New AASHTO Wind Load Provisions for Completed Bridges and Bridges During Construction

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DISCLAIMER

The work presented herein was performed under the NCHRP Project 20-07/Task 325. The opinions and conclusions expressed or implied herein are those of the Contractor. They are not necessarily those of the Transportation Research Board, The national Academies, or the program sponsor.

PROJECT CONTRACTOR

At the time the work was performed, the Principal Investigator, Dr. Wagdy Wassef, was employed by Modjeski and Masters, the project contractor.

NCHRP 20/07 Task 325 Project Scope

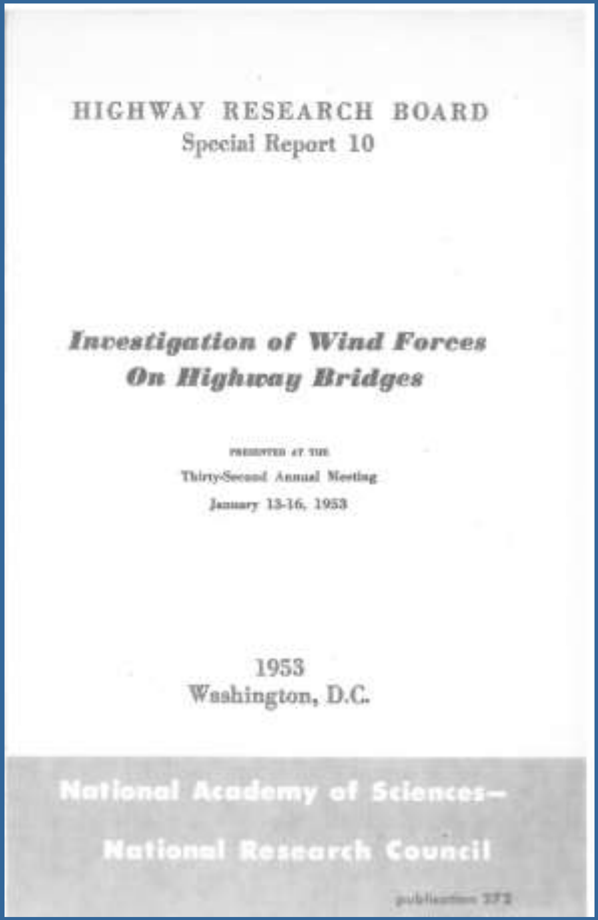
Originally, the project scope was to develop wind loads provisions for completed bridges in AASHTO LRFD format.

Project was expanded to include:

- Wind tunnel testing of typical bridges (I-girders and Box-Girders) during construction
- Develop guidelines to identify bridges that may be vulnerable during construction
- If possible, incorporate design provisions for wind during construction.

Literature Search

- Highway Research Board Special report No. 10 in 1953
- Formed the basis for the wind load provisions in AASHTO Standard Specifications
- When the AASHTO LRFD was introduced in 1994, new method was introduced but several aspects of the provisions in the standard specifications were kept



HIGHWAY RESEARCH BOARD
Special Report 10

Investigation of Wind Forces On Highway Bridges

Thirty-Second Annual Meeting
January 13-16, 1953

1953
Washington, D.C.

National Academy of Sciences—
National Research Council

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Literature Search

- Most publications are related to aeroelastic stability
- Work by FDOT
- Reviewed wind provisions in ASCE 7 and several international design specifications including:
  - Pre-2015 AASHTO LRFD
  - Eurocode 1 ¨Actions on Structures”
  - Australian/New Zealand Standard Structural Designations
  - Canadian Highway Bridge Design Code
  - British Highways Agency, Design Manual for Roads and Bridges
  - "Structures Design Guidelines," FDOT, January 2013 (in effect when the work was performed)

Pre-2015 AASHTO LRFD Provisions

Wind on structure:

- Wind speed may be taken from the ASCE 7-88 map, site specific study or 100 mph. The latter was used by most designers even though the map has lower value for most of the country (highest value on the map was 110 mph).
- The ASCE 7-88 wind maps are for fastest mile wind speeds which translate to different averaging time
- Assumes same base wind speed for the entire country (100 mph) then adjust for topography and height.
- If warranted by local conditions, wind pressure may be adjusted to account for a different base wind speed.
- For full design wind speed, load factor for service = 1.0 and for strength =1.4. Load factor is then adjusted to account for the wind speed assumed for each load combination

Pre-2015 AASHTO Provisions

- Four limit states include wind:

Limit State	*Perm. loads*	*LL*	*WA*	***WS***	***WL***	*FR*	*TU*	*TG*	*SE*
Strength III	γ_p	—	1.00	**1.40**	**—**	1.00	0.50/1.20	γ_{TG}	γ_{SE}
Strength V	γ_p	1.35	1.00	**0.40**	**1.00**	1.00	0.50/1.20	γ_{TG}	γ_{SE}
Service I	1.00	1.00	1.00	**0.30**	**1.00**	1.00	1.00/1.20	γ_{TG}	γ_{SE}
Service IV	1.00	—	1.00	**0.70**	**—**	1.00	1.00/1.20	—	1.00

- **Strength III**—Bridge exposed to wind velocity exceeding 55 mph. No LL. (Design wind speed with load factor of 1.4 for WS)
- **Strength V**— Normal vehicular use of the bridge with wind of 55 mph velocity. (Design wind speed with load factor of 0.4 for WS = 1.4 *(55/100)^2 = 0.42, rounded to 0.4

Pre-2015 AASHTO Provisions

- **Service I**—Load combination relating to the normal operational use of the bridge with a 55 mph wind and all loads taken at their nominal values (For WS: Design wind speed with load factor of = 1.0 *(55/100)^2 = 0.3

- **Service IV**—Tension in prestressed concrete columns with the objective of crack control. Ten year mean reoccurrence wind or 84 mph with no LL (For WS: Design wind speed with load factor = 1.0 *(84/100)^2) =0.7

(load factor of 1.0 for WL in Strength V and Service I because the pressure is specified and it was calculated based on 55 mph wind)

