Free Spanning Pipelines

Discussion Session

Wind Induced Vibrations

presented by

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Content of presentation

- WiV examples
- Wind modelling
- Wind loads
- WiV state-of-the-art
- Case studies from North slope pipelines

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Wind Induced Vibrations – The true picture!

- The Tacoma bridge disaster : On November 7, 1940, at approximately 11:00 AM, the first Tacoma Narrows suspension bridge collapsed due to wind-induced vibrations. Situated on the Tacoma Narrows in Puget Sound, near the city of Tacoma, Washington, the bridge had only been open for traffic a few months. There is a short video of the bridge just before break-down.

- Vibrations of stay cables

Wind Induced Vibrations – Pipelines

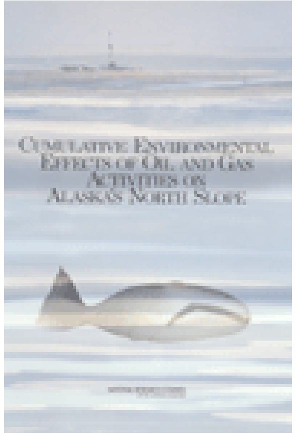
Spill Prevention

State and federal regulatory agencies and the oil industry have studied each spill incident, to develop "lessons learned" and measures to reduce the likelihood and effects of future spills. For example, the 575 bbl (24,150 gallons) crude oil spill that occurred on 30 December 1993 (Table F-2) resulted when wind-induced vibration caused a crack in a flowline leading from a well house to the manifold building. Although this failure mode was anticipated and "first generation" wind-induced vibration dampers had been developed, they were not installed on this pipeline. Immediately following the spill, the pipeline was fitted with a vibration damper, along with all other pipelines not already fitted. The design was also improved as a result (Norris et al. 2000). Dampers are required only on pipelines less than 24 in. (61 cm) in diameter, oriented perpendicular to prevailing east-west winds and having a specific weld type (Norris et al. 2000).

Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope (2003)

1999 : A six-foot section of the Badami crude oil pipeline was replaced after a crack was discovered that had been caused by wind induced vibration.

Source: http://www.jpo.doi.gov/events.htm Joint Pipeline Office: Anchorage, Alaska



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Wind Induced Vibrations – Elevated pipelines

Northstar pipelines

- The overland portion is supported 5 feet above the tundra:
  - to prevent thawing of permafrost soils and
  - to avoid blocking caribou herd migrations
- Optimisation of support locations is usually performed.

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Wind Measurements

45 m mast

- Field measurements
- Satellite Winds

- Wind speed at 5, 10, 20, 42, & 46 m above land surface (+4 m)
- Wind direction at 45 m
- Air temperature at 5 & 45 m

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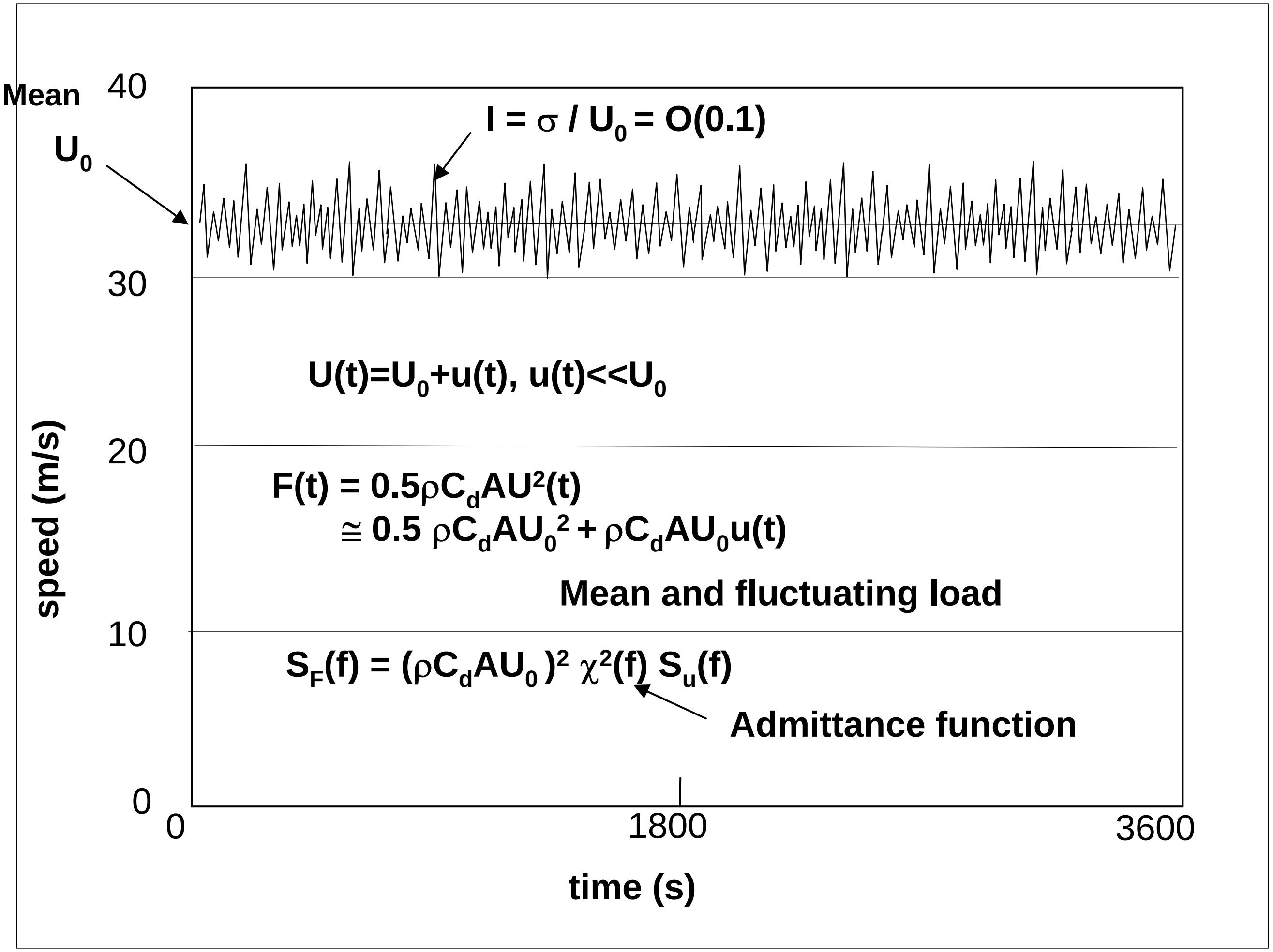
Idealized Wind Record



