Drilling and Integrity of Geothermal Wells - Issues and Challenges

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Geothermal Well Integrity

- Geothermal wells generally present as *high temperature, low pressure* applications
- Characterized by hot brine production at extremely high rates
- Areas affecting Well Integrity
  - Drilling / Well Planning
  - Production Fluids – Chemistry
  - Well Design and Operations
  - Well Construction

Drilling / Well Planning

- Formations are hard, abrasive, and at high temperature
  - Hot (150°C to 300°C), abrasive, hard (> 240 MPa or 35,000 psi UCS)
  - Bit and BHA selection and QA/QC is challenging –premature failures reported
- Lost Circulation
  - Most geothermal reservoirs are associated with local or regional faulting
  - High permeable features are common
  - Major problem- typically represent ~15% of well costs
  - LC issues also affect cementing
  - Mud Cap drilling / Drilling with Casing are options
- Formation Damage while drilling

Drilling / Well Planning

- Cementing and bringing cement to surface
  - Important to have good cement to surface – reverse circulation is an option
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Production Fluid Chemistry

- Virtually all geothermal fluids contain CO_2 and H_2S, and other corrosive elements and compounds; Acid Discharge is also possible.
- Chemical composition of produced fluid is often overlooked or ignored, but it has enormous impact on
  - Corrosion- mechanism, rate and mitigation
  - Cracking and brittle failure
  - Material selection (and not just the well!)
  - Scaling and precipitation
  - Monitoring and maintenance programs
  - Thermodynamic assurance and surface system design
- It is important to test production fluids and define chemical composition.
- Overlooking this can lead to many avoidable drilling and well integrity problems and affect well life.

Well Design and Operations

- High Temperatures
  - Working Stress Design may result in choice of higher grades than necessary, compromising material selection constraints
  - Appropriate choice is a post-yield design basis, as pressures are usually quite low
- Low Temperatures
  - Quench load imposes coldest thermal conditions- increasing temperature swing
  - Low temperature creates conditions favorable to cracking and brittle failure
  - Rate of quench may result in thermal shock conditions
- Cycling between production and shut in / quench causes fatigue
  - A Low Cycle Fatigue Approach is needed
- Connection Selection is often overlooked or oversimplified
  - Most thermal well failures occur in connections
  - API connections with high make-up hoop stress threaten well integrity
  - Appropriate connection qualification and LCF-based selection criteria are required

Well Design and Operations

- Well design for geothermal wells is very similar to that of conventional oil and gas wells
- Specific to tubular design, challenges in geothermal wells arise from
  - Temperature and thermal effects
  - Chemical composition of produced fluids
  - Rate of production / Pressure depletion
- Similarities to other thermal service wells (Steam Stimulation)
  - High temperature cyclic loading
  - Geomechanically induced strain
- Differences
  - No hydrocarbon produced (except in co-production)
  - Corrosion considerations are more important (produced fluids)

Typical Loads to Consider in Design

- Key loads for a geothermal production string
  - Running and Overpull
  - Cementing
    - Bump Plug
    - Cementing – Bleed
    - Cementing – Evacuated
    - Reverse Cementing
  - Pressure test – 70% API MIYP† and/or 1100 psi
  - MAWP at surface; fracture gradient at casing shoe; pore pressure outside
  - Kick
  - Production (thermal)
  - Cold Shut-in (thermal)
  - Bullhead Kill
  - Quenching (thermal), typical rates 10-20 BPM
  - Cold Collapse (during Quench)
- Liners may have additional loads (pre-perforated, slacked off, hanger loads)

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Temperature and Thermal Effects

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Typical Causes of Failure

- Mechanical
  - Cyclic loading and fatigue
  - Connection failures
  - Quenching / Bullhead Kill overloading
  - Cement Related – Unsupported section buckling, APB, cement de-bonding, deterioration, Wellhead forces, surface string overload
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Mitigations - Mechanical

- Cyclic loading and fatigue
  - Use LCF approach at design stage, thermal management
- Connection failures
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Mitigation – Material Selection

- Corrosion
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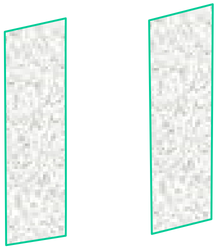
Post-Yield Design - An Example



- Geothermal Producer with cemented casing heated from 70^{o}F to 550^{o}F.
- Thermal stress
- For a low carbon steel, this is approximately equal to 96,000 psi
- What grade should we select?
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Modified Holliday Approach

- A deterministic High Temperature, Post Yield design approach analogous to WSD, wherein the *extent of post-yield strain* is limited by restricting the allowable stress

- Holliday Stress Ratio

  Where the VME stress includes bending stress from doglegs or buckling of unsupported sections

- Maximum allowable stress ratio is restricted, to conservatively account for all the thermal effects, and limit tensile plasticization
  - 6 5 ” W R - I R U /

Uniaxial Design Basis

- For quick analysis, a uniaxial design check can be used to select or assess a casing grade for thermal application

$$\frac{|\sigma_a| + |\sigma_b|}{SMYS} \leq 1.60 \quad (K55);$$
$$\leq 1.40 \quad (L80)$$

Axial stress σ_a can be approximated in psi as *200 ΔT(°F)*, or *°C)*

Bending stress σ_b is from dogleg or post-buckling

- Applying this to our example at the beginning:
  - SR = 96,000/55,000 = 1.75 for K55
    = 96,000/80,000 = 1.20 for L80
  - Thus L80 is a viable choice from Modified Holliday Approach
- The Modified Holliday Approach cannot be directly applied to connection selection, as connection stresses are not known.

