Project SHA/UM/5-01 2nd Quarter Meeting

The Calibration of the AASHTO ASD and LRFD for Maryland Sign and High Mast Lighting Structure Design

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(http: www.best.umd.edu)

@UMD College Park TVB conference room

August 15, 2019

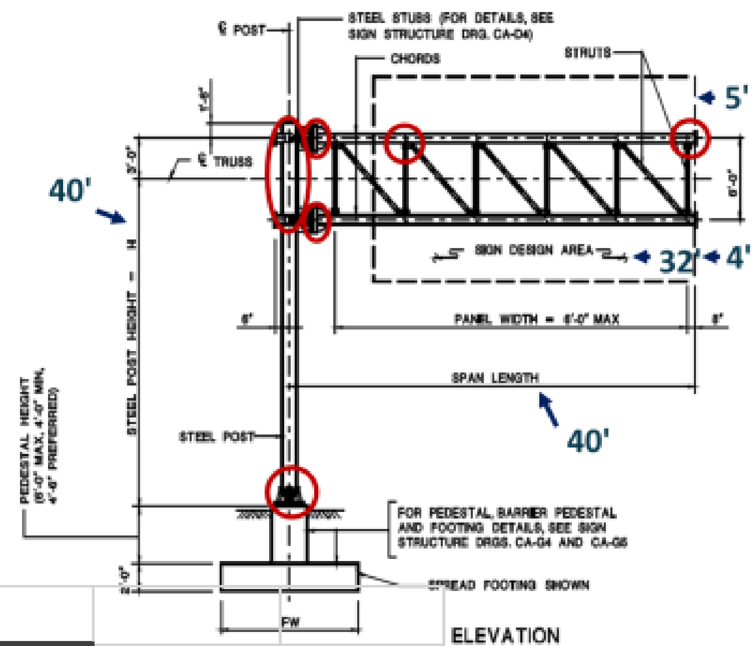
Agenda

- Stress range output from SABRE.
- Methodologies of fatigue checks in new standards.
- Missing fatigues checks:-
  - Chord to splice plate stress range.
  - Stress range for column and gusseted struts as well as diagonals on the columns.
- U-bolts connection stress range for VAMS to truss chord and chord to post. (How to extract loads from sabre.)
- Values for the properties of cohesive and cohesionless soils (shear strengths, unit weights and friction angle) from the research summary.
- Status on the LRFD version. Any differences with respect to fatigue checks.
- For the overhead sign structure; is there a need to check for fatigue at the T-section that connects the truss to the post.

3. Task 3– Fatigue Design Calibration (review)

Fatigue calibration with NJDOT Ex. 1

Overhead Cantilever Sign Structure – Flat Panel Sign Board



Example 1

Fatigue II		Sabre	NJDOT Report	Corrected	Staad.Pro	% Diff
Joint load (kips)	**Gallop**	7.056	7.056		7.056	
	Natural.W	**3.779**	**4.146**	**3.2551**	**3.239**	
	NW sign	2.534	3.6048	2.545		
	NW chord	0.703		0.17		
	NW column	0.543	0.5401	0.5401		
	Truck.W	**0.408**	**1.438**	**0.469**	**0.408**	
	TW sign	0.134	0.357	0.134	0.134	
	TW chord	0.274	1.0811	0.335	0.274	
Moment (K-ft)	**Gallop**	167.8	141.6	169.34	169.3	**0.89%**
	Truck.W	13.7	49.9	14.51	13.87	**1.23%**
Torsion (k-ft)	**Natural.W**	63.6	81.9	57.65	61.92	**-2.71%**

(Revised 5/29/2019)

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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)

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1. Introduction : Fatigue Design Loads

- **Galloping**: (or Den Hartog instability) results in large-amplitude resonant oscillations in a plane normal to the direction of wind flow.

$$P_G = 21 I_F \text{ (psf)}$$

- **Natural Wind Gust** : Because of the inherent variability in the velocity and direction, natural wind gusts are the most basic wind phenomena

$$P_{NW} = 5.2 C_d I_F \text{ (psf)}$$

C_d is the appropriate drag coefficient based on yearly mean wind velocity of 11.2 mph

- **Vortex Shedding**: High-level, high-mast lighting structures shall be designed to resist vortex shedding-induced loads for critical wind velocities less than 45 mph.

$$P_{VS} = \frac{0.00256 V_c^2 C_d I_F}{2\beta} \text{ (psf)}$$

- **Truck-Induced Gust**: Passage of trucks beneath support structures may induce gust loads on the attachments mounted to the horizontal supports of these structures

$$P_{TG} = 18.8 C_d I_F \text{ (psf)}$$

C_d is the appropriate drag coefficient based on truck speed of 65 mph

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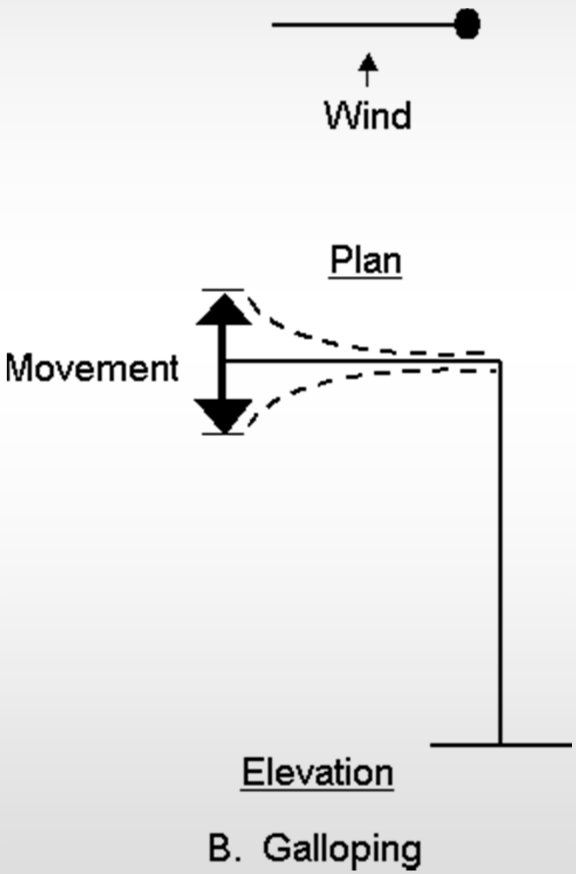
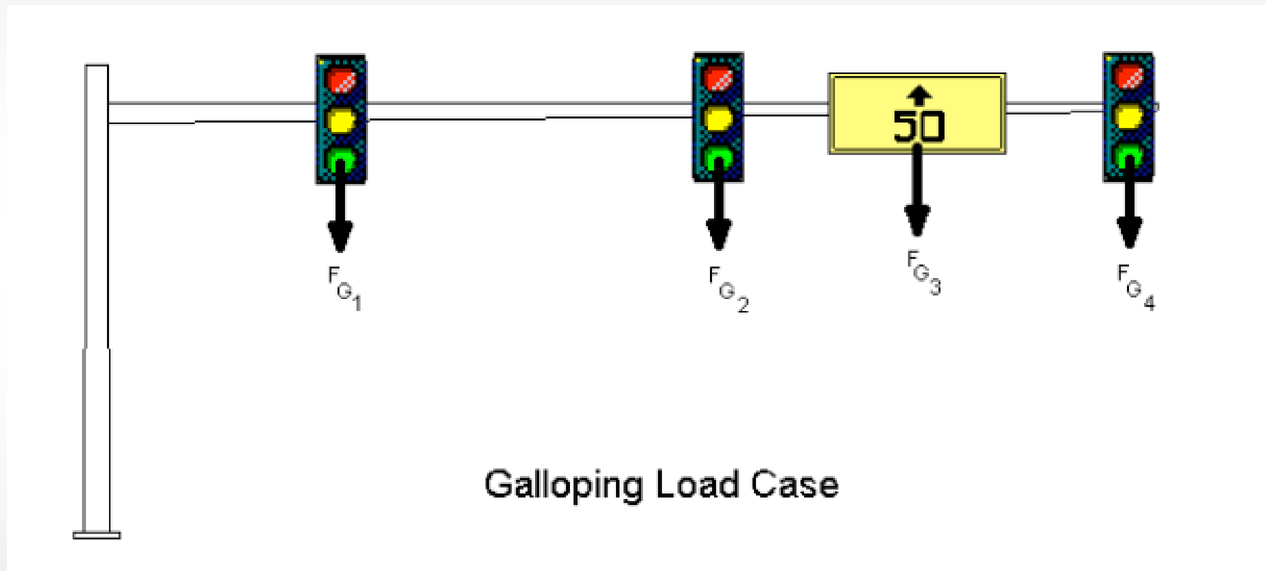
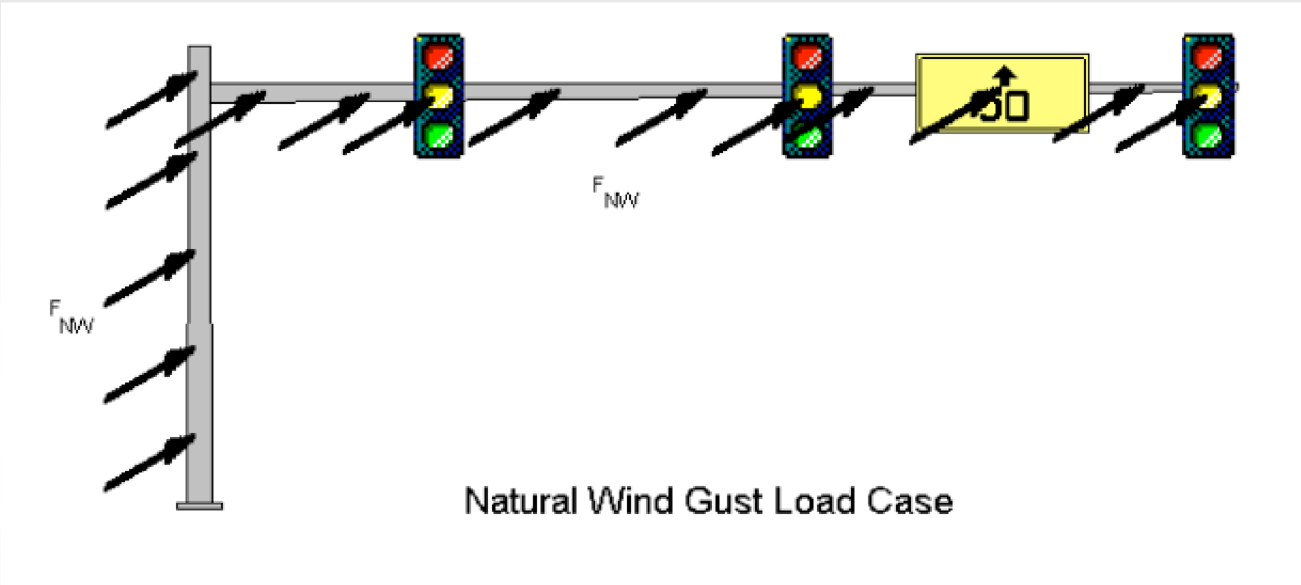
1. Introduction : Fatigue Design Loads - Galloping



