A Presentation to Blow You Away:
Wind Turbine Foundations

Kirk B. Morgan, P.E., P.Eng.

Senior Civil Engineer

Barr Engineering Co.

Overview

Foundation Types

Materials

Market Regulation

Design Requirements

Design Brief

Future Developments

Foundation Types

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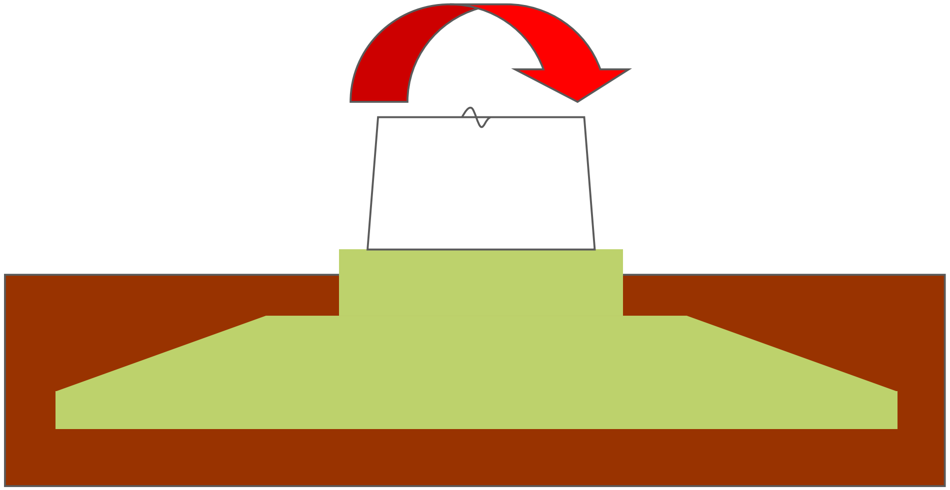
BASE
case

Photo credits: Jenny Hager, Kirk Morgan

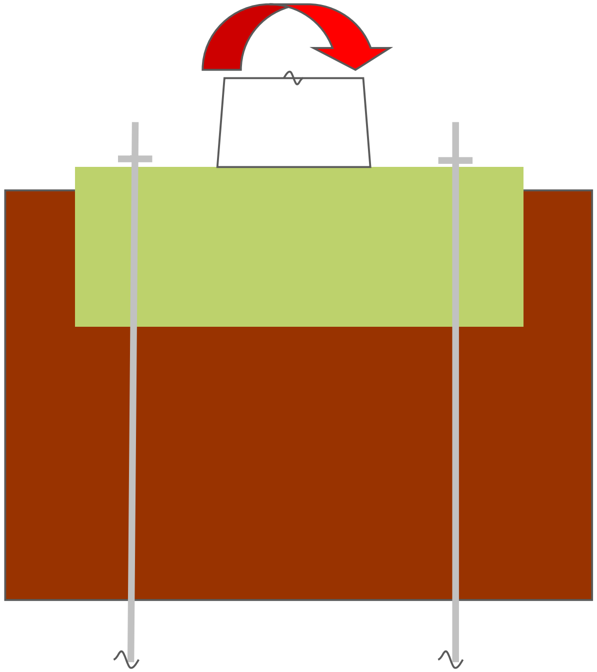
Spread Footing



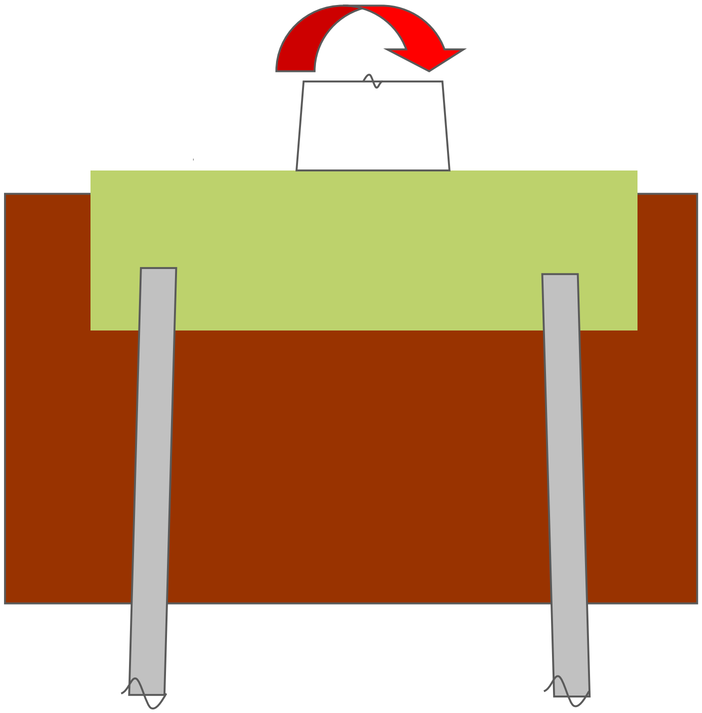
- 50-70 ft across x 8-12 ft deep
- Cast-in-Place
- Robust

Rock Anchors and Cap

– Smaller excavation (30ft dia)
– Anchors
  - installation testing
  - fatigue design
  - corrosion protection
  - long-term monitoring



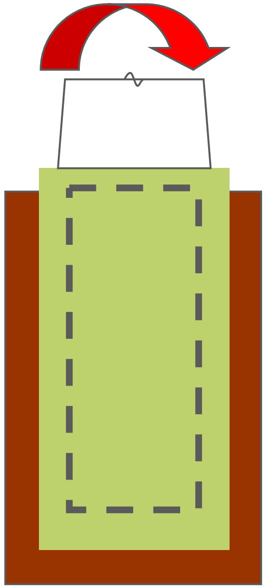
Piles and Cap



- Costly
- Cap dead weight
- Soil / structure interaction
- Stiffness offset issues
- Pile steel fatigue design