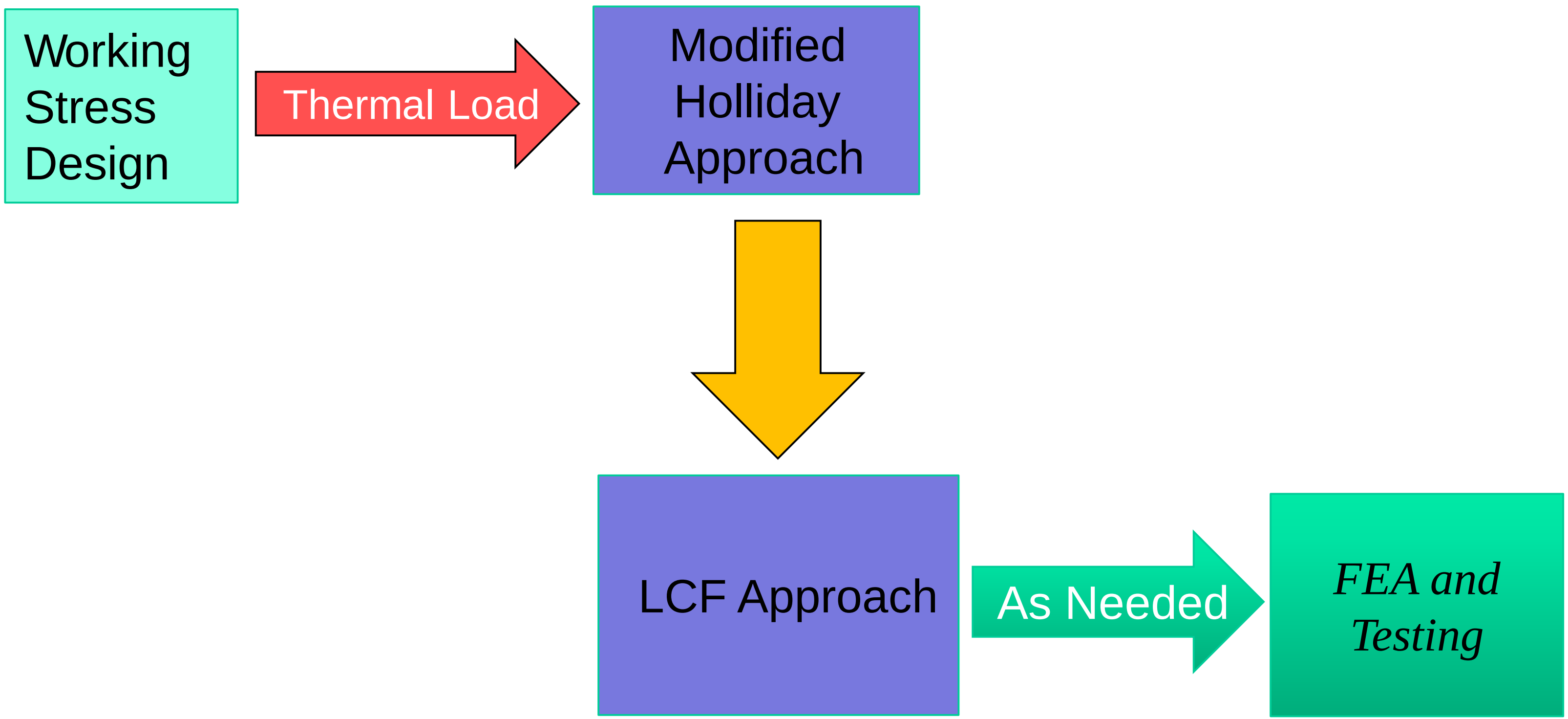
LCF Approaches

- Non-satisfaction of Holliday criteria does not imply failure.

Design Using MHA and LCF

- For a typical geothermal well completed with a 13 3/8” liner/tieback
- Design shows that the string satisfies WSD criteria for all loads (including quenching) except for Hot Production (VME SF = 1.03)
- Using Modified Holliday Approach
  - VME Stress = 67,900 psi.
  - Holliday Stress Ratio (L80) = 0.87
  - Holliday Stress Ratio (K55) = 1.23
  - *Even K55 is an option according to MHA!*
- Using LCF Approach
  - Full thermal cycles (production to quench)
  - Proprietary connection assumed
  - LCF limit for L80 is 238 cycles
  - Even for K55, LCF limit is greater than 150 cycles (functional requirement)

Proposed Design Process



Summary

- Water Chemistry assessed as a function of temperature, pressure and time
  - Incorporate acid gas and other intervention events into the design
- Ensure Corrosion analyses is part of the well design
- Incorporate relevant well loading scenarios into design that includes chemistry
  - Sulfide Stress Cracking
    - Low pH, Low Temperature
  - Stress Corrosion Cracking (Caustic Cracking)
    - High pH (over 9) and High Temperature
- Connection has to be addressed with chemistry and cracking in tow
- These considerations may help prevent well failure
  - Better cement job
  - Packer completion
  - Lower grade pipe (using Post Yield design)