2nd International Symposium on Multi-Scale Experimental Mechanics

Sub-structural Testing of Large Composite Structures – a Hybrid Simulation Approach

Jacob Paamand Waldbjørn
Postdoctoral Fellow
Department of Mechanical Engineering
Technical University of Denmark

Introduction and background -

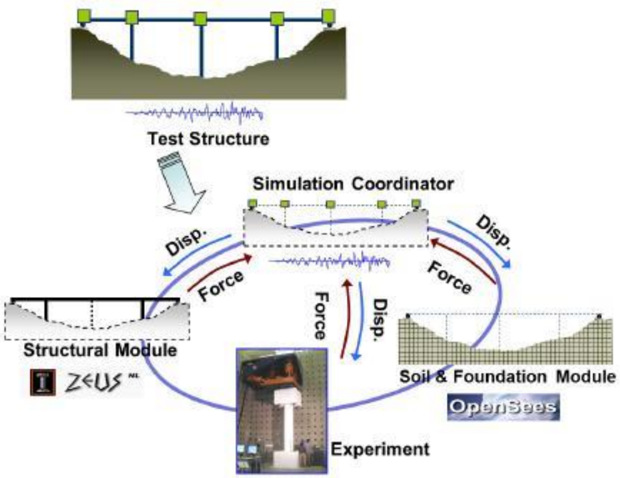
Hybrid simulation for structural assessment

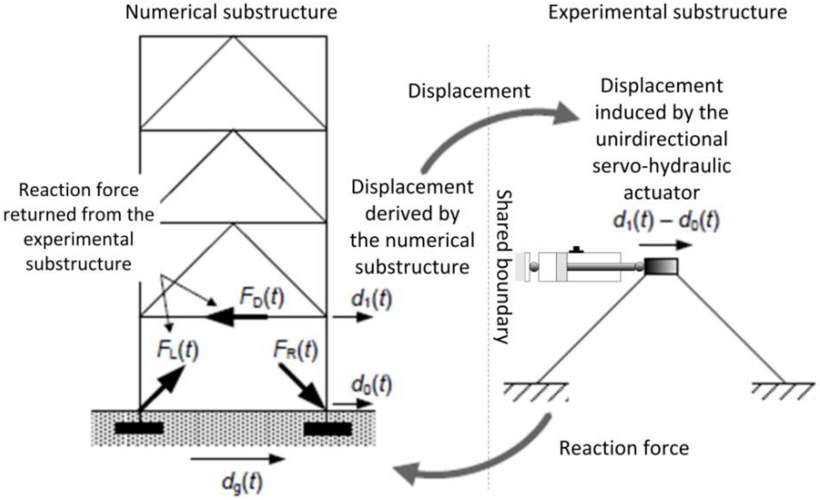
Purpose and aim

- Cost effective alternative to full scale testing
- Substructural technique
- Experimental substructure represents e.g. crack propagation, buckling, delamination, etc.
- The remaining portion (typically the majority) exhibits predictable mechanical behavior
- Coupling through the partitioning
- In the literature named: hardware-in-the-loop
  hybrid testing
  hybrid simulation
- QS, PsD and RT hybrid simulation (HS)

Approach

- Apply external load $d_g(t)$
- Acquire computed displacement $d_1(t) - d_0(t)$
- Apply displacement at sheared boundary
- Acquire restoring force R to reveal response of emulated structure
- Apply next load-step $d_g(t+1)$

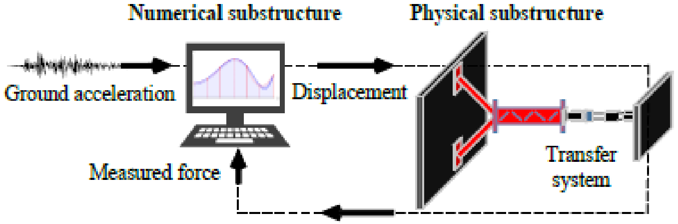




Introduction and background -
Single component vs. conventional hybrid simulation

