

STUDY REPORT

Havindustritilsynet

**USE CEMENTED SHOE TRACK AS A WELL
BARRIER**

360NOR-PRJ-451-25



Study Report Information:

Date	September 17 th , 2025
Our reference	360NOR-PRJ-451-25
Revision	Issued as Final Report
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Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION OF CHANGE
00	17/09/2025	First report issue
01	02/10/2025	Include recipients' comments
02	05/11/2025	Include NORSOK's comments and add a technology

Abstract

This report sums up the investigation made on the reliability of cemented shoe track used as a well barrier. The industry has identified a gap in the verification requirements for such practice and several well control incidents have occurred while relying on shoe track as a sealing barrier against hydrocarbons.

The investigation aimed at gathering industry knowledge on cemented shoe track used as a well barrier in order to propose an enhancement of the verification requirements for this. It mainly focuses on well construction but can serve as basis of improvement for temporary abandonment also.

It reviews industry history to spotlight major well control events involving this practice and the lessons learned from these incidents. A combination of literature review, case study analysis and experts' interviews are employed to draw the current industry situation and try to find a way forward to a sustainable and safe solution. It also explores technologies available on the market or under development that can improve safety and reliability of shoe tracks used as a well barrier.

This work tries to improve well integrity by challenging experts on the current field practices. It digs into technical problems that were lying on the floor due to non-acceptable solutions available. By exposing facts, this investigation tries to bring the subject into light, so it won't be ignored anymore. By providing mitigation measures, it shows that a solution can be engineered. A technical discussion needs to start between major actors of the industry to find a reliable and safe solution and more than ever, avoid new accidents involving the use of cemented shoe track as a well barrier.



Table of Contents

1	Introduction	6
1.1	Cemented shoe track.....	6
1.2	Float equipment	6
1.3	Frame the challenge	7
1.3.1	Macondo accident (Gulf of Mexico, 2010)	7
1.3.2	Visund incident- NCS (2016)	8
1.3.3	Rang Dong experiences - Vietnam.....	8
1.3.4	Why not a barrier element?.....	8
2	Standards	9
2.1	NORSOK D-010:2021	9
2.2	Offshore Energies UK (OEUK).....	9
2.3	API 65-2.....	10
2.4	ISO 10427-3	10
2.5	Conclusion on standards	10
3	Field practices	12
3.1	Lessons learned from Macondo accident.....	12
3.2	Lessons learned from Visund incident	12
3.3	Other practices and feedback from industry	13
4	Technologies	14
4.1	Easy implementation techniques	14
4.1.1	Dual valve float equipment	14
4.1.2	Dual wiper plugs.....	14
4.1.3	Lead and tail cement.....	15
4.1.4	Account for fluid compressibility	16
4.1.5	Minimize rathole or fill with densified fluid.....	16
4.1.6	Learning curve.....	16
4.2	Additional mitigation measures	17
4.2.1	Diverter plate in float collar	17
4.2.2	Filter shoe or debris catcher	18
4.2.3	Flow protected spring	19
4.2.4	Gas tight float valves	20
4.2.5	Bridge plug.....	20
5	Summary	22
6	References	23



List of Tables

Table 1: Standards & Guidelines summary	11
---	----

List of Figures

Figure 1: Citadel casing solution 338 Ultra mag valve (left), IRI-oiltol (center), Weatherford (right)	14
Figure 2: Cement channelling & diverter plate (Hibbeler et al. 2000)	17
Figure 3: Citadel Casing Solution (left), Farley et al. 2016 (right)	18
Figure 4: poppet valve with secure recess for the spring (Farley et al. 2016)	19
Figure 5: IRI oiltol HPHT float valve design	19
Figure 6: GasVault™ Float Valves (Halliburton)	20
Figure 7: BarrierCure™ technology (Expro)	21

Disclaimer

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1 Introduction

To drill a deep well, a succession of drilling phases, with reducing hole sizes, is intercalated with casing steps, where the newly drilled section is cased with a steel tube through which the next section will be drilled. To maintain the casing in place and also isolate the new hole from the above formations, cement is pumped into the annular space between the casing and the drilled hole. This cement travels actually inside the casing and exits at the bottom to fill part or the entire annulus. To avoid re-drilling a long section inside the casing full of cement, a fluid (usually separated from the cement by a wiping plug) is used to push the cement downhole until the bottom of the casing. This deepest point of the casing will be near the weakest point for the next section to be drilled, so it has to be cemented correctly with good and competent cement. A “wet shoe” refers to the occurrence of unset, contaminated or no cement around the casing shoe after the primary cement job (Ali et al 2024). To avoid this, a buffer zone is engineered to leave a few casing joints with cement inside. This zone is called the shoe track.

1.1 Cemented shoe track

The shoe track acts as a buffer in case the top plug gets stuck (e.g., in the cement head or somewhere in the casing) and the slurry bypasses it. The objective is to avoid over displacement of the slurry and get a wet shoe. Given the API tolerances, the casing inner diameter is larger than nominal. Consequently, cementation ends up pumping more mud than predicted. At some point, normally half of the shoe track, the displacement needs to stop even if the plug hasn't bumped. That's why it is preferable to have a long shoe track to ensure plug bumping.

The shoe track also cumulates another function which makes it not uniformly cemented. In fact, the separation of the cement slurry and the mud used to push the slurry down hole is made by a wiping plug. As its name indicates, this plug is wiping the inside wall of the casing to ensure proper separation of the two fluids on each side of the plug. The consequence of this is that the plug is wiping a thin film of mud present on the casing internal diameter (ID) that pollutes the cement slurry close to the plug. The percentage of contaminated slurry is proportional to the length of the casing wiped. The shoe track aims at storing this contaminated cement at the tail of the slurry, so it does not go into annulus. A well designed shoe track should then have contaminated cement on top and competent hard cement at its bottom.

1.2 Float equipment

To stop the cement slurry displacement, the wiping plug lands into a collar which then causes a pressure increase that indicates cement is in place. In these cases, the fluid plus cement inside the annulus are heavier than the fluid inside the casing. Thus, U-tubing effect tends to push cement inside the casing again. In the early 20th century, float equipment were introduced (Hibbeler et al. 2000, Rogers et al. 2005).

