# *DESIGN CODES AND DUE DILIGENCE FOR WIND RESILIENT PV TRACKERS*

**ÁLVARO CASADO**
*AMEA Manager*

# PVH: who are we?


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**2009**
- First fixed-tilt racking in Pescopennataro (Italy) for GRS

- First single-axis tracker in Letur (Spain) for GRS

**2010**

**2011**
- PVH incorporated in San Francisco (CA)

**2012**
- First tracker in USA Newman (CA)

- First USA project in Fallon (NV) 26MW

**2013**
- Lesedi (80MWp) and Letsasi (80MWp) projects in South Africa

- AXONE single-axis tracker installed in Hyder II (AZ) 21MWp

**2014**
- PVH opens metal work in Cheste, Valencia (Spain)

- First tracker in Central America in Zacapa Guatemala

- AXONE 1.0 in Taft Co (CA) 26MWp

**2015**
- PVH opens metal work in Jundiai Sao Paolo (Brazil)

- AXONE 2.0 installed in Phoenix (AZ) 31.8MWp

- Agua Fría, Honduras 59.5MWp

**2016**
- AXONE 4.0 installed in Camargo (Mexico) 35MWp

- NC1 (NC) 53MWp

**2017**
- Mohammed bin Rashid Al Maktoum Solar Park (Phase III) 1054MWp in UAE

**2018**
- 1st Middle East manufacturer with over 1 GW manufactured

**2019**
- Esplendor 50 MWp in Spain

- First project in Australia, Lilyvale 100MWac

- 3rd PVH becomes the third tracker manufacturer in the world

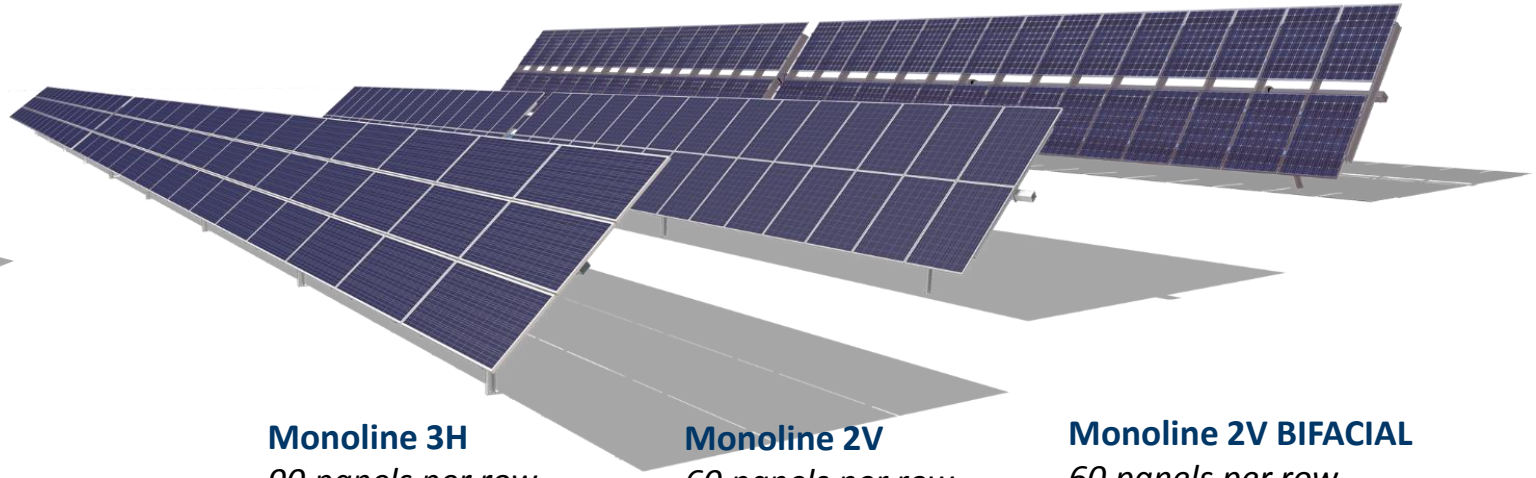
**ÁLVARO CASADO** *AMEA Manager*

# PVH: who are we?

AXONE

**AXONE DUO, 1V**
*Up to 2x64 modules*

MONOLINE



**Monoline 3H**
*90 panels per row*

**Monoline 2V**
*60 panels per row*

**Monoline 2V BIFACIAL**
*60 panels per row*

**ÁLVARO CASADO** *AMEA Manager*

# PVH: who are we?

- ✓ Good sample distributed around the world. **More than 5,2 Gw** with different climatic conditions to have a **solid knowledge database**.
- ✓ A **Vast experience** that helps us perform proper assessments and understand where the issues might occur.
- ✓ Always **improving** and integrating the feedback from clients and partners. With our innovation facility our testing's are performed fast to **match the evolution of this fast-paced market**.
- ✓ Technical team, required installations and best partners to check the integrity of the structures and make sure that we don't only meet the technical requirements but **warrantee the integrity of the structure**.

