of the pipe under shearing force. The damage model is critical to the accuracy of the shearing simulation result.
There have been several damage models developed over the last decades for metals. For pipe shearing simulation, the Johnson-Cook damage model [8] has been widely used to describe the damage behavior of steel pipes. The model is shown as below:

$$\overline{\varepsilon^p}^f = (D_1 + D_2 exp D_3 \sigma^*)\left(1 + D_4 ln \frac{\dot{\overline{\varepsilon^p}}}{\dot{\overline{\varepsilon}}_0}\right)\left[1 - D_5\left(\frac{T - T_0}{T_{melt} - T_0}\right)^m\right]$$

where D1 to D5 are damage parameters and the parameters are conventionally obtained from a destructive lab test using the pipe material sample.

Test Free Simulation Method

The paper proposes a test free method, where the parameters D1 to D5 are derived from generic material properties as shown below:

$$\vec{D} = (D1, D2, D3, D4, D5) = f(E, \nu, YS, UTS, El, RA)$$

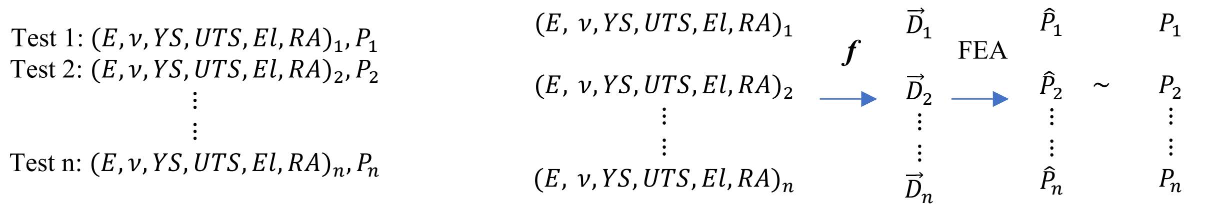
where E is elastic modulus, v is Poisson's ratio, YS is yielding strength, UTS is tensile strength, El is elongation, and RA is reduction in area. Array $\vec{D}$ represents all the damage parameters $D1$ to $D5$. Function f is the damage parameter function proposed in this paper. The damage parameter function is found through analyzing the correlation between the pipe generic properties and shear pressure in the Cameron BOP shearing test database.

Fig. 5(a) shows the structure of BOP shearing test data, where a large amount of tests (total number denoted by n) have been applied over the last decades. For each test, the pipe generic material property (E, v, YS, UTS, El, RA) and the max shear pressure P are recorded.

Fig. 5(b) shows the process to generate the function from the test data. For a given (or trial) damage parameter function f, the damage parameters $\vec{D_i}$ are generated using the generic material property for each test i, and FEA simulation is applied to generate the shear pressure prediction $\hat{P_i}$. Then the predictions of all cases ($\hat{P}_1$, $\hat{P}_2$, …, $\hat{P}_n$) are compared with the test recorded shear pressures (P_1, P_2, …, P_n). If the difference is larger than targeted error tolerance, then the function f will be modified and the process will be repeated until the difference falls within the error tolerance.

Previous publications [7, 9, 10] of BOP shearing simulations have reported the errors in the range of 5.8% to 18.7%. This work chose the error tolerance as 15% and successfully found a parameter function.

With this function, the test-free shearing simulation can then be applied following the workflow shown in Fig. 4(b). Compared with the traditional simulation workflow shown in Fig. 4(a), the test free method uses the pipe generic material property to generate the damage parameter and the damage model. This allows the analyst to run the simulation without the lab tests.



(a). BOP shearing test data.

(b). Illustrations of using shearing test data to develop the damage parameter function, f.

Figure 5. Illustrations of using shearing test data to develop the damage parameter function, f.

