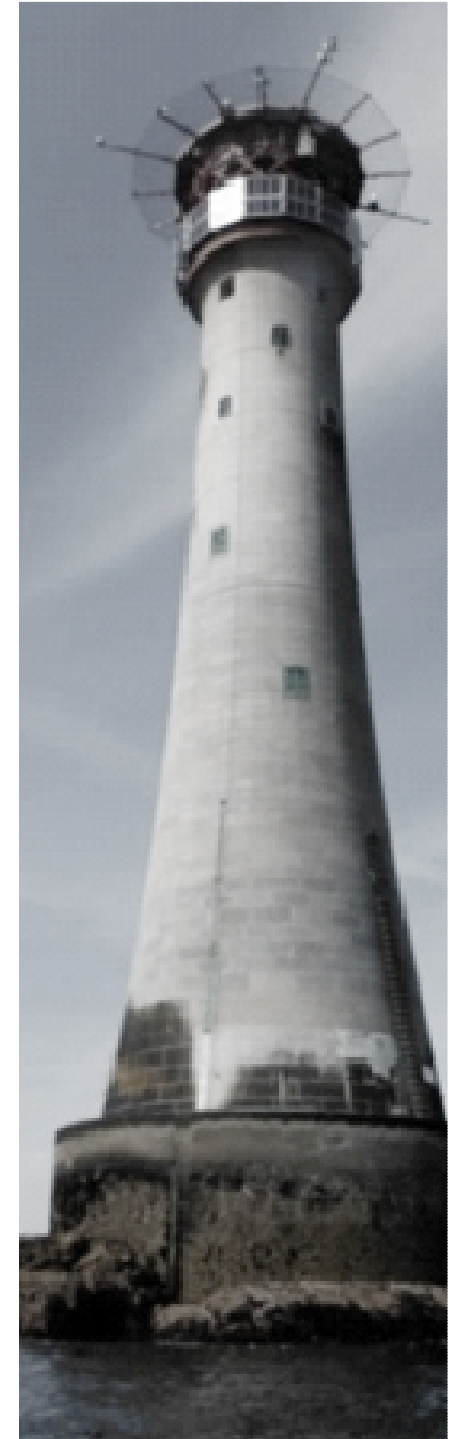


**RESEARCH  
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# Monitoring and modelling of rock lighthouses

Alison Raby



# Anecdotal Observations

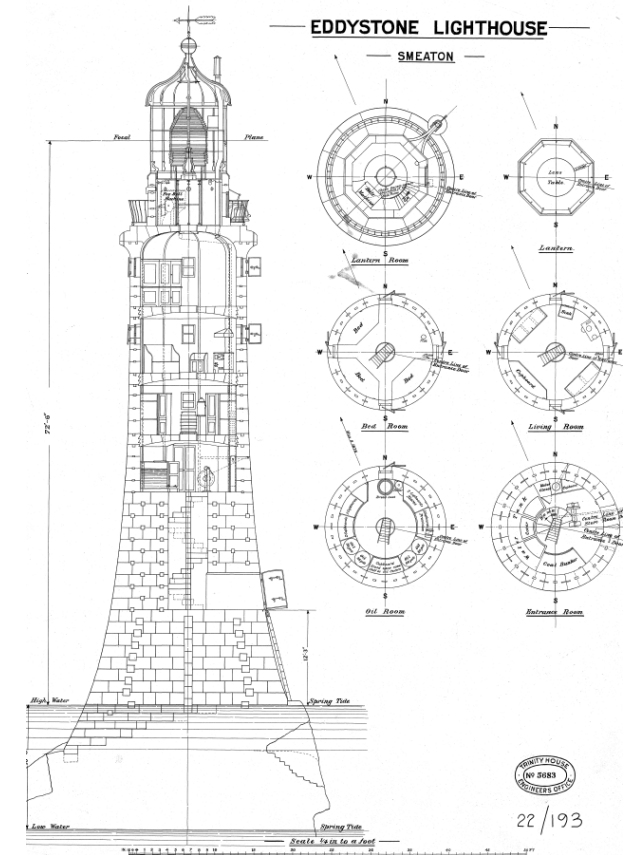
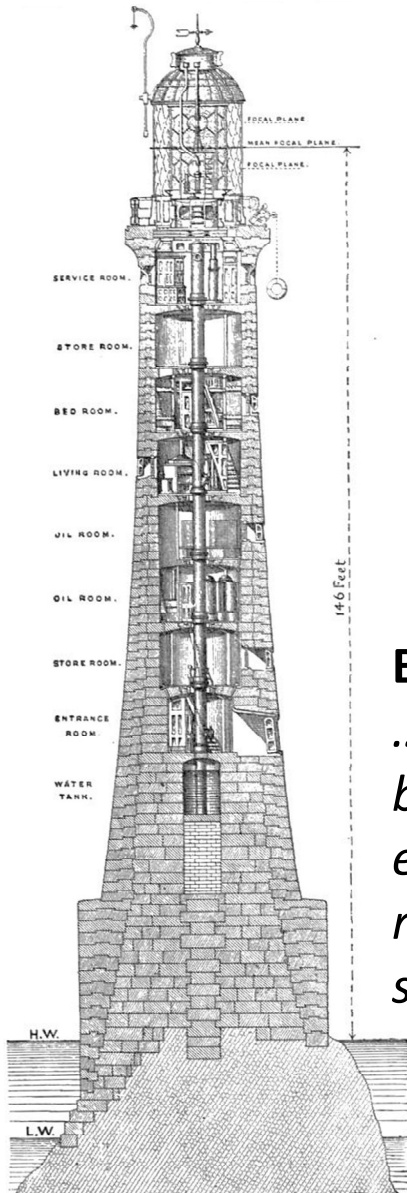
**Eddystone Lighthouse** Principal keeper's log:

- particularly violent storm caused *"considerable motion of the cylinder glasses fixed in the lamps"* ...
- tower appeared to *"jump as if resting on an elastic body"*.

**1800s**

**Bishop Rock Lighthouse** report:

*...awoken by severe wave impact accompanied by a loud booming noise ...oscillation of tower similar to minor earthquake ...accompanying groaning noise with a rattling ...chinking of glasses in cupboards ...when seated, motion felt like gentle rocking.*