Pre-2015 AASHTO Provisions

- Friction velocity (V_0) and friction length (Z_0) are given for three exposure conditions (Open Country, Suburban, City)
- Provisions for wind force on sound barriers are in Chapter 15 and include two additional exposure conditions (Coastal and Sparse Suburban) added to match earlier guide specifications

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Basic Parameters used by Other Design Codes

- Averaging time for reference wind speed
- Return period for design wind speed
- Mean wind speed profile
- Dynamic analysis
- Spatial correlation of gusts
- Exposure categories
- Drag coefficients and shape factors

- ❑ Parameters varied widely between different specifications
- ❑ The provisions from any specifications should be accepted as a package; mix-and-match does not work

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Example of Variation in Value of Basic Parameters used by Different Design Codes

AVERAGING TIME FOR REFERENCE WIND SPEED

• Pre-2015 AASHTO	Fastest-mile wind speed (Variable averaging time. Close to a one-minute average)
• ASCE 7-10	3-second gust wind speed
• Canadian Code	One-hour averaged wind speed
• Eurocode	Ten-minute averaged wind speed
• AS/NZS	3-second gust wind speed
• BS5400	One-hour averaged and gust wind speed
• 2013 FDOT SDG	3-second gust wind speed

AASHTO LRFD Wind Load Provisions for Completed Bridges

AASHTO LRFD Wind Loads Provisions (1)

Design wind pressure = $P_Z = 2.56 \times 10^{-6} V^2 K_Z G C_D$

- P_Z Design wind pressure, ksf
- V Reference 3-second gust wind speed, at 33 ft. elevation, "open country setting, with 7% probability of being exceeded in 50 years (MRI = 700 years)
- K_Z Pressure exposure and elevation coefficient
- G Gust effect factor
- C_D Drag coefficient

AASHTO LRFD Wind Loads Provisions (2)

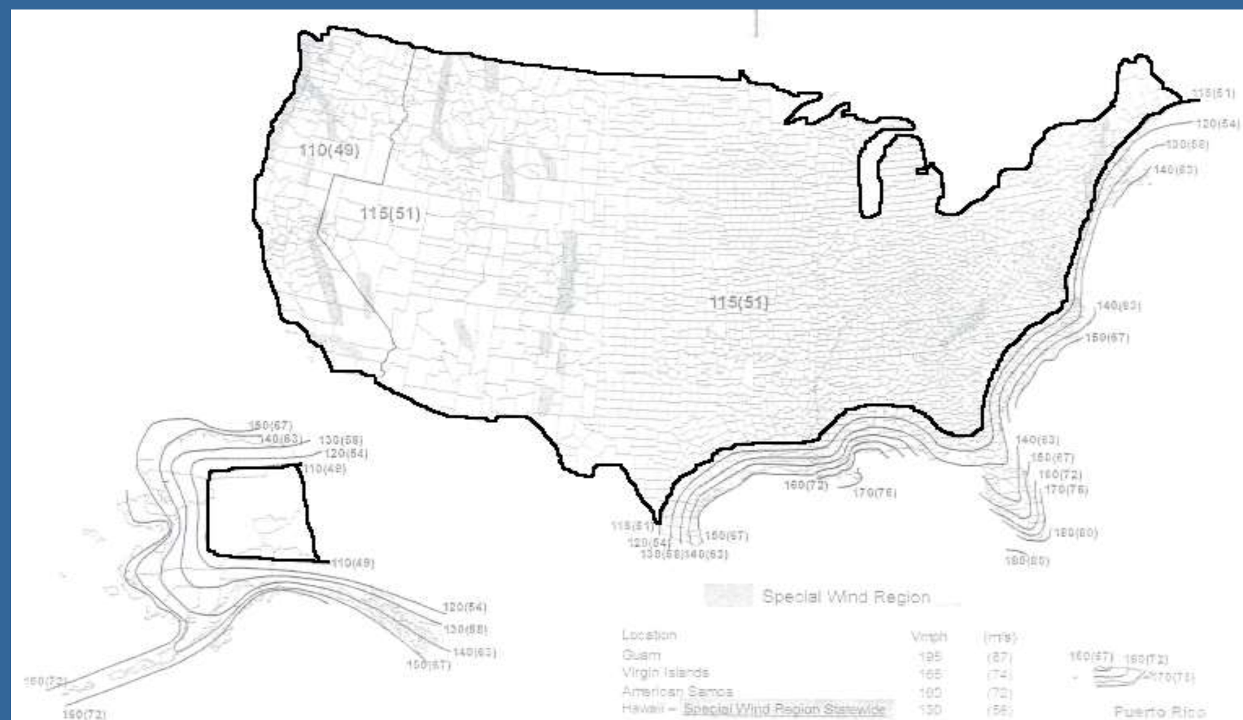
V Wind Speed

Load Combination	3-Second Gust Wind Speed (mph), V
Strength III	Wind speed taken from Figure 3.8.1.1.2-1.
Strength V	80
Service I	70
Service IV	0.75 of the speed used for the Strength III limit state

AASHTO LRFD Wind Loads Provisions (3)

- Reference 3-second gust wind speed, at 33 ft. elevation, "open country“ setting, with 7% probability of being exceeded in 50 years (MRI = 700 years)

For Strength III



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AASHTO LRFD Wind Loads Provisions (4)

- K_Z pressure exposure and elevation coefficient

Equations for K_Z are provided along with tabulated values.

