Recent Wind Tunnel Experiments in Canada on Inclined and Yawed Stay Cables

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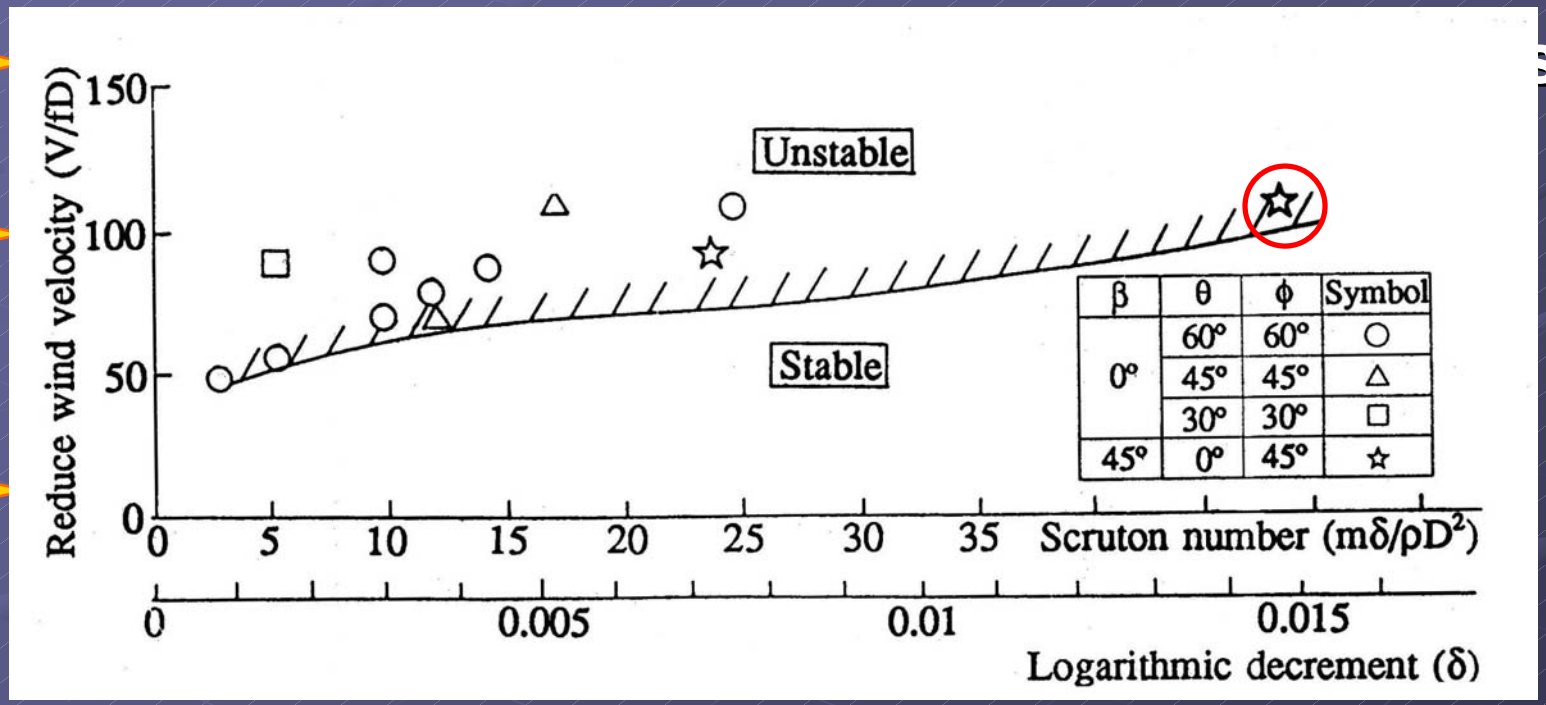
2006 Wind Induced Vibration of Cable Stay Bridges Workshop, April 25-27

Outline

- Project Background
- What have been done and what have we learned
- How the results affect stay cable design
- What questions have been raised and the follow on works
- How other researchers responded to the issues
- What is left to be done

Project Background



Sc=48

Ur=108

D =160 *mm*

f =1.6 *Hz*

m=100 *kg/m*

U=10 *m/s*

ζ=0.24%

Objectives

- Confirm the existence of dry inclined cable galloping
- Clarify the excitation mechanisms
- Assist in developing a more reliable stay cable design guideline

What has been done

and

what have we learned

PHASE I

— *Dynamic model wind tunnel tests*

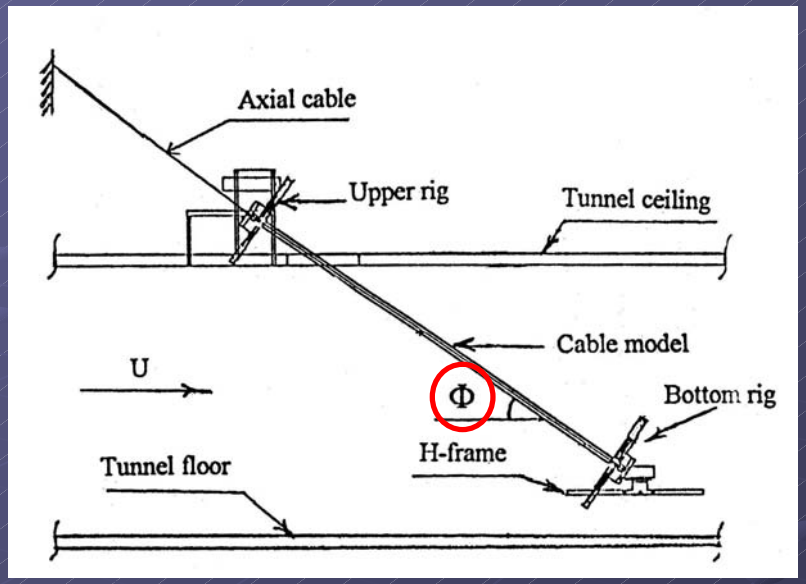
- ***Facility***
  - **Propulsion wind tunnel (NRCC/IAR)**