Short Pier*

- 16-18+ ft diameter x 25-35 ft depth
- Stiffness offset issues
- Construction challenges
- Economical



** Not the same as a rock socket foundation*

Materials (US)

spread foundations

materials –

concrete

- 300 to 500 yds and more
- 4500 to 6000 psi (typically 5000 psi)
- ¾″ to 1 ½″ coarse aggregate
- Entrained air per code
- Fly Ash or GGBFS (less common)
- ASR avoided (or sealers used)
- site geotechnical can influence cement type

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materials – *concrete*

- standard cylinders
- hot / cold weather concrete
- mass concrete measures
- workability not a concern with good practice
- attention to curing in extreme conditions

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materials – *reinforcing*

- ASTM A615 60 and 75 ksi
- deformed bars
- #4 to #11 size
  - #14 increasingly used; still not that common

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materials – *anchor bolts*

- ASTM A615 (f_y = 75 ksi)
- Custom (e.g. f_y = 90 ksi)
- ASTM A722 (f_y = 120 ksi)
- cold-formed threads

- common sizes 1 1/4″ and 1 3/8″
- sleeves (PVC, heat shrink)

- post-tensioned (80 to 100 kips)

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materials –

alignment ring & embedment plate

- ASTM (A36, A529, A572, etc.)
- 1 to 2 in thick
- dimensions matching tower flange typically

materials –

tower flange grout

- modified cementitious or epoxy
- 8000 – 15000 psi
- formed above or recessed
- 1 ½ to 3 in thick
- volume extended

Market Regulation

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Standards Bodies / Codes

DOMESTIC >>>

- International Code Council (ICC)
  - American Concrete Institute (ACI)
    - Committee 378 Concrete Towers
  - American Institute of Steel Construction (AISC)
- American National Standards Institute (ANSI)
  - American Wind Energy Association (AWEA)
    - Wind Standards Committee and Subcommittees

EUROPEAN >>>

- International Electrotechnical Commission (IEC)
  - Technical Committee No. 88
- EN Eurocodes
- CEB-FIP

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Independent Engineers

- Finance
- Equity
- Transactions

UL AWS TRUEPOWER

BLACK & VEATCH

DNV·GL

WJE

Sargent & Lundy

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Certification Bodies

- Projects
- Turbines
- Components
  - Blades
  - Towers
  - Foundations
  - Misc

DNV·GL

BUREAU VERITAS

TÜV SÜD

TÜV NORD

UL

ABS

Foundation Design Requirements

Performance Criteria

- Stability
- Strength
- Rotational Stiffness
- Settlement
- Durability
- Economy

Photo credits:
News-Gazette of Central Illinois, www.orkney.com

Foundation Design Requirements

US industry document (used outside US too)

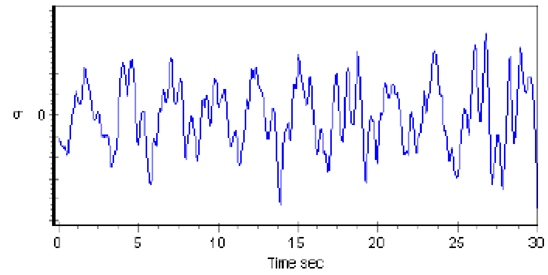
ASCE/AWEA RP2011, Recommended Practice for Compliance of Large Land-Based Wind Turbine Support Structures

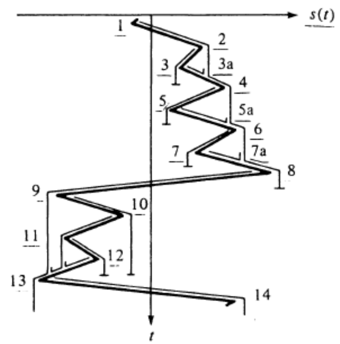
US and International codes and standards

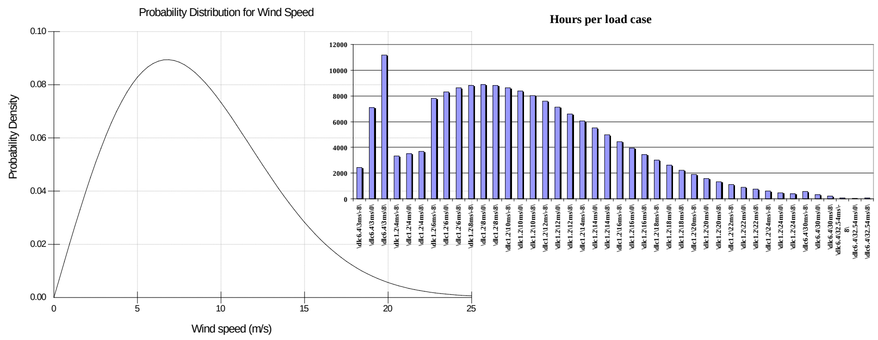
- "IEC 61400-1 Ed.3: Wind turbines – Part 1: Design requirements"
- *FUTURE – "IEC 61400-6: Wind turbines – Part 6: Tower and foundation design requirements"*
- ICC, "International Building Code"
- CEB-FIP Model Code 1990
- DNV, "Offshore Standard C502 Offshore Concrete Structures"
- GL, "Guideline for the Certification of Wind Turbines"

