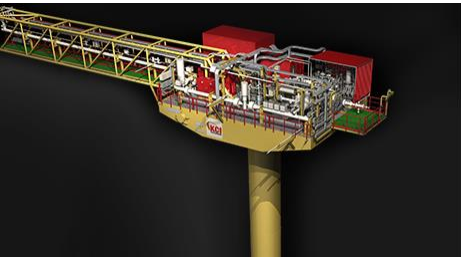
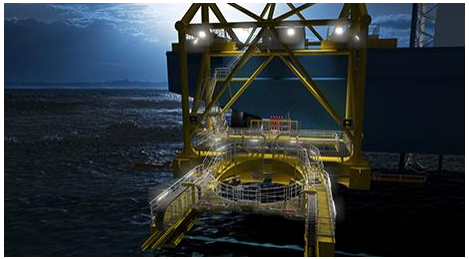





Dubai-I

“Voor en Door Staalconstructeurs”

23-11-2016

ir. R. van der Geer & ir. S. Maljaars

Westpoint Building 2 | De Brauwweg 60 | 3125 AE Schiedam | The Netherlands | www.kci.nl | info@kci.nl

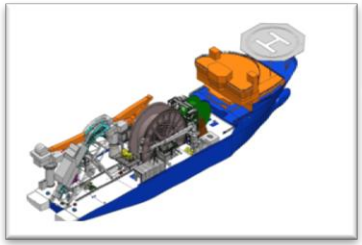
KCI Company profile

- Founded in 1987
- Main markets are
  - Oil & Gas
  - Renewables
  - Equipment
  - Wheels
- ISO 9001 certified
- FPAL registered no. 10049367
- Part of Oceanteam group

"It's our drive to create the best solutions for our customers assets"

Our Market Segments

- **Renewables / Offshore Wind**
  - Substations (topsides & foundations)
  - WTG foundations
  - Cable lay solutions
- **Oil & Gas**
  - Field development
  - Platforms, foundations & pipelines
- **Equipment**
  - Specialized equipment design for lifting, pipe & cable lay
  - Transport & Installation Engineering
    - Transport and lay analyses
    - Procedures
- **Wheels**
  - Design & engineering of observation wheels



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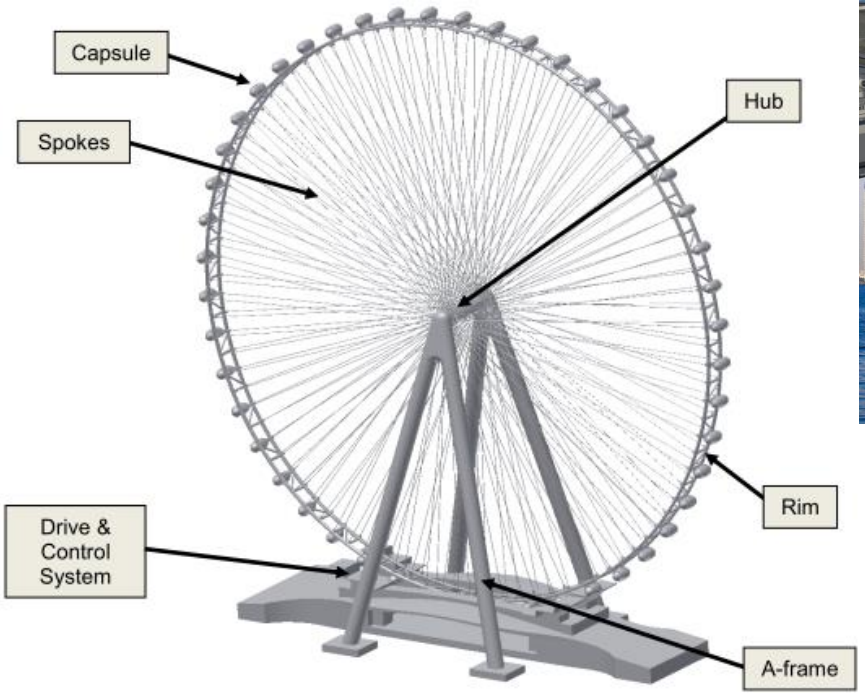
THE ENGINEERS

1 General Project Info

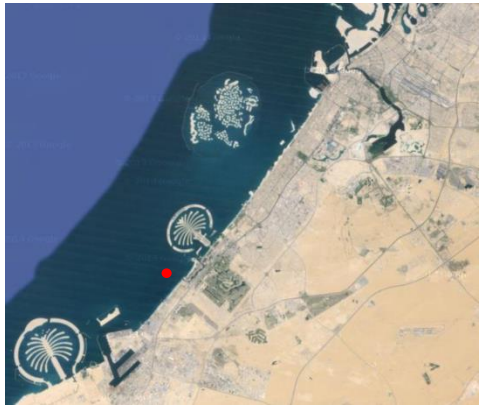
General Project Info – Introduction

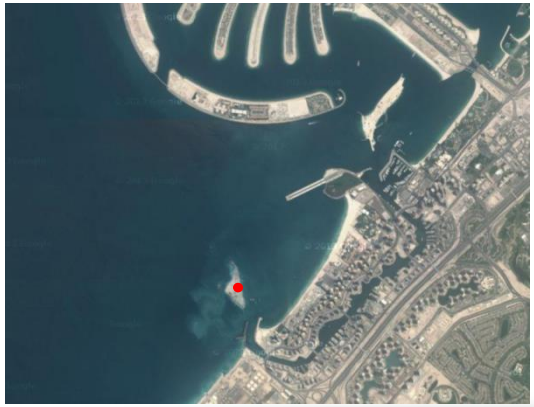


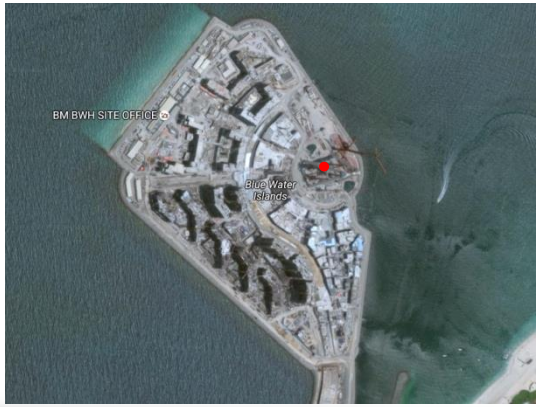
Key Figures:

- Approx. 250m Top Elevation
- 137.5m Spindle Elevation
- 238m Rim Diameter
- 48 Capsules (40p. Capacity Each)
- 192 Spoke Cables
- 4 Towers with Drive & Guide Units
- Total Mass approx. 11,000mton

