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Structural Integrity Assessment of FPSO Conversions

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ABS
Background

● Industry demand
  - World offshore oil and gas production has increased significantly. Forecast is for 150 FPSOs being in service or on order by 2010.
  - Number of FPSOs in operation has doubled, from 50 to 104, since 1998. The number of FPSOs predicted to again double by end of 2010*.

● Technical challenge
  - Environment: US Gulf/Gulf of Mexico, Canada, South America, UK/Norway North Sea, West Africa, Mediterranean, Asia/Pacific, South Africa
  - Ship type: Aframax FPSOs, Suezmax FPSOs, VLCC/ULCCs, Specialist FPSOs, LNG FPSOs, LPG FPSOs, CNG FPSOs

* Carnegie Securities Research
FPSO – Ship Shaped Offshore Structure

- FPSO hull structure arrangement generally similar to normal trading tanker – similar number and size of cargo holds, longitudinal stiffened plating, connection details, etc.
- Tanker technology therefore transferable to FPSO design practice
- FPSOs are however operated in different manner than tankers
FPSO Conversion – Ship Type Offshore Structure

Offshore Environment
- site specific, transit

Offshore Operation
- loading condition

Offshore Design
- topside, mooring

Offshore Maintenance
- inspection, repair

Structure Assessment
- yielding, buckling, ultimate strength, fatigue
Overview

- General approach for FPSO assessment based on converted tankers
- Strength and fatigue assessment
  - Environment effect
  - Global & local strength assessment
  - Hull girder ultimate strength
  - Fatigue assessment
FPSO Conversion

- Prediction of environmental loads for strength and fatigue assessment
  - Tanker trading history
  - Transit to site
  - On-site operation
- Determination of renewal scantlings based on transit, on-site, inspection and repair conditions
- Evaluation of scantlings including hull girder ultimate strength assessment
FPSO Conversion Guide

- Assessment of local and global strength for yielding, buckling and fatigue failure modes
- Fatigue damage assessment calculations including high cycle and low cycle fatigue
- Methodologies use some of the requirements in Common Scantling Rules suitably modified to reflect FPSO operating practice
Strength and Fatigue Assessment in ABS FPSO Analysis

- Structural evaluation comprise three main elements
  - SEAS (Sea Environment Assessment System)
    - Factors accounting for different wave climates during life as a trading tanker, transit to site, and on site
  - ISE (Initial Scantling Evaluation)
    - Rule-based strength and fatigue evaluation
  - TSA (Total Strength Assessment)
    - First principle-based strength and fatigue evaluation
Environmental Effects - SEAS Concept in ABS FPSO Analysis

Environmental Severity Factors

Sea Loads Analysis

SEAS
(Sea Environment Assessment System)

FPSO on Site & Transit

North Atlantic Environment
Role of ABS SEAS Software in FPSO Analysis

**SEAS**

**Wave Conditions**
- ESF, β
- ESF, α

**FPSO on Site and Route**
- Site-specific & Transit
- Historical sites and routes
- Various wave spectra
- Seakeeping analysis
- Extreme value analysis
- Component-based spectral fatigue analysis
- Sea and swell

**ISE**
(Initial Scantling including fatigue)

**TSA**
(FE based Strength & Fatigue)

- Generation of Hull Configuration Model
- Calculation of Loads
- Determination of Scantlings/Compliance with Strength Criteria
- Fatigue Assessment

- Generation of FEM Model
- Calculation of Loads
- Finite Element Analysis
- Assessment of Failure Modes
  - Yielding
  - Ultimate Strength
  - Buckling
  - Fatigue
Initial Scantling Evaluation

- Hull Girder Longitudinal Strength and Local Scantling Requirement (Trading Tanker)
- Re-assessed Scantling Determination (On-site Condition with Hull Girder Section Modulus, including inspection, repair and transit conditions) – determine Steel Renewal Assessment for longitudinal members
- Fatigue Assessment – Remaining fatigue life evaluation
- Hull Girder Ultimate Strength Assessment
- Hull Girder Shearing Strength Assessment
- Transverse Bulkhead and Main Supporting Members Assessment
- Sloshing Assessment
- Double Bottom / Floor and Girder Assessment
Hull Girder Ultimate Strength

The hull girder ultimate strength, $M_u$, is the maximum bending capacity of the hull girder beyond which the hull will collapse. The hull girder ultimate strength state limit defined by

\[ \gamma_s M_s + \gamma_w \phi_w M_w \leq \frac{M_u}{\gamma_u} \]

$M_s, M_w$ - still water bending moment and wave induced bending moment

$M_u$ - hull girder ultimate strength

$\gamma_s, \gamma_w, \gamma_u$ - partial safety factors corresponding to still water bending moment, wave-induced bending moment and hull girder ultimate strength

$\phi_w$ - load combination factor
Total Strength Assessment

- TSA assesses adequacy of the structural configuration and the initially determined scantlings
  - Environment
    - Transit
    - On site
  - Loading conditions
    - Operation
    - Inspection
    - Repair
    - Transit
Total Strength Assessment

- Structures evaluated
  - Hull structure
  - Topside-hull interface
  - Mooring-hull interface
Fatigue Assessment

- Remaining fatigue life of FPSO Conversion
  - Tanker phase: accumulated fatigue damage during tanker operation for actual trading routes
  - Transit phase: transit environment
  - FPSO phase:
    - High cycle fatigue: operating condition, on-site environment
    - Low cycle fatigue: loading and off-loading
Low Cycle Fatigue Analysis Procedure

1. **Simplified or FE analysis**

2. **Elastic Peak Stress Range**
   \( (\sigma_{LCF}, \text{hot spot stress}) \)

3. **Plasticity Correction Factor**
   \( (K_e) \)

4. **Pseudo Hot Spot Stress Range**
   \( (K_e \times \sigma_{LCF}) \)

5. **Damage Calculation**
   \( (S-N \text{ curve, Miner’s Rule}) \)
Plasticity Correction Factor $K_e$

- Material property dependent
- Developed based on cyclic strain-stress curve and Neuber’s rule

![Graph showing Plasticity Correction Factor $K_e$ vs Elastic Hot Spot Stress Range $S_e$ (MPa)]
S-N Curve for Low Cycle Fatigue

Test specimen from TWI (1974)

Testing specimen presented in Heo et. al. (2004)
Low Cycle Fatigue

- Pseudo Hot Spot Stress range of low cycle fatigue (LCF) region is obtained by calculation of peak stress range considering static and dynamic stress range

- Using obtained stress range and assumed design cycle, fatigue damage of LCF can be calculated with Miner’s rule
Summary

- Structural assessment of FPSO conversions
  - Environmental effect
  - Strength (global and local)
  - Fatigue
  - Structural Interfaces – hull/topside, hull/position mooring
- ABS Guide for Building and Classing Floating Production Installations and ABS FPSO Software