Methods and material for sustainable and cost effective structural supporting systems

WP5: Innovative wood tower

Modvion is a Swedish company developing modular wind turbine towers from laminated wood for heights of +130 meters.

Motivation:

1. Easier transportation of tower modules

   As wind towers rise above 100 meters in height transportation causes considerable problems as 4.3 meters is the limit for transport width in most parts of the USA and the EU.

2. Decreased cost for lower weight and higher height

3. Positive environmental impact

   Emissions of about 2000 tonnes of CO_2 are avoided in tower production only

Modvion´s patented module technology

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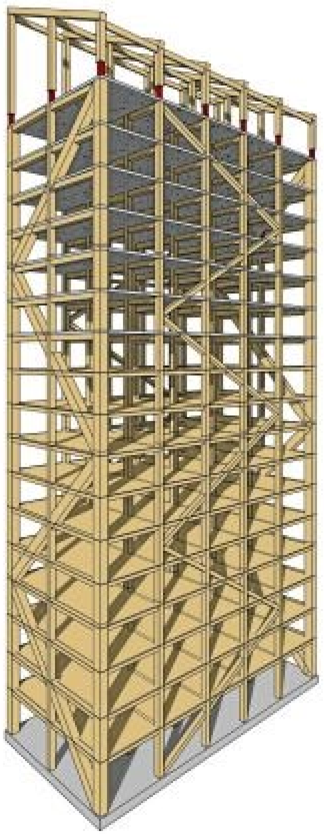
WP5: Innovative wood tower

The 81 meter high Mjösa tower in Brumunddal, Norway.

Fire impregnated Glue-Laminated Timber

High buildings made from wood is the future



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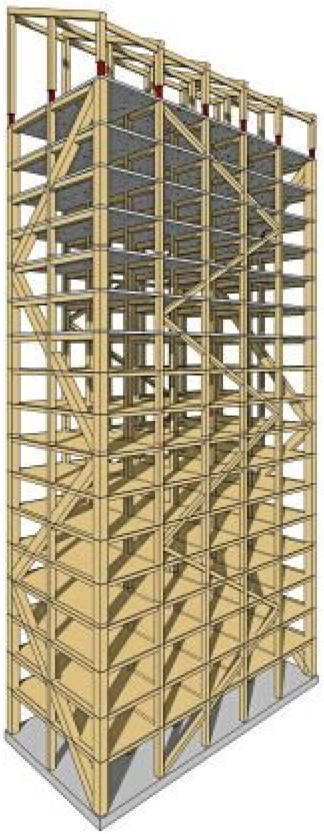
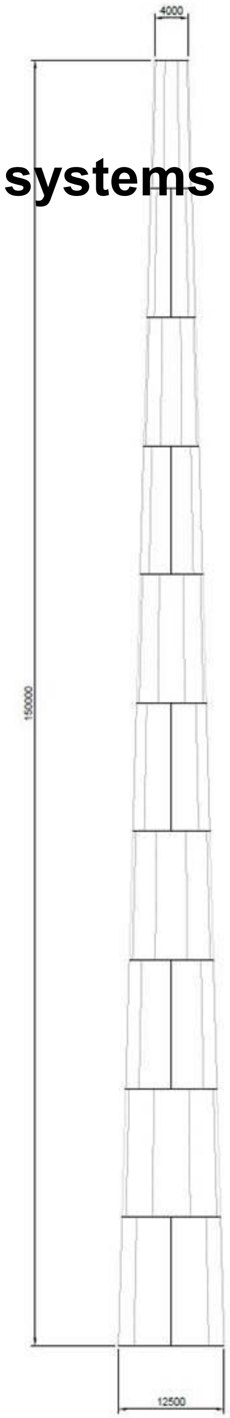
WP5: Innovative wood tower

The full size laminated wood tower next to the Mjösa tower





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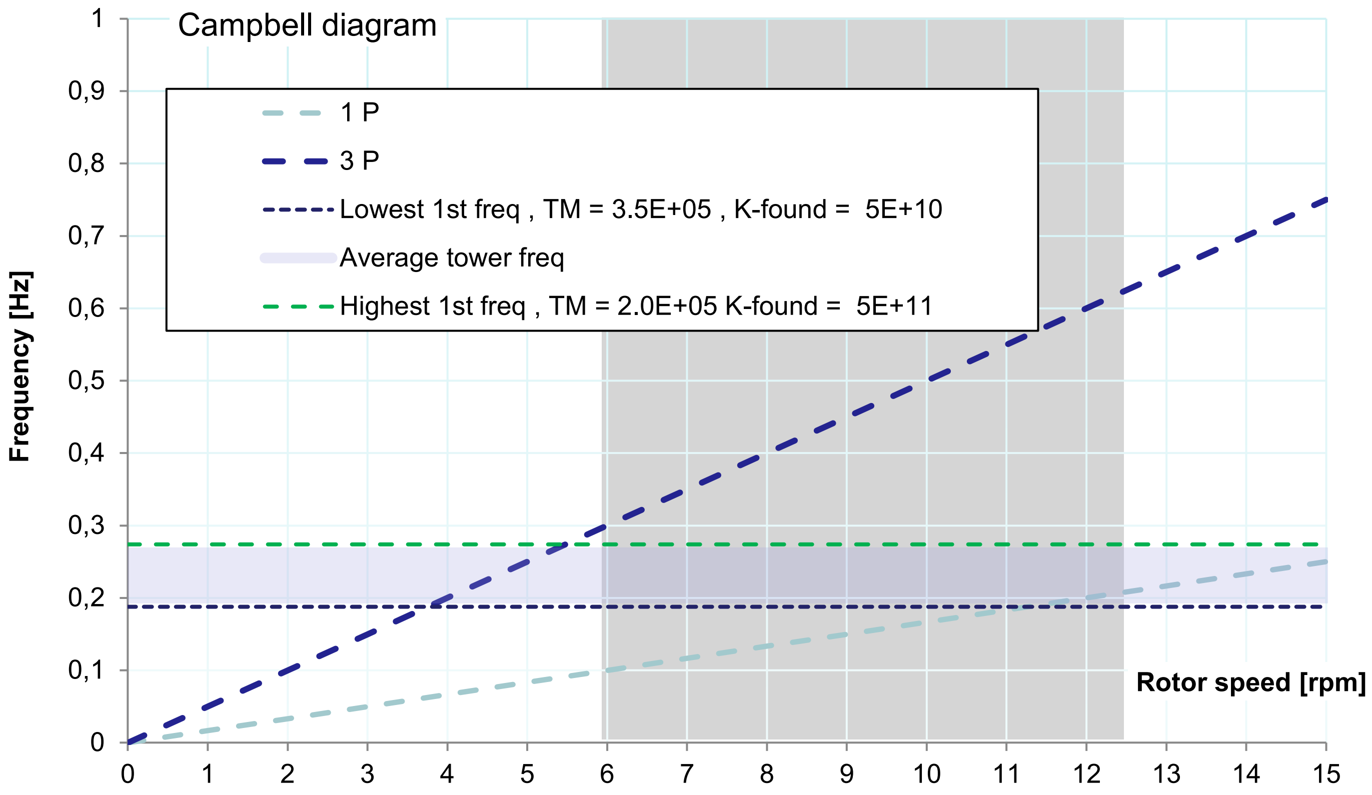
WP5: Innovative wood tower

The structural dynamics of a 150 meters laminated wood tower is similar to a 120 meters steel tower.

But wood has better damping properties.



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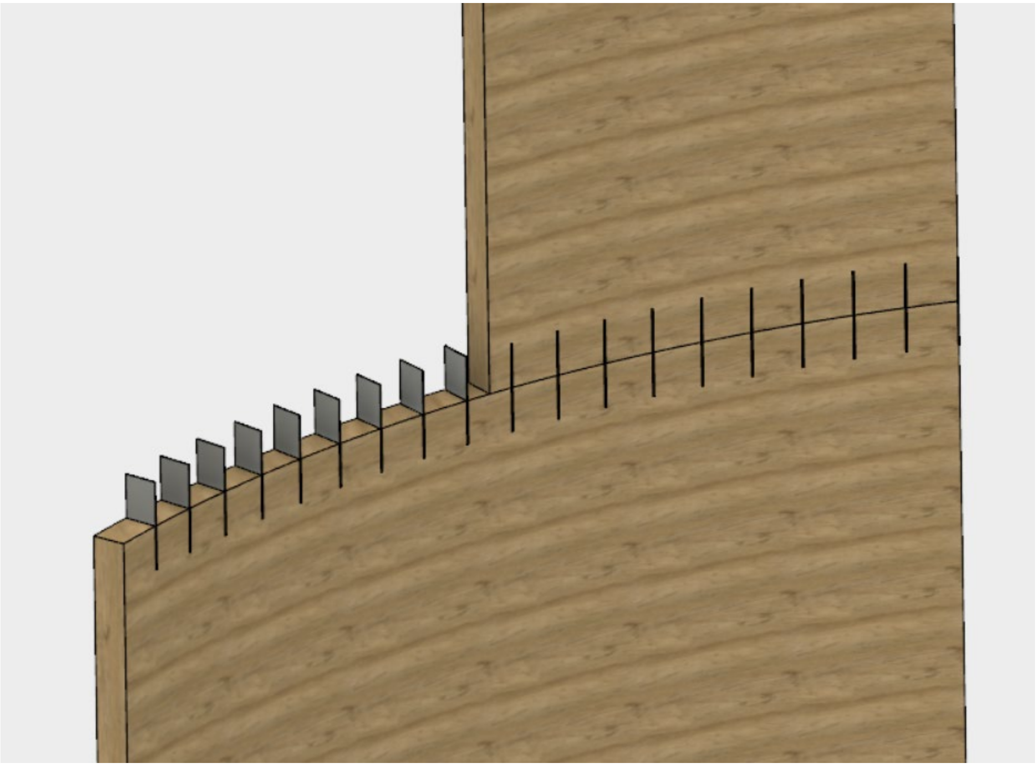
WP5: Innovative wood tower

The joint consists of perforated steel plates which are connected to the wooden structure by special glue for the purpose



Modvion´s patented module technology

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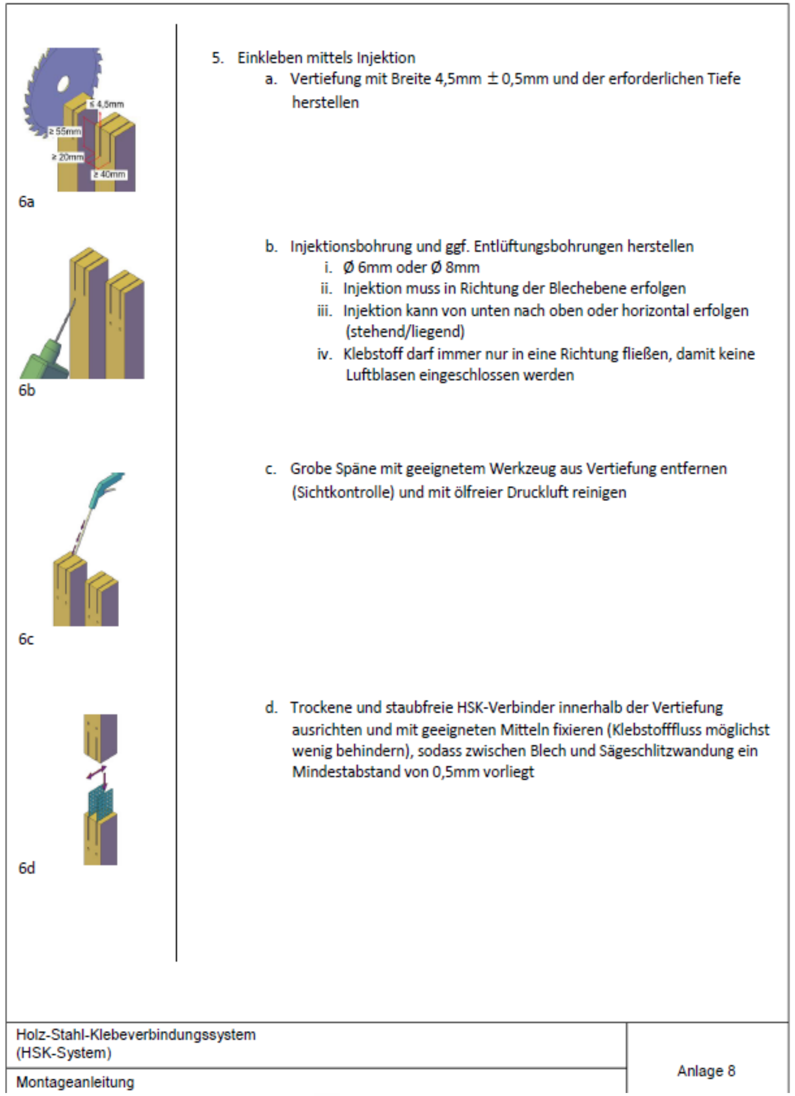
WP5: Innovative wood tower

There is an existing German instruction from DIBt and specification for general connections of wood parts.

