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Development of an integrated tool for risk analysis of drilling operations

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ABSTRACT

Most risk analysis of drilling operations failed to distinguish and capture evolving risk during different stages of drilling operations. This paper presents a new integrated dynamic risk analysis methodology. This methodology comprises models applicable at different stages of drilling operations. These models capture evolving situations in terms of changes in the probability and consequences of unwanted scenario (unstable well condition). The dynamic consequence models are developed in terms of loss functions dependent on changing bottom-hole pressure during different stages of drilling operation. The proposed methodology is tested using real life case. It is observed that the proposed methodology help monitoring and maintaining well stability during different stages of drilling operations.

1. Introduction

On the 21st of August 2009, at the Timor Sea offshore Australia, the Montara wellhead platform experienced a blowout at the H1 well. The probable cause was later identified as a failed casing shoe cementing. It was the worst of its kind in the Australian offshore industry which led to the spill of about 400 barrels of crude oil per day for over 10 weeks into the sea until it was killed with heavy mud from a relief well after 4 attempts on November 3, 2009. The fortunate part of the accident was the safe evacuation of all 69 personnel on board; however, the cleanup operation was highly complex, consuming large volumes of dispersants and many response teams (Christou and Konstantinidou, 2012; IAT, 2010). About four months later, on December 23, 2009, Transocean crew narrowly avoided a blowout on the Sedco 711 semi-submersible drilling rig in the Shell North Sea Bardolino field due to a misinterpreted positive pressure test from a damaged valve at the bottom of a well (Feilden, 2010). Again, four months later, on April 20, 2010, an unprecedented blowout occurred in the history of the US oil and gas industry. 11 crew members died and 16 others were injured with the destruction and sinking of the Deepwater Horizon rig, and a spill of about 4 million barrels of oil into the Gulf of Mexico. Coincidentally, Transocean was involved in the drilling of the well and again, poor casing shoe cementing and poor interpretation of negative pressure test were identified as some of the contributing factors (BOEMRE, 2011; Chief Counsel's Report, 2011). The proximity of these events and the frequency, with which incidents occur in the industry, implies the existence of a vacuum in the safety culture of personnel involved in the operations. Risk assessments are often conducted in the design stage of the operations prior to the implementation to reduce design risk whereas the mechanisms to reduce operational risks are less rigorously implemented. This paper seeks to bridge the existing gap in the safety and risk assessment of oil and gas drilling operations. In so doing, a detailed risk analysis of the operational phases or sub-operations involved in drilling operations is conducted.

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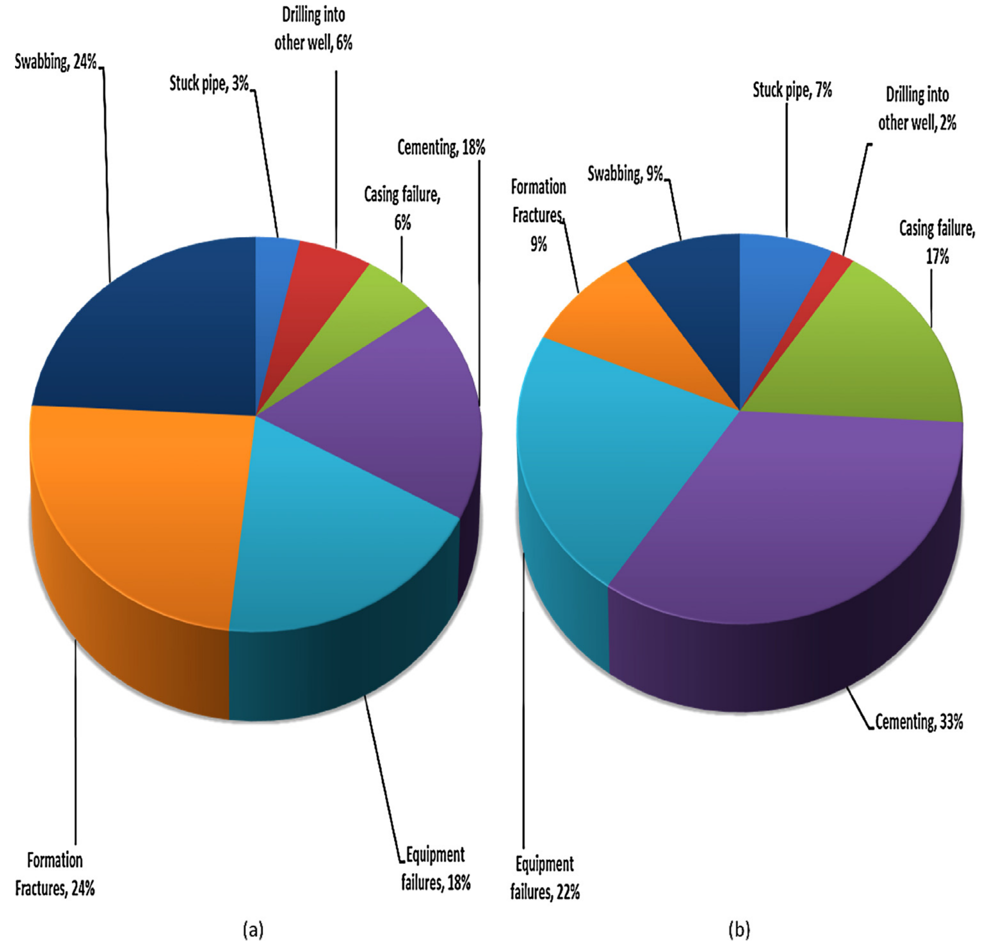

