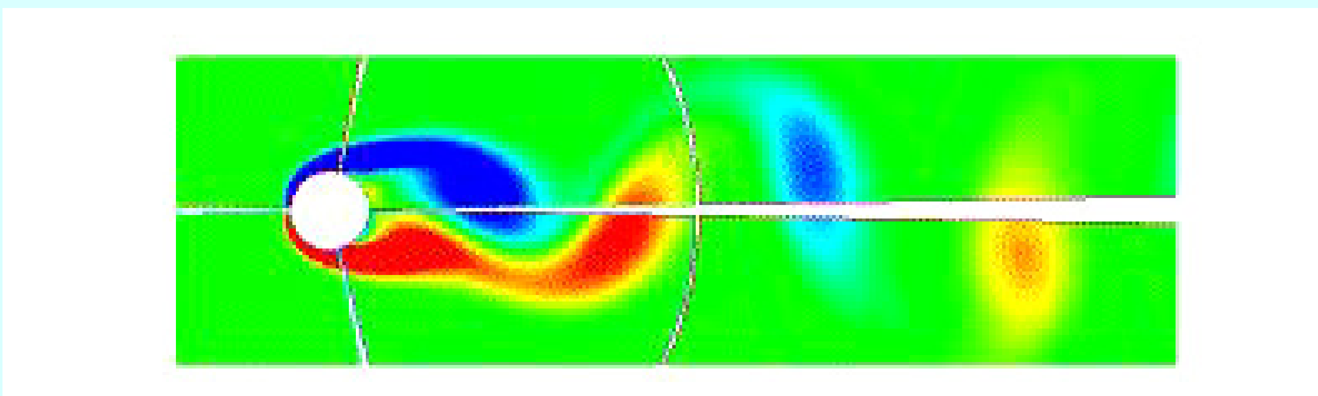
Report from Vortex Induced Vibration Specialist Committee of the 26th ITTC



Presented by Halvor Lie
Chairman of the comittee

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- Members & meetings
- Introduction
- Review
  - Numerical prediction models
  - Experimental methods
- Benchmark study
- Nomenclature
- Procedure for VIV and VIM testing
- Technical conclusions

Members of the VIV Committee of the 26th ITTC

- **Halvor Lie** (Chairman, MARINTEK, Norway)
- **Elena Ciappi** (INSEAN), Italy)
- **S. Huang (**Universities of Strathclyde, UK)
- **S. Hong** (Moeri, Korea),
- **Z. Zong** (DUT, China)

Recommendation given to the committee

1. Update the state-of-the-art for predicting vortex induced vibrations and motions emphasizing developments since the 2008 ITTC in various current profiles at ultra deep water. The update shall cover both small-diameter structures (e.g. risers) and large-diameter structures. (e.g. SPAR platforms)

2. Organize, conduct and report the results of benchmark VIV tests. Cooperate with OMAE on the benchmark activity.

3. Prepare standard nomenclature for VIV and VIM investigations

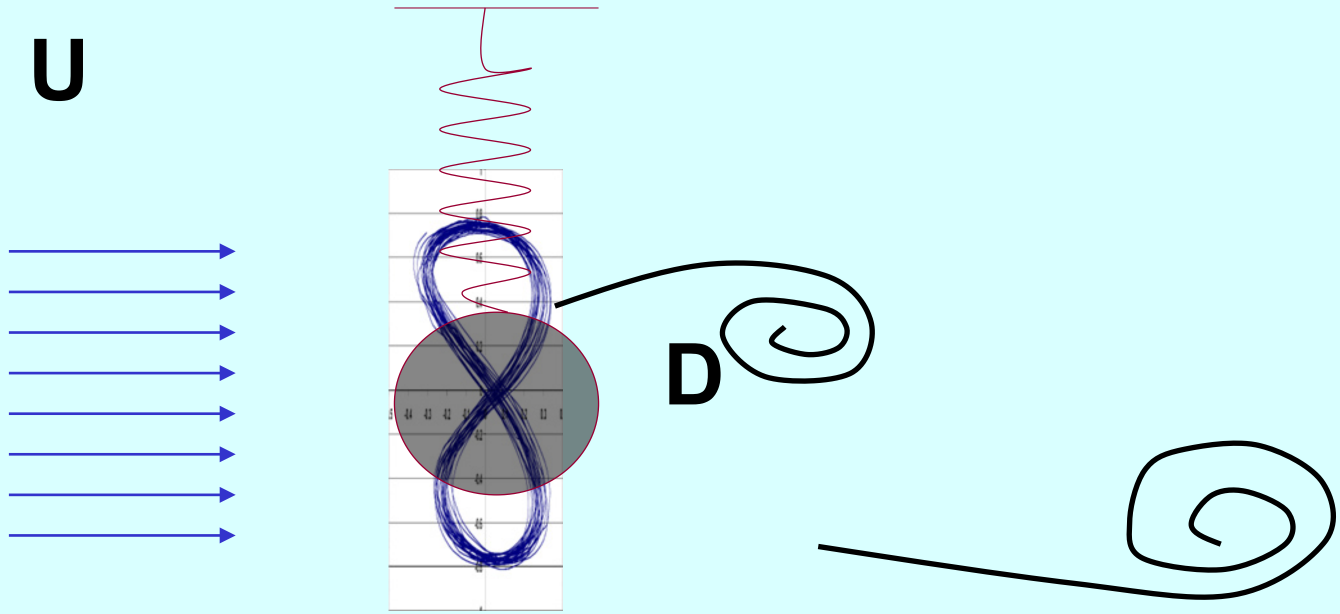
4. Write a procedure for VIV and VIM testing for marine applications

Three committee meetings

- CNR-INSEAN, Italy, November 2009
- Shanghai (OMAE 2010), China, June 2010
- University of Strathclyde, Glasgow, UK, February 2011

INTRODUCTION

Vortex Induced Vibrations

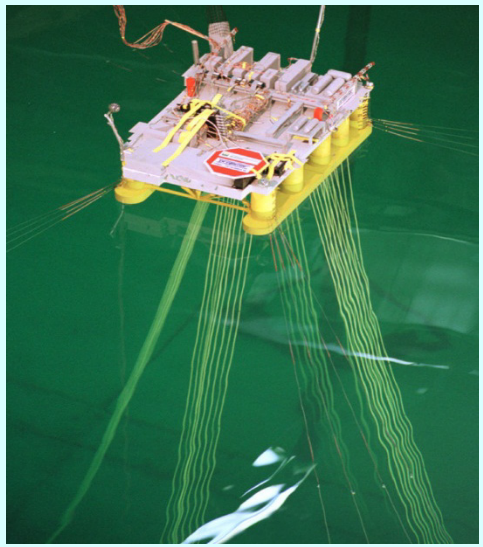


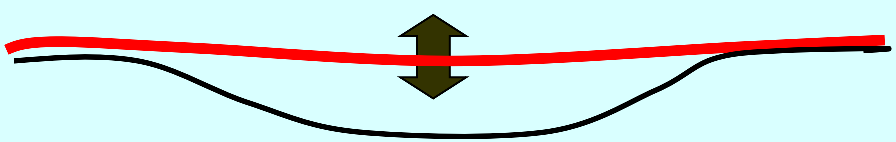
Shedding frequency (fixed cylinder)

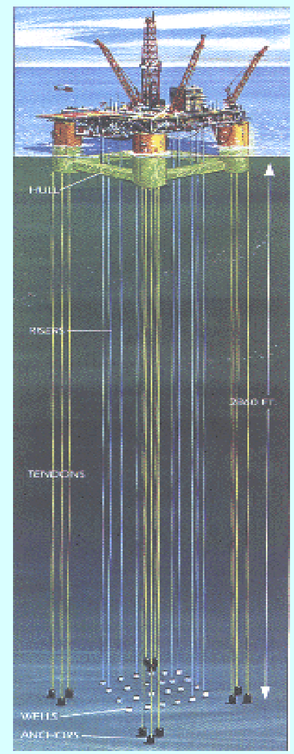
f_{st} = St U/D, St ≅ 0.15 – 0.3

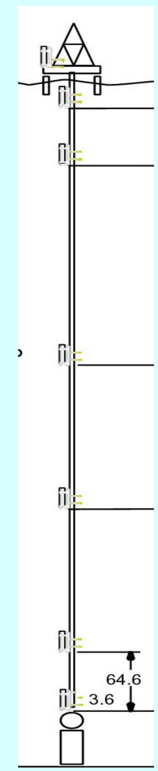
The cylinder starts to oscillate

VIV problem areas







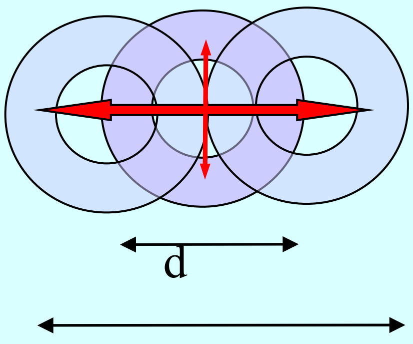


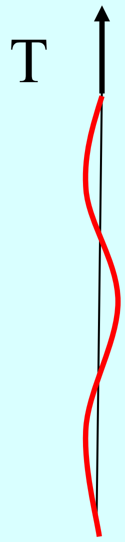
SPAR with D=30 m, U=1.5 m/s, $f_{St} \cong 0.01$ Hz (T_{St}=100 s)

Riser with D=0.30 m, U=1.5 m/s, $f_{St} \cong 1$ Hz

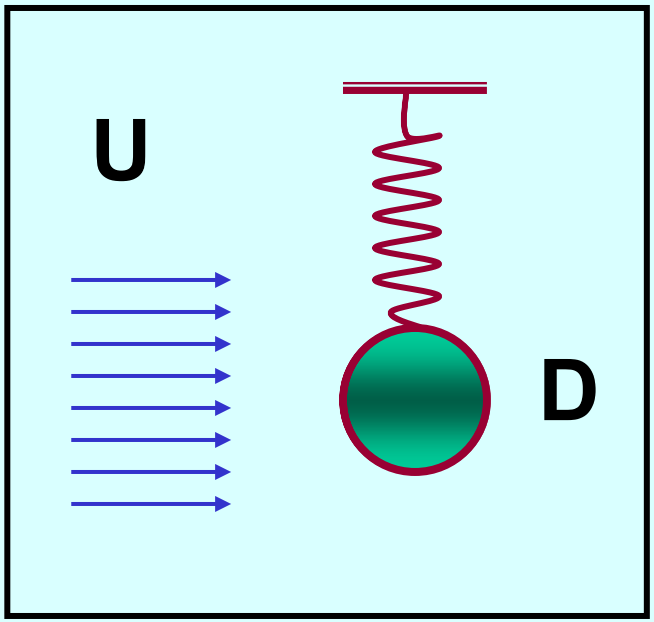
Consequence

- Long elastic cylinders (VIV):
  - Reduced fatigue life
  - Increased drag
  - Increased axial tension
  - Increased deflection
- Platforms (VIM):
  - Increased global motions
  - Increased drag (Off-set)
  - Increased mooring line tensions (ULS &FLS)





