LoadTide – Final Report August 2022

Supergen Offshore Renewable Energy

1 Progress Report Summary

- The project requested a further no-cost extension due to supply chain issues encountered during test setup, delaying the development of the load introduction saddles. The project now concludes on the 31st of August 2022.
- The work of Task 1 & 2 has led to a conference paper.
- A final publication of the fatigue testing carried out is being written and is planned to be published within a year.

2 Partners

University of Edinburgh – Eddie McCarthy (PI), David Garcia-Cava (Co-I), Francisca Martinez-Hergueta (Co-I)

University of Oxford – Chris Vogel (PI)

3 Introduction

This project was to measure the fatigue performance of a decommissioned tidal turbine blade to help tidal stream developers reduce their uncertainty in blade design life. Understanding the loads and impact on blade structural performance is crucial in order to avoid premature failure and to increase confidence in tidal blade design, leading to reduced cost of energy. This project will model, define and apply these fatigue loads to develop a process for full-scale tidal blade testing.

4 Aims and Objectives

To address the challenges above, LoadTide aimed to investigate and demonstrate the fatigue failure mechanisms of tidal blades from representative ocean load cases for de-risking designs of full-scale tidal blades.

To achieve the above aim, four main operational objectives are envisaged:

#	Objective	Progress
1	Extract information from decommissioned blades to predict future fatigue failures.	100%
2	Demonstrate a pathway from ocean conditions to full-life tidal blade fatigue testing.	100%
3	Investigate failure mechanisms of tidal blades under representative fatigue load conditions.	100%
4	Maximise the uptake of this additional knowledge within the tidal community.	*100%*

5 Project Plan

This project combined state-of-the-art experimental facilities with leading numerical analysis to develop the pathways shown in Figure 1 that link ocean conditions to structural testing to determine blade fatigue performance. To do so, the project used existing metocean data, to study the transfer of wind load characterisation techniques to tidal scenarios, and trial new methods for test definition of full-scale tidal blade fatigue tests.

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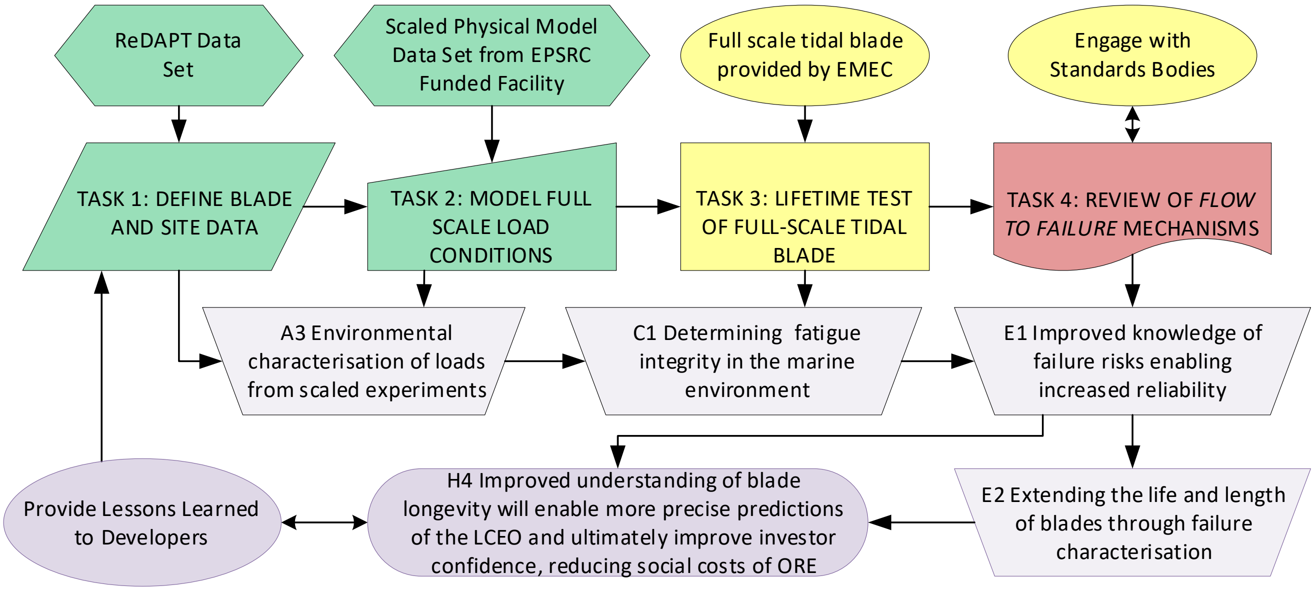