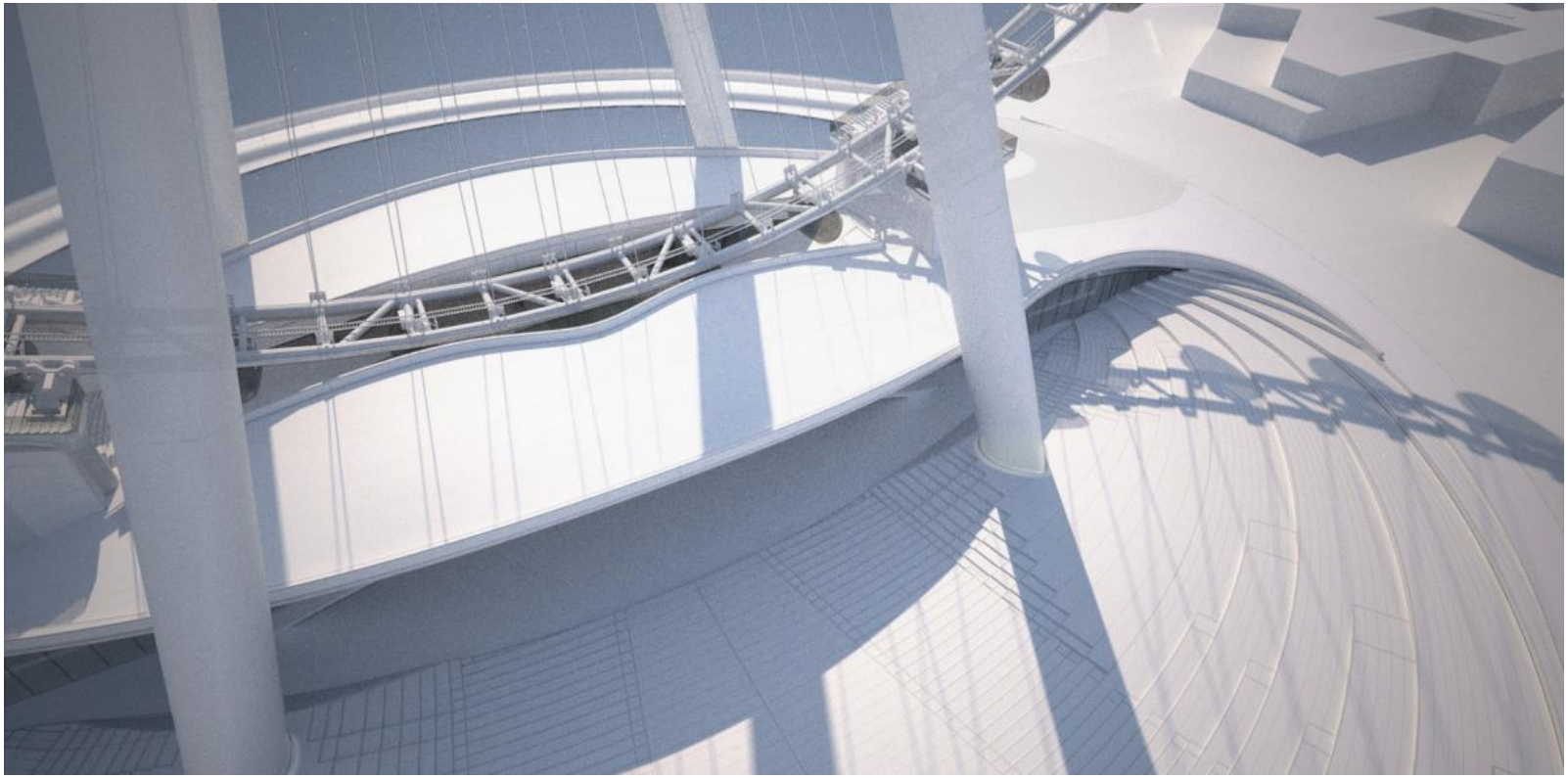
General Project Info – Project Location





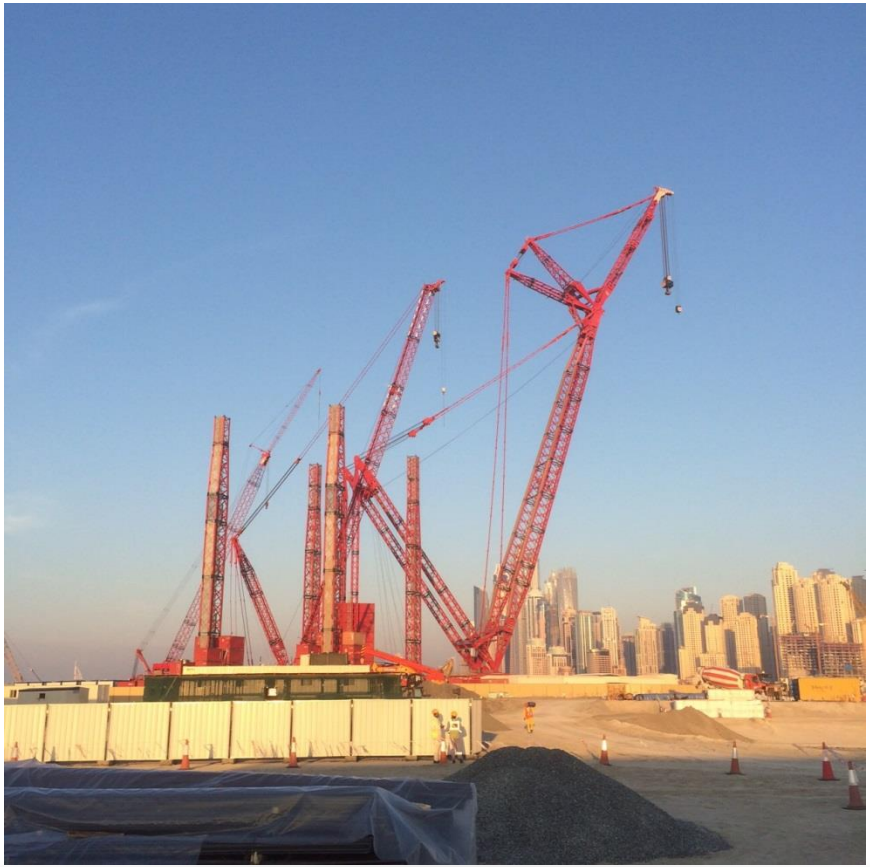


General Project Info – Artist impressions



General Project Info – Artist impressions

General Project Info – Installation Status



General Project Info – Installation Status

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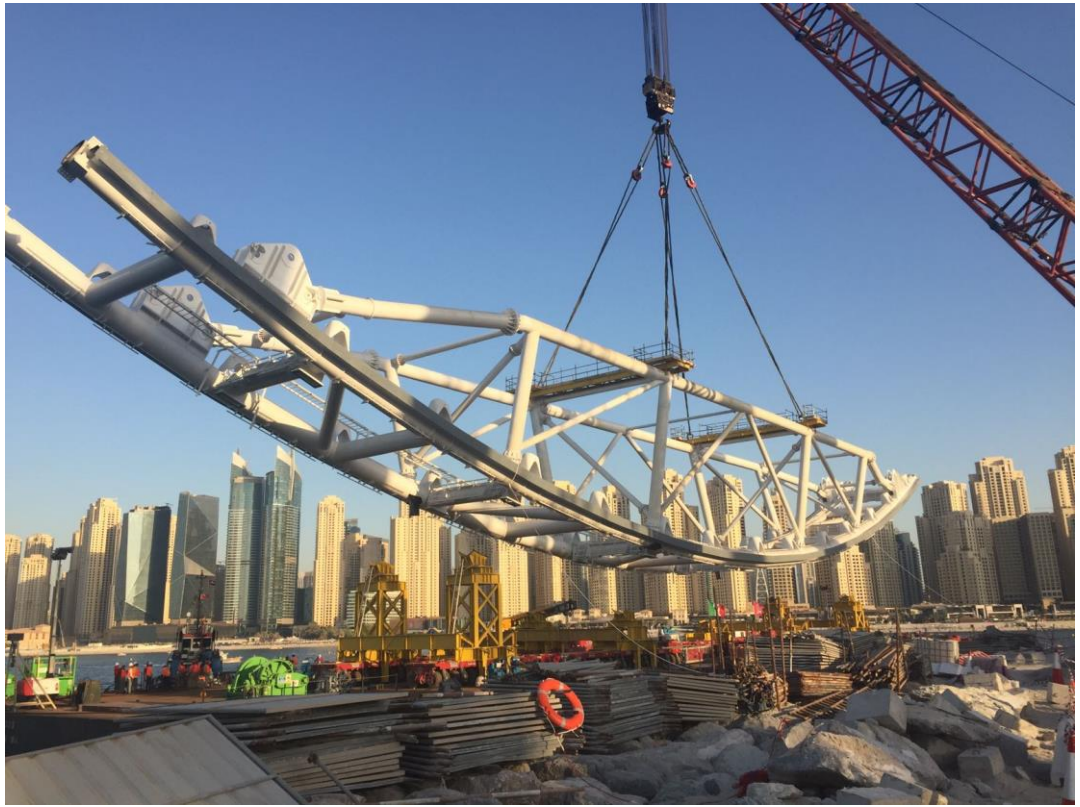

General Project Info – Installation Status

Specific Engineering & Design Topics

- **Static Analyses - Wind Load**
- **Dynamic Wind Response**
- ANSYS Post-Processing Routines
- Static Wind Tunnel Tests
- Dynamic Wind Tunnel Tests
- Spectral Seismic Analyses
- Seismic Time-History Analyses
- **Various Fatigue Analyses**
- Various Detailed Analyses
- SCF Calculations
- Capsule Design
- Evacuation Strategy
- Guide/Drive Unit Design
- Storm Lock Design
- Collector Gear Design
- Temperature Effects
- Rim Pushover Analyses
- A-Frame Pushover Analyses
- A-Frame Footing Design
- Imperfections
- Installation Analyses
- Bearing Design
- Spoke Cable Design
- Cable Socket Design
- Bent Limiter Design
- Cable Damper Design
- Vortex Induced Vibrations
- Tuned Mass Dampers
- Bearing Replacement
- Bearing Pad Exchange
- Bearing Tests
- Foundation Stiffness Variation
- Various Sensitivity Studies
- Restraint Tower Stiffness
- Hub-Drive Design
- Boarding Platform Gap Analyses
- Cable Replacement Analyses
- Accidental Spoke Cable Snap
- ... Many More

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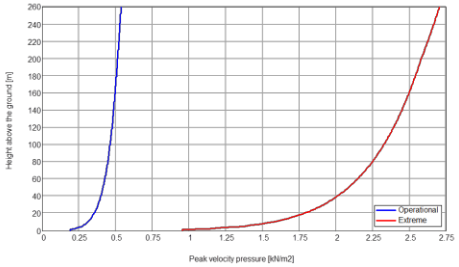
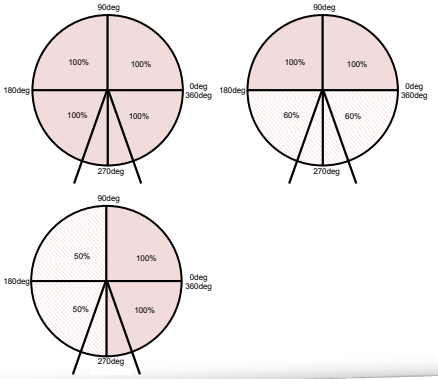
THE ENGINEERS