Float equipment was originally developed to reduce the effective load on wooden derricks from running casing by trapping a buoyant air chamber inside of the casing, hence the term float equipment or float valve. The primary purpose later became maintaining cement placement at the conclusion of primary cementing.



Cement is typically denser than mud and/or displacement fluid and thus will create a hydrostatic differential pressure acting on the float valve, which keeps the cement in the annulus, rather than u-tubing back into the casing to equalize the hydrostatic imbalance (Champeaux et al. 2020).

A float equipment is generally a term referring to a short piece of casing fitted with check valves. These can be (i) flapper type (ii) ball type or (iii) spring type. Two valves are usually installed for redundancy. One in the casing shoe and one in a collar further above the first one. This collar is where the wiper plugs will land, and it is often referred as landing collar or float collar.

1.3 Frame the challenge

Since 2003, the notion of well barrier has been present in the industry. The concept of dual (primary & secondary) independent barriers is now well spread across the world. These barriers aim at preventing free flow of the well into the external environment or intermediate formations. The primary barrier is the barrier exposed to the source, the source being formation, lift gas, injection fluids, etc. The secondary barrier is the barrier that is exposed to the source only in the event of the primary barrier failure (NORSOK D-010:2021). In some cases, the primary barrier needs to include the cemented shoe track. In fact, after cementing, the plan might be to drill ahead in a depleted formation, remove blowout preventors (BOP) to install wellhead, or install completion. In these cases, the fluid weight inside the well may need to be lowered. Thus, the fluid can no longer act as the primary barrier. Another option would be to set a plug in the newly run casing that would take the role of primary barrier. This takes time to set and unset and is then added cost. Consequently, the primary barrier is usually assumed to include the cemented shoe track, considering that the cement inside the casing and the float valves will provide a sealing barrier against hydrocarbons. This is not done without verification of integrity such as pressure tests, etc. As seen previously in sections 1.1 and 1.2, float equipment and shoe track are not designed for that purpose and may pose barrier risk.

The following paragraphs expose facts and discuss known industry events where shoe track has been used as part of the primary well barrier and was later proven to have failed.

1.3.1 Macondo accident (Gulf of Mexico, 2010)

One of the major events in the oil & gas industry is the deep-water Macondo well, drilled by the semisubmersible rig Deepwater Horizon in 2010. In this case, the well entered a blowout following a loss of integrity that led to catastrophic consequences. In “*Lessons Learnt From Root Cause Analysis of Gulf of Mexico Oil Spill 2010*” (Garg & Gokavarapu, 2012), the authors highlight that, based on available evidence and calculations, part of the hydrocarbons entered the casing through the shoe track. It is important to note that in this case, several precautions had been taken before relying on shoe track integrity. The cement job went as planned, the shoe track was inflow tested and the float collar had two check valves. According to the investigations, several factors contributed to the catastrophic output. Among them, the misinterpretation of the inflow test results which were deemed acceptable to proceed with the next operations, even though they unequivocally showed signs of a leak (Investigation report volume 1, Explosion And Fire At The Macondo Well, US Chemical Safety And Hazard Investigation Board, June 5th, 2014). It is also worth mentioning that the float valves, although redundant, did not isolate the hydrocarbons. The cement in the shoe track likewise failed, despite indications of a proper cement job.



1.3.2 Visund incident- NCS (2016)

Another incident occurred on the Norwegian Continental Shelf (NCS) in 2016. After cementing a production liner shallower than planned, the shoe track was inflow-tested and assessed as a verified primary well barrier element. While pulling the wash string out of hole, a gas ingress was detected, and the well was shut in. The secondary barrier worked as planned and prevented loss of containment. However, the situation became critical due to a jammed valve on the top drive that prevented the well from being killed. Fortunately, this incident did not lead to a dramatic outcome, but it illustrates once again the unreliability of the cemented shoe track as a barrier. Investigations later identified contributing factors such as cementing with a long horizontal rathole and performing an inflow test without sufficient differential pressure margin. However, the company had complied with all the current requirements and regulations on the NCS. This suggests that current requirements are not strong enough to prevent such events.

1.3.3 Rang Dong experiences - Vietnam

In Vietnam, several shoe tracks were assessed for well integrity. In the paper “*New Float Collar Design to Eliminate Wet Shoe Tracks*” (IADC/SPE 62751), the different cases revealed that the presence of hard cement in the shoe track does not guarantee sealability against hydrocarbons, especially gas. Moreover, hard cement in the shoe track or above the float collar does not prevent a wet shoe. A properly executed cement job alone is insufficient to establish the shoe track as a reliable barrier. Finally drilling into or tagging hard cement in the shoe track is not a barrier verification method, since cracks may occur, allowing gaseous hydrocarbons to migrate through.

1.3.4 Why not a barrier element?

Considering the facts exposed above and to sum-up the industry challenges this report tries to address, the use of cemented shoe track as a well barrier element could be a dangerous practice.

The float equipment is tested to prevent flow back after cementation, not to be gas tight. The standard that regulates float equipment testing stipulates testing conditions sometimes far away from field realities. For example, pieces of cement or pieces of the wiper plug can fall and prevent the float valve to seal. More generally, in case of using autofill device or reverse circulation, debris can enter the casing and during cementation get stuck into the valve seat.

The cement in the floating equipment holding the check valve in place can crack due to bad handling or during run in hole (RIH) through high doglegs or forcing the tubular into a ledge, etc. The pressure test of the equipment prior to RIH is therefore not sufficient to ensure good functioning downhole.

Finally, the shoe track in itself has proven to be unreliable. Contaminated cement is difficult to estimate even in case of good cementation job. Cement channels can open in the shoe track due to mud gels. The hard cement does not secure gas-tight protection against reservoir.

These aspects shows that something else is needed here. Either another element that will act as a reliable barrier or ways to mitigate as much as possible the problems mentioned above.



2 Standards

The previous section presented the challenge the oil & gas industry is facing. It highlighted through field experience that regulations and/or technical requirements are insufficient to prevent accident when the primary barrier includes the cemented shoe track. This part is dedicated to the review of the different industry standards on the subject.