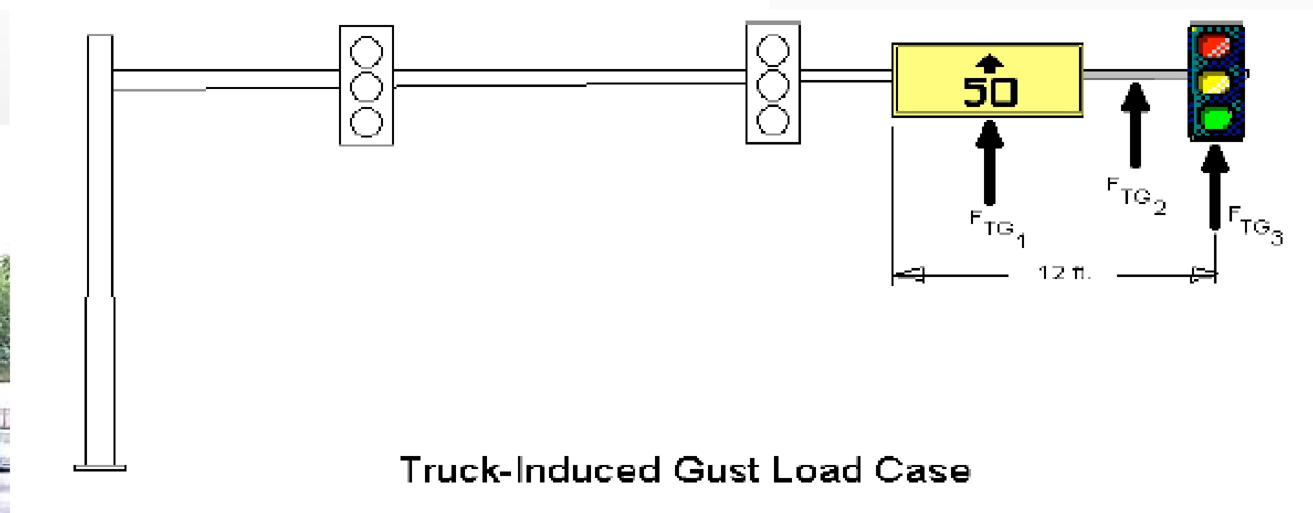


https://www.youtube.com/watch?v=fRIUOXpfiyI

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



Natural Wind Gust Load Case



Truck-Induced Gust Load Case

1. Introduction: Fatigue Importance Factors

Fatigue Importance Category			Galloping	Natural Wind Gusts	Truck-Induced Gusts
Cantilevered	**I**	Sign **Traffic Signal**	1.0 **1.0**	1.0 **1.0**	1.0 **1.0**
	II	Sign **Traffic Signal**	0.70 **0.65**	0.85 **0.80**	0.90 **0.85**
	III	Sign **Traffic Signal**	0.40 **0.30**	0.70 **0.55**	0.80 **0.70**
Non-Cantilevered	I	Sign Traffic Signal	x x	1.0 1.0	1.0 1.0
	II	Sign Traffic Signal	x x	0.85 0.80	0.90 0.85
	III	Sign Traffic Signal	x x	0.70 0.55	0.80 0.70

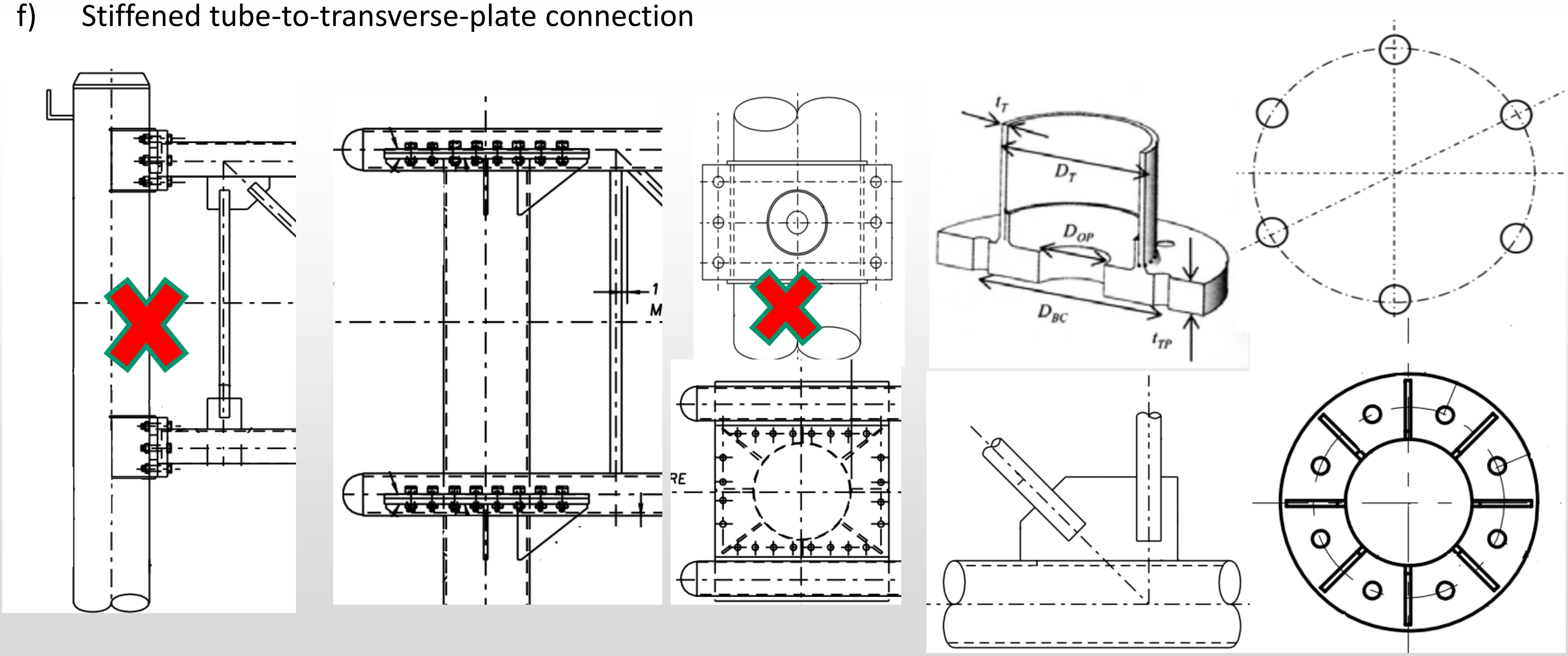
Cat. I - roadways with a speed limit in excess of 60 km/h (35 mph) and average daily traffic (ADT) exceeding 10,000 or average daily truck traffic (ADTT) exceeding 1000

