Dielectric®

Vibration and Fatigue Criteria in the Design of Television Transmission Antennas

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Fatigue Assessment of Television Transmission Antennas Part 1

Goal is to integrate a fatigue assessment into Dielectric's antenna design methodology.

Part 1 Focuses on the effects of reoccurring wind gusts
- Basis of the wind gust loading
- Design features of concern (welds and stress concentrations)
- Assessment of stress concentrations

Part 2 Focuses on vortex shedding.
- Basis of Vortex Shedding analysis of top mounted cylindrical antennas.
- Design features of concern (welds and stress concentrations)
- Provide an example of showing the effects of a fatigue requirement on an actual antenna design.
- Issues and areas of continuing work.

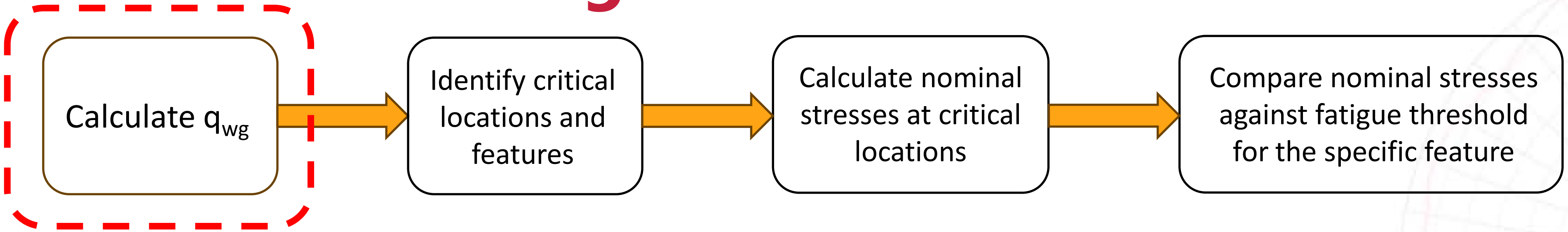
Wind Gust Loading

Calculate q_{wg} → Calculate stresses at critical locations → Calculate nominal stresses at critical locations → Compare nominal stresses against fatigue threshold for the specific feature

Method follows CSA S37-18 Annex N Tower Dynamic Effects and Fatigue
Recommended as a clear method for calculating loads
Similar to other standards

- TIA-222H Structural Standard for Antenna Supporting Structures, Antennas and Small Wind Turbine Support Structures
- ASME STS-1 Steel Stacks
- AASHTO Structural Supports for Highway Signs, Luminaires, and Traffic Signals
- EN 1991-1-4 Actions on Structures, Part 1-4 General Actions - Wind Actions

Wind Gust Loading Assessment Methodology



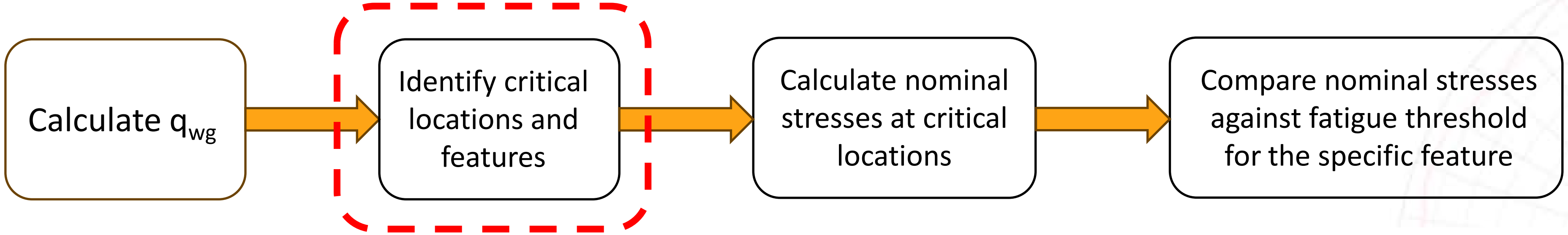
CSA S37-18 Annex N Tower Dynamic Effects and Fatigue

q_{10}- **10-year return period mean hourly wind pressure**

- $z = z_{antenna}$
- Importance Factor same as used for stress analysis
- Gust Factor = 1
- LF = 1.0, Wind Load Factor
- No Dead Loads

q_{10} can be calculated from V_{basic} or with V_{10} from the ASCE 7 Hazard Tool using the Durst Curve to adjust the measurement period and the formula from Peterka [3] to change the recurrence interval to a 10-year return period.

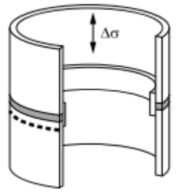
Wind Gust Loading Assessment Methodology



Nominal stresses using q_{10} loads are compared to the allowable stress ranges for typical details found in AASHTO and CSA S37-19

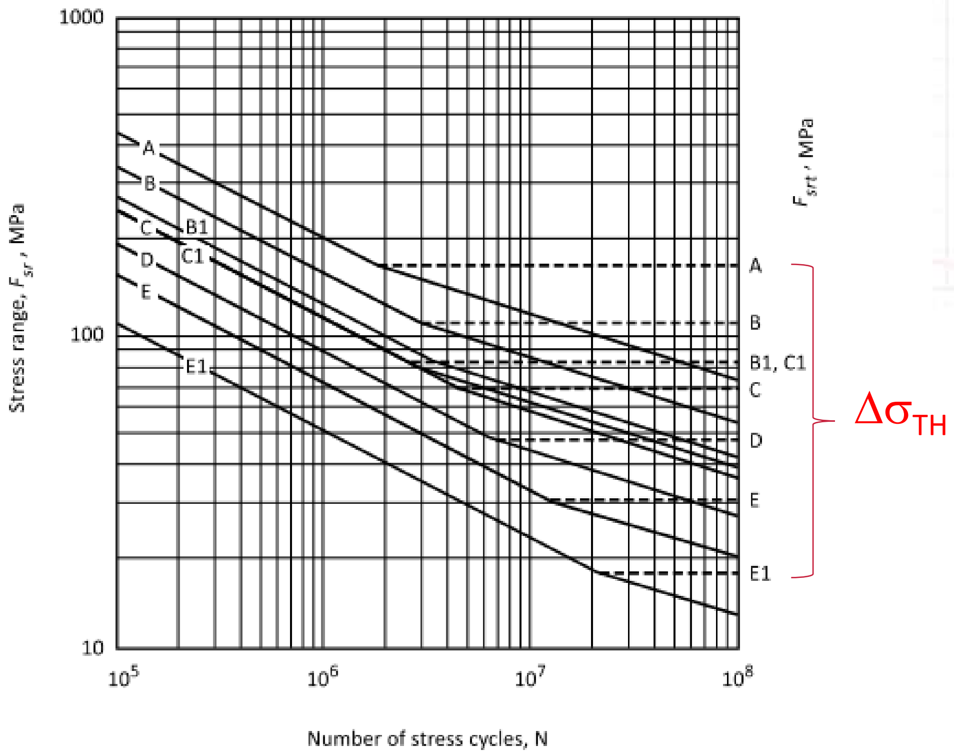
$$\Delta\sigma_{TH} = K_I S_e$$

- $\Delta\sigma_{TH}$ The allowable stress range
- S_e The material endurance limit
- K_I The stress concentration factor