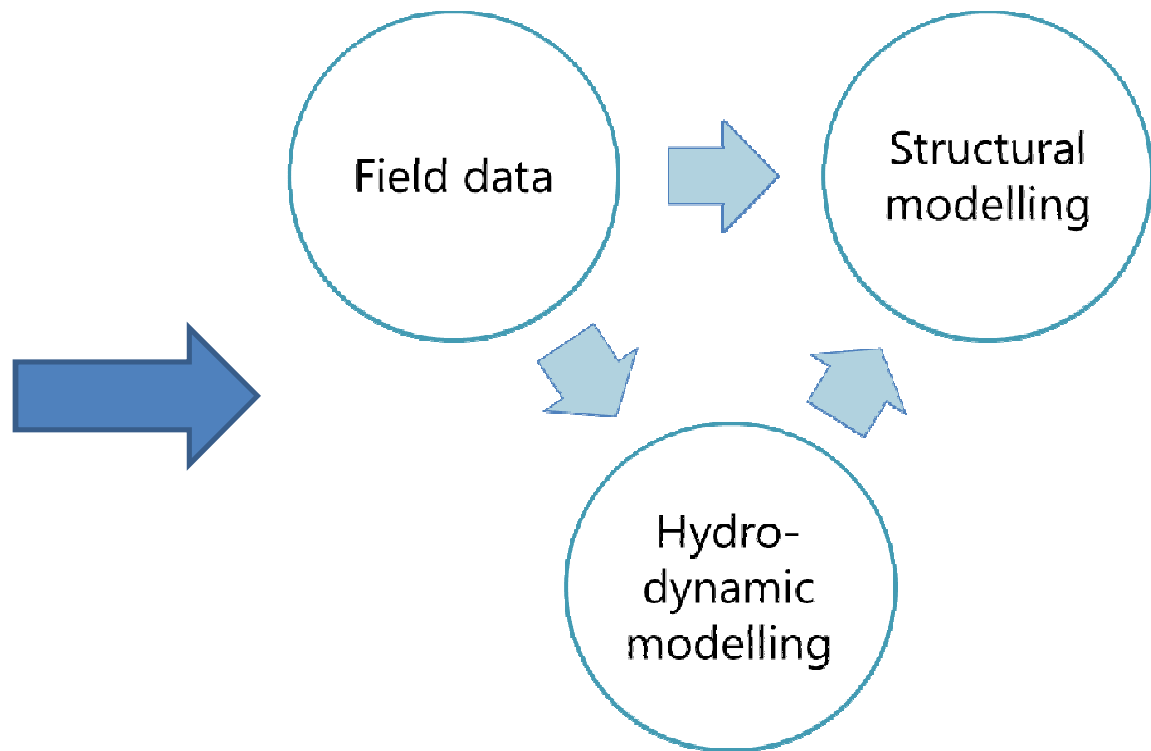


**5th February 2014**

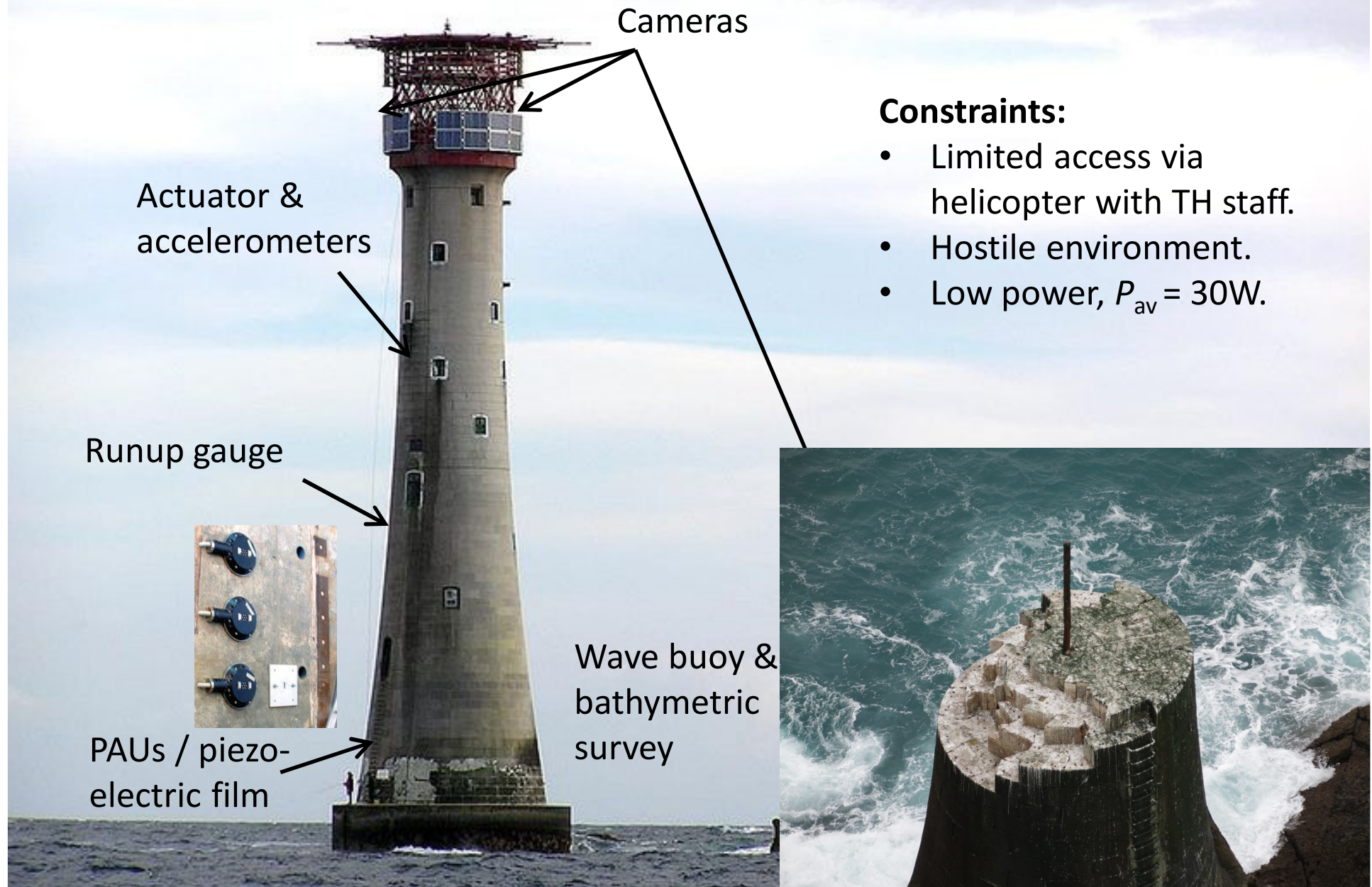
# Research questions

- What is the nature of the applied wave load?
- How do rock lighthouses respond to the load?
- How can an isolated lighthouse be instrumented to measure structural response?
- Will rock lighthouses continue to be operationally safe?

