ETIPOCEAN

European Technology & Innovation Platform for Ocean Energy

Technology Theme Webinar

Investigating alternative materials and manufacturing processes for device structures

8th June 2018

Agenda

Moderator	Speakers		
Shona Pennock	Ricardo Neta	Aneel Gill	George Walker
The University of Edinburgh	Composite Solutions	Balmoral Offshore Engineering	Arup

Questions and comments from the audience

Balmoral Offshore Engineering
R&D

70044 – Wave Energy Scotland (WES) Development Project

Presenters
Dr. Aneel Gill,
John Drummond

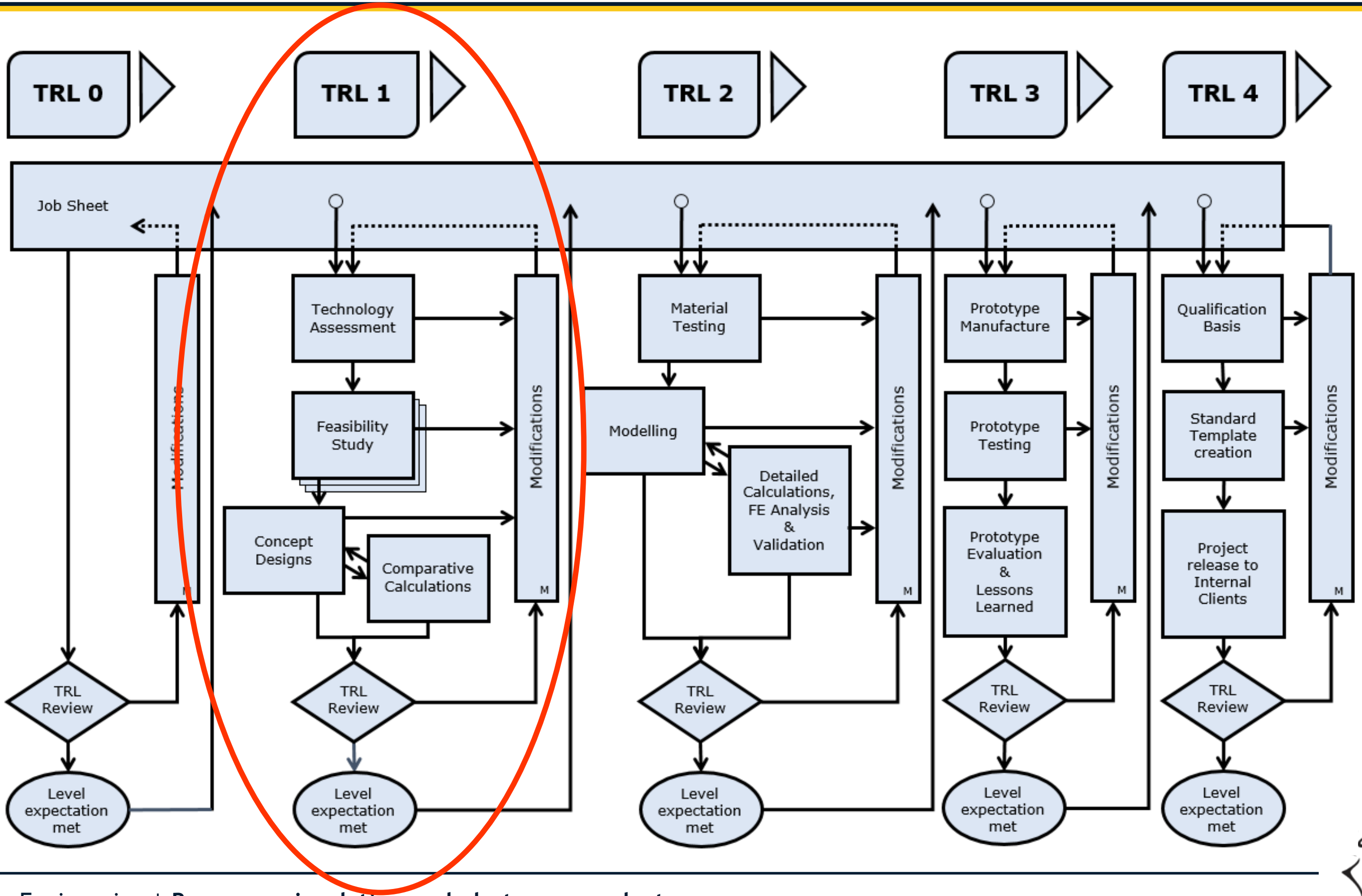
Introduction to WES

- Who are WES?
  - Government funded organisation set up in 2014
- 4 Funding Programmes
  - Power Take Off (PTO)
  - Novel Wave Energy Convertor
  - Structural Materials and Manufacturing Processes
  - Control Systems
- £28.8 million of funding across 77 projects

Project Aim

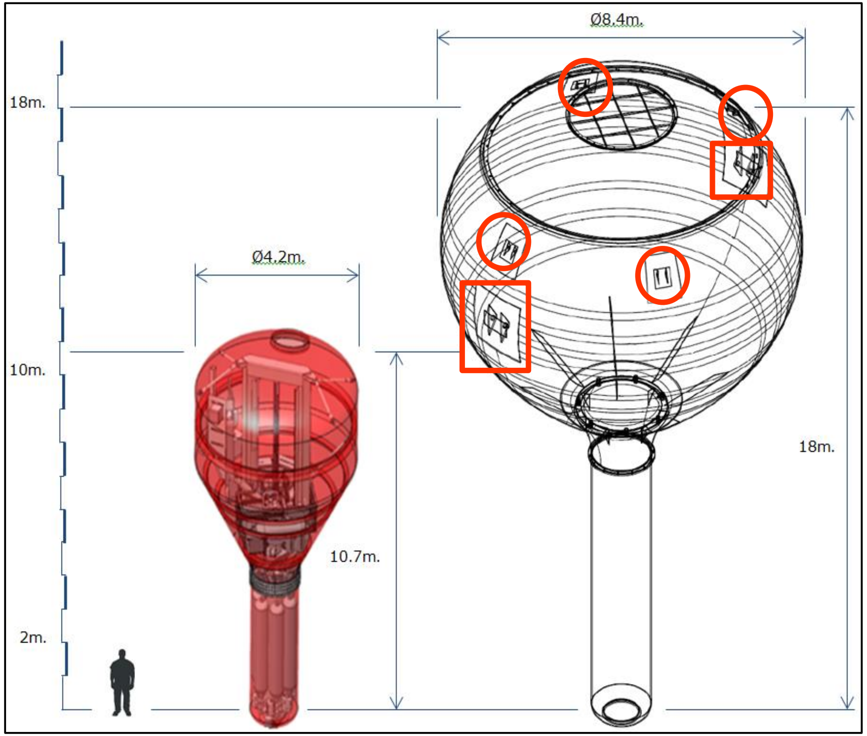
- Investigates innovative materials and manufacturing processes for wave energy device structures
- Use Balmorals R&D process to evaluate and complete this stage of the development
- In order to complete any material study, a part must be used as a benchmark
- Project involved consortium of CorPower and WaveVentrue

Balmoral Offshore Engineering – R&D Process



Project Aim

- Design a hull to house Corpower's PTO
  - Lightweight solution (< 14 tonne)
  - Structural integrity remains intact throughout the entire design life – 20yr
  - Component deflection allowable limits
    - 50mm in strut locations
    - 100mm in wave spring locations



BALMORAL

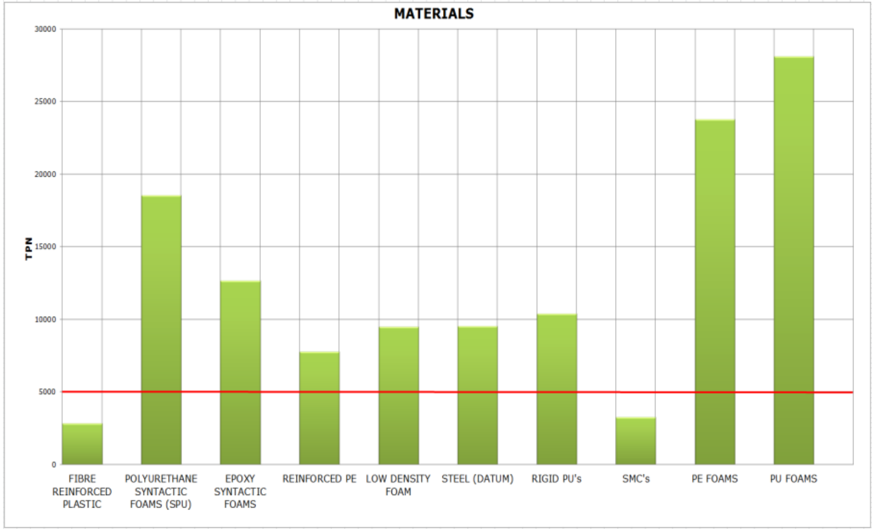
Project Deliverables

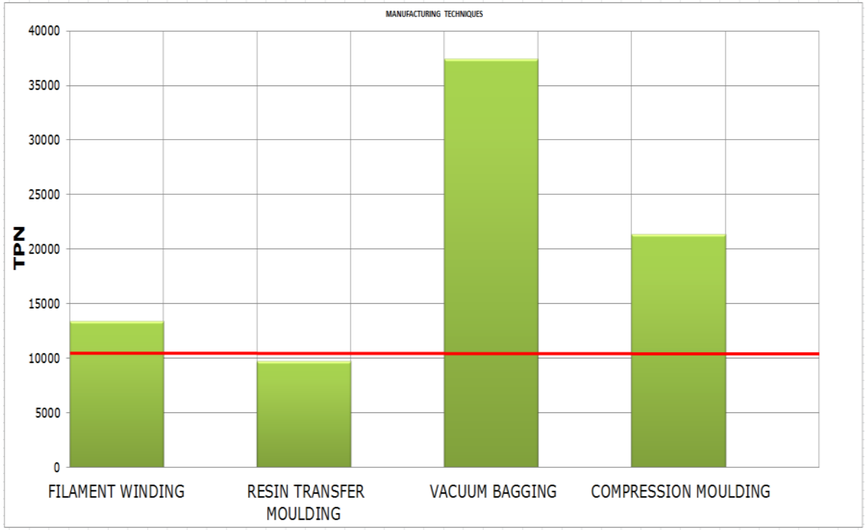
- Balmoral had 4 key deliverables
  - Material Selection (process & properties)
  - Manufacturing Methods, Cost Evaluation & Logistics/Handling
  - Design and Stress Analysis
  - DFMECA & Test Plan – Recommendation for Future Testing

