

Structural condition assessment of rock lighthouses

Professor Alison Raby

IALA ENG Committee,
Monday 30 September 2019



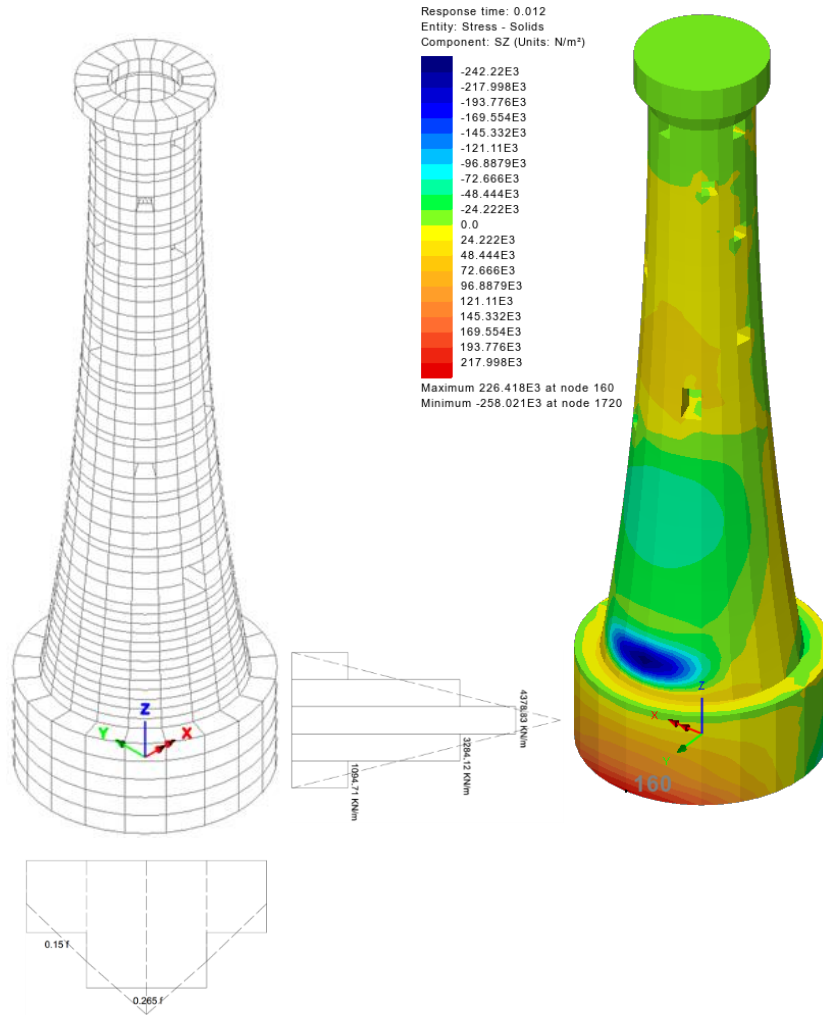
Presentation outline

- Motivation for the presentation
- Techniques used in the STORMLAMP investigations
- Major findings and implications for the lighthouse authorities

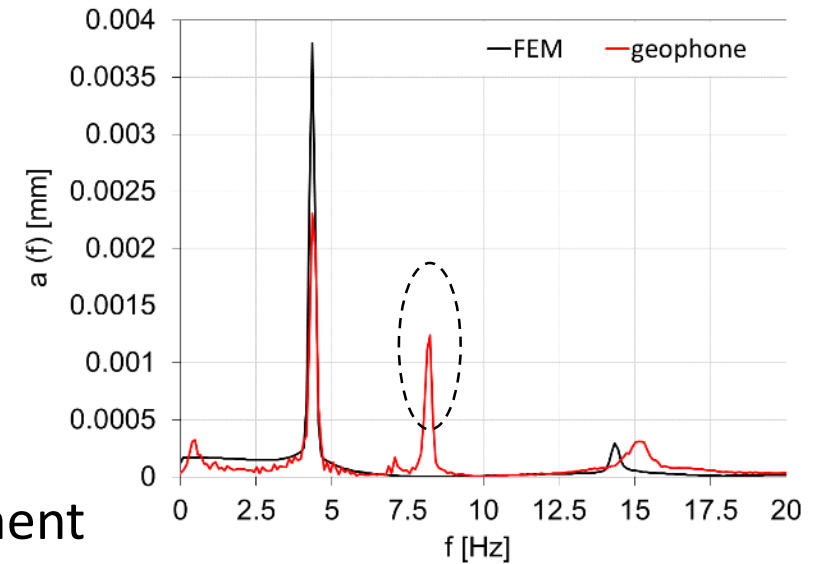
Motivation for presentation

- Appraise IALA ENG Committee of STORMLAMP project progress to date
- Discuss how these findings might be used by international lighthouse authorities

Eddystone pilot project



Max.
displacement
~0.1 mm



Stable under:

- Material failure, inside Mohr diag. envelope
- Overturning $M_{destab.} < M_{stab}$, FOS~6.3
- Sliding $R_{wave} < R_{friction}$, FOS~8

For failure (overturning), $H_{max,critical} \approx 17.5$ m

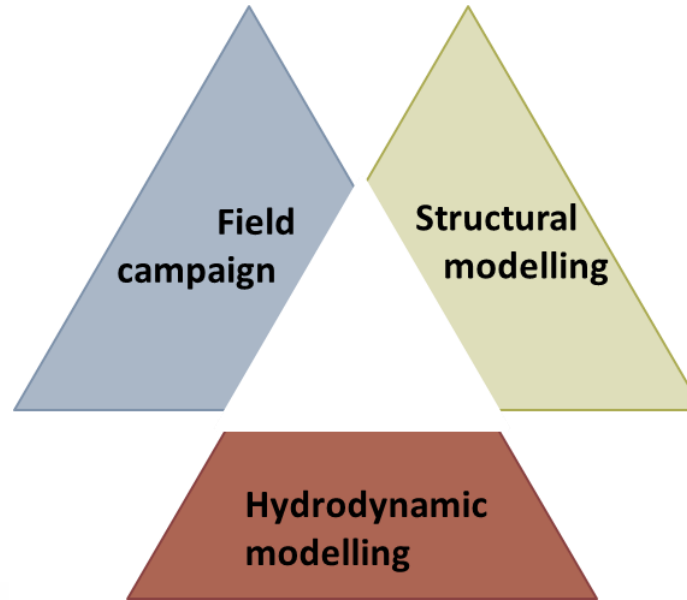
Raby *et al.* (2015) Wave loading on rock lighthouses, *ICE Maritime Engineering*

Trinh *et al.* (2016) Modelling the Eddystone Lighthouse response to wave loading, *Engineering Structures*

STORMLAMP project



Prof Brownjohn
Mr Bassitt
Expertise in field testing of structures



Prof D'Ayala
Dr Pappas
Expertise in FEM/DEM of masonry structures



Prof Raby Expertise in wave
Prof Greaves hydrodynamics (statistical,
Dr Ransley physical and numerical)
Dr Antonini
Dr Dassanayake

Industrial Partners:

Roland Pyzer, AECOM
Andrew Wareing, Atkins
Nick Ely, Environment Agency
William Allsop, HR Wallingford (rtd.)



STORMLAMP



Engineering and Physical Sciences
Research Council

STORMLAMP structural condition assessment investigations

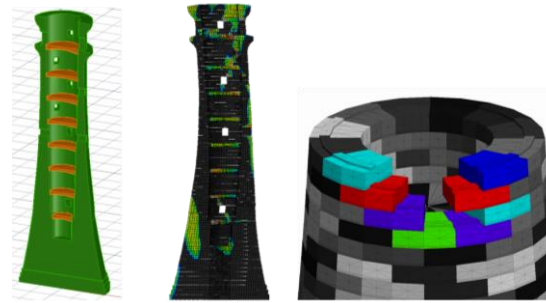
1. Field modal testing



2. Long-term monitoring



3. Structural analysis



4. Hydrodynamic modelling



Investigation 1 - Field modal testing

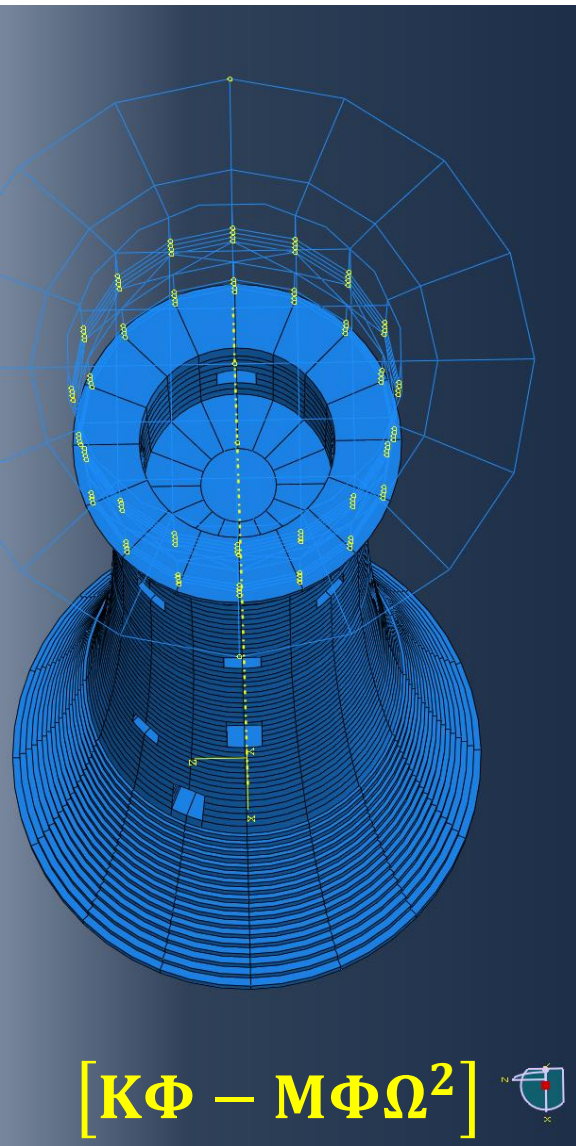


Field modal testing: overview (1/2)