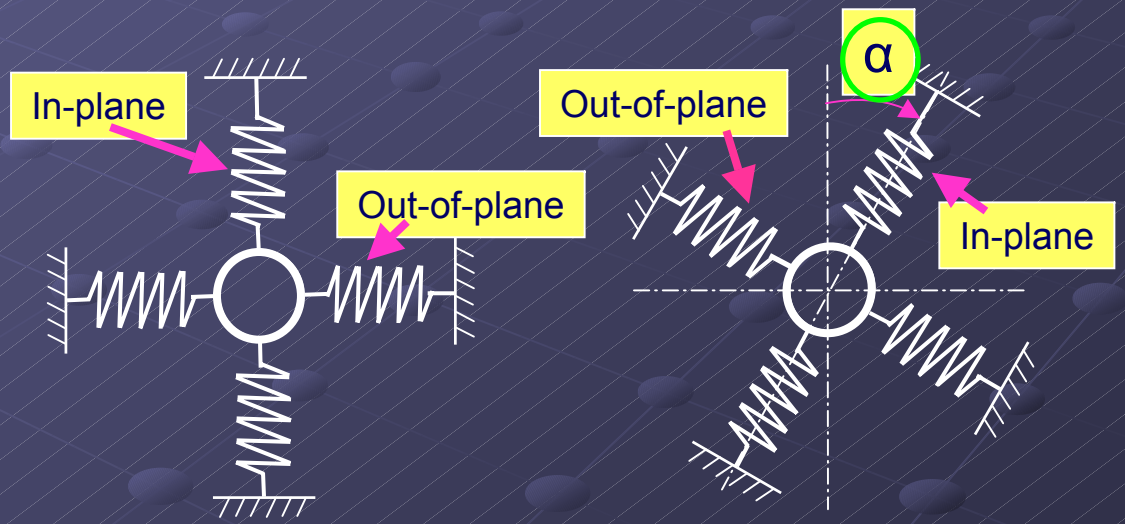
- **Open circuit**
- **Max. wind speed: 39 *m/s***
- **Working section**

$$3m(W) \times 6m(H) \times 12m(L)$$

Cable model

- Length: 6.7 *m*
- Diameter: 160 *mm*
- Unit mass: 60.8 *kg/m*





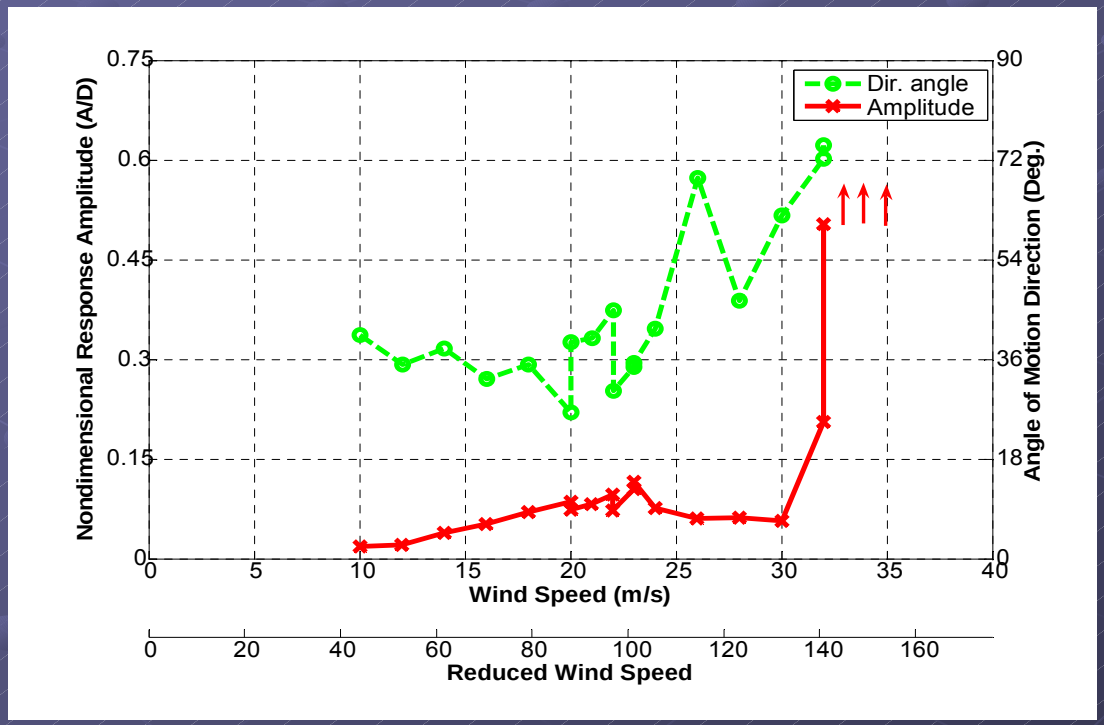
Testing Program

Model Setup	Full-scale cable angles (deg.)		Model cable angles (deg.)	
	θ	β	Φ	α
1B	45	0	45	0
1C	30	35.3	45	54.7
2A	60	0	60	0
2C	45	45	60	54.7
3A	35	0	35	0
3B	20	29.4	35	58.7

Aeroelastic responses

Divergent type (Setup 2C)

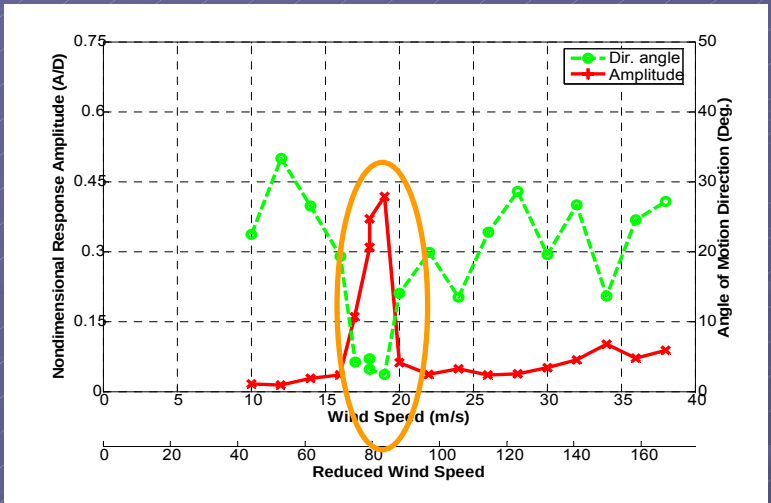
$$\left.\begin{aligned}\Phi &= 60^\circ \\ \alpha &= 54.7^\circ\end{aligned}\right\} \Longleftrightarrow \left\{\begin{aligned}\theta &= 45^\circ \\ \beta &= 45^\circ\end{aligned}\right.$$



