AADE Fluids Management Group Presentation

HPHT Cementing, What Might Be Different?

Feb. 23, 2011

Bob Carpenter
Cementing Consultant
Chevron ETC

HPHT Cementing: What Might Be Different?

1. Integrate Casing Program & Cement Job Planning
   - Planning the Cement Job should begin 6-18 months prior to spud or with the *Start* of Casing Program
   - Examine "Other" Casing Load Factors; Trapped Annular Pressure - Subsea Wellheads & Sustained Casing Pressure/Annular Pressure Migration; Thermal & Pressure Cycles
   - Corrosion – CO_2 and H_2S

HPHT Cementing: What Might Be Different?

2. Cement Properties for Long-Term Isolation
   - Temperature Induced Strength Retrogression
   - Why is an Analysis of Cement Stress Important?
   - Impact of Well Design and Operation on Cement Durability
3. Mud Displacement/ECD Management
   - ECD vs Pore/Frac Limitations and Optimization Strategies
   - Increasing Depth vs Decreasing Cement Volume
4. Cement and Cement Spacer Design; Lab Testing Issues
   - Laboratory Test Equipment Issues
   - Cement and Spacer Additive Temperature/Pressure Limitations

1. Integrate Casing Program & Cement Job Planning

- Start Early (6 to 18 months)
  - The lead-time for casing and hardware items can be more than a year out!
  - Being able to drill to TD does not ensure one can successfully cement it. Ensure that achieving the necessary cementing objectives is an integral part of successfully designing the casing string.
  - Development and/or qualification of new technology and equipment can also require more than a year; need to have Plan B's and time to implement.

1. Integrate Casing Program & Cement Job Planning

- Utilize Team Approach - Drill the Well on Paper - Identify technical challenges, limits, and identify long-lead time issues early
  - What problems were seen with offsets; where and why were they successful? Is this well the same or different?
  - Look for opportunities to reduce risk, cost and drilling time?
  - Qualify and select vendors on their ability to perform at expected HPHT's
  - Use elements of the team to provide technical support throughout the well (execution) program; don't settle for a report and "well wishes".

1. Integrate Casing Program & Cement Job Planning

- Use Cement ECD and Mechanical Properties simulations as an integral part of the casing design optimization process:
  - Use cementing simulators to predict and manage cementing ECD: With the planned casing program, can I reasonably expect to lift good, uncontaminated cement high enough to secure zonal isolation; if not, is the well a failure?
  - Use computer simulators to predict thermal & mechanical stresses upon cement sheath to predict long-term cement integrity and cement mechanical properties needed.
- Are specialty casing alloys or cement designs required, do they require further development or qualification testing?
- Continue technical support during execution phase and do “Lesson’s Learned”–type feedback loop for future applications
- Resolve technical challenges before spud date and have contingency plans ready for potential “unplanned” events

2. Cement Properties Needed For Long-Term Isolation

- Temperature Induced Strength Retrogression
  - Typically, 35% Silica added above 230F-250F
  - Silica Sand vs Silica Flour?
  - In some cases, it may be advantageous to increase silica content to 50% -100% BWOC for applications above 350F
- Why is an Analysis of Cement Stress Important?
  - Cement or casing stress failures ran result in loss of isolation or even the well
  - Preventing cement failures requires awareness and preplanning

2. Cement Properties Needed For Long-Term Isolation

- Impact of Well Design and Operation on Cement Durability
  - Impact of casing weight, width of annulus, centralization on cement durability?
  - Operational temperature and pressure effects upon cement
  - Rate and range of cool down/heat-up events, as well as the number of cycles, determines cement durability.
- Cement Mechanical Property Analysis

Why is an Analysis of Cement Stress Important?

- Even when we initially establish good zonal isolation with cement, subsequent well operations can impart strains that damage or destroy isolation and casing support
  - Pressure tests
  - Fluid swap-outs to lower or higher density fluids
  - Steam, cool water, or gas injection
  - Production of liquids or gas
  - Stimulation treatments or kill operations
  - Cement failure may permit casing corrosion, casing collapse or parting, loss of reserves, and/or surface casing pressure or loss of well
  - How we operate the well is a big part of cement durability
  - There’s more to properly designing the well than we once thought!

Why is an Analysis of Cement Stress Important?