2-D case:



f_v : Vortex shedding frequency, fixed cylinder

f_0 : Eigenfrequency, still water

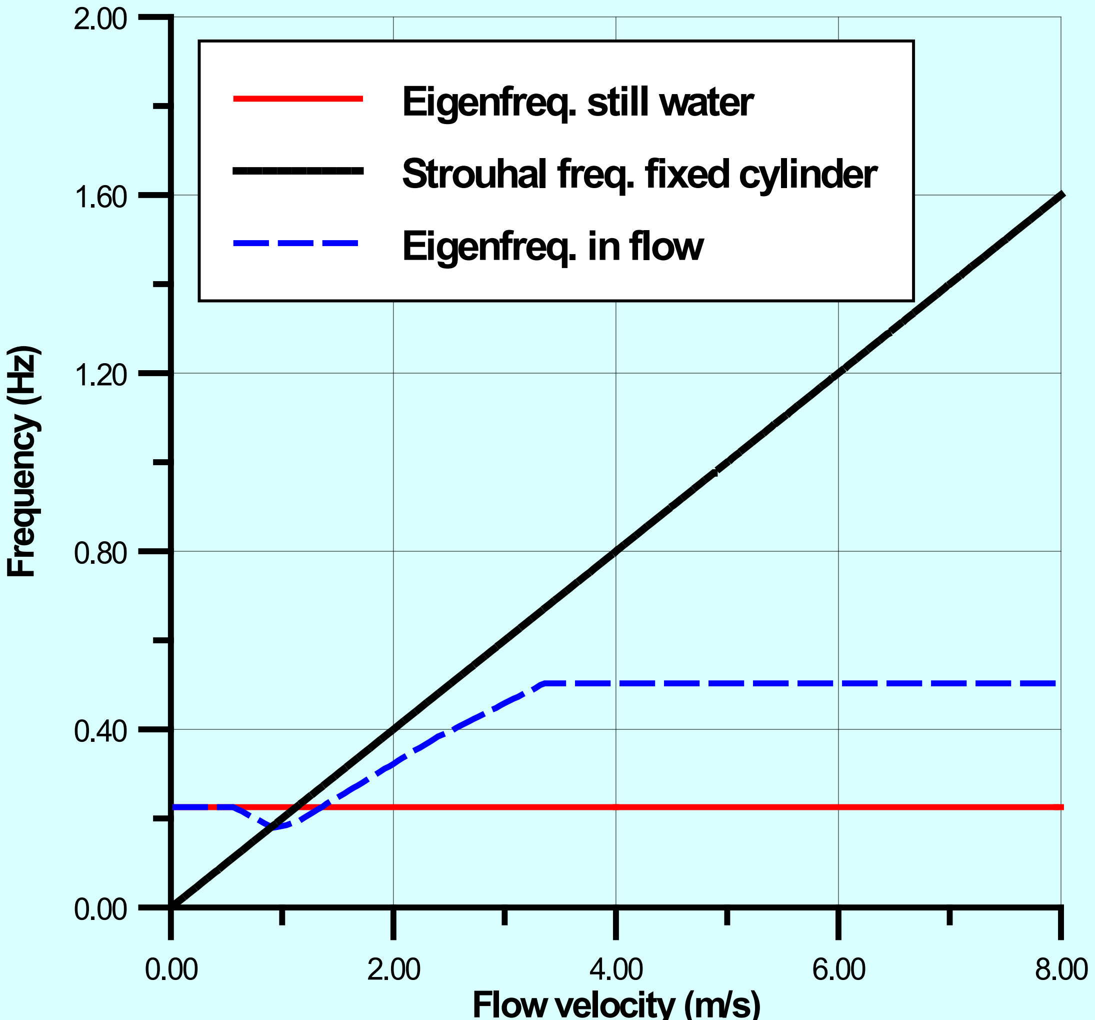
f_{osc} : Oscillation frequency

Comment on terminology:

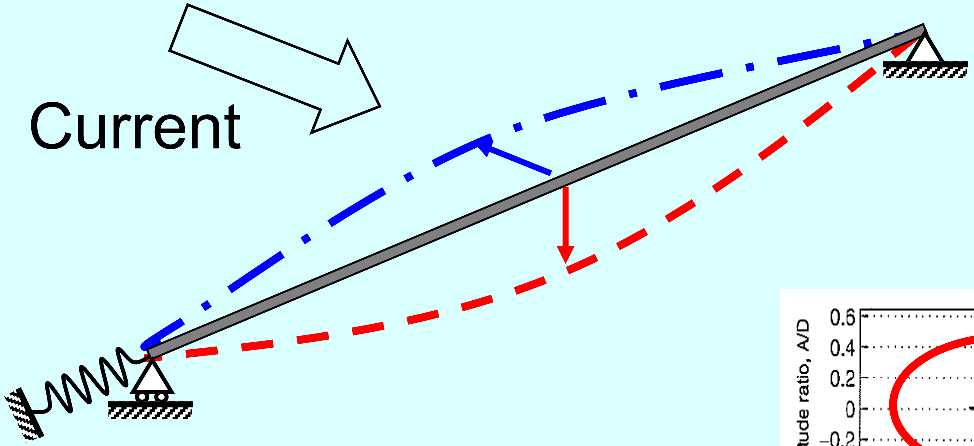
Three key parameters each linked to a frequency type:

- Reduced velocity $U_R = \dfrac{U}{D \cdot f_0}$
  Eigenfrequency, still water
- Non-dimensional frequency $\hat{f} = \dfrac{f_{osc} \cdot D}{U}$
  Oscillation (response) frequency
- Strouhal number $St = \dfrac{f_v \cdot D}{U}$
  Vortex shedding frequency, fixed cylinder