**ÁLVARO CASADO** *AMEA Manager*

# Market overview: is code compliance enough? Other tracking system issues worlwide.

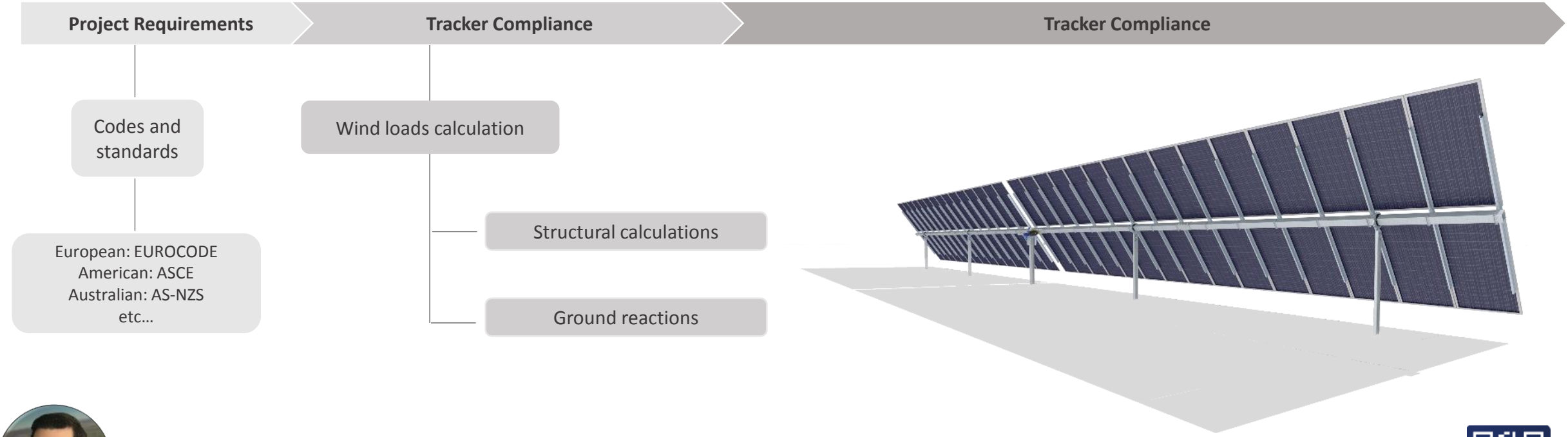


**Note: these events do not correspond to projects supplied by PVH*

2018 2019 Today

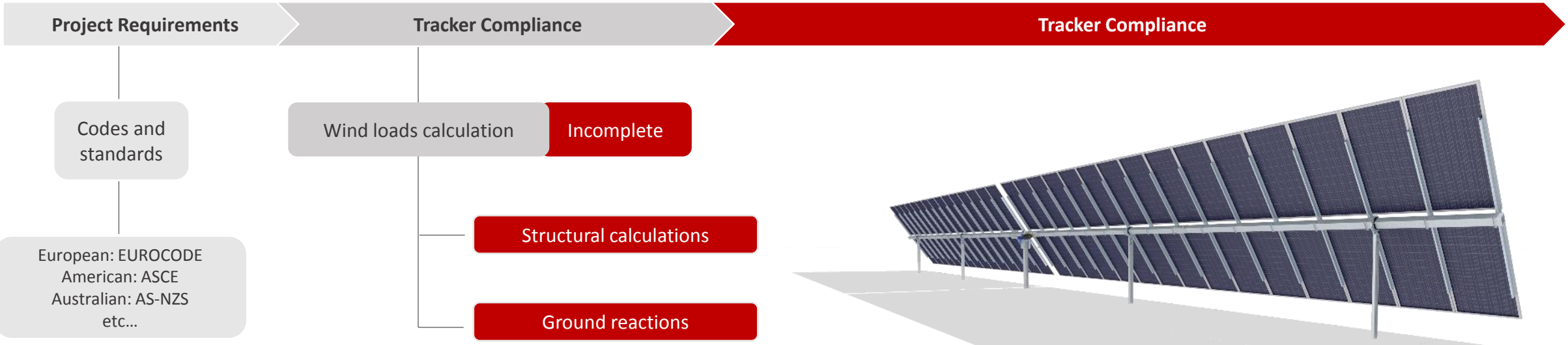
# Market overview: is code compliance enough?

