The Re-Wind Project and BladeBridge

Engineers Ireland
CORK
Celebrating 80 years!

The Institution of Structural Engineers

07.12.2021

Speakers:

Paul Leahy

School of Engineering & Architecture & MaREI Centre, University College Cork

Kieran Ruane

Civil, Structural and Environmental Engineering Department,
Munster Technological University

Re-Wind Network

University College Cork, Queens University Belfast,
Georgia Tech, Munster Technological University

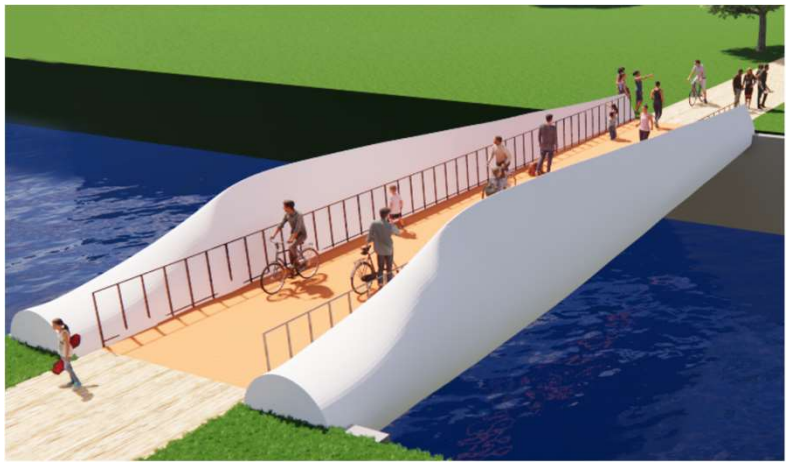
Gerard Mullally, Niall Dunphy, Zoe Zhang, Angela J. Nagle, Fergal Gough, Heloisa Lemmertz, Peter Deeney, Emma Delaney, Jennifer McKinley, An Huynh, Conor Graham, Marios Soutsos, Lawrence Bank, T. Russell Gentry

RE-WIND NETWORK
BLADE REPURPOSING SOLUTIONS
WWW.RE-WIND.INFO

Georgia Tech | Queen's University Belfast | CUNY The City University of New York | UCC University College Cork, Ireland Coláiste na hOllscoile Corcaigh | MTU Ollscoil Teicneolaíochta na Mumhan Munster Technological University

Presentation Overview

- Wind Energy in Ireland 1990-2038
- Wind Farm Life Cycle
- End-of-life Turbine Blades
- Transdisciplinary Methods
- The Re-Wind Project
- Blade Repurposing
- Greenway Opportunities
- Integrated Assessments: How Sustainable is Repurposing?

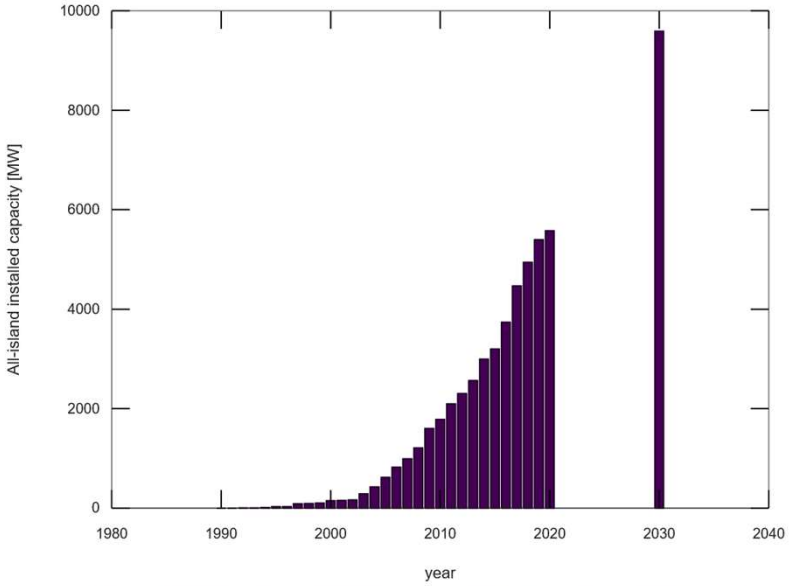


Re-Wind Catalog Modeling and Graphics: Asha McDonald, Chloe Kiernicki, Mehmet Bermek, Zoe Zhang, Alex Poff, Sakshi Kakkad, Emily Lau, Franco Arias, Russell Gentry.

Wind Energy in Ireland

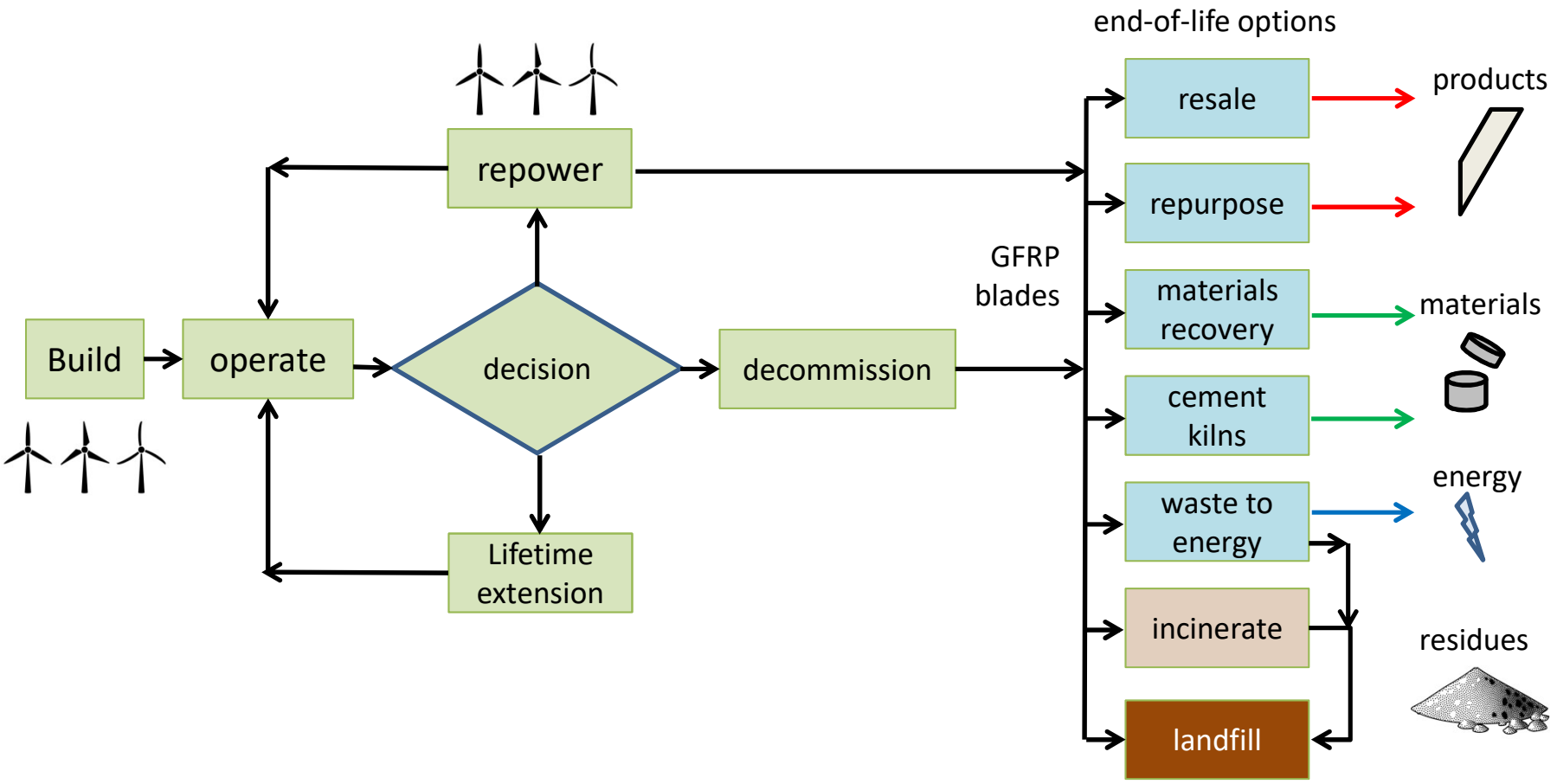
- Wind Energy capacity in Ireland:
  - 153 MW in 2001
  - 5,576 MW in 2020
  - 9958 MW by 2030

- Wind turbine typical design life is 20 years
- Wind turbine decommissioning will accelerate in the next five years



Lower image: decommissioning, energyfacts.eu

Wind farm lifecycle



Wind farm end of life decision factors

When does a wind plant reach end of life?

- End of design life
- Expiration of planning permission
- Market reforms
- Expiration of subsidies
- Operating costs: wear, fatigue, failures, outages, repairs
- Obsolescence

What happens next?

- Decommission
- Repower
- (continue operation)

Altamont Pass, USA.
Image: Noah Berger, National Geographic

End of life wind turbine blades: a circular economy challenge

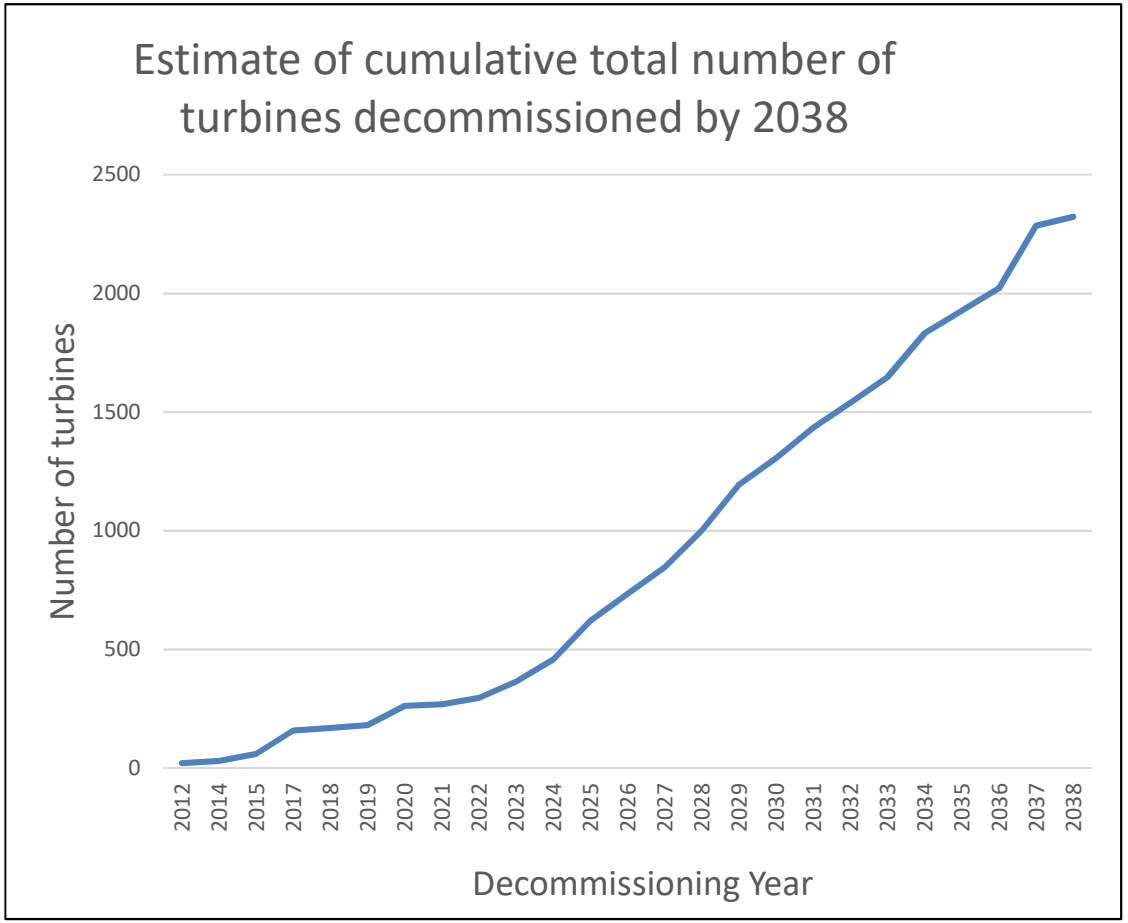
- Wind turbine blades are primarily composed of non-biodegradable GFRP composite materials
- Annual global blade waste is expected to reach 40 million tonnes by 2050
- Current solutions: incinerate, stockpile, landfill, grind for aggregates
- Can feasible repurposing options be found?

Cut GFRP composite waste
Image: BRIO project
Credit: Elhuyar Fundazioa

Turbine decommissioning & the mounting blade ‘waste’ issue

Approximately **2,323** turbines to be decommissioned in Ireland by 2038

Landfill will soon no longer be an option for end-of-life blades in Ireland



Emma Delaney, QUB

Complex challenges require transdisciplinary approaches

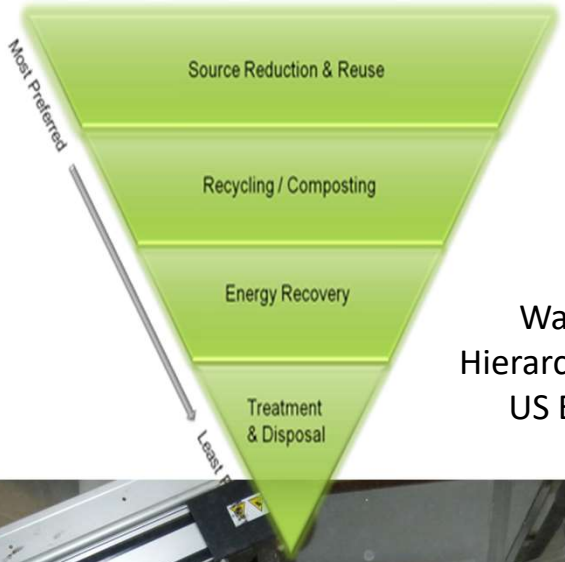
- Re-Wind adopts a transdisciplinary approach to determine environmentally, socially and economically sustainable repurposing options for blades
- Academic Investigators (UCC)
  - Dr. Paul Leahy, Wind Energy Engineering,
  - Dr. Niall Dunphy, Cleaner Production Promotion Unit
  - Dr. Ger Mullally, Sociology
- Disciplines: Architecture, Structural Engineering, Sociology, Energy Engineering, Business Model Discovery, Geographical Information Science

Postdocs & PhDs

Dr Peter Deeney (Finance),
Angela Nagle (Environmental),
Fergal Gough (Social/Community),
Heloisa Lemmertz (Circular Business Models)

Composite wind turbine blade waste: what to do?

- Wind turbine blades primarily composed of non-biodegradable GFRP composites
- Current solutions: incinerate, stockpile, landfill, grind for aggregates
- Highly engineered, unique structural properties
- Can technically, economically, environmentally & socially feasible **repurposing** options be found?



Waste Hierarchy: US EPA

Cut GFRP composite waste Image: BRIO project Elhuyar Fundazioa

Volumes of plastic and composite waste is a global environmental problem

Image: Korle Lagoon, Accra, Ghana

https://www.abc.net.au/news/2021-08-12/fast-fashion-turning-parts-ghana-into-toxic-landfill/100358702

August 12th 2021

Re-Wind: Driving Innovation in the Re-Use of Decommissioned Wind Turbine Blades

Supported by InvestNI/Department for the Economy (DFE), Grant USI-116; by Science Foundation Ireland, Grant 16/US/3334; and by the U.S. National Science Foundation under grants numbers 1701413 and 1701694, under the project "Re-Wind".
Re-Wind, 2020.

- Wind Thrust
- Mechanical Thrust
- Design Thrust
- Geographical Information Science (GIS) Thrust

Re-Wind Project (2017-2021) Partners: UCC, QUB, Georgia Tech, City University of New York

Re-Wind:
Wind Energy / Circular Economy thrust

- The Re-Wind UCC team is focussed on:
  - Environmental sustainability
  - Social acceptability
  - Sustainable business models
- for second (& third) life applications for decommissioned wind turbine blades
- Complex, multifactorial problem…

Blade Repurposing: Methodology

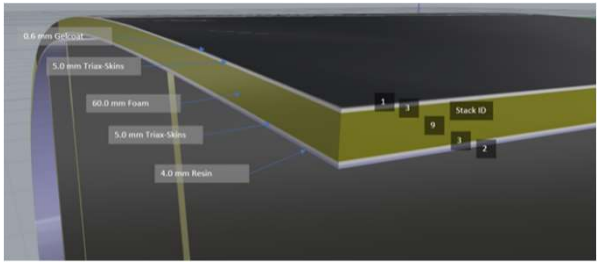
More than **50 blade repurposing concepts** identified initially

Design Office exercise (Winter 2019, Belfast)

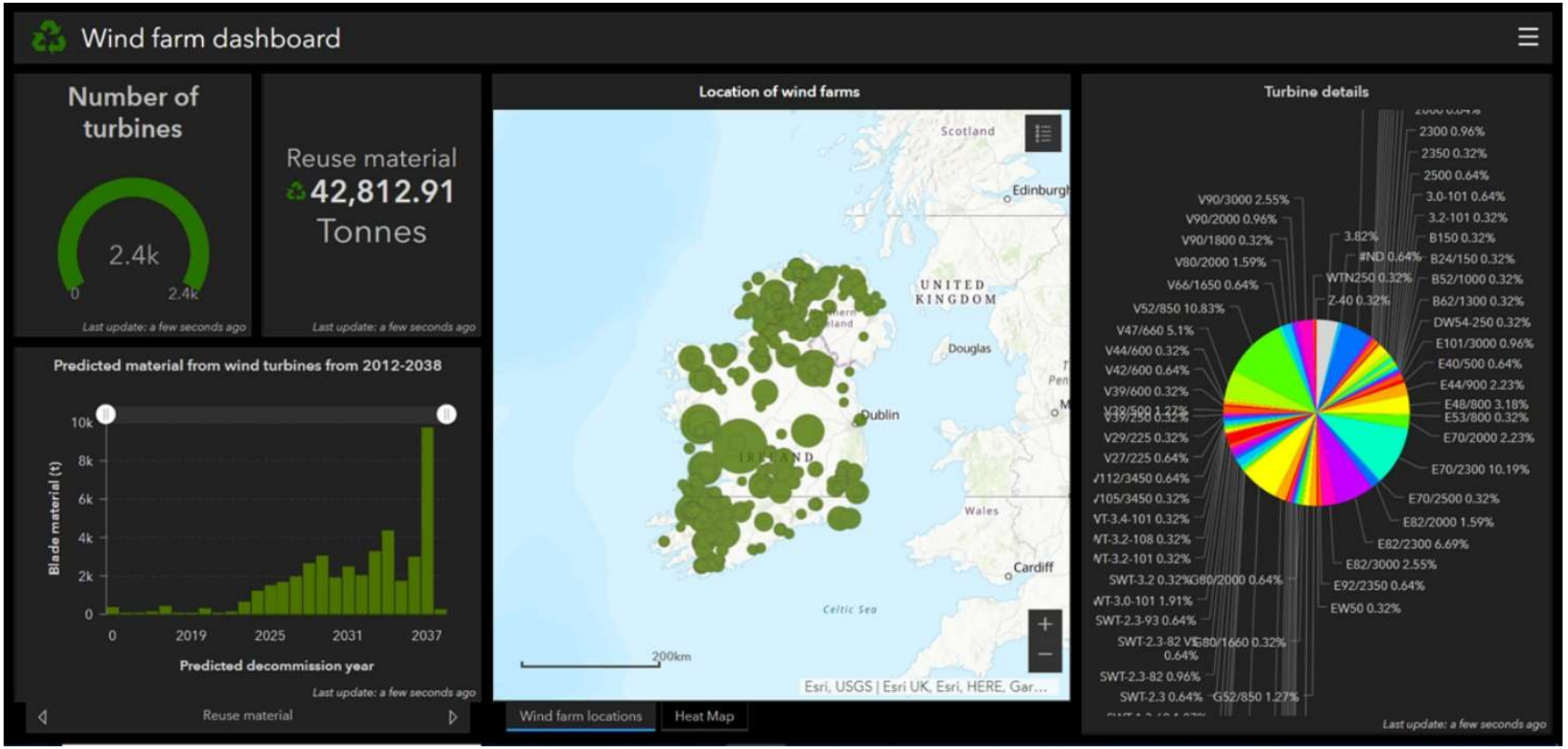
The success of reuse cases depends on **technical feasibility**, **location** & **social**, **environmental** and **economic** sustainability