Cat. II - speed limits 60km/h (35 mph) or less

4. Task 3 - Fatigue Design and Fatigue Resisting Connections

Collected details of Maryland signal poles which need to be modified in order to increase the fatigue resistance have been identified and recommended by this University of Maryland Research Team. The recommended modifications of current design on the sign/signal pole structures include:

a) Chord-to-pole connections
b) Groove welds for both pole and arm connections
c) Fillet-welded end connections
e) 6-bolt/8-bolt patterns for both arm and pole connections
f) Stiffened tube-to-transverse-plate connection



4. Task 3– Fatigue Design Details

A. Cantilever sign structures:

1) Fillet tube-to-tube connections for the chords

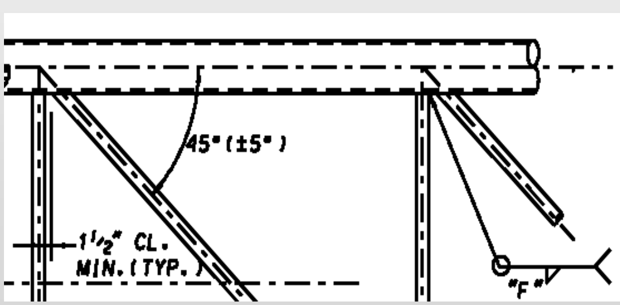
- The fatigue design follows Details 5.5
- In a branching member with respect to the stress in the branching member:

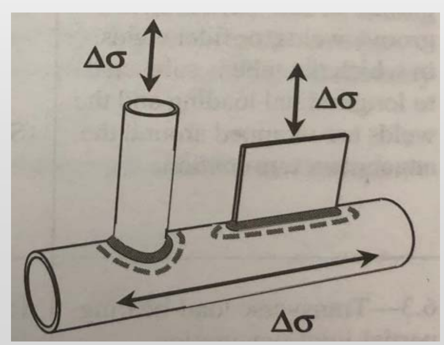
$$(\Delta F)_{TH} = 1.2ksi; when \frac{r}{t} \leq 24\ for\ the\ chord\ member$$

$$(\Delta F)_{TH} = 1.2 \times \left(\frac{24}{\frac{r}{t}}\right)^{0.7} ksi; when \frac{r}{t} \geq 24\ for\ the\ chord\ member$$

- In a chord member with respect to the stress in the chord member

$$(\Delta F)_{TH} = 4.5\text{ksi}$$





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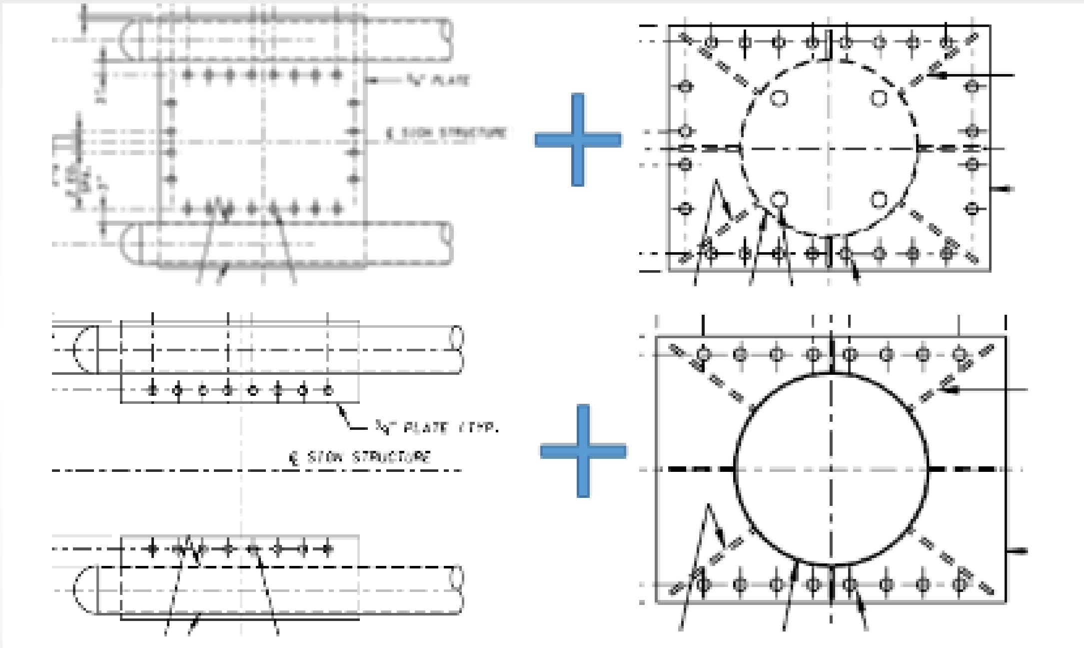
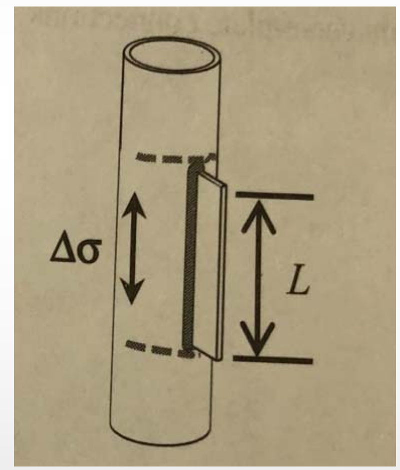
4. Task 3– Fatigue Design Details

2) Pole to truss connection (Two types)

Left

Right





a) for the chord to plate connection:

- The fatigue design follows 6.1 where the main member subjected to the longitudinal loading:

