Offshore Platform Fluid Structure Interaction (FSI) Simulation

Ali Marzaban, CD-adapco
Murthy Lakshmiraju, CD-adapco
Nigel Richardson, CD-adapco
Mike Henneke, CD-adapco

Guangyu Wu, Chevron
Pedro M. Vargas, Chevron
Owen Oakley, Chevron
Introduction

- The main objective of this study was to predict the permanent deformation of an offshore platform from a large wave incident during a storm using Fluid Structure Interaction (FSI).
- A representative sub-modeled 1/8th section of the offshore oil platform that was deformed permanently during a hurricane is demonstrated.
- Study was divided into three phases to progressively develop a FSI methodology to predict the permanent deformation of the platform:
  - Phase 1: Static and transient dynamic structural investigation was conducted on a sub-model section of the platform to predict potential wave energy required to cause the field observed deformation (around 40 cm deformation was reported on one of the plate girders).
    - ABAQUS 6.11 was used for Finite Element Analysis (FEA).
  - Phase 2: Hurricane waves were simulated using Computational Fluid Dynamics (CFD) to determine wave characteristics required to induce the magnitude of pressure needed to observe same deformation on a structure (Based on Phase 1).
    - STAR-CCM+ 6.06 was used for CFD analysis
  - Phase 3: One-way coupled simulations were modeled to study impact analysis on the structure due to wave pressure.
Phase 1 – Finite Element Analysis

- A 3D finite element model of an offshore platform was generated from Chevron provided 2D drawings.

- The model was investigated for a single wave impact event using ABAQUS 6.11 to study the permanent plastic deformation.

- The model has been analyzed using both static and transient dynamic (implicit) approach.

- Varying pressure loads were applied in the static cases to validate recorded field data deformation (40 cm on one of the plate girders).

- Pressures were applied at different periods during the implicit analysis studies.
Phase 2 – Computational Fluid Dynamics

- A uni-directional wave field was generated based on 60 individual wave components (provided by Chevron) using a Fortran based user sub-routine code.

- 2D simulations were performed without the platform to determine the position of the peak wave occurrence to place the structure.

- 2D simulations also helped in estimating the mesh size and time step for coupling fluid-structure interaction phase.

- Platform was situated such that maximum energy would be imparted on the structure.
Phase 3 – One-way Coupled Fluid Structure Interaction

• One-way coupling scheme: Fluid imparted pressures on the structure will be transferred to the FE model but the response of the structure to the fluid will be neglected.
  – Structure is treated as a rigid body in the CFD model

• One-way coupling analysis was performed to predict the observed deformation on plate girders using STAR-CCM+ and ABAQUS co-simulation.
Laser Scan Measurement of Plate Girders

Max: 40 cm  Max: 43 cm

August 13, 2013
Phase 1
Modeling Assumption and Material Properties

- The 3D FEA model was generated from 2D drawings provided by Chevron.
- C3D20R elements were used to model all solid parts.
- Local connection details (bolts and welds) were not considered. All joint were considered to be infinitely stiff.
- Elastic-plastic material properties was used for plate girders.

For plate girders A588 typical material properties was used:
- Initial Elastic Modulus: 200 GPa
- Poisson’s ratio: 0.3
- Density: 7830 kg/m³
- Yield Stress: 379.2 MPa
- Ultimate Stress: 530.9 MPa

![Stress-Strain Curve](image)
Finite Element Mesh – Full Assembly

ELEMENTS: 21,114
NODES: 118,200
Applied Boundary Conditions

- Gravity is applied in negative z-direction.
- Uniform pressure distribution was applied to the plate girder in positive x-direction.
Displacement for 300kPa Pressure in Static Analysis

August 13, 2013
**Static Analysis**

- In the static analysis, the load was applied as a uniform pressure.
- Five different load cases with different maximum pressure of (100, 150, 200, 250 and 300kPa) was considered.
- The pressure was applied as a ramp from zero to max from $t=0$ to $t=0.5s$. Then the pressure was released as a ramp from the max pressure to zero from $t=0.5s$ to $t=1s$.

![Displacement of node A in x-direction with different pressures](image1)

![Deformed location of node A in x-direction with different pressures](image2)

43cm deflection
Pressure=277kPa
Implicit Analysis

- In the implicit analysis, the load was applied as a uniform pressure with the maximum pressure of 300kPa.
- Four different load cases with different total times of (T=0.01, 0.05, 0.1 and 1 second) was considered.
- The pressure was applied as a ramp from zero to max (300kPa) from t=0 to t=0.5T. Then the pressure was released as a ramp from the max pressure (300kPa) to zero from t=0.5T to t=T. A zero pressure was applied from t=T to t=3T.
Displacement in x-direction for Different Times in Implicit Analysis

Displacement of node A in x-direction with different Frequency for 300kPa

Applied Force vs Time
**Required Pressure for 43 cm Displacement**

<table>
<thead>
<tr>
<th>Total Time (s)</th>
<th>Pressure (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>415</td>
</tr>
<tr>
<td>0.1</td>
<td>322</td>
</tr>
<tr>
<td>0.5</td>
<td>273</td>
</tr>
<tr>
<td>1</td>
<td>270</td>
</tr>
<tr>
<td>5</td>
<td>275</td>
</tr>
<tr>
<td>Static</td>
<td>277</td>
</tr>
</tbody>
</table>