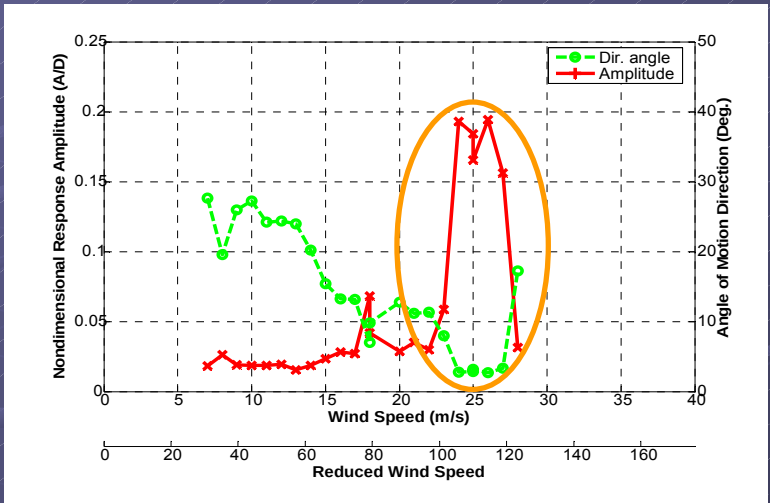
Onset wind velocity:
U= 32 *m/s*

Max. double amp.:
about *1D*

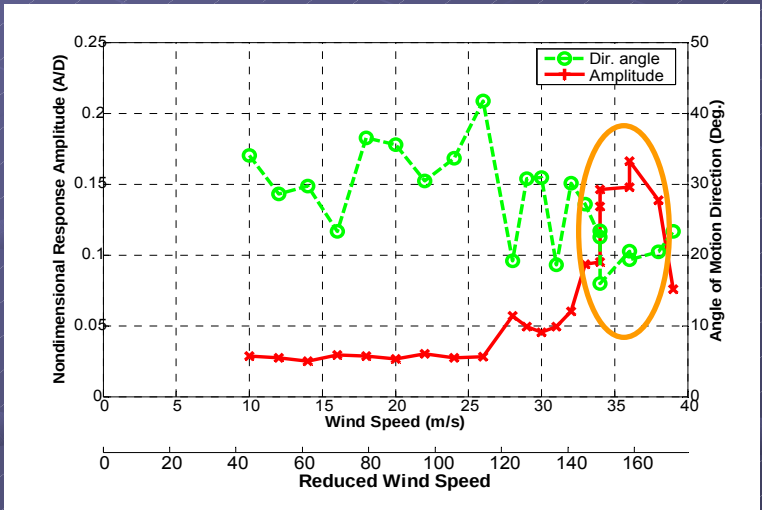
Limited-amplitude vibration



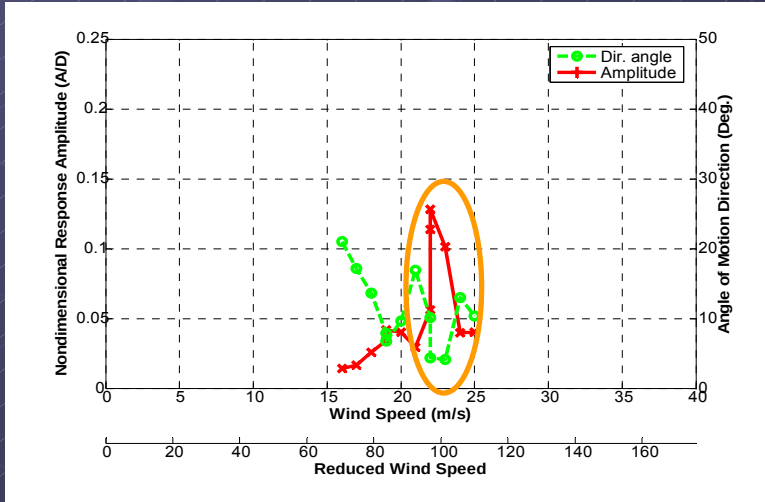
Setup 2A



Setup 1B

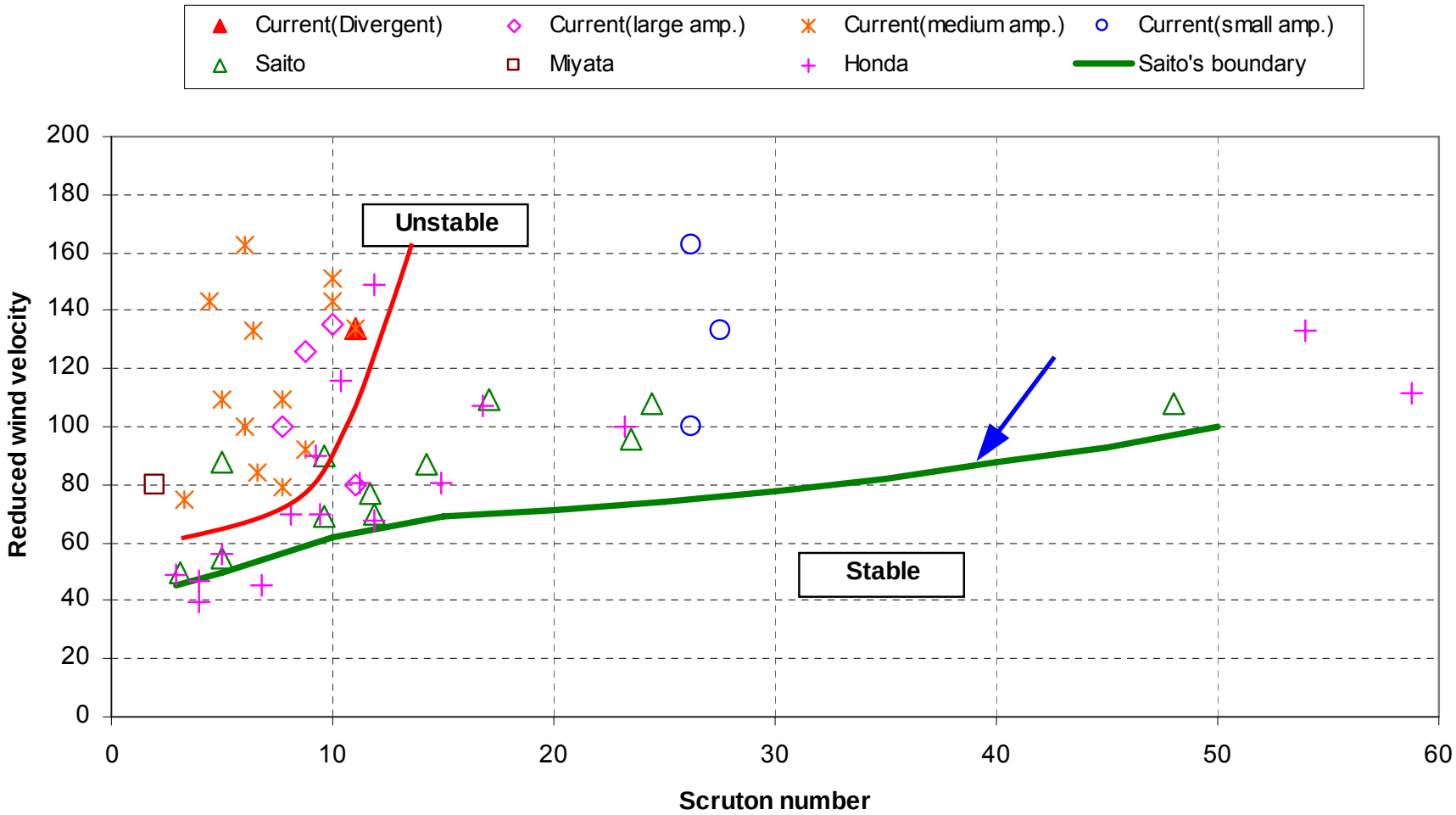