Structure Height, *Z* (ft)	Wind Exposure Category B	Wind Exposure Category C	Wind Exposure Category D
≤33	0.71	1.00	1.15
40	0.75	1.05	1.20
50	0.81	1.10	1.25
60	0.85	1.14	1.29
70	0.89	1.18	1.32
80	0.92	1.21	1.35
90	0.95	1.24	1.38
100	0.98	1.27	1.41
120	1.03	1.32	1.45
140	1.07	1.36	1.49
160	1.11	1.40	1.52
180	1.15	1.43	1.55
200	1.18	1.46	1.58
250	1.24	1.52	1.63
300	1.30	1.57	1.68

AASHTO LRFD Wind Loads Provisions (5)

Ground Surface Roughness Categories

- Ground Surface Roughness B: Urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions
- Ground Surface Roughness C: Open terrain with scattered obstructions having heights generally less than 33 ft.
- Ground Surface Roughness D: Flat, unobstructed areas and water surfaces or mud flats

≤

AASHTO LRFD Wind Loads Provisions (6)

Wind Exposure Categories

- Wind Exposure Category B: Ground Surface Roughness Category B prevails in the upwind direction for a distance greater than
  - 1,500 ft. for structures with height ≤ 33 ft.
  - The greater of 2600 ft. or 20 times the height of the structure for structures with height >33 ft., respectively.
- Wind Exposure Category C: All cases where Wind Exposure Categories B or D do not apply.
- Wind Exposure Category D:
  - Ground Surface Roughness Category D prevails in the upwind direction for a distance greater than 5,000 ft. or 20 times the height of the structure, whichever is greater.
  - The structure is within a distance of 600 ft. or 20 times the height of the structure, whichever is greater, from a Ground Surface Roughness Category D condition, even if Ground Surface Roughness Category B or C exist immediately upwind of the structure.

AASHTO LRFD Wind Loads Provisions (7)

C_D : Drag Coefficients

Component		Drag Coefficient, C_D	
		Windward	Leeward
I-girder and box-girder bridge superstructures		1.3	N/A
Trusses, Columns, and Arches	Sharp Edged Member	2.0	1.0
	Round Member	1.0	0.50
Bridge Substructure		1.6	N/A
Sound Barriers		1.2	N/A

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AASHTO LRFD Wind Loads Provisions (8)

G : Gust Effect Factor

Structure Type	Gust Effect Factor, G
Sound Barriers	0.85
All other structures	1.0

AASHTO LRFD Wind Loads Provisions (9)

Skew Coefficients for Various Azimuth Angles of Attack

	Trusses, Columns and Arches		Girders	
Skew Angle (degree)	Transverse Coefficient	Longitudinal Coefficient	Transverse Coefficient	Longitudinal Coefficient
0	1.000	0.000	1.000	0.000
15	0.933	0.160	0.880	0.120
30	0.867	0.373	0.820	0.240
45	0.627	0.547	0.660	0.320
60	0.320	0.667	0.340	0.380

- For typical girder and slab bridges W/ individual span lengths <125 ft. & maximum height of 33 ft, the following wind loading combination may be used
  - 100% transverse
  - 24% longitudinal

AASHTO LRFD Wind Loads Provisions (10)

Sound Barriers

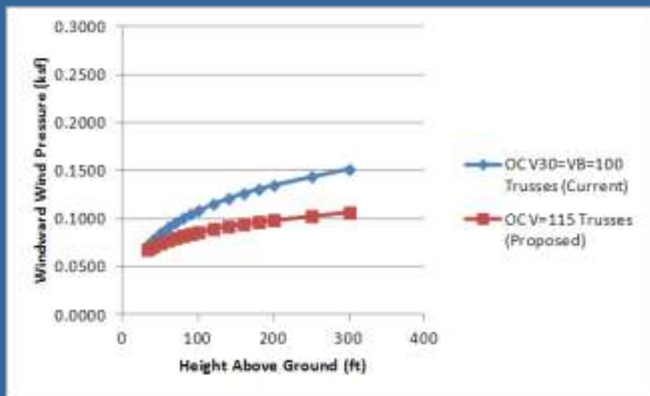
- Same basic wind pressure equation
- The elevation, Z, shall be taken as the top of the sound barrier.
- The wind load is taken as a line load equal to the pressure times the sound barrier height, and applied at 0.55 times the sound barrier height from the bottom of the barrier.

AASHTO LRFD Wind Loads Provisions (11)

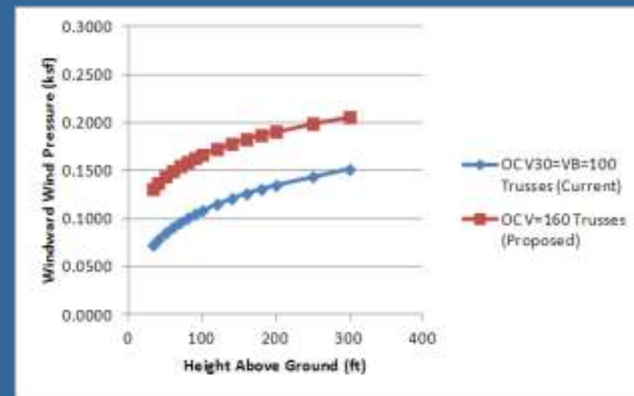
Load Factors

Limit State	*Perm. loads*	*LL*	*WA*	***WS***	***WL***	*FR*	*TU*	*TG*	*SE*
Strength III	γ_p	—	1.00	**1.00**	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}
Strength V	γ_p	1.35	1.00	**1.00**	**1.00**	1.00	0.50/1.20	γ_{TG}	γ_{SE}
Service I	1.00	1.00	1.00	**1.00**	**1.00**	1.00	1.00/1.20	γ_{TG}	γ_{SE}
Service IV	1.00	—	1.00	**1.00**	—	1.00	1.00/1.20	—	1.00

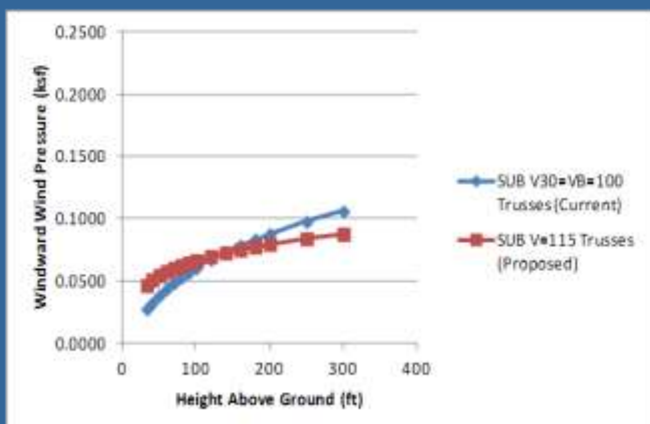
Wind Pressure Comparisons - Trusses (1)



