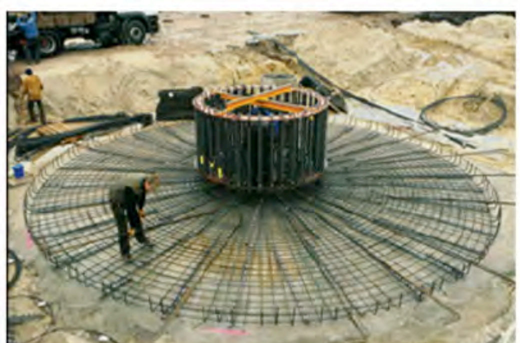
Sustainable solutions for faster construction of the higher tower and foundation

Tech. Dr. Martin Nilsson
Luleå University of Technology
Division of Structural and Construction Engineering – Structural Engineering
Martin.C.Nilsson@ltu.se

Prof., Tech. Dr. Milan Veljkovic
Luleå University of Technology
Division of Engineering and Construction Structural – Steel Structures
Milan.Veljkovic@ltu.se

Agenda

- Introduction, demands on improved competitiveness.
- The complete assessment: design, environmental and economical life cycle assessment.
- Innovations in foundations.
- Conclusions.



Future requirements

By year 2020, 30 TWh of the electricity consumption in Sweden should be produced by wind power. (Target by Swedish Wind Energy).

Wind power plants will be constructed at remote locations, in short time and under harsh climate conditions. The plants must have good locations, good turbines and be built both quickly and competitively

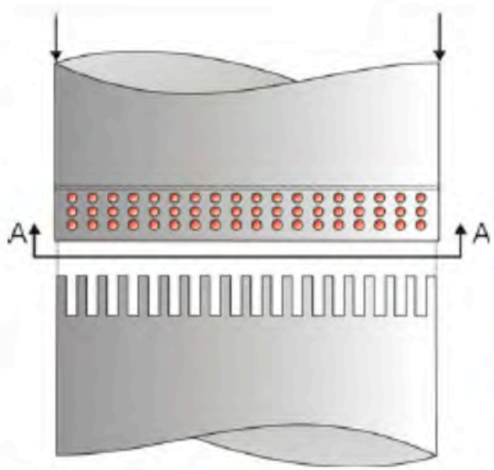
Wind power plants must be designed with sustainable solutions, both environmentally and economically.

Turbines have to be built higher than 100 m to gain stable and more constant wind.

New demands for competitiveness on wind energy sector

The future requirements impose new demands on costs and effectiveness of:

- turbine design,
- wings, including de-icing where necessary,
- **bearing structural components – towers and foundations, production and assembling for higher towers**

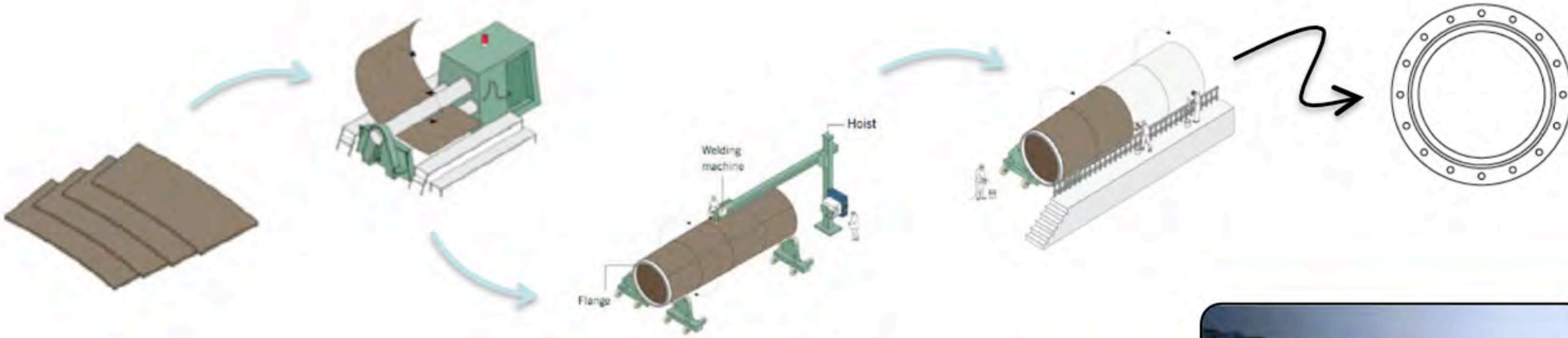


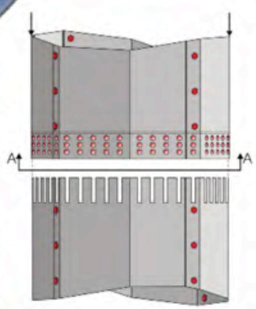
Economics of Wind Power

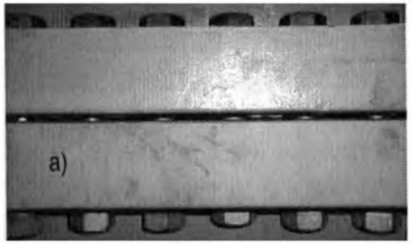
UK experience

Element	On-shore Cost as % of total	Offshore Cost as % of total
•Turbine	•33%	•21%
•Blades	•22%	•15%
•Tower	•20%	•13%
•Foundation	•9%	•21%
•Grid connection	•6%	•21%
•Design & Manag	•10%	•9%
•Total cost per MW	•€1.5 - 2 million	•€2.5 – 3.5 million