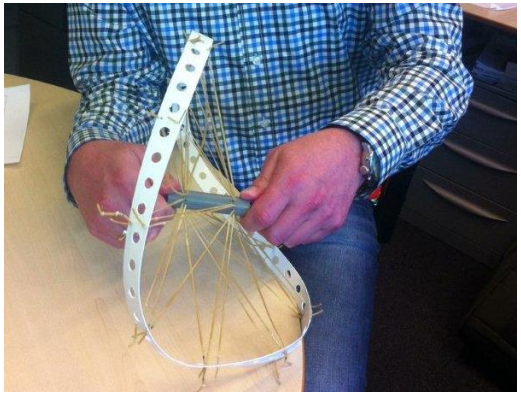
2 Static Analyses

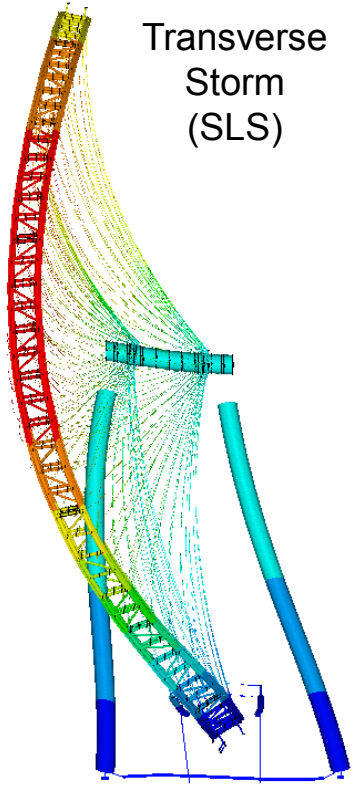
Static Analyses – Wind Load

- Operational Wind Speed Limit : **20m/s** (3s gust)
- Extreme Wind Speed Limit : **45m/s** (3s gust)
- 5 Wind Directions
- 3 Wind Gust Distributions









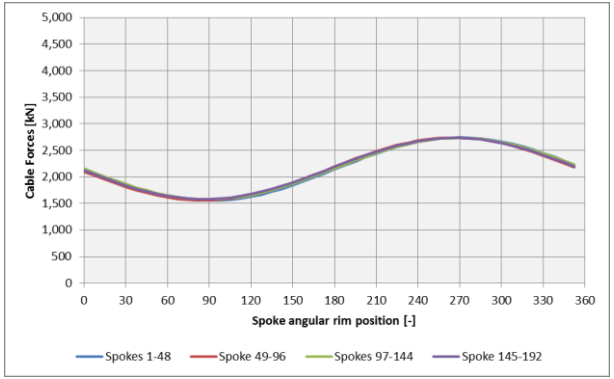
Transverse Storm (SLS)

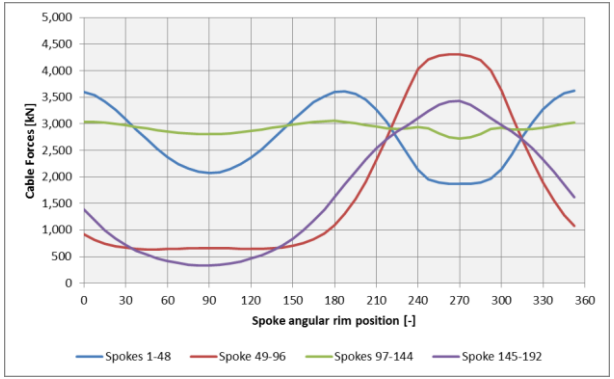
Scaled 50x

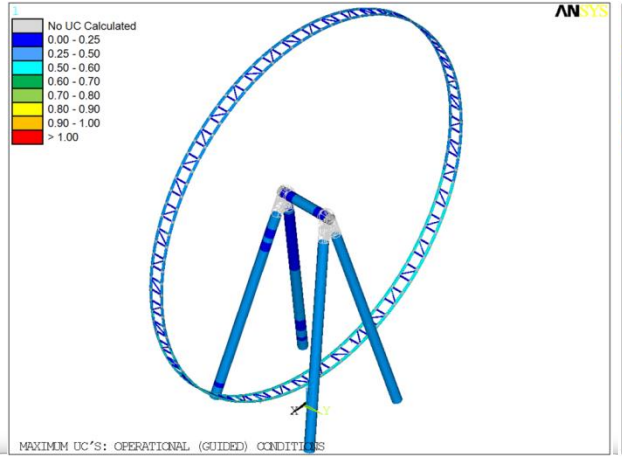
Static Analyses – Monitored Parameters

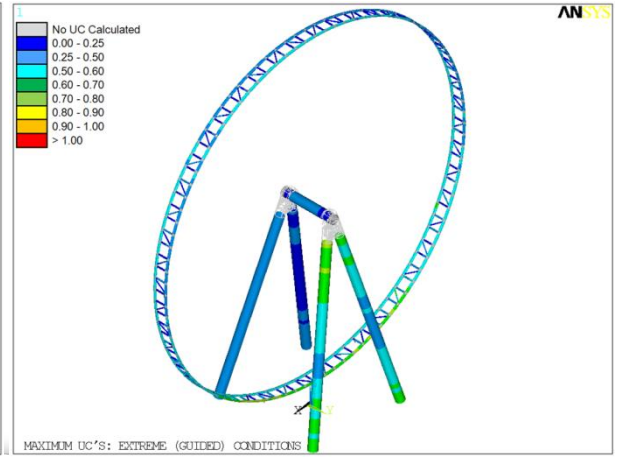
Monitored Results with User-Defined ANSYS routines:

- Cable Forces
- Member UC's
- Tubular Joint UC's
- Bearing Loads
- A-Frame Support Reactions
- Drive & Guide Forces
- Deflections
  - Spindle
  - A-Frame Foundations
  - Rim
  - Capsules at Boarding Platform



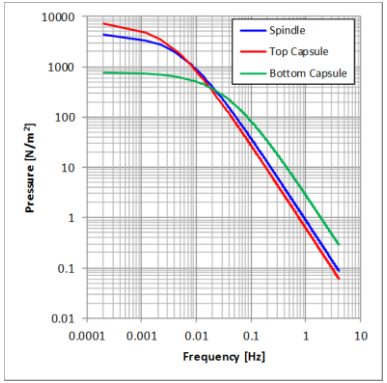


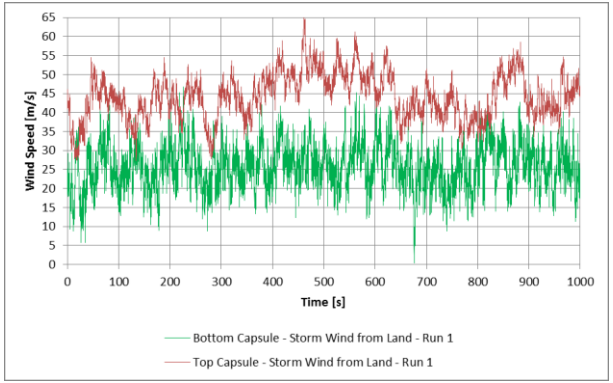


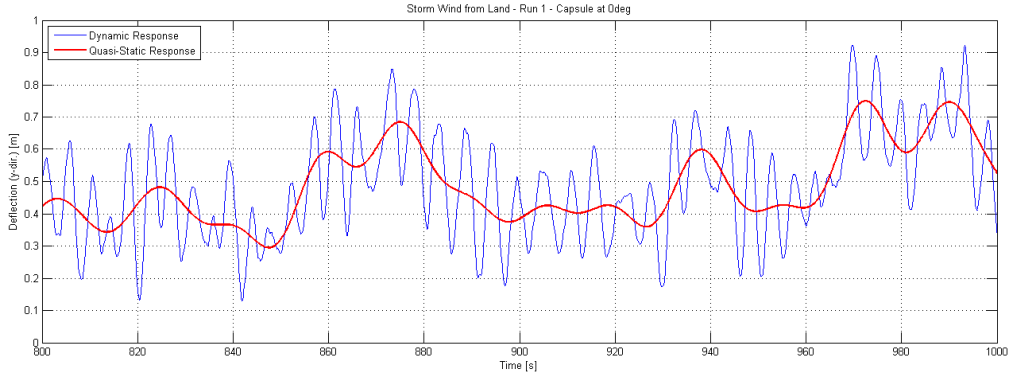


Dynamic Wind Response

- **Wind Response**
  - Time History Analysis
  - DAF-factor
  - Human Comfort







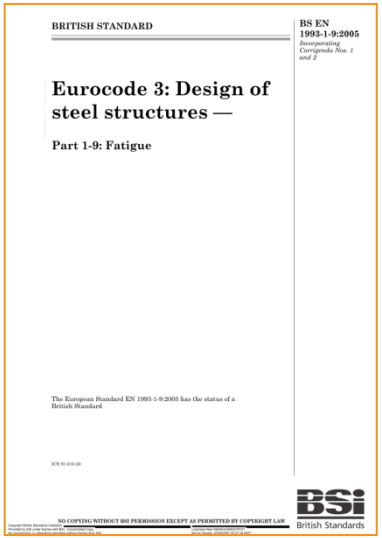
3 Fatigue Analyses

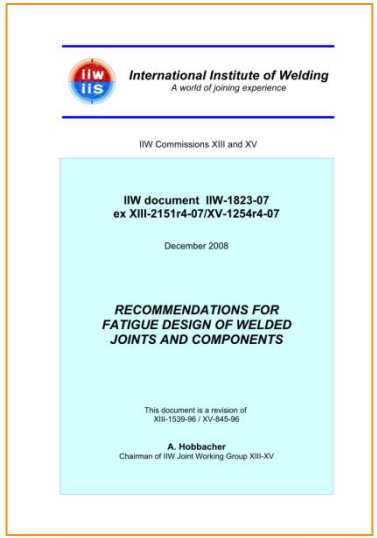
Fatigue Analyses - Introduction

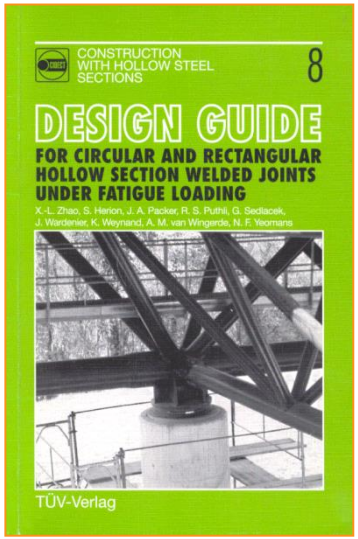
- Applied codes
- Fatigue loadings
- Applied methods
- Calculation examples
- Conclusions