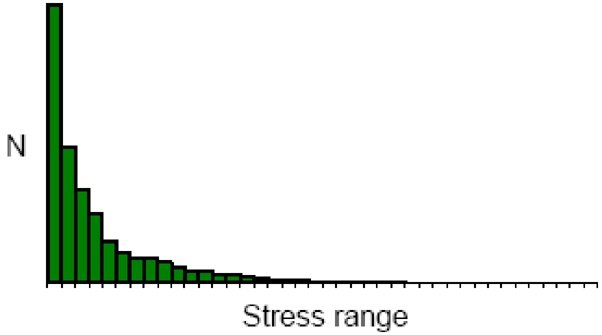
IEC Load Cases

- Operational
- Start-up, shut-down, e-stop
- Machine faults
- Grid interaction
- Extreme wind events
- Combinations of the above



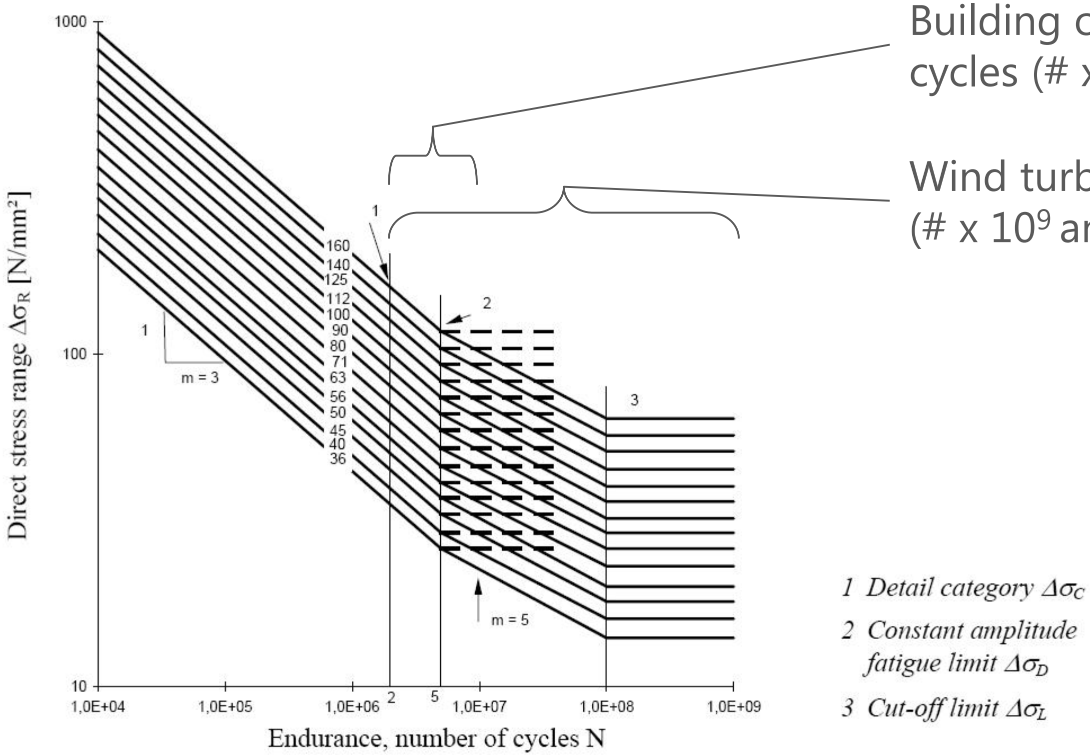






From Guidelines for Design of Wind Turbines, 2nd Edition, DNV 2002 and Garrad Hassan and Partners, Bristol, U.K.

Perspective



Building or bridge code cycles (# x 10^6)

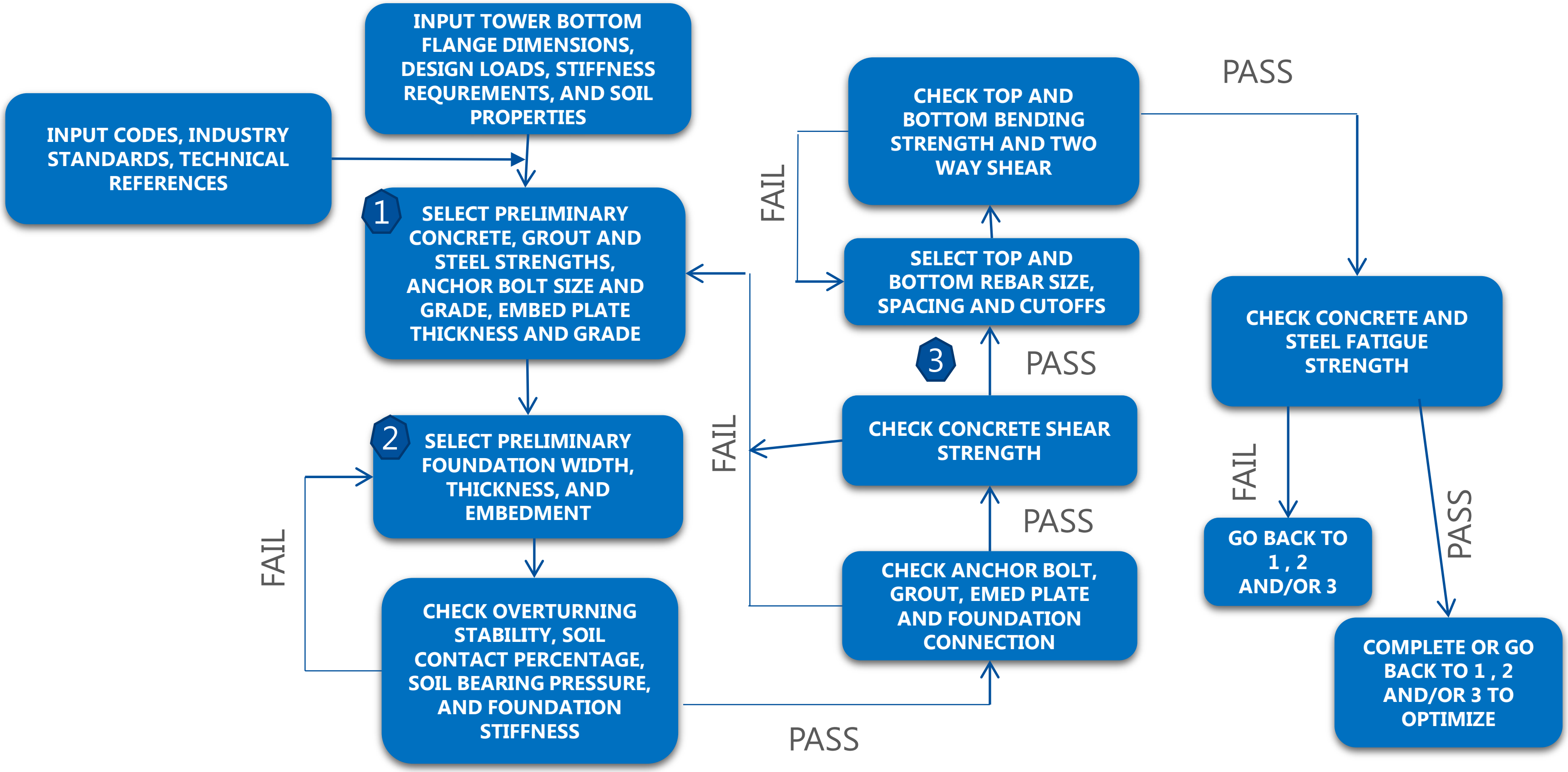
Wind turbine cycles (# x 10^9 and below)