Response frequency as function of flow velocity

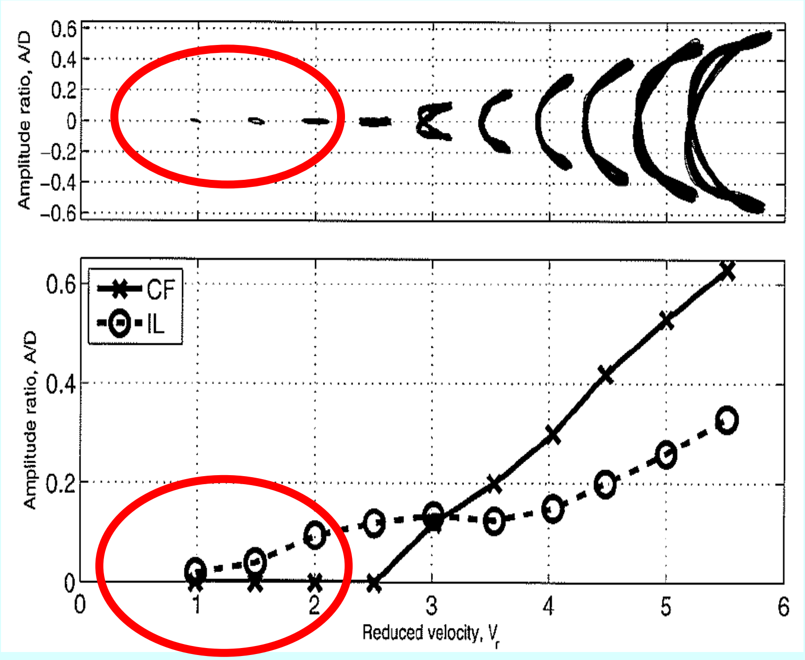


Pure IL VIV: Free spanning pipelines

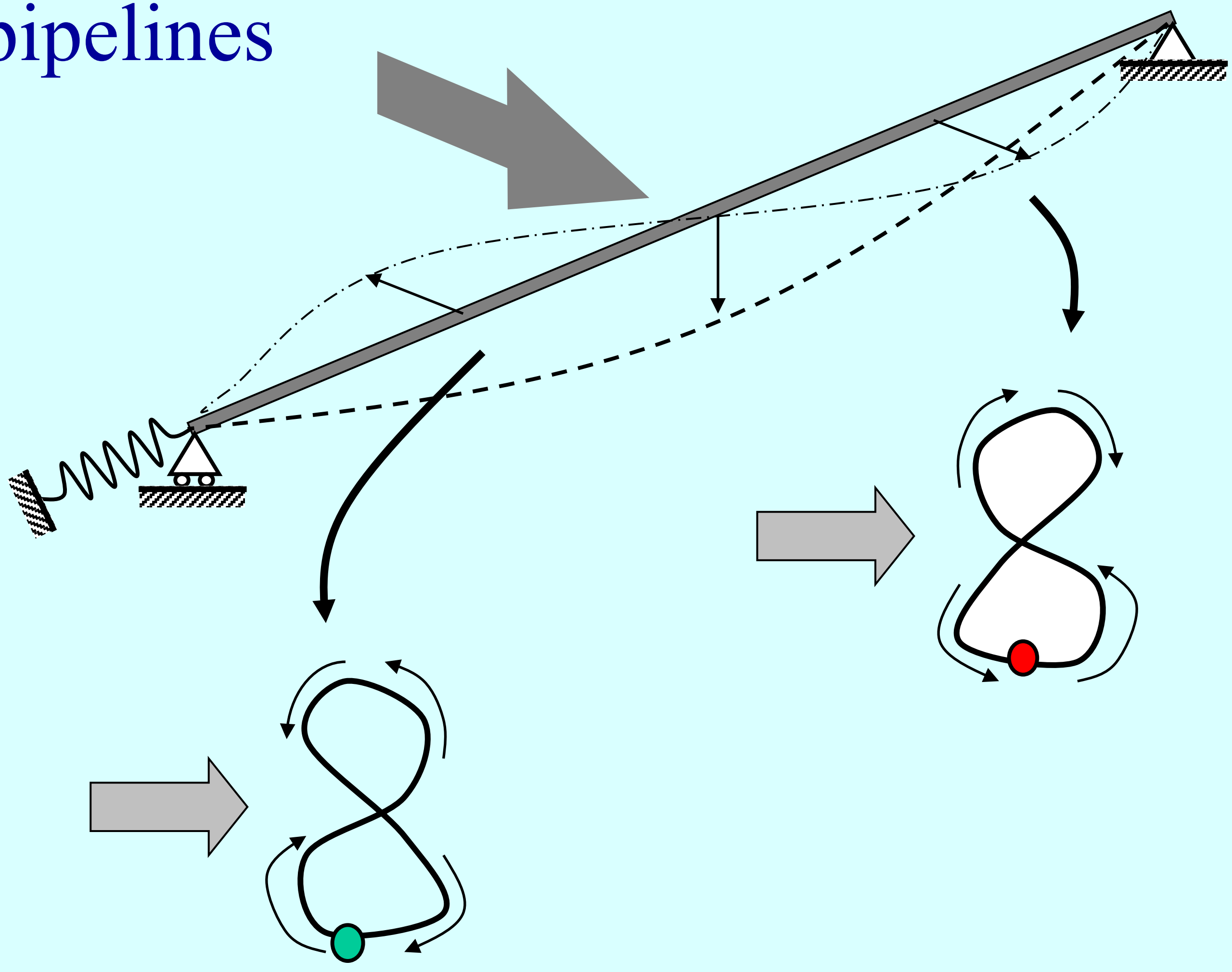


Measured orbits
From free spann model tests

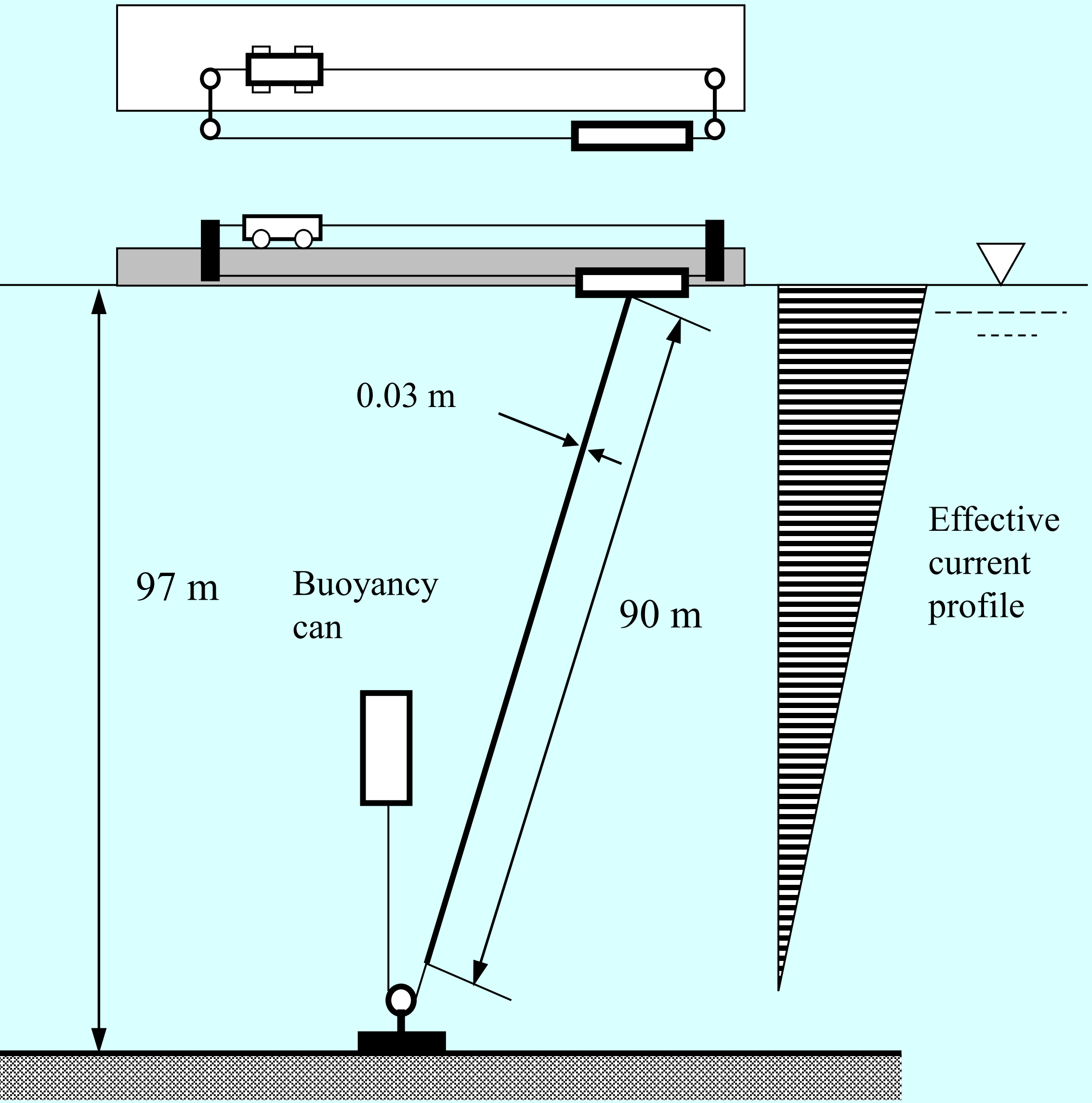
Small amplitudes, but still more fatigue damage from pure IL than CF in many cases



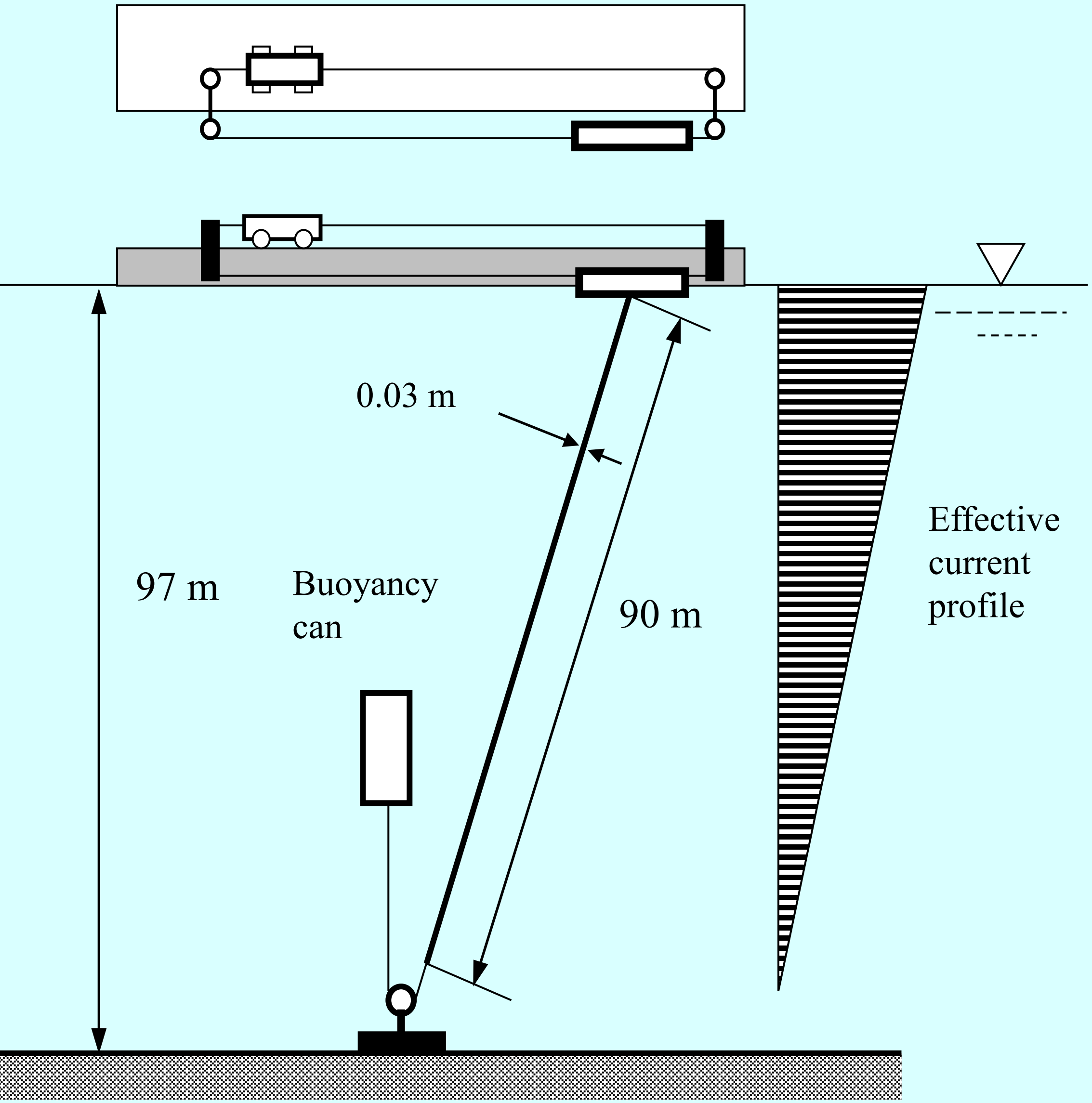
Coupling between IL and CF oscillations; free spanning pipelines