2.1 NORSOK D-010:2021

NORSOK D-010 barely mention this practice in completion activities and temporary abandonment activities. It states that for using shoe track as a Well Barrier Element (WBE), the following applies:

- the bleed back volume from placement of annulus cement shall not exceed the calculated volume; and
- it shall be pressure tested or inflow tested at maximum expected differential pressure.

NORSOK D-010 put a requirement on cement placement that aims at avoiding wet shoe. The second requirement is meant to verify the barrier element itself with a pressure test. Note that both positive or negative (inflow) tests are allowed.

In Annex C, Element Acceptance Criteria (EAC) table 22 about annulus cement, NORSOK recommends ("should" statement) the shoe track to have a minimum length of 25 m.

2.2 Offshore Energies UK (OEUK)

Well life cycle integrity guidelines issue 4, from March 2019, are more extensive on the subject. They first mention that failure of cemented shoe track to prevent flow has been a key factor in several blowouts. And by default, shoe tracks should be treated as open ended strings unless they are designed as a barrier.

It then provides requirements to use shoe track as a barrier:

- **Length of cement in the shoe track:** a minimum length of shoe track should be considered to contain any contaminated cement generated by the displacement process (assuming dual plug cementing technique is used).
- **Quality of cement in the shoe track:** cement should be properly mixed and uncontaminated. On that topic, it suggests that there should be a minimum of good cement in the shoe track: *"Any leakage around plugs or over displacement may reduce the quality and volume of uncontaminated cement in the shoe track."*
- **Pressure test:** a positive pressure test is not acceptable for OEUK, justifying this by the fact that top wiper plug holds pressure from above. Inflow test is then mandatory and should be carefully planned and carried out. In fact, OEUK warn about specific problems that can occur during the inflow test, such as:
 - The top plug might be held in place by a small amount of cement

- The float valves are designed to seal against cement slurry but not necessarily against gas. Besides, even if this equipment is tested prior installation, they could have been damaged or washed-out during cementation.

Finally, this standard provides alternatives to the use of cemented shoe track as a barrier and mitigation measures to de-risk this practice. As compensations, OEUK propose the use of a mechanical or cement plug on top of the shoe track. To better verify the barrier, it recommends to drill plugs and float equipment to assess the length of “good” cement in the shoe track.

2.3 API 65-2

This standard addresses the Isolation of potential flow zones during well construction. At the time of writing, the available version was the second edition from 2010. The only requirements given by this standard are that shoe track barrier element must have two independent float valves with a shoe track of set cement. In addition, it provides guidance on float equipment selection such as type of service, autofill, valve design, etc, and specifies that standard float equipment is not designed to be gas tight.

2.4 ISO 10427-3

This standard deals with testing of float equipment. It is also known as API RP 10F (Recommended Practice) and has been upgraded to a proper specification (API Spec 10F) in 2018. The limitation of this document is that it is not applicable to float equipment in non-water-based fluids (Farley et al, 2016). Besides, sand content considered for testing equipment is maximum 4%. This solid content seems far from field reality considering cement slurry or mud with suspended solids and cuttings. Moreover, it does not consider gas.

It somehow mentions that floating equipment can be considered as a primary well control device. It also suggests in a very indirect way that cement plugs can be installed on top of the shoe track to test pressure integrity.

2.5 Conclusion on standards

A review of the main industry standards (API, ISO, etc) has been conducted, and it shows that they barely mention or address the issue. On the contrary, more local standards such as OEUK appear to be more advanced on the subject, although it should be emphasised that OEUK is a guideline rather than a standard. Furthermore, the recommendations to drill float equipment to assess the length of competent cement in the shoe track has proven to be an unreliable verification method as experienced in Rand Dong field.

ISO 10427-3 recognizes float equipment as a primary well control device, which may be acceptable for dynamic conditions such as running in hole (RIH) or in cases where the primary barrier held by the fluid is lost. However, after cement is pumped through the float equipment, its potential to seal cannot be verified.



	NORSOK D010	OEUK	API 65-2	ISO 10427-3 or API 10F
Pressure test	Shoe track shall be pressure tested or inflow tested at maximum expected differential pressure.	An internal (or positive) pressure test of the casing does not qualify the shoe track as a barrier, because, typically the top wiper plug holds pressure from above but not from below. An inflow test should be carefully planned and carried out to provide a robust demonstration that the shoe track is an adequate barrier (see Section 4.6 for inflow testing guidelines). Specific problems are: - The top plug may be held in place by a small amount of cement which may fail as the casing flexes with temperature or pressure changes or with time - The float valves may seal against cement slurry initially but if hydrocarbon, (especially gas), * builds up under the float valve the barrier may fail	Standard float equipment is not designed to provide a gas-tight seal.	X
Placement verification	the bleed back volume from placement of annulus cement shall not exceed the calculated volume;	There shall be remaining good cement in the shoe track	X	X
Length of cement shoe track	EAC Table 22 – Shoe track: A casing/liner should have a shoe track length of minimum 25 m MD.	With the dual plug cementing technique, the well operator usually chooses a shoe track length to contain any cement contaminated by mud during the displacement process.	Shoe track of set cement + double float valves	X

Table 1: Standards & Guidelines summary

3 Field practices

This section looks at how standards are applied by the operating and service companies. Field practices have been gathered by performing interviews of well integrity and drilling experts.

3.1 Lessons learned from Macondo accident

In response to the Gulf of Mexico accident in 2010, some companies revised their practices, introducing an element acceptance criteria (EAC) table for the shoe track used as a well barrier. Updated well integrity manuals now define acceptance criteria for shoe tracks, including minimum length and equipment requirements in line with API 65-2 recommendations.

Mandatory verifications for some operators now include an inflow test of the shoe track **and** a positive pressure test. Some operators also require a minimum annular pressure or a minimum differential pressure between the annulus and inside the casing for the inflow test to be valid. Float equipment and cemented shoe track are considered a single barrier element.

These internal requirements include important conditions:

- A cemented shoe track shall not be considered a well barrier element (WBE) in case there is evidence or suspicion of a wet shoe.
- Its use as a barrier is allowed only if more than 90% of cement volume pumped in the shoe track was mixed at a density of no more than 0.3 SG below the planned cement slurry density.