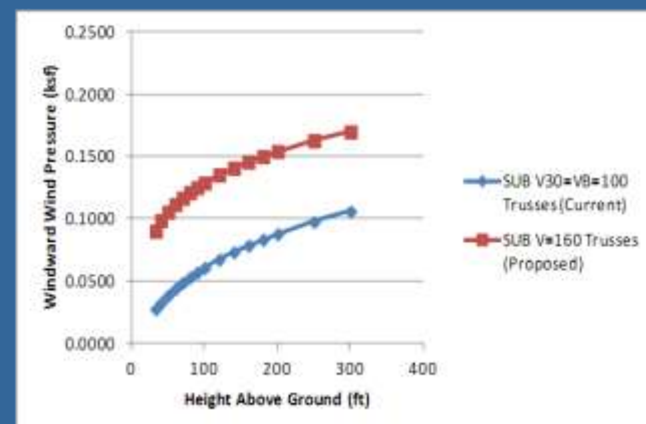
Open Country V_{30} = 100 mph V_{prop} = 115 mph



Open Country V_{30} = 100 mph V_{prop} = 160 mph

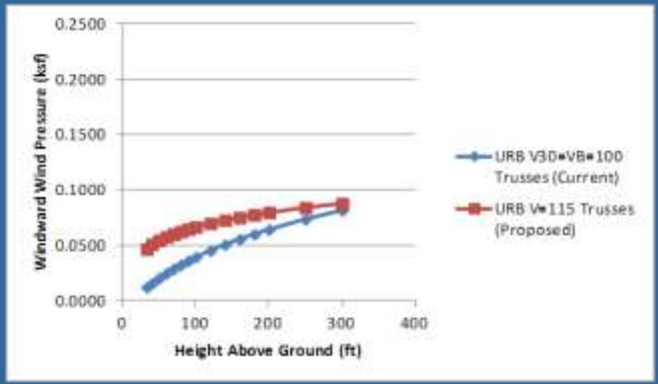


Suburban V_{30} = 100 mph V_{prop} = 115 mph

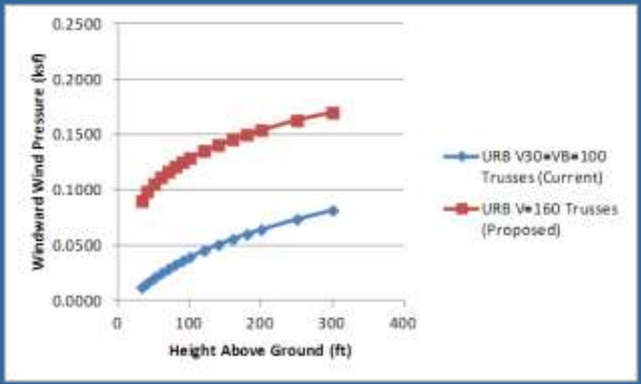


Suburban V_{30} = 100 mph V_{prop} = 160 mph

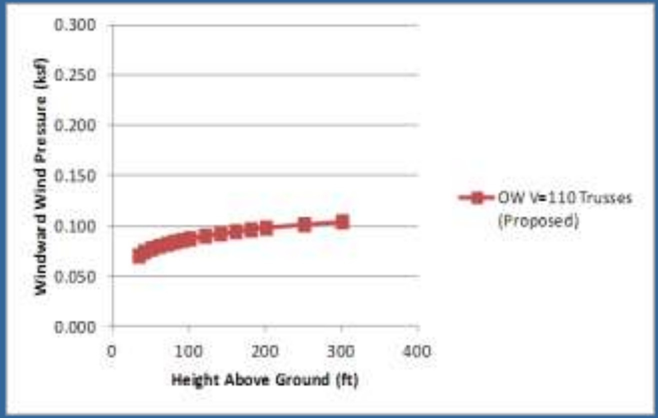
Wind Pressure Comparisons - Trusses (2)



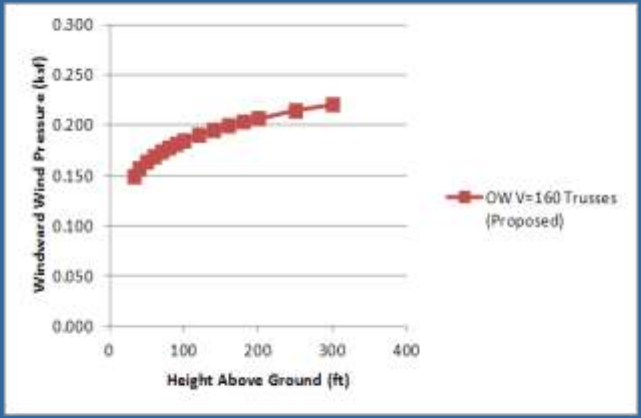
Urban V_{30} = 100 mph V_{prop} = 115 mph