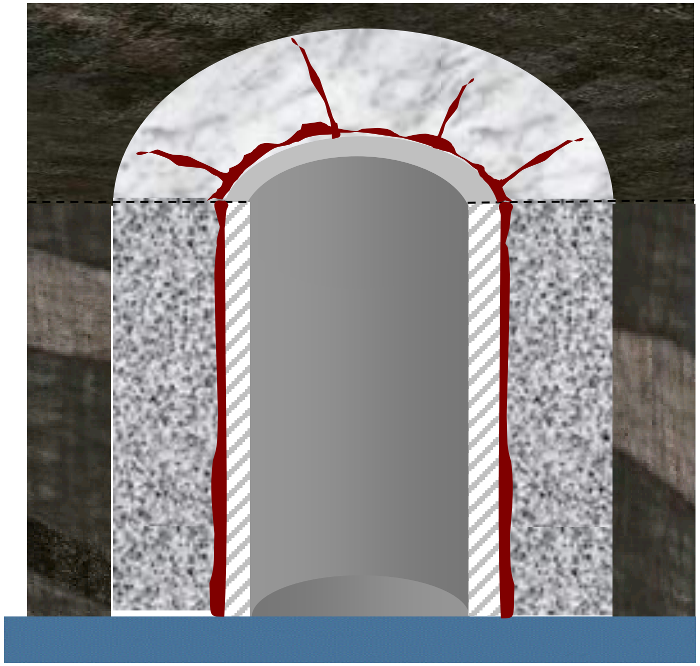
- HPHT wells are more likely to suffer such damage due to more extreme pressure and temperature changes over the life of the well

- Stresses within Injection/Production Wells
  - Cool down or heat-up rate and delta T
  - Injection/draw down pressure

Why is an Analysis of Cement Stress Important?

Cement Sheath Failure Mechanisms

- Vertical radial cracking is normally due to tangential stress producing a tensile failure
  - May produce loss of isolation



- Bonding failure of the cement sheath is normally due to excessive radial stress producing either a compressive, or tensile failure
  - May also result in loss of isolation

Cement Mechanical Properties Analysis

Typical Mechanical Property Inputs

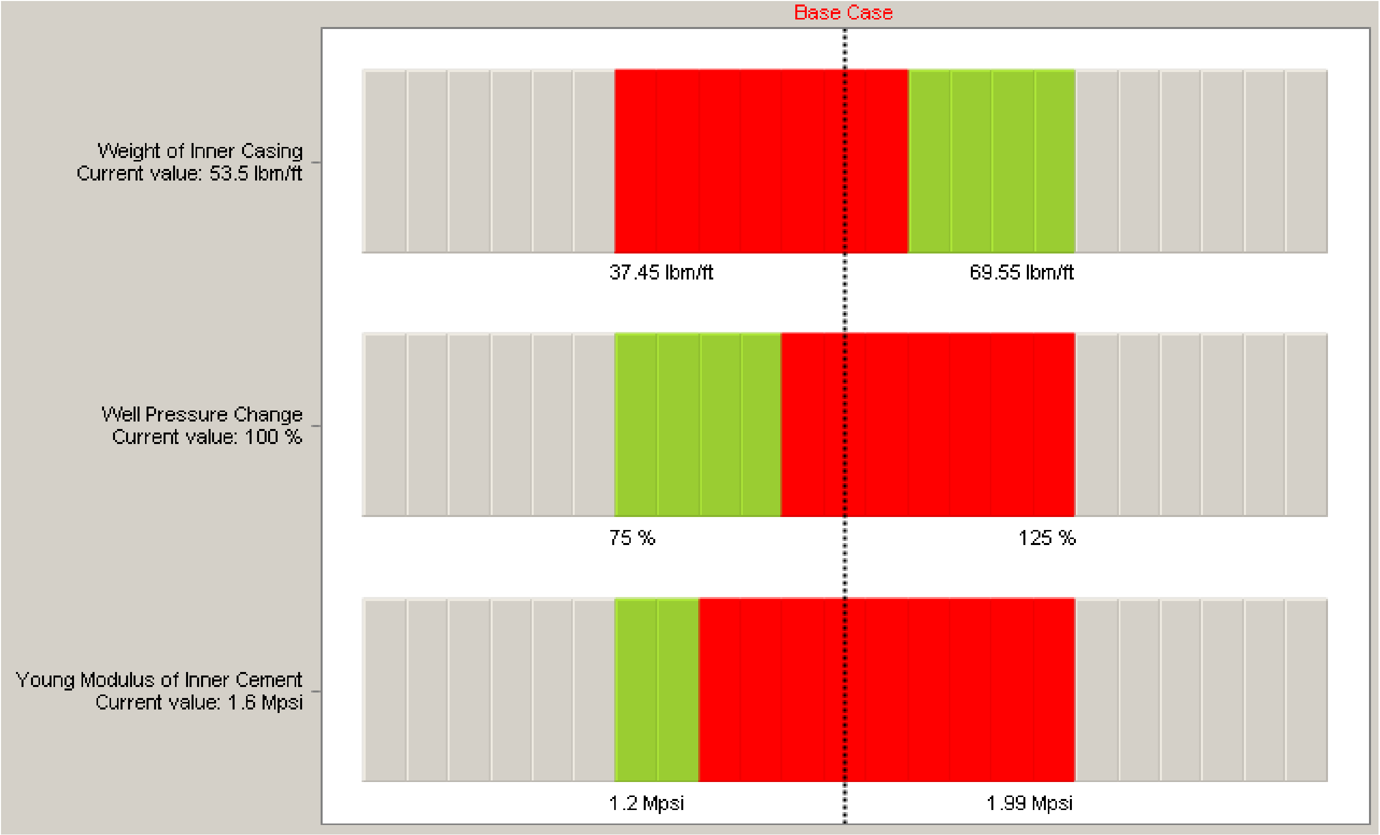
Formation	
Material Name:	Shale 13084
Density:	112.3703 lbm/ft3
Young Modulus:	0.8003 Mpsi
Poisson Ratio:	0.243
Thermal Conductivity:	1.2134 Btu/h.degF.ft
Specific Heat Capacity:	0.2818 Btu/(lbm.degF)
Thermal Exp. Coefficient:	7.2222 1E-6 1/degF