3.2 Lessons learned from Visund incident

Visund was an incident, it had not the catastrophic consequences as Macondo. But still, the companies involved made changes into their operating procedures in order to prevent this kind of event to happen again. The major change is about the inflow test requirements, where the positive pressure tests are no longer accepted. Then, the max differential pressure is currently set to a fixed value. However, this is meant to evolve in order to be recalculated for each well rather than a static criterion. The new criteria should be the max differential pressure expected, accounting for fluid deterioration plus a margin.

In addition to this, the governing documents recommend installing a deep plug on top of the float collar. This is particularly recommended in case of cementation in horizontal sections or near horizontal inclination. Note that this is a recommendation rather than a requirement. Also, the verification of such plug would be a challenge due to its proximity with the float collar. In fact, it is not possible to test the space between the plug and the float collar. Therefore, it is possible that the float collar can hold pressure while the plug is leaking or vice versa.

3.3 Other practices and feedback from industry

More generally, most of the companies try to not be in the situation where the primary barrier includes the cemented shoe track. They prefer to keep the fluid as primary barrier knowing the uncertainty of cemented shoe track reliability.

Besides, lot of wells are drilled in mature fields where reservoir is depleted and thus inflow test is difficult to achieve. Speaking about deep water and High-Pressure High Temperature (HPHT) wells, it is a common field practice (Carpenter 2014 and confirmed by subject matter experts) to secure the shoe track with a bridge plug.

Moreover, as local regulation like NORSOK allows positive pressure test to verify shoe track integrity, it may be considered safer to avoid putting the well underbalance.

Others have developed a “flow potential and gas-tight system assurance” for cementing production liners in Extended Reach Drilling (ERD) wells, which philosophy can be of inspiration for future standards requirements. In their publication “*Sustainable Practices for ERD Cementing: Success Story from Arabic Gulf*” (Sarmiento et al. 2024), the authors recommend compensating equipment depending on a risk assessment of flow potential. In their flow potential and gas-tight system assurance, the risk is scored and then ranked in 5 categories providing a gradual implementation of different mitigation measures to preserve well integrity:

- **0 to 1:** Annular flow is unlikely; a conventional design without anti-fluid migration systems/techniques is sufficient.
- **1 to 3:** Consider using fluid-loss additives and reduce the cement column, if possible.
- **3 to 8:** Moderate flow potential; designs that feature short transition times and gas-tight properties are recommended.
- **8 to 15:** Severe flow potential; a gas-tight system and compressible cement slurry are essential.
- **Greater than 15 (critical range):** A complete redesign of the cement program is required to lower the flow potential, including multi-stage cementing, the maintenance of back pressure, reduced cement height, and other techniques.



4 Technologies

Although the uncertainty about cemented shoe track reliability is known in the industry, some technologies already on the market or in development give hope that an appropriate solution can be engineered. The techniques presented below are not meant to solve the problem individually. It is the combination of them that may mitigate the risk of wet shoe or barrier breach.

4.1 Easy implementation techniques

4.1.1 Dual valve float equipment

Already adopted by some operators and service companies, this type of float equipment provides a redundancy in case one of the valves get damaged during cementation process. Usually available for float collars, the shoe can be equipped also with double valves. Both technologies, flapper type or ball type are available in that dual configuration.

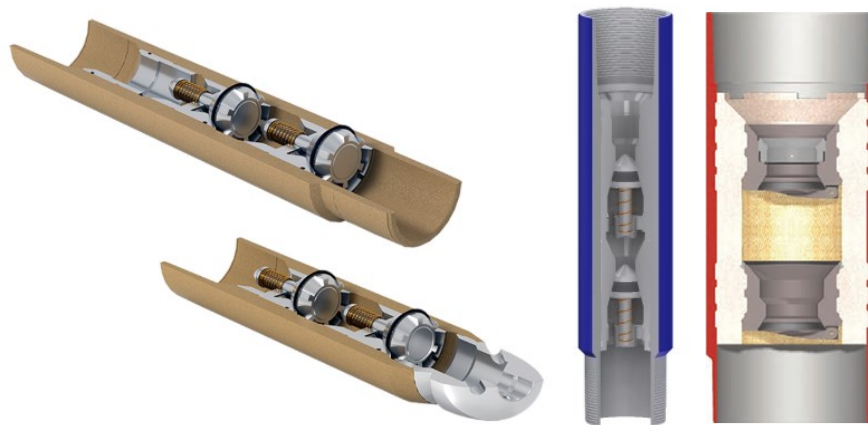


Figure 1: Citadel casing solution 338 Ultra mag valve (left), IRI-oiltool (center), Weatherford (right)

4.1.2 Dual wiper plugs

In the old days, beginning of the 20th century, a single plug was often used. Today, this is still current practice for liners in other part of the world. In that case the main purpose is:

- i. to separate the cement from the displacing fluid (e.g. mud), and
- ii. give indication of complete displacement.

Double plugs are most commonly used today. It is mentioned here to highlight its benefits for successful cementation and particularly for Extended Reach Drilling (ERD) wells (Sarmiento et al. 2024).

The bottom plug separates the mud used to clean the hole before cementation from the cement mixed. This physical barrier between the fluids has several key functions:

- i. avoid the cement slurry to be mixed with mud so it keeps its quality and ensure good annular isolation once in the annulus.
- ii. The bottom plug also reduces contamination of the cement slurry by wiping the mud on the internal diameter of the casing. Such contamination can prevent the cement from setting.

The top plug avoids the tail cement to be contaminated by the spacer or flushing fluid with the same concept of physical separation. Thus, it contributes to good cement displacement down hole and reduce the risk of having unset cement around shoe.

Proper size and material selection of the wiper plugs are a key factor for good and efficient cementation (Rogers and Heathman 2005). Both body and rubber material need to be engineered to accommodate for the well conditions. Failure to do so can expose to failure such as wear of the plug rubber, disintegration of the plug when bumping on float collar, etc.

The dual wiper plug system is meant to eliminate some of the major factors contributing to a wet shoe (Ali et al. 2024):

- Insufficient mud removal
- Absence of bottom wiper plug
- Compromise of top plug's sealing ability

It is worth noting that this is a direct recommendation of API 65-2 for all casing cementation jobs.

Nowadays it is even more common to use three plugs (two bottom and one top plug). To avoid the mud contaminating the spacer fluid that is pumped ahead of the cement, possibly from a thin mud film on the casing inner wall.

