

Deepwater Cementing – A Holistic Approach to Landing Sub Sea Release Wiper Plugs

George A. Fuller, PE, Darko Kupresan, and Cecil Bernhard, Shell International Exploration and Production Inc.

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Abstract

Performing a successful primary cementation in a deepwater environment poses many unique challenges. Large casing diameters and deep shoe depths provide for large displacement volume to land plugs. Thus, the failure to recognize the indicators from critical components which make up the landing of subsea launched plugs could result not only in non-productive time which has an impact on the drilling and operational efficiency, but also the more costly remedial cementation. Besides the key drivers of fluid separation and mechanical wiping of the casing inside wall, the pressure response indicators associated with the drill-pipe darts and plugs represent the down-hole location with respect to physical volumes pumped and must be clearly understood. Using these indications in conjunction with the accurate measurement of system variables will result in a successfully displaced cement job.

The volume of fluid pumped to displace the darts and plugs to the final location is determined by measured pipe capacity calculations, compressibility calculations, and accurate metering of the physical placement method by either the rig pumps or the cementing unit. Determination of the final calculations for landing plugs combined with key pressure response during displacement provide for better results than relying on predetermined calculations alone.

Results will be presented from recent deepwater case histories to illustrate the successful application of this methodology and approach for landing subsea plugs.

Introduction

A large amount of engineering time goes into the planning, communication, and delivery of a deep-water cement job prior to the final execution. As wellbore trajectory, architecture, and downhole conditions as the casing is landed become more challenging with large diameter casing strings, positive bumping of subsea release plugs become an integral contributor to overall cementing success. Positive indication of bottom plug landing, understanding the deltas associated with calculated

capacity versus actual capacity to land the bottom plug, and the reactive plan to positively bump the top plug must be clearly addressed before the job is started. Reduced time associated with shoe track drill-out can bring a substantial savings to rig costs. Cementing plugs perform best when bumped at the finality of the cement job as the combined locking with float collar provide the best drill-out feature. Preventing wet shoes, reducing shoe track drill-out time, and good pressure trends with cement lift are the keys to a highly successful primary cement job. Traditionally, the practice for landing plugs has been performing drill-pipe/casing capacity calculations using the nominal inside diameter with the upper end volume pumped of no more than half the volume of the shoe track capacity. For a design job with calculated capacity of 2000 bbls and half the shoe track of 10 bbls, this leaves very little margin for landing the top plug. For large diameter casing, has the true ID been calipered? What are the effects of the synthetic based mud downhole with fluid compression on the darts/plugs as they land, release, and finally bump at the float collar? Also in the planning phase, should the cementing unit be used to displace the darts/plugs or is the rig pumps better suited for this operation. Have the rig pumps been checked for efficiency and what is that factor considered to be correct for the displacement calculations. The table below represents the plug bump ratio over a set time interval for a cross-section of deep-water rigs operating in the Gulf of Mexico.

Table 1 – Rig Pump Efficiency vs Plug Bump Ratio

| RIG | Rig Pump Efficiency % | Plug Bump Ratio % | Comments |
|-----|-----------------------|-------------------|---|
| A | 95.5 | 90 | Also strap pits while displacing. |
| B | 97 | 95 | Rig pump efficiency qualified at shipyard plus additional routine checks. |
| C | 97 | 50 | |
| D | 97 | 50 | |
| E | Cmt unit | 70 | Counting tanks on the cement unit |
| F | 95 | 95 | |

Although, most rigs will lean toward using the rig pumps to displace the plugs as can be observed from table above, there are some operations that still routinely use the cement unit. Displacing the plugs using a 10 bbl tank by tank measurement and qualified by more than two personnel counting is an acceptable practice although in most operational setups, there will be limitations on maximum pump rate due to transfer of the displacing fluid to the measuring tanks on the cement unit. This does however allow for visual certainty of fluid movement by a precise “fill/suck-down” approach. Regardless of the practice used by a specific rig, there are some key drivers for success that will be covered in the following text.

