Fatigue Resistant Design Criteria for MD SHA Cantilevered Mast Arm Signal Structures

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1. Introduction: AASHTO Standard Specifications for Sign Structures

Group Load Combinations (1994-LTS3)	
Group Load	Load Combinations
I	DL
II	DL + W
III	DL + Ice + ½ (W)

Group Load Combinations (2001, 2009, 2013-LTS4, 5, & 6)	
Group Load	Load Combinations
I	DL
II	DL + W
III	DL + Ice + ½ (W)
IV	Fatigue

Percent of Allowable Stress		
Group Load	1994	2001, 2009, & 2013
I	100%	100%
II	140%	133%
III	140%	133%

Up and Coming: AASHTO LRFD Specifications (available in August 2015)

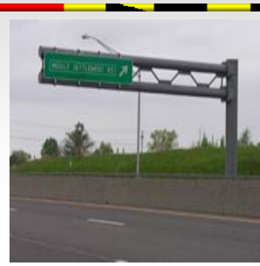
1. Introduction: Fatigue Design: Design Loads

AASHTO's 6th Edition:

- Sign and Traffic Signal Structures
  - Galloping
  - Natural Wind Gust
  - Truck-Induced Gust
- High Mast Lighting Towers (HMLTs)

AASHTO's 5th Edition:

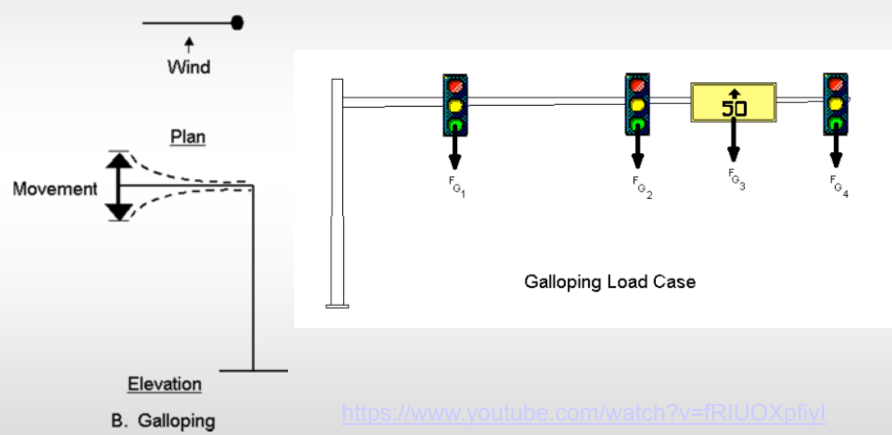
- Galloping
- Natural Wind Gust
- Vortex Shedding
- Truck-Induced Gust



Sign Structure (Overhead Cantilevered)

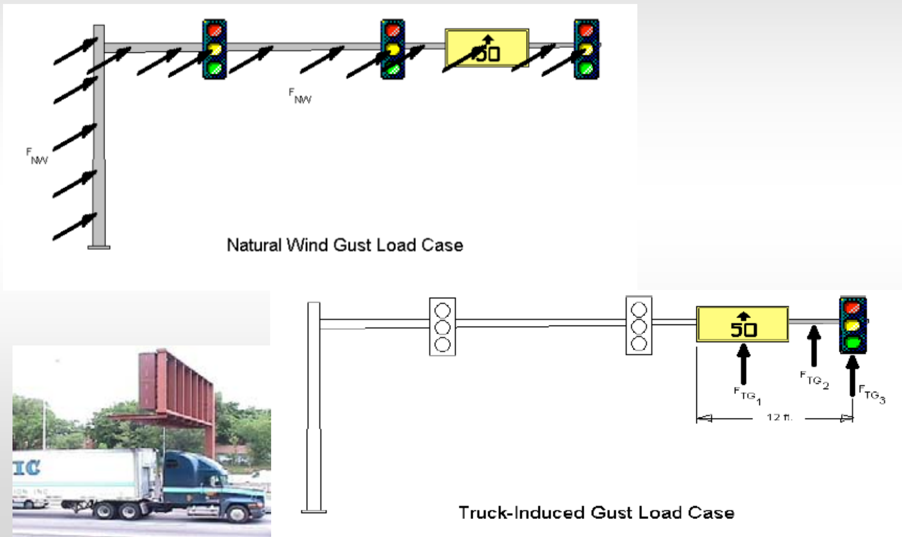
High Mast Lighting Tower (HMLT)