4.1.3 Lead and tail cement

Inadequate slurry design has been pointed out as one of the reasons responsible for the Macondo accident (Garg & Gokavarapu, 2012). Among the key factors contributing to a wet shoe, some are directly linked to cement design:

- Insufficient waiting-on-cement (WOC)
- Cementing long sections with single slurry
- Utilizing a single slurry for the specialized jobs requiring extended static periods

The slurry has to be split into lead and tail so that the tail could set faster while facing minimum contamination, whereas the lead could maintain an extended thickening time to be pumpable for the required operational time (Ali et al. 2024).

Experts feedback on this is to first get confident with the cement design and field prove it on the first wells of the campaign before using cemented shoe track as a barrier.

4.1.4 Account for fluid compressibility

Fluids such as water base mud are barely compressible. However, oil/synthetic base mud is more compressible, and this can generate bad cementation readings if the compressibility of the fluid is not considered. In fact, more compressible fluid will tend to show low pressure bumps when the top wiper plug lands on the float collar (Farley et al. 2016). The bleed back volume will also be greater when using compressible fluid. One can think that float equipment or wiper plug might have failed while experiencing high bleed back volume with low bump pressure. A compressibility calculator shall help in this case to assess if the float equipment is holding or not and if volume can be bled off, or back pressure has to be maintained.

Accounting for fluid compressibility is important in order to avoid misinterpretation of the cementation parameters. Wrong readings of that kind can lead to cement over displacement and so the occurrence of a wet shoe.

4.1.5 Minimize rathole or fill with densified fluid

The excessive rathole was one of the causes responsible for the Visund incident. Sometimes, the casing or liner get stuck while RIH. Therefore, a significant distance may remain between the bottom of the drilled hole and the casing shoe. This volume is filled with mud that can contaminate the cement coming out of the shoe. It can also result in a wet shoe in case of horizontal well. Consequently, when this long rathole cannot be avoided, it is recommended to fill it with densified fluid so it won't mix with the cement slurry.

4.1.6 Learning curve

One of the conclusions of the Macondo accident reported by Garg & Gokavarapu 2012, is that the cement used had not been tested enough and the experience with this type of complex cement slurry was not field proof.

In a drilling campaign, several wells shall be drilled. The cement jobs should be executed better and better as the campaign progress due to the cementing crew familiarizing with the rig, the cementing equipment, the field and the type of wells drilled. This is called the learning curve. Several shoe tracks shall be drilled while delivering the first wells of the campaign, thus assessing the quality of the cement jobs performed, the shoe track and float equipment reliability. A way to evaluate can be to keep records of hard cement length found in the shoe tracks drilled. Also pressure tests can be performed while drilling the shoe track like in the Rang Dong wells. If one or several wells in the campaign need to set the primary barrier on the cemented shoe track, experience accumulated from the beginning of the campaign can help validate shoe track integrity. However, the crew shall pay special attention to any deviating parameters previously observed.

4.2 Additional mitigation measures

The above mitigation measures may be considered as standard practice. Even if they are not observed, they should be easy to put in place in companies drilling manuals and people should be trained on it. The below measures are less common in the industry and need more engineering to be used. They are presented as additional mitigation measures to the above.

4.2.1 Diverter plate in float collar

During displacement, the cement passing through the float collar is not separated from the front fluid by the bottom wiper plug which stopped at the float collar. In case of heavy mud or high gel strength mud, the cement can open a channel into the mud in the shoe track instead of flushing it out (see Figure 2 left side):

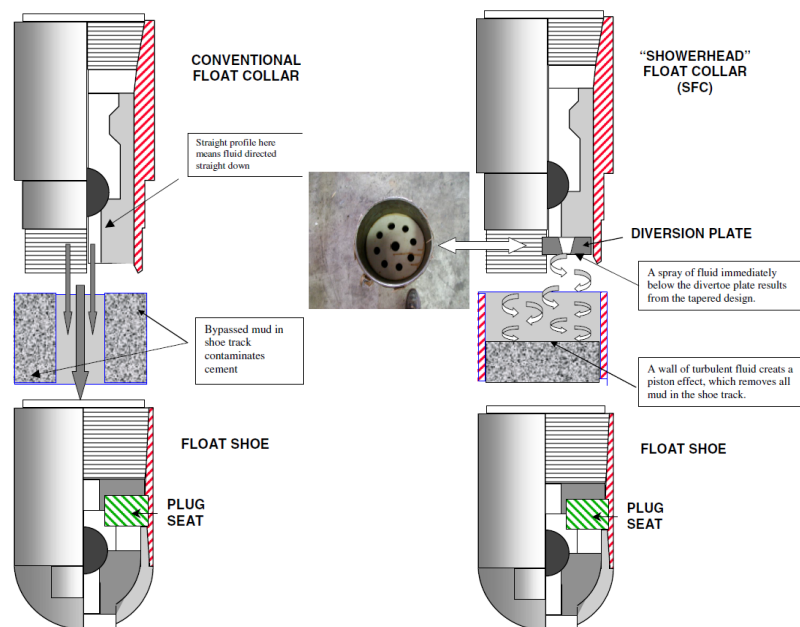


Figure 2: Cement channelling & diverter plate (Hibbeler et al. 2000)

Some float equipment providers engineered a diverter plate placed at the bottom of the float collar that creates turbulence in the fluid exiting the collar. Thus, reducing the risks of cement channelling into the mud and wet shoe track.

