Design and Construction
Tallest Wind Turbine Tower in the U.S.

SIEMENS

Wind Tower Technologies

American Concrete Institute
Always advancing

Strategic Development Council
aci Foundation

Development / Commercial Partnership

WTT
WIND TOWER TECHNOLOGIES

- Preliminary Design
- Patents / IP Licensing
- Final Design (EOR)
- Construction Technology
- On Site Technical Support

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SIEMENS

- Turbine Simulations
- Financing
- TuvSud Certification
- Prototype Construction
- Serial Production

Sub-Consultants / Contractors

Thornton
Tomasetti

Engineering sub-consultant
- Internals design assistance
- Dynamic analysis / peer review
- Concrete mix requirements

BAKER
CONCRETE CONSTRUCTION

Off Site Construction testing
- Mock Up – Houston
- Full scale operating Prototype
  Siemens / MidAmerican Energy

INTERNATIONAL
BRIDGE
TECHNOLOGIES, INC.

Engineering sub-consultant
- Segmental peer review
- Transition segment peer review

EFCO

Formwork System
- Engineering
- Fabrication

U.S. Wind Market

Global wind industry market growing 40% annually

- 350,000 turbines installed worldwide to date
- 60,000 installed in United States to date

Wind energy cost reduction trends in United States

- 55% lower over last 5 years
- 90% lower over last 30 years
  - Improved turbine equipment & technology (rotors, blades, maintenance,..)
  - Taller towers produce more power

Wind Power Market projected in United States

- Today: 5,500 towers under construction, 14,000 MW
- 2016 to 2020: 18,000 towers or 3,600 towers/year, 45,700 MW
- 2.5 MW/tower: 3.6M households/year or 10M persons/year

Iowa generates 31% of total power production from wind

- 40% goal by 2020

Taller Towers reduce cost of Energy

Concrete Tower Benefits vs. Steel

Steel Tower Limitations

- Difficult to source locally
- Transportation costs of steel towers are expensive
- Transportation limits base diameters > limits tower height or increases tower weight
- Bolted tower section joints require routine inspection & maintenance
- Vortex induced vibration restricts tower construction process

Concrete Benefits

- Tower heights not limited by the base diameter or transportation (onsite production)
- Longer useful tower life - 50 years vs. 20 years
- Use of local materials and labor higher
- Heavier tower reduces the size of a gravity foundation
- Vortex induced vibration is not a restriction during construction

Precast Segmental Technology

Background

- Industrialized construction process
- Proven cost effective for bridges w/ many common segments (> 1000 segments)
- Technology transfer: Bridge Structures > Tall Wind Towers over 100 meters

Full Scale Operational Prototype

Mid American Energy, Iowa

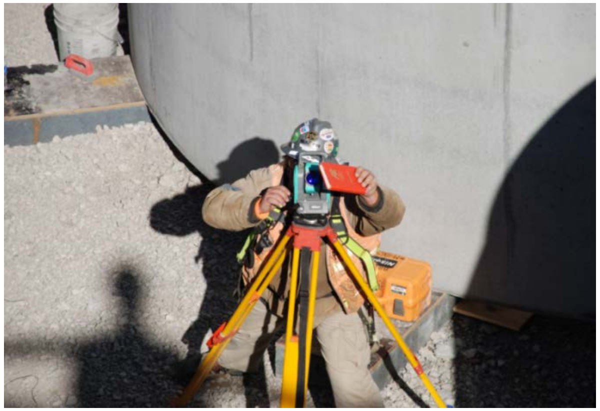
https://www.youtube.com/watch?v=DNfadvU2Y8g

On Site
Casting Operations

Match Casting Segments – Full Diameter

- Tight horizontal joints
    - Eliminates field grouting during segment erection
    - Faster segment installation time
    - Monolithic tower in service - lower maintenance
- No vertical joints
    - Fewer precast elements to install
    - Eliminates vertical field grouting at elevation

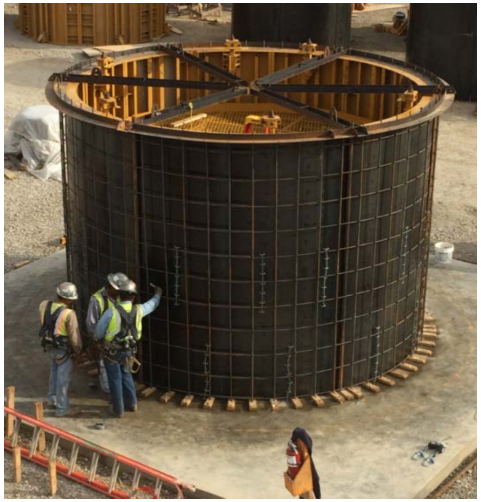
Geometry Control

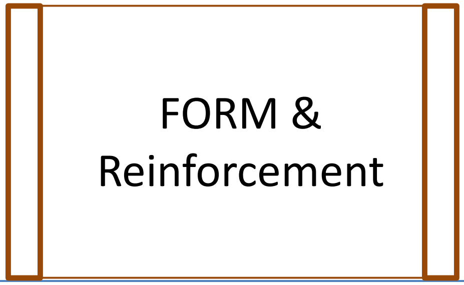


- Occurs in the casting yard operations
- Segment control points track 3D geometry
- Geometry adjustments
    - Casting yard - segment geometry tracking
    - Erection – setting base segment on foundation