Existing and alternative tubular steel tower solutions



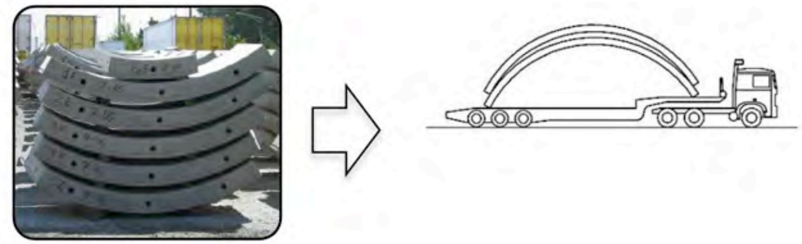


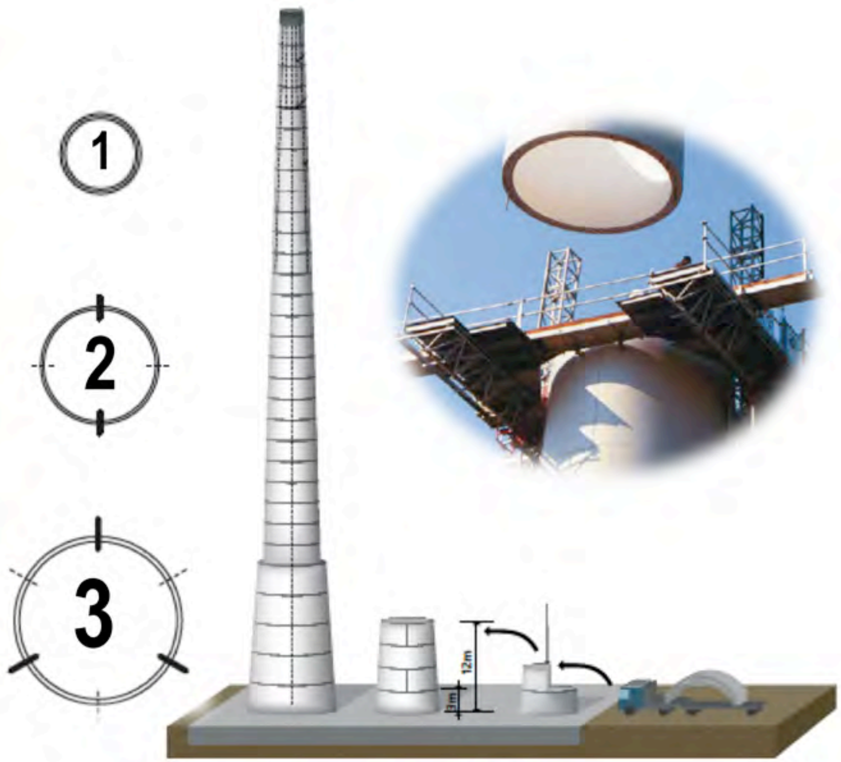


Existing concrete tower solutions

Prefabricated elements

In-situ cast with slip form





Environmental and economical assessment

Economical and environmental life cycle assessment of an on-shore wind power structure focusing on embodied equivalent CO_2 emissions and energy consumed in manufacturing, transportation, erection and dismantling.

Example from Master Thesis by Josep Pigem Rodeja, LTU:
The mass of CO_2
and energy used per
produced kWh at consumers
place for a 100 m high tubular steel
tower and a pre-stressed
concrete tower with foundation

Environmental and economical assessment

Approximate structural design, equivalent loading

✓ 1. Ultimate Limit State (ULS)

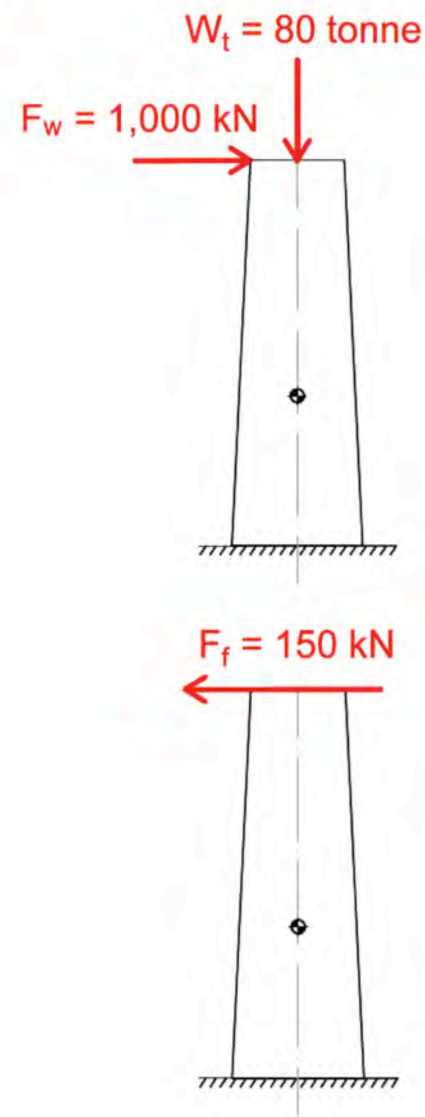
- Enough strength of materials.
- Instability phenomena.

