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

Experience with Visco-Elastic and Hydraulic Dampers for Stay Cables

by
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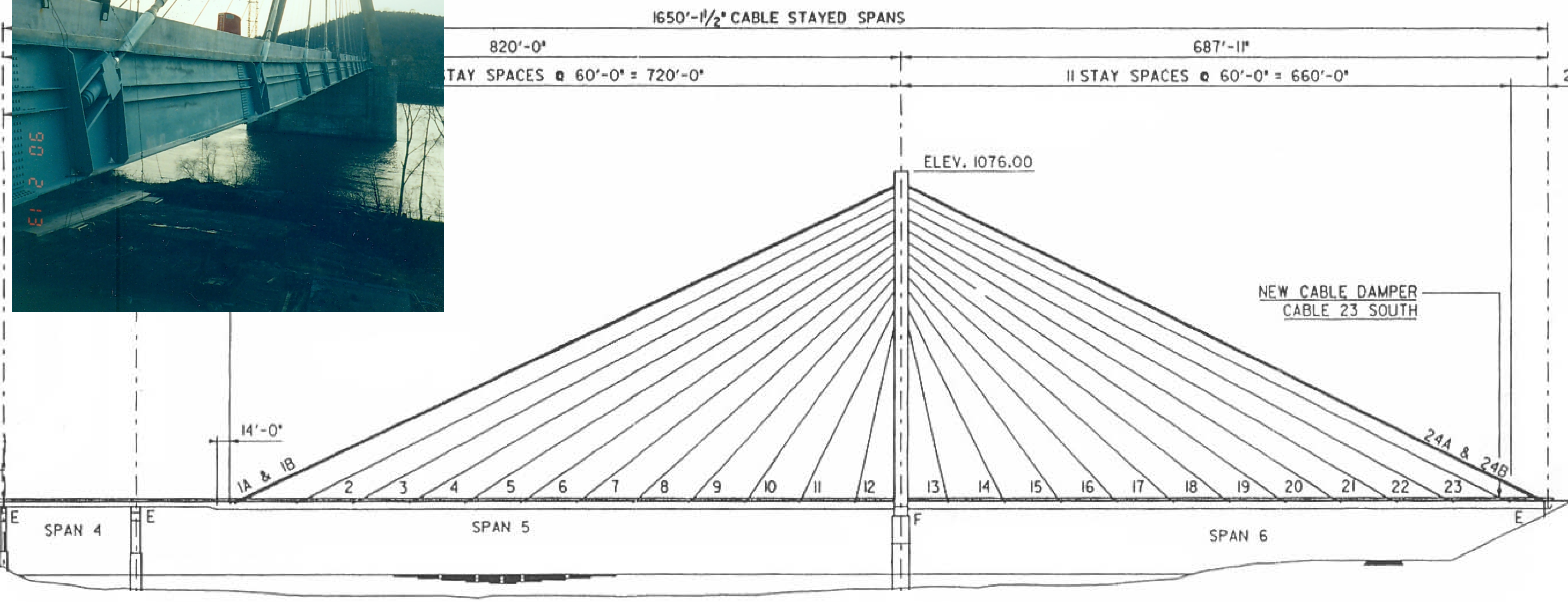
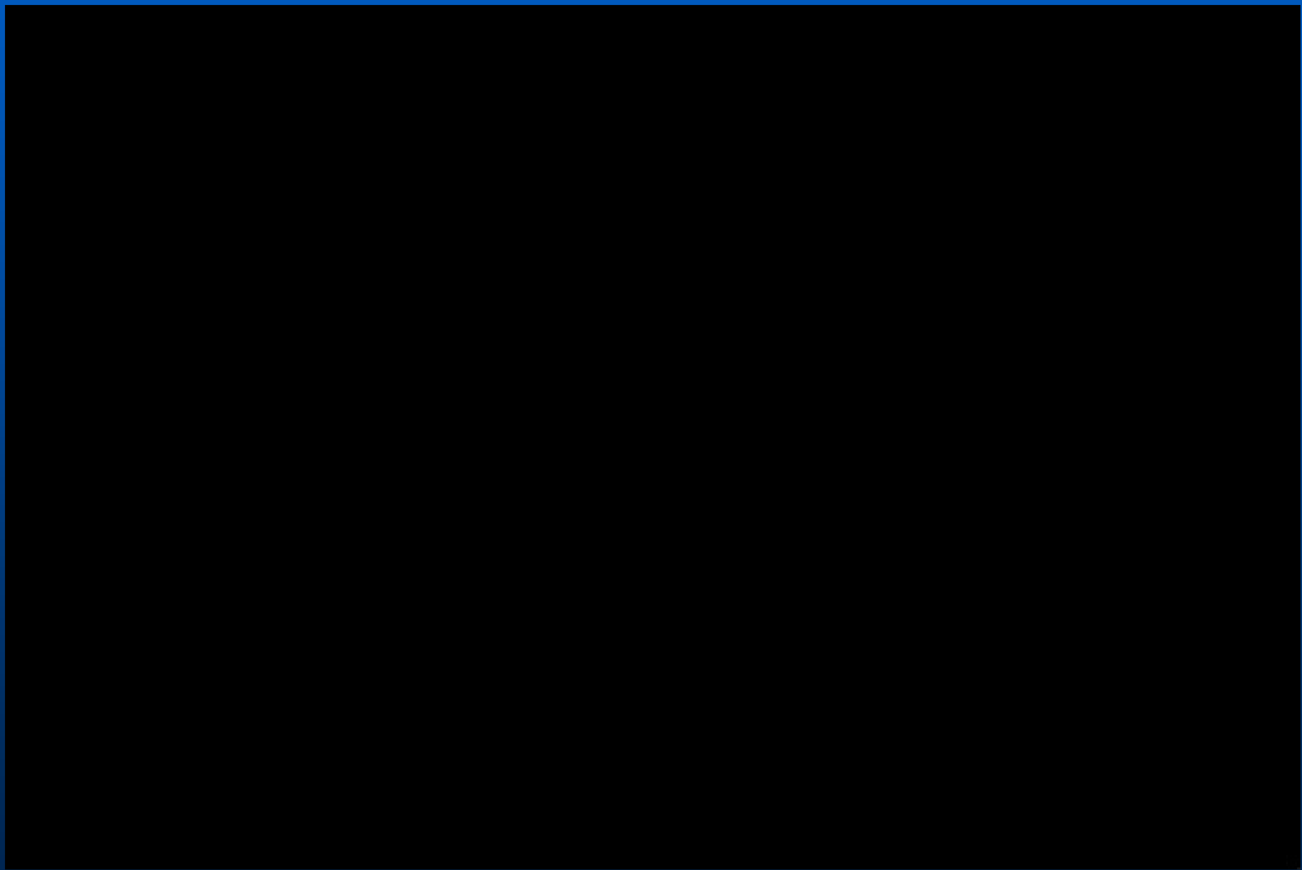
Western

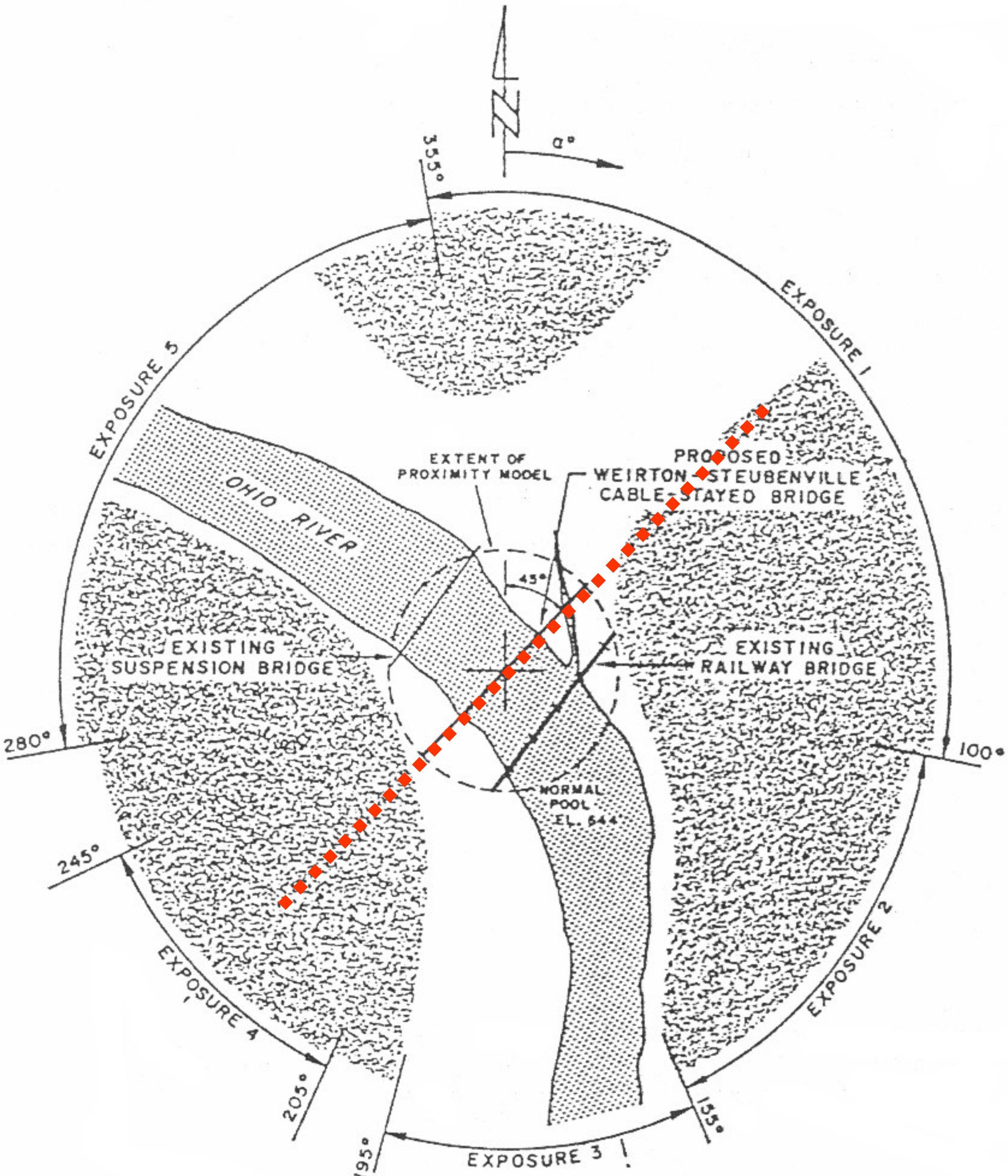
The Veterans Memorial Bridge (Weirton, WV - Steubenville, OH)