Figure 1: Overview of LoadTide project process indicating support. Red indicates incomplete, yellow is ongoing and green is complete.

6 Progress To Date

Task	Leader	Progress to date	% Complete
Task 1	UoE	• Defining blade conditions is complete. • Met ocean datasets is complete.	100%
Task 2	UoO	• Numerical simulations and results are provided to design the test program.	100%
Task 3	UoE	• The blade for testing was shipped from EMEC on 14/05/21 and arrived in Rosyth on 16/06/2021. • Natural frequency, static and fatigue testing has been carried out on the blade provided by EMEC to IEC 62600-3 standard	100%
Task 4	UoE	• Jeff Steynor has served on IEC TC-114 committees and IECRE to ensure alignment. • The project delivered testing to IEC 62600-3 specifications. The test report, compliant with IECRE OD300-3, will be made available at the conclusion of the loadtide project to support knowledge dissemination within the tidal community.	100%

7 Task Milestone Reports

7.1 IMAGES

Sanding off marine anti-fouling coating

Marking sensor locations prior to painting

Base coat of matt white

DIC speckle pattern over first 3.5m of blade

Figure 2 - Blade Surface Preparation for DIC

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Figure 3 - Articulated Pad Saddle


Figure 4 - MDF Clamp Saddle

Figure 5 - Blade weight and centre of gravity measurements

Table 1: Blue is to be completed, green complete..

Gantt chart of LoadTide project

	Tasks and Subtasks	November 2020	December 2020	January 2021	February 2021	March 2021	April 2021	May 2021	June 2021	July 2021	August 2021	September 2021	October 2021	November 2021	December 2021	January 2022	February 2022	March 2022	April 2022	May 2022	June 2022	July 2022	August 2022
TASK 1	Take delivery and measure 3D geometry of tidal blade																						
	Define ocean conditions from ReDAPT and physical modelling data																						
TASK 2	Setup and perform line actuator simulations																						
	Validate numerical simulations with tank data																						
	Scale up simulations with ReDAPT data																						
	Determine Fatigue Load Case and Blade Test Specification																						
TASK 3	Produce blade test design report																						
	Procure testing apparatus and fixtures																						
	Carry out fatigue test of tidal blade																						
	Perform NDT to characterise the failure mode																						
TASK 4	Review Test Results and Root of Failure																						
	Characterise structural response																						
	Produce test analysis report																						
	Review flow-to-failure process																						
Proj Mgmt & Dis-semination	Face-to-face project meetings (if permitted)																						
	Produce 2 Open Access Peer Reviewed Papers																						
	Provide feedback to IEC TS 62600-3 and DNVGL ST 0164																						
	Produce final report for public domain																						

7.2 Summary of structural test report on 5.25m tidal turbine blade

The following section summarises the testing which was carried out on the Tidal Generation Limited (TGL) blade which was provided to the University of Edinburgh by EMEC. The full report is attached and will be made available along with relevant testing data online.

7.2.1 Introduction

The Scope of this report is to give a detailed account of the tests carried out by the University of Edinburgh on the Deepgen III tidal turbine blade, free issued by the European Marine Energy Centre: EMEC. One static and one fatigue load case, defined by the project partners at Oxford University, were carried out. Deflection, strain, position, applied load, acceleration and temperature were logged throughout the test.

7.2.2 Static Testing

The target static load was 273.33 kN which was held for 1 hour, after a 2 minute ramp up and a 2 minute ramp down. This load profile is shown in Figure 6. A full explanation of the static test including errors and test deviations can be found in the attached test report. The report also describes all sensors, sensor locations, loading setups and test definition.