**Pilot study on  
Eddystone lighthouse  
(UK GLAs and  
Plymouth University)**

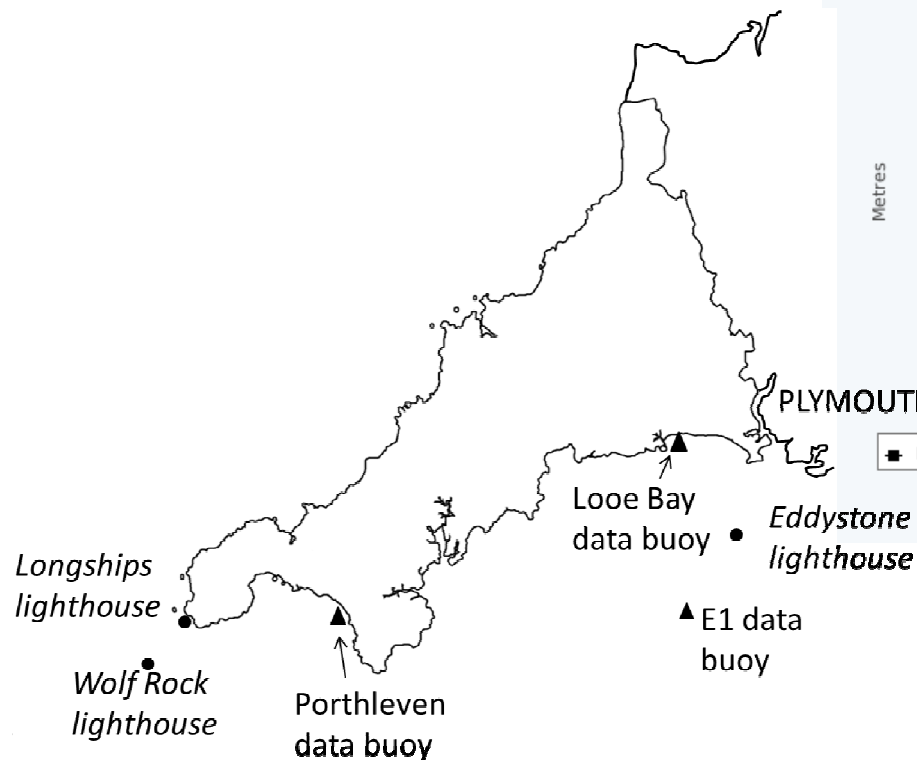
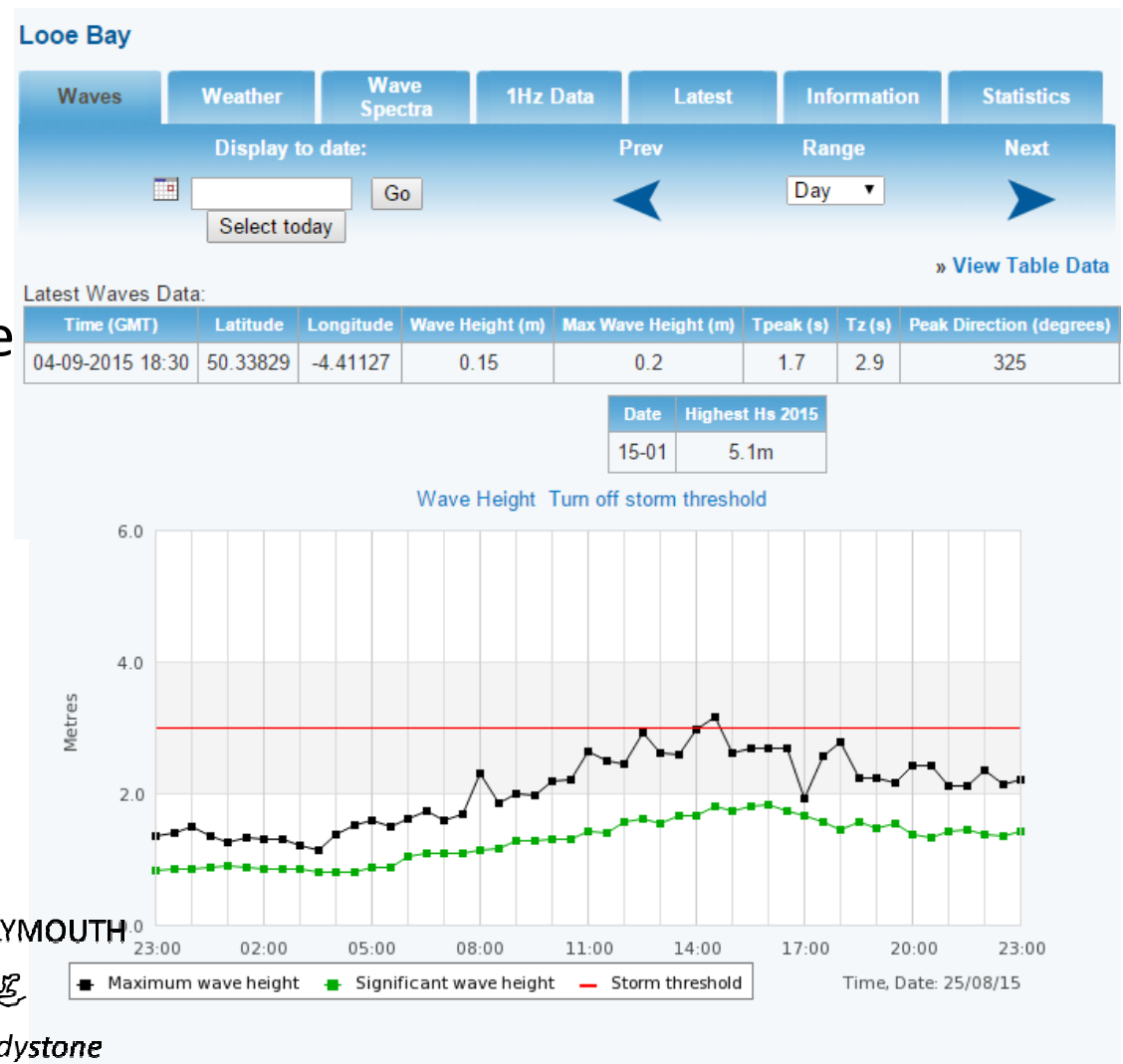


# Ideal Eddystone tower instrumentation



# Pragmatic approach to instrumentation

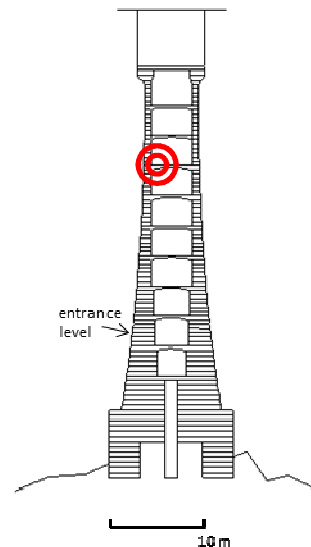
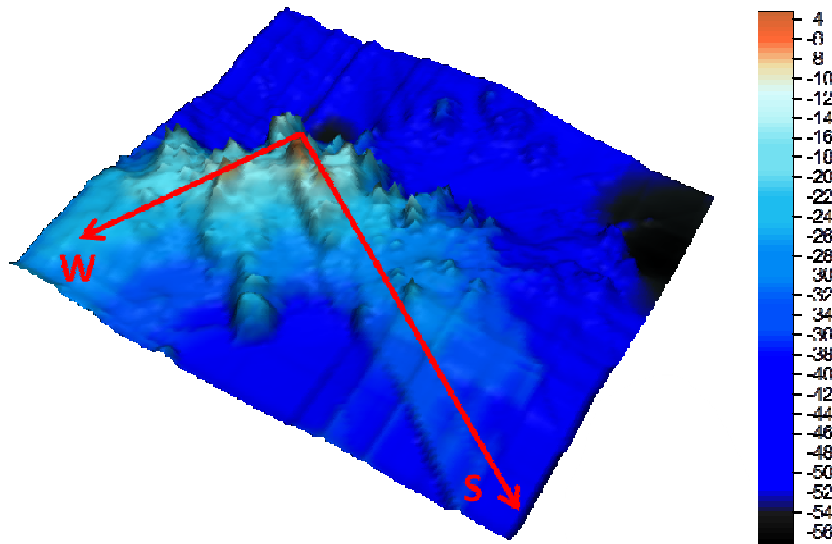
## 1. Wave buoy data: Channel Coastal Observatory and Met Office





# Pragmatic approach to instrumentation

## 2. Bathymetric survey: Wave transformation.



## 3. Geophones:

- GSM Mobile phone network
- 3 x axis velocity time histories.
- Displacement from Integration & PCA.



# Pragmatic approach to instrumentation

## 4. Cameras

- 4 bullet cameras.
- 1fps -> 5fps.
- Remote control via wireless link to ensure  $P < 30W$ .