Fatigue Analyses – Applied codes

- Eurocode 3 - *BS EN 1993-1-9:2005*
- International Institute of Welding IIW - *document IIW-1823-07*
- DG-8-CIDECT - *Design guide for circular and rectangular hollow sections welded joints under fatigue loading*
- Several papers

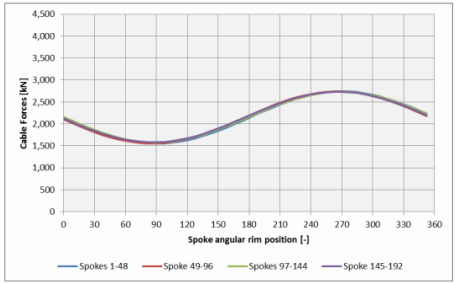


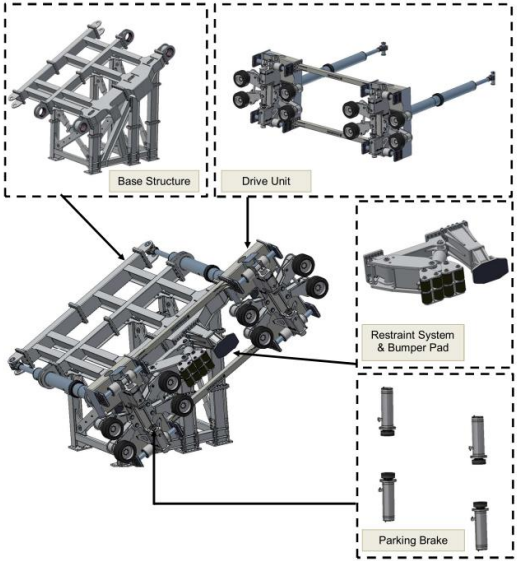


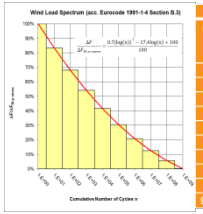


Fatigue Analyses – Fatigue loadings

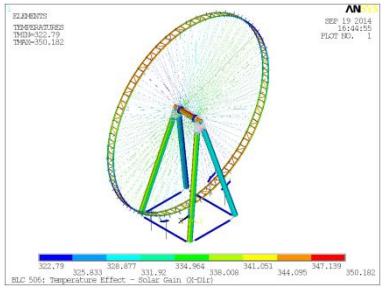
- Wheel rotation (gravitational force)
- Interaction between rim drive box and drive and restraint system
- Wind effect
- Temperature effects
- Seismic acitivity

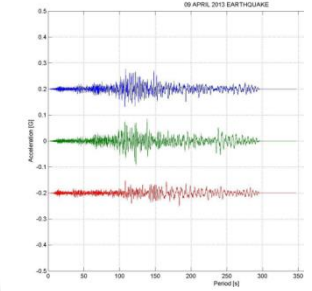






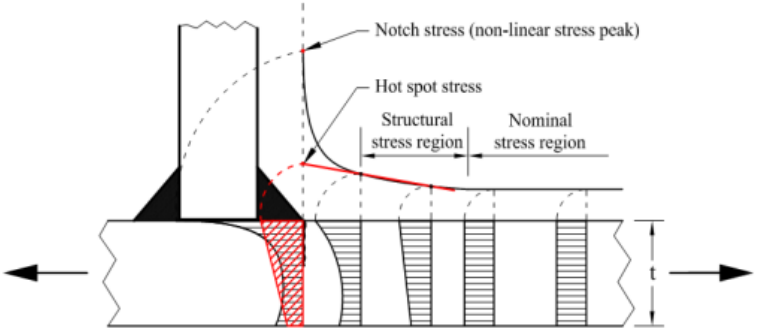
For 50-years		
Number of Cycles per Bin	Cumulative Number of Cycles	Load Ratio
1	1	100.0%
9	10	83.3%
90	100	68.0%
900	1,000	54.1%
9,000	10,000	41.6%
90,000	100,000	30.5%
900,000	1,000,000	20.8%
9,000,000	10,000,000	12.5%
90,000,000	100,000,000	5.6%
900,000,000	1,000,000,000	0.1%





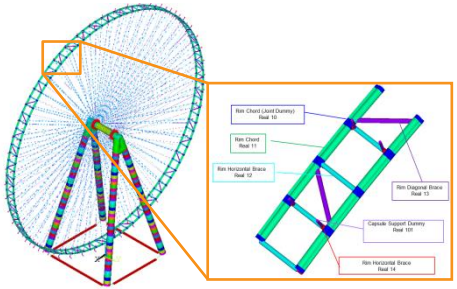
Fatigue Analyses – Applied methods

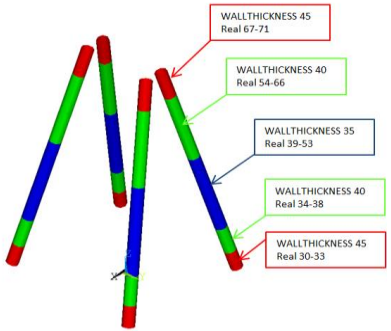
- Nominal stress method
- Hot spot stress method
- Notch stress method
- Fracture mechanics approach

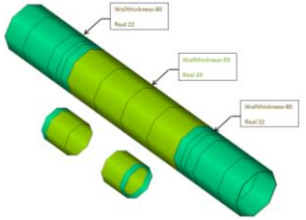


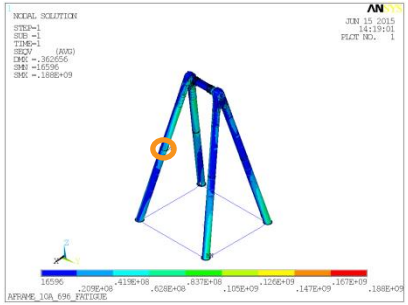
Fatigue Analyses – Calculation examples

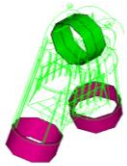
- **Nominal stress method**
  - Rim chord cross section
  - A-frame leg and spindle welds