From Eurocode 3: Design of steel structures, Part 1-9: Fatigue, 2006

Photo credits:
Windpower Monthly, BBC

Design Brief

wind turbine foundation design steps
spread footing



Rigid plate analysis

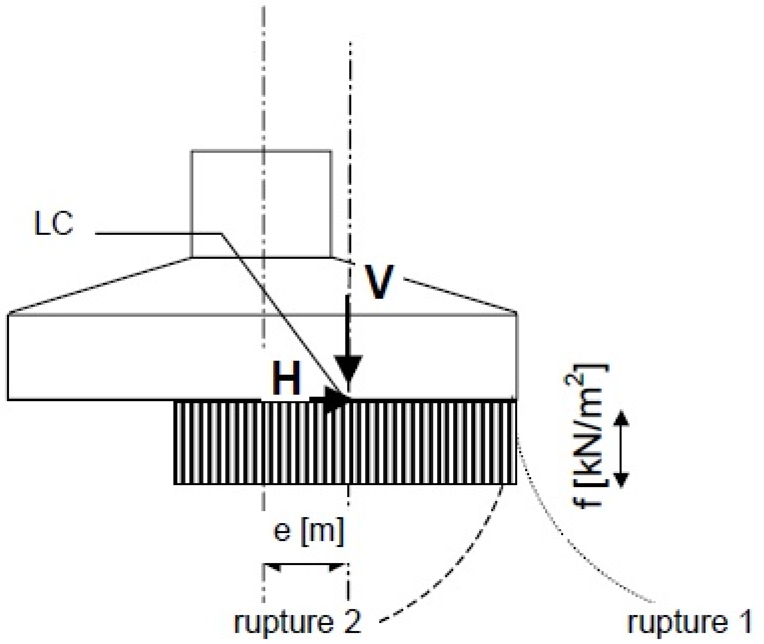


Figure 8-1. Loading under idealised conditions.

Effective bearing area

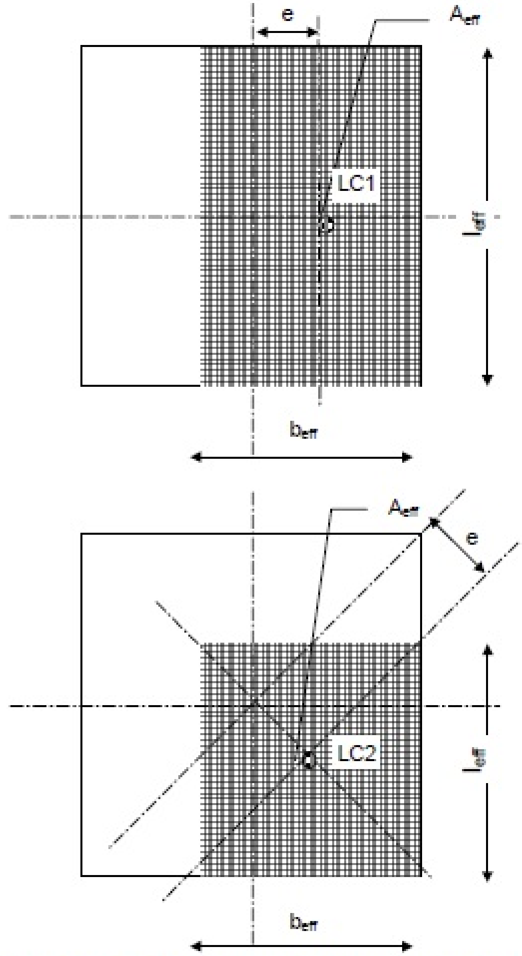


Figure 8-2. Quadratic footing with two approaches to how to make up the effective foundation area.