A **transdisciplinary approach** has developed tools to assess all of these:

- All-Ireland blade geodatabase
- 3-D LiDAR scanning
- Blade geometry reconstruction software
- Structural analysis & testing methods
- Community engagement methodology
- Lifecycle analysis (LCA)
- Robust set of internationally-deployable success indicators : environmental, social and economic



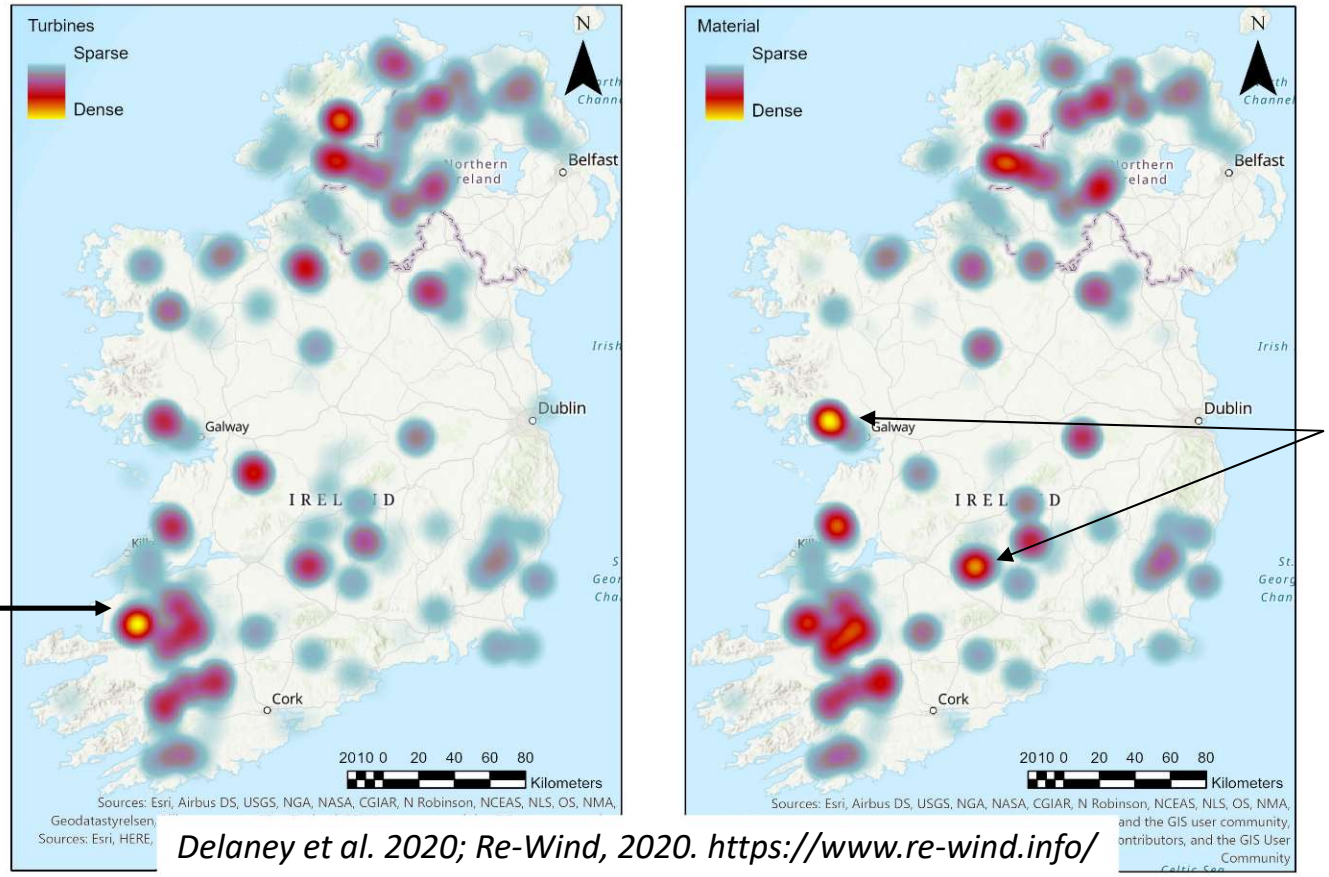
GIS Dashboard & Database



Tool allows database to be queried by: location, turbine type, blade dimensions, projected decommissioning date (Re-Wind, QUB Team)

Delaney et al. 2020
www.re-wind.info/

Material Locations



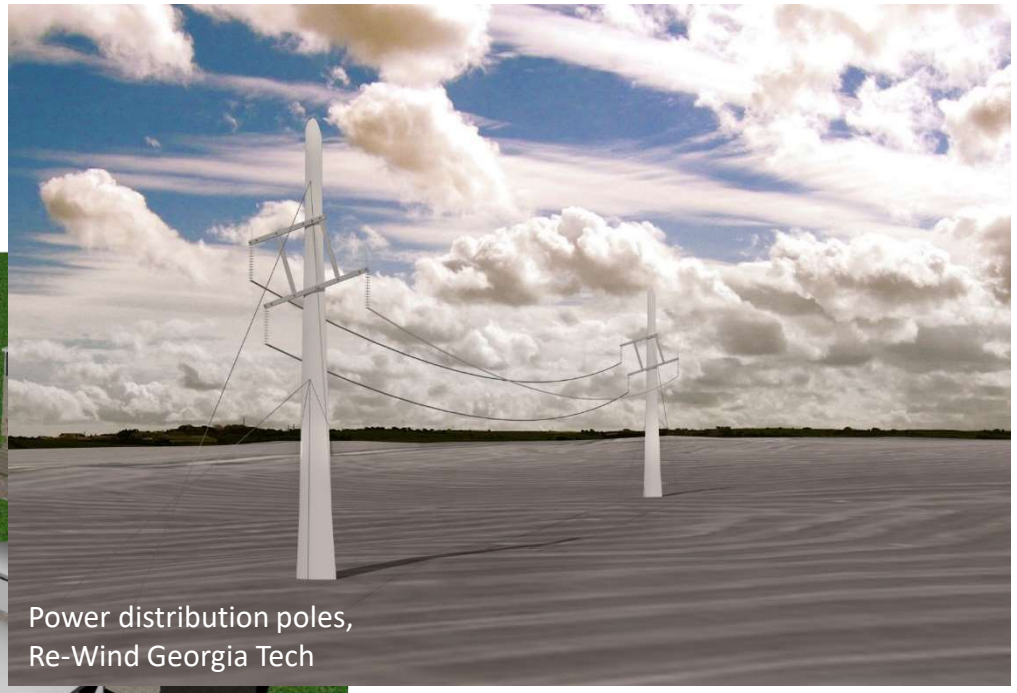
Highest density of turbines

Highest density of repurposing material

Delaney et al. 2020; Re-Wind, 2020. https://www.re-wind.info/

Blade repurposing use cases

Bank et al.,
Recycling 2018



Power distribution poles,
Re-Wind Georgia Tech

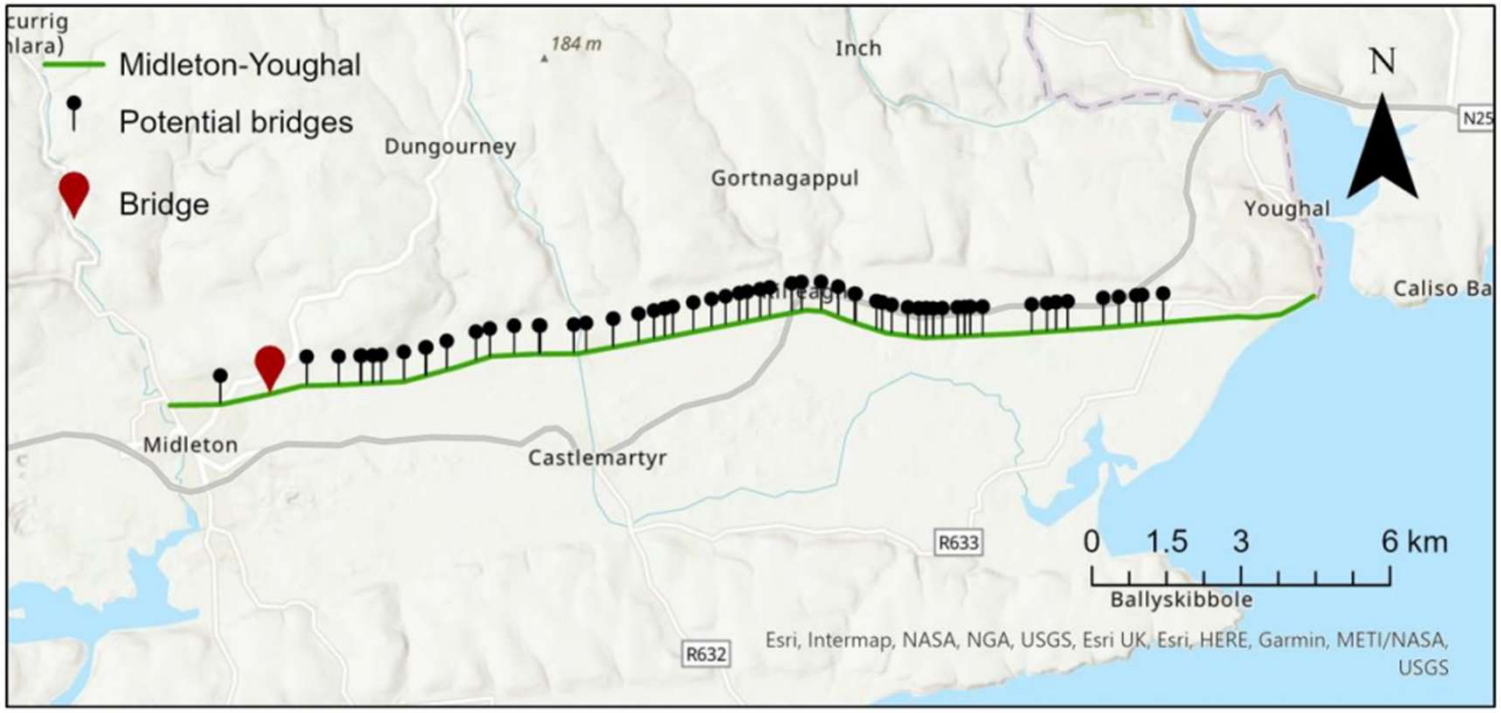
QUB LiDAR scanning of Nordex N29 Blades at Everun Ltd, Belfast

Growth of Greenways in Ireland

- Greenways are a means of repurposing disused or underused transportation infrastructure for sustainable transport
- Co-benefits in rural development, tourism and public health
- 240 km of greenways in RoI by 2022
- Further 800 km proposed
- In NI there are 1,000 km of former transport routes suitable for greenways

Map by Riddlinrussell - boards.ie [google maps]

Youghal-Midleton Greenway, Cork



(Emma Delaney, Re-Wind QUB)

- 23 km route under development by Cork County Council
- Funded by the Project Ireland 2040 initiative.
- Expected completion 2022, sections will open earlier
- The Youghal-Midleton Greenway route was surveyed for potential blade bridge crossings, April 2020

BladeBridge
LCA Boundary Setting & Assumptions

Functional Unit: Disposition of 4500 kg blade waste over 60 years (Cradle to Grave)

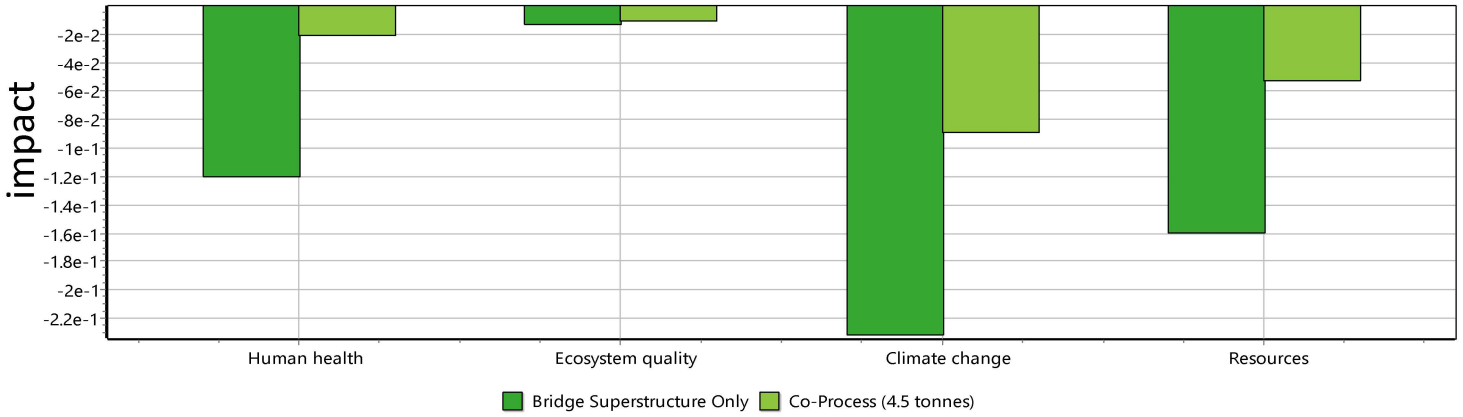
- Blades transported Belfast to Cork
- Lower 2/3 blade replaces steel girders made with partially recycled material
- Top 1/3 blade sent to landfill
- Blades coated in epoxy protective layer
- End of Life Plan: Co-processing of GFRP girders, recycling of hardware

Wooden decking material, abutments, and maintenance schedule assumed equal to bridge made with steel girders

Presented by Angie Nagle,
ReComp 25th November 2020

Blade bridge : environmental assessment

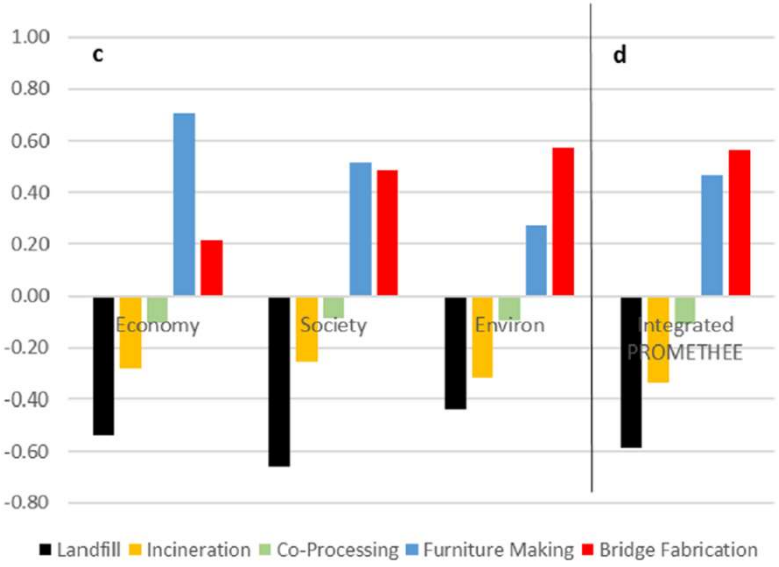
- Blade bridge **environmentally** preferable to alternative end-of-life treatments: co-processing or landfill (baseline, not shown)
- Impacts calculated using Life Cycle Analysis (LCA) by Angie Nagle



Method: IMPACT 2002+ V2.15 / IMPACT 2002+ / Normalisation
Comparing 1 p 'Bridge Superstructure Only' with 1 p 'Co-Process (4.5 tonnes)';

Sustainable Business Models

- Future repurposing must be sustainable in terms of social, environmental and economic aspects
- Inclusive configuration of stakeholder in which different needs and interests are reflected
- Consideration of different types of value flows – not just focused on monetary outcomes
- Importance of engaging communities where blades are located and likely to be reused or recycled
- There is a possible role for so-called social business models
- **Repurposing scores well on integrated metrics compared to "conventional" end-of-life disposal**



End-of-Life alternatives for wind turbine blades: Sustainability Indices based on the UN sustainable development goals

Peter Deeney [a,b,g,*], Angela J. Nagle [a,b], Fergal Gough [a,c], Heloisa Lemmertz [a,c], Emma L. Delaney [d], Jennifer M. McKinley [d], Conor Graham [d], Paul G. Leahy [a,b,g], Niall P. Dunphy [a,b,e,g], Gerard Mullally [a,c,e,f,g]

Resources, Conservation & Recycling 171 (2021) 105642

Greenway Blade Bridge: Initial Conclusions

- We can address several societal challenges through greenway blade bridges: circular economy/ resource reuse, decarbonising transport, healthy lifestyles, sustainable rural development
- Technical feasibility of repurposing blades as infrastructure is being demonstrated
- Detailed life cycle analysis shows environmental benefits:
  - Repurposing blades as bridges is superior to cement kiln co-processing or landfilling the blades
- A huge opportunity exists for repurposed bridges and other artefacts on the growing greenway network in Ireland and beyond

Re-Wind Fall 2021 Design Catalogue

- Blade Bridge
- Blade Pole
- Blade Barrier
- Bicycle Shelters

- https://www.re-wind.info/update/2021/11/11/re-wind-publishes-its-fall-2021-design-catalog

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Poll

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Acknowledgements to Re-Wind network team at University College Cork, Queens University Belfast, and Georgia Tech and Munster Technological University. Blade donation: Everun Ltd.

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Ger Mullally,
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Paul Leahy

Speaker 2: Kieran Ruane, MTU: Blade Bridge

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MaREI

Science Foundation Ireland sfi For what's next

National Science Foundation

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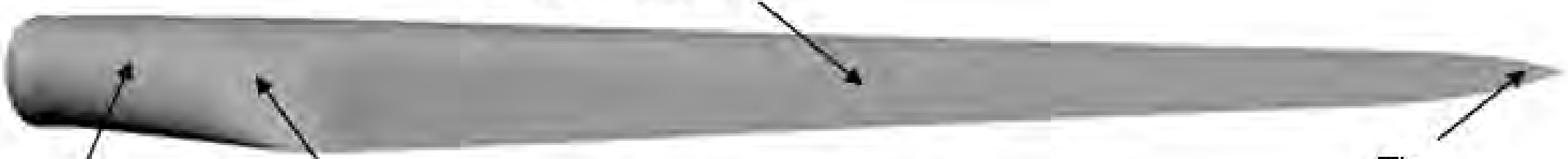
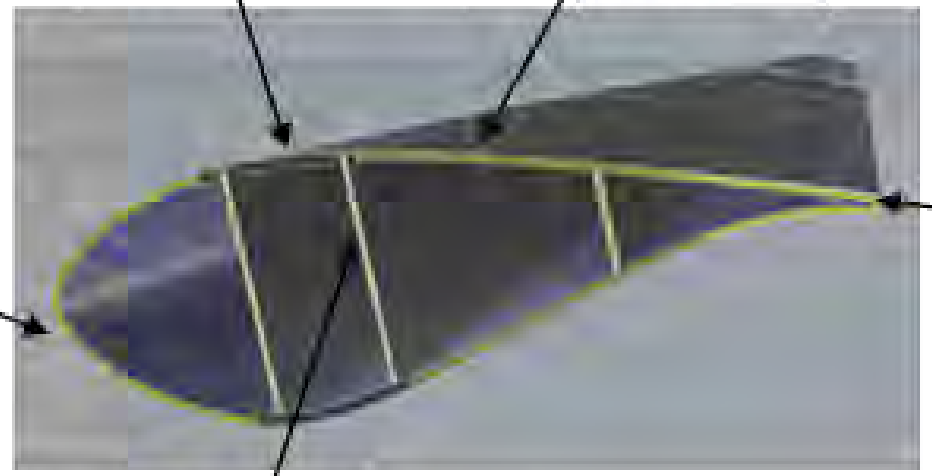
Georgia Tech | Queen's University Belfast | CUNY The City University of New York | UCC University College Cork, Ireland Coláiste na hOllscoile Corcaigh | MTU Ollscoil Teicneolaíochta na Mumhan Munster Technological University

(a)


Airfoil cross-sections
Root (circular cross-section)
Transition region (from circular to airfoil cross-sections)
Tip

(b)


Spar Cap
Shell
Leading Edge
Trailing Edge
Shear Web

Fibre Reinforced Polymers (FRPs)

