Deepwater Horizon – Failure of Blowout Preventer (BOP)

Jim Thomson
September 2016
20 April 2010, Gulf of Mexico

- 11 dead
- $350m (2001 cost) platform destroyed
- Largest ever oil spill
- BP CEO sacked
- New regulator (BSEE) created

Total BP liability (2016) $61 bn, plus other lesser liabilities:

- Anadarko (junior non-operating partner)
- MOEX (junior non-operating partner)
- Transocean (operator/owner)
- Cameron (BOP designer)
- Halliburton (drilling contractor)

Final total cost ~$80 bn ??

Most expensive ever accident (except Chernobyl and Fukushima)

129 people on board:
- 6 BP personnel
- 30 Halliburton
- Others mostly Transocean
1. Why didn’t the Blowout Preventer work?

2. Were there any common causes between Deepwater Horizon and the 2005 Texas City Refinery accident?

A cautionary tale of bad standards, weak regulation, and minimal compliance
The BOP was designed and manufactured to API standards by Cameron International (Texas), and owned and operated by Transocean (Switzerland) under contract to BP.

Cameron: 20000 employees  
$8.5$ bn turnover (2012)

Cameron International was bought by Schlumberger in 2016 for $14.8$ bn.

Transocean: 18000 employees  
$10$ bn turnover (2012)

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The role of the BOP was to shear the drill pipe and seal the well bore. It was actuated by the ‘Automatic Mode Function’ (AMF) (aka ‘Deadman system’) in the event of loss of power from Deepwater Horizon.
Primary cause: The BOP was not mechanically fit for purpose

“When the Blind Shear Ram was activated, the drill pipe was positioned off-centre near the inside wall of the Blowout Preventer, partly outside of the range of the BSR cutting blades.”

The drill pipe buckled due to high internal pressure - “effective compression”.

“Cameron had never tested an off-centre pipe. API standards are silent on the topic of off-centre and do not provide a design standard, a testing protocol, nor service condition recommendations.”
Annular preventers: These act to close the annular gap between the well bore and the drill pipe.

Blue and yellow pods: These contained control computers sealed in subsea electronic modules (SEMs). Each was a twin-channel system, making four channels in total. Each communicated with the surface via a modem and a copper wire. Electrical power came from the surface but was battery-backed with each pod having its own batteries. Hydraulic power also came from the surface but was backed up by hydraulic accumulators.

The ‘deadman’ system was designed to actuate the blind shear ram when power and communications from the surface were lost (as occurred after the blowout), by using local battery power and stored hydraulic pressure.

Design intent was one out of four logic to operate the deadman system.

However, in the accident, the blind shear ram was actuated by only one of the four channels.
Figure 4. SEM from the Deepwater Horizon (left) with its protective housing removed (right) as observed during Phase 1 testing.
Mis-wiring caused the critical 27V battery to drain, thereby making both channels inoperable.

Critical design features:

- In each pod, a single 27V battery served both channels.
- Each channel also had a dedicated 9V battery.
- Both the 27V and 9V batteries were safety-critical.
- Each pair of channels operated a single solenoid valve via two coils (one for each channel).
- There were no diagnostics so operators were unaware of battery status/system health.
- It was impossible to test channels separately.

One of the solenoid coils was wrongly wired, so the two channels opposed each other. This by itself would have prevented solenoid valve actuation. However, a drained 9V battery in the yellow pod left one of the coils in the solenoid valve inoperable, allowing the other coil to activate unopposed and initiate closure of the blind shear ram.
• The ineffectiveness of the Blind Shear Ram in cutting offset drill pipe should have been revealed in development testing!

• All wiring faults should have been revealed during Factory Acceptance Testing (FAT)!

• There should have been built-in diagnostics systems which could have advised operators of battery failures!

• The system should have enabled the testing of each channel separately!

ALL OF THE ABOVE ARE REALLY JUST BASIC GOOD PRACTICES WHEN DESIGNING AND MANUFACTURING HIGH-INTEGRITY SYSTEMS.
Culture of GoM drilling industry – what CSB said (2016):

“[A] culture of minimal regulatory compliance continues to exist in the Gulf of Mexico and risk reduction continues to prove elusive,” six years after the catastrophic April 20, 2010, event that killed 11 workers and caused the biggest oil spill in the history of offshore drilling. While the Macondo blowout occurred under the direction of Transocean and BP, it affected the oil and gas industry worldwide by demonstrating that high-hazard risk management continues to be a challenge in the offshore environment.