This has been used and refined in the Modvion tower application.



5. Einkleben mittels Injektion
   a. Vertiefung mit Breite 4,5mm ± 0,5mm und der erforderlichen Tiefe herstellen
   b. Injektionsbohrung und ggf. Entlüftungsbohrungen herstellen
      i. Ø 6mm oder Ø 8mm
      ii. Injektion muss in Richtung der Blechebene erfolgen
      iii. Injektion kann von unten nach oben oder horizontal erfolgen (stehend/liegend)
      iv. Klebstoff darf immer nur in eine Richtung fließen, damit keine Luftblasen eingeschlossen werden
   c. Grobe Späne mit geeignetem Werkzeug aus Vertiefung entfernen (Sichtkontrolle) und mit ölfreier Druckluft reinigen
   d. Trockene und staubfreie HSK-Verbinder innerhalb der Vertiefung ausrichten und mit geeigneten Mitteln fixieren (Klebstofffluss möglichst wenig behindern), sodass zwischen Blech und Sägeschlitzwandung ein Mindestabstand von 0,5mm vorliegt

Holz-Stahl-Klebeverbindungssystem (HSK-System)	Anlage 8
Montageanleitung	

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WP5: Innovative wood tower

The current joint design of Modvion’s laminated wood tower has been investigated by experimental tests with respect to the structural integrity.

The specimen in the machine which has a capacity of ± 300 kN (compression/tension)

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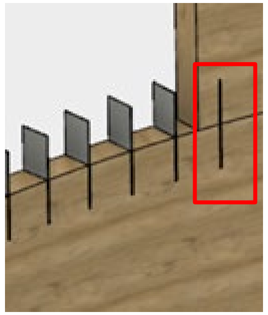
WP5: Innovative wood tower

The steel is designed to be the weaker part of the joint.

It means that failures, in case of both ultimate and fatigue loads, occur in the steel plate itself.

This is validated in the workshop tests.



Picture of the tested samples with cyclic loading
Test sample nr. 7

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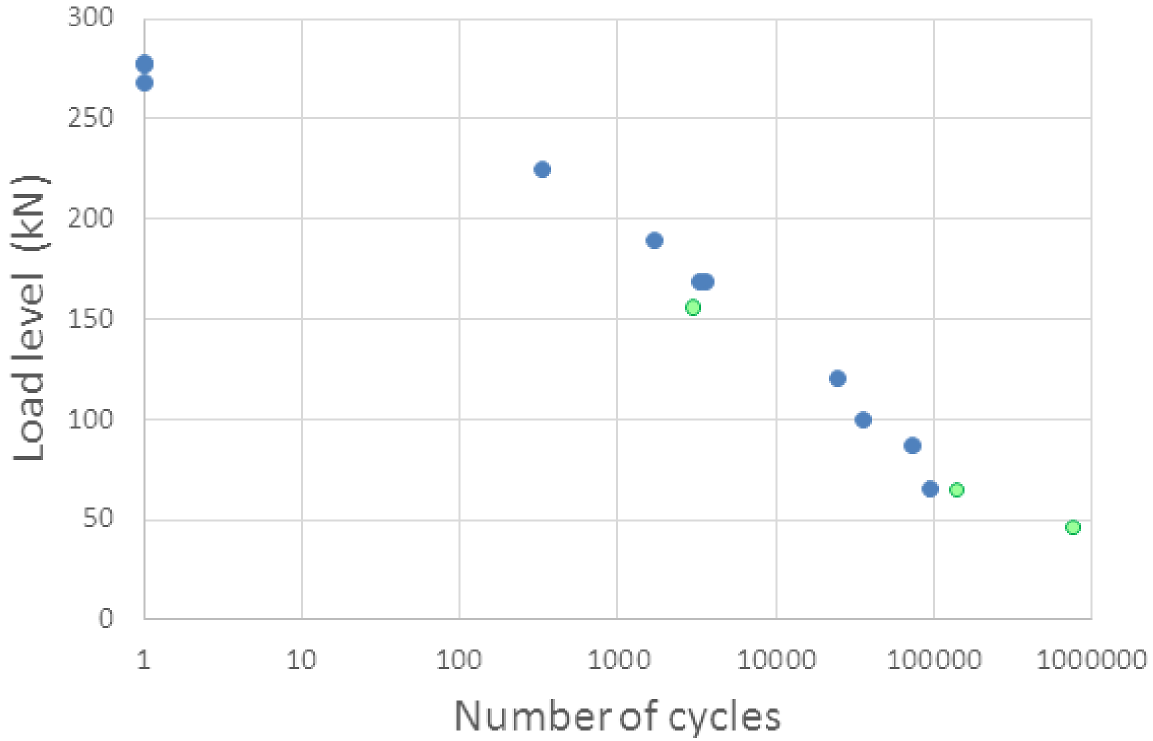
WP5: Innovative wood tower

The first group of three samples were tested to failure to establish an estimated failure load. Another 11 samples, were tested with a sinus shaped cyclic load with a stress ratio between the “upper” load and the “lower” load of R = -1.



Loads and results for the tested samples Blue dots mark “Failure”, Green dots “Test stopped without failure”

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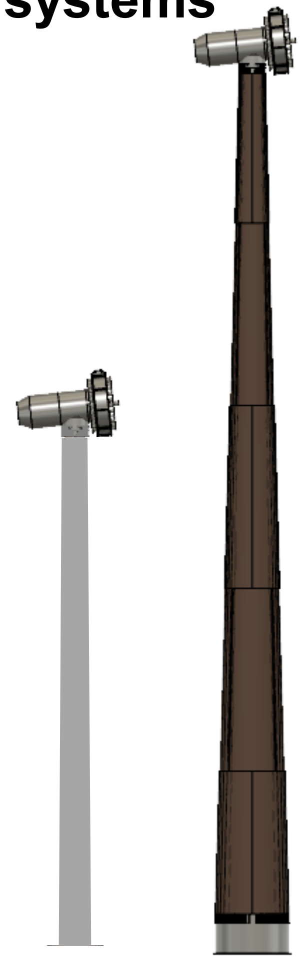
WP5: Innovative wood tower

The first pilot tower, 30 m height, is designed for the Chalmers upgraded test turbine in Gothenburg.

Manufacturing at Moelven in Töreboda



Original steel tower
vs updated wooden tower

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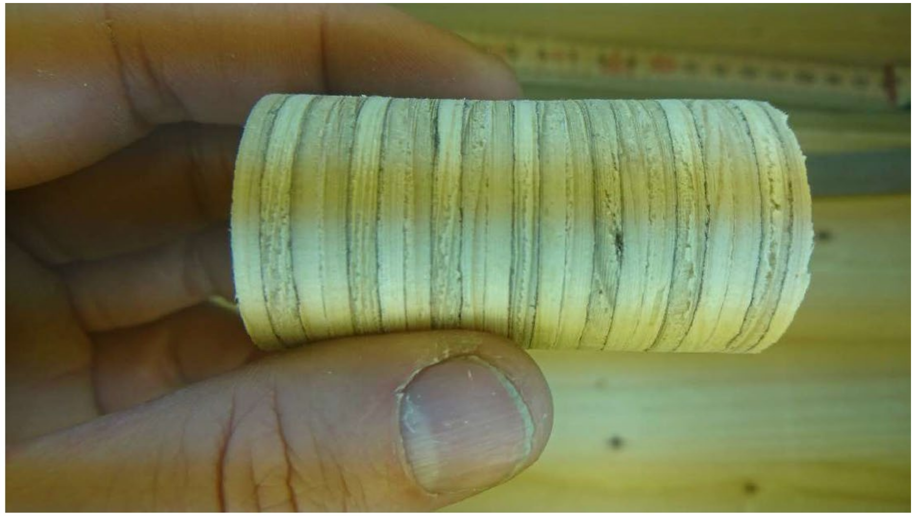
WP5: Innovative wood tower

Evaluation of the strength of lamination and the shear transferring capacity between modules.



Inspection and measuring of bondline thickness of test specimens

Figure 2 Making test specimens from the laminated module

Figure 3 ID for each test specimen

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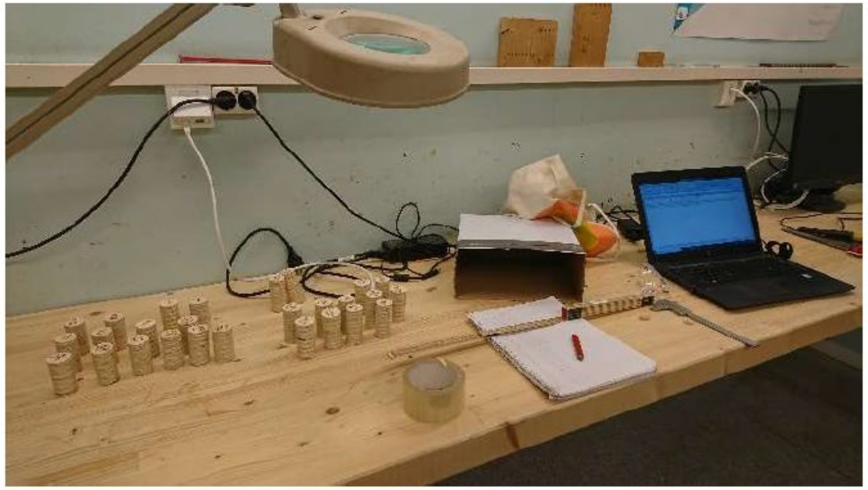
WP5: Innovative wood tower

Based on the result from the tests, the design shear strength of the bondline can be calculated according to Eurocode recommendations.