- ✓ **Any wind** study will be enough to **comply** with most RFQ.
- ✓ There is usually no specific requirement so it's **up to tracker manufacturers to provide their studies**.
- ✓ Wind studies have a **direct impact on structural calculations**.




# Market overview: is code compliance enough?

- Some wind studies **don't provide complete information** on tracker behaviour.
- Tracker would be **approved** but might have **issues with site conditions**.




# Market overview: is code compliance enough?

- **There is currently an issue.** Code compliant trackers don't warrantee the integrity of the structure.
- In the past year **more than seven** large scale PV plants **had wind related issues.**
- It is only the sample to which we had access to, there were probably a lot more that weren't brought to attention.
- Manufacturers and developers own interest play against the evolution of the market. **Lessons learnt only come with past experiences.**

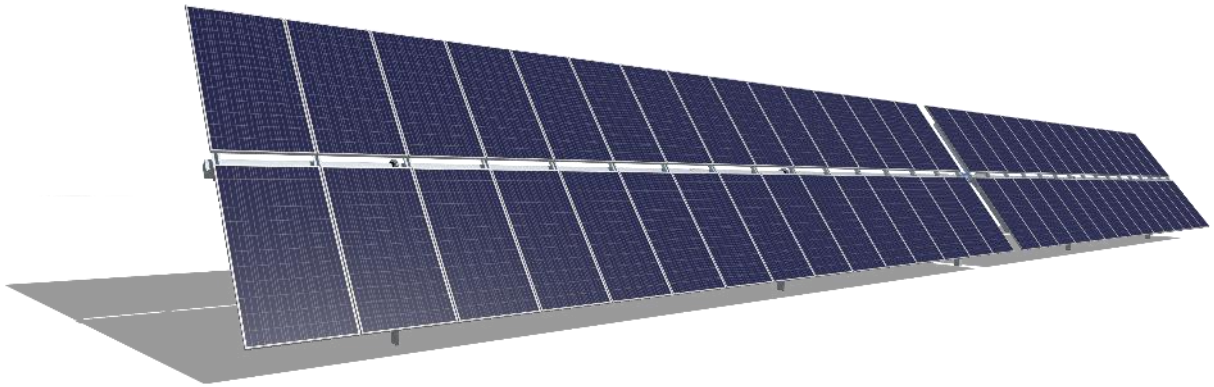
**ÁLVARO CASADO** *AMEA Manager*

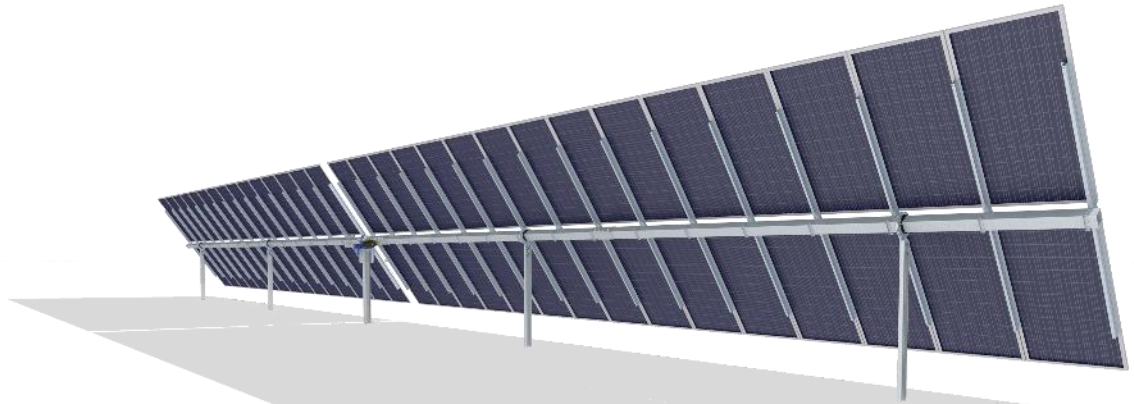
PVH

# *DESIGN CODES AND DUE DILIGENCE FOR WIND RESILIENT PV TRACKERS*

**EDUARDO CHILLARÓN**
*Design and Engineering Manager*

# Market overview: How is PVH handling the issue





Project requirements → Static wind study → Aerolastic wind study → Structural calculations → **FLUTTER FREE TRACKER**