Cable Motion – 1st Mode



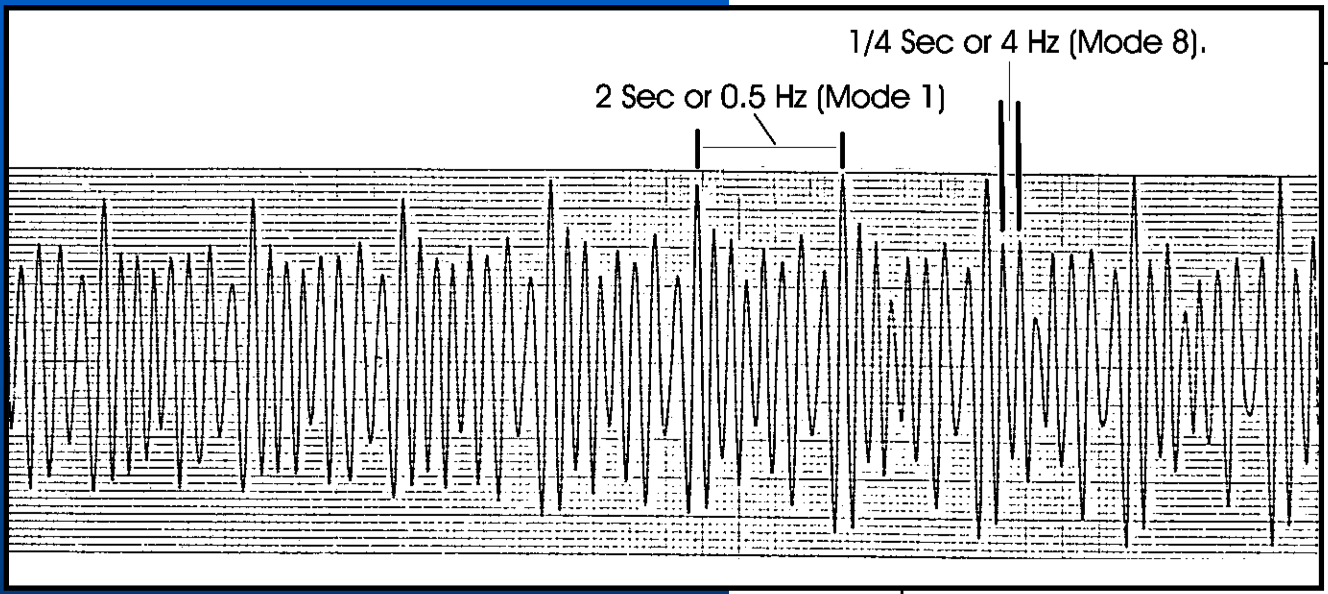
Cable Motion – 2nd Mode

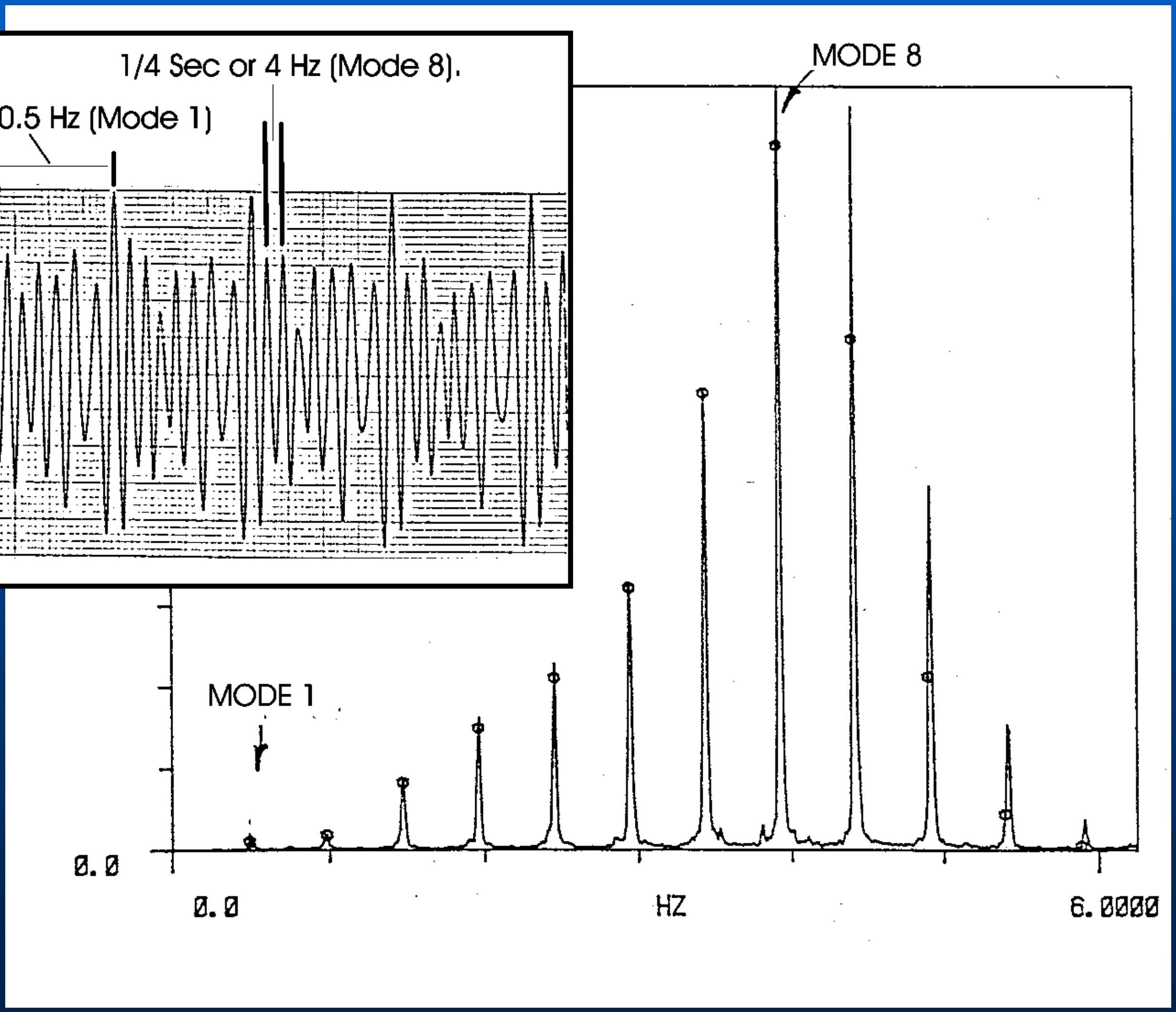


355°
α°
EXPOSURE 1
EXPOSURE 5
EXTENT OF PROXIMITY MODEL
PROPOSED WEIRTON - STEUBENVILLE CABLE-STAYED BRIDGE
OHIO RIVER
45°
EXISTING SUSPENSION BRIDGE
EXISTING RAILWAY BRIDGE
280°
100°
NORMAL POOL EL. 644
245°
EXPOSURE 2
EXPOSURE 4
205°
195°
EXPOSURE 3
155°