Background

Over the period of several years, a focus was placed on the success rate of landing the large diameter subsea release plugs. Individual rig practices across the fleet were studied to identify best results and to implement these as a standard work pack practice. From a job base of more than 300 deployments, a small percentage (less than 3 %) of unsuccessful plug bumps were determined to go back to fluid bypass. Table 2 below highlights the casing size ranging from 14” to 18” OD where fluid bypass was suspected. The outcome of these events has led to unsuccessful casing test, contaminated shoe tracks, and lower than expected shoe test results. In some outcomes, remediation of the shoe was required. The industry of the service providers reacted with modifications to the engineering design of the cementing top plug. (1)

Table 2 – Wiper Plug Landing / Fluid Bypass

| Job | Casing Size [in] | Casing MD [ft] | Casing ID [in] | Shoe Track Length [ft] | Hard Cement in Shoe Track [ft] | Wiper Plug Efficiency | Comments |
|-----|------------------|----------------|----------------|------------------------|--------------------------------|---|---|
| 1 | 14 | 11786 | 12.400 | 178 | 0 | Bottom plug landed 17 bbbls early, but top plug did not land. | Displaced half the shoe track but did not bump plug. Did not see pressure response from passing through indicator collar. Failed casing test. |
| 2 | 18 | 8214 | 17.000 | 88 | 44 | Bottom plug landed 13 bbbls early. Top plug did not land. | Tagged top plug 520' above shoe. Drilled through plug and washed down to float collar. Ratty cement throughout the shoe track interval. |
| 3 | 16 | 17776 | 14.885 | 148 | 30 | Bottom plug landed 4 bbbls late, NO TOP PLUG BUMP. | Full Returns throughout job, Tagged top plug 1200' above the float collar. Majority of shoe track was contaminated. |
| 4 | 18 | 13954 | 17 | 96 | 40 | Bottom plug landed 30 bbbls late, top plug did not land. | Used cement unit to displace. Did not bump top plug after pumping 1/2 shoe track additional volume. Found top plug at liner top. |
| 5 | 18 | 14565 | 17.000 | 92 | 0 | Plug did not bump found near liner top. | Tagged wiper plug at 7990' and pushed to bottom. Attempted to get casing test. Had to perform a shoe squeeze. |
| 6 | 14 | 24398 | 12.400 | 146 | 15 | Bottom plug landed 54 bbbls early, but top plug did not land. | Poor cement from bottom of float collar to the float shoe. Did not see pressure indication with top plug at indicator collar. |
| 7 | 14 | 18588 | 12.376 | 143 | 0 | Bottom plug landed 70 bbbls late, did not bump top plug. | Did not land top plug after 1/2 shoe track. Had a failed casing test which indicated fluid bypass around top plug. |
| 8 | 18 | 12930 | 16.750 | 80 | 68 | Bottom plug landed 125 bbbls late, top plug did not land. | Top plug found 20' below TOL. |
| 9 | 14 | 20453 | 12.376 | 98 | 0 | Bottom plug was late, top plug did not bump. | Did not bump top plug after pumping 1/2 the shoe track. Unsuccessful casing test. |

In addition to the focus on sub-sea release plug improvements, new technology was introduced to utilize indication collars for identification of the top plug location due

to pressure response. (2,3) This technology has been deployed to many large casing diameter, deep-water jobs and the increase in success rate has been limited as well as escalating the overall job costs. Further recent studies were deployed into the wiper plug endurance to determine the wear on the wiper plug fins thus to determine if fluid bypass could be expected on a large capacity displacement job. (4) These studies have qualified that fin wear is not a concern as much as the dart to plug latch and maintaining this barrier throughout the landing of the top plug.

From all the data assembled and the results analyzed, it has come to the closure of the data collection in this manuscript that if the darts and plugs are in proper working order through all the quality controls performed, then the rig practices should be addressed to maximize the success in bumping plugs on every job. The increased well cost and NPT has been well documented in many of the referenced documents and reports.