Effect of imperfect correlation of wind fluctuations is introduced conveniently through an aerodynamic admittance function.

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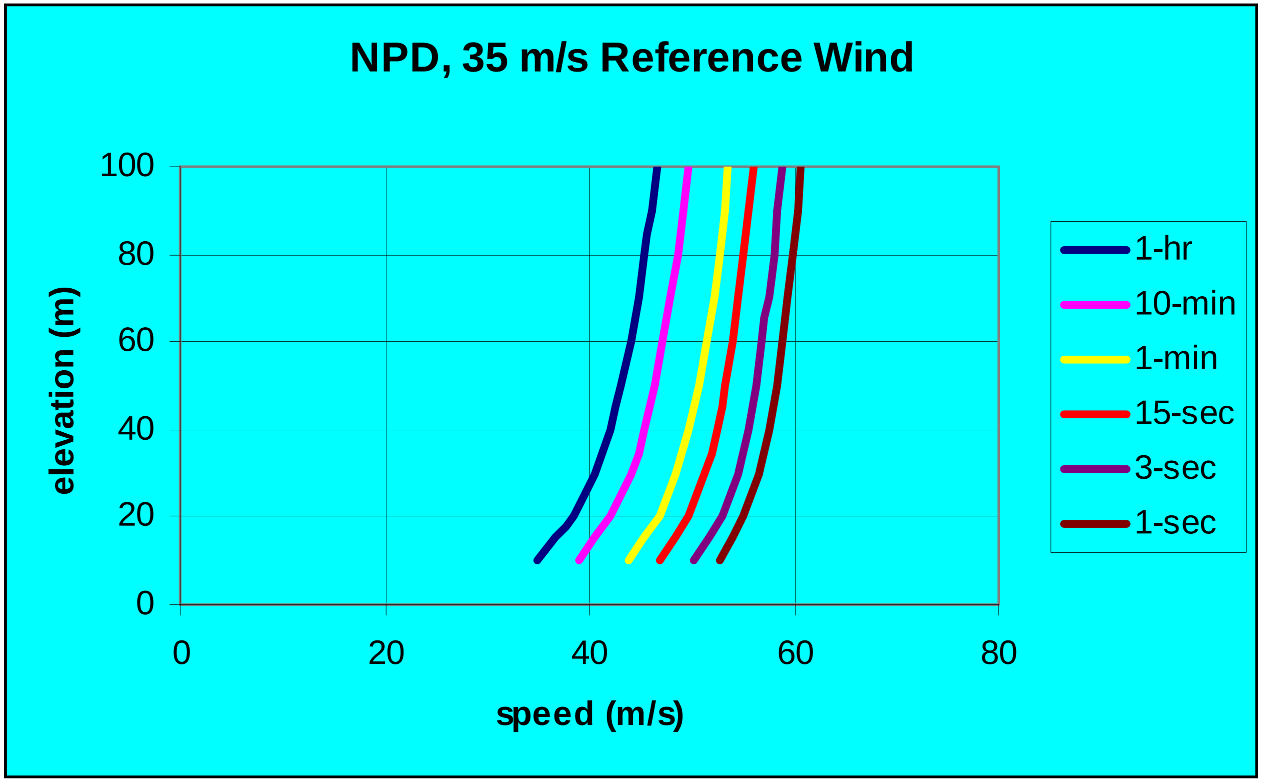
Wind Induced Vibrations – Wind modelling

$$\overline{U}(z) = \overline{U}_{ref}\left(\frac{z}{z_{ref}}\right)^{\alpha}$$

- The vertical variation of the mean wind velocity, U , can be represented by a logarithmic relationship, or by a power law.
- z_{ref} is the reference height, U_{ref} is the mean reference velocity, and α is a constant that varies with the roughness of the terrain.