Inner Cement	
Material Name:	Class G - 15.8 ppg *
Density:	118.18 lbm/ft3
Compressive Strength:	5366.39 psi
Tensile Strength:	536.64 psi
Young Modulus:	1.6 Mpsi
Poisson Ratio:	0.17
Chemical Exp. Factor:	0 %
Thermal Conductivity:	0.6933 Btu/h.degF.ft
Specific Heat Capacity:	0.5016 Btu/(lbm.degF)
Thermal Exp. Coefficient:	5 1E-6 1/degF

Inner Casing	
Material Name:	Steel
Density:	495.5462 lbm/ft3
Casing OD:	9.625 in
Casing ID:	8.535 in
Standoff:	100 %
Young Modulus:	29.0075 Mpsi
Poisson Ratio:	0.27
Weight:	53.5 lbm/ft
Thermal Conductivity:	8.6668 Btu/h.degF.ft
Specific Heat Capacity:	0.1194 Btu/(lbm.degF)
Thermal Exp. Coefficient:	7.2222 1E-6 1/degF

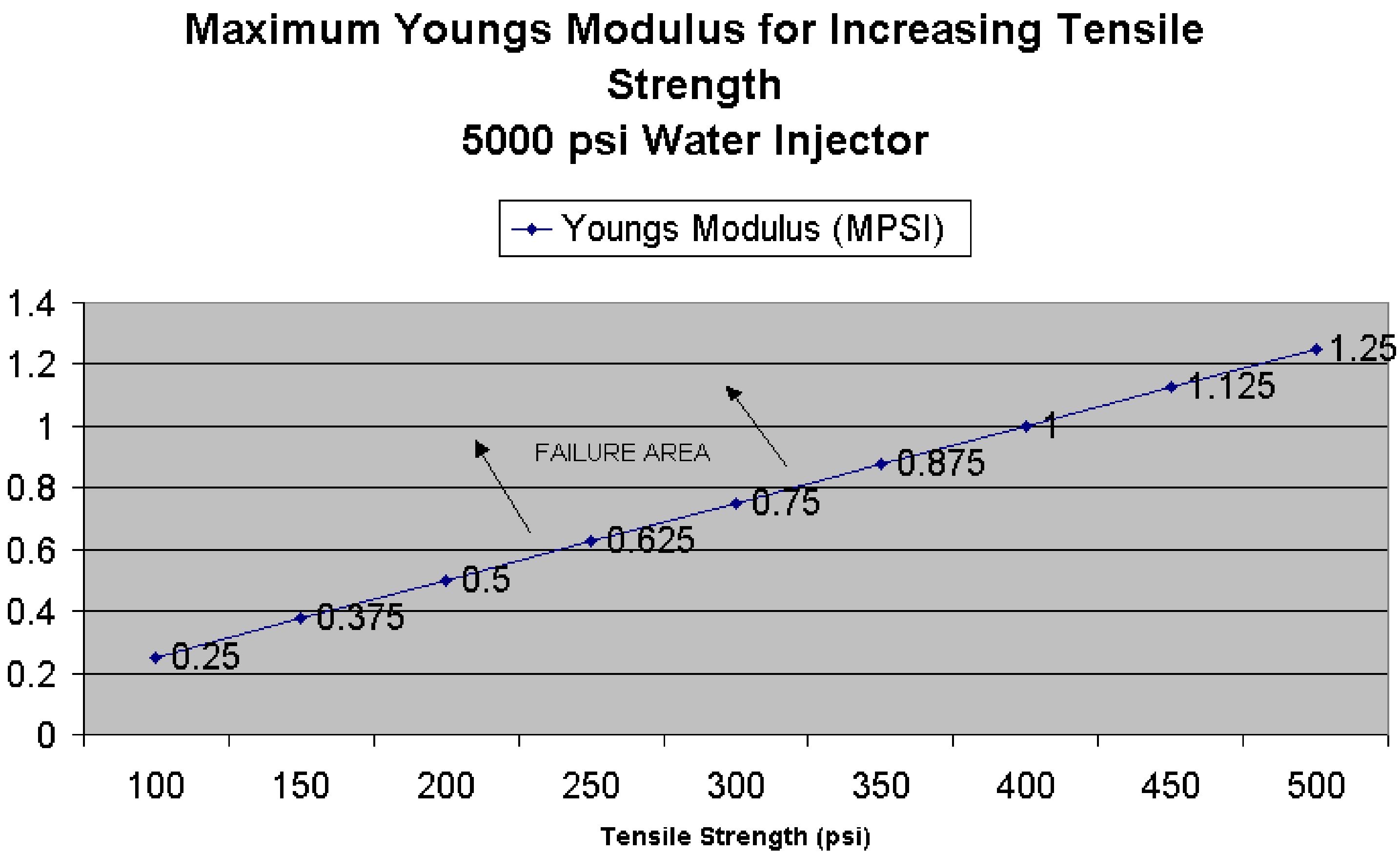
Mechanical Properties / Stress Simulators

Schlumberger: CemSTRESS Sensitivities



Mechanical Properties / Stress Simulators

CemSTRESS Tensile vs Modulus



Mechanical Properties Slurry Design Considerations

- Conventional cement designs are still used in majority of wells
  - Generally include 35% or more high purity crystalline silica to prevent strength retrogression at temperature >230°F - 250°F
  - High (uni-axial) compressive strength, 2,500 - 4,500 psi
  - Relatively brittle, Elasticity ≥1,200,000 psi
  - Tensile strength ~10% of uni-axial compressive strength, but varies from about 8%-12% (and more) depending upon cement composition
  - Conventional cement may experience slight hydration shrinkage