Casing Caliper

When it comes to cement job and displacement to land the plugs, another important variable is the casing capacity. Large diameter casing is provided with pipe data which included is the nominal ID. Many jobs are planned around the calculations of casing capacity from the manufacturers published nominal ID. With the understanding that this can be oversize pipe, the ID many times is 1 % or more larger with respect to the true casing ID. (5)

As per API 5CT Specifications for Casing and tubing the wall thickness can be less than 87.5% of the nominal value which means that on big jobs like a 14” long string the discrepancy can be over 50 bbl in some cases just due to a larger ID (see Table 4 below). In order to better quantify the true ID, deep-water operators utilize laser caliper performed at the bank, which on the other hand can affect the well operations overall job cost.

A more affordable option is to purchase a two- or three-point micrometer and caliper casing ID on the deck. Usually 10% of the joints to be run is a good enough sample size to obtain an average capacity for the displacement. This will decrease capacity variability from nominal value and provide a more accurate casing volume for displacement.

Rig Pump Efficiency

The rig pump efficiency variability can significantly affect the cement job displacement. This value is mostly affected by the pump’s condition, flow rate and properties of the fluid being pumped. The accepted efficiency range in the industry is usually between 93-97%, dependent on the operator. One of the useful tests that can be performed on the rig would be an efficiency test or “pit-to-pit” test.

If water is used, the fluid can be pumped from a pit into the trip tank or a pit of a larger volume at a designated flow rate. The test is repeated several times and an average efficiency is obtained. If possible, the efficiency test should be done with at least two different drilling fluid weights and at least three

different pump rates ranging from 4 to 12 bpm. The pits used for the test should preferably be of a larger volume (500-1000 bbl) to obtain a better accuracy with a smaller margin of error.

When it comes to pump inspection, one of the good practices to do is a preventative maintenance on at least two pumps prior to every cement job. This pre-job maintenance consists of inspecting the discharge valves and seats, cleaning the suction screens and inspecting swabs and liners. This maintenance can provide confidence that at least two pumps are in good shape just in case one of them goes down during the cement displacement.

Mud Compressibility Review

Another factor that can contribute to the landing of plugs on large displacement jobs and should be included with the final calculations is associated with the fluid compressibility of the synthetic based mud. Since all SBM's carry a percentage of base oil in the makeup, this has an impact on the downhole volume to land plugs and pressure up to either rupture or bump at the final position of the landing collar. Previous studies of the mud compressibility capacity determination go back casing jobs performed in the early 2000's where it was observed that only a small percentage of plugs landed without the realization that this number had to be included. (6) There are independent models in the market used to simulate downhole conditions while displacing the plugs to the landing collar. When these models are used for determining the amount of compressible capacity downhole the variance can be significant as seen in table number 3 below.

Table 3 – Compressibility Volume over Calculated

| Casing Size (inches) | Calculated capacity (bbls) | Compressibility | | | Compressibility observed (yes/no) |
|----------------------|----------------------------|------------------------------|-----------|-----------|-----------------------------------|
| | | Model I | Model II | Model III | |
| | | Vol / % of calculated (bbls) | | | |
| 14 | 2849 | 96 / 3.4 | 50 / 1.75 | 70 / 1.76 | yes |
| 14 | 2914 | 96 / 3.2 | 50 / 1.7 | 63 / 2.2 | yes |
| 14 | 1655 | 35 / 2.1 | 7 / 0.4 | 30 / 1.8 | no |
| 14 | 3380 | 128 / 3.7 | 100 / 2.9 | 112 / 3.3 | yes |

Cement Volume

Recognizing the variables that could be taken into the design consideration as detailed above, the planned cement volume to be mixed and pumped should equate to a practical and reasonable comparison to offset possible shortage in the landing of the top plug. An example based on a job design where the estimated variability due to the compressibility of the SBM mud would calculate to be 90 bbls, then the planned

cement volume to be mixed should be equal or slightly more such as 100 bbls of final slurry to be mixed. Confidence in the exact volume of cement mixed should be confirmed by measuring the mixing fluid as the slurry is pumped downhole.