The testing was carried out in accordance with procedures in ISO 6891:1983



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WP5: Innovative wood tower

The first pilot tower was erected in the summer 2020

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WP5: Innovative wood tower

The first pilot tower was erected in the summer 2020

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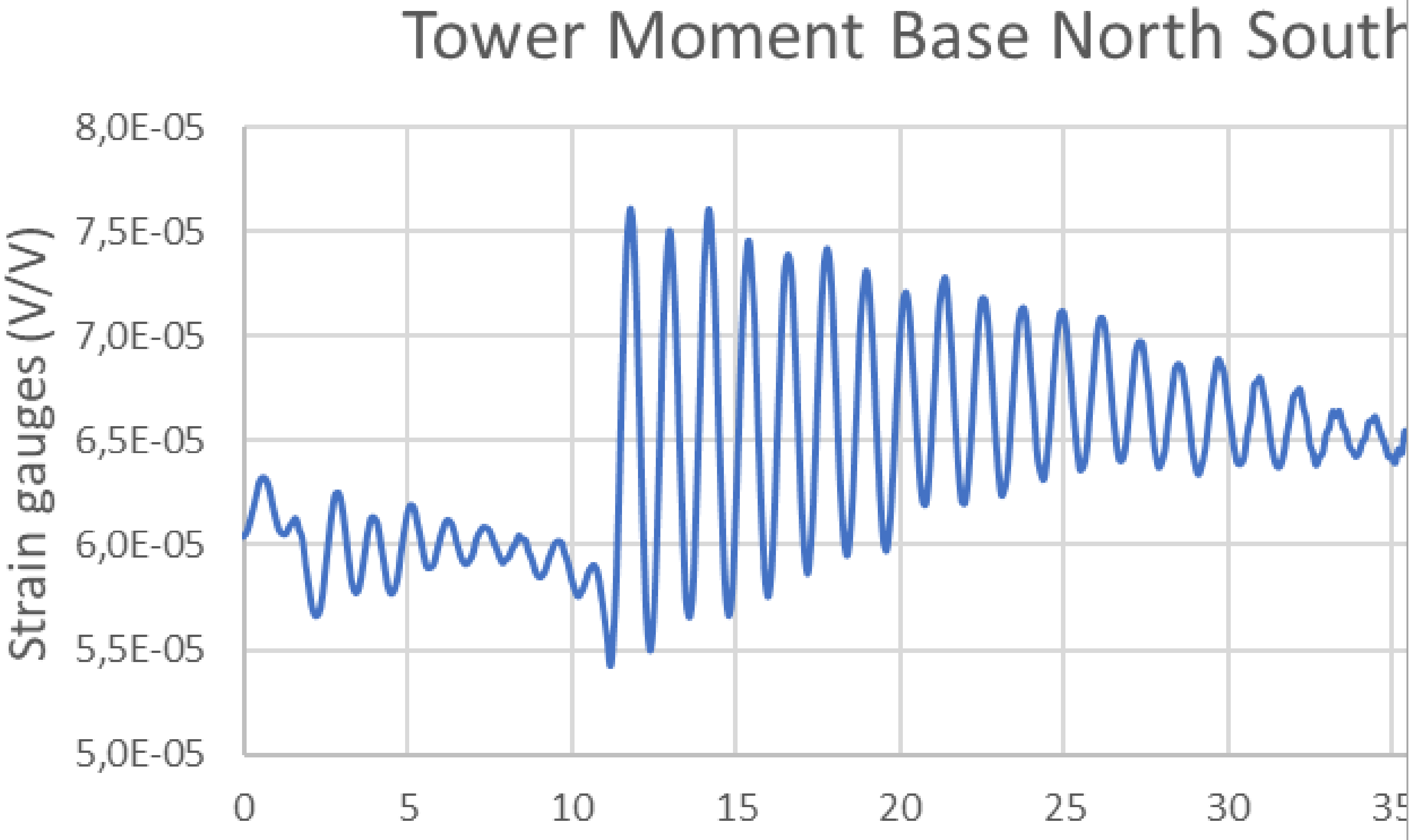
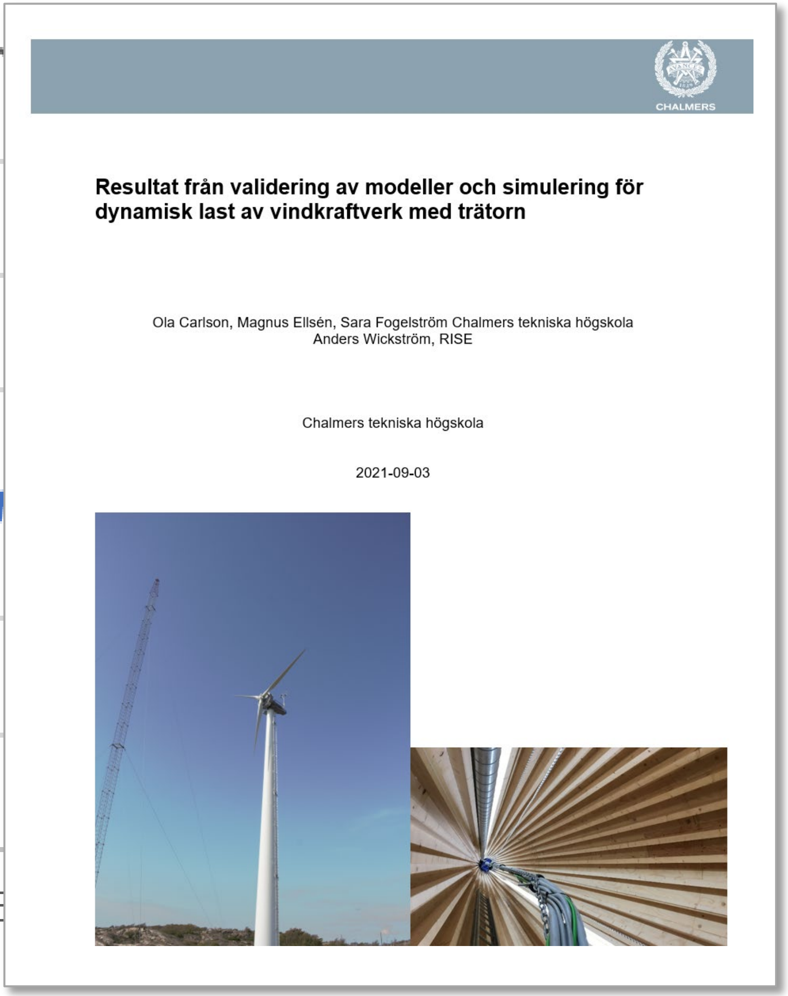
Structural dynamics and damping based on experience from Björkö tower

WP5: Innovative wood tower





Resultat från validering av modeller och simulering för dynamisk last av vindkraftverk med trätorn

Ola Carlson, Magnus Ellsén, Sara Fogelström Chalmers tekniska högskola
Anders Wickström, RISE

Chalmers tekniska högskola

2021-09-03

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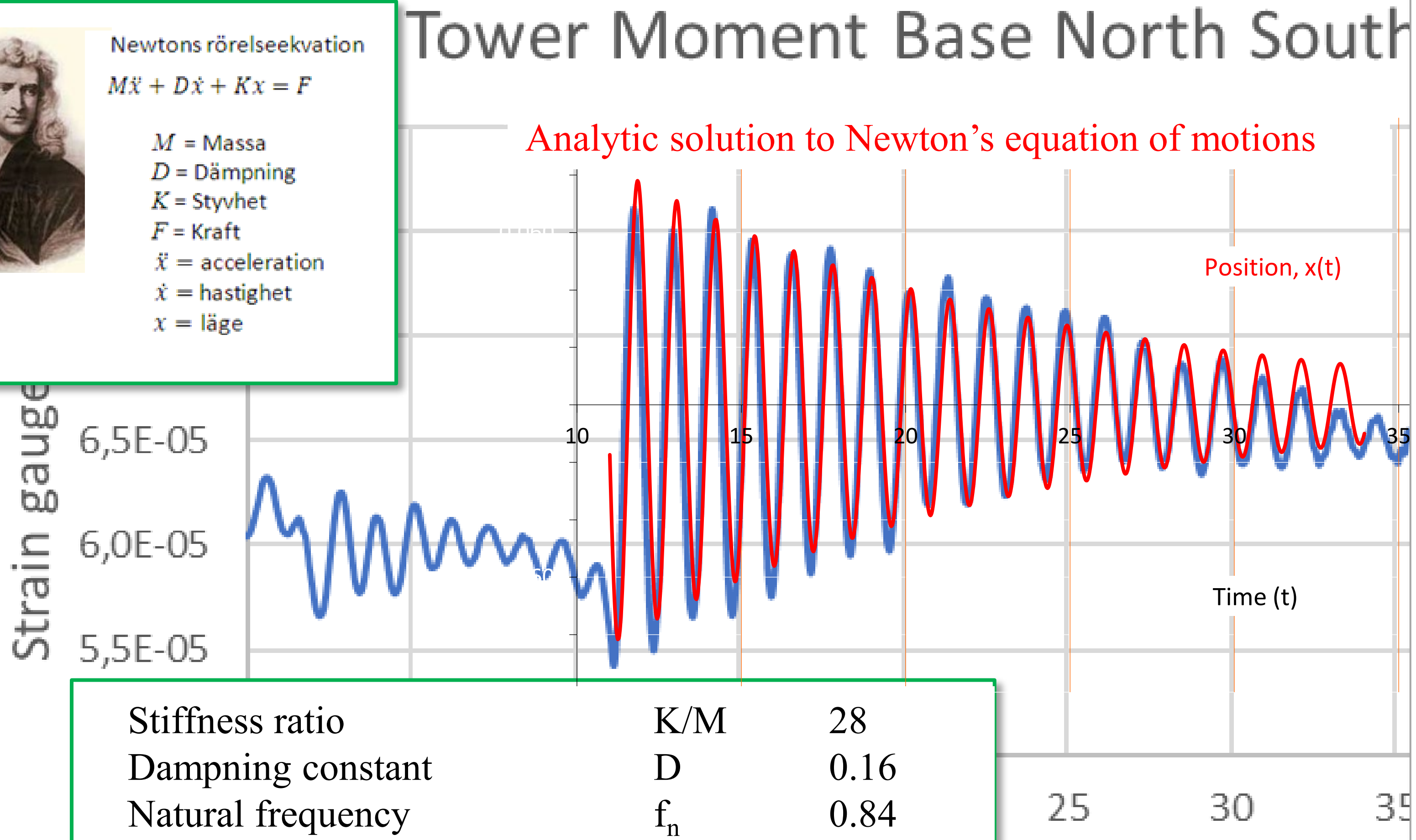
Structural dynamics and damping based on experience from Björkö tower

WP5: Innovative wood tower

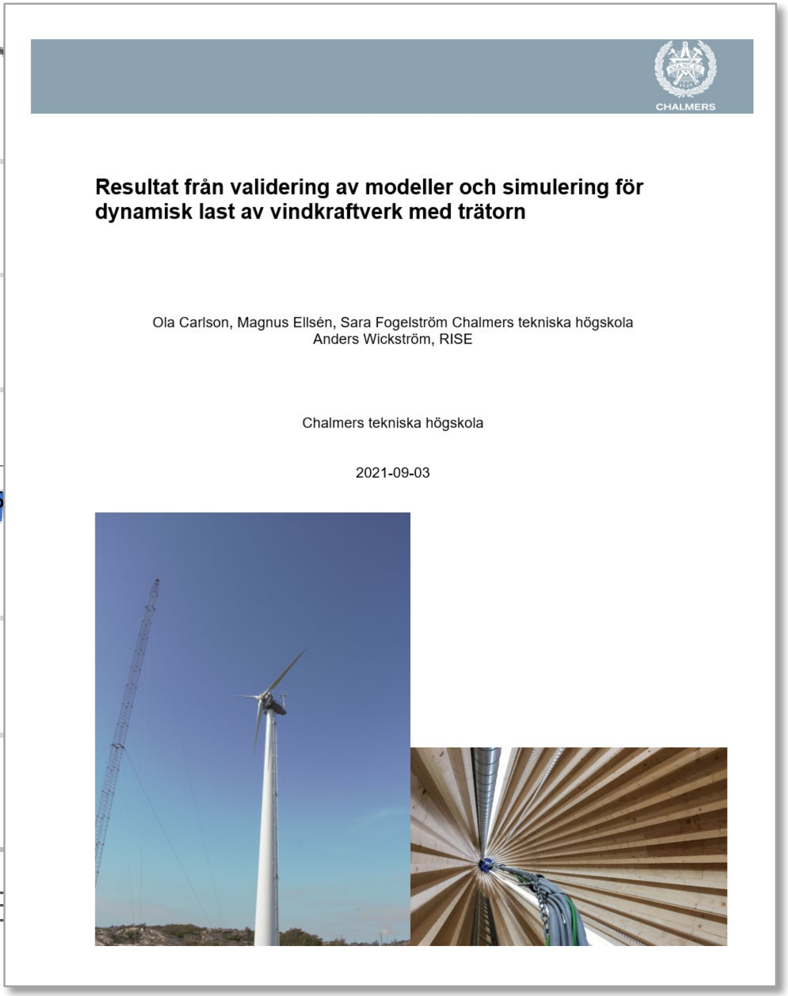
Newtons rörelseekvation

$$M\ddot{x} + D\dot{x} + Kx = F$$

- M = Massa
- D = Dämpning
- K = Styvhet
- F = Kraft
- $\ddot{x}$ = acceleration
- $\dot{x}$ = hastighet
- x = läge