Profiles of Wind Speed



Shorter gusts have more uniform profiles.

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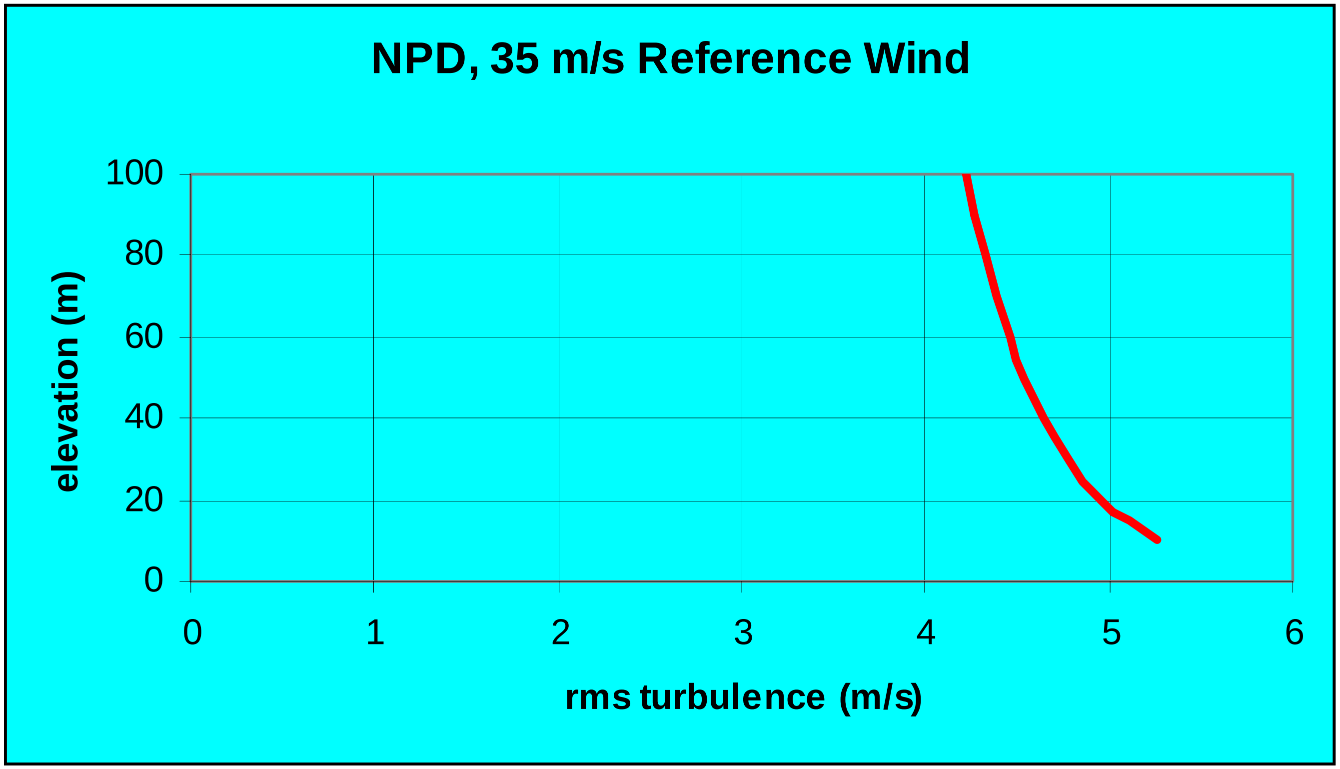
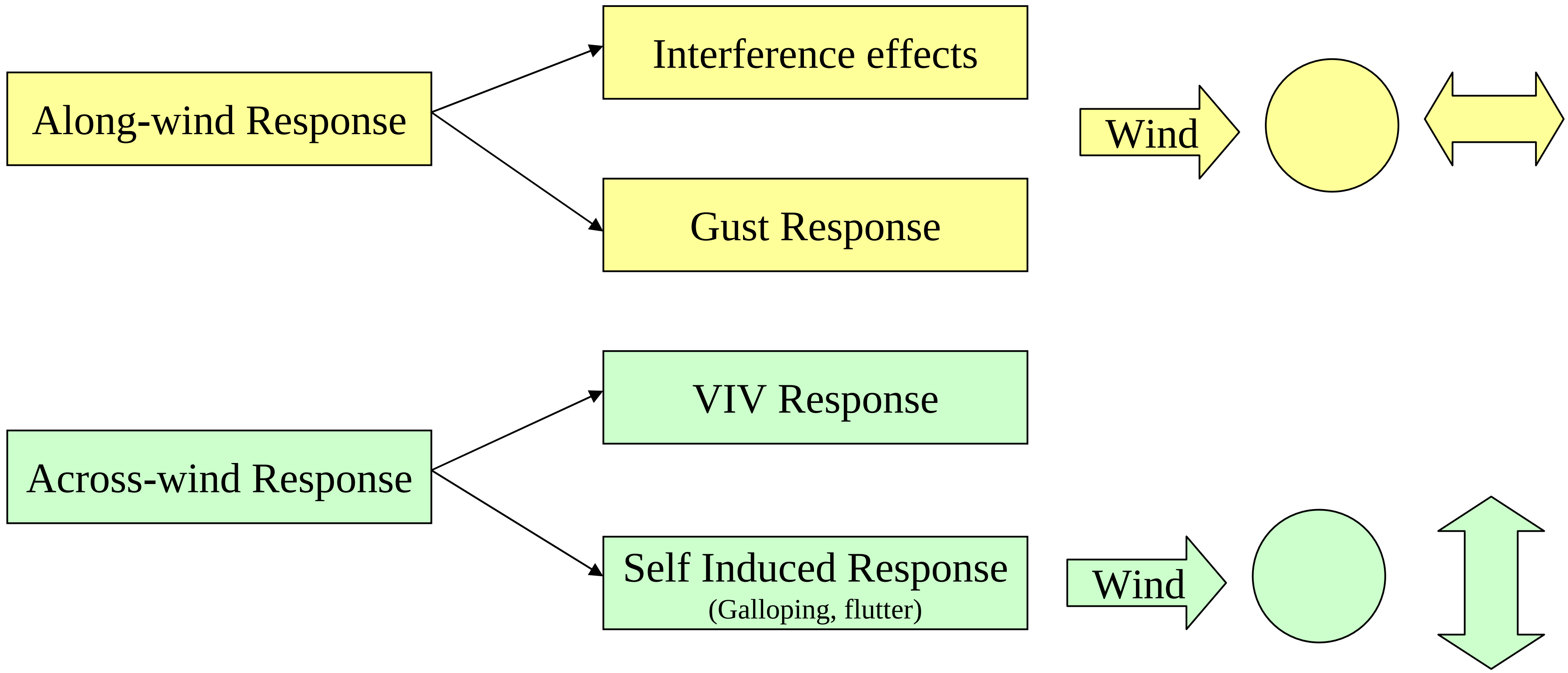
Profile of RMS Turbulence

