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Deepwater Horizon disaster

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Summary

On 20 April 2010, a catastrophic oil well blowout occurred onboard the Deepwater Horizon oil rig which resulted in eleven deaths, the demise of the rig, and the largest oil spill in history. The uncapped well impacted both local wildlife and the fishing industry within the Gulf of Mexico. The events which led to the accident and immediately after the explosions and fire have since become a landmark case in process safety, law and politics. There are several important process safety management (PSM) lessons to be learned from this incident. If the lessons learned are diligently followed by the industry, mistakes can be avoided and the chances of a similar accident happening again will be greatly reduced.

Keywords: Deepwater Horizon, oil spill

Introduction

The deep-sea drilling platform, Deepwater Horizon, was engulfed by fire after a catastrophic 'blowout', eleven out of the 126 crew lost their lives, and 17 others were injured. Following the explosion, Deepwater Horizon sank, resulting in the uncapped well releasing an estimated 4.9 million barrels of crude oil into the Gulf of Mexico over a period of 87 days. Deepwater Horizon is considered to be the largest marine oil spill to date[1]. The rig was owned by Transocean and operated by Haliburton on behalf of BP for the Macondo Well. A number of senior staff were direct employees of BP who were ultimately responsible for the performance and safety of the rig. BP pleaded guilty to 14 criminal charges[2], with total damages paid exceeding $65bn[3].

Deepwater Horizon

Deepwater Horizon was a dynamically positioned, semi-submersible drilling rig built in 2001 in South Korea. The rig measured 114m long and 41.5m wide and could accommodate 150 people. The total displacement was 50,000 tonnes of heavy mud. The Blowout Preventor (BOP) was located on the seabed and acted as the first safety barrier. The BOP is a complex electrical and hydraulic device, essential for controlling the well and preventing a disaster on the rig above. The main function of a BOP is to prevent flammable hydrocarbons travelling up the riser to the drilling rig, achieved by sealing the area around the drill pipe known as the annular space[4].

How the event occurred

The Deepwater Horizon rig was in the "temporary abandonment" phase of drilling the Macondo well in the Gulf of Mexico[5]. "Temporary abandonment" is the period between the completion of drilling to prove the oil reserves, and the commercial exploitation of the well. It involves the drilling rig plugging the well with cement in order to seal and secure it, allowing the BOP and marine riser to be removed from the well site[6]. This means the well can be "abandoned" in a safe state until the exploitation rig arrives to re-open the well and commence extraction of the well reserves.

In the early hours of 20 April 2010, cement was pumped into the well. Normal procedures would dictate that a Cement Bond Log (CBL) test would be conducted to test the integrity of the cement seal. The CBL test is an acoustic sonic and ultrasonic test, performed to measure the strength of the bond between the casing and the cement placed in the annulus. This indicates if the well is effectively sealed by the cement bond, as when the cement is bonded, the vibrations are proportional to the bonded surface, and when there is no cement, the pipe vibrates creating a loud sound[7].

However, the three-man Schlumberger team who had been flown out to the rig to conduct the CBL were sent home to save costs. The CBL test would have incurred a $128,000 dollar fee, adding strain to a project which was already late and over budget. The omission of this fundamental safety step proved to be a significant factor leading to the accident. Had the full CBL test been carried out, the fault in the concrete seal would have