✓ 2. Fatigue Limit State (FLS)

- Steel: structural details.
- Concrete: Separately by material

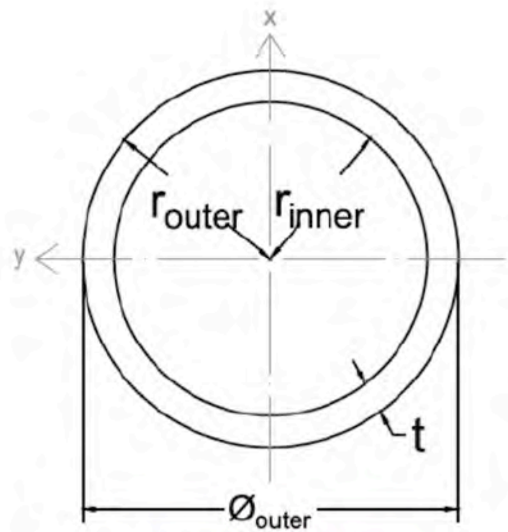
✗ 3. Dynamic Stability

- Vibration behaviour.
- Avoid resonance problems.

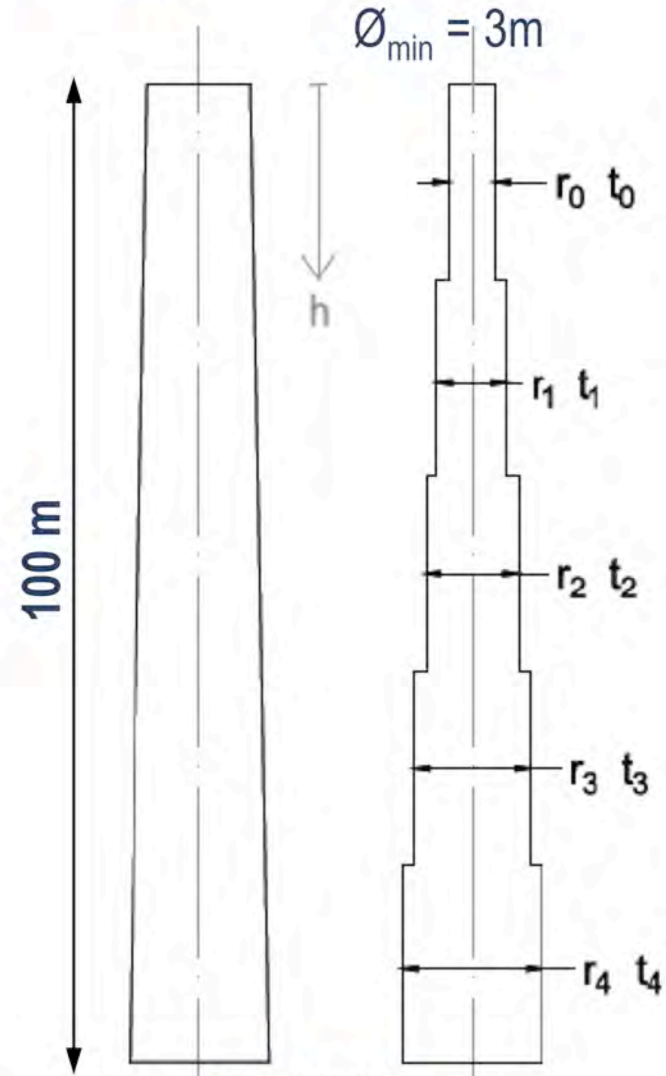


Environmental and economical assessment

Geometrical approach



Cross-section



Conical tower

Environmental and economical assessment

Steel tower

		Ultimate Limit State		Ultimate Fatigue State			
		Strength and stability		Plate to plate connection		Flange connection	
Cylinder #	h [m]	$\varnothing_{outer}$ [m]	t [mm]	$\varnothing_{outer}$ [m]	t [mm]	$\varnothing_{outer}$ [m]	t [mm]
1	20	3.30	13	3.30	18	3.30	-
2	40	3.55	18	3.55	28	3.55	18
3	60	3.85	22	3.85	34	3.85	-
4	80	4.25	25	4.25	38	4.25	28
5	100	4.50	30	4.50	42	4.50	40