Case Study Review

Case Study I

In this first case study of a deep-water well drilled in the Gulf of Mexico in water depth of 3000 ft, an intermediate long string consisting of 14" casing was run to a measured depth of 11,800' with a final inclination of 60 degrees on 6 5/8" drill-pipe. Prior to shipping the casing to the rig, an ID caliper was performed at the pipe yard on 10 joints of casing and from this measurement an average ID was determined to be 12.492". See Table 4 for more information. The shoe track consisted of 178' with a capacity of 27 bbls. An indicator collar was located 133' above the landing collar. This distance represented a capacity of 20 bbls for top plug pass-through indication. Prior to the start of cementing operations, the well was circulated with full returns at 5 bpm. The job consisted of testing surface lines to 6000 psi and then pumping 70 bbls of weighted spacer plus water wetting surfactants at a design density of 13.2 ppg. The bottom drill-pipe dart was launched and 160 bbls of 14.2 ppg cement was mixed and pumped. The top drill-pipe dart was released and the rig pump resumed displacement at 5 bpm. Both darts were observed to latch at calculated capacities with clear pressure indications. The second dart released at 2500 psi. The rig pump continued displacing the casing and the bottom plug was observed to land at 10,034 strokes (1167 bbls) of 12.2 ppg SBM with 1000 psi to rupture. This marker was observed 17 bbls early based on calculations and rig pump strokes with rig pump efficiency of 96 %. Displacement continued with a total of 11,590 strokes (1348 bbls) without landing the top plug. There was no pressure spike of top plug passing through the indication collar. Pressure was released and floats held with 8 bbls returned and measured. A casing pressure test was performed within 24 hours of final cementing operation and was unsuccessful. Subsequent shoe track drill-out operations concluded that the top plug did not reach the landing collar and contaminated cement was washed throughout the shoe track interval. From the results of this operation a modified wiper plug set was developed for future 14" long string cementing operations.

Table 4 – Nominal vs Caliper ID

| Project | Casing Size & weight | Nominal ID | Caliper ID | Capacity bbls (Nominal ID) | Capacity bbls (Caliper ID) | Delta Volume (bbls) |
|----------------|----------------------|------------|------------|----------------------------|----------------------------|---------------------|
| Case Study I | 14" 115 ppf | 12.376 | 12.492 | 1242 | 1270 | 28 |
| Case Study II | 14" 115 ppf | 12.376 | 12.492 | 2762 | 2814 | 52 |
| Case Study III | 14" 115 ppf | 12.376 | 12.466 | 3335 | 3384 | 49 |
| Case Study IV | 12 1/4" 134.25 ppf | 10 | 10.058 | 1403 | 1420 | 17 |

Case Study II

This well drilled in the Gulf of Mexico in water depth of 3000 ft, also with intermediate long string consisting of 14" casing run to a measured depth of 22,000' on 6 5/8" drill-pipe. Prior to shipping the casing to the rig, an ID caliper was performed at the pipe yard on 10 % or 43 joints of casing and from this measurement an average ID was determined to be 12.492". See Table 4 for more information. The shoe track consisted of 163' with a capacity of 25 bbls. There was no indication collar utilized for this operation. Prior to the start of cementing operations, the well was circulated for 1 hour up to a rate 5 bpm. The job consisted of testing surface lines to 6000 psi and then pumping 100 bbls of weighted spacer plus water wetting surfactants at a design density of 15.5 ppg. The bottom drill-pipe dart was launched and 200 bbls of 16.4 ppg cement was mixed and pumped. The top drill-pipe dart was released and the rig pump resumed displacement at 6 bpm. Both darts were observed to latch at calculated capacities with clear pressure indications. The second dart released at 4000 psi. The rig pump continued displacing the casing and the bottom plug was observed to land at 27,718 strokes (2714 bbls) of 14.7 ppg SBM with 1780 psi to rupture. This marker was observed 30 bbls over based on calculations and rig pump strokes with rig pump efficiency of 95.26 %. In this job, mud compressibility was not included in the volume to land the bottom plug. A calculations reset was made for the 30 bbls over for mud compressibility and the volume to land the top plug was based on cement volume pumped. Displacement continued with a total of 29,540 strokes (2892 bbls) to bump the top plug. Pressure was released and floats held with 22 bbls returned. Casing test was successful and hard cement was found throughout the shoe track with a good FIT and drilling operations continued. See Figure 1 displaying the cementing job chart.