Segment Match Casting

Formwork Assembly and Reinforcing Pretie

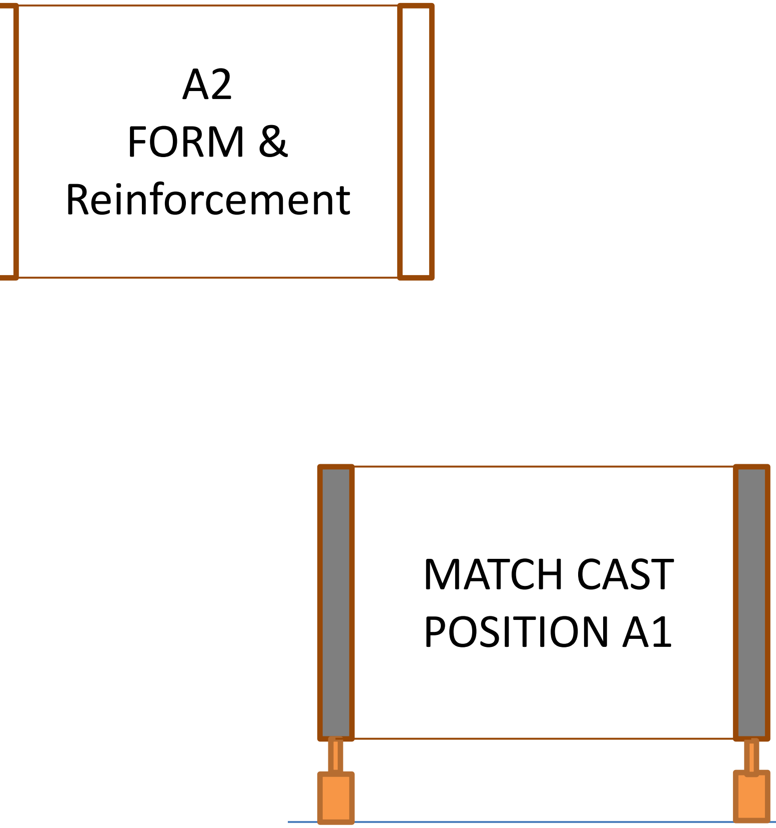




FORM & Reinforcement

Segment Match Casting

Step 1 Placing the form

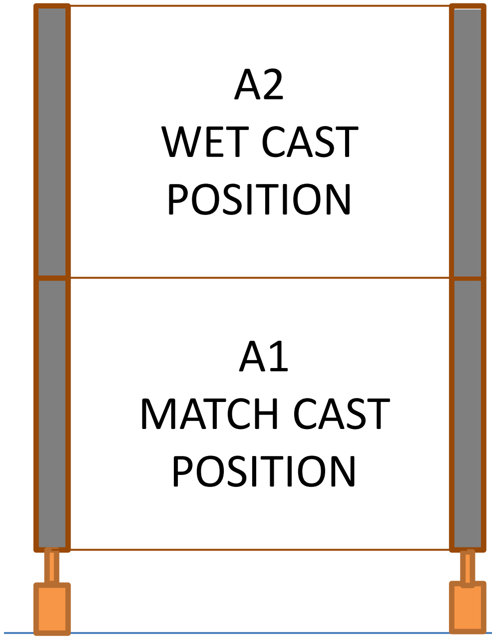


A2
FORM &
Reinforcement

MATCH CAST
POSITION A1

Segment Match Casting

Step 2 Filling the Form

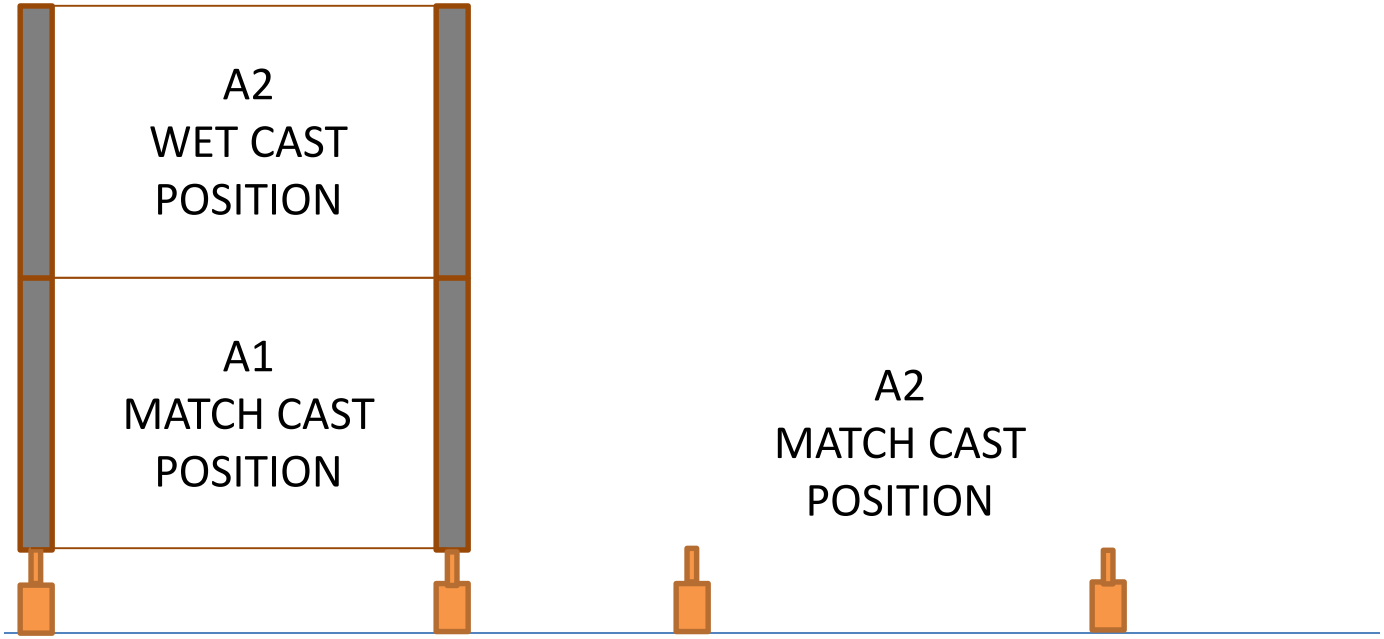


A2
WET CAST
POSITION

A1
MATCH CAST
POSITION

Segment Match Casting

