Outline

- Background
- Key conclusions
- Observed VIV in-field
- Instrumentation
- VIV Software Calibration
- Key findings and software limitations
  - VIV occurrence in the field
  - Suppression devices
  - Higher harmonics
  - Time sharing
- Conclusions and recommendations
VIV Monitoring: Background and Objectives

**Motivation**
- Equipment damage
- Excessive waiting on weather
- Observed BOP stack VIV
- Low confidence in conservative design tools
- Limited performance data on off-the-shelf VIV suppression devices (fairings/fins)

**Approach**
- GoM drilling riser VIV monitoring program kicked off
  - Drilling risers with and without suppression devices

**Objectives of Monitoring Campaign**
- Ensure safe operations and feed back important information to wells teams
- Calibrate design tool (SHEAR7) with field measurements
- Identify and understand sources of discrepancies
- Assess suppression performance via ad-hoc field trials

What is actually happening to our risers?
Key Conclusions

- VIV **DOES** occur in the field
- Measured damage is generally **less than predicted** – Risers are being operated safely
- VIV fatigue analysis tool SHEAR7 can be/is being calibrated using field data, however, only in an average sense
  - Large scatter in predictions requires use of a large FoS
- Complex fundamental physical phenomena have been observed that are not included in analysis models
- Revised VIV prediction tools/approaches are required to account for the physics involved as well as to reduce scatter
- Based on limited data, suppression devices that BP has employed appear to perform well
- Sufficient uncertainty in riser VIV response is identified to warrant continued monitoring
VIV Does Occur: Riser and BOP Stack Response
Gulf of Mexico BP Riser Monitoring

- 7 Drilling Risers
  - 4,100 – 6,800 ft WD
  - 10 – 20 accelerometers each

- Instrumentation – Accelerometers / Angular Rate Sensors

INTEGRI pod-M™
Analysis Tools Overpredict VIV Damage of Connected, Unsuppressed Drilling Risers

Typical design parameters – AVERAGE factor of 30 overprediction

Includes data from earlier monitoring campaigns WoS, Brazil, North Sea (OMAE Paper 2005)
Adjust Input Parameters to Reduce Conservatism

- Overprediction reduced from factor of 30 to 10
- Difficult to reduce further because of scatter
Another Layer of Conservatism: VIV Does Not Occur as Often as Predicted

- Higher VIV occurrence in the field is observed for higher fatigue damage estimates
- Analysis tools almost ALWAYS predict VIV

![Graph showing VIV occurrence vs. increasing average predicted damage rate]
Suppression Performance: *Full-wrap* fairings

**Fairings Data:**
- 7 buoyant joints (525’) equipped with fairings
- Shell Global Solutions, Inc. (SGSI) - full wrap design
- Chord/Diameter (C/D) Ratio: 1.5
- Length: 6 ft

**Monitoring Data:**
- 9 months of monitoring
- 1.6% VIV occurrence
- Max current below 0.5 knots except for period of 21st July to 27th July 07 when a max current speed of 2.1 knots observed
Riser DOES NOT vibrate in one instance of high current in faired zone

- From 21\textsuperscript{st} July to 27\textsuperscript{th} July 07 max current speed of 2.1 knots observed
- VIV did not occur with highly sheared 2 knot current loading on the fairings
Riser DOES vibrate when moderate currents are below faired region

Full-wrap Fairing Performance

- 4 days of measured currents with ~0.8 knot mid-depth current
- VIV events identified during this period
- Buoyant joint VIV excitation: Mode = 2-3, Frequency = 0.0475 – 0.0627 Hz
Assessment - Fairings

- Field measurements indicate that fairings suppress VIV
- The measured response of the risers with fairings showed no unstable behavior
- Operational personnel confirmed that the fairings improved operability
- Data are VERY limited and more are needed to confirm the effectiveness of fairings
Suppression Performance: Riser Fins

- Slick (Finned Joint)
- Lankhorst Fins
- Continuous Buoyancy
- Staggered Finned/Buoyant Joints
- Buoyant Joint
Percentage Occurrence of VIV: Riser with Fins

- VIV (above threshold) occurred only 2.02% of the time in 17 months
- For a similar period, VIV occurred 13.8% on a drilling riser w/o suppression
- 31.3% of finned riser VIV occurred when riser disconnected (fins retrieved)
Example: Fins Reduce Damage