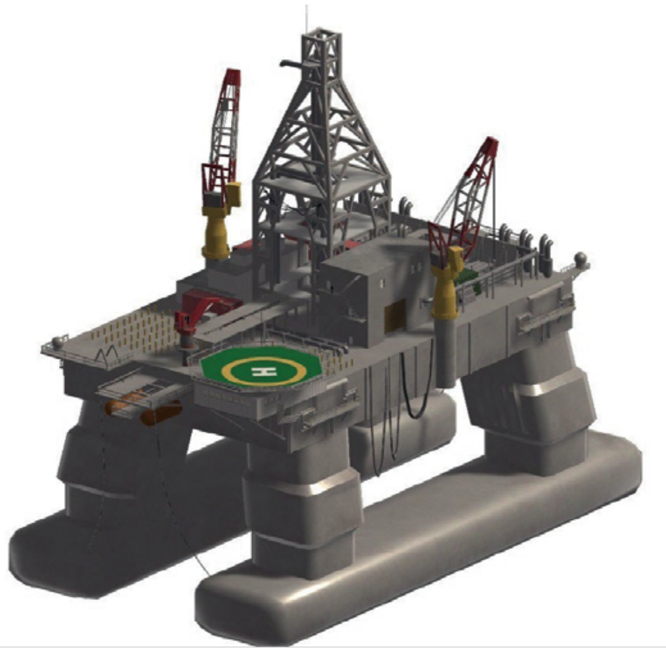

Figure 1 – Model of the Deepwater Horizon rig

knowledge and competence

engineering and design

systems and procedures

assurance

human factors

culture

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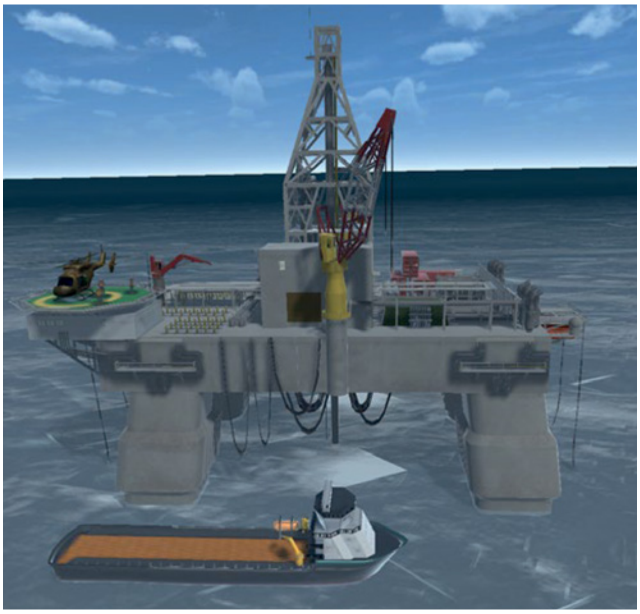

Figure 2 – Screenshot of the interactive experience (www.deepwaterhorizon.co.uk)

been identified. Normal procedure would then dictate that this would have been followed up by remedial action, preventing the well kick and consequential blowout[8]. Pressure tests, which under normal circumstances, would follow successful completion of the CBL tests were then conducted, despite this being incomplete.

The positive pressure test was successful; however, the negative pressure test, used to indicate whether the cement barrier had isolated the formation fluids from the wellbore, indicated pressure anomalies[6]. A well kick (an uncontrollable influx of fluids into the wellbore[9]) followed, which resulted in hydrocarbons and heavy mud escaping from the wellbore, thus causing the blowout.

When the hydrocarbons reached the Deepwater Horizon drill deck, high-pressure gas was discharged from the mud gas separator (MGS) relief vents. At this point multiple gas alarms were sounded as the gas rapidly dispersed. Eventually, the gas migrated to an ignition source and resulted in two explosions occurring at approximately 21:49pm. The explosions were followed by a class 2 conflagration fire which quickly engulfed the platform. During this time, many attempts were made to seal the well and stem the hydrocarbon leak via the Emergency Disconnect Sequence (EDS). However, the scale of challenges faced made all attempts unsuccessful. On 22 April 2010, after the rig had been burning for 36 hours, Deepwater Horizon eventually sank. The now uncapped well continued leaking oil into the Gulf of Mexico for 87 days[10].