Material Selection (Process & Properties)

Feasibility studies conducted

- Materials
- Based upon prime material selection - Manufacturing evaluation



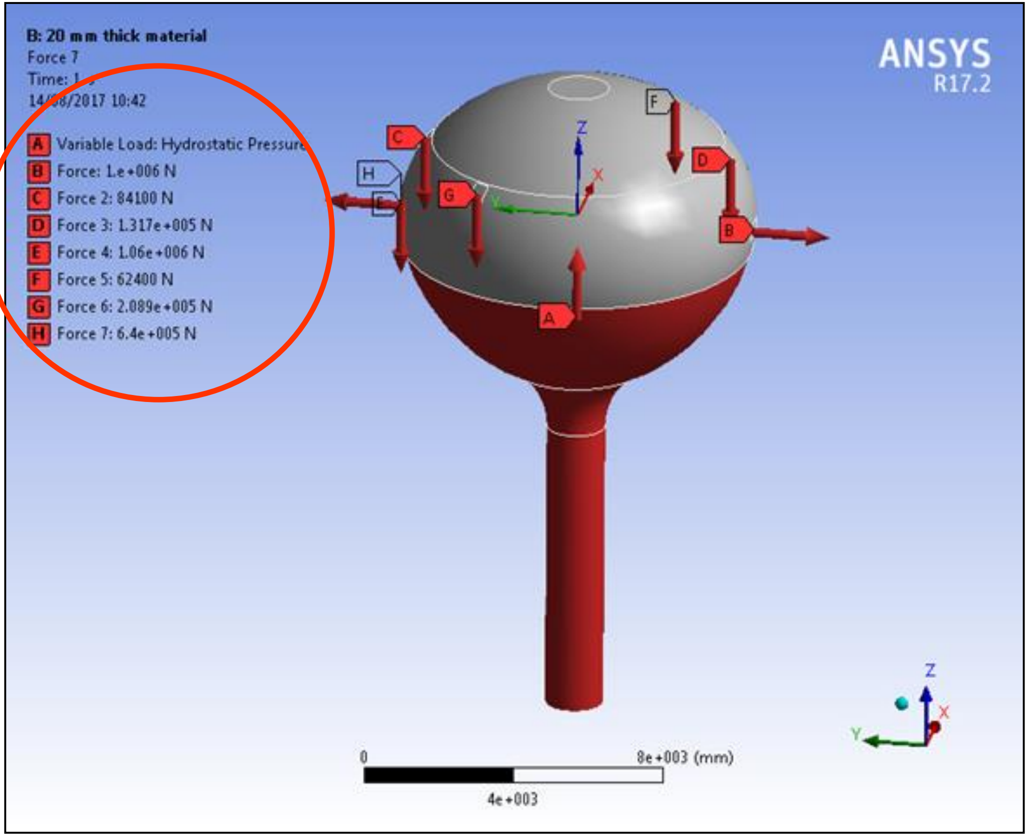


Materials

- Initial materials considered
  - Fibre reinforced plastic (FRP)
  - Epoxy syntactic foams
  - Rigid Polyurethanes
  - Steel (as a baseline)

- Feasibility study identified 5 composite materials
  - Epoxy/E-Glass, Epoxy/S-Glass, Epoxy/Carbon, Epoxy/Kevlar
  - Polyester/E-Glass

Steel analysis (baseline)

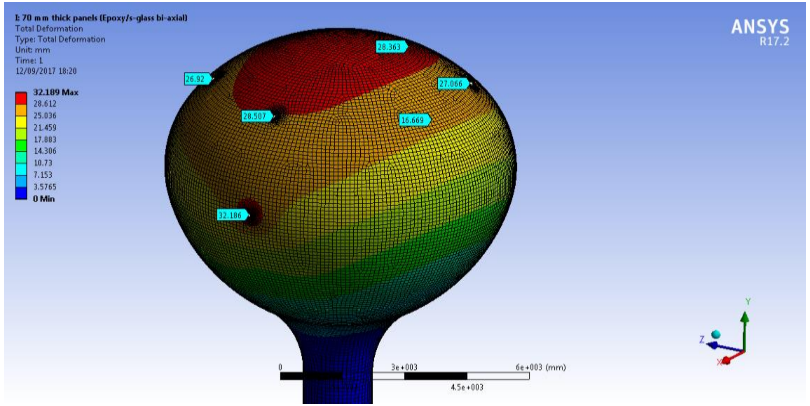


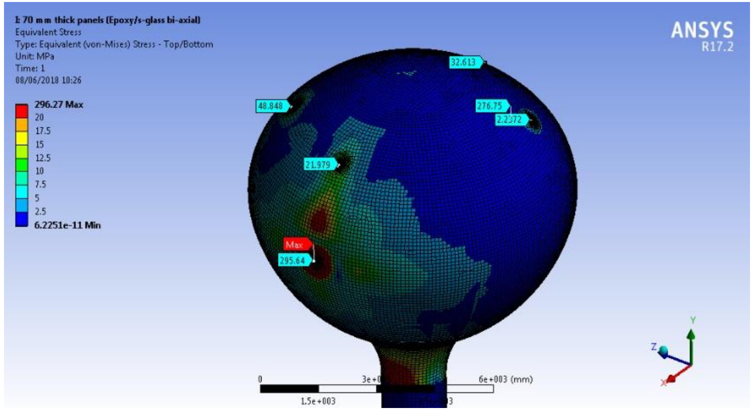
- Load cases based upon 100 year storm condition
- Uniform thickness shell model (based on CorPower full scale hull geometry)
- 10-50 mm thick shell

Thickness (mm.)	Max. Stress at wavespring (MPa)	Max. Stress at PTO Strut (MPa)	Allowable stress (MPa)	Max. Deflection at wavespring (mm.)	Max. Deflection at PTO strut (mm.)	Weight (Tonne)
40	209	37	238	4	3	78
50	151	24		3	2	97

Composite Shell

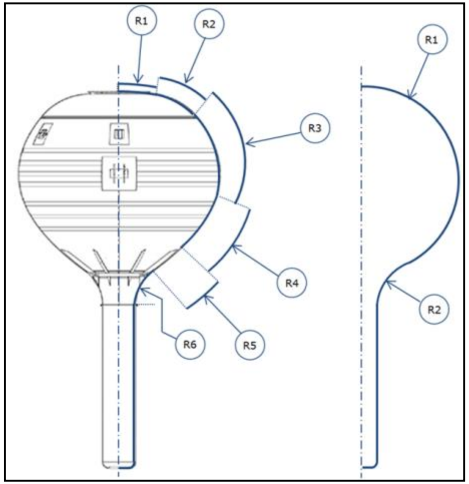
- 45, 60 and 70 mm shell analysed
- Unidirectional and bi-axial lay-up of material
  - Unidirectional results unfavourable
  - Bi-axial performed much better
- Majority of deflection values above allowable limit
- All of the models were still above the weight limit





Hull Structure

- Original half scale was filament wound
- Updated shape is more hydrodynamic than the half scale (Filament winding becomes impractical)
- Structure needed to be deconstructed (ease manufacture and transport)
- Alternatively a factory in a box technique to build hull structure at key side

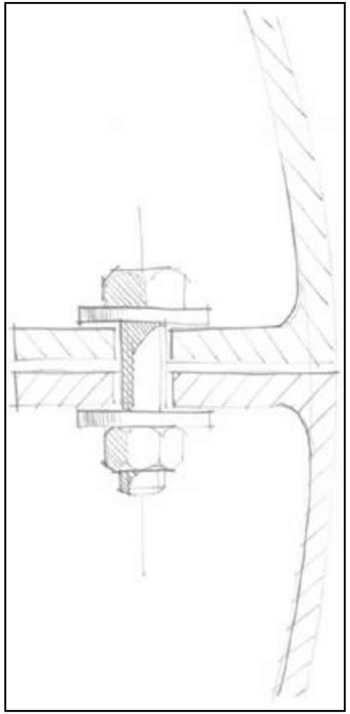


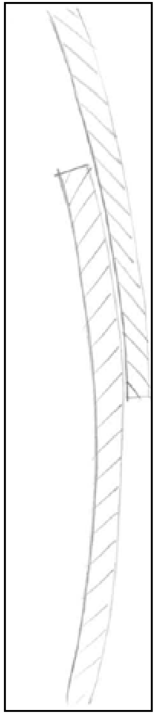
Jointing

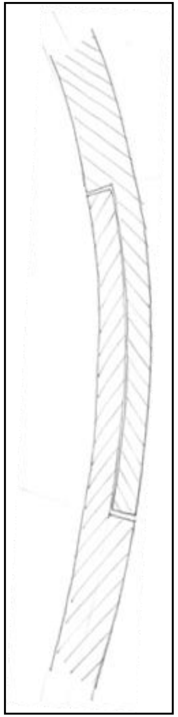
- 2 different ideas
  - Flange
  - Bonded overlap

- Flange joint ruled out due to significant amount of fasteners

- Bonded joint the preferred option
  - Suitable bonding adhesive required
  - Balmoral utilised 3M partner to help select an appropriate bonding medium



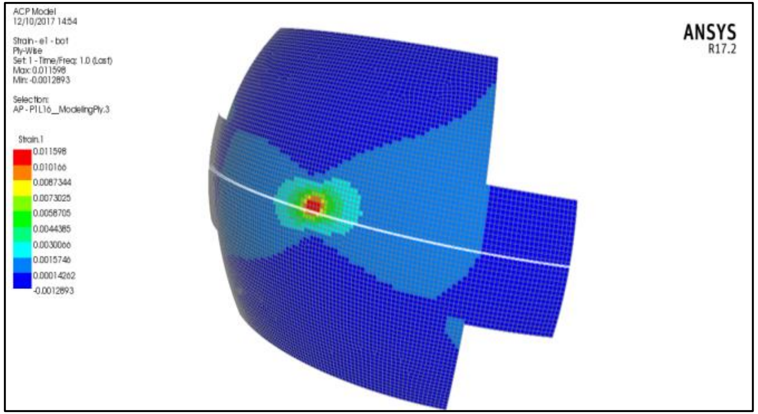


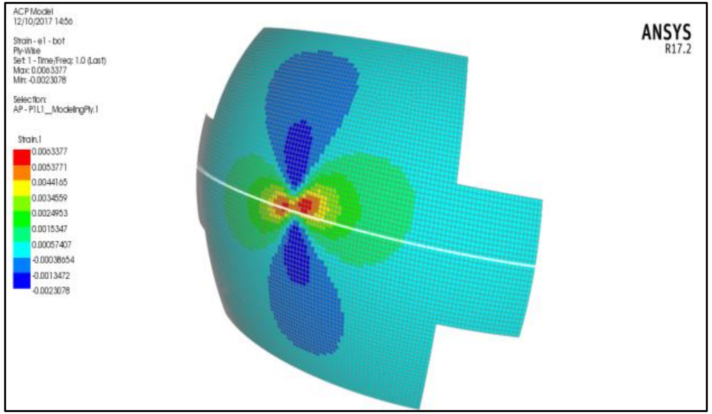


Sandwich Structure

- Sandwich structure used to reduce weight, while maintaining the mechanical properties
  - Already used in renewable sector
- ANSYS Composite used to analysis interaction between the layers

