VIV Application to Deepwater Risers

Steve Leverette
Atlantia Offshore Limited
December 2-3, 2003

Agenda

- Introduction
- Environment
- Riser Response to Currents
- Fatigue
- Tendons
- The FIX
- Analysis Methods and Programs
- Model Tests and Data Sets
- Other Issues
- Areas of R&D
- Industry Experience
- Conclusion

Thanks to:

- Thanos Moros, BP
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- Kim Vandiver, MIT
- Guy Mansour, Atlantia
- T. Sarpkaya, Naval Postgraduate School
- Don Allen/Li Lee, Shell Global Solutions
- Rodney Masters, AIMS

Introduction

Risers and tendons

- –Steel Catenary Riser: SCR
- –Top Tensioned Riser: TTR
- –Flexible Riser
- –Free Standing Riser: FSR
- –Highly Compliant Riser: HCR
- –Tendons

Perspective from the industry:

The offshore industry has been made painfully aware of what may go wrong, how VIV may affect operations.

The industry is having to be conservative because of uncertainties in environment and in engineering prediction tools.

For water depths to 5000’, we can proceed with reasonable solutions. For 10,000’, we cannot afford high levels of conservatism and still afford to make money producing oil.

VIV is a resonant feedback phenomena

Engineering in uncertainty:

Risks not generally in getting design numbers wrong,

but in not designing for new phenomena.

Risks and Cost Impacts

- Risers and Tendons represent critical structural and oil containment systems
- Uncertain environment – “new” phenomena being discovered
- Uncertain response – highly non-linear, stochastic in nature
- Failure has high cost

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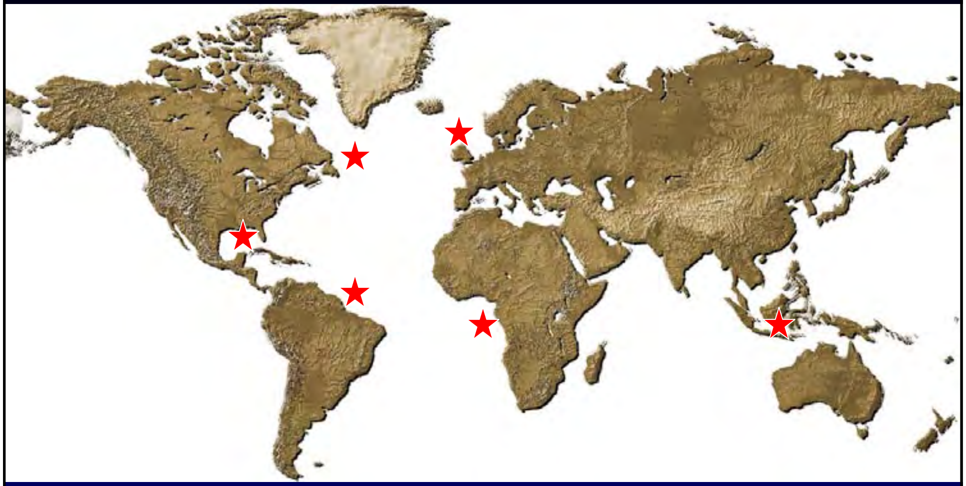
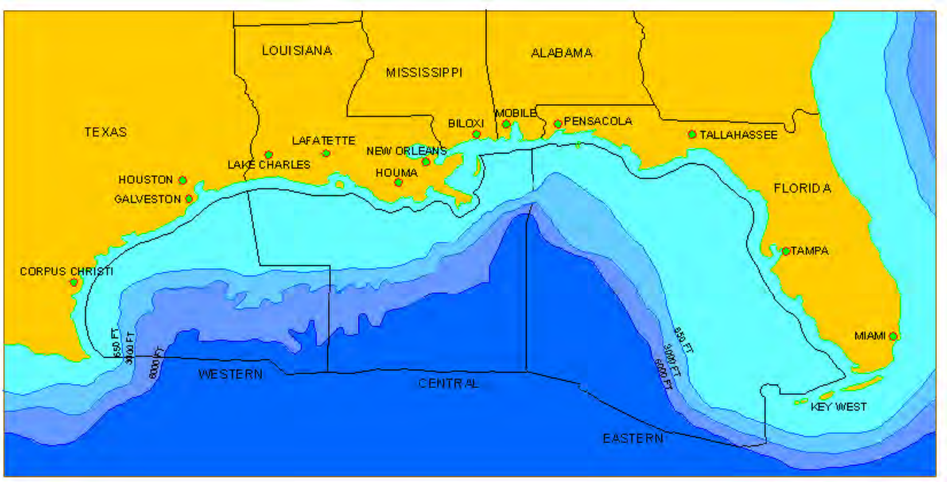
Environment

- Geography
- Mode experiment
- Types of Ocean Currents
- Typical and extreme magnitudes
- Durations
- Uncertainties, unknowns
- Combination with other events
  - Ratio of environmental forces, shallow to deep

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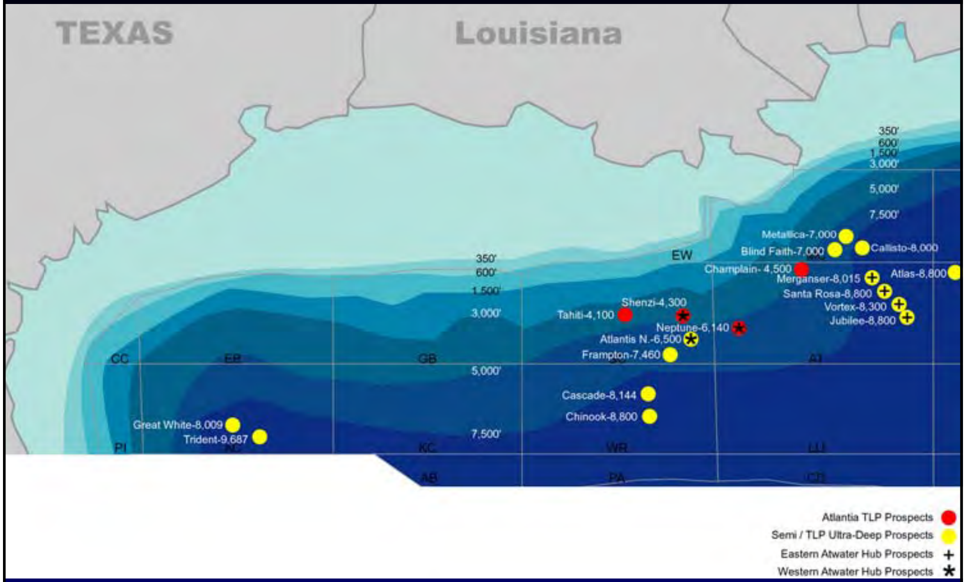
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Metallica-7,000
Blind Faith-7,000
Callisto-8,000
EW
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Merganser-8,015
Atlas-8,800
Santa Rosa-8,800
Vortex-8,300
Jubilee-8,800
Shenzi-4,300
Tahiti-4,100
Neptune-6,140
Atlantis N.-6,500
Frampton-7,460
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Cascade-8,144
Chinook-8,800
Great White-8,009
Trident-9,687
7,500'
PI
KC
WR
LU
AB
PA
CD
Atlantia TLP Prospects ●
Semi / TLP Ultra-Deep Prospects ●
Eastern Atwater Hub Prospects +
Western Atwater Hub Prospects ★

MODE Experiment

- WHOI - 1970’s
- Weather in the Oceans
- Fronts, temporal variation
- Large scale turbulence
- Vertical Structure

Ocean Currents

- Tidal Currents (how they exist in deep water)
- Loop
- Eddy
- Storm (wind stress model)
- Inertial
- Slope
- Bottom Boundary Current (Sigsby Escarpment)

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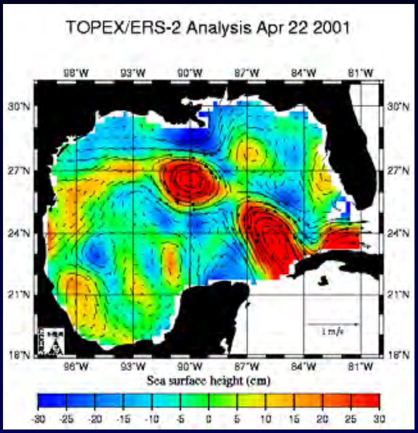
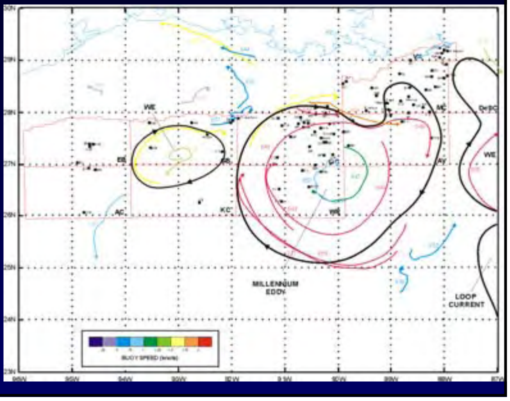
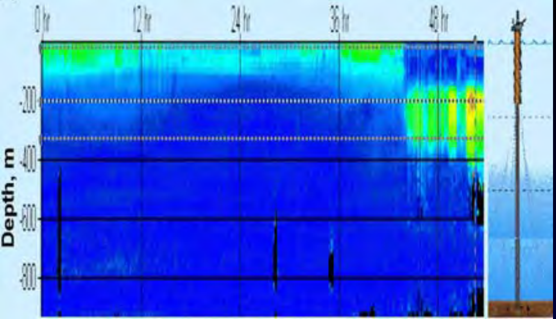
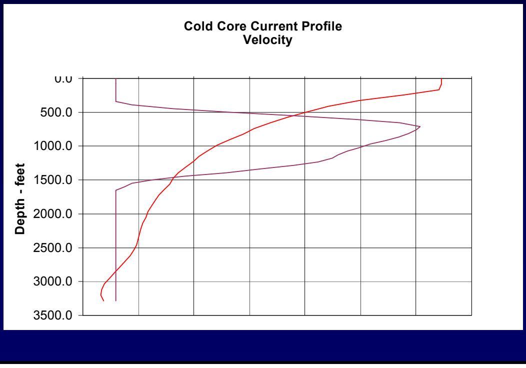
Ocean Currents
loop current / eddy current





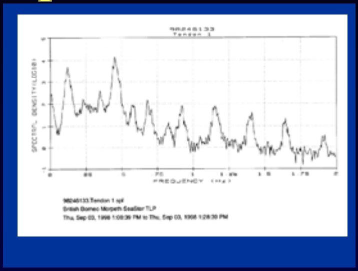


Ocean Currents
Cold Core Eddy



Inertial and Slope currents

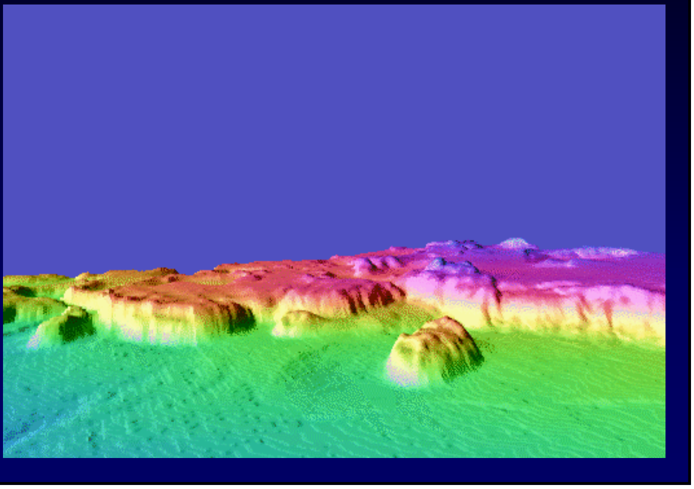
- Morpeth
  - Hurricane Earl

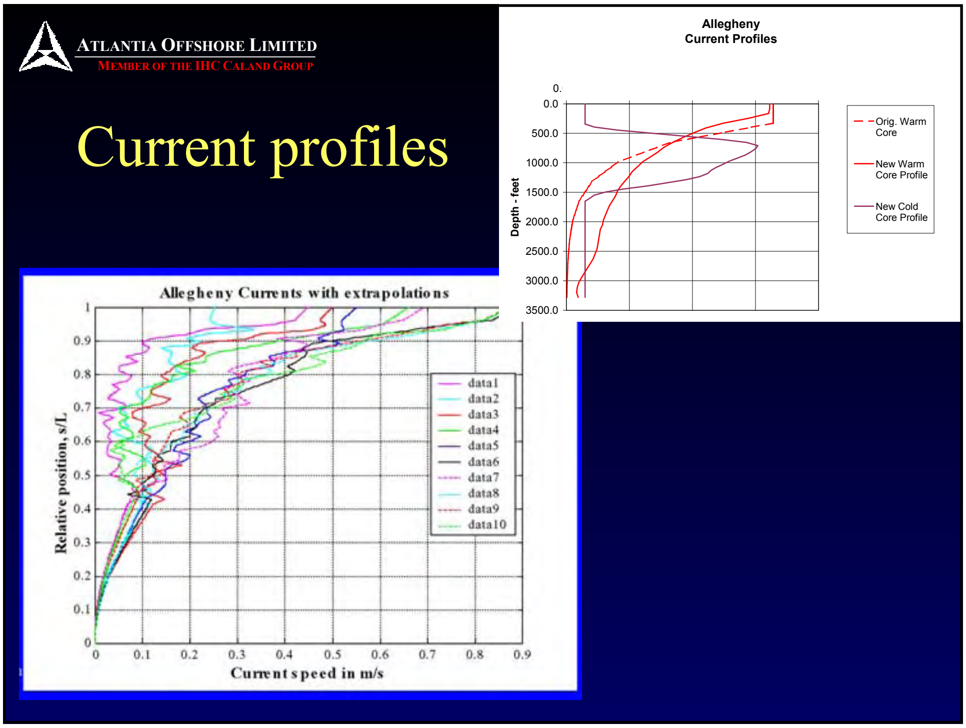


- Neptune
  - Hurricane Georges
  - 1.8 – 2.2 kts in 2000’

Sigsbee Escarpment

Currents identified from bottom furrows





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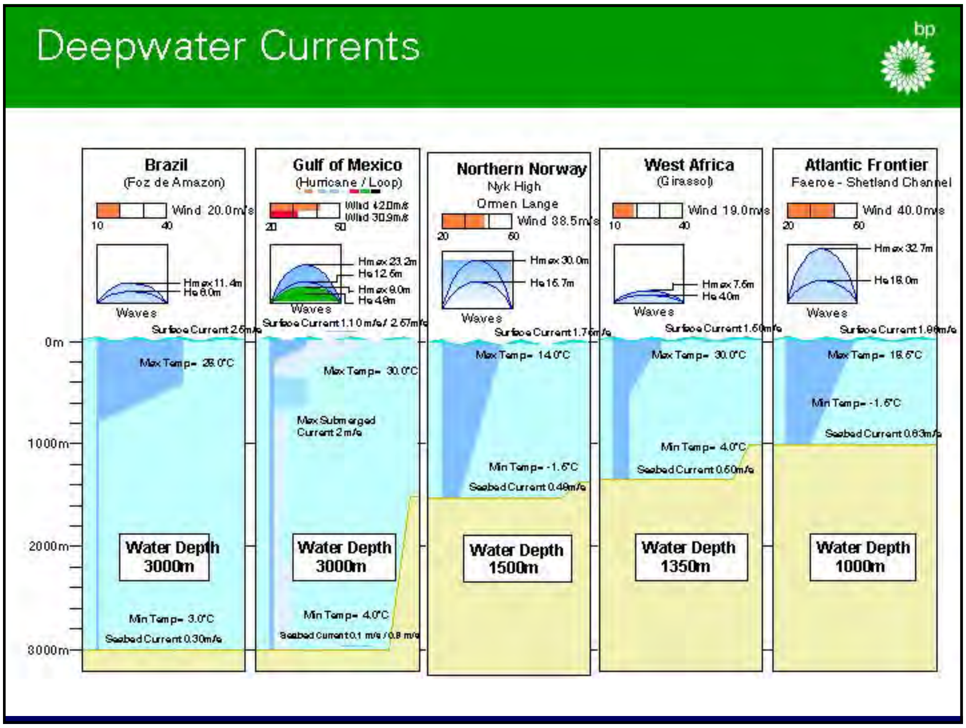
Current profiles



Deepwater Currents

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Environment

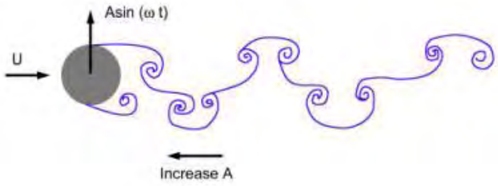
Insert DW Currents presentation

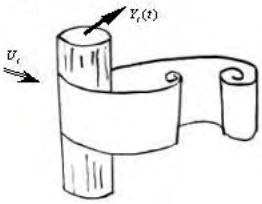
VIV Principles

- When flow passes a structure separates, forming a vortex street.
- The vortices have an alternating shedding pattern and interact with the structure, causing the so called "Vortex Induced Vibrations".
- Inline vibrations generally generated by symmetric vortex shedding, (but twice the fs)are also important.
- Two main parameters define the behaviour of vortices.

$$\mathrm{Re} = UD/\nu \qquad f_s = StU/D \qquad f_i/f_s$$

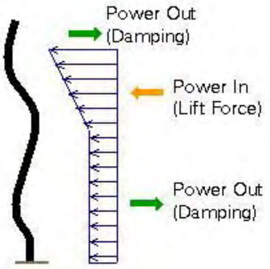
- The frequency of vortices depends on the spacing.
- Structure can vibrate with amplitudes in excess of 1D.
- When the fvi = fs lock in occurs.

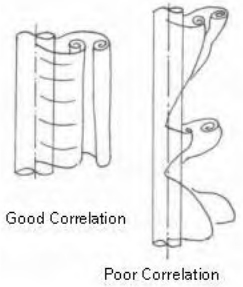


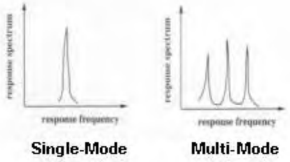


VIV Principles

- In a 3D structure with non uniform currents, the vortex sheet is not uniform along the length of the riser. The vortices along the length are not fully correlated, making the problem more complex to analyse.
- In a shear current the strong velocities near the top will excite the structure, while lower speeds will offer damping.
- Long Structures in a non uniform current tend in general to respond to multi-modes







VIV Principles

- The resultant vibrating amplitude is a function of both lift & damping

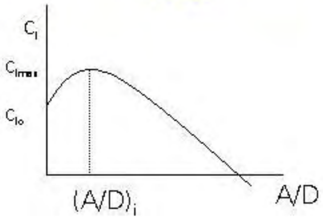
$$A/D = f\left(\frac{LiftForce}{Damping}\right)$$

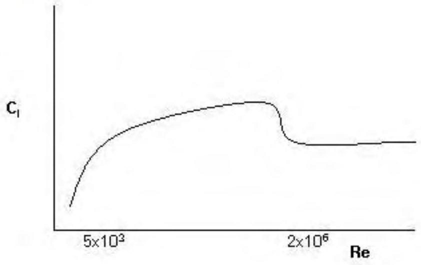
Hydro + Structural

\>>

- Lift Depends on vibrating Amplitude and Re, f_i/f_s.