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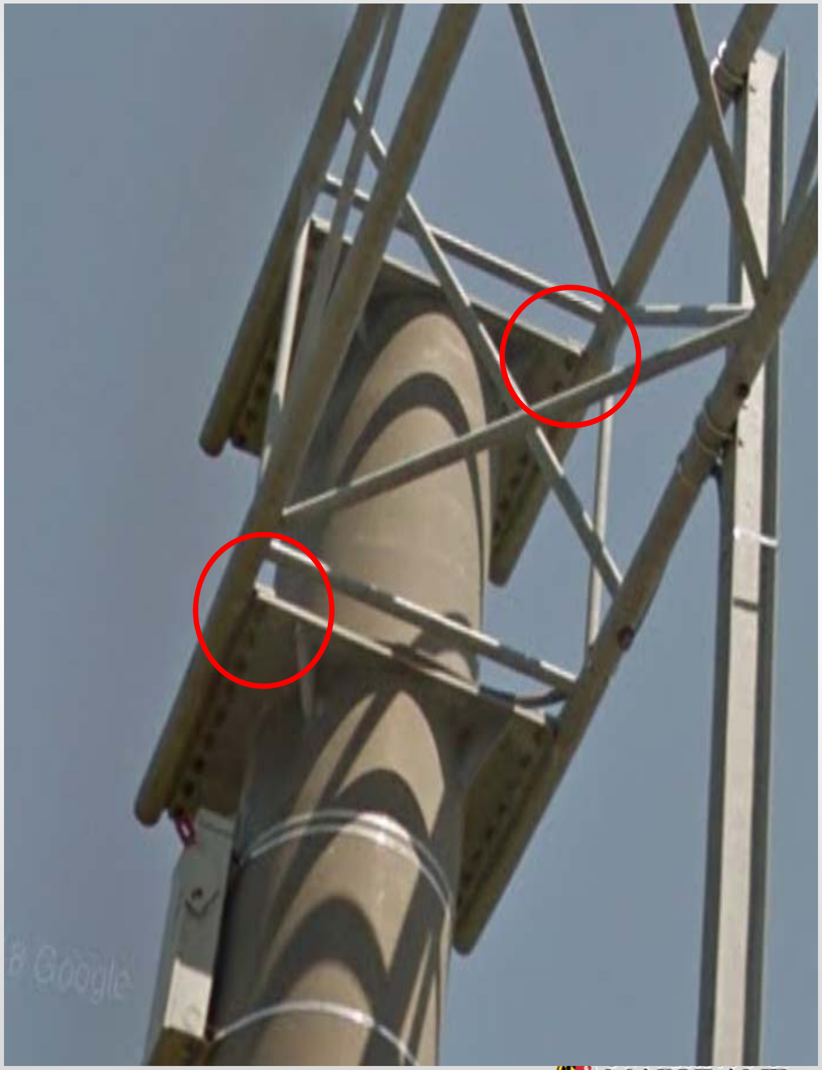

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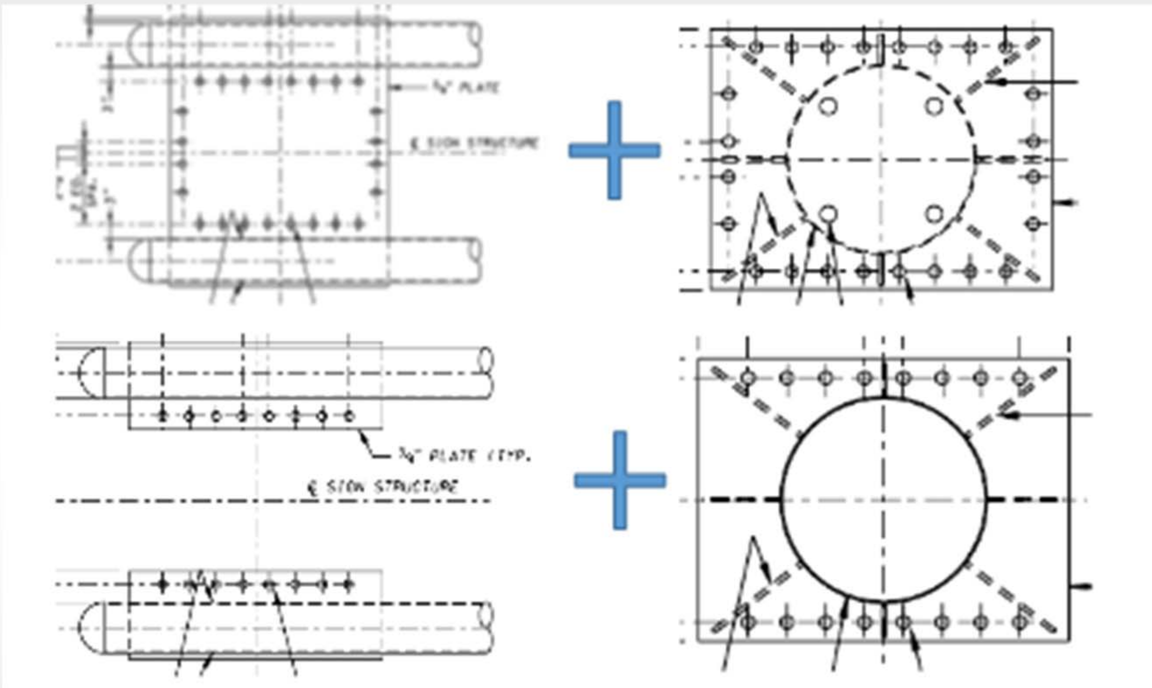
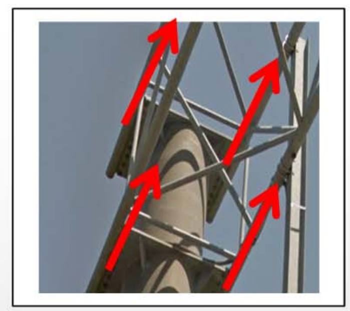
Box-type Cantilever Type Connection

Discussion on “Box-type cantilever type connection”



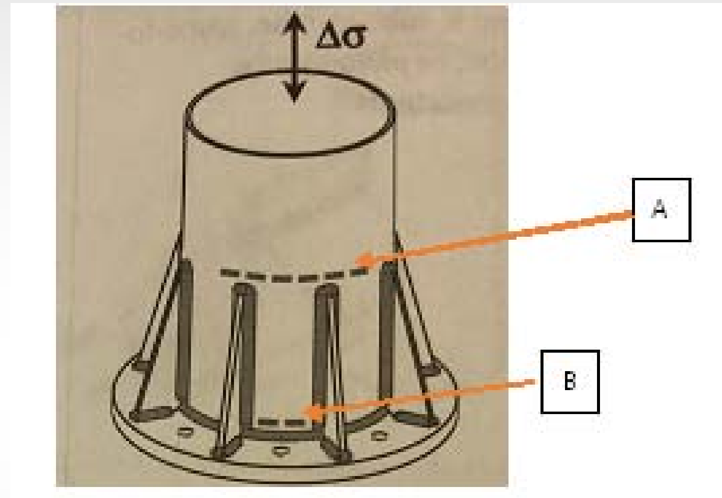


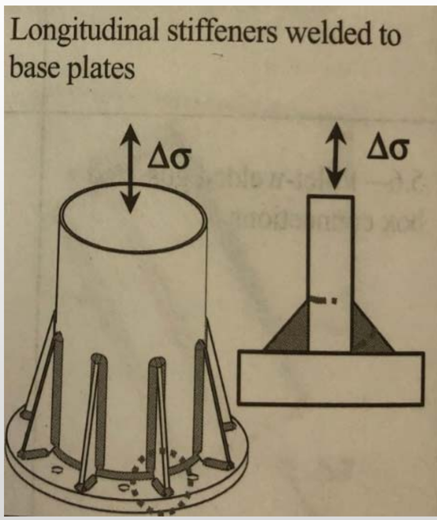
- Main forces are along the horizontal chords of the box truss so it’s the shear action of top and bottom
- stiffened plates. It is similar to Detail 5.7 of the AASHTO Specifications. As per AASHTO Article 5.6.7, the
- connected parts are in infinite life.

4. Task 3– Fatigue Design Details

b) For the pole to plate connection:

- The design following the detail 6.2 and 6.3
- Detail 6.2 (stress in tube):
  - There are two locations:
  - A: $K_I \leq 5.5: (\Delta F)_{TH} = 7.0ksi$
  - B: Following detail 5.4
    - $K_I \leq 4.0: (\Delta F)_{TH} = 7.0ksi$
    - $4.0 < K_I \leq 6.5: (\Delta F)_{TH} = 4.5ksi$
    - $6.5 < K_I \leq 7.7: (\Delta F)_{TH} = 2.6ksi$
- Details 6.3 (stress in stiffeners)
  - $(\Delta F)_{TH} = 10.0ksi$