Step 3 Moving the Segment



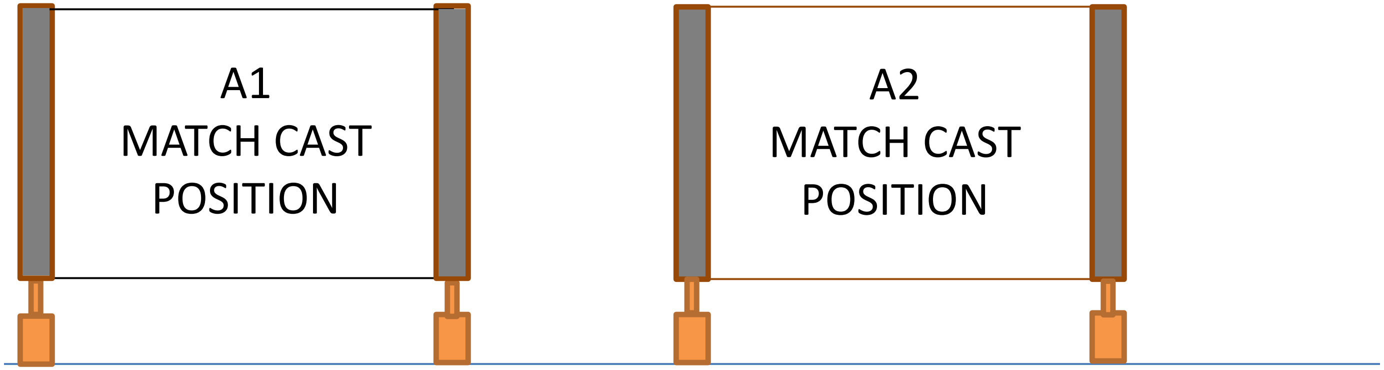
A2
WET CAST
POSITION

A1
MATCH CAST
POSITION

A2
MATCH CAST
POSITION

Segment Match Casting

Step 4 Stripping the Form and moving segment to storage

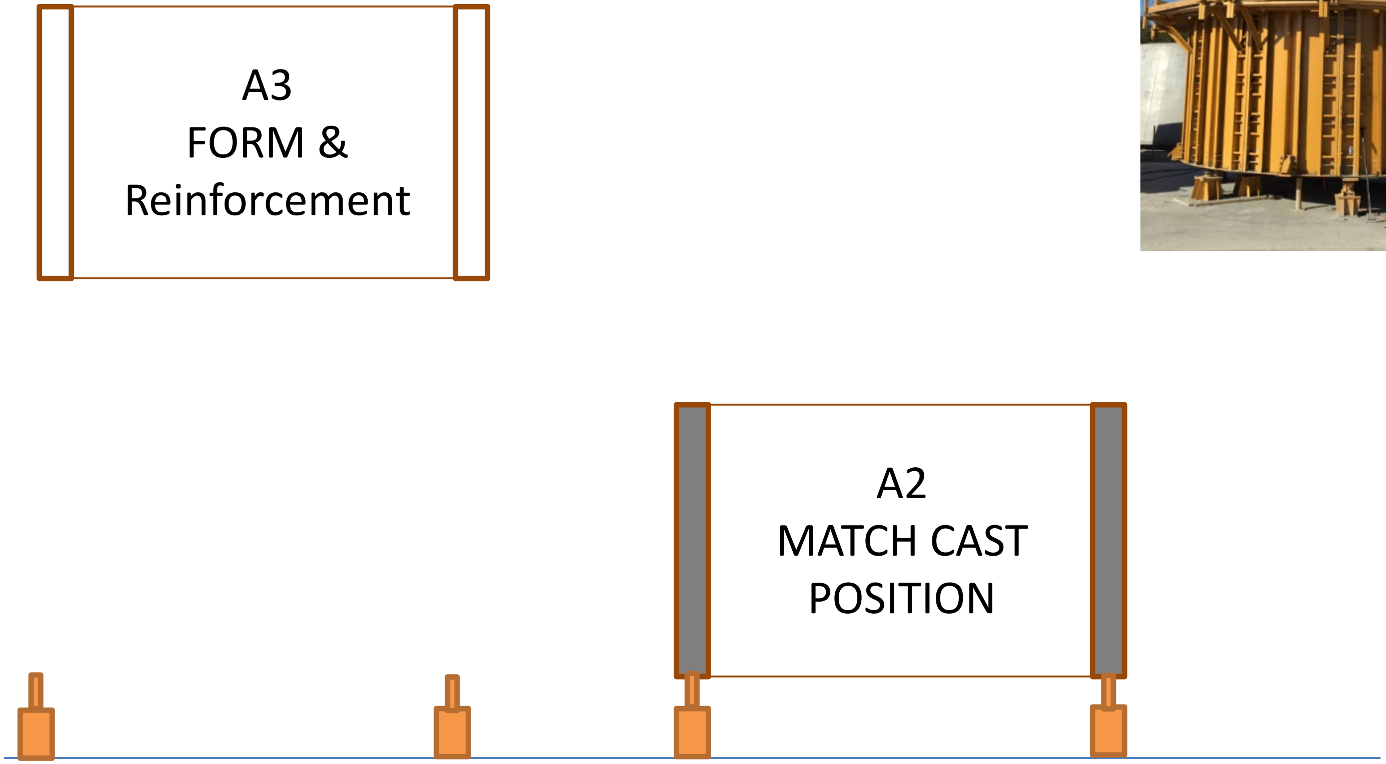


A1
MATCH CAST
POSITION

A2
MATCH CAST
POSITION

Segment Match Casting

Step 5 Setting next Form

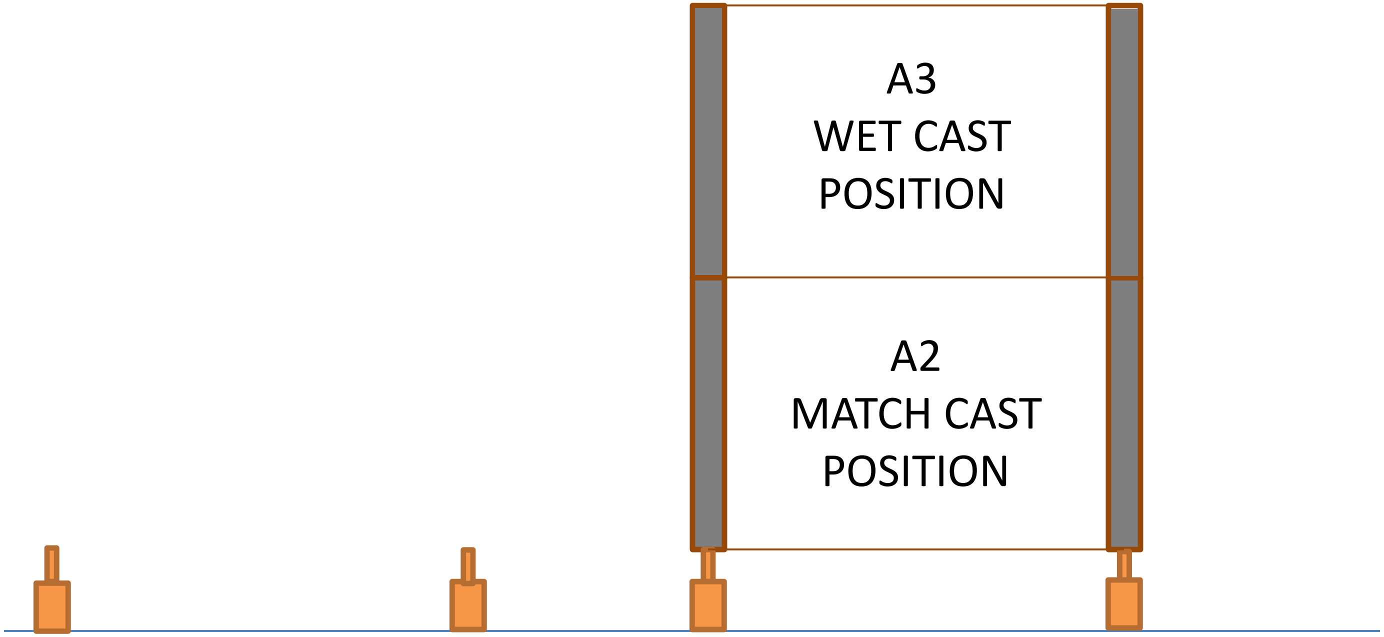


A3
FORM &
Reinforcement

A2
MATCH CAST
POSITION