4.3 – Full penetration groove-welded splices with weld reinforcement not removed (with or without backing ring)	E	In tube wall along weld toe	Column butt-splices 

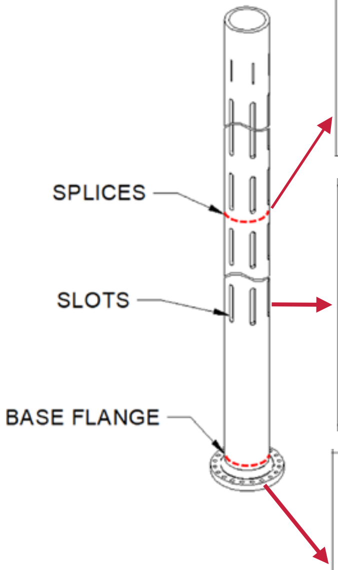
Typical Fatigue Details from CSA/AASHTO

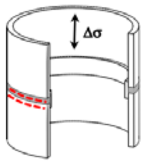
Figure N.2
Stress range vs. number of cycles for various detail categories (A to E1)
(See Clause N.3.2)

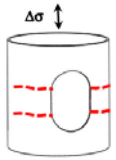


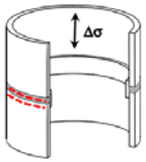
Wind Gust Loading Antenna Fatigue Details

Calculate q_{wg} → Identify critical locations and features → Calculate nominal stresses at critical locations → Compare nominal stresses against fatigue threshold for the specific feature

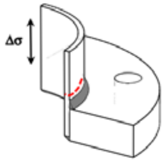


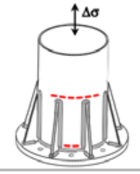
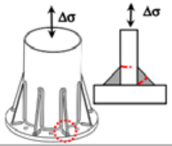
4.2—Full-penetration groove-welded splices with welds ground to provide a smooth transition between members (with or without backing ring removed)	7500 (22.0)	48 (7.0)	In weld through the throat or along the fusion boundary	Column or mast-arm butt-splices 

3.1—Net section of unreinforced holes and cutouts	85200 (250.0)	165 (24.0) (See note e)	In tube wall at edge of unreinforced hand hole	Wire outlet holes, Drainage holes, Unreinforced hand holes 

4.2—Full-penetration groove-welded splices with welds ground to provide a smooth transition between members (with or without backing ring removed)	7500 (22.0)	48 (7.0)	In weld through the throat or along the fusion boundary	Column or mast-arm butt-splices 

Note an extra 16% stress concentration is added to slots

5.4—Fillet-welded tube-to-transverse-plate connections	$K_F \leq 3.2$: 1330 (3.9)	$K_I \leq 4.0$: 48 (7.0) $4.0 < K_I \leq 6.5$: 31 (4.5) $6.5 < K_I \leq 7.7$: 18 (2.6)	In tube wall along fillet-weld toe	Column-to-base-plate or mast-arm-to-flange-plate socket connections 

6.2—Tube-to-transverse-plate connections stiffened by longitudinal attachments with partial- or full- penetration groove welds, or fillet welds in which the tube is subjected to longitudinal loading and the welds are wrapped around the attachment termination.	$K_F \leq 2.5$: 3750 (11.0) (See Detail 5.4)	$K_I \leq 5.5$: 48 (7.0) (See Detail 5.4)	In tube wall at the toe of the attachment to tube weld at the termination of attachment In tube wall at the toe of tube-to-transverse-plate weld	
6.3—Transverse load-bearing partial-joint-penetration groove-welded or fillet-welded attachments where $t \leq$ 13 mm (0.5 in.) and the main member is subjected to minimal axial and/or flexural loads (When $t >$ 13 mm [0.5 in.], see note c)	15000 (44.0)	69 (10.0)	In base metal at the weld toe or through weld throat	Longitudinal stiffeners welded to base plates 

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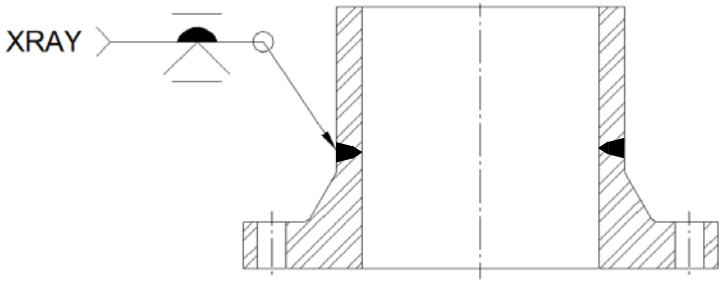
Flange Designs

These are the (3) common flange designs used in this analysis

Weld Neck Flange

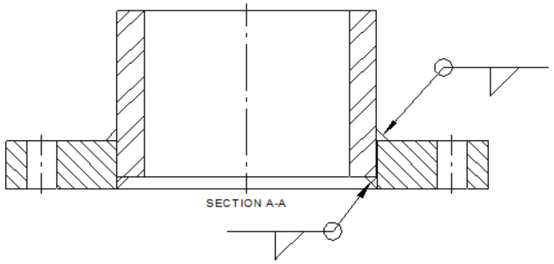
FULL PENETRATION WELD GROUND SMOOTH
ABOVE THE STRESS CONCENTRATION
INSPECTABLE



Weld is 100% inspectable
Weld is located above the stress concentration
Taper effectively acts a continuous 360º gusset