Process safety

In order to maintain control of the well and minimise risk, the drill crew should have questioned and investigated the cause of the pressure anomalies sighted during the CBL test. The well kick which occurred after the negative pressure test, was a significant factor when considering process safety during the temporary abandonment phase of drilling. Kick detection on board the rig was dependent on situational awareness (SA). This is a cognitive skill which allows the operator to monitor the work environment and predict how situations could develop[11]. The crew, although recognising the signs of the kick, missed the significance and unfortunately were unable to prevent the blowout. At the time of the incident no standard tool for investigating human factors within drilling and or well intervention incidents existed[9].

Despite the requirement for all drill crew to complete

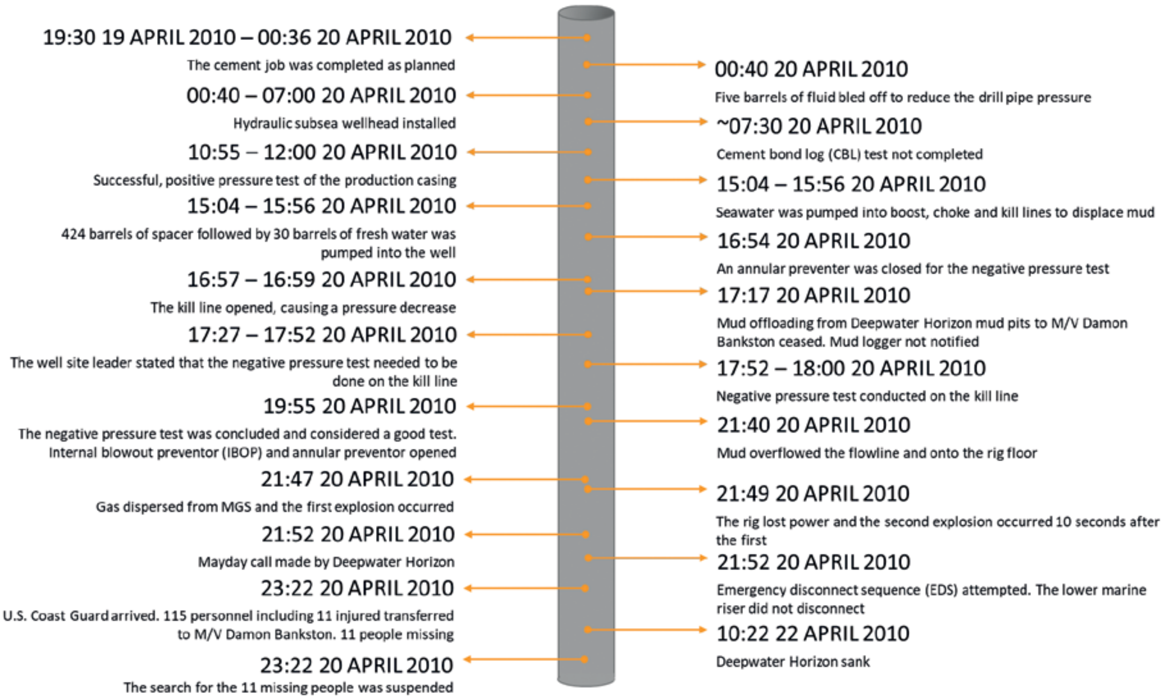

Figure 3 – Timeline of events onboard the rig

certified well control courses, the training was more focused on technical aspects and not SA[9]. However, since Deepwater Horizon, the importance of non-technical skills (NTS), such as SA, have been recognised, and the oil and gas industry have begun training operators in these areas[11].

Process safety management

Process safety management (PSM) is critical within the oil and gas industry, to prevent the release of hazardous and flammable materials. The Occupational Safety and Health Administration (OSHA) specifically recommends documented inspections of relevant systems, as well as the use of tools such as 'what-if analysis' to determine the hazards involved in a process[12]. Had both of these elements been applied onboard the Deepwater Horizon, the disaster would have been mitigated or completely avoided altogether.

The failure in management and communication was undoubtedly a contributory factor leading up to the blowout. Various companies operated on the rig at any one time – BP, Transocean, Halliburton, and Schlumberger, which demanded a clear hierarchical structure, in which the various corporate cultures and internal procedures worked cohesively. If the communication culture within each of the separate companies and between the cross-company work, had been improved, the accident would have been heavily mitigated.