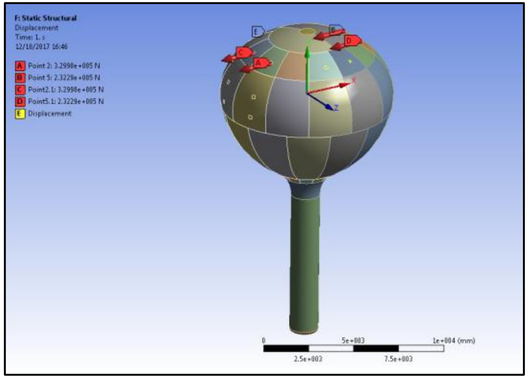
	Solid Material	Core Thickness t	Core Thickness 3t
Stiffness	1.0	7.0	37.0
Flexural Strength	1.0	3.5	9.2
Weight	1.0	1.03	1.06

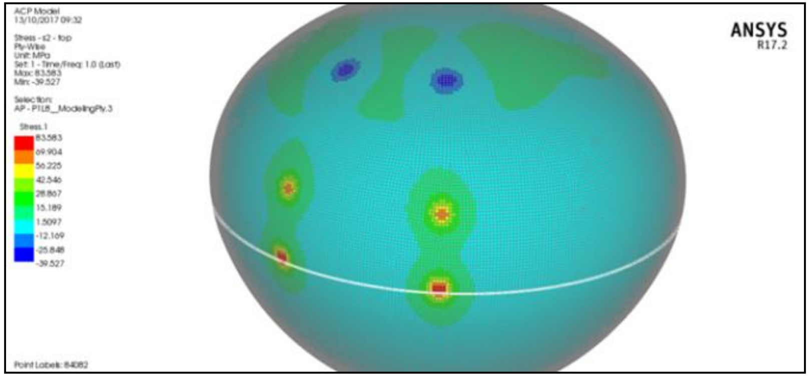


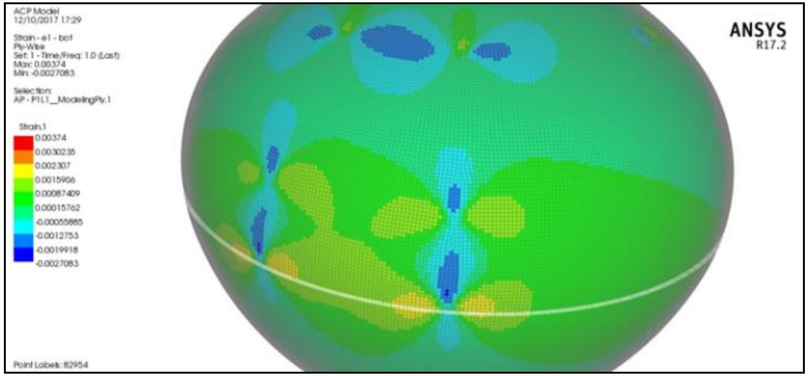


Full scale model

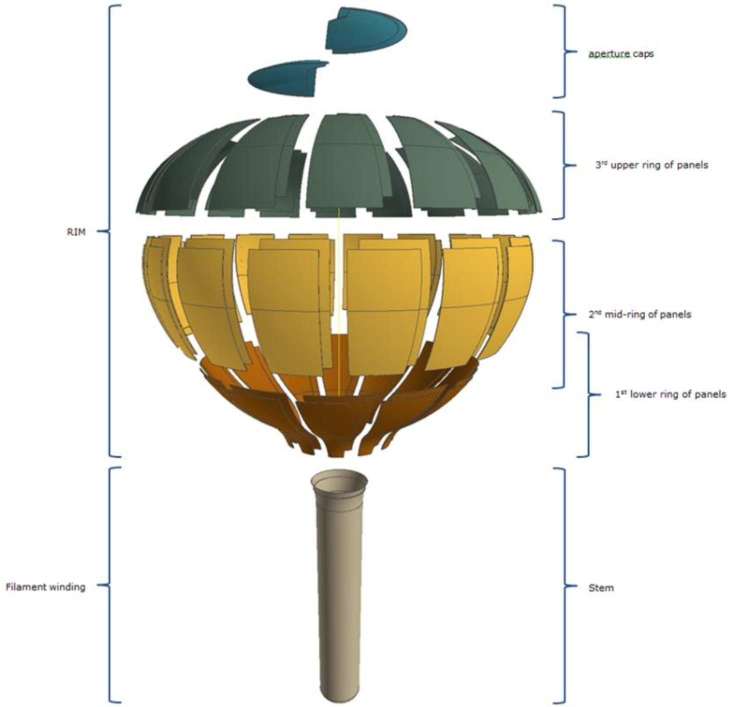
- Two different glass cloths were to be used
  - 0°/90°
  - 45°/-45°
- 1.5 mm thick glass cloth
- 60 mm thick panel (36 mm core)
- Loading split across multiple points

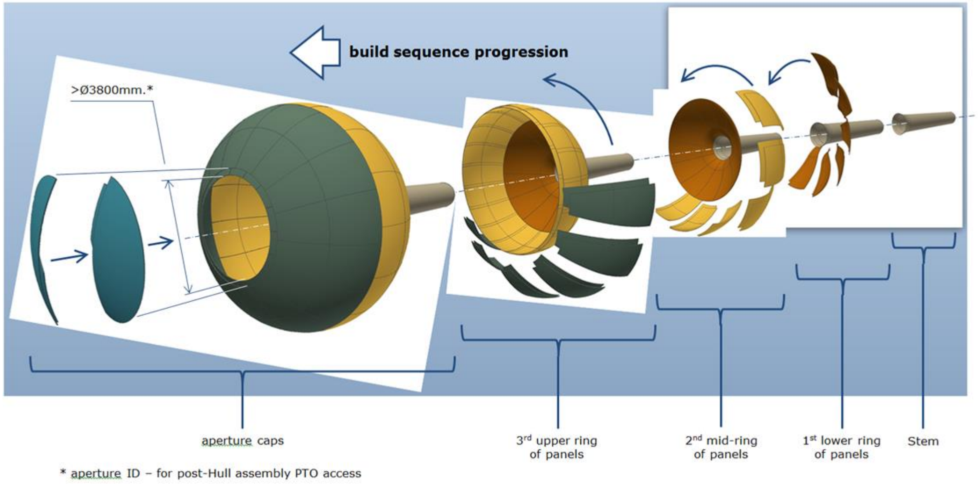






Final Design

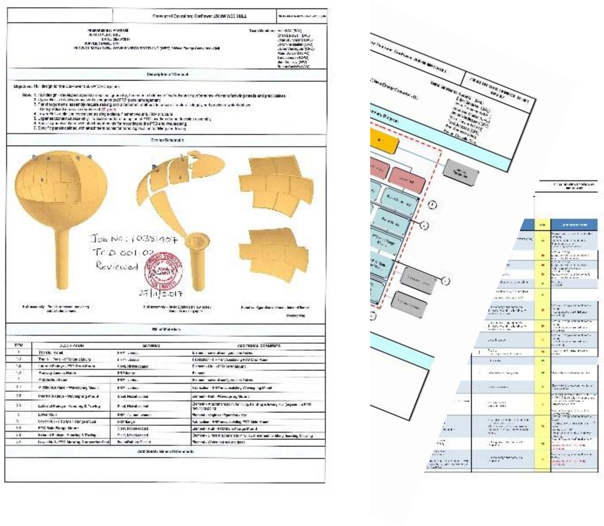


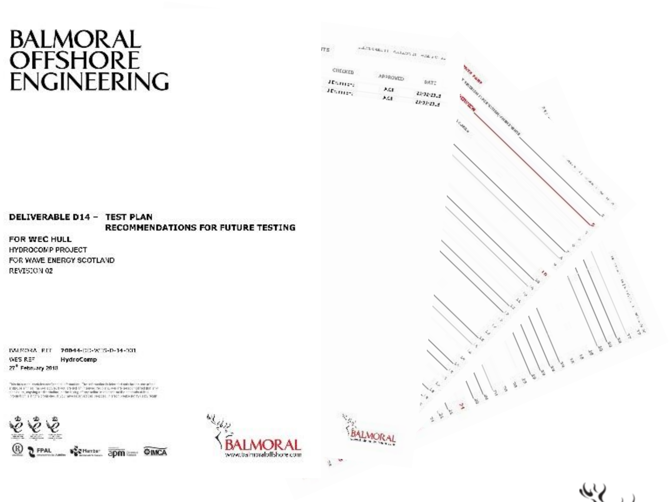


Testing and DFMECA

- Based upon the finalised initial concept design Balmoral facilitated a consortium wide DFMECA with BV as third part approver

- Output of the DFMECA allowed for a rigorous and complete testing plan to be specified in preparation for WES stage 2





Conclusions

- Composites are proven materials with in a marine environment
  - But rarely used in high load and fatigue environments.
  - Don’t typically have to last for 20 years, minimal intervention
- Balmoral using appropriate analysis techniques as well as design experience have proven a composite solution will
  - Operate in these extreme environments
  - Provide a cost effective solution to ensure LCOE is competitive
  - Manufacturing capabilities which are scalable from prototype to 100MW farms
  - Using robust development procedures and risk management tools (based upon oil and gas experience) to give industry wide confidence in Wave devices which may not have traditionally existed