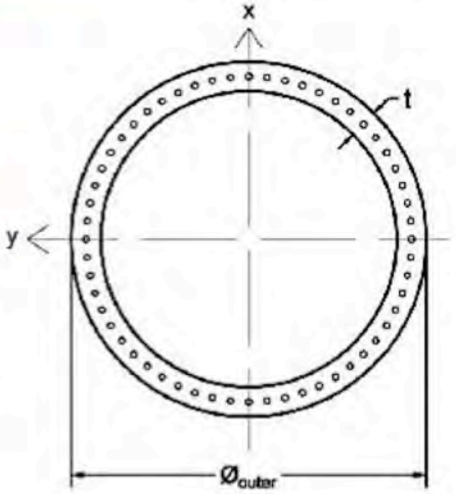
Concrete tower

$\varnothing_{strand} = 15.7$ mm

$n_s = 12$

$n_{tendon} = 56$

ϕ_{outer} [mm]	t [mm]	Driving criteria
4	260	ULS
4.5	300	ULS
5	350	ULS
5.5	400	FLS
6.5	500	FLS



Environmental and economical assessment

Material data

Material	Carbon intensity [kg CO_2/kg]	Energy intensity [MJ/kg]	Recovery
Steel plates	11.78	0.800	11 % reused, 88 % recycled, 1 % landfill
Reinforcement	12.42	0.870	11 % reused, 88 % recycled, 1 % landfill
Concrete	0.50	0.091	5.8 % recycled, 94.2 % landfill
Reinforced concrete	0.53	0.099	5.8 % recycled, 94.2 % landfill

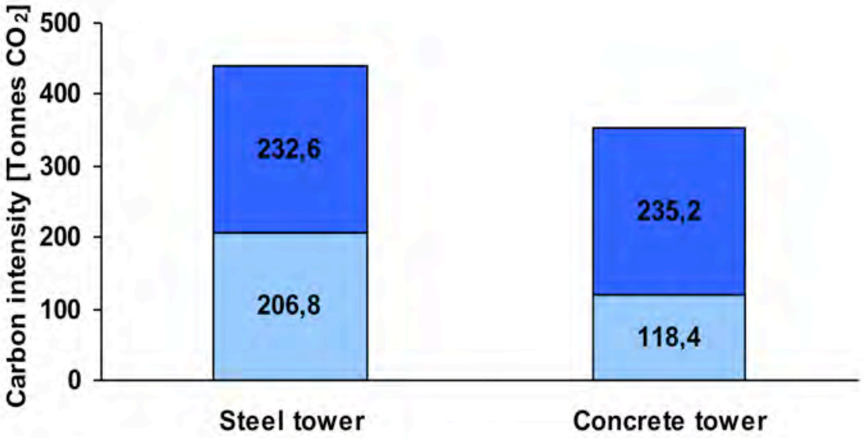
EPD – Environmental Product Declarations, www.environdec.com

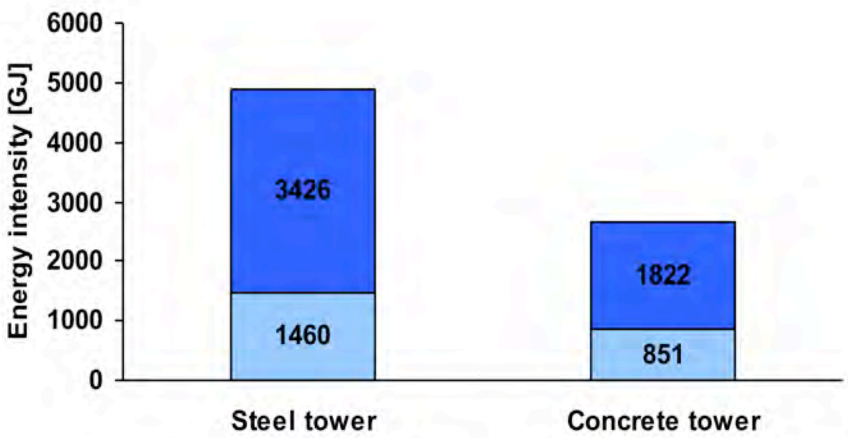
Environmental and economical assessment

Manufacturing

Tubular steel tower		
Material	Carbon intensity [tonne]	Energy intensity [GJ]
Steel plates	232.6	3 426
Concrete	169.9	934
Reinforcement	36.9	526
Sum	**439.4**	**4 866**

Pre-stressed concrete tower		
Material	Carbon intensity [tonne]	Energy intensity [GJ]
Concrete segments	172.1	921
Steel tendons	63.1	901
Reinforcement	22.9	326
Concrete	95.5	525
Sum	**353.6**	**2673**