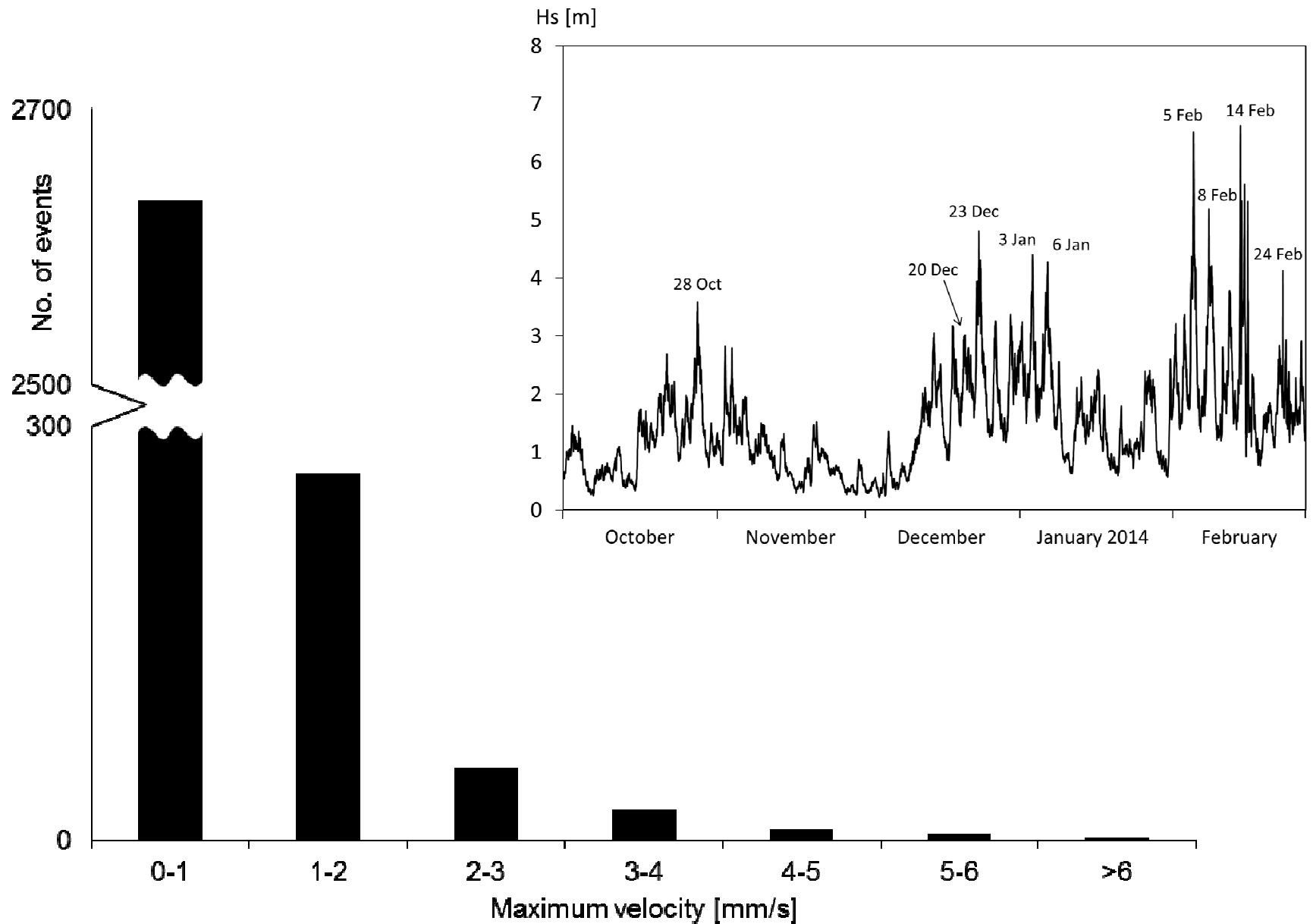
Camera 4

2014/01/06 12:12:09

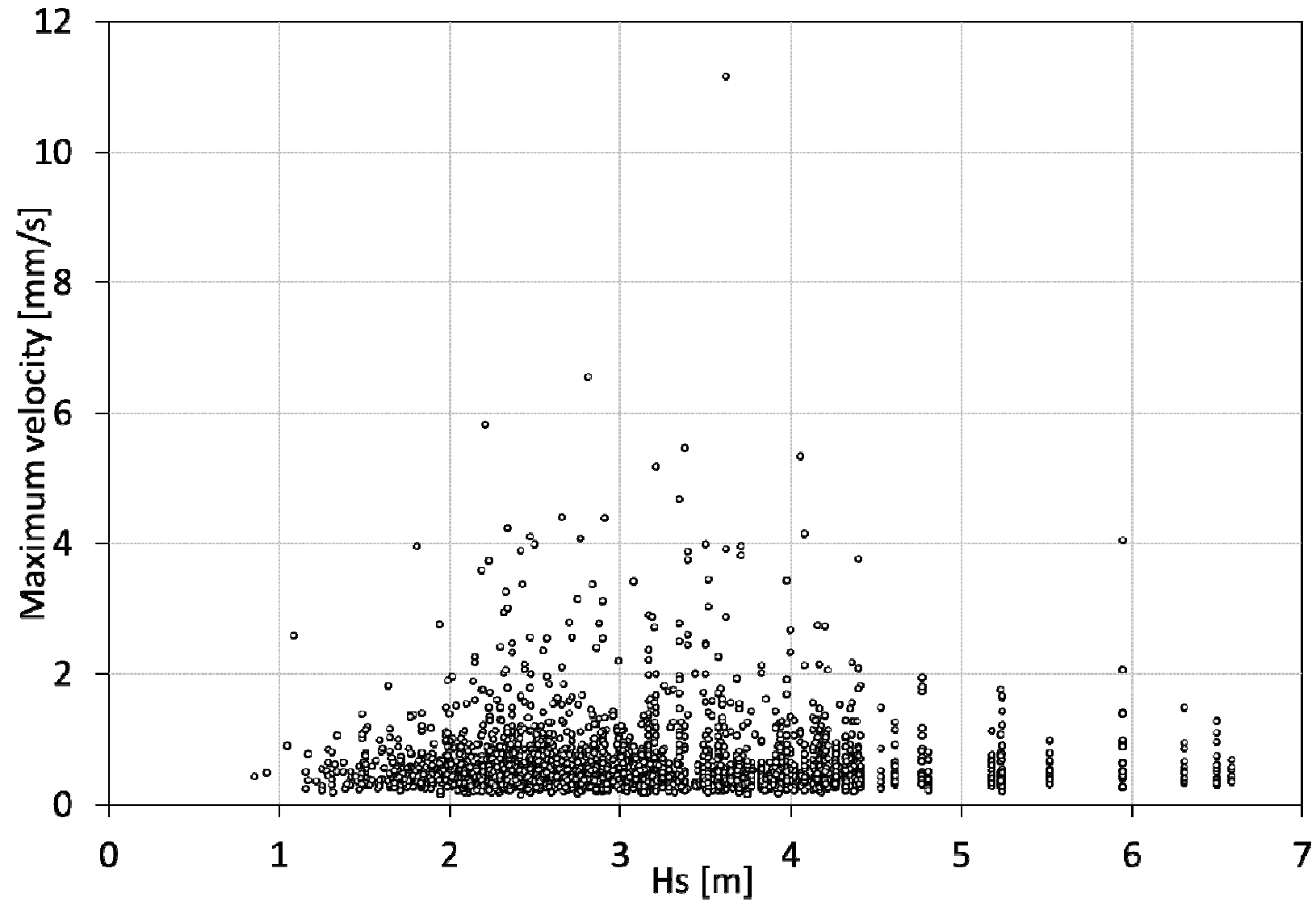
06/01/2014  
12:12:08



# Winter storms of 2013/14

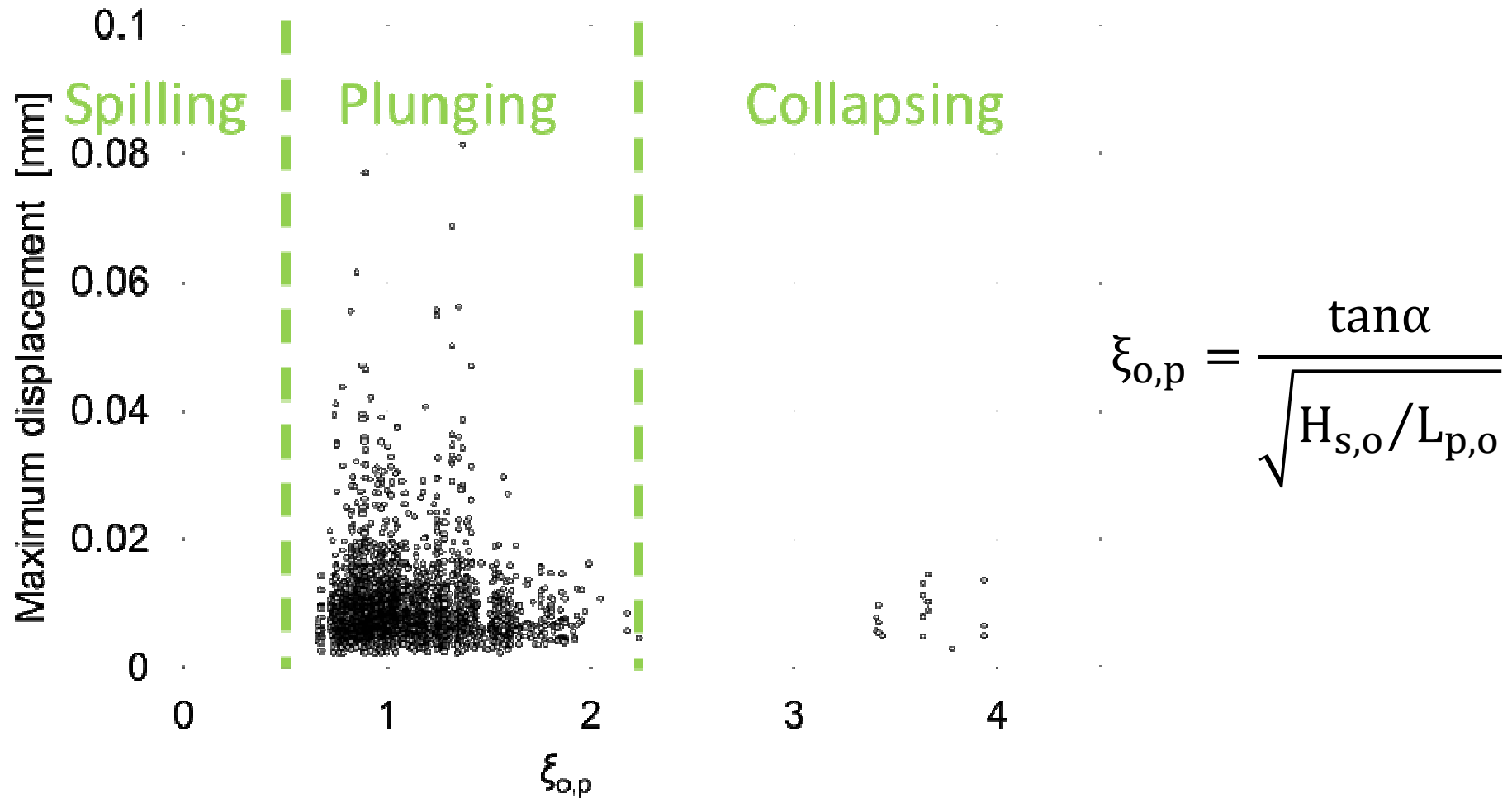