Typical Lift Curve used in many VIV codes

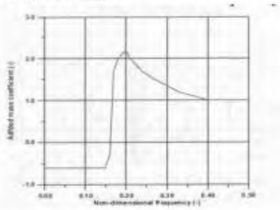




VIV Principles

- Damping = O($C_D(i)$ $y'(i,r)$ + $f(\omega_r, m_t, \zeta_s)$)
- Hydrodynamic local C_D is function of Re.
- m_t includes the structural and added mass.
  - Added Mass is a function of local St, $fn = f_{osc} D / U$

Added Mass Curve.



- ζ_s for most of typical pipes is ~0.003. – For non standard pipes, damping experiments are required.
- Drag amplification of oscillating structure is higher than stationary.

$$C_D(i)/C_{D0} = 1 + 1.043\left(2\frac{y_{rms}(i)}{D}\right)^{0.65}$$

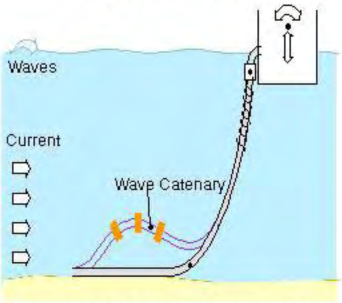
VIV Principles

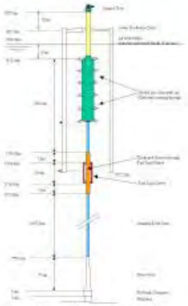
- Other parameters that affect VIV are
  - Roughness of the structure, tends to change the Re Regime, then Cl, Cd & St.
  - Turbulence in the flow. – Similar effects to roughness.
- Little data exist on the behaviour of the above parameters.
- Whatever exists is proprietary to some oil majors.

VIV - Why Important to Risers

Compliant Risers

Top Tension & Free Standing





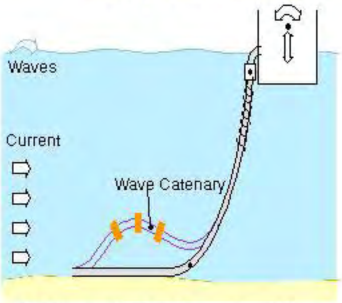
Needs to be understood and catered for in design and operations to avoid failures like

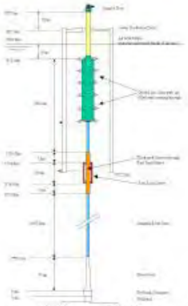
- Over-stressing Joints
- Fatigue of critical components
- Riser Interference.

VIV - Why Important to Risers

Compliant Risers

Top Tension & Free Standing





VIV contributes significantly to the fatigue life of the riser.

- For Compliant:
  - Top Articulation
  - TDP
- For TT & Free Standing
  - Keel Joint
  - Well head connection
  - Below buoyancy Tank
  - Seabed Connection

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Riser Response to Currents

Types of Risers:

- TTR - top tensioned riser
- SCR - steel catenary riser
- Flexible riser
- HCR - highly compliant
- FSR - free standing riser

Riser Response to Currents

- Typical dimensions
  - 4” flowline SCR
  - 4” flowline SCR with 9” buoyancy
  - 21” drilling riser
  - 48” drilling riser with buoyancy
  - 18” export SCR
  - 120” aircans
  - 8” tieback risers

Effects of End Conditions

- Taper Joint
- Flexjoint
- Keel joint
- Tensioner/Gimbal
- Guide frames
- Cantilever wellhead

Drilling Roller frame

FEB 6 2003

Grand Valley Machine

FMC TSJ #5 Complete thru turning of tapered section

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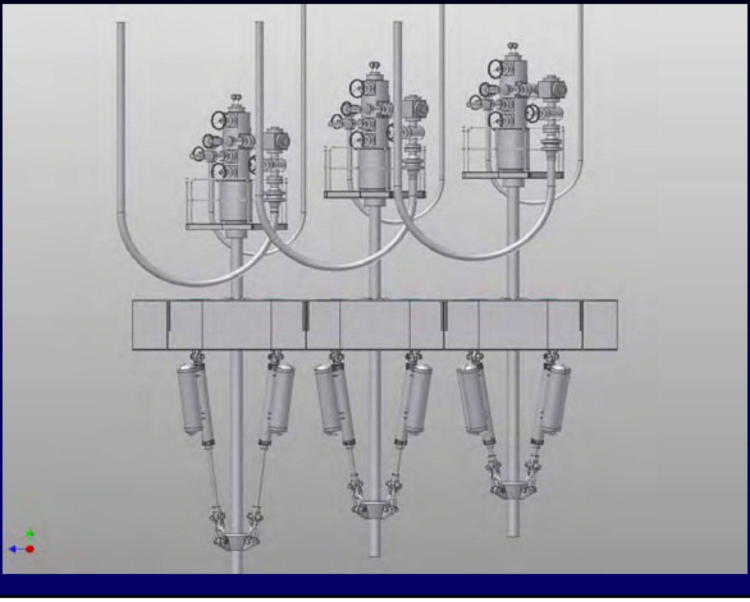
PRT at Full Extend, Null, Full Retract



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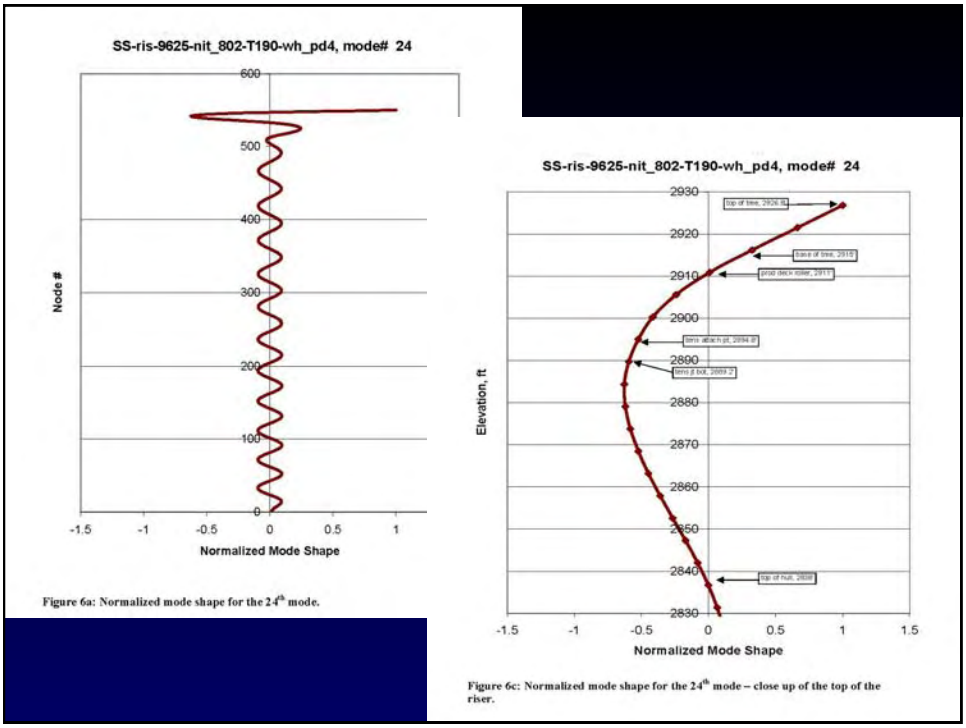


Figure 6a: Normalized mode shape for the 24th mode.

Figure 6c: Normalized mode shape for the 24th mode – close up of the top of the riser.

Riser Response to Currents

- Buoyancy, cladding, strakes, etc
- Touchdown point

KingKong riser with Buoyancy

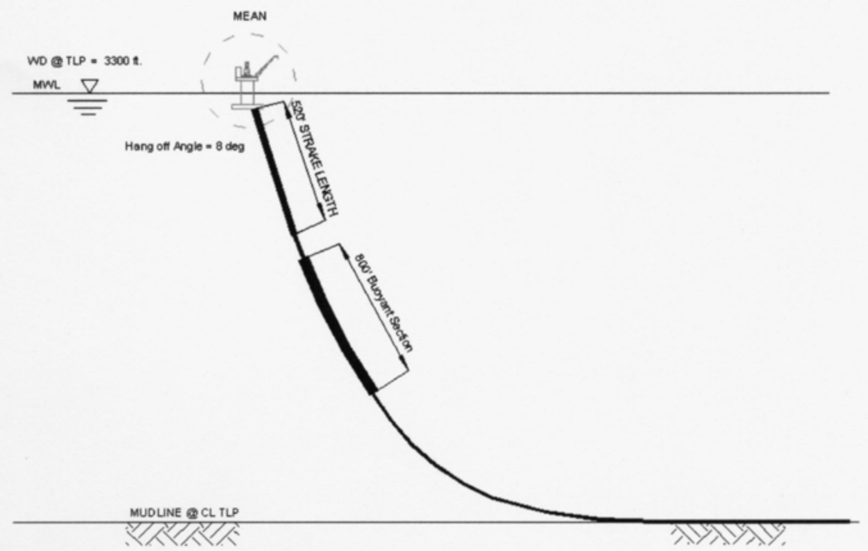


Figure 6.2 Schematic View 6" SCR

Riser Response to Currents

Static response

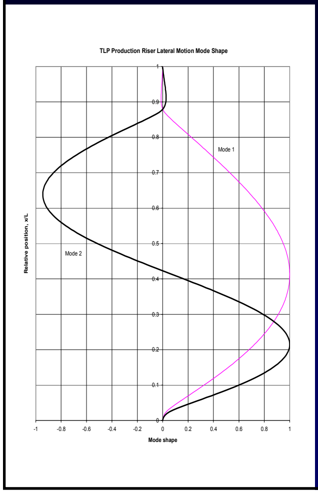
- Vessel Offset
- Increased drag due to VIV
- Interference analysis
- Touchdown trench effects

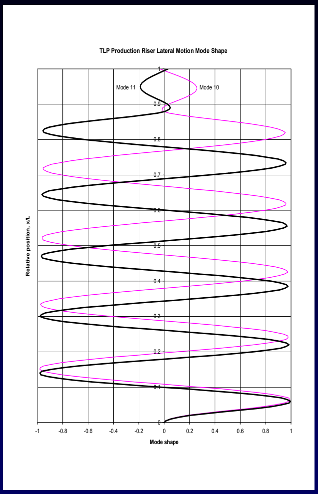
Riser Response to Currents

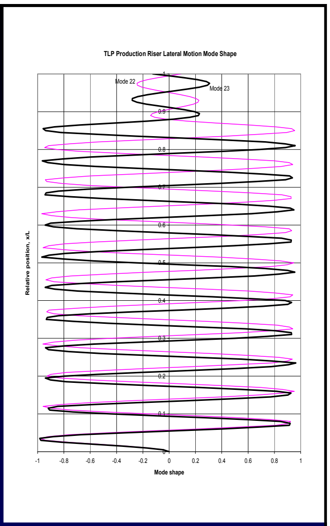
Dynamic response

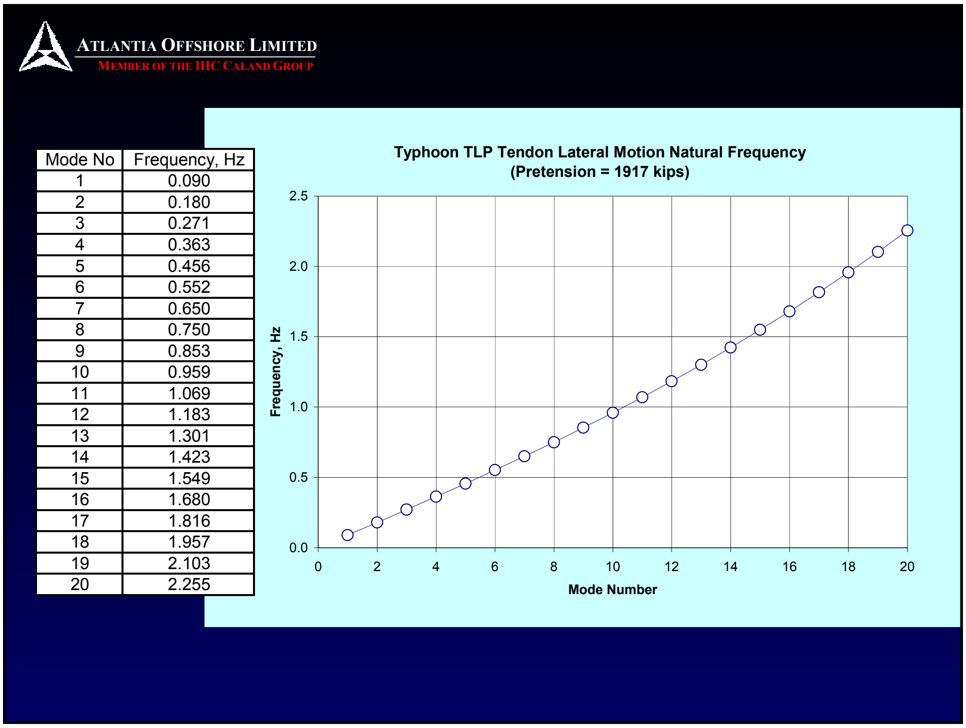
- Modal analysis (string, beam models)
- Bending vs axial modes
- Finite versus infinite transmission models

TLP production Riser Modes 1-2,11-12,22-23









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Mode No	Frequency, Hz
1	0.090
2	0.180
3	0.271
4	0.363
5	0.456
6	0.552
7	0.650
8	0.750
9	0.853
10	0.959
11	1.069
12	1.183
13	1.301
14	1.423
15	1.549
16	1.680
17	1.816
18	1.957
19	2.103
20	2.255

Typhoon TLP Tendon Lateral Motion Natural Frequency
(Pretension = 1917 kips)

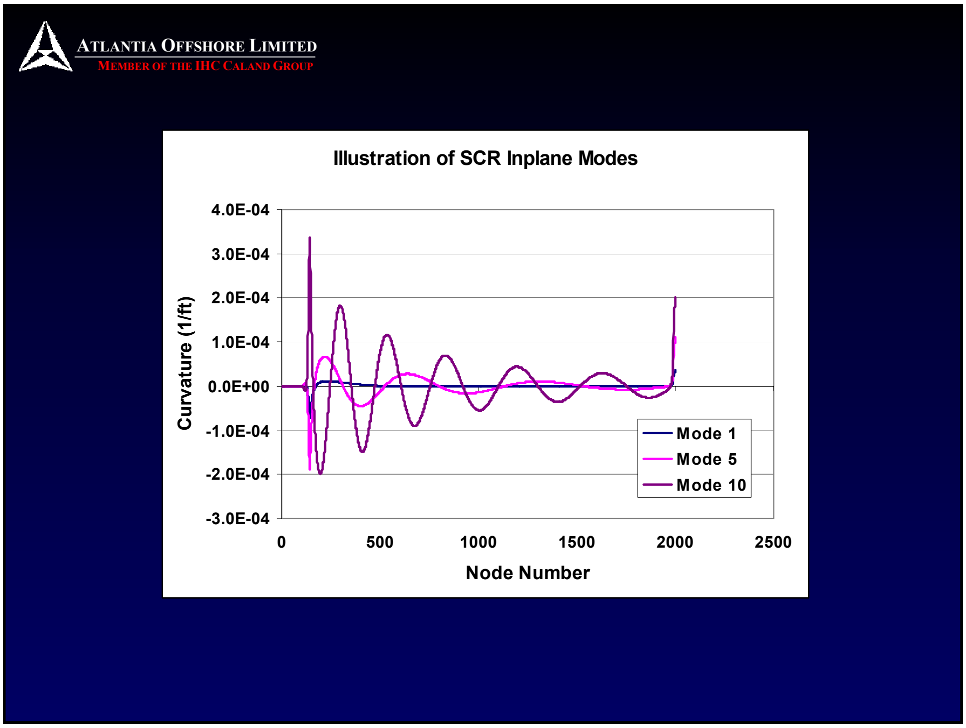

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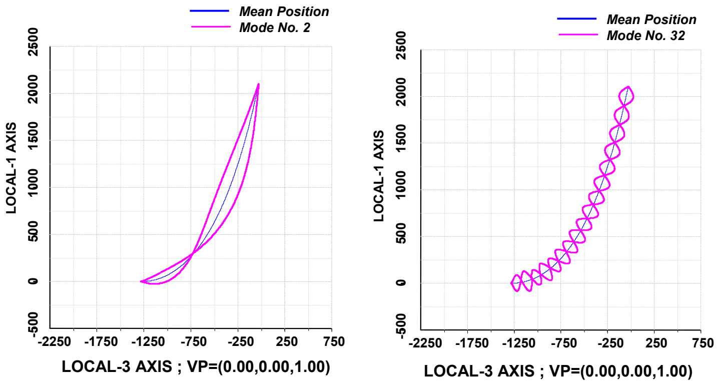
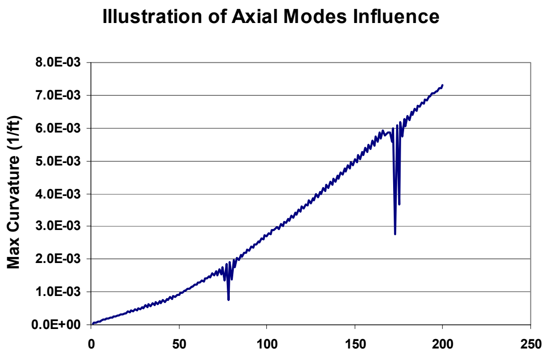
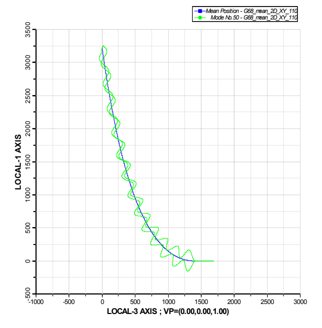
Illustration of SCR Inplane Modes