- System identification of seven lighthouses, two without helidecks, 2016-2019.
- First tests were planned as single day exercise with severe time constraints but later tests involved overnight or (sometimes enforced) extended stays.
- Technology of forced vibration testing (FVT) and ambient vibration survey (AVS).
- FVT used electrodynamic shaker to generate frequency response functions and AVS used sophisticated 'operational modal analysis' - provided complementary information on



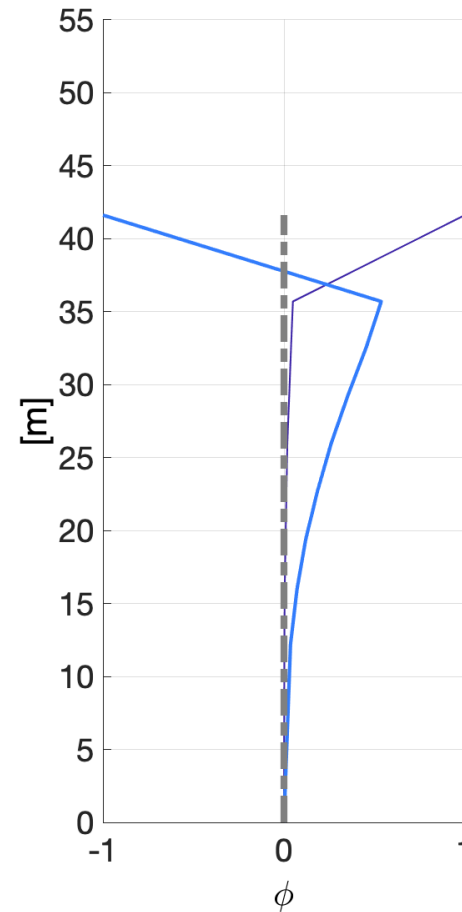
Field modal testing: overview (2/2)



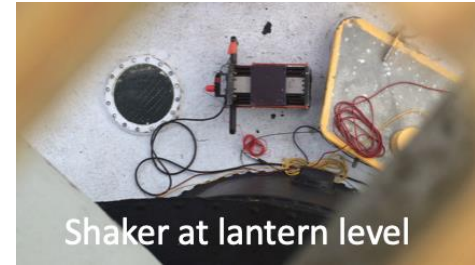
Analytical approach →



Analytical modes
 f_n, ϕ_n, m_n
Very educated guess,
 high resolution.
No damping ζ_n



Experimental modes
 $f_n, \zeta_n, \phi_n, m_n$
The truth,
poor resolution.



← Experimental approach



Field modal testing: key findings

- Modal properties can confirm masonry tower structural integrity, since measurements are consistent with modelling as monolithic structures.
- Helidecks modify the modal mass, and hence the response to impulsive breaking wave loads.
- Complexity of modal 'signature' suggests 20th century helideck structures require much greater attention than the masonry towers.
- Modal identification is extremely useful for inverse analysis of monitoring data, allowing estimation of wave loads.

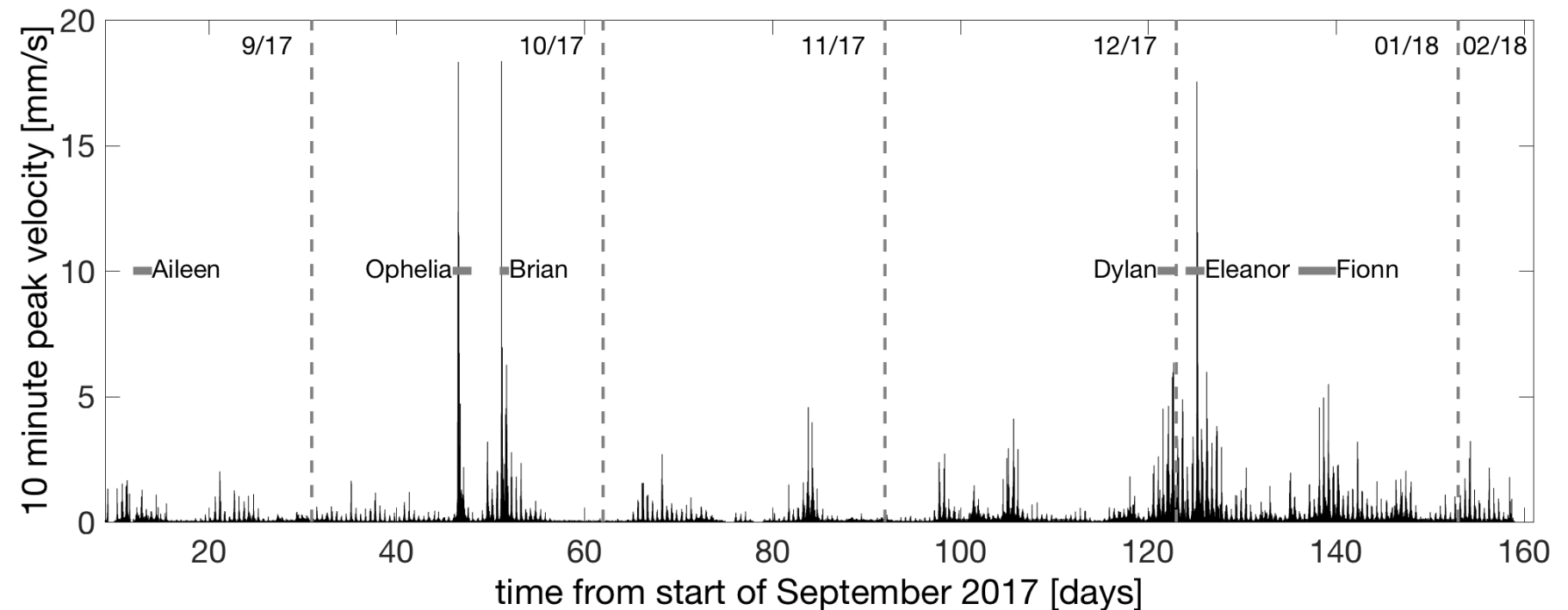
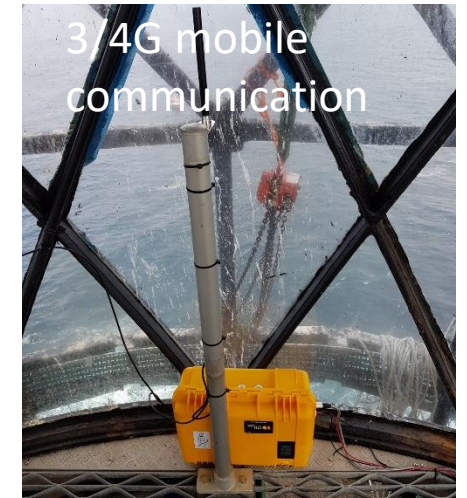
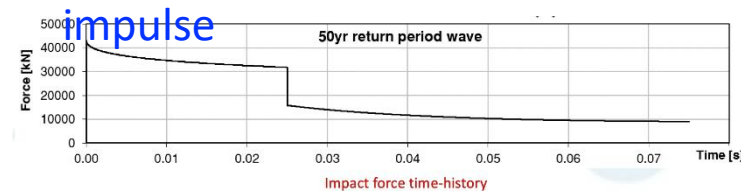
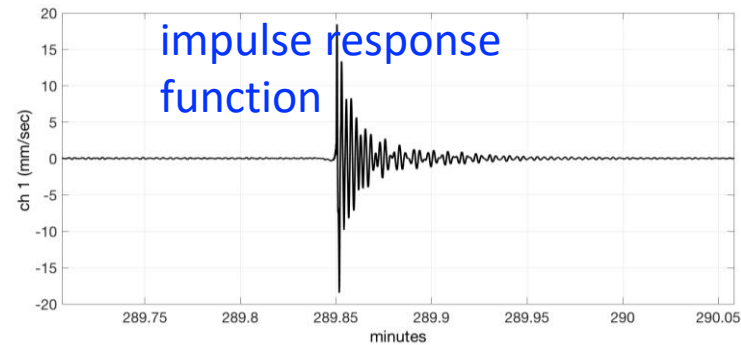
Implications

- Analytical studies and sample extra measurements suggest that targeted campaign on helidecks would be useful for supporting inspections.

