Composite Tween Deck Prototype

JiP Project Presentation and Results

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JiP Project Objectives

The prototype shall confirm the main aspects of construction of the final panels

- The testing in laboratory shall confirm the material properties
- The prototype testing shall confirm the theoretical strength calculations and the quality of the construction
- The production method shall be confirmed as suitable
- Impact strength and repair methods shall be demonstrated.
- The photo/video documentation and brochure material of the physical model of the tween deck shall create interest and confidence to potential customers.

JIP Partners

Oshima Shipbuilding Co. Ltd.

- A shipbuilder for dry bulk carriers. Located in Nagasaki Prefecture, Japan

DNVGL

- Purpose is to safeguarding life, property and the environment. World largest Class Society

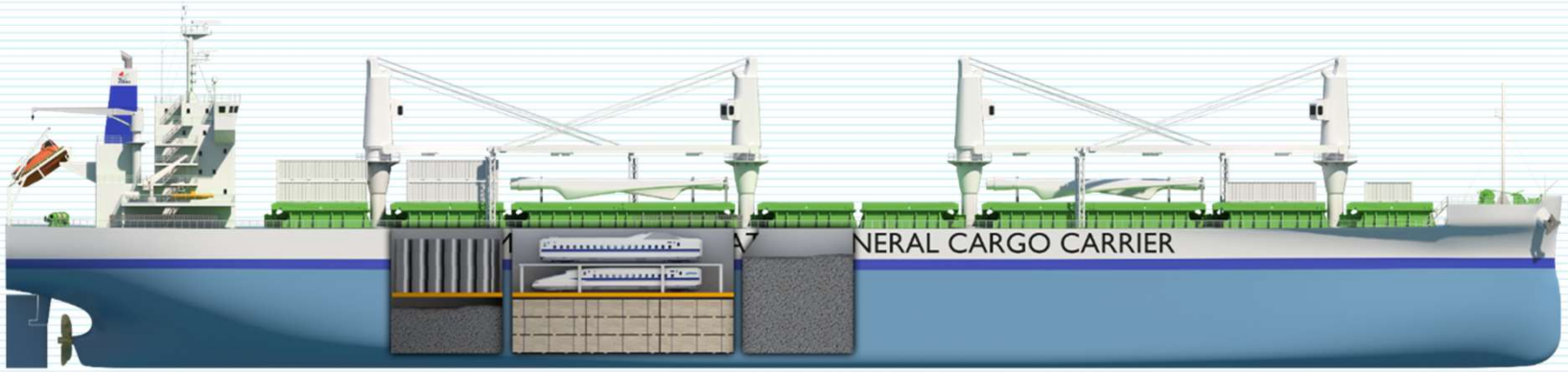
Compocean

- An independent supplier of composite solutions for the onshore and offshore industry

IKnow Machinery

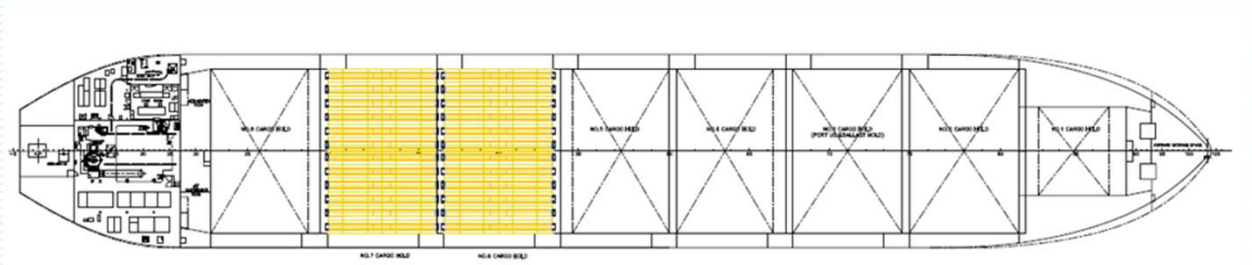
- Builder of ship cranes, hatch covers and tween decks. Fully owned by Oshima

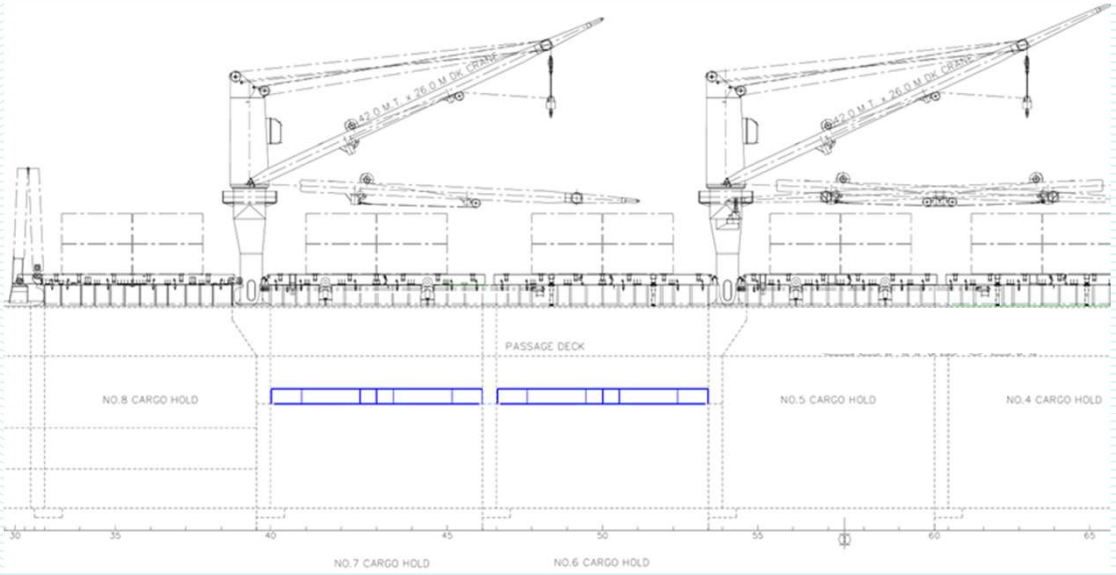
Tween decks in selected holds



Large variation in type of cargo

The ship with tween decks





The ship:

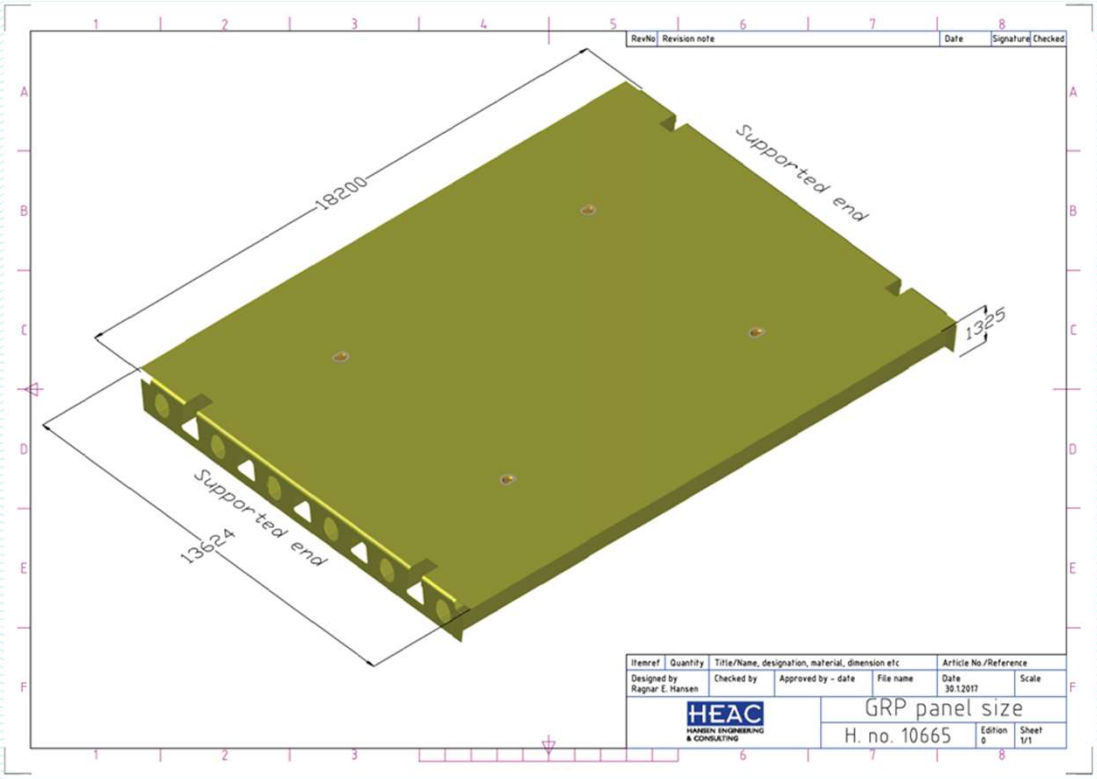
- L = 200 m
- DWT= 62.8 k

Design loads

- Uniform cargo loading 3.0 t/m^2
- Ship acceleration in waves
- Selfweight
- Green-sea loads when panels are stored on deck
- Lifting/moving of decks