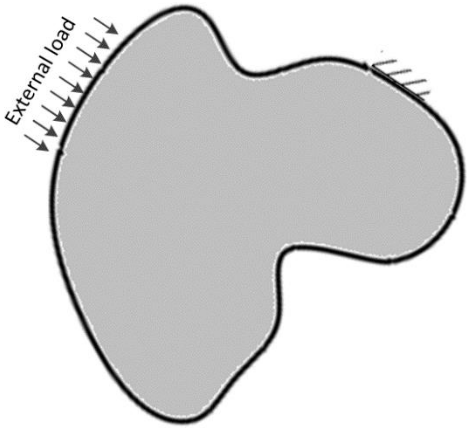
Multi-component (conventional) HS

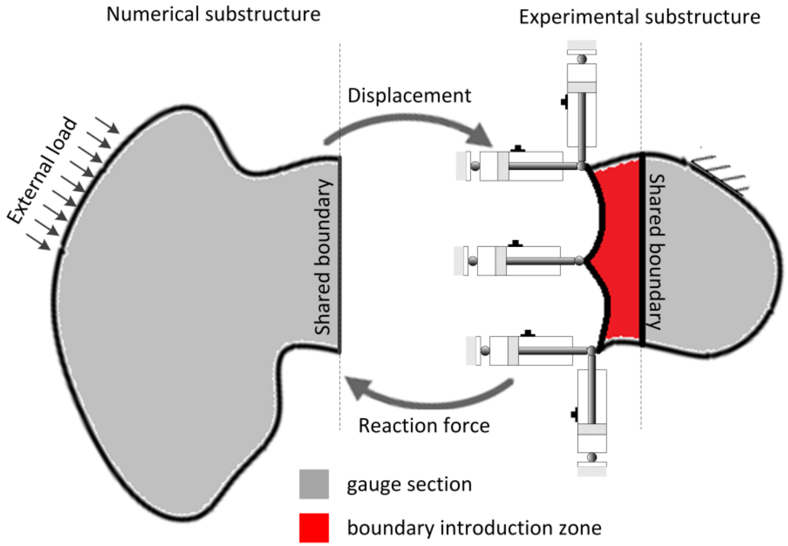
- Originated in the late 1960's
- Several discrete components
- Simple connection in the partitioning
- Few dofs in the partitioning (e.g. damper loaded by a unidirectional actuator)
- Mature and reliable approach which enables HS within other areas



Single-component HS

- Contains a single component
- Complex connection in the partitioning
- Infinite dofs in the partitioning (in theory)
- Complex numerical and experimental substructure (loads and geometry)



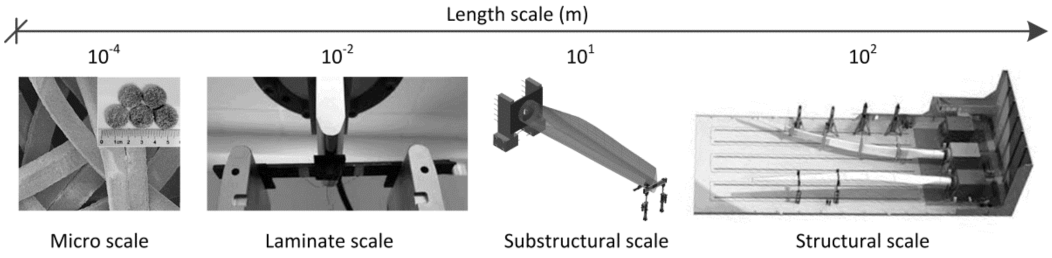


Introduction and background -

Perspective within single-component hybrid simulation

Expanding application areas

- larger composite structures including: wind turbine blades, ship vessels, cars, aero planes, etc.
- Wind turbine blade: laminate and structural scale testing
- Service link between laminate (idealized stress and strain states) and structural scale testing (tested with significant simplications)
- Advanced load configurations: dynamic and static contribution