Urban V_{30} = 100 mph V_{prop} = 160 mph



Open Water V_{prop} = 115 mph



Open Water V_{prop} = 160 mph

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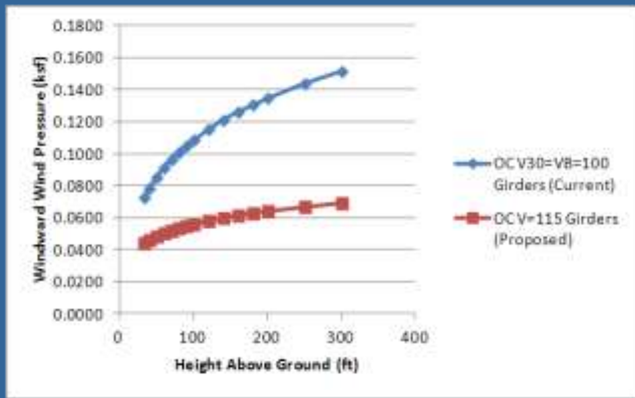
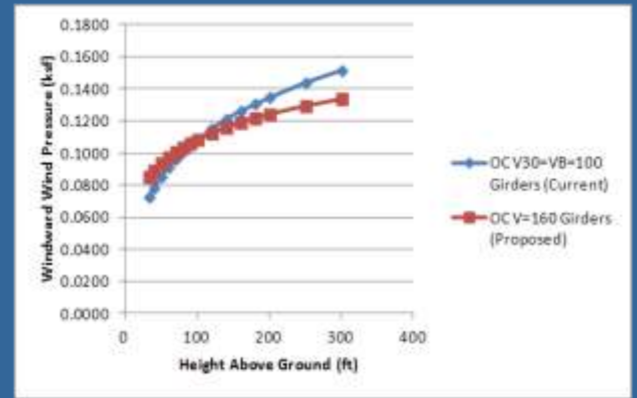
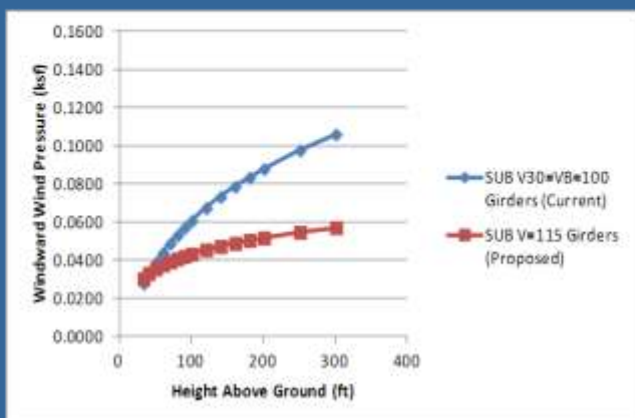
Wind Pressure Comparisons - Girders (1)



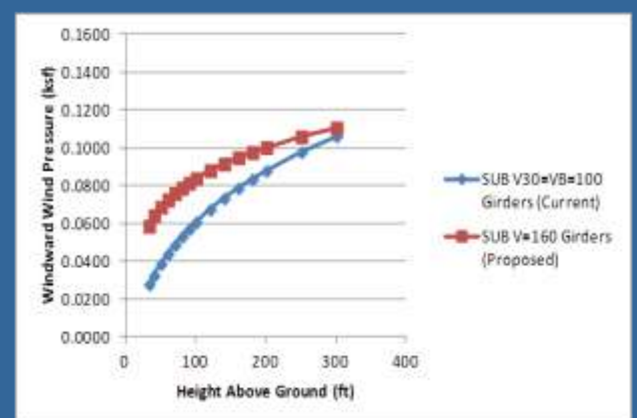
Open Country V_{30} = 100 mph V_{prop} = 115 mph



Open Country V_{30} = 100 mph V_{prop} = 160 mph

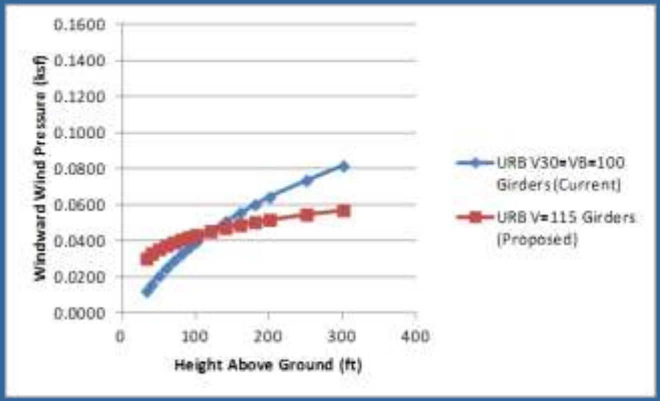


Suburban V_{30} = 100 mph V_{prop} = 115 mph

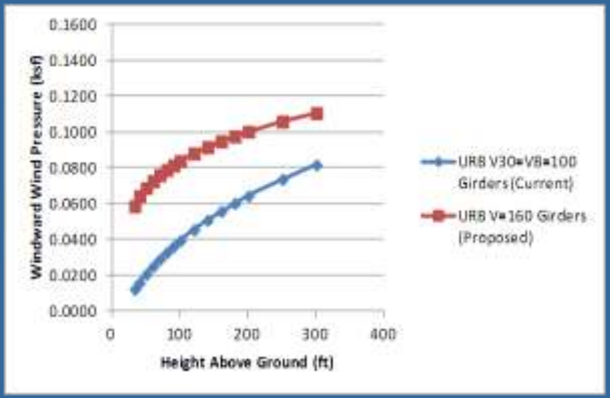


Suburban V_{30} = 100 mph V_{prop} = 160 mph

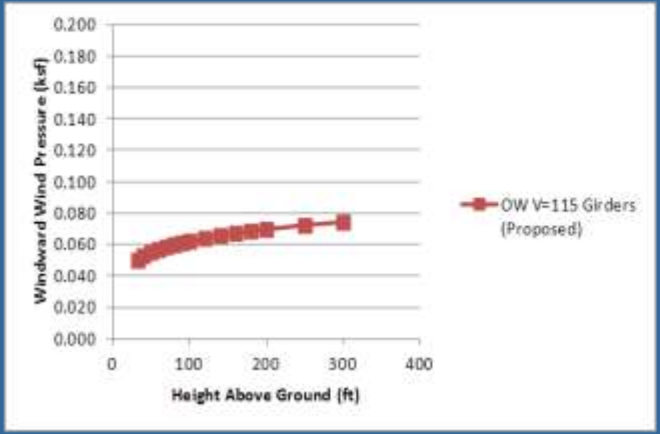
Wind Pressure Comparisons - Girders (2)



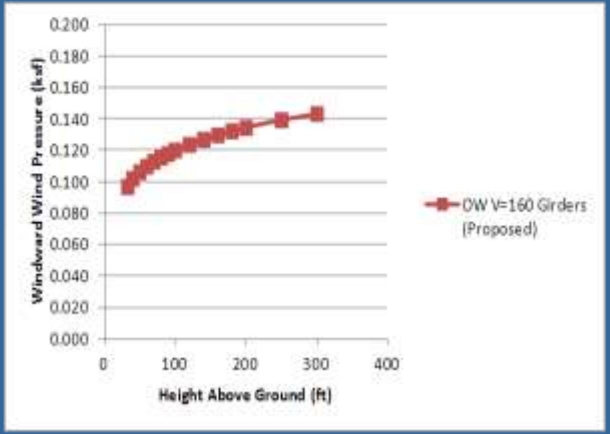
Urban V_{30} = 100 mph V_{prop} = 115 mph



Urban V_{30} = 100 mph V_{prop} = 160 mph



Open Water V_{prop} = 115 mph



Open Water V_{prop} = 160 mph

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Possible Refinement For WS

During the development of these provisions, another factor, K_L: Adjustment factor based on MRI was considered. The value is as follows:

= 1.04 to convert V^2 to a 7% probability of being exceeded in 75 years (MRI = 1000 years)

= 1.08 to convert V^2 to a 7% probability of being exceeded in 100 years (MRI = 1400 years)

Due to the approximate nature of the wind load, this was thought to imply a degree of accuracy that does not exist.