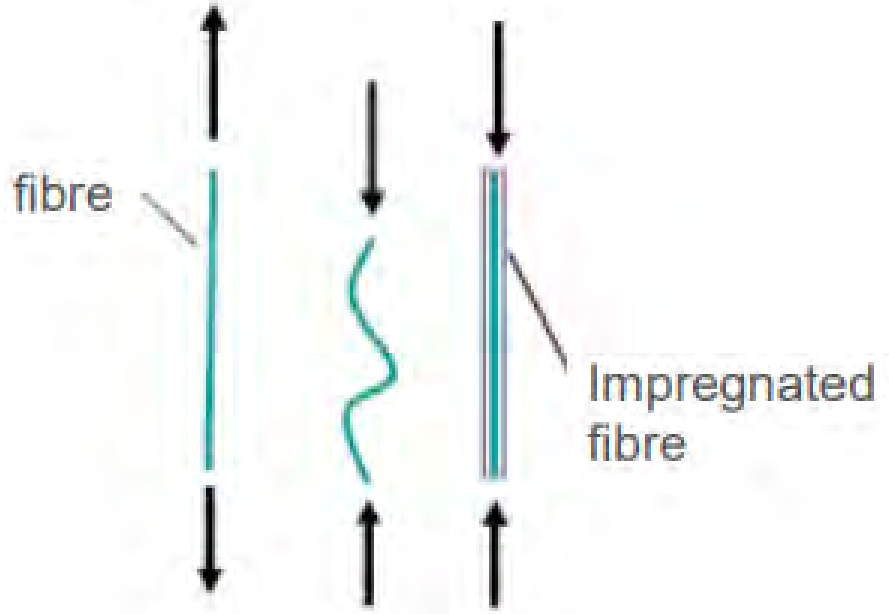
A composite material

Fibres (reinforcement)

Load-bearing function

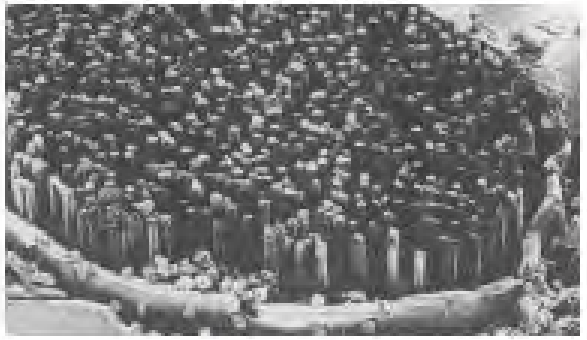
Polymer resin (matrix)

1. Fixing fibres
2. Transferring the forces
3. Preventing buckling
4. Protecting the fibres



Tiny fibres are grouped to form reinforcement

Fibre (filament)



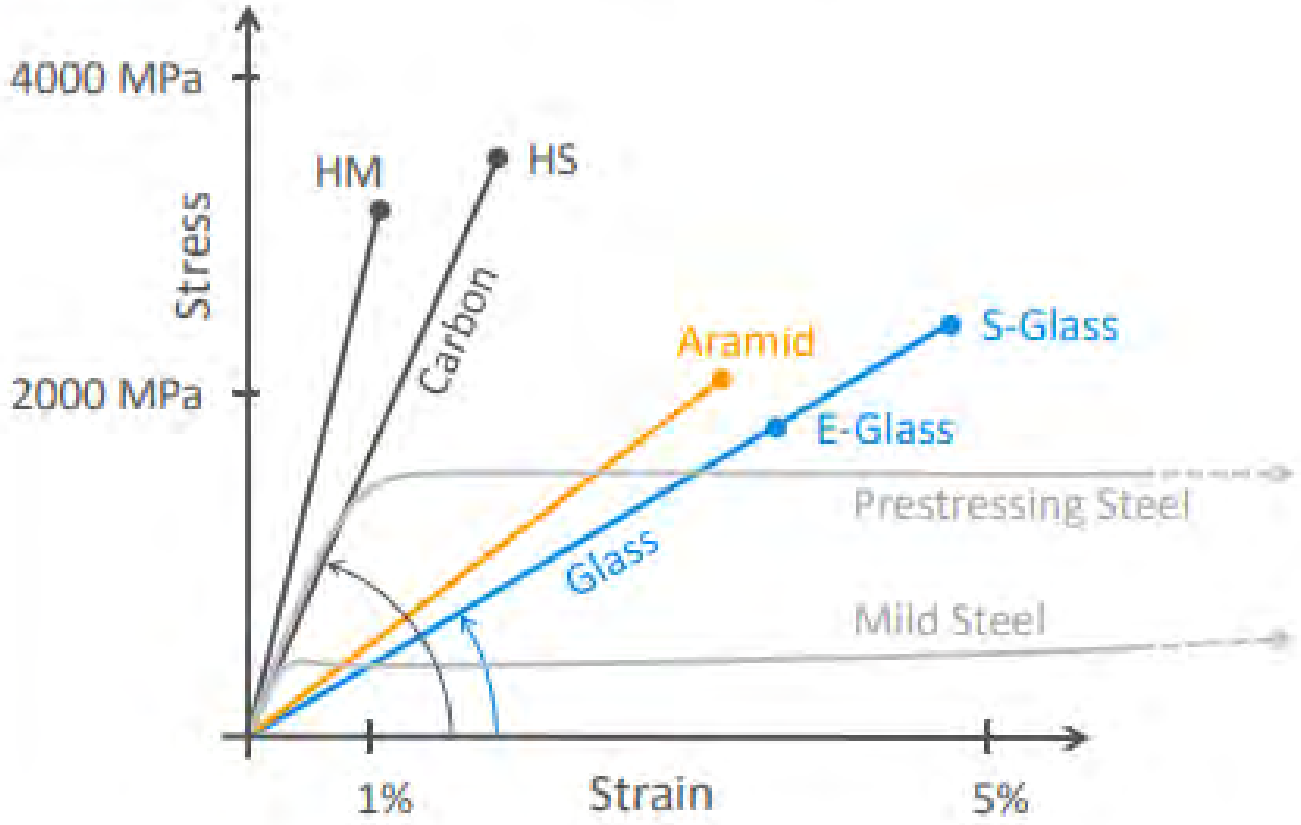
Bundle

Fabric

Roving

Fibre
Mat

How strong are the fibres?

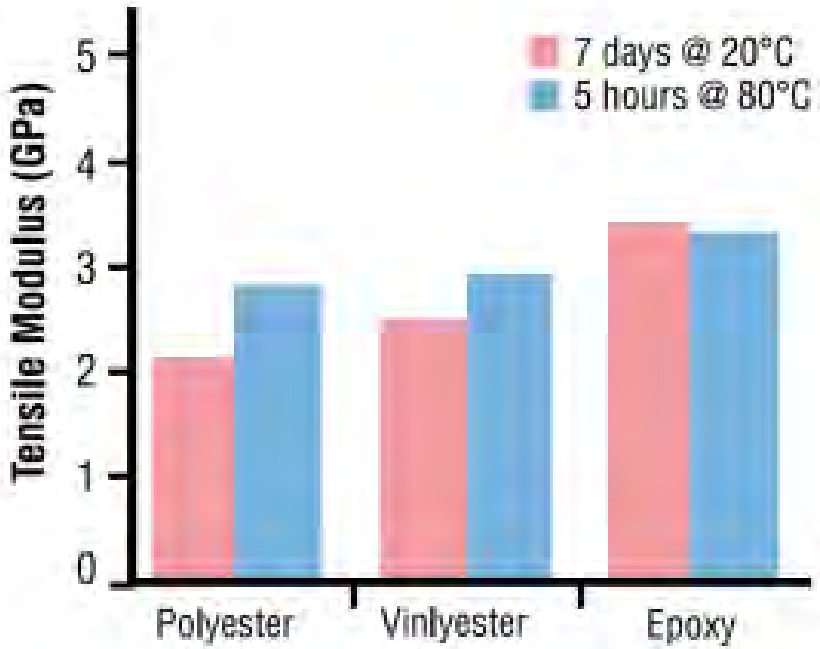


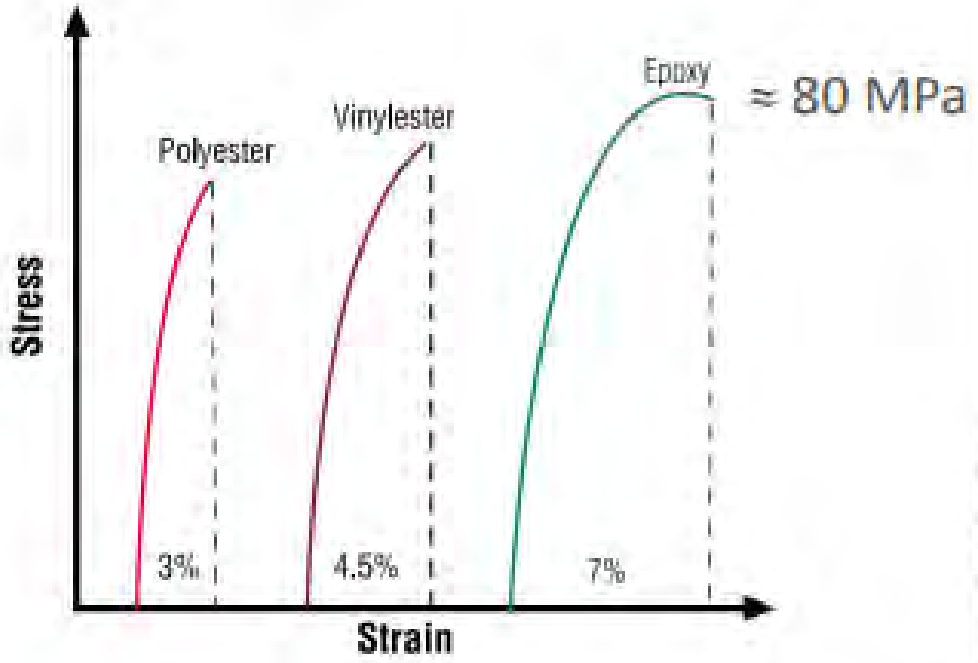
Glass fibres

Carbon fibres

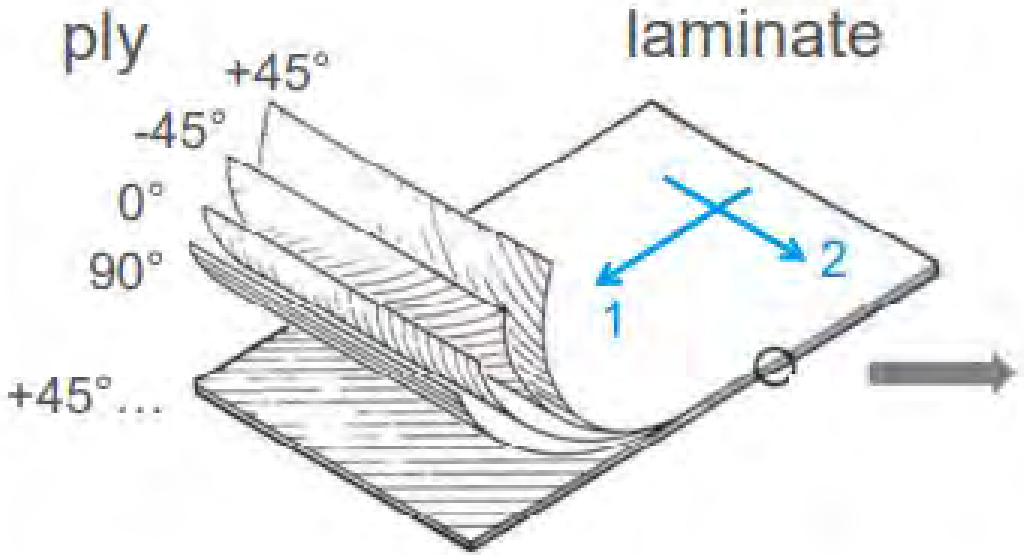
Aramid fibres

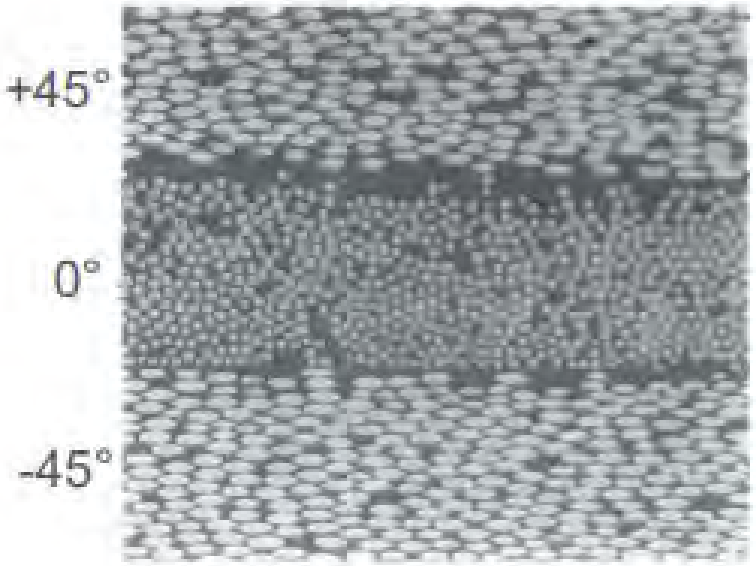
Resin is much more flexible but ductile compered to fibres!





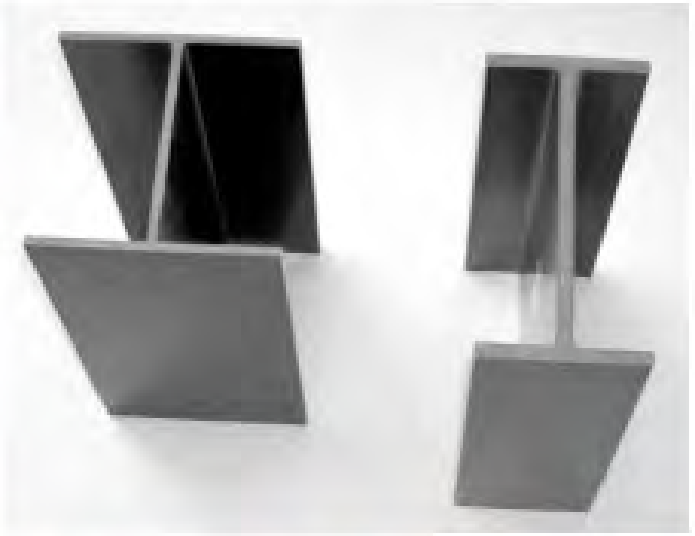
How do we combine fibres and resin?





FRP is tailorable material, we can design it ourselves!

- Type of fibre and resin
- Type of reinforcement
- Orientation of fibres
- Amount of fibres
- Production process

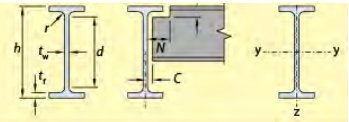


Type	Depth	Area	Height of centroid above soffit	Section modulus		Second moment of area	Self weight/m	Top of beam dimensions	
	D	A	Y_c	Z_t	Z_b	I_{xx}		L1	L2
	(mm)	mm^2	(mm)	($mm^3 \times 10^6$)	($mm^3 \times 10^6$)	($mm^4 \times 10^3$)	(kN/m)	(mm)	(mm)
U1	800	479470	353.4	68.2	86.19	30.459	11.99	1195	520
U3	900	510460	398.4	84.39	106.27	42.335	12.76	1208	558
U5	1000	543840	444.8	102.49	127.91	56.898	13.60	1236	586
U7	1100	577220	491.7	121.93	150.83	74.168	14.43	1264	614
U8	1200	610600	539	142.68	174.99	94.315	15.27	1292	642
U9	1300	643980	586.5	164.69	200.36	117.51	16.10	1320	670
U10	1400	677360	634.3	187.93	226.9	143.91	16.93	1348	698
U11	1500	710740	682.2	212.4	254.6	173.69	17.77	1376	726
U12	1600	744120	730.4	238.07	283.45	207.03	18.60	1404	754

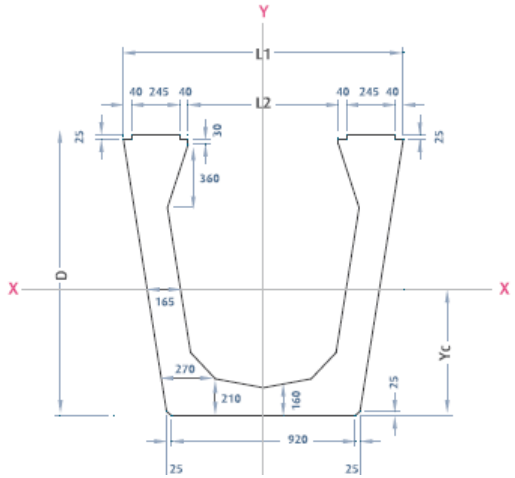
Universal beams (UB) — Section properties

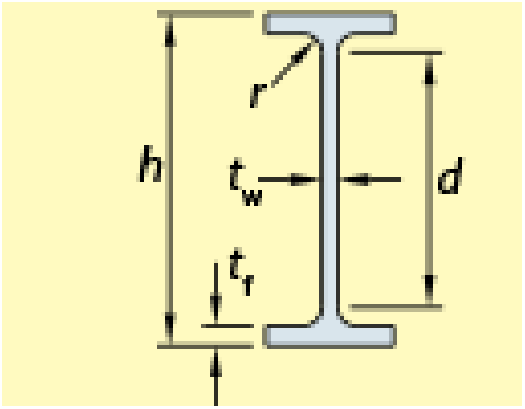
Dimensions & properties

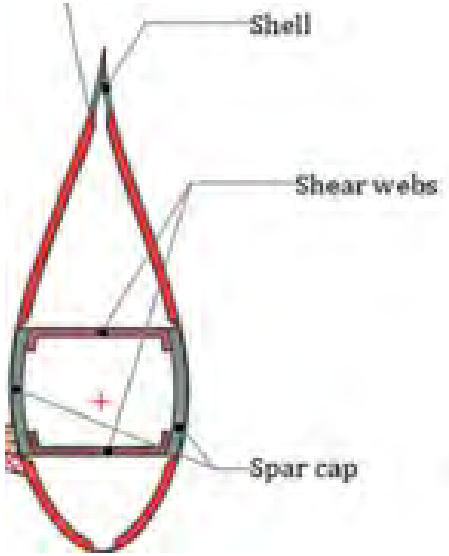
Print design data | Export to excel



Section designation		Properties										
		Radius of gyration		Elastic modulus		Plastic modulus		Buckling parameter	Torsional index	Warping constant	Torsional constant	Area of section
		Axis y-y	Axis z-z	Axis y-y	Axis z-z	Axis y-y	Axis z-z					
		cm	cm	cm^3	cm^3	cm^3	cm^3	U	X	I_w dm^6	I_T cm^4	A cm^2
	x 176	33.1	5.90	5890	535	6810	842	0.856	46.5	13.0	221	224
762 x 267	x 197	30.9	5.71	6230	610	7170	958	0.869	33.2	11.3	404	251
	x 173	30.5	5.58	5390	514	6200	807	0.865	38.0	9.39	267	220
	x 147	30.0	5.40	4470	411	5160	647	0.859	45.2	7.40	159	187





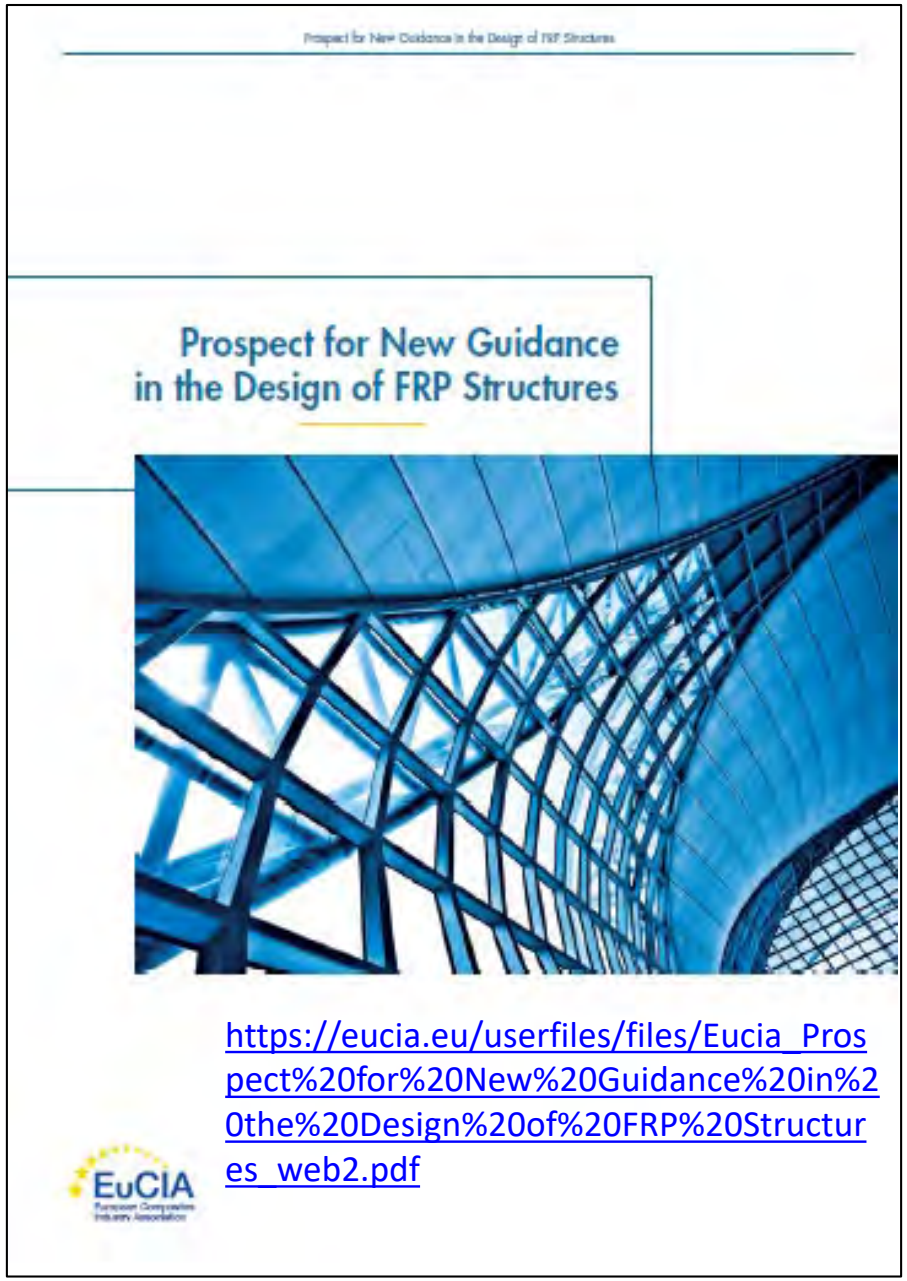


?