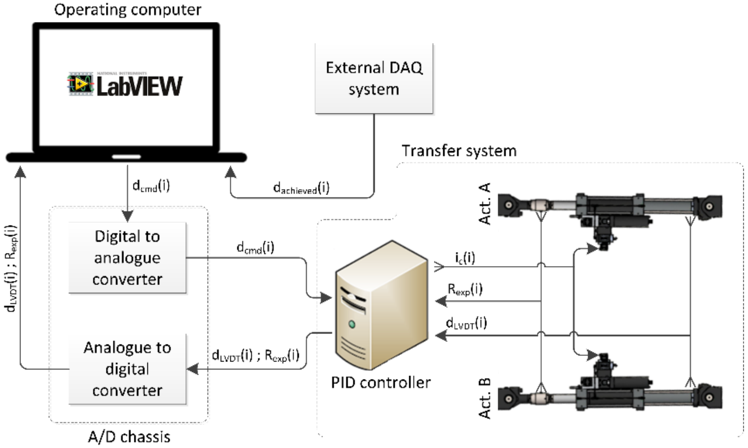


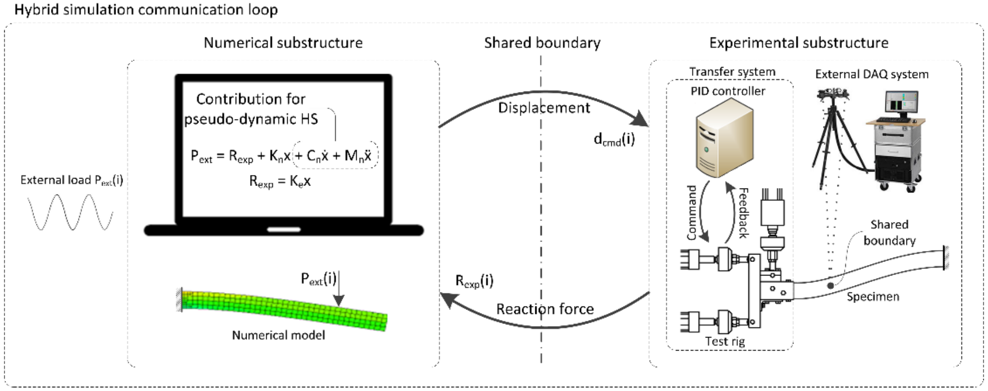
Single component HS-

Overall system architecture

Current architecture of the HS test setup

- Operating computer to handle the numerical model, operating software and enable the required communication with conditioner and external DAQ system
- Servo hydraulic system is operated through a conventional digital PID controller
- A/D and D/A converters to enable a reliable communication between the operating computer and PID controller.



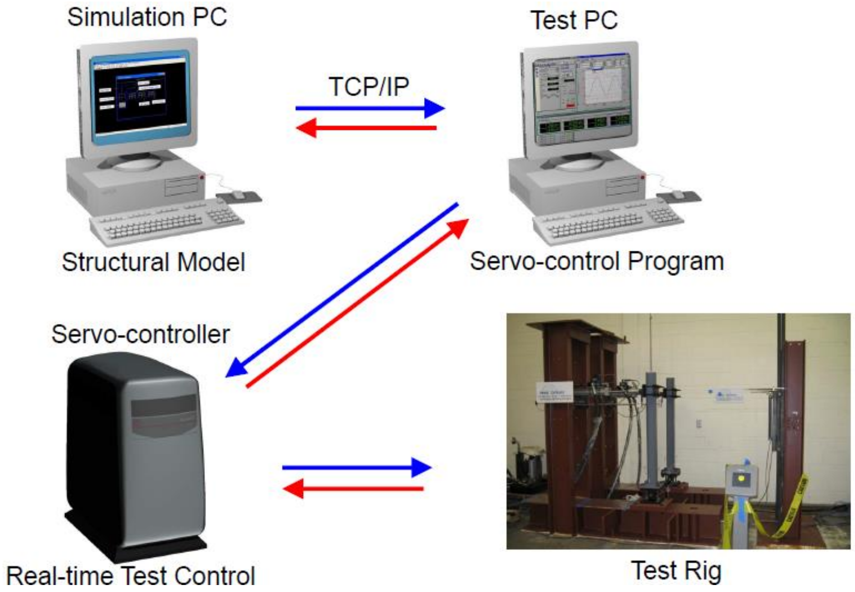


Single component HS-

Overall system architecture

Future architecture of the HS test setup (installation mid November)

- Simulation PC included to operate the numerical substructure (most commercially available)
- OpenFresco (open source code developed at UC - Berkley) to establish a communication protocol between the simulation and Test PC
- Communication to the PID controller (FT100 controller) through the 793 software on the test pc
- Couplings matrix defining the relation between the partitioning and operation of the multi-axial load train

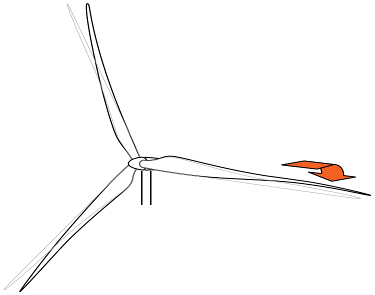


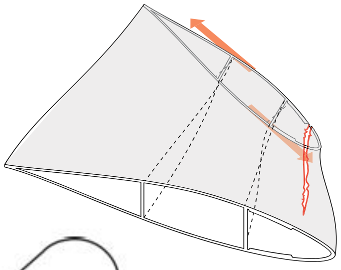
Outlook within single component HS-

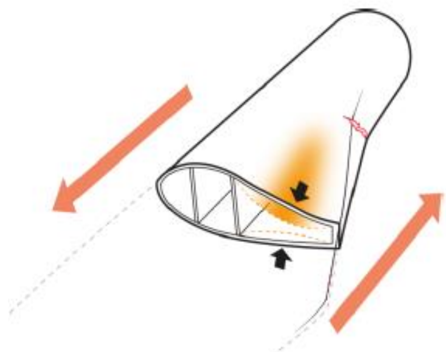
Substructural scale testing of a SSP34m wind turbine blade