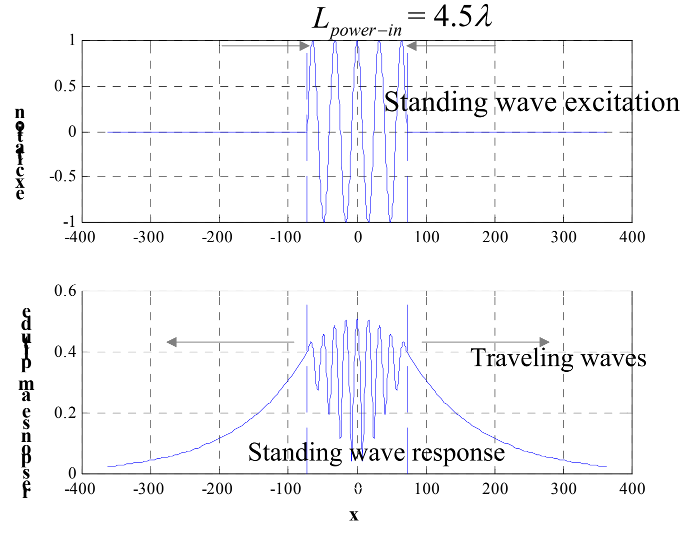


Examples of SCR Mode Shapes





Steady Flow Response for an Infinite Beam with Finite Length Excitation



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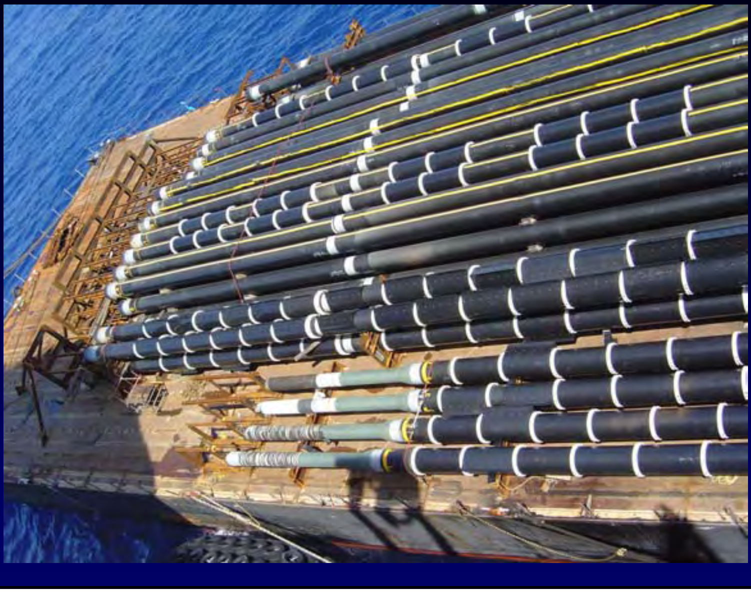
Matterhorn Production Risers


A2 10 3/4 Riser Boldened Fairing Joints

Matterhorn production riser from main deck



Jolliet Single Piece Tendon

Steel tendons 24” in diameter.

**Provided by
Steve Leverette
Atlantia Offshore Limited**

Riser Response to Currents

- VIV response characterization
  - Strouhal number, Reduced velocity
  - Cl (AOD, Re, Vr)
  - Pre-lockin, Lock-in, lock-out
  - Power in, versus damping and radiation
  - Effects of damping on response
  - Power balance solution

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VIV Characteristics

$St = \frac{f_{st} D}{U}$ Strouhal Number

$V_r = \frac{U}{f_{st} D}$ Reduced Velocity

$St=0.2$, $V_r=5$

Historical Shear7, C_{lift} Formulation

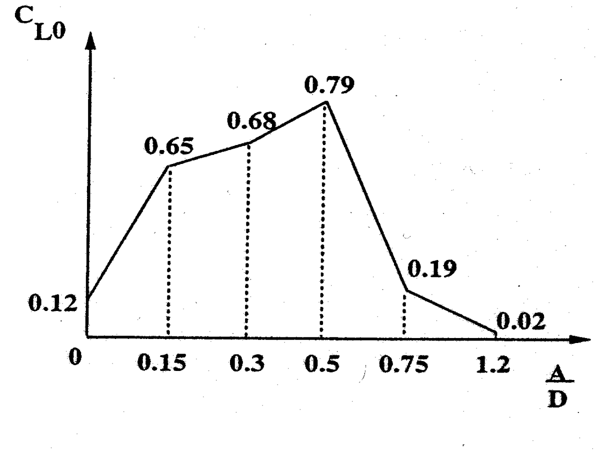
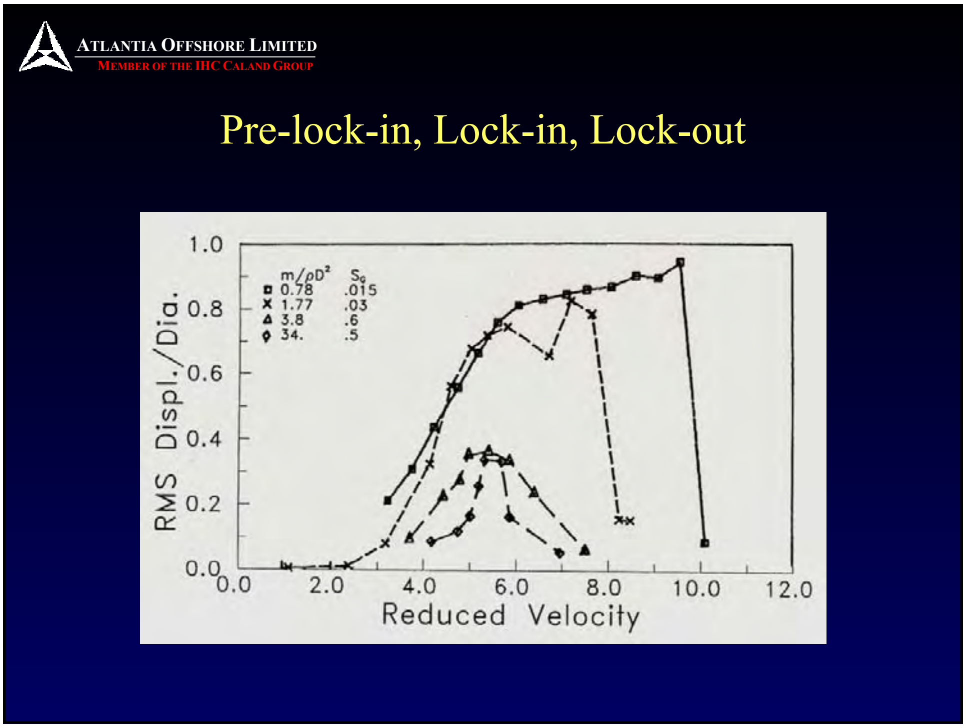
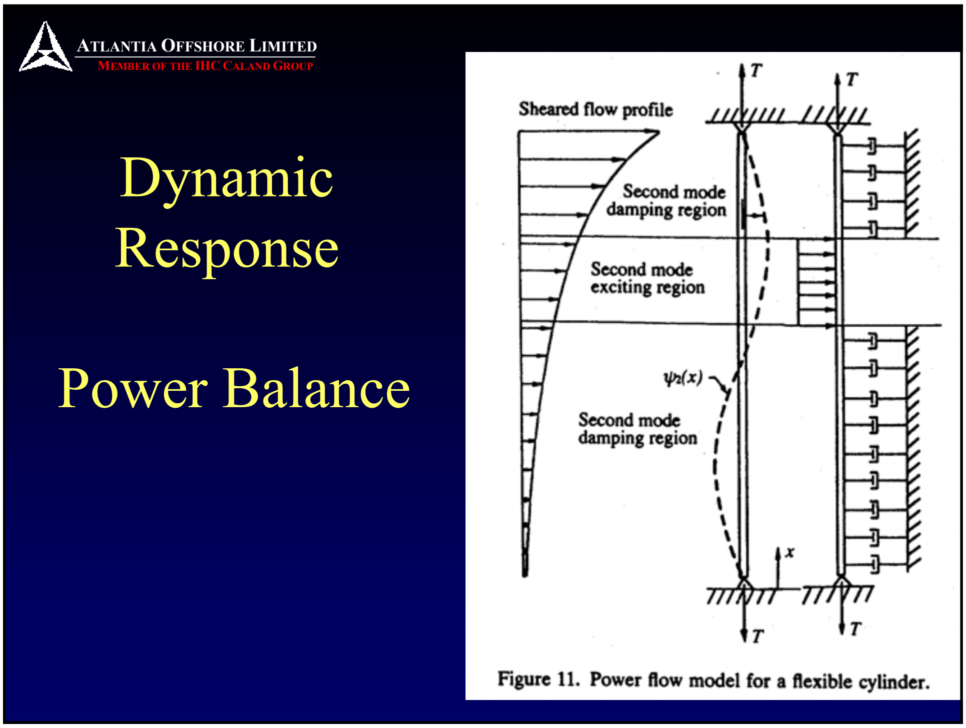


Figure 8: The lift coefficient as a function of $\frac{A}{D}$



Pre-lock-in, Lock-in, Lock-out



Dynamic Response

Power Balance

Figure 11. Power flow model for a flexible cylinder.

Power Balance

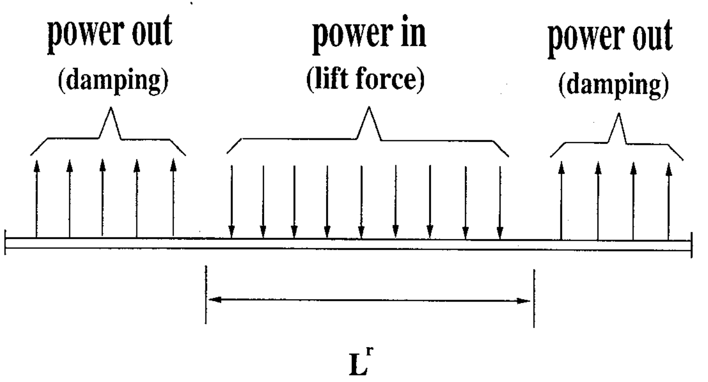


Figure 7: Modal power balance

Riser Response to Currents

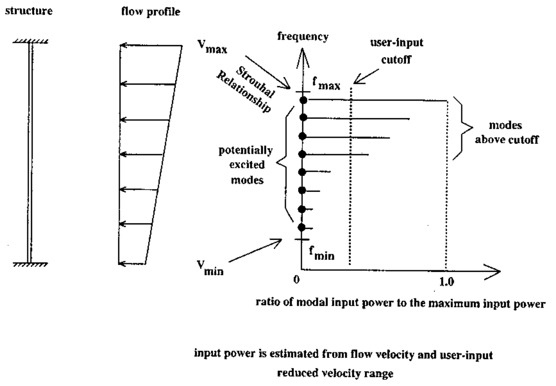


Figure 5: The identification of important modes

Riser Response to Currents

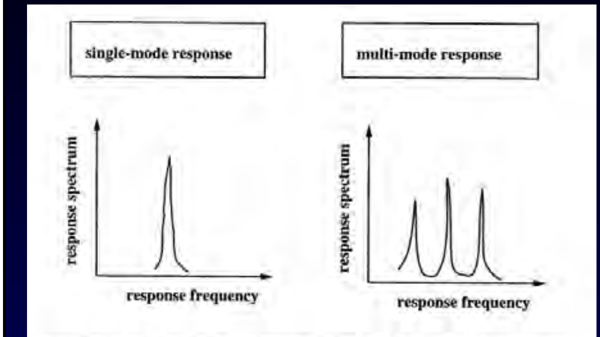


Figure 2: Vortex-induced vibration response behavior of a cylinder in a sheared flow

Single-mode vs
Multi-mode

In-line vs
transverse

Riser Response to Currents

- Bending and increased drag effects
- Spectral approach to response
- Uncertainties in response
- Typical hot spots
- Types of currents that are problematic
- Effect of increased tension (decrease mode, reduce bending)

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Fatigue caused by VIV

Fatigue

$$D = \sum_{i=1}^{k} \frac{n_i}{N_i}$$

Miner’s rule

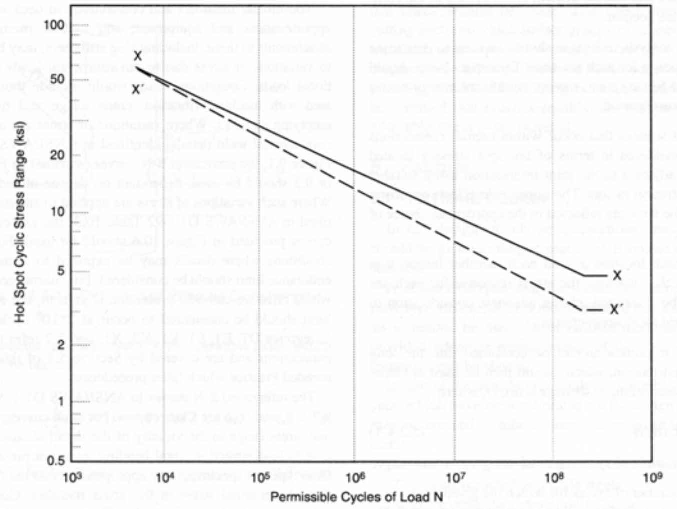
$\log N = \log a - m \log \Delta\sigma$

$\log N = \log a - m \log [\Delta\sigma (t/t_{ref})^k]$

API, AWS

DOE, DnV

Fatigue



Note: These curves may be represented mathematically as

$$N = 2 \times 10^6 \left(\frac{\Delta_\sigma}{\Delta_{\sigma ref}}\right)^{-m}$$

where N is the permissible number of cycles for applied cyclic stress range Δ_σ, with $\Delta_{\sigma ref}$ and m as listed below.

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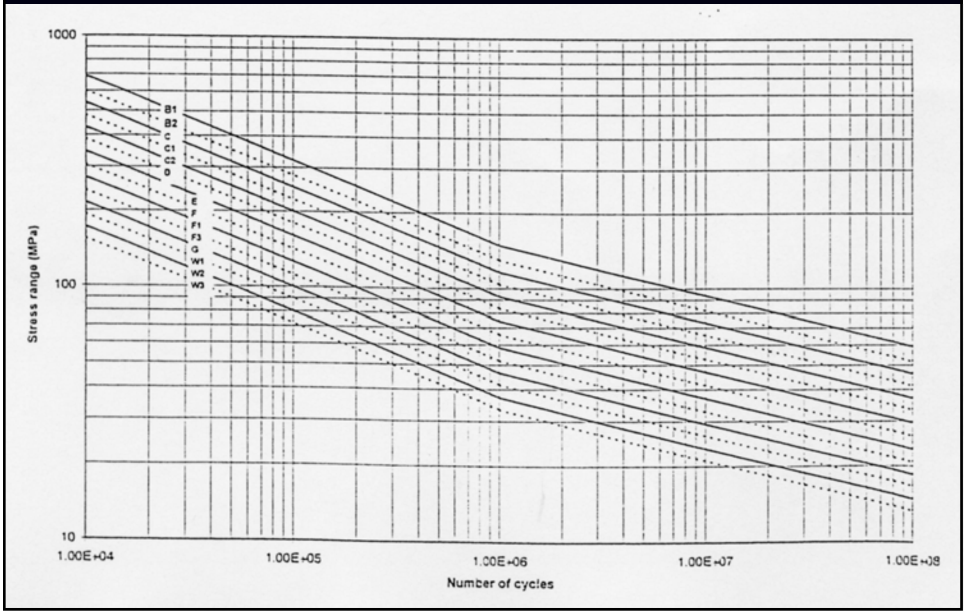
Fatigue



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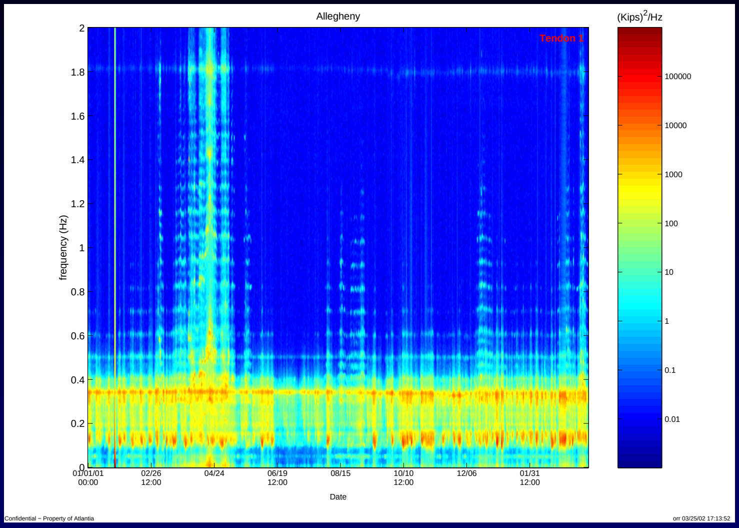
One Year of Tension Spectra



Safety Factors

- Depends on application

- Typically 3 for structures
- Typically 10-20 for risers

Fatigue

- Fracture Mechanics

- Frequency Sensitivity: mode, curvature, no. cycles
- Ways to combine response modes
  - Rainflow
  - Spectral approach to fatigue (Wirsching, Dirlik)
- Sensitivity to assumptions

Agenda

- Introduction
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- **Tendons**
- The FIX
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- Industry Experience
- Conclusion