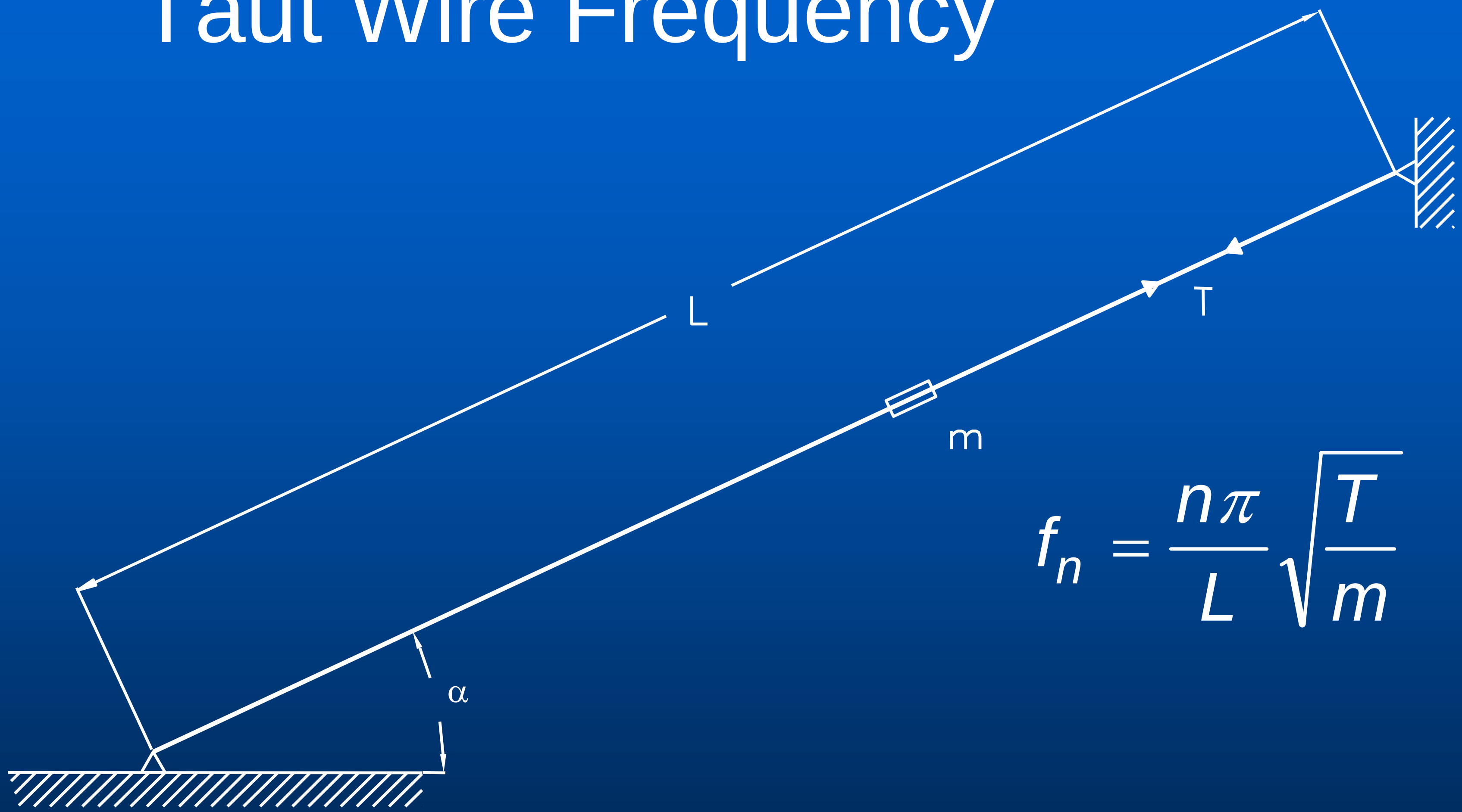
Immediate Solution – Cable Tie

1990 Ambient Vibration – Wind & Traffic



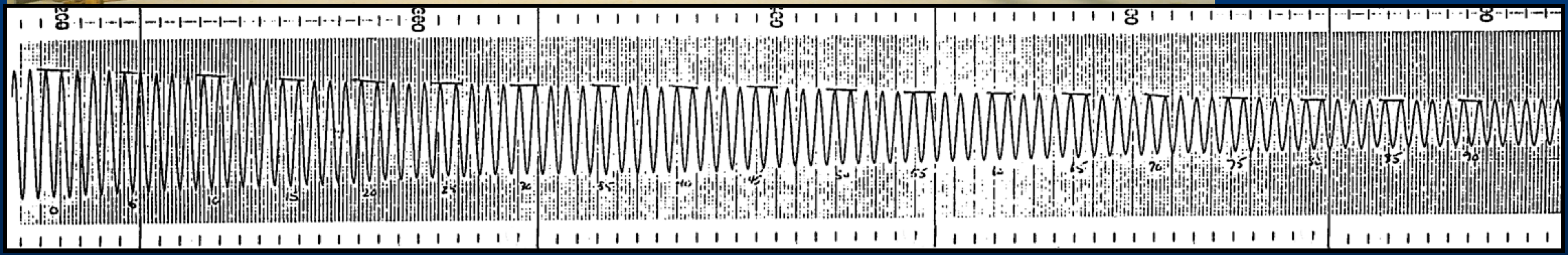


Taut Wire Frequency



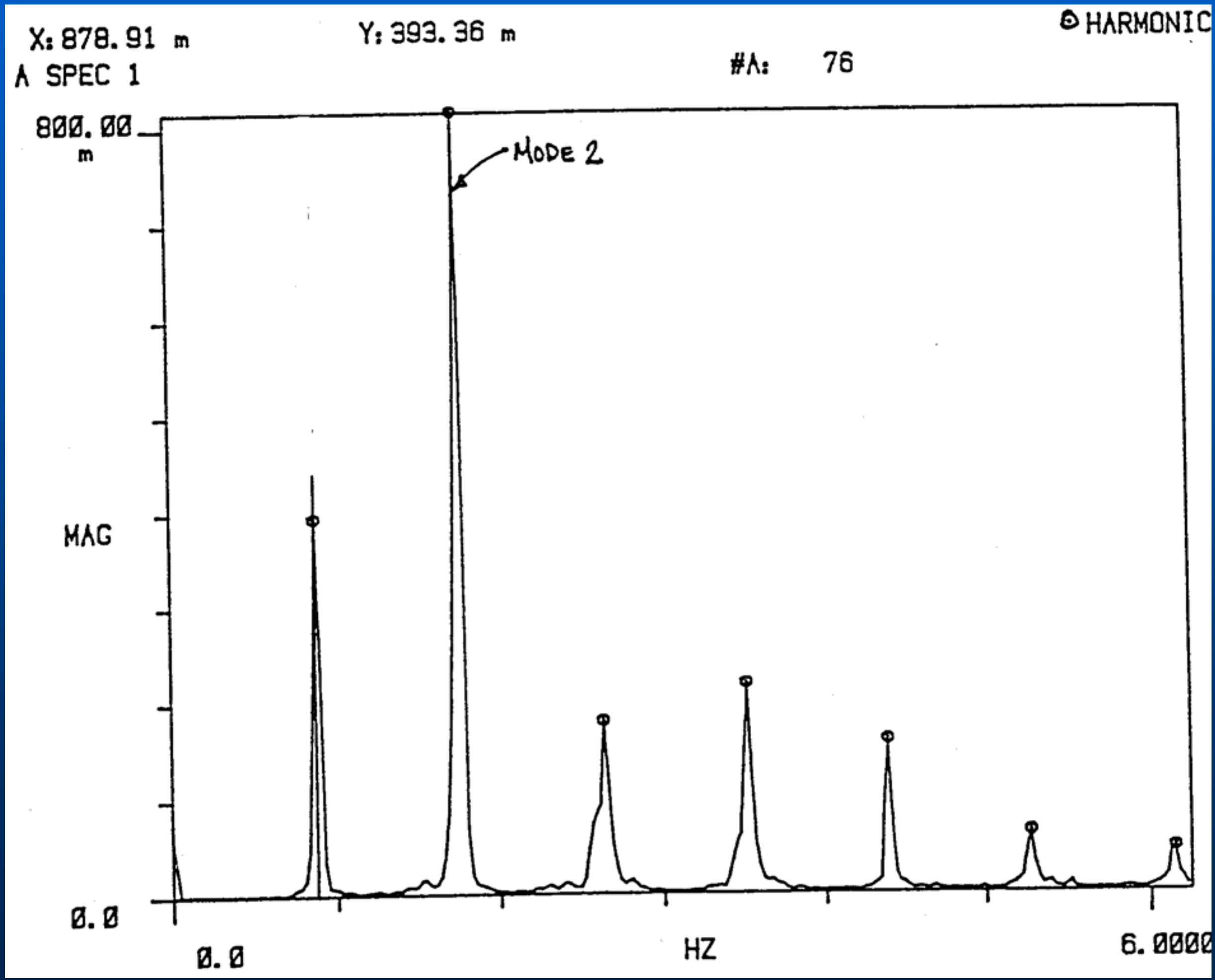
$$f_n = \frac{n\pi}{L}\sqrt{\frac{T}{m}}$$

Manual Excitation of Mode 1



ζ=0.18%

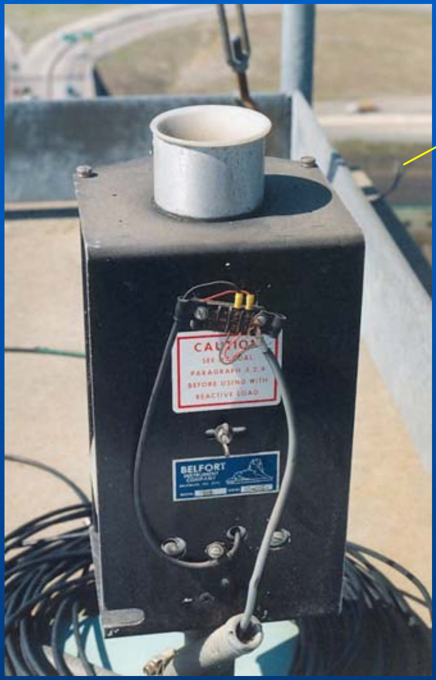
Spectrum of Acceleration under Forced Oscillation

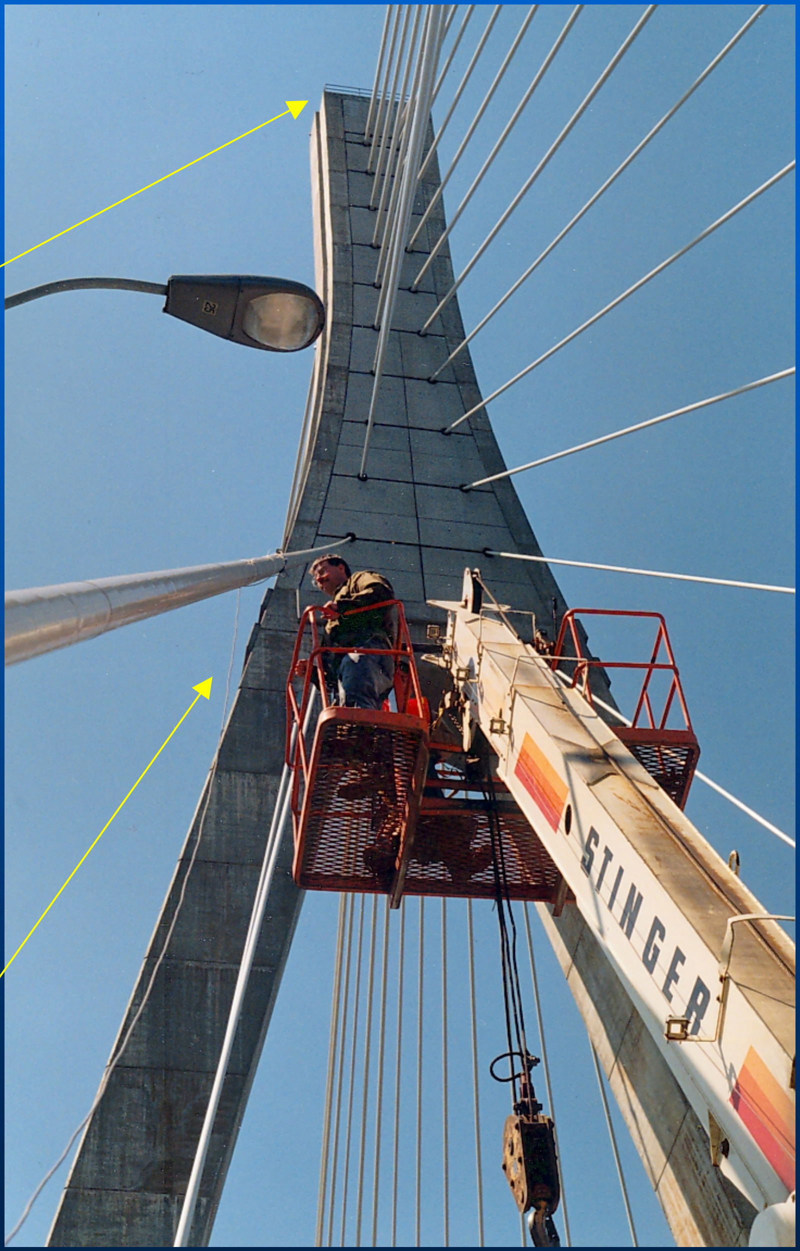


Neoprene "Damper Ring"