4.2.2 Filter shoe or debris catcher

In the introduction of this report, the potential of float valve obstruction due to debris was evoked. This danger is mainly present when using an autofill float system. With such device in the string, the mud can enter the casing so it reduces the surge pressure and the time to fill the casing with mud (Farley et al. 2016). The consequence of it is that debris present in the mud with cuttings or Lost Circulation Materials (LCM) can enter the casing. During circulation or cement displacement, it can get stuck into a float valve preventing it to seal. It can also damage the valve seat which will results in the same. Thus, some companies have engineered debris catcher that can be integrated into the float equipment to protect the float valves from the debris. Some examples of these are illustrated below:

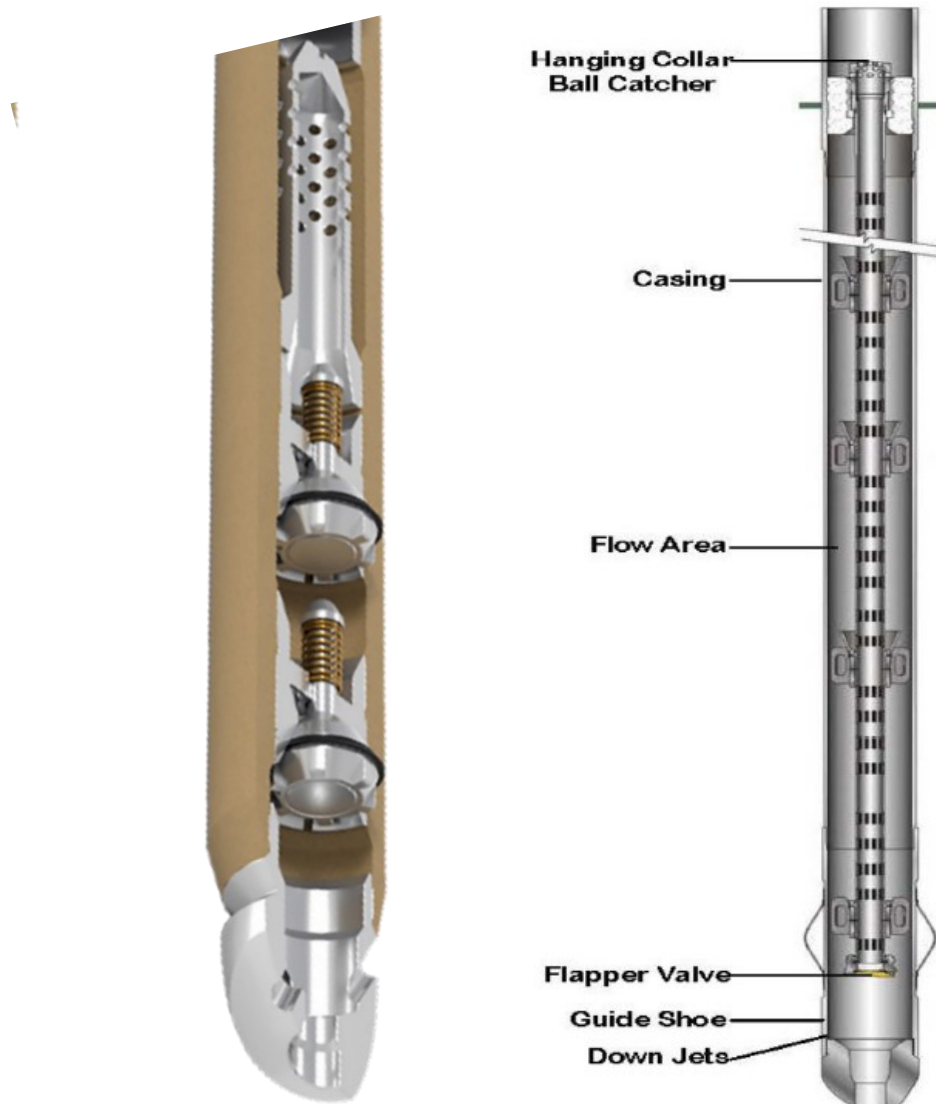


Figure 3: Citadel Casing Solution (left), Farley et al. 2016 (right)

4.2.3 Flow protected spring

One factor responsible for float valve degradation is the erosion of the float components during cement displacement. That's why there is an uncertainty on float valve reliability after cementation. As seen in the section on standards, ISO 10427-3 (or API 10F) requires the equipment to be tested with 4% sand content. However, the float valves usually see much more abrasive fluids while cementing or circulating mud with cuttings.

Poppet or ball type float valves are more reliable than flapper designs (Farley et al. 2016). Because it opens in a more uniform manner, wear is evenly distributed on the valve seat rather than concentrated in a specific location. Other parts of the float valve, such as the spring, can be degraded too. This can jeopardize valve capacity to seal by not having enough strength to close the poppet. Also, debris can be stuck in the space between the spring coils preventing proper valve function.

In some designs, the poppet protects the spring from flow. Two technologies have been engineered:

1. the poppet pushes the spring into a recess in which it is completely sheltered from flow path.

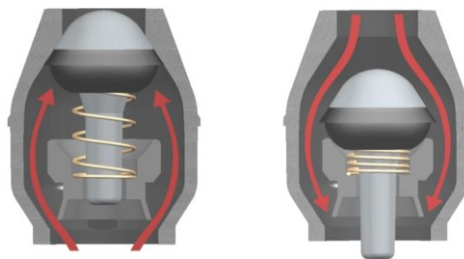


Figure 4: poppet valve with secure recess for the spring (Farley et al. 2016)

2. The "bell" shape poppet act as a shield for the spring

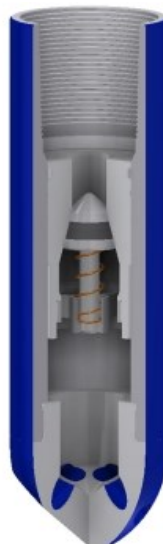


Figure 5: IRI oiltool HPHT float valve design

4.2.4 Gas tight float valves

In the paper: “*Qualification and Deployment of Float Equipment as an Independent Mechanical Barrier in Unconventional Wells*” (Champeaux et al. 2020), a test protocol is designed to address the fluid and gas integrity requirements over the expected service life of float equipment (~50 days). The project presented in the paper initiate a paradigm shift in the industry that float equipment can indeed be used as an independent mechanical barrier.

Scanning the technologies available on the market, Halliburton commercializes a GasVault™ Float Valves that aspires to be gas tight. This valve effectively presents interesting features that might solve some of the problems mentioned in the introduction of this study on float equipment. For example, a steel shroud is used to secure the valve in the outer shell (collar or shoe) instead of concrete. Thus, no risk to crack this concrete during handling and RIH. No time is used to drill this concrete after cementation. The solution provided by Halliburton features a flow protected spring and a double seal gas-tight mechanism.