Case Study III

This deep-water well was drilled in the Gulf of Mexico in 3000 foot of water depth. An intermediate long string of 14" casing was run to a measured depth of 24,743' on a 6-5/8" 60 ppf drill pipe. The total length of the casing was 22,600' with and based on the ID caliper conducted on the rig, the 10% sample size (50 joints) averaged the ID of 12.466". See Table 4 above for more information. The shoe track consisted of 230' feet with a 35 bbl capacity. Prior to starting the cement operations, the well was circulated for 2.5 hours up to a rate of 11 bpm. Total of 400 bbl of 15.8 ppg low-yield SBM was pumped during this circulation. The job consisted of testing the surface lines to 5000 psi and then pumping 120 bbl of 16 ppg spacer ahead of 4 bbl of 16.4 ppg cement. The bottom drill-pipe dart was launched and remaining 125 bbl of 16.4 ppg cement was mixed and pumped. The top drill-pipe dart was released and the rig resumed displacement at 8 bpm. Both darts were observed to latch at calculated capacities with clear pressure indications. The second dart released at 2270 psi. The rig pump continued displacing the casing and the bottom plug was observed to land at 29,124 strokes (3460 bbls) of 15.8 ppg SBM

with 2664 psi to rupture. This marker was observed 133 bbl over based on calculations and rig pump strokes with rig pump efficiency of 97%. A calculations reset was made for landing the top plug based on cement volume pumped. Displacement continued with a total of 29,975 strokes (3561 bbl) to bump the top plug. Pressure was released and floats held with 18 bbl returned. Casing test was successful and hard cement was found throughout the shoe track with a good LOT and drilling operations continued.

Case Study IV

This deep-water well was drilled in the Gulf of Mexico in 7400 foot of water depth. An intermediate long string of 12.25" casing was run to a measured depth of 21850' on a 6-5/8" 60 ppf drill pipe. The total length of the casing was 14,450' with and based on the ID caliper conducted on the rig, the 10% sample size (28 joints) averaged the ID of 10.058" vs 10" ID Nominal. See Table 4 above for more information. The shoe track consisted of 126' feet with a 12.3 bbl capacity. Prior to starting the cement operations, the well was circulated staging uprates from 1 bpm to 8 bpm. A total of 400 bbl of 13.1 ppg low-yield SBM was pumped during this circulation. The job consisted of testing the surface lines to 6000 psi and then pumping 70 bbl of 14 ppg spacer ahead of 4 bbl of 15.8 ppg cement. The bottom drill-pipe dart was launched and remaining 222 bbl of 15.8 ppg cement was mixed and pumped, 120 bbl batched mix ahead of time. The top drill-pipe dart was released and the rig resumed displacement at 4 bpm. Both darts were observed to latch at calculated capacities with clear pressure indications. The rig pump increased rate to 8 bpm once top dart launched displacing the casing and the bottom plug was observed to land at 10850 strokes (1288 bbls) of 13.24 ppg SBM with 1342 psi to rupture. This marker was observed 14 bbl over based on calculations and rig pump strokes with rig pump efficiency of 97%. A calculations reset was made for landing the top plug based on cement volume pumped. Displacement continued with a total of 1504 bbls to bump the top plug. Pressure was released and floats held with 8 bbl returned. Casing test was successful and hard cement was found throughout the shoe track with a good LOT and drilling operations continued. See Figure 2 displaying the cementing chart along with real-time matching results.

Table 5 – Summary of Case Studies

| Job | Displacement Rate | Casing Displacement Volume | Pump Efficiency | Bottom Plug Indication | Successful |
|-----|-------------------|----------------------------|-----------------|------------------------|------------|
| 1 | 5 bpm | 1270 bbl | 96% | -17 bbl | No |
| 2 | 6 bpm | 2814 bbl | 95.3% | +30 bbl | Yes |
| 3 | 8 bpm | 3384 bbl | 97% | +133 bbl | Yes |
| 4 | 8 bpm | 1420 bbl | 97% | +14 bbl | Yes |

Conclusions

Careful preparation and consideration of the variety of factors involved in displacement can lead to successful jobs, and reduction in NPT. While some jobs can have unfavorable results due to top wiper plug failure as seen in Case Study 1, this is typically not the normal expectation and has occurred in less than 3% of the 300 jobs that were captured for this study.