Investigation 2: Long-term monitoring



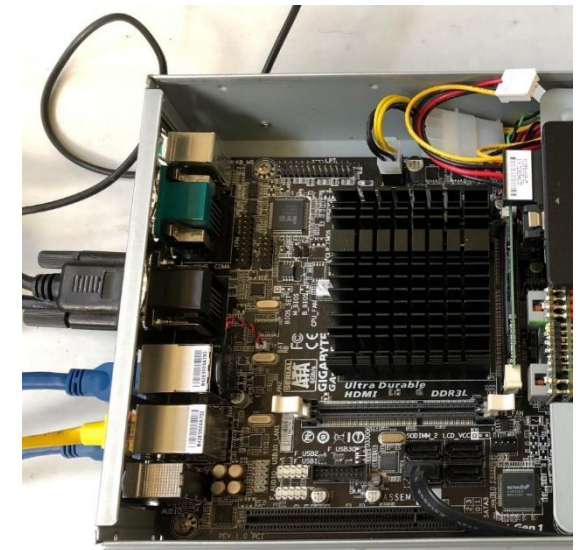
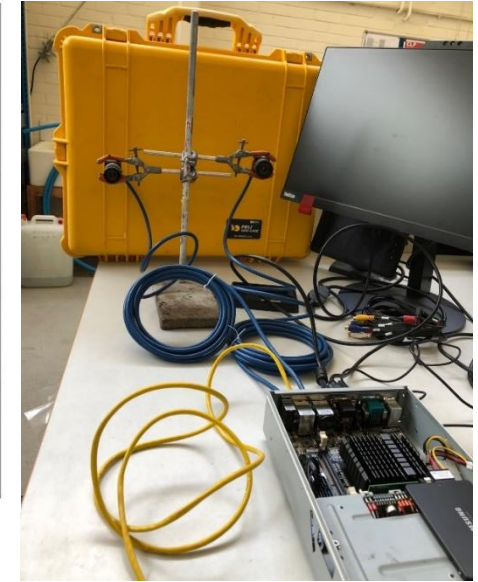
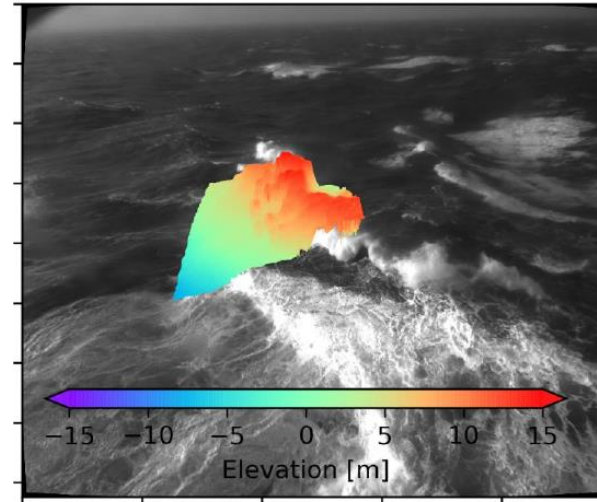
Long-term monitoring: overview



Long-term monitoring: camera system

- Guidance received from Dr Alvis Benetazzo from ISMAR – CNR, Venice who designed similar system for La Jument.
- 2 x 5MP synchronised cameras,
- microprocessor with GPS and GSM connection for control,
- linux computer for image acquisition and control
- final data storage to a network attached storage (NAS) drive.
- bespoke software designed so system 'sleeps' until woken for storm measurements.
- wiped and heated camera housings rated to IP66 and computing hardware housed in waterproof/crushproof (submersible!) case.
- System is controlled primarily via the GSM network that enables sampling to be initiated via a coded SMS message. Additional wireless bridge network connection links the Wolf Rock camera system to the Cape Cornwall Coastwatch station, and then to the University of Plymouth.

2018-01-03 09:42:07.999998



Cameras



Long-term monitoring : key findings

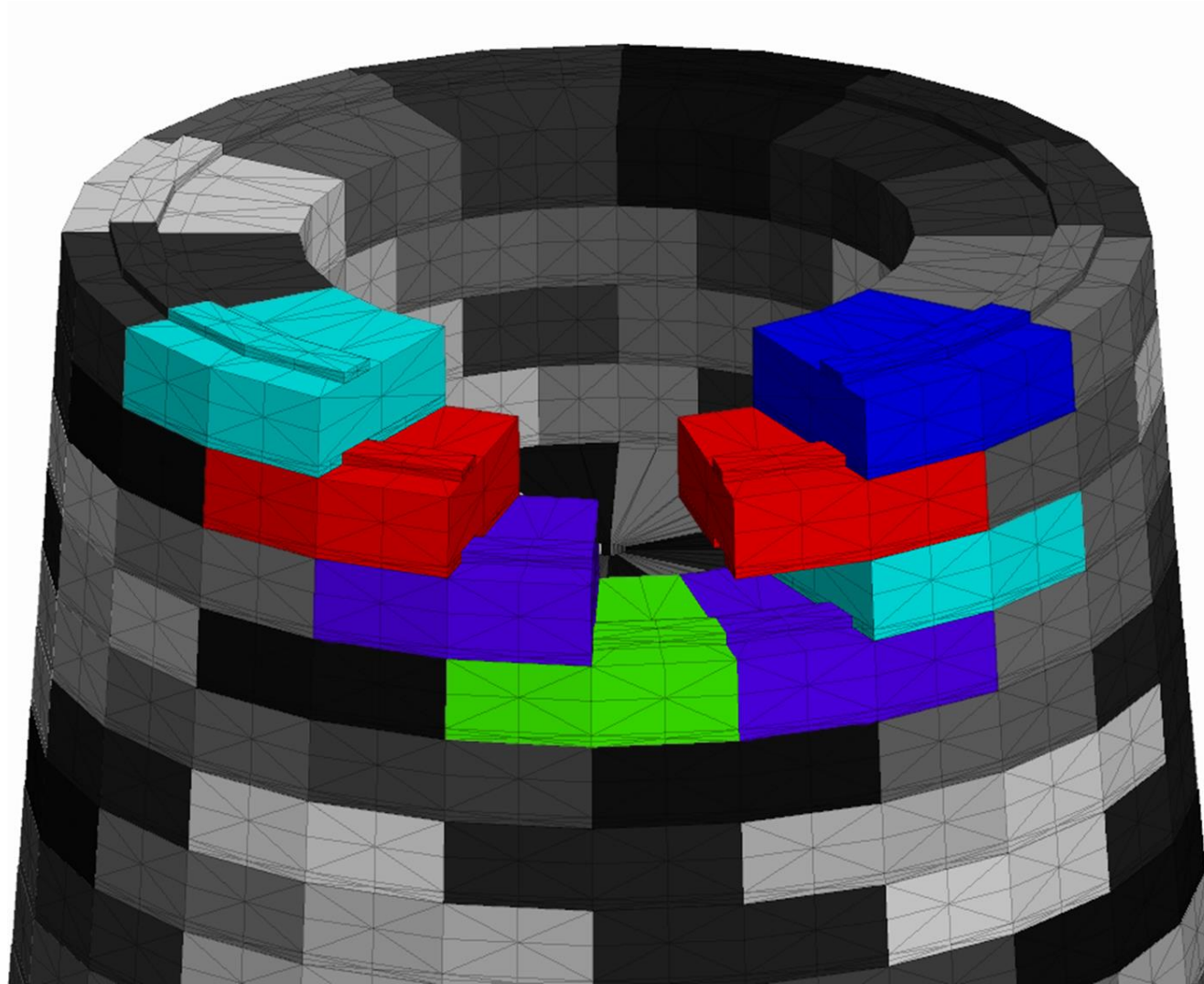
Early days but ...

- Accelerations due to wave impacts occasionally exceeded 0.2 g.
- Notable peak velocities occurred in 2017 storms: Ophelia and Brian.
- This winter should obtain first video data which will provide quantification of waves approaching the Wolf Rock lighthouse.

Implications

- On-going monitoring of structural response at Wolf Rock lighthouse will yield valuable data to estimate wave loading, useful for future design work.
- Operational decisions could be made by considering vibration thresholds.