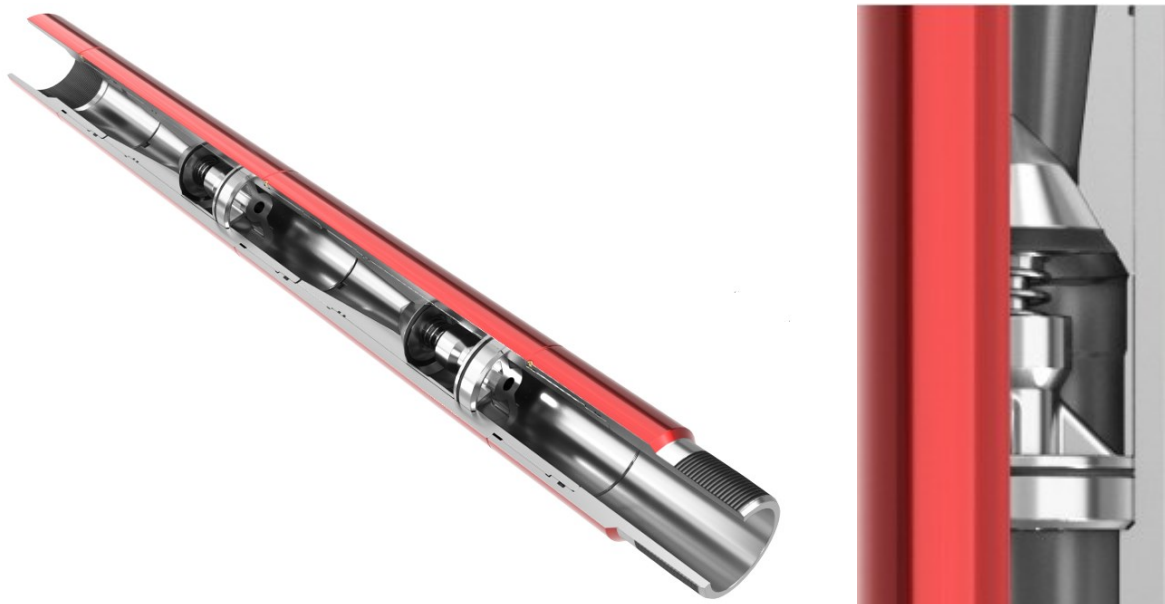


Figure 6: GasVault™ Float Valves (Halliburton)

4.2.5 Bridge plug

In their publication “*A High-Pressure/High-Temperature Bridge Plug*” (Carpenter 2014), the author mentions the need for a standalone barrier element to isolate the shoe track in HPHT wells. This barrier element is required in these applications to mitigate uncertainties related to shoe-track integrity. In specific applications, and according to experts’ feedback, it is a common method to secure shoe track with a bridge plug. One will remember that this is a recommendation put in place by companies involved in the Visund incident.

There are two limitations to this solution:

1. First, it is costly mobilizing the equipment and it takes rig time to run, set, test and unset the plug.
2. The second limit is the verification of the plug as a barrier which might be challenging due to its proximity with the float collar.

An interesting technology has been developed by Expro which works similarly as a bridge plug without the deployment inconvenient. The BarrierCure™ technology is a plug which is run with the cementation string and can be activated at the end of the cement slurry displacement. It features metal-to-metal seals that are protected from erosion while RIH, cementing or circulating. It establishes a barrier immediately above the shoe track, as a bridge plug would do.