What is needed for Engineering Analyses

1. **External geometry** – Airfoil shapes along the length, prebend and twist along the length.
2. **Internal geometry** – location and thickness of spar caps, webs, and shell sandwich panels along the length.
3. **Material types** (e.g., glass, polyester, epoxy) and laminates (or sandwich laminates) for spar cap, shell and webs, Mass (or volume fractions) of fiber and resin in the laminates in the spar cap, shell and webs, Fabric types used (e.g., +-45, mats, UD)
4. **Strength and stiffness** in the longitudinal and transverse directions and shear strength and stiffness of the spar cap, shell and web laminates; of the spar cap, shell and web laminates. Bearing strength for connections. As-received properties and estimate of residual related to virgin.
5. **Global blade structural properties** along the length EI_x, EI_y, GJ, kAG (where x and y and the chord axis and its perpendicular through the centroid of the cross-section. Principal axes and shear centre.)

2016



https://eucia.eu/userfiles/files/Eucia_Prospect%20for%20New%20Guidance%20in%20the%20Design%20of%20FRP%20Structures_web2.pdf

2017

https://www.ciria.org/ItemDetail?iProductCode=C779F&Category=FREEPUBS

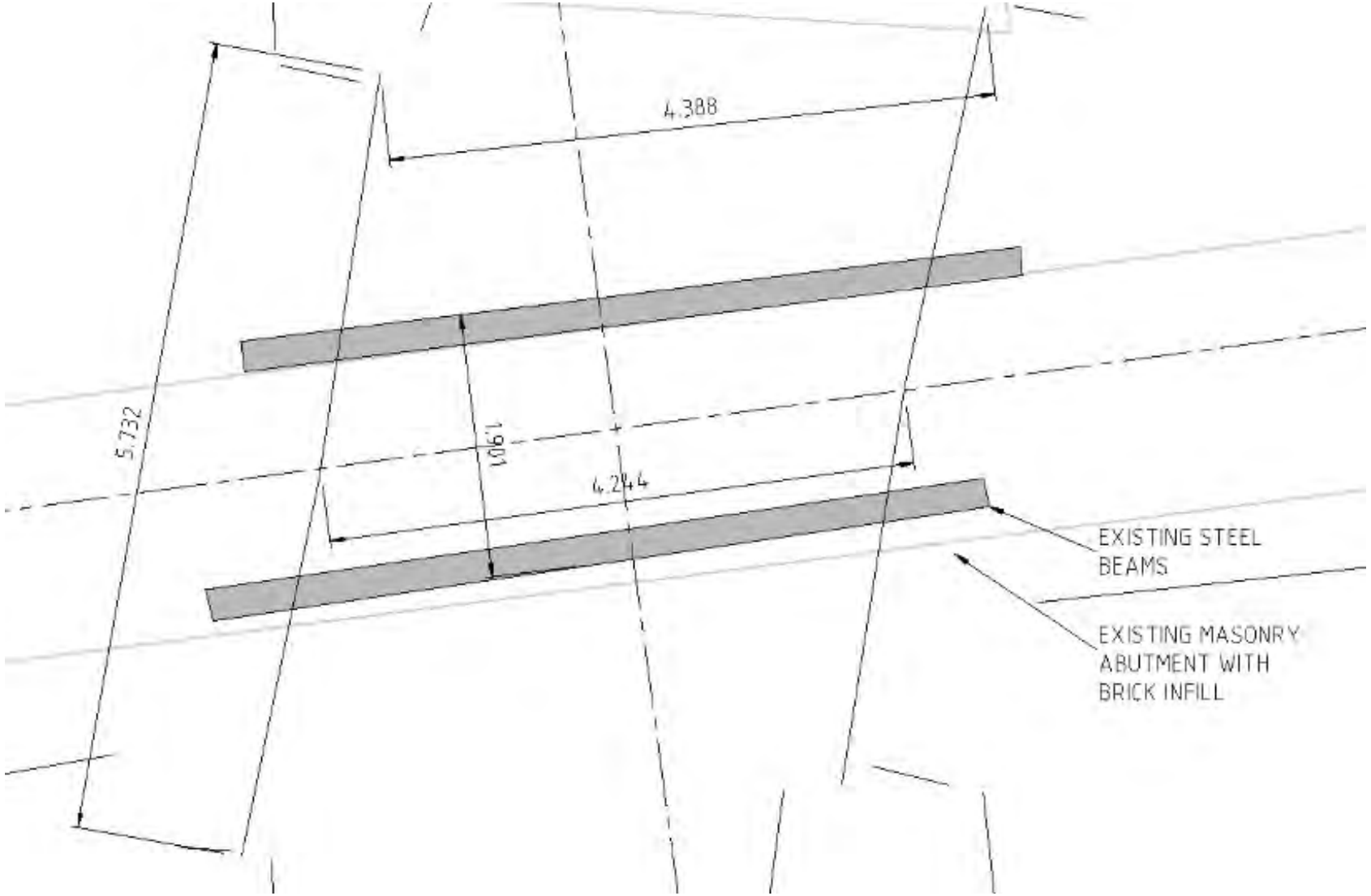
2017

Context


Shannon
Limerick
Thurles
Kilkenny
Gorey
Adare
M8
Cashel
Tipperary
Enniscorthy
M9
New Ross
Clonmel
Wexford
Waterford
Rosslare Harbour
Tramore
Kilmore Quay
Mallow
M8
Dungarvan
Midleton
Youghal Beach
Ballincollig
Cobh
Kinsale
Clonakilty

Context

Context

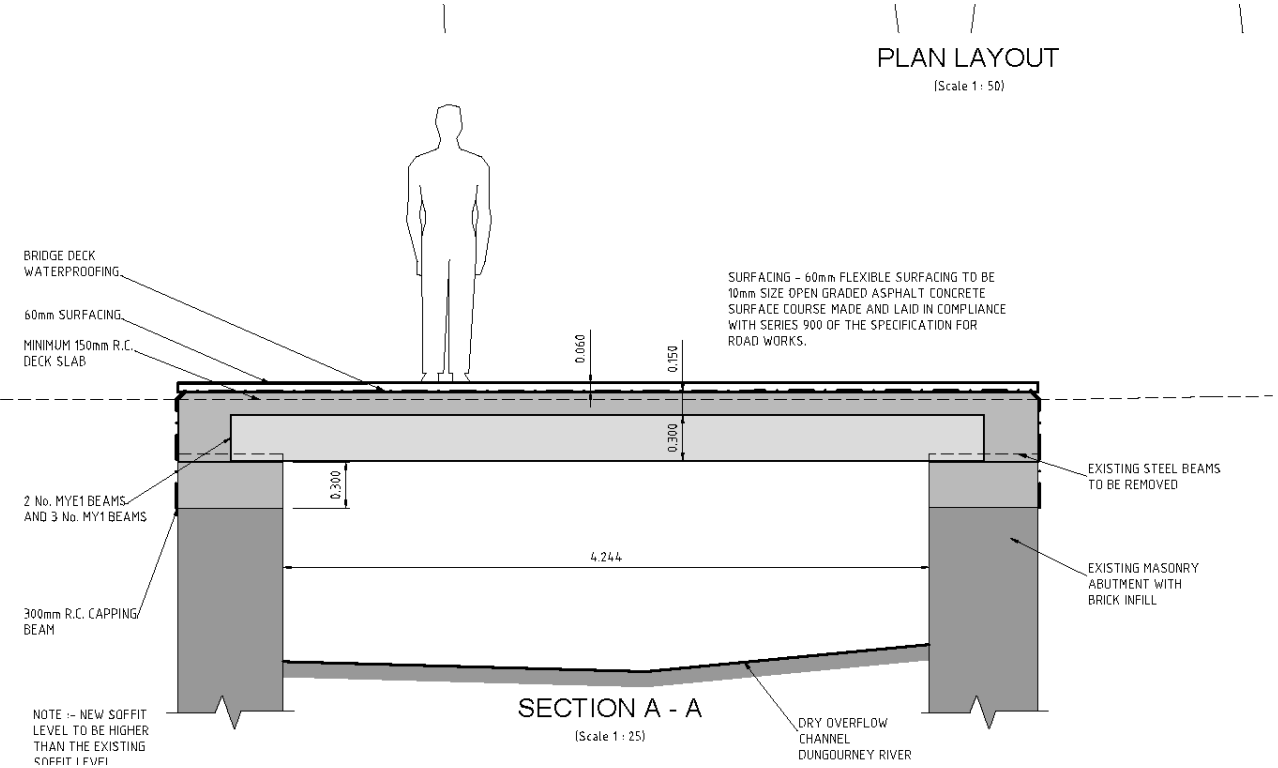


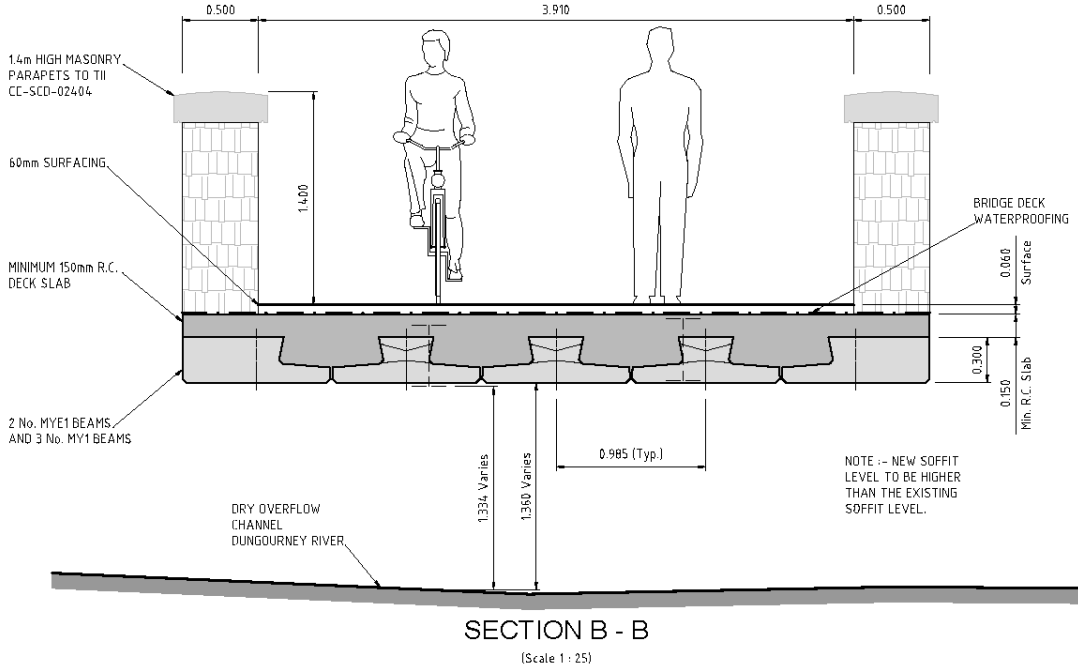
Span ~ 5.0

Width ~ 3-4m

Skew ~ 18°

Context – Original Plan





Conceptual Design

Ms. Zoe Zhang, GT

Conceptual Design

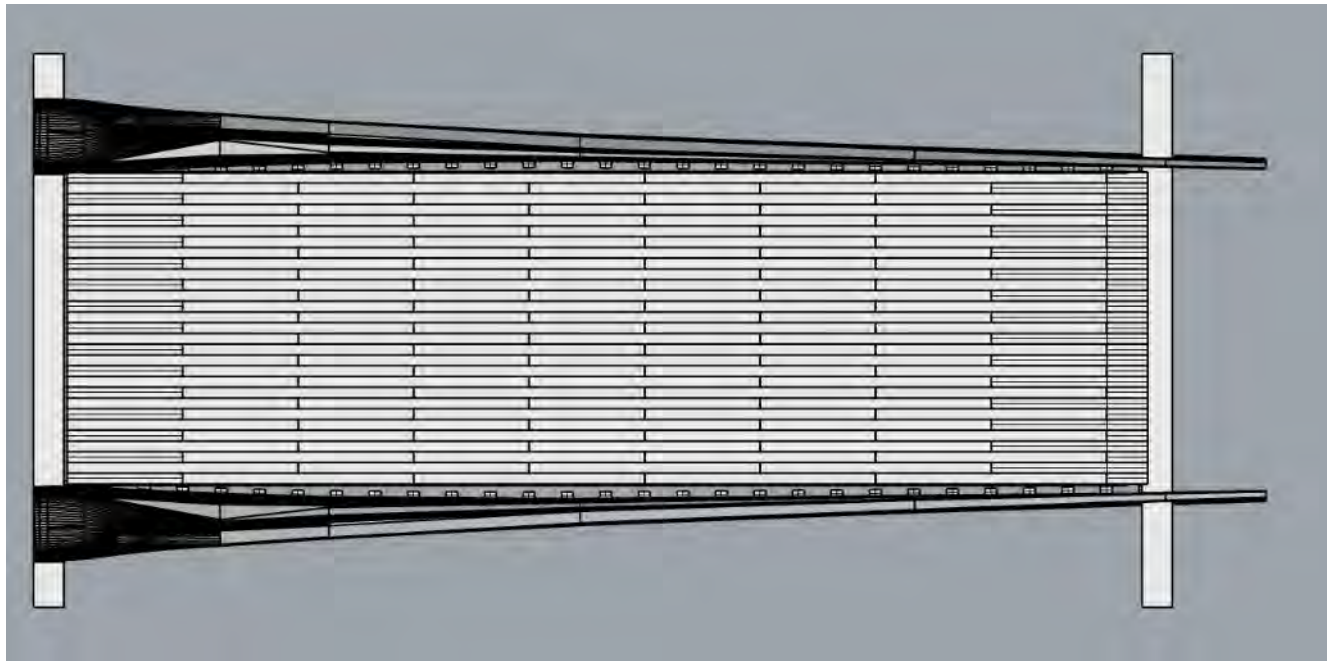
Ms. Zoe Zhang, GT

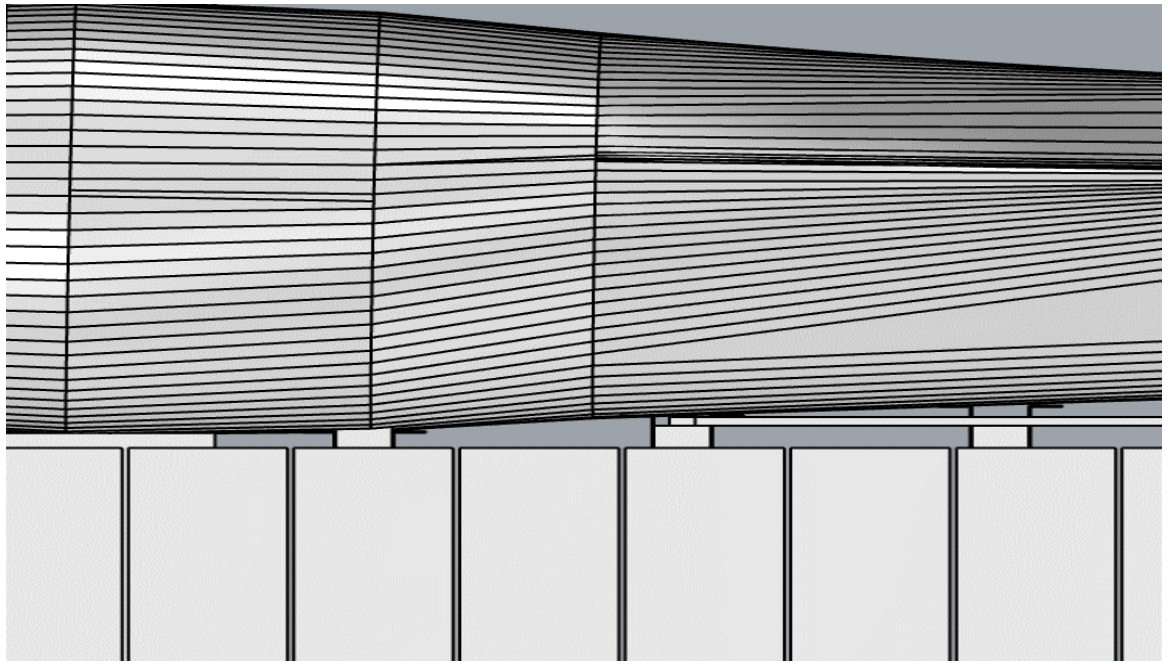
Conceptual Design

Ms. Zoe Zhang, GT

Conceptual Design

Windblade Alignment





Ms. Zoe Zhang, GT

Complexity of Geometry must be accounted for in actual designs:
Pitch of blades, straightness of blades, spacing between blades