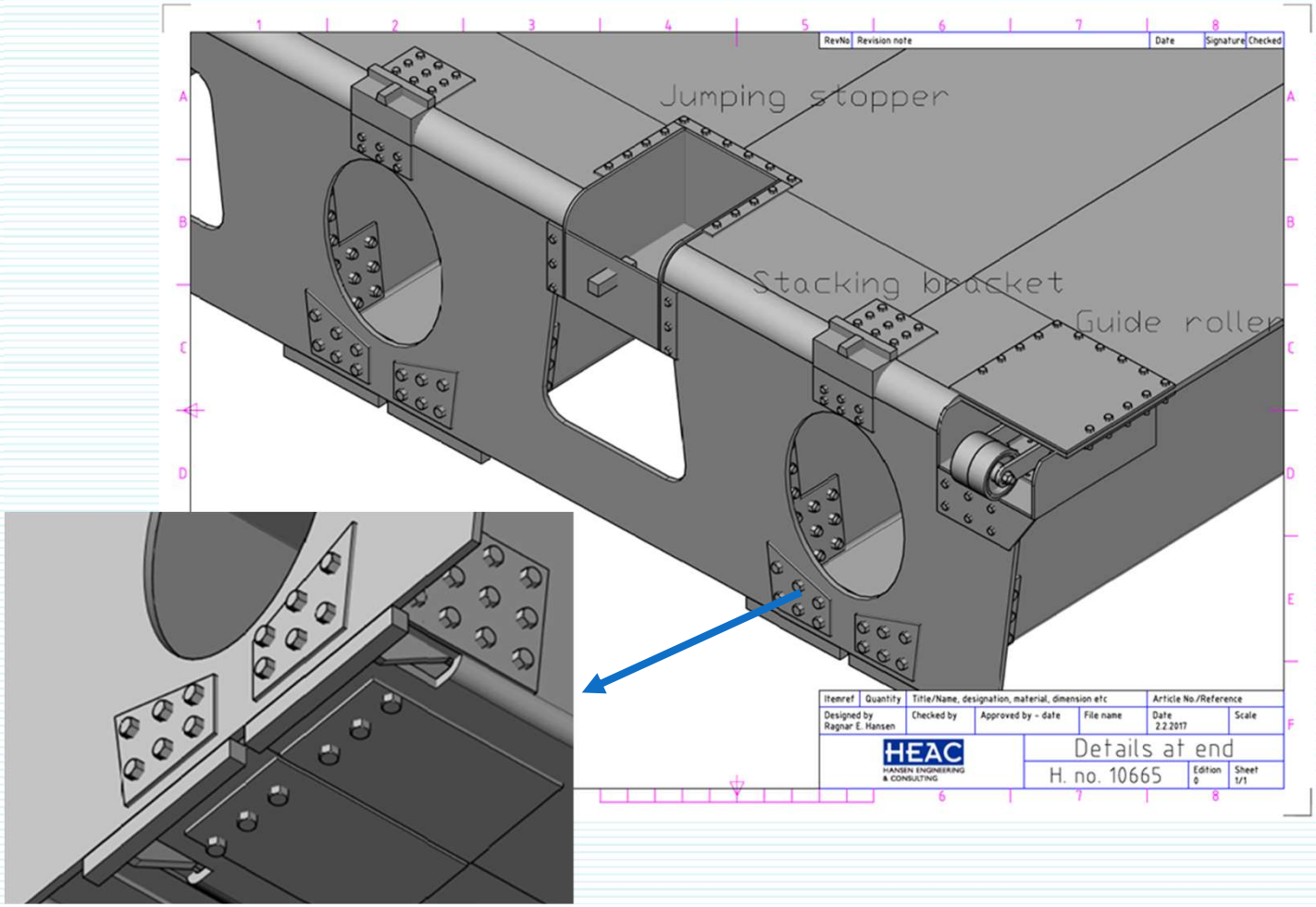
The tween deck panel

Size adapted to deck crane lifting capacity (40 tons)