AASHTO LRFD Wind Loads Provisions (12)

- Wind load on live load: Similar to pre-2015 AASHTO LRFD

Skew Angle	Transverse Component	Longitudinal Component
(degrees)	(klf)	(klf)
0	0.100	0.0
15	0.088	0.012
30	0.082	0.024
45	0.066	0.032
60	0.034	0.038

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AASHTO LRFD Wind Loads Provisions (13)

Other provisions:

- Vertical wind load
- Guidance on identifying bridges prone to dynamic wind effects

CONSTRUCTION WIND LOADS

What is different about wind during construction?

- **Shorter exposure to winds - lower construction wind speeds**
- **Historically, for large bridge studies 10 to 25 year wind speeds (with LF = 1.4) are the norm**

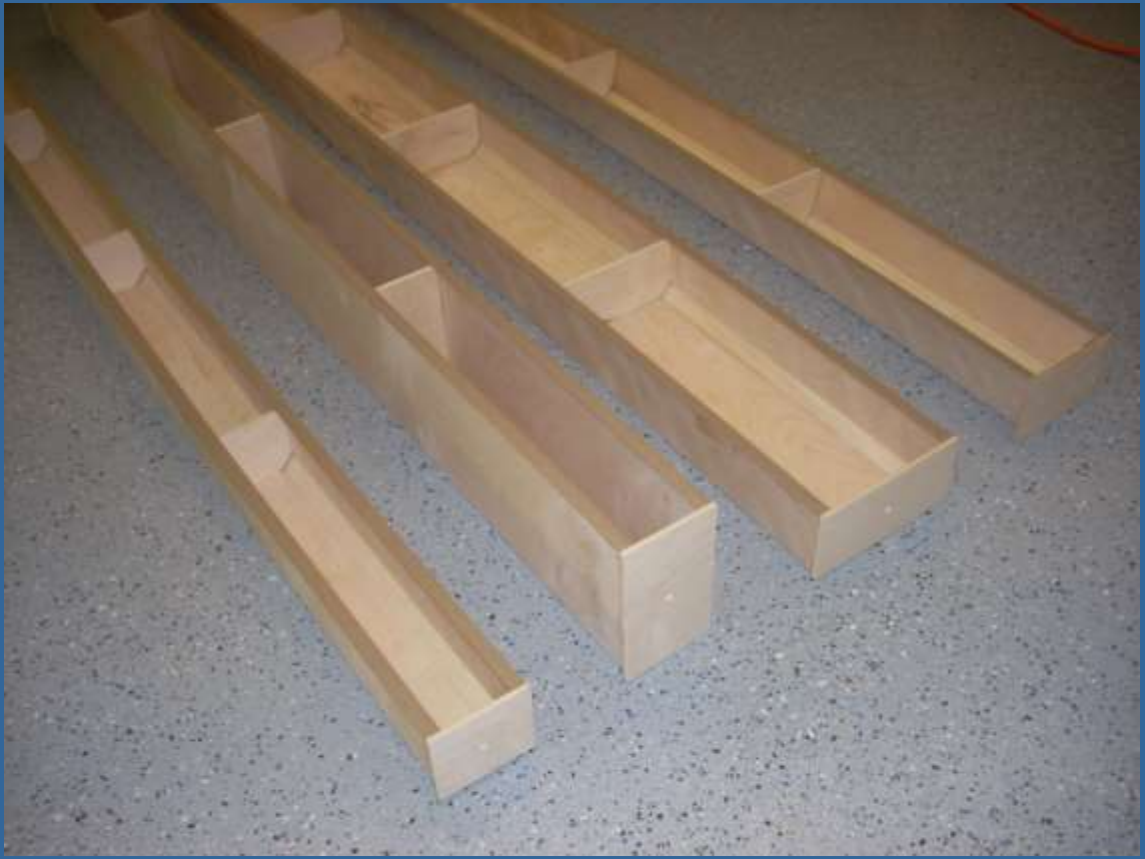
CONSTRUCTION WIND LOADS

What is different about structure?

- **Frequently there are series of beams and boxes in place without a deck during construction (different aerodynamics)**
- **Each girder will be subjected to wind loading albeit the magnitude varies from one girder to another**
- **There is a potential for vortex induced motions and aeroelastic instabilities for long, slender, flexible, unsupported members common during construction**
- **AASHTO is currently considering construction wind as a stand-alone document**

AASHTO Wind Loads

AASHTO Wind Loads



AASHTO Wind Loads

AASHTO Guide Specifications for Wind Loads during Construction (1)

- The guide specifications is a stand alone document modeled after AASHTO LRFD Section 3.8
- For bridges during construction, it replaces Section 3.8 of the design specifications
- All other sections of the design specifications apply

AASHTO Guide Specifications for Wind Loads during Construction (2)

Difference between completed bridges and bridges during construction

- The absence of the deck changes the wind characteristics of the bridge
- Before the deck is cast, all girders are subjected to lateral wind load, however, the magnitude varies depending on their position from the windward exterior girder
- For the purpose of the guide specifications, bridges are considered to be “during construction” up to the time the deck is cast

AASHTO Guide Specifications for Wind Loads during Construction (3)

Definitions:

- *Active Work Zone*—Work zone during the time workers are on-site and erection of the structure is in progress.
- *Inactive Work Zone*—Work zone during the time construction work is not being performed including time between work shifts and overnight and the time between the erection of the girders and the placement of the deck.