WIND TUNNEL TEST CERTIFIED
FLUTTER FREE
PVH
WIND TUNNEL TEST CERTIFIED

# Project Requirements

- ✓ Codes applicable to project:
  - ASCE
  - Eurocode
  - AS-NSZ
  - …
- ✓ Parameters to obtain from the code:
  - Basic wind pressure
    - Return period
    - Wind terms
  - Topographic parameters

## ASCE

1. Values are nominal design 3-second gust wind speeds in miles per hour (m/s) at 33 ft (10m) above ground for Exposure C category.
2. Linear interpolation between contours is permitted.
3. Islands and coastal areas outside the last contour shall use the last wind speed contour of the coastal area.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.
5. Wind speeds correspond to approximately a 15% probability of exceedance in 50 years (Annual Exceedance Probability = 0.00333, MRI = 300 Years).

[In SI: $q_z = 0.613 K_z K_{zt} K_d V^2$ (N/m$^2$); $V$ in m/s]

## Eurocode

(1)P The fundamental value of the basic wind velocity, $v_{b,0}$, is the characteristic 10 minutes mean wind velocity, irrespective of wind direction and time of year, at 10 m above ground level in open country terrain with low vegetation such as grass and isolated obstacles with separations of at least 20 obstacle heights.

$$q_b = \frac{1}{2} \cdot \rho \cdot v_b^2$$

## AS-NSZ

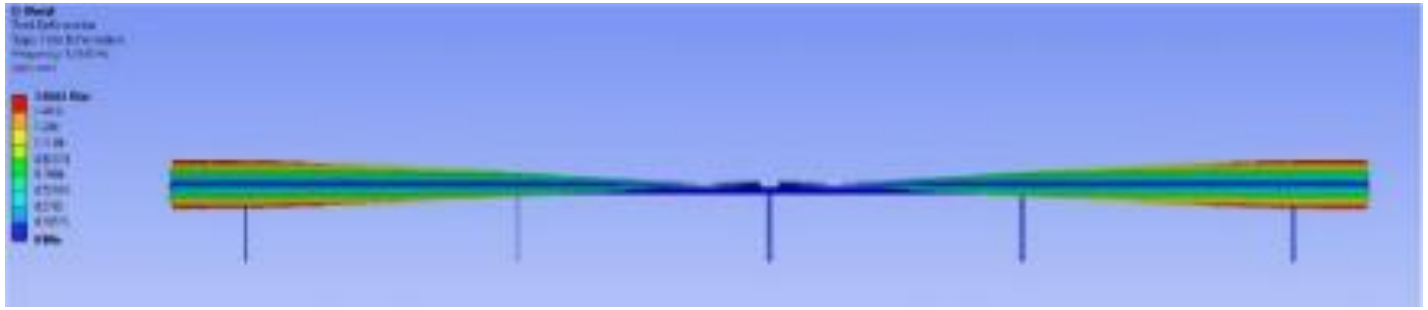
$V_R$ = regional 3 s gust wind speed, in metres per second, for annual probability of exceedence of 1/R, as given in Section 3

$$p = (0.5\ \rho_{air})\ [V_{des,0}]^2\ C_{fig}\ C_{dyn}$$

**EDUARDO CHILLARÓN** *Design & Engineering Manager*

# Static Wind Study

- **Static Wind Loads:** there is a **consensus** in the market about this calculation.
  - ✓ Wind pressure **from code** in line with the wind tunnel test done
  - ✓ **Static wind tunnel** test to obtain **GCm** and **GCf** coefficients
  - ✓ Dynamic Amplification Factors
  - ✓ Damping factor