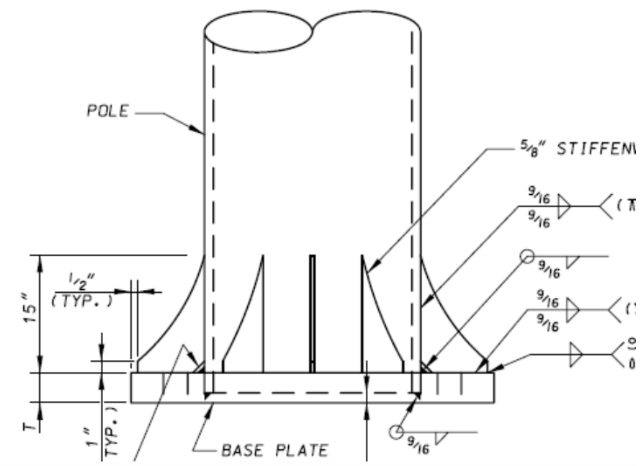




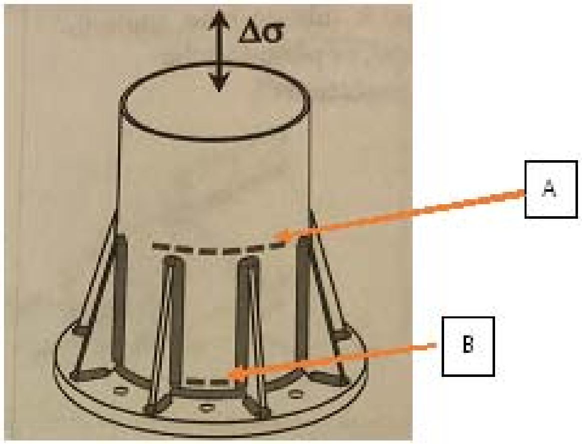
4. Task 3– Fatigue Design Details

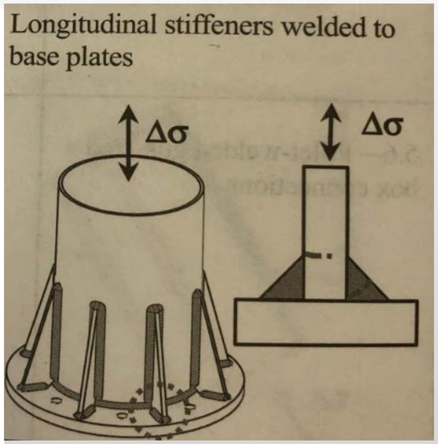
3) Pole to base connection

- The design following the details 6.2 and 6.3
- Detail 6.2 (stress in tube):
  - There are two locations:
  - A: $K_I \leq 5.5$: $(\Delta F)_{TH} = 7.0 ksi$
  - B: Following detail 5.4
    - $K_I \leq 4.0$: $(\Delta F)_{TH} = 7.0 ksi$
    - $4.0 < K_I \leq 6.5$: $(\Delta F)_{TH} = 4.5 ksi$
    - $6.5 < K_I \leq 7.7$: $(\Delta F)_{TH} = 2.6 ksi$



- Detail 6.3 (stress in stiffeners):
  - $(\Delta F)_{TH} = 10.0 ksi$





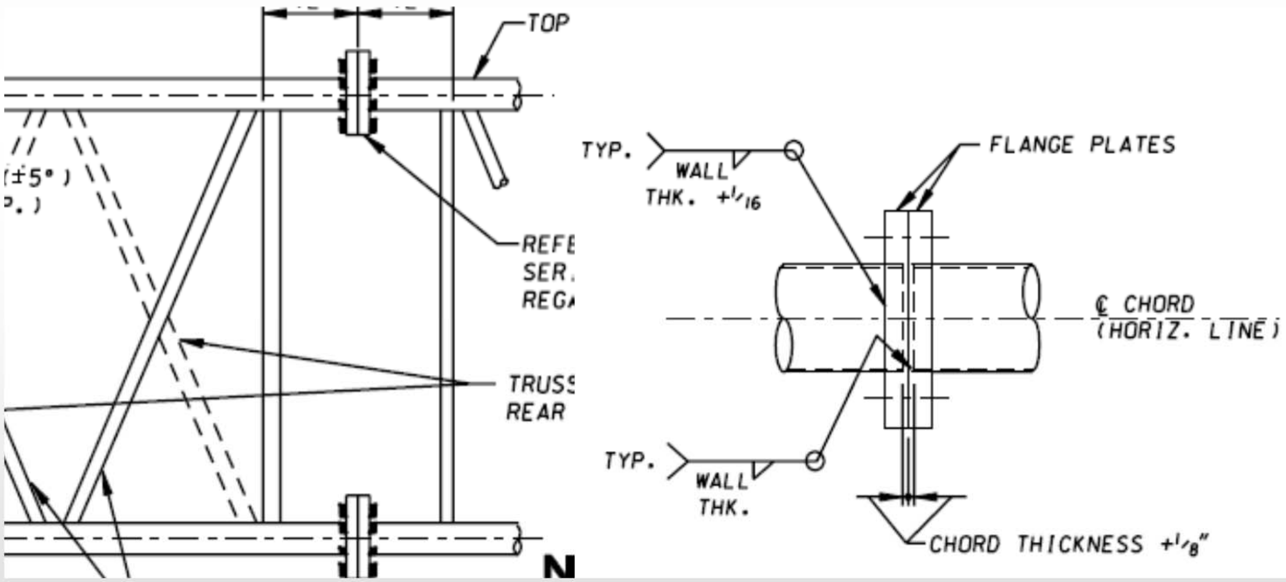
4. Task 3– Fatigue Design Details

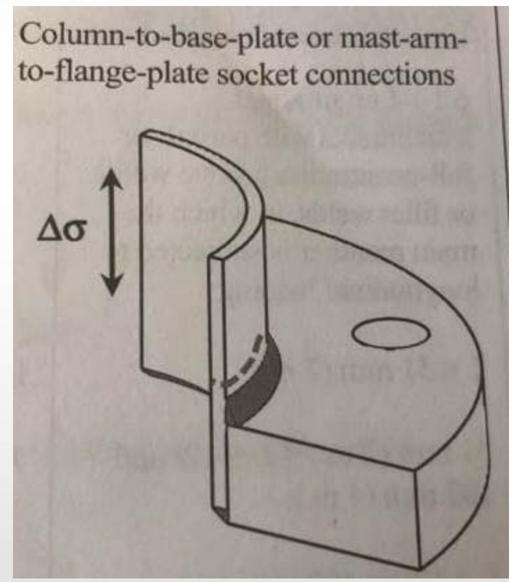
B. Overhead sign structures:

1) Fillet weld and tube-to-tube connections for the chords

   Same as the cantilevered sign structure

2) Flange connection for the chords





Detail 5.4

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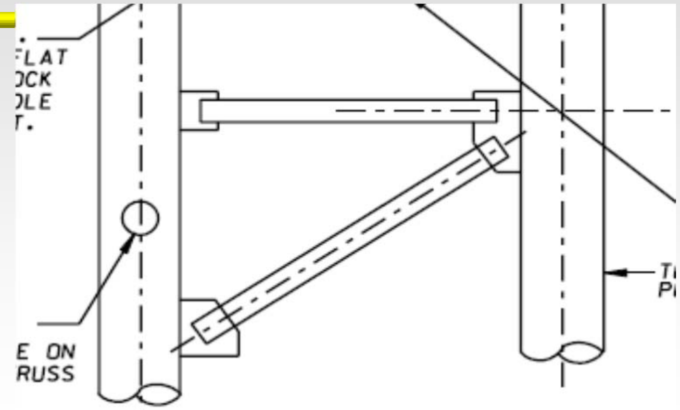
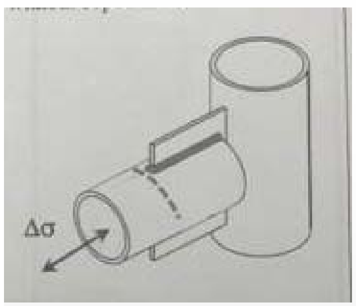
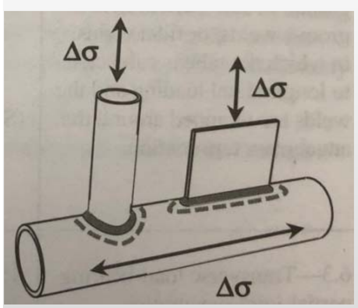
4. Task 3– Fatigue Design Details