A complex interplay of physical, operational, and organizational barriers failed that day, sending oil and gas from deep below the ocean floor onto the drilling rig, triggering explosions and ensuing fire that left 11 of the 126 workers dead and critically injured at least 17 others.”
Relevant C&I design standard

API (American Petroleum Institute) Spec 16D

Specification for Control Systems for Drilling Well Control Equipment and Control Systems for Diverter Equipment establishes design standards for systems used to control blowout preventers (BOPs) and associated valves that control well pressure during drilling operations. The design standards applicable to these systems and components do not include material selection and manufacturing process details but may serve as guidance to the purchaser. Although diverters are not considered well control devices, their controls are often incorporated as part of the BOP control system and therefore are included in this specification. The requirements provided in this specification address the following control system categories: • control systems for surface mounted BOP stacks; • control systems for subsea BOP stacks (common elements); • discrete hydraulic control systems for subsea BOP stacks; • electro-hydraulic/multiplex control systems for subsea BOP stacks; • control systems for diverter equipment; • auxiliary equipment control systems and interfaces; • emergency disconnect sequenced systems; • backup systems; • special deepwater/harsh environment features.

The API re-affirmed their bad standard after the accident.

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API 16D is broad in scope and narrow in detail

The actual relevant content about design of safe and reliable C&I systems covers less than two pages, e.g.:

5.2.12.1.1 A minimum of two control pods shall be used, affording redundant control of all subsea functions. The surface control manifold directs pilot command signals to operate the pressure regulators, control valves, and straight-through functions in both pods.

5.2.12.1.2 Each control pod shall contain all the pressure regulators, valves and straight-through functions required to operate all subsea functions.

5.2.12.1.3 Isolation means shall be provided so that, if one pod or umbilical is disabled, the other pod and the subsea functions shall remain operable.

There are no requirements regarding, e.g., diagnostics, software, FMEA, or numerical reliability. Requirements for inspection and maintenance are ‘recommended’ only.
Regulatory Gaps

7. While US offshore regulations have undergone important changes since Macondo, more can be done to ensure a focus on preventing major accident events and to drive continuous safety improvement. The primary US offshore safety management regulation, Safety and Environmental Management Systems,

   a. Is not risk-based nor does it have an explicit focus on major accident events (Chapter 4.0);

   b. does not require demonstration by industry that process safety concepts for hazard assessment and management, such as layers of protection and hierarchy of controls, have been used in managing major accident hazards (Chapter 4.0);

   c. does not require demonstration that barriers to prevent major accidents are effectively implemented to a targeted risk reduction level (Section 4.1).

   d. does not require industry to identify and manage all safety critical elements and tasks through defined performance standards, nor does it require assurance and verification activities to ensure a safety critical element is appropriate, available, and effective throughout its life cycle (Chapter 5.0).

8. At the time of the incident, neither recommended industry practices nor US regulations required testing of the AMF/deadman system. Despite post-incident changes that call for function testing the AMF/deadman, deficiencies identified during the failure analysis of the Deepwater Horizon BOP could still remain undetected in BOPs currently being deployed to wellheads (Section 5.3.2).
Post-Macondo, attitudes still need to change

Many positive changes have taken place in response to the International Oil and Gas Producers Association (OGP) recommendations for well control training. Following the OE, April 2014

We witnessed take-up followin tiny it brought h further changes h been accepted by the industry.

In its proposed well control rule 38 C.F.R. Part 250, US regulator BSEE aims to enhance well control and equipment reliability, but API and other industry bodies have voiced opposition. (Image courtesy API)

Proposed rule seeks stricter well control regulations

On April 17, 2013, the Bureau of Safety and Environmental Enforcement (BSEE) announced its new proposed BOP and well control requirements rule for the outer continental shelf federal waters, 30 C.F.R. Part 250. Several years in the making, it aims to enhance well control and equipment reliability, and includes a suite of reforms in well design, well control, costing, commenting, real-time well monitoring, and subsis containment.

Sarah Parker Musarra
Editor

Its final communications to operators and contractors, which are termed Notices to Lessees and Operators.

“We had a lot of recommendations arising out of Deepwater Horizon, some of which related to BOP maintenance work must be “qualified and trained pursuant to original equipment manufacturer recommendations.” The traceability of this equipment and its critical components is a key point in the new rule: the third-party equipment audit is one way that BSEE is seeking to ensure it, even if the equipment is serviced or repaired under federal jurisdiction. The bureau also doubles the current BOP pressure testing interval for systems not subject to a schedule requirement.”

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Offshore, Feb 2016
OE, March 2016:

The industry has failed to update BOP design standards, so the US regulator has threatened to produce its own new standard. The industry has kicked back, claiming this will affect profits, future oilfield developments, and tax payments.
BSEE proposed rule changes – what is there not to like?

Extracts from BSEE website (August 2016) regarding scope of proposed rule changes:

• Clarify the operator's regulatory obligations related to life cycle analysis of critical equipment.

• Life cycle analysis is the control and traceability of a wide range of activities during the service life of the equipment ranging from design verification to repair and maintenance.

• Add rigorous design and testing requirements for boarding shut down valves, as they are the most critical component of the subsea system. These valves allow hydrocarbon flow to a facility to be stopped in an emergency. These new requirements will ensure the maximum level of safety for personnel located on the production facility.