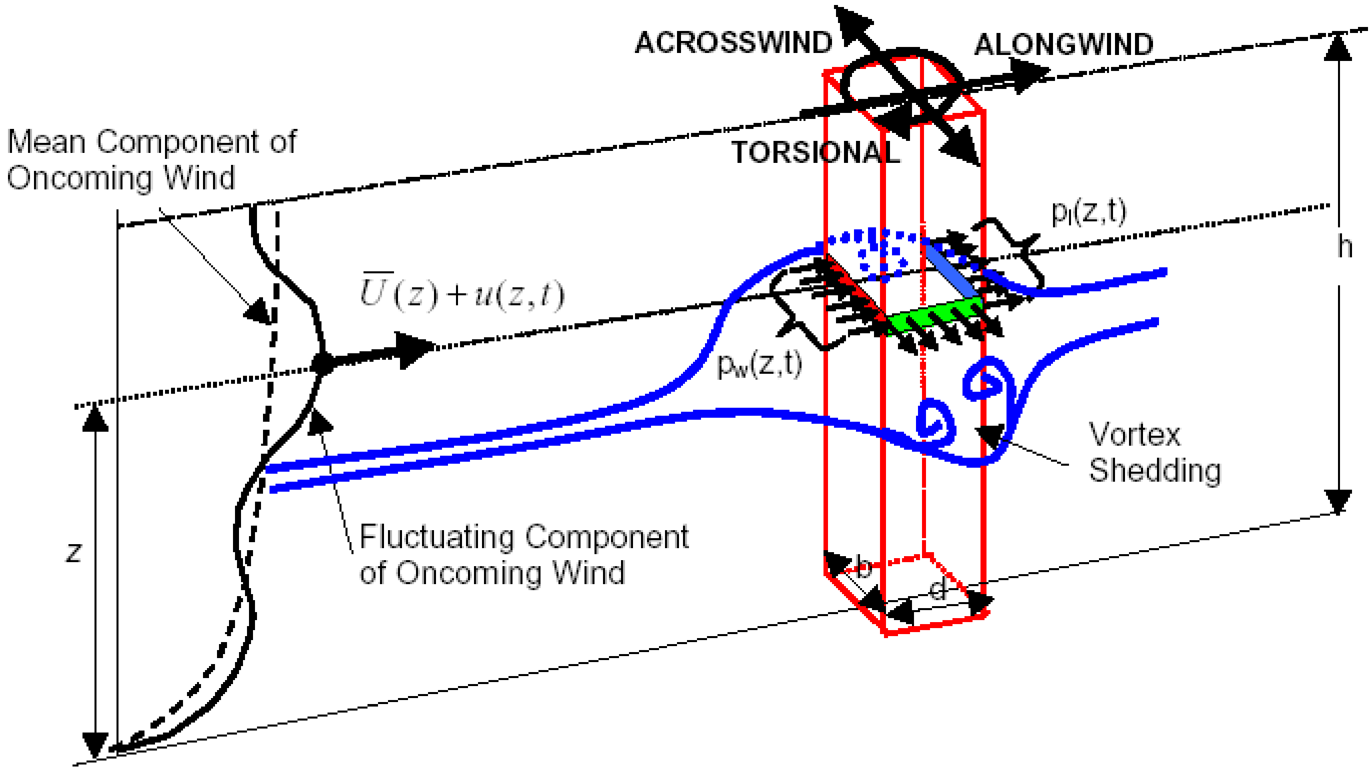


Turbulent energy decreases with elevation.

Wind Loads in general



Wind Loads in general



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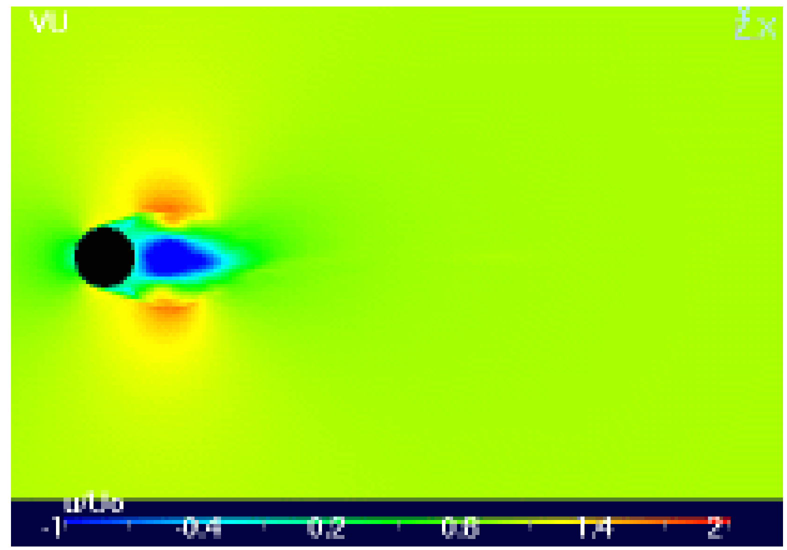
Wind Induced Vibrations – Types of vibrations

- Vortex Induced Vibrations
- Galloping
  - Classical galloping
  - Interference galloping
- Divergence & Flutter
  - Instabilities which occur for flexible plate like structures (f.e. bridges)
- ….
- ….



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Wind Induced Vibrations – VIV

Strouhal Number

- The shedding of vortices generates a periodic variation in the pressure over the surface of the structure. When the frequency of this variation approaches one of the natural frequencies of a structure, vortex-induced vibration can occur.

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

Scruton number