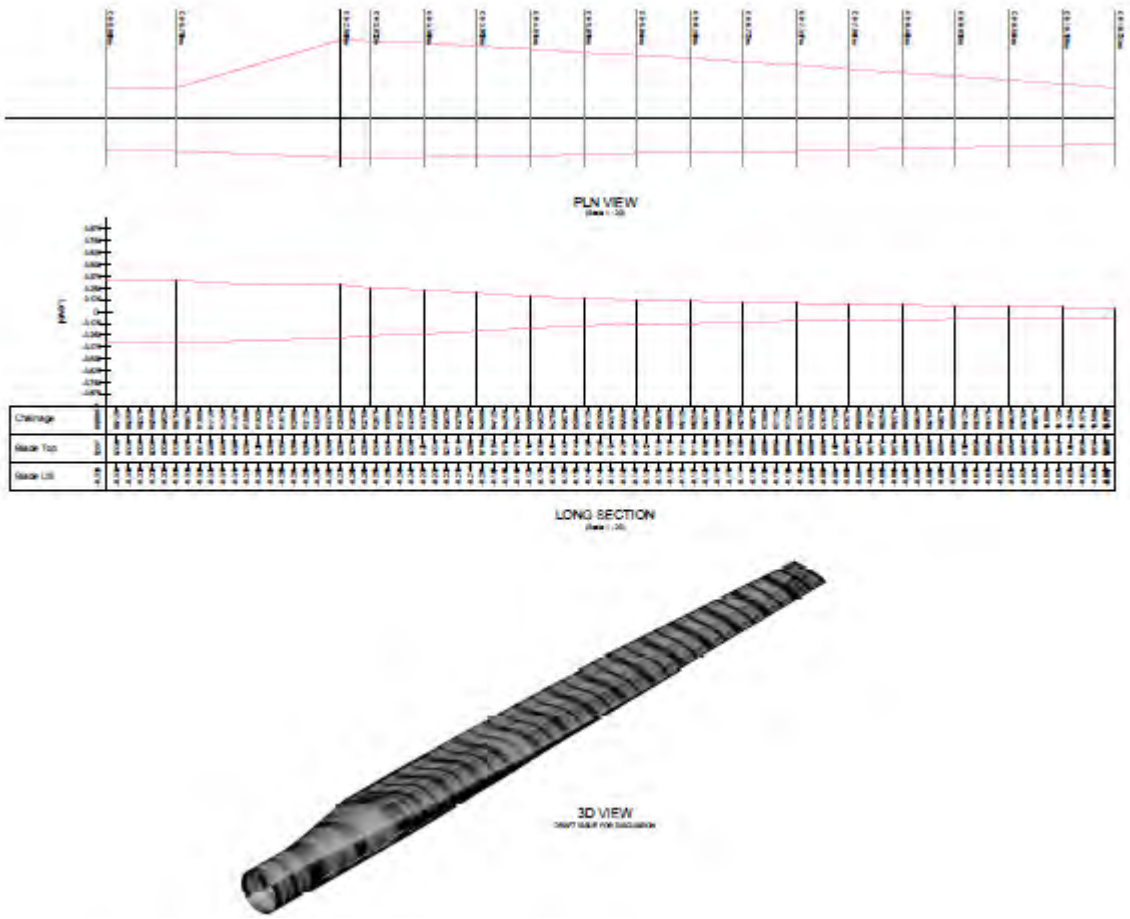
Sourcing Blades – Laser Scanning

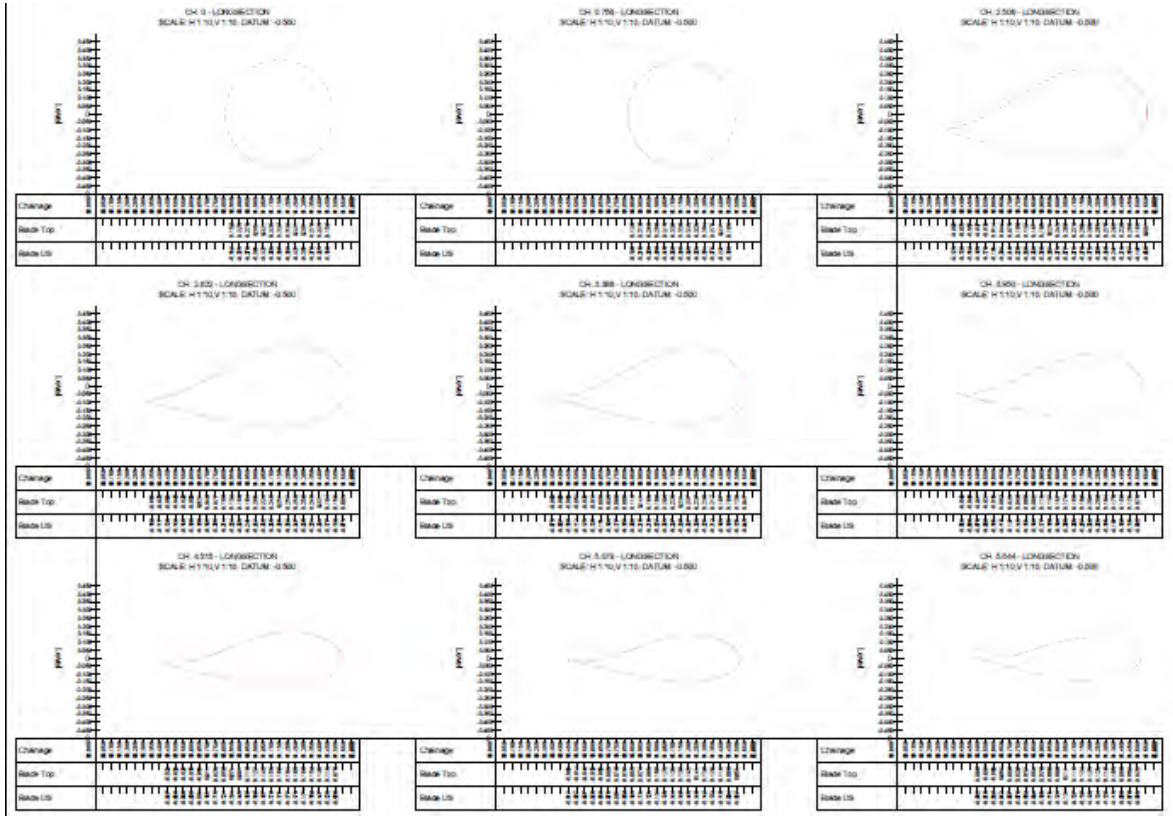
Working with the N29 Blades – MTU Structures Laboratory

Working with the N29 Blades – MTU Structures Laboratory

Working with the N29 Blades – Scanning & Measuring

Working with the N29 Blades – Scanning and Measuring





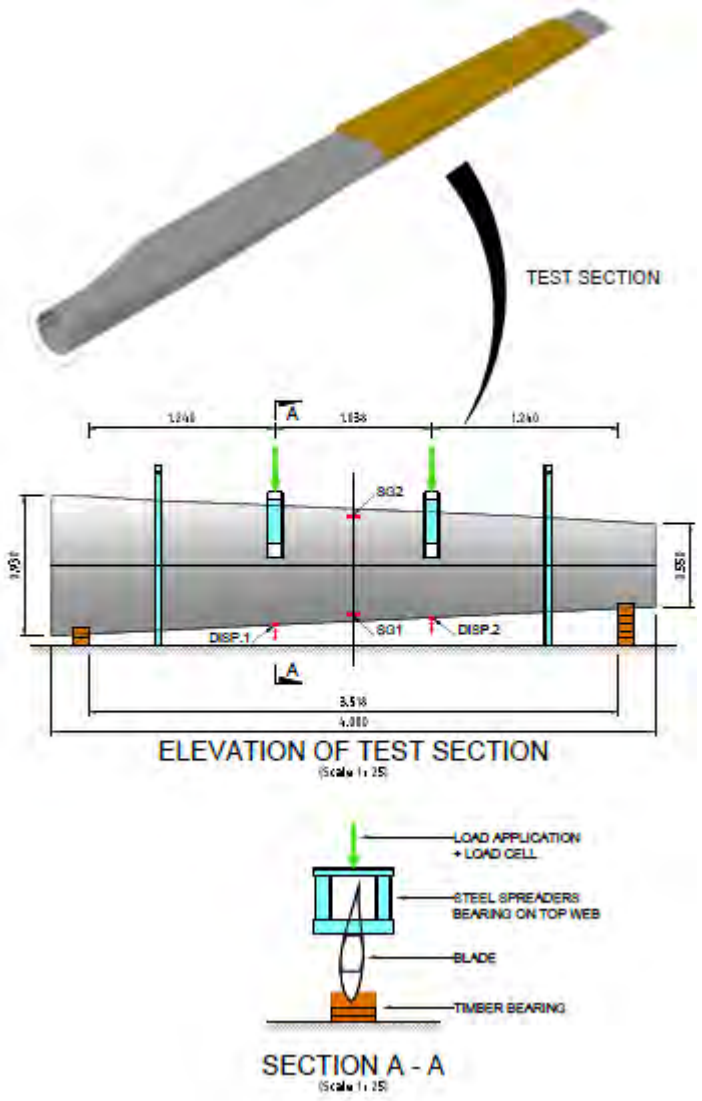
N29 Testing and Investigating

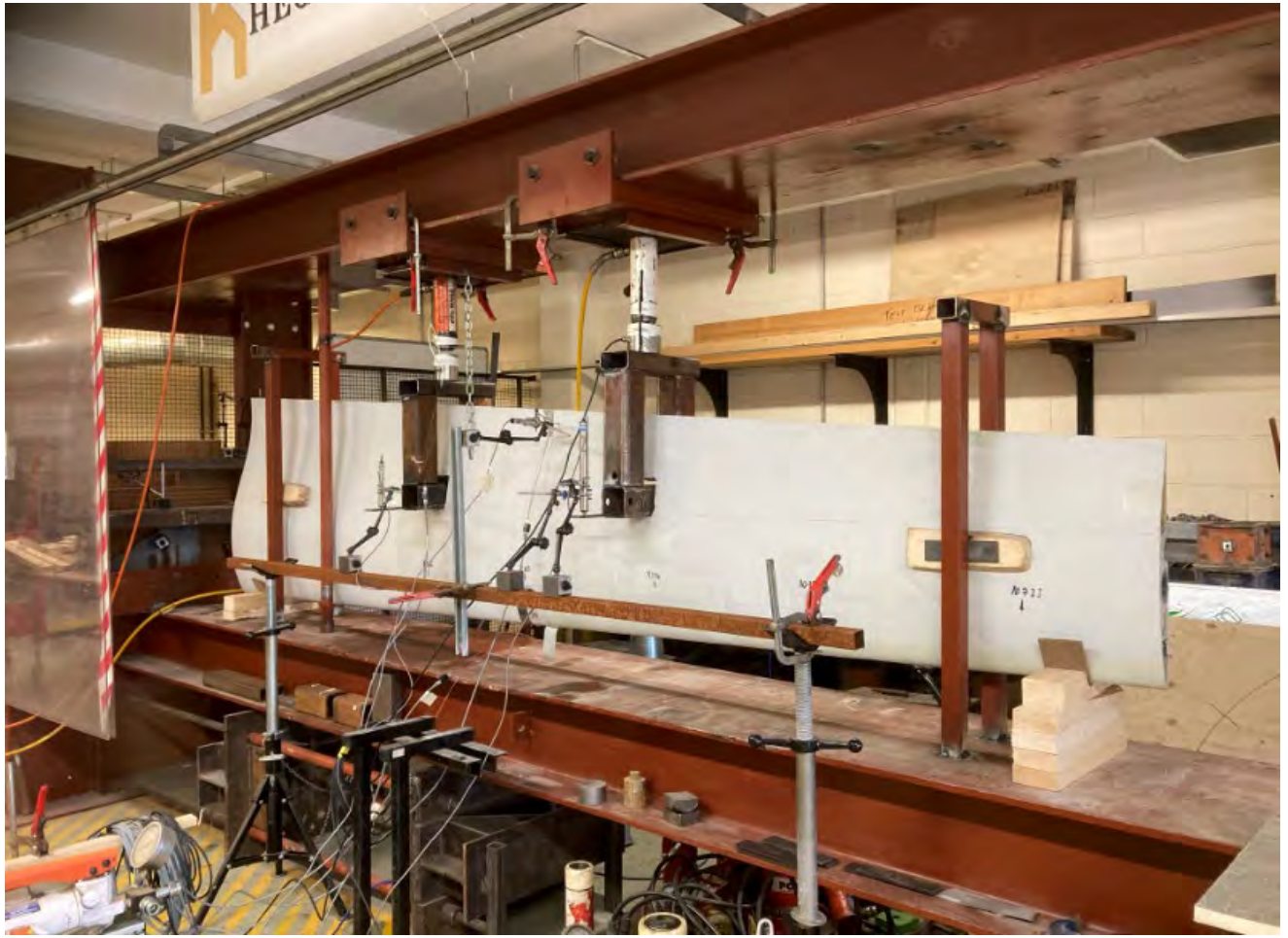
Static loads

Connections

GFRP burn-out

N29 Testing and Investigating – Static Load Tests

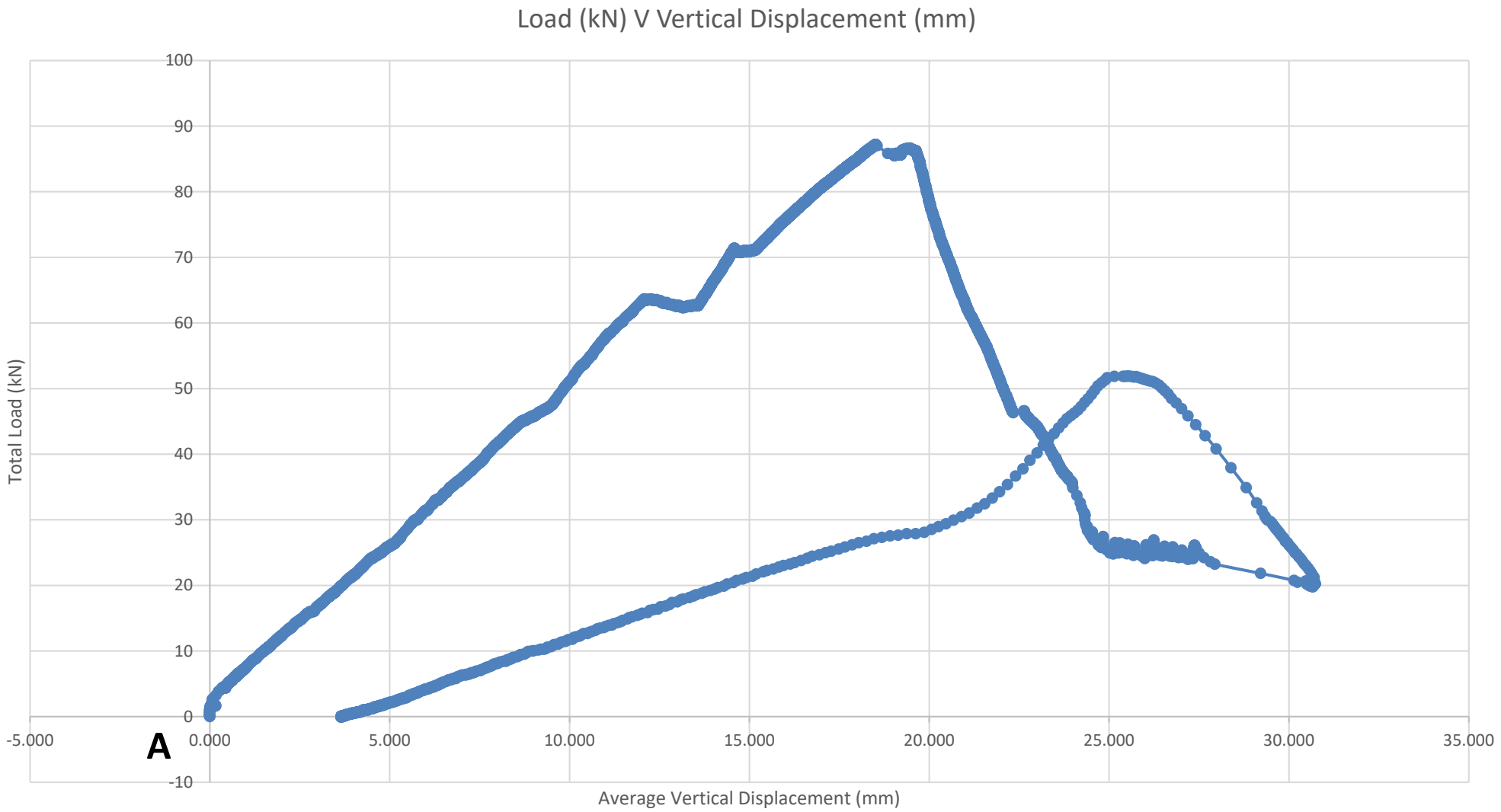




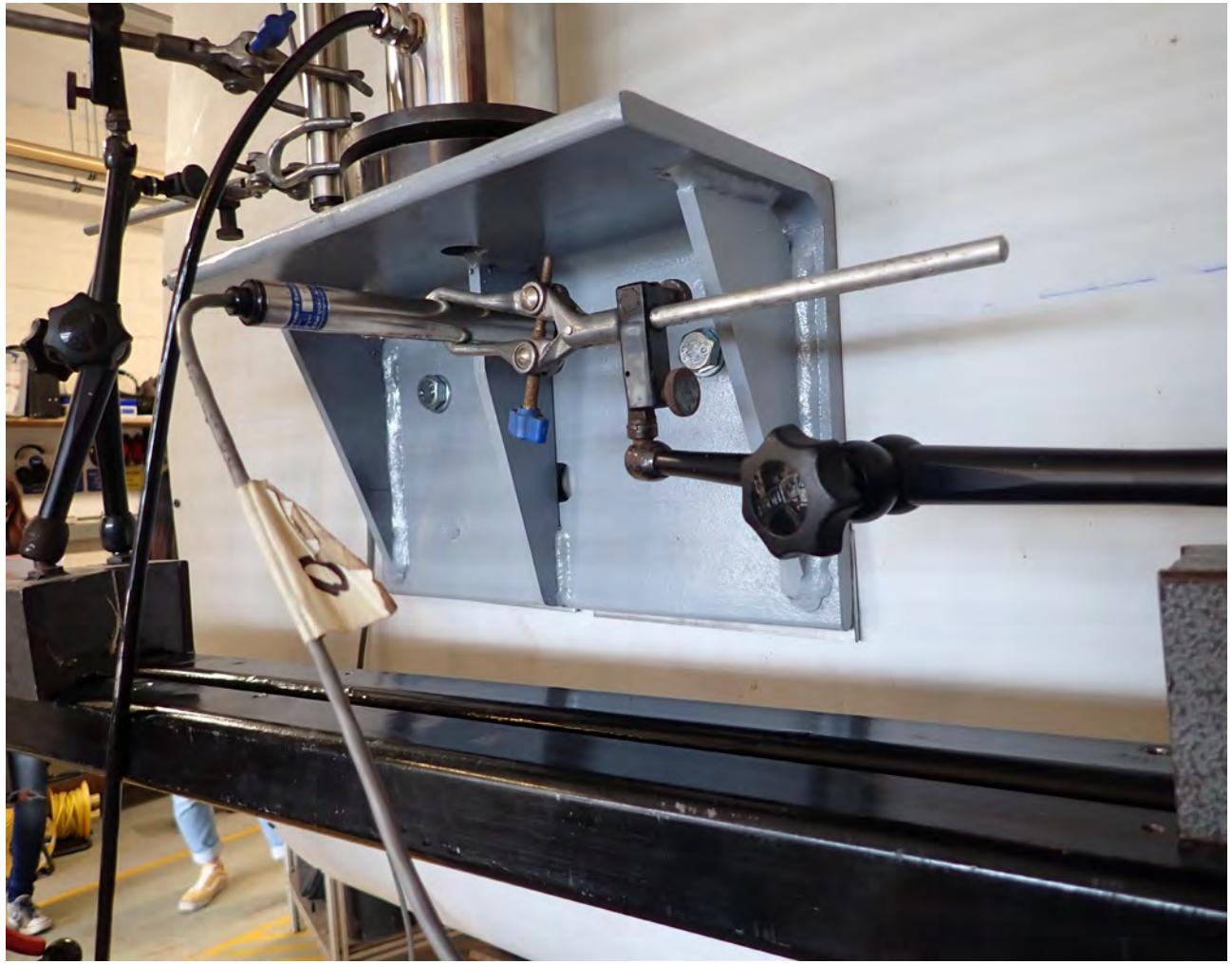
N29 Testing and Investigating – Static Load Tests

N29 Testing and Investigating – Static Load Tests

N29 Testing and Investigating – Static Load Tests



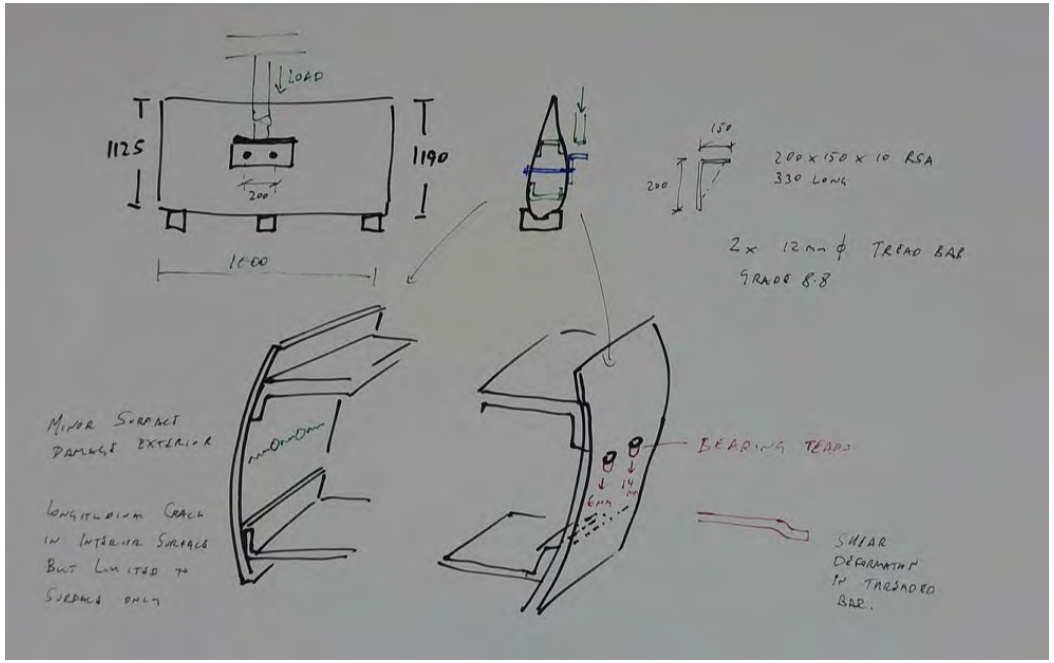
N29 Testing and Investigating – Connection Tests (3 No.)