Current AASHTO LRFD Wind Loads Basic Equation for Completed Bridges

Design wind pressure = $P_Z = 2.56 \times 10^{-6} V^2 K_Z G C_D$

- P_Z Design wind pressure, ksf
- V Reference 3-second gust wind speed, at 33 ft. elevation, "open country setting, with 7% probability of being exceeded in 50 years (MRI = 700 years)
- K_Z Pressure exposure and elevation coefficient
- G Gust effect factor
- C_D Drag coefficient

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AASHTO Guide Specifications for Wind Loads during Construction (4)

Design wind pressure = $P_Z = 2.56 \times 10^{-6} V^2 R^2 K_Z G C_D$

- V 20 mph (or as specified by the owner) for active work zones and from the wind map for inactive work zone
- R wind speed reduction factor during construction of the superstructure taken as 1.0 for active work zones and from Table 4.2.1-1 for inactive work zones.

For major bridges, the minimum allowed wind speed reduction factor for inactive work zone shall be taken as 0.77. For construction duration greater than 7 years, wind speed reduction factor shall be taken as 1.0. (dim).

AASHTO Guide Specifications for Wind Loads during Construction (5)

Wind Speed Reduction Factor during Construction, *R*

Superstructure Construction Duration	Wind Speed Reduction Factor during Construction, R
0-6 weeks	0.65
6 weeks to 1 year	0.73
>1-2 years	0.75
>2-3 years	0.77
>3-7years	0.84

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Current AASHTO LRFD Drag Coefficient for Completed Bridges

C_D : Drag Coefficients

<table>
<tr><th rowspan="2" colspan="2">Component</th><th colspan="2">Drag Coef., C_D</th></tr>
<tr><th>Windward</th><th>Leeward</th></tr>
<tr><td colspan="2">I-girder and box-girder bridge superstructures</td><td>1.3</td><td>N/A</td></tr>
<tr><td rowspan="2">Trusses, Columns, and Arches</td><td>Sharp Edged Member</td><td>2.0</td><td>1.0</td></tr>
<tr><td>Round Member</td><td>1.0</td><td>0.50</td></tr>
<tr><td colspan="2">Bridge Substructure</td><td>1.6</td><td>N/A</td></tr>
<tr><td colspan="2">Sound Barriers</td><td>1.2</td><td>N/A</td></tr>
</table>

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AASHTO Guide Specifications for Wind Loads during Construction (6)

Drag coefficient for bridges during construction

- **Base Drag Coefficient** for Bridge Superstructures During Construction

Superstructure Type	Base Drag Coefficient ($C_{D, base}$)
Steel Plate Girders	2.2
Rolled I-beams	2.2
Concrete I-Beams	2.0
Closed and Open Box-Girders	2.1
Round Members	1.0

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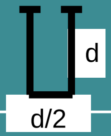
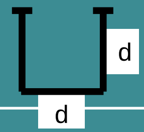
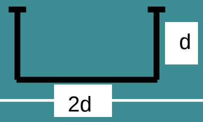
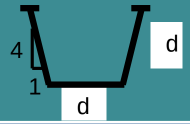
AASHTO Guide Specifications for Wind Loads during Construction (7)

Drag coefficient for bridges during construction

Measured Base Drag Coefficient for Box-Girder Bridge Superstructures During Construction

Box Geometry	Base Drag Coefficient ($C_{D,\ base}$)
	2.05
	1.66
	1.35
	1.39

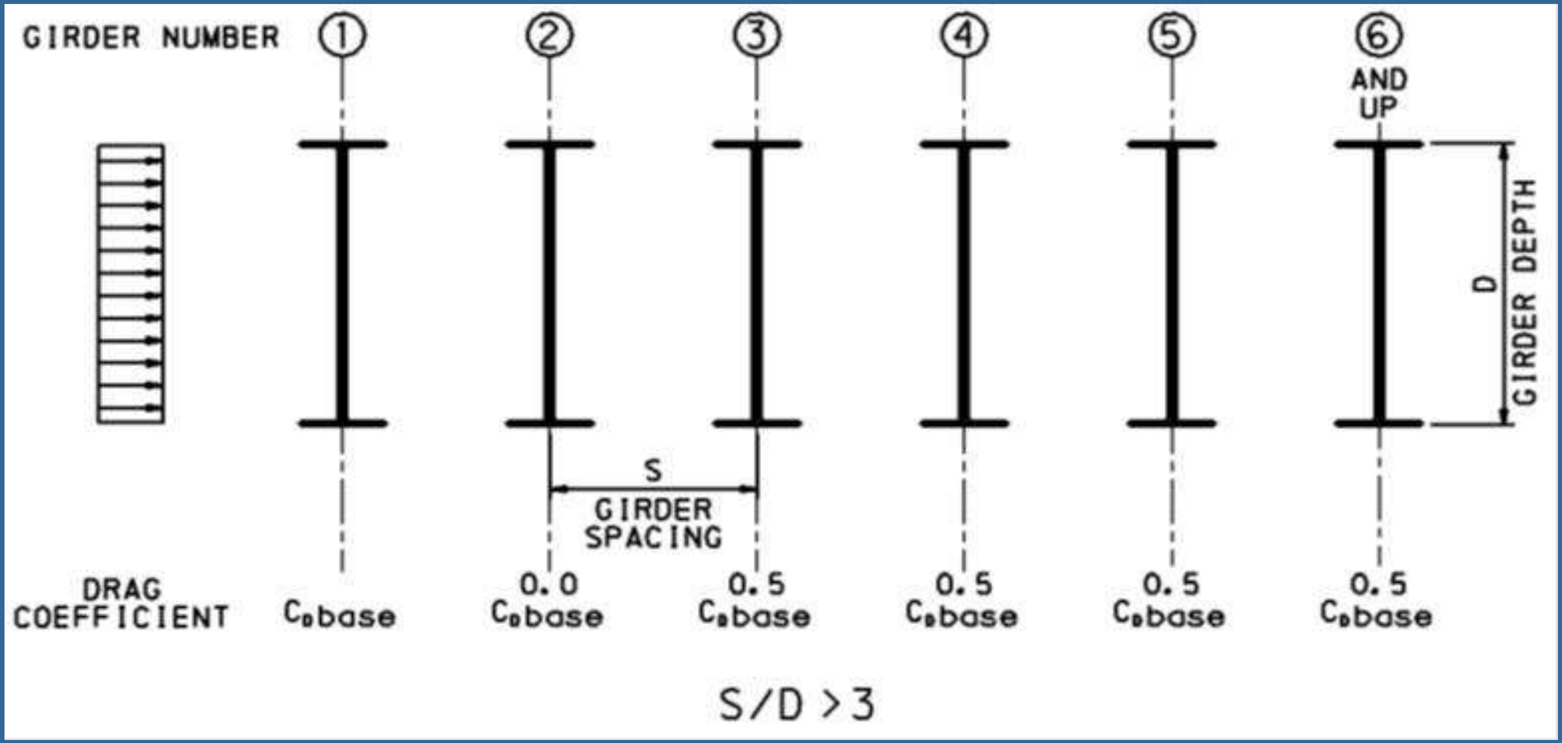
AASHTO Guide Specifications for Wind Loads during Construction (8)