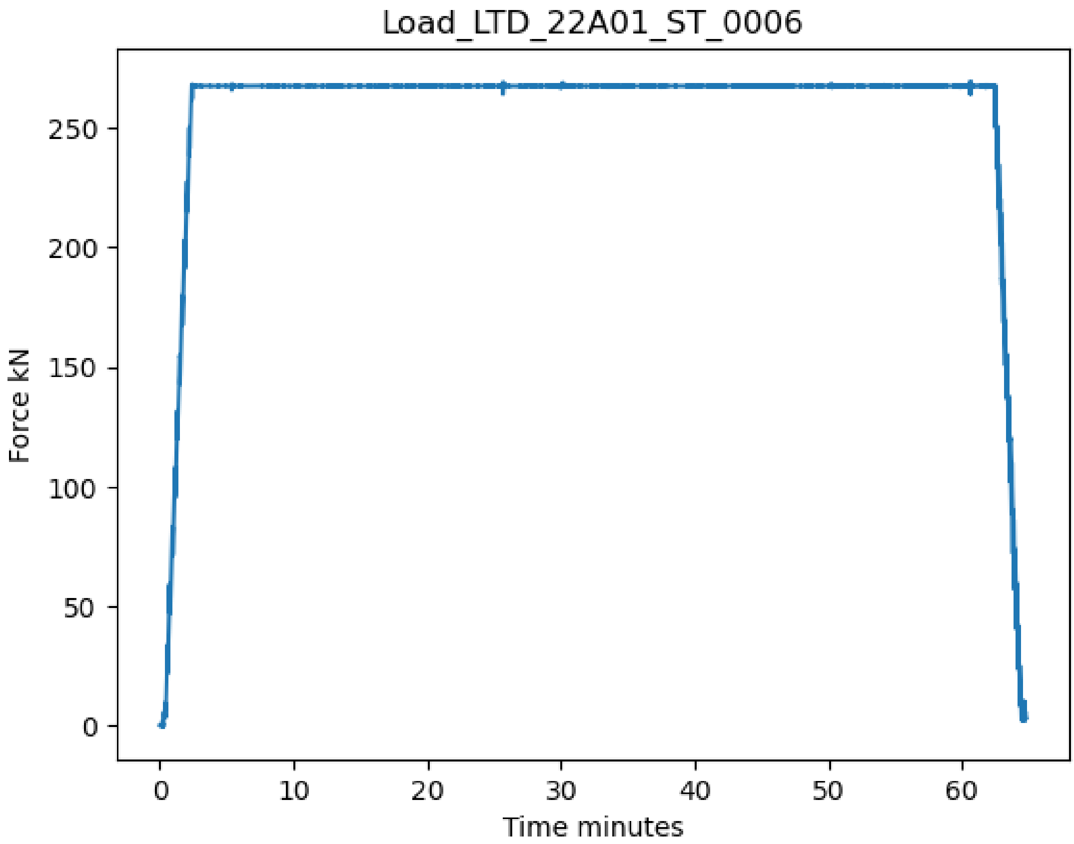
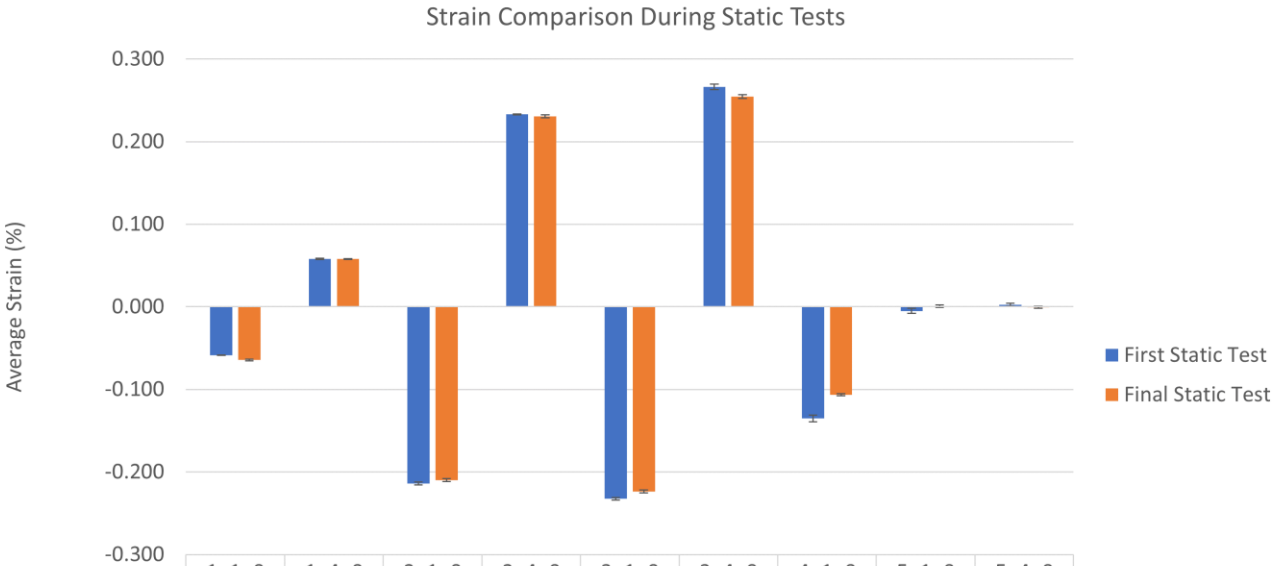