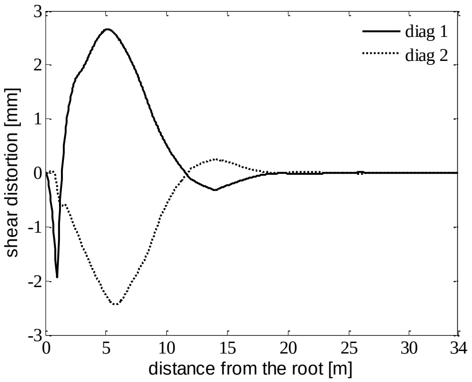
Motivation

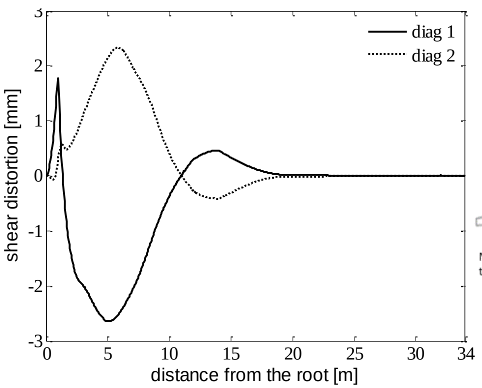
- Investigation of cross sectional shear distortion in the max chord section when loaded in the edgewise direction
- Increase the stresses in the leading edge region
- Experimental substructure located in the root section
- The numerical substructure includes the remaining part of the SSP blade
- Also effects like the pumping/breathing behaviour in the transition zone could be investigated in this configuration

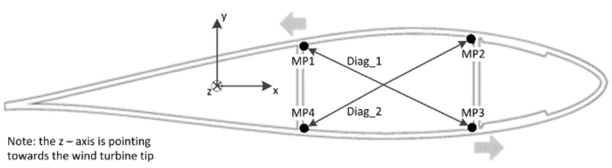










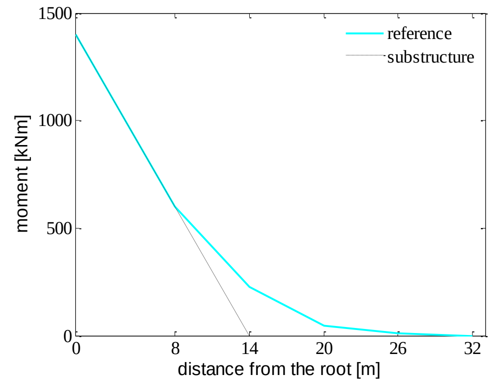


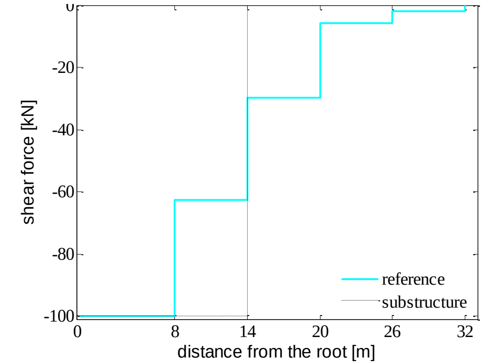
Outlook within single component HS-

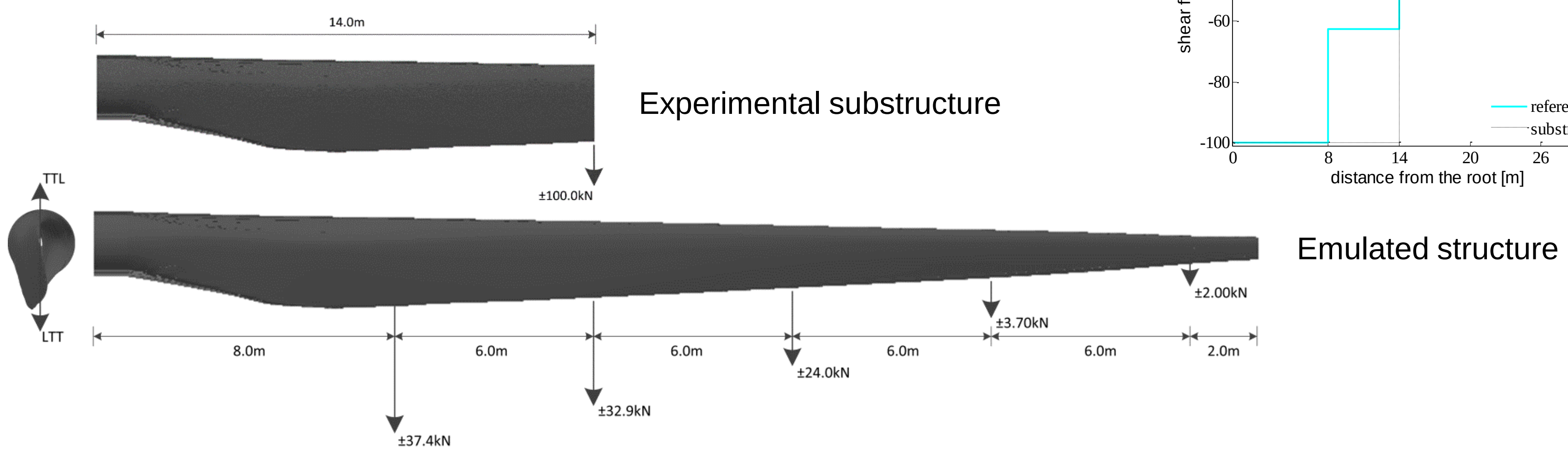
Substructural scale testing of a SSP34m wind turbine blade