Scenario 1 corresponds to load eccentricity with respect to one of the two symmetry axes of the foundation. By this scenario, the following effective dimensions are used:

$$b_{eff} = b - 2 \cdot e\,,\ l_{eff} = b$$

Scenario 2 corresponds to load eccentricity

capacity of the foundation is the effective area representation to be chosen.

For a circular foundation area with radius R, an elliptical effective foundation area A_{eff} can be defined as

$$A_{eff} = 2\left[R^2 \arccos\left(\frac{e}{R}\right) - e\sqrt{R^2 - e^2}\right]$$

with major axes

$$b_e = 2(R - e)$$

and

$$l_e = 2R\sqrt{1 - \left(1 - \frac{b}{2R}\right)^2}$$

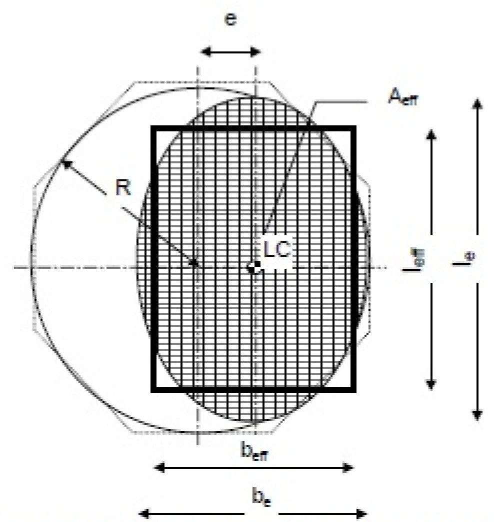
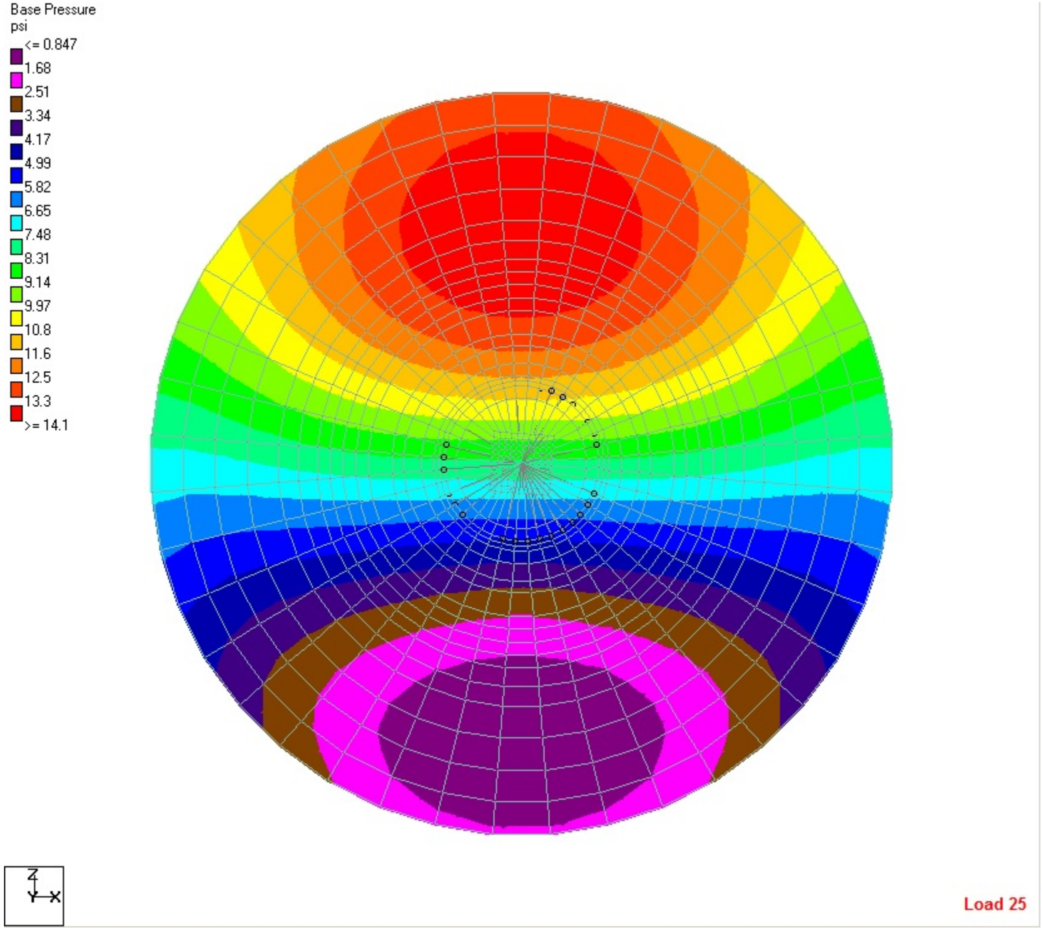


Figure 8-3. Circular and octangular footings with effective foundation area marked out.