# Influence of wave parameters



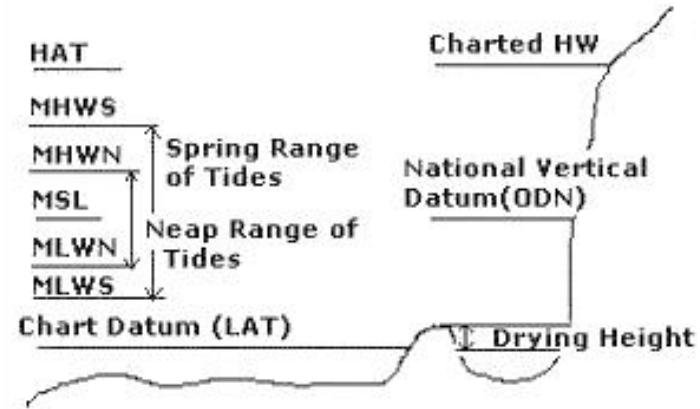


# Influence of wave parameters

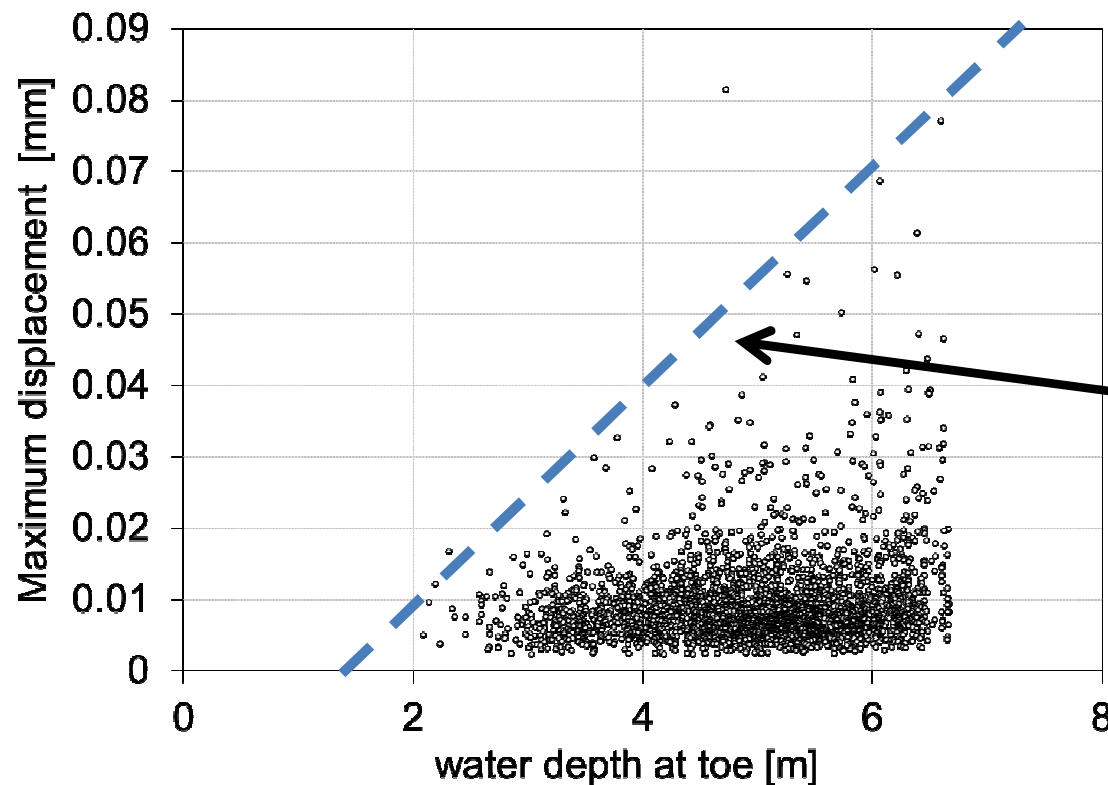


Dependence on Iribarren number needs videos to explain data in 'Collapsing' region.