Tendons in VIV

- OTC Paper
  - Leverette, Rijken, Thompson, Dooley

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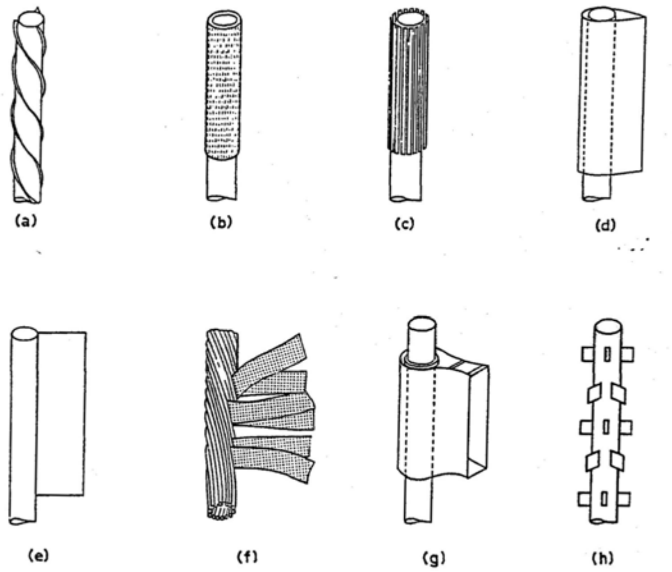
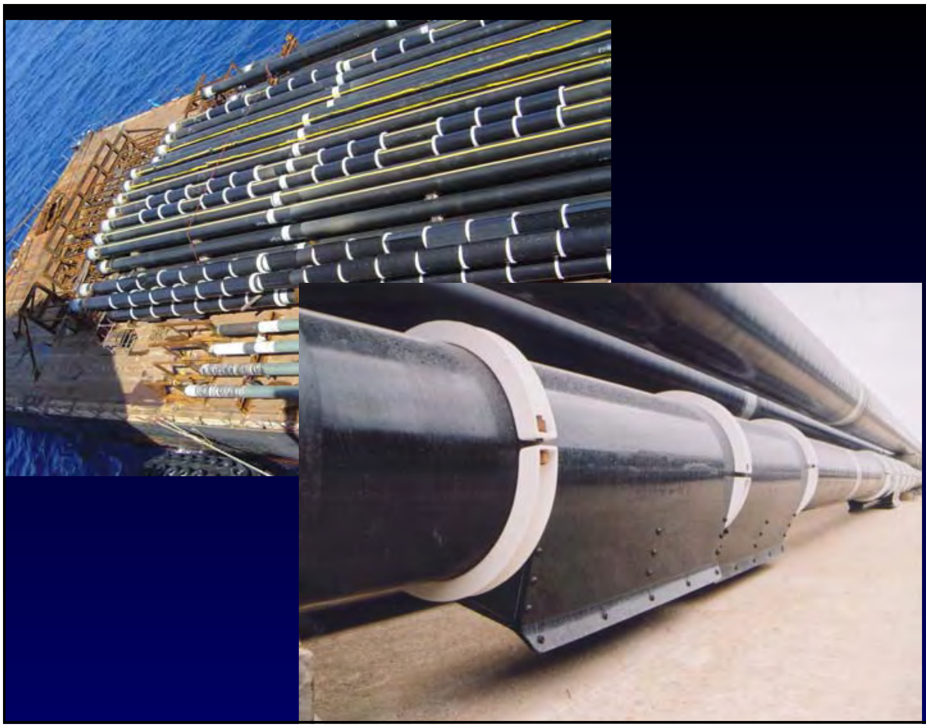
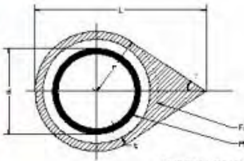


Fig. 3-23 Add-on devices for suppression of vortex-induced vibration of cylinders: (a)

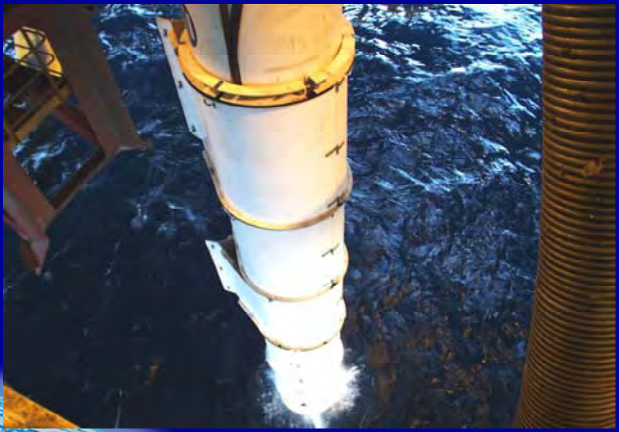


VIV Suppression (cont)

Shell Global Solution Fairing Design



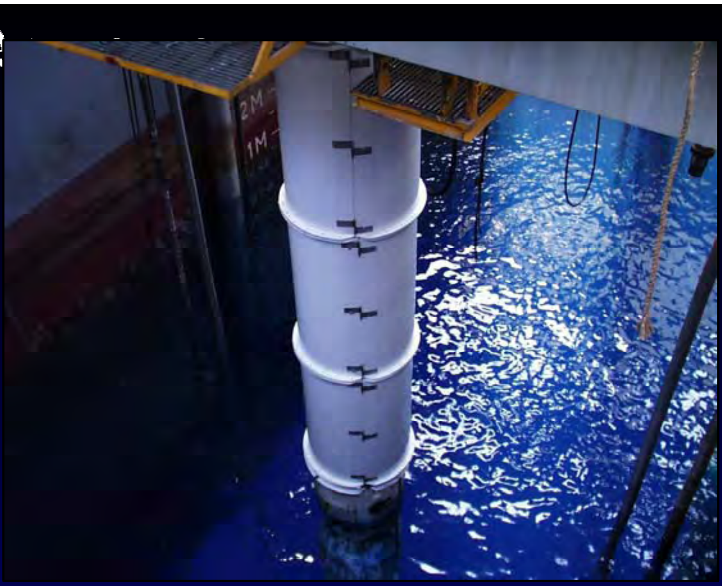
Schematic Cross-Section of Fairing



Shell Global Solutions

Fairings for drilling riser

Fairings for TLP tendon



Fairings in moonpool

Half strakes for pipelines

VIV Suppression (cont)

bp

CRP Marine
Shell based with straps,

Al Brown
Continuous strakes bonded.

In terms of performance both strake exhibit similar suppression behaviour.

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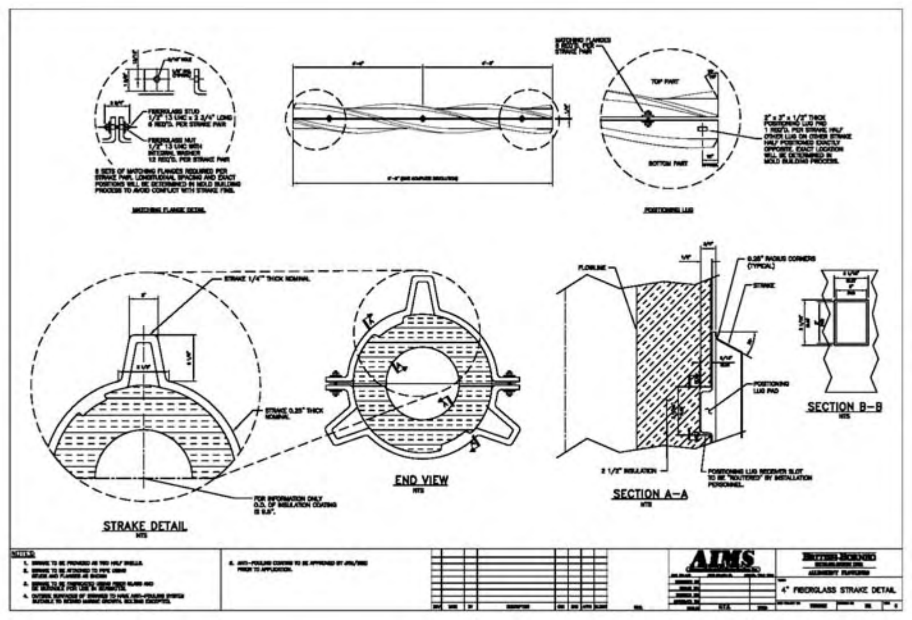

VIV Suppression (cont)

bp

- Typical fairings and strakes both offer very good suppression in terms of A/D in the 90s%
- Fairings have lower drag and tend to be more efficient in a downstream riser for riser in arrays.
- For risers in arrays, the strake efficiency of the downstream riser is lower than that in a free stream.
  - Experiments at MIT have indicated downstream riser efficiency of the order of 50% less to the upstream.
- Strakes non susceptible to marine growth need to be selected for near surface applications.
  - Marine growth significantly affects the strake performance and subsequence the riser fatigue life.
  - A 30% reduction in efficiency could result in 70% reduction in fatigue life.

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Tools for Predicting VIV

- There are a number of models in the industry that can be used to analyse risers against VIV behaviour.
- The models can be classified in two main categories:
  - Semi-empirical
    - Shear7
    - VIVA
    - VIVANA
    - IFP model
    - Model from University of Milan
    - The Technip time domain model

The majority of these tools are based on an energy balance, (power in = power-out) and rely on semi-empirical formulations for lift, drag and damping coefficients.

Codes are either frequency or time domain.

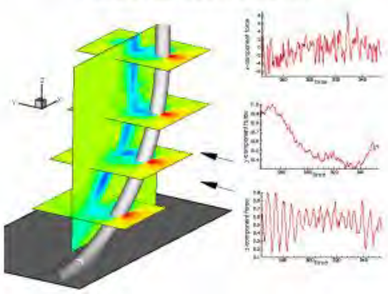
Tools for Predicting VIV (cont)

– CFD Models

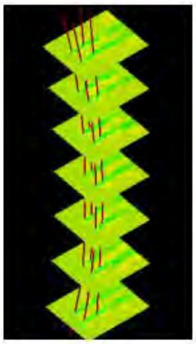
Based on the fundamentals of fluid mechanics, but not fully advanced yet and take considerable computing time to run. Tend to use a semi-empirical model for the structural coupling.
e.g: Imperial College Model, UT, DHI

CFD application in SCR, IC

Flexible riser pipe in cross-flow



CFD application in TT risers, NH



Tools for Predicting VIV (cont)

- CFD codes are still slow for use in a project environment, when large number of calculations (number of current profiles can exceed 60) are required.
- CFD today tends to be used on detail studies, i.e understand SPAR TT VIV behavior.
- Industry tends to use more the semi-empirical models for design.
  - Response is very sensitive to the parameters used, i.e Cl, St, Single/Multimode, damping,...
  - The most widely used code is Shear7 although VIVA and VIVANA have been recently used in a number of designs.
  - Most of these codes were "tuned" for cylindrical structures. - New designs do not always fit to this approximation.
  - There have been a number of lab and field initiatives to collect data for different riser types, and calibrate the codes.

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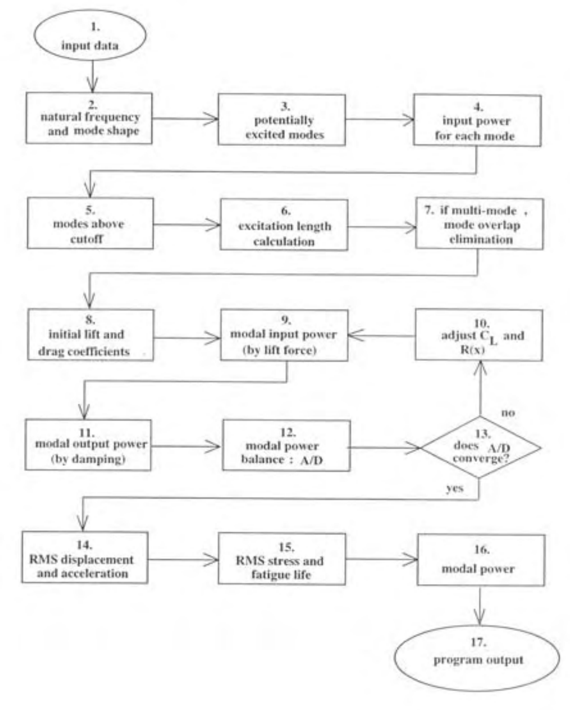
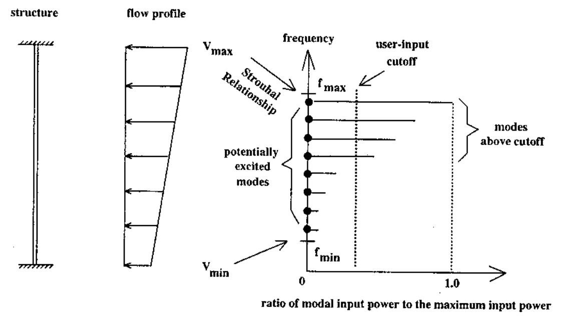
Analysis Methods and Programs

- Engineering tools, not simulators
- Summary of how they work
- Comparisons
- Why they vary so much
- CFD
- Wake models and other approaches

Flow diagram of Shear 7 Analysis



Riser Response to Currents



input power is estimated from flow velocity and user-input reduced velocity range

Figure 5: The identification of important modes

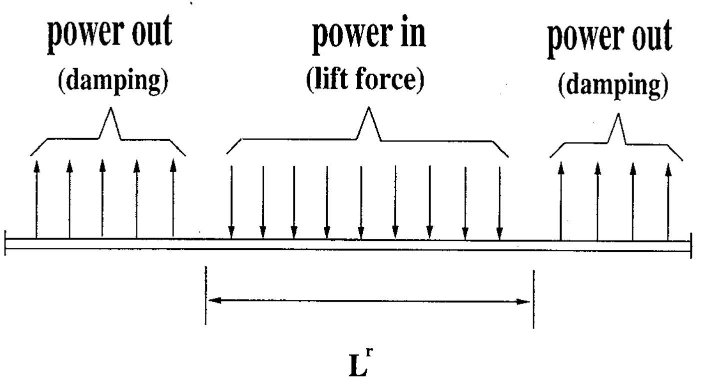


Figure 7: Modal power balance

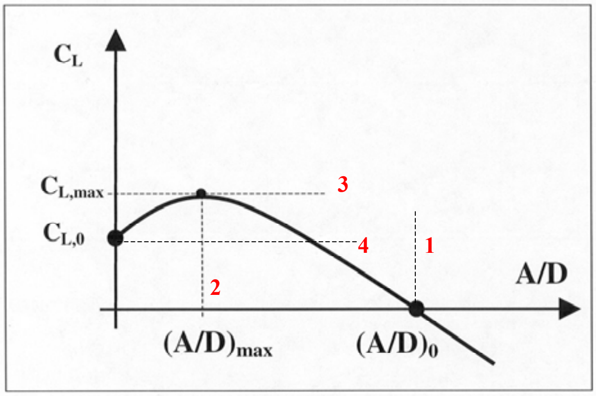
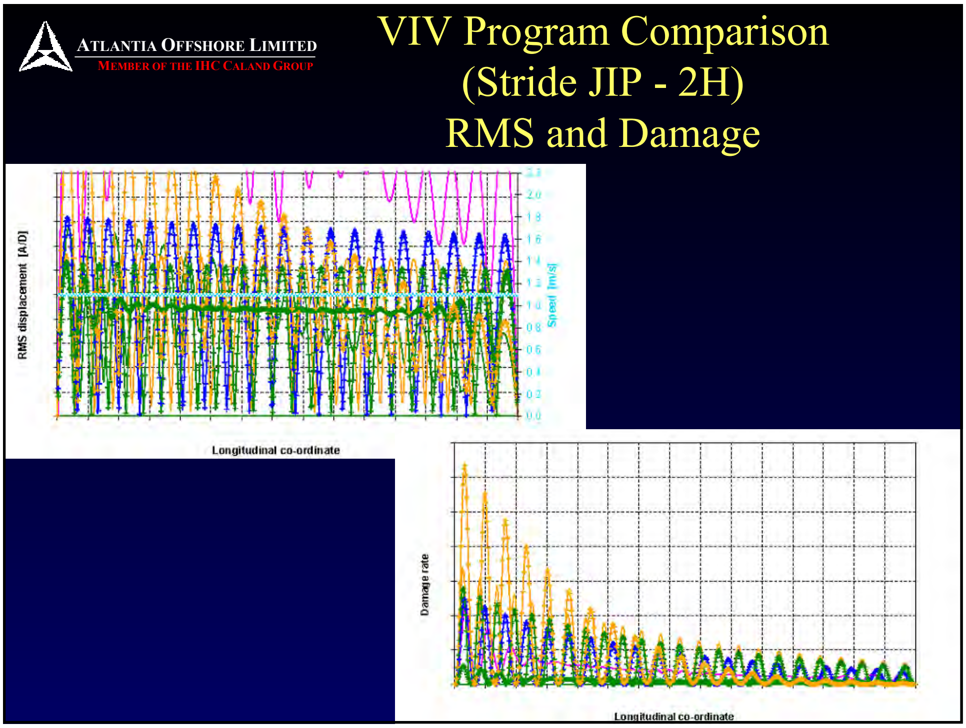


Figure 8: Shear7 4.3 defines a smoothed lift coefficient curve by fitting two parabolas to three points defined by four user-specified values.