Finite Element Analysis

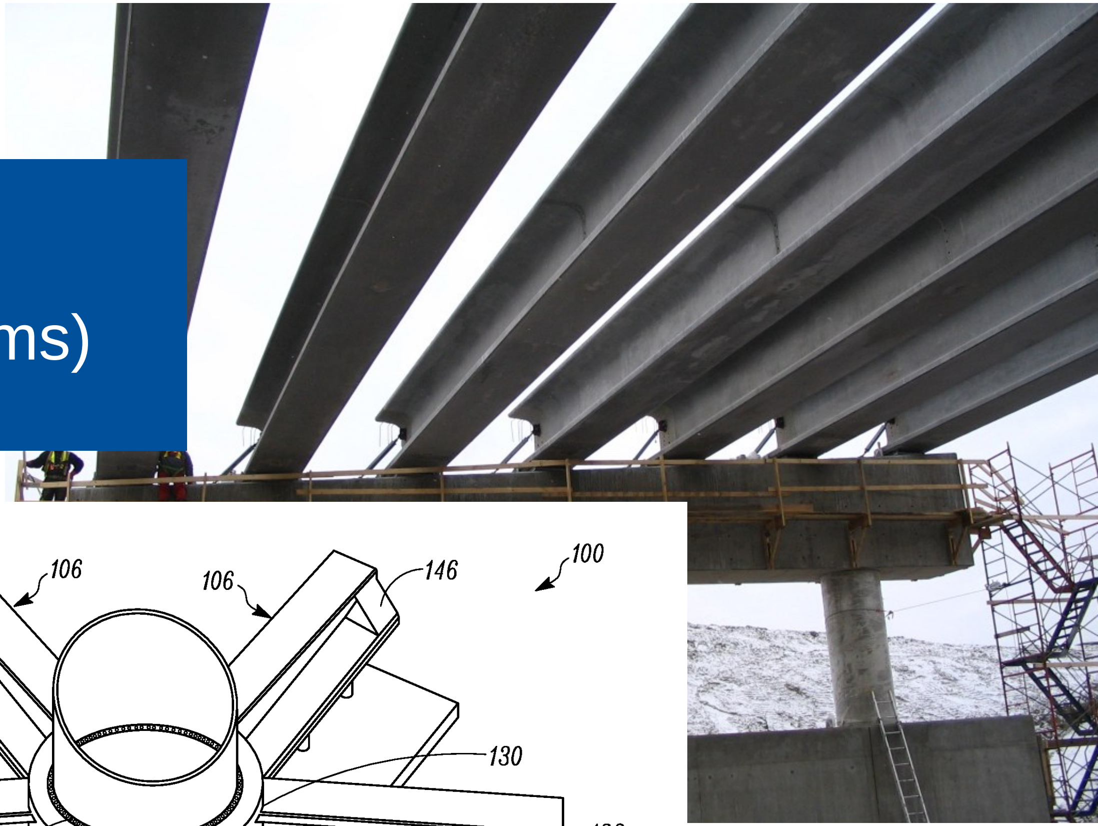


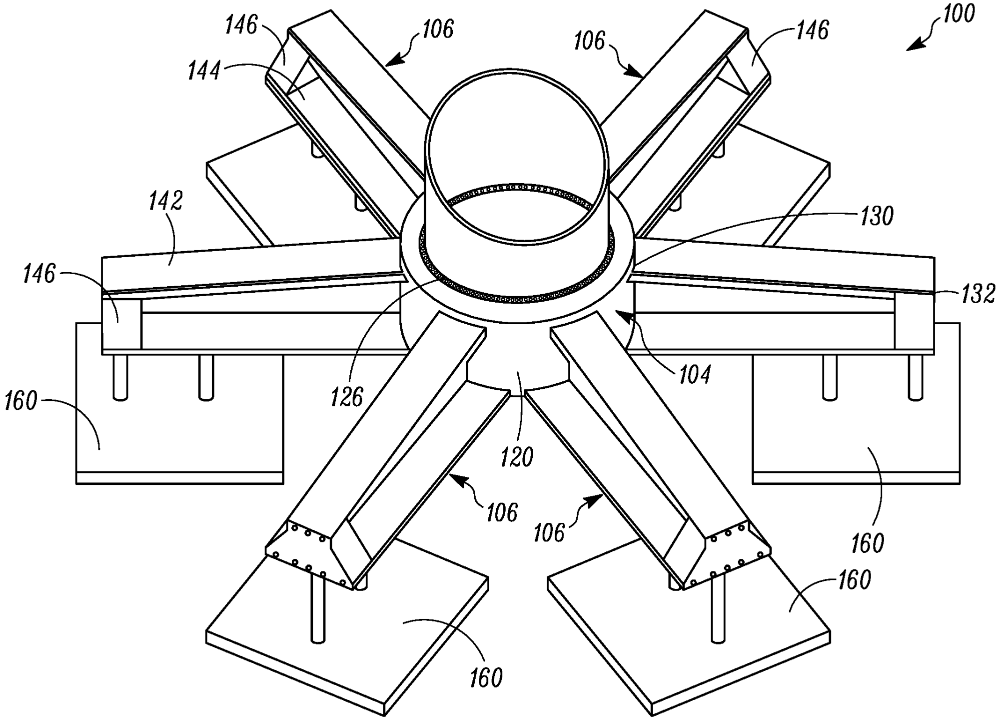
Barr Iowa Wind Foundation Projects

- Barton I and II
- Carroll
- Century I, II and III
- Charles City
- Crane Creek
- Eclipse
- Endeavor II
- Flying Cloud
- Hawkeye
- Highland
- Ida Grove
- Intrepid
- Laurel
- Lundgren
- Macksberg
- Morninglight
- New Harvest
- Pomeroy I, III and IV
- Rippey
- Rolling Hills
- Tjaden
- Top of Iowa I and III
- Valmont
- Victory
- Vienna I and II
- Walnut
- Wellsberg