Investigation 3: Structural analysis



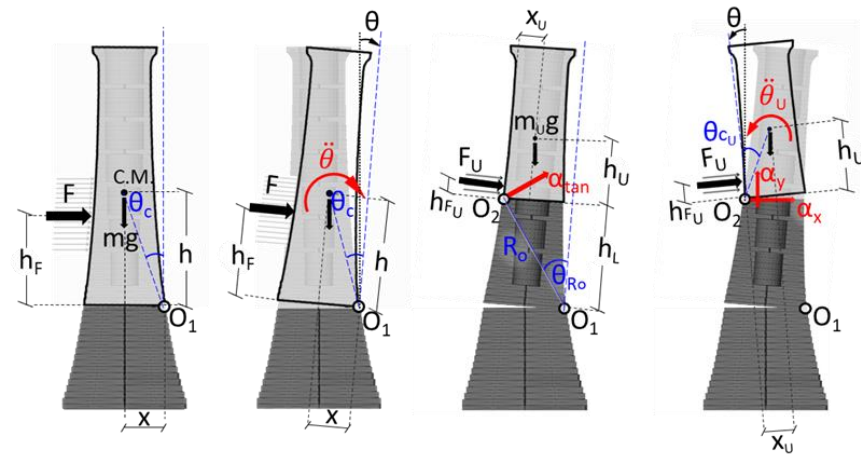
Structural analysis : overview

The structural response of the Lighthouses to wave impacts is assessed with:

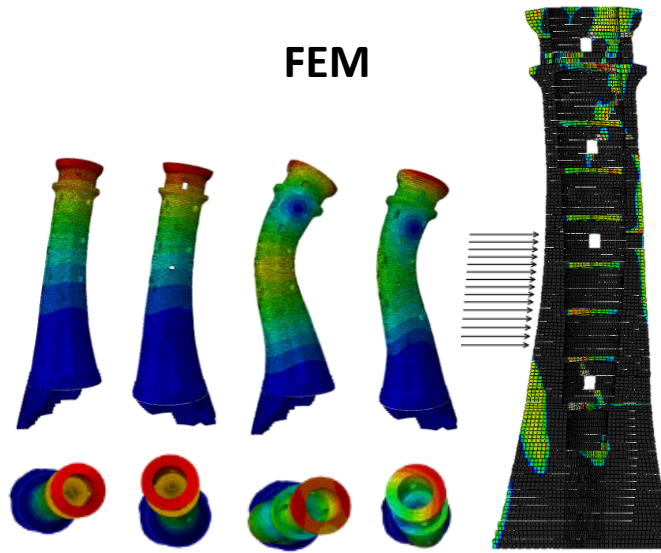
- Limit Analysis
- Finite Element Method (FEM)
- Discrete Element Method (DEM)

(+ combination between DEM and FEM for the assessment of the helidecks)

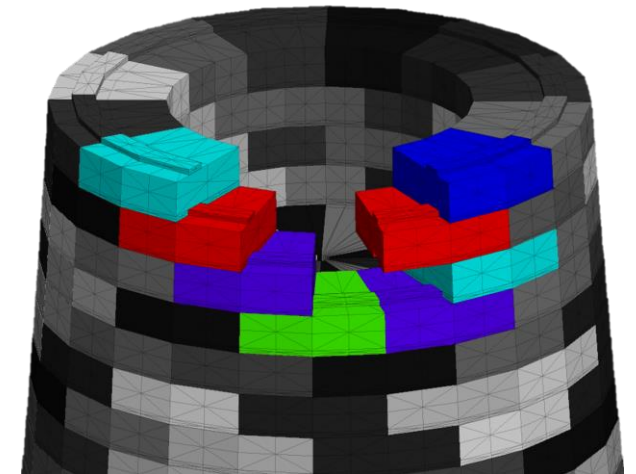
Limit analysis



FEM

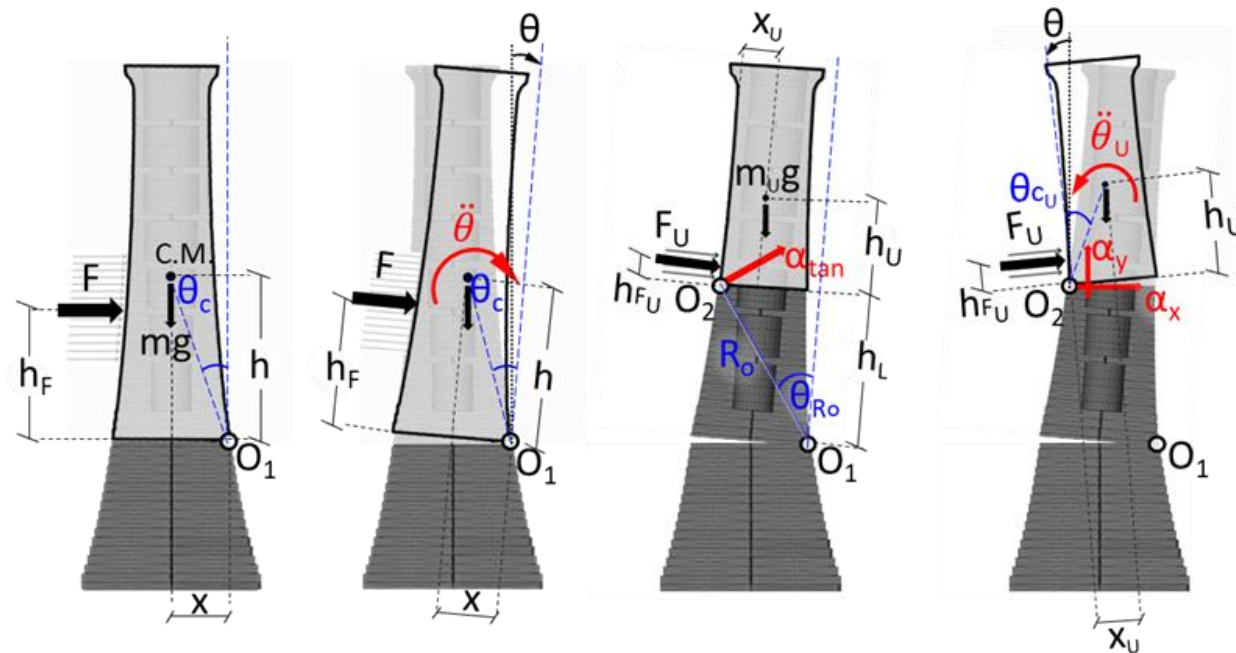


DEM

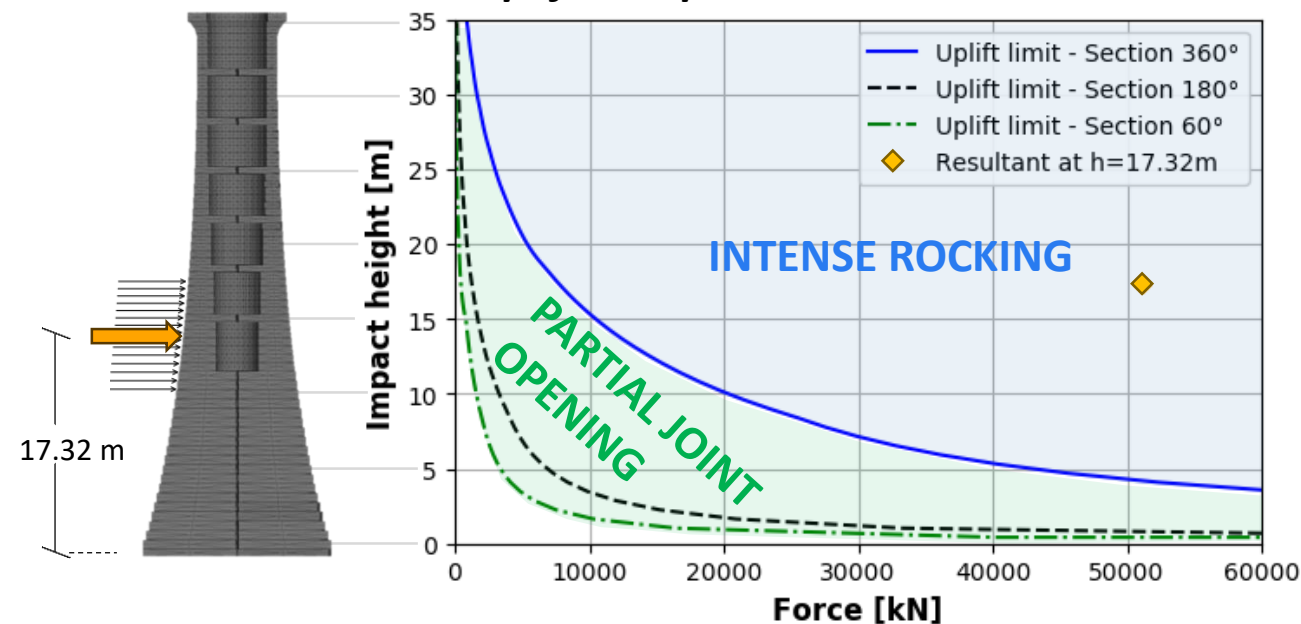


Limit Analysis

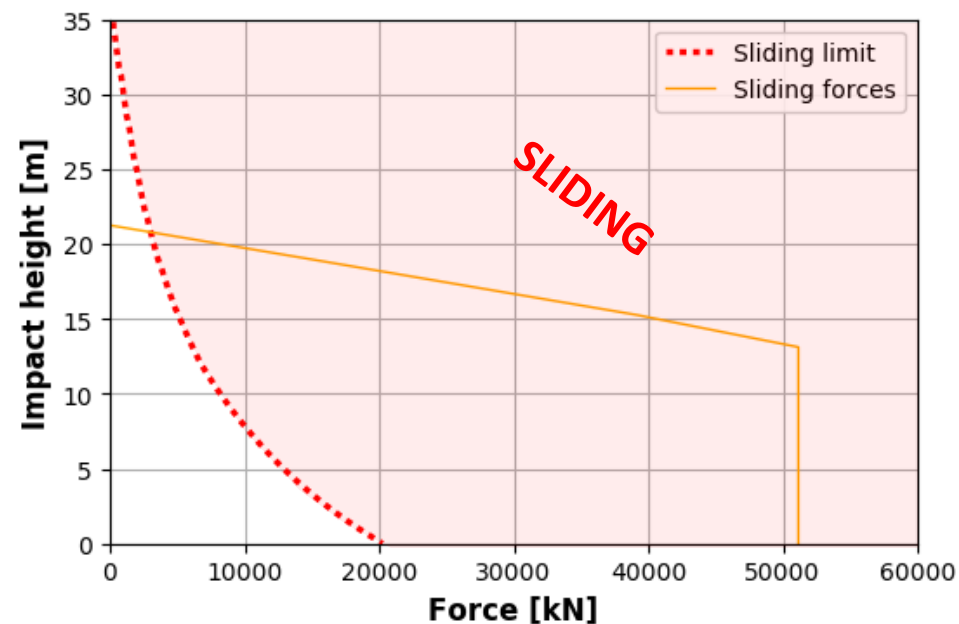
- Calculates the critical **overturning load**
- Calculates the critical **sliding load**
- Code implemented in Python language
- Useful tool for **preliminary assessment** and **prioritisation** of detailed analysis and interventions