# Influence of water depth



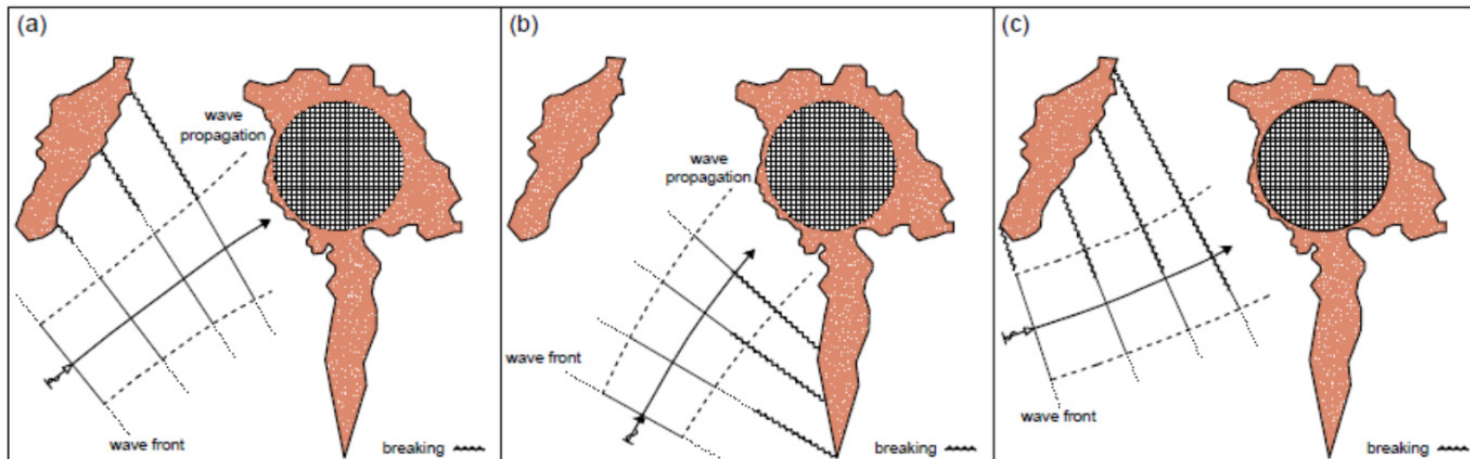
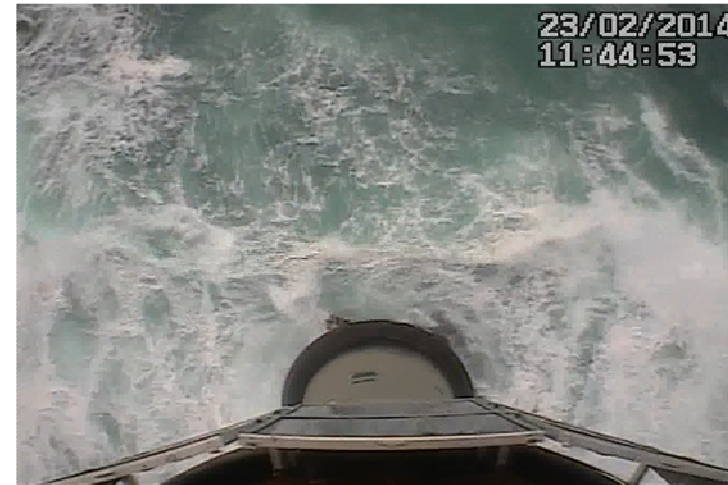
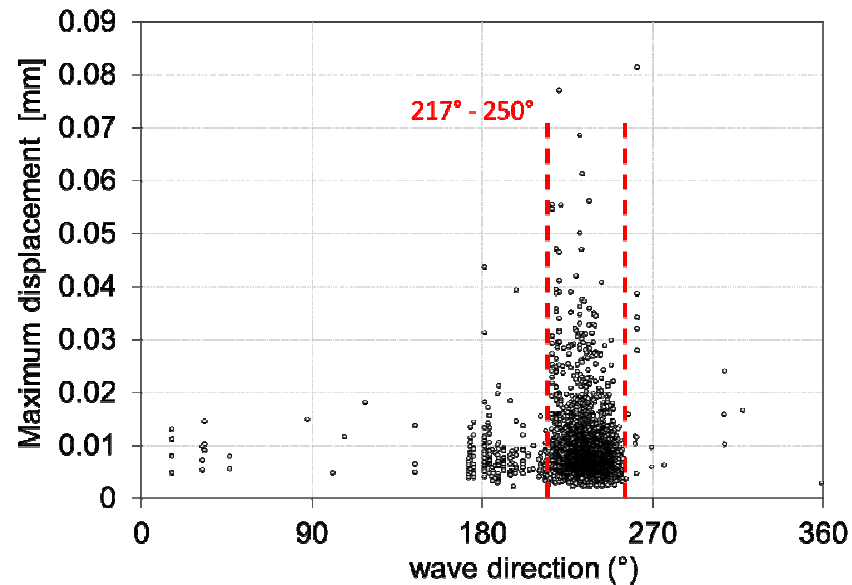
Port of London  
Authority



- “Port tide level” converted to Eddystone water depth from time-stamped photographs.

*N.B.* Linear upper envelope to max displacement

# Influence of wave direction



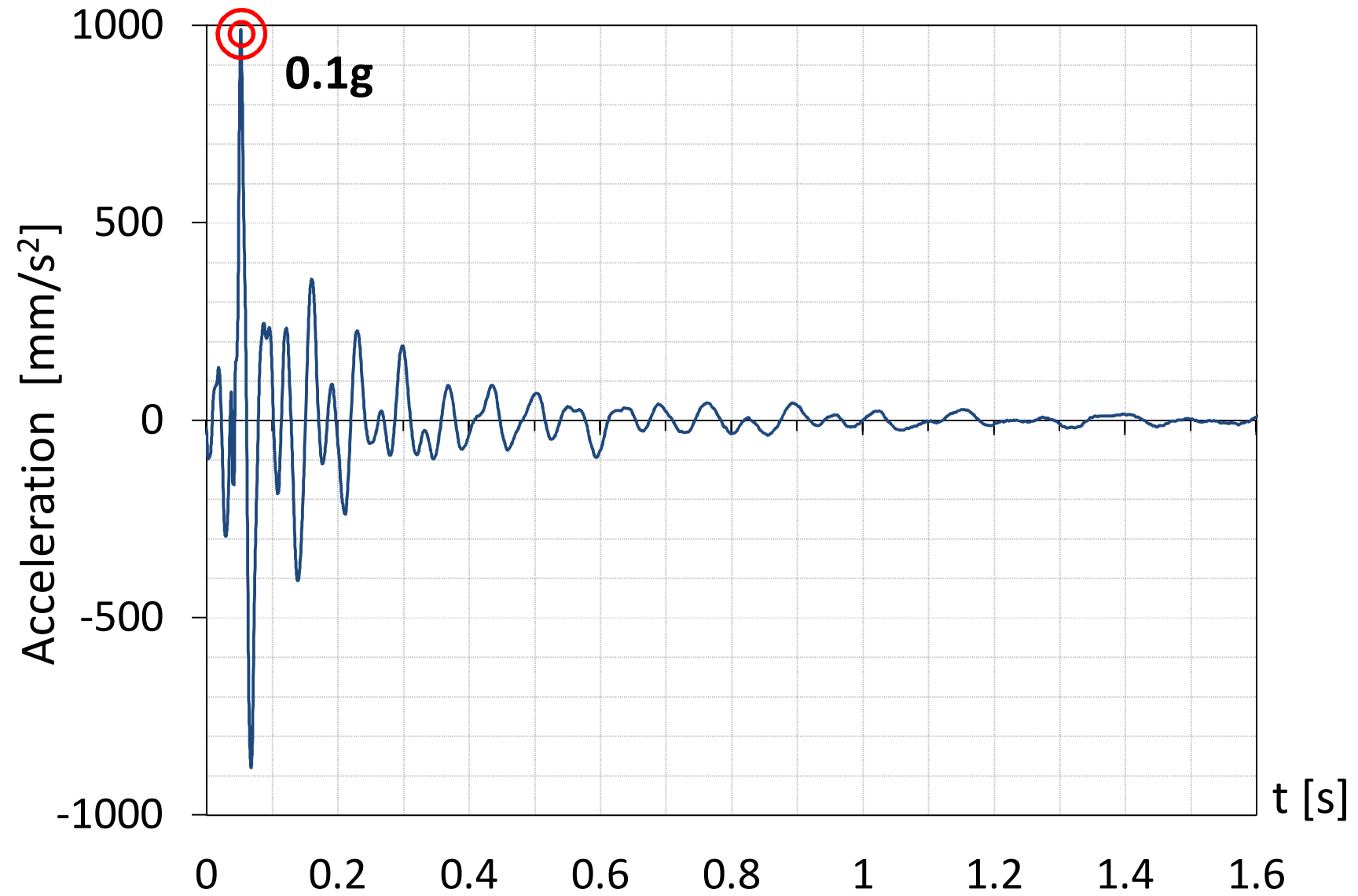
Middle of the free  
sector so full impact  
of waves