Stiffness ratio	K/M	28
Dampning constant	D	0.16
Natural frequency	f_n	0.84
Relative damping	ζ	0.015
Logaritmic decrementet	δ	0.094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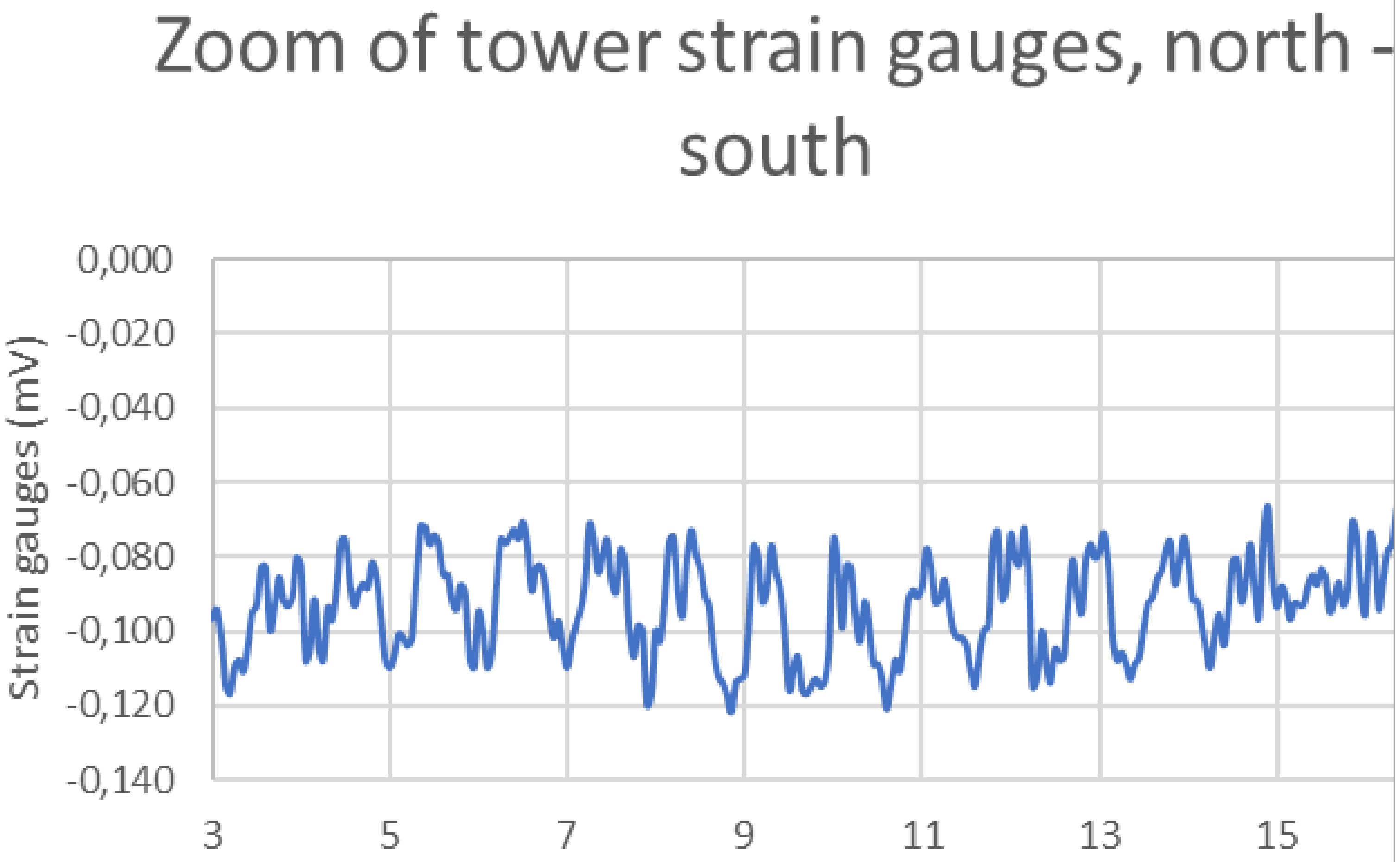
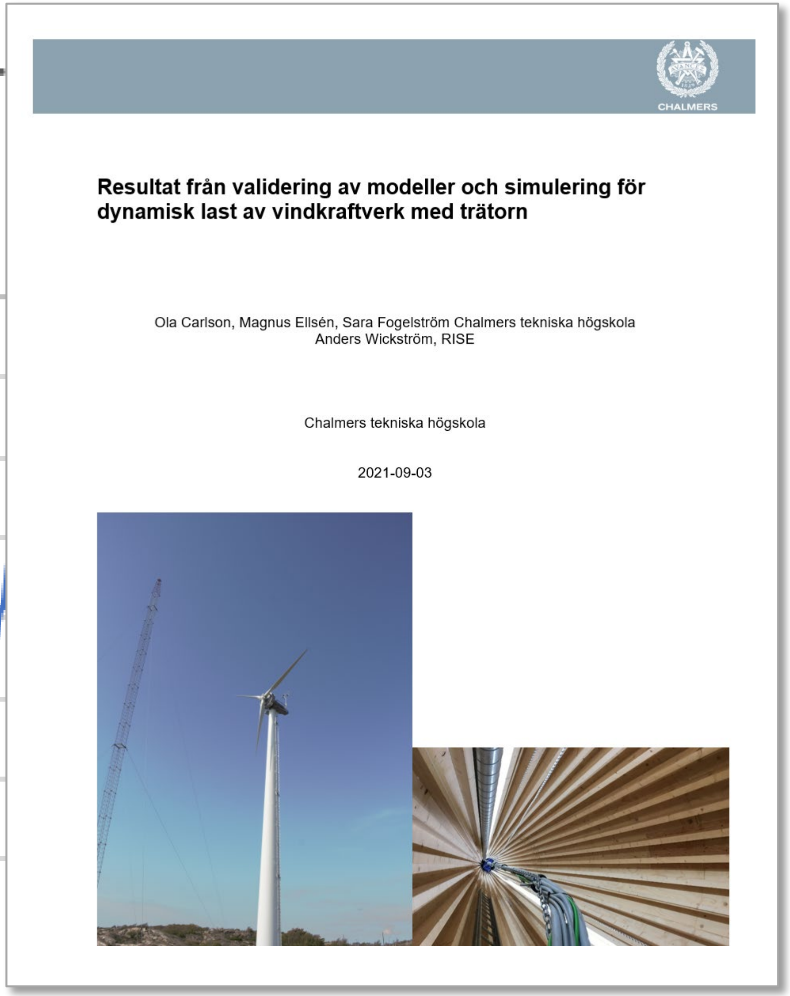
Structural dynamics and damping based on experience from Björkö tower





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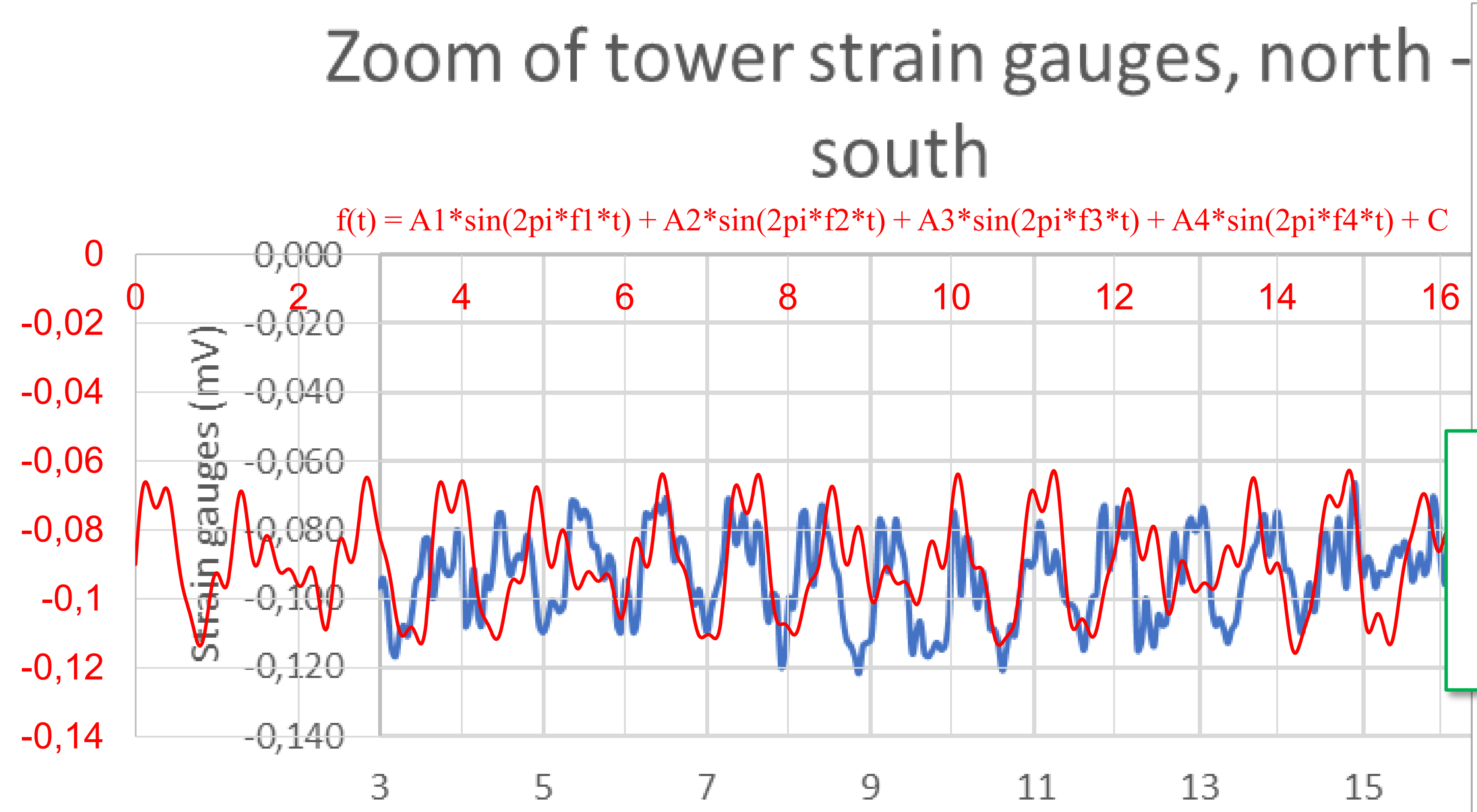
Structural dynamics and damping based on experience from Björkö tower



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Resultat från validering av modeller och simulering för dynamisk last av vindkraftverk med trätorn

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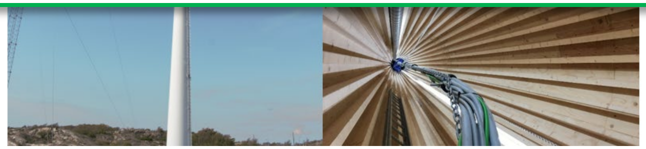
Chalmers tekniska högskola

2021-09-03

Varvtal	n	=	66	rpm
		1P		3P
f-nr	1	2	3	4
A	0.015	0.010	0.005	0.005
f	0.83	1.10	2.50	3.30
C	-0.09			



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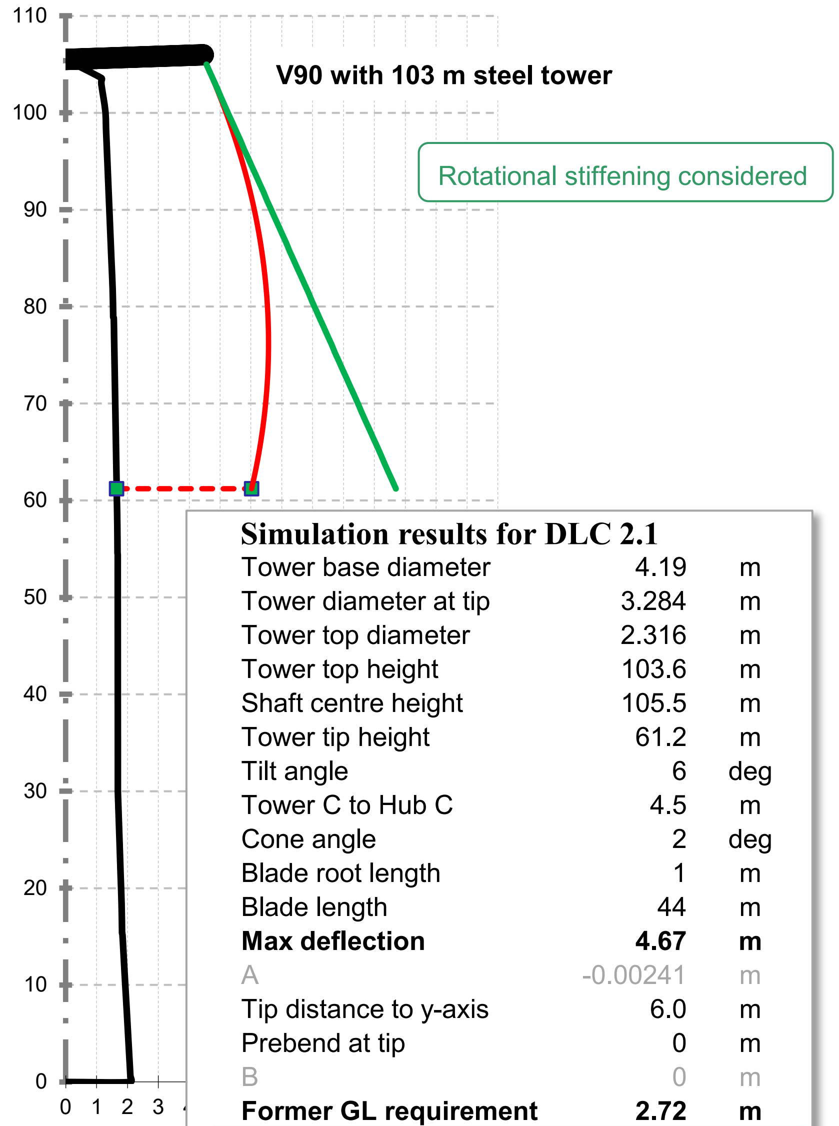
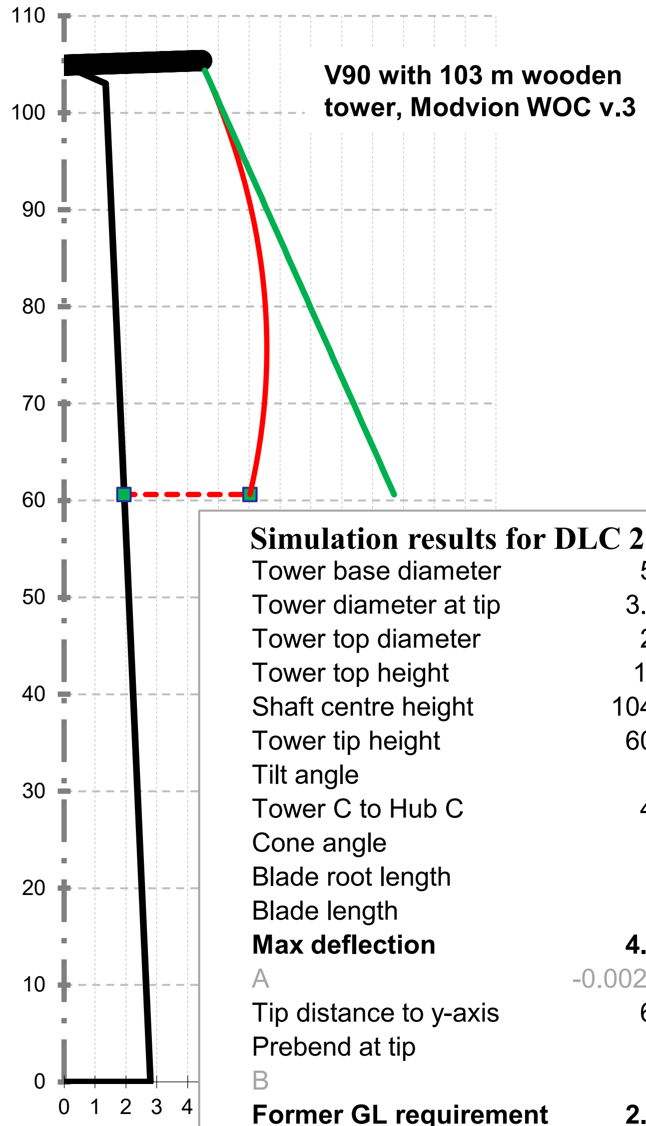
Calculation of tower clearance based on a Vestas V90 on different towers