Setup 1C



Setup 3A

Comparison with other studies



PHASE II

— *Static model wind tunnel tests*

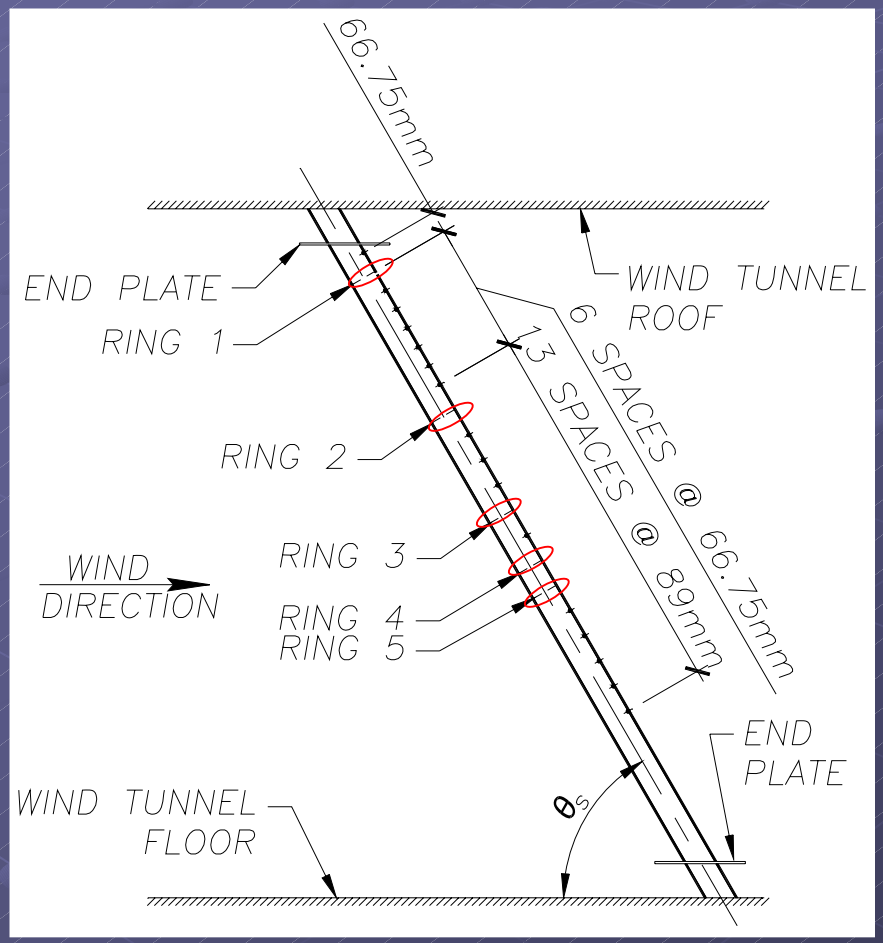
Wind tunnel:

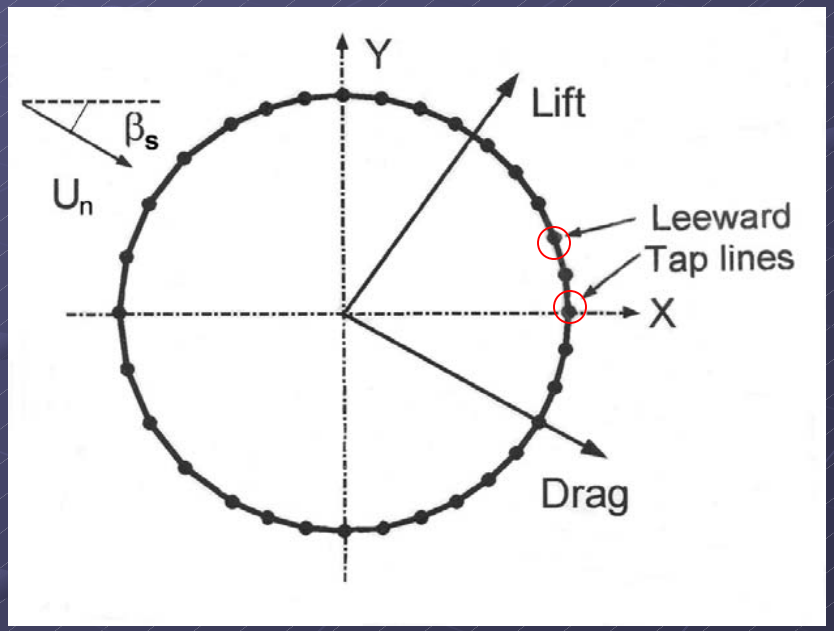
- 2m(H) × 3m(W)
- Closed-circuit
- U_{max} : 140m/s