	Mode 1	Mode 2
Without Ring	0.07%	0.06%
With Ring	0.15%	0.08%

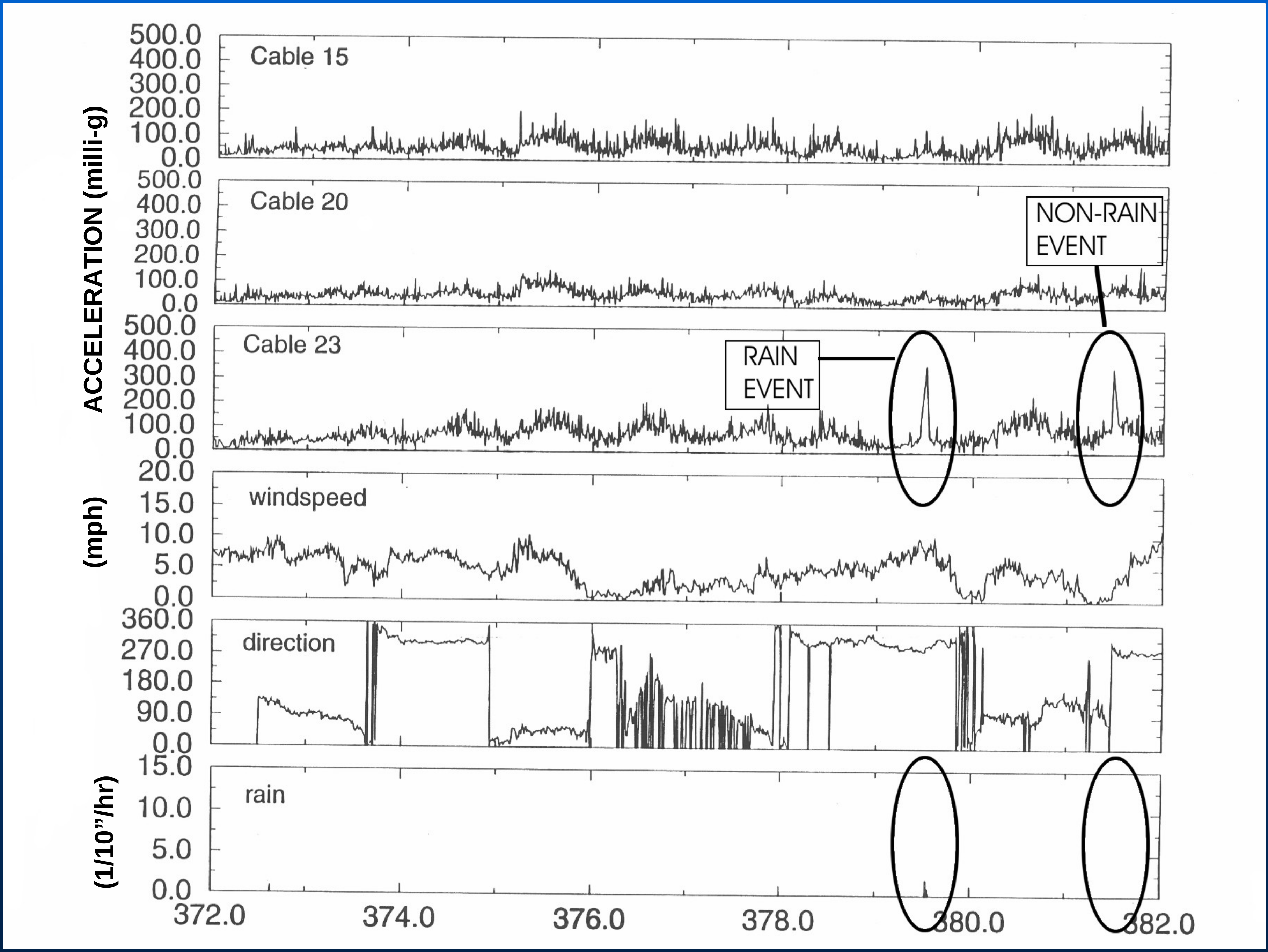
Anemometer & Rain Gage on Tower Top





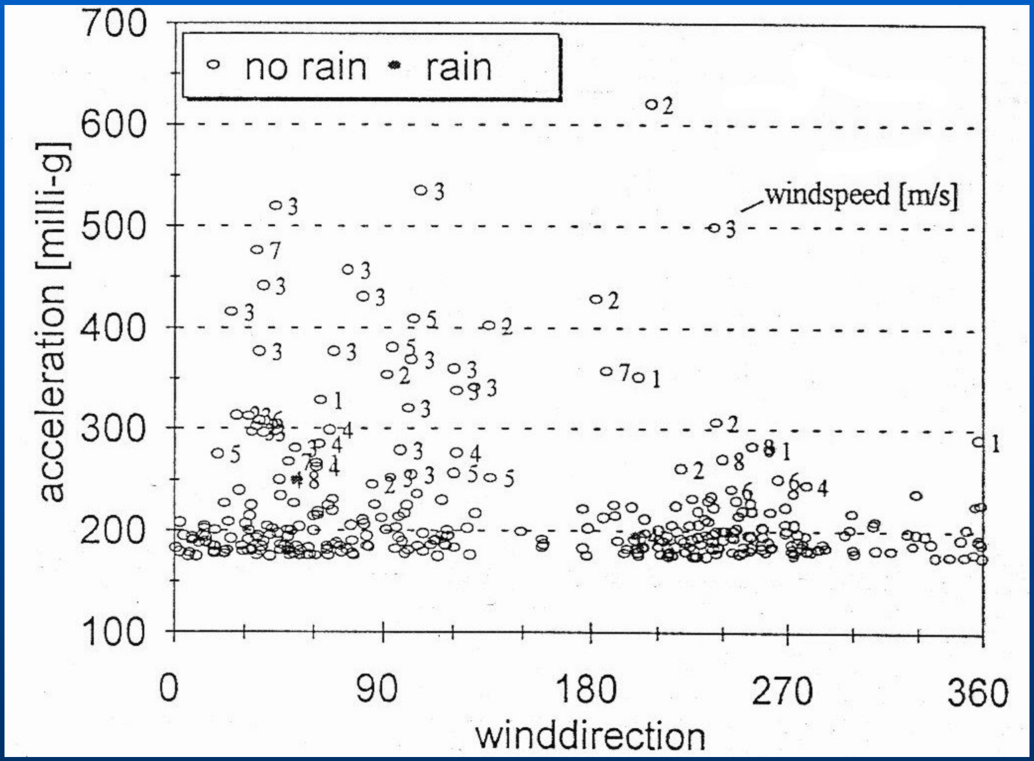
Installation of Accelerometer

Data Logger inside Tower

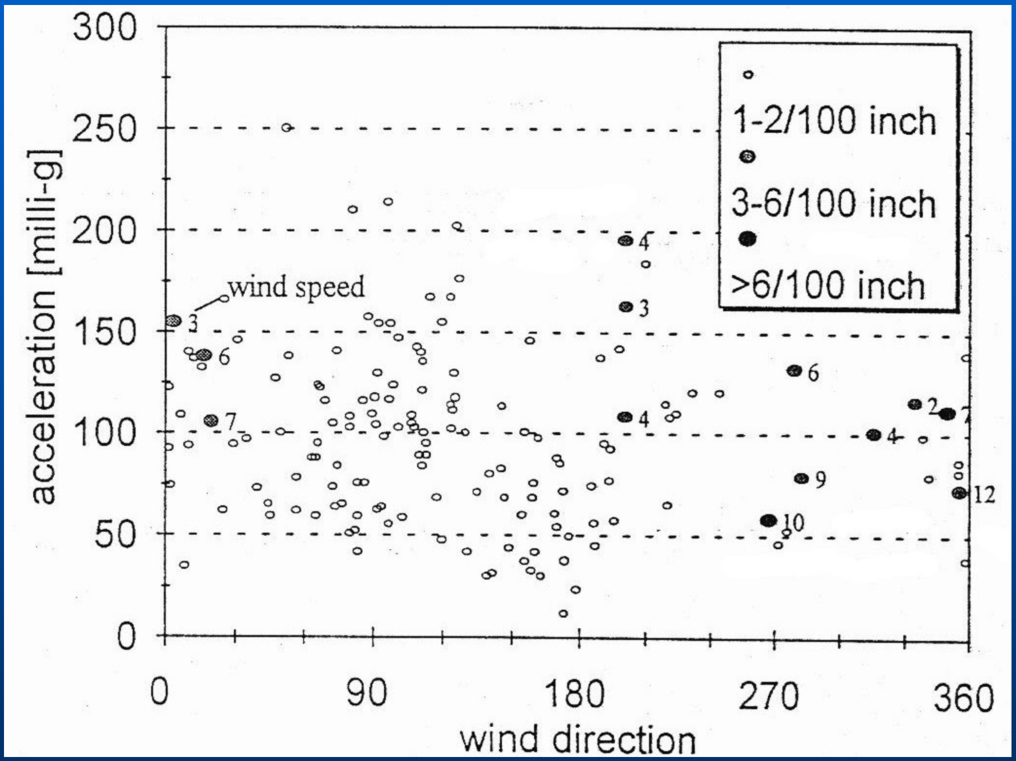


ACCELERATION (milli-g)
Cable 15
Cable 20
Cable 23
NON-RAIN EVENT
RAIN EVENT
500.0
400.0
300.0
200.0
100.0
0.0
(mph)
windspeed
20.0
15.0
10.0
5.0
0.0
direction
360.0
270.0
180.0
90.0
0.0
(1/10"/hr)
rain
15.0
10.0
5.0
0.0
372.0
374.0
376.0
378.0
380.0
382.0

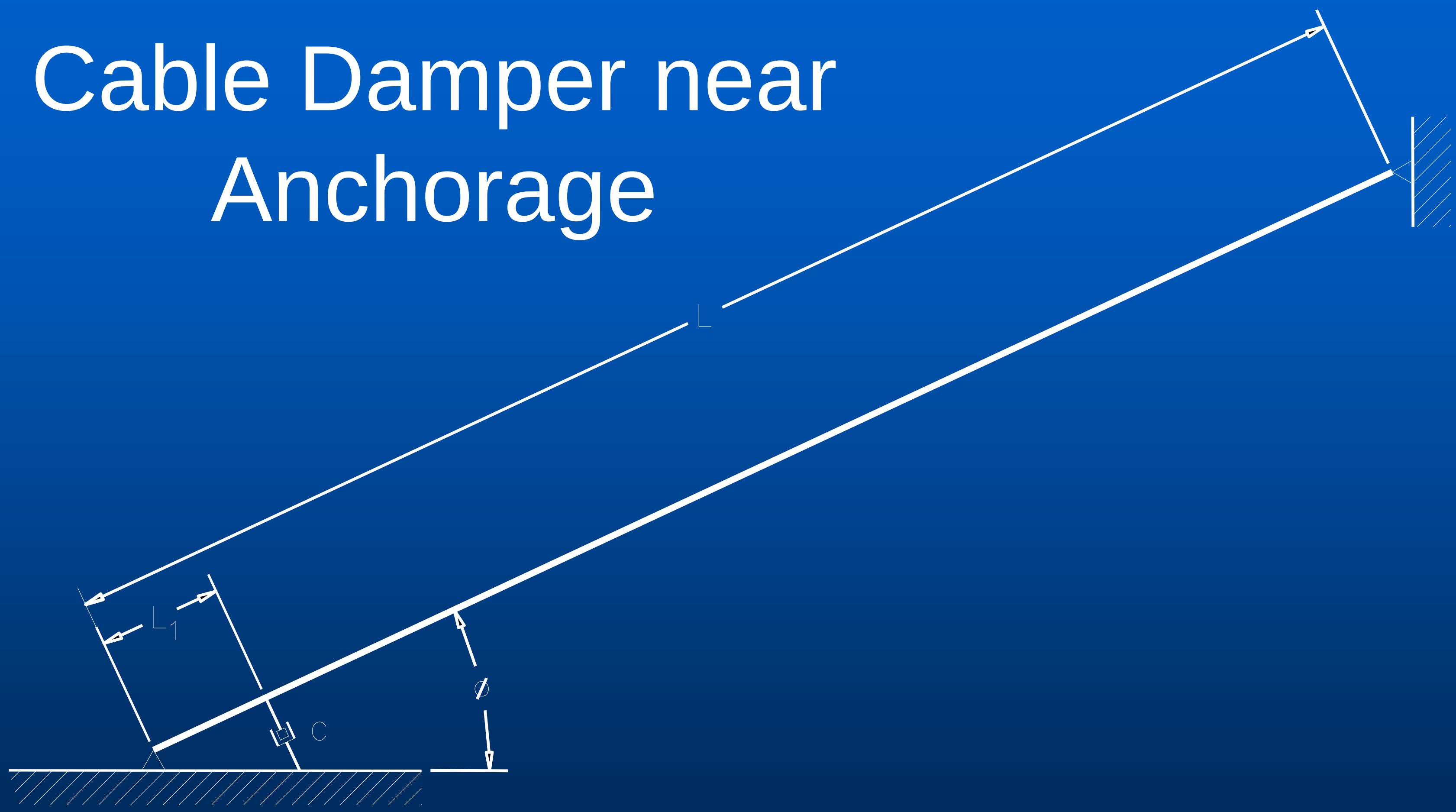
ALL EVENTS



RAIN EVENTS



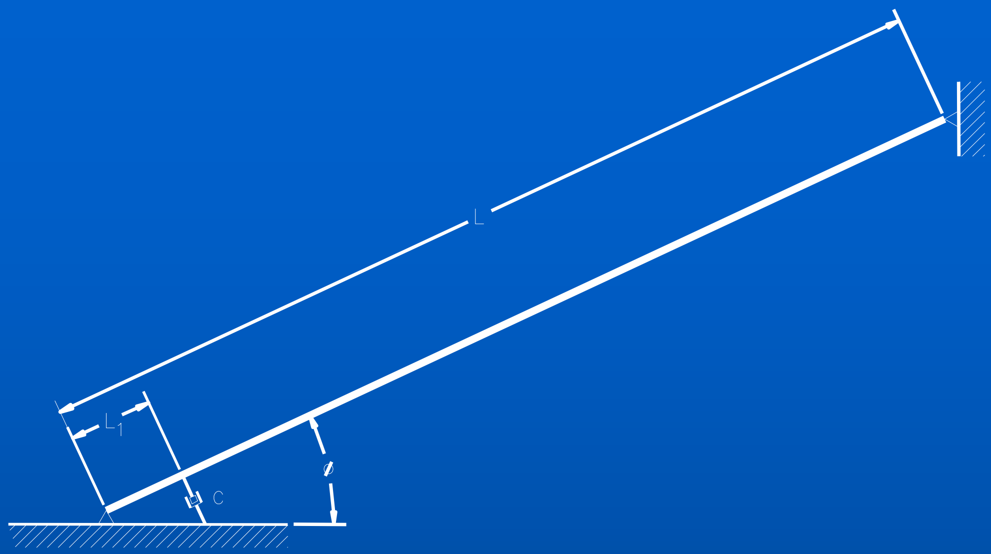
Cable Damper near Anchorage



How much Damping is Enough?