Rig pump efficiency as well as pipe ID caliper are direct measurements, whereas mud compressibility is based off a model. Mud compressibility models have limitations and different assumptions are given amongst the competing models. The variability in the displacement volume pumped over calculated after the bottom plug has landed and ruptured is clearly evident as each of the four case studies have been analyzed and presented.

In general, if due diligence is practiced by measuring rig pump efficiency, true casing ID, and considers the effects of compressibility as well as monitoring pressure indications throughout the displacement there is a high chance of a successful plug bump and thus positive casing test and a solid shoe track upon drill-out. Figure 3 provides a flowchart with these recommendations outlined as the job is pumped.

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Nomenclature

| | |
|-------------|----------------------------------|
| <i>BBL</i> | = Barrel |
| <i>FT'</i> | = Foot or Feet |
| <i>IN''</i> | = inches |
| <i>ID</i> | = Inside Diameter |
| <i>OD</i> | = Outside Diameter |
| <i>BPM</i> | = Barrel Per Minute |
| <i>PPF</i> | = Pounds Per Foot |
| <i>PPG</i> | = Pounds Per Gallon |
| <i>NPT</i> | = Non-Productive Time |
| <i>ECD</i> | = Equivalent Circulating Density |
| <i>EMW</i> | = Equivalent Mud Weight |
| <i>BHA</i> | = Bottom-hole assembly |
| <i>SBM</i> | = Synthetic Based Mud |
| <i>TOC</i> | = Top of Cement |
| <i>TOL</i> | = Top of Liner |

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Figure 1 – Cement Job Chart Case Study II