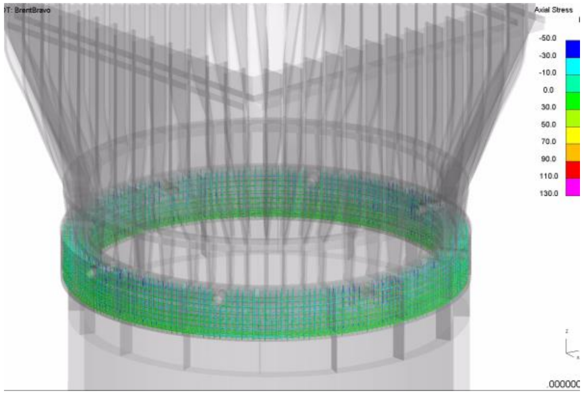
THANK YOU for your attention

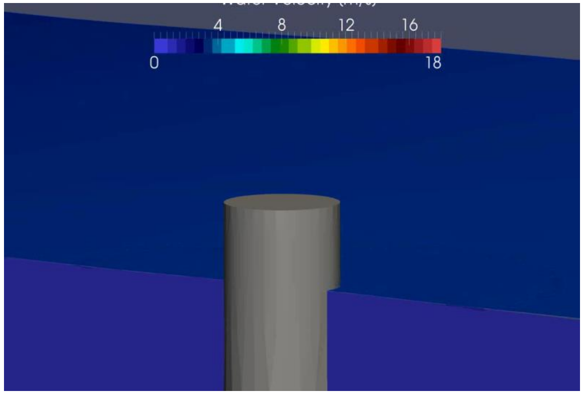
WES CREATE

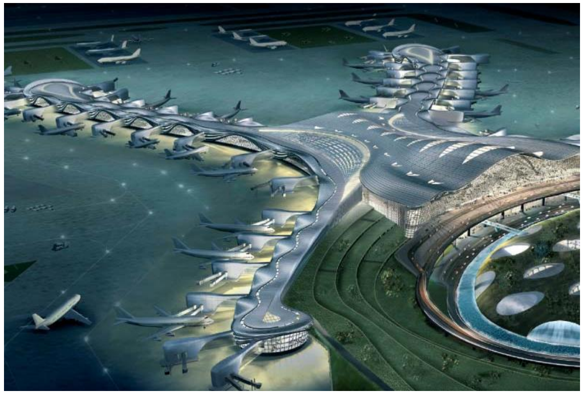
Concrete as a Technology Enabler

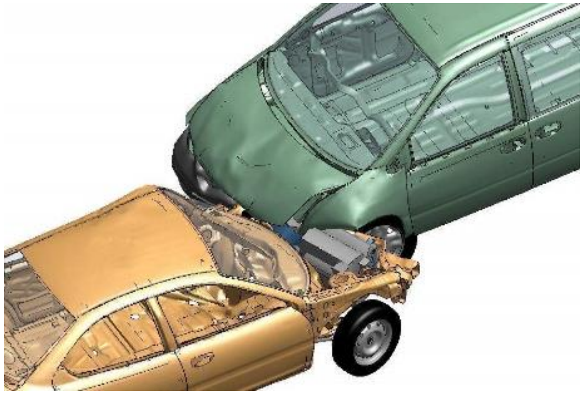
ETIP Webinar, 8th June 2018

George Walker, Arup
george-a.walker@arup.com
+44 20 7755 2502

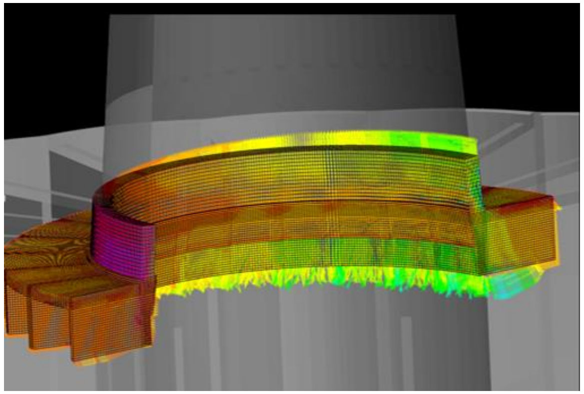


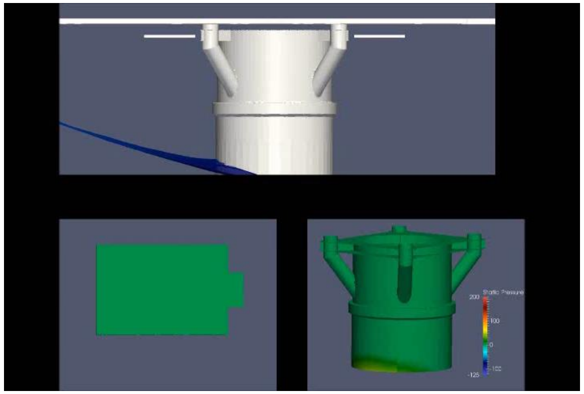


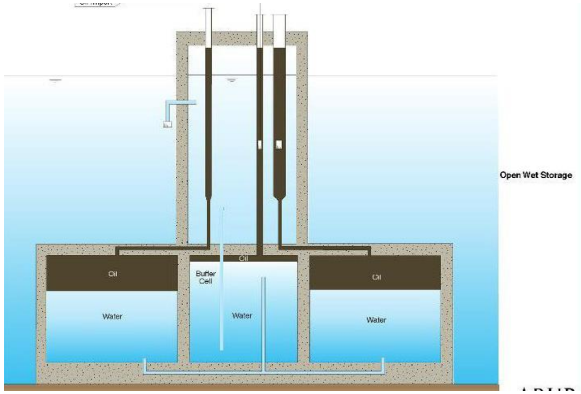




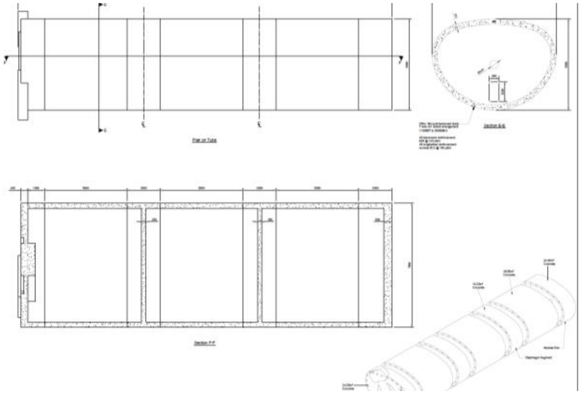
Arup and the Advanced Technology and Research Group

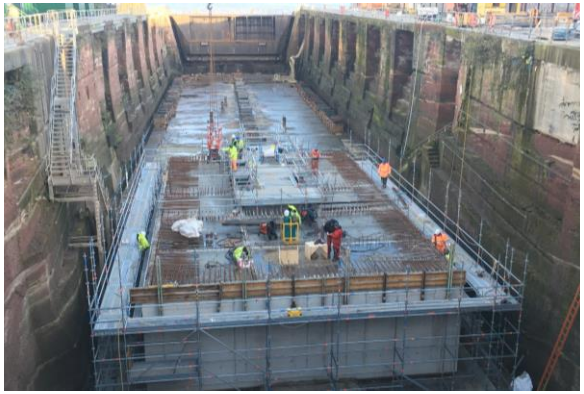






Reinforced concrete is a well understood technology in the offshore environment, with a range of applications in oil and gas and offshore renewables.





ARUP

Design Choice: Reinforced Concrete vs. Steel

Reinforced concrete has the potential to offer a low cost solution taking advantage of a mature supply chain: the focus of the CREATE project

	Reinforced Concrete	Steel
Material Properties	Strength ~ 60 MPa Density ~ 2600 kgm^{-3}	Strength ~ 350 MPa Density ~ 8000 kgm^{-3}
	Concrete solutions are likely to be heavier than steel	
Cost	Lower unit and fabrication cost	Higher unit and fabrication cost
Manufacture	Mature supply chain with simpler fabrication available at more locations	More specialist and less available fabrication methods
Other Advantages	• Corrosion resistant • Less maintenance overhead • Better fatigue performance (typically)	• Corrosion protection required • Maintenance of corrosion protection • Worse fatigue performance (typically)

Project Summary

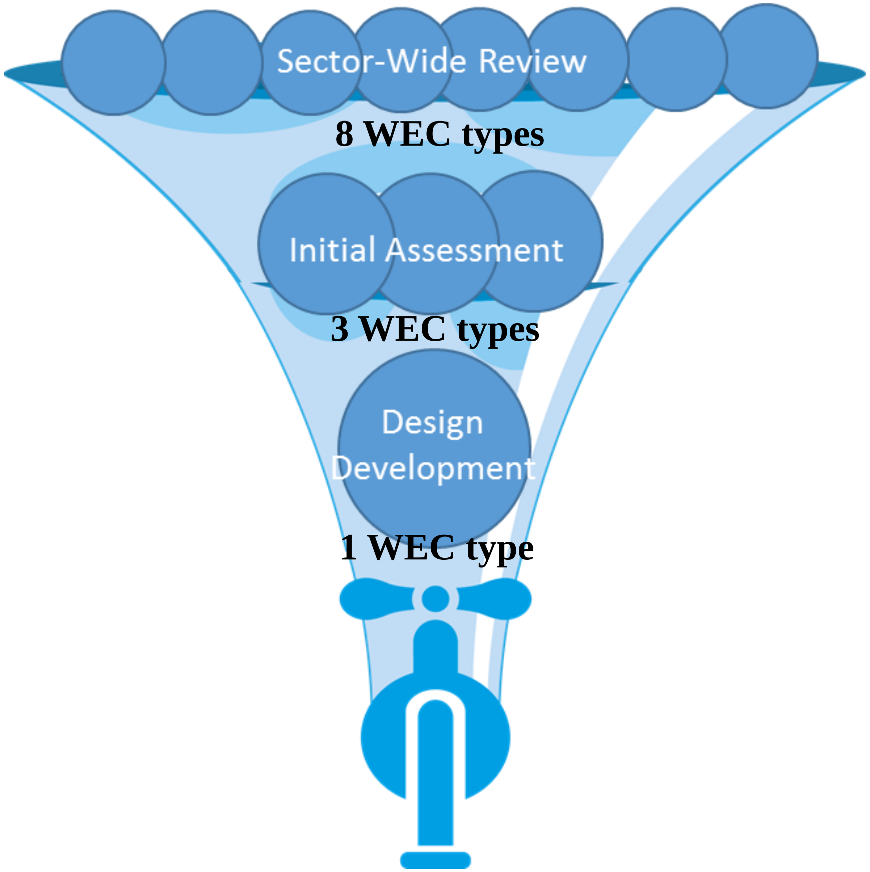
The CREATE project took a sector wide approach to identify **where concrete has potential** for WEC prime mover structures and then developed the most promising option to a **pre-FEED level** with potential for commercialisation.

The project comprised three stages:

Stage I: sector wide review to identify where concrete and which concrete technologies have potential for WEC prime movers;

Stage II: initial design, cost and manufacturing assessment of the 3 most promising options;

Stage III: Pre-FEED level design, manufacturing and cost assessment.