Model:

- Circular cylinder
- O.D. : 88.9mm
- Length: 3.0m

Pressure tap arrangement



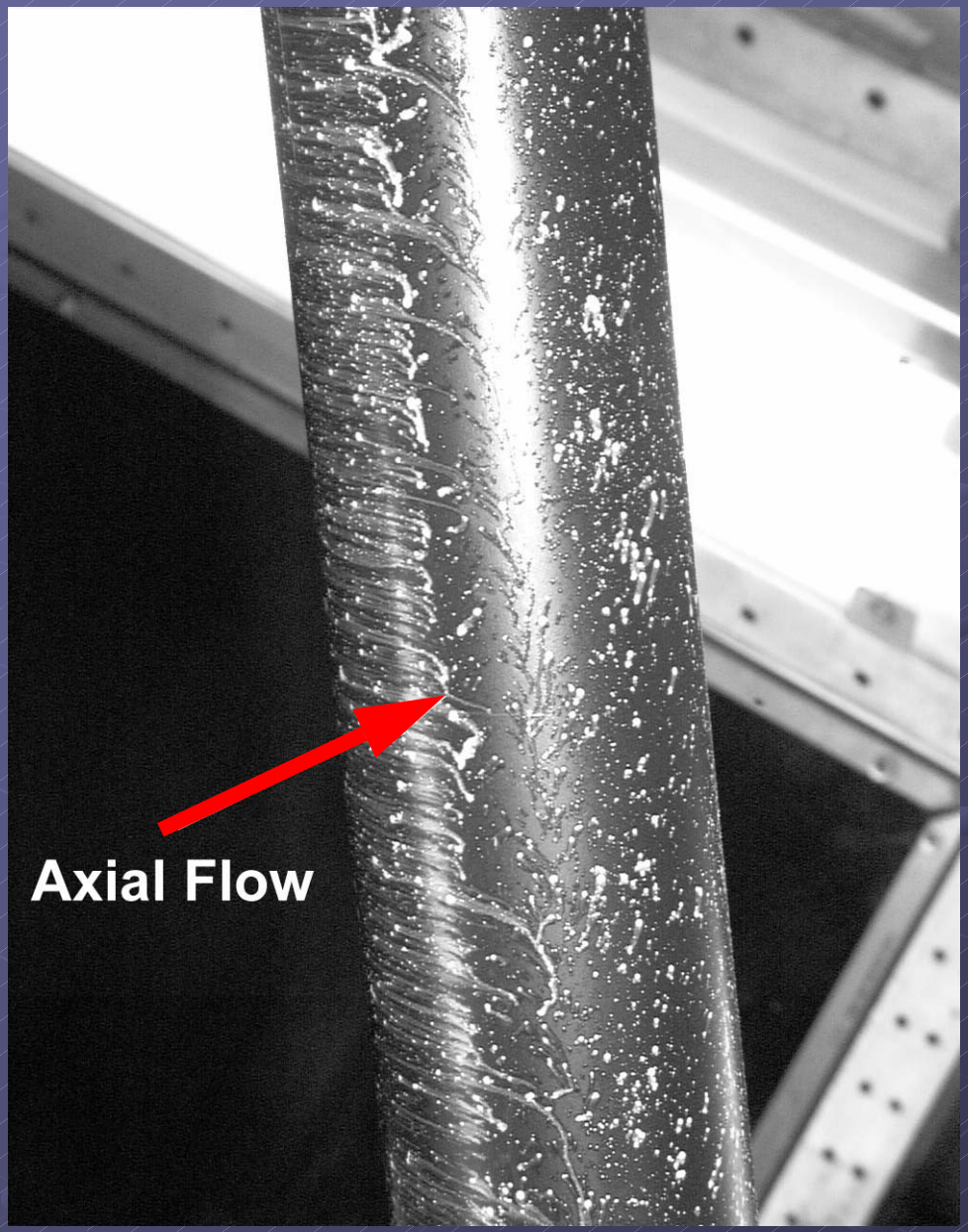


Testing program

- Model orientation
  - Vertical angle: 90°, 60°, 54.7°
  - Yaw angle: 0°–120°
- Wind speed: 15 – 99m/s
- Same Reynolds number in the dynamic and static tests
- Sampling rate: 400Hz, 1200Hz

Critical condition of the divergent motion

Model Tests	Model orientation		Wind speed (m/s)
	Ver. angle	Hor. Angle	
Dynamic	60°	54.7° (spring rotation angle)	32 (R_e=3.3×10^5)
Static	54.7°	30°	50-60 (R_e=2.9-3.5×10^5)