All of the above is just good engineering practice and common sense.
Legal response (from lawyers acting on behalf of drilling companies):

“The Department of Interior’s Bureau of Safety and Environmental Enforcement (BSEE), the federal agency that regulates offshore oil and gas, has made it clear that it intends to hold not just operators and leaseholders accountable for offshore pollution, but also contractors and service providers who do not act as the owner, operator, or person in charge of a vessel, onshore facility, or offshore facility (oilfield contractors). Such action is unprecedented, and there is good reason to question the BSEE’s authority in this regard. Litigation over this issue is likely...........”
BP to Halliburton in ‘Barroom Brawl’ as Drillers Slash Costs

- Oil industry cost cuts for 2015 to 2020 total $1 trillion
- Service providers that reduced rates say discounts to end

Mad Dog, BP Plc’s drilling project deep in the Gulf of Mexico, could be Exhibit A in the oil industry’s war on cost. When the British oil giant announced the project’s second phase in 2011, it put the price at $20 billion. Last month, after simplifying plans and benefiting from a sharp drop in everything from steel to drilling services, Chief Executive Officer Bob Dudley said he could do the job for $9 billion.

Across the industry, companies have taken a chainsaw to expenses, slashing spending for the 2015-to-2020 period by $1 trillion through cutting staff, delaying projects, changing drilling techniques and squeezing outside contractors, according to consulting firm Wood Mackenzie Ltd. That’s cushioned businesses as oil prices plunged 60 percent since 2014. Now producers seek to show they can make the savings stick, while service providers try to reverse their losses.
Conclusions regarding BOP failure:

1. Root causes of BOP failure are related to drilling industry standards and culture.
2. The Cameron BOP was “the most critical component of the subsea system”, but there were no FMEAs, identified safety critical elements, diagnostics, or reliability analyses.
3. The BOP system was neither tested nor testable under operational conditions.
4. The BOP’s Blind Shear Ram was unable mechanically to shear an offset drill pipe.
5. The ‘deadman’ function was totally dependent on the viability of at least one 9V battery pack and the 27V battery pack in the same pod.
6. The 1004 redundant, non-diverse, C&I system had multiple defects which meant that only one channel operated.
7. C&I test arrangements were inadequate, especially the inability to test each channel separately.
8. API Specification 16D is the relevant standard but it is woefully inadequate. As of September 2016, API 16D is unchanged and still applicable, although change is in the air.
9. BSEE has proposed its own rules..............expect litigation.............
Drilling companies kicking back at proposed regulatory changes

To date the following actions have been taken by drilling companies:

- They have criticised and partly discredited the 2011 DNV investigation into the BOP failure.
- They have missed an opportunity to improve the API standards for BOP design (2013).
- They have challenged in court the CSB’s authority or competence to investigate the DWH accident (2015).
- They have threatened to challenge in court BSEE’s proposed new regulations on well control equipment (30CFR 250) (ongoing 2016).

However, in September 2016, the drilling companies, via the International Association of Drilling Contractors (IADC), have now proposed their own new Deep Water Well Control Guidelines “to facilitate safe and efficient deepwater drilling operations”.
Common causes between Texas City (2005) and Deepwater Horizon (2010)?

BP’s safety management practices were severely criticised by both the Baker Panel and the CSB reports into the 2005 Texas City refinery accident.

The CSB Deepwater Horizon-Macondo report volume 3 section 4.4 (2016) notes that:

• In 2008, BP CEO Tony Heyward stated “…we are making good progress in addressing the recommendations of the Baker Panel and have begun to implement a new Operating Management System (OMS) across all of BP’s operations.”

• However, before Deepwater Horizon-Macondo, **BP did not apply the Baker and CSB process safety lessons learned post-Texas City that led it to adopt OMS.** Instead it adopted a commercial risk management approach, with less rigorous definitions of risk.

• Using this (old) approach, an uncontrolled well event at Deepwater Horizon-Macondo was classified as a ‘medium’ risk with a likely cost of $1-3 million based on the team’s subjective evaluation. This level of risk was accepted with no additional actions.
Selected Bibliography

CSB reports are available at http://www.csb.gov/macondo-blowout-and-explosion/

- Volume 1 - cause of the blowout (2014)
- Volume 2 - BOP failure (2014)
- Volume 3 - human and organisational factors and safety culture (2016)
- Volume 4 - regulation (2016)

An excellent 2016 Transocean animation of the BOP failure is available at www.youtube.com/watch?v=esk2JN7CLT0

Other older reports:

3. Deepwater Horizon Accident Investigation Report and Appendices, BP, 8 September 2011
4. Deepwater Horizon Containment and Response: Harnessing Capabilities and Lessons Learned, BP, 1 September 2010
8. Excellent articles by Ian Fitzsimmons and others in the magazine ‘Offshore Engineer’ during 2010 and 2011, also available online at www.oilonline.com