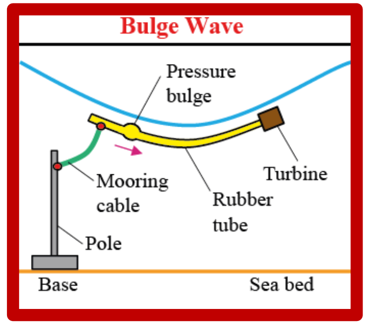


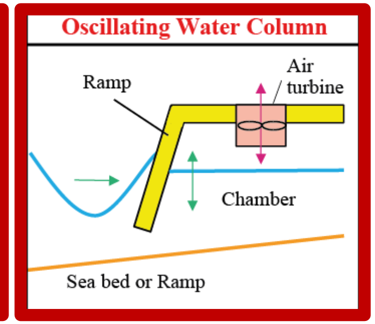
ARUP

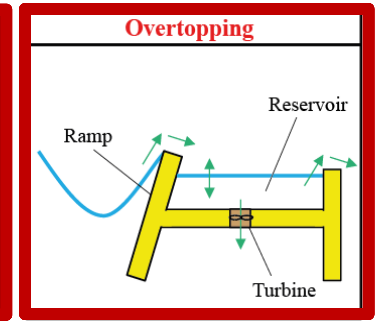
Stage I [Sector Review]: Overview

Category I:

- Unsuitable, or massive static structures with limited learning opportunity.

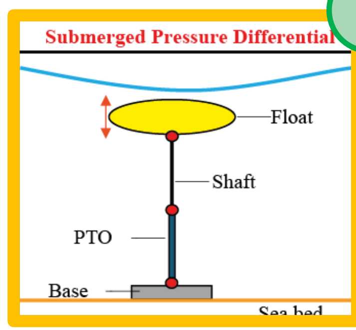


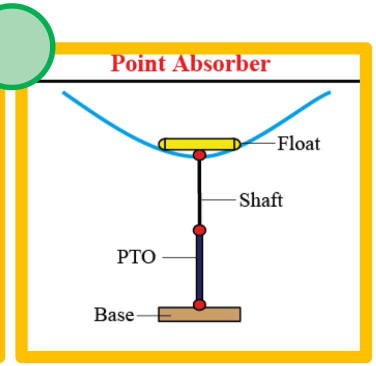


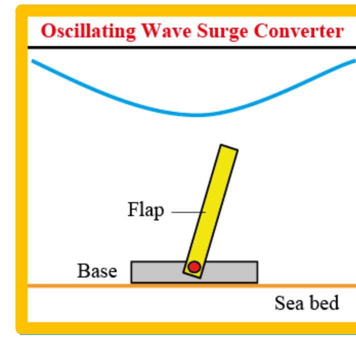


Category II:

Possibly suitable, but likely to require expensive/novel concrete technology.

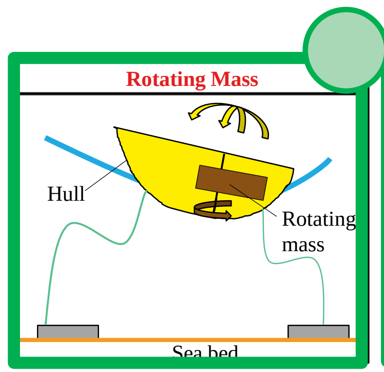


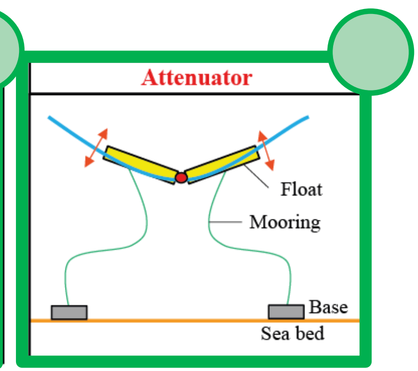




Category III:

- Possibly suitable using conventional reinforced concrete.

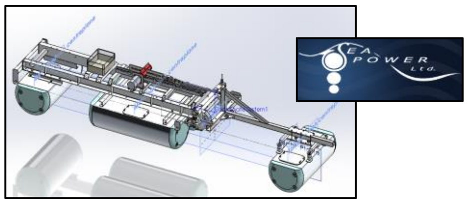




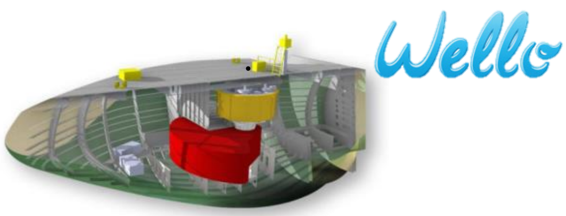
ARUP

Stage II [Initial Assessment]: Overview

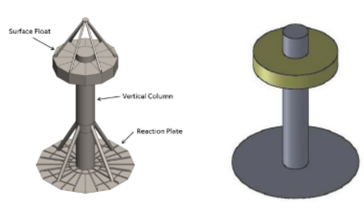
- Stage II comprised scoping level calculations to quantify the advantages associated with concrete WECs for the three most promising options identified in Stage I.
- These structures encompass a wide range of the potential benefits and risks associated with a concrete WEC enabling sector-wide conclusions.



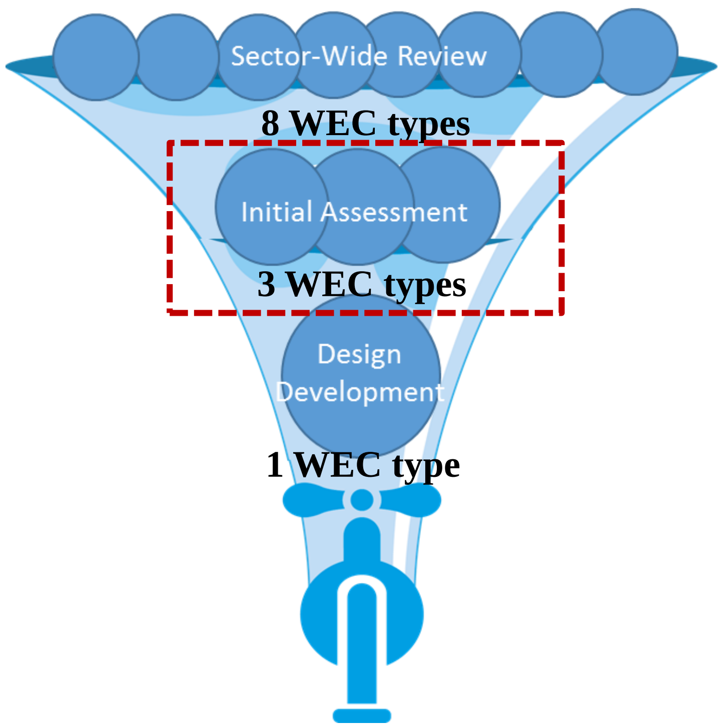
1. Attenuator Device



2. Rotating Mass Device

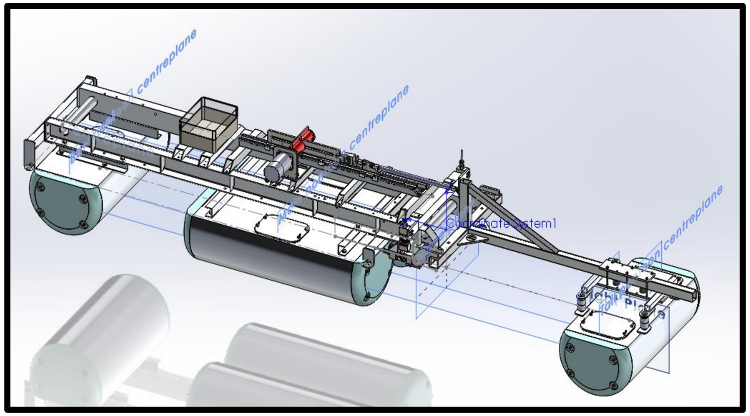


3. Point Absorber Device

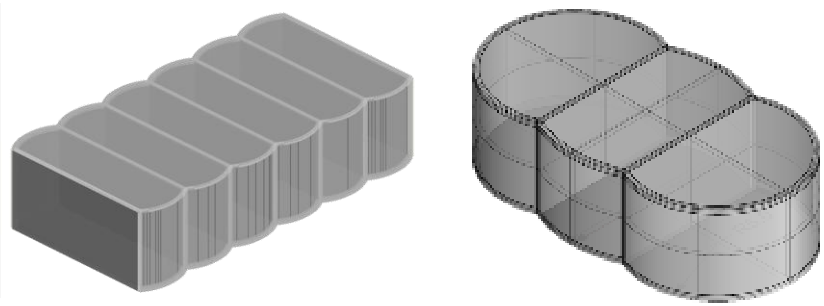


ARUP

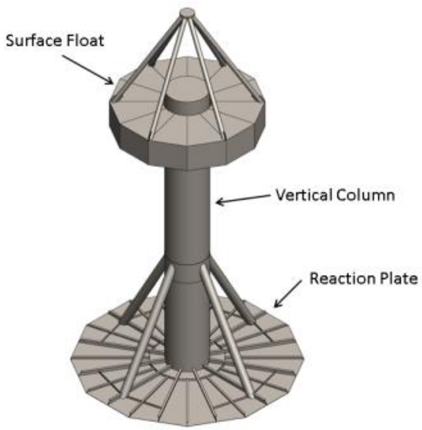
Stage II [Initial Assessment]: Attenuator



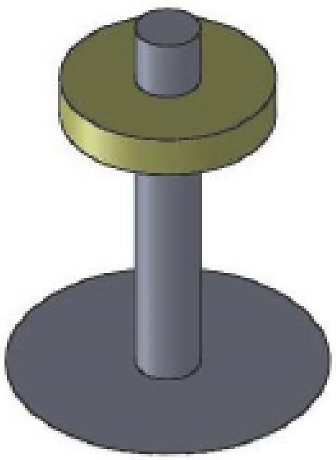
SeaPower Platform



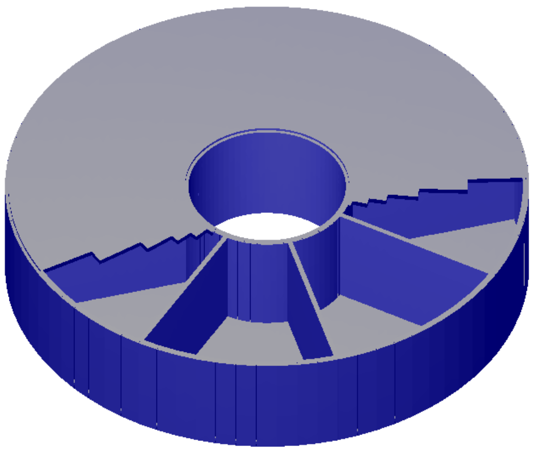
Concrete Pontoons Designs [750te]