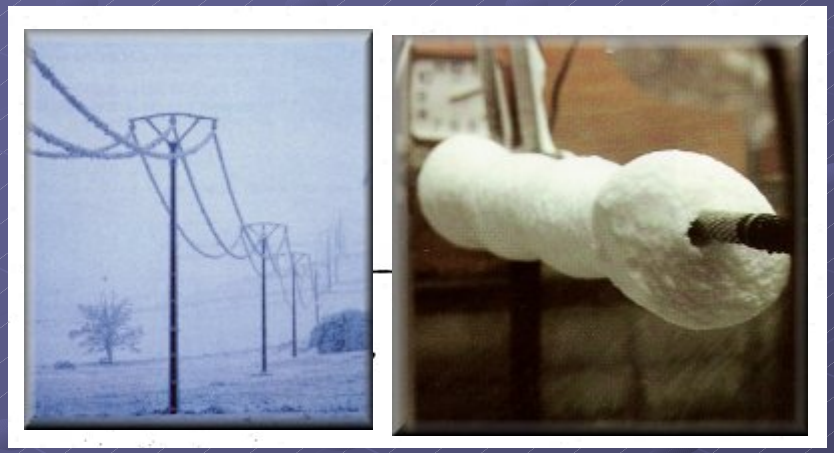
U=55m/s

θ_s=54.7°

β_s=30°

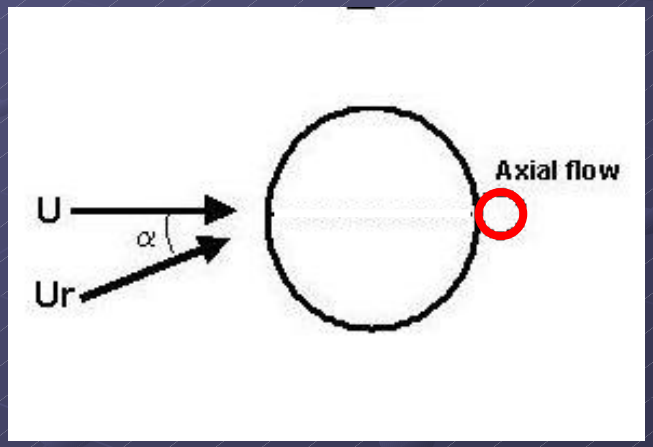
Possible excitation mechanism

Iced cable galloping



$$\partial C_L / \partial \alpha + C_D < 0$$

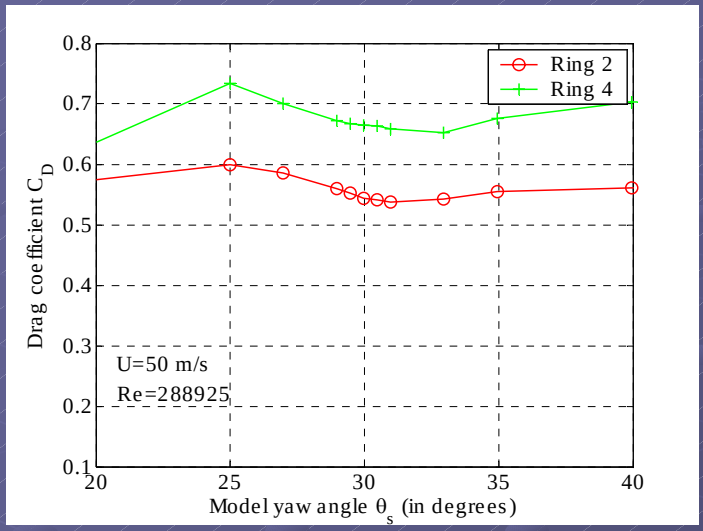
Dry inclined cable galloping

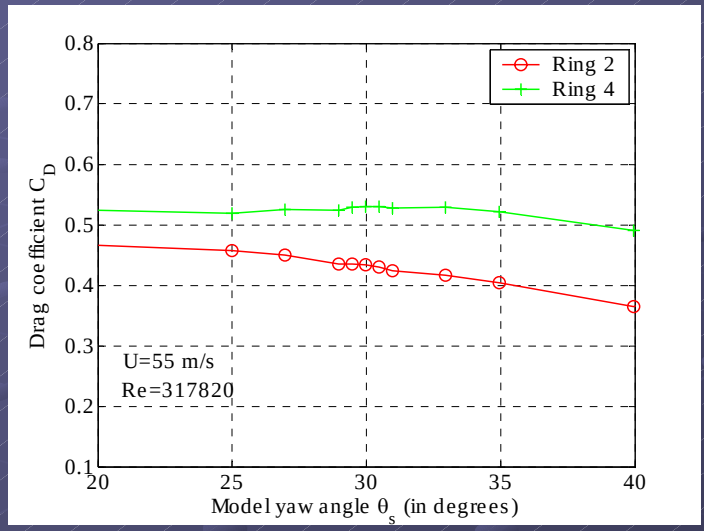


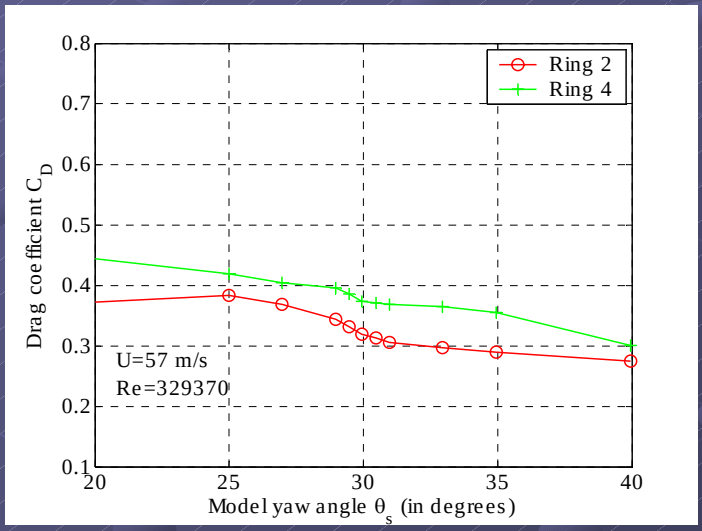
$$(\partial C_L / \partial \rho_s) / A + C_D < 0$$

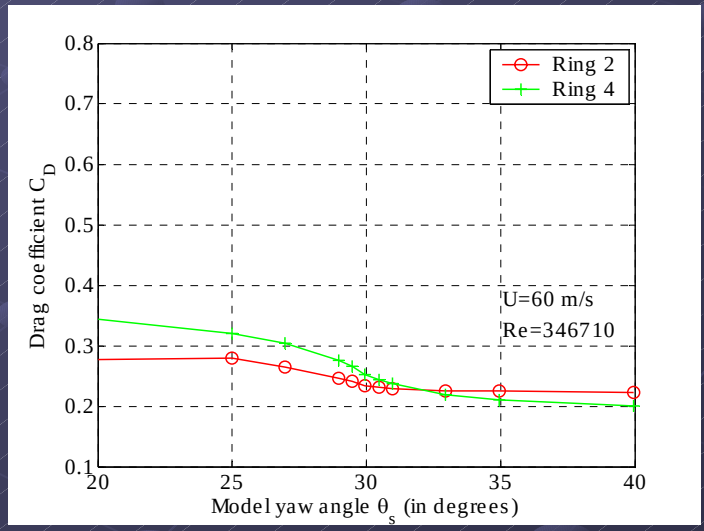
???