Figure 4 – Model of the BOP

Mechanical failures

Although some of the underlying causes of the blowout can be directed at PSM and poor operator risk management, there were also many mechanical failures which contributed to the incident.

Deepwater Horizon utilised a BOP with two annular preventers and five sets of metal shear rams to cut through the drill pipe in an emergency situation[8]. Due to the lack of preventative maintenance onboard the rig, three out of the four backup systems within the BOP, failed. This was due to defective solenoid valves and low battery charge.

Firstly, the backup system, the AMF (Automatic Mode Function) Deadman, was operated by two control systems known as the yellow and blue pods, comprised of identical enclosed computers and sets of solenoid valves. These pods contained a backup 27-volt and two 9-volt batteries to power the solenoid valves and the computers which activate them respectively. However, evidence indicated that the blue pod had been mis-wired before the BOP was lowered onto the seafloor, causing the 27-volt battery to drain and render it impossible to operate the solenoid valve, in order to activate the blind shear ram[20].

Secondly, within the redundant yellow pod, the coils within the solenoid valve were mis-wired causing the coils to oppose each other, which meant the wires were unable to generate a magnetic field, thus leaving the valve paralysed. Only a third, unplanned failure, within the AMF Deadman allowed the yellow pod to operate. One of the 9-volt batteries, used to power the solenoid valves computer, had failed. As a result, the affected computer system could not initiate the command to energise the mis-wired coil and rendered one coil inoperable. This allowed the other coil to open the solenoid valve by itself and in turn, initiated the closure of the blind shear ram[20].

Finally, despite the fact the blind shear ram activated, it was unsuccessful at cutting the pipe, due to the large differential pressure otherwise known as 'effective compression'. Although pipes used in oil rigs appear to be perfectly straight, they have minor bends and irregularities, invisible to the naked eye, designed to give the longer side of the pipe a greater surface area. When there are large differences in pressure between the inside and outside of the pipe, the longer side experiences a larger bending force which can buckle even heavy pipes. During the events of Deepwater Horizon, this occurred, and the drill pipe buckled, essentially bending the pipe off-centre pushing sections of the drill pipe outside the reach of the blind shear ram[20]. This created an insufficient seal of the well, allowing oil and gas to flow up towards the rig, resulting in the second explosion[16]. Secondly, the manually activated emergency disconnect sequence (EDS) should also have closed the blind shear ram, and caused a successful closing of the pipe, securing the wellbore. Although the EDS was initiated, and successfully activated the blind shear ram, it was ineffective partly due to the damage to the electrical instrumentation and hydraulic cable from the first explosion[8], and partly due to effective compression, as the blind shear rams could not seal the well properly. If working correctly, this would have severed the drill pipe riser, sealed the well and completely disconnected the rig from the BOP.

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Failure summary

The incident occurred not as the result of any one cause but due to a number of contributing factors, the most significant of which were:

- **Schedule and budgeting:** Drilling of the Macondo well was almost six weeks behind schedule and more than $58 million over budget. In addition, following the 2005 explosion at the Texas City refinery and the 2006 oil spill in Alaska, there was an urgency to improve public opinion of oil safety and the company's reputation[13]. Increasing profit was also a key factor contributing to the disaster, hence the decision not to undertake the CBL.
- **Poor rig maintenance:** The Deepwater rig had a backlog of maintenance issues; the 2009 BP safety audit listed 390 items requiring 3,545 man-hours of work[13]. This was not completed by BP due to pressures on schedule and budget. It could be argued that responsibility for the condition of the rig laid with Transocean as the owners.
- **Experience sharing and learning from incidents:** Four months prior to Deepwater, on 23 December 2009, a similar incident occurred on a Transocean rig operating in the Bardolino Well in the North Sea[15]. In this incident, a lack of experience and SA training was also responsible for poor monitoring and misinterpretation of critical kick indicators[11]. In this instance, unlike the Macondo well incident, the BOP successfully closed the well. But the experience and lessons learned were not communicated throughout the organisation and sufficient training was not given to rig staff, to prevent this type of incident from occurring again.
- **Lack of regulatory enforcement:** The Minerals Management Service (MMS) was responsible for regulating oil resources in the Outer Continental Shelf (OCS) of the United States. Unfortunately, the MMS failed to enforce tight safety regulations which enabled the oil and gas industry to favour profit over safety[14].