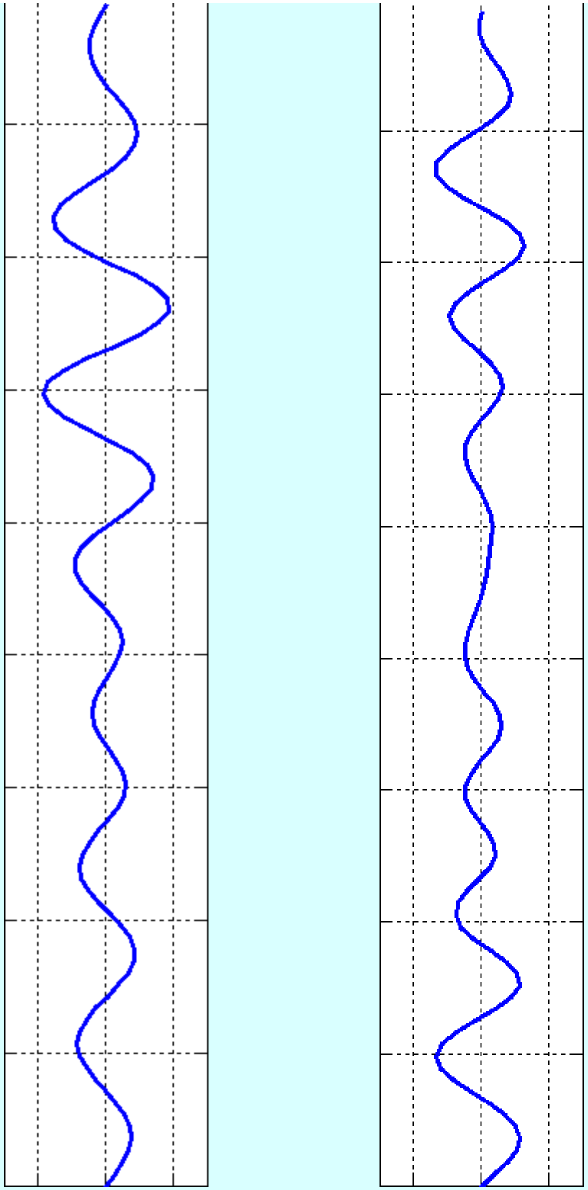


The Hanøytangen Experiment Set-Up

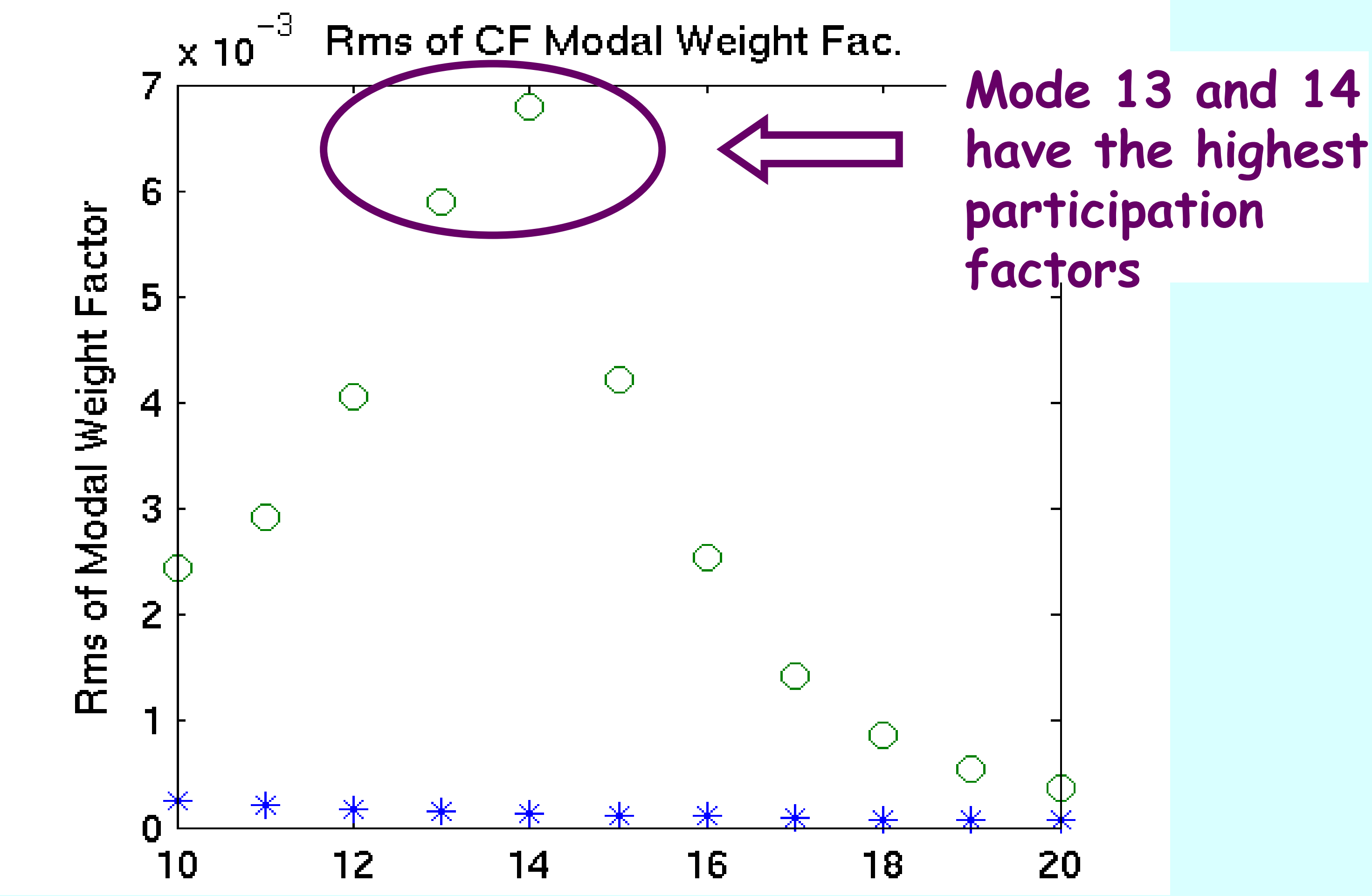


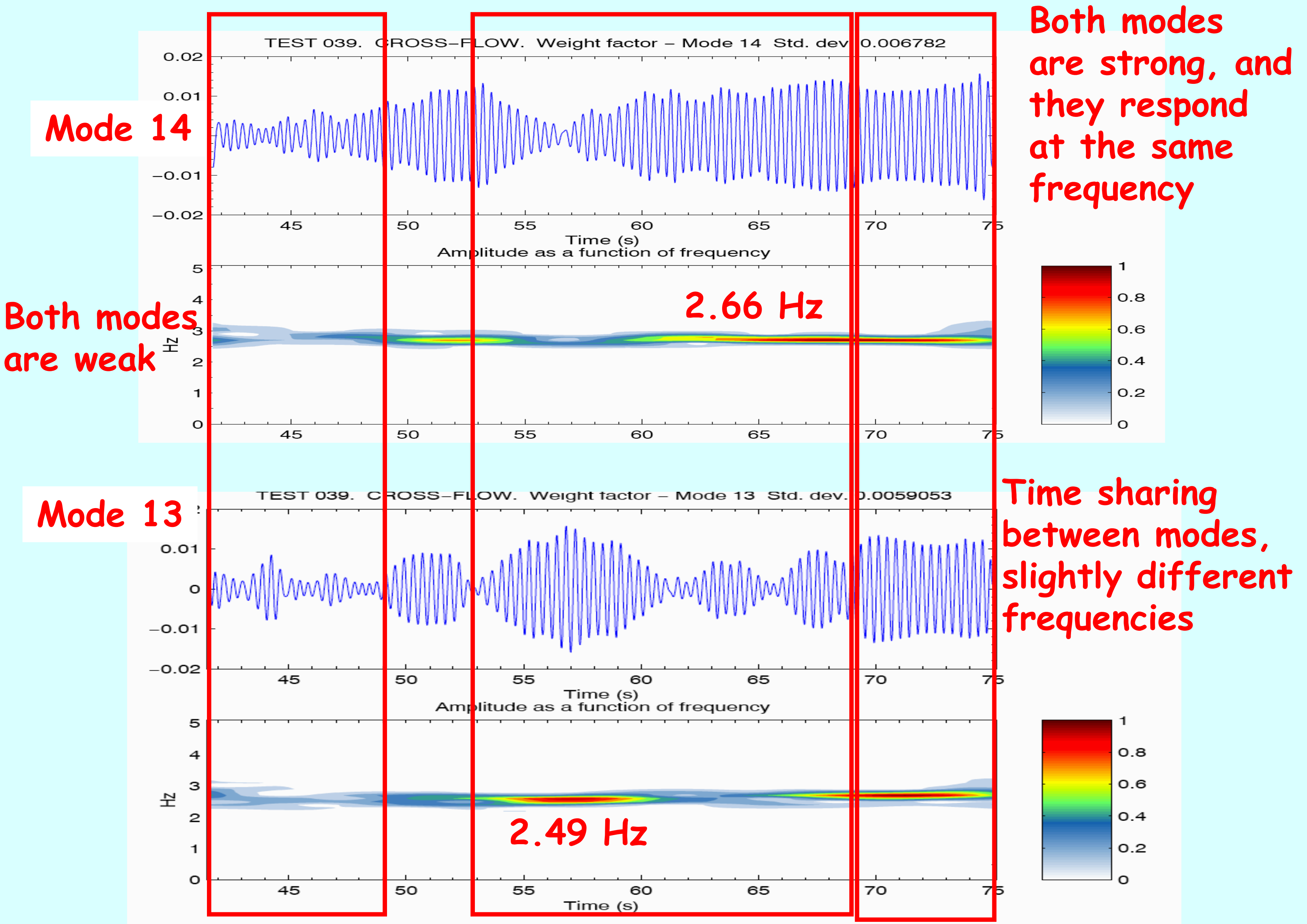
The Hanøytangen Experiment





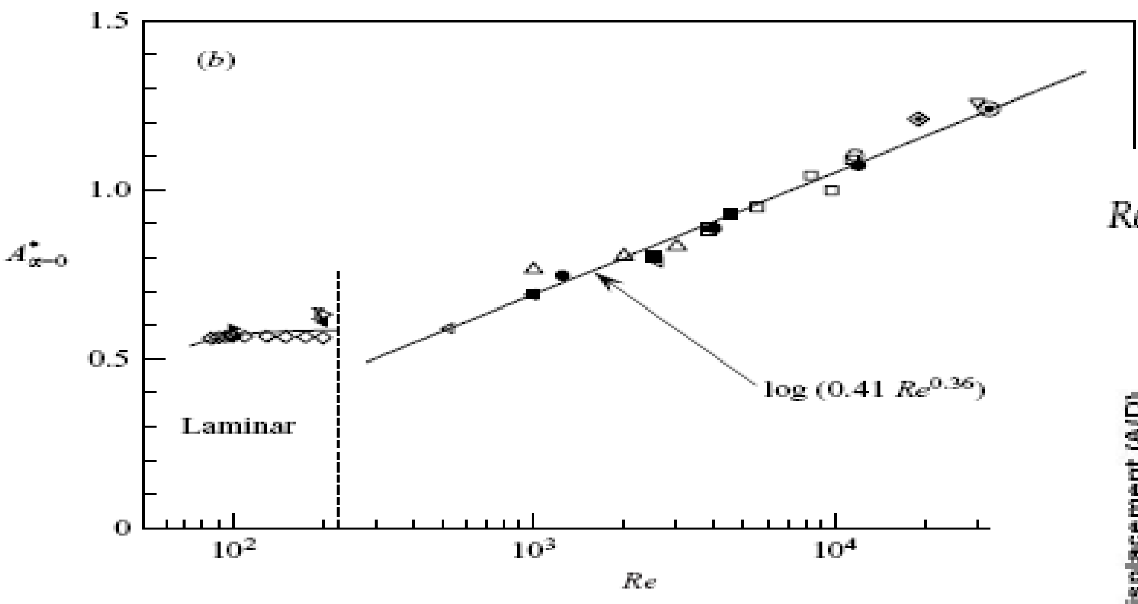
Modal analysis of one case



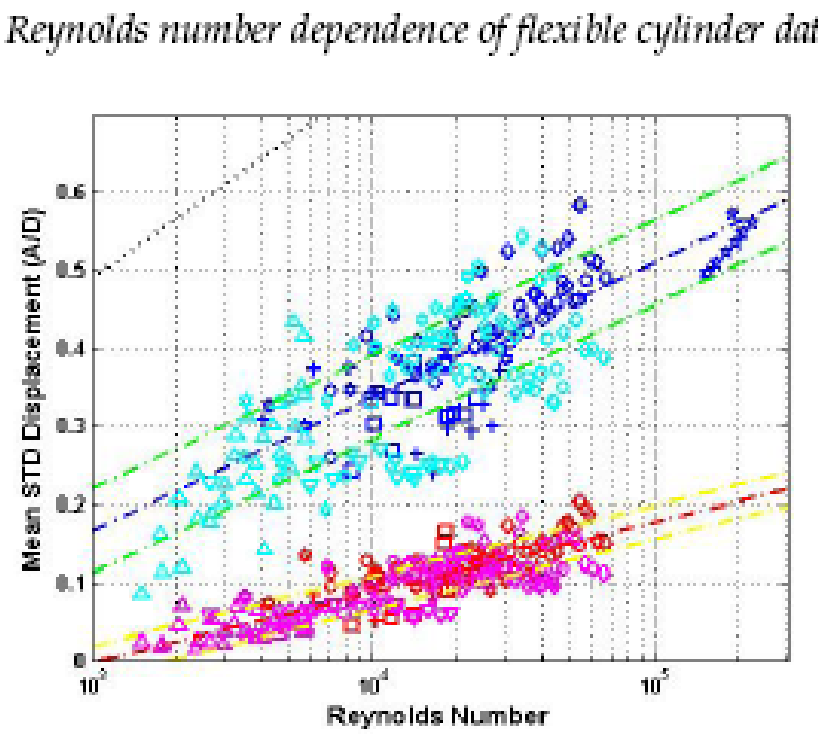

Mode 14
TEST 039. CROSS-FLOW. Weight factor – Mode 14 Std. dev. 0.006782
Time (s)
Amplitude as a function of frequency
Hz
2.66 Hz
Mode 13
TEST 039. CROSS-FLOW. Weight factor – Mode 13 Std. dev. 0.0059053
Time (s)
Amplitude as a function of frequency
Hz
2.49 Hz
Time (s)
Both modes are weak
Both modes are strong, and they respond at the same frequency
Time sharing between modes, slightly different frequencies