- M12 Grade 8.8 Bolts
- M12 Grade 8.8 BlindBolts
- 12 dia Threaded Bar

N29 Testing and Investigating – Connection Tests (3 No.)

N29 Testing and Investigating – Connection Tests (3 No.)



N29 Testing and Investigating – Connection Tests (3 No.)

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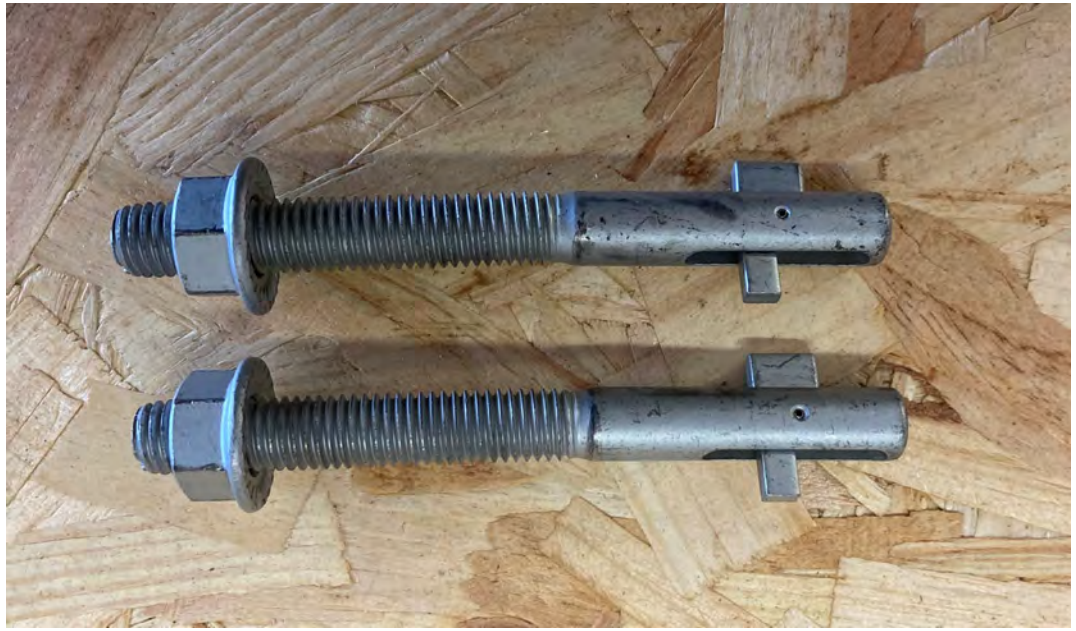
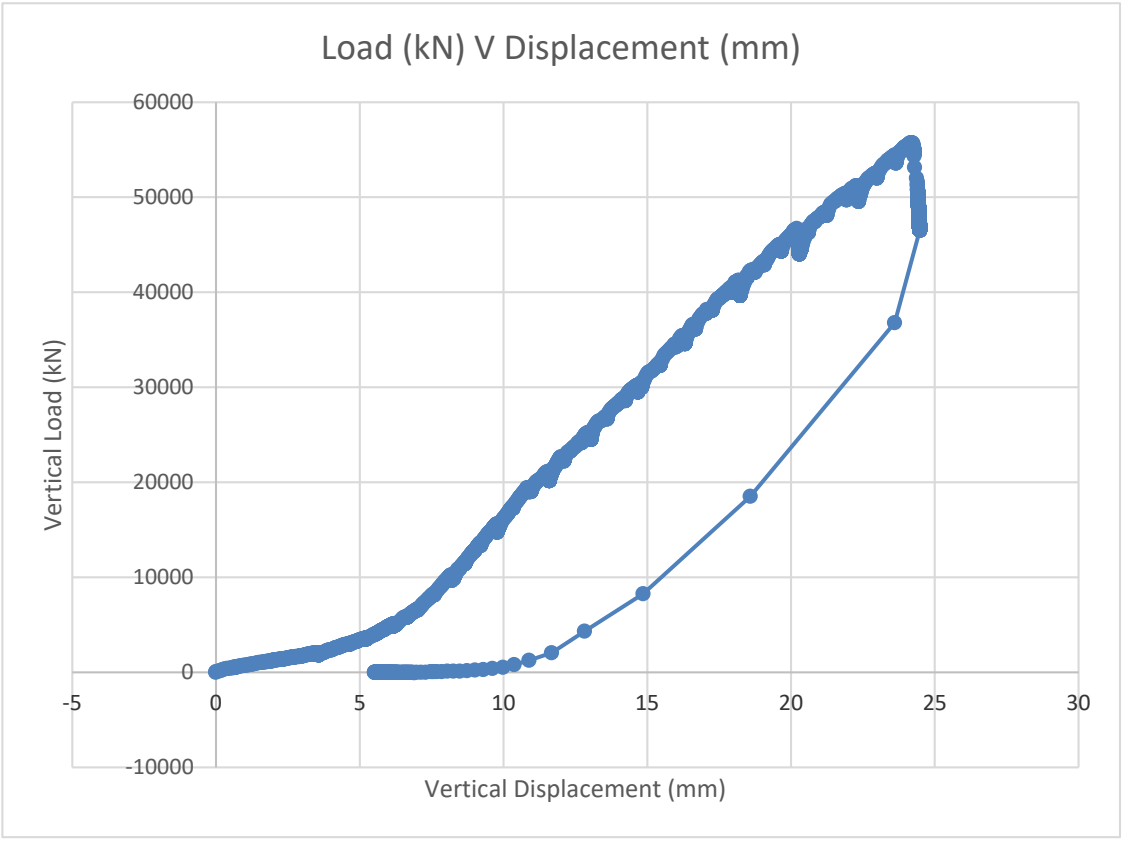




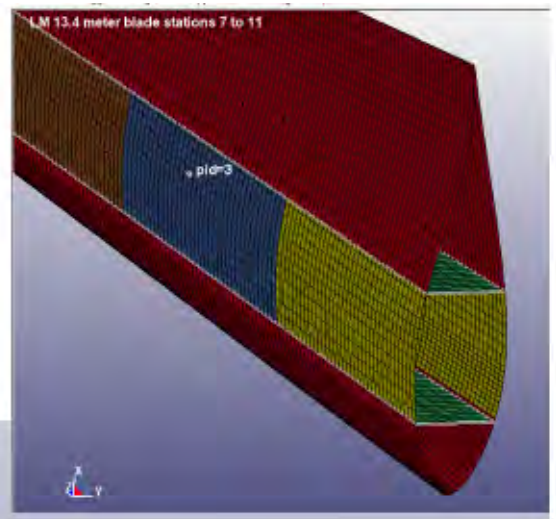
N29 Testing and Investigating – GFRP Burnout & LS-DYNA FEA (GT)

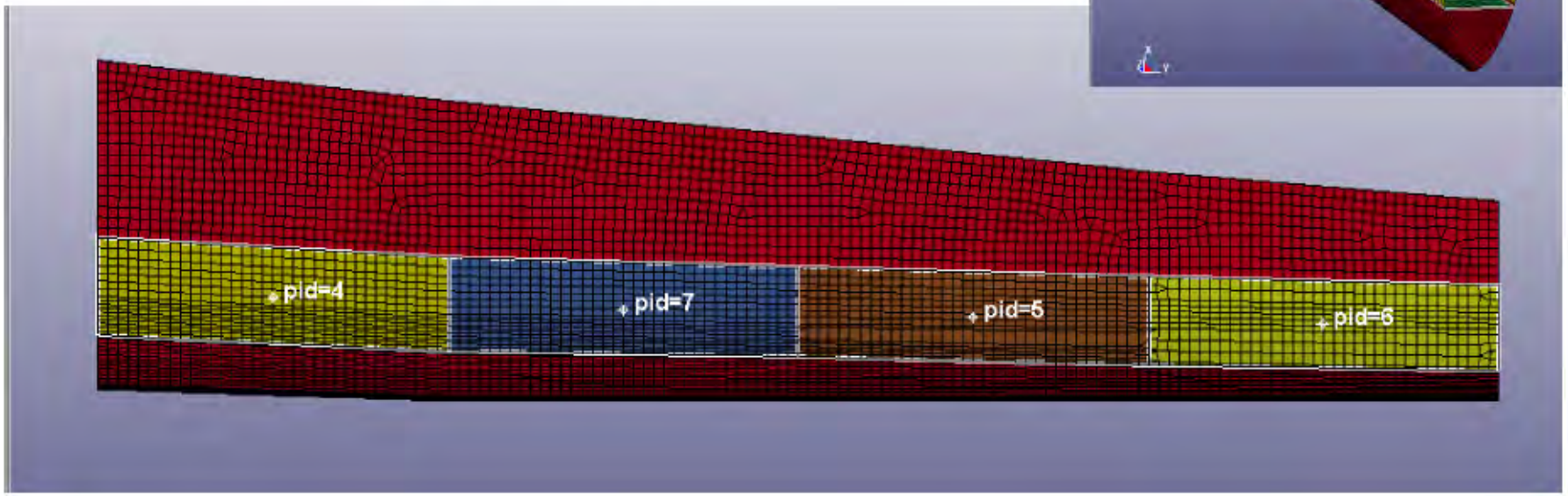
N29 Testing and Investigating – GFRP Burnout & LS-DYNA FEA (GT)

Part and Material Identification

Part 1 – Shell
Part 3 – Webs

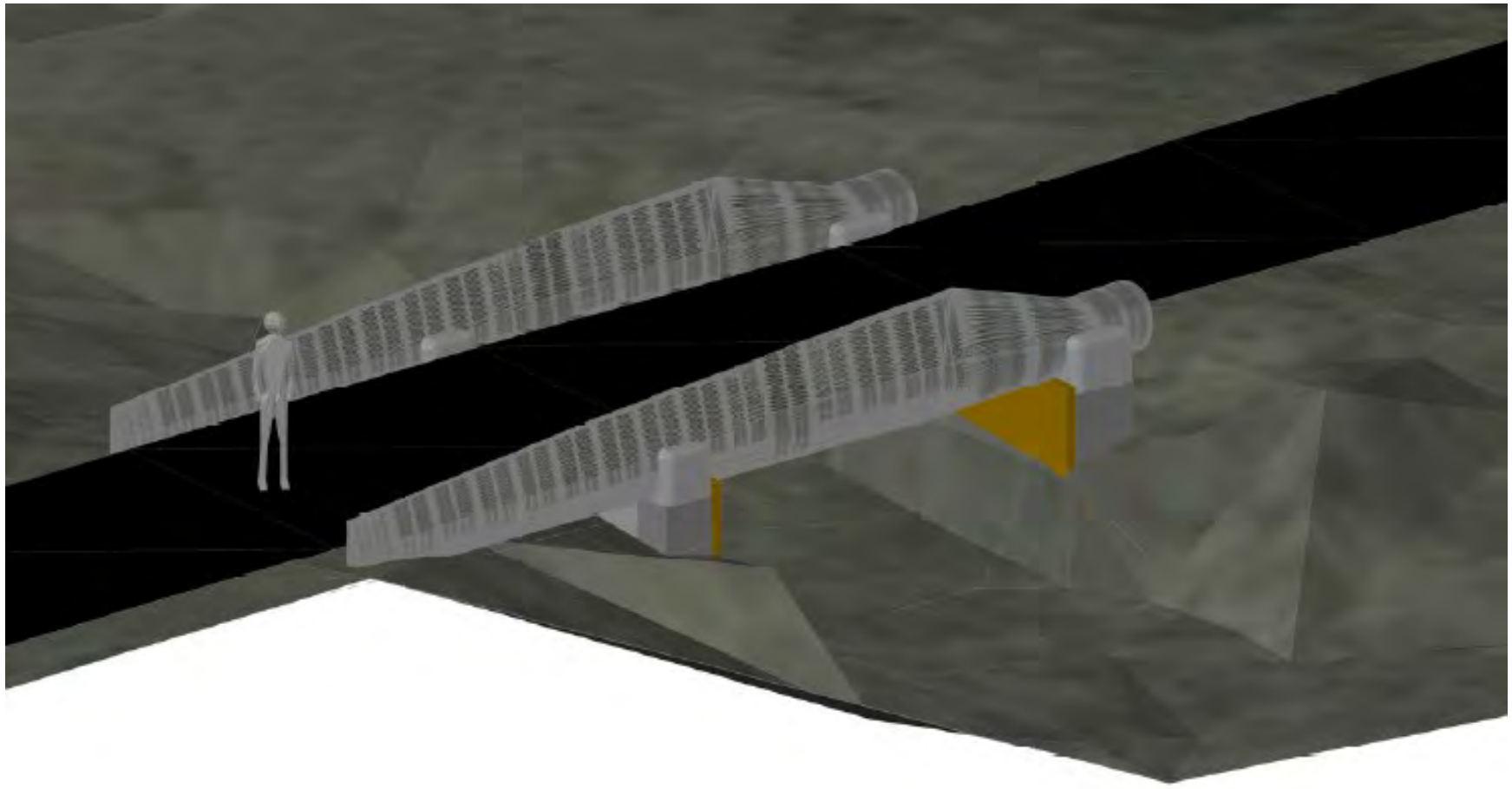
Part 4 – Spar cap from 7m to 8m
Part 7 – Spar cap from 8m to 9m
Part 5 – Spar cap from 9m to 10m
Part 6 – Spar cap from 10m to 11m