Lessons learned

When considering the series of events which occurred during the Deepwater Horizon accident, there are many lessons which can be learned. Perhaps the most important one is the

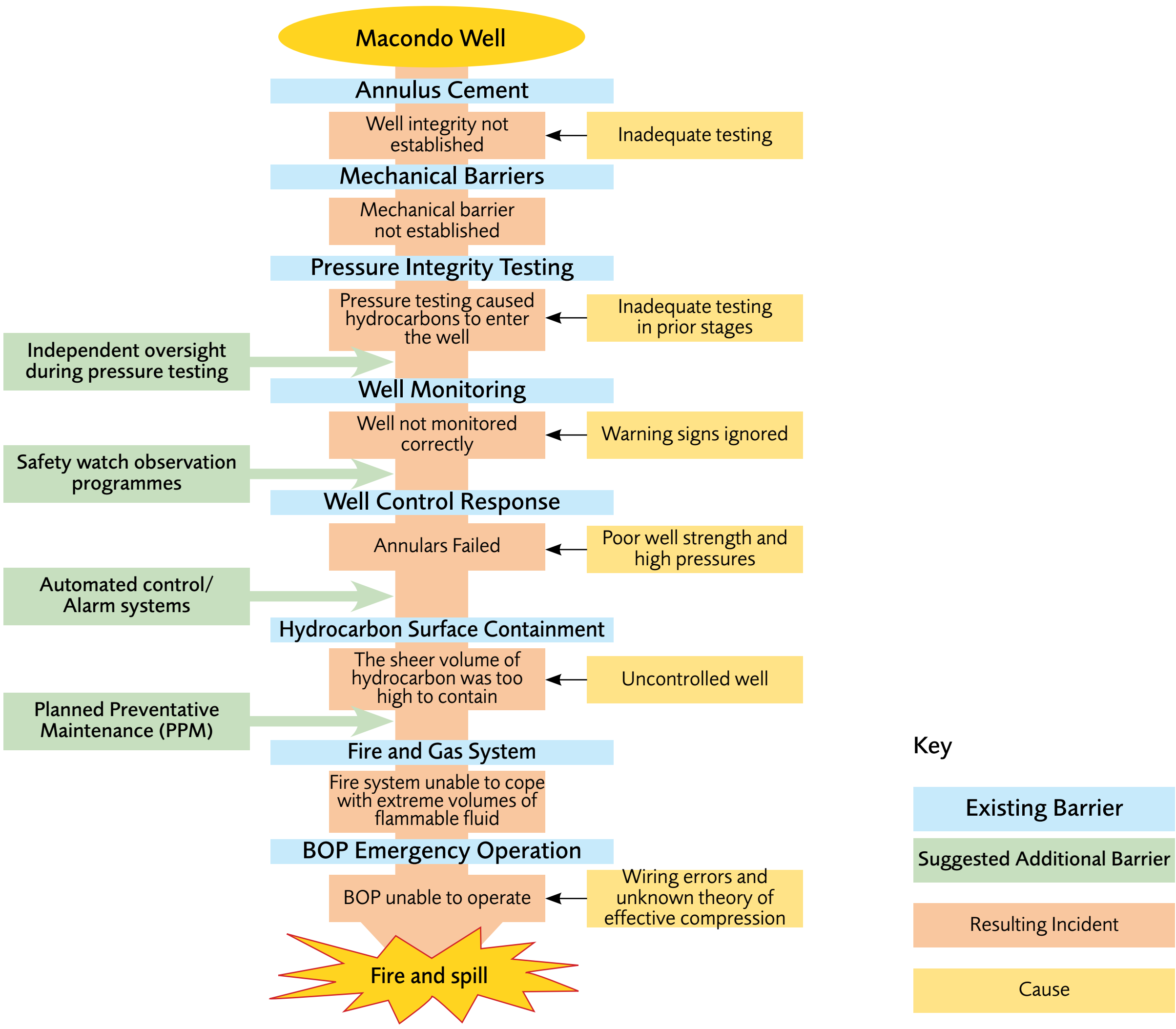

Figure 5 – Barrier analysis and barrier improvement recommendations diagram

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importance of a strict process safety management culture in high-risk chemical process environments. Due to time and monetary constraints felt by top-level management, the safety and integrity of mechanical equipment and operatives were compromised. This was evident by the fact that the 2009 safety audit highlighted several key safety failings which needed attention, but the recommendations were disregarded in order to avoid costly downtime and loss of production[13].

When considering the negative pressure test and inadequate BOP safety and maintenance procedures, it was clear the quality assurance (QA) and ISO 9001 procedural practices were insufficient. The negative pressure test was not documented and had no recommended safe operating limits. This highlights the importance of ensuring all standard operating procedures (SOP) are documented and shared company wide. It is also beneficial to share information industry wide, from both onshore and offshore oil and gas incidents. All changes made to the SOP's must be correctly documented through Management of Change procedures (MOC) and fully communicated via stringent training. Training is not only important for technical process skills but also non-technical skills, particularly situational awareness.

Safety systems onboard were faulty, and when considering PSM, it is important that alarms are functional, and when triggered, corrective actions are undertaken and not ignored. The activation of the EDS also required manual intervention, which elevated the risk of harm to process and personnel. If the control systems on the deck were automated, the process deviations which occurred during the negative pressure test could have been identified and adapted automatically. The process onboard the rig relied upon personnel to flag up issues, as evidenced by the negative pressure test, in which operators were expected to mitigate discrepancies in pressure readings as the test was running. Had this been automated, the problems with the defective cement seal could have been identified sooner, significantly reducing the level of risk associated with human intervention on the drill deck.