Availability often must be machined out of a blank

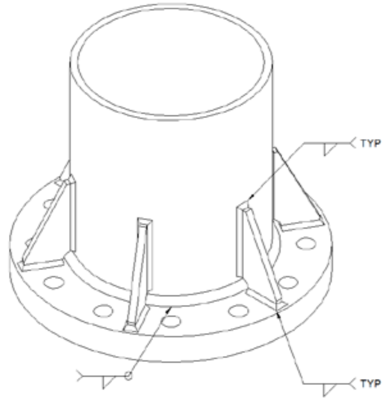
Fabricated Socketed without Gussets

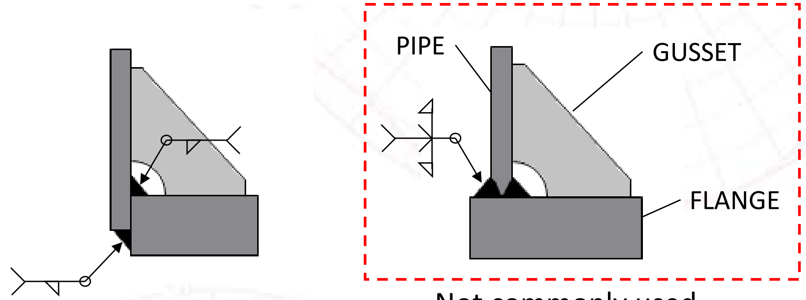


Inexpensive easy to manufacture

Weld can only be partially inspected either visually, ultrasonic, or by mag particle
Weld is located at the stress concentration
Flange warpage can be an issue

Fabricated Socketed with Gussets





Not commonly used

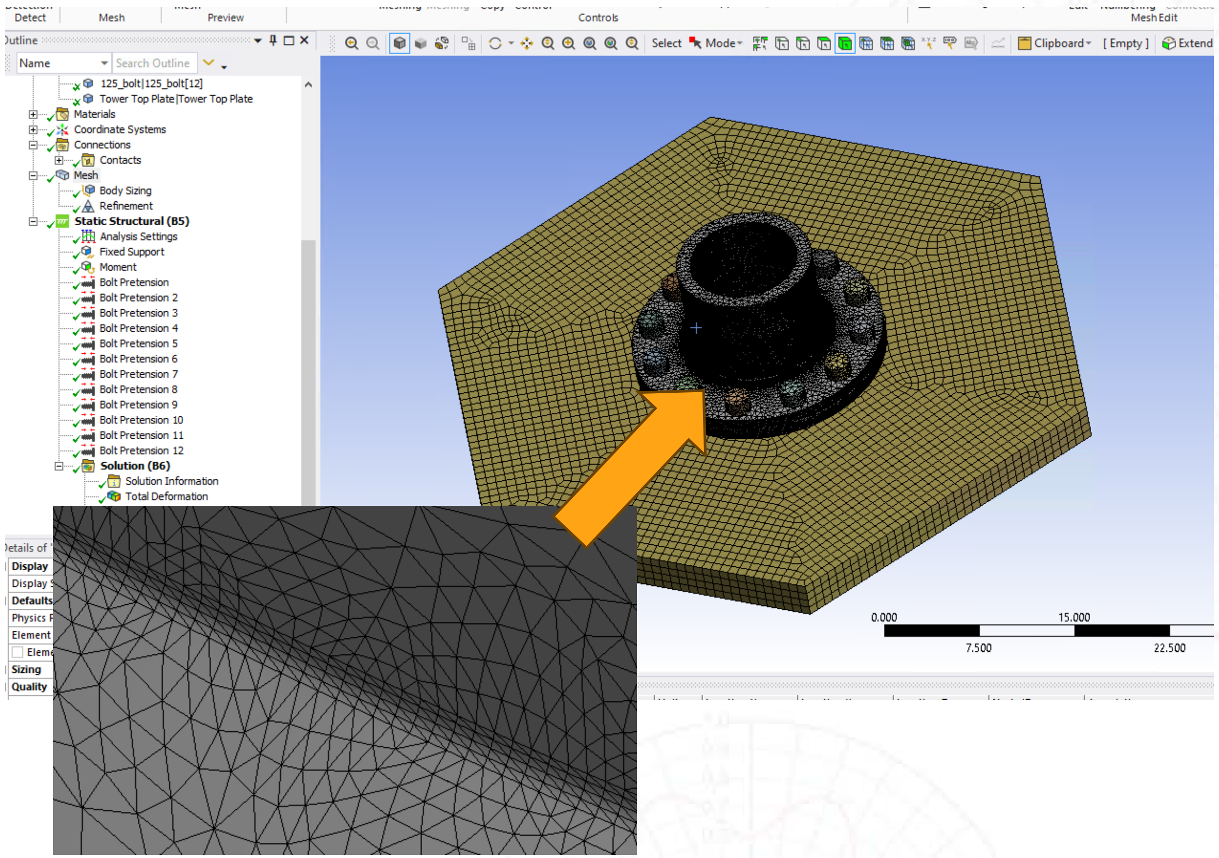
Gussets eliminate flange twisting and reinforce the socketed joint

Weld can only be partially inspected either visually, ultrasonic, or by mag particle
Weld is still located at the stress concentration, but the stresses are lowered by the gussets
Flange warpage can be an issue
Adding gussets usually requires less bolts.