VIV Displacement vs. Reynolds Number

Free oscillation of rigid cylinder



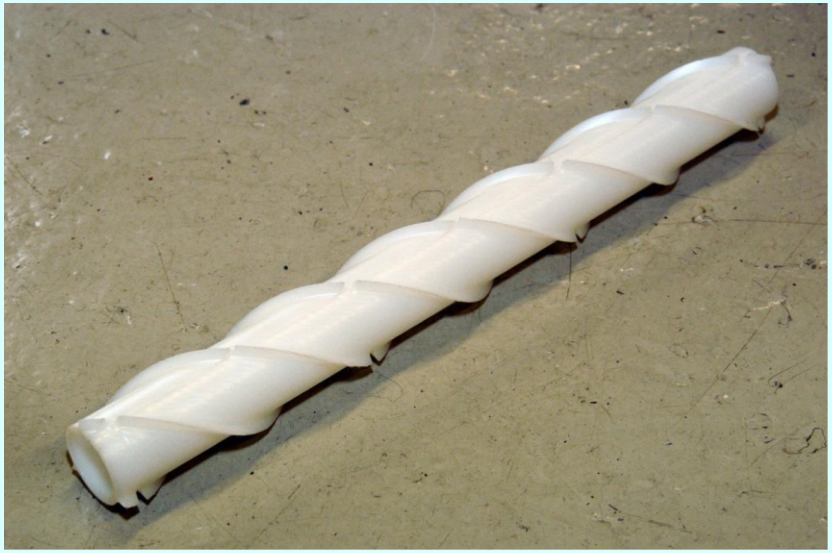
Godvardsen and Williamson



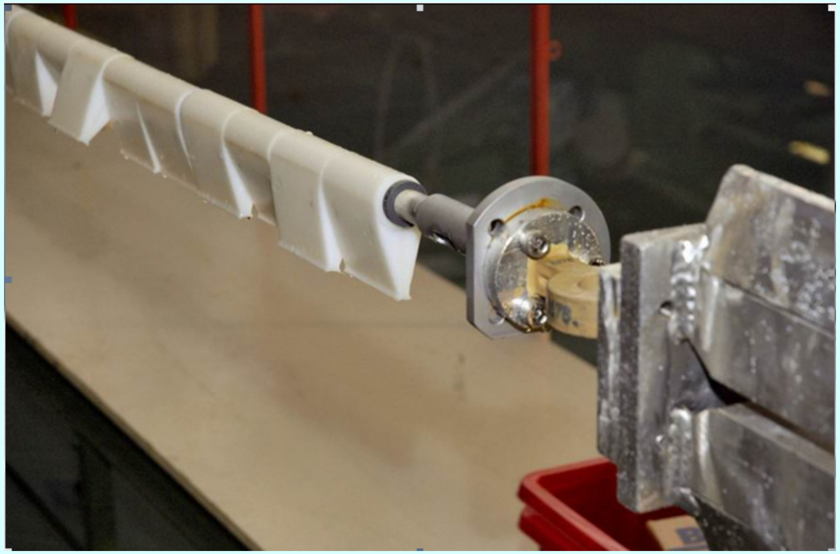
Swithenbank et al.

Suppression devices

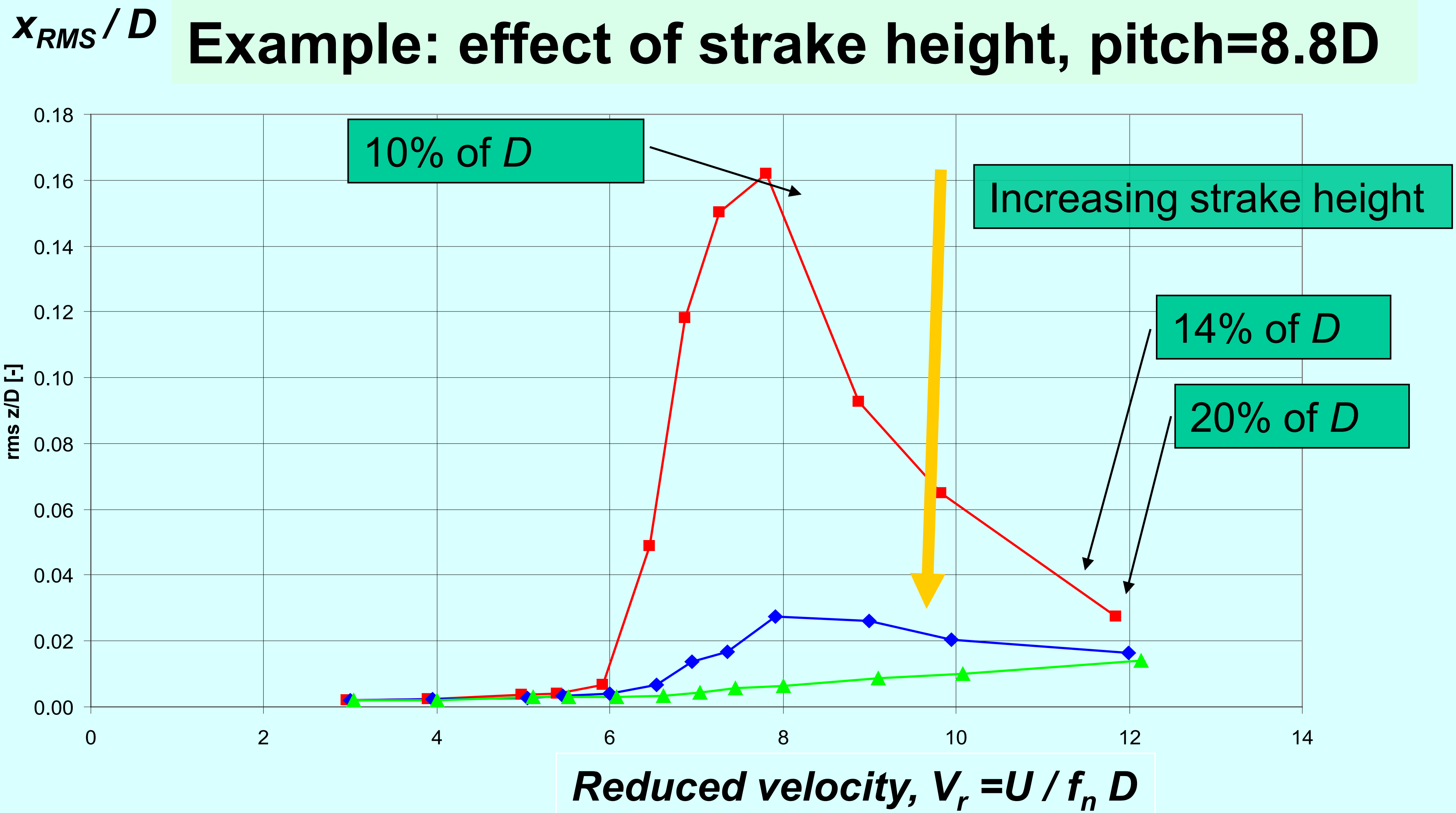
Strakes



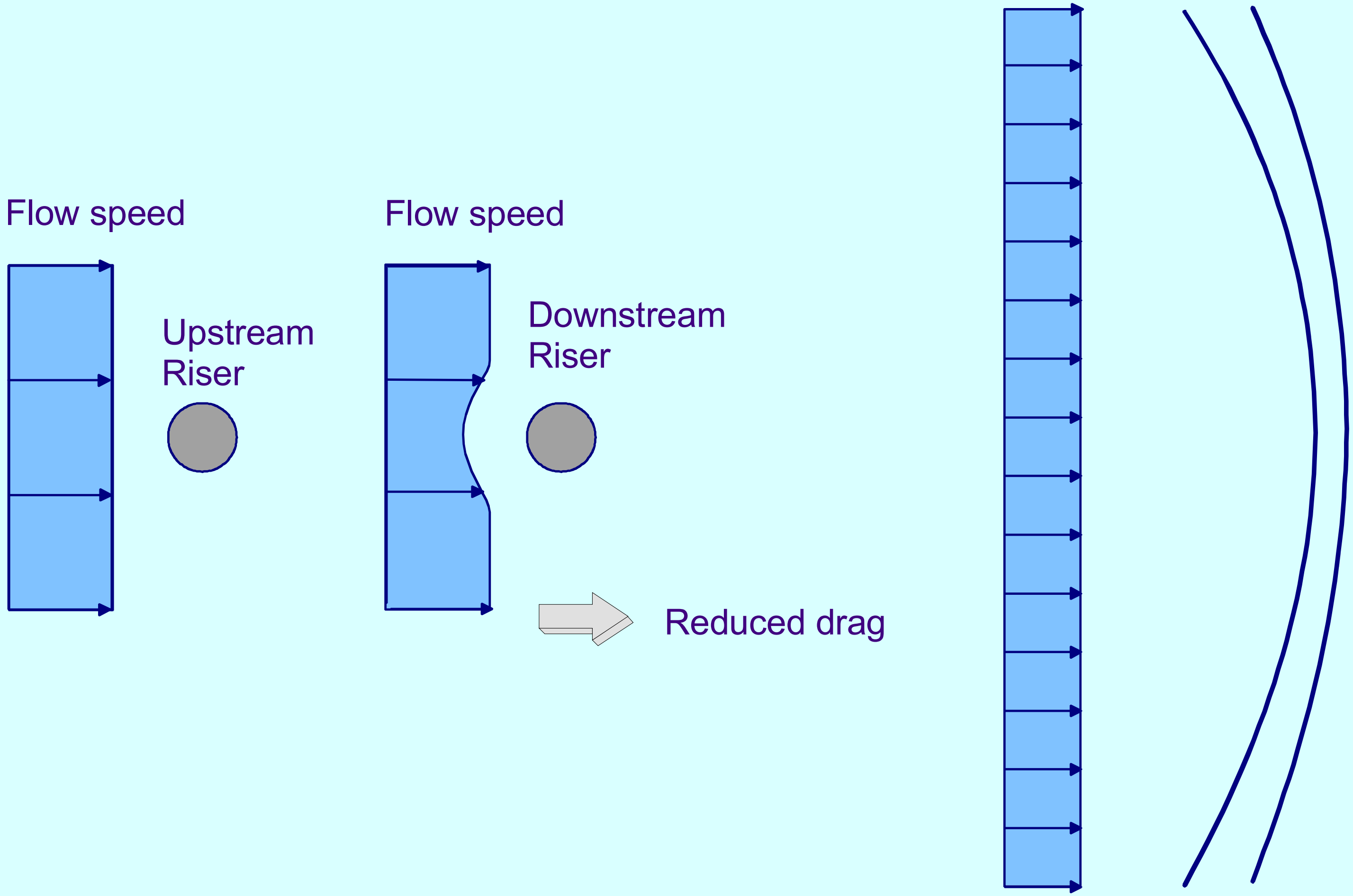
Fairings



Example: effect of strake height, pitch=8.8D



Riser interaction



REVIEW

Contents of review (last 3 years)

- General trends
- Numerical models
  - CFD (Single & multiple cylinder configuration)
  - Wake oscillators
  - Semi-empirical methods
- Experiments
  - 2D tests
  - 3D tests
  - Fields measurements

General trends

- Offshore oil and gas industry still have a strong interest in VIV of marine risers, free spanning pipelines, tethers and floating vessels.
- Great attention of research community, huge number of VIV papers both from industry and from academia
- VIV still not fully understood
- Even less for multi-cylinders

Computational Fluid Dynamics

- Prediction methods:
  - Direct numerical simulations (DNS)
  - Large Eddy Simulations (LES)
  - Reynolds Averaged Navier-Stokes (RANS)
  - Detached Eddy Simulations (DES) using finite difference, finite volume and finite element.
- Most of them are 2D or quasi 3D (strip theory)

Computational Fluid Dynamics

- A quite large number of in house and commercial codes have been developed in the past to simulate the VIV response of isolated rigid and flexible cylinders
- Recent comparisons between numerical and experimental data show promising results in terms of both in-line and cross-flow motion and of fatigue life also for long flexible risers (L/D=250) at moderately high Reynolds number.