3) Pole-chord connection

- Detail 5.3 and Detail 5.5:
- Detail 5.3:
  - $(\Delta F)_{TH} = 2.6ksi$
- Detail 5.5:
  - In a branching member with respect to the stress in the branching member
    - » $(\Delta F)_{TH} = 1.2\text{ksi}$
  - In main member with respect to the stress in the main member(Column):
    - » $(\Delta F)_{TH} = 1.0ksi; when \frac{r}{t} \leq 24 \; for\ the\ chord\ member$
    - » $(\Delta F)_{TH} = 1.0 \times \left(\frac{24}{\frac{r}{t}}\right)^{0.7} ksi; when \frac{r}{t} \geq 24 \; for\ the\ chord\ member$





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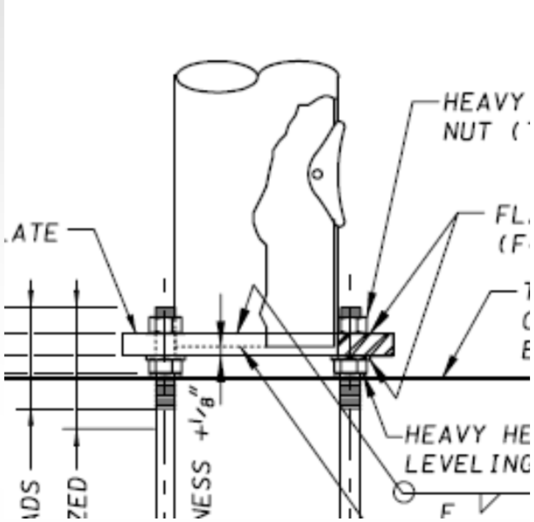
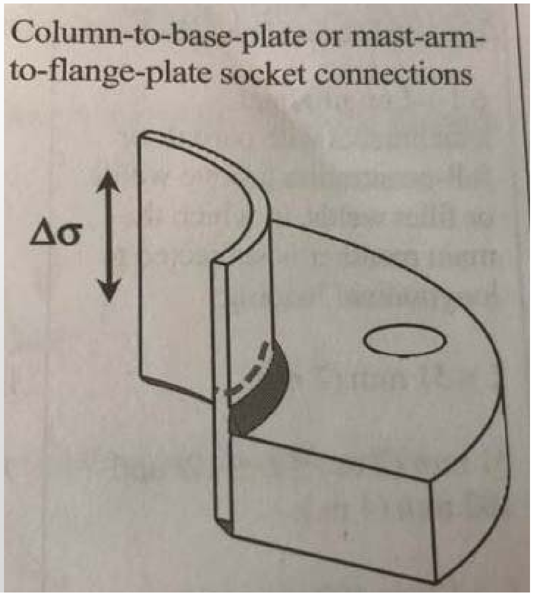
4. Task 3– Fatigue Design Details

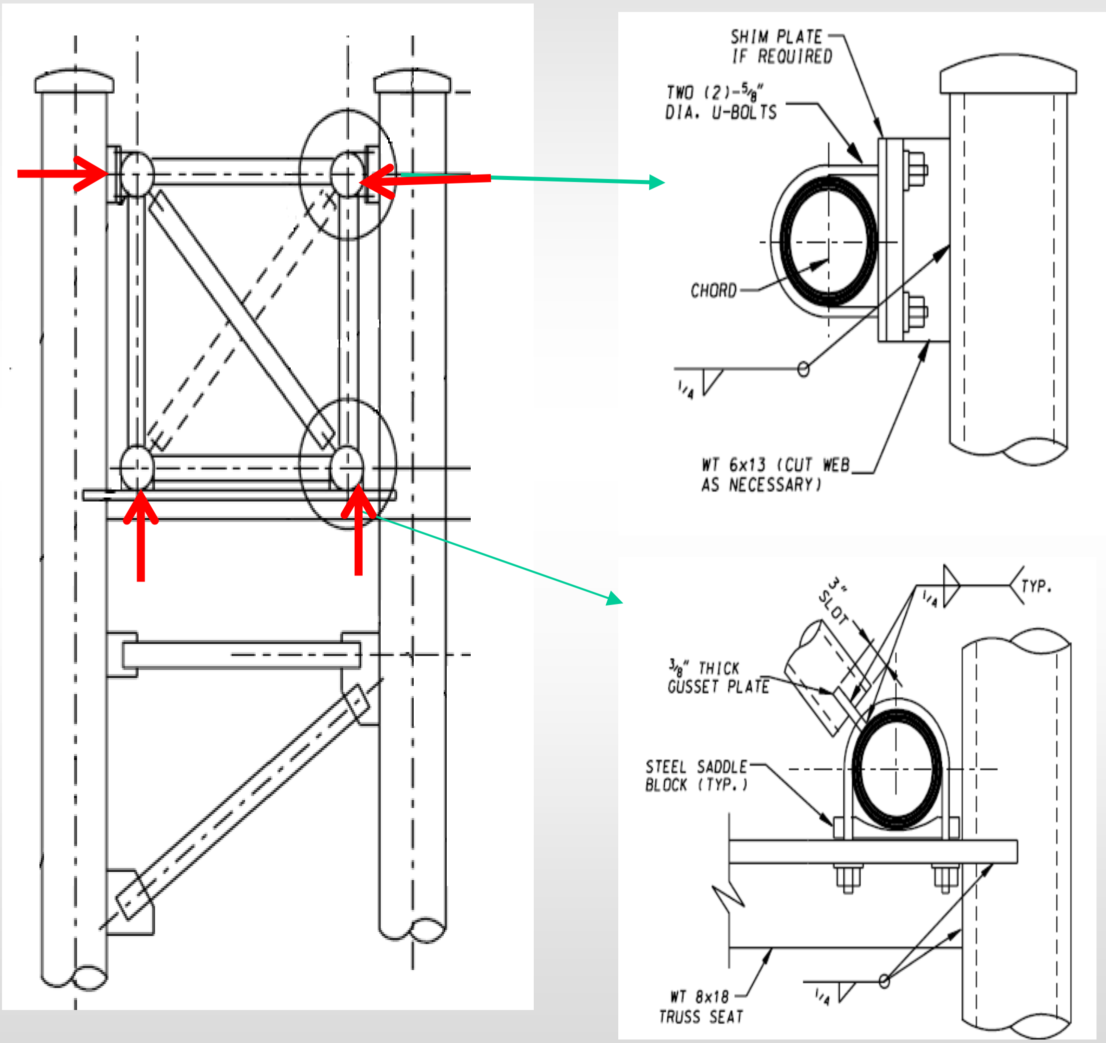
4) Pole-base connection

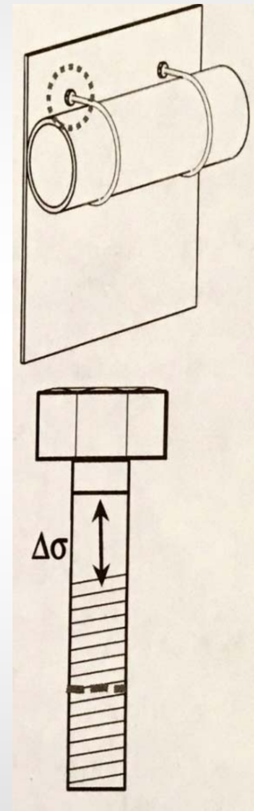
- Detail 5.4:
  - $K_I \leq 4.0: (\Delta F)_{TH} = 7.0ksi$
  - $4.0 < K_I \leq 6.5: (\Delta F)_{TH} = 4.5ksi$
  - $6.5 < K_I \leq 7.7: (\Delta F)_{TH} = 2.6ksi$