Fig. 1 – Factors contributing to blowouts from The US Outer Continental Shelf from (a) 1971–1991 and (b) 1992–2006.

A sound knowledge of the stages/phases of drilling operations is essential for an accurate and reliable risk assessment of drilling operations. According to Arild et al. (2009), there are five operational phases of drilling operations, namely: drilling ahead, tripping, static conditions, casing and cementing operations. These operational phases are studied in this paper. A brief description of these stages is presented in Section 2. It is our belief that a detailed understanding of these stages of drilling operations will help forestall or reduce future occurrences of accidents. Among the factors contributing to a blowout include: cementing, swabbing, equipment failure, stuck pipe and drilling into other well (Danenberger, 1993; Izon et al., 2007). A summary of the findings from the studies of Danenberger (1993) and Izon et al. (2007) on the incidents in The US Outer Continental Shelf is presented in Fig. 1. It is observed that these factors transcend all the stages of drilling operations. A blowout is an uncontrolled flow of hydrocarbons (oil and gas) from a well to the surface (surface blowout) or to an adjacent underground formation (underground blowout). A blowout occurs when a kick – an influx of formation fluid into the wellbore when the bottom hole pressure falls below the formation pore pressure – is not detected or has not been properly killed when detected. The killing of a kick involves the use of well control methods in preventing a kick from resulting to a blowout.

Studies on risk assessment and analysis of drilling operations have looked into various aspects of drilling without a linkage among the sub-operational stages. For instance, in evaluating the performance of the blowout preventer (BOP) system during drilling operations, Cai et al. (2012) conducted a reliability analysis based on Markov method to establish the preferential stack configuration for subsea BOP systems. In the study, seven independent Markov models were developed for the segmented BOP system modules to investigate common-cause failures. The subsea control pods and control stations were determined to be of higher priority in the design of subsea BOP system (Cai et al., 2012). In the use of reliability data to calculate the failure rates of BOP components and rig downtime, Holand and Rausand (1987), and Holand (1991, 1999, 2001) estimated the availability of subsea BOP systems using fault tree analysis (FTA) method (Holand and Rausand, 1987; Holand, 1991, 1999, 2001). Fowler and Roche (1994) used both Failure Modes and Effects Analysis (FMEA) for the reliability analysis of a BOP and a hydraulic control system, and FTA in tracing undesired events to their primary causes (Fowler and Roche, 1994).

In addition to the studies on the BOP, modelling of blowout phenomenon to determine the causal relationships among successive events, leading to its occurrence has been conducted. Foremost was Bercha (1978) in the development of a fault tree model for the analysis of drilling operations in the Canadian arctic waters on both artificial island and offshore rigs. As the study employs a static model and specific to the Canadian arctic region; the deductions from the study are of less applicability to other tropical regions of the world. Andersen (1998) presented a fault tree model for the stochastic analysis of a kick as an initiating event to a blowout during exploration drilling. In line with the studies of the aforementioned authors, Khakzad et al. (2013) conducted a quantitative risk analysis of offshore drilling using bow-tie