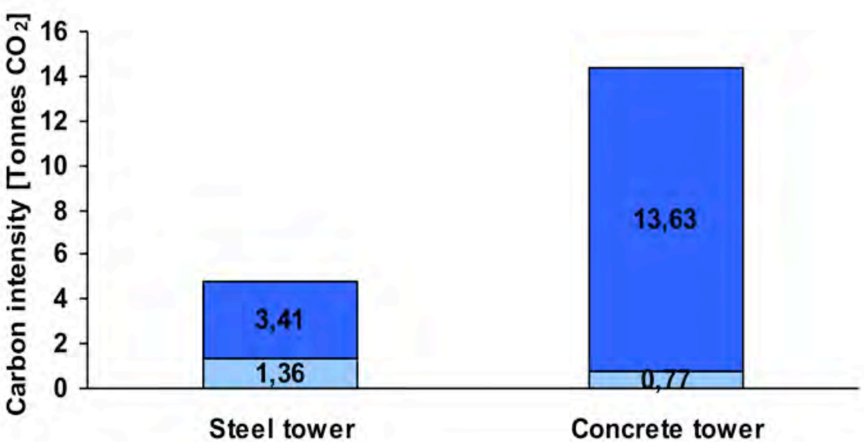


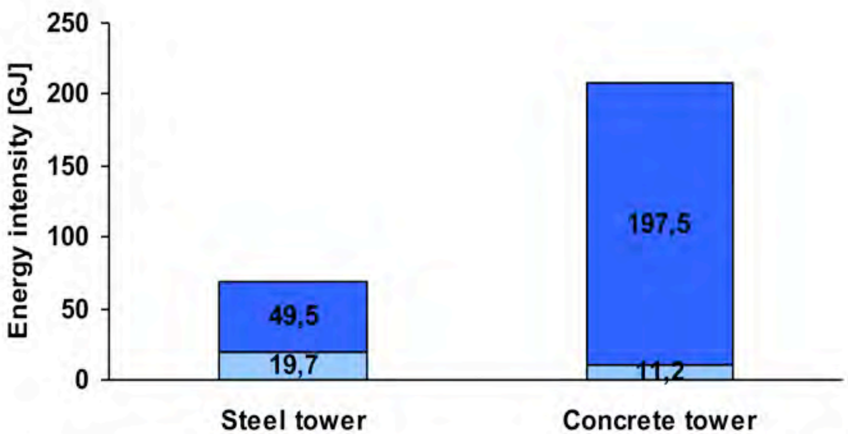
Environmental and economical assessment

Transportation

Tubular steel tower		
Material	Carbon intensity [tonne]	Energy intensity [GJ]
Steel plates	3.41	49.5
Concrete	1.28	18.5
Reinforcement	0.08	1.2
Sum	**4.77**	**69.2**

Pre-stressed concrete tower		
Material	Carbon intensity [tonne]	Energy intensity [GJ]
Concrete segments	13.49	195.5
Steel tendons	0.14	2.1
Reinforcement	0.05	0.7
Concrete	0.72	10.4
Sum	**14.4**	**208.7**



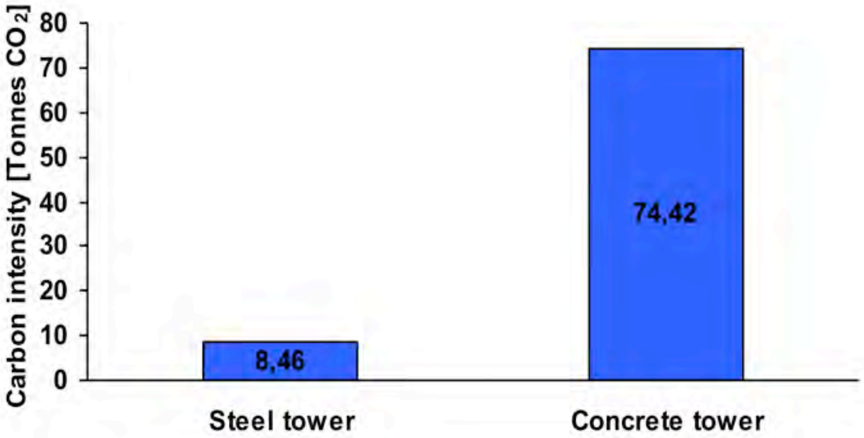


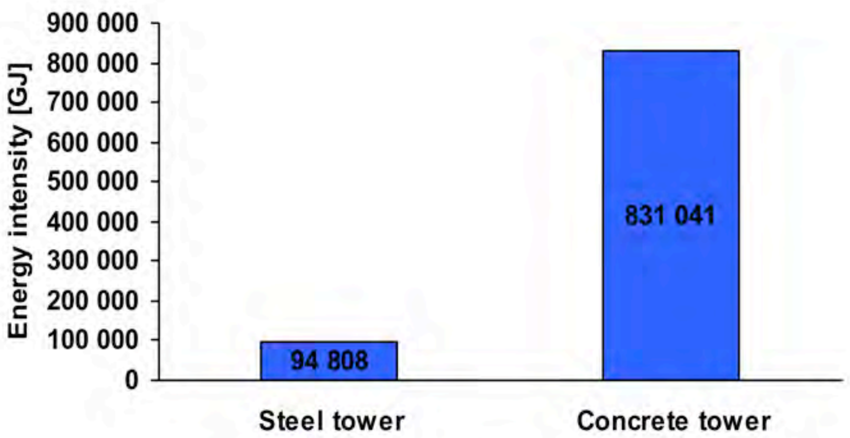
Environmental and economical assessment

Erection (fuel consumption of cranes, foundation excluded)