**EDUARDO CHILLARÓN** *Design & Engineering Manager*

# Aerolastic wind study

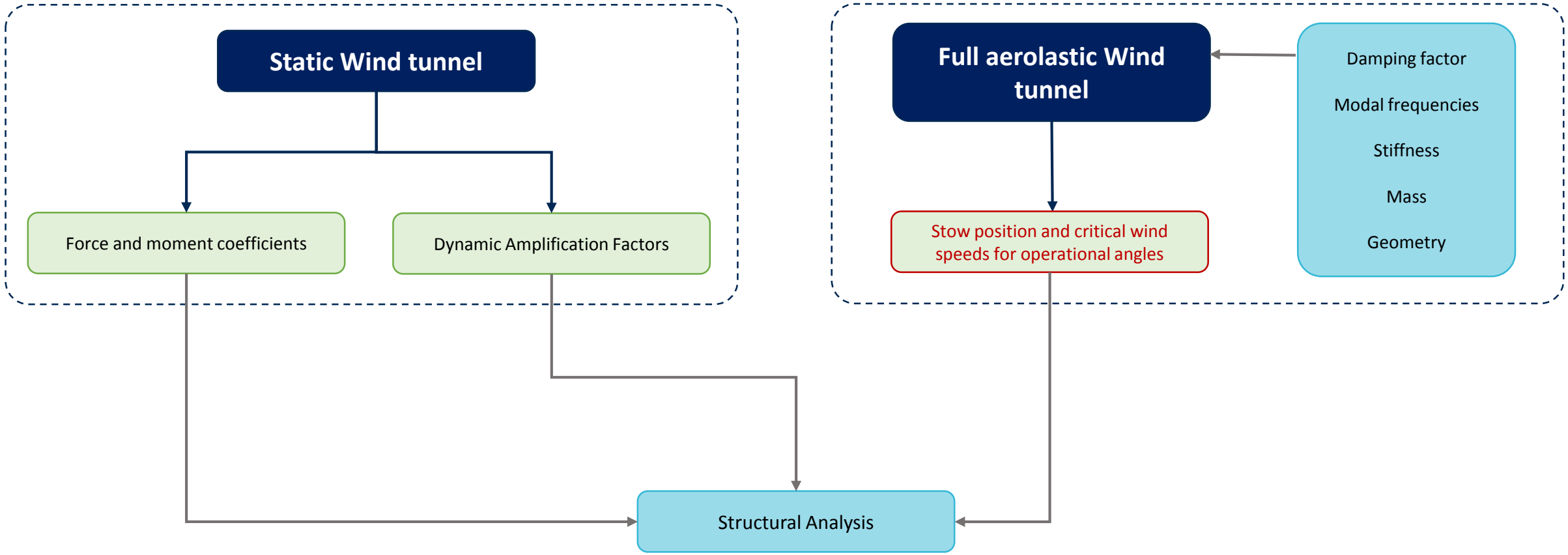
Codes **do not cover the aerolastic instability** check for this kind of structures. Some of them only fix the criteria of a natural frequency higher than 1Hz.

**AEROLASTIC WIND TUNNEL TEST TYPES**

**Sectional**

**Full aerolastic**


# Calculation procedure for wind loads

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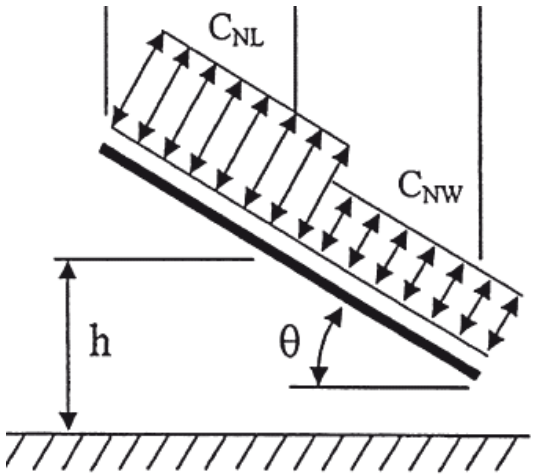
# *DESIGN CODES AND DUE DILIGENCE FOR WIND RESILIENT PV TRACKERS*

**DAVID BANKS**
*Solar Services Manager*

# Regulatory context: Current codes do not have what you need




| Clear Wind Flow | |
|---|---|
| $C_{NW}$ | $C_{NL}$ |
| 0.9 | 1.5 |

Wind Direction ⇐

$\gamma = 180°$

- ✓ <u>If you make code coefficients the basis for the contract</u>, you will only get a good design by accident.
- ✓ Then, if you have failures in a windstorm, everyone will say it was not their fault, and they will be right. The design engineer and due-diligence reviewer will have done their best to apply code provisions that were never intended for solar.