Simulation results for DLC 2.1

Tower base diameter	4.19	m
Tower diameter at tip	3.284	m
Tower top diameter	2.316	m
Tower top height	103.6	m
Shaft centre height	105.5	m
Tower tip height	61.2	m
Tilt angle	6	deg
Tower C to Hub C	4.5	m
Cone angle	2	deg
Blade root length	1	m
Blade length	44	m
Max deflection	**4.67**	**m**
A	-0.00241	m
Tip distance to y-axis	6.0	m
Prebend at tip	0	m
B	0	m
Former GL requirement	**2.72**	**m**
Tip to tower	**4.38**	**OK**

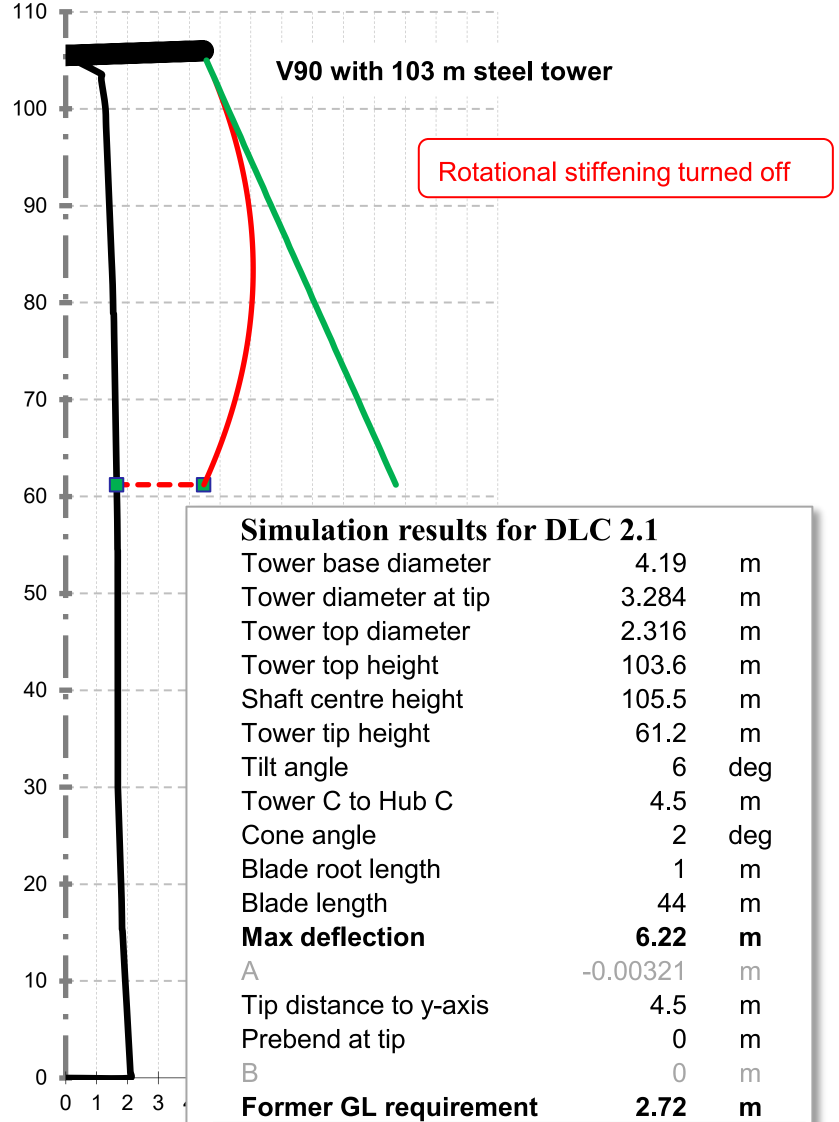


Simulation results for DLC 2.1

Tower base diameter	5.6	m
Tower diameter at tip	3.89	m
Tower top diameter	2.7	m
Tower top height	103	m
Shaft centre height	104.9	m
Tower tip height	60.6	m
Tilt angle	6	deg
Tower C to Hub C	4.5	m
Cone angle	2	deg
Blade root length	1	m
Blade length	44	m
Max deflection	**4.67**	**m**
A	-0.00241	m
Tip distance to y-axis	6.0	m
Prebend at tip	0	m
B	0	M
Former GL requirement	**2.62**	**m**
Tip to tower	**4.08**	**OK**

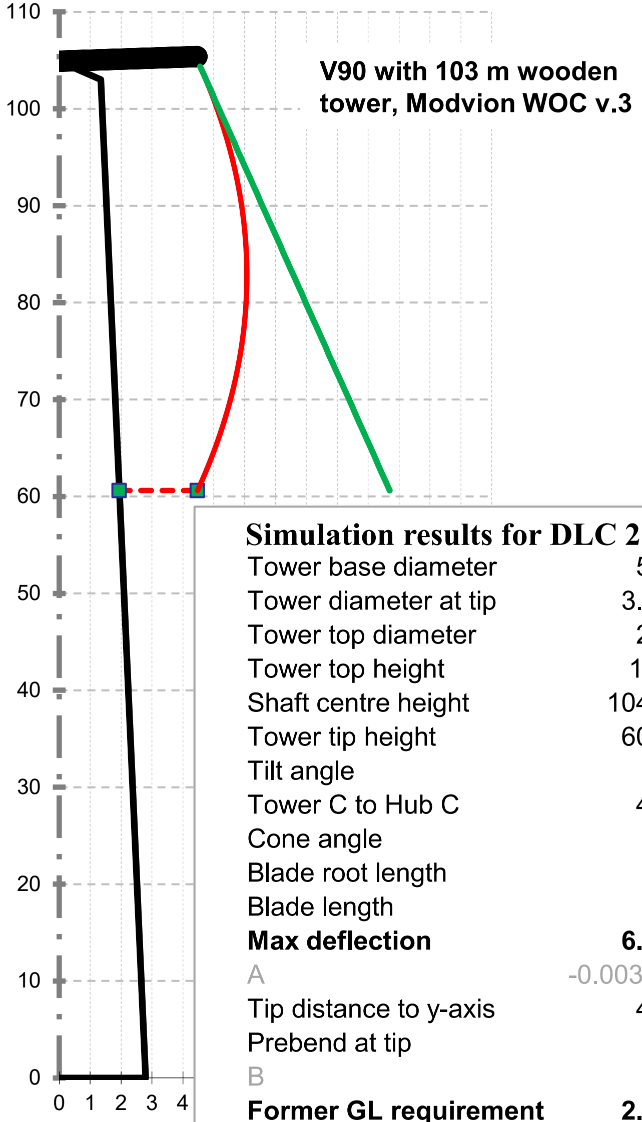
Check of tower clearance due to larger tower diameter than the ordinary steel towers used for Vestas V90

Calculation of tower clearance based on a Vestas V90 on different towers



Simulation results for DLC 2.1

Tower base diameter	4.19	m
Tower diameter at tip	3.284	m
Tower top diameter	2.316	m
Tower top height	103.6	m
Shaft centre height	105.5	m
Tower tip height	61.2	m
Tilt angle	6	deg
Tower C to Hub C	4.5	m
Cone angle	2	deg
Blade root length	1	m
Blade length	44	m
Max deflection	**6.22**	**m**
A	-0.00321	m
Tip distance to y-axis	4.5	m
Prebend at tip	0	m
B	0	m
Former GL requirement	**2.72**	**m**
Tip to tower	**2.83**	**OK**



Simulation results for DLC 2.1

Tower base diameter	5.6	m
Tower diameter at tip	3.89	m
Tower top diameter	2.7	m
Tower top height	103	m
Shaft centre height	104.9	m
Tower tip height	60.6	m
Tilt angle	6	deg
Tower C to Hub C	4.5	m
Cone angle	2	deg
Blade root length	1	m
Blade length	44	m
Max deflection	**6.22**	**m**
A	-0.00321	m
Tip distance to y-axis	4.5	m
Prebend at tip	0	m
B	0	m
Former GL requirement	**2.62**	**m**
Tip to tower	**2.53**	**NOT OK**

Check of tower clearance due to larger tower diameter than the ordinary steel towers used for Vestas V90

Methods and material for sustainable and cost effective structural supporting systems

WP5: Innovative wood tower

Examine and validate fire resistance

Ignition sources

Test plan with time for fire exposure

Test specimen	Wood crib	Burner 30 kW	Burner 100 kW
Test trial 1			
Unprotected wood	~70 min*	30 min	-
Test trial 2			
Unprotected wood	-	-	60 min
Wood with coating	~70 min*	60 min	60 min

* Test continues until the wood crib is fully consumed.

Methods and material for sustainable and cost effective structural supporting systems

Examine and validate fire resistance

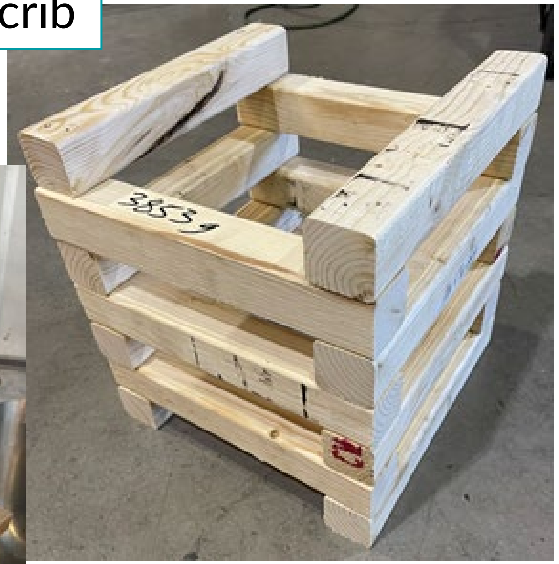
Ignition sources

Three ignition sources:

1. Burner – 30 kW
2. Wood crib, 300x300x300mm
3. Burner – 100 kW

Fibre board (200x95x10mm)
soaked with 1 dl methanol

Woo
d crib



Burner

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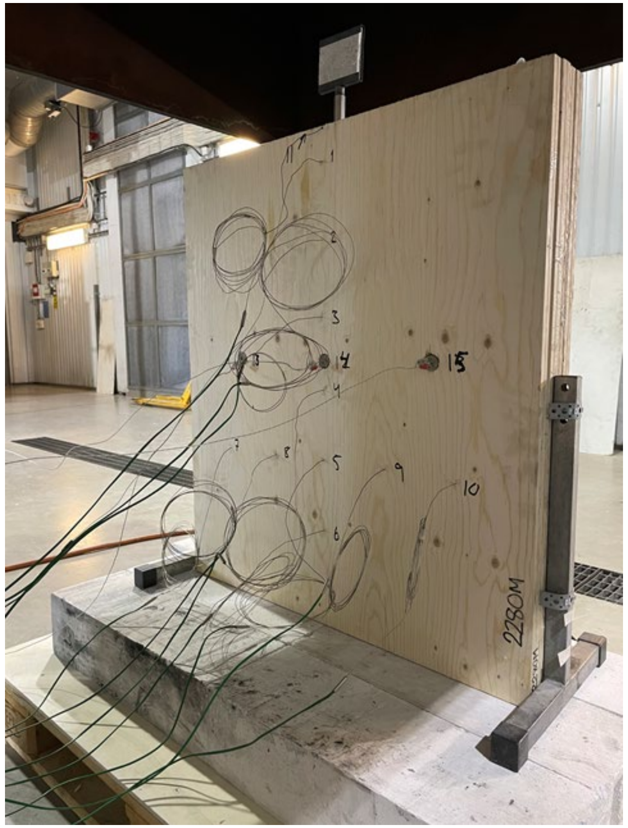
Methods and material for sustainable and cost effective structural supporting systems