Figure 6 - Static test load profile



	1_1_0	1_4_0	2_1_0	2_4_0	3_1_0	3_4_0	4_1_0	5_1_0	5_4_0
First Static Test	-0.059	0.058	-0.214	0.233	-0.232	0.266	-0.135	-0.005	0.003
Final Static Test	-0.064	0.058	-0.210	0.231	-0.223	0.255	-0.106	0.001	-0.001

Strain Gauge Location Code

Figure 7 - Strain on top and bottom surfaces along blade length

The strain results from the static testing on the blade both before and after the fatigue testing are shown in Figure 7. In general, the strain has dropped at all measurement locations on the final static test. This indicates that it is unlikely any significant damage has been done to the blade as a result of the testing. Also, that the alterations to the test procedure as a result of changing the loading saddle (full description in attached report) have influenced the measured strain on the blade. As no other reason for a reduction in measured strain for the same applied load seemed plausible.

7.2.3 Fatigue Testing

Throughout the fatigue test 31,775 cycles were completed. This is equivalent approximately 21.7 years of tidal cycles. The load cycles were applied sinusoidal at a frequency of 1Hz

The target load was 183.7 kN with an R ratio of 0.1. giving a target load delta of 165.34. Throughout the fatigue testing the delta load achieved was 155.46 kN with a resulting R ratio of 0.14. This deviation from the target was a result of the tuning of the FastBlade test system which is being commissioned as part of this test. The large spikes in delta load seen in Figure 8 are a side effect of the test starting and stopping during the tuning process