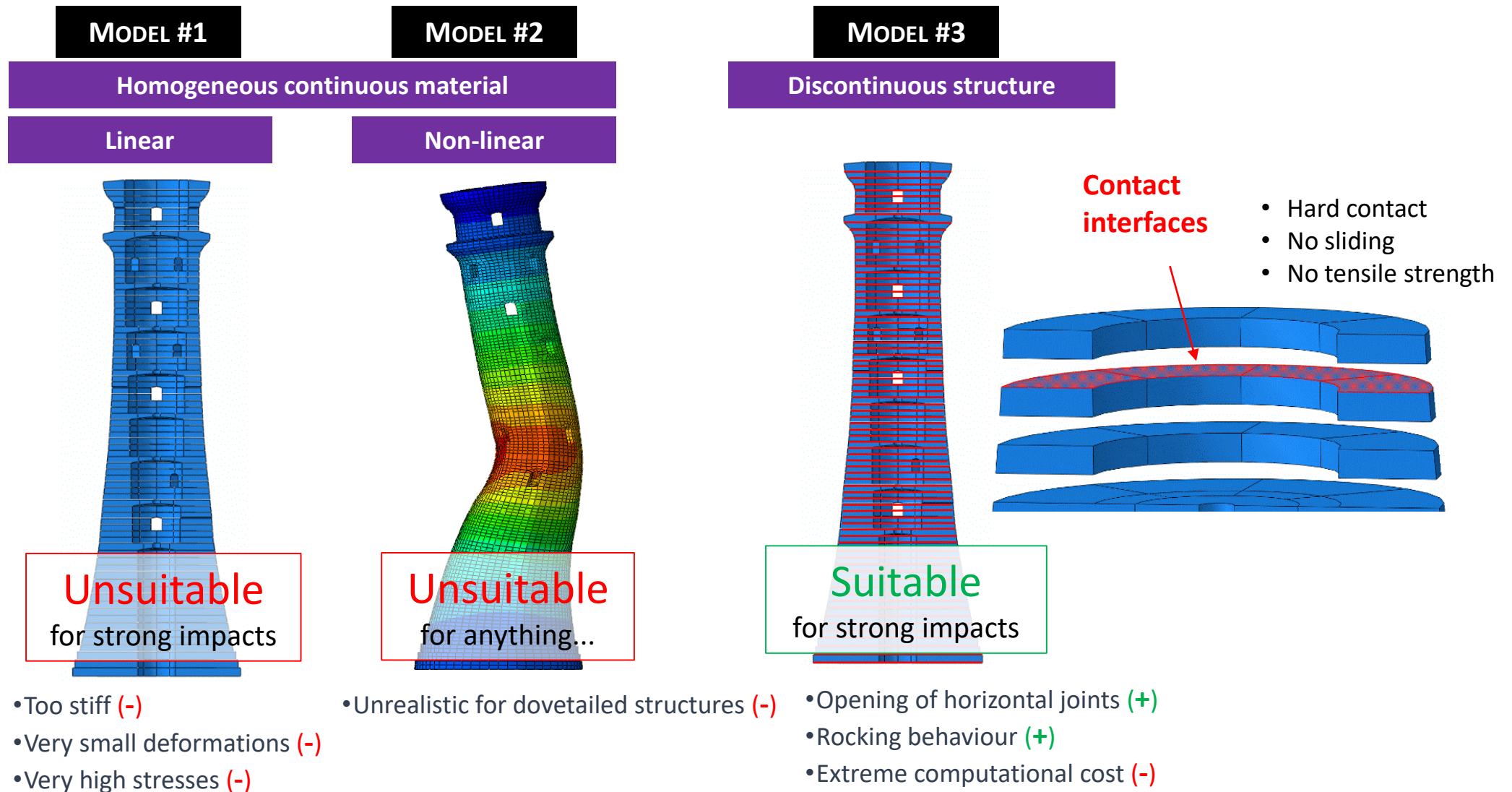
Resultant force >> Overturning limit
Uplift is expected !



Resultant force >> Sliding limit
But... the interlocking prevents any sliding !

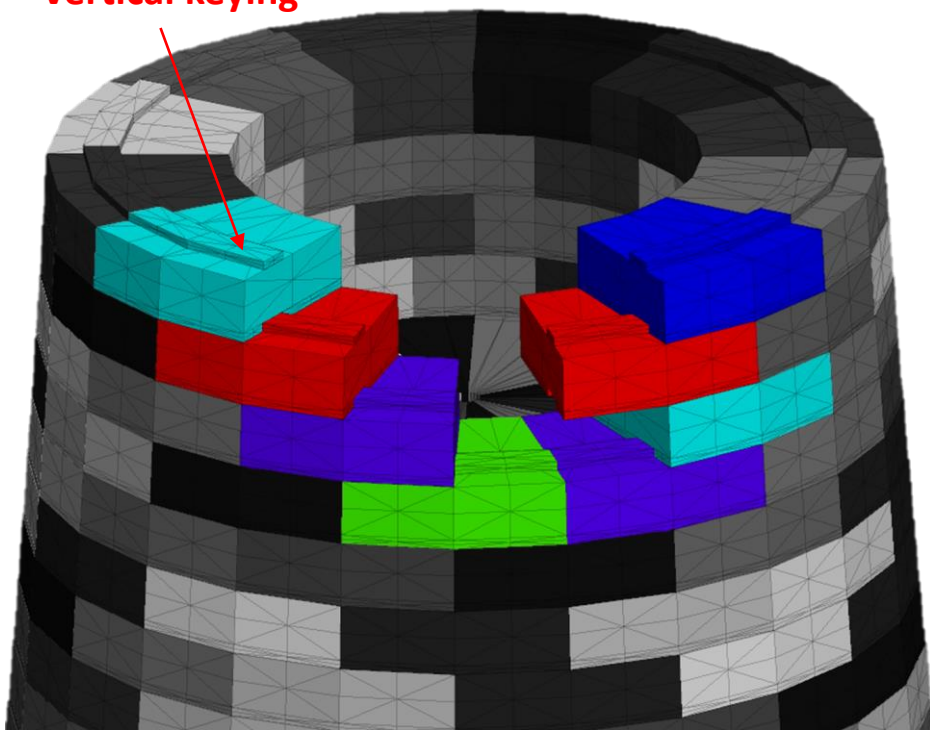


- The discontinuous structure has a highly non-linear behaviour.
- Different FEM modelling approaches were tested.



- Allows **detachment and separation** of blocks
→ Essential for this **non-continuous** structure
- Detailed geometry is needed
→ Python script was developed