Typical FEA Model for Flange Design

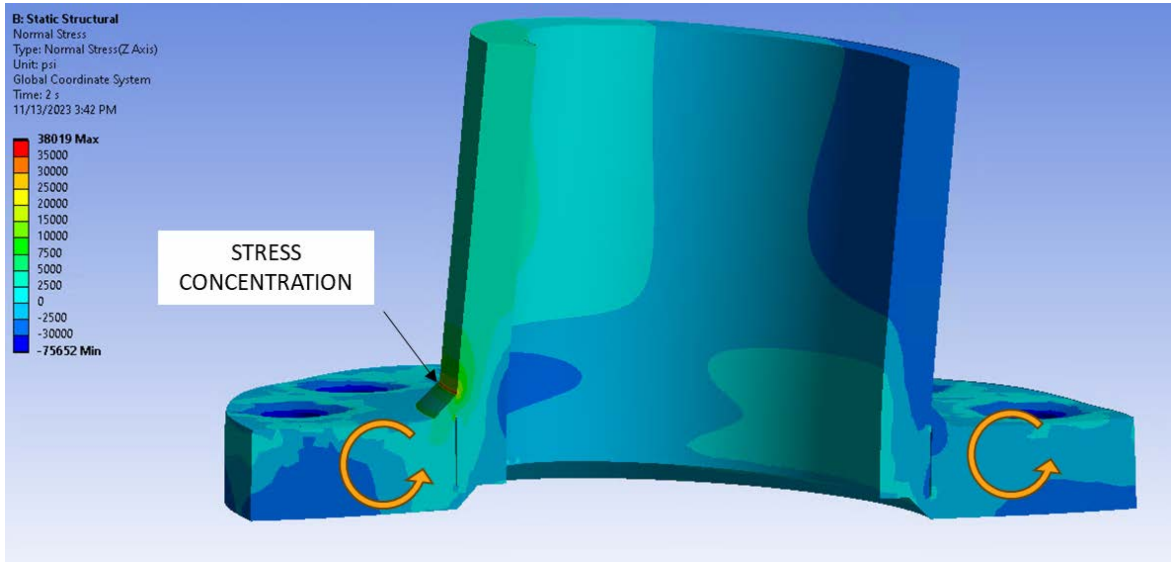
Typical ANSYS FEA Model

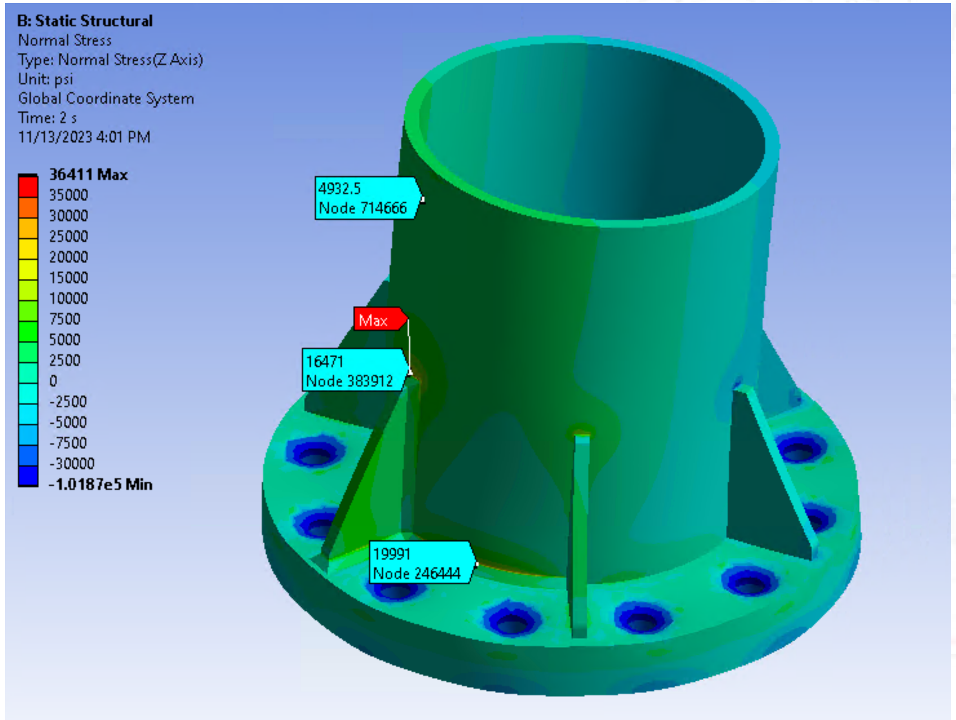
- Linear material properties
- Frictional contacts at bolts and flange (η = .15)
- Run in two load steps
  - Bolt Preload
  - Moment Application
- Bending moment applied at top of pipe
- 1 mm (0.04 in) radius at roots of fillet welds with (4) elements across per AASHTO guidelines



REFINEMENT AT TOE OF WELD

Typical FEA Antenna Flanges in Bending





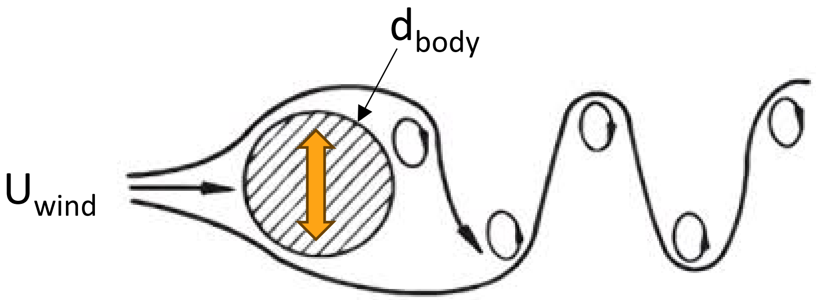
Flanges twist due to the offset between the mast pipe and the bolt circle

Vortex Shedding

What is Vortex Shedding?

It is a phenomena occurring when a fluid flows over a blunt body such as a cylinder. The fluid moves over the body and then detaches downstream on either side leaving a twin trail of vortices. Under certain flow conditions the vortices can become periodic and lead to a pressure imbalance.

The pressure imbalance can drive the body to oscillate perpendicular to the flow direction.



3 Key non-dimensional parameters

$$Re = \frac{Ud}{\nu}$$

Reynolds Number
U –upstream flow speed
d – diameter of cylinder (or characteristic body dimension)
ν – the kinematic viscosity of the fluid

Relates flow momentum to viscosity

$$S = \frac{f_s d}{U}$$

Strouhal Number
f_s –the frequency of the shedding vortices
U –upstream flow speed
d – diameter of cylinder (or characteristic body dimension)

Relates the speed of the flow to frequency of the shedding vortices

$$Sc = \frac{2\delta_s m_e}{\rho d^2}$$

Scruton Number
d_s –the structural damping ratio
m_e– distributed mass of the body
ρ – the density of the fluid

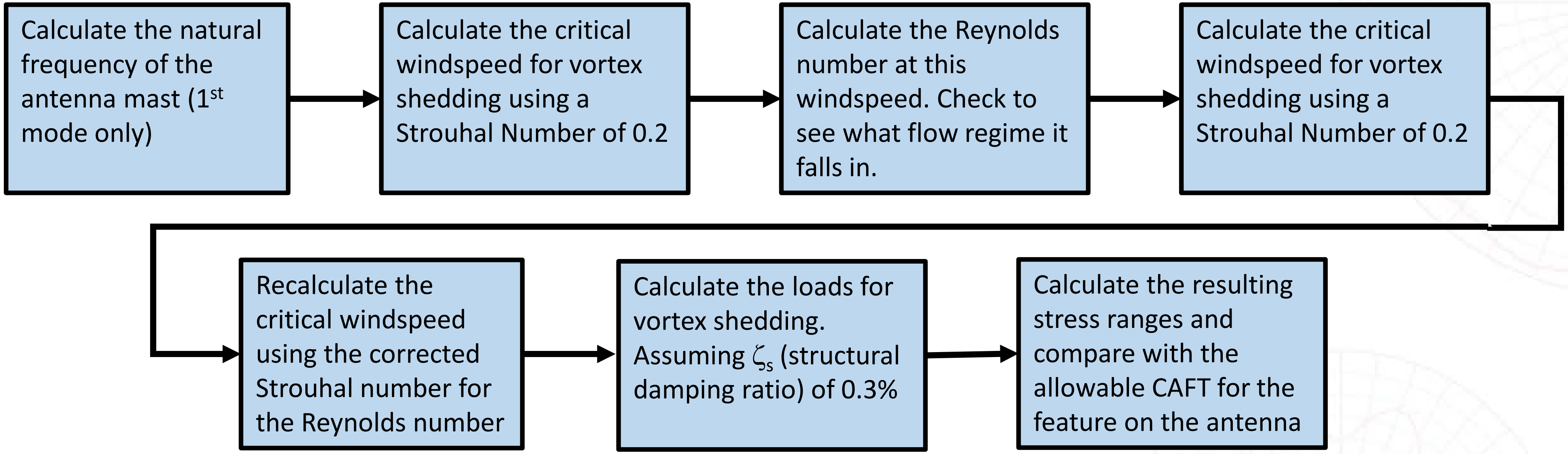
Relates the structural mass to the fluid mass