- The magnitudes of these vibrations are governed both by the structure's inherent damping characteristics and by the mass ratio between the structure and the fluid it displaces. These two effects are often combined in the *Scruton number*.

$$K_S = \frac{4\pi m_e \zeta_T}{\rho \cdot D^2}$$

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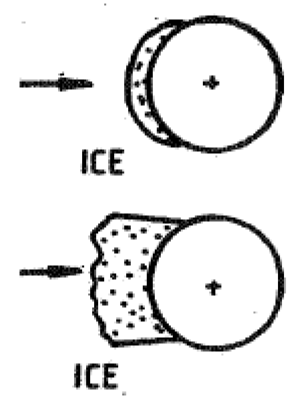
Wind Induced Vibrations – Galloping

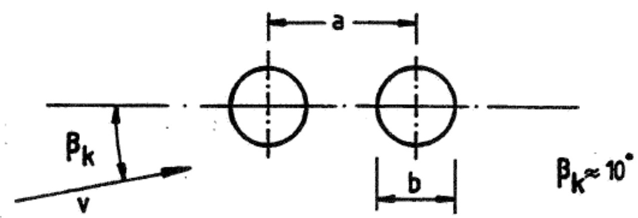
Classical

- Galloping occurs for some types of cross sections at frequencies below the VIV frequencies.
- Self induced vibration
  - (e.g. oscillations of circular cross-sectioned cables in freezing rain, due to change in cross-section)
- Normally the amplitudes increase with increasing wind speed.



Interference

- When two or more cylinders are placed close to each other, self excited oscillations may commence.