Examine and validate fire resistance

Test 1_A1
Untreated wood panel/Burner 30 kW

Test set up - Burner

Thin skin calorimeter



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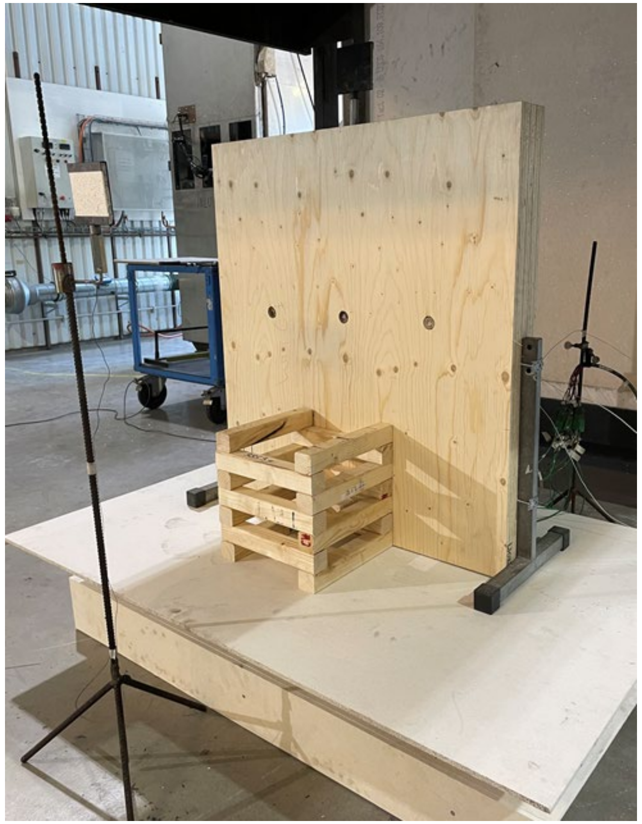
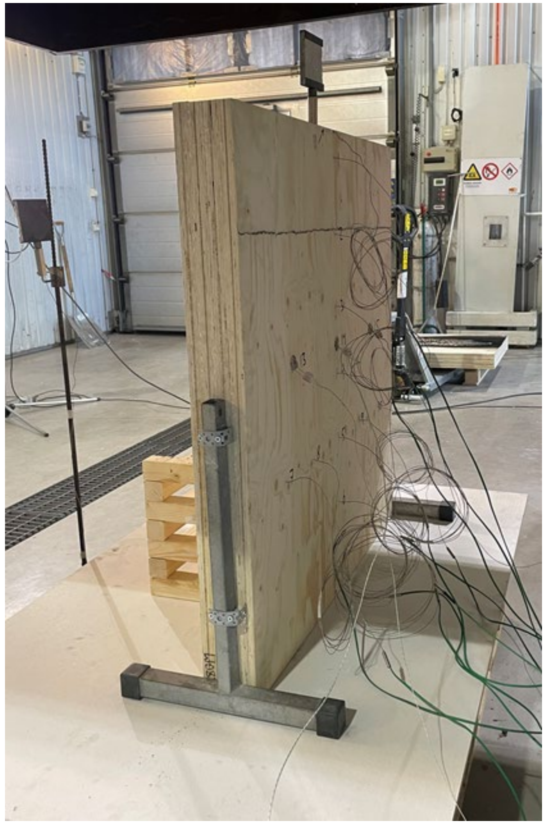
Methods and material for sustainable and cost effective structural supporting systems

Examine and validate fire resistance

Test 2_B1
Untreated wood panel/Wood crib

Test set up – Wood crib

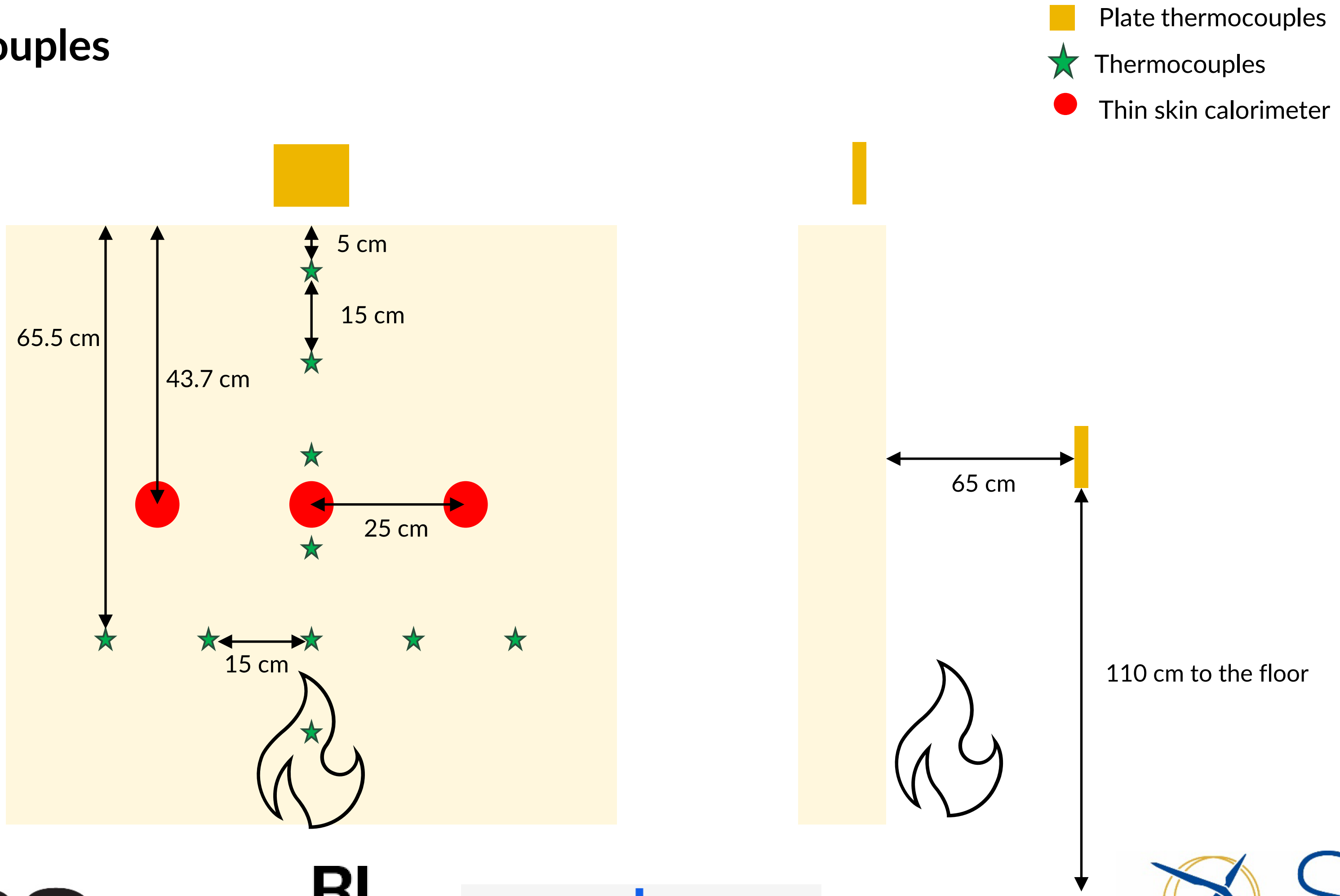




Methods and material for sustainable and cost effective structural supporting systems

Examine and validate fire resistance

Positions of thermocouples



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Methods and material for sustainable and cost effective structural supporting systems

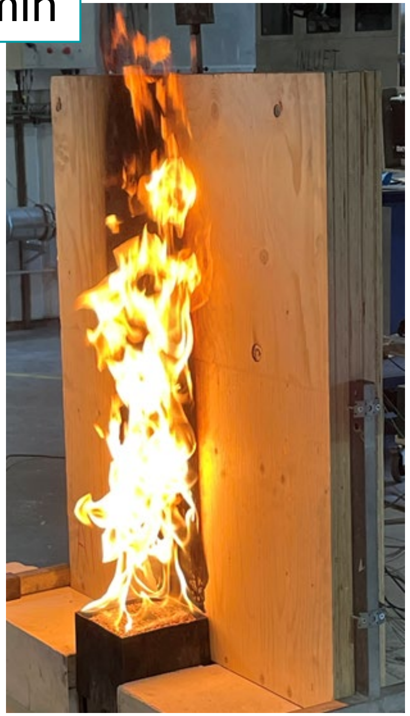
Examine and validate fire resistance

Test 1_A1
Untreated wood panel/Burner 30 kW

During fire test with burner

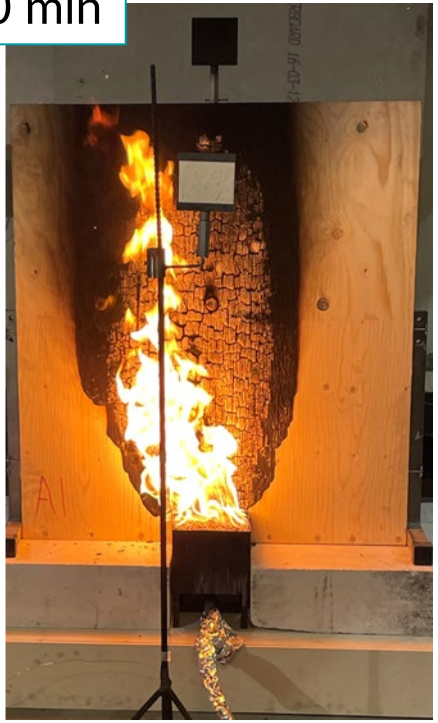
1 min

5 min



15 min

30 min



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Methods and material for sustainable and cost effective structural supporting systems

Examine and validate fire resistance

Test 1_A1
Untreated wood panel/Burner 30 kW

Result - Burner

Depth of charred wood ≈ 1 cm
Protecting inner layers of wood

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Methods and material for sustainable and cost effective structural supporting systems

Examine and validate fire resistance

During fire test with wood crib

Test 2_B1
Untreated wood panel/Wood crib

2 min

5 min

30 min

45 min

60 min

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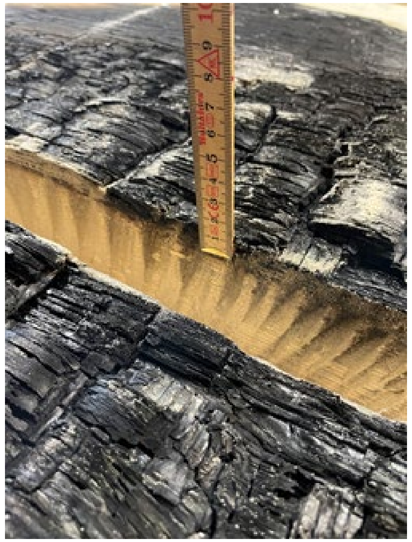
Examine and validate fire resistance

Test 2_B1
Untreated wood panel/Wood crib

Result – Wood crib



Depth of charred wood ≈ 1 cm
Protecting inner layers of wood

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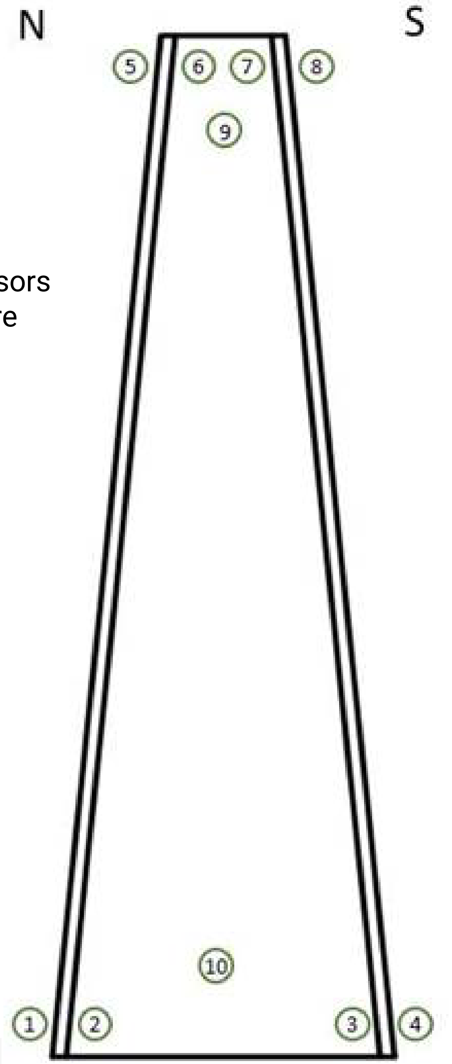
Methods and material for sustainable and cost effective structural supporting systems