Vortex Shedding Assessment Methodology

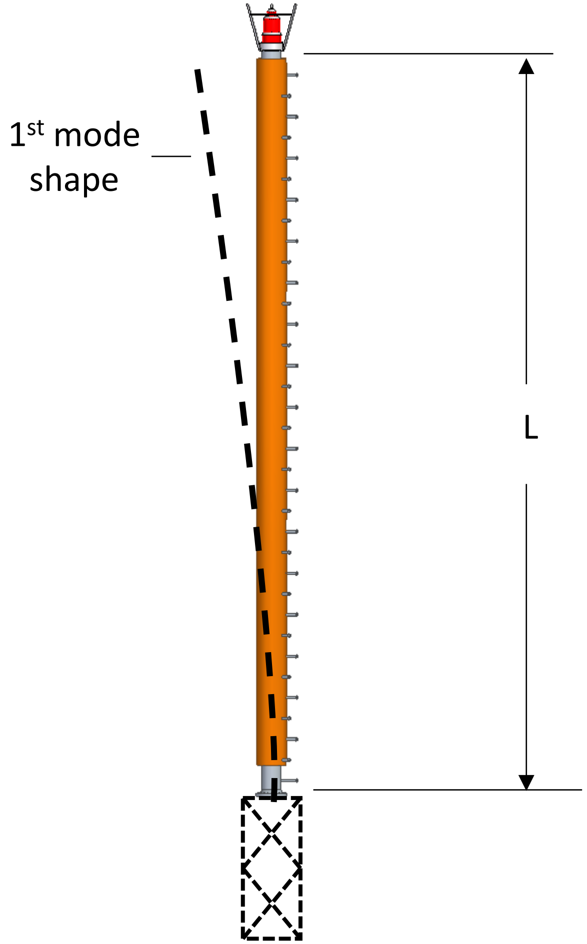
Follows the approach laid out in CSA-S37-18 (similar to ASME STS-1)

Implemented as part of the standard steel top mount pylon assessment

Currently uses the 1st mode of vibration and assumed structural damping ration of 0.3%



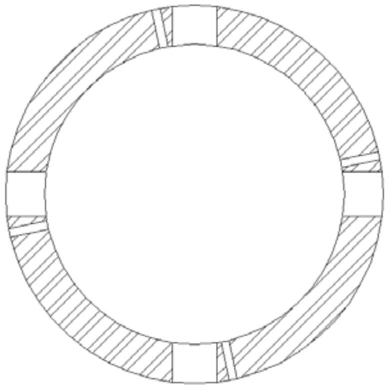
Vortex Shedding Natural Frequency Calculation



- Steel flanged mount antennas
- 1st Mode of vibration
- Uses slotted section properties

$$f_n = \frac{3.52}{2\pi}\sqrt{\frac{E_{steel}I_{slotted}}{\left(\frac{W_{ant}}{Lg}\right)L^4}}$$

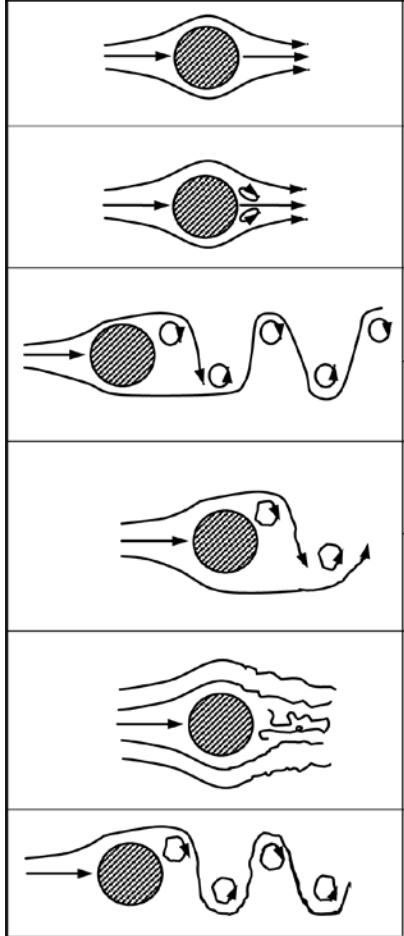
f_n	– the natural frequency in hz
E_{steel}	- 28 x 106 psi
$I_{slotted}$	- the section inertia (in^4)
W_{ant}	- the weight of the antenna (lbf)
g	- gravitation constant 386.4 in/sec^2
L	- the length of the antenna (in)



example of a typical slotted antenna cross section

Vortex Shedding Critical Windspeed Calculation

Reynolds Number



Reynolds Number	
$Re < 5$	Regime of unseparated flow
$5 \leq Re < 40$	A fixed pair of vortices in wake
$40 \leq Re < 90$	Vortex street is laminar
$90 \leq Re < 150$	Vortex street is laminar
$150 \leq Re < 300$	Transition range to turbulence in vortex
$300 \leq Re < 3(10^5)$	Vortex street is fully turbulent
$3(10^5) \leq Re < 3.5(10^6)$	Laminar boundary layer has undergone turbulent transition and wake is narrower and disorganized
$3.5(10^6) \leq Re$	Reestablishment of turbulent vortex street

Ranges of vortex shedding

$$V_{cr} = \frac{f_n D_{ant}}{S}$$

V_{cr} -Critical windspeed for vortex shedding to occur
f_n -Natural frequency of the antenna mast
D_{ant} –Diameter of the antenna the wind sees
S - The Strouhal number