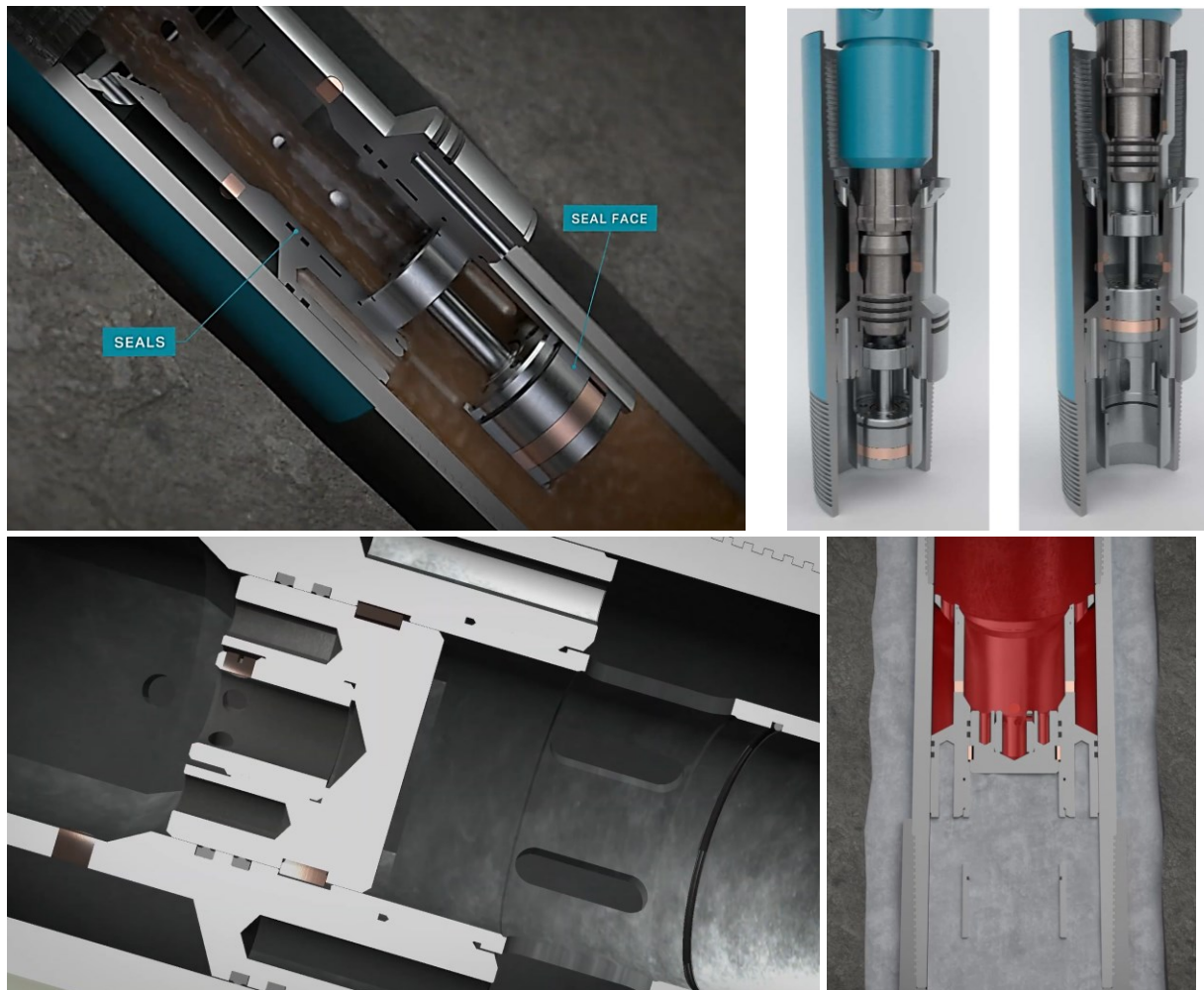


Figure 7: BarrierCure™ technology (Expro)

Even if the drillable version is not gas tight, the concept is interesting and show that efforts are made to secure cemented shoe track as well barrier. On the other hand, the non-drillable version (which is gas-tight) can already serve as a barrier element for temporary abandonment for example.

5 Summary

A barrier uncertainty has not been addressed in the industry and needs to be raised in order to be solved. The use of cemented shoe track as a barrier element is a real challenge and companies have to address it with care.

Even if this study presents solutions that may make this practice more reliable, experience has proven that bad shoe track design is a key contributor to wet shoe. Some companies barely design their shoe track with sufficient casing joints. During well construction, it is considered as time lost when drilling out the cement and they usually ignore the proper functions of a shoe track.

Consequently, one possible way forward from this study would be to examine drilling manuals, seeking for ALARP (As Low As Reasonably Practicable) guidelines to avoid wet shoe while designing shoe tracks.

The companies involved in the major events mentioned in this report, have already updated their well integrity manuals, including EAC table for cemented shoe track used as a barrier element. The examinations mentioned above can be extended to well integrity manuals. It must focus on potential records of cemented shoe track used as a barrier element and that an EAC table for this practice is present in the governing documents. This exercise must also review the inflow test procedure, seeking for evidence of accounting for fluid compressibility when calculating the expected differential pressure and surge and swab margins. The test procedure needs to specify which barrier elements are tested: packer vs float equipment vs cement vs both.

Finally, many mitigation measures are presented in this report. The goal is not necessarily to implement them all. If updating the standards requirements is the objective, a gradual response can be suggested depending on the situation faced. Considering risk and flow potential assessments, the new requirements may recommend a different set of mitigation measures. Inspiration can be taken from the “flow potential and gas-tight system assurance” in the publication *“Sustainable Practices for ERD Cementing: Success Story from Arabic Gulf”* (Sarmiento et al. 2024), to build the new guidance.

Although this report focuses on well construction practises, inspiration can be taken to improve well integrity when using cemented shoe track as a well barrier for temporary abandonment.

6 References

- Ali, Wajid, Al Turki, Faisal Abdullah, Bouaraki, Mouloud, and Don Woody Lawrence. "A Systematic Cementing Approach to Improve the Shoe Track Integrity: Case Studies from Saudi Arabia." Paper presented at the International Petroleum Technology Conference, Dhahran, Saudi Arabia, February 2024. doi: <https://doi.org/10.2523/IPTC-23227-MS>
- API 65-2, 2010
- Carpenter, Chris. "A High-Pressure/High-Temperature Bridge Plug." *J Pet Technol* 66 (2014): 113–115. doi: <https://doi.org/10.2118/0914-0113-JPT>
- Champeaux, Christopher J., Arrazola, Alvaro J., Patin, Vincent , Stair, Todd , and Hank Rogers. "Qualification and Deployment of Float Equipment as an Independent Mechanical Barrier in Unconventional Wells." Paper presented at the SPE Annual Technical Conference and Exhibition, Virtual, October 2020. doi: <https://doi.org/10.2118/201264-MS>
- Farley, Douglas , Barannikow, Ivan A., and Brandon L. Bourg. "The Anatomy of High Performance Float Equipment and Potential Failure Modes." Paper presented at the IADC/SPE Drilling Conference and Exhibition, Fort Worth, Texas, USA, March 2016. doi: <https://doi.org/10.2118/178876-MS>
- Feedback from 7 drilling and well integrity experts with experience on the NCS and worldwide.
- Garg, Tanu , and Swetha Gokavarapu. "Lessons Learnt From Root Cause Analysis of Gulf of Mexico Oil Spill 2010." Paper presented at the SPE Kuwait International Petroleum Conference and Exhibition, Kuwait City, Kuwait, December 2012. doi: <https://doi.org/10.2118/163276-MS>
- Herrera, Juan Isaias Sarmiento, Nino, Adriana Contreras, Sasso, Alejandro De La Cruz, and Rodney Masoud Zuleta. "Sustainable Practices for ERD Cementing: Success Story from Arabic Gulf." Paper presented at the ADIPEC, Abu Dhabi, UAE, November 2024. doi: <https://doi.org/10.2118/222472-MS>
- Hibbeler, Jeff, Graham, Tim, and Jeff Ehlinger. "New Float Collar Design to Eliminate Wet Shoe Tracks." Paper presented at the IADC/SPE Asia Pacific Drilling Technology, Kuala Lumpur, Malaysia, September 2000. doi: <https://doi.org/10.2118/62751-MS>
- ISO 10427-3 / API spec 10F, 2018
- Investigation report Visund - well-control incident in well 34/8-A-20 AH, Havindustritilsynet, 16.3.2016. <https://www.havtil.no/en/supervision/investigation-reports/2016/statoil---visund---investigation-of-well-control-incident/>
- Investigation report volume 1, Explosion And Fire At The Macondo Well, Us Chemical Safety And Hazard Investigation Board, June 5th, 2014.
- NORSOK D-010:2021
- OEUK: Well life cycle integrity guidelines issue 4, 2019
- Rogers, H., and J. Heathman. "Cementing Casing Equipment: Proper Selection Vital To Success." Paper presented at the Offshore Technology Conference, Houston, Texas, May 2005. doi: <https://doi.org/10.4043/17083-MS>



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