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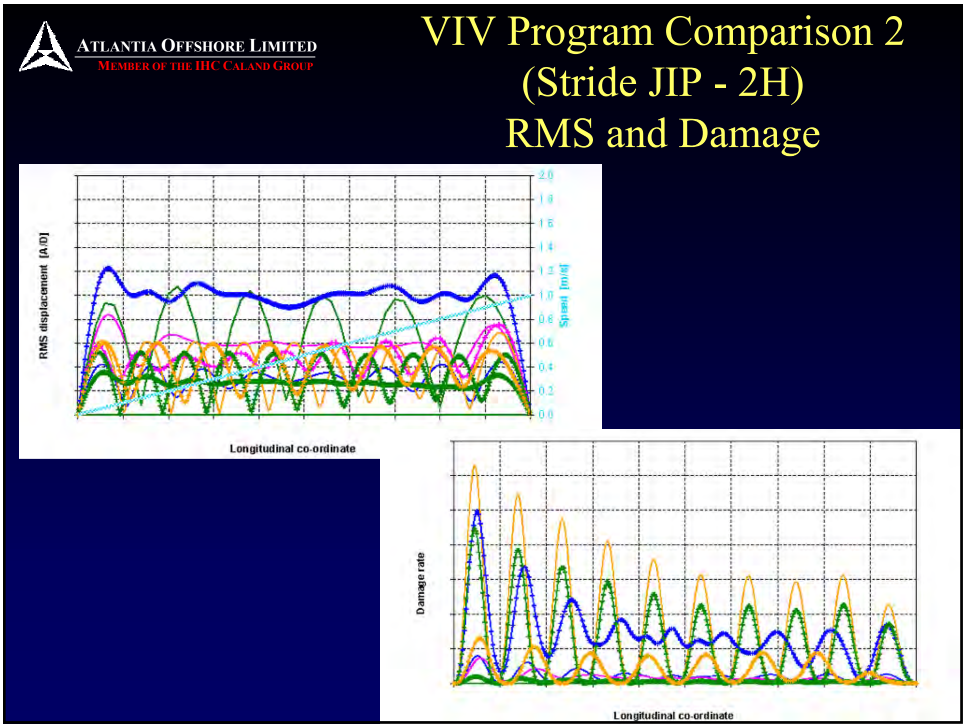
VIV Program Comparison (Stride JIP - 2H) RMS and Damage



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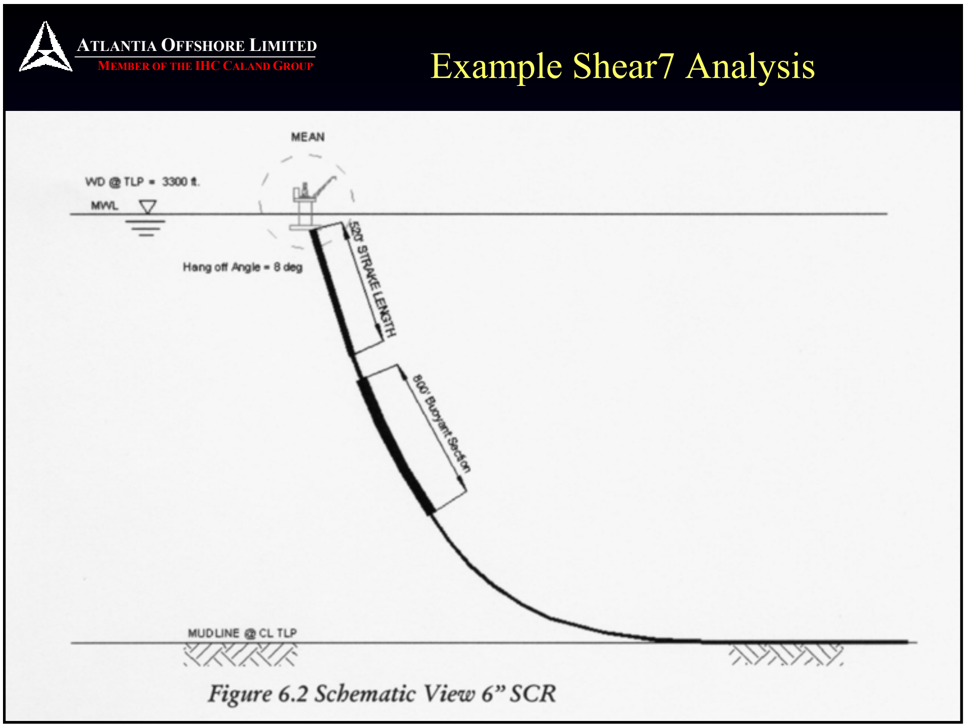
VIV Program Comparison 2 (Stride JIP - 2H) RMS and Damage



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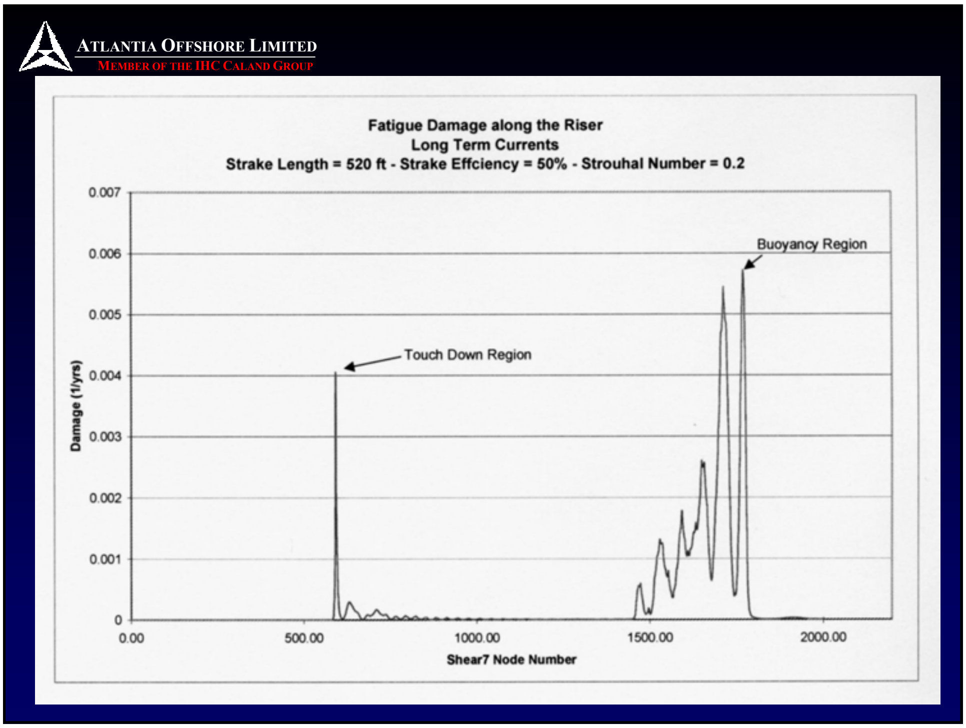
Example Shear7 Analysis

Figure 6.2 Schematic View 6" SCR



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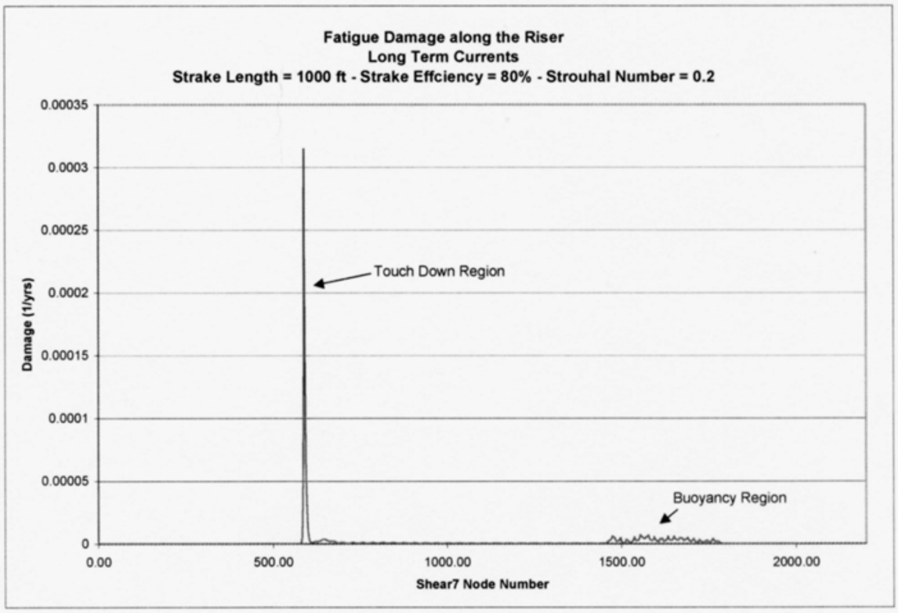
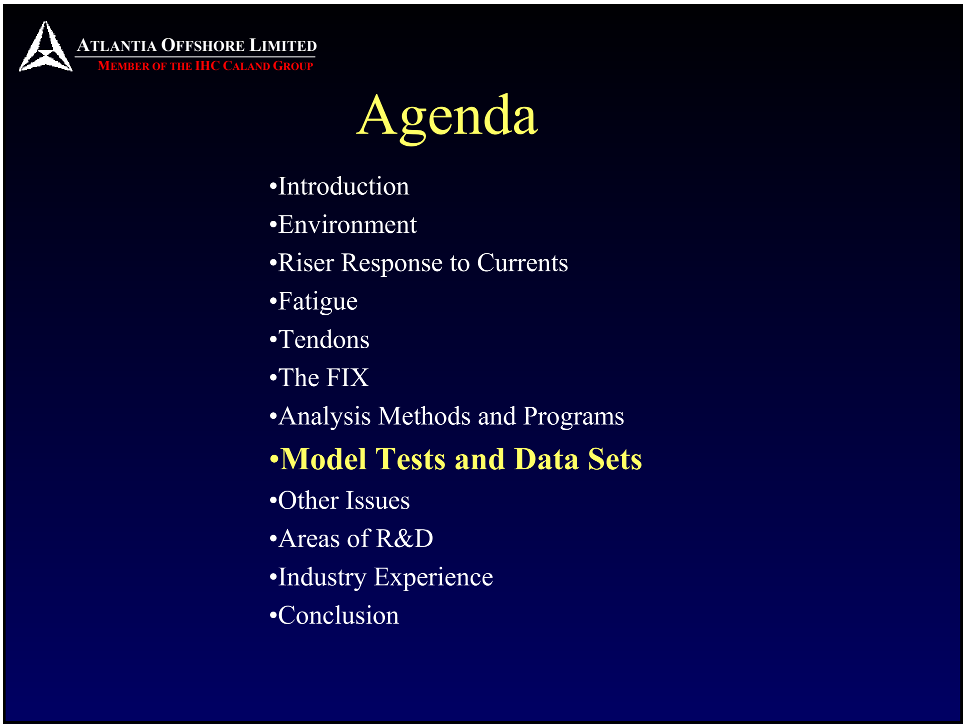
Fatigue Damage along the Riser
Long Term Currents
Strake Length = 520 ft - Strake Effciency = 50% - Strouhal Number = 0.2



Analysis Methods and Programs

- Shear7, Viva, Vivana, Vivarray
- Engineering tools, not simulators
- Summary of how they work
- Comparisons / Example
- Why they vary so much
- CFD
- Wake models and other approaches



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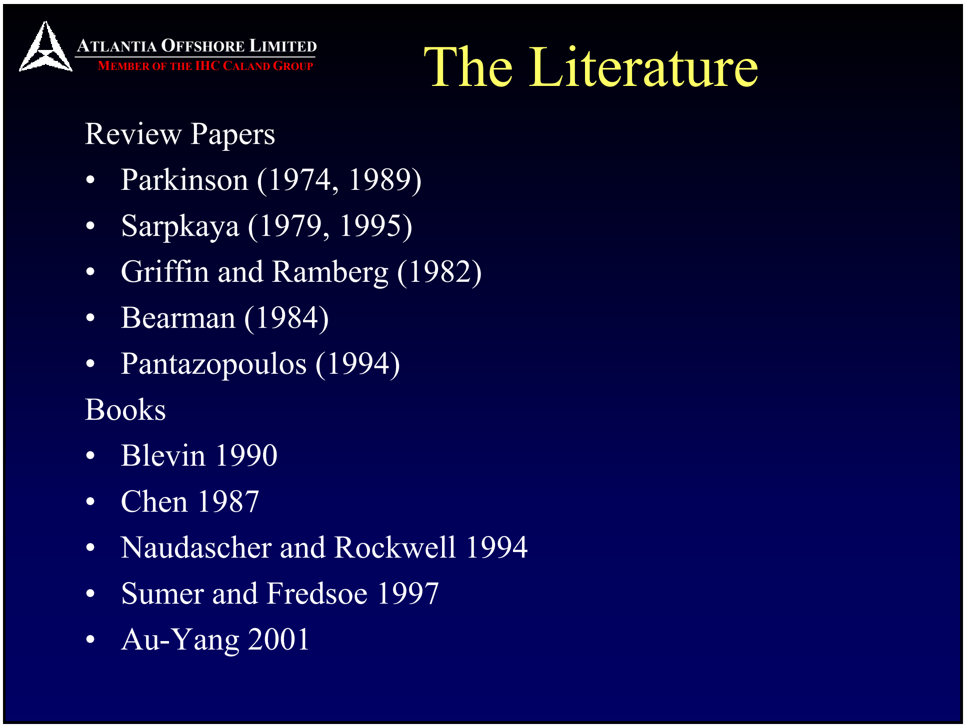

The Literature

Review Papers

- Parkinson (1974, 1989)
- Sarpkaya (1979, 1995)
- Griffin and Ramberg (1982)
- Bearman (1984)
- Pantazopoulos (1994)

Books

- Blevin 1990
- Chen 1987
- Naudascher and Rockwell 1994
- Sumer and Fredsoe 1997
- Au-Yang 2001

Recent Model Tests and Data Sets

- Deepstar – St Johns, CFD, Lake Seneca
- Stride (2H Allegheny and model tests)
- VIVA
- PMB HCR Lake Pend Oreille
- BP
- Exxon
- Shell

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Other Issues

- Wake effects, riser arrays
- High Re performance of fairings/strakes
- Issue of low mass systems, frequency independence
- Directionality of currents, resulting stress hot spots
- Directionality of response amplitude
- Trenching

Trenching

Agenda

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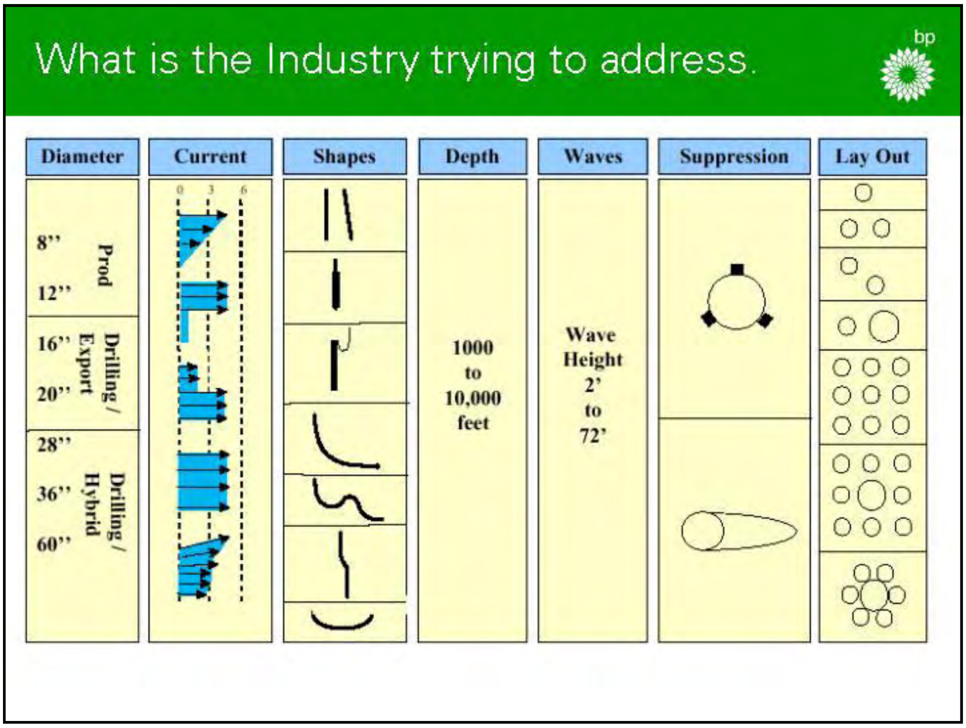
- Industry Experience
- Conclusion

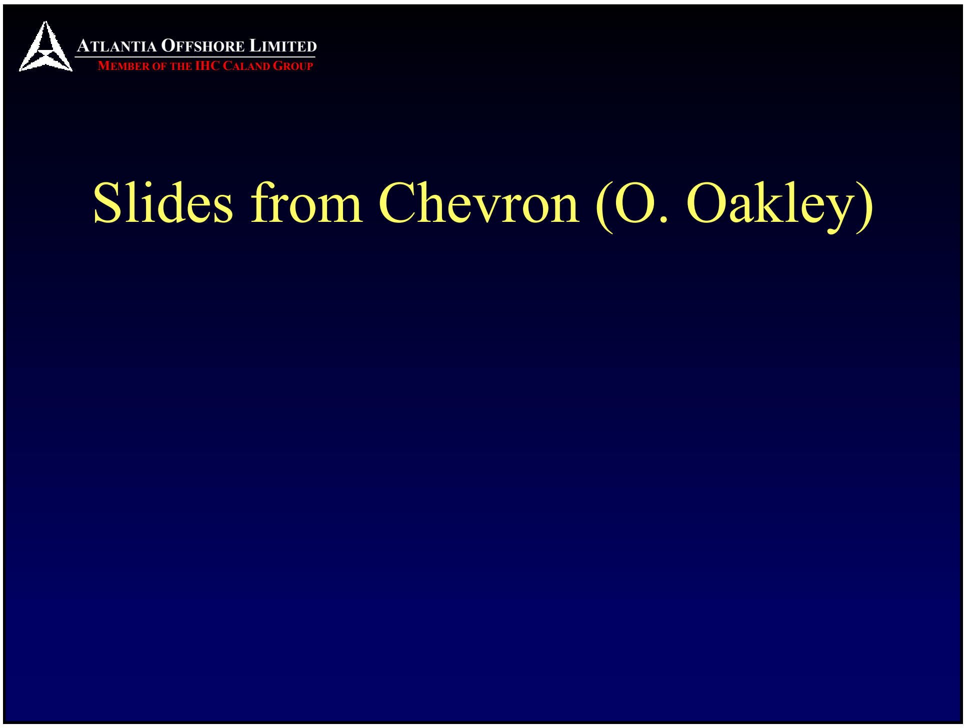
Areas of Research and Development

- Empirical
- CFD
- Fairings
- JIP’s
  - MIT - VIVA
  - MIT - Vandiver JIP and Shear7
  - Deepstar (ARA CFD, Principia CFD, Lake Seneca, St. Johns)
  - Several CFD proposals out



What is the Industry trying to address.