Vertical keying



3DEC DP 5.00

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Academic Model

Step 488

Components: X Y Z

Applied load vectors

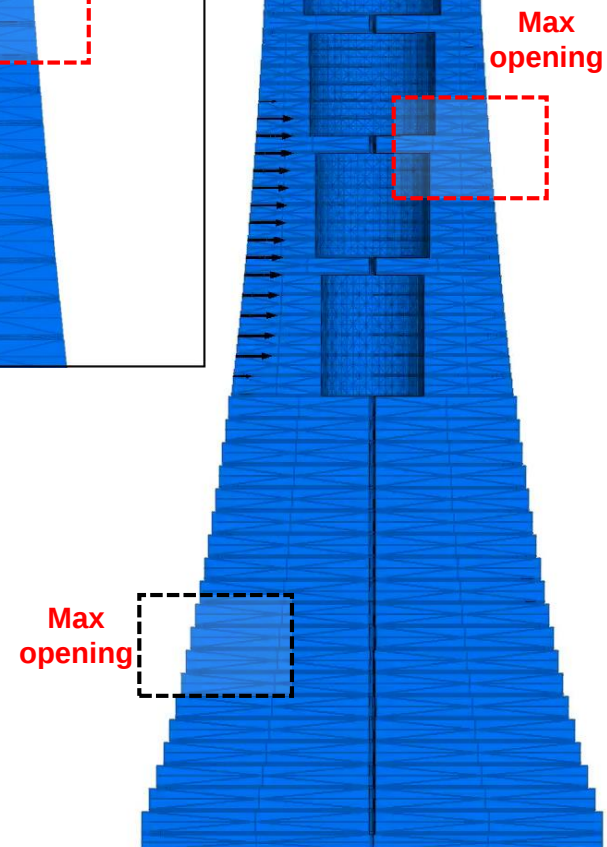
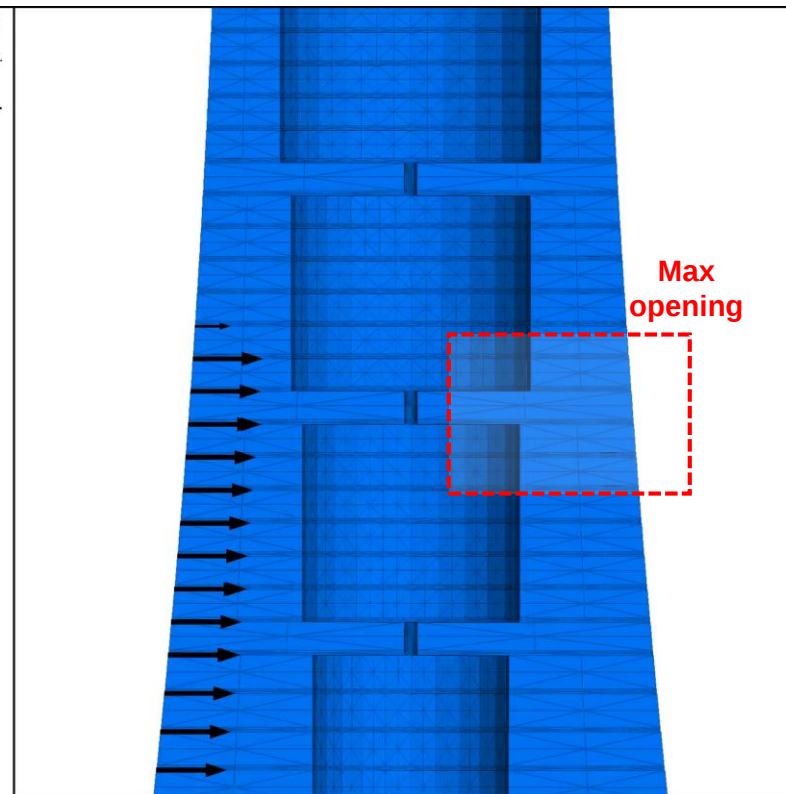
Maximum: 1.15651e+06

Scale: 8.52391e-07

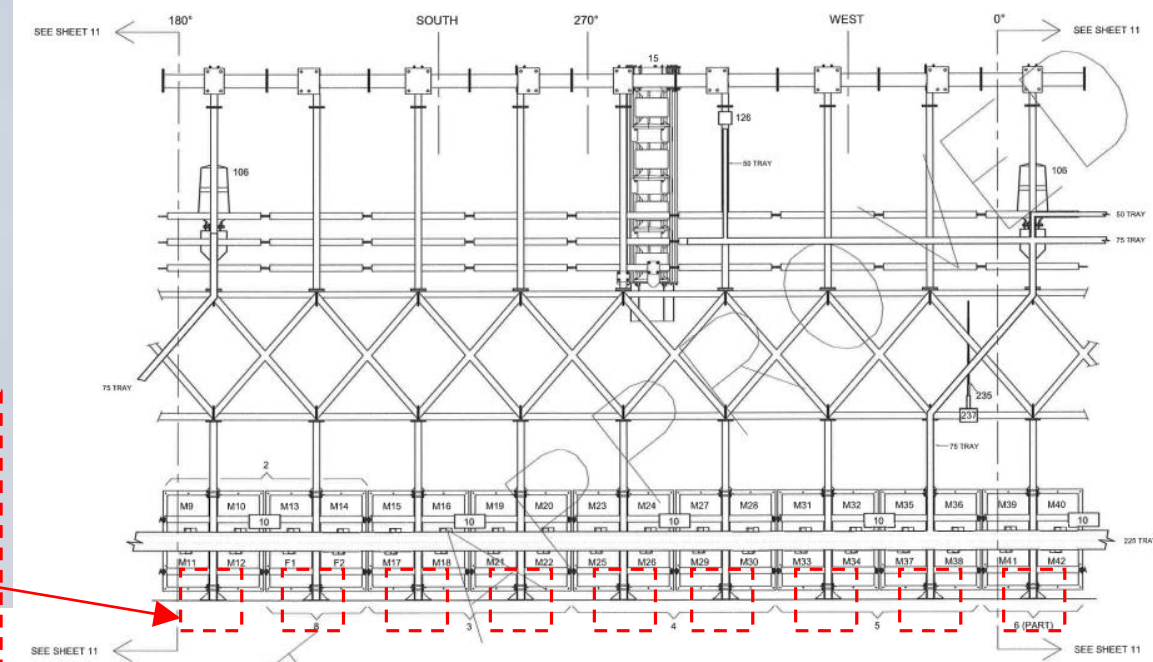
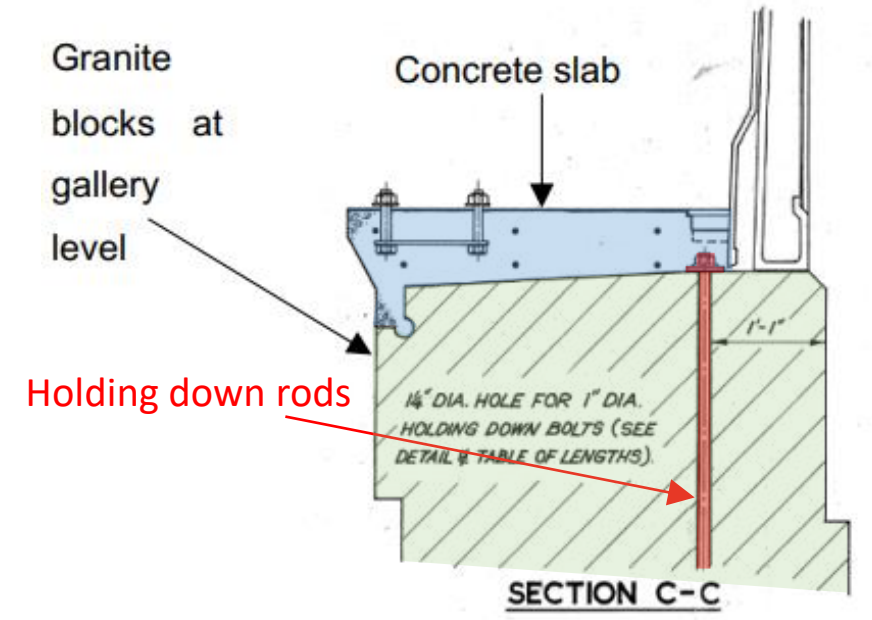
FOB force vectors

Maximum: 0

Scale: 1



- Construction: 1870
- Helideck: 1973

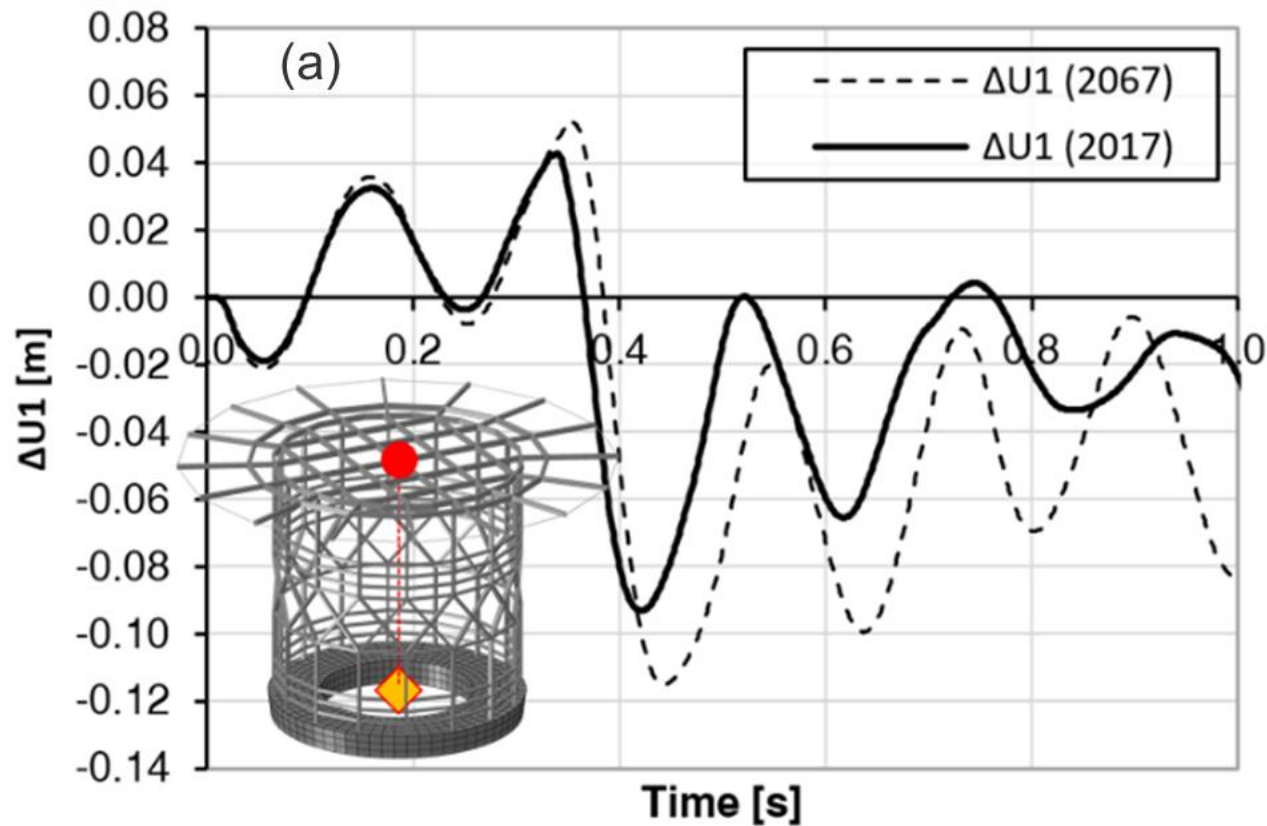
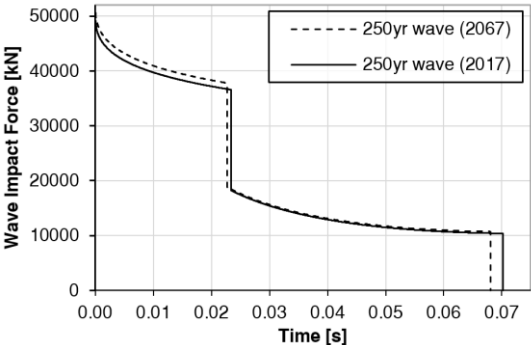