Waves break on reef  
south of tower

Protection from reef on  
which Smeaton's stump  
stands



# Geophone accelerations





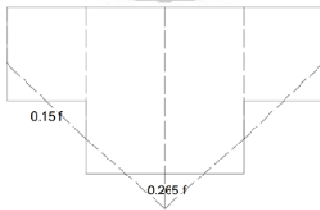
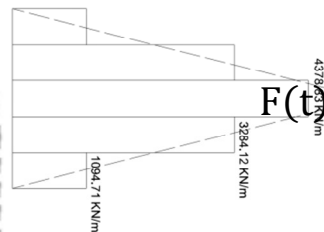
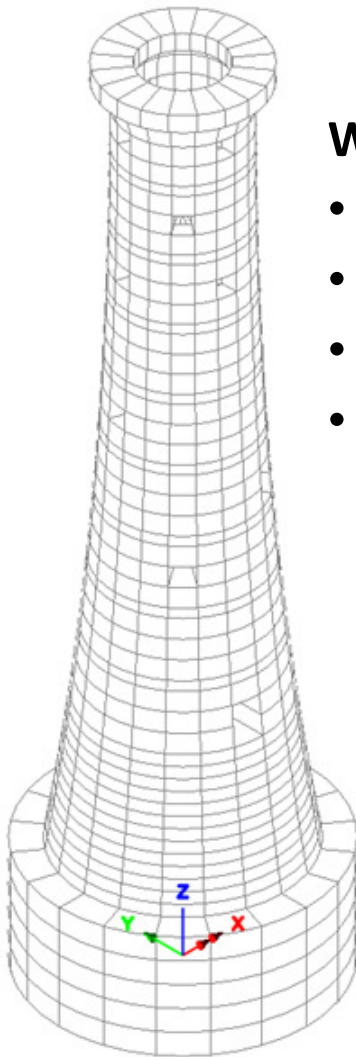
# Finite Element Modelling

## Wave loading:

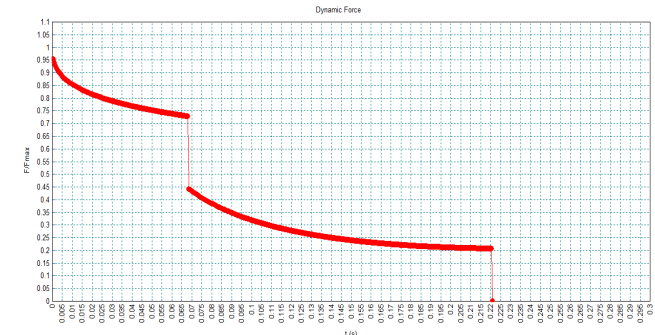
- Based on largest measured response.
- Dynamic load component: Wienke & Oumeraci (2005).
- Azimuthal horizontal distribution: Wienke & Oumeraci (2005).
- Vertical distribution: Tanimoto et al. (1986).

$$F(t) = \lambda \eta_b \cdot \rho \cdot R \cdot V^2 \left( 2\pi - 2 \sqrt{\frac{V}{R}} t \cdot \operatorname{atanh} \sqrt{1 - \frac{1}{4} \frac{V}{R}} t \right) \quad 0 \leq t \leq \frac{1}{8} \frac{R}{V}$$

$$F(t) = \lambda \eta_b \cdot \rho \cdot R \cdot V^2 \left( \pi \sqrt{\frac{1}{6} \frac{R}{V} t'} - \sqrt[4]{\frac{8}{3} \frac{V}{R} t'} \cdot \operatorname{atanh} \sqrt{1 - \frac{V}{R} t'} \sqrt{\frac{V}{R} t'} \right) \quad \frac{3}{32} \frac{R}{V} \leq t' \leq \frac{12}{32} \frac{R}{V} \quad t' = t - \frac{1}{32} \frac{R}{V}$$



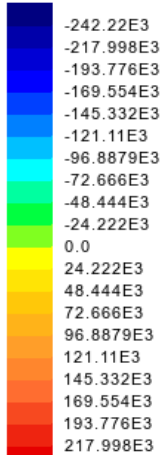
Curling factor	$\lambda$	0.46
Crest elevation	$\eta_b = 0.78 H_{\max, b}$	6.24 m
Water density	$\rho$	1025 kg/m <sup>3</sup>
Average radius	$R$	4.83 m
Water velocity	$V$	8.86 m/s



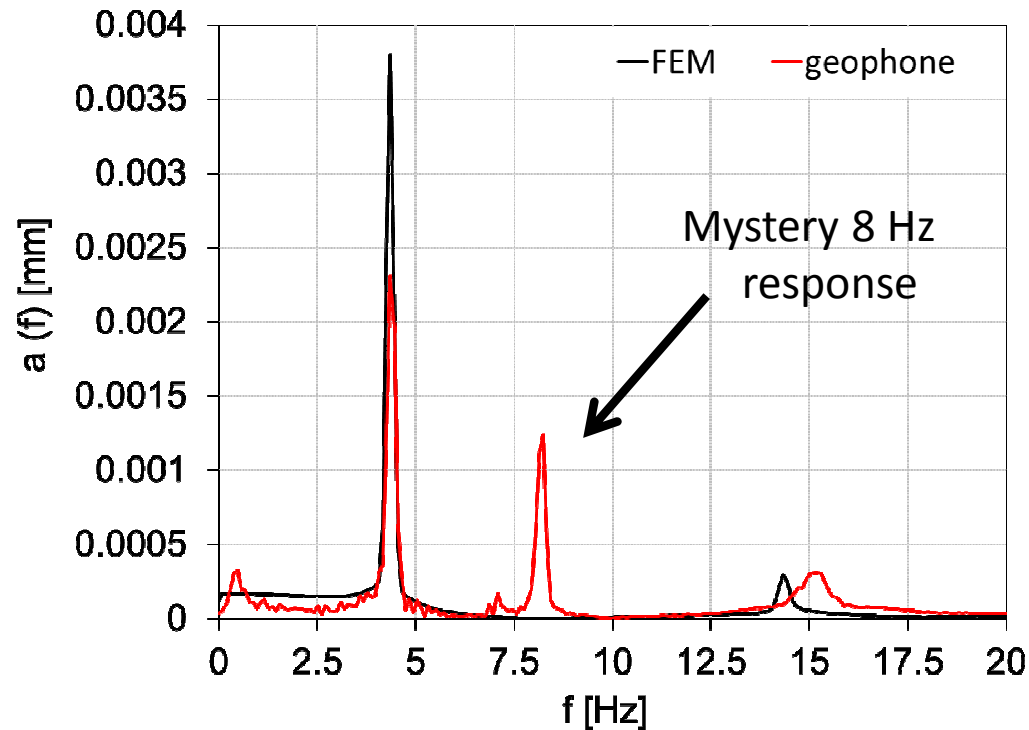
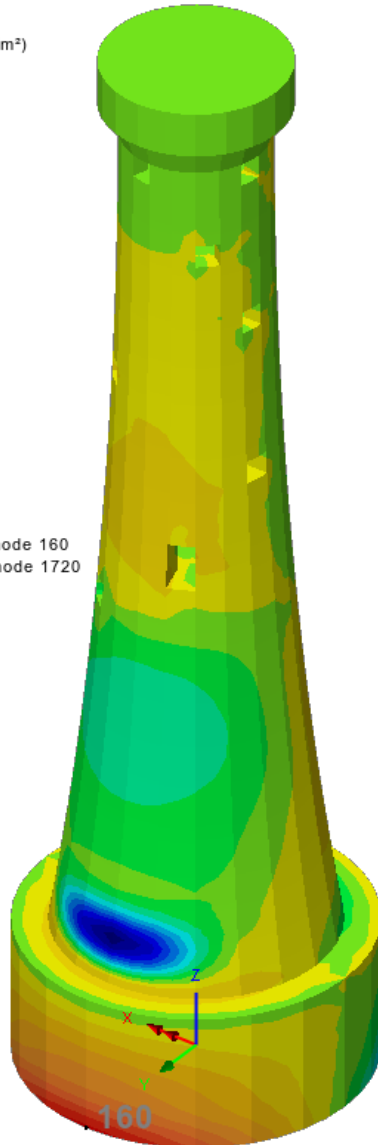