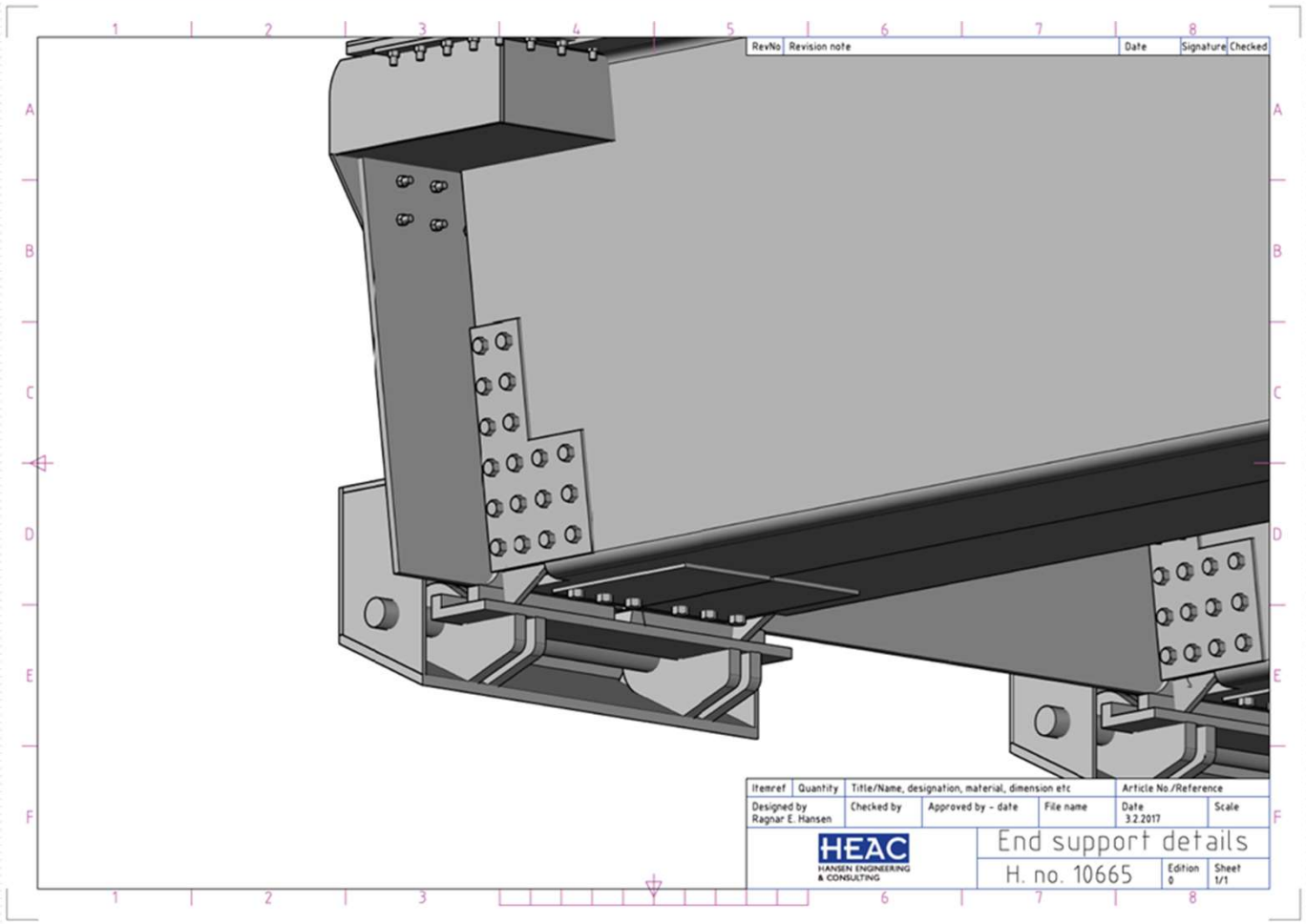


Overall dimensions:
L = 18.20 m
B = 13.62 m
H = 1.325 m

Steel brackets at end supports



Tween deck end support



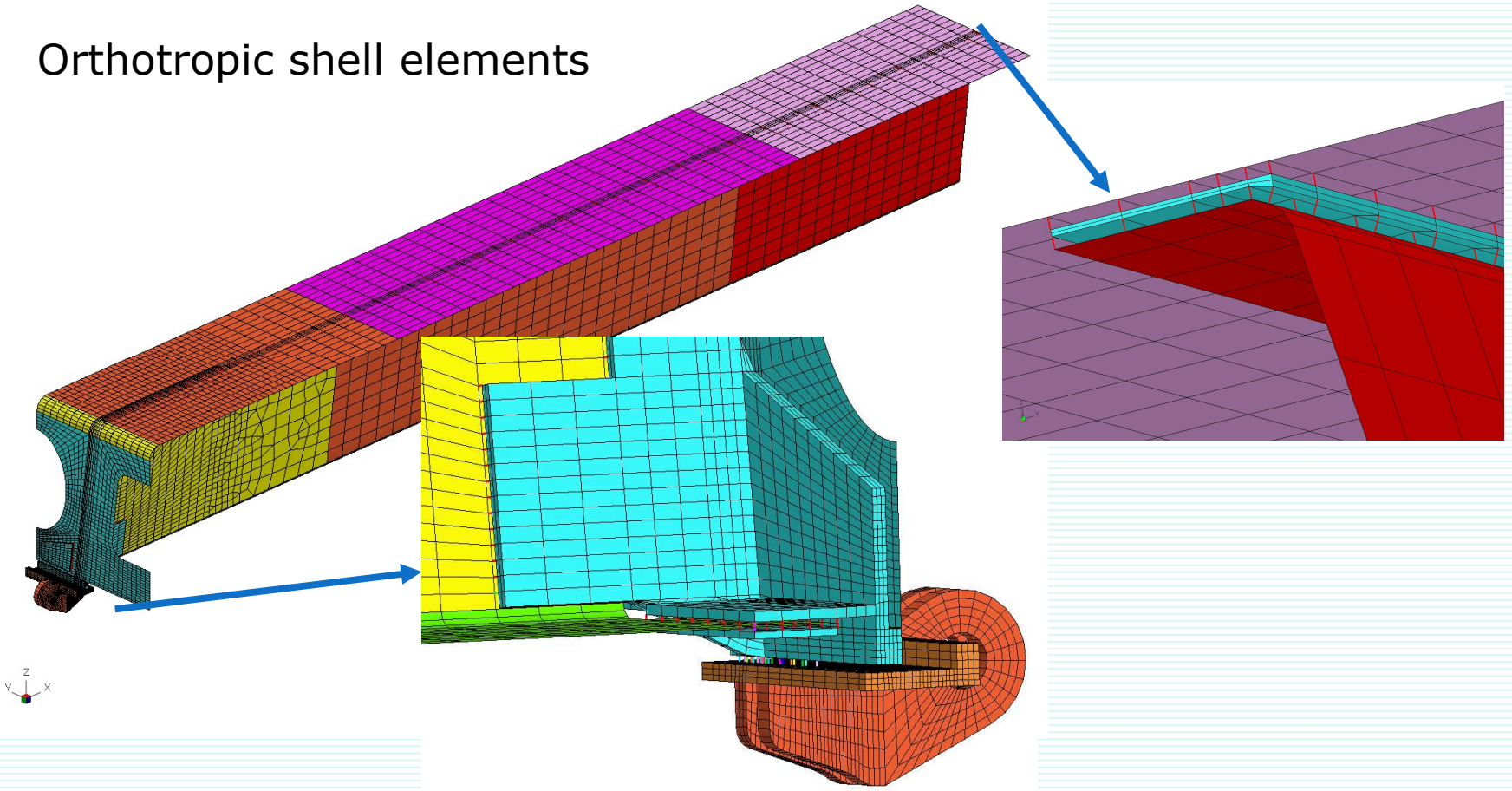
Properties of laminates

GRP laminate #	Location	Fibre direction (degrees)	% of fibre in each fibre direction	E_1 (MPa)	E_2 (MPa)	v_{12}	G_{12} (MPa)
1	Top plate	0-90-45-45	40-40-10-10	23202	23202	0.19	4736
2	Corrugation bottom flange	0-90-45-45	40-40-10-10	23202	23202	0.19	4736
3	Corrugation web	0-90-45-45	10-10-40-40	14135	14135	0.21	9944
4	End walls	0-90-45-45	25-25-25-25	17890	17890	0.31	6590

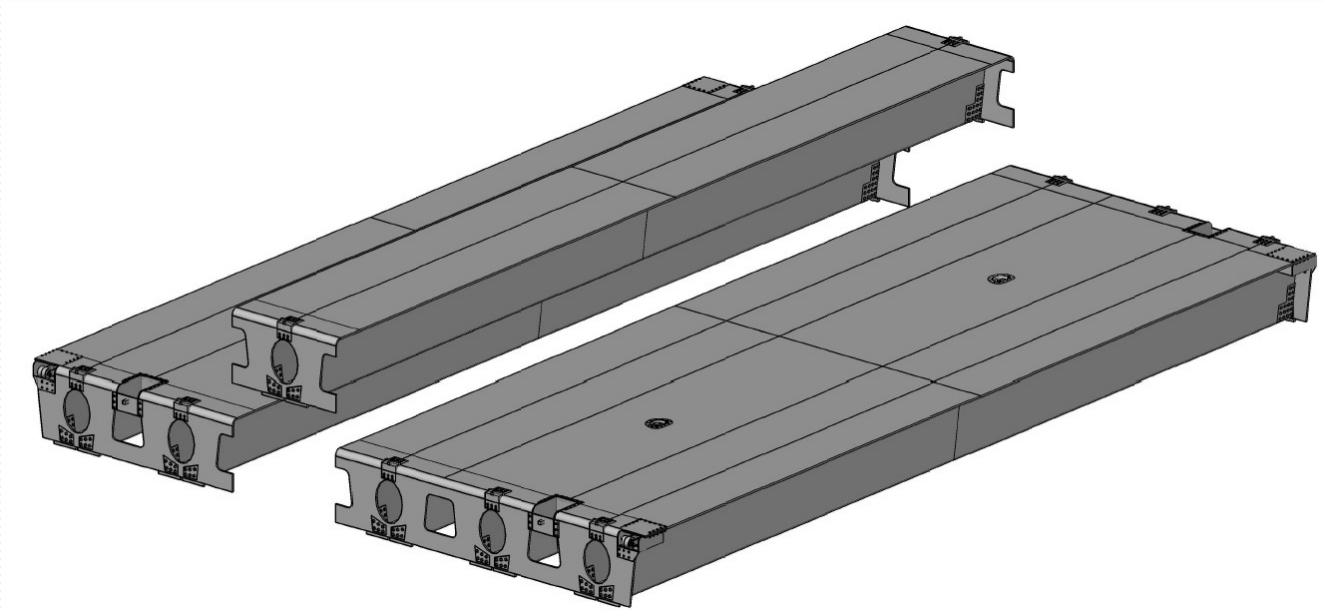
GRP laminate #	Ultimate strength - tension (MPa)	Ultimate strength- compression (MPa)	Ultimate strength – shear (MPa)	Allowable stress – tension (MPa)	Allowable stress – compression (MPa)	Allowable stress – shear (MPa)
1	390	400	110	137	140	38
2	390	400	110	137	140	38
3	220	230	250	77	81	88
4	313	320	200	110	112	70

FEM: Static strength analyses

Orthotropic shell elements



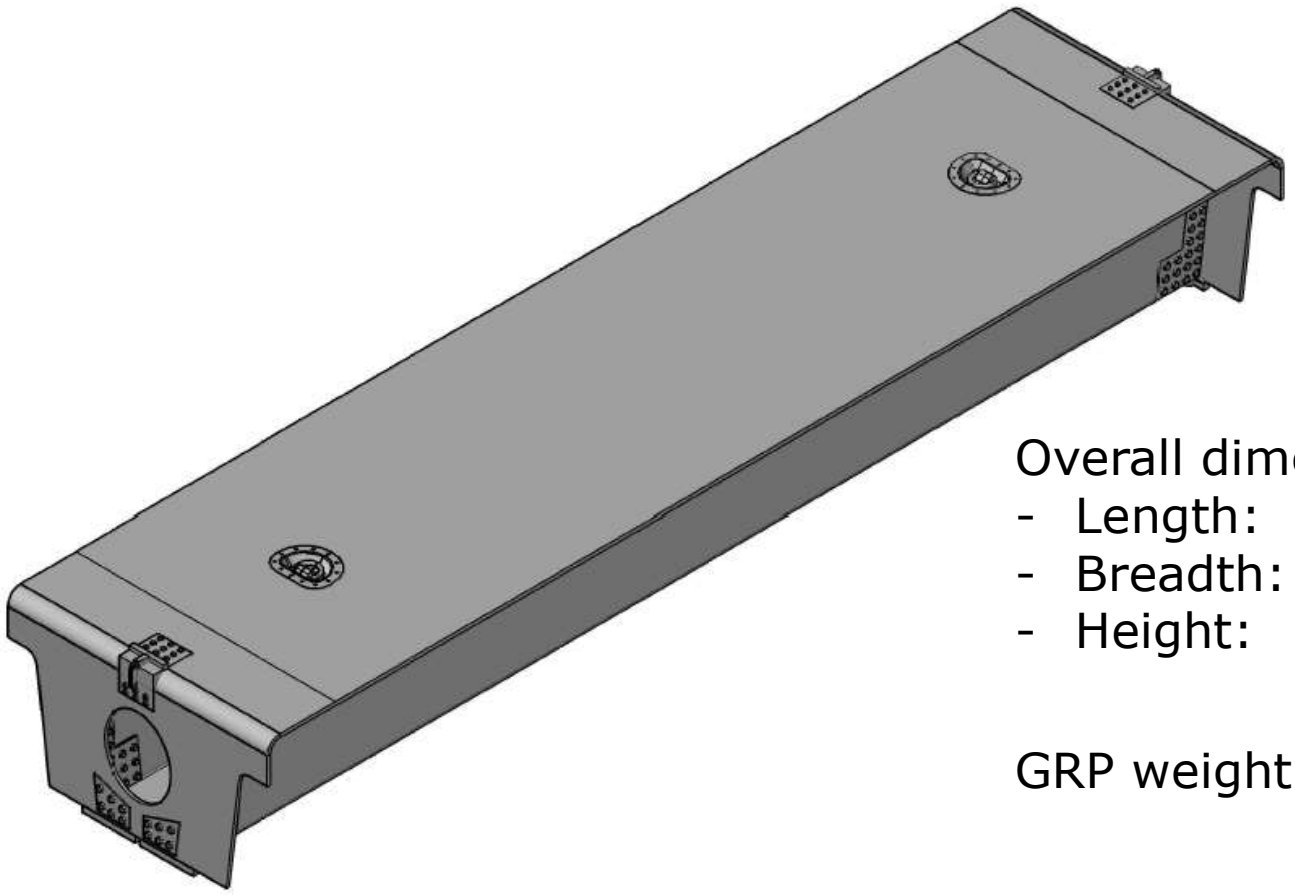
Extent of the prototype



Prototype extent:

- One corrugation «beam» – half span, i.e 9.1m
- Steel brackets at ends
- Lifting brackets
- Laminate design and thickness as full scale tween deck

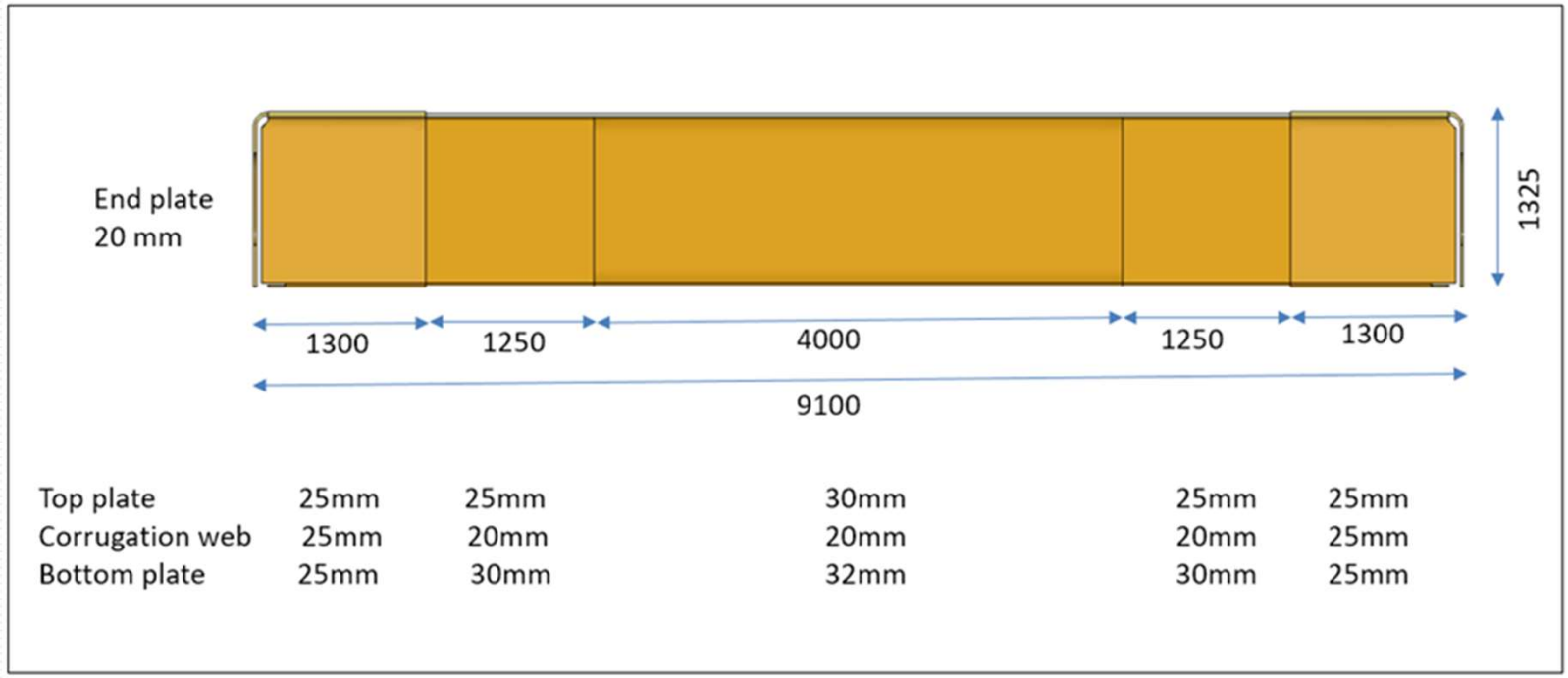
The prototype as designed



Overall dimensions:
- Length: 9.1 m
- Breadth: 2.32 m
- Height: 1.325m

GRP weight: 2,700 Kg

Prototype laminate thickness



Top plate	25mm	25mm	30mm	25mm	25mm
Corrugation web	25mm	20mm	20mm	20mm	25mm
Bottom plate	25mm	30mm	32mm	30mm	25mm

Fabrication Process

- Mould Construction
- Preparation
- Materials
- Vacuum Infusion
- Assembly

Mould Construction

- Female moulds (mould outside product)
- Simple construction due to one-time use.
- Based on wooden construction with plywood sheets, covered with fiberglass surface and mould gelcoat.

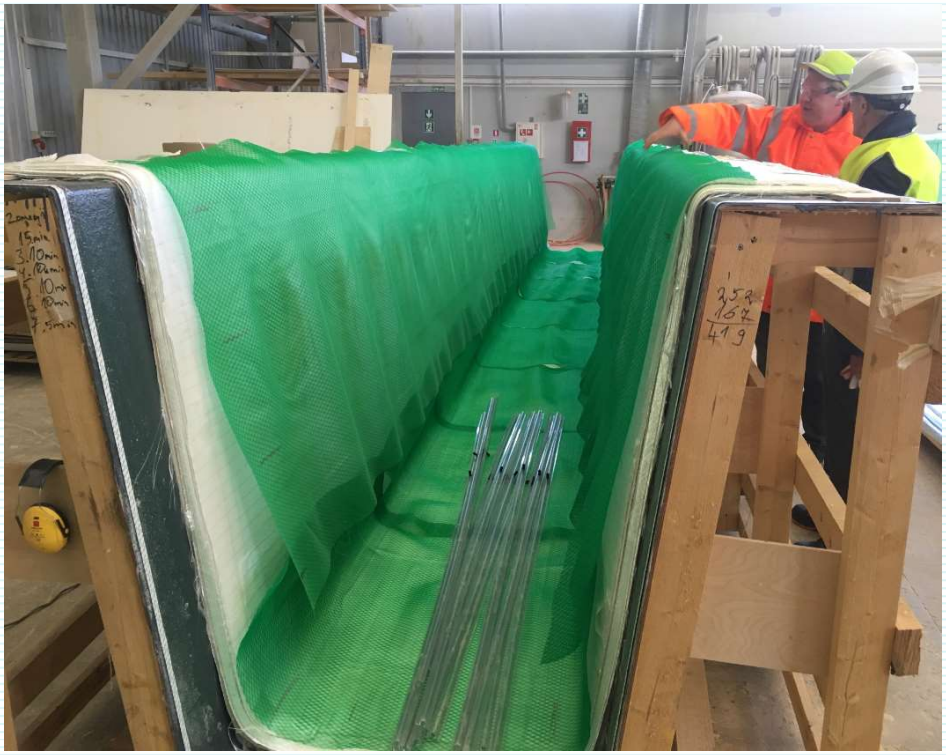
Preparation

- Test laminate for coupon testing
- Mould control (dimension, release agent etc.)
- Vacuum infusion test of stiffener profile
- Resin gel test

Materials

- Multiaxial stitched glass fibre fabrics (0/90 balanced and unbalanced, +45/-45), area weight of 1700 and 800 grams
- Marine grade Polyester for injection molding
- Structural adhesive (Urethane acrylate)
- White topcoat

Vacuum Infusion

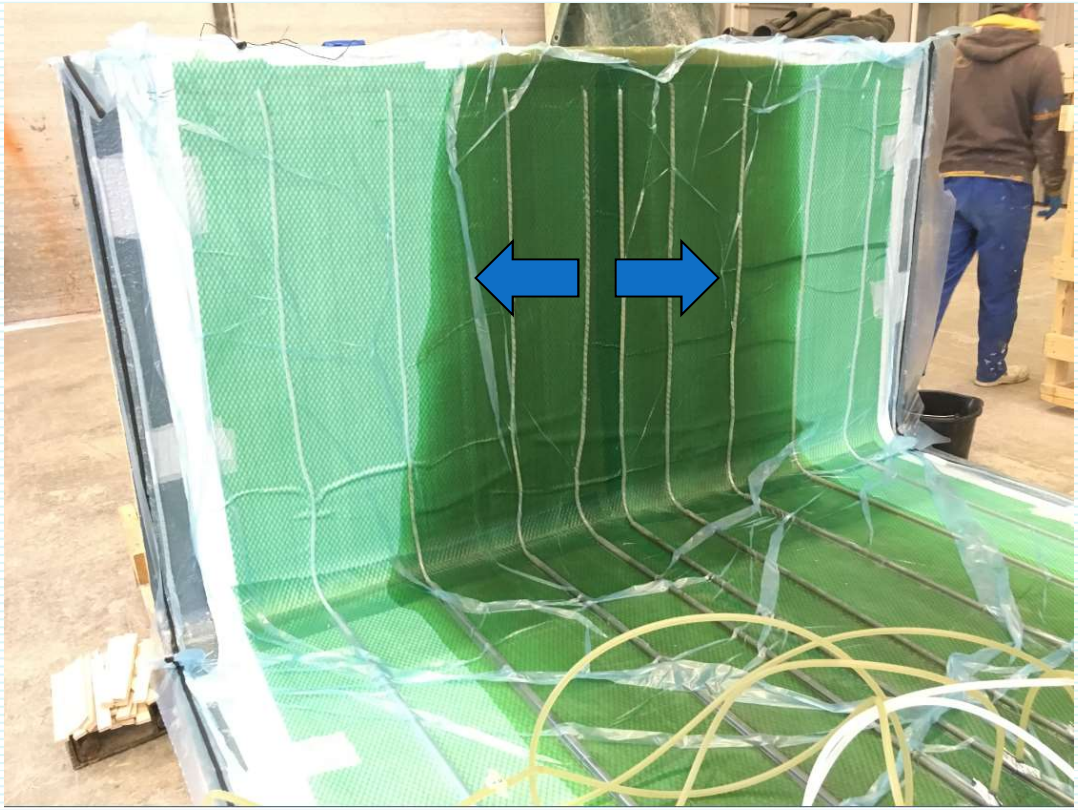


- Fabric lay up
- Peel ply
- Distribution net (green flow medium)
- Resin feed lines
- Vacuum lines
- Spray adhesives
- Sealant tape
- Vacuum bag
- Vacuum pumps
- Leak detection
- Resin traps