RM3 Point Absorber Device



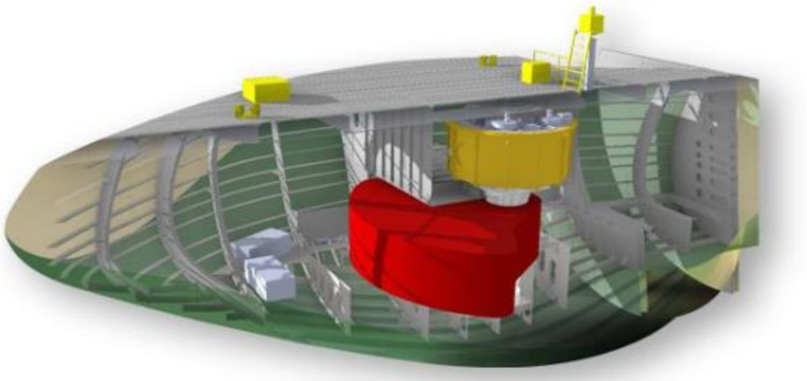
RM3 Point Absorber BA



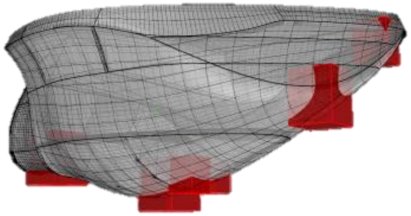
RM3 Concrete BA [650te]

ARUP

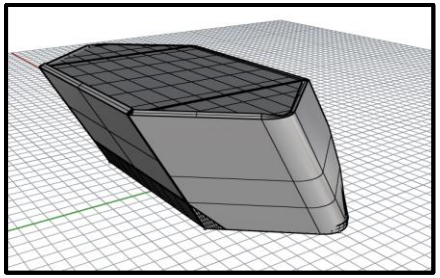
Stage II [Initial Assessment]: Rotating Mass Device



Wello Device



Wello Device I [1250te]



Wello Device II [1250te]

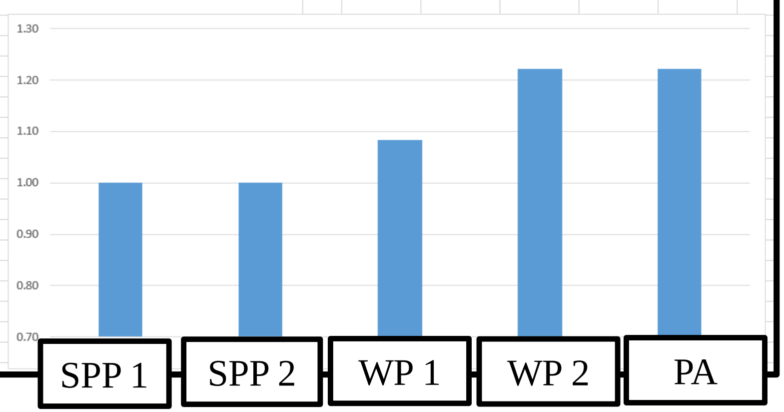
	Wello I	Wello II
Metric 1: LCoE relative to steel	**-15%**	**-20%**
Metric 2: CAPEX relative to steel	**-30%**	**-40%**
Metric 3: Manufacturability	Sprayed in-situ concrete (shot-crete).	Cast in-situ construction or on site pre-cast.
Metric 4: Installability	Dry-dock, slipway or quayside with submersible barge.	Dry-dock, slipway or quayside with submersible barge.
Metric 5: Scalability	Scalable within dry dock.	Scalable within dry dock.
Metric 6: Other technical risks	Bilge pumps would be relied upon for water-tightness as not PT.	

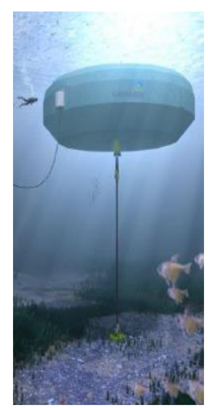
ARUP

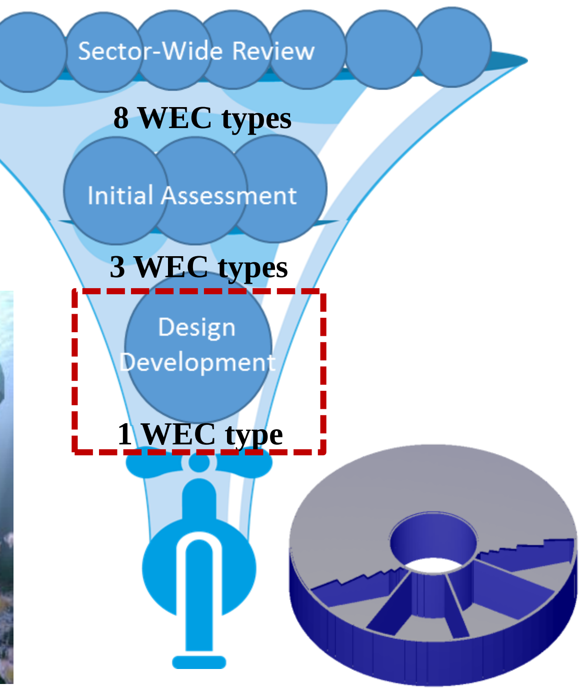
Stage II [Initial Assessment]: Overview

- The devices were compared against the key metrics. This highlighted the potential of constructing the **RM3 Point Absorber BA** and the **Wello Rotating Mass Device** with a simplified geometry using concrete. If a simpler rotating mass hull geometry more suited to concrete construction was developed, concrete could offer significant benefits for rotating mass devices

		Weighting	SPP I	SPP II	Wello I	Wello II	Point Absorber
Metric 1	LCoE relative to steel (incl. survivability/performance)	2	4	4	6	6	5
Metric 2	Concrete component CAPEX relative to steel	2	4	4	5	5	5
Metric 3	Manufacturability	2	4	4	2	4	5
Metric 4	Ease of launch (installability)	1	4	4	5	5	5
Metric 5	Scalability	1	4	4	4	4	5
Metric 6	Other technical risks	1	4	4	4	5	4
	Totals		36	36	39	44	44
	Normalised comparison		1.00	1.00	1.08	1.22	1.22

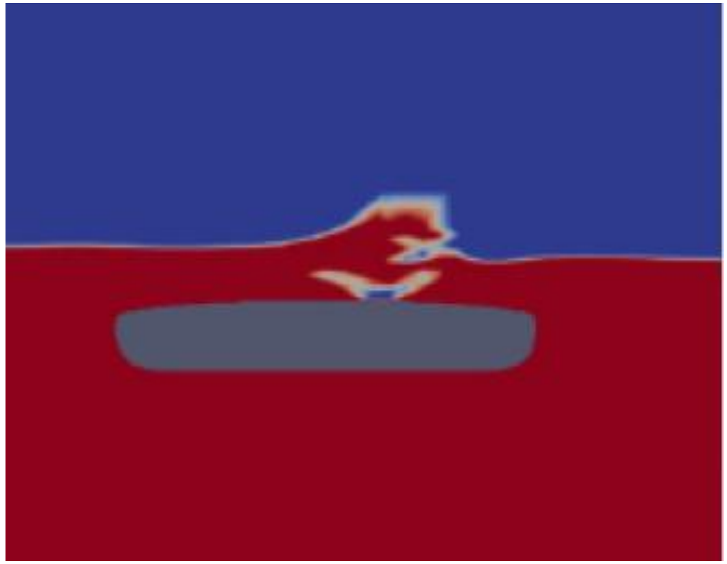




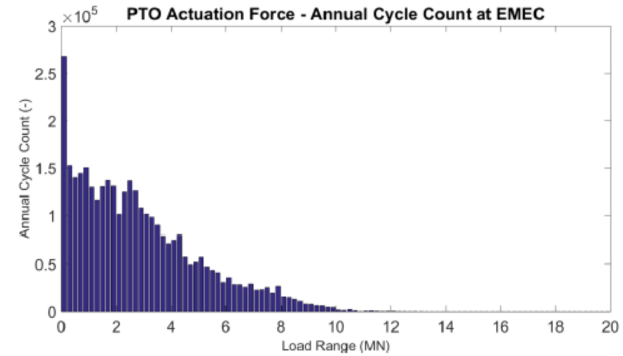


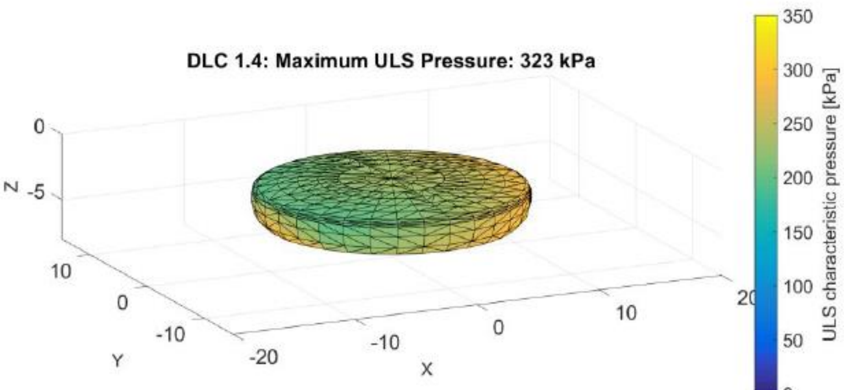
ARUP

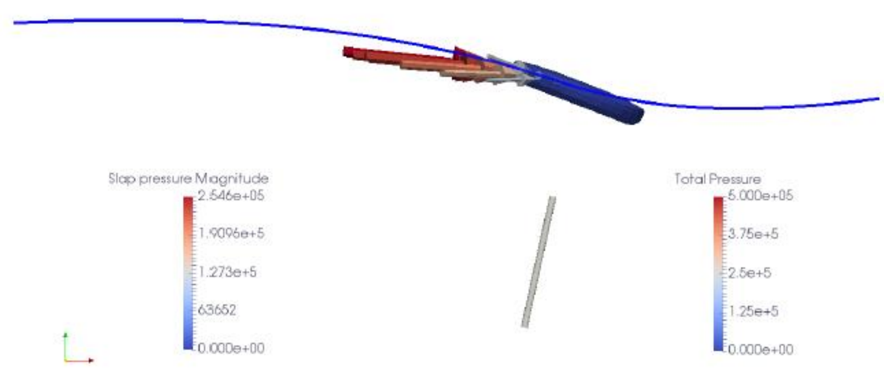
Stage III: Loads + Performance Assessment