Partitioning of the SSP34m blade

- Investigation of cross sectional shear distortion in the max chord section (critical section)
- A load introduction zone of 6m to erase the distortion induced by the load train (meaning the numerical substructure is 26m with an experimental substructure of 14m)
- Section forces in the gauge zone of the experimental substructure is equivalent to the forces optained in the same zone in the emulated structure
- Response of the experimental substructure is evaluated in the following to numerically to verify the setup





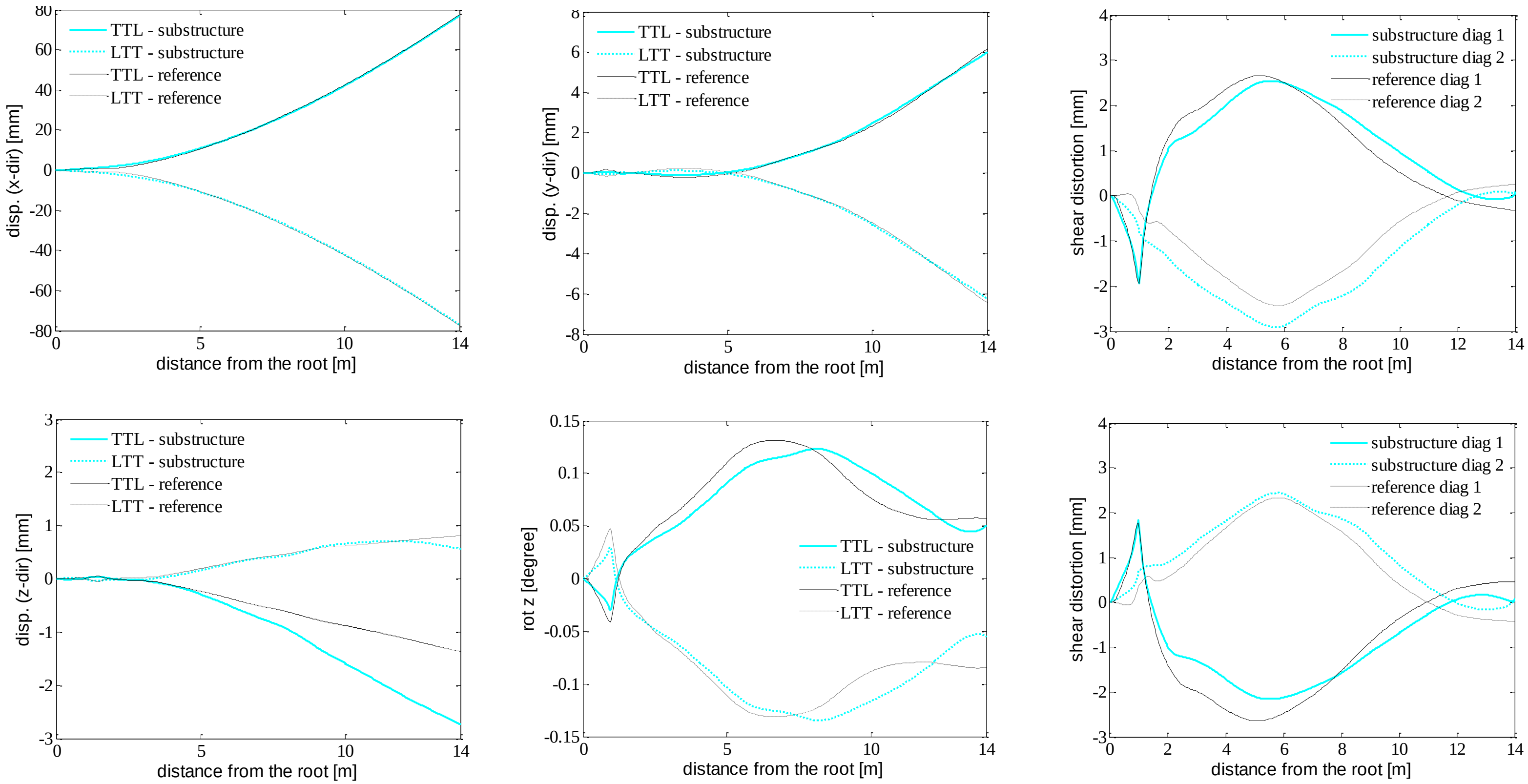


Outlook within single component HS-

Substructural scale testing of a SSP34m wind turbine blade

Numerical evaluation of the experimental substructure

- Global response of the emulated and experimental substructure

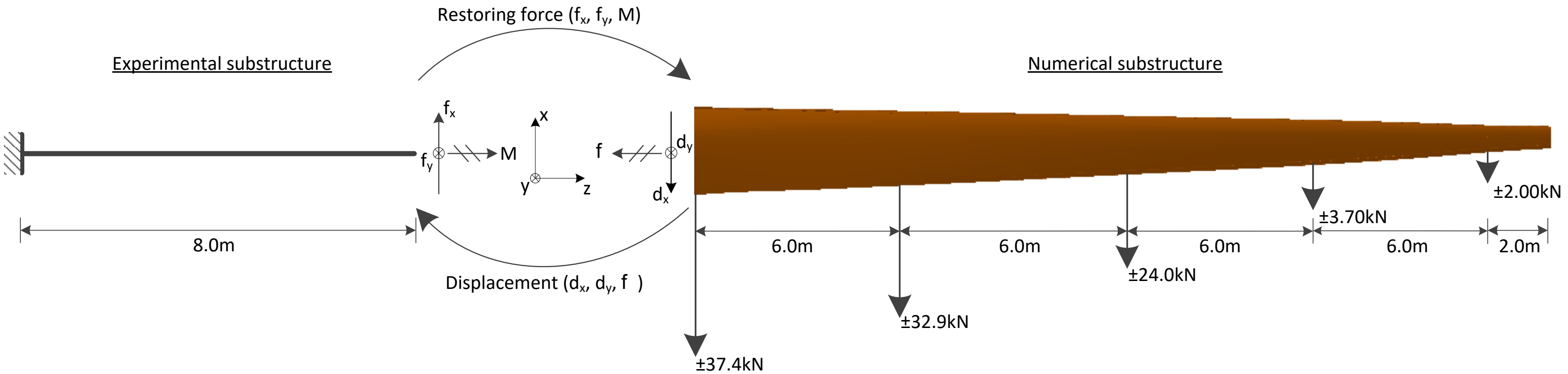