Tubular steel tower		
Material	Carbon intensity [tonne]	Energy intensity [GJ]
Steel plates	8.46	94.8
Sum	**8.46**	**94.8**

Pre-stressed concrete tower		
Material	Carbon intensity [tonne]	Energy intensity [GJ]
Concrete segments	13.49	834.0
Sum	**13.49**	**834.0**



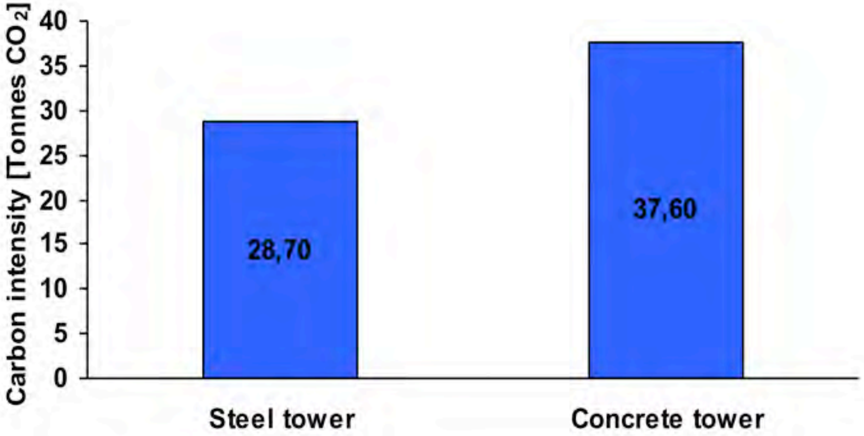


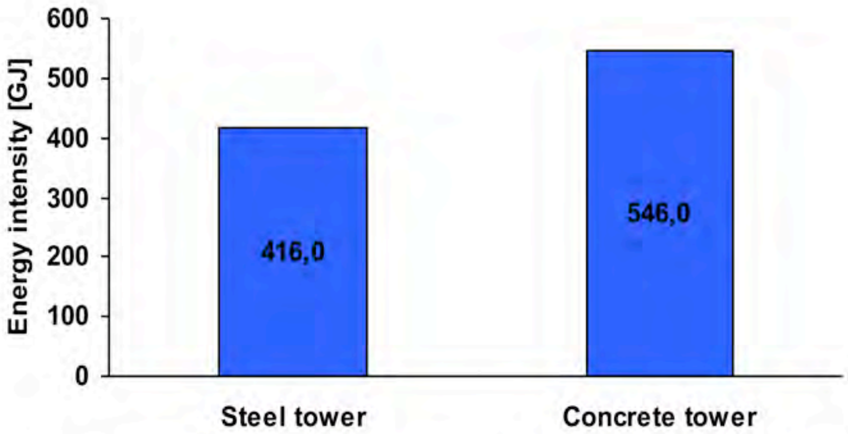
Environmental and economical assessment

Dismantling (recycling/incinerating plant situated 200 km away)

Tubular steel tower		
Material	Carbon intensity [tonne]	Energy intensity [GJ]
Steel plates	28.70	416.0
Sum	**28.70**	**416.0**

Pre-stressed concrete tower		
Material	Carbon intensity [tonne]	Energy intensity [GJ]
Concrete segments	37.60	546.0
Sum	**37.60**	**546.0**