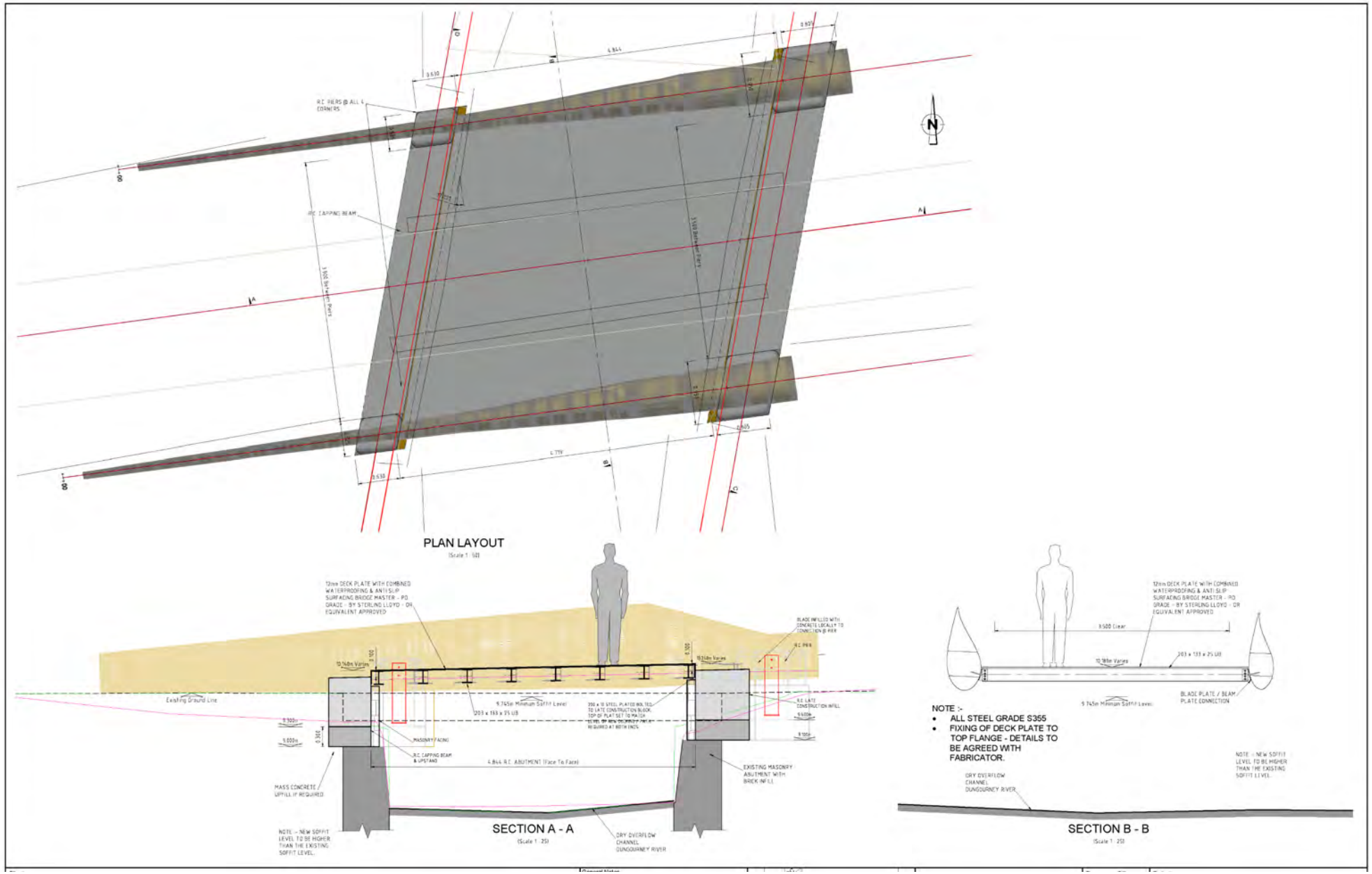


Dr. Russell Gentry, GT

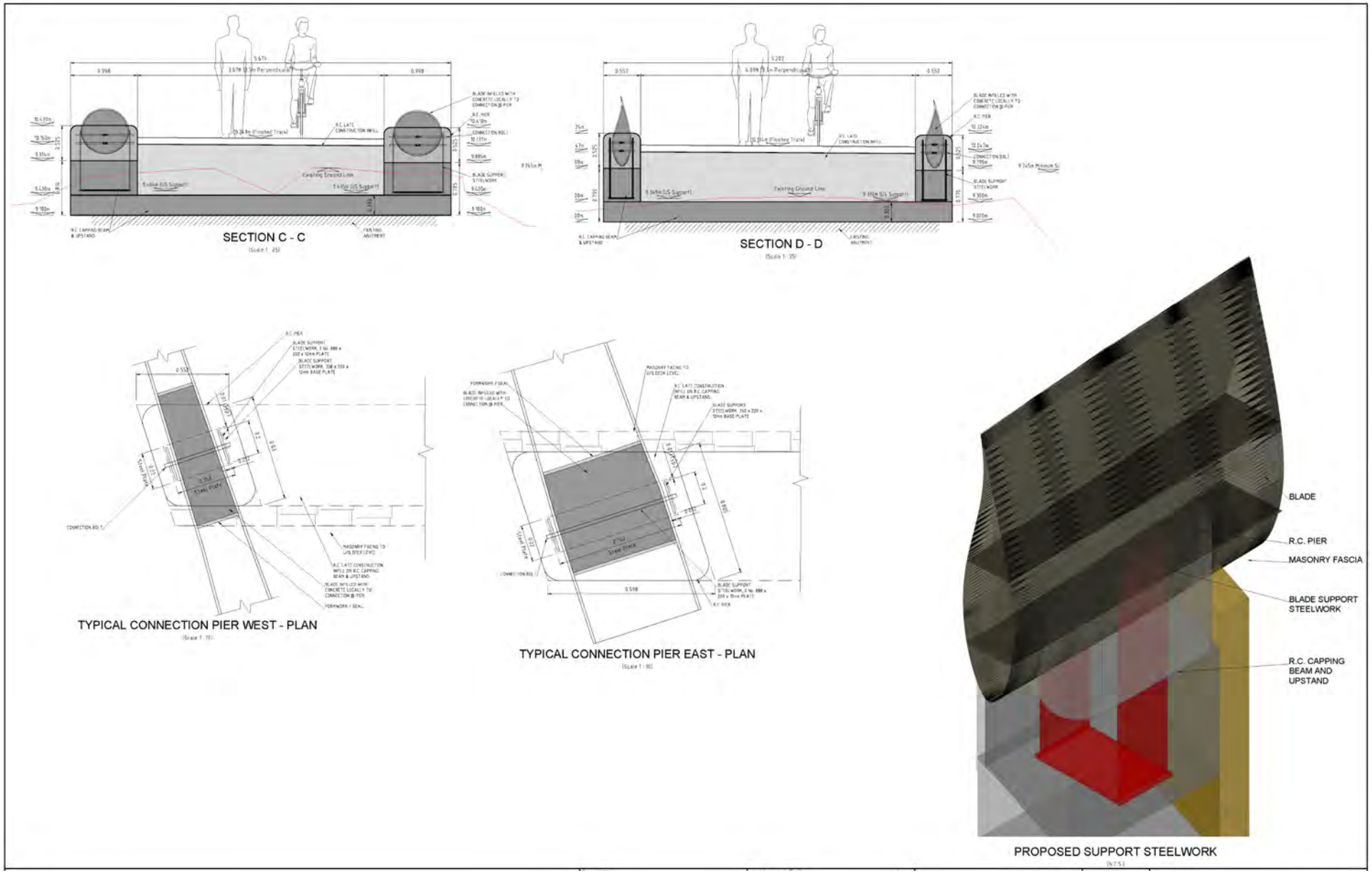
Blade Bridge – Design Development



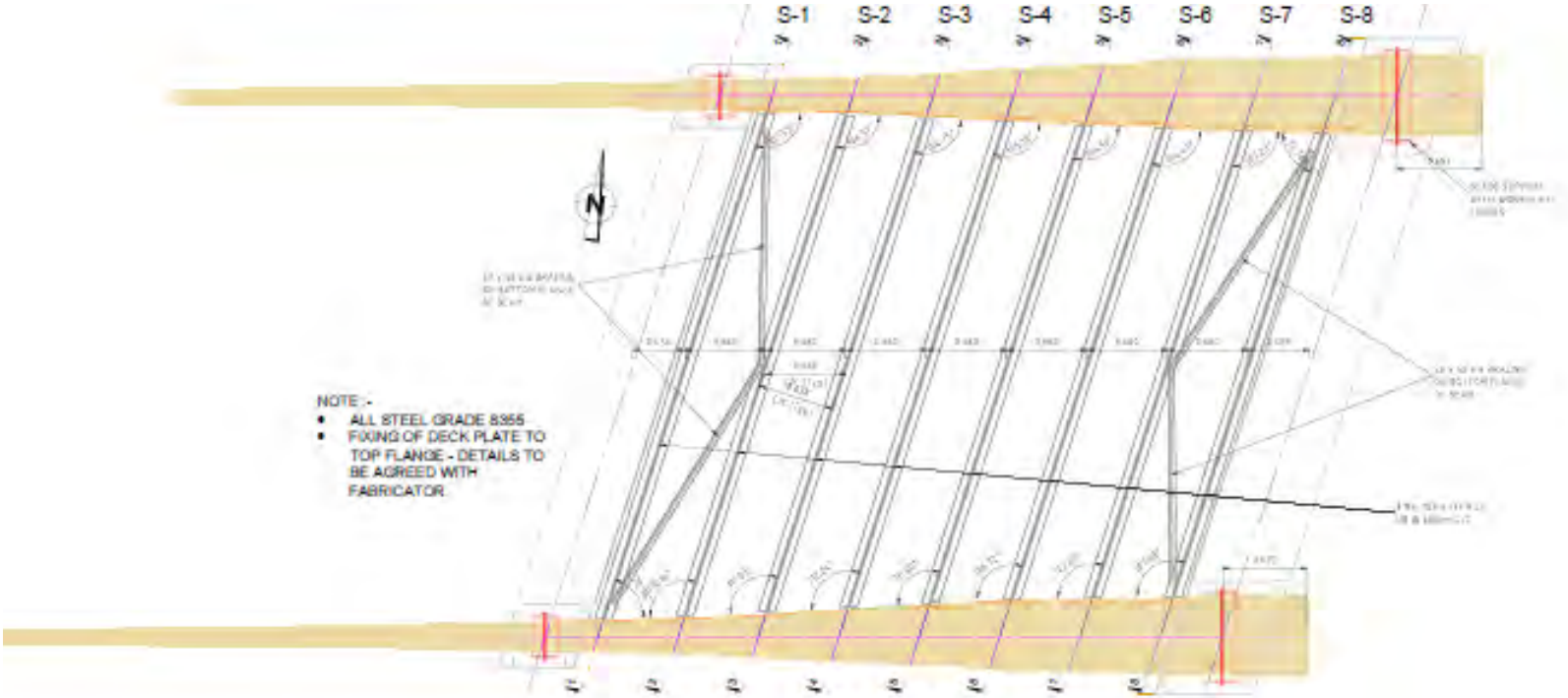
Blade Bridge – Design Development



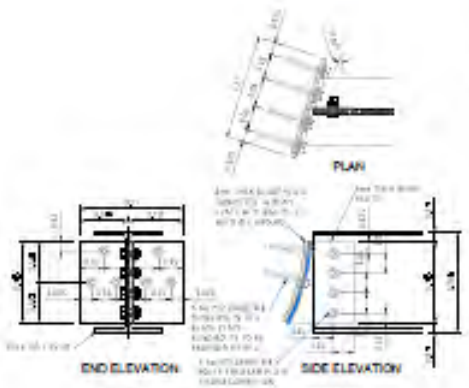
Blade Bridge – Design Development



Blade Bridge – Design Development



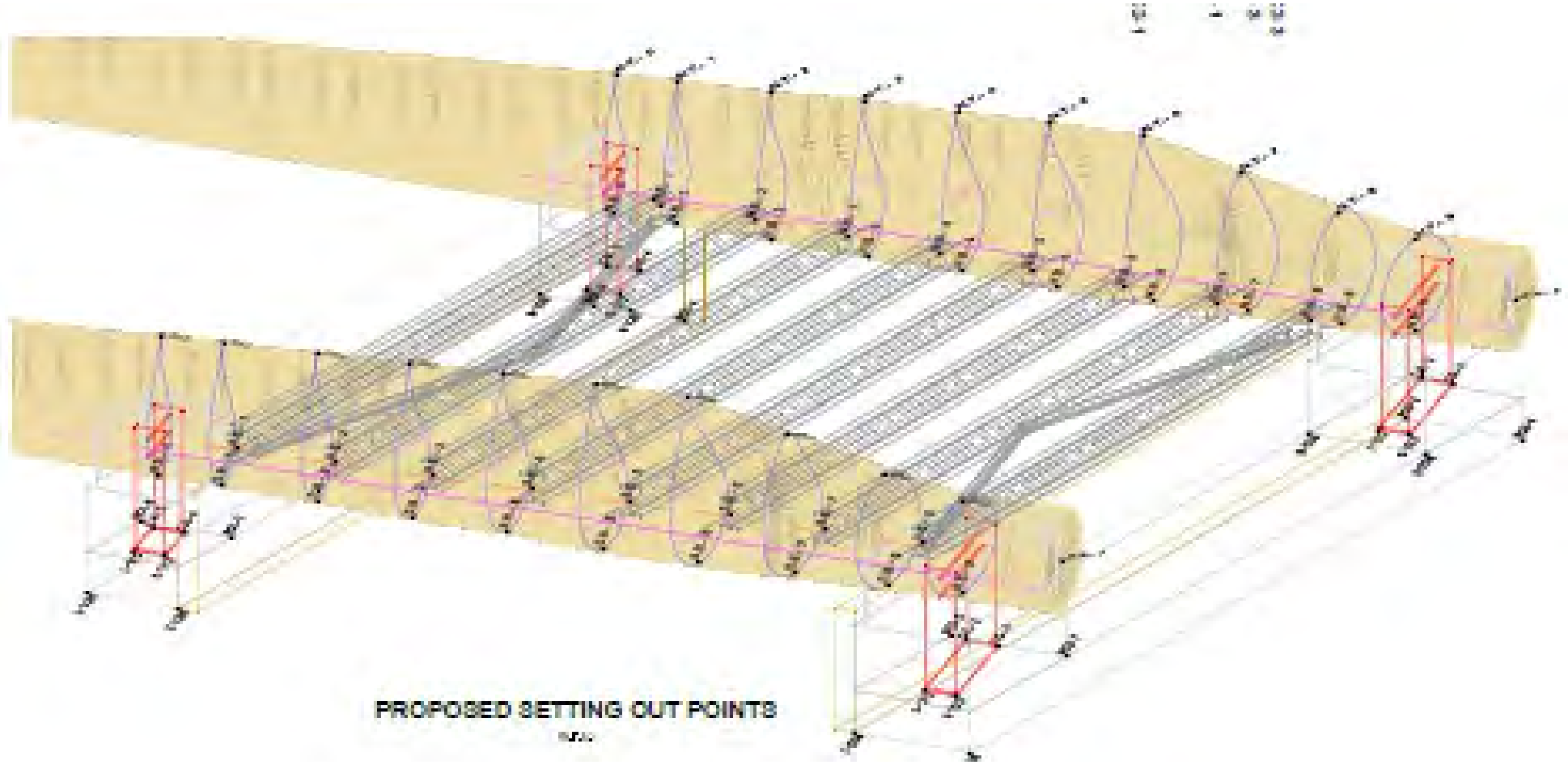
STEELWORK PLAN



TYPICAL BLADE PLATE / BEAM PLATE CONNECTION DETAIL

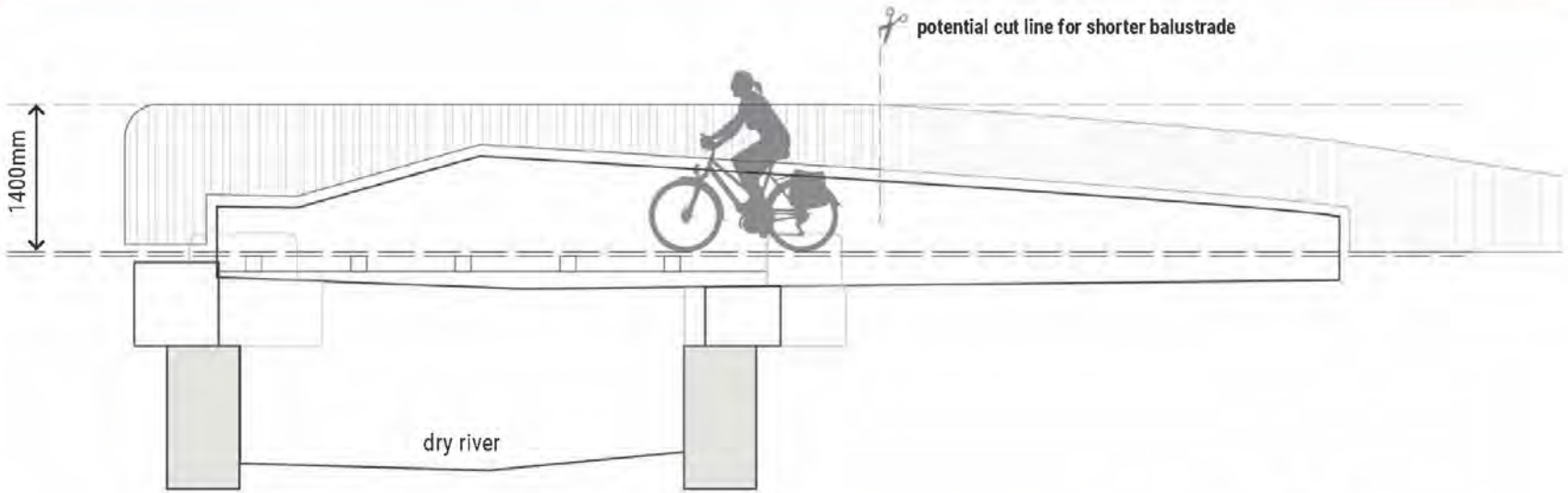
PROPOSED BLADE PLATE TO DECK PLATE CONNECTION

Blade Bridge – Design Development



Blade Bridge – Design Development

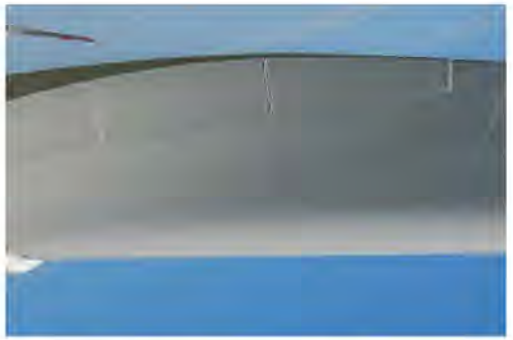
Turbine blade bridge balustrade - Idea 1



Idea 1 - railing offset from blade

- balustrade appears to float above the blade, and tapers smoothly away at the point there is no further risk of falling
- maximises width of path between railings, ensuring required 3m is achieved
- retains access to the surface of the blade, allowing its smooth surface and tacility to be experienced without obstruction

Top and bottom rail, galvanised flat bar. Intermediate posts galvanised square hollow section. Infill of upright galvanised steel solid circular bar or mesh.



above: turbine blades are usually seen from a distance. The bridge creates an opportunity to appreciate them closer at hand.

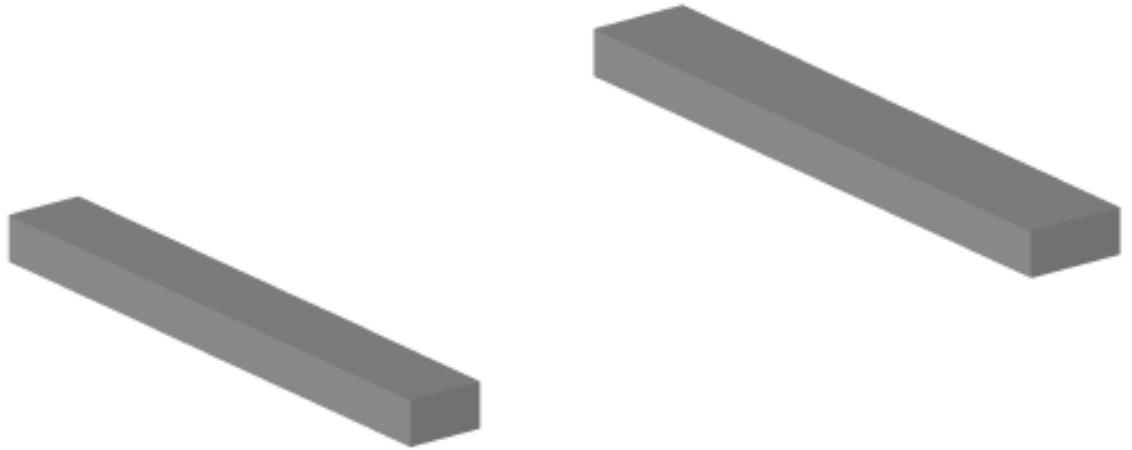
Section:

Balustrade is fixed to bridge structure on the off-side from the deck, allowing the balustrade to "float" above the blade.

thepaulhogarthcompany

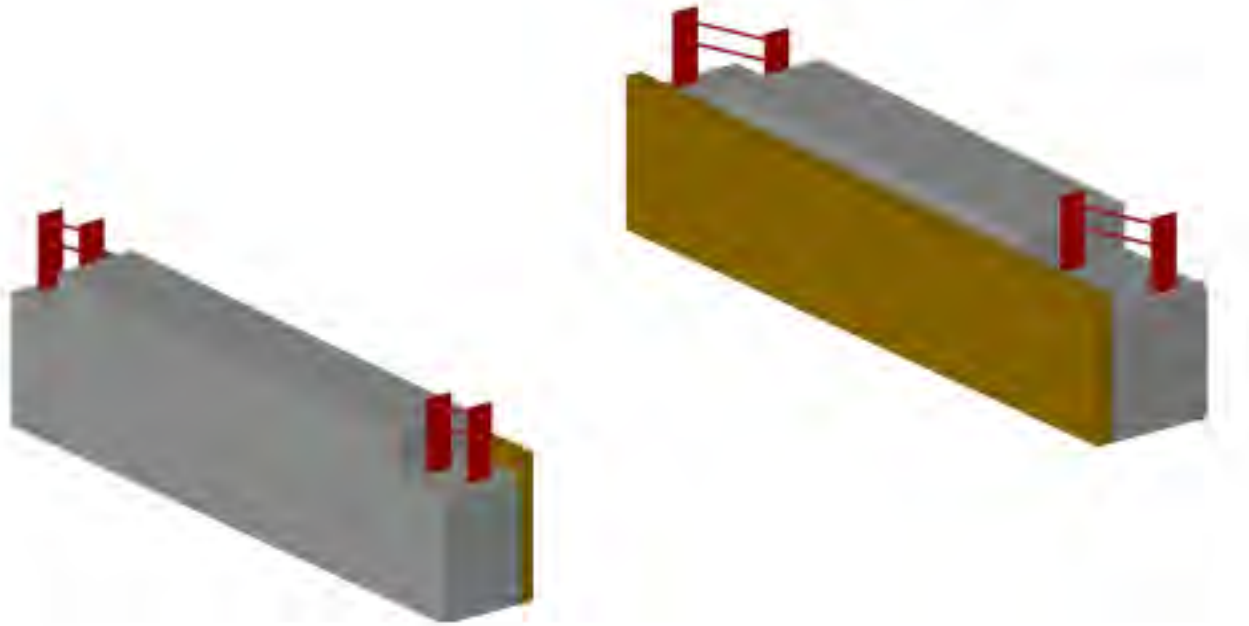
Comhairle Contae Chorcaí
Cork County Council