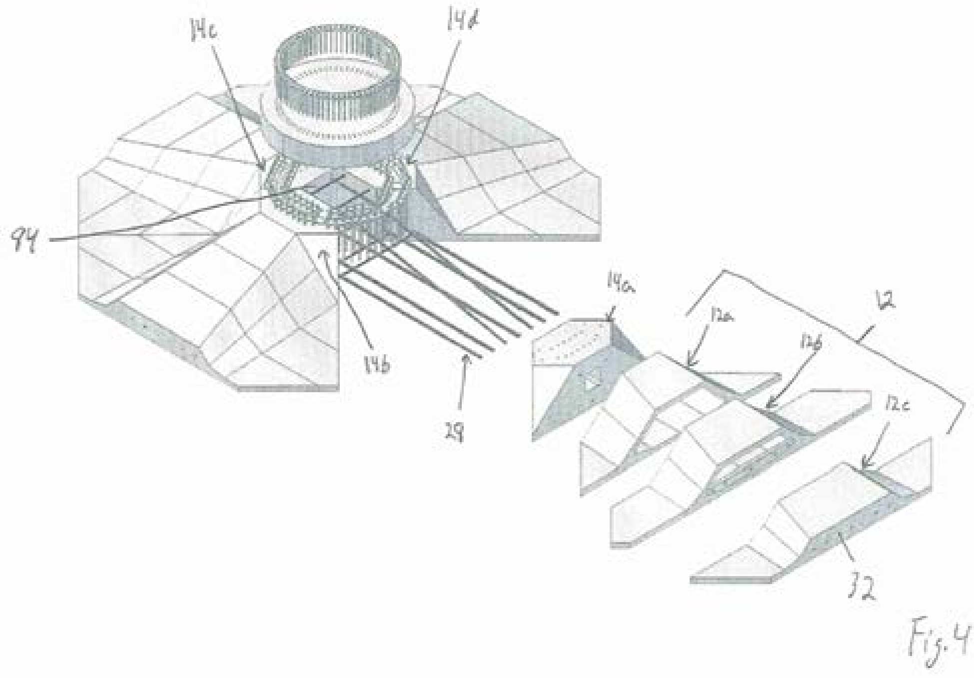
Future Developments

Anchored precast beams (RUTE Foundation Systems)

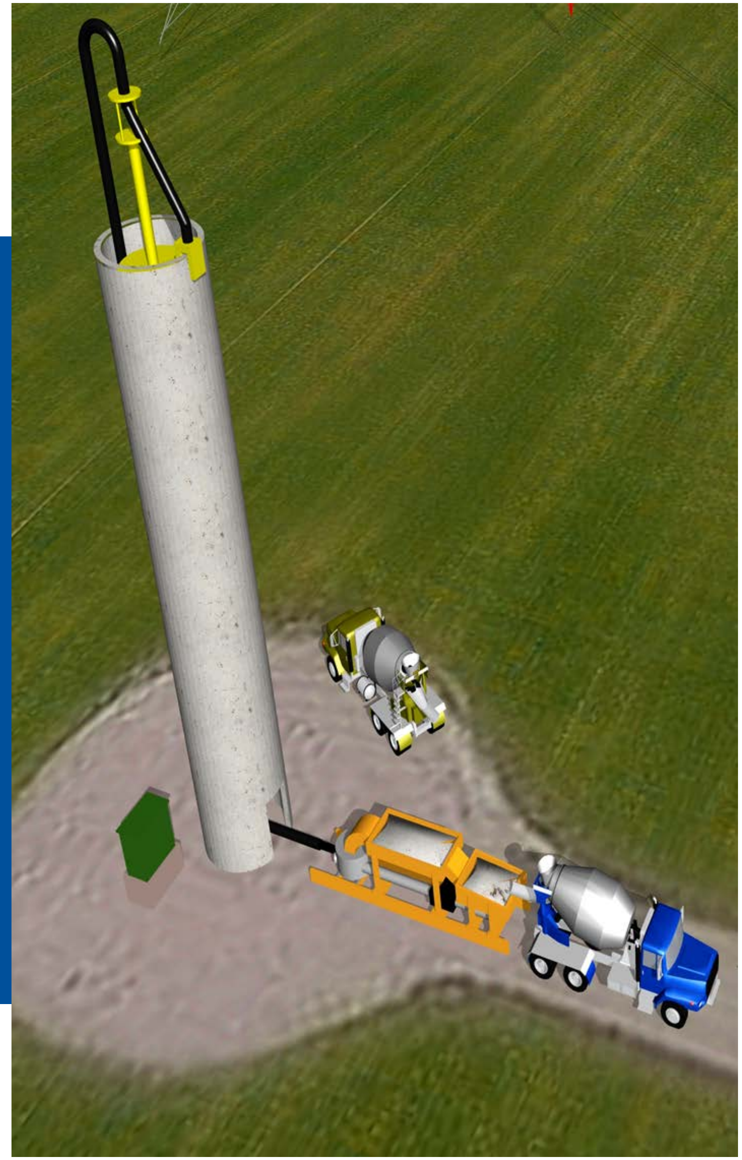


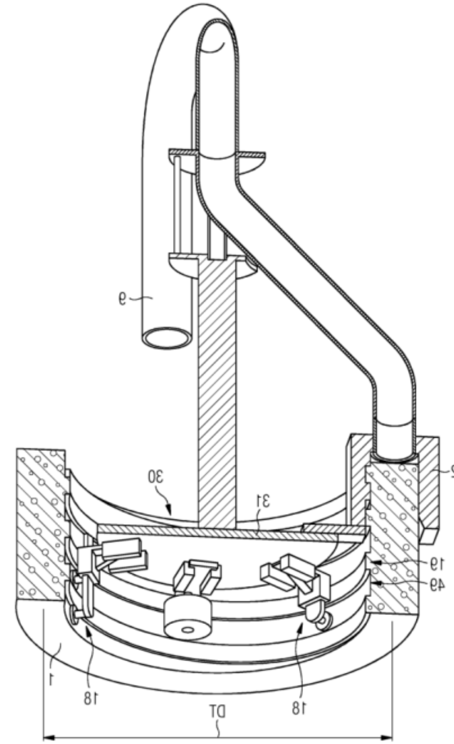


Precast box spread
(RUTE Foundation Systems)