Segment Casting Methodology

Step 6 Filling the Form



A3

WET CAST

POSITION

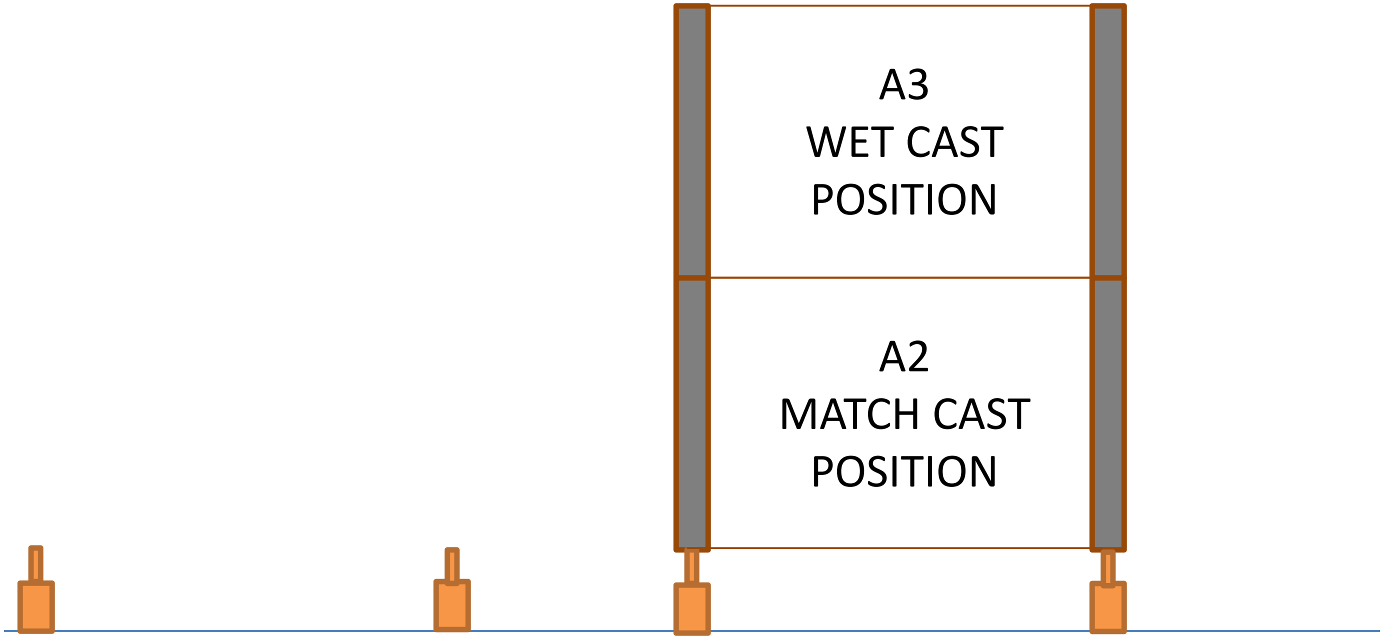
A2

MATCH CAST

POSITION

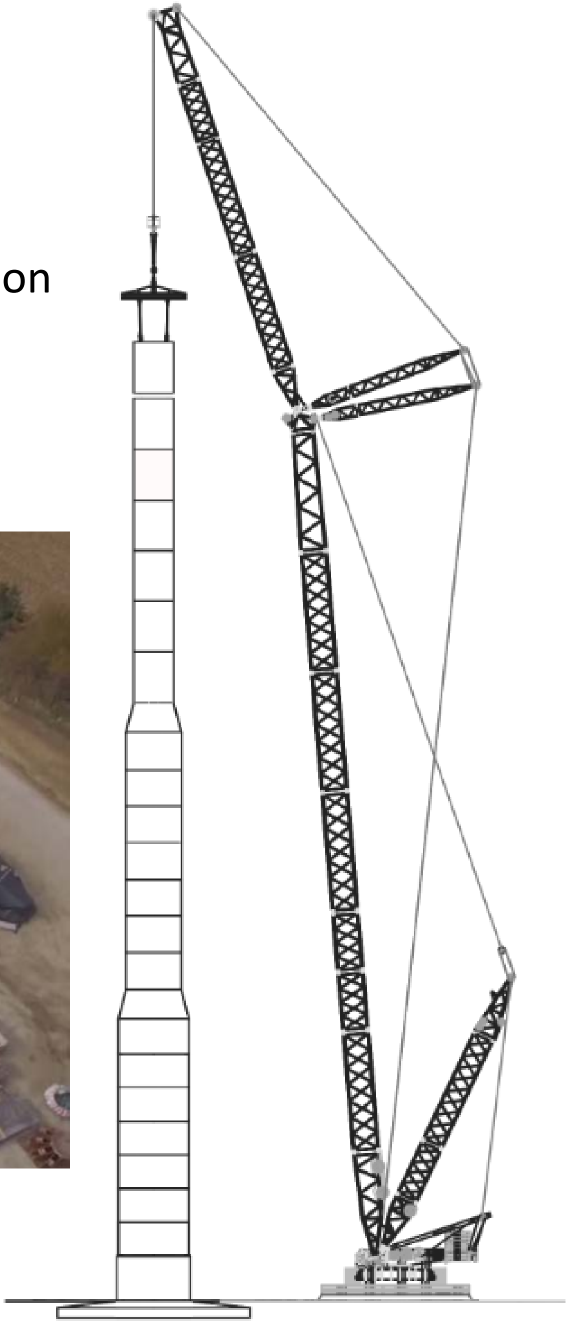
Segment Casting Methodology

Step 7 REPEAT



Segment Erection

- Tower stacked at 5 towers per week in Serial Production
- Heaviest pick is around 70 tons
- Tower is stacked to 100 meters before stressing
- Post tensioning is installed off critical path

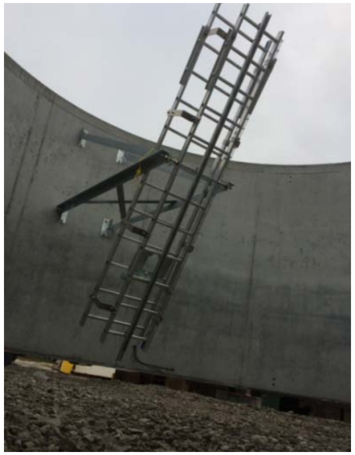


Unbonded External Post Tensioning

- Tendons can be installed off critical path of the large crawler cranes
- Concrete segments can be stacked out before tendon stressing
- Stressing can be done from the bottom or the top of the tower
- External tendons can be visually inspected throughout the life of the structure
- Designed to maintain full compression across joints under service loads.