Hs[m] / Tp[s]	4	5	6	7	8	9	10	11	12	13	14	15	16
0.75	0	0	1	1	3	1	1	1	1	1	1	0	0
1.25	0	2	5	19	20	16	15	13	5	5	3	2	1
1.75	1	6	43	61	66	66	53	41	29	22	16	11	5
2.25	2	17	83	128	130	113	100	75	63	44	35	28	18
2.75	5	44	146	204	184	190	151	120	95	80	61	43	35
3.25	9	74	215	268	274	247	201	165	134	105	84	70	58
3.75	16	109	286	335	367	282	264	209	177	133	115	92	82
4.25	23	155	354	409	412	347	313	264	205	179	144	109	106
4.75	33	184	415	500	489	439	369	311	260	218	182	133	124
5.25	46	226	501	571	532	504	414	379	288	249	205	185	135
5.75	56	281	579	665	648	578	465	412	349	282	222	208	171







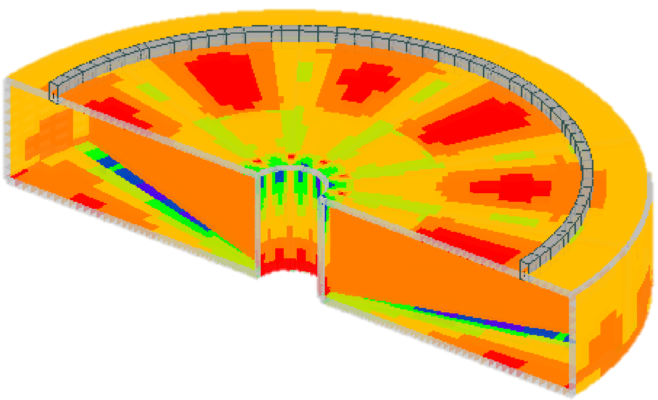
cruz atcheson
CONSULTING ENGINEERS

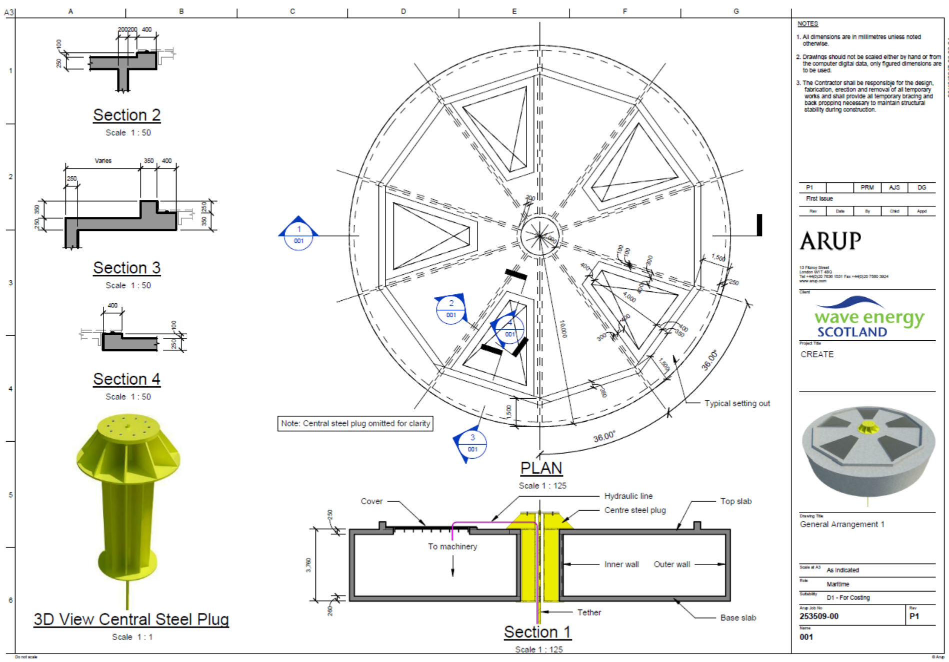
ARUP

Stage III: Structural Design

- Structural design was conducted to a **pre-FEED level**, including assessment of ULS, FLS and SLS. This proved the feasibility of a concrete BA and accurate mass estimations to enable costing.

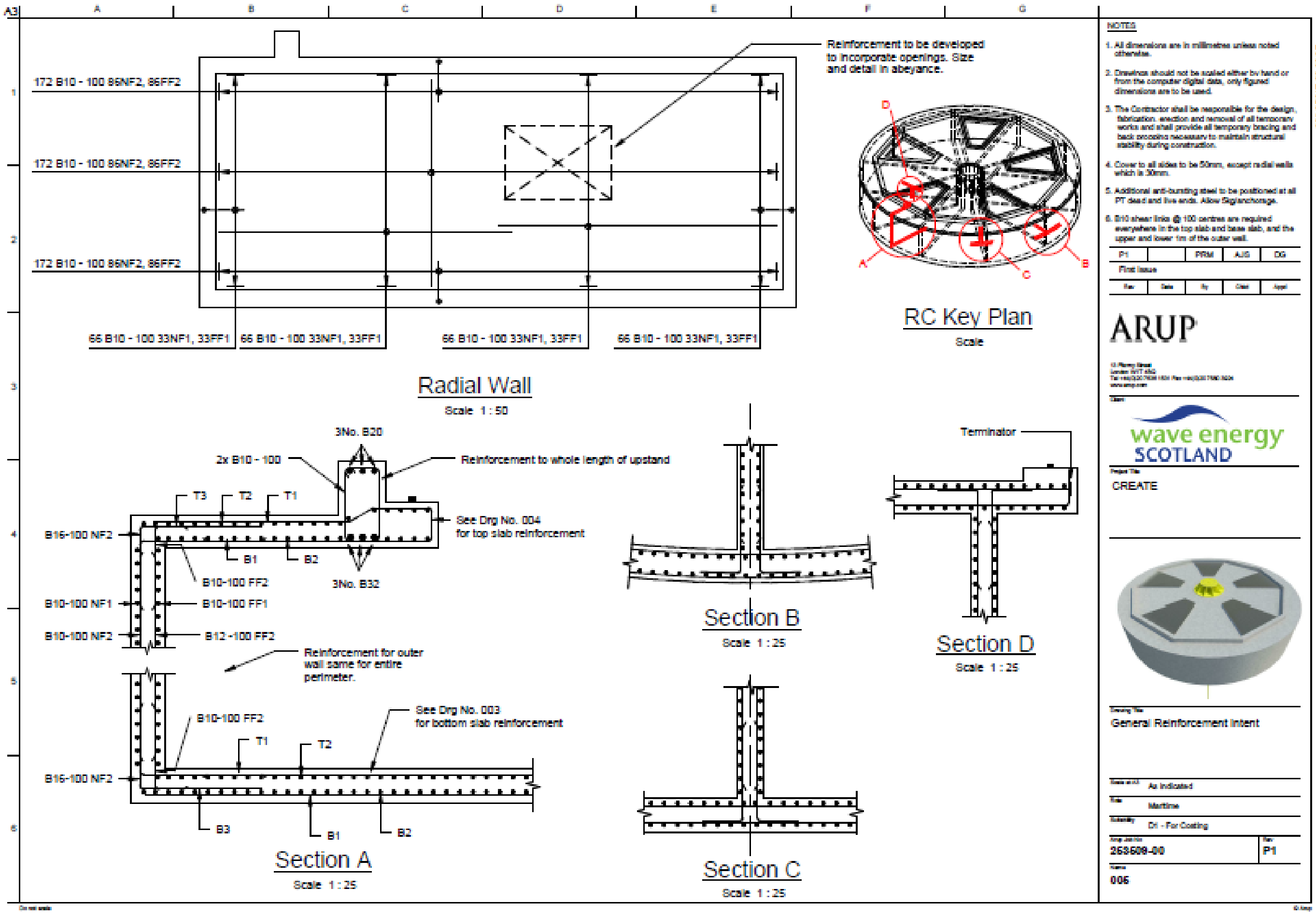
Target BA Mass (Steel)	BA Mass: Conventional Concrete	BA Mass: Modified Normal Density Concrete (MNDC)
770te	860te (+10%)	790te (+3%)





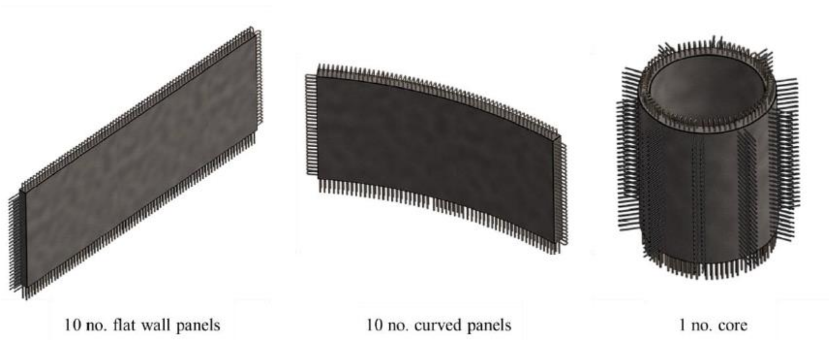
Stage III: Structural Design

- A pre-FEED level of design was completed to understand the complexity of the connections. This will help **control costs** and **reduce construction risks**.

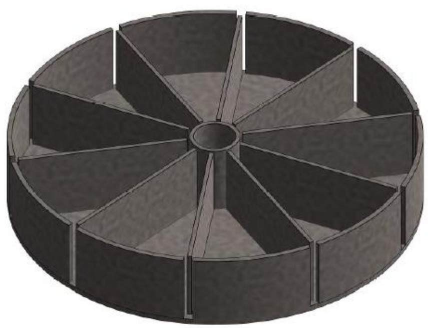


Stage III: Manufacturing Assessment

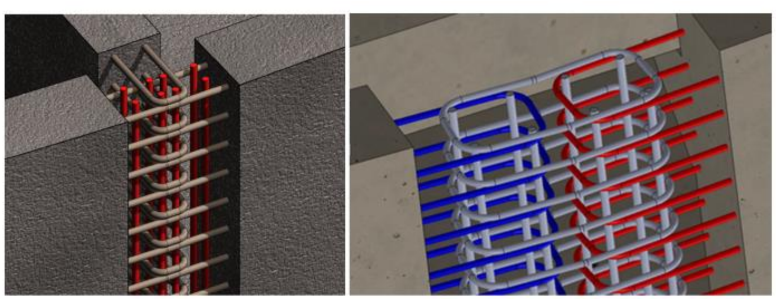
- A workshop with **experienced contractors** and **members of the supply chain** was used to confirm the best manufacturing method and possible UK construction sites, with a focus on Scotland.