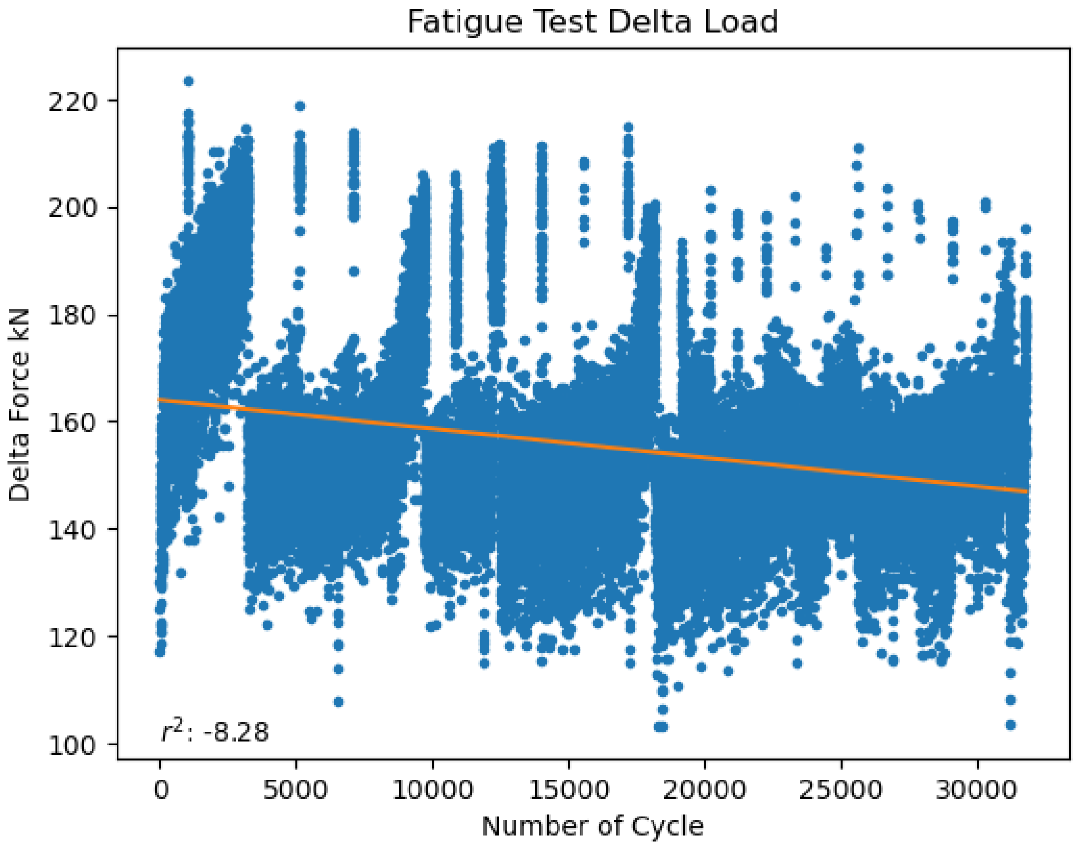


Figure 8 - Force delta during fatigue testing

The results shown in Figure 9 indicate that a very slight reduction in stiffness may have occurred during the fatigue testing of the blade. However, the variations caused by the tuning variations of the control system throughout the testing make it difficult to draw accurate conclusions as the indicated change is subtle.