Drag force coefficients (θ_s=54.7°)

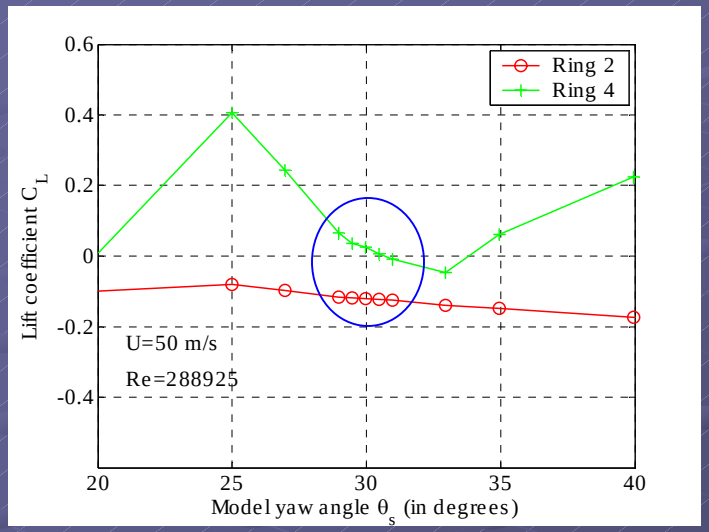


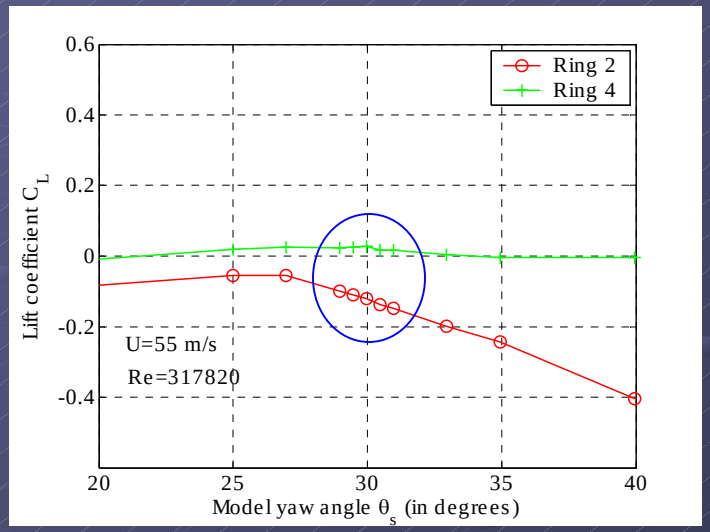


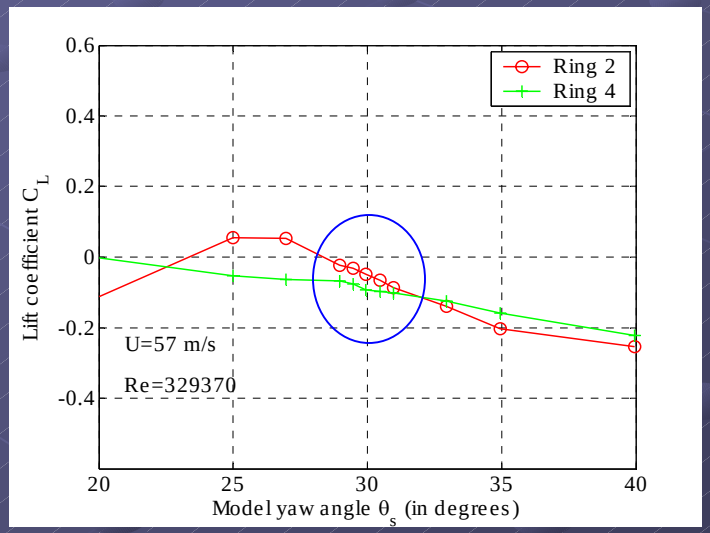


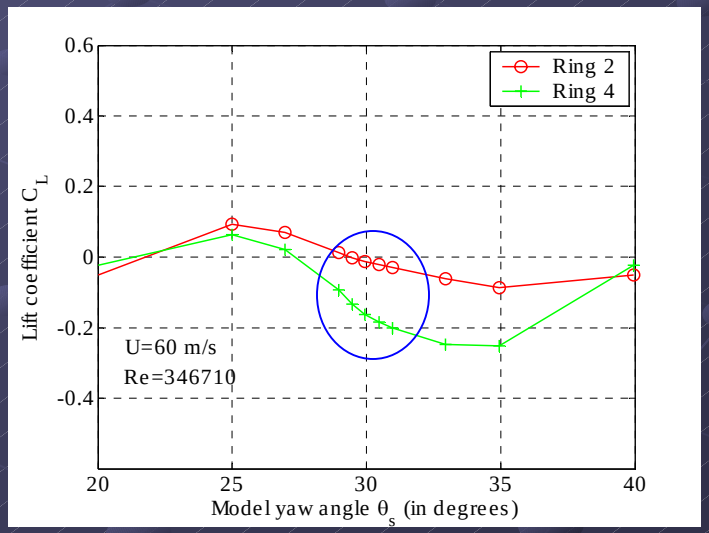


Lift force coefficients (θ_s=54.7°)