Blade Bridge – Construction Sequence



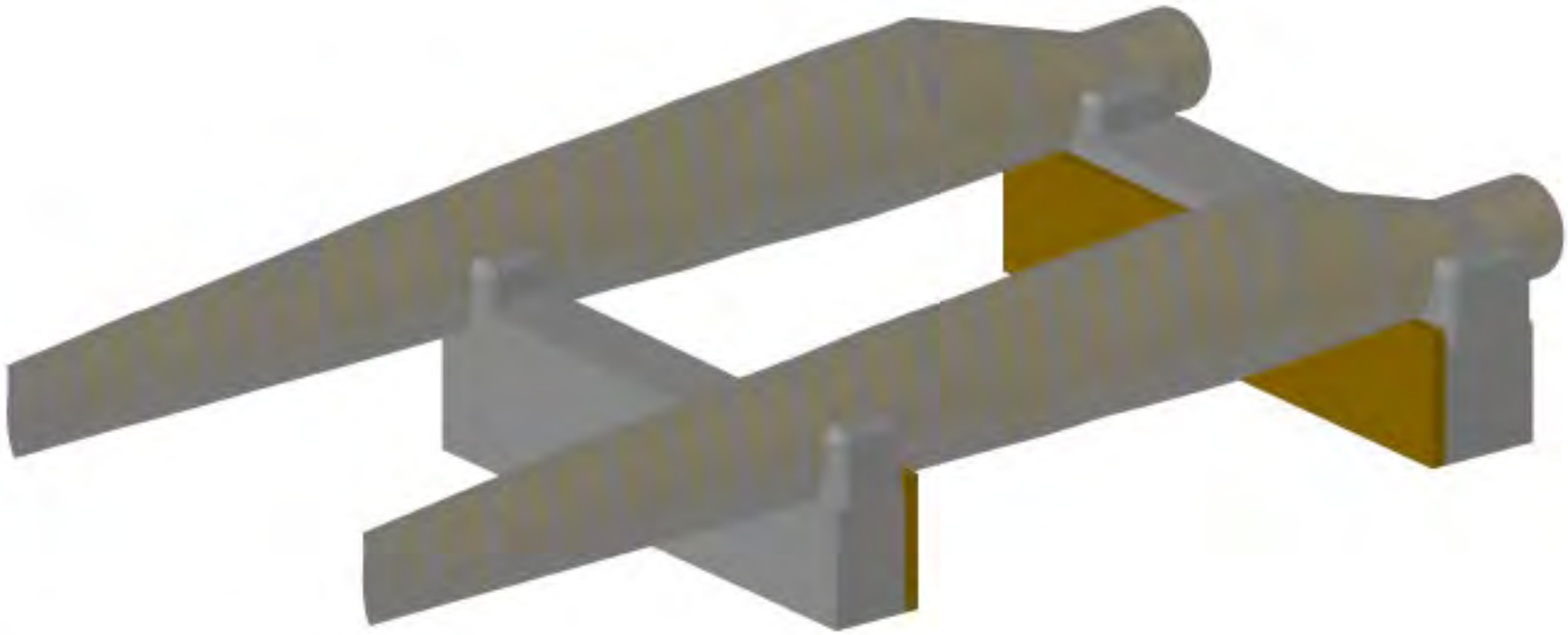
PHASE 1 :- CONSTRUCT CONCRETE ABUTMENTS

Blade Bridge – Construction Sequence



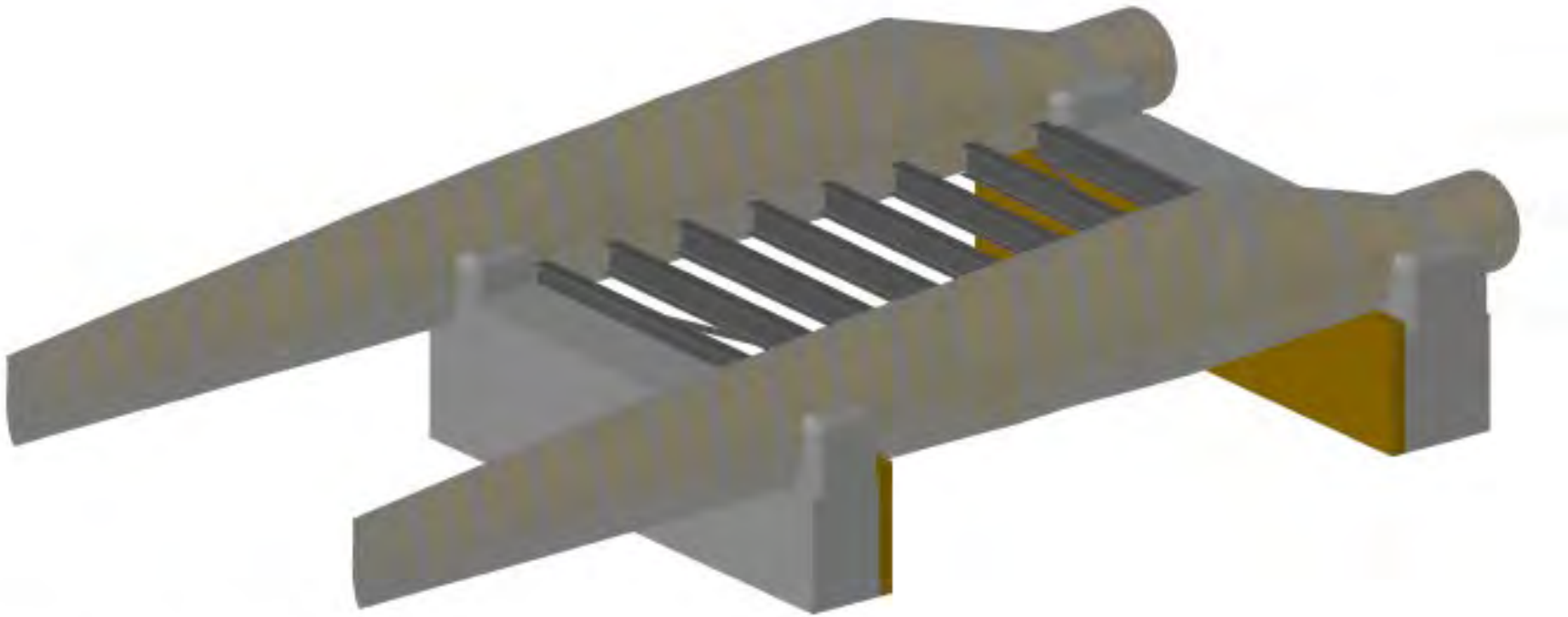
PHASE 2 :- INSTALL SUPPORT STEELWORK

Blade Bridge – Construction Sequence



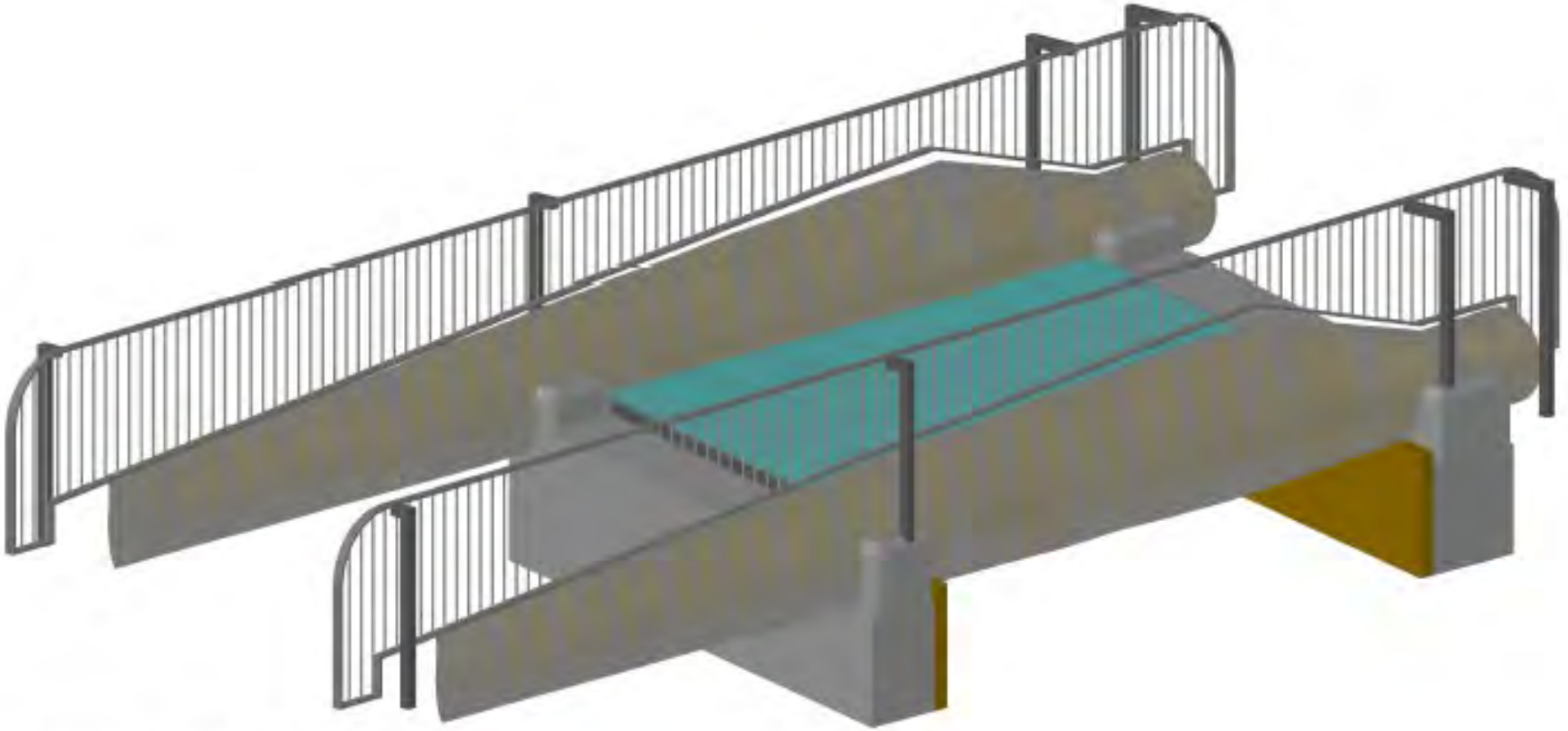
PHASE 3 :- INSTALL BLADES, CAST CONCRETE PIERS

Blade Bridge – Construction Sequence



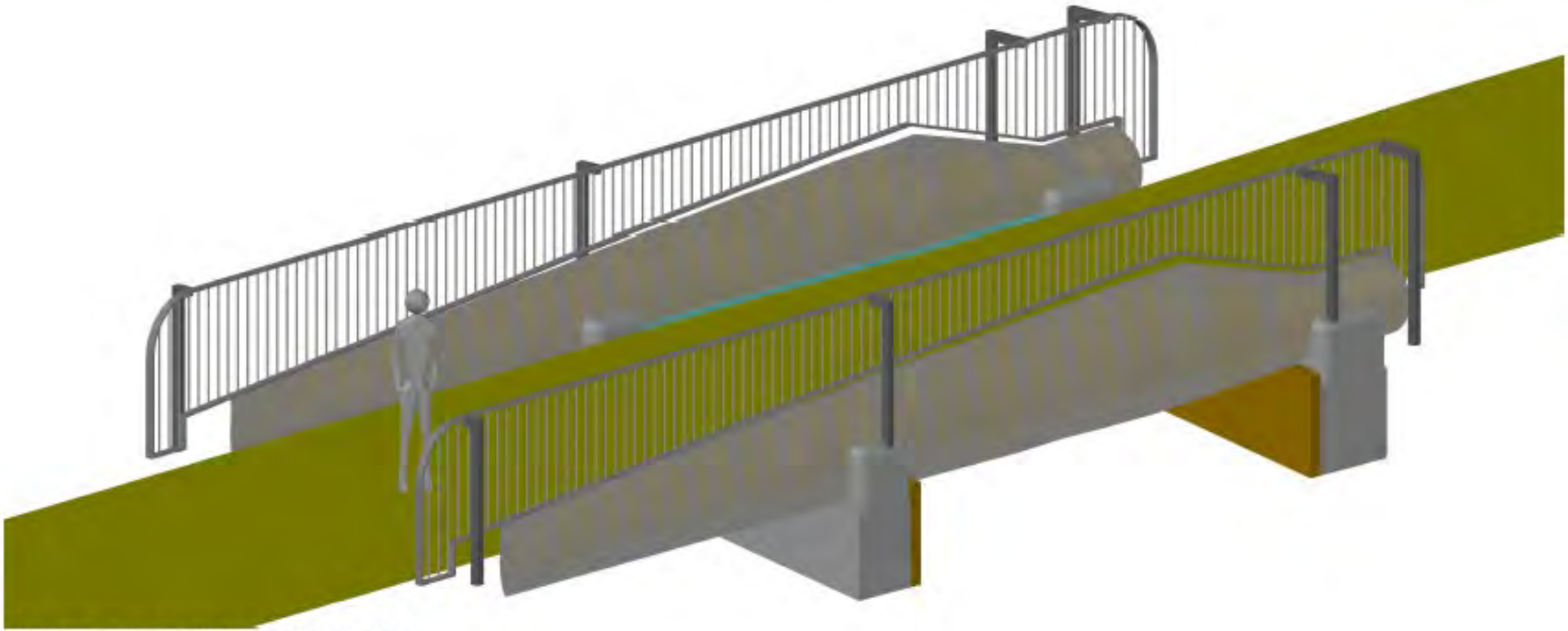
PHASE 4 :- INSTALL DECK CROSS STEELWORK

Blade Bridge – Construction Sequence



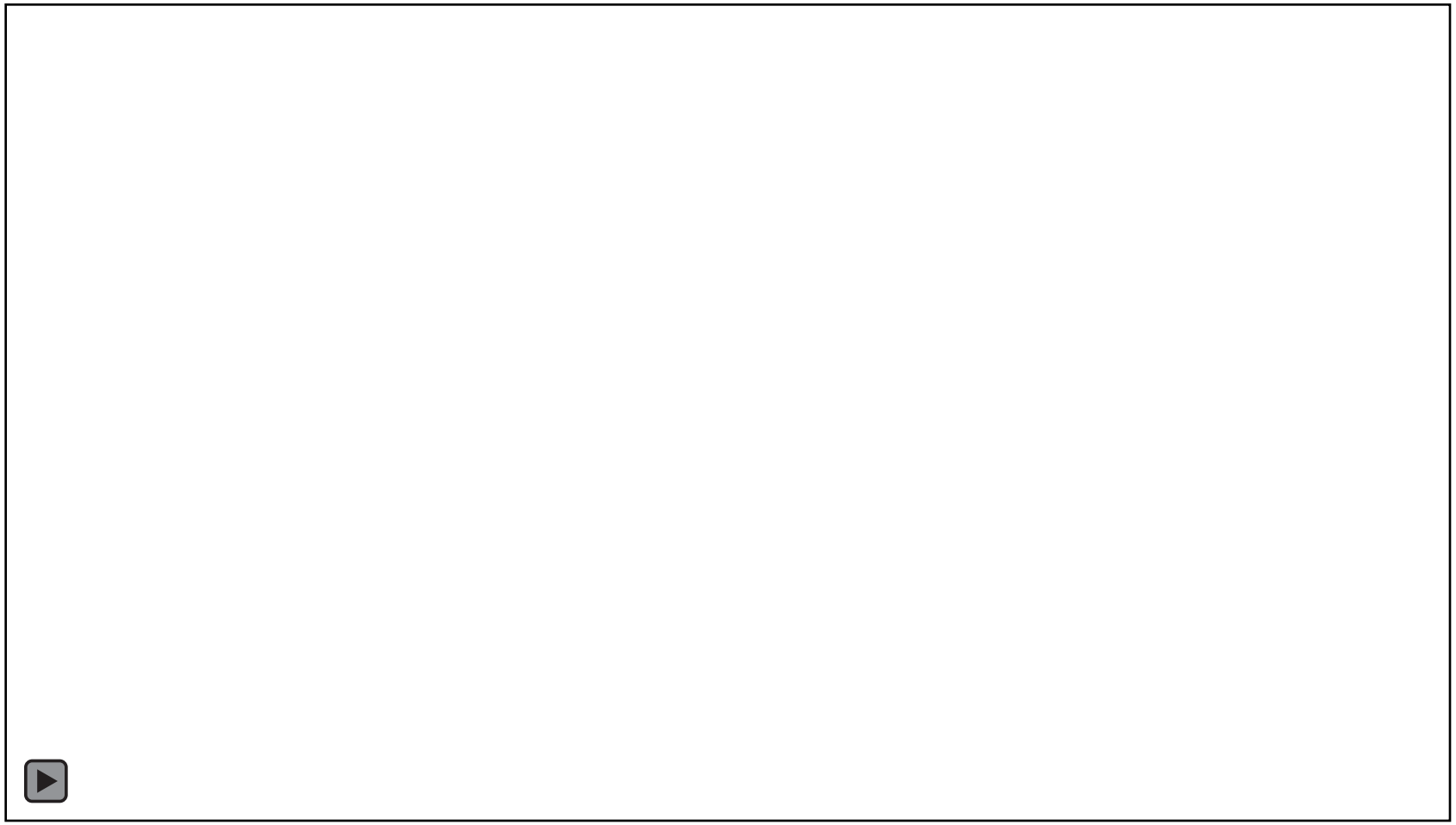
PHASE 5 :- INSTALL DECK PLATE

Blade Bridge – Construction Sequence

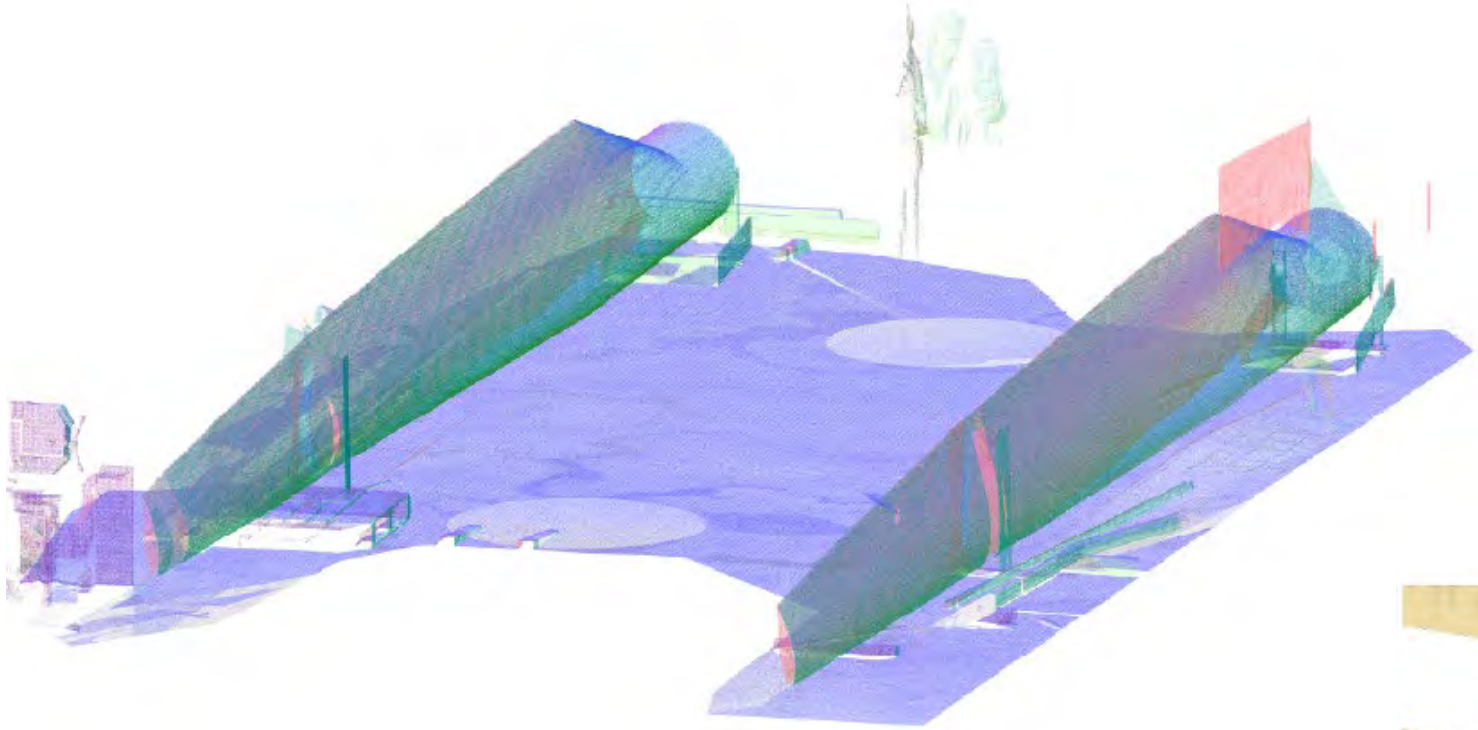


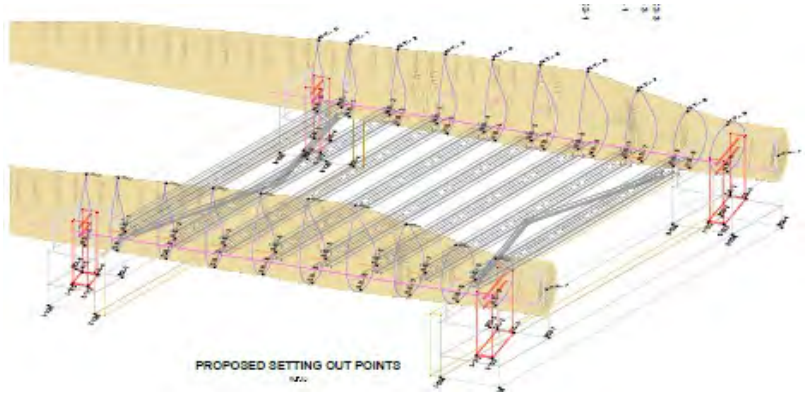
PHASE 6 :- FINISH GREENWAY

Blade Bridge – Fabrication Stage – AR Brownlow Ltd. Carrigaline



Blade Bridge – Fabrication Stage – AR Brownlow Ltd. Carrigaline





Blade Bridge – Fabrication Stage – AR Brownlow Ltd. Carrigaline

Blade Bridge – Fabrication Stage – AR Brownlow Ltd. Carrigaline

Blade Bridge – Fabrication Stage – AR Brownlow Ltd. Carrigaline

Blade Bridge – Programme

Complete Fabrication: December 2021

Galvanising: January 2022

Yard Assembly and Load Testing: January 2022

Deployment: January 2022

Acknowledgements

Re-Wind Sponsors: NSF, SFI, DfE, MTU, ENEL Green Power, Logisticus, **Cork County Council,** Everrun, Lemac, AR Brownlow

Technical Drawings and Geometry: Denis Cronin; HD Surveys

Re-Wind Cork BladeBridge Team: Paul Leahy, Kieran Ruane, Russell Gentry, Larry Bank, Angie Nagle, Zoe Zhang, An Huynh, Marios Soutsos, Jim Morgan, Liam Jones, Maggie Shorten

Re-Wind Principal Investigators: Larry Bank (CUNY/GT), Russell Gentry (GT), Paul Leahy (UCC), Jenny McKinley (QUB), Jian-Fei Chen (QUB)

Please see our website: https://www.re-wind.info/

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