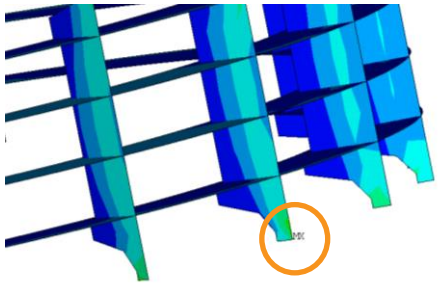


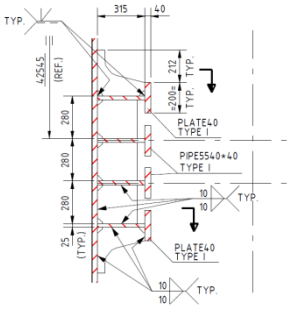










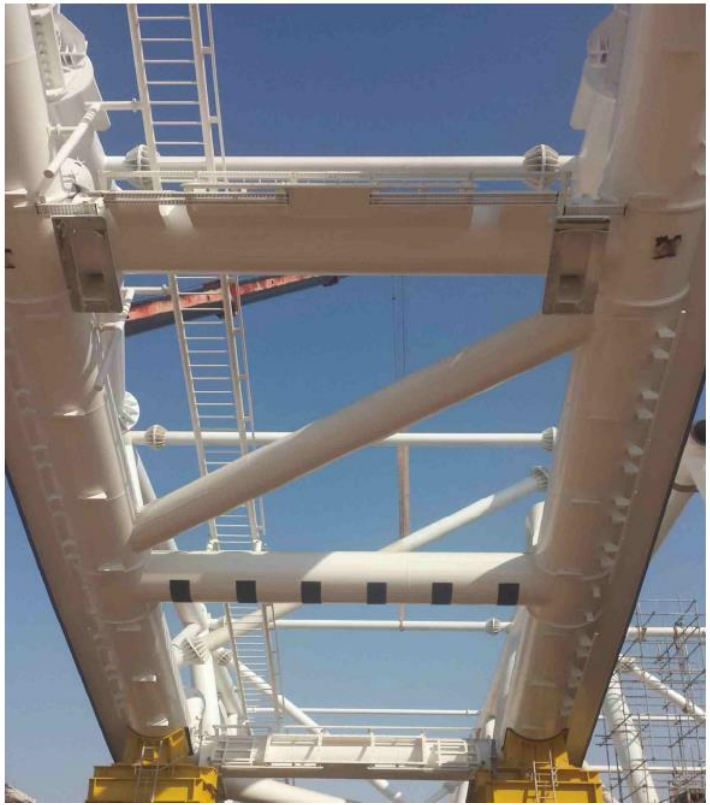


STRESS IN THE WELD DUE TO:	FX	τ1.x	[MPa]	-65.28
	FY	τ2.y	[MPa]	0.82
		σ2.y	[MPa]	N.A.
	FZ	τ2.z	[MPa]	N.A.
		σ2.z	[MPa]	21.53
	MX	τ2.Mx	[MPa]	N.A.
		σ2.Mx	[MPa]	0.62
	MY	τ2.My	[MPa]	N.A.
		σ2.My	[MPa]	81.65
	MZ	τ2.Mz	[MPa]	1.70
		σ2.Mz	[MPa]	N.A.
COMBINED STRESS		τv1	[MPa]	2.52
		τv2	[MPa]	-65.28
		σv1	[MPa]	103.80
WF STRESSES		τwf	[MPa]	65.28
		σwf	[MPa]	103.83

For 60-years					
Number of Cycles per Bin	Cumulative Number of Cycles	Load Ratio	Stress range (Δσ_R)	Allowable Number of Cycles (N_R)	Damage (n_r/N_r)
1	1	100.00%	104	1.76E+05	5.67E-06
9	10	83.00%	87	3.05E+05	2.95E-05
90	100	68.00%	71	5.61E+05	1.61E-04
900	1000	54.10%	56	1.11E+06	8.09E-04
9000	10000	41.60%	43	2.45E+06	3.68E-03
90000	100000	30.50%	32	7.18E+06	1.25E-02
900000	1000000	20.80%	22	4.87E+07	1.85E-02
9000000	10000000	12.50%	13	INFINITE	0.00E+00
90000000	100000000	5.60%	6	INFINITE	0.00E+00
9E+08	1000000000	0.10%	0	INFINITE	0.00E+00
				D_WIND	0.0357

Fatigue Analyses – Calculation examples

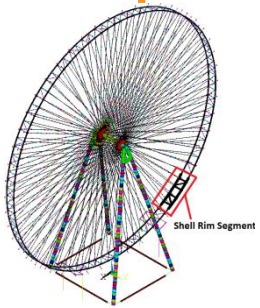
- **Nominal stress method**
  - Rim chord cross section
  - A-frame leg and spindle welds
  - Secondary steel attachments

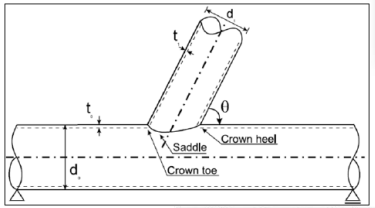


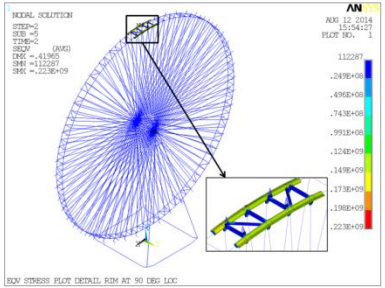
Fatigue Analyses – Calculation examples

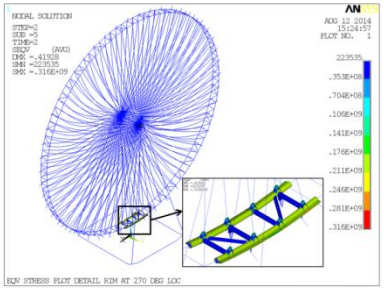
- **Nominal stress method**
  - Rim chord cross section
  - A-frame leg and spindle welds
  - Secondary steel attachments

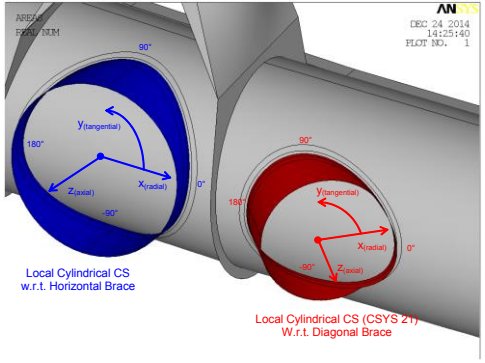
- **Hot spot stress method**
  - Rim chord tubular joints (SCF functions CIDECT)
  - Rim chord tubular joints (hot spot stress according to CIDECT)
  - Local details in rim (hot spot stress according IIW)
  - Weld details in A-frame and Brace

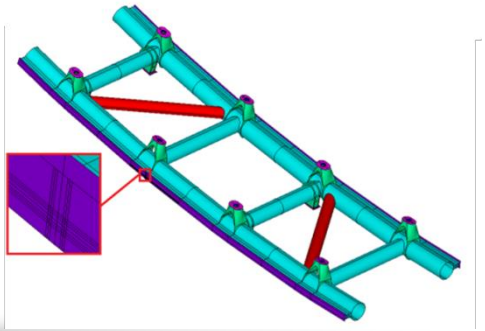








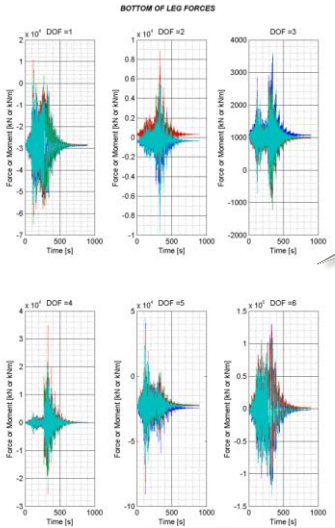


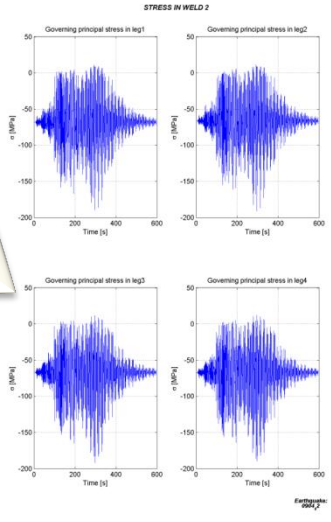


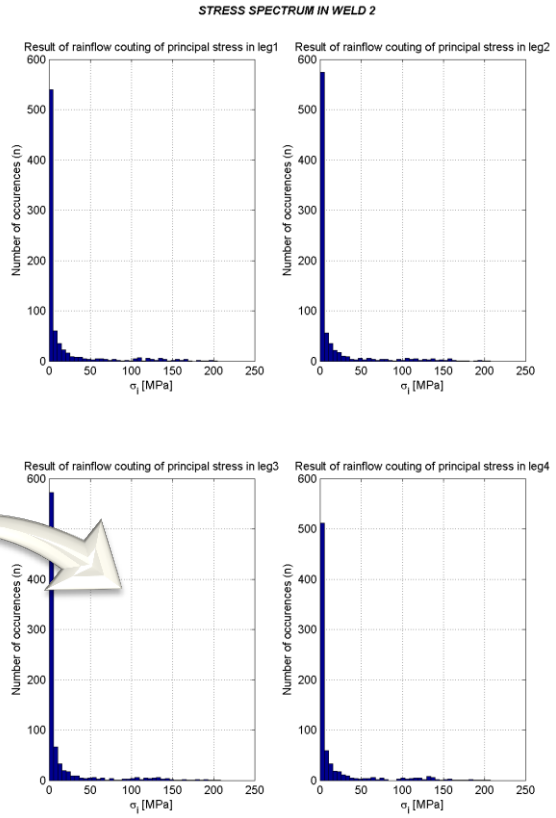
Fatigue Analyses – Calculation examples

Weld details in A-frame and Brace

- Fatigue due to a seismic event (time domain analysis)
- Member loads are calculated (beam model)
- Hot spot stress signal over time
- Rainflow counting applied on the stress signal
- Miner rule for damage accumulation