Examine and validate content of moisture in the air

Evaluation of measurements and investigation/test of air- and rain leakage

Positions of RH and T sensors and electrodes for moisture content measurement



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Methods and material for sustainable and c

Examine and validate content of moisture in the air

Evaluation of measurements and investigation/te and rain leakage

RI. SE

UTLÅTANDE

Kontaktperson RISE	Datum	Beteckning	Sida
Lars Olsson Samhällsbyggnad +46 10 516 50 23 lars.olsson@ri.se	2022-05-06	P105307-F1	1 (5)

Modvion

Inledande utvärdering av klimat och luft o regnläckage i trätorn, Björkö

(6 bilagor)

Uppdrag/bakgrund

RISE har fått i uppdrag av Modvion att utvärdera klimatmätningar i ett trätorn på Björkö i Göteborg samt en inledande luftläckagesökning och regn-/vatteninläckagesökning vid botten av trätornet med mera. Modvion har låtit utföra kontinuerliga fukt- och temperaturmätningar (mätdata) som har delgivits RISE via åtkomst till Celsiview (Celsicom).

Trätornet har en konisk form och är 30 m högt, se bilaga 5. Väggarna består av laminerat trä, LVL, med tjocklek av 60 mm och reglar invändigt. Utsidan har en coating av polyurea, med primer av epoxy och topcoat av polyuretan. Insidan är obehandlad.

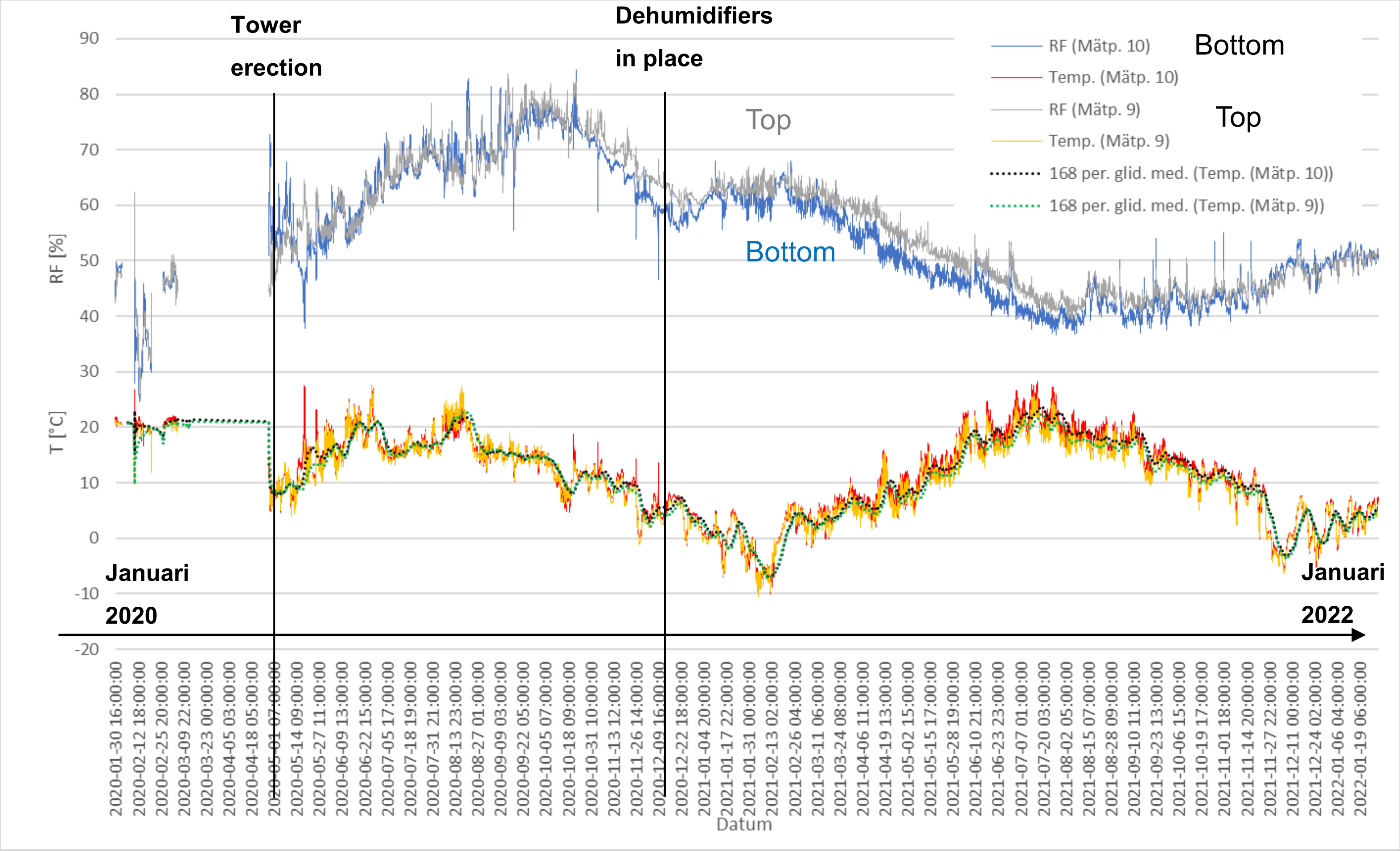
Methods and material for sustainable and cost effective structural supporting systems

Examine and validate content of moisture

Measurements of RH and temp.

There are small differences in Relative Humidity (RH) and temperature of indoor air in the tower at bottom space and top space. because of mechanical air mixing.

Dehumidifier installed late 2020 seems to work well (results in approx. 50% RH)



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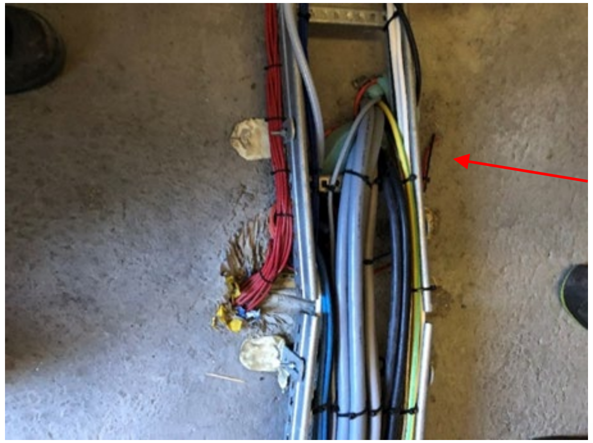
Methods and material for sustainable and cost effective structural supporting systems

Examine and validate content of moisture in the air

Investigation of moisture sources

- Air leakage in door, gaps between sealing strip and door, and through pipes in floor.
- Rain/water penetration between tower and concrete foundation during ongoing test and water penetration in door.
- Probably ongoing moisture evaporation from concrete foundation.

Inward leakage of water



Inward leakage of air through pipes from ground

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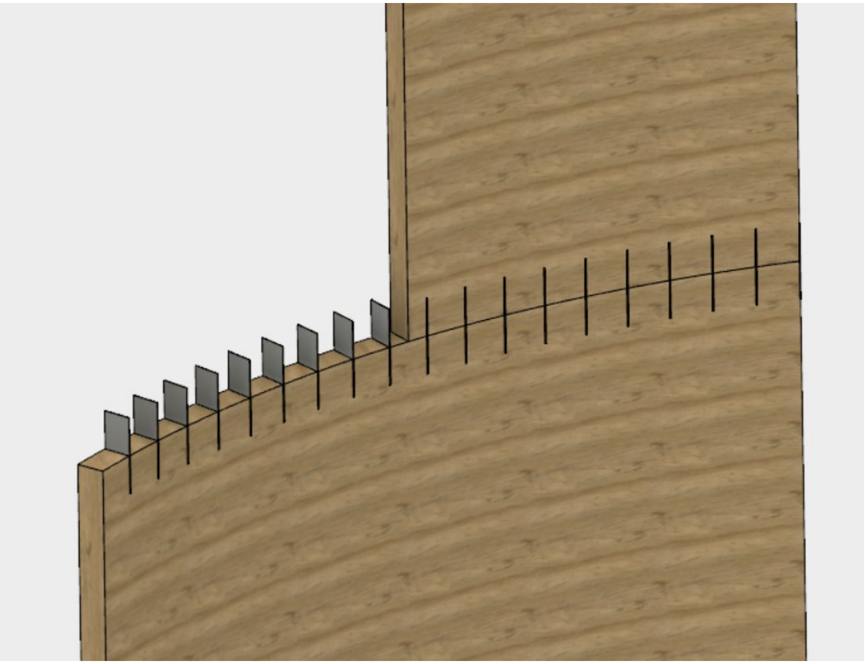
Methods and material for sustainable and cost effective structural supporting systems

I ur och skur – Whether Weather

On-site gluing and weather effects on tall wooden wind turbine towers

Modvion’s glued connections offer:

- Quick assembly at the construction site.
- High strength and stiffness.



Modvion´s patented module technology

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Glues vary in properties depending on temperature and moisture content.

Glues are dominantly applied in controller indoor climates.

Raumtemperatur	17 °C	20 °C	30 °C
Frühester Zeitpunkt, zudem eine mechanische Beanspruchung von höchstens 75 % der Maximallast erfolgen darf in Tagen	3	2	1
Zeitdauer bis zum Erreichen der endgültigen Klebfugenfestigkeit in Tagen	14	7	3

Deutshes Institut für Bauteknik DIBt, Z-9.1-896 – Henkel & Cie. AG – 2K-PUR Klebstoff LOCTITE CR 821 PURBOND zum Einkleben von Stahlstäben in tragende Holzbauteile, 2020

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On-site gluing and weather effects on tall wooden wind turbine towers

To investigate how weather effects influence the performance of the joints.

Temperature and Moisture

How does the temperature and moisture content of the surrounding air impact the bond quality of the joints?

Loads during curing

How does the strength increase during curing and when is full capacity reached?

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On-site gluing and weather effects on tall wooden wind turbine towers

Small scale tensile test

The following tests will be performed:

- Curing time of 7 days

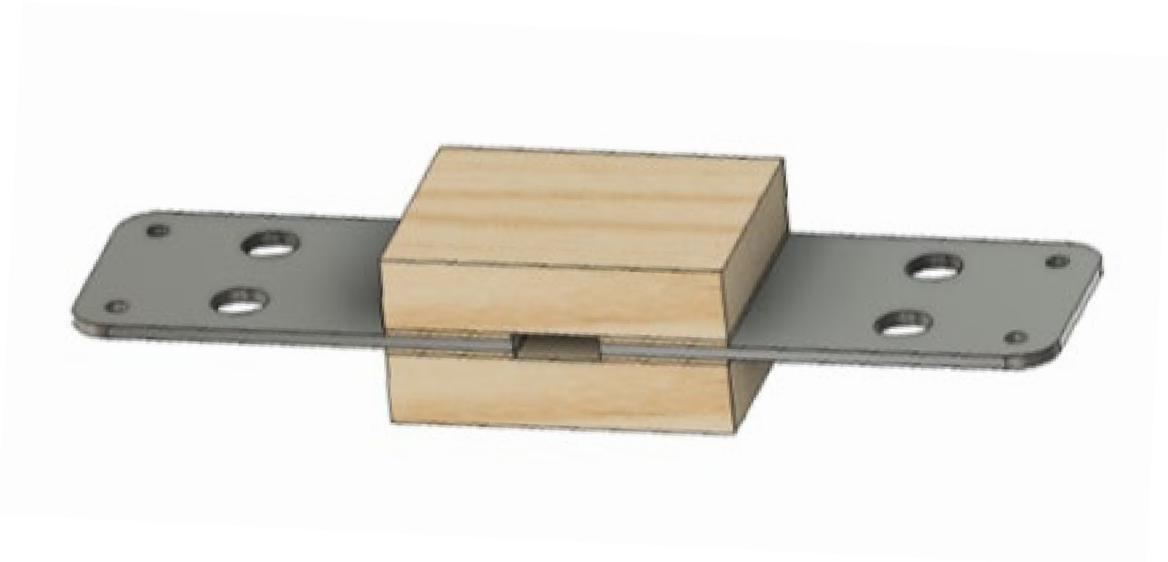

Table 1. *Test series at different curing times*

Test Batch	Curing times	Number spec.
Batch CT1	1 hour	5
Batch CT2	3 hours	5
Batch CT3	6 hours	5
Batch CT4	12 hours	5
Batch CT5	24 hours	5
Batch CT6	2 days hours	5
Batch CT7	4 days hours	5