Validation Case Study

The method is validated by representative test cases of commonly used pipe types that cover the categories of tubing, casing, and tool joints. Table 1 lists the selective cases, which are one 4.5-in outside diameter (OD) pipe, one 6-5/8-in OD pipe, one 12.25-in OD casing, and one 8.5-in OD tool joint. Fig. 6 plots the comparison of the shear pressure between FEA prediction (y axis) and lab test measurement (x axis) for those cases. Proprietary test result units of measure have been removed from Fig. 6. However, the figure still provides a visual explanation of FEA vs. physical testing. A reference dash line is plotted to represent the case when prediction is the same as the measurement. The predicted shearing pressure agrees with the test data, and max error is 11%.

In addition to the prediction on shear pressure, it is also found the sheared pipe cross section can be predicted using this method. Fig. 7 shows the comparison of pipe cross section for cases No. 1 to No. 3, and the prediction matches the test observations.

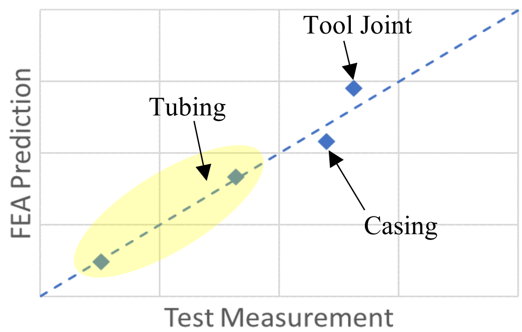


Figure 6. Predicted max shear pressure vs. lab test.

Table 1. Selective test cases of commonly used pipe types.

Case No.	Pipe Dimension	Error in Max Shear Pressure
1	OD 4.5 in, ID 3.8 in	-3.9%
2	OD 6.625 in, ID 5 in	2.0%
3	OD 12.25 in, ID 10 in	-9.7%
4	OD 8.5 in, ID 4.25 in	10.6%

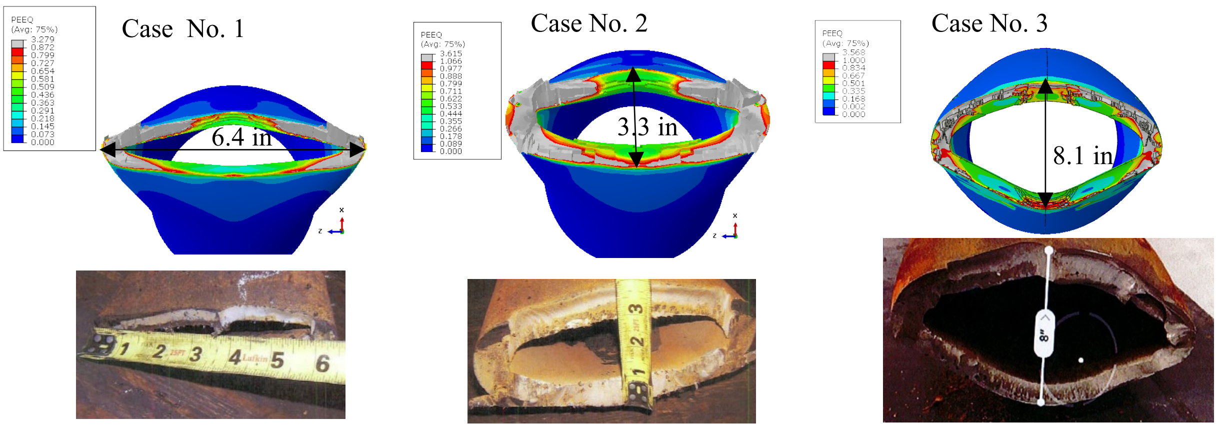


Figure 7. Cross section of sheared pipe, simulation prediction vs. lab test.

Conclusion

This paper presents the test-free simulation method for the ram BOP pipe shearing process. This method is developed based on big data accumulated through historical Cameron Ram BOP shearing tests over the last decades. It allows analysts to generate accurate prediction on the max shear pressure and pipe sheared cross section without the requirement on lab tests. This makes the simulation test free and significantly reduces the lead time and costs.

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