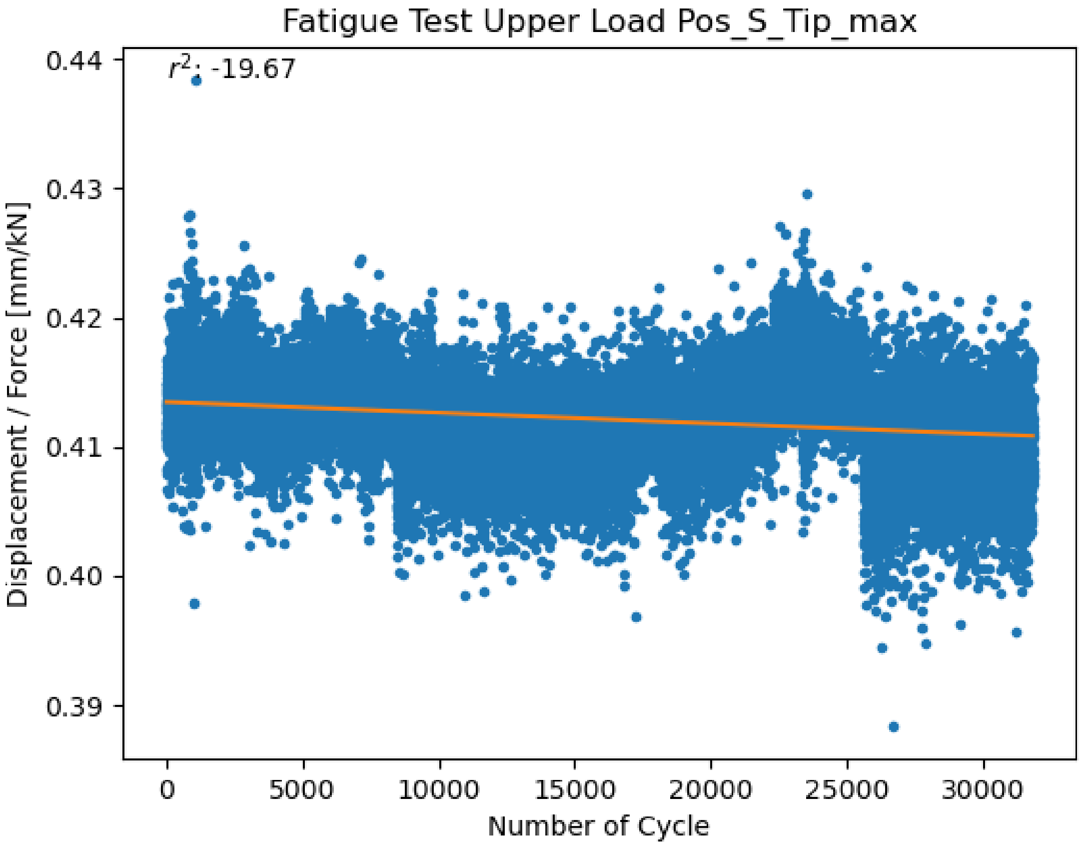


Figure 9 - Spring stiffness of blade vs fatigue cycles

7.2.4 Natural Frequency testing

The natural frequency of the blade was measured at various points throughout the testing. A reduction in the natural frequency would indicate a decrease in stiffness of the blade as a result of damage. Figure 10 shows the change in natural frequency measured when the blade was first mounted along with subsequent testing stages. It can be seen that the frequency has dropped from 18.03 Hz to 17.93 Hz. These changes were very repeatable with low standard deviations between the test repeats. This indicates that it is likely the stiffness of the blade has reduced as a result of the testing carried out.

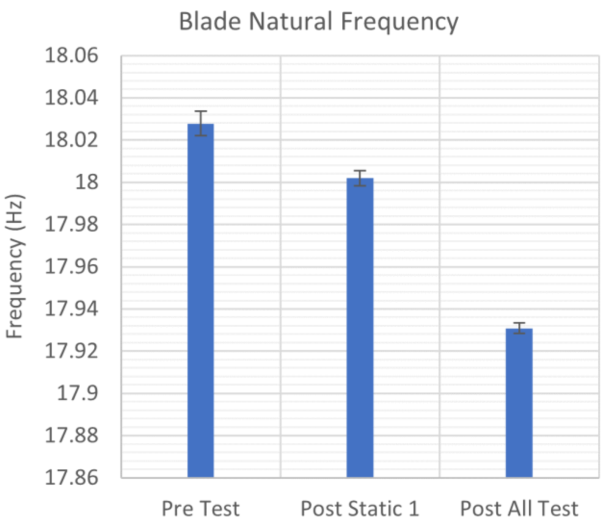


Figure 10 - Blade natural frequency results

7.2.5 Conclusions

- The blade survived the worst-case static load criteria as defined by the blade developer.

- The blade withstood 20 years (equivalent) of accelerated fatigue loading, without catastrophic failure.

- The natural frequency decreased during the testing, from 18.03 Hz to 17.93 Hz. It is likely that this is a result of minor damage to areas of the blade, but the change may be influenced by other factors such as root connection bolt tension variations.

- As the blade met the requirements set out in the load conditions from the blade developer, it appears that the time the blade spent deployed in the ocean, has not negatively affected its ability to withstand an additional 20 years of loading.

- No specific failures were observed throughout all testing. No audible sounds of failure were detected, and no sudden changes in position or load, indicating a fracture were detected. The DIC system did not detect any areas of exceptionally raised strain. The highest strain measured with strain gauges was 0.266 % on the bottom surface of the blade, near the loading saddle.

- Multiple improvements to the testing procedure have been identified during this test including control strategies, load introduction, instrumentation layout, instrument calibration, and test design.
- To detect a catastrophic failure, the blade would have to be pushed significantly beyond the extreme loading cases designed for by the developer or modelled by Oxford University. This falls outside the scope of this project