Conclusion

The Deepwater Horizon blowout is regarded as one of the most catastrophic events in offshore drilling operations[17]. As well as avoidable deaths and injury to operators, it caused one of the largest oil spills in history, with oil reaching several hundred miles of shoreline, having a disastrous environmental impact on marine and wildlife[18]. The implementation and maintenance of process safety measures in drilling operations is fundamental in ensuring risk is kept as low as reasonably practicable[17]. There has been much debate about the US moving away from a rules-based, and towards a goals-based offshore safety regime, as it has been applied in much of Europe and Oceania. This sentiment has also been echoed by the 2010 Presidential Commission of inquiry into the Macondo blowout[21]. However, a full transition to this type of system has yet to be made.

Whilst the events of the disaster highlighted the lack of operational standards and safety procedures within the industry, these have since been improved. Rig crew training now includes technical and non-technical skills, and the design of BOPs now includes active redundancy to improve reliability[19]. Despite the causes being due to many factors — human, process, and maintenance, the lessons learned from Deepwater Horizon have helped to prevent the same mistakes from happening again.

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Abbreviations

Abbreviation	Description
AMF	Automatic Mode Function
BOP	Blowout Preventor
CBL	Cement Bond Log
EDS	Emergency Disconnect Sequence
ISO	International Organisation for Standardisation
MGS	Mud Gas Separator
MMS	Minerals Management Service
MOC	Management of Change
NTS	Non-Technical Skills
OCS	Outer Continental Shelf
PSM	Process Safety Management
QA	Quality Assurance
SA	Situational Awareness
SOP	Standard Operating Procedure
OSHA	Occupational Safety and Health Administration

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