The current analysis uses the recommended Strouhal numbers found in CSA-S37-18

$S = 1/6$ $Re < 200000$
$S = 1/5$ $Re > 250000$

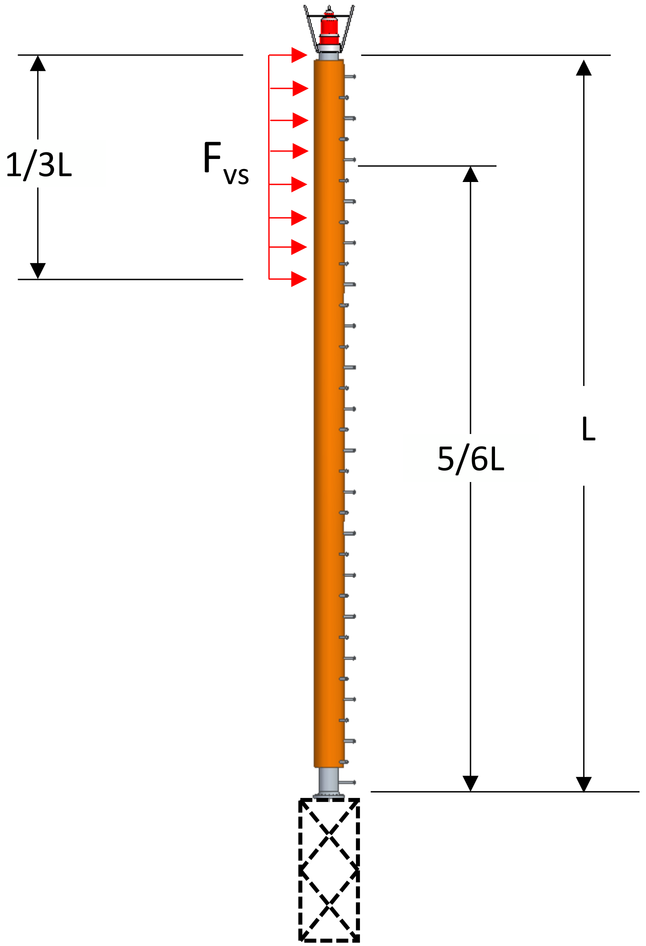
Other standards and literature use

Periodic — $S = 0.18$ to 0.2 $Re < 300000$

Random — $300000 < Re < 3500000$ requires random vibration analysis

Periodic — $S = 0.25$ to 0.30 $Re > 3500000$

Vortex Shedding Loads Calculation



$$F_{vs} = \frac{C_1}{\sqrt{\lambda}\sqrt{\zeta_s + \zeta_a}} q_H D_{ant}$$ applied to the upper third of the mast

F_{vs} - The effect static distributed load (lbf/in)
λ - The aspect ratio (L/D_{ant})
ζ_s - The structural damping (assumed to be 0.3%)
ζa - The aerodynamic damping (see below)
q_H - The wind pressure corresponding to V_{cr}

$$\zeta_a = -C_2 \frac{\rho_{air} D_{ant}^2}{m_{ant}}$$ negative!

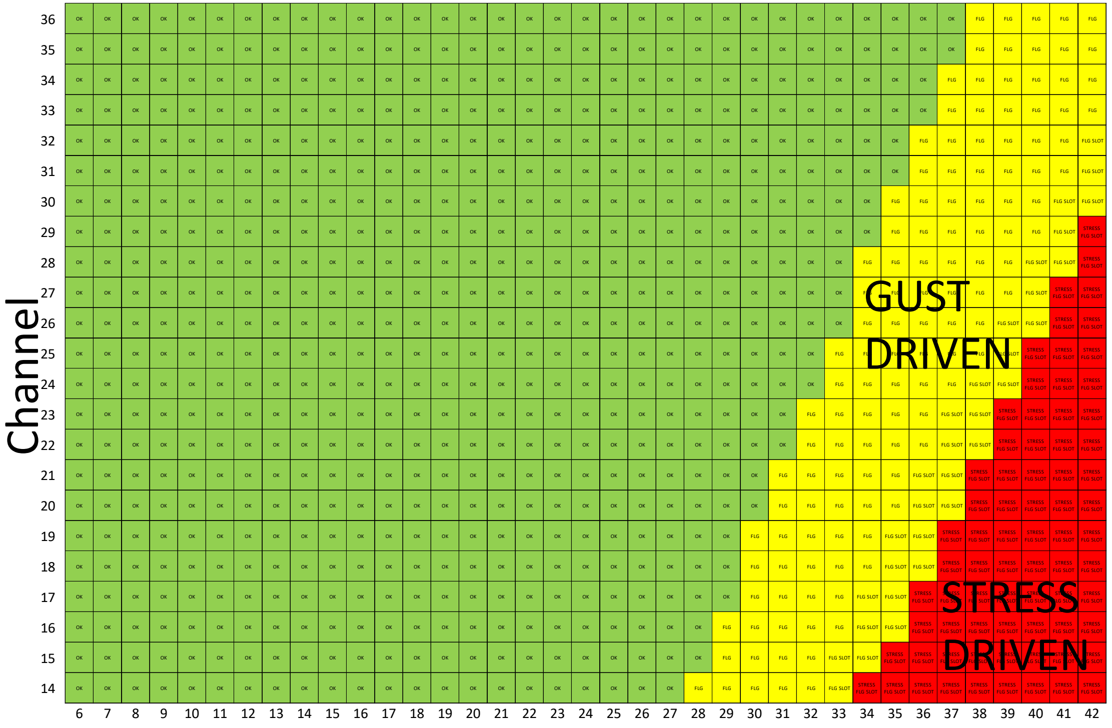
ρ_{air} - The density of the air at 42°F
m_{ant} - The distributed mass of the antenna (lbm/in)

$C_1 = 3$ $C_2 = 0.6$ if $\lambda > 16$
$C1 = 0.75\lambda^{0.5}$ $C_2 = 0.6$ if l < 16
or
if $\lambda > 12$ and $V_{cr} < 22.4$ mph (10 m/s)
$C_1 = 6$ $C_2 = 1.2$