Outlook within single component HS-

Substructural scale testing of a SSP34m wind turbine blade

Substructural testing using single-component HS

- The numerical substructure is discretized through a FE - model
- A representative load configuration is applied the numerical substructure
- The response of the experimental substructure is included in the model through a spring in the partitioning
- To fit the response at the sheared boundary the spring stiffness for all dofs of interest are adjusted
- The coupling is governed through the communication loop which ensures compatibility and equilibrium at the interface

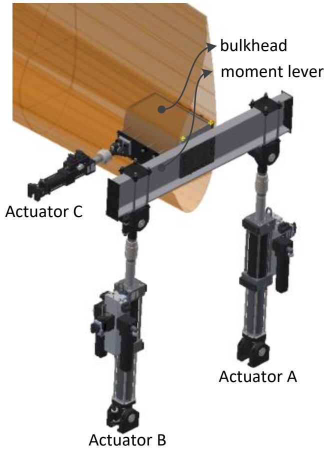


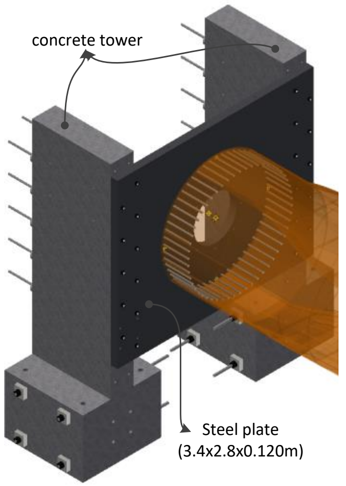
Outlook within single component HS-

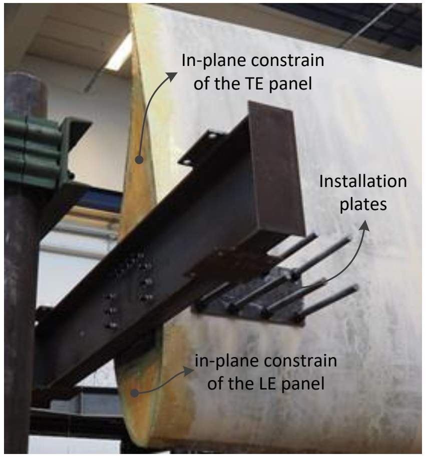
Substructural scale testing of a SSP34m wind turbine blade