4. Task 3–Strength/Fatigue Design of U-Bolt





$$(\Delta F)_{TH} = 7.0ksi$$

Tensile Capacity = 0.56 * (Tensile Strength) * πr^2

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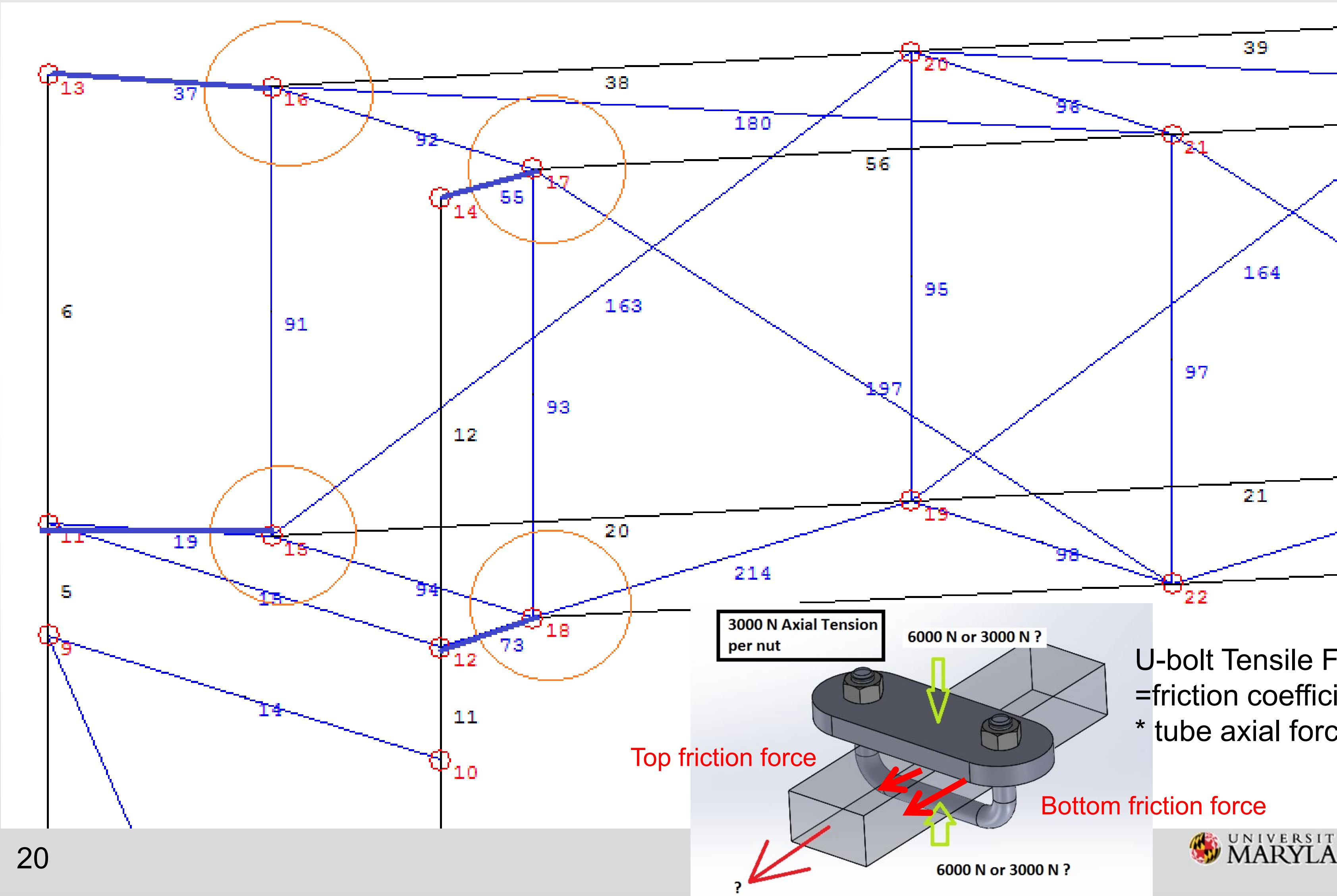
4. Task 3–Strength/Fatigue Design of U-Bolt



U-bolt Tensile Force
=friction coefficient (0.3)
* tube axial force

6. Shaft Foundation Design Check

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6. Shaft Foundation Design by LRFD

AASHTO LRFD for Cohesive Soils based on Brom's Method

The required embedment length L can be found:

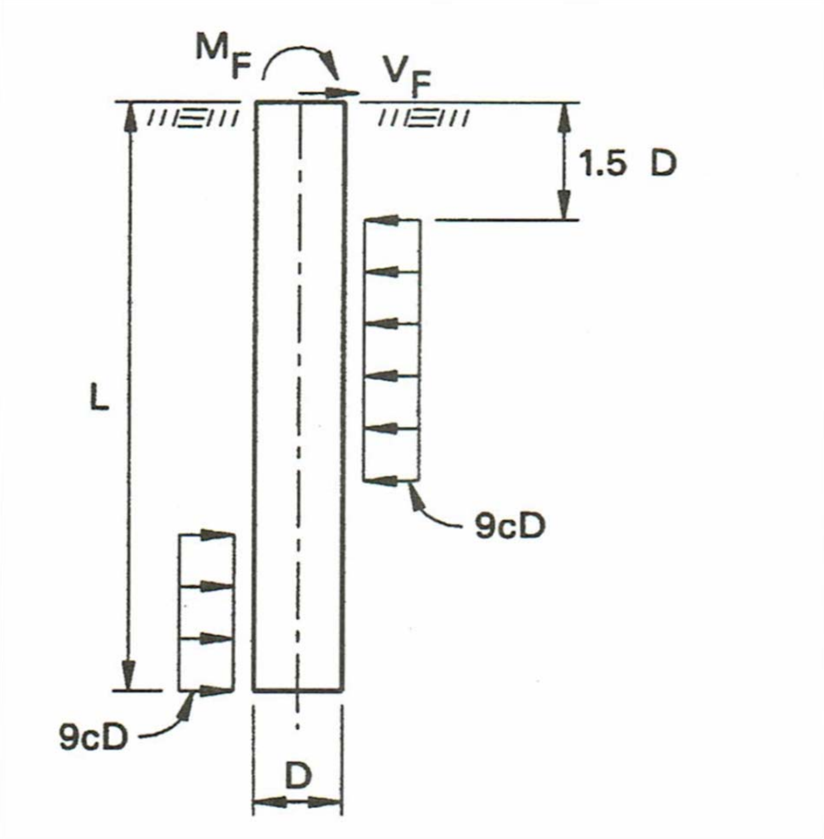
$$L = 1.5D + q[1 + \sqrt{2 + \frac{(4H + 6D)}{q}}]$$

Where:

$$H = \frac{M_F}{V_F}$$

$$q = \frac{V_F}{9cD}$$

$M_u = V_F(H + 1.5D + 0.5q)$ and located at (1.5D+q) below groundline



6. Shaft Foundation Design by LRFD

AASHTO LRFD for Cohesionless Soils based on Brom's Method

The required embedment length L can be found by using trial and error:

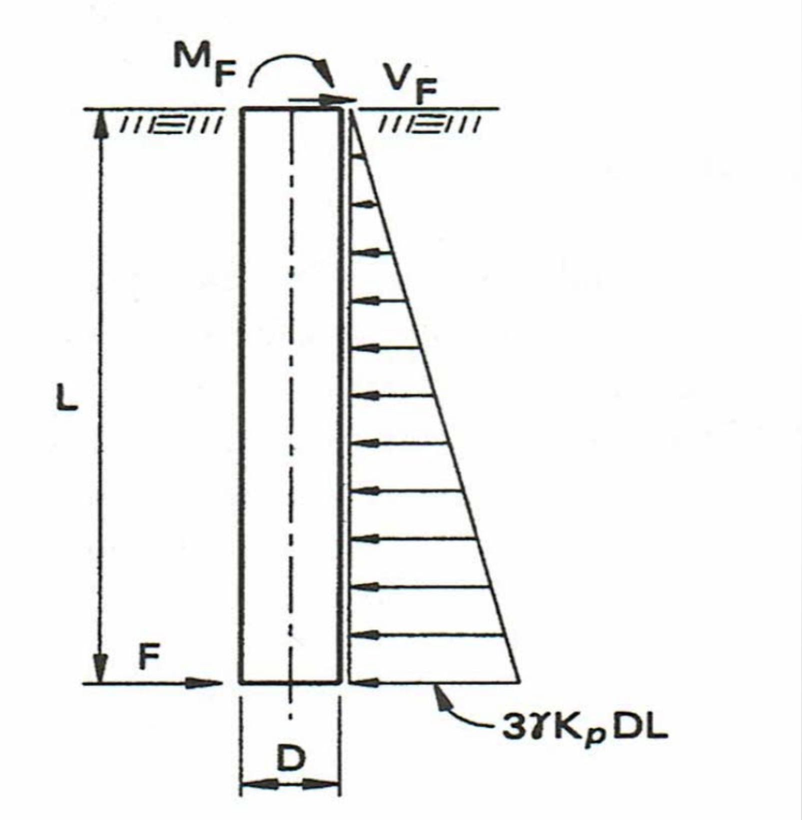
$$L^3 - \frac{2V_F L}{K_p \gamma D} - \frac{2M_F}{K_p \gamma D} = 0$$

Where:

$$K_p = tan^2(45 + \frac{\varphi}{2})$$

$M_u = V_F(H + 0.54\sqrt{\frac{V_F}{K_p \gamma D}})$ and located at

$0.82\sqrt{\frac{V_F}{K_p \gamma D}}$ below groundline



6. Shaft Foundation Design by LRFD

Analytical Methods for Torsional Capacity

The torsional capacity of drilled shafts consists of shaft and toe torsional resistance

$$T = T_s + T_t$$

T_s = shaft torsional resistance
T_t = toe torsional resistance.