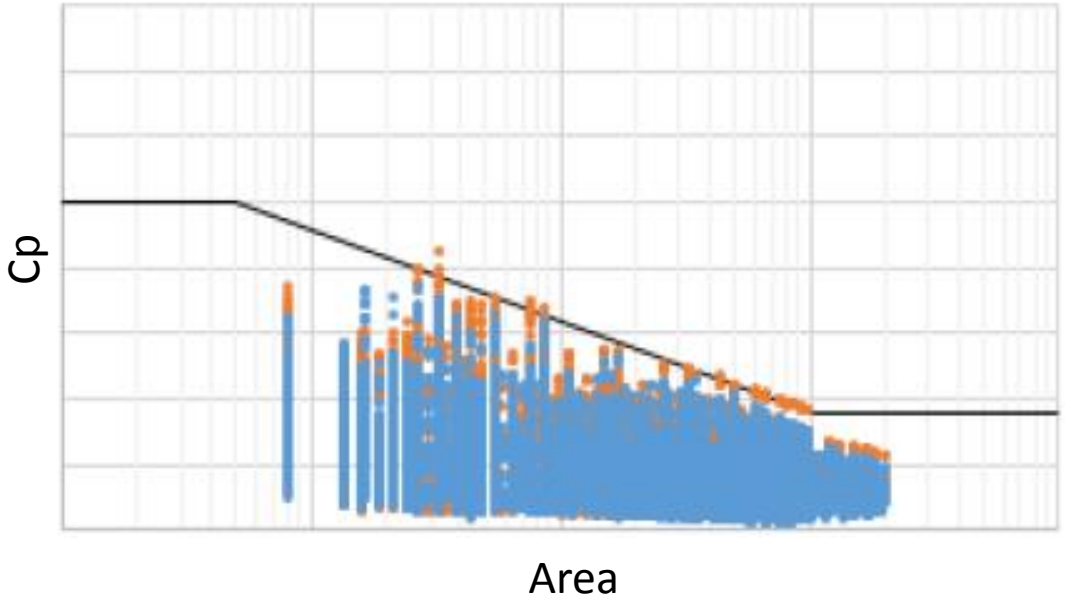
# Regulatory context: Current codes do not exclude getting the right answer

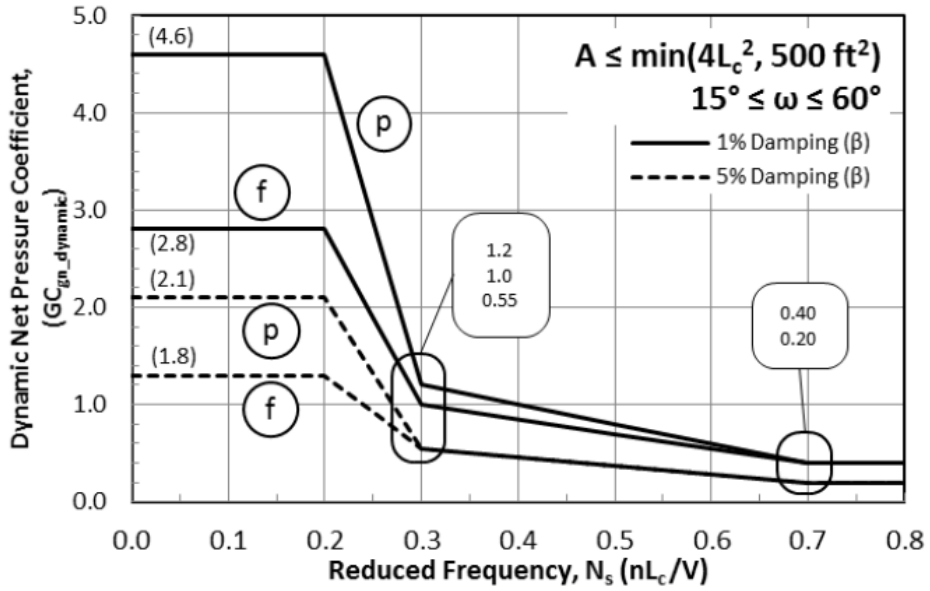
## CHAPTER 31
## WIND TUNNEL PROCEDURE

> **User Note**: Chapter 31 may always be used for determining wind pressures for the MWFRS and/or for C&C of any building or other structure. This method is considered to produce the most accurate wind pressures of any method specified in this standard.

- It is anticipated in the code that suitable coefficients will not be included for every possible structure.
  - ✓ ABL wind tunnel testing is the recommended recourse.
- The code provides a framework for what is needed (statics, dynamics, caution for aeroelastic).

# Regulatory context: New Codes. ASCE 7-22 is expected to include static and dynamic coefficients




- ✓ These will be conservative, due to need for brevity and simplicity
  - For example, differences due to underside structure
- ✓ So maybe a solar guidebook, rather than a small section in between tanks and signs?
- ✓ Better yet, what about some software from a database certified by full scale experience?
  - Careful of “sacred software”

# Regulatory context: A solar wind loading standard informed by experience


?ILE PHOTO: Grounded Boeing 737 MAX aircraft are seen parked in an aerial photo at Boeing Field in Seattle, Washington, U.S. July 1, 2019. REUTERS/Lindsey Wasson/File Photo

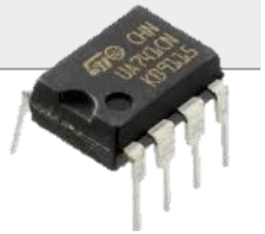

- Nothing beats full-scale failure testing
  - ✓ In solar, failure information is not shared. Each owner and designer learns for themselves.
  - ✓ Consensus not needed, debate not declared.