Working Platforms

Working platform allows for contractors to receive the segment and jump to the next segment during the erection process.



Ladder sections are installed before erection:

- Provides egress for workers at the erection platform
- Adjustability built in the design provides proper installation
- Takes installation of ladders off critical path

Testing

- Concrete Mix Design / Properties
- Full Scale (pre-prototype) Mock-Up
- Post-Tensioning
- Structural Behavior Monitoring
- Tower Natural Frequency in Service

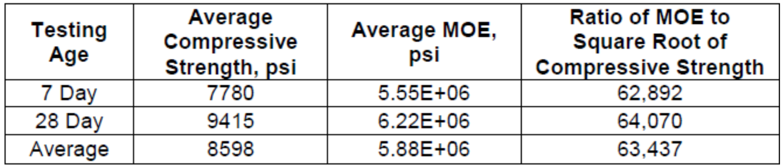
Concrete Tower Mix Design

Concrete Mix Design requirements

- High early break strength, 2500psi in 6 hours
- High slump mix, small aggregate size
- 5% air entrainment
- Turbine manufacturer 0.4 Hz (stiff) natural frequency restriction.
- 28 day design strength of 7000psi

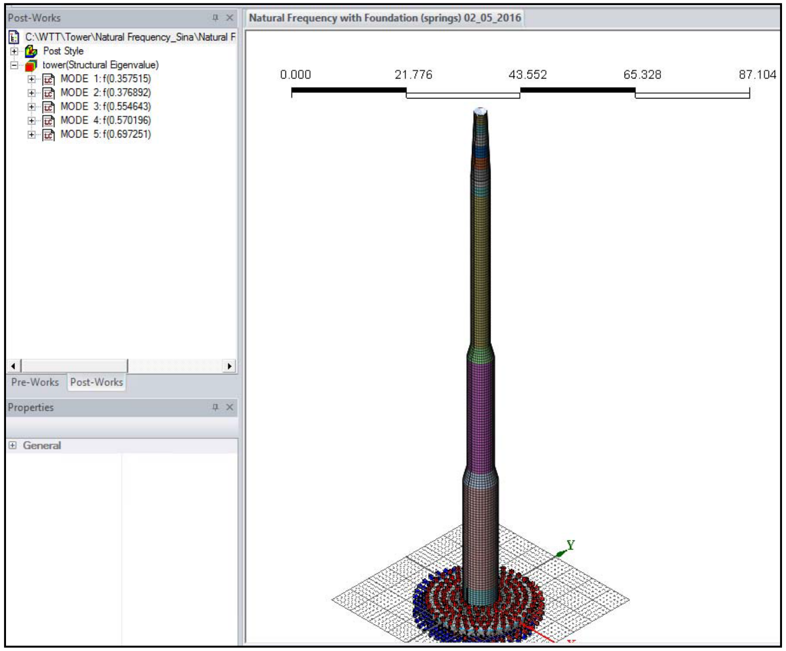
Tower Performance

Testing Based MOE Equation



Testing Age	Average Compressive Strength, psi	Average MOE, psi	Ratio of MOE to Square Root of Compressive Strength
7 Day	7780	5.55E+06	62,892
28 Day	9415	6.22E+06	64,070
Average	8598	5.88E+06	63,437

Modeling Calibration



Frequency Results Comparison

- Calculated = .3575 Hz
- Measured = .351 Hz

Within 1.8% of FEA calculated Natural Frequency

Off Site Initial Testing & Mock Up

Location – Houston, TX, Baker Concrete Facilities

Date – April 2015 to July 2015

Baker Concrete Provided a small casting yard in Houston

Testing Activities Included

- Erection Platform Testing
- PT Equipment Testing
- Casting 4 segments (Match Casting)
- Picking the heaviest segment
- Proving technology