1. Florida Structures Design Office Method (cohesionless)
2. Florida District 7 Method (cohesionless & cohesive)
3. CDOT Design Method (cohesionless & cohesive)
4. IDOT Design Method (cohesionless & cohesive)

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6. Shaft Foundation Design by LRFD

Analytical Methods for Torsional Capacity

IDOT Design Method

Cohesive	Cohesionless
$T_s = a_t*\pi*D*L*(0.5D)$	$T_s = f_t*\pi*D*L*(0.5D)$
$a_t = c*\alpha$	$f_t = \sigma_v*\beta$
c = cohesion (ksf)	σ_v= effective vertical soil pressure (ksf)
α = adhesion factor	$\beta = 1.5 - 0.135\sqrt{h} \leq 1.2$

6. Shaft Foundation Design by LRFD

AASHTO Load Factor

M_factor = 1.6 (Load Combination Strength I)

V_factor = 1.6 (Load Combination Strength I)

Assumed properties of soil for hypothetical cases

Soil Type	Soil Category	Cohesion	Unit Weight	Friction Angle
Cohesive	Stiff clay	2.16 (ksf)	N/A	N/A
Cohesionless	Clean gravel-sand	N/A	0.12 (kcf)	30

Reference: FHWA-NHI-10-016 (2010). “Drilled Shaft: Construction Procedures and LRFD Design Methods”

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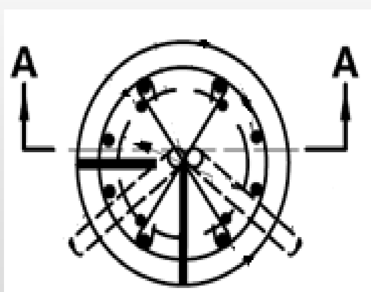
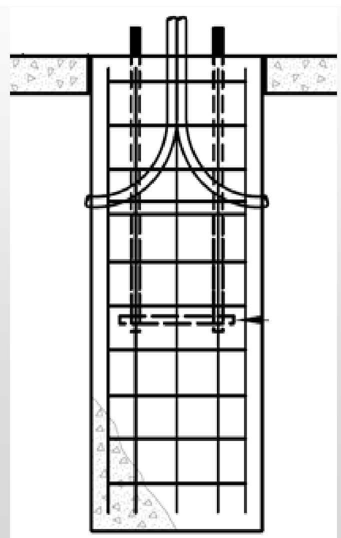
6. Shaft Foundation Design by LRFD

Case Study - MDSHA Design

POLE TYPE	ARM LENGTH OR POLE SIZE	BOLT CIRCLE (IN.)	ANCHOR BOLT SIZE (IN. x IN.)	ANCHOR BOLT MAX. PROJECTION ABOVE FOUNDATION (IN.)	FOUNDATION		REINFORCEMENT		CONCRETE REQUIRED (C.Y.)
					DIAMETER 'D' (FT.)	HEIGHT 'H' (FT.)	VERTICAL REINF.	HORIZONTAL REINF.	
MAST ARM	38' SINGLE	16	1 1/2 x 54	6 1/2	3	10	8 NO.10	NO.4@12"C.C.	2.7
	50' SINGLE AND TWIN	18	1 3/4 x 66	7 1/2	3	10	8 NO.10	NO.4@12"C.C.	2.7
	60' & 70' SINGLE	22	2 x 72	8	4	10	16 NO.10	NO.4@12"C.C.	4.7
	50'/ 60' - 70' TWIN	22	2 x 72	8	4	10	16 NO.10	NO.4@12"C.C.	4.7





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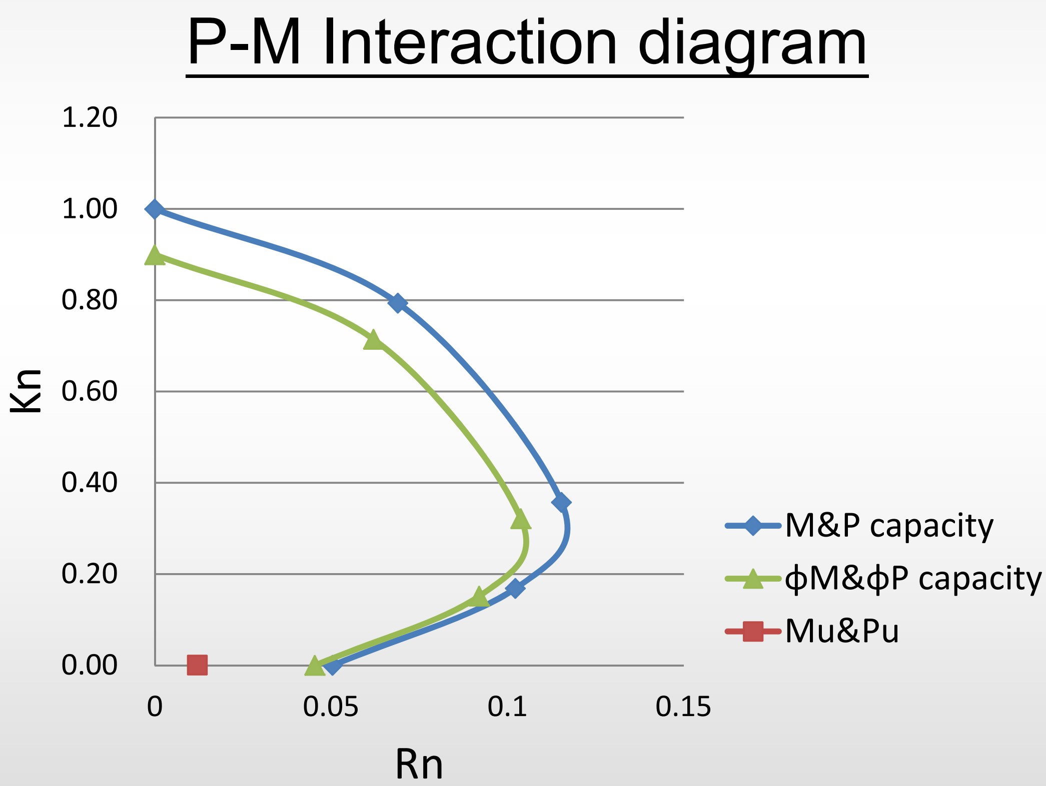
6. Shaft Foundation Design by LRFD

Case Study Result – Rebar Check



Case: Arm length = 75 ft
D= 4 ft
Rebar #: 8
Rebar Size: 10
(tension control, φ = 0.9
Check vertical rebar capacity

6. Shaft Foundation Design by LRFD

Case Study Result – Torsional capacity check

Based on IDOT Design Method

Soil Type	Torsional capacity (kip-ft)	Max Torsion* (kip-ft)
Cohesive	298.6	132
Cohesionless	161.8	132

* Pole base of 75’ arm

6. Review: LRFD Shaft Foundation Design

Case Study Results

Arm Length	Soil Type	Load Type	Design Length(ft)	Required Length(ft)	Length Check	Rebar Check
50ft	Cohesive	W1	10	7.76	v	v
	Cohesionless	W1	10	8.92	v	v
60ft	Cohesive	W1	10	8.98	v	v
	Cohesionless	W1	10	8.24	v	v
70ft	Cohesive	W1	10	9.27	v	v
	Cohesionless	W1	10	8.78	v	v
75ft	Cohesive	W1	10	9.33	v	v
	Cohesionless	W1	10	8.89	v	v

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