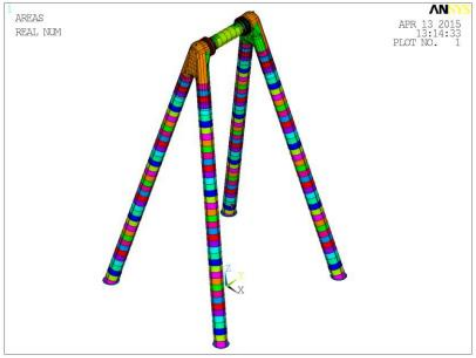


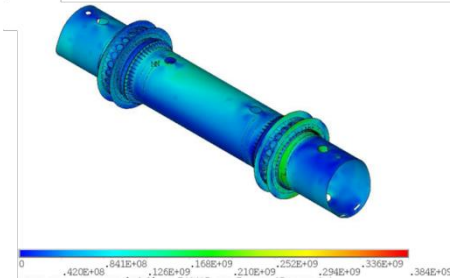


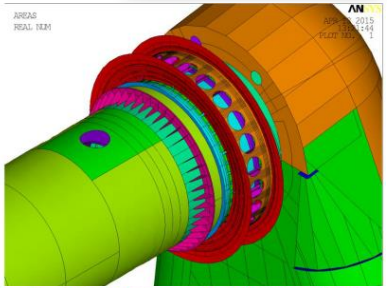
Fatigue Analyses – Calculation examples

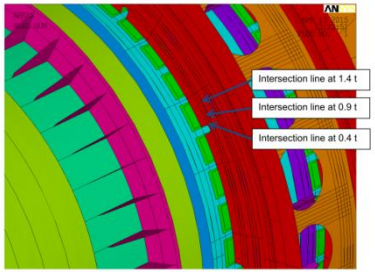
- **Nominal stress method**
  - Rim chord cross section
  - A-frame leg and spindle welds
  - Secondary steel attachments

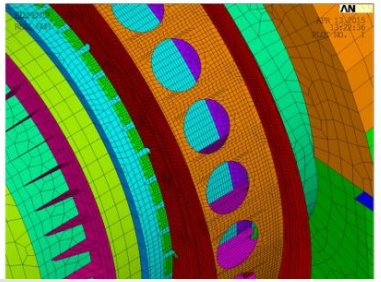
- **Hot spot stress method**
  - Rim chord tubular joints (SCF functions CIDECT)
  - Rim chord tubular joints (hot spot stress according to CIDECT)
  - Local details in rim (hot spot stress according IIW)
  - Weld details in A-frame and Brace
  - All welds in the rotating hubs











Fatigue Analyses – Calculation examples

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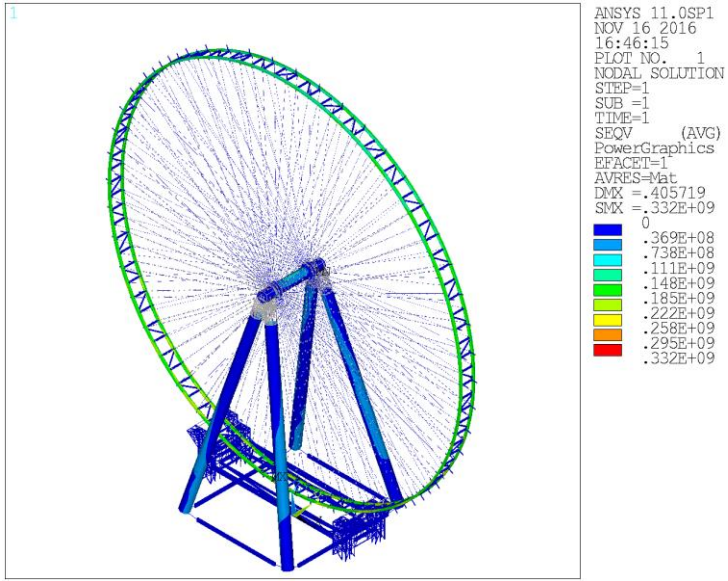
  - Weld details in A-frame and Brace
  - All welds in the rotating hubsnubs

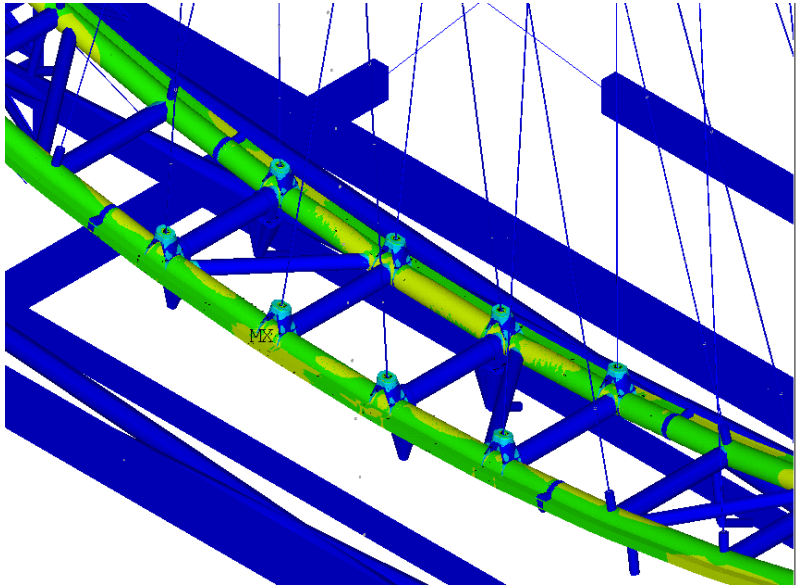
- **Notch stress method**
  - Conical spoke to rim joint