Load Cell Measurements During Stressing

Table 3: Load cell 1 measurements and calculations

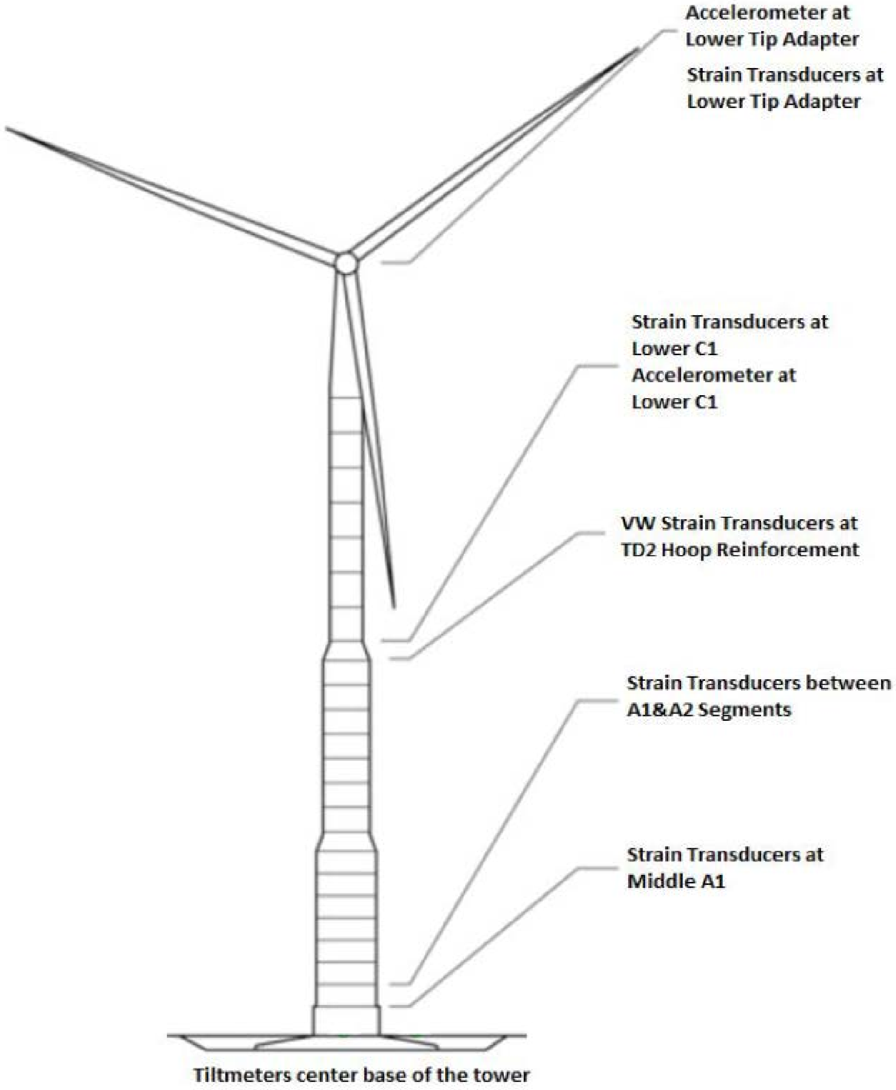
Load Cell 1						
Gage #	1	2	3	Anticipated Load (kips)	AVG	Load (kips)
Initial (No Jack)	7462.5	7150.6	7379.9	3.5	7331.0	4.4
Initial	7464.8	7148.7	7385.7	3.5	7333.1	3.8
20 % (1000 PSI)	7260.7	6769.6	7150.3	80.5	7060.2	84.6
65% (3300 PSI)	6745.4	6246.7	6605.2	261.6	6532.4	240.7
100% (5024 PSI)	6191.0	5728.9	6020.6	402.5	5980.2	404.2
Delta Strain	1271.5	1421.7	1359.3			

Table 4: Load cell 2 measurements and calculations

Load Cell 2						
Gage #	11	12	13	Anticipated Load (kips)	AVG	Load (kips)
Initial (No Jack)	7357.6	7197.1	7322.1	3.5	7292.3	3.2
Initial	7352.5	7192.2	7318.8	3.5	7287.8	4.5
20 % (1000 PSI)	7053.9	7049.9	7056.8	80.5	7053.5	74.2
65% (3300 PSI)	6505.8	6557.9	6574.9	261.6	6546.2	225.1
100% (5024 PSI)	5953.9	6044.5	6029.3	402.5	6009.2	384.8
Delta Strain	1403.7	1152.6	1292.8			