Diameter	Current	Shapes	Depth	Waves	Suppression	Lay Out
8'' 12'' Prod 16'' 20'' Drilling / Export 28'' 36'' 60'' Drilling / Hybrid	0 3 6		1000 to 10,000 feet	Wave Height 2' to 72'		



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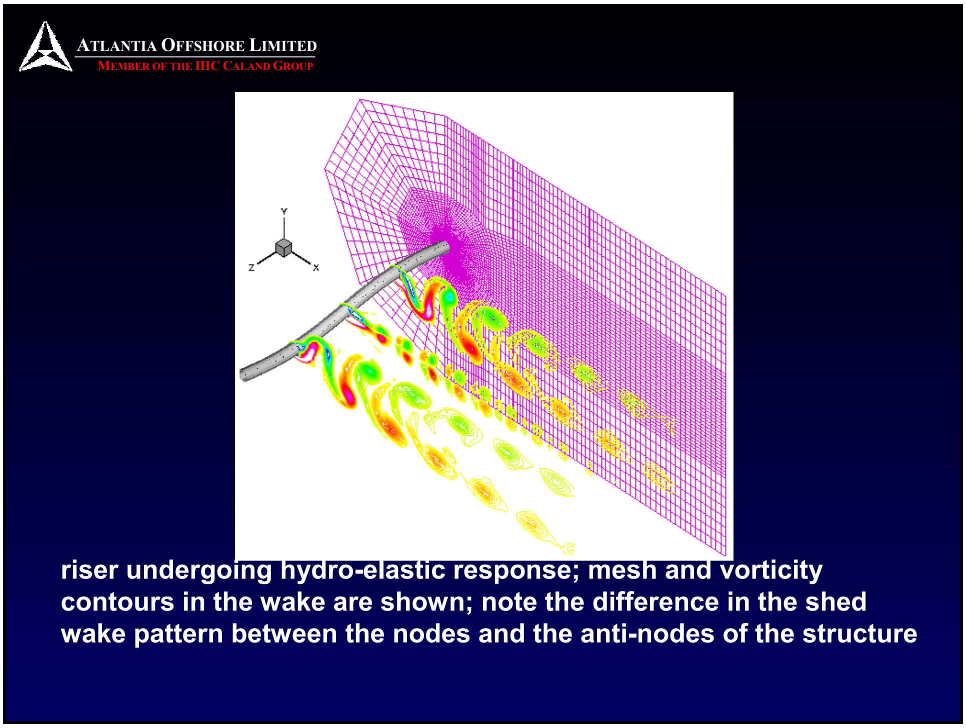
Slides from Chevron (O. Oakley)



riser undergoing hydro-elastic response; mesh and vorticity contours in the wake are shown; note the difference in the shed wake pattern between the nodes and the anti-nodes of the structure

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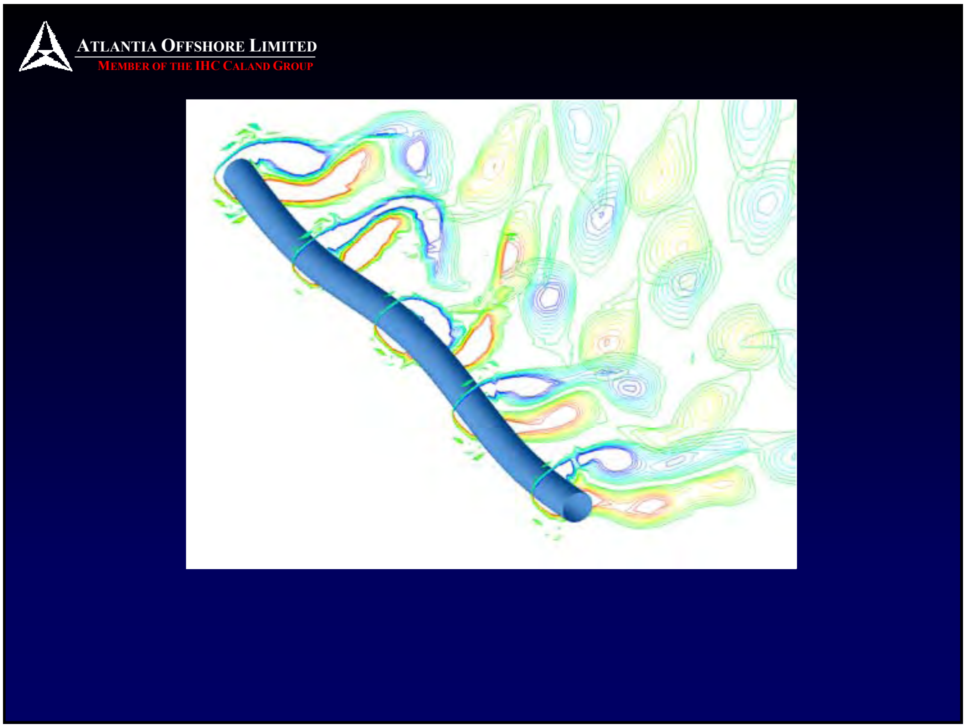
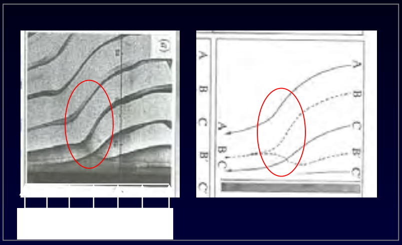
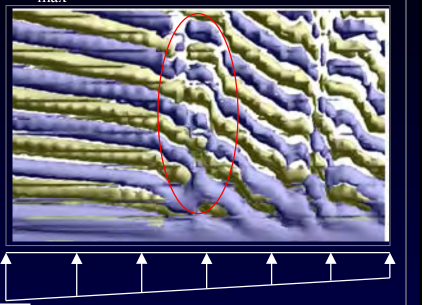


Vortex Dislocations Visualizations

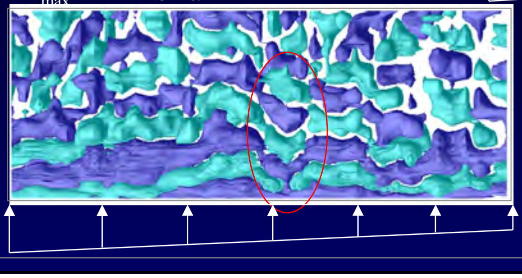
$Re=100$ Experiments C.H.K. Williamson (1989)

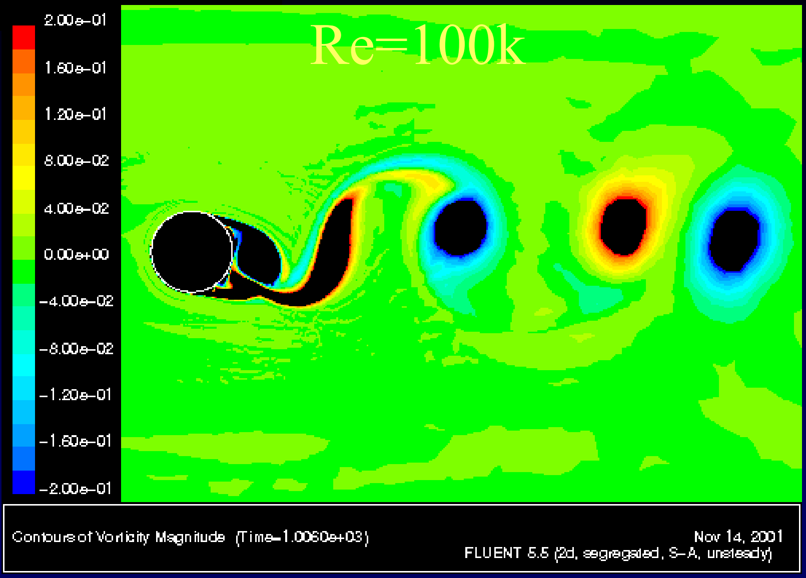


$Re_{max}=100$ **NεκTαR-DNS** Simulations



$Re_{max}=1000$ **NεκTαR-DNS** Simulations



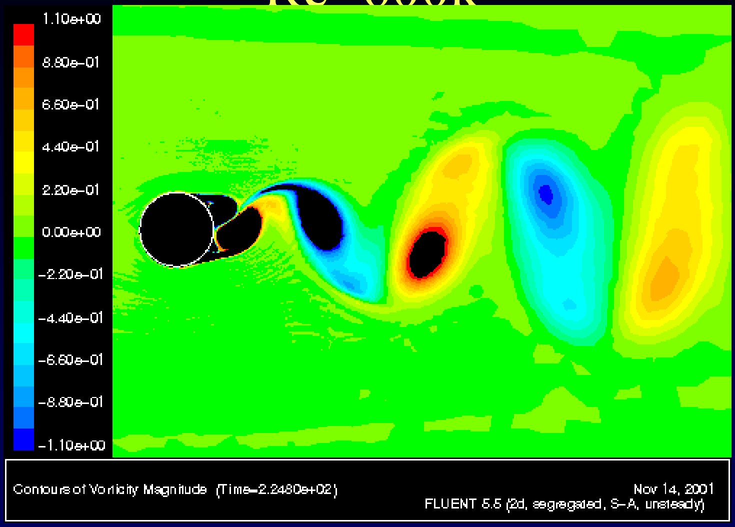


Contours of Vorticity Magnitude (Time=1.0060e+03)

Nov 14, 2001
FLUENT 5.5 (2d, segregated, S-A, unsteady)

[redacted]

Re=600k

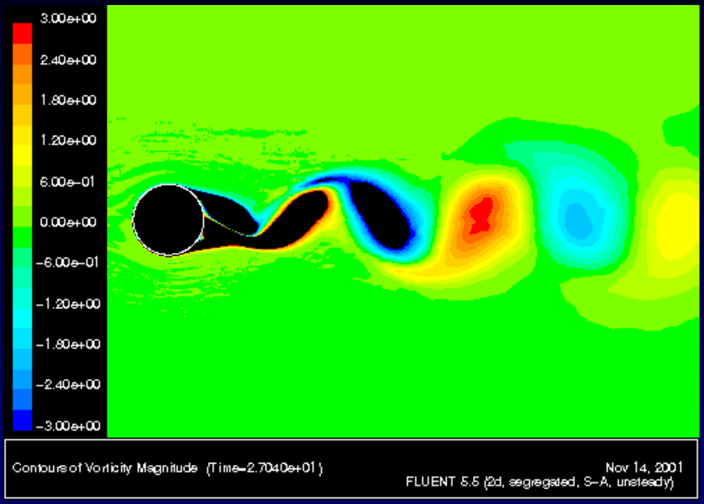


Contours of Vorticity Magnitude (Time=2.2480e+02)

Nov 14, 2001
FLUENT 5.5 (2d, segregated, S-A, unsteady)

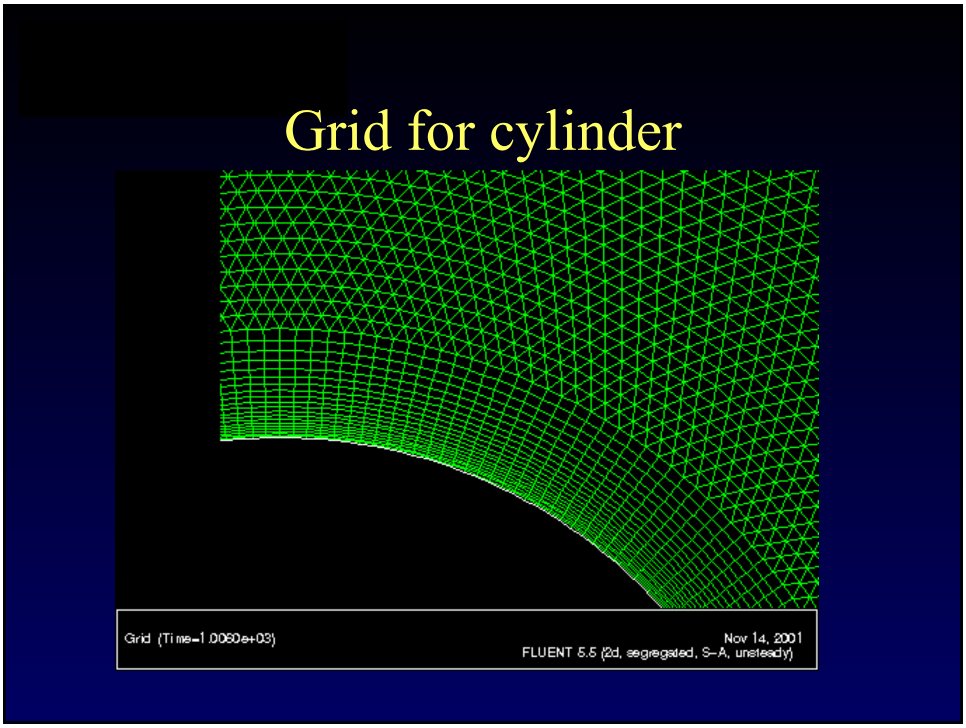
[redacted]

Re=4MM

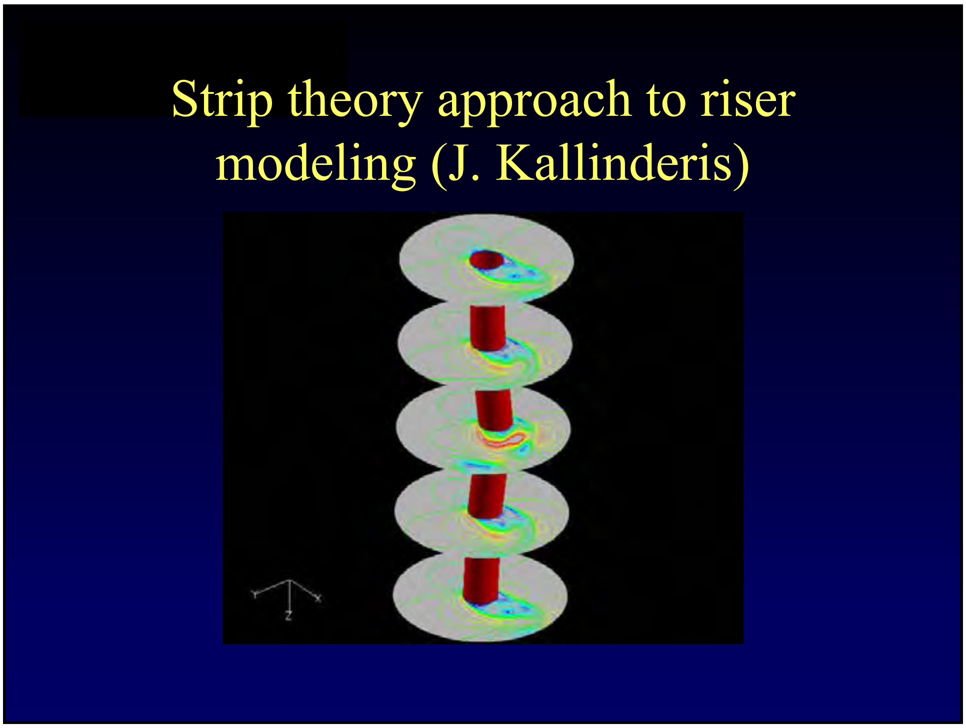


Contours of Vorticity Magnitude (Time=2.7040e+01)

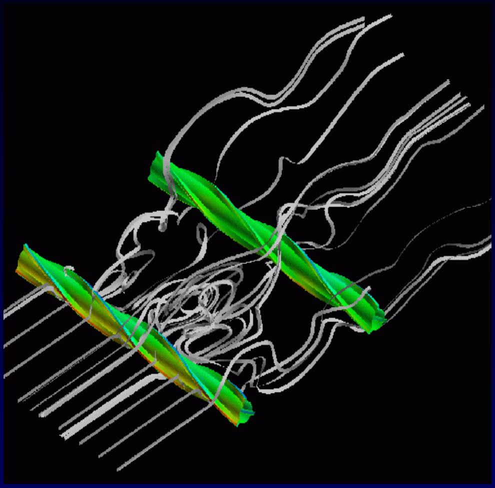
Nov 14, 2001
FLUENT 5.5 (2d, segregated, S-A, unsteady)



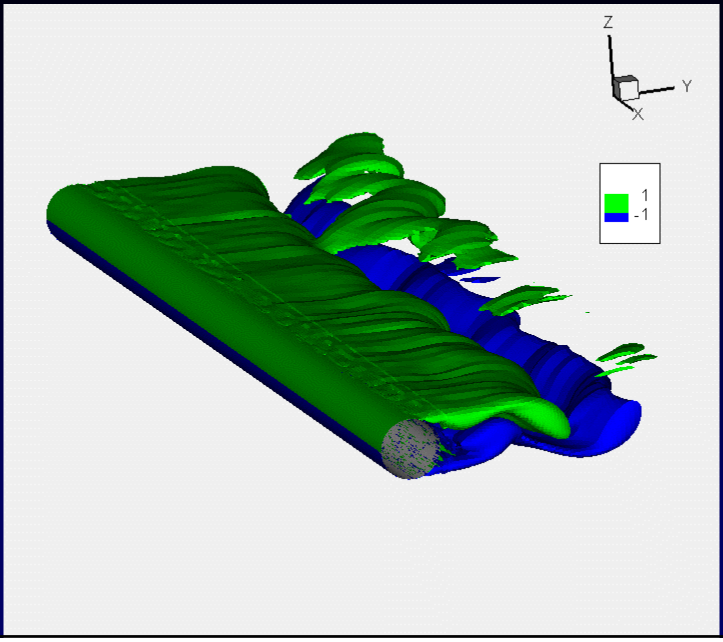
Grid for cylinder



Strip theory approach to riser modeling (J. Kallinderis)



Constant Contours of Spanwise Vorticity (non-dimensional)



Numerical Modeling

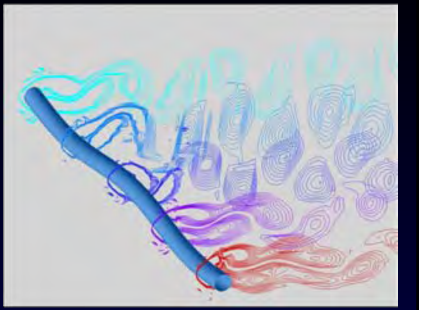
CFD = computational fluid dynamics, solution of Navier-Stokes equations for fluid flow

$$\frac{\partial \hat{U}}{\partial x_i} = 0$$

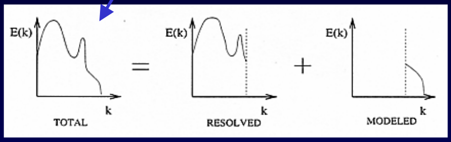
$$\hat{U}_j \frac{\partial \hat{U}_i}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\nu \frac{\partial \hat{U}_i}{\partial x_j}\right) - \frac{1}{\rho}\frac{\partial \hat{\rho}}{\partial x_i}$$

$$\hat{U}_j \frac{\partial \hat{\Theta}}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\Gamma \frac{\partial \hat{\Theta}}{\partial x_j}\right)$$

CFD Approach:	**DNS**	**LES**	**RANS**	**DES**
Turbulence Model	none	Smag.	S-A	S-A
		S-A	k-ε	
		..	k-ω	
			SMC, …..	