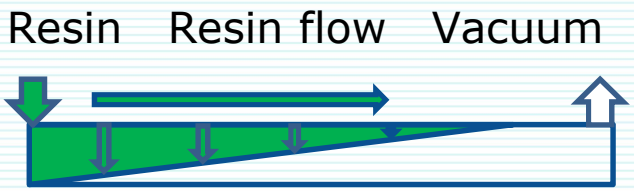
Vacuum Infusion Top Plate

- Ready for infusion

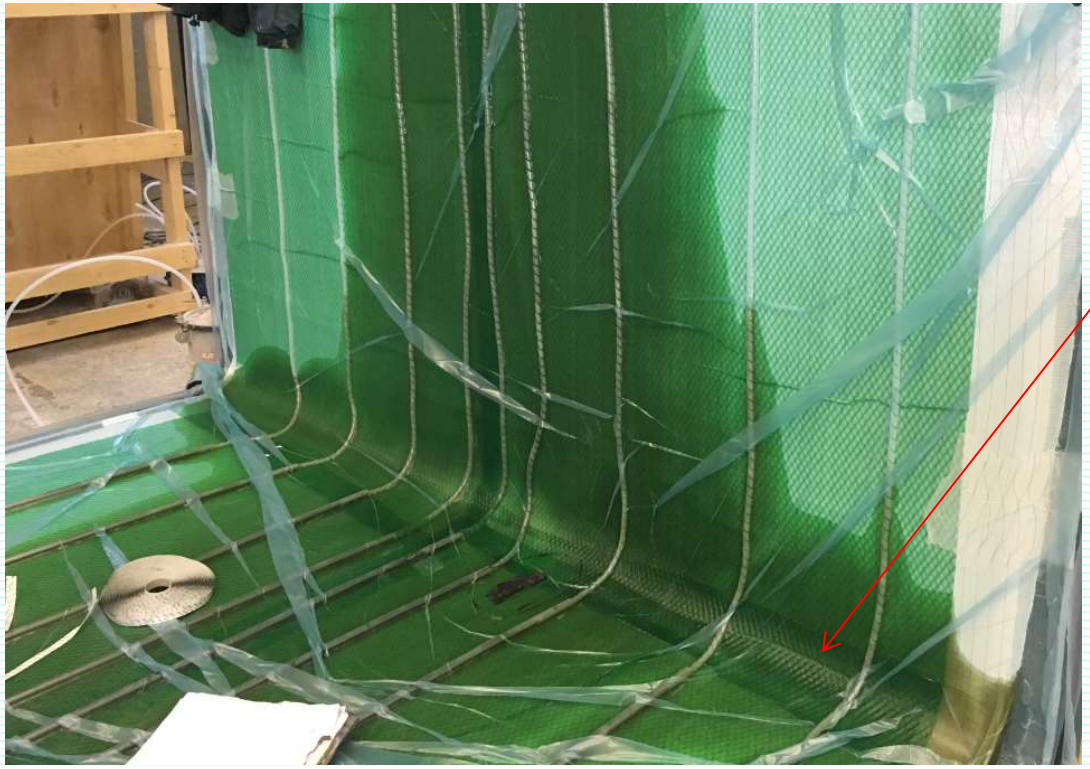
Vacuum Infusion Top Plate



- Flow on surface and through the thickness infusion

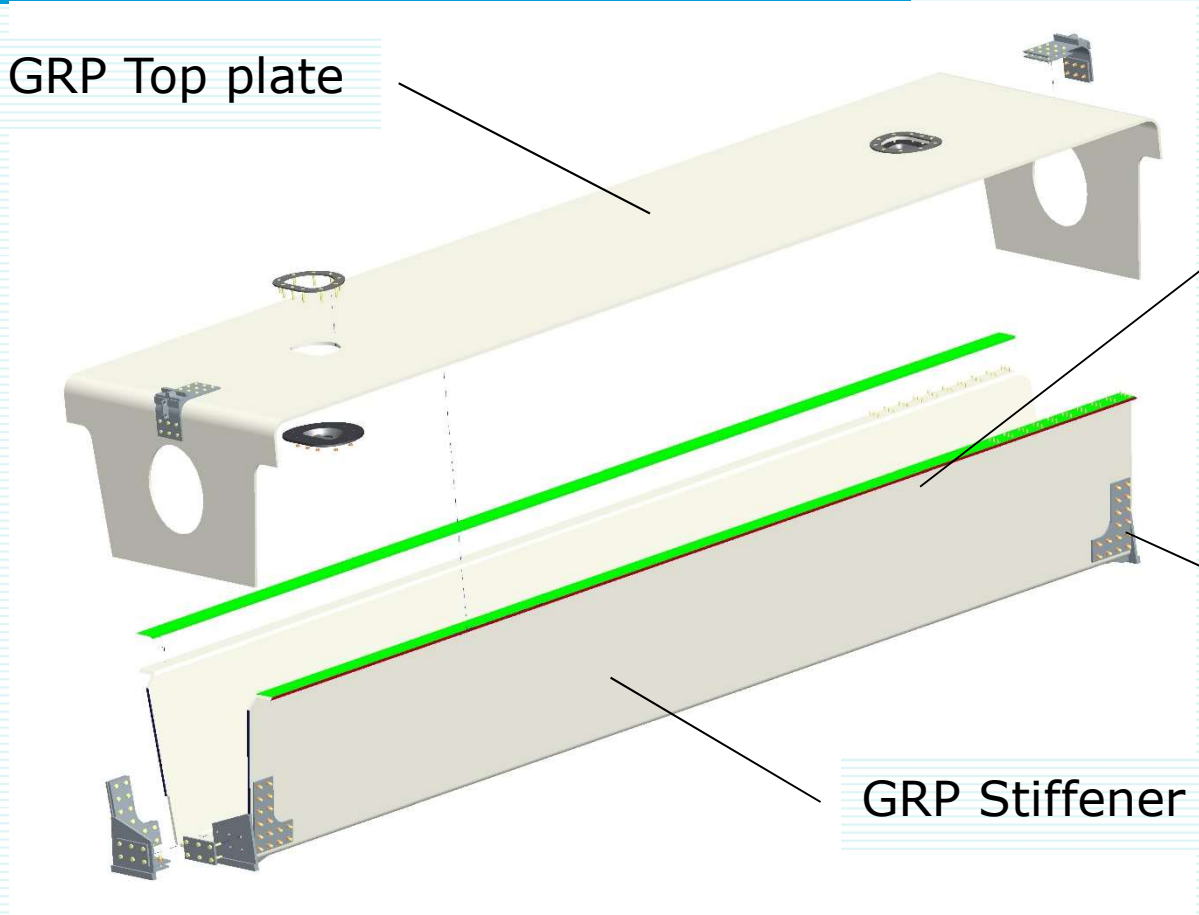


Vacuum Infusion Problems



- Bridging can cause problems and shortcut flow
- Can be controlled with resin distribution system

Assembly


GRP Top plate
Marine grade structural adhesive
Steel parts boltet to structure
GRP Stiffener section

Assembly Gluing

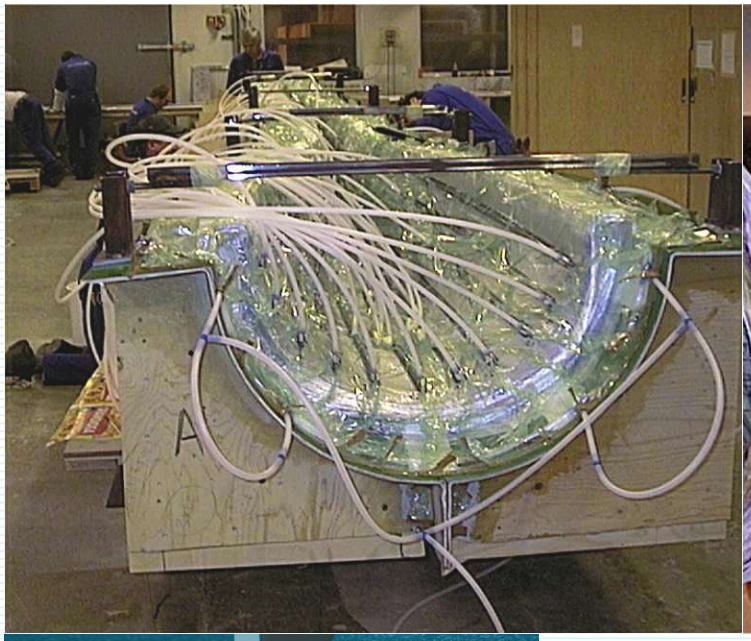
Prototype Ready For Testing

Vacuum Infusion Samples

Vacuum Infusion Samples

Vacuum Infusion Samples

Vacuum Infusion Samples



Vacuum Infusion Samples

Fabrics

- focus on 3 types of fabrics used in fabrication
  - (0/90) bal.
  - (±45) bal.
  - (0/90) unbalanced.