ANCLO load cells and plates

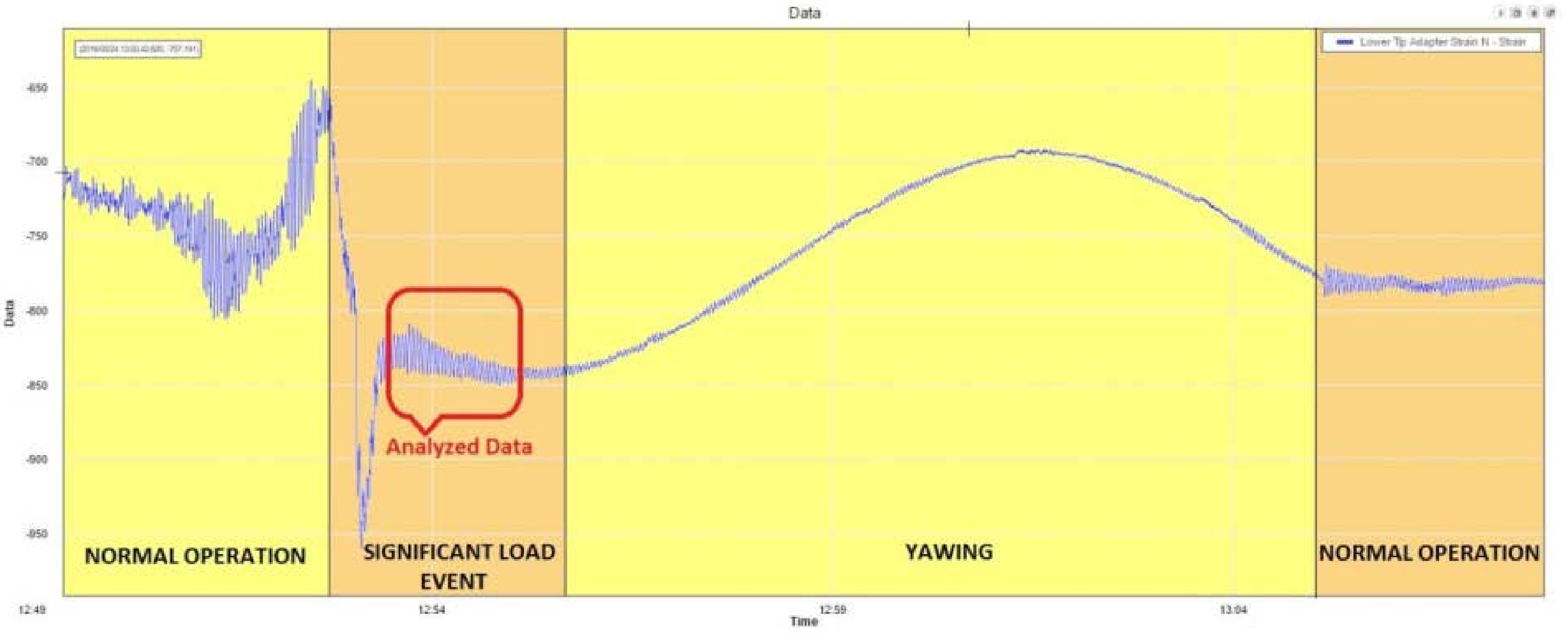
Structural Behavior Monitoring



- 12 Accelerometers Installed
- 14 Strain Transducers Installed
- 2 Tilt Meters Installed
- 8 Vibrating Wire Strain Gages Installed
- 6 PT Load Cells Installed

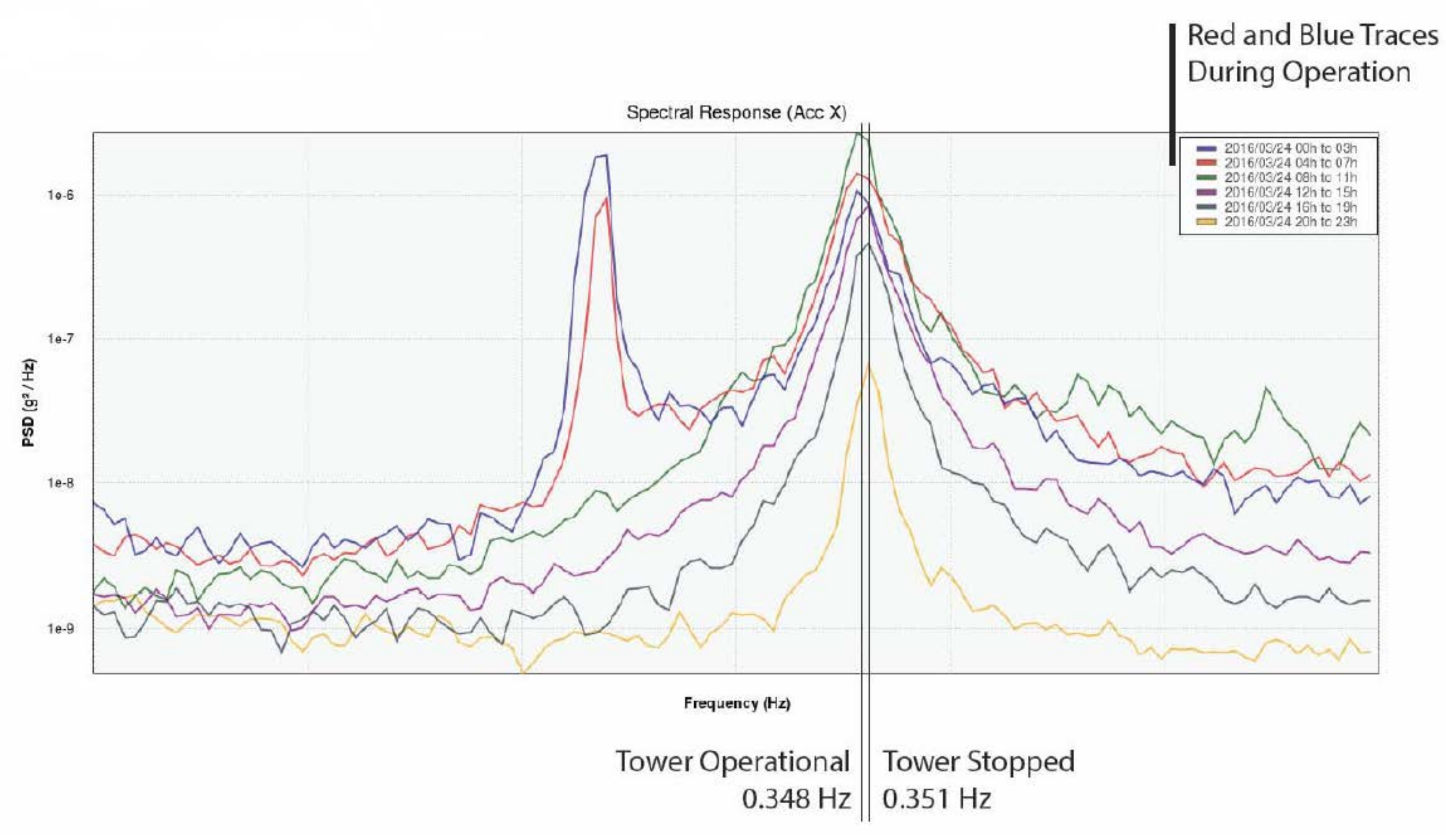
Total=42 Sensors Installed

Controlled Remote Monitoring



Natural Frequency Verifications

- **Frequency requirements in the 1p fore-aft and 3p side to side for resonance prevention, soft-stiff tower design is desired**



Red and Blue Traces
During Operation

Tower Operational
0.348 Hz

Tower Stopped
0.351 Hz