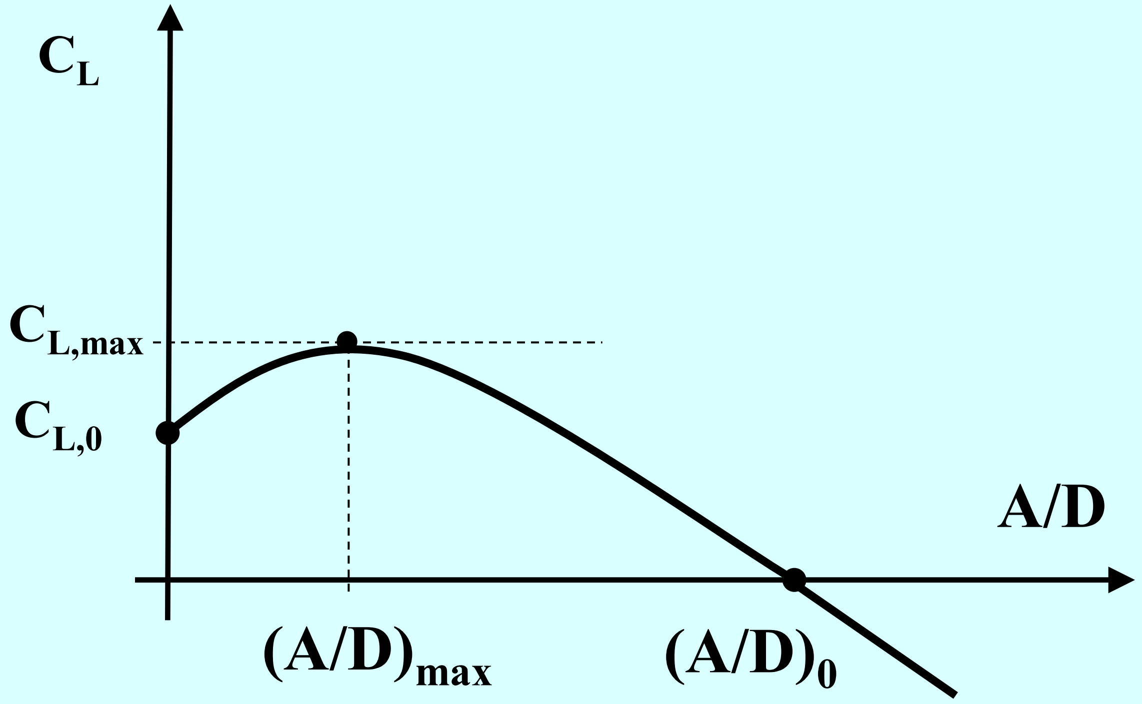
Computational Fluid Dynamics

- In last three years a great attention has been devoted to the study of multiple cylinder configurations.

Semi-empirical VIV models

- Semi-empirical models for VIV response analysis use the hydrodynamic force coefficients such as drag coefficient, lift coefficient, added mass coefficient and hydrodynamic damping coefficient as input
- These coefficients are normally obtained from rigid-cylinder model tests with forced motions

Example of lift coefficient model



Semi-empirical methods

- Semi-empirical models are still the technique currently used in the design of marine risers
- Large scatter between different codes in the fatigue damage prediction is observed leading the designers to adopt extremely large factors of safety
- There is a demand for systematic comparisons with full scale data

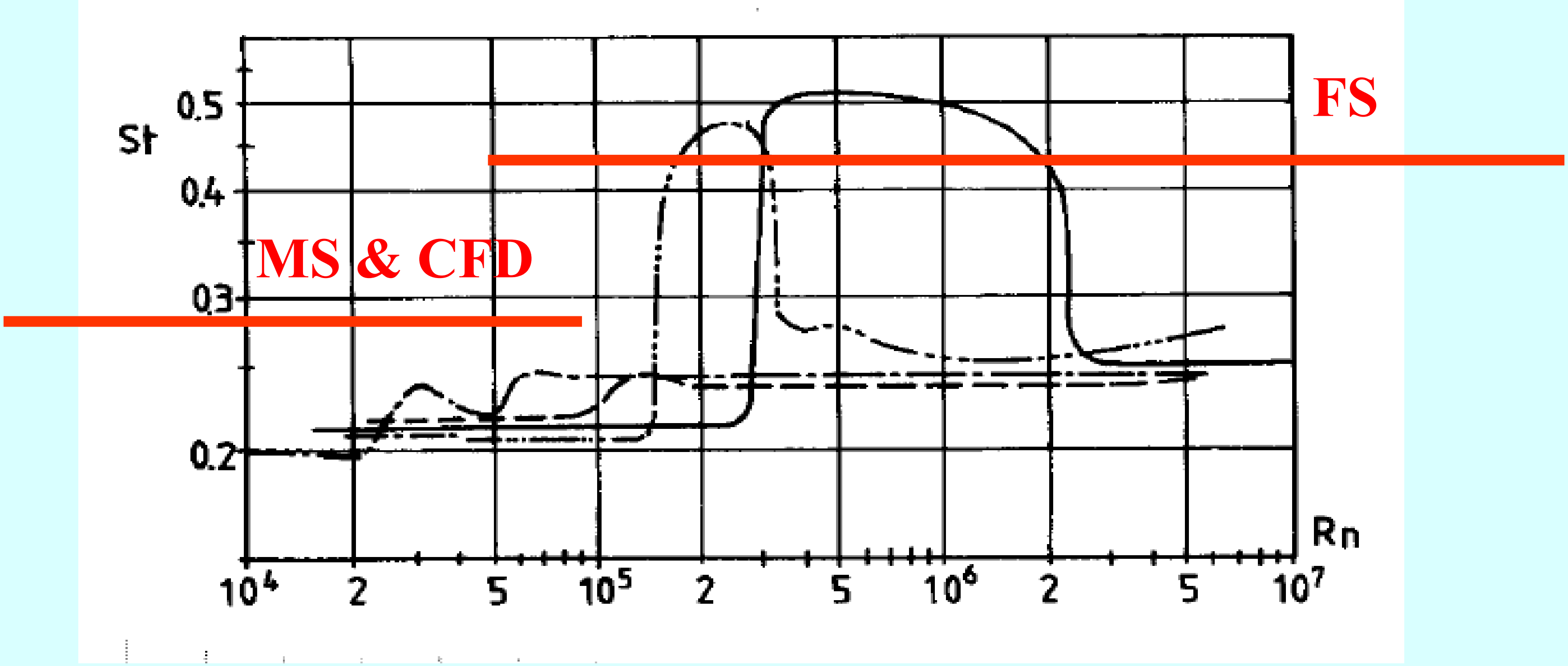
Wake Oscillator Models

- Use a van der Pol oscillator to represent the time-varying force, which is coupled to body motion
- The models generally have the following characteristics
  - Oscillator is self-exciting and self-limiting
  - Natural frequency of the oscillator is proportional to the free stream velocity such that the Strouhal relationship is satisfied
  - Cylinder motion interacts with the oscillator

Wake oscillator models

- Wake oscillator has received a renewed attention
- Sophisticated wake oscillator models have been developed in last three years but most of the results obtained show only a qualitative agreement with experimental observations.

Strouhal Number vs. Reynolds Number



Experimental studies

- Still a lack of high Reynolds number model test and full scale measurement data devoted to the determination of the coefficients used in the semi-empirical codes

- For validation of prediction tools and for further research of VIV new experiments are needed for both single and multiple flexible cylinders at moderate and high Reynolds numbers for both bare cylinders and for cylinders with suppression devices (e.g. strakes and fairings)

Experimental studies

- Some flow field measurements performed by PIV technique are available for validation of numerical codes. New PIV experimental campaigns should be performed specifically devoted to CFD validation at high Reynolds number for single cylinder and at low and high Re for the multiple cylinder configurations.

BENCHMARK STUDY

Objectives of the proposed benchmark study

- To ascertain uncertainties in VIV model testing
- To compare results from different tank organizations
- To provide a set of authoritative experimental data for verifying CFD results
- ITTC VIV committee has establish cooperation with OMAE on the benchmark activity, where ITTC can provide valuable experimental data to OMAE and OMAE provide benchmark of CFD data vs. measurement data
- The test results will be presented anonymous

Specification of benchmark test

- Vr range from 2 to16, preferably up to 20, with an increment 0.1 or less
- L/D ratio 8-15
- Effective cylinder mass to displaced fluid mass ratio around 2 (within range 1-3)
- Cross-flow vibration only
- No in-line nor rotational motion
- Re number range (sub-critical) $15{,}000 < Rn < 100{,}000$
- Turbulence level low
- Roughness of cylinder low
- Low structural damping (in air) $< 2\%$ of the critical damping, preferably $< 1\%$
- Endplates, or other means, to remove the end effects

Specification of benchmark test, cont.

- Measurements: Towing speed, cross-flow motion, preferably drag and lift as well
- Sampling rate:100 points per oscillating cycle
- Data processing: Amplitude (with its definition) or standard deviation of cross-flow (and in-line) motions, and drag and lift.
- Steady response duration: at least 30 cross-flow oscillation cycles in the steady state condition, preferably 50 or more
- Preferable PIV measurement of the flow (for validation of CFD results)

Participants

- The benchmark study initially 7 participants
  - 2 withdrew
  - 2 reported unforeseen delay

- By summer 2011 we have results from the following institutions
  - MARINTEK, Norway
  - INSEAN, Italy
  - University of Strathclyde. UK