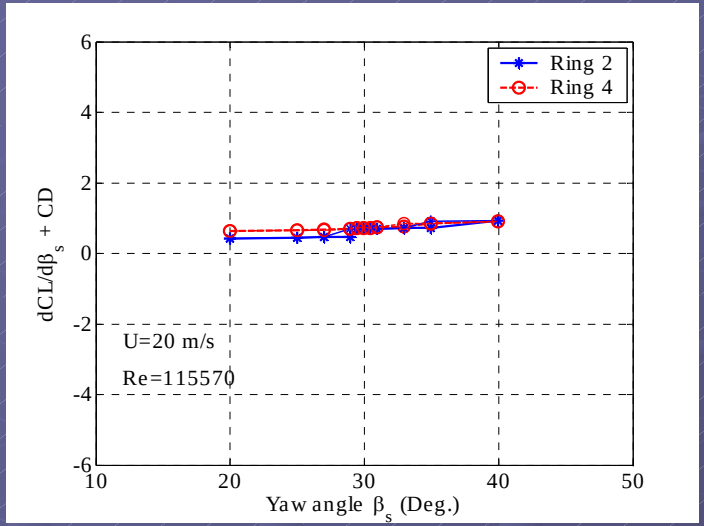


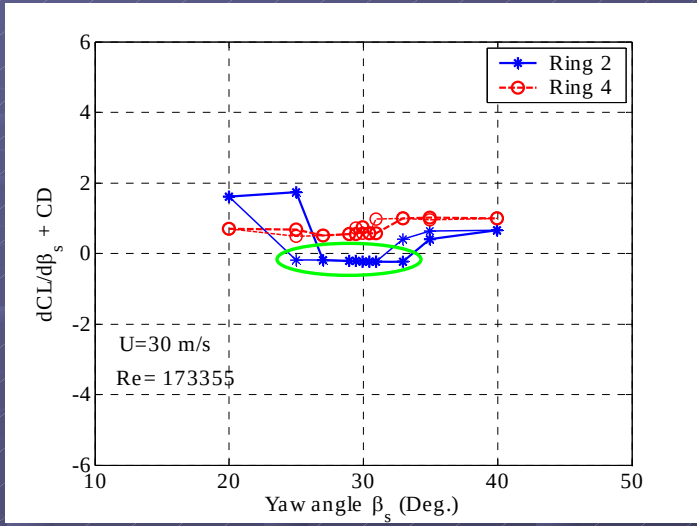
Significant decrease of C_D

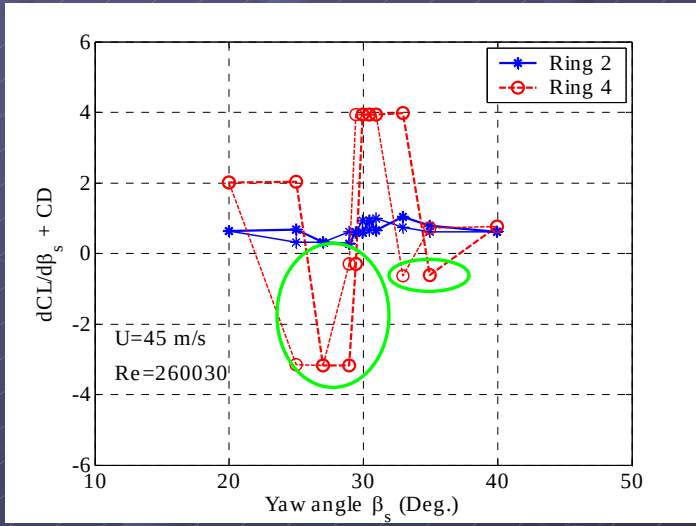
Negative slope of C_L-β_s curve

A mechanism similar to classical galloping

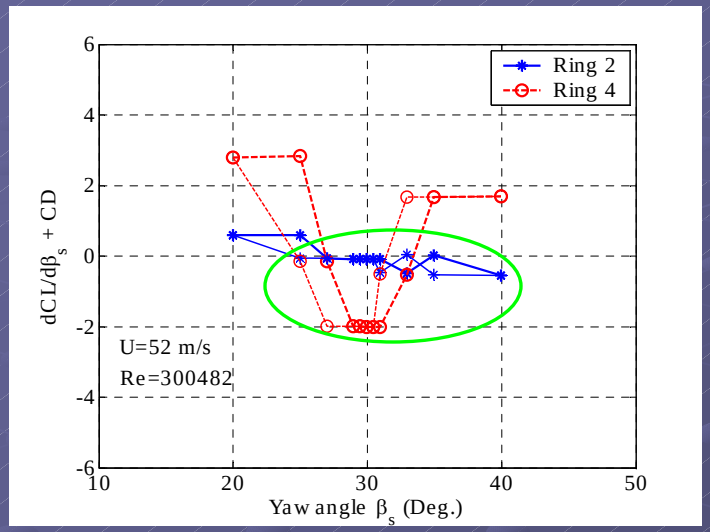
Application of Den Hartog criterion

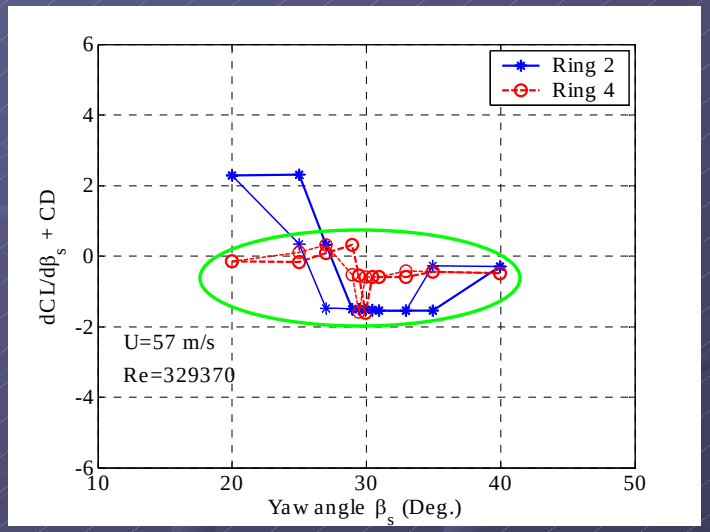


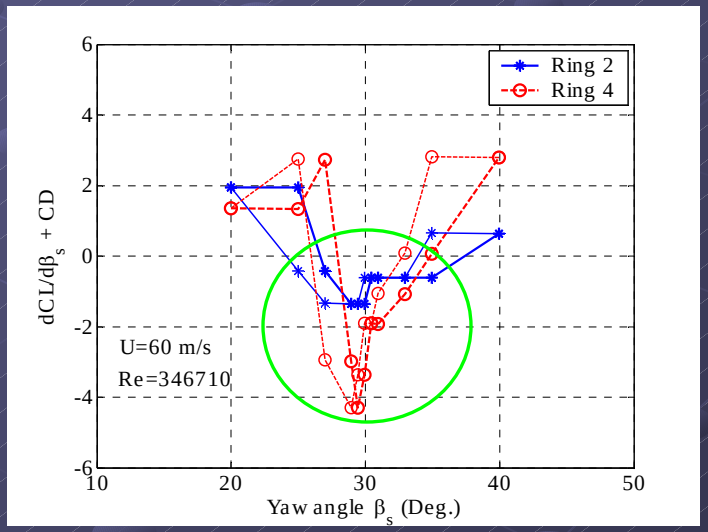




Application of Den Hartog criterion (Cont'd)







How the results

affect

stay cable design

- Dynamic test results have been considered in the Post Tensioning Institute Guideline
- Appreciation from bridge engineers
- Now wind tunnel tests on cables of long span cable-stayed bridges is mandatory
- Attracted interests from both academic and industrial side internationally