DNS – direct numerical solver



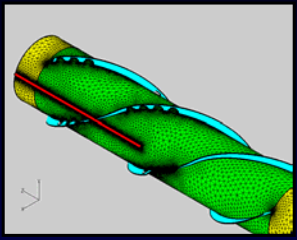
LES turbulence model – spatial filter representation of turbulence fluctuations

---

CFD – Spars

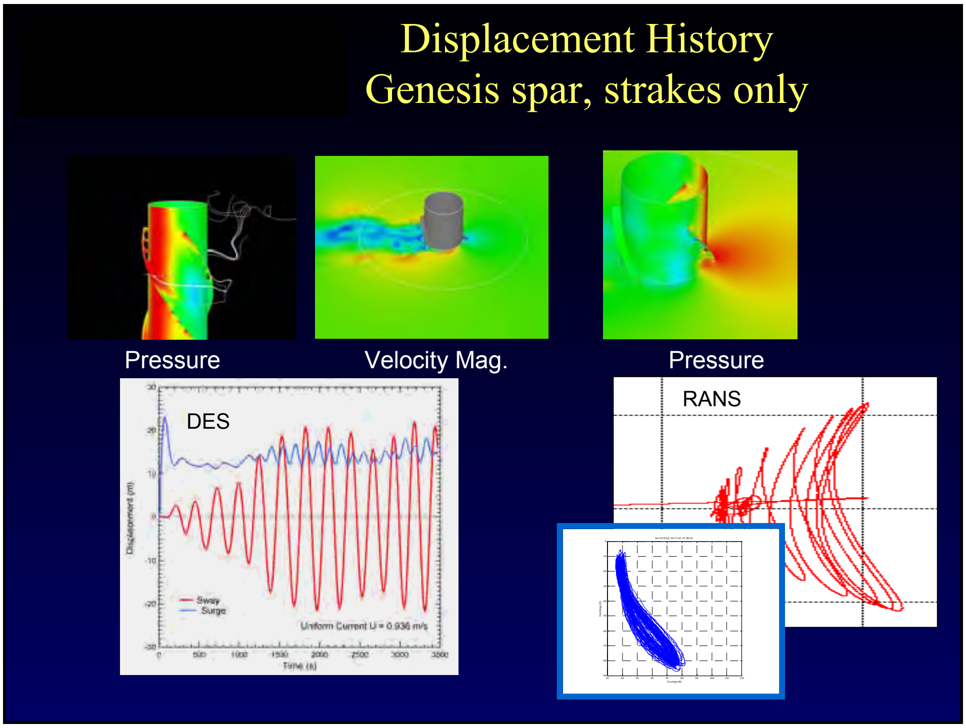
2dof Modeling – Straked Cylinder

- No chains, pipes or anodes
- S-A turbulence model
- Re = **34MM**
- Navier-Stokes Solution:
- **URANS** - time averaging
- LES – space averaging
- **DES** – RANS in boundary layer & LES outside



RANS Grid

DES Grid



Displacement History
Genesis spar, strakes only

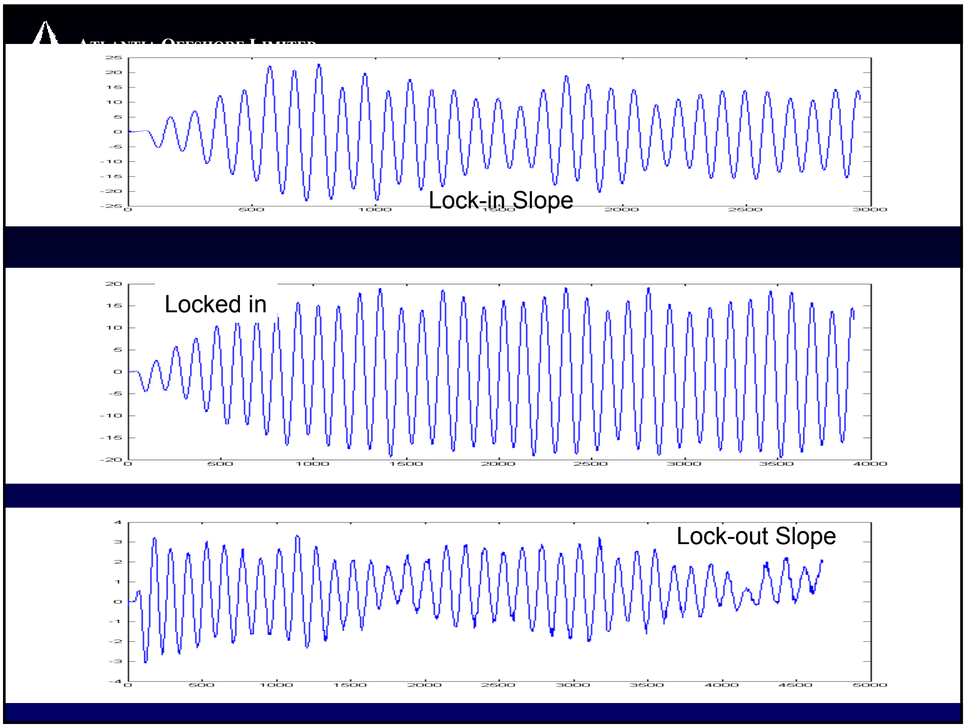
Pressure

Velocity Mag.

Pressure

DES

RANS



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Lock-in Slope

Locked in

Lock-out Slope

Objectives and Challenges for High Mode Number, Flow-Induced Vibration Model Tests in Sheared Flow

Prof. J. Kim Vandiver

MIT

June 3, 2003

IUTAM International Union of Theoretical and Applied Mechanics

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Principal Issues for High Mode Number VIV Response Prediction

- Does lock-in occur at high mode number in uniform and sheared flow?
- What are the statistics of single versus multi-frequency response in sheared flow?
- What are the statistics of in-line and cross-flow response?

Principal Issues for High Mode Number VIV Response Prediction

- Do hydrodynamic damping models need improvement?
- What fairing or strake coverage is required
- What is the effect of Reynolds number on S_t, C_L damping and suppression effectiveness.

Important dimensionless groups

1. $\frac{m}{\rho_f D^2}$ mass ratio

2. $V_R = \frac{U(x)}{f_v D}$, Reduced velocity

3. $\frac{R_n \omega_n}{\rho_f U^2(x) L_{in}}$ Reduced damping

4. What about correlation length?

5. $\zeta_s = \frac{r_s}{2\omega_n m}$, $and\ \ n\zeta_t = \frac{2L}{\lambda}\zeta_t$

Modal damping and wave attenuation

6. $R_e = \frac{DU(x)}{\nu}$, Reynolds number

How is lock-in affected by mass ratio versus reduced velocity bandwidth?

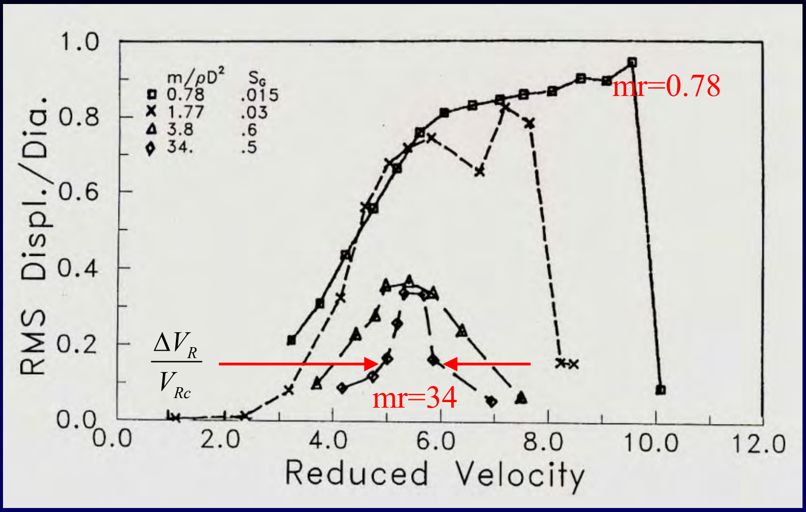
1. $\dfrac{m}{\rho_f D^2}$ mass ratio

2. $V_R = \dfrac{U(x)}{f_v D}, \quad dV_R = \dfrac{\Delta \mathrm{V_R}}{V_{Rc}}$ = lock-in bandwidth

$\mathrm{f_v}$ = the vibration frequency

- Is the response different if the wake adjusts its frequency to match the cylinder or the natural frequency adjusts to match the wake.

A/D versus Reduced velocity (based on a fixed natural frequency)



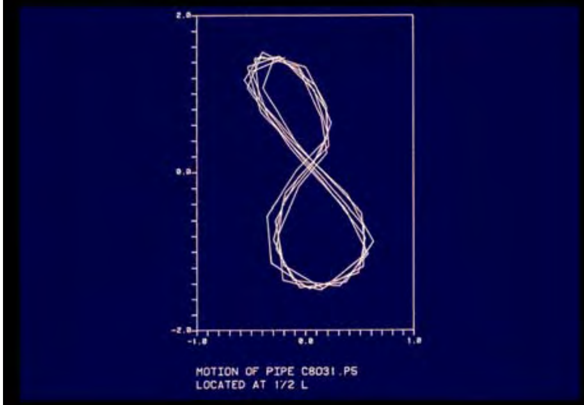
$\dfrac{\Delta V_R}{V_{Rc}}$

mr=0.78

mr=34

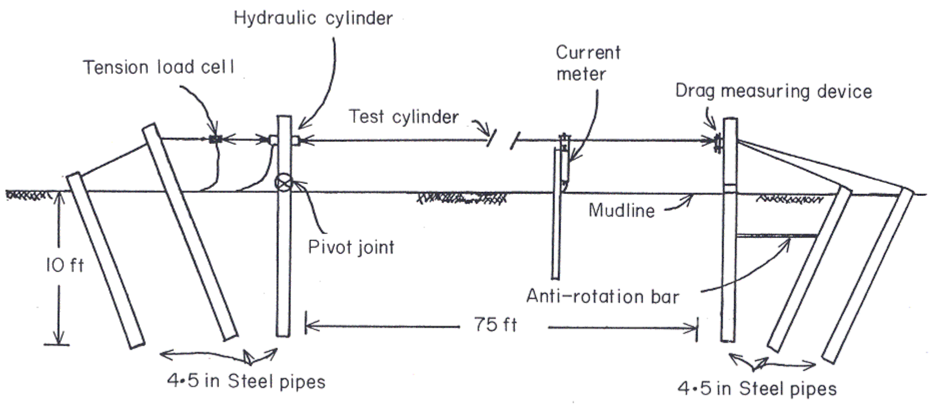
Castine field experiment in uniform flow(1981)

- Uniform flow on short lengths(75 feet)



MOTION OF PIPE C8031.PS
LOCATED AT 1/2 L

Site layout



Cable, pipe and wire rope properties

- Cable was PVC plastic tubing with accelerometers, wires, strength members and potting compound, D=1.25 inches., s.g.=1.4
- Pipe was 1.631 inch steel tube with the cable pulled inside as the measuring instrument. S.g.=2.4
- Wire rope was polyethylene coated oceanographic wire, 3x19 construction. D=.28 inches, s.g.=2.5

Castine pipe response, L=75 ft, D=1.63 inches, specific gravity = 2.4

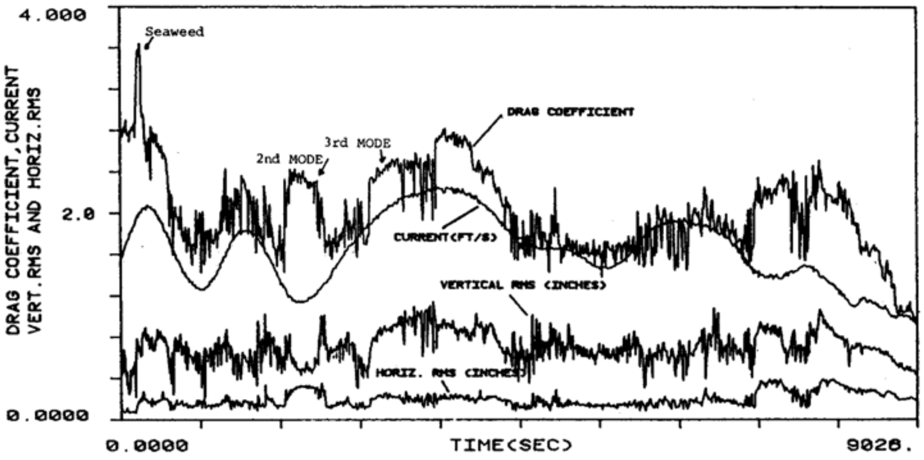
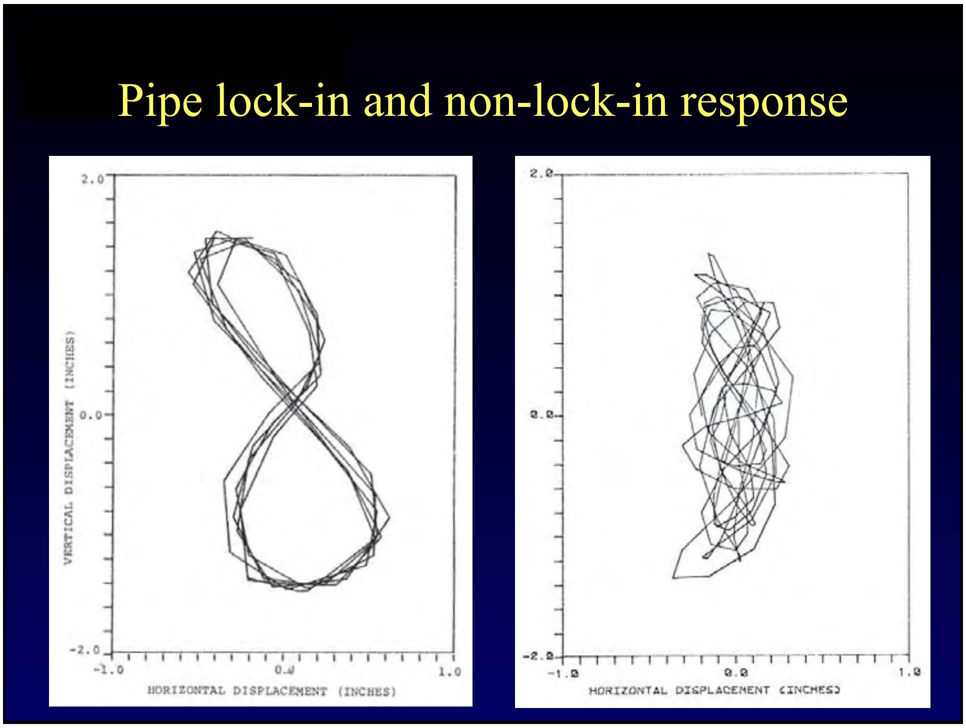
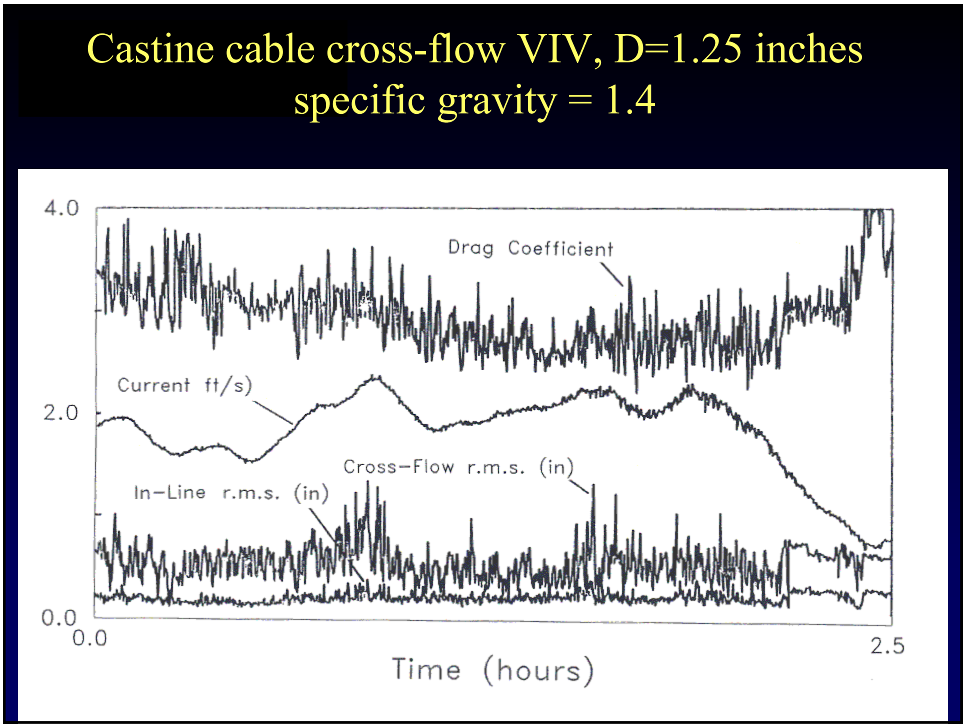


Fig. 4—Drag coefficient, current, and RMS displacement at L/6 for the pipe.

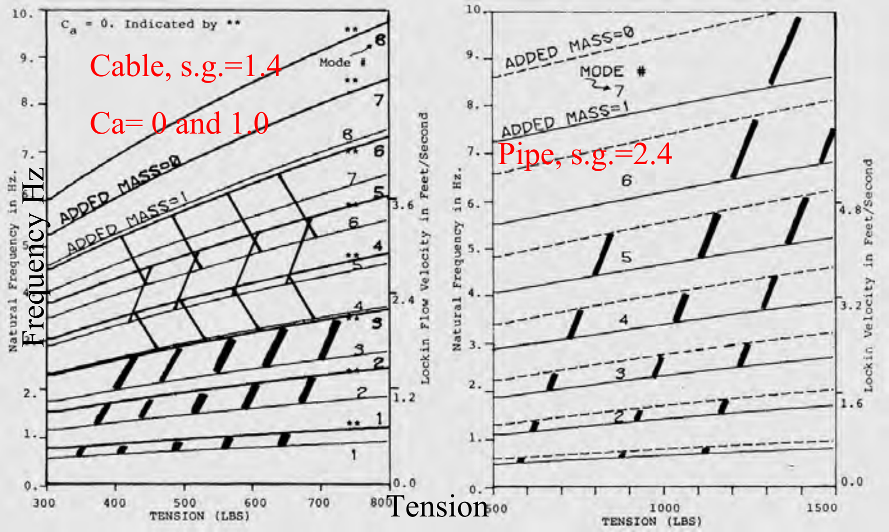


Pipe lock-in and non-lock-in response

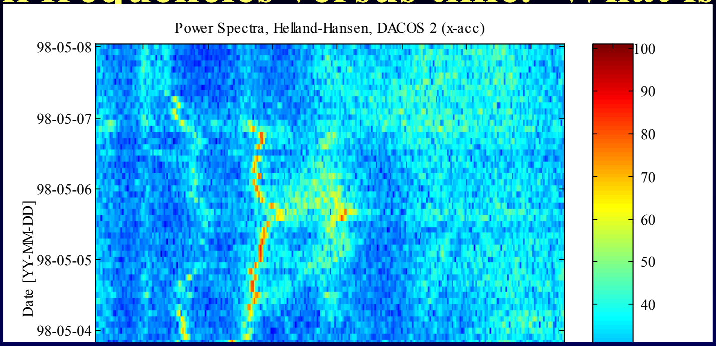


Castine cable cross-flow VIV, D=1.25 inches specific gravity = 1.4

Stable lock-in events are aided by isolated natural frequencies with no overlap.