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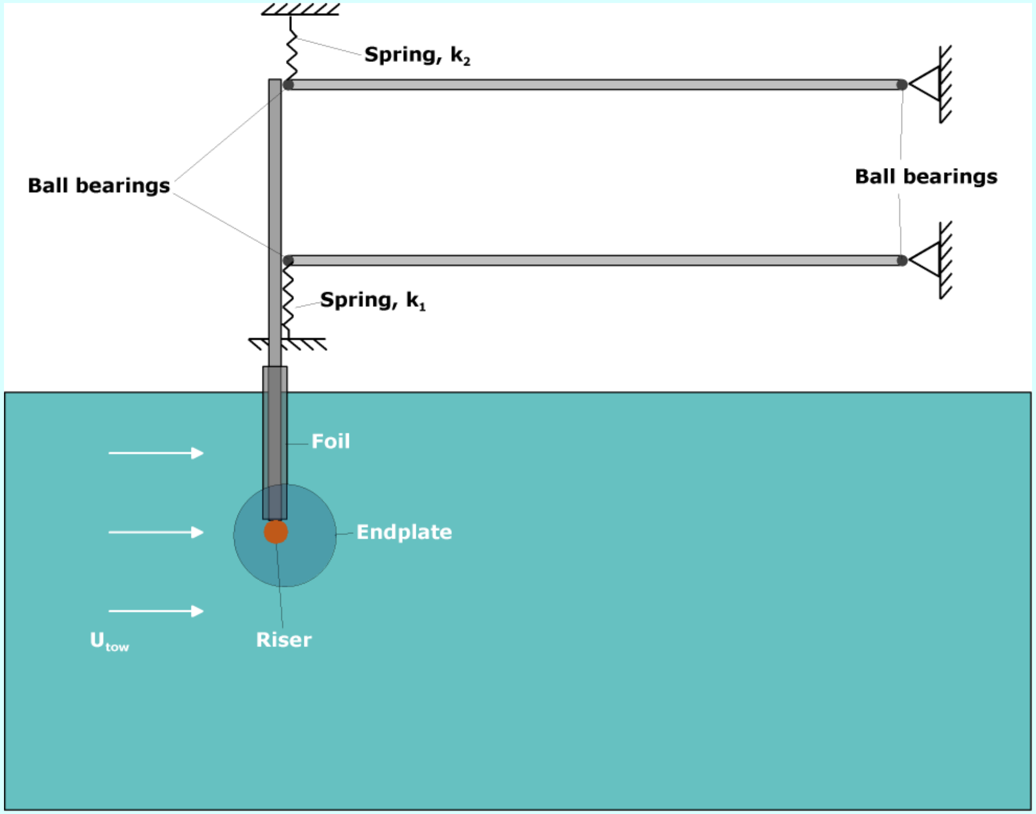
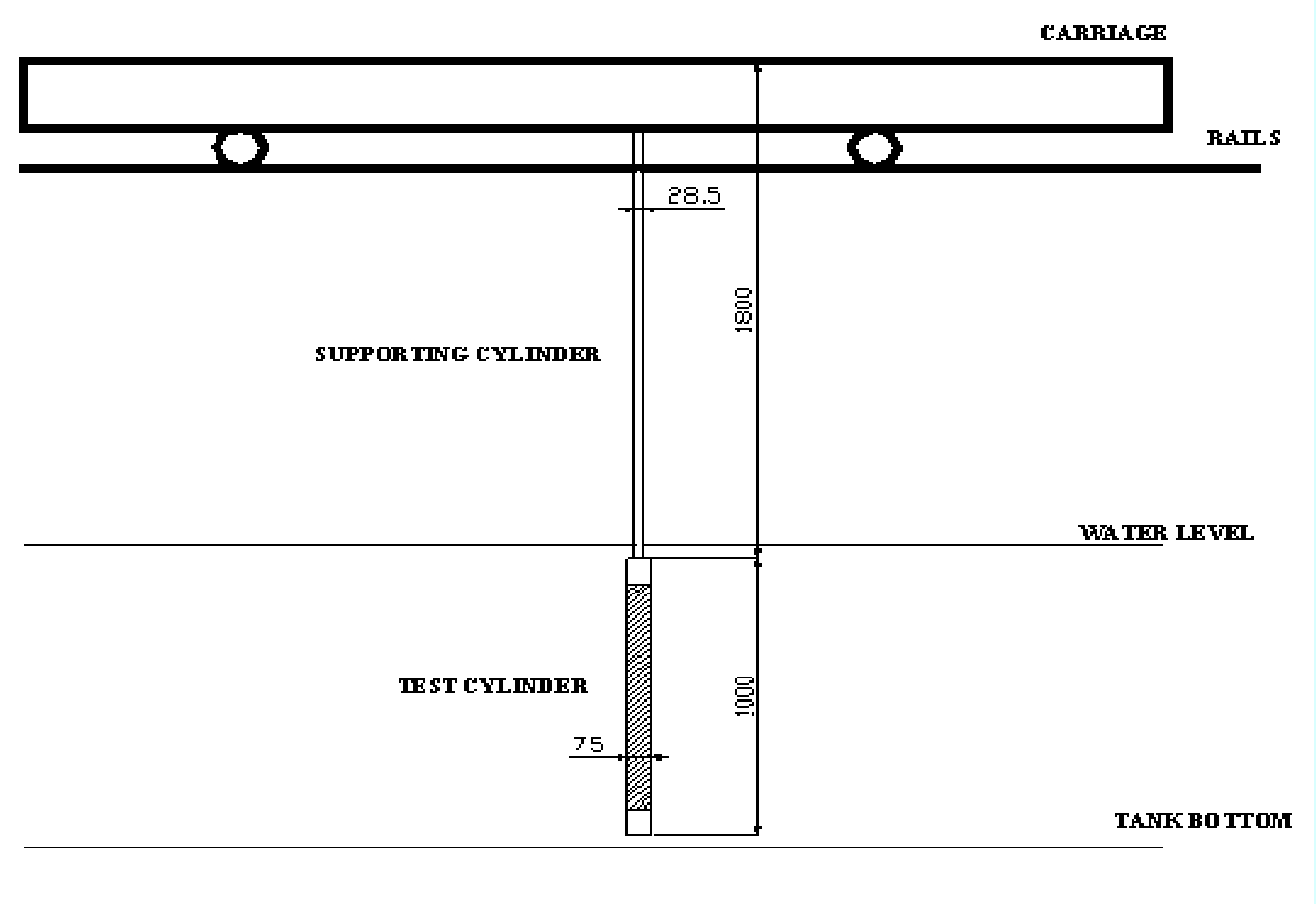
Activity suggested to continue in ITTC27:
NEW PARTICIPANT HEARTLY WELLCOME !