  - Shrinkage increases if the cement is deprived of water during set, casing-casing laps, and casing-shale intervals

Mechanical Properties Slurry Design Considerations

- Conventional, but Non-Shrinking or Expansive Cement
  - Expansive agent added to provide gradual, post-set expansion to positively pre-stress cement and thus reduce potential for radial tensile failure. Some initial shrinkage damage or decoupling may still occur
  - Expansion agent can reduce tensile stress and risk of decoupling, but questionable to the extent of benefit once a decoupling failure occurs
  - Excessive, unconfined expansion can be detrimental to cement durability
- Flexible/ductile/elastic cement
  - Flexible particulates and/or polymeric materials are added to the cement to increase cement elasticity
  - The increased elasticity permits greater elastic and non-elastic displacement/deformation before failure occurs
  - Expansion agents are typically included to pre-stress the cement

Mechanical Properties Slurry Design Considerations

- Self-”healing”/sealing cement
  - Hydrocarbon or aqueous reactive aggregates are added to the cement such that subsequent exposure expands the aggregate and effects a seal-”healing” seal
  - Same basic process as Swell Packer elements
  - Hydrocarbon reactive aggregates DO NOT react in dry gas, $\geq$95% methane
  - The hydrocarbon-reactive aggregates also increase cement elasticity
  - Potentially reduce the impact of radial cracks and micro-annuli