Material ID	Thickness (*) [mm]	Areal weight [g/m²]				
		0¹	90	+45	-45	CSM
Fabric F1	1.21	840	857			
Fabric F2	0.58			401	401	
Fabric F3	1.36/1.44	1344	469			100

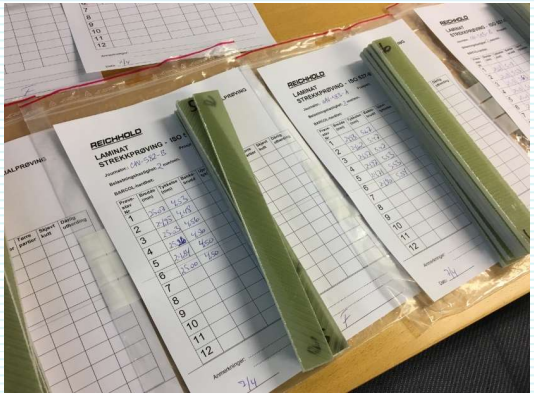
Basic laminates for testing

- focus on 3 types of basic laminates
  - only (0/90) bal.
  - only (±45) bal.
  - only (0/90) unbalanced.

Laminate ID	Laminate specification with fabric reference	Laminate specification with orientation reference	Comments
P1	$\{2*[\text{Fabric F1}]\}^{S}$	$\{2*[0/90]\}^{S}$	about 4.8mm, 4 layers
P2	$\{4*[\text{Fabric F2}]\}^{S}$	$\{4*[45/-45]\}^{S}$	about 4.6mm, 8 layers
P3	$\{2*[\text{Fabric F3}]\}^{S}$	$\{2*[0/90]_{UB}\}^{S}$	about 5.8mm, 4 layers

Materials properties

- engineering constant and strength
  - E and G moduli, Poisson's ratio
  - longitudinal and transverse properties
  - tensile
  - compressive
  - in-plane shear
  - interlaminar shear
- glass content

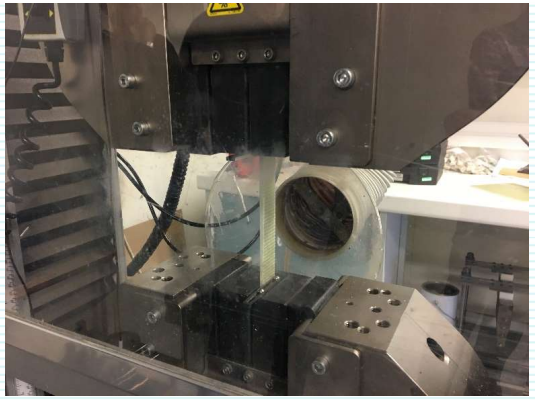


Glass content

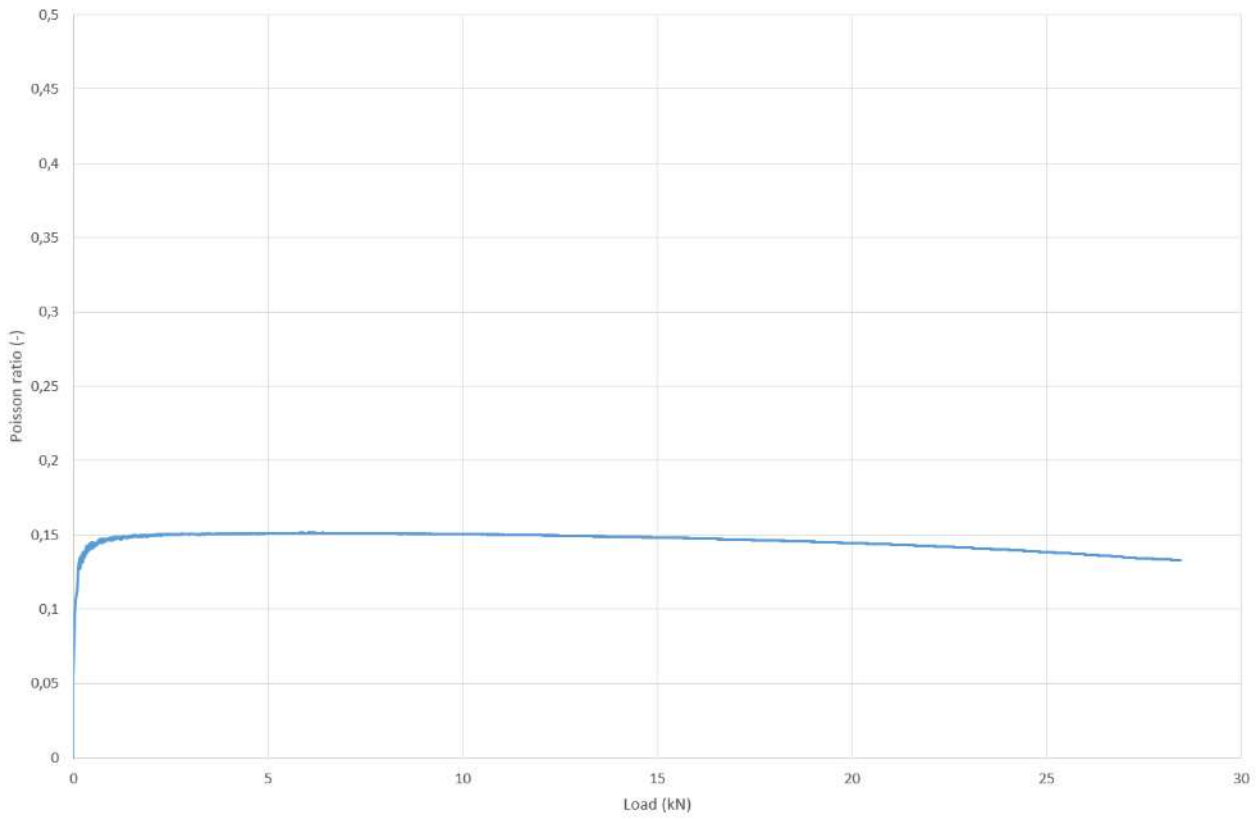
- **P1 (0/90) balanced**
  - 74.6% by weight
- **P2 (±45) balanced**
  - 73.2%
- **P3 (0/90) unbalanced**
  - 71.0%

Some typical strength values

- **P1 (0/90) balanced**
  - Long.: σ=559 Mpa, tension
  - Trans: σ=310 Mpa, compression
  - τ=36.4 Mpa, in-plane shear
- **P2 (±45) balanced**
  - Long.: σ=452 Mpa, tension
  - Trans: σ=412 Mpa, compression
  - τ=36.8 Mpa, in-plane shear