1. Introduction : Fatigue Design Loads - Galloping

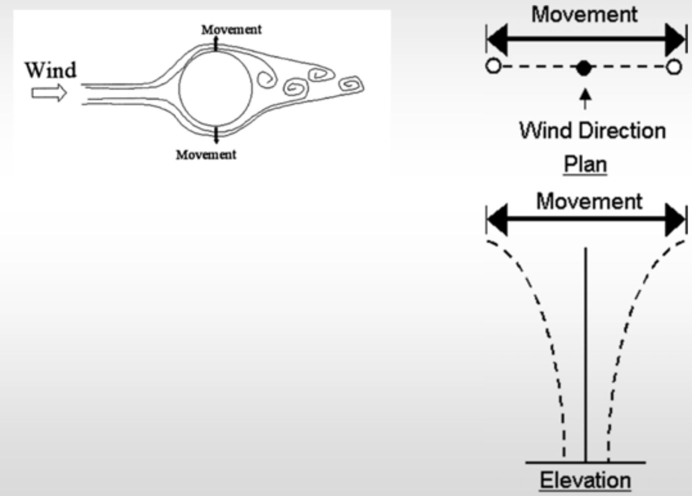


https://www.youtube.com/watch?v=fRIUOXpfiyI

1. Introduction : Fatigue Design Loads – Natural Wind & Truck-Induced Gust



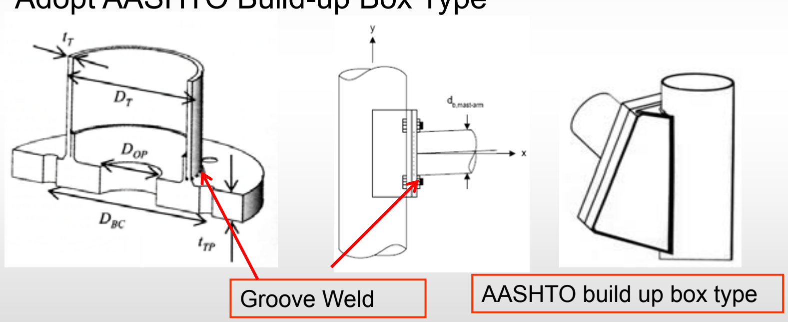
1. Introduction: Fatigue Design: Vortex Shedding



A. Vortex Shedding

2. Summary of Maryland New Criteria

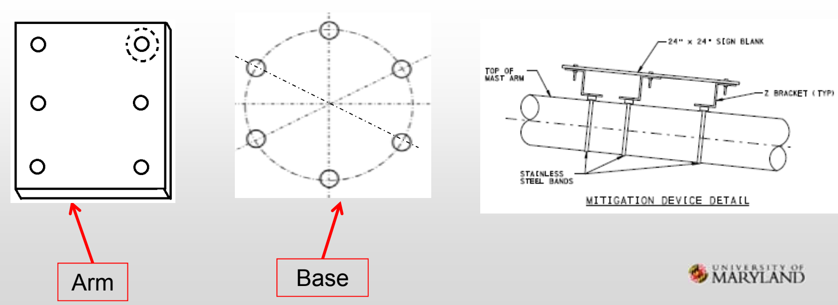
1) Use Importance category II with mitigation device
2) Use 50-year design life
3) Apply groove welds for both arm and pole connections.
4) Adopt AASHTO Build-up Box Type



Bolted connection - $(\Delta F)_{TH}$ = 7.0 ksi
Groove weld - If $K_i \leq 3.0$ $(\Delta F)_{TH}$ = 10. ksi

2. Summary of Maryland New Criteria

5) Use signal head back plate
6) Use non-stiffened pole base (as before)
7) Use 6-bolt pattern for both arm and base connections
8) Use wind plate as the mitigation device; adopt PennDOT 24”x24” design
9) Use 100-mph wind speed for LTS-6 design (as before)

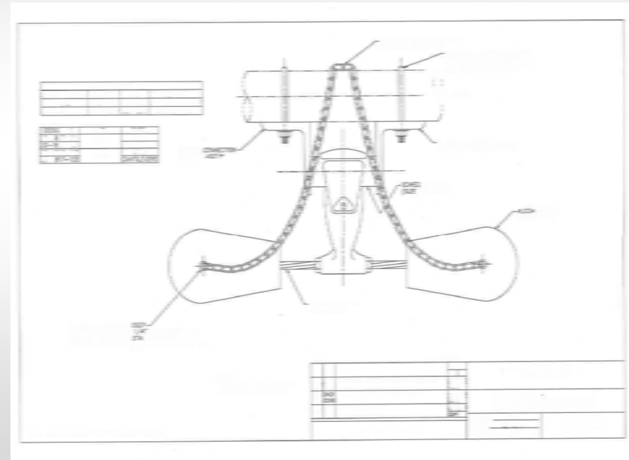


3. Vibration Mitigation Methods

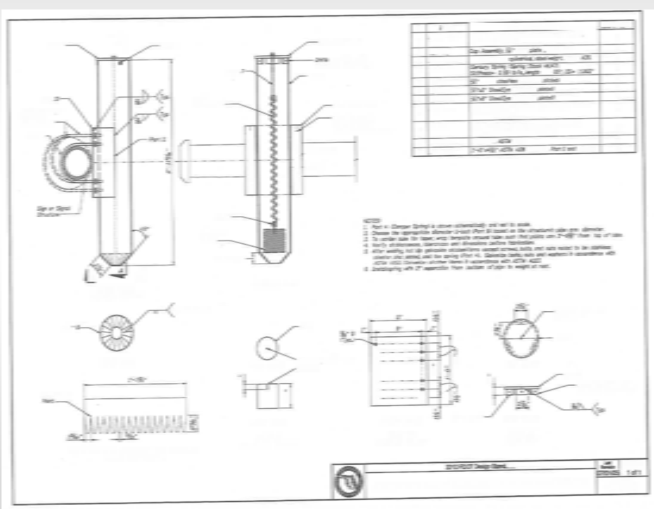
Vibration and fatigue in cantilevered structures can be mitigated in one of three ways:

1. Increase the stiffness of the structure by increasing member sizes or changing structural configuration (e.g., trusses instead of monotubes). This is the simplest, but most expensive, method.
2. Damping out motion by using mechanical devices.
3. Adding damping plates and louvered backplates, among other techniques, to alter the aerodynamic characteristics of the structure and preclude the possibility of galloping.

3. Mitigation Device – UNION METAL



3. Mitigation Device – FDOT

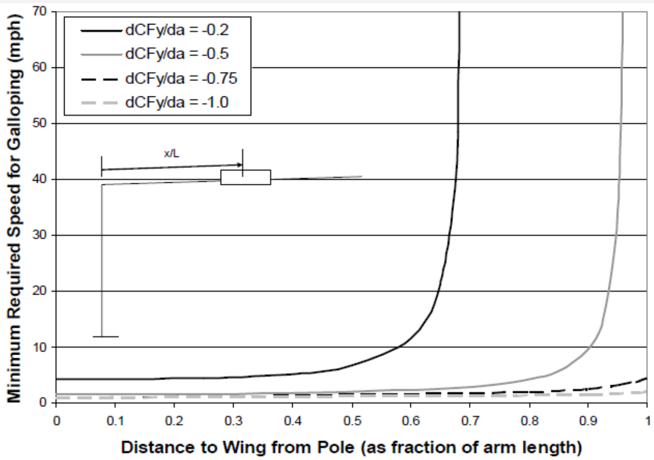


3. Mitigation Device UMD Experiment Plan

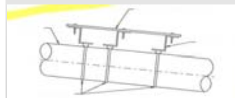
Mechanical damping device similar to the one supplied by Union Metal was used

3. Mitigation Device – Wing Plate

Aerodynamic Damping Device –
Parametric study of wing plate from TXDOT report FHWA/TX-07/4586-1



For maximum benefit, the wing should be located as far out toward the tip of the mast arm as possible.



3. Mitigation Device – Wing Plate

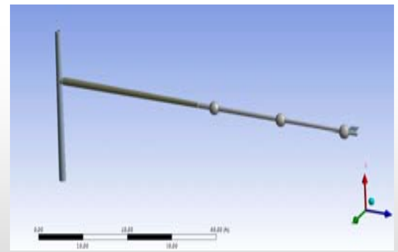
FSI (fluid structure interaction) analysis was conducted in ANSYS Workbench

Wind speed: 5m/s (11.18Mph)

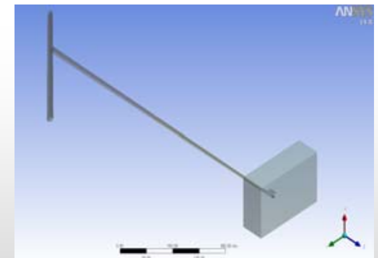
Wind plate: 24 in X 24 in at the tip of the arm

Mast-arm length: 75ft

Initial vibration: 100-lbf upward force for 1 second at the tip



Spheres in the graph are point masses without volume

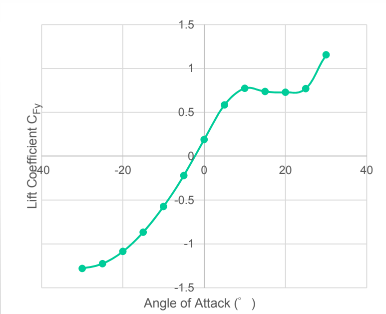


Cuboid zone is the fluid domain

3. Mitigation Device – Wing Plate

Lift coefficient variation with attack of angle (Compared with TXDOT report in 1995)

When $dC_{Fy}/d\alpha > 0$, the device can mitigate galloping



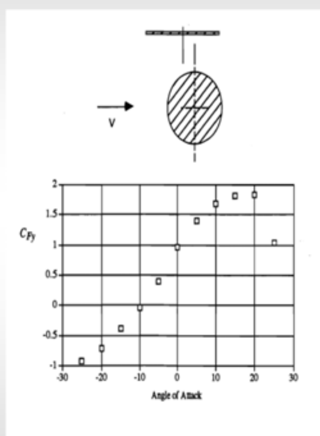


FIGURE 7.15. C_{Fy} VERSUS ANGLE OF ATTACK FOR A DAMPING PLATE

3. Mitigation Device – Wing Plate

Time history in 10s

It shows that compared with free vibration, the vertical displacement at the tip of the arm was reduced to about 65% percent at about 10 seconds.