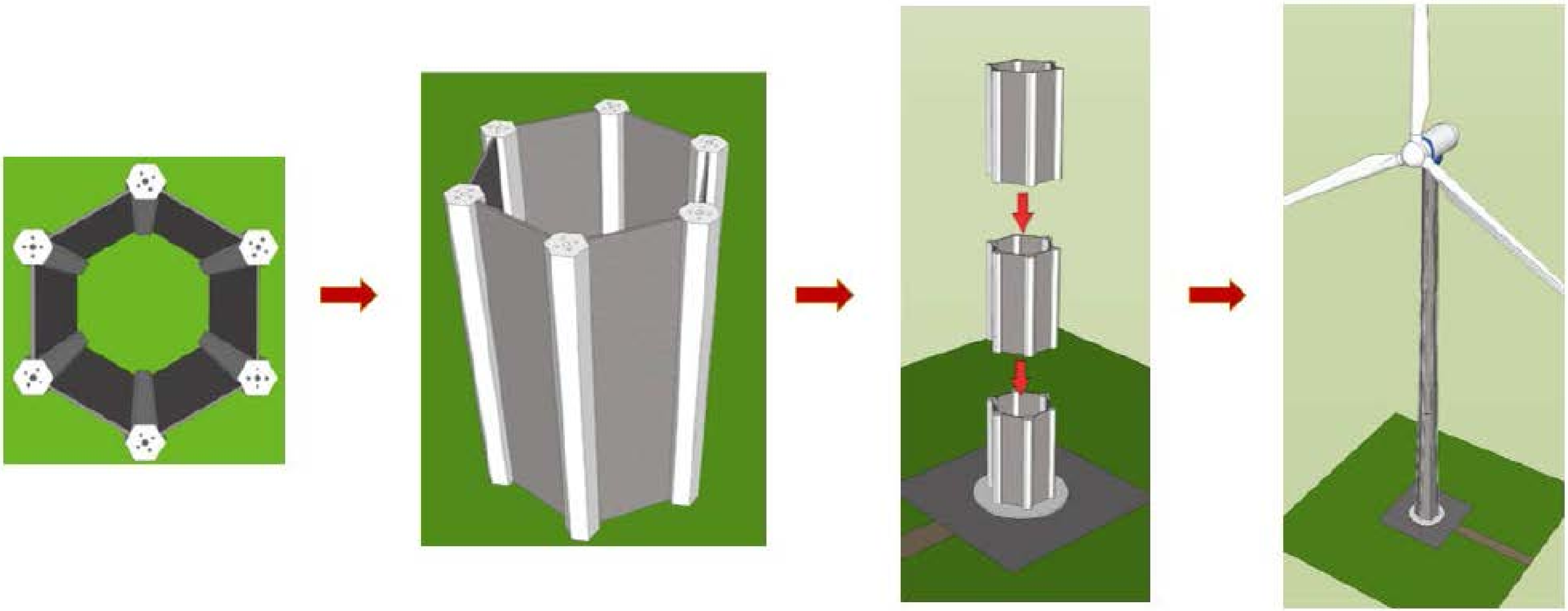


Formless integrated tower and foundation (RCAM)





Tower of precast column and panels (Hexcrete, ISU)



Questions?

unexpected conditions –

cattle

- cattle on plastic / curing concrete
- evaluate for restoration via composite action with prepared overlay
- hydro-demolition, preparation and overlay

Are wind turbines designed for tornados?

- Extreme winds in range of 50 m/s
- Gust factoring / load factoring equivalent speed in range of 100 m/s (230 mph) which is less than some tornados.
- Intense shears and reversals across rotor not considered (blade fail / tower strike)

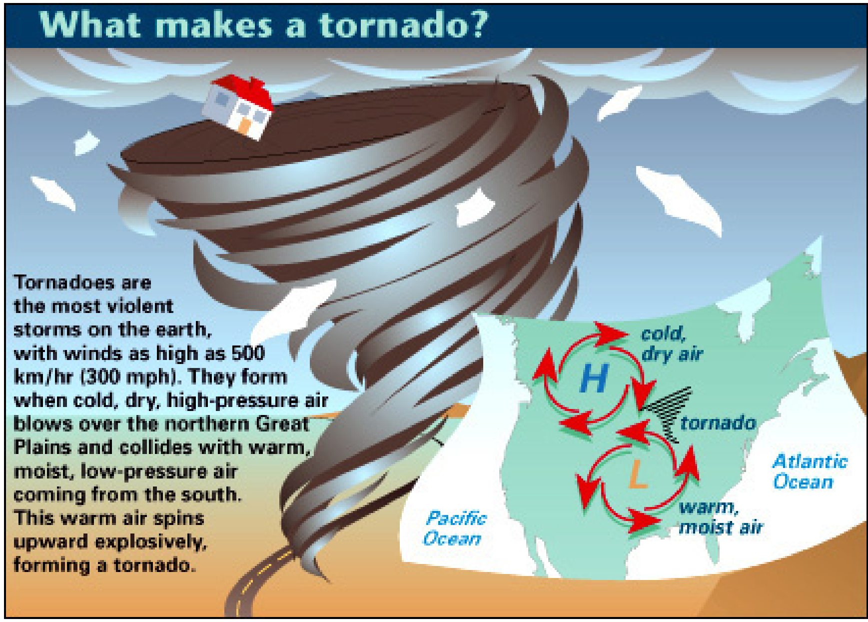


Image: www.bluechannel24.com

Thank you!

Kirk B. Morgan, P.E., P.Eng.
kmorgan@barr.com