Fatigue Analyses – Calculation examples

Conical spoke to rim joint

1. Beam/shell model

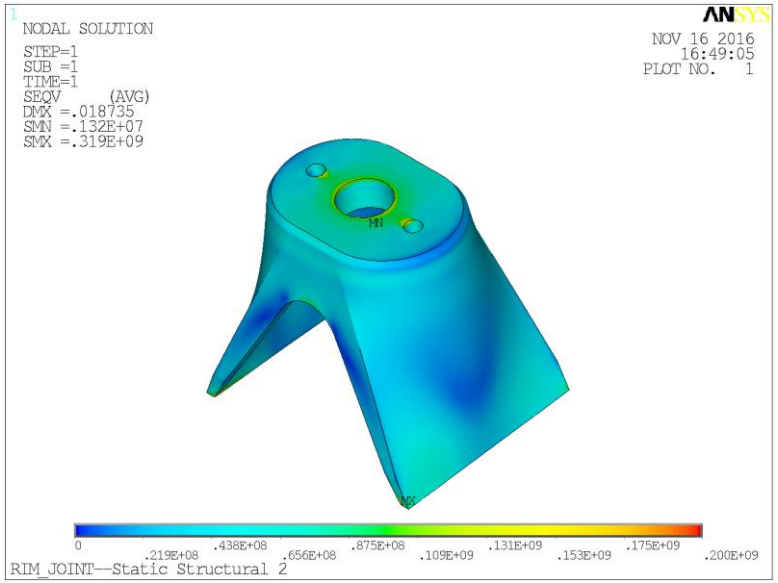


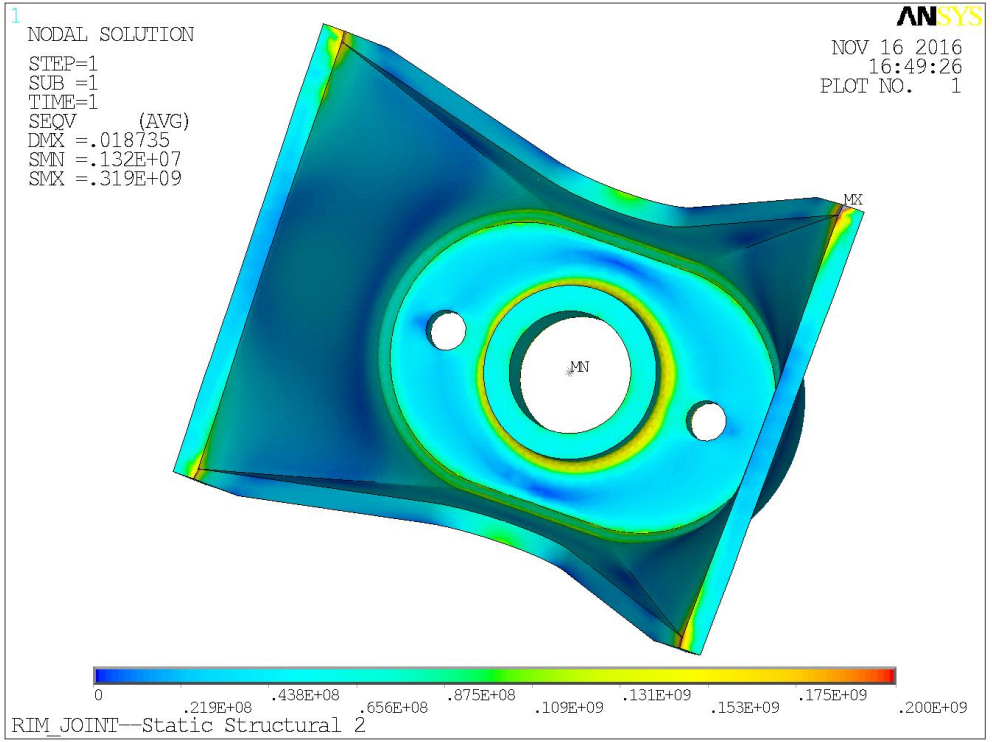


Fatigue Analyses – Calculation examples

Conical spoke to rim joint

2. Solid sub-model



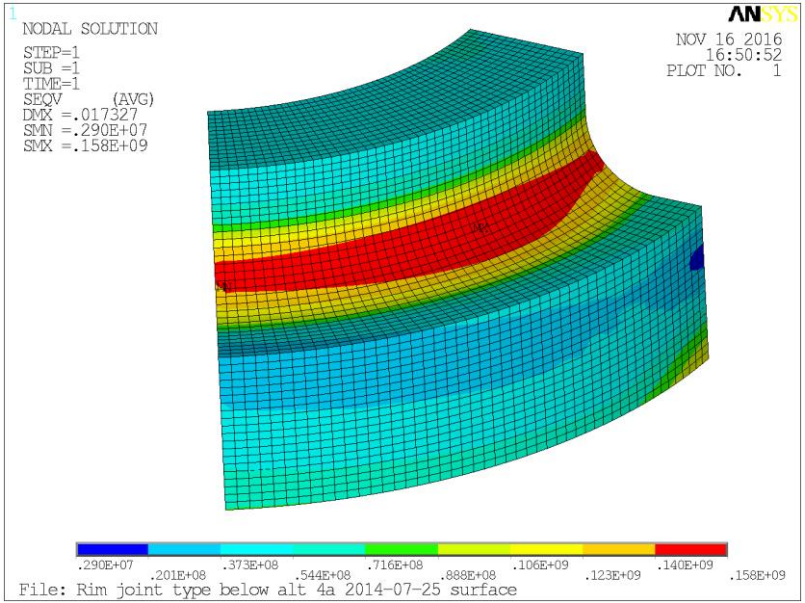


Fatigue Analyses – Calculation examples

Conical spoke to rim joint

3. Solid sub-sub-model

- Grinded weld is modeled (R=35mm), FAT 112 is used
- Principal stress is used



Fatigue Analyses – Calculation examples

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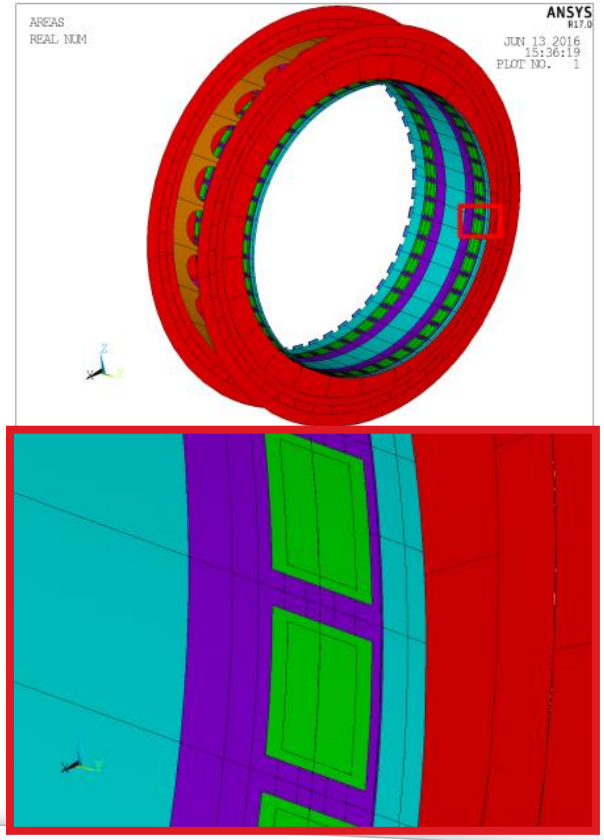
- **Hot spot stress method**
  - Rim chord tubular joints (SCF functions CIDECT)
  - Rim chord tubular joints (hot spot stress according to CIDECT)
  - Local details in rim (hot spot stress according IIW)
  - Weld details in A-frame and Brace
  - All welds in the rotating hubsnubs
- **Notch stress method**
  - Conical spoke to rim joint
  - Weld details in rotating hubs