Gallery post base

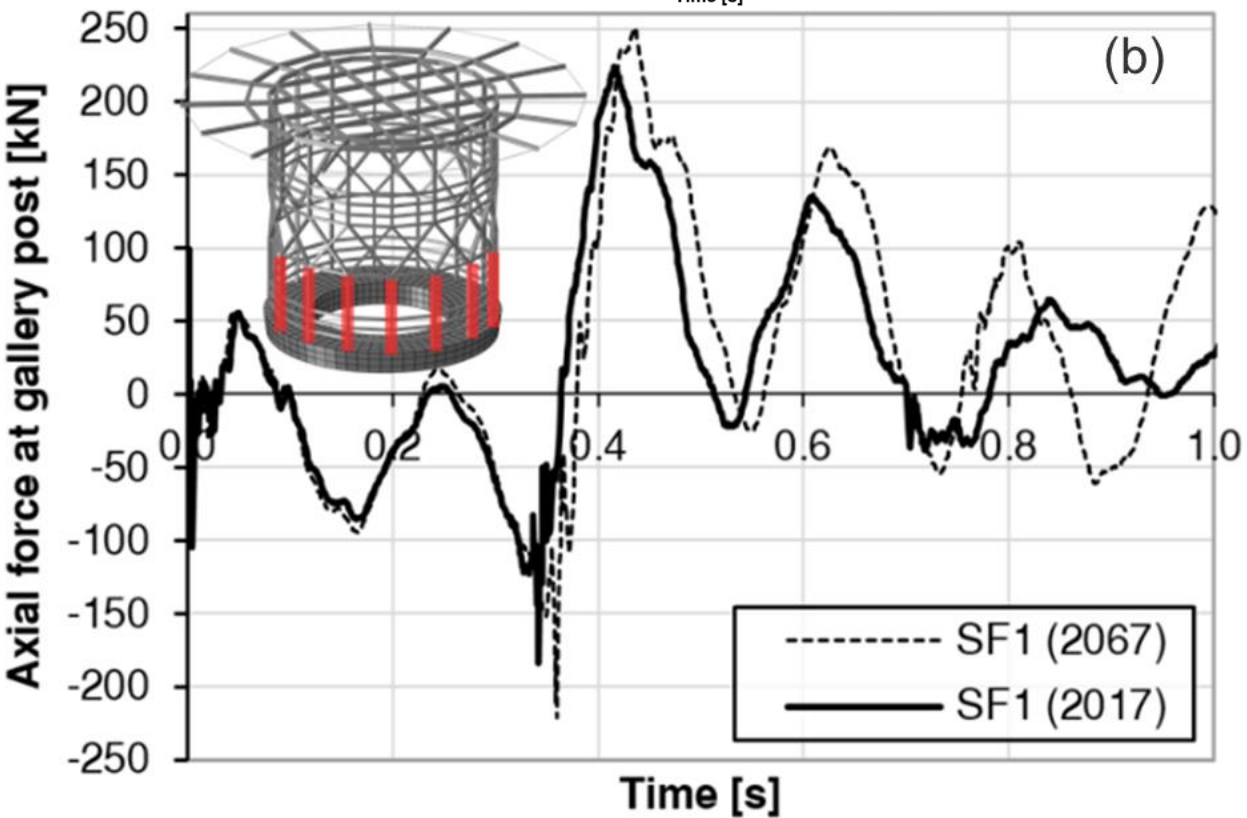
DEM analysis for the masonry tower and FEM analysis for the steel helideck

250 year return period wave (2017 - 2067)

WITH sea level rise and future wave climate

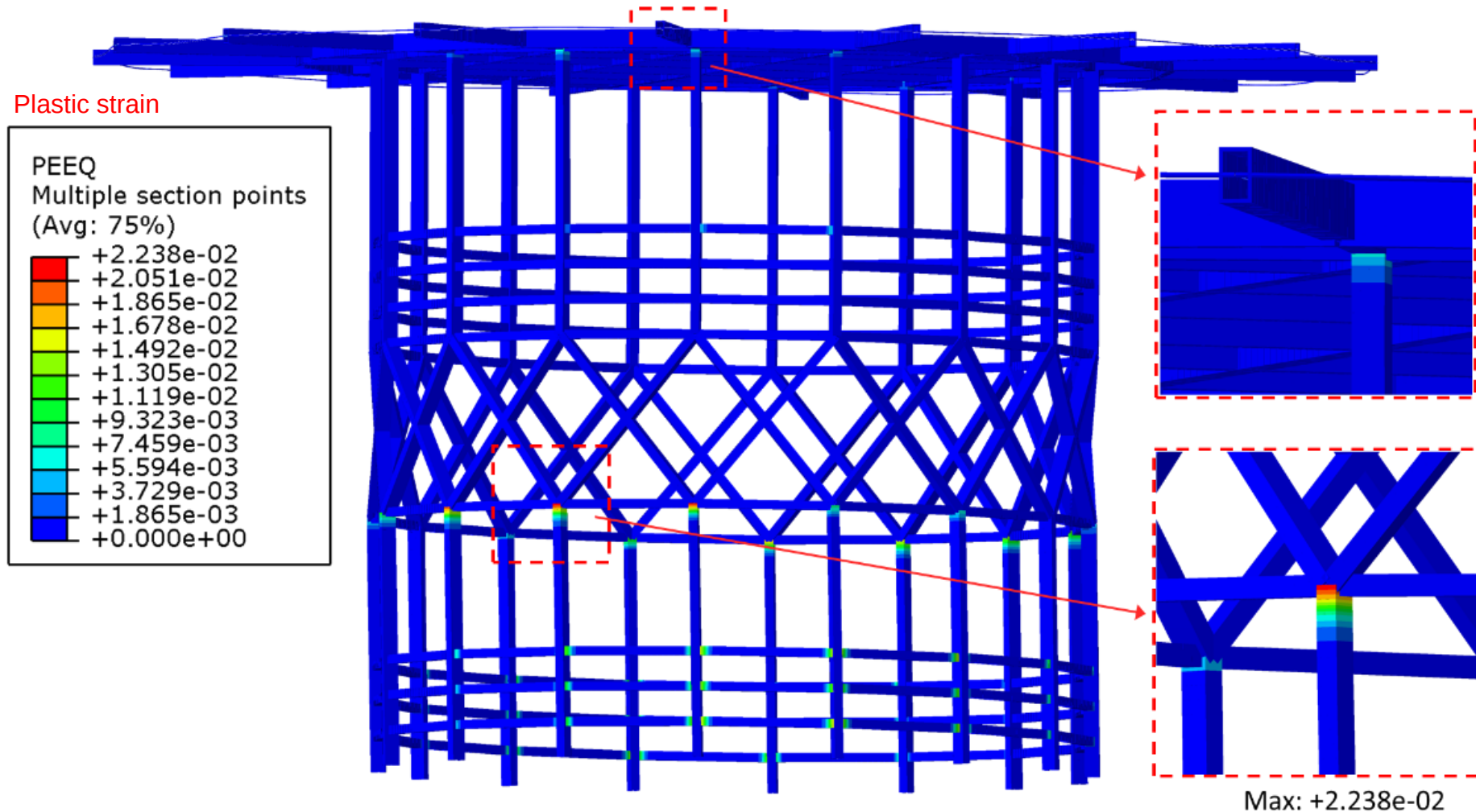


Max horizontal deformation equal to 93 mm and 115 mm (2017 and 2067 scenarios respectively)



Tensile reaction equal to 224 kN and 251 kN (2017 and 2067 scenarios respectively)

Most problematic areas: tops of the vertical gallery posts



Plastic strain levels around 7% and 12% of the assumed plastic strain capacity (2017 and 2067 scenarios respectively)



Damage is expected but not immediate collapse

Structural analysis : key findings

- Fastnet lighthouse can withstand worst of Atlantic storms.
- The 250 year return period wave impact for Wolf Rock causes intense rocking and opening of the horizontal joints but it is not expected to cause collapse. It would not be able to survive the impact of that wave without the presence of vertical keying.
- Wolf Rock helideck exhibits measurable displacements from wave loading, with associated high tension forces and plastic strain. Large axial forces on vertical gallery posts too, enough to damage bolts at the base of the helideck and the encased bars.