3. Mud Displacement/ECD Management Issues

- The need for more casing strings to reach TD objective can drive one to tight annular clearances and narrow pore/frac relationships; 22” x 17-7/8”, 17-7/8” x 16”, 16” x 13-5/8”, 13-5/8” x 11-3/4”, & 11-3/4” x 9-7/8”
- A very narrow pore/frac window, compounded by narrow annuli, can present well control issues and present an annulus that is difficult or sometimes impossible to cement properly.
- Know your cementing objectives; do I need extensive cement coverage or just tack the shoe and liner top packer?
- Are there 1,000-4,000 ft casing-casing overlaps that preclude mud flow, much less cement? Consider using liner and tieback

3. Mud Displacement/ECD Management Issues

- May need cement in liner lap or far up hole
  - Shorter liner laps can be very useful
  - Controlled rheology fluids
  - Brine washes, optimum fluid selection and sequence, and pump rate
- Is another casing string necessary? What triggers this decision?
- Long string or liner and tieback?
- Is it better to have a longer or shorter liner lap and/or tieback mandrel (PBR)?
- Combination string, different weights, OD’s, & ID’s
- Stage Tools vs Lower Density cement designs, which is better
- Pipe movement?
- Too Little Cement Traveling Too Far!

Too Little Cement, Traveling Too Far?

7” liner @ 29,501 ft

Liner Hanger @ 26,868 ft

6-5/8” DP

- Total Displacement Volume: 865 bbl
- Total Cement Volume: 60 bbl
- % Cement vs Displacement Volume: 7%
- With Displaced Annular Cement Volume: 6.5%
- Assuming ~300 ft of contaminated mud/cement at leading interface in annulus or DP; another 3 or 5 bbl of cement is lost.
- Assuming 1/32” (0.031”) NAF Film Wiped by Top Plug: 10 bbls of mud placed at shoe
- There is a minimum volume one can pump and expect to get some acceptable cement in the shoe and annulus and numerous factors are involved, some anecdotal evidence suggests ~100 bbls

11 3/4” Liner Friction Pressure Analysis

Section		Friction	Fraction Total Annular Friction
		psi	%
Tie Back Assembly	11,300 to 11,326 ft	52	36.1
Packer Assembly	11,326 to 11,327 ft	4.4	3.1
Liner Hanger Sleeve	11,327 to 11,328 ft	0.25	0.2
Liner Hanger Assembly	11,328 to 11,334 ft	11.8	8.2
Liner Lap	11,334 to 11,585 ft	64	44.4
15″ x 11 ¾″ Open Hole	11,585 to 12,916 ft	11.8	8.2

- 47.6 % of Total Annular Friction thru Liner Hanger Assembly
- 88.2 % of Total Annular Friction thru Liner Lap Area

4. Cement and Spacer Design & Lab Testing Issues

Cementing Temperature

- Use temperature simulators for BHCT prediction
  - API tables can be 25°F- 100°F higher than simulated BHCT
  - These lower computer simulation temperatures have been used successfully in field operations to prevent over-retardation, excess WOC time, and reduced incidence of gas/fluid influx (annular flow)
- MWD temperatures can lead to erroneous predict of BHCT's higher than know BHST with some drilling assemblies, particularly in extensive salt intervals
- When do I collect the temperature data and from which sensor; during drilling, tripping in, or both?

Laboratory Equipment Limitations

- **HPHT Consistometers (Thickening Time Tests)**
  - Typical consistometer; 400°F/25,000 psig
  - Fewer 600°F/40,000 psig “Super Consistometers” available
- **Fluid Loss**
  - Stirred Fluid Loss cells typically limited to 400°F-450°F
  - Many labs have only “static” fluid loss cells which have serious limitations
  - Safety
  - Accuracy, as typically used