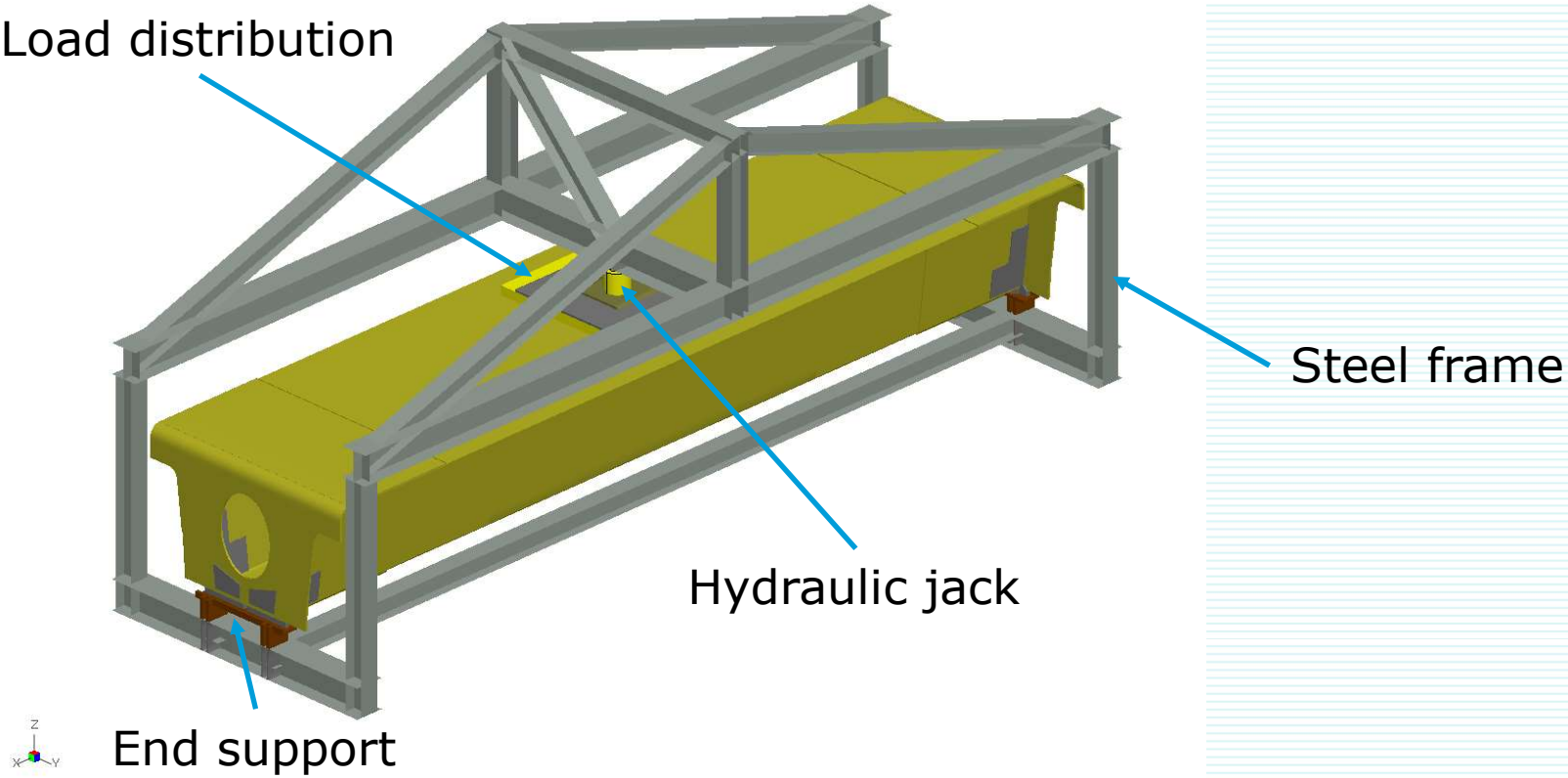
Poisson’s ratio



Back calculations

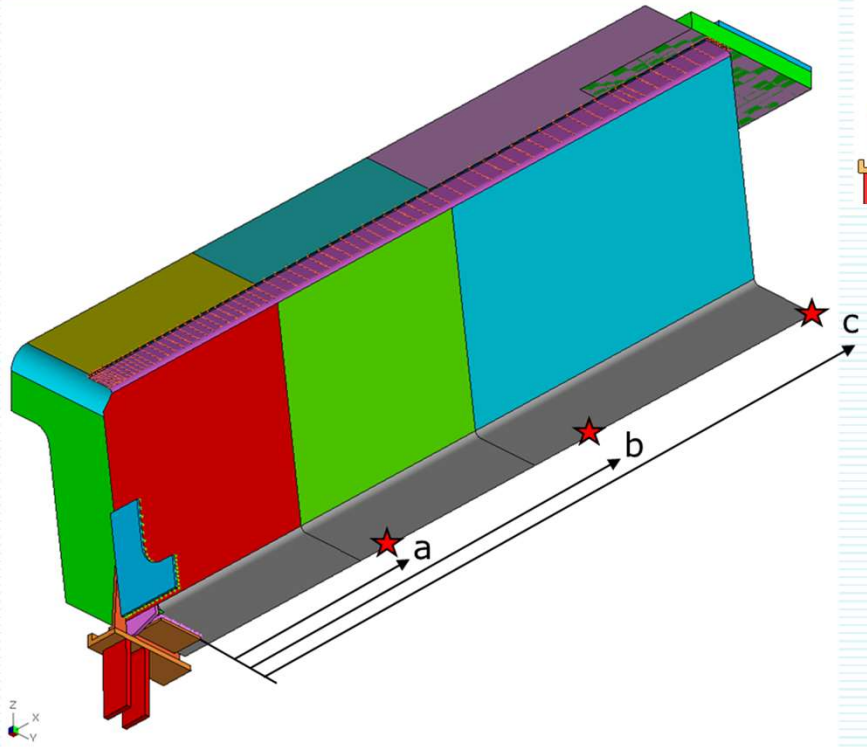
- Ply properties back-calculated from basic laminates properties using
  - classical laminated theory
  - standard failure criteria
  - damage factor

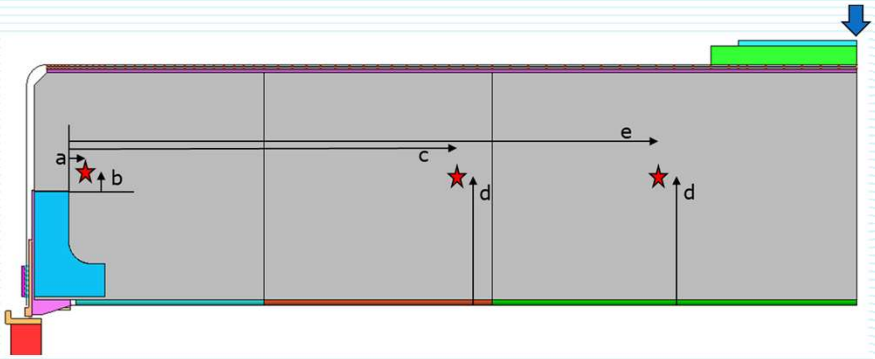
Static testing setup

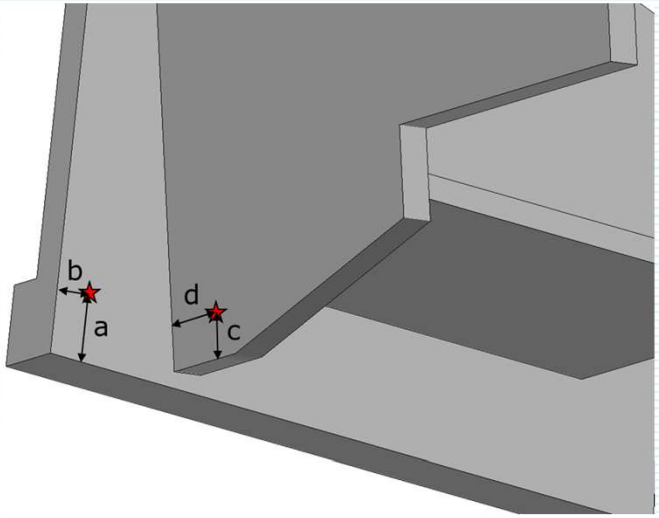


Strain gauge locations

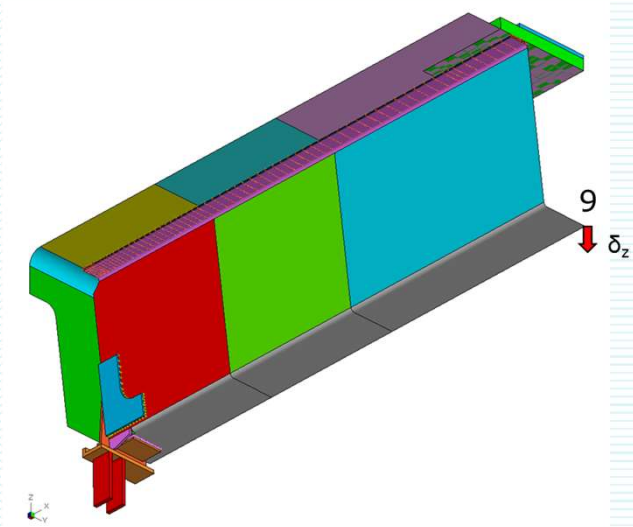
All gauges are places on the inside surface