- Aerodynamic tests in wind tunnel indicated damping of the order of 0.6-0.8% of critical would be sufficient
  - Solution:
    - Hydraulic Dampers
    - Visco-elastic dampers

V-E dampers
Damping:



$$\zeta = \frac{G'' A / t d^2}{2m(2\pi f^2)}$$

where :

G'' = Loss Modulus of VE material

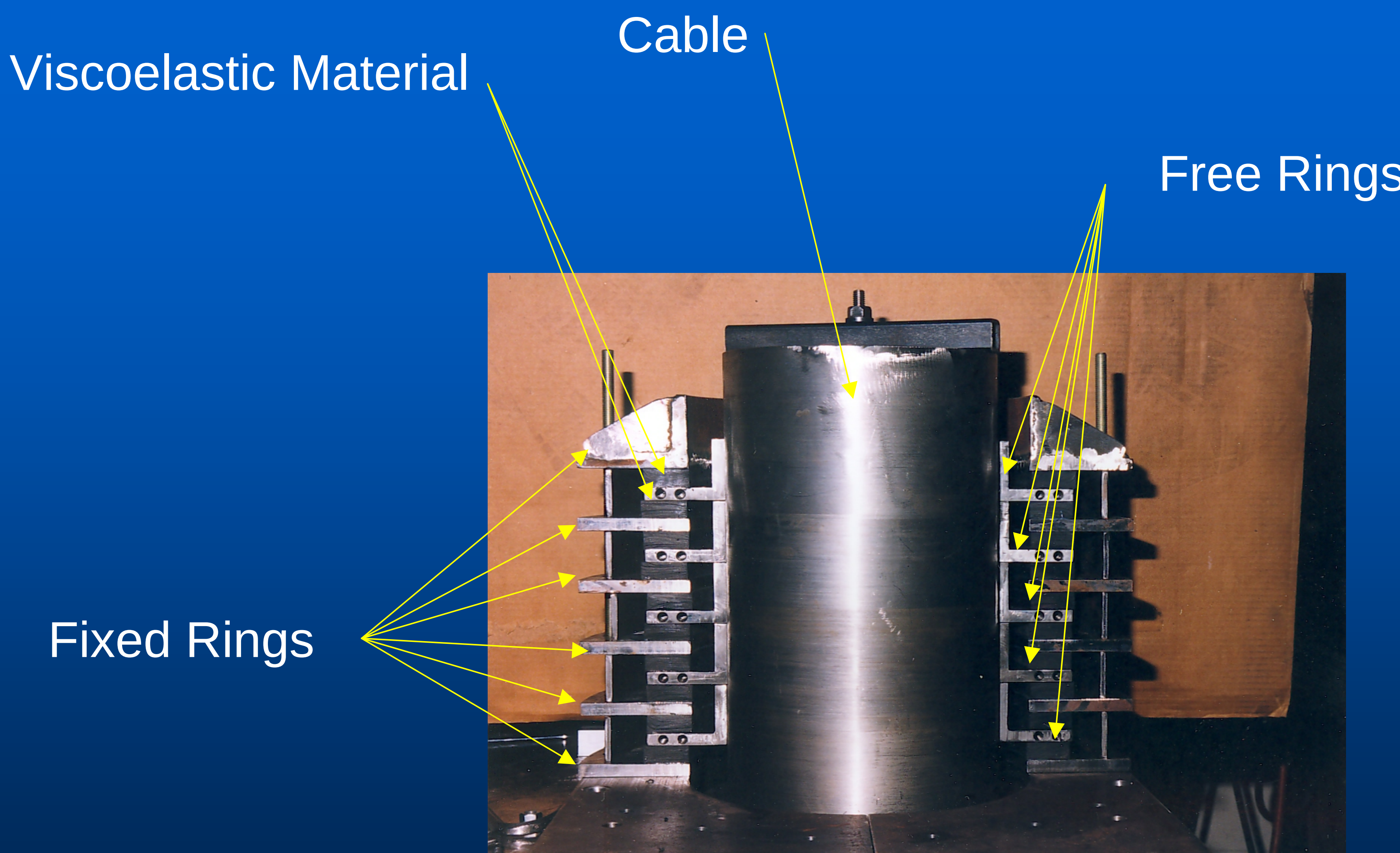
A = Surface area of VE layer

t = thickness of VE layer

m = modal mass of cable

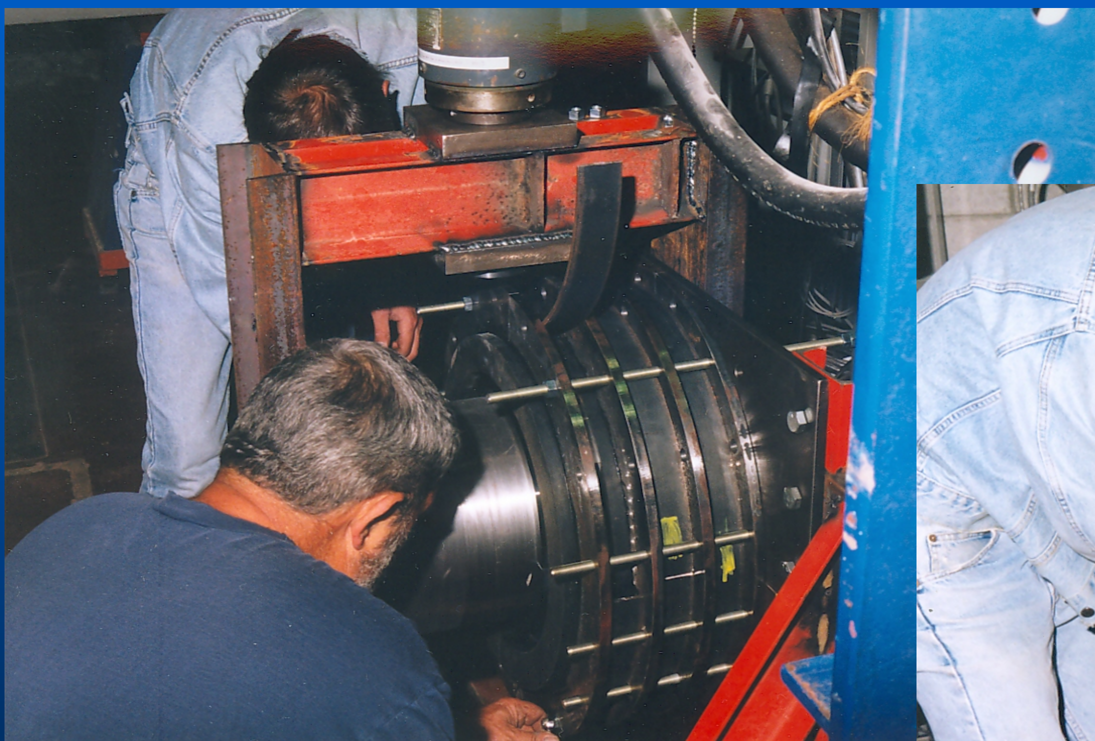
f = frequency of cable

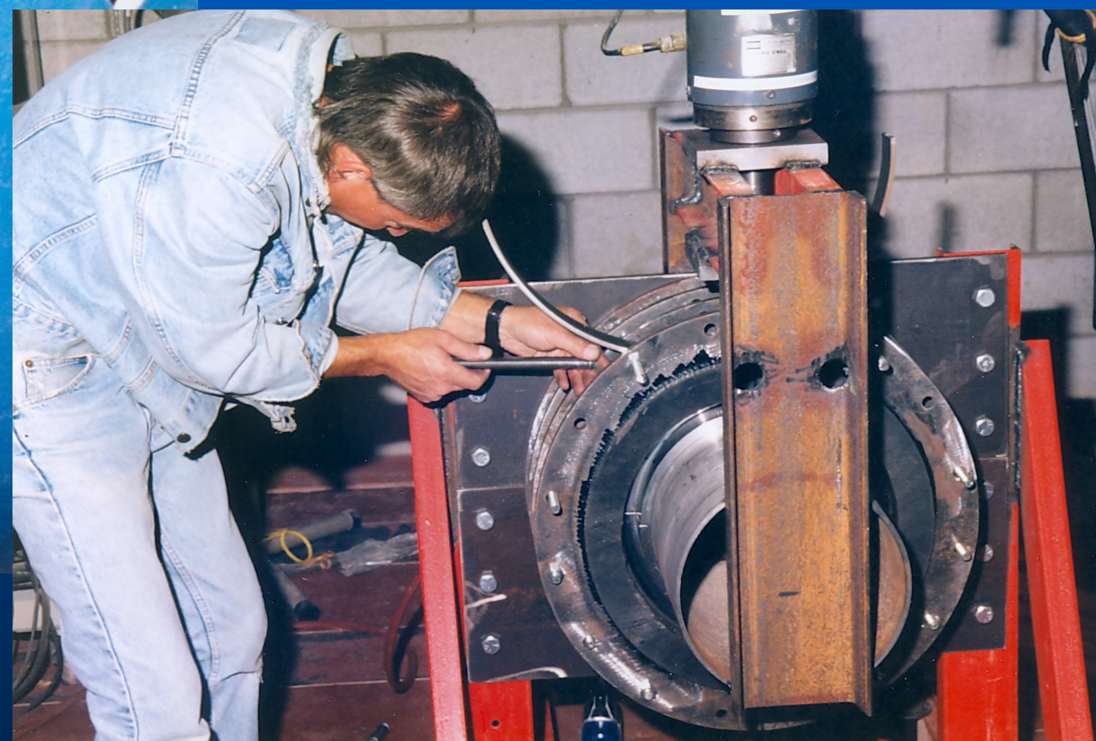
d = shear displacement

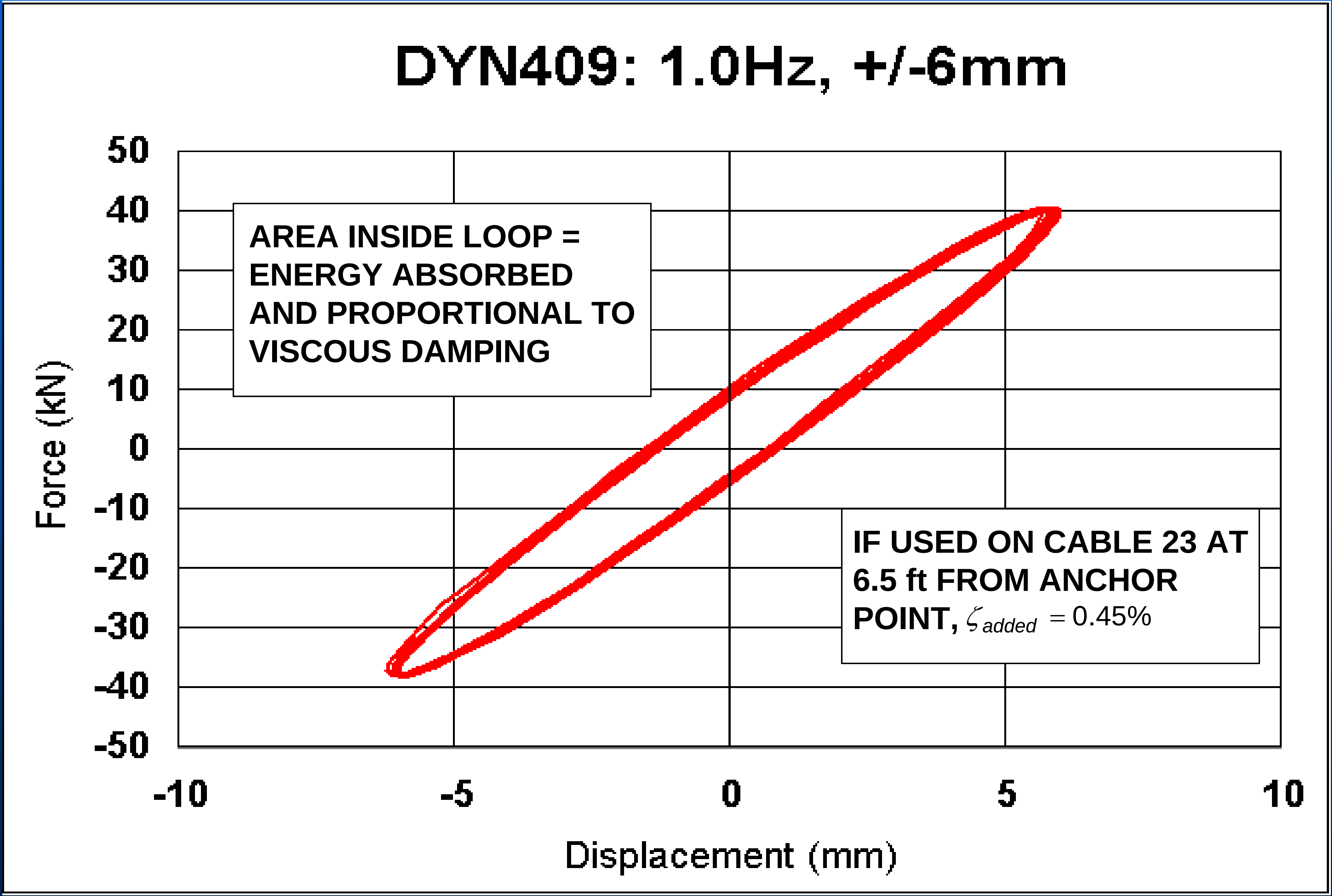

Cable
Viscoelastic Material
Free Rings
Fixed Rings

Lab Study

Hydraulic Ram





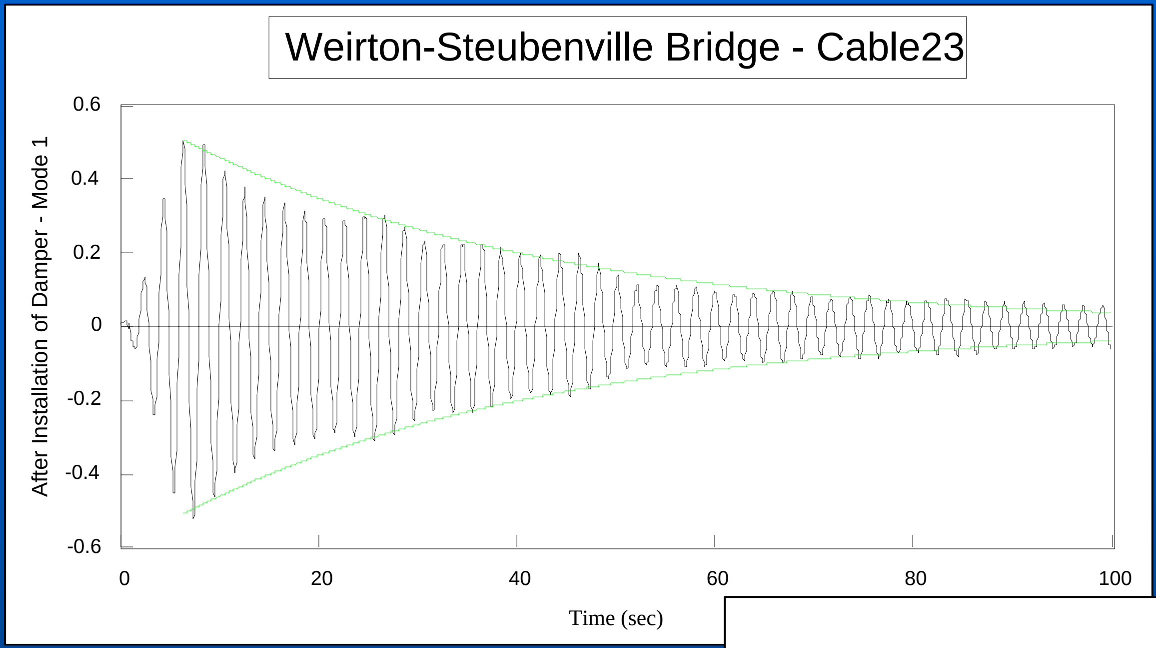

DYN409: 1.0Hz, +/-6mm
AREA INSIDE LOOP = ENERGY ABSORBED AND PROPORTIONAL TO VISCOUS DAMPING
IF USED ON CABLE 23 AT 6.5 ft FROM ANCHOR POINT, $\zeta_{added} = 0.45\%$
Force (kN)
Displacement (mm)
50
40
30
20
10
0
-10
-20
-30
-40
-50