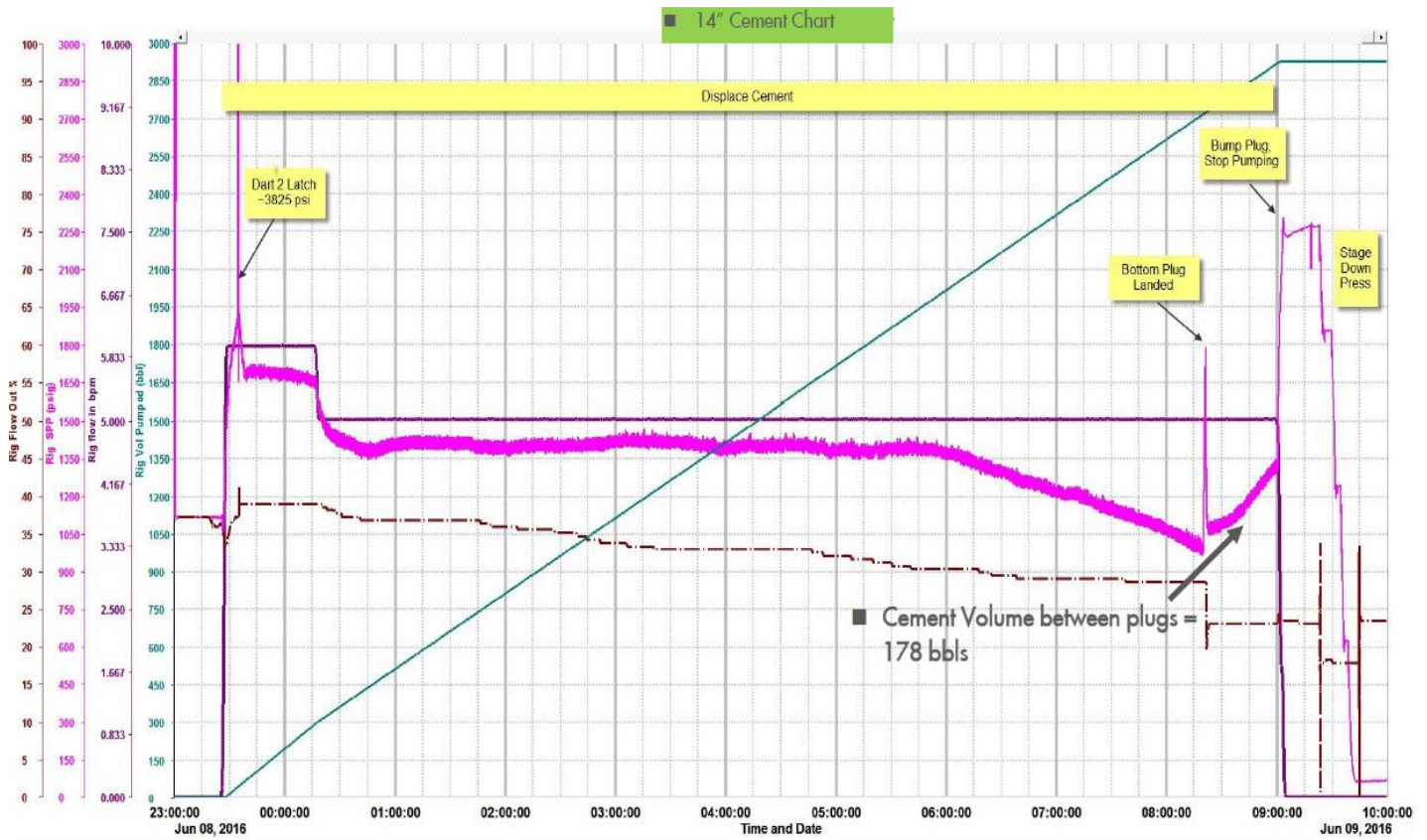


Figure 2 – Cement Job Chart Case Study IV

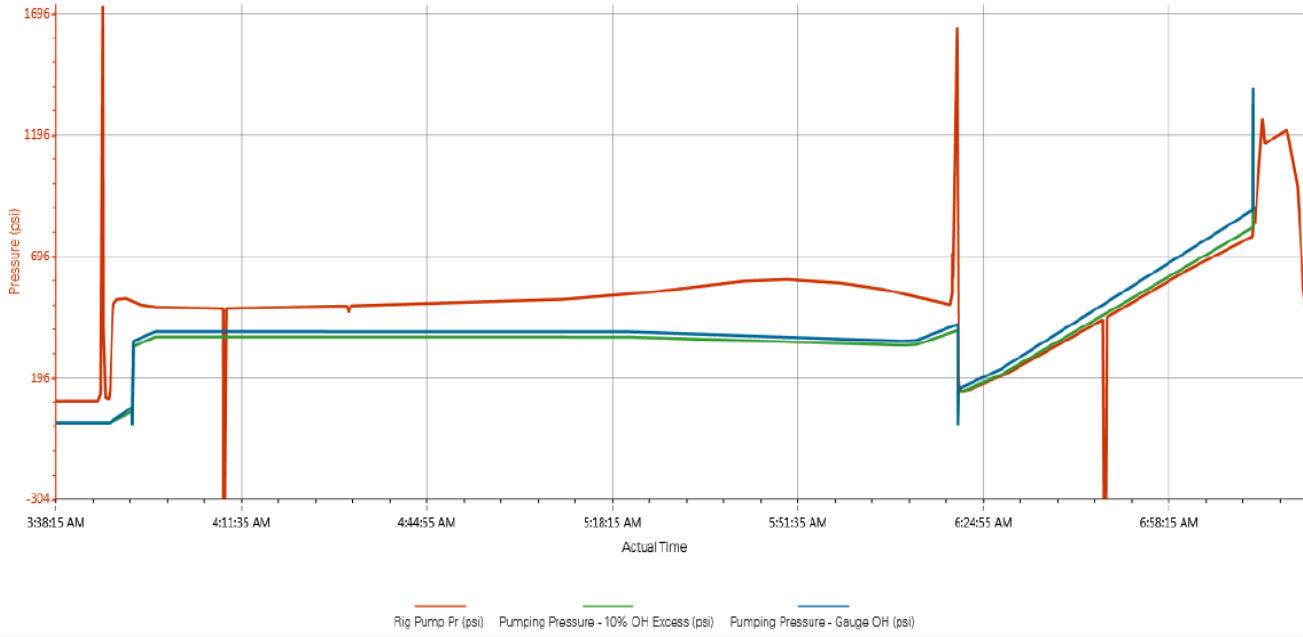


Figure 3 – Displacement Decision Flow Chart