VIV Benchmark Study

- VIV testing of elastic mounted rigid cylinder
- Example of test set-up

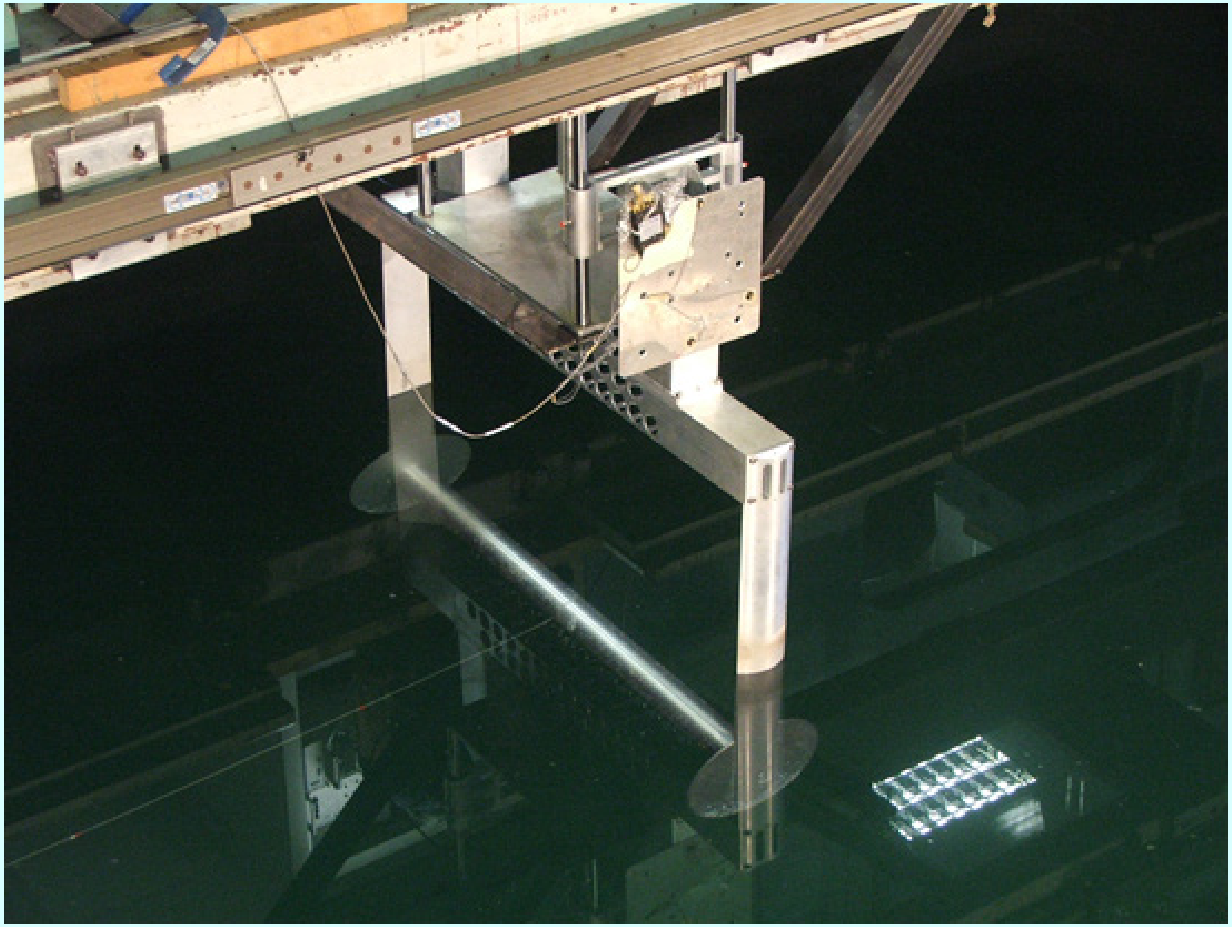


VIV Benchmark Study Example of test rig

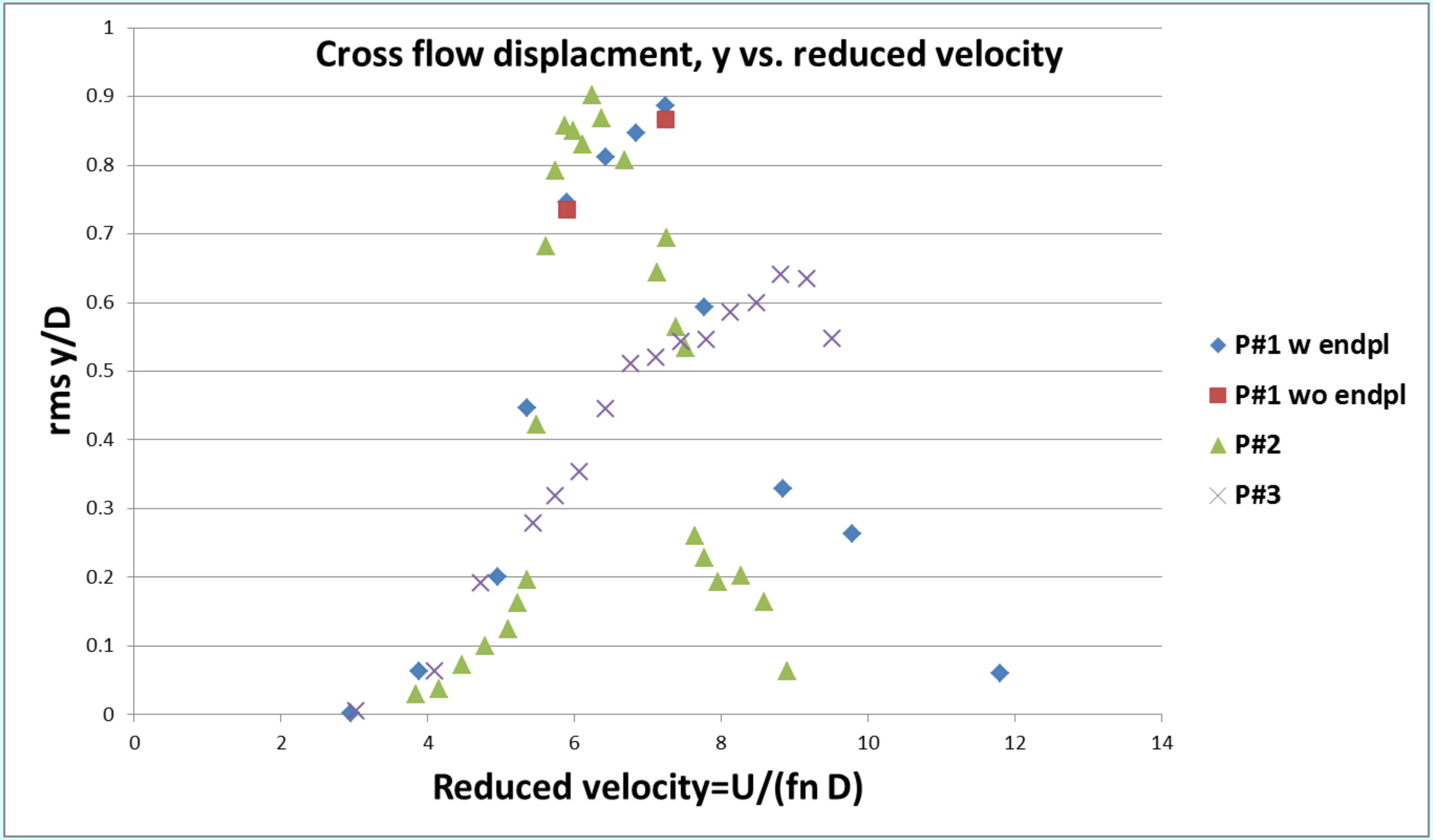


VIV Benchmark Study

- **Example of test rig**



VIV Benchmark Study - Example of tentative results



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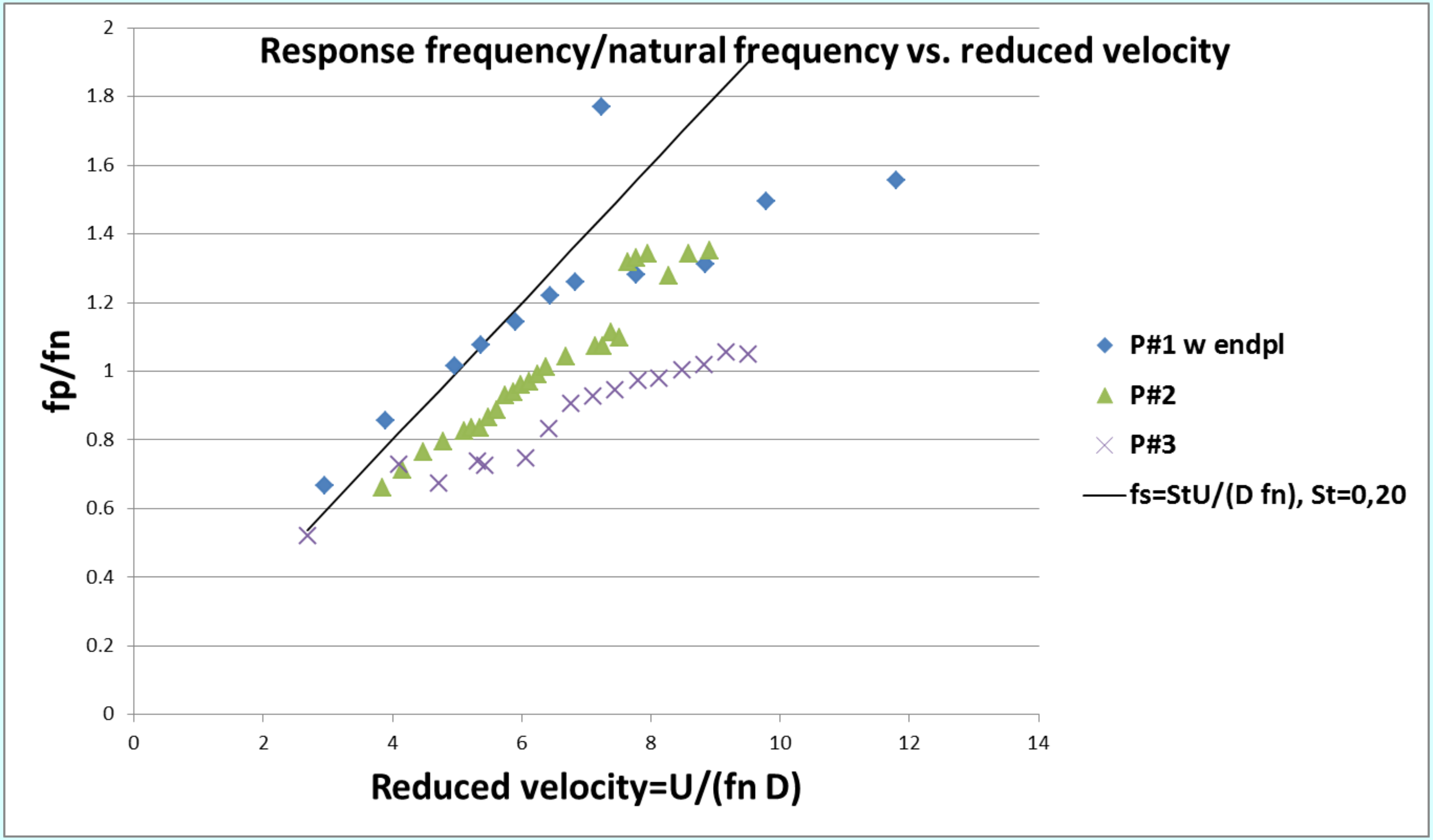
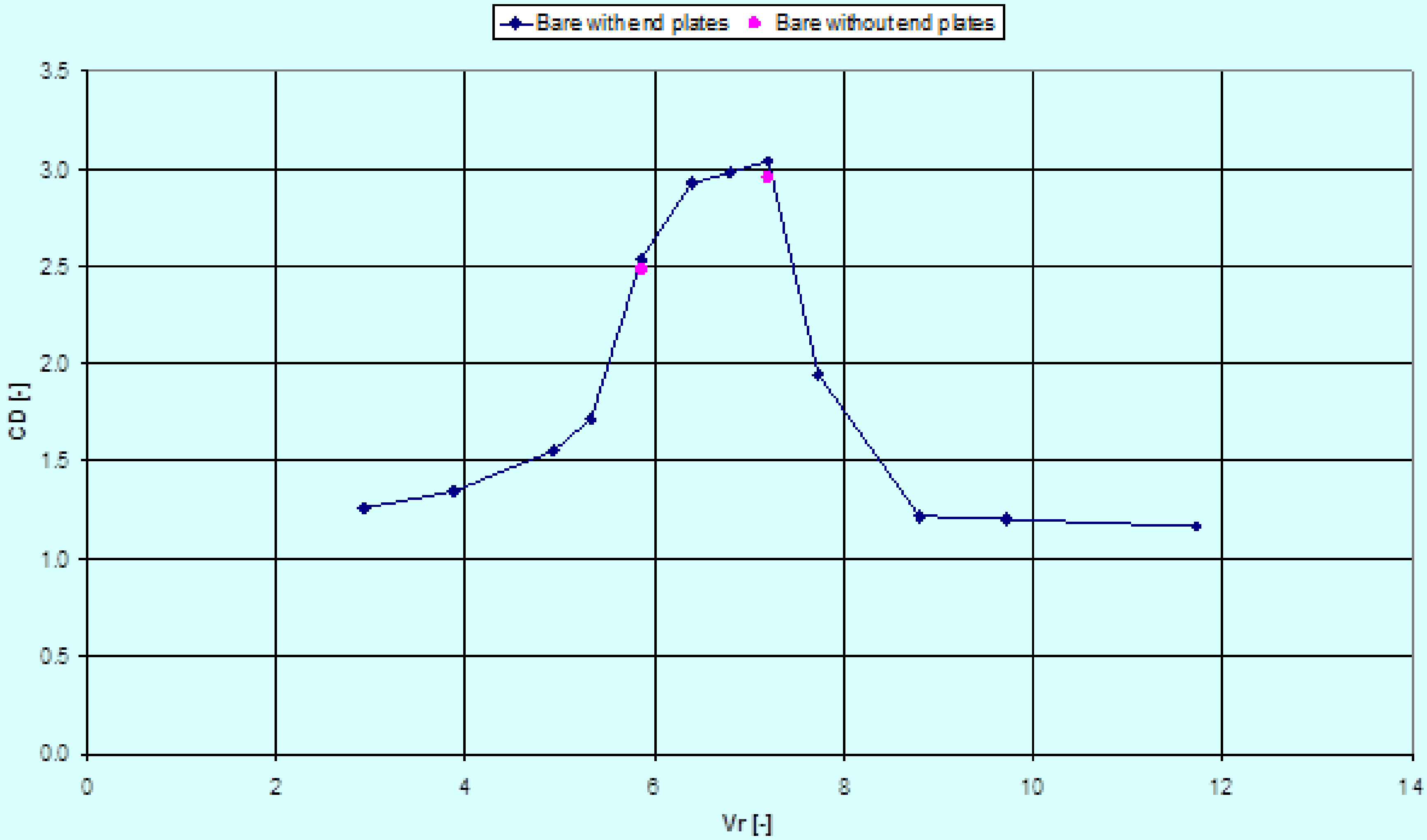


VIV Benchmark Study - Example of tentative results: CD vs. Vr



NOMENCLATURE

Nomenclature, Extracted Symbols

A	Displacement amplitude
C_a	Added mass coefficient
C_e	Excitation coefficient, i.e. force coefficient in phase with cylinder velocity
C_D	Drag coefficient
C_L	Lift coefficient
D	Cylinder diameter
f_0	Natural frequency in still water
f_{osc}	Oscillation frequency
f_s	Vortex shedding frequency
$\hat{f}$	Non-dimensional frequency, $\frac{f_{osc}D}{U}$
m_a	Hydrodynamic mass per unit length, $m_a = C_a A_e \rho$. For a circular cylinder, $m_a = C_a \frac{\pi}{4} D^2 \rho$

m_s	Mass per unit length (including internal fluid)
m_e	Effective mass per unit length, $m_e = m_a + m_s$
$\overline{m}$	Mass ratio, $\overline{m} = \frac{m_s}{m_a}$ where Ca=1
R_e	Reynolds number, $\frac{DU}{\upsilon}$
S_t	Strouhal number, $\frac{f_s D}{U}$
U	Flow velocity
V_r	Reduced velocity, $\frac{U}{f_0 D}$
$V_{r,osc}$	Reduced velocity (oscillating cylinder), $\frac{1}{\hat{f}}$

PROCEDURE FOR VIV AND VIM TESTING

Guideline (GL) for VIV and VIM Testing

- Purpose of GL is to ensure that laboratory model test of vortex induced responses are adequately performed and documented.
- VIV and VIM testing has much in common with floating offshore platform experiments. Hence it is recommended to also confer Procedure 7.5-02-07-03.1 *Floating Offshore Platform Experiments*
- The new GL focus on topics that are particular important for VIV/VIM testing
- Status: Draft prepared and sent to AC for comment

Guideline for VIV and VIM Testing

1. INTRODUCTION
2. GL FOR VIV & VIM TESTING
2.1 Test Agenda and Run Matrix
2.2 Model Scaling and Geometry
2.3 Test Rig
2.4 Instrumentation
2.5 Calibration of Current
2.6 Collection of data
2.7 Data Analysis
2.8 Presentation of Results
2.9 Pre-Test considerations
2.9.1 Instrumentation Sign Check
2.9.2 Calm Water Acquisition
2.9.3 Acquisition from calm water
2.9.4 Decay and pluck tests in air
2.9.5 Decay and pluck tests in water
2.9.6 Pluck test on test rig

Guideline for VIV and VIM Testing

- Remaining work:
  - Include effect of VIV/VIM due to marine growth
  - Test of riser interaction
  - Minor improvement of the text
- The 26 ITTC-VIV Committee recommends that the GL should be completed in the next ITTC period

Summary of Activities

- Task 1. The review is presented in the proceedings.
- Task 2. The benchmark study initially 7 participants. 2 withdrew and 2 reported unforeseen delay. Therefore results from only 3 participants were reported in the end of spring 2011. Considered too sparring for the benchmark study. The committee recommends ITTC to continue and complete the Benchmark study in the next ITTC period.
- Task 3. A nomenclature is included in the review.
- Task 4. The committee has made a draft version of a guide line (GL) and recommends that the GL should be completed during the next ITTC period

Thank you for your attention!