An example from Helland Hansen: Peak frequencies versus time. What is



From Robit Helland Hansen Report

Wire rope: L=75 ft, D=0.25 inches, specific gravity = 2.6
Steady beating around 6th mode, components 0.6 Hz apart
Reduced velocity bandwidth of +-20%=+-2.6Hz

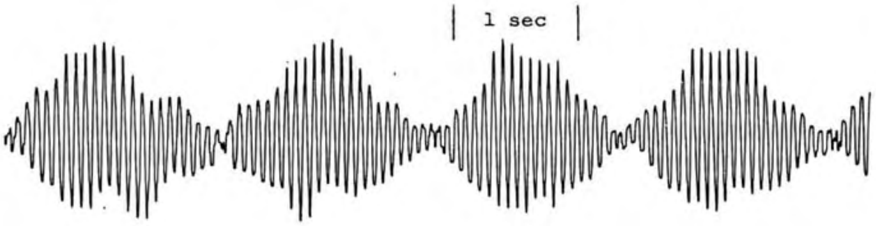
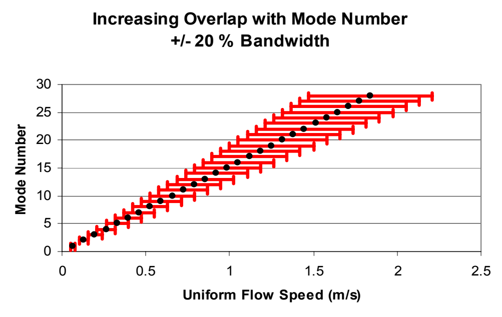


Figure 4. Pronounced beating. Wire rope at 180 lbs tension. Current: 1.9 ft/sec, displacement: .152"/cm on trace. Component frequencies: 13.1 and 13.7 Hz.

Does lock-in occur at High Mode Number ?

Increase in Uniform flow speed → Increasing overlap of competing modes

Reduced velocity bandwidth of +-20% would include many modes. Can just one respond in a uniform flow? What happens in shear?



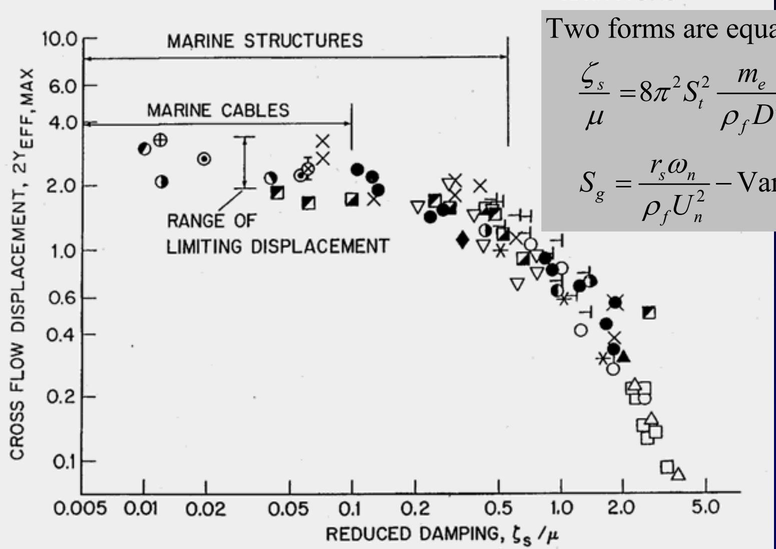
Wire rope: L=900 ft, D=0.280 inches, specific gravity = 2.5

- Nearly uniform flow on a 900 foot long sample.
- +- 10% flow variation along the length
- Lock-in at 50th mode

Conclusions:

- High mass ratio provides stable sharp resonances.
- V_R bandwidth allows for some spatial tolerance to flow variations. Single frequency dominance is possible in nearly uniform flows, even at high mode number.

The role of damping in uniform flow? The reduced damping is a statement of dynamic equilibrium.



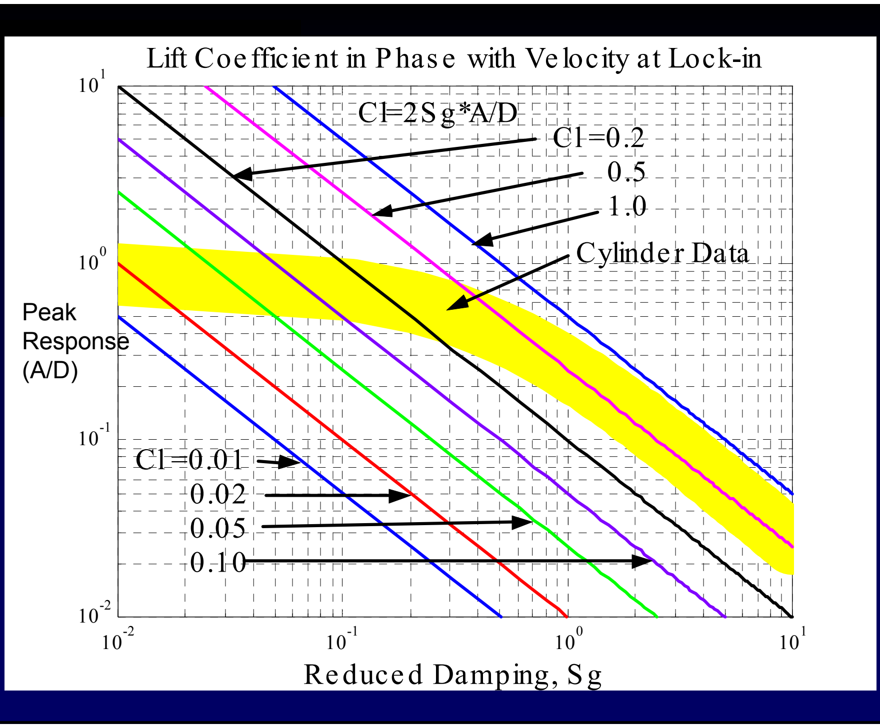
Two forms are equal:

$$\frac{\zeta_s}{\mu} = 8\pi^2 S_t^2 \frac{m_e}{\rho_f D^2}\zeta_s \text{ - Griffin}$$

$$S_g = \frac{r_s \omega_n}{\rho_f U_n^2} - \text{Vandiver}$$

A useful property is that:

$$< C_{L,n} > = 2S_u \frac{q_n}{D},$$ the equation of an hyperbola for lines of constant lift coefficient.



A flexible cylinder in a non-uniform flow with a power-in region of length L_{in} has a resonant modal response given by:

$$\frac{q_n}{D} = \frac{\langle C_{L,n} \rangle}{2} \frac{\rho_w U_n^{\ 2} L_{in}}{R_n \omega_n} = \frac{\langle C_{L,n} \rangle}{2 S_u}$$

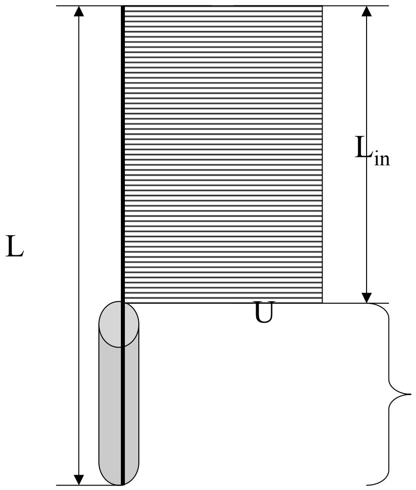
In red are 3 key parameters in prediction programs. They form a dimensionless group S_u and

$\langle C_{L,n} \rangle \equiv$ Average modal lift coefficient

$$S_u = \frac{R_n \omega_n}{\rho_w U^2 L_{in}} = \frac{8\pi^2 S_t^2 M_n \zeta_n}{\rho_w D^2 L_{in}}$$

Consider a simple slab flow problem first to illustrate the example of limited power-in length.

Shroud created a still water damped region



Uniform flow power-in region

Shroud covers this length, creates still water around the cylinder

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Example Experimental Data for a Slab Flow

- Tsahalis, D. T., *Experimental Study of the Vortex Induced Vibrations of a Long Model Riser Exposed to Uniform and Nonuniform Steady Flow*, Houston, Texas, Westhollow Research Center, 1985.
- Thank you to Shell Global Solutions for allowing me to publish these results.

Experiment Details

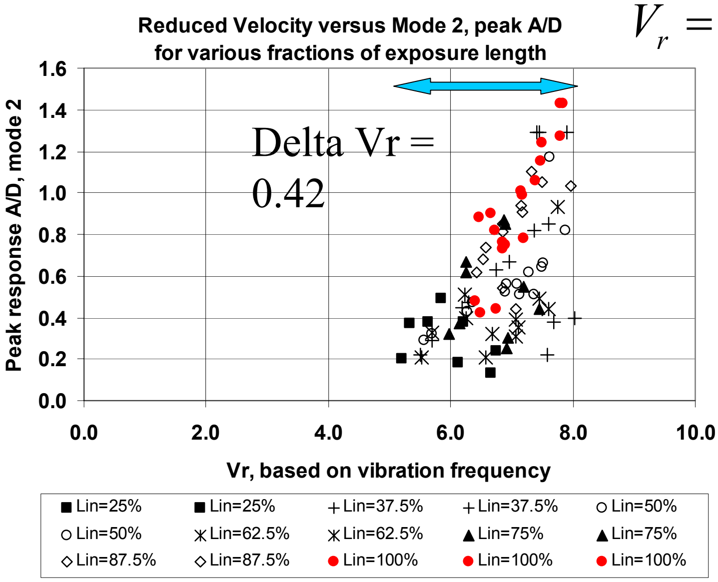
- Steel pipe, O.D. = 1.5in(3.81cm)
  I.D. = 1.334in(3.39cm)
- U= 0.33 to 6ft/s(0.1 to 1.83 m/s) in steps of 0.33ft/s(0.1m/s), modes 1 thru 3.
- Biaxial accelerometers at 5 points: L/8, L/4, L/2, 5L/8, AND 5L/6.

Shrouds used to simulate slab flow cases.

Exposed length of cylinder in 7 steps

- 100%
- 87.5%
- 75.0%
- 62.5%
- 50.0%
- 37.5%
- 25.0%

$$V_r = \frac{U}{f_v D}$$


Reduced Velocity versus Mode 2, peak A/D for various fractions of exposure length

Delta Vr = 0.42

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Jump to DS 6402 presentation

Agenda

- Introduction
- Environment
- Riser Response to Currents
- Fatigue
- Tendons
- The FIX
- Analysis Methods and Programs
- Model Tests and Data Sets
- Other Issues
- Areas of R&D
- **Industry Experience**
- Conclusion

Industry Experience (interesting bits of history)

- BNOC West of Shetlands
- BP Scheihellion experiences
- Exxon Brazil
- Andaman Sea
- West Seno Risers and Tendons
- Auger Top Tensioned Sales Riser
- Allegheny SCR clashing
- Allegheny trenching
- Matterhorn (effects of cantilevered wellhead, strakes help installation, cold core re-fit)
- Typhoon SCR design and cold core issue
- Discovery of cold core/submerged current events
- Atlantis (and Thunder Horse) Sigsby Escarpment, high bottom currents, full straked riser – 7200’ WD, 12 deg top, ~10,000’ for 2 export, 6 production

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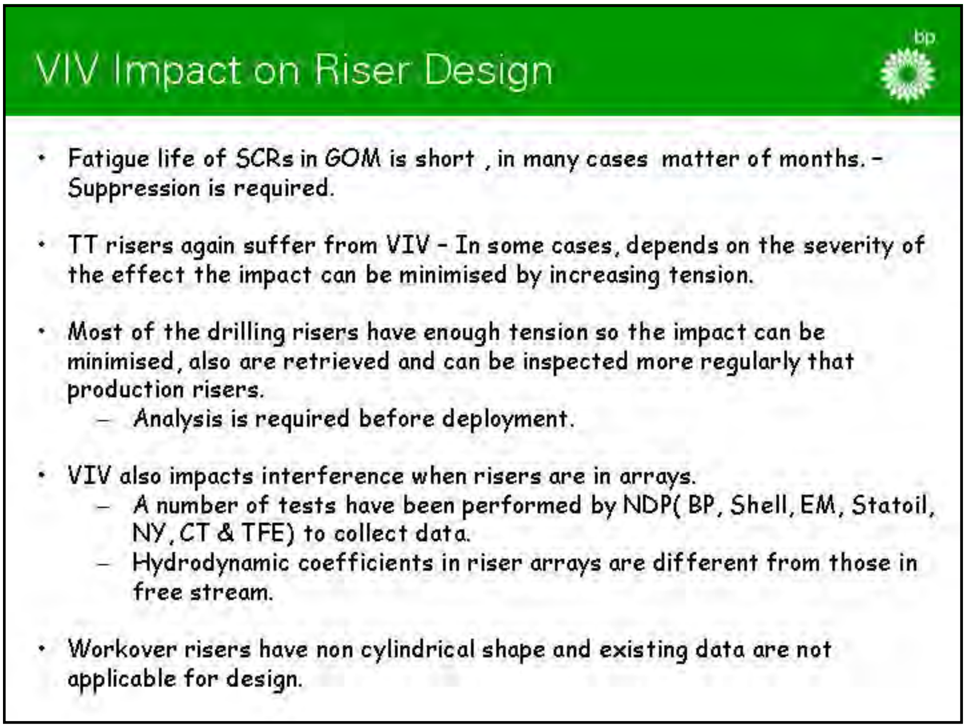
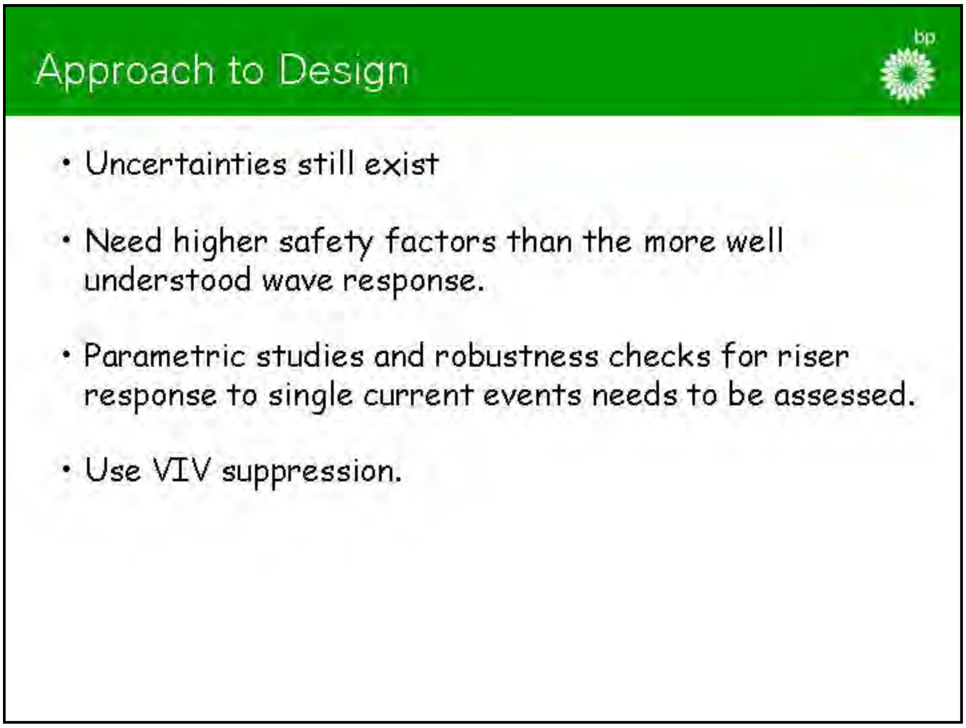


VIV Impact on Riser Design

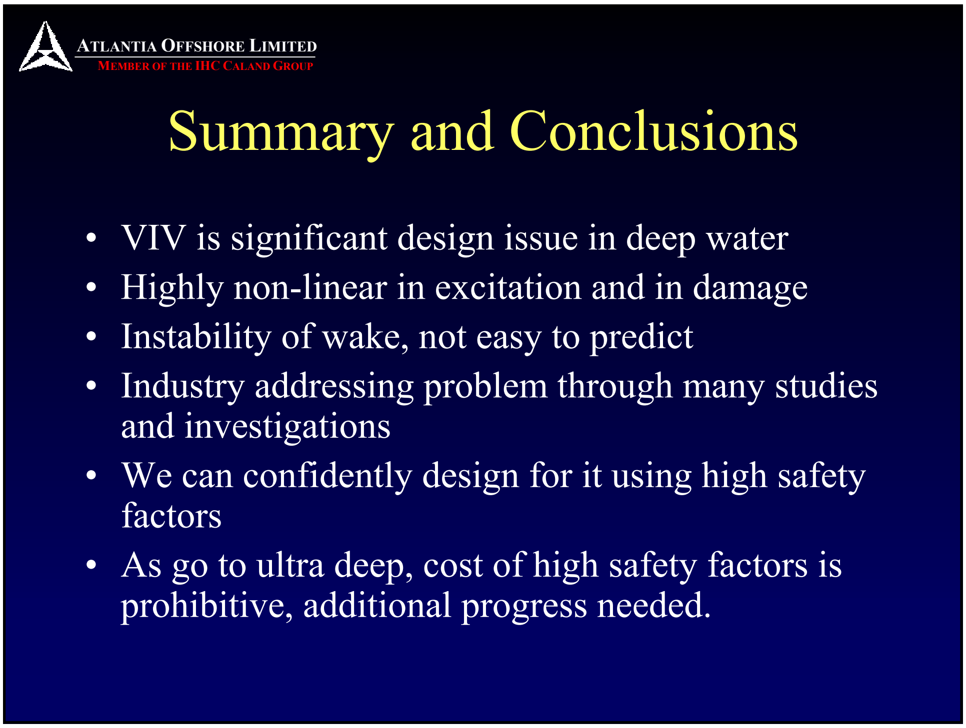
bp

- Fatigue life of SCRs in GOM is short , in many cases matter of months. - Suppression is required.
- TT risers again suffer from VIV - In some cases, depends on the severity of the effect the impact can be minimised by increasing tension.
- Most of the drilling risers have enough tension so the impact can be minimised, also are retrieved and can be inspected more regularly that production risers.
  - Analysis is required before deployment.
- VIV also impacts interference when risers are in arrays.
  - A number of tests have been performed by NDP(BP, Shell, EM, Statoil, NY, CT & TFE) to collect data.
  - Hydrodynamic coefficients in riser arrays are different from those in free stream.
- Workover risers have non cylindrical shape and existing data are not applicable for design.



Approach to Design

- Uncertainties still exist
- Need higher safety factors than the more well understood wave response.
- Parametric studies and robustness checks for riser response to single current events needs to be assessed.
- Use VIV suppression.



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Summary and Conclusions

- VIV is significant design issue in deep water
- Highly non-linear in excitation and in damage
- Instability of wake, not easy to predict
- Industry addressing problem through many studies and investigations
- We can confidently design for it using high safety factors
- As go to ultra deep, cost of high safety factors is prohibitive, additional progress needed.