Fatigue Analyses – Calculation examples

Weld details in rotating hubs

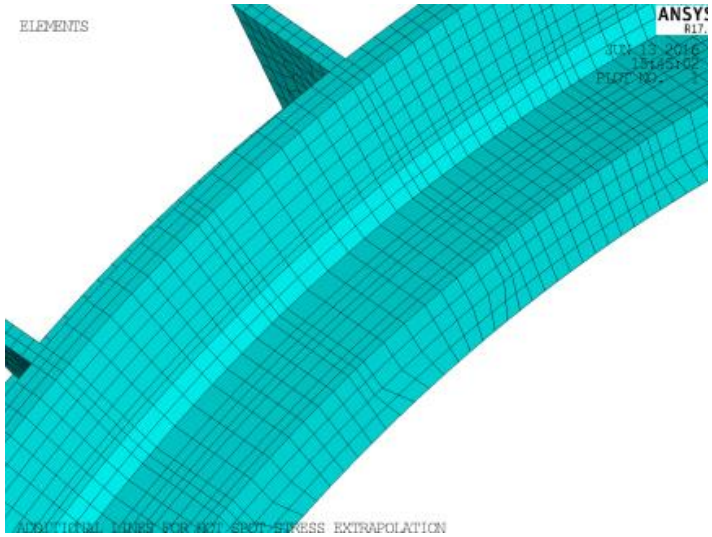
1. Shell model

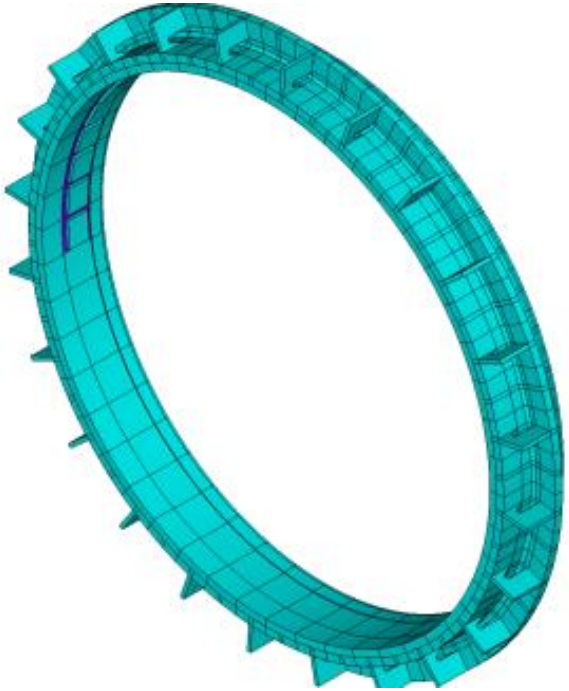


Fatigue Analyses – Calculation examples

Weld details in rotating hubs

2. Solid sub-model

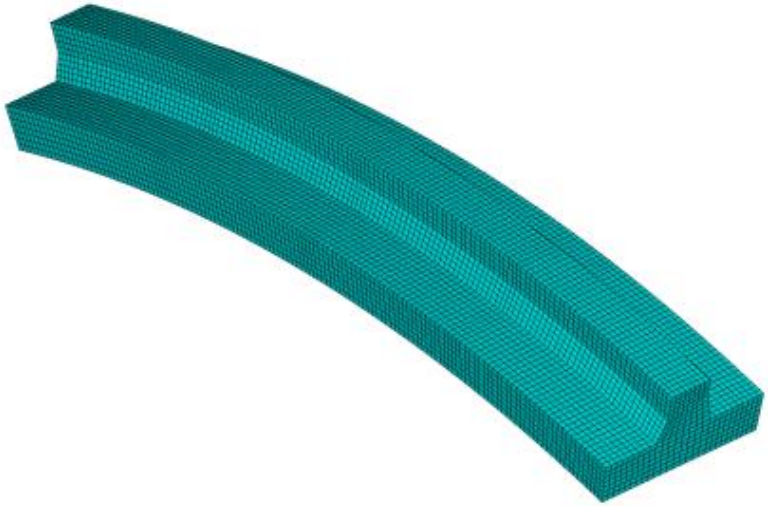


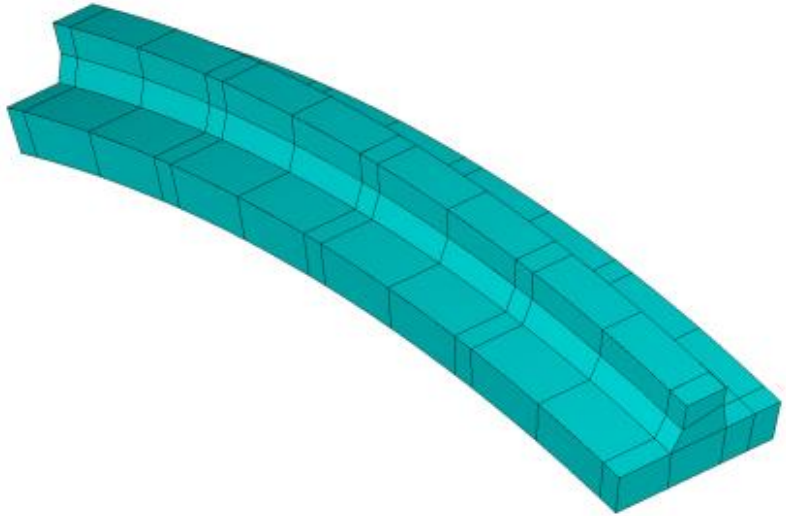


Fatigue Analyses – Calculation examples

Weld details in rotating hubs

3. Solid sub-sub-model

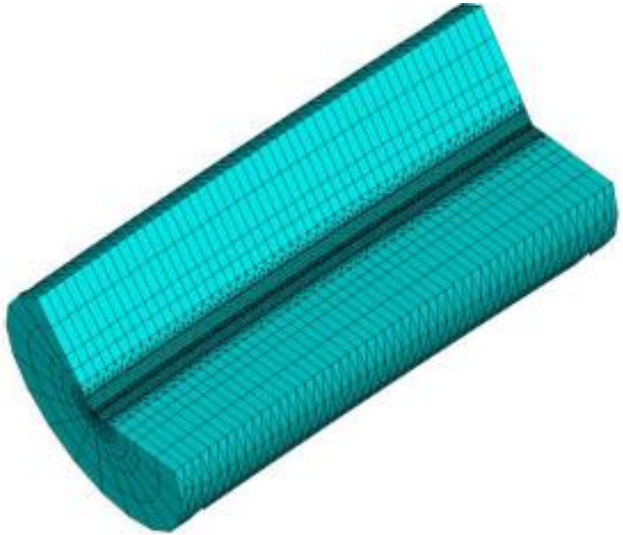




Fatigue Analyses – Calculation examples

Weld details in rotating hubs

4. Solid sub-sub-sub-model

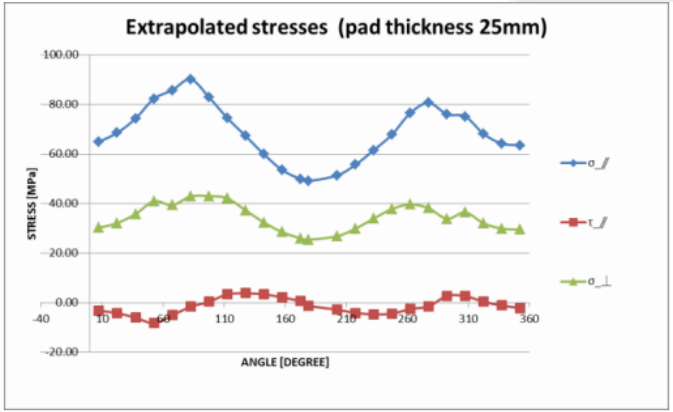


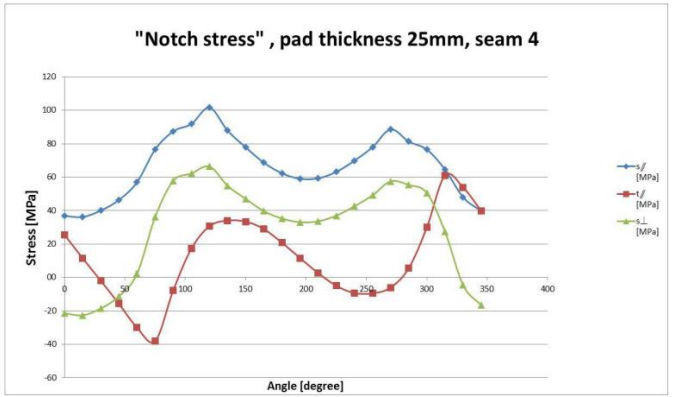
Fatigue Analyses – Calculation examples

Weld details in rotating hubs

5. Fatigue calculation

- Result of 2 typical weld details (as-welded)
- Result of 2 typical weld details (grinded)
- Which outcome is correct?





Weld detail	HSS / NSA (as-welded)	HSS / NSA (grinded)
1)	250	55
2)	32	10

Fatigue Analyses – Calculation examples

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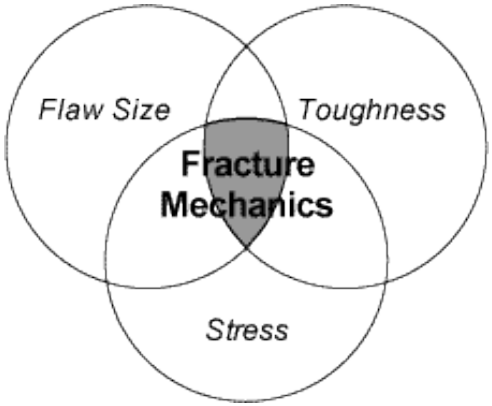
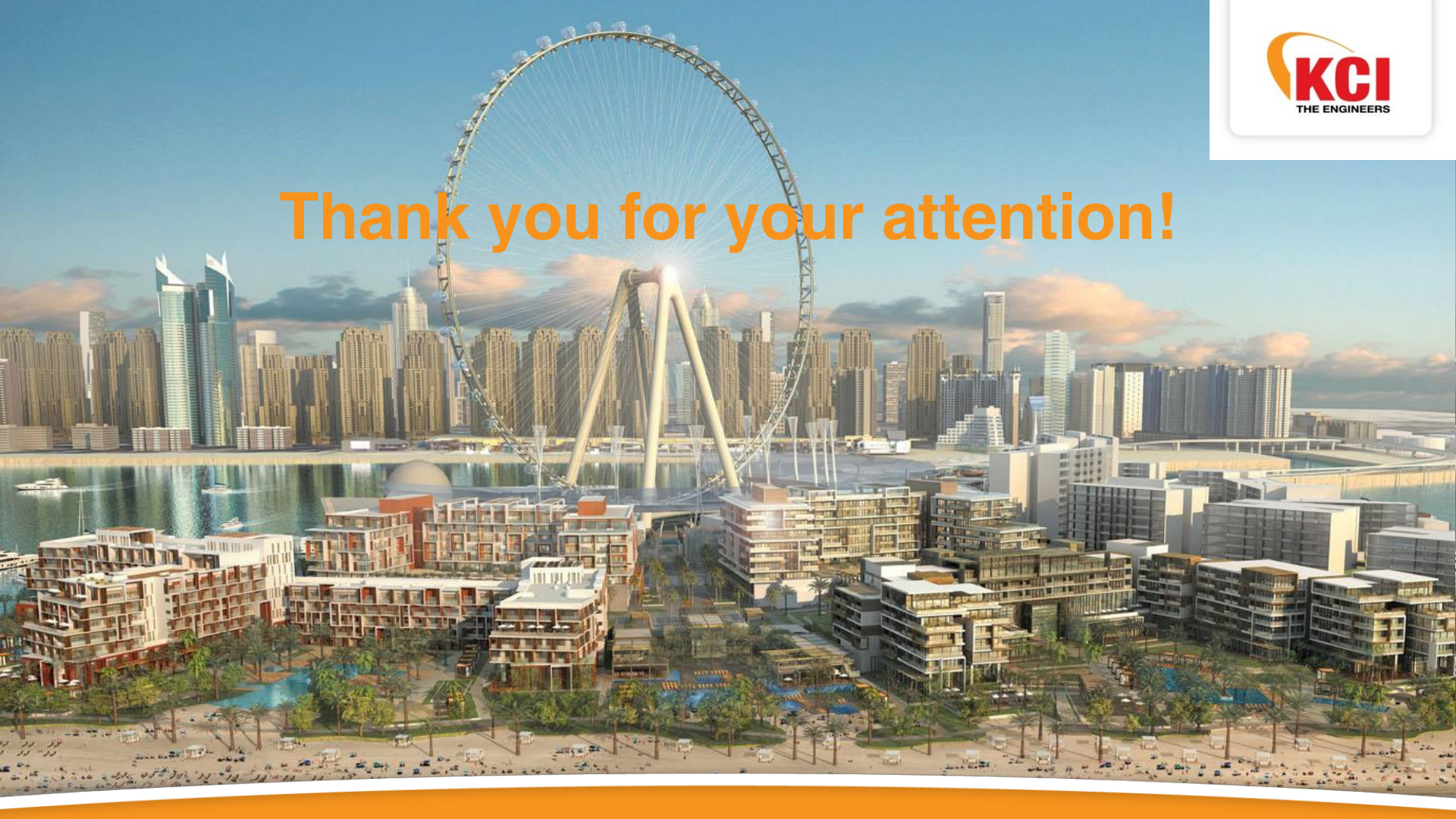
- **Hot spot stress method**
  - Rim chord tubular joints (SCF functions CIDECT)
  - Rim chord tubular joints (hot spot stress according to CIDECT)
  - Local details in rim (hot spot stress according IIW)
  - Weld details in A-frame and Brace
  - All welds in the rotating hub
- **Notch stress method**
  - Conical spoke to rim joint
  - Weld details in rotating hubs
- **Fracture mechanics approach**
  - Currently under consideration



$$K = Y\sigma\sqrt{\pi\, a}$$

Fatigue Analyses – Conclusions

- **Nominal stress approach**
  - Easy to use in beam/tubular structures
  - Relative quick lifetime estimation for standard weld details
- **Hot spot stress approach**
  - Predict fatigue in geometric complex structures
  - Fatigue predictions in (relative) thin walled structures
  - Be carrefull while using this method in very thick walled structures
- **Notch stress approach**
  - Can be used at machined weld details
  - Can be used for non-categorized weld details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Thank you for your attention!