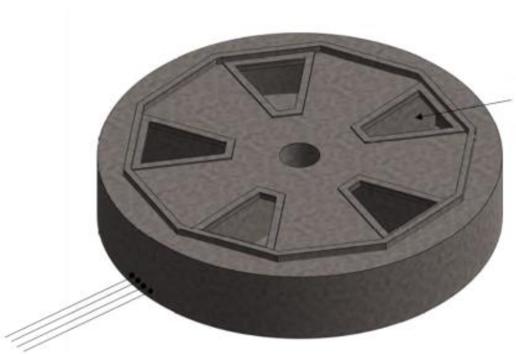
Stage 1: Create Precast Components



Stage 2: Lift components into place and cast base slab



Stage 3: Stitch together wall units



Stage 4: Cast top slab and add post-tensionng

ARUP

Stage III: Manufacturing Assessment

- The supply chain workshop identified a number of facilities that would be suitable for construction of concrete WECs.

Kishorn dry dock and hard standing, currently being prepared for construction of 8 floating concrete wind energy turbines

Rosyth dockyard, including a 2000te ship lift

Nigg Dry dock and hard standing. Permanent craneage (1200te). Being used for steel construction of Beatrice wind farm.

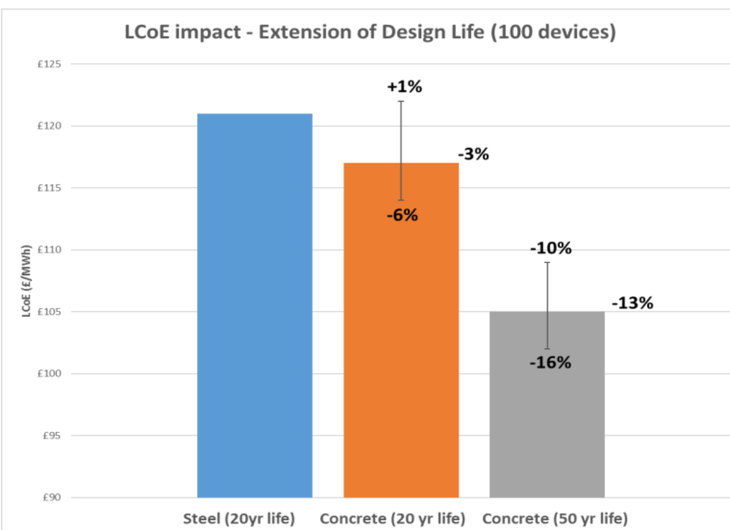
Port of Blyth dry dock currently being used for concrete gravity wind turbine foundations.

Stage III: Cost Assessment

Followed a structured evaluation of cost impact:

1. Determined a baseline CAPEX (steel fabrication for 1, 10, 100 units)
2. Compared to concrete CAPEX for similar volumes
3. Evaluated CoE impact
4. Considered sensitivity to design life
5. Noted conservatism in assumptions
6. Identified scope for further analysis

Item	Short description	Quantity	Unit	Productivity Hrs/unit	Unit rate £		Cost for 1 WEC £
							1
1	CONSTRUCTION FACILITY						
1.01	Modification / refurbishment	1.0	item		inc		
1.02	Dock/slipway rental	3.0	month		20,000.00		60,000
	Total Facility Cost						
	FACILITY TOTAL						60,000
2	1nr UNIT CONSTRUCTION IN DRY DOCK/SLIPWAY						
2.01	base preparation for casting	310.9	m^2		10.00		3,109
2.02	base - formwork supply and fix	18.0	m^2		64.00		1,149
2.03	base - reinforcement supply	22.8	te		628.00		14,294
2.04	base - reinforcement fix	22.8	te	17.0	21.73		8,408
2.05	base - concrete supply	81.0	m^3		155.00		12,555
2.06	base - concrete place	81.0	m^3	1.5	16.34		1,985
2.07	base - post-tensioning supply, thread, stress & grout	2.0	te		3,500.00		7,076
2.11	Outer Wall - formwork supply and fix	40.8	m^2		72.00		2,939
2.12	Outer Wall - reinforcement supply	9.2	te		628.00		5,786
2.13	Outer Wall - reinforcement fix	9.2	te	8.0	21.73		1,602
2.14	Outer Wall - concrete supply	37.0	m^3		155.00		5,735
2.15	Outer Wall - concrete place	37.0	m^3	1.0	16.34		605
2.61	Lids	10.0	te		4,000.00		40,000
2.62	Central Steel Plug	8.5	te		4,000.00		34,000
	SPP CONSTRUCTION SUB-TOTAL (excl indirects)						263,891
4	CONSTRUCTION INDIRECTS						
4.01	management and supervision		item		20.0%		52,778
4.02	office establishment & expenses		item		5.0%		13,195
4.03	plant & equipment		item		15.0%		39,584
4.04	small tools		item		2.0%		5,278
4.05	freight		item		0.5%		1,319
	Total Including Construction Indirects					0.43	112,154
	CONSTRUCTION TOTAL						376,044
5	ENGINEERING						
5.01	FEED and tender preparation/evaluation		item		10.0%		37,604
5.02	Detailed Design		item		20.0%		75,209
5.03	Certification		item		5.0%		18,802
6	CONTRACTOR OVERHEAD & PROFIT		item		12.0%		45,125
	SUB TOTAL						176,741
				Total per WEC		£	612,785



ARUP

WES CREATE – Concrete as a Technology Enabler

ARUP | cruz atcheson CONSULTING ENGINEERS | mpa The Concrete Centre | Carnegie wave energy | Wello | Sea Power Ltd.

Reinforced concrete has the potential to offer a **low cost solution** taking advantage of a **mature supply chain.** The CREATE project has taken a sector wide approach to identify **where concrete has potential** for WEC prime mover structures, and developed the most promising option to a **FEED level** with potential for commercialisation.

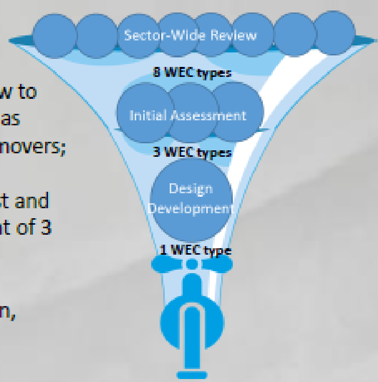
Methodology

The CREATE project consists of three stages:

Stage I: sector wide review to identify where concrete has potential for WEC prime movers;

Stage II: initial design, cost and manufacturing assessment of 3 promising options;

Stage III: FEED level design, manufacturing and cost assessment.



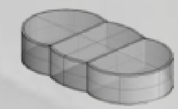
Stage I: Sector Wide Review

The Stage I review identified four categories of WEC in terms of the potential feasibility of concrete.

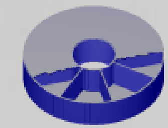
	Suitability of Concrete	WEC Types
Category I	Unsuitable	• Bulge wave
Category II	Large static structures that are likely suitable, or are already fabricated from concrete	• Oscillating water column • Overtopping device
Category III	Possibly suitable, but may require expensive/novel concrete technologies	• Submerged pressure differential • Point absorber • OWSC
Category IV	Possibly suitable using standard concrete technology	• Rotating mass • Attenuator

Stage II: Initial Assessment

Structural design, manufacturing and cost assessment were carried out for three WEC types highlighted in Stage I. The assessment highlighted the cost saving potential of a concrete point absorber float and a rotating mass device, if a simplified hull shape was adopted.



SeaPower: Concrete Pontoon



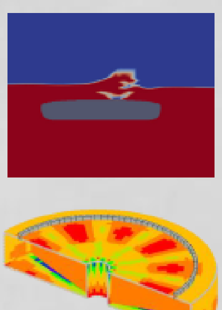
Generic Point Absorber: Concrete Float

Wello: Concrete Hull (simplified and original geometry)

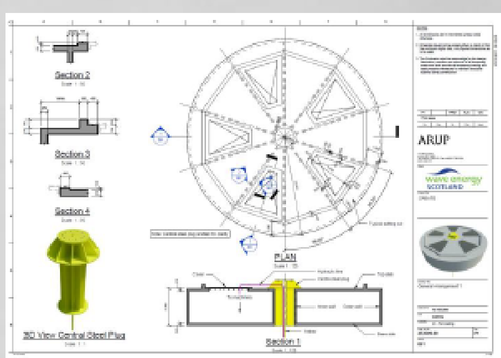
Stage III: FEED Activity

Following the findings of Stage II, the float structure of the Carnegie CETO 6 device was chosen as an example geometry for more detailed assessment. A FEED level design has been developed, highlighting the risks and potential of a commercial concrete device. An independent manufacturing and supply chain assessment has been led by The Concrete Centre and British Precast to verify the key advantage of concrete – access to a mature supply chain.

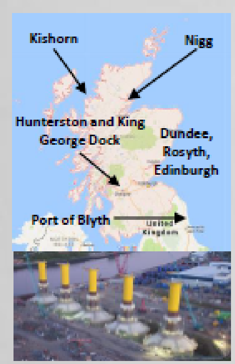
The Carnegie CETO Device



Detailed Loads and Structural Analysis



Structural Drawings and Cost Assessment



Independent Manufacturing and Supply Chain Assessment

Conclusions

- Reinforced concrete is a feasible structural material for the prime mover of many WEC types. It is particularly suitable for those with significant ballast requirements, including **rotating mass, submerged pressure differential** and **point absorber devices.**
- A cost, manufacturing and supply chain assessment has confirmed the advantages of **low cost** and **access to a mature supply chain** for a concrete point absorber and submerged pressure differential WEC, with potential fabrication sites identified in Scotland.
- Further work into loads assessment and the manufacture of complex geometries would address current challenges. There is further opportunity for **standalone PTO manufacturers** to use a low cost concrete float and for development of **concrete foundations** for floating structures.

HIE | wave energy SCOTLAND | ARUP

Email: george-a.walker@arup.com jacob.ahlqvist@arup.com

Wave Energy Scotland Annual Conference – 28th November 2017 – Edinburgh

WES CREATE

Concrete as a Technology Enabler

ETIP Webinar, 8th June 2018

George Walker, Arup
george-a.walker@arup.com
+44 20 7755 2502

Staying in Touch

www.etipocean.eu

https://www.linkedin.com/in/etip-ocean-316262133/

info@etipocean.eu

https://vimeo.com/channels/1210250

@etipocean

Rue d'Arlon 63
B-1040 Brussels
Belgium

www.etipocean.eu

Coordinated by

Ocean Energy Europe

Partners

THE UNIVERSITY of EDINBURGH

EERA
European Energy Research Alliance

Supported by

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727483