Structural and Fatigue Performance of HPHT Subsea Drilling and Production Systems

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Outline

• HPHT Systems Requirements and Challenges

• Wellhead System Overview
  • Structural Integrity
    - System Verification Analysis
    - System Validation Testing – New Horizontal Test Machine
  • Fatigue Performance

• New HPHT Wellhead System Design Concept

• Advanced Product Quality Planning (APQP)

• Conclusions
HPHT Subsea Systems

• Requirements
  ➢ Pressure > 15 KSI and/or Temperature > 350°F
  ➢ Higher Structural Load Capacity Requirements
  ➢ Longer Fatigue Life Requirements
  ➢ Need for Next Generation HPHT Equipment

• Challenges
  ➢ Uncertainties with Environmental Effects on Material Properties
  ➢ Lack of HPHT Material Properties at Different Environments
  ➢ More Stringent Regulatory Requirements for Analysis and Testing
  ➢ New Tools and Technology Needed
Subsea Wellhead Systems Overview

The Wellhead is the topmost component of a well, suitable for the life of the well, non-retrievable, and provides:

- External Load Resistance
- Pressure Containment
- Pressure Controlling Interfaces
- Hanging Interface & Weight Support
- Fatigue/Cyclic Load Resistance
- Barrier to Environment
Verification Analysis

- Traditional (Hand Calculations, Equivalent Tension, 2D FEA)
- Advanced (3D FEA)

Limitations
- Equivalent Radius
- Compression Side of Bending
- Combined Load Effects
- Non- Axisymmetric Features (dog segments, etc.)
- Two capacity points determined with hand calculation cover all combined loads.
3D FEA Capacity Chart

INTERNAL PRESSURE VS. BENDING WITH TENSION/COMPRESSION AND PRESSURE END LOAD

- Tension
- Compression
- Rated
- Extreme
- Survival

- W/O PEL
- W/ PEL
Wellhead System Global Analysis

- **Loading Conditions**
  - Mechanical Preload
  - External Loads
  - Pressure
  - Pressure End Load (i.e. shear rams closed)
  - Casing Program & Weights
  - Thermal Loads
  - Cyclic Loads

- **3D FEA Model**
  - 200 ft Below Mudline
  - Non-linear Geometry Behavior
  - Over 1 Million Elements
  - No Tied Constraints
  - Modeled with Cement
  - Soil Properties
  - Installation sequence closely mimics field conditions

- **Static and Fatigue Evaluation**
Fatigue Evaluation

SN Method

Fracture Mechanics

**Change in Loc. Peak Stress**  
**Change in Ref. Average Stress**

\[ SAF = \frac{\text{Change in Loc. Peak Stress}}{\text{Change in Ref. Average Stress}} \]

\[ D_{Total} = \sum_{Bin=1}^{Bin_{max}} \text{Damage}_{Bin} \]

\[ T_{Total} = \frac{1}{D_{Total}} \]
Standardized Analysis Inputs

• Analysis Inputs Required for Each Specific Application
  ➢ Water Depths
  ➢ Vessel Types
  ➢ Environments
  ➢ System Configurations
  ➢ Soils
  ➢ Cements
  ➢ Static and Dynamic Loads
  ➢ Environmental Effects on Material Properties
  ➢ Etc.

• Industry Standardized Inputs
  ➢ Standard set of input data that can be used to qualify the equipment to a certain performance level is needed. This data should be categorized for various regions of the world, different water depths, vessel types, etc., and should encompass a range of various load levels from benign to intermediate/extreme and survival conditions.
API PER15K System Analysis & Testing

Wellhead System

- Assembly:
  - Wellhead Connector
  - Low Pressure Housing
  - High Pressure Housing

- Process:
  - Preloaded System
  - 6MM lbf. Casing Weight
  - Apply Loads per Capacity Chart
  - Results Comparison
  - Inspection
  - Third Party Witness

Horizontal Test Machine Load Capacity

- $20 \times 10^6$ ft•lbf (27.7 $\times$ $10^6$ N•m) Bending
- $13 \times 10^6$ lbf (57.8 $\times$ $10^6$ N) Tension/Compression
- $6 \times 10^6$ lbf (26.7 $\times$ $10^6$ N) Simulated Casing Loads
- Combined Loads
20Ksi & 15Ksi Connector Comparison

15 Ksi Connector

~2 × Capacity

20 Ksi Connector

Internal Pressure (ksi)

Bending Moment (ft-lbf)

Pressure End Load (kips)
Conclusions & Recommendations

• A wellhead system verification analysis and validation test has been successfully completed and provided better understanding of the wellhead system performance.

• System validation testing provided critical information needed to make proper adjustments to the verification analysis methodology.

• Knowledge obtained from this test program has been applied for HPHT development work of 20 Ksi subsea systems.

• A new 35” wellhead system/connector design concept is presented with superior structural capacity and fatigue resistance characteristics expected to meet the HPHT industry needs for the future decades.

• There is a need for industry standardized analysis inputs and material properties. Recommendations for data format is presented.
Thank You!

Questions?
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