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On-site gluing and weather effects on tall wooden wind turbine towers

Small scale tensile test

The following tests will be performed:

- Curing time of 7 days
- Temperatures of 0 to 30 °C
- Relative humidity of 10 to 95 %

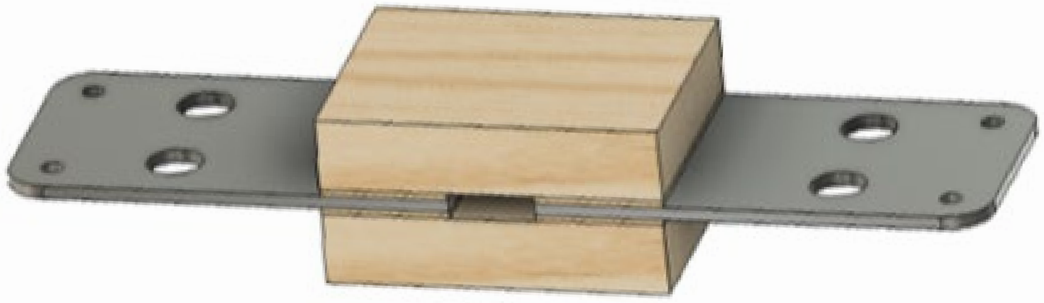

Table 2. *Test series at different climate conditions*

Test batch	Storing, gluing and curing conditions (surrounding air)	Number of specimens
Batch T1	0 °C / 65% RH	5
Batch T2	5 °C / 65% RH	5
Batch T3	10 °C / 65% RH	5
Batch T4	30 °C / 65% RH	5
Batch RH1	20 °C / 95% RH	5
Batch RH2	20 °C / 10% RH	5

Note: Mostiure equilibrium at respective RH

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World Conference on Timber Engineering Oslo 2023

WEATHER RELATED EFFECTS ON HYBRID JOINTS GLUED ON-SITE

Viktor Norbäck[1], Pierre Landel[2], Erik Dölerud[3], Anders Wickström[4]

ABSTRACT: Modvion develops modular wind turbine towers made of wood. The application requires strong and stiff connections. To achieve the desired performance a hybrid connection with perforated steel plates slotted into LVL modules is used. The parts are glued together on site, using a polyurethane adhesive (PUR), providing high stiffness to the connection. This study aims to investigate how temperature and relative humidity of the surrounding air during assembly will influence the quality of the bond glued on site. In addition, the strength growth during curing is investigated. The results will serve as an initial screening, identifying which parameters will influence the performance of the timber to steel connections glued on site.

KEYWORDS: Tensile strength, Polyurethane adhesive, On-site gluing, LVL, Glued-in plates connection type

1 INTRODUCTION

The Swedish company Modvion AB is developing modular wind turbine towers made of wood. To be competitive, the production method must be both reliable and fast. To achieve this a recently developed joining technique is used, where the LVL wall-modules are assembled on-site, combining adhesive and perforated steel plates. Thin plates made of high strength steel are inserted into slots in the wall-modules and bonded using a two-component polyurethan (PUR) adhesive. The method results in strong and stiff connections with glue-dowels through the holes of the plate. This hybrid type of glued-in plate joints has been used in different timber building applications to elegantly assemble CLT, LVL and GLT elements. The method is similar to glued-in rods, which also is adhesively bonded steel and timber. Research and development works have been performed in central Europe [1] and in Germany, where the commercial and certified HSK-system from the company TiComTec is available [2].

Connections with glued-in plates provides a strong and stiff connection compared to more traditional mechanical connections for timber structures, e.g. screws and dowels. It can be applied with high precision and keeps the steel elements encapsulated in the timber structure. However, the application process of adhesives for structural timber products is recommended for controlled conditions that

parameters temperature, humidity and curing time are investigated experimentally to determine their impact on the tensile capacity of the joints. This screening is aimed to identify suitable weather conditions and which environmental parameters require further investigation.

2 TEST PROCEDURE

Several testing series are planned to investigate how gluing conditions impact the strength of the hybrid joints. A reference series of ten hybrid joint specimens will be conditioned and assembled at 20 °C and 65% RH. The PUR adhesive used is Loctite PURBOND CR821 which reaches full bond strength in 7 days according to the manufacturer Henkel and 75% after 2 days [3]. When full strength is obtained, the specimen is tested in tension until failure. The ultimate load is recorded and will serve as a cross-reference, representing ideal bonding of the joint. A principal sketch of the test specimens is illustrated in Figure 1.

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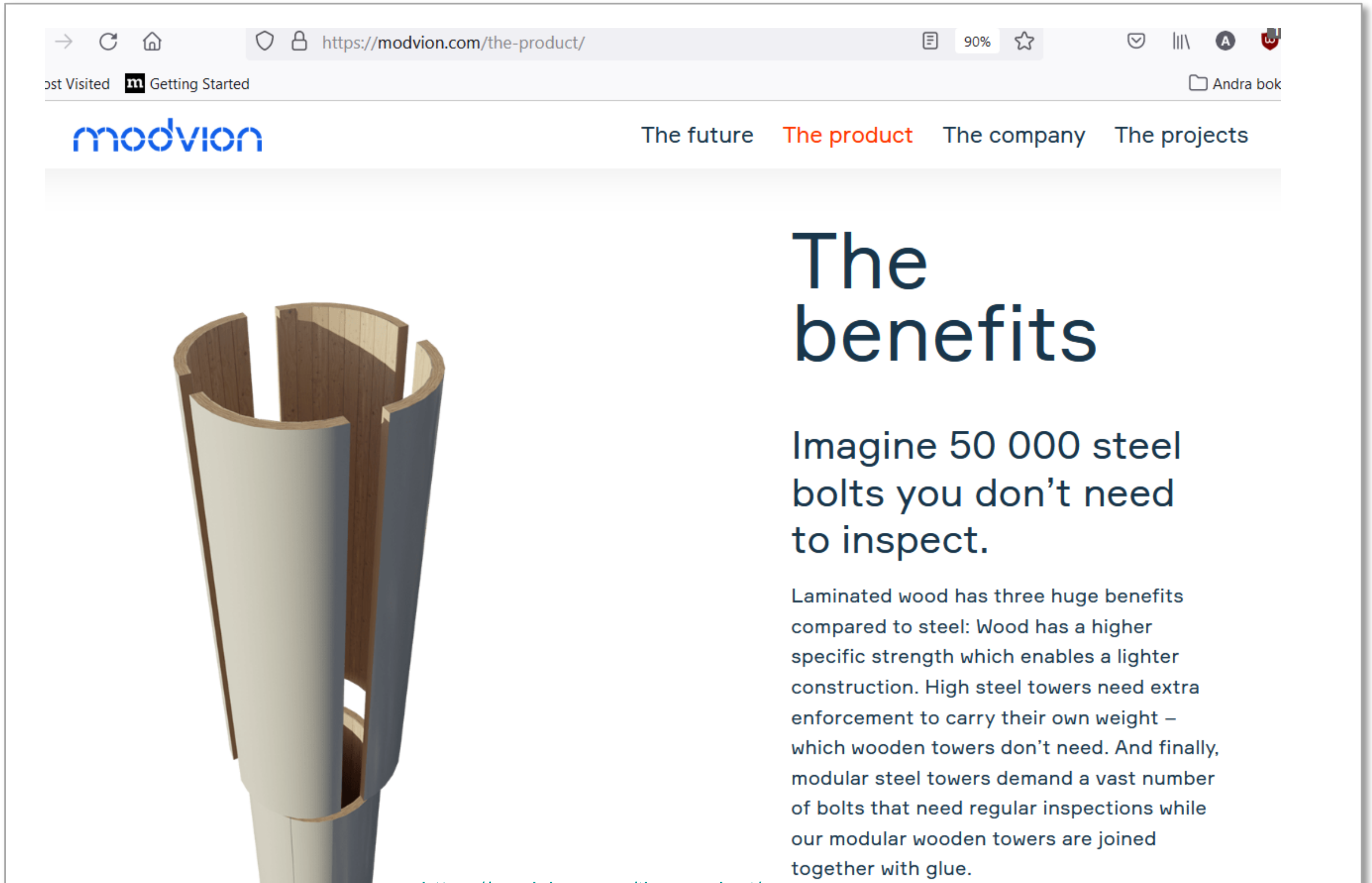

https://modvion.com/the-product/

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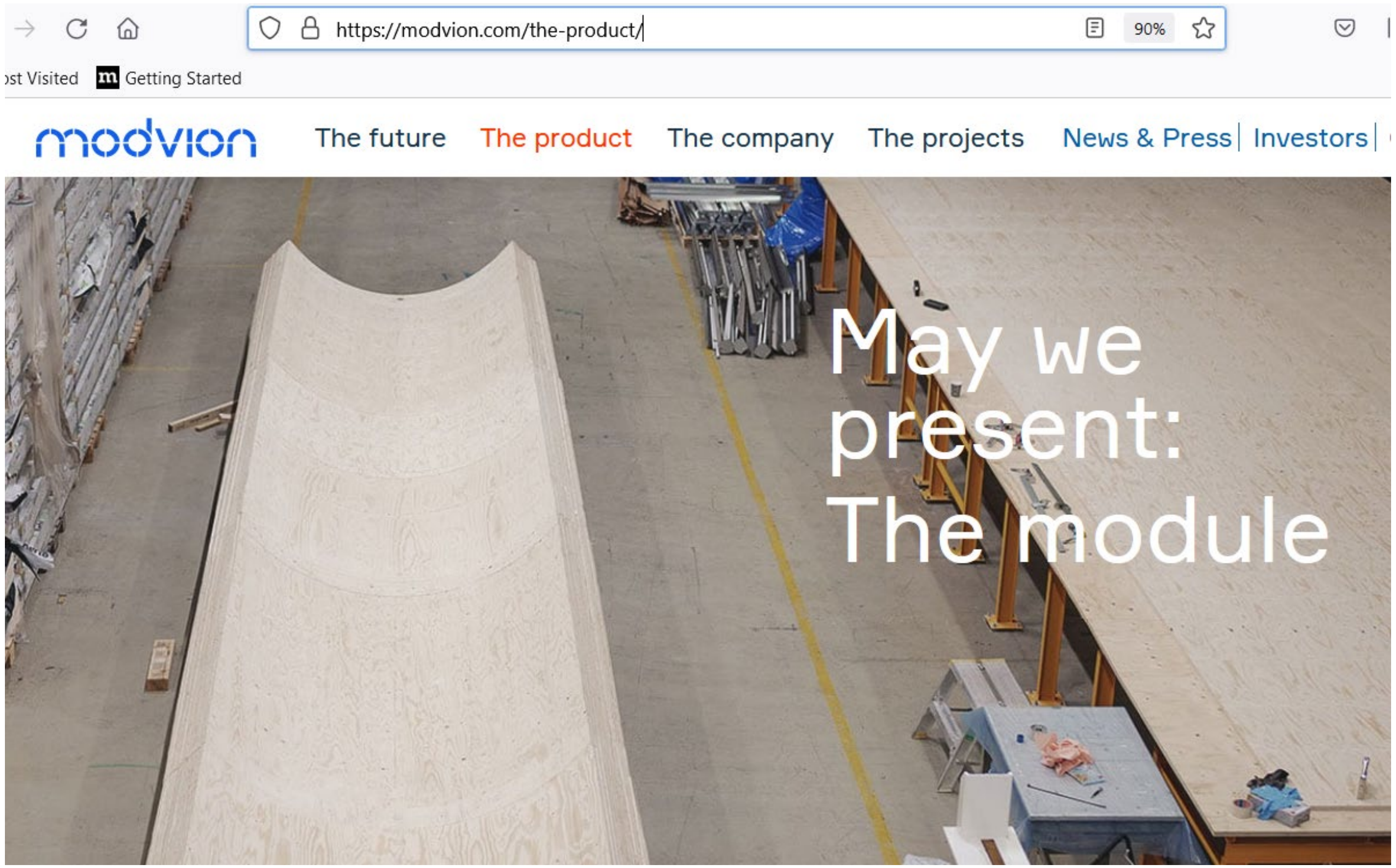

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