Finned Riser Response: Connected

Expected power in region;
Critical velocity = 0.3 kts

Damage Rate = 2.2E-6 /yr

Finned Riser Response: Hung Off

Expected power in region;
Critical velocity = 1.7 kts

Damage Rate = 0.2 /yr
VIV response frequency comparison on *finned riser* data

SHEAR7 frequencies match measured VIV frequencies assuming finned joints have 100% suppression

**MEASURED vs SHEAR7 ZERO CROSSING FREQUENCY**

- **Overestimated**
- **Underestimated**

![Graph showing comparison of measured and SHEAR7 frequencies.]

- **Event 486**
- **Event 353**

Legend:
- **Equality**
- **Calibrated Reduced Lift Curve**
- **100% Suppression in Finned Joints**
Higher Harmonics Prolific in Model Tests

- Higher harmonics observed in recent model tests
  - NDP high mode
  - Deepstar Miami - Gulf Stream
- In the tests higher harmonic fatigue damage can exceed cross flow VIV by > factor of 10
- Currently not considered by any of the existing industry VIV tools
- BP field measurements used to confirm the risk of higher harmonic VIV in full scale risers

Example higher harmonic response

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crossflow (1X)</td>
<td>Inline (2X)</td>
</tr>
<tr>
<td>(3X)</td>
<td></td>
</tr>
</tbody>
</table>
Higher harmonic fatigue does occur in full-scale drilling risers

Resulting fatigue damage is minimal compared to cross flow VIV with exception of one occurrence during rig move

Differences between tests and full scale are not yet fully understood

Additional data would assist in understanding when higher harmonics are a risk
Time Sharing of Modes Prolific in Model Tests

Time sharing example from Deepstar Gulf Stream test

- Definition: Multiple VIV frequencies occurring non-concurrently under the same flow conditions
- SHEAR7 Version 4.5 has been developed based on the principle of time sharing
- Full scale drilling riser measurements used to confirm, or otherwise
Time Sharing of Modes is Rare in Field Observations

- Single mode, multi mode and time sharing VIV observed
- Single mode VIV occurs majority of time
- **Occurrence of time sharing is low**
- Time sharing typically observed during rig moves – varying effective current speed
Conclusions

- Drilling riser monitoring has confirmed safe operations
- VIV design tools are conservative, on average
  - Lot of scatter >> high factor of safety
- Phenomena identified that are not currently considered in VIV design
  - Similarities and differences from model-scale
  - Suppression devices
- At this time uncertainties (and limited data to resolve them) justify continued monitoring

Recommendations

- Continue monitoring as the most reliable means of assessing VIV fatigue and extracting fundamental physics at full scale
- Pursue smarter monitoring that provides operational assistance
  - 1 rig day saved >> annual cost of instrumentation
- Champion development of improved software tools that reflect observed physics
  - DATASETS AVAILABLE ON BENCHMARKING WEBSITE
  - INITIATIVES IN DEEPSTAR AND RPSEA JIPs
Back up slides
• BOP stack natural frequency excitation has been observed during relatively high-speed loop currents

• This can result in high accumulated fatigue damage at the fatigue critical conductor connector below the mudline

• Motion data collected from an accelerometer placed on the LMRP of the Ocean Confidence drilling riser is presented here
Just how bad is it?

- BOP stack vibration at 0.16Hz (6.25 sec stack natural period), and 2\textsuperscript{nd} and 3\textsuperscript{rd} harmonic
- Total fatigue consumption at the first connector is 40% in 12 days
Conclusions