Implications

- Structural verification can be prioritised as potential failure mechanisms have been identified and damage prone areas (*e.g.* helidecks, pointing between courses) highlighted.



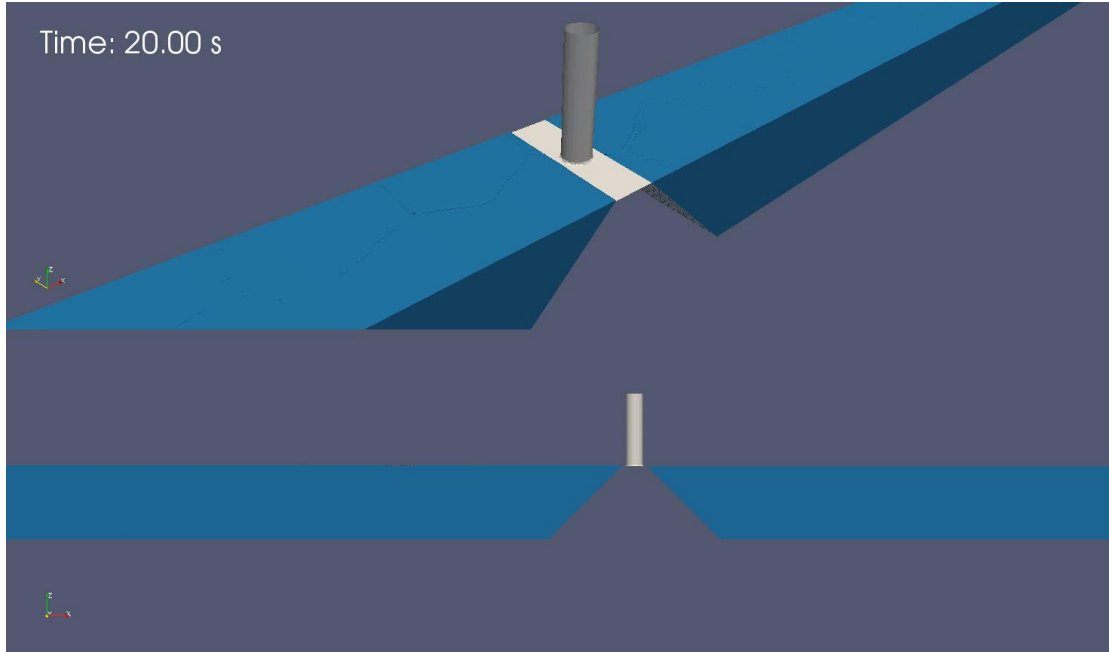
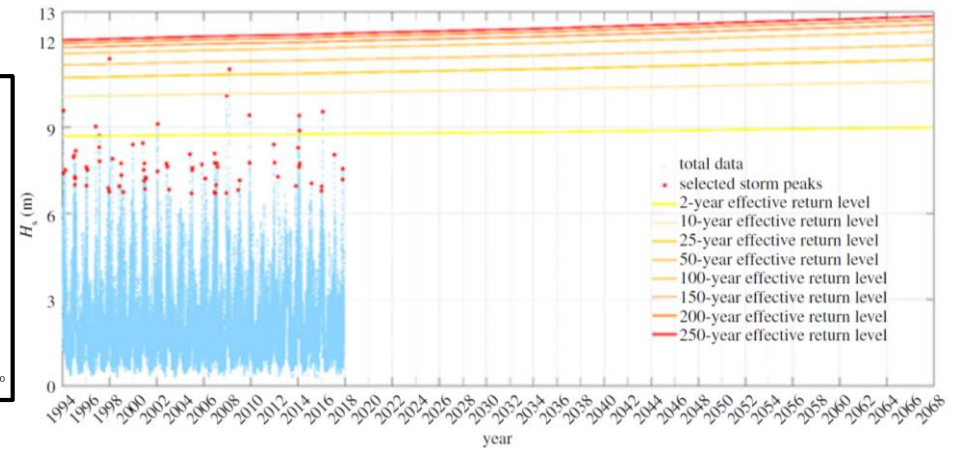
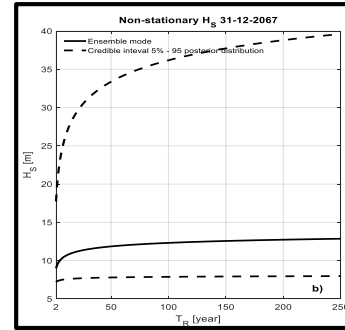
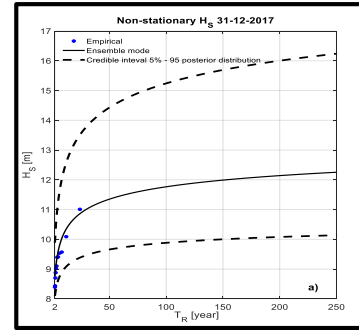
Investigation 4: Hydrodynamic modelling

Hydrodynamic modelling: overview

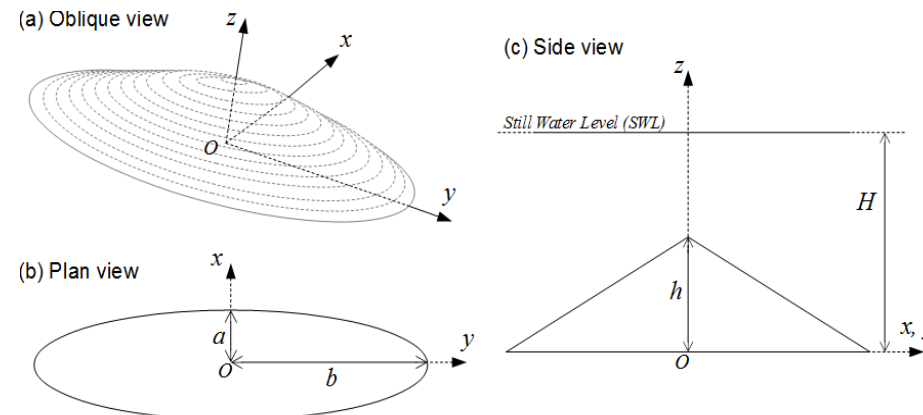
- Wave climate predictions 50 years into the future.
- Creation of physical and numerical models of the wave interacting with the reef then tower.
- Investigations provide:
 - insight into the wave transformation process to understand the wave runup and wave load distributions;
 - method for assessing wave loading on specific and generic structures; and
 - input data for structural models.

Hydrodynamic modelling: field and numerical details

Wave loading estimations using Bayesian extreme analysis at different locations.



Computational Fluid Dynamics using varied parameters: H_s , T_p , γ , shoal shape (a,b), shoal height and area, water depth.

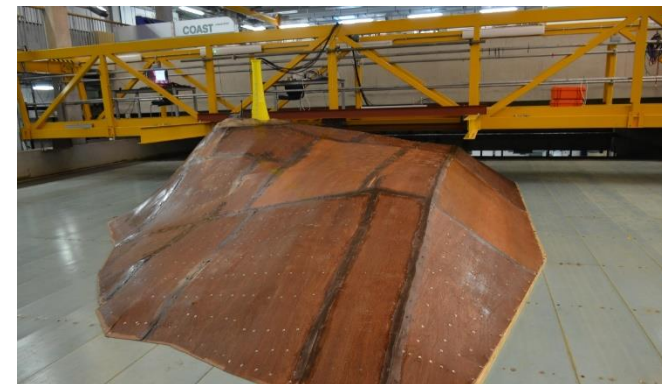
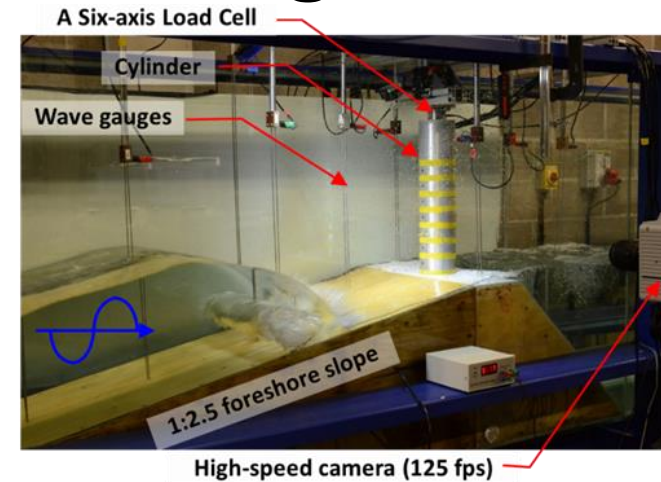


Hydrodynamic modelling: tank testing details

- Flume (35m) tests with generic cylinder at 1:81 scale.
- Coastal basin (15.5m x 10m) with generic cylinder tests at 1:81 scale.
- Ocean basin tests with Wolf Rock lighthouse replica (35m x 15.5m x 3m) at 1:40 scale.

+++ COMPLEXITY

+++ SCALE



points: 6,205,900





TLC200 PRO 2019/08/30 14:28:58



- Total force from 6 DOF load cell
- 12 pressure transducers
- Optical tracking system
- Surface elevation gauges
- High speed camera

09