Planning and construction of substructural test rig (details)

- Load train capable of inducing an in plane load configuration with 3 dofs
- Bulkhead extending 750mm into the free end of the load carrying box girder
- Pretensioned threadbars and glue to transfere the loads from the bulkhead to the load carrying box girder
- Clamped support consist of: two concrete towers and a steel plate with the dimensions (3.4x2.8x0.120m)
- Ply wood panels are installed at the trailing and leading edge in the free end of the wind turbine blade to avoid critical peeling stresses in the adhesive bond lines





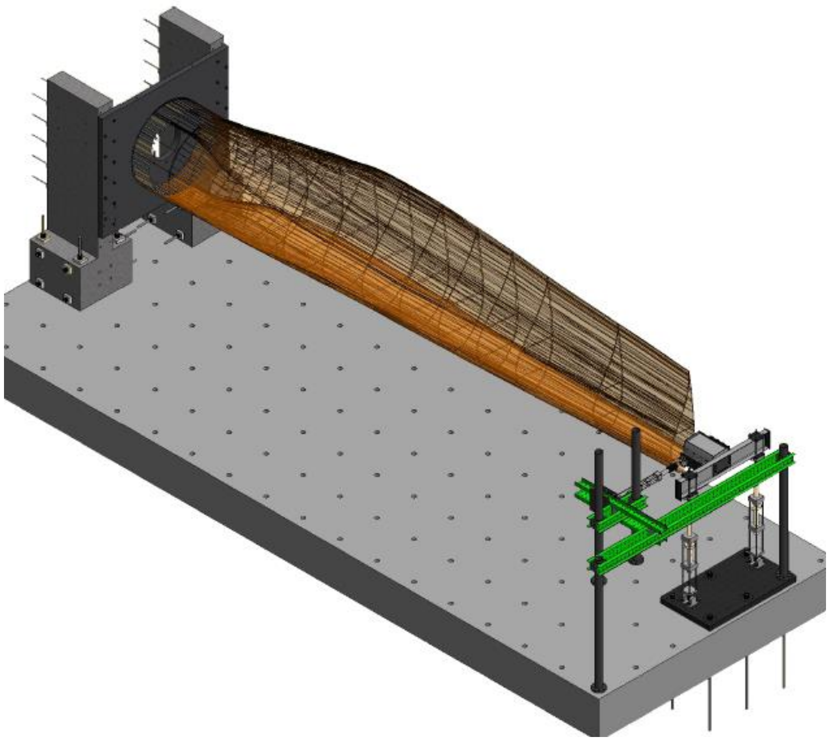


Outlook within single component HS-

Substructural scale testing of a SSP34m wind turbine blade

Planning and construction of substructural test rig (overall setup)

- Clamped support and load train combine to form a fatigue rated test rig
- The test setup exhibits the following load and deformation capacity:
    I. Flapwise: ±50kN and 500mm
    II. Edhewise: ± 100kN and 500mm
    III. Moment: ±100kNm and 25 degree