- Loop currents can cause BOP stack excitation which poses serious threat to conductor integrity
- Resulting fatigue damage consumption can be high (40% in 12 days in the example here)
- This may result in insufficient fatigue margins for future well intervention or work-over activities
- Conditions that lead to large BOP motions are poorly understood
- Many unknown factors about what's going on below mudline (soil properties, quality of cement job)
- It is recommended that:
  - contributing factors to BOP VIV receive further study
  - fatigue critical connectors be placed well below the mudline to improve fatigue capacity
<table>
<thead>
<tr>
<th>Field/MODU</th>
<th>Water depth</th>
<th>Monitoring system</th>
<th>Period of monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6000 ft</td>
<td>13 INTEGRIpod-SM data loggers</td>
<td>May 04 – Present</td>
</tr>
<tr>
<td>2</td>
<td>6800 ft</td>
<td>1 INTEGRIpod-SM data logger</td>
<td>Nov 04 – Apr 05</td>
</tr>
<tr>
<td>3</td>
<td>6800 ft</td>
<td>20 INTEGRIpod-SM data loggers</td>
<td>Nov 05 – Present</td>
</tr>
<tr>
<td>4</td>
<td>4100 ft</td>
<td>10 INTEGRIpod-SM data loggers</td>
<td>Apr 06 – Present</td>
</tr>
<tr>
<td>5</td>
<td>4600 ft</td>
<td>10 INTEGRIpod-SM data loggers</td>
<td>May 06 – Feb 07</td>
</tr>
<tr>
<td>6</td>
<td>6000 ft</td>
<td>14 INTEGRIpod-SM data loggers 3 real-time strain sensors</td>
<td>Jan 07 – Present</td>
</tr>
<tr>
<td>7</td>
<td>4500 ft</td>
<td>12 INTEGRIpod-SM data loggers</td>
<td>Jan 07 – Present</td>
</tr>
</tbody>
</table>
Instrumentation for VIV

- Motion
  - INTEGRI pod-M™

- Strain
  - INTEGRI stick™
VIV software calibration
DD2 riser response whilst connected

- Measured frequency = 0.025 Hz
- This indicates likely excitation in continuous buoyancy section
- Staggered finned and buoyant arrangement are not powered-in in spite of being subjected to high currents

Damage Rate = 2.2E-6 /yr

Expected power in region; Critical velocity = 0.3 kts
Hang Off Riser VIV

- Measured frequency = 0.13 Hz; Excitation in continuous buoyancy
- High currents in continuous buoyancy yields orders of magnitude higher fatigue damage than high currents in staggered buoyant and finned joints

Damage Rate = 0.2 /yr
Key findings and software limitations
VIV occurrence in the field

- VIV occurs 17% of the time for our monitored drilling risers
- VIV design tool identifies VIV majority of the time
Field data for determining higher harmonics

<table>
<thead>
<tr>
<th>Field</th>
<th>Location</th>
<th>Rig</th>
<th>Water Depth (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schiehallion</td>
<td>West Of Shetland</td>
<td>Paul B. Lloyd</td>
<td>1,181</td>
</tr>
<tr>
<td>Svinoy</td>
<td>Faroes</td>
<td>West Navion</td>
<td>3,510</td>
</tr>
<tr>
<td>Assynt</td>
<td>Faroes</td>
<td>West Navion</td>
<td>3,166</td>
</tr>
<tr>
<td>Reki</td>
<td>Amazon Basin</td>
<td>C.R. Luigs</td>
<td>3,172</td>
</tr>
<tr>
<td>Thunder Horse</td>
<td>Gulf of Mexico</td>
<td>DEN</td>
<td>6,200</td>
</tr>
</tbody>
</table>

Drill pipe test

- Keel 6000 ft
- Drill floor 6133 ft
- Vessel mounted motion logger
- 5 motion loggers
- 1080 ft
- 6040 ft
Conclusions

- *DD2* riser typically demonstrates mild VIV response compared to *Enterprise* which is in a similar water depth and current conditions and does not have any suppression.

- The difference between *DD2* and *Enterprise* is the presence of finned slick joints and staggered finned and buoyant joints.

- Maximum VIV damage on *DD2* is accumulated when it is partially deployed and the continuous buoyancy section is exposed to high surface currents.
**Tail-fin drilling riser fairings**

Fairings Data:
- 14 buoyant joints (1050’) equipped with fairings
- SGSI - two strap “Tailfin” fairings
- Chord/Diameter (C/D) Ratio: 1.45
- Length: 6 ft

Monitoring Data:
- 2 months of monitoring
- 4.1% VIV occurrence
- Max current speed: 0.95 knots
Case study – Does time sharing occur for a riser undergoing VIV?

Sustained currents > 2 knots and VIV observed 42% of time
Case study – Does time sharing occur?

Fatigue damage rates are 10 to 100 times higher during hang-off