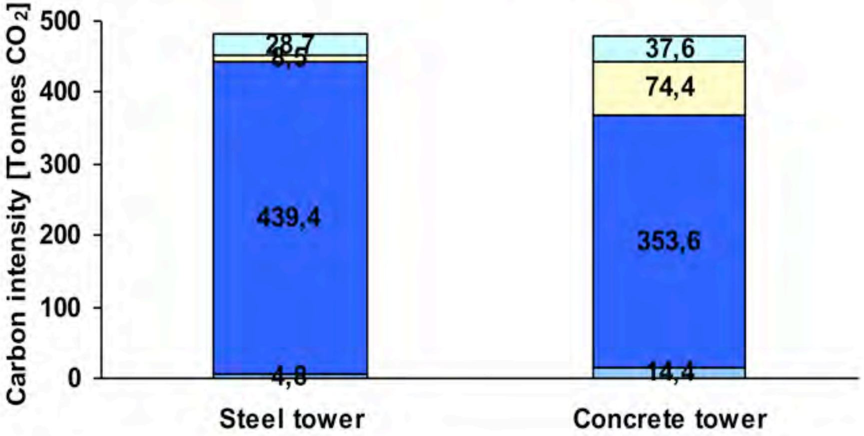


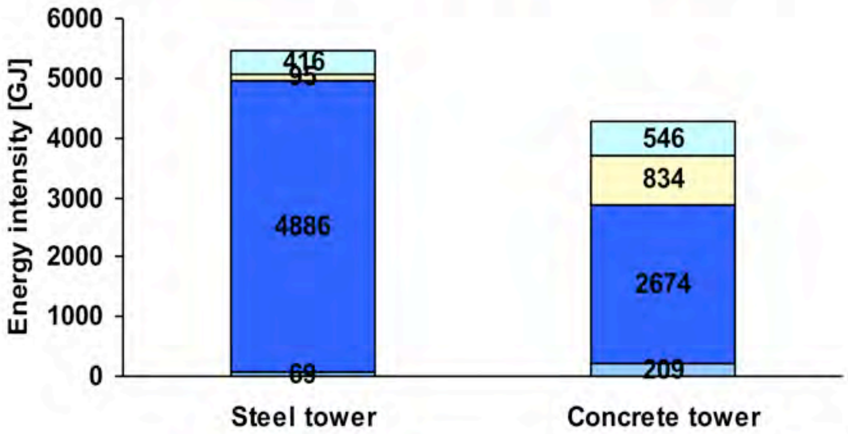
Environmental and economical assessment

Total carbon and energy intensity

Tubular steel tower		
Material	Carbon intensity [tonne]	Energy intensity [GJ]
Manufacturing	439.4	4886
Transportation	4.8	69
Erection	8.5	95
Dismantling	28.7	416
Sum	**481.4**	**5466**

Pre-stressed concrete tower		
Material	Carbon intensity [tonne]	Energy intensity [GJ]
Manufacturing	353.6	2674
Transportation	14.4	209
Erection	74.4	834
Dismantling	37.6	546
Sum	**480.0**	**4262**





Environmental and economical assessment

Embodied CO_2 in electricity produced

	Total emissions [tonnes]	Electricity produced [GWh]	g CO_2/kWh
Steel tower	480.1	70.1	6.85
Concrete tower	481.4	70.1	6.87

Energy payback time

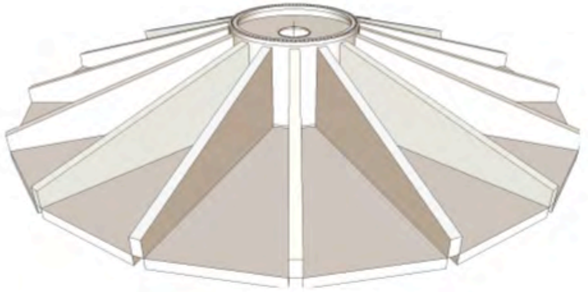
	Embodied energy [MWh]	Produced Energy [MWh]	Months to recovery
Steel tower	1 518.3	292	5.2
Concrete tower	1 183.9	292	4.1

Innovations in foundations

More prefabrication

E.g. more prefabricated reinforcement:

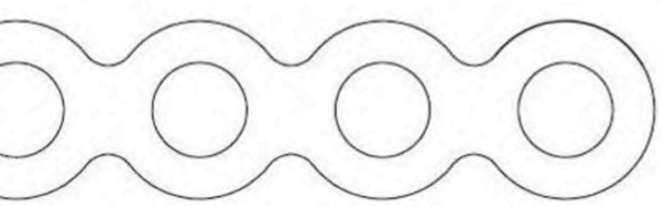
- cages
- cell reinforcement
- roll out reinforcement



Alternative reinforcement solutions in foundations

Cell reinforcement – a new type of reinforcement in high strength steel (1000 MPa). Rows of rings with specific ring diameters with great ductile capability. Several rows of rings in two different directions form a net reinforcement.

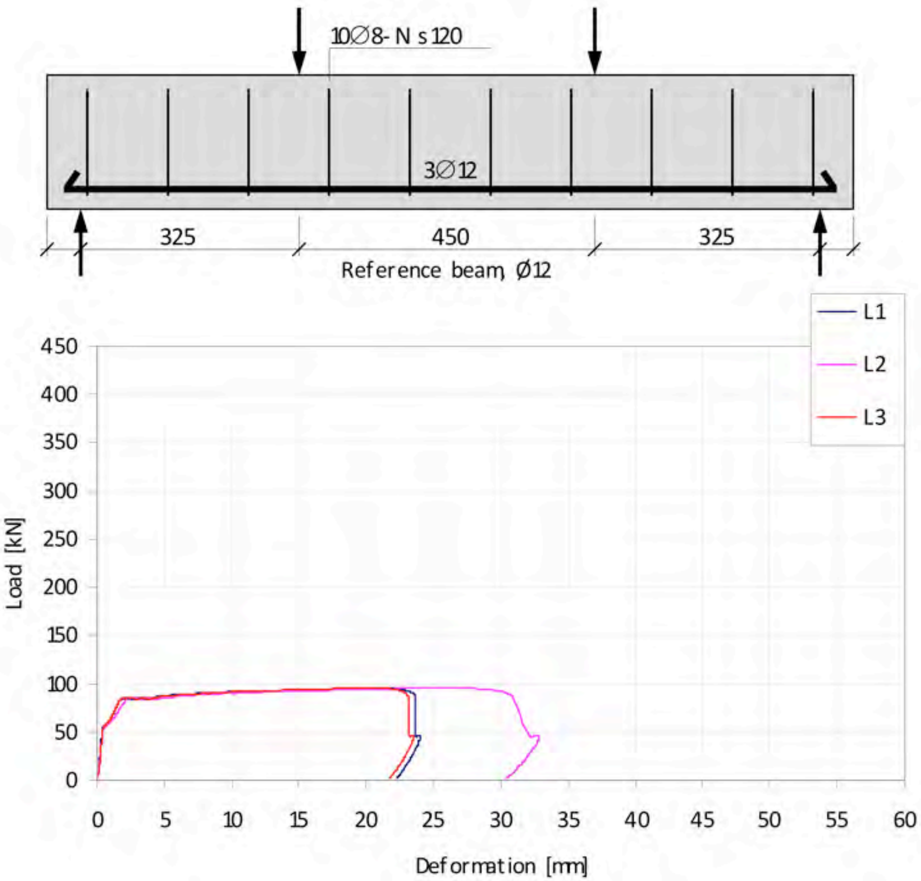
Vindforsk project on-going with dynamic tests of cell-reinforced beams and slabs for possible application in foundations.