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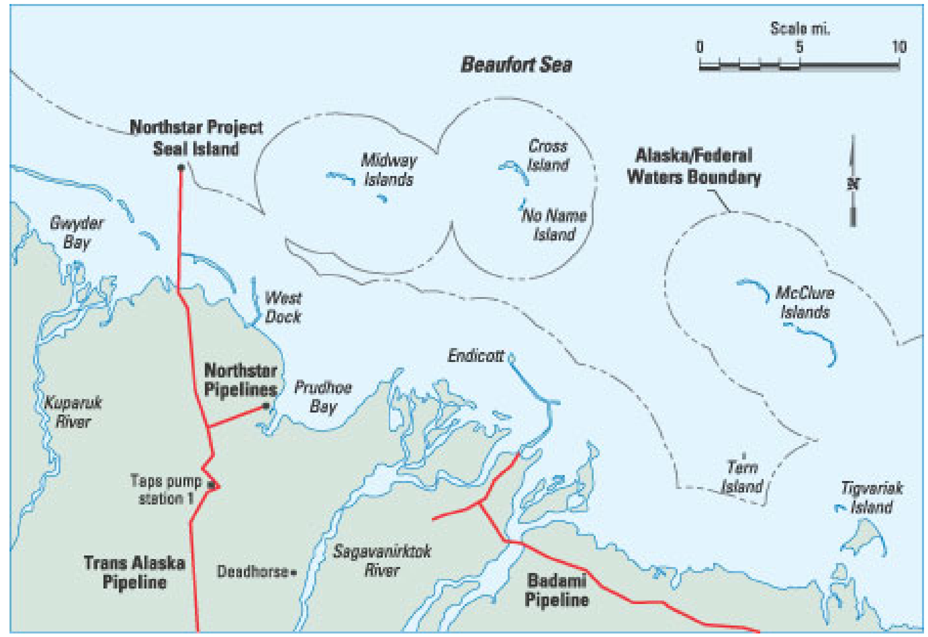
North Slope Pipelines

- Alpine
- Nuiqsut Natural Gas Pipeline
- Northstar
- Liberty
- Milne Point Enhanced Oil Recovery Project
- Phillips Tyonek Deep
- Badami



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Northstar Pipelines

- Pipeline
  - 10 inch gas pipeline
  - 10 inch oil pipeline
  - 48 inch casing pipeline
- Based on the assessments performed by SSD Inc.
  - WIV screening and analysis
  - Calculation of fatigue using AWS X1 and X2 SN curves
  - Design of Pipeline vibration dampers

Northstar Pipelines: 10 inch gas pipeline

- Modal data:
  - Primary mode frequencies lie in the range of 2.38Hz to 5.06Hz
  - Modal stress (per unit inch modal displacement) range from 3.7 to 9.8ksi
- Critical wind speed is from 10.0 to 21.2mph
- WIV assessment
  - Laminar
    - WIV midspan displacement under laminar (locked-in) wind conditions is 3.3inches (peak to peak)
    - Maximum WIV stress range of 12ksi
  - Turbulent
    - Under turbulent conditions (which is more typical), WIV midspan displacement is 0.86 inches, peak to peak
    - Maximum WIV stress range of 4.6ksi

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Northstar Pipelines: 10 inch gas pipeline

- Design life of 20 years
- WIV assessment using AWS-X1 SN curve
  - 5% Laminar flow was assumed
    - Few pipeline sections, with an azimuth angle of 72^o did not require any mitigation.
    - Few pipeline sections, with an azimuth angle of 0^o and 166^o had fatigue life lower than 20 years and required mitigation.
- WIV assessment using AWS-X2 SN curve
  - All pipeline sections required mitigation.
- Pipeline Vibration Dampers (PVD) were designed by SSD Inc.
  - Stress reduction by a factor of 3.6
  - Predicting theoretically infinite fatigue life

Northstar Pipelines: 48 inch casing pipeline

- Critical wind speeds for the primary modes of the system are 33mph and 51mph.
- Reynolds No. range for the primary modes was estimated as 1.3e+06 to 2.6e+06.
- These exceed the critical Re for laminar and turbulent winds.
- For this system, it implies:
  - Uni-modal response is extremely unlikely to occur.
  - The pipeline is outside the narrow banded WIV range.

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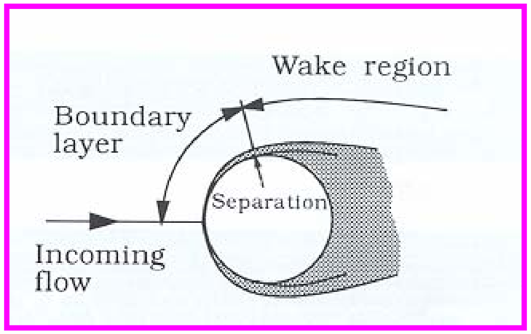
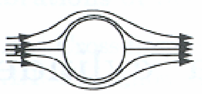
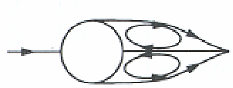
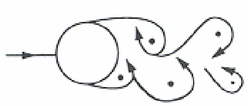
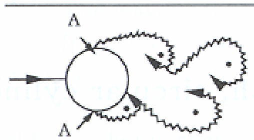
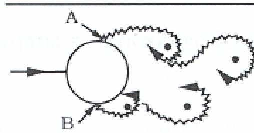
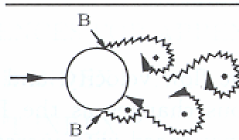
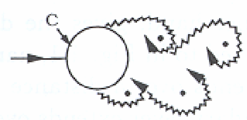
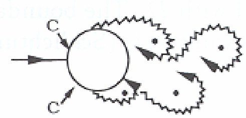
Flow Regimes- Reynolds number