-10
-5
0
5
10

V-E Dampers - Field Installation


EXIT 1
2
SOUTH
Follansbee
Wheeling
EXIT ONLY

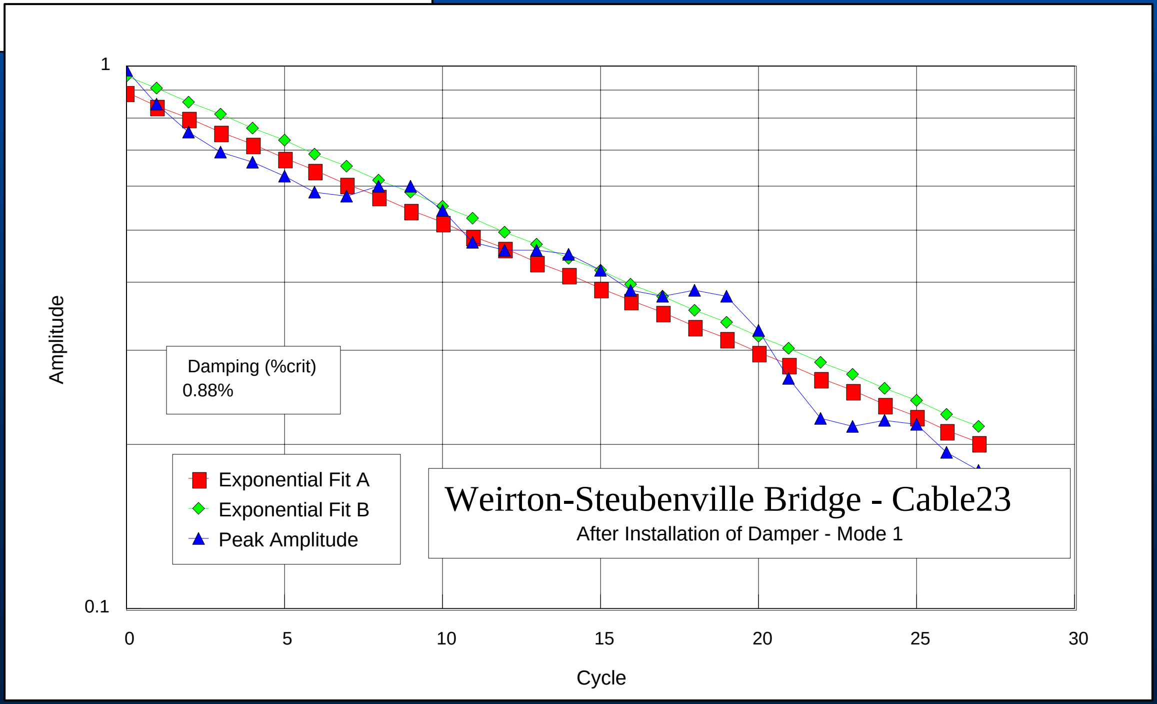
INSTRUMENTING CABLE

ACCELEROMETER



After Installation of Visco-Elastic damper Assembly

Damping = 0.88% of Critical



Monitoring

- Cable fitted with Visco-elastic damper monitored for 18 months along with another “control” cable
- No excessive motions observed: +/-2” vs +/- 12” prior to damper installation
- Damper performed well even in winter months

V-E damper

Mild corrosion at 18 month inspection

But:

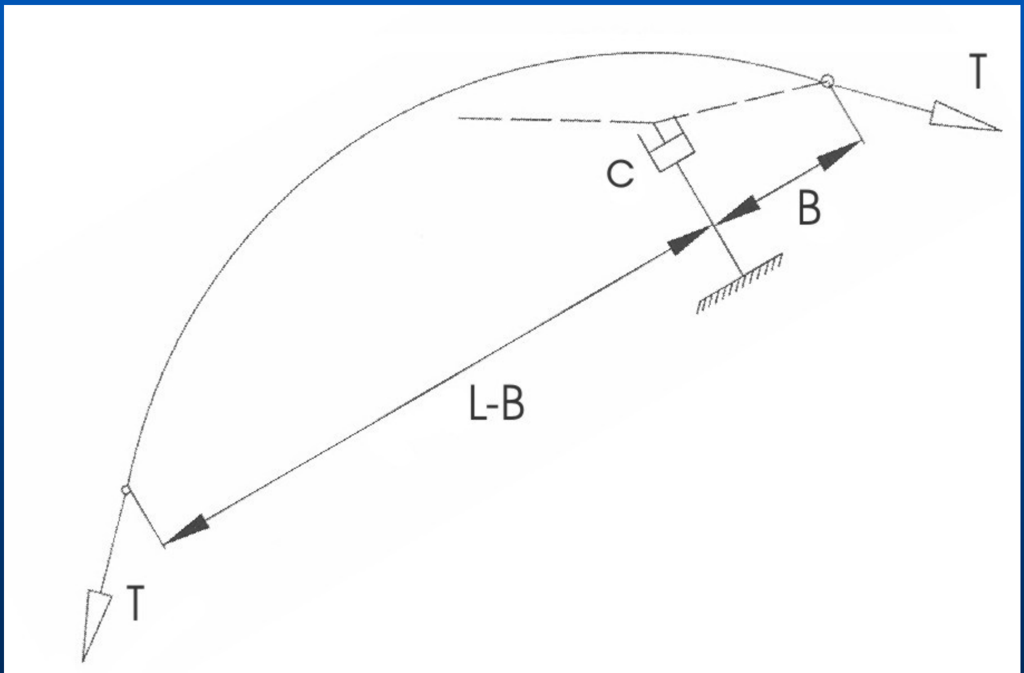
- costly to manufacture
- aesthetics questioned
- satisfactory performance

Hydraulic Damper

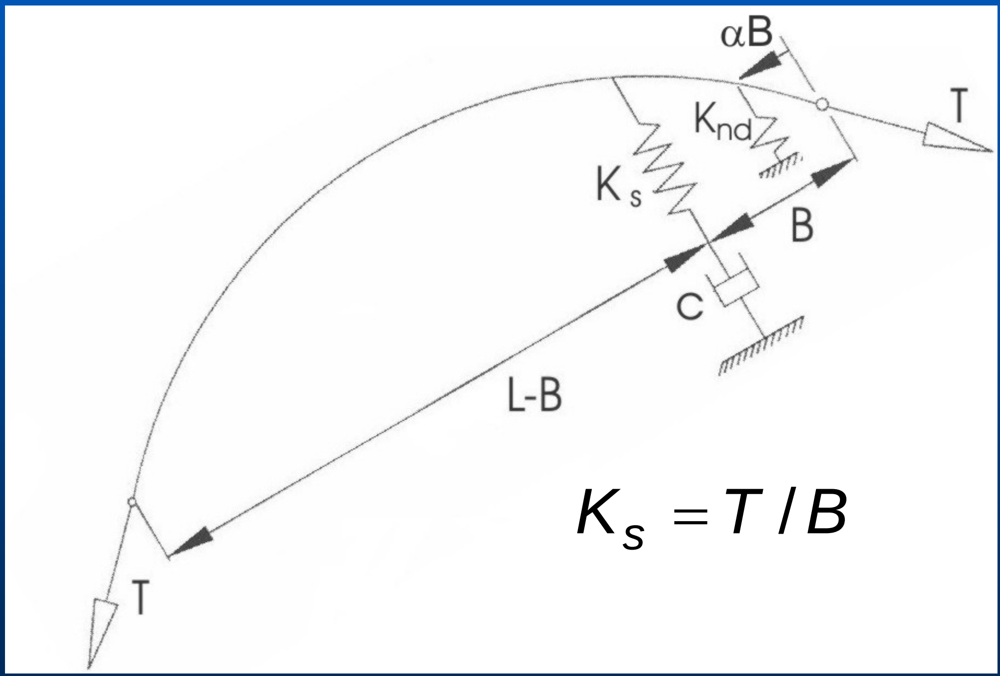
- Design methodology well established on several cable stayed bridges
- Able to install damper assemblies behind precast facia panels in tower head
- Relatively economical

DESIGN PARAMETERS

Actual
(deformed mode)