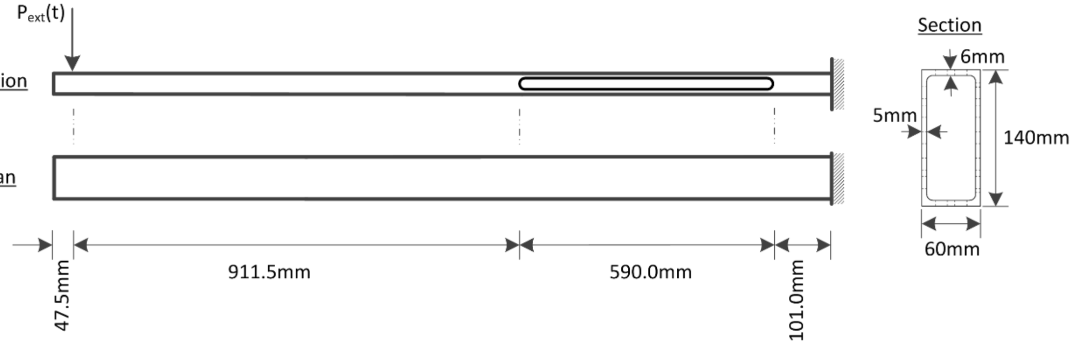


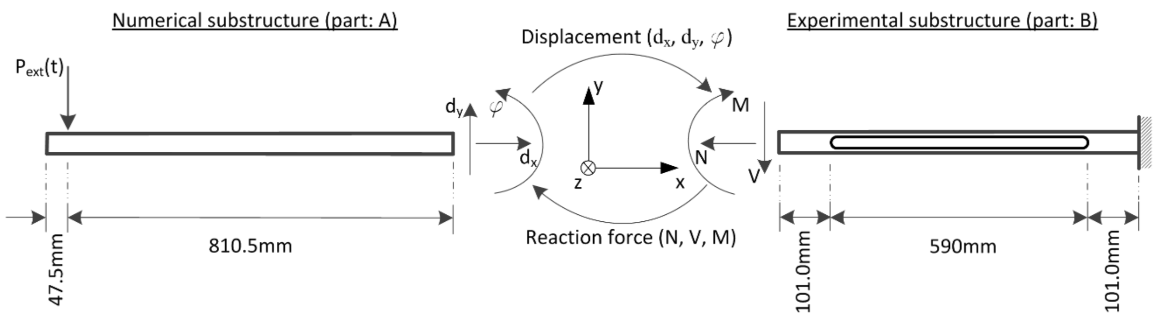
Outlook within single component HS-

Substructural scale testing of a SSP34m wind turbine blade

Introductory pilot test in quasi-static regime

- Virtual hybrid simulation to evaluate system performance on simplified geometry
- Presented results in the linear elastic regime loaded in a sinusoidal load pattern
- Stiffness response transferred from the experimental to numerical substructure through a spring with an adjustable stiffness k for each dof



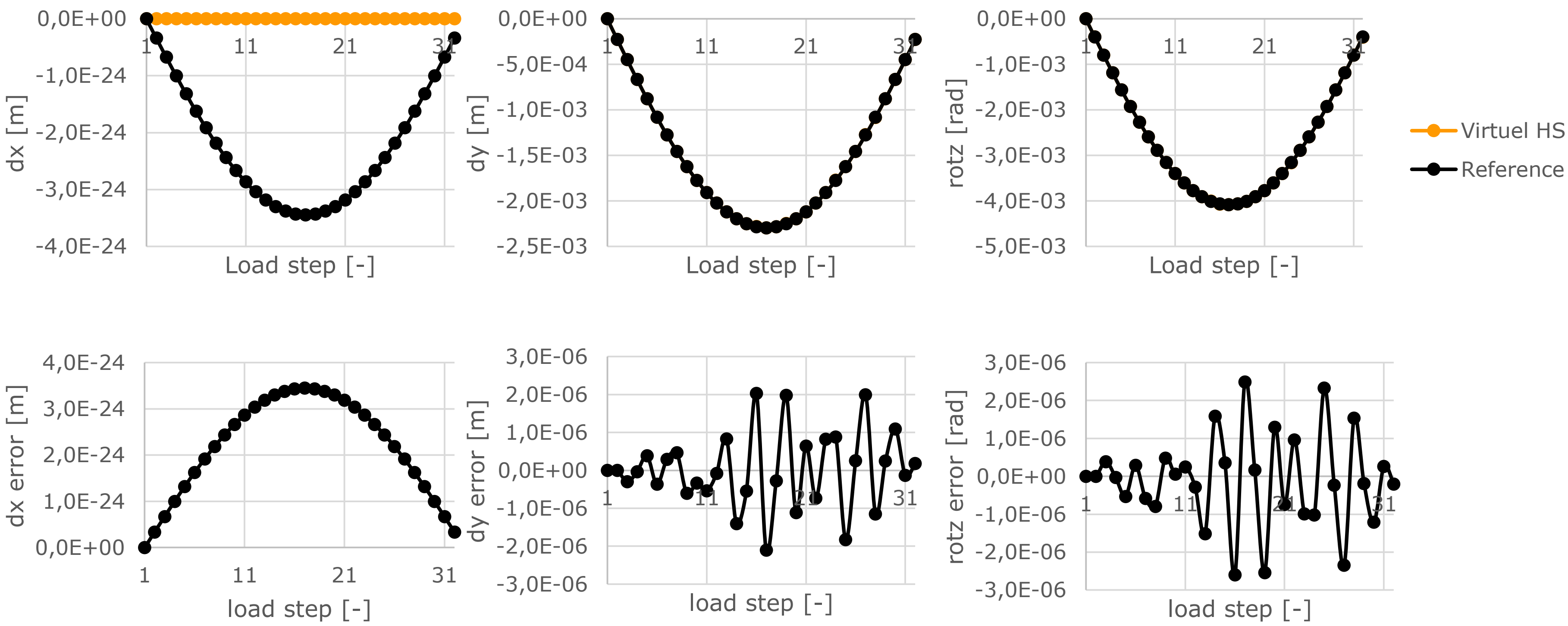


Outlook within single component HS-

Substructural scale testing of a SSP34m wind turbine blade

Introductory pilot test in quasi-static regime

- Result in the linear elastic regime
- Communication delay as the only source of error
- Actuator accuracy and precession will be included



THE END

Thanks for your attention!

Any questions?