$$Re = \frac{U \cdot D}{\nu} = \frac{\text{inertial force}}{\text{viscous force}}$$

a)		No separation. Creeping flow	Re < 5
b)		A fixed pair of symmetric vortices	5 < Re < 40
c)		Laminar vortex street	40 < Re < 200
d)		Transition to turbulence in the wake	200 < Re < 300
e)		Wake completely turbulent. A:Laminar boundary layer separation	$300 < Re < 3\times10^5$ Subcritical

f)		A:Laminar boundary layer separation B:Turbulent boundary layer separation;but boundary layer laminar	$3\times10^5 < Re < 3.5\times10^5$ Critical (Lower transition)
g)		B: Turbulent boundary layer separation;the boundary layer partly laminar partly turbulent	$3.5\times10^5 < Re < 1.5\times10^6$ Supercritical
h)		C: Boundary layer completely turbulent at one side	$1.5\times10^6 < Re < 4\times10^6$ Upper transition
i)		C: Boundary layer completely turbulent at two sides	$4\times10^6 < Re$ Transcritical

Similar effect as a VIV suppression device.

Correlation length along the pipeline is reduced drammatically.

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Similarity to VIV mitigation

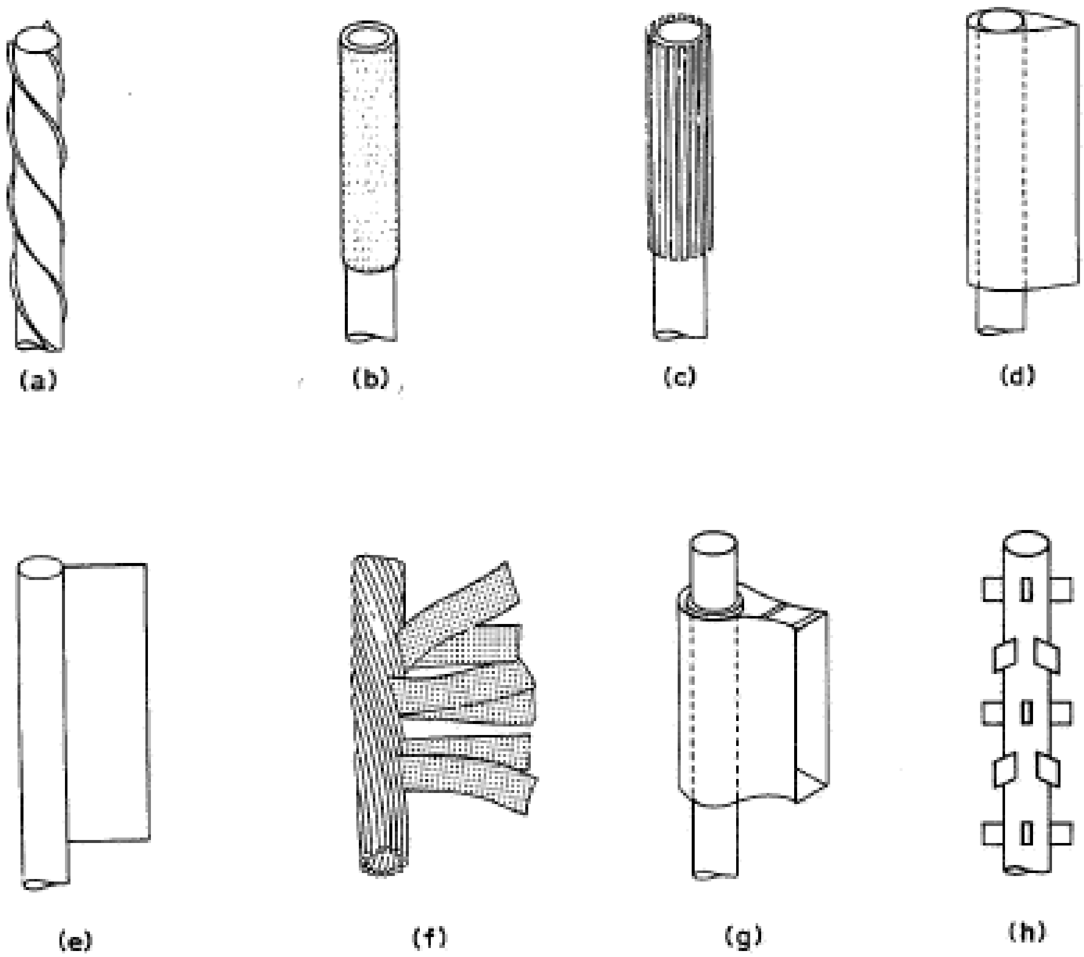

Fig. 3-23 Add-on devices for suppression of vortex-induced vibration of cylinders: (a) helical strake; (b) shroud; (c) axial slats; (d) streamlined fairing; (e) splitter; (f) ribboned cable; (g) pivoted guiding vane; (h) spoiler plates.