Laboratory Equipment Limitations

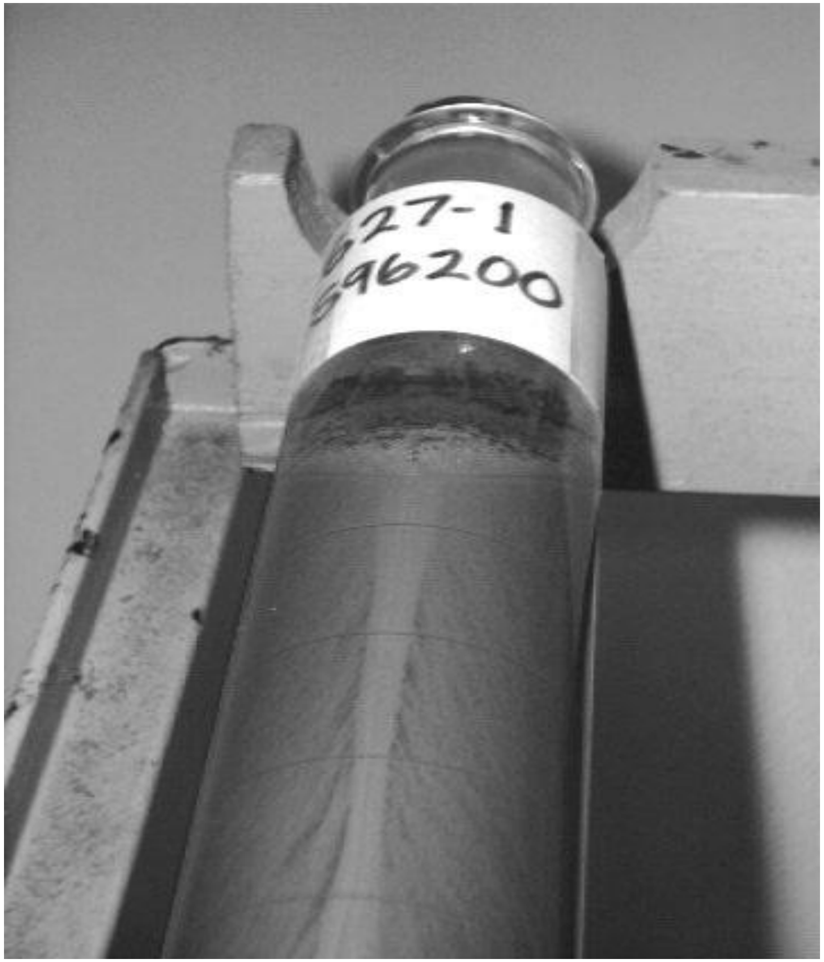
- Rheology
  - Test equipment limited to 190°F, temperature effects on rheology are not!
  - Use Fann 50, 70, 75 or 77 data for measurement of mud rheology!
- Compressive Strength
  - Ultrasonic test equipment typically limited to 400°F/20,000 psi
  - Curing chambers generally limited to 750°F/5,500 psi, 700°F/25,000 units are available, but rare

Retarders: Effect of Temperature and Pressure

- Retarder performance varies significantly between companies at >350°F
- Not all companies have retarders suitable for circulating temps exceeding 400°F, nor do they perform equally well
- Performance of these retarders are often less linear and more erratic
- Compressive strength development can be much slower for a given thickening time and time to reach 500-1,000 psi may range to 48 - 90 hours. This can be a particular problem if lab equipment capabilities do not permit testing at full BHP or BHST.
- HTHP retarders are very strong dispersants

Cement Free Fluid/Free Water

- A free fluid/free water channel is a pathway for annular communication
- Sedimentation of cement solids can create bridging issues
- Low down hole viscosity compromises mud displacement
- Common polymeric anti-settling additives don’t work, they generally “breakdown” at >280°F
- Providing sufficient down hole viscosity to impart free water control, solids suspension, fluid loss and good mud removal may create surface mixing issues



Free Fluid and Solids Segregation

Example of solids segregation and free fluid in 19.0 ppg slurry conditioned at 442°F.

In reality, cement condition down hole could be still worse.

Onsite Cement QA/QC

There is a lot more to onsite QA/QC is more than counting washers/displacement tanks:

- Who makes up the cement spacer?
- Who checks to see that it was mixed correctly?
- How many have ever supervised spacer mixing and done a material balance once it is mixed?
- Checked rheology and density of spacer at well site?
- Why would this be important?
- Who checks to make sure all the additives are in the cement mix water and that the cement is mixed to density?
- Was a blend test (dry-blended) performed and how do results compare to Pilot?
- Were lab tests done with same lot number (liquid additives) as will be used at rig?