Vortex Shedding Loads Assessment

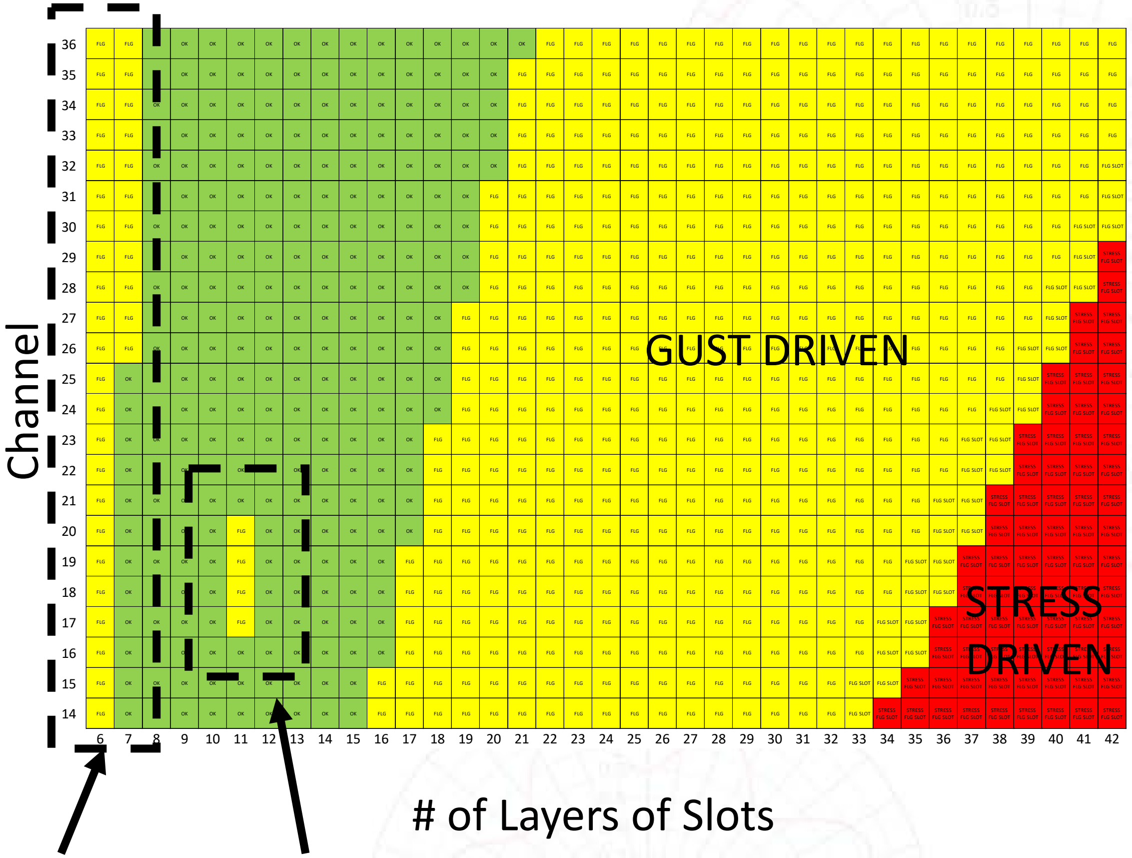
Same basic antenna design with different flange designs of the same thickness

Weld Neck Flange



# of Layers of Slots

Socketed Fabricated Flange No Gussets



# of Layers of Slots

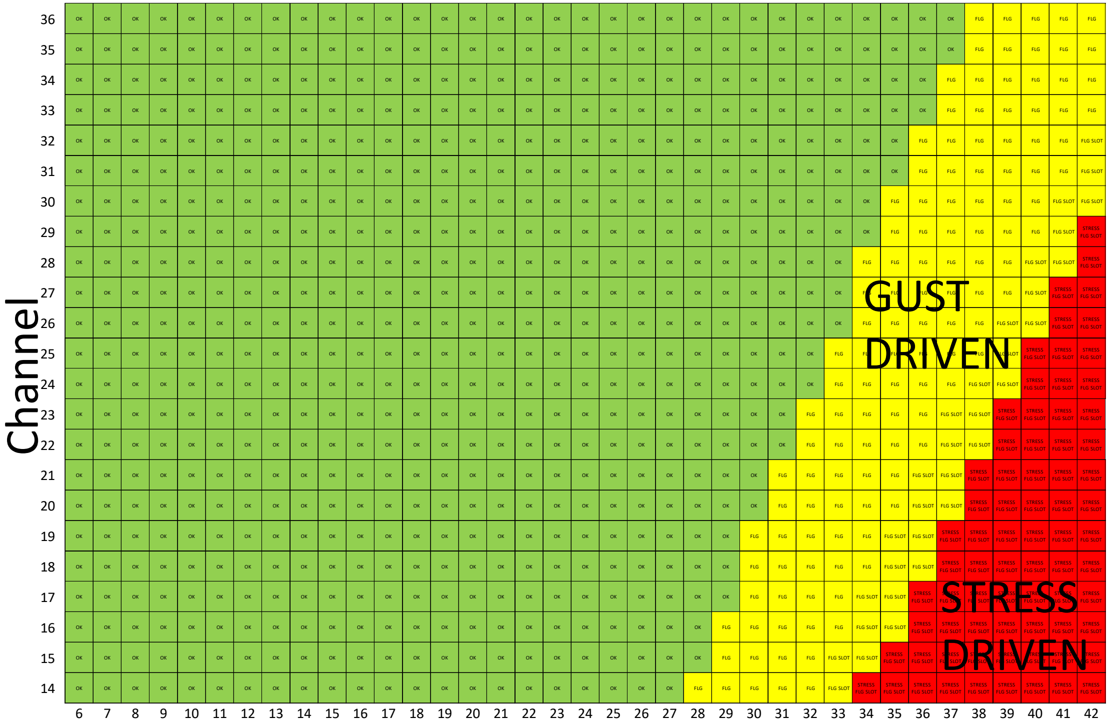
FALL IN RANDOM VIBRATION RANGE 300000<Re<3500000