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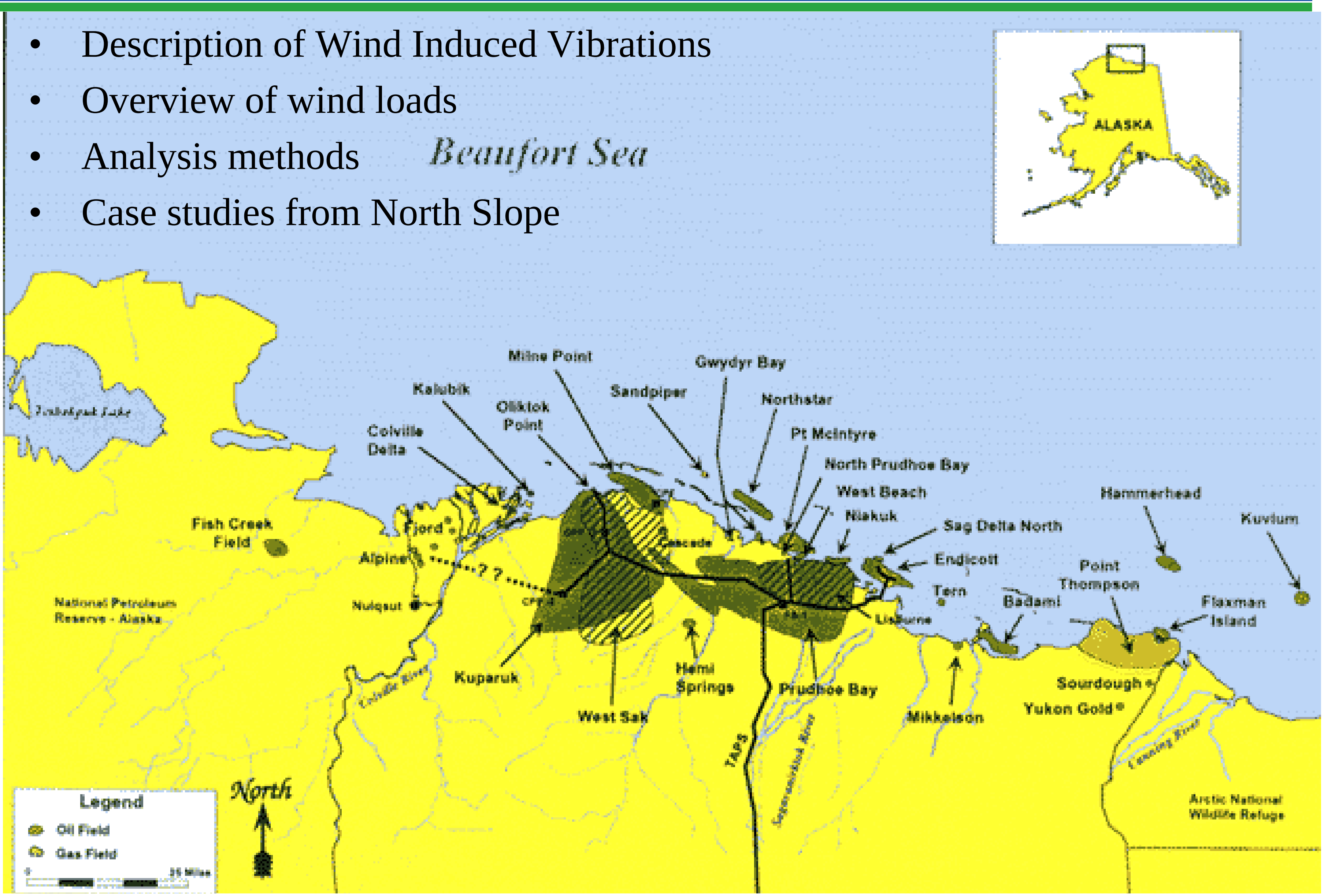
Few issues

- Assessment tools
  - ESDU
  - Modified FatFree
- Design Standards and Industry practices
  - Design codes for onshore pipelines
  - Screening approach
  - Detailed multimode fatigue analysis guidance
- Cross-flow and in-line
  - Importance assessments of in-line VIV
- Safety factors for fatigue damage
  - Is it 10?
- Validity of duration of laminar flow assumptions
  - Site specific
- Effects of shielding
- Bundled pipe configurations
- Assessments for other types of WIV, i.e. other than VIV
- Ice on pipe – Galloping and modified pipeline modal characteristics

Summary

- Description of Wind Induced Vibrations
- Overview of wind loads
- Analysis methods
- Case studies from North Slope



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