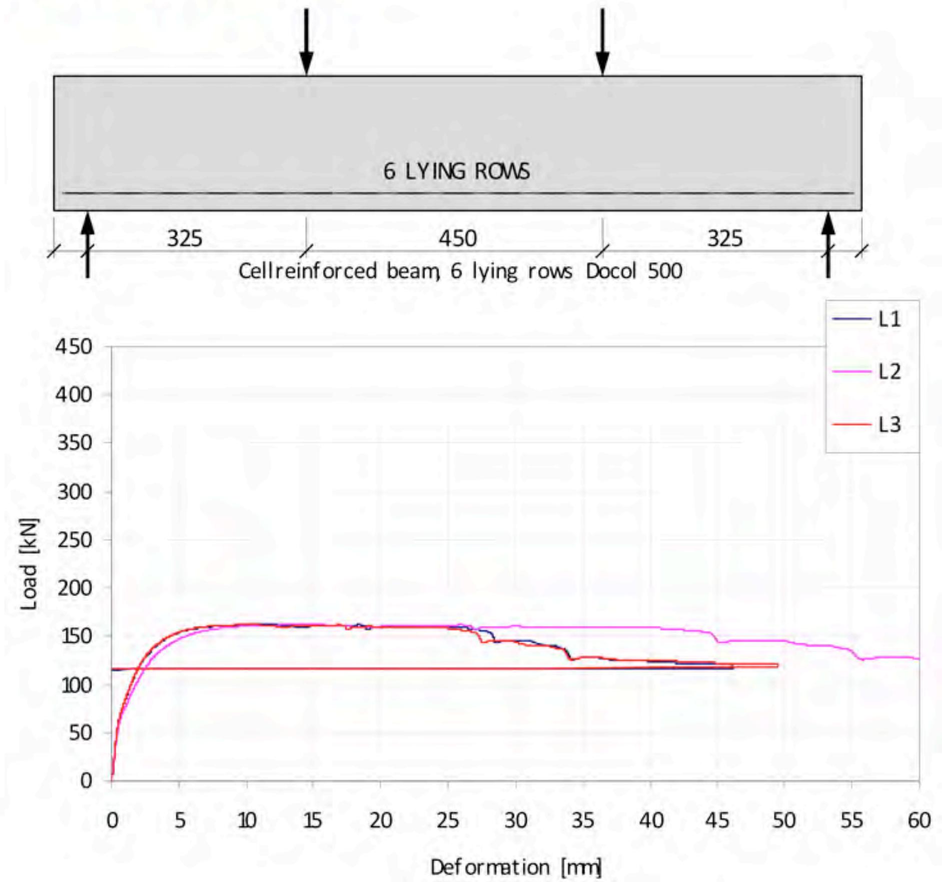


Alternative reinforcement solutions in foundations

Cell reinforcement

Example from static tests:
Yield strength 500 MPa
Ductile behaviour





Conclusions

- The competiveness of a wind power plant relies on 1. good wind conditions, 2. good and reliable turbines, 3. the height of the towers and how fast and cheap they can be built
- Requirements for building higher towers: more cost effective, lower (no) maintenance costs, competitive foundations.
- Solution is in innovations in the construction sector, that has a supportive role for the wind sector but may improve the image. Innovations such as new assembling techniques for steel towers, new reinforcement, design and construction of foundations, blade materials and design …

Conclusions

- Environmental and economical assessment are important tools for future investments (given example shows almost no difference between steel or concrete structures; about 7 g CO_2/kwh)

- Possible solutions and competence are within Swedish Universities of the Built Environment (LTU, Chalmers, KTH, LTH) where further improvements are planned.