VORTEX SHEDDING

Vortex Shedding Loads Assessment

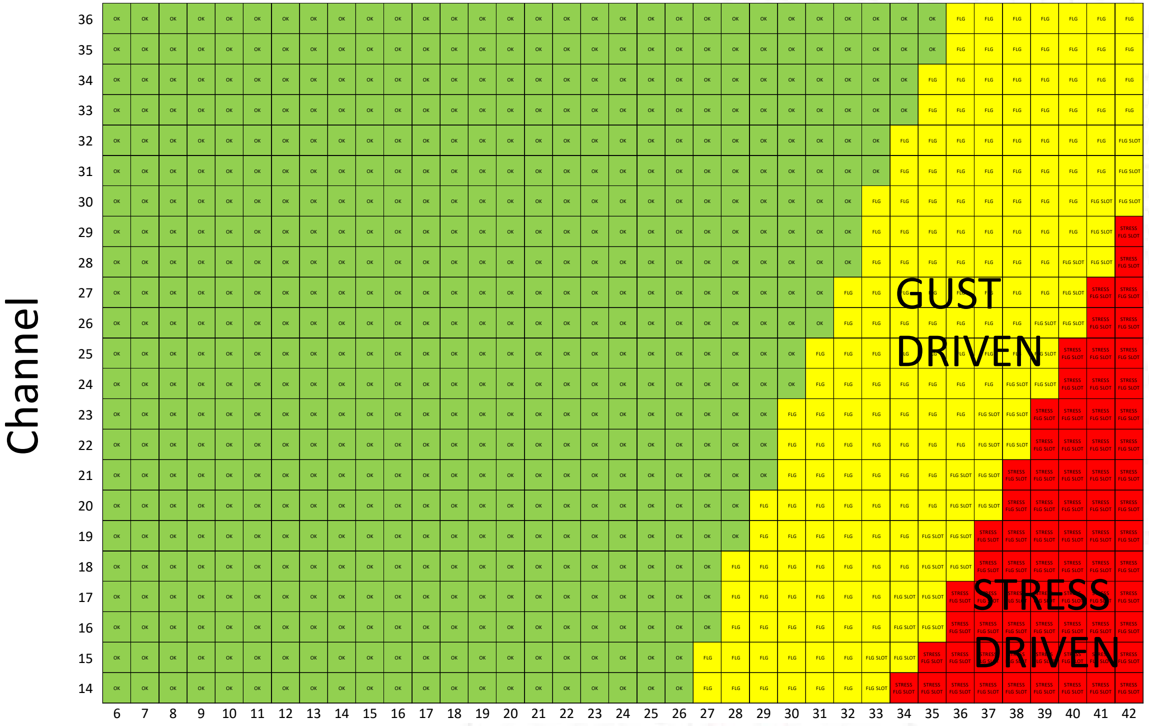
Same basic antenna design with different flange designs of the same thickness

Weld Neck Flange



# of Layers of Slots

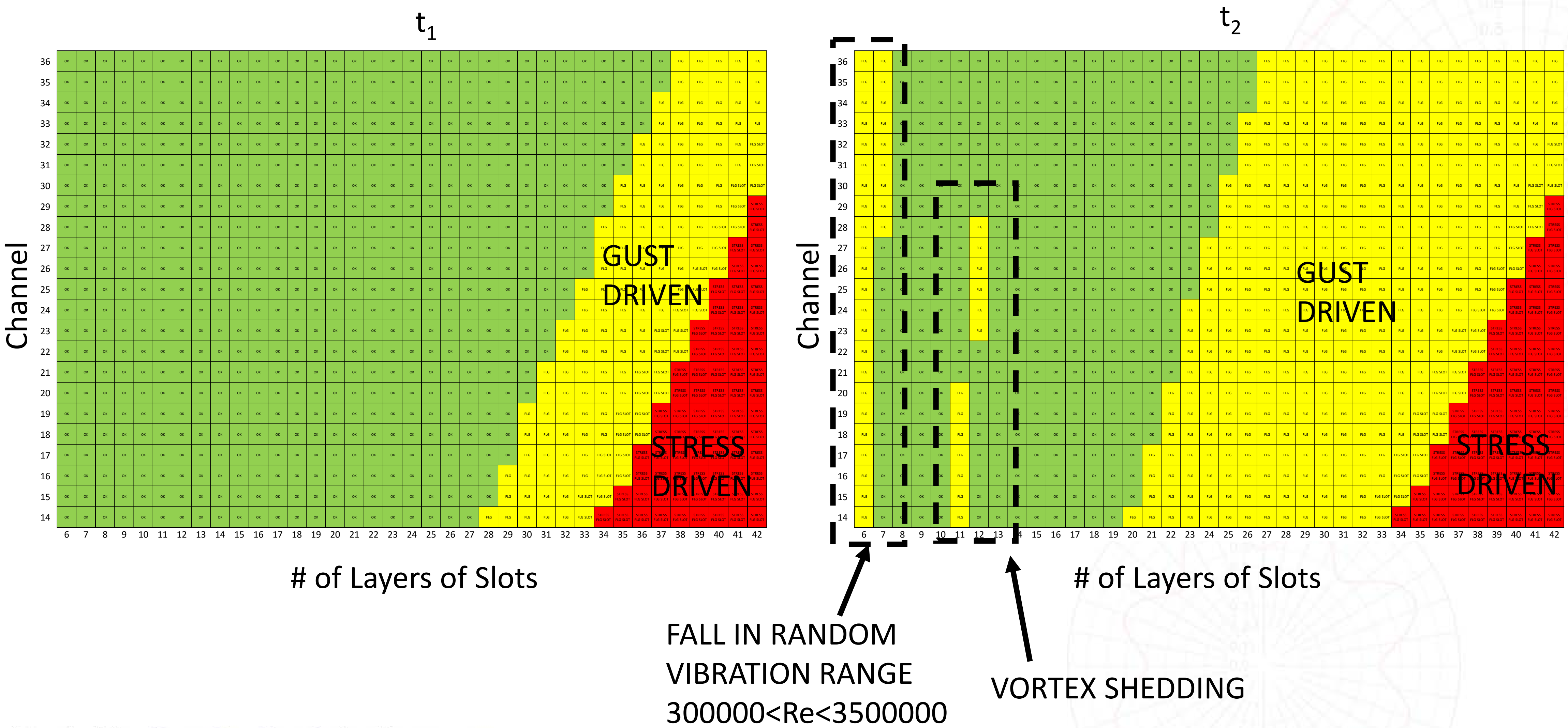
Socketed Fabricated Flange with Gussets



# of Layers of Slots

Vortex Shedding Loads Assessment

Same basic antenna design with gusseted-fabricated flanges of different thicknesses ($2/3t_1 = t_2$)



Vibration and Fatigue Issues and Continuing Work

Issues

- Not all antenna mast/flange designs fit within the limits stated for the fatigue details in relevant standards.
- Review how well the standard details apply to flanges in bending.
- Extend Vortex shedding calculations to better include the range random excitation.

Continuing Work

- Running parametric FEA models of the common welded flange designs to determine stress concentrations in bending (following AASHTO guidelines)
- Research the Fatigue details to fully understand the parameters used to create them.
    - Materials (different ultimate strengths)
    - Fatigue factors used (e.g., C_{surf} = 0.8 appears to have been used)
- Goal is to create usable fatigue design criterion for all Dielectric top mounted masts.

THANKS FOR YOUR TIME!

ANY QUESTIONS?

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