![Graph showing pressure vs total time]
Phase 2
Computational Domain, Mesh and Boundary Conditions – Without Structure

Mesh: 101,600
Delta X is fixed: 3m and Delta Y is fixed: 2m (One cell thick domain)

Mesh size near free surface, Refined area 1 (Z=-25m to 25m): Delta Z = 1m

Mesh size near free surface, Refined area 2 (Z=-50m to -25m & 50m to 25m): Delta Z = 1.5m

In water, Delta Z increases to 10m (at ocean bottom)

In air, Delta Z increases to 20m (at Top)
**CFD Methodology**

- Physical Models used:
  - Three dimensional
  - Implicit unsteady
  - Gravity
  - Multiphase mixture
  - Eulerian multiphase
    - Water: Constant density
      - Density: 997.561 Kg/m³ and Dynamic viscosity: 8.887E-4 Pa-s
    - Air: Constant density
      - Density: 1.18415 Kg/m³ and Dynamic viscosity: 1.85508E-5 Pa-s
  - Volume of Fluid
  - VOF waves - Flat water condition (for generating mean free surface)
  - Turbulence:
    - SST (Menter) K-Omega turbulence model with High y+ Wall treatment
  - Wave Damping
    - Imposed from 400m from outlet
Wave specifications

- Water depth: 1754 ft (534.6m)
- Peak wave period: 14.8s
- Zero crossing (Mean) wave period: 10.2s
- Maximum wave height: 74 ft ±1.5 ft (22.55m ± 0.457m)
- Significant wave height: 43.3 ft (13.19m)
- Surface current (above – 200ft) velocity: 2.1 knots (1.08m/s)
- Static wind speed: 85 knots (43.72 m/s)
  - Direction of surface current and wind speeds are unknown
  - Assumption: static current and wave speed direction is same as the wave advancing direction.
- Height of the lower deck to free surface: 56 ft (17.07 m)

- Wave properties: (provided by Chevron)
  - Superposition of 60 waves
  - Highest crest is 16.92m at 1325.6m and 166.0 s
  - Velocity, height, volume fraction: calculated on a point-by-point basis from given data using a FORTRAN subroutine
CFD Methodology

- Initial Conditions:
  - Pressure: Hydrostatic Pressure of mean free surface
  - Velocity: User code
    - Used single wave velocity field at t=130s for wave
  - Volume fractions:
    - Air: 0.0
    - Water: User code

Wave Height at 130.0s From Fortran (Initial condition)
Wave Height Monitor

Wave Height at X = 1000m

Wave Height at X = 1200m

Wave Height at X = 1400m
Computational Domain and Boundary Conditions

Inlet: User Code
Outlet: Pressure Outlet
Top: Wall (Slip condition)
Bottom: Wall (No-slip) - Ocean bed
Sides: Symmetry

Platform Model in CFD Analysis

Platform:
Length along X: 15.7m
Depth along Y: 16.1m
Height along Z: 1.56m
I-Beam 3 at X=1150m
Bottom of Structure = 17m

X: Wave Advancing Direction
Z: Normal to Wave Advancing Direction – Along Gravity
Mesh

Mesh : 7,154,319

Mesh size near free surface, Refined area (Z= -15m to 25m): Delta X & Delta Y = 2.44m, Delta Z = 0.609m
Away from free surface: Delta X = 19.5, Delta Y = 9.75m, Delta Z = 19.5m

August 13, 2013
Mesh – Plane Y=0m
Wave history plots and surface elevation plot indicates free surface in 3D model is close to that of the free surface from 2D model.
Phase 3
**3D- Domain**

Model:
I-Beam 3 at X=1150m
Bottom of Structure = 13m
Finite Element Mesh – Full Assembly

269,361 linear hexahedral elements of type C3D8R
Total Elements: 269,361
Total Nodes: 408,231
C3D8R: 8-node linear brick, reduced integration with hourglass control

* The connection details has been ignored. All joint were considered to be infinitely stiff.
**Applied Boundary Condition**

- Fixed in X, Y-direction (Connected to rest of the deck)
- Fixed in Z-direction (Supports)
- Fixed in X, Y-direction
- *Top deck was vertically restrained*
Displacement Magnitude

Case 7-C

<table>
<thead>
<tr>
<th>Displacement Magnitude (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>47cm</td>
</tr>
<tr>
<td>17cm</td>
</tr>
</tbody>
</table>

Solution Time 0.001 (s)

August 13, 2013
Comparison of Deformation of Plate Girders with Field Data

![Graph showing comparison of deformation of plate girders with field data.](image)

- Member A - Field Data
- Member A - Analysis Results
- Member B - Field Data
- Member B - Analysis Results

Length = 12.0 m

Length = 0.0 m

August 13, 2013
Conclusions

• A One-way coupled Fluid Structure Interaction was investigated for predicting permanent deformation on an offshore platform from a large wave incident during a storm.

• Results are comparable to the actual field measurements

• The deformation on plate girders can also be due to several wave impacts during the hurricane and the deformation magnitude of the plate girders will be superimposed due to these multiple impacts

• Results suggest that sufficiently accurate solution for the design of offshore platforms can be obtained with this methodology.