# FEM dynamic loading results

Response time: 0.012  
Entity: Stress - Solids  
Component: SZ (Units: N/m<sup>2</sup>)



Maximum 226.418E3 at node 160  
Minimum -258.021E3 at node 1720



- Modal response frequencies.
- Model provides stresses and displacements.
- Stable under:
  - Material failure, inside Mohr diagram envelope.
  - Overturning  $M_{destab.} < M_{stab}$ , FOS  $\sim 8$ .
  - Sliding  $R_{wave} < R_{friction}$ , FOS  $\sim 6$ .
- For failure (sliding),  $H_{max,critical} \approx 14$  m.

## **Pilot study conclusions**

- Battery/remote-controlled equipment : limited but useful information but issues with flying Lithium batteries
- 3D complex bathymetry complicates impact process
- Modelling masonry structure as monolith: reasonable comparisons with measurements (mystery 8Hz: foundation, reef, helideck, air coupling?)
- Extension of camera work – photogrammetry
- COAST lab PhD experiments
- Eddystone is stable in current condition!

# STORMLAMP

*(STructural behaviour Of Rock Mounted Lighthouses At the Mercy of imPulsive waves)*

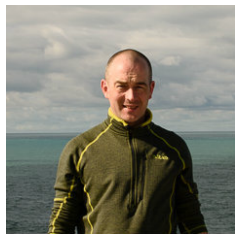
## Objectives:

1. Identify mode frequencies and shapes of 6 vulnerable rock lighthouses.
2. Monitor response of one rock lighthouse over 3 years.
3. Develop more comprehensive structural numerical models.
4. Physical and CFD modelling of wave interactions to investigate worst-case hydrodynamic loading.
5. Formulate guidance on the technologies and procedures for structural condition assessment and management of rock lighthouses for the UK GLAs.

Ultimately will provide the ability to **identify structural distress and reduce risk of failure** through preventative measures.



# STORMLAMP



## Field campaign

- Low-power monitoring and modal testing.
- Extreme value statistics.
- Anecdotal records/perception linking to measurements.

## Structural modelling

- Mode/deflections in extreme loads
- Rigid body dynamic models.

- Response to extreme wave loading
- Decision support for at-risk structures.

## Hydrodynamic modelling

- Laboratory and numerical modelling:
- Kinematics, localised pressures and overall force.
- Worst-case bathymetries.



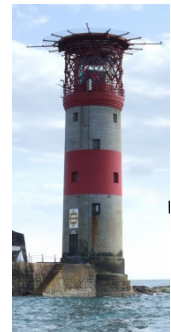
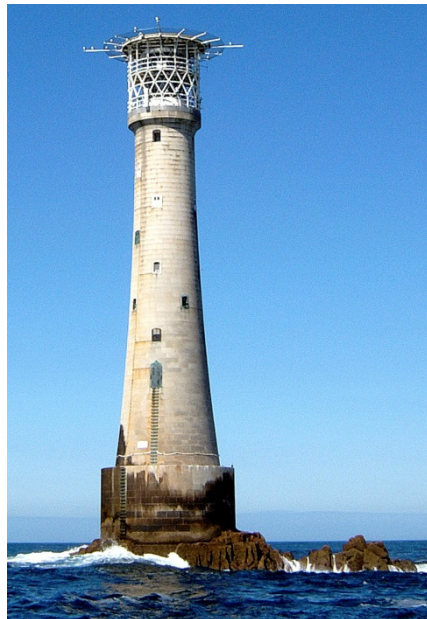
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# STORMLAMP

Fieldwork:

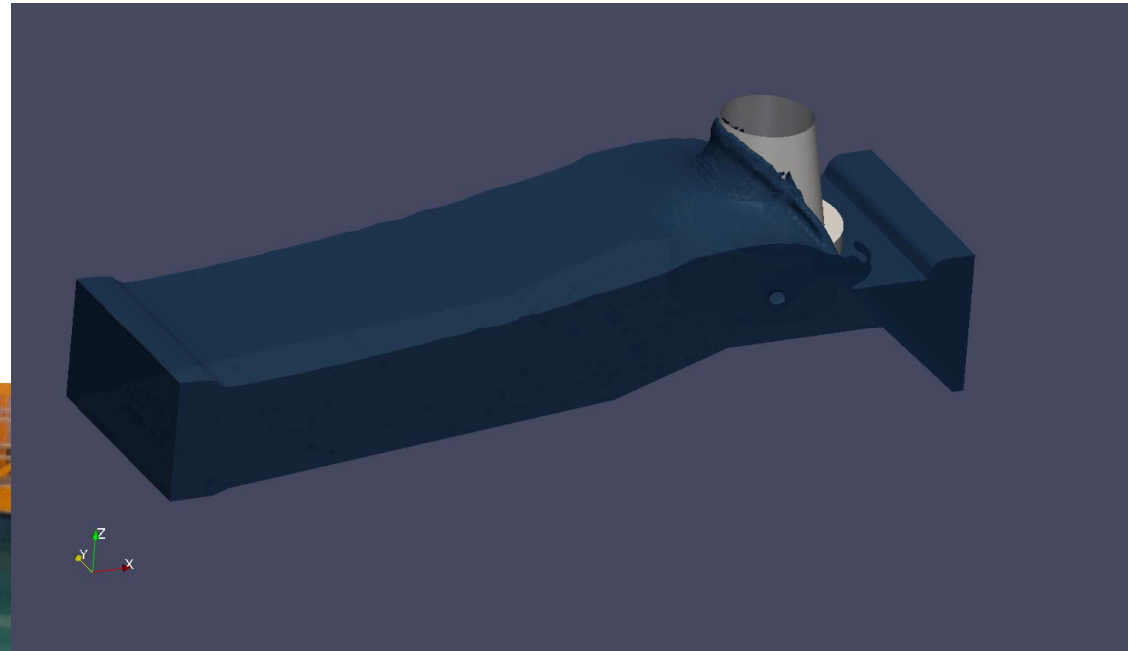
Modal testing of six  
at-risk lighthouses  
around British Isles to  
start in June 2016.





# STORMLAMP

Hydrodynamic Modelling



OpenFOAM  
Numerical  
Modelling

COAST  
Laboratory  
Physical  
Modelling



# Acknowledgements

- UK GLAs
- School of Marine Science and Engineering, Plymouth University PhD studentship



Thank you.  
Any questions?