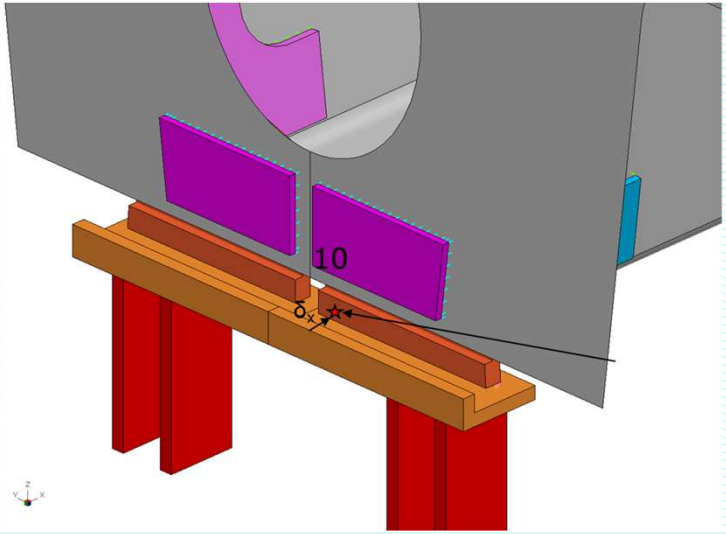


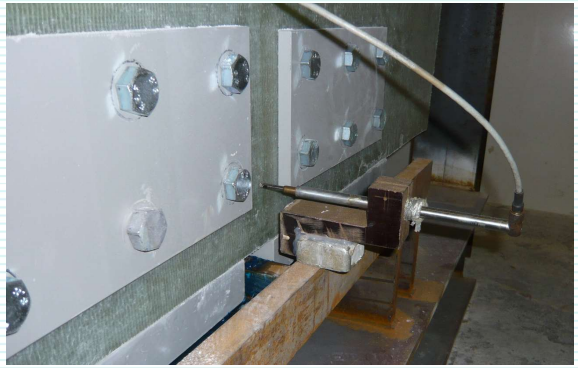




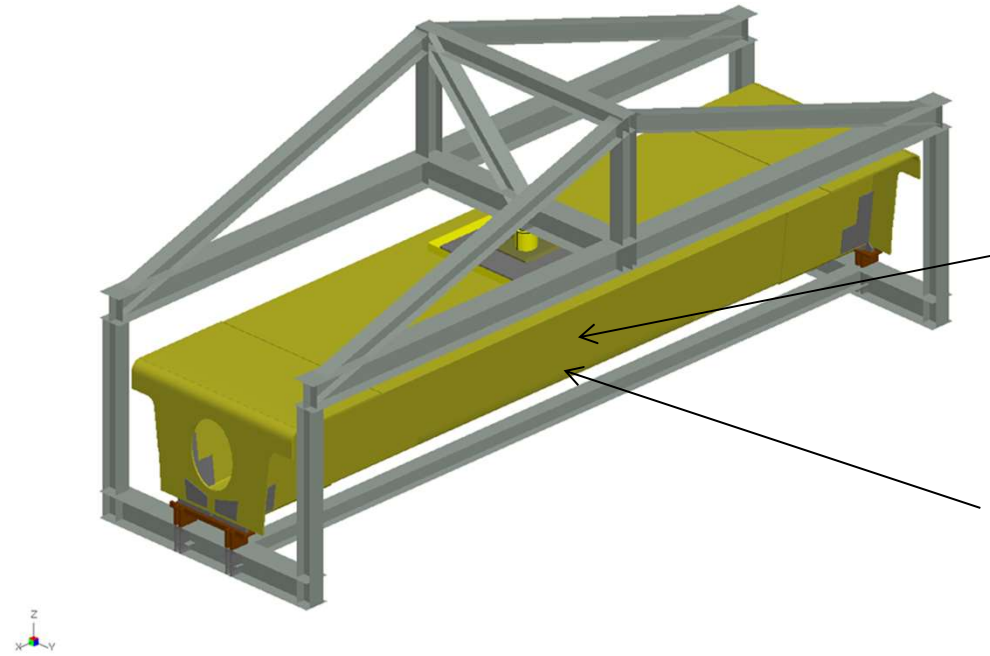
Displacement measurements







Calculations compare well with measurements



Stress in bottom laminate:
Calculated axial stress:
- 45-51 Mpa (Various friction assumption)

Measured:
- 50 MPa

Deflection of bottom laminate:
Calculated vertical defl.:
- 38 mm

Measured
- 33 mm

Impact testing set-up

Mobile crane was used to lift the objects to wanted height

The drop object was released manually by pulling a line to a release mechanism

Prototype is mounted in a steel jig

The drop weights:

25 kg	Drop height: 1 – 10 m
1000 kg	Drop height: 0.2 – 1.25 m

Drop tests – 25 kg object

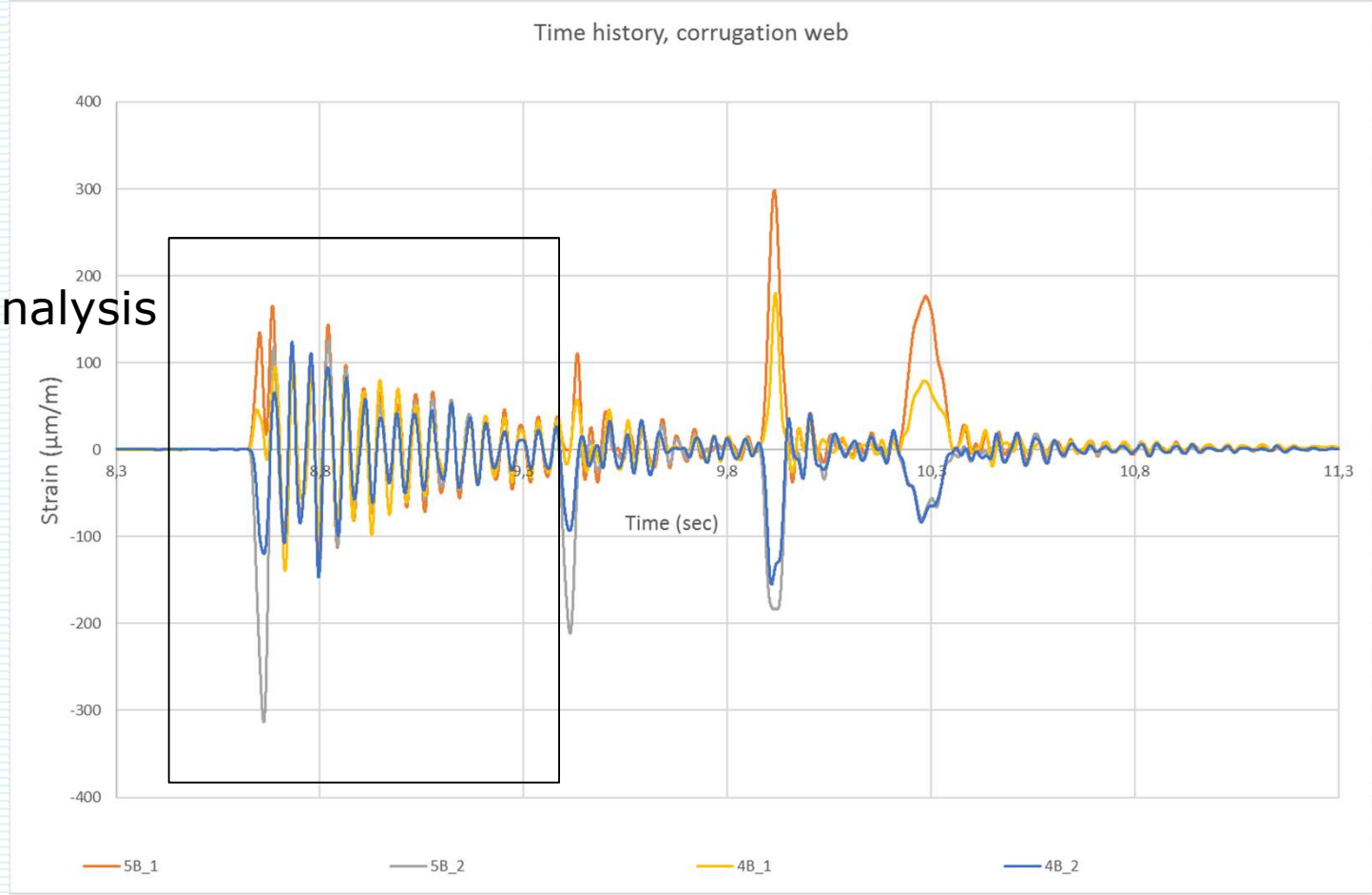
Cut through 2 glass plies, i.e. about 2-3 mm deep.
Delamination somewhat deeper

Drop tests – 1000 kg object

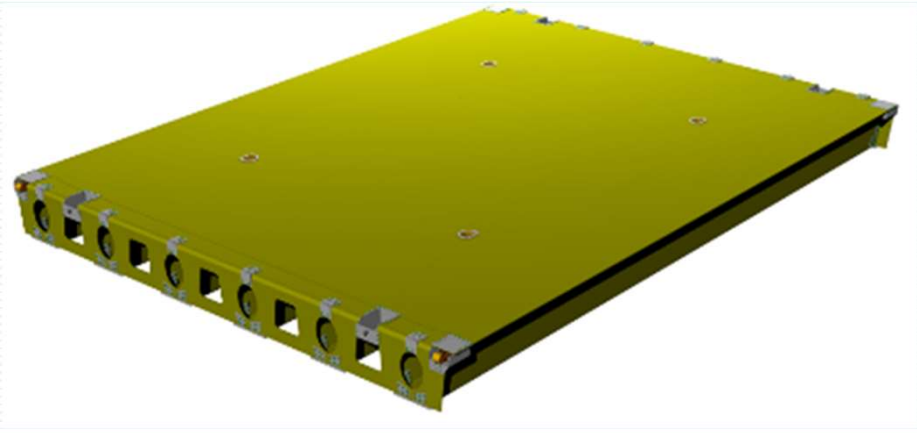
Delamination observed: interlaminar shear failure in radius web/flange

Strain recording

FFT analysis



Composite tween deck benefits



- 50% weight reduction, compared to a traditional steel tween deck
- Fewer panels => Shorter handling time
- Reduced maintenance cost (composite material is non-corrosive)
- Simple and cost-effective production process => short delivery time
- Excellent impact strength
- Easy repair of small damages

Conclusions

All objectives of the prototype JIP have been met

- Material properties better than assumed
- Calculations compare well with measurements
- Production method proven
- Impact strength is excellent
- Design verified by 2nd party (AiP from DNVGL)
- Simple repair method documented

This new design has created interest in the maritime market