Equivalent
(spring added)



$$K_s = T / B$$

- Taking Neoprene “Damper” Stiffness into account:

  Equivalent Distance to Anchor Point:

$$B_e / B = \frac{1-\alpha}{1-\left\{\dfrac{\alpha}{k\alpha(1-\alpha)+1}\right\}}$$

$$k = K_{nd} \cdot B / T$$

Note that as :

$k \Rightarrow 0$ then $B_e / B \Rightarrow 1$

and

$k \Rightarrow \infty$ then $B_e / B \Rightarrow (1-\infty)$ and the Neoprene Damper Ring becomes the anchor point

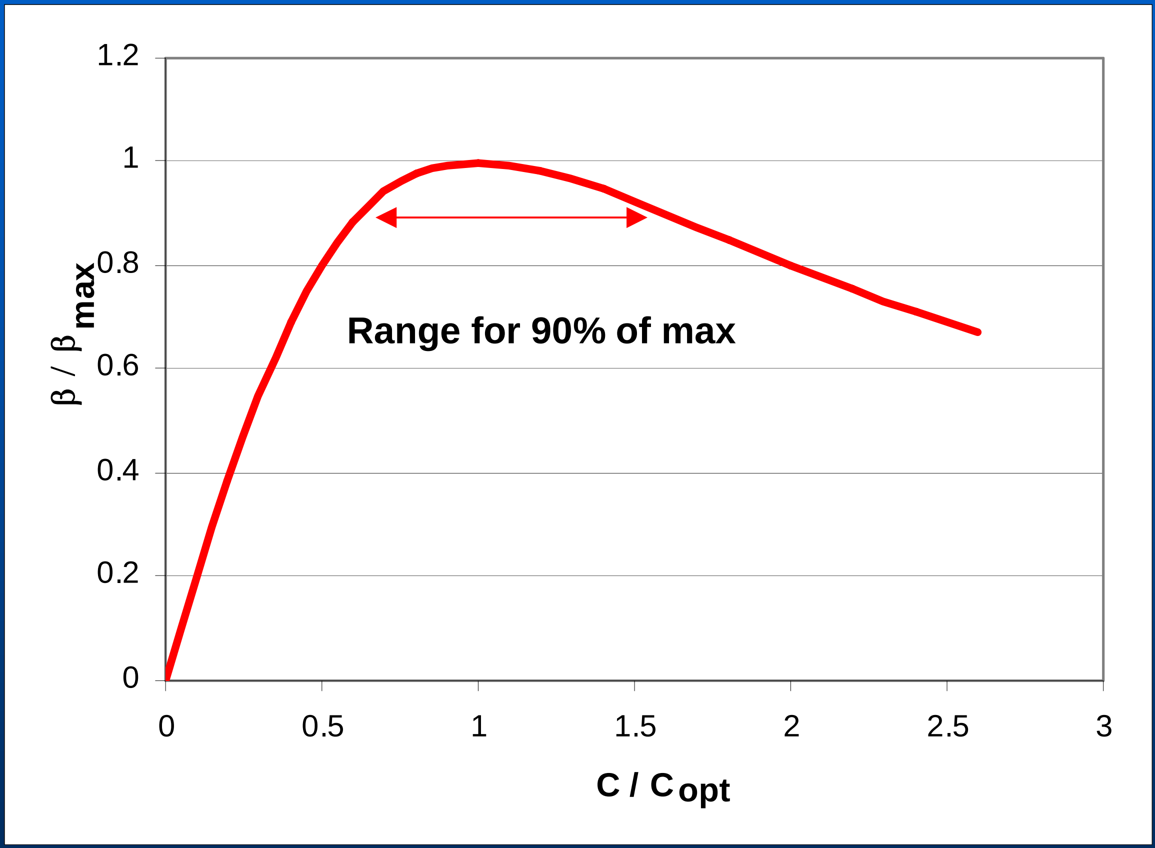
Added Damping to Cable:

Function of:

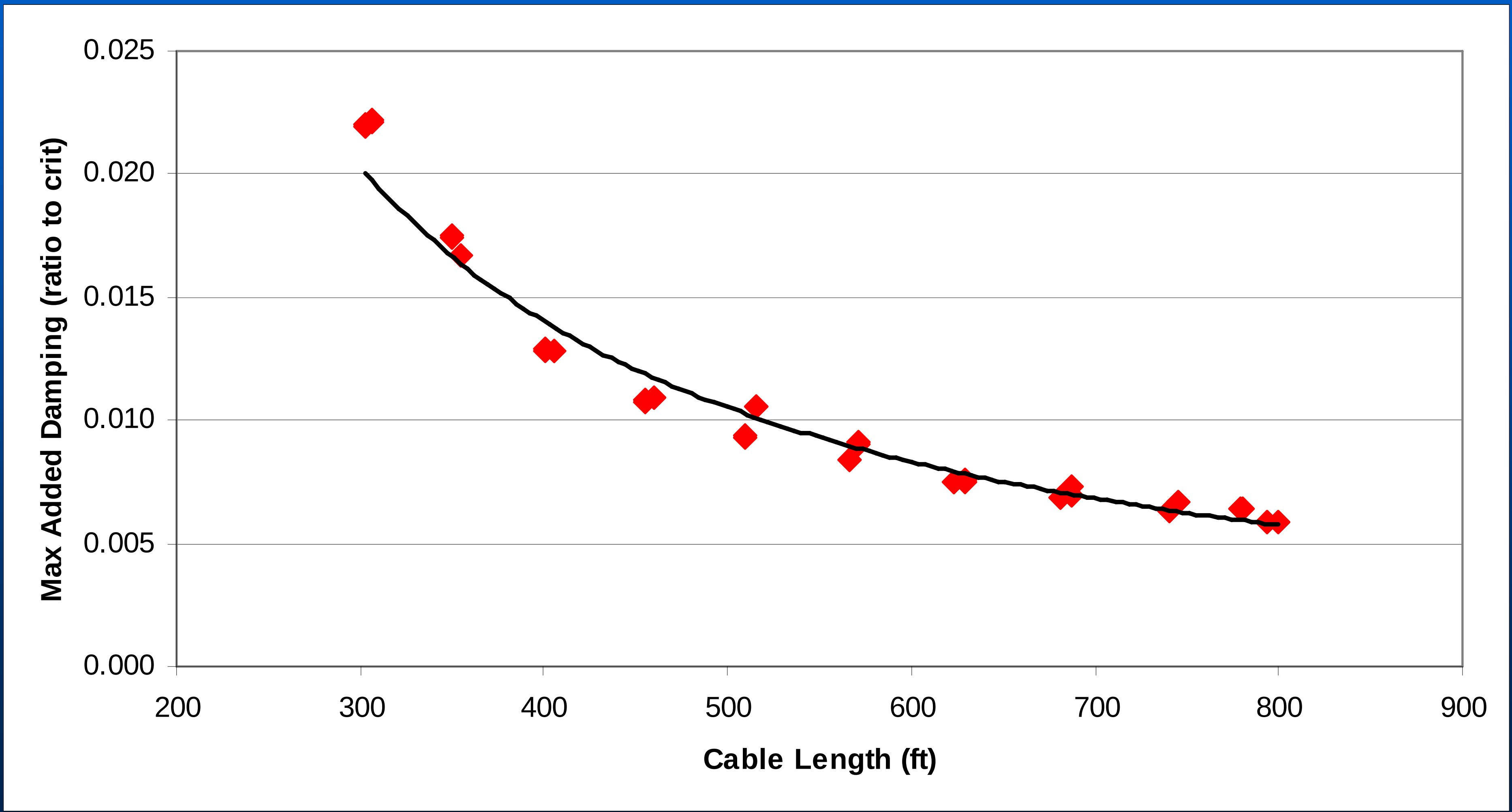
- Damper Capacity, c and Placement, B_e
- Mass, m, Length, L Frequency of Cable ω_1
- Equivalent Stiffness of Damper and Neoprene Plug, K_e

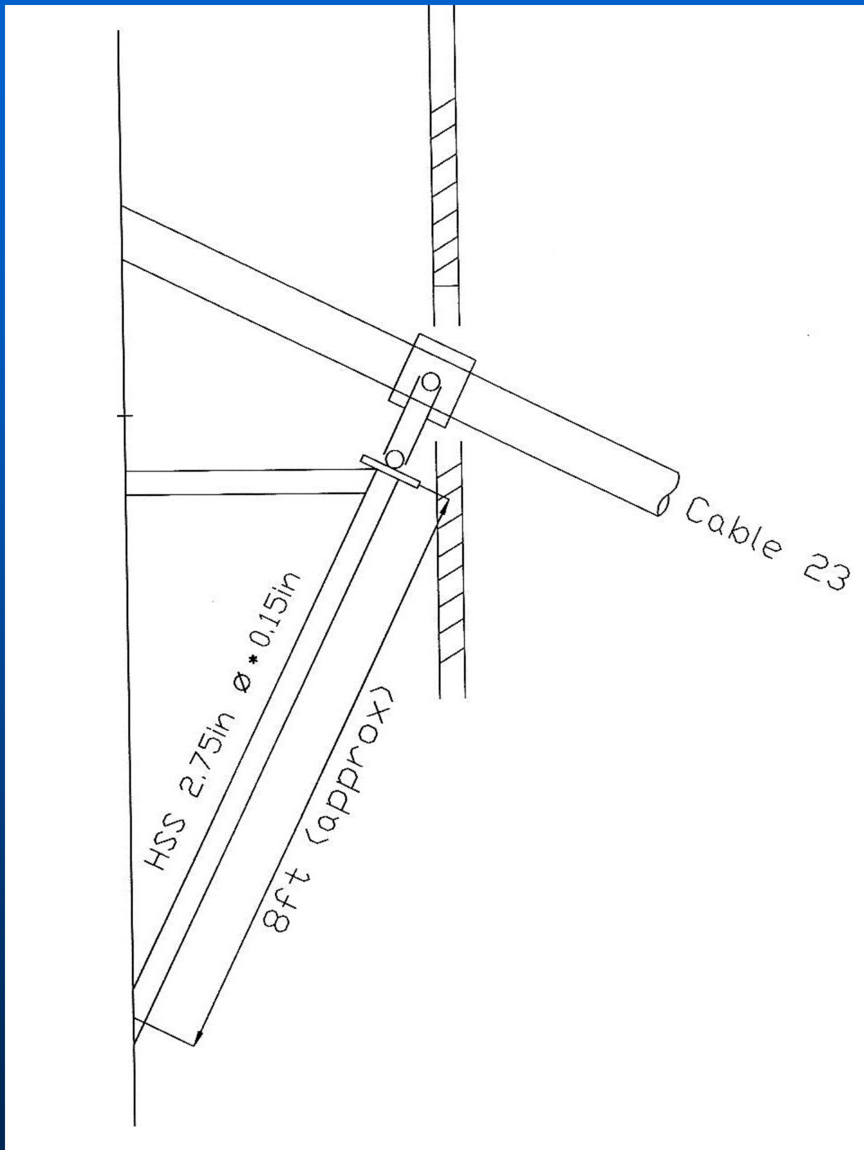
$$\beta = \frac{\dfrac{c}{mL\omega_1}\left(\dfrac{\pi B_e}{L}\right)^2}{1+\left(\dfrac{c\omega_1}{K_e}\right)}$$

- Desirable to maximize Damping provided
- Optimum damper capacity for maximum damping provided