Girder		Drag Coefficient (C_D)
Windward girder in multi-girder I-girder and box-girder systems and for single box-girder systems		$C_{D,\ base}$
Second girder, windward side in multi-girder systems	In two-box-girder systems with a clear distance between the two boxes of no more than twice the girders depth	$0.5\ C_{D,\ base}$
	In all other systems	0.0

Girder		(C_D)
Third, fourth and fifth girders, windward side in multi-girder systems	In multi I-girder systems with ratio of girder spacing to girder depth is not greater than 3	$0.25\ C_{D,\ base}$
	In multi I-girder systems with ratio of girder spacing to girder depth is greater than 3	$0.5\ C_{D,\ base}$
	In multi box-girder systems	$0.5\ C_{D,\ base}$
All other girders		$0.5\ C_{D,\ base}$

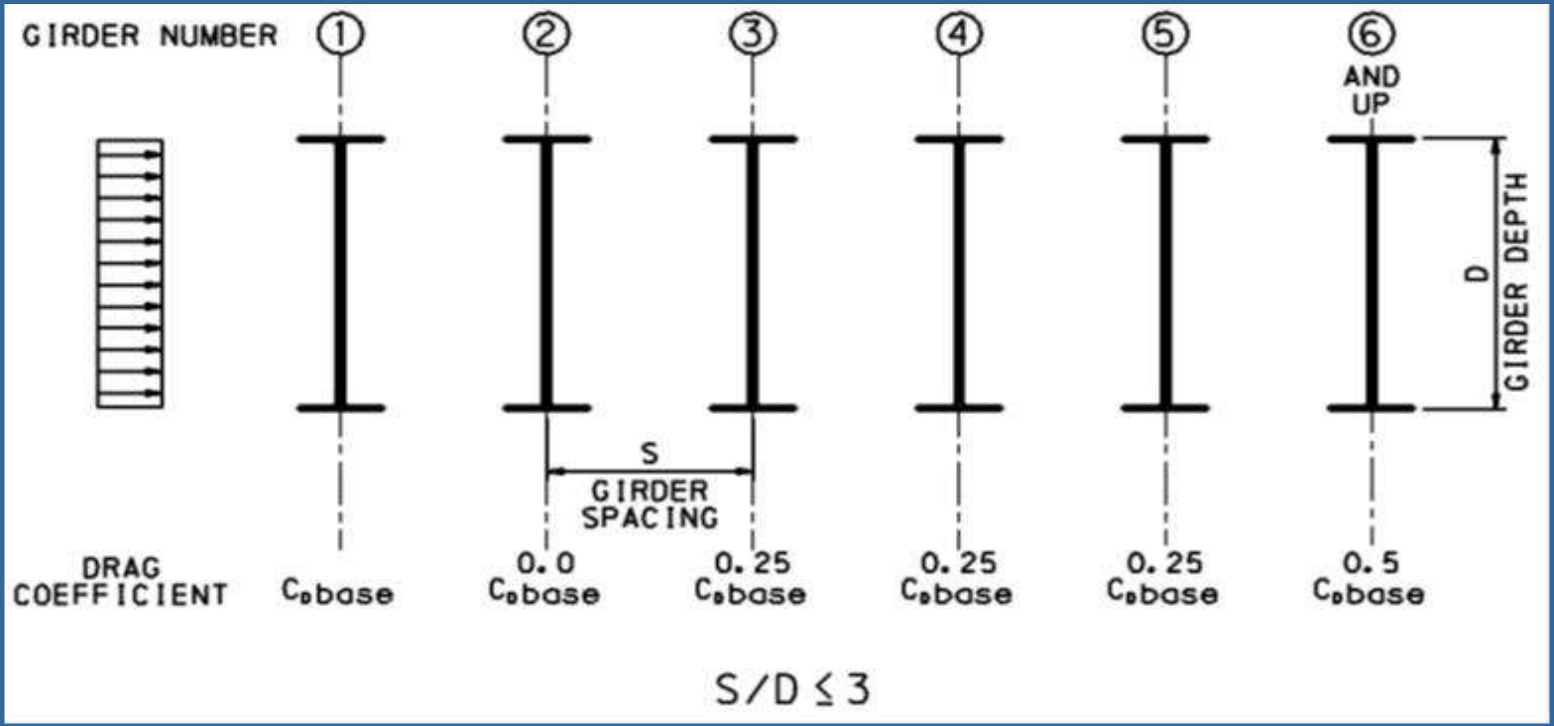
AASHTO Guide Specifications for Wind Loads during Construction (9)

Drag Coefficient for different girders in Multi I-Girder Systems



AASHTO Guide Specifications for Wind Loads during Construction (10)

Drag Coefficient for different girders in Multi I-Girder Systems



AASHTO Guide Specifications for Wind Loads during Construction (11)

- For inactive work zones at any stage of construction, the wind load on the girders will be determined taking into consideration the position of the girder in the cross-section during the construction stage being considered.
- For total wind loads transmitted to the substructure, The C_D in the wind pressure equation becomes the sum of the CD’s for all girders.

THANK YOU FOR YOUR ATTENTION

QUESTIONS?