# Regulatory context: What kind(s) of solar wind loading standard(s)?

## Compare to building cladding.

**Certification**

- Not done for whole building
- Cladding test facilities



# Regulatory context: What kind(s) of solar wind loading standard(s)?

## Compare to building cladding.

| Certification | Prescriptive (compliance) | Performance (reliability) |
|---|---|---|
| ▪ Not done for whole building<br>▪ Cladding test facilities | ▪ "Design wind pressures on C&C elements of low-rise buildings shall be determined from the following equation and figures."<br>▪ Limits on applicability | ▪ "The building envelope shall remain attached to the structure in a 1:700 year wind event."<br>▪ New methods extend limits |

✓ Either way, still need due diligence

- Prescriptive can be misinterpreted, or extended outside of intended limits.
- Performance-based analysis implies wide range of possible methods.

# Tracker Instability: the case for multi-row full tracker aeroelastic testing


- ✓ Widely accepted that full aeroelastic model is superior to section model
  - Where there is disagreement, full model is more accurate.
  - Section model generally intended to save money.
- ✓ Full ABL and relevant turbulence captured
  - Turbulence larger than the tracker can trigger instability at low tilts.
  - Smooth flow (typical for section model tests) is not conservative in this case.
- ✓ Instability is very sudden
  - triggered by gusts.
  - section testing often assumes mean speeds.

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# Tracker Instability: the case for multi-row full tracker aeroelastic testing

- The whole tracker does not twist the same to the same angle (as is the case in the section model); only the free end has the full twist. This must be accounted for by some assumptions in the section test, but it is modelled explicitly in the full tracker testing.
- Instability in one row can trigger instability in neighboring rows.

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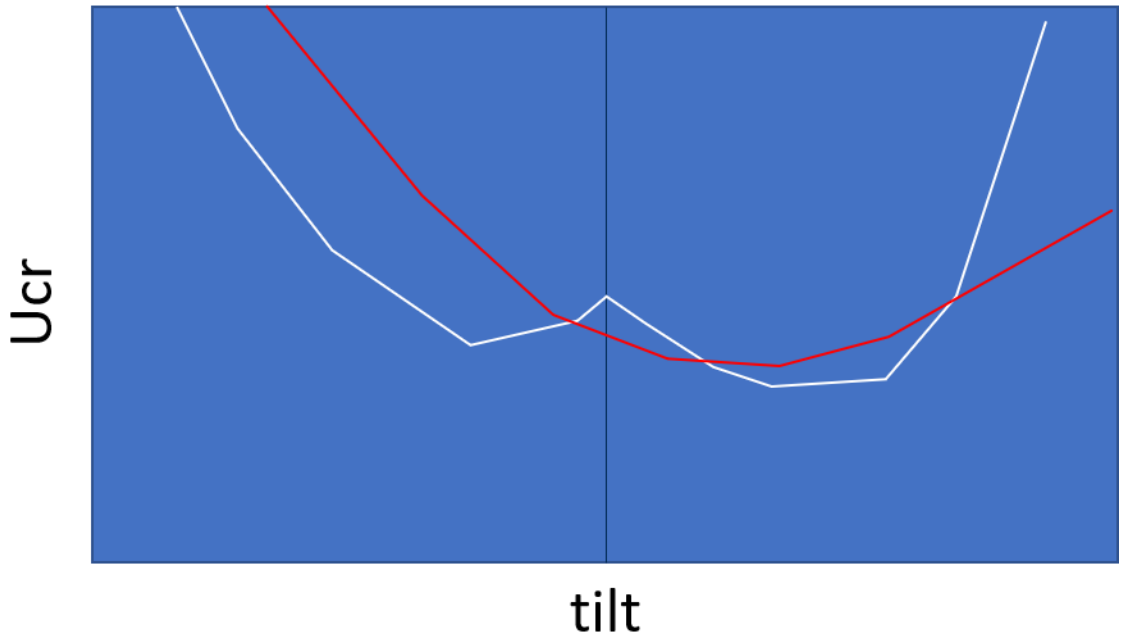
# Tracker Instability: the case for multi-row full tracker aeroelastic testing