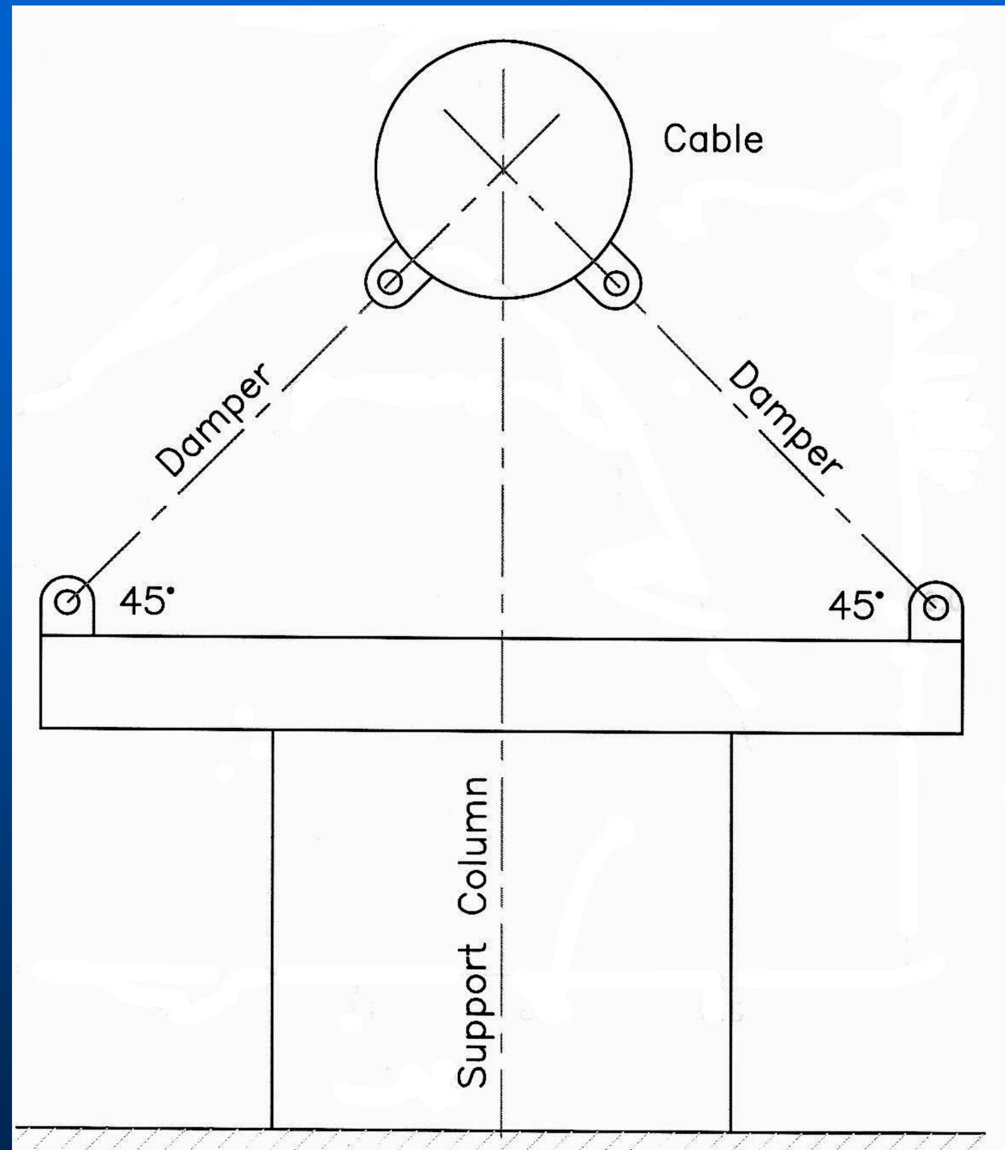


Maximum Added Damping

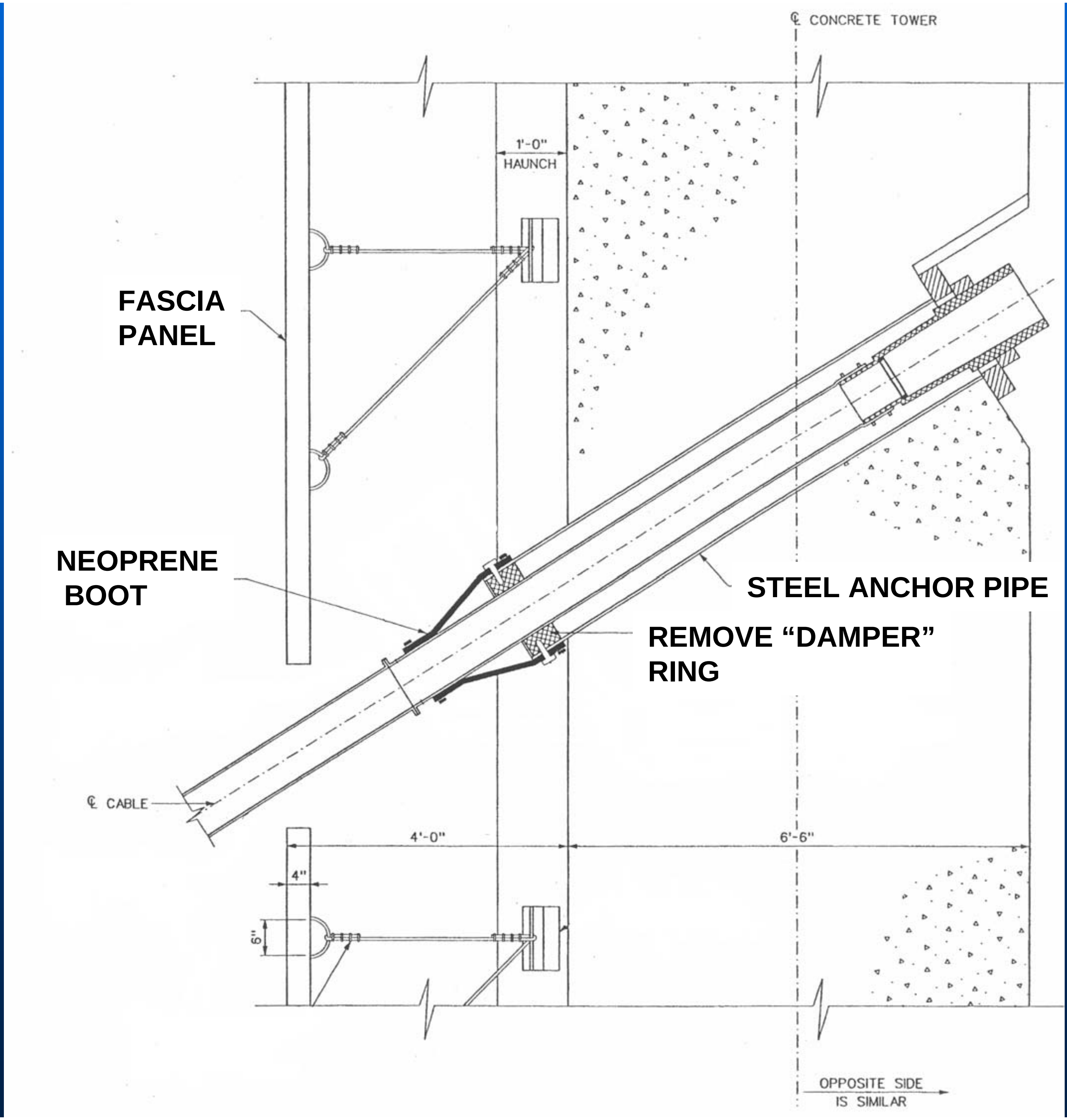


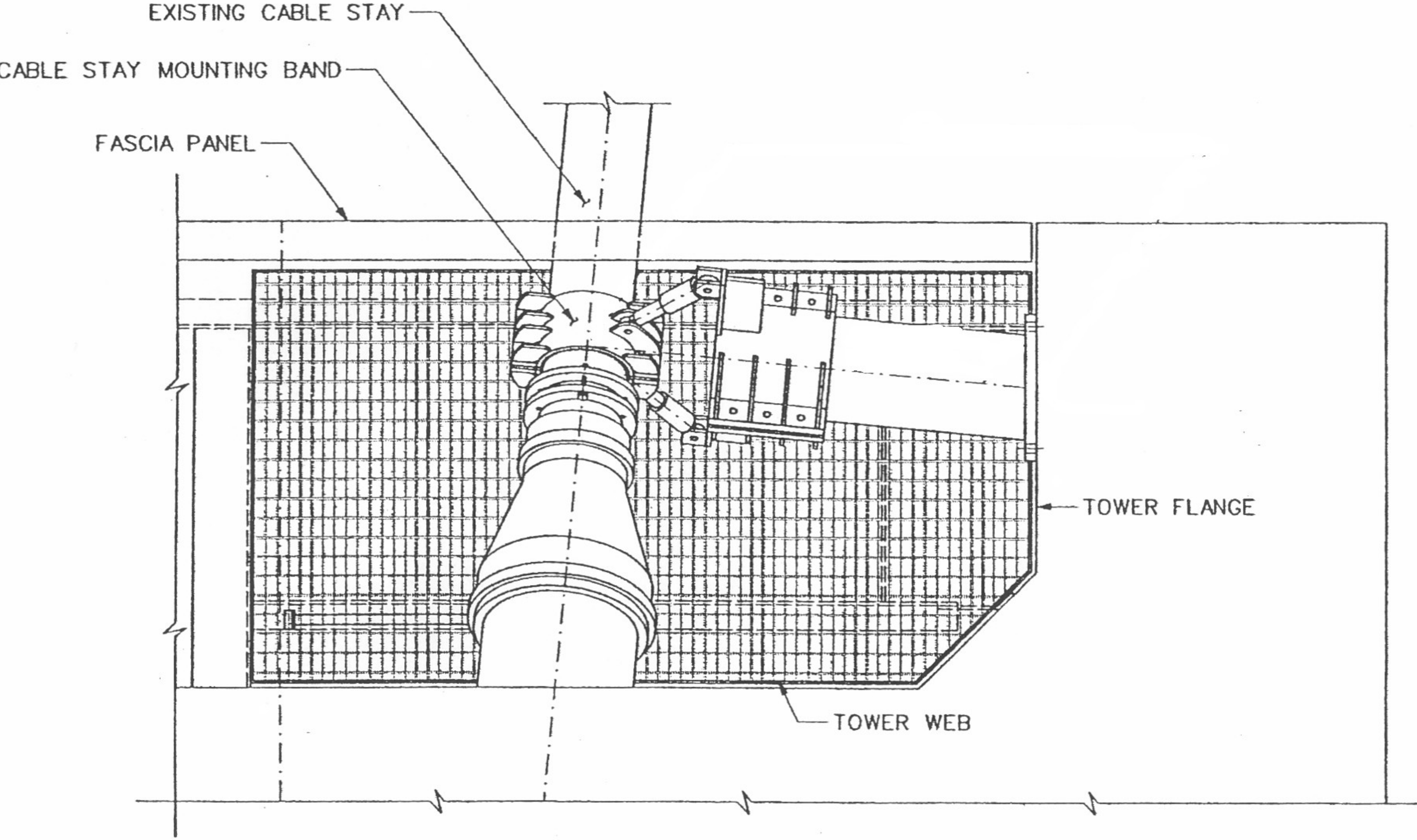


Cable 23
HSS 2.75in ø * 0.15in
8ft (approx)



Cable
Damper
Damper
45°
45°
Support Column


℄ CONCRETE TOWER
1'-0"
HAUNCH
FASCIA PANEL
NEOPRENE BOOT
STEEL ANCHOR PIPE
REMOVE "DAMPER" RING
℄ CABLE
4'-0"
6'-6"
4"
6"
OPPOSITE SIDE IS SIMILAR


EXISTING CABLE STAY
CABLE STAY MOUNTING BAND
FASCIA PANEL
TOWER FLANGE
TOWER WEB

PLAN

Conclusions

- Viscoelastic Dampers can provide additional damping to stay cables at levels sufficiently high to prevent wind-induced oscillations
- Hydraulic Damper systems are at present, a more practical and economical option

Acknowledgements

- WVADOT
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- Graduate students