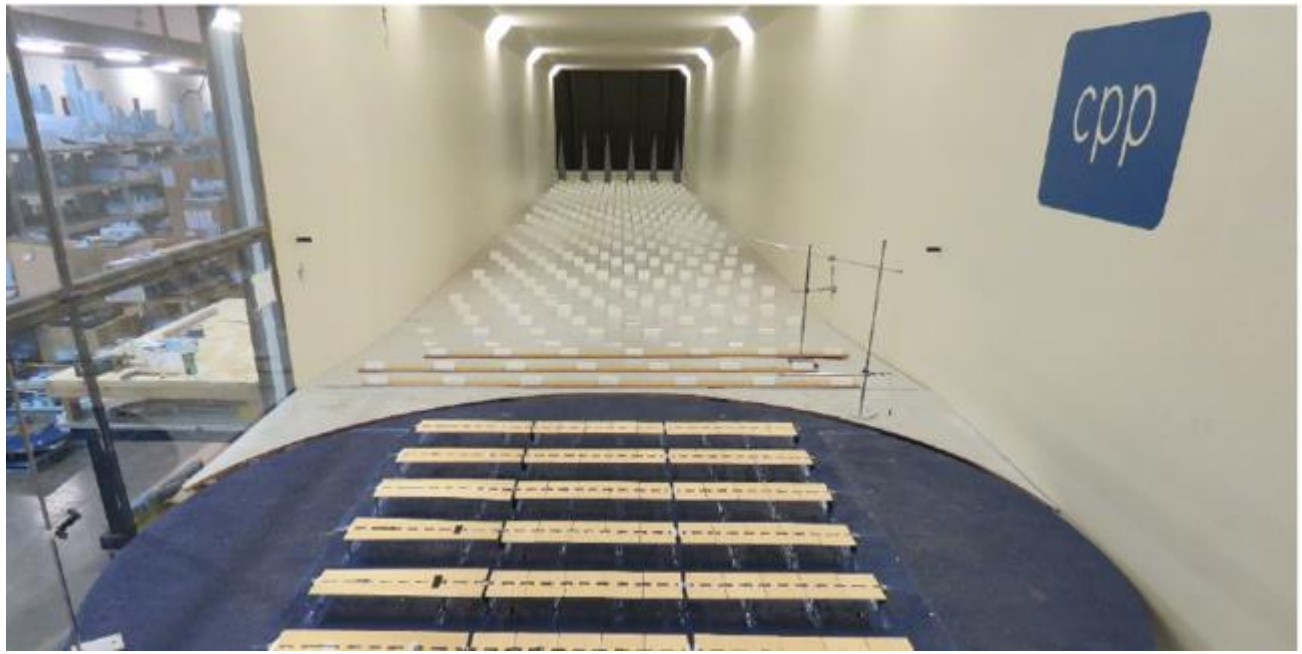



- High tilt instability behavior varies significantly with chord, span, flexibility, damping. We have tested 10 different trackers, including 3 for PVH. There is not one curve shape.

# Tracker Instability: +30° tilt, 30° WD, interior-row-only instability

- At higher tilts, we have seen instability happen in the array interior at a lower speed than the first row.
- We have seen interior rows go unstable in second mode of twist, which is not modelled in the section test.
- We have seen lower instability speed for cornering winds, which cannot be modelled in a section test.
- First row sometimes twists a lot, generally sheltering downwind rows.

# Advantages of full-tracker multi-row aeroelastic ABL WT testing




- ✓ Easily modify row spacing and ground clearance.
- ✓ Test rows at different tilts or heights from each other.
- ✓ Measure GCmy (tracker moment) for the deformed shape (better than static test).
- ✓ Model changes in stiffness along the span (e.g. thicker torque tube near center).

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# *THANKS FOR YOUR ATTENTION*

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PVH

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# Regulatory context: Current Codes

**BUILDING AND OTHER STRUCTURE, FLEXIBLE:** Slender buildings and other structures that have a fundamental natural frequency less than 1 Hz.

… the resonant response of most buildings and structures with lowest natural frequency above 1 Hz will be sufficiently small that resonant response can often be ignored.

# Avoiding aerolastic effects: Conclusions

- How aware are clients of tracker manufacturers of the problems with wind stability? What are they asking for and what should they be asking for?
- What steps does PV Hardware take to ensure each project is safe.
- Sectional vs. full aeroelastic model testing, what are the fallacies and risks.
- Structure codes in the PV industry; good or bad?  Why did the industry not have any so far, and what type of codes do we really want?
- How would a structure code chapter for PV help with either simplifying that process of ensuring for each client and each project that everything is safe and secure?
- How could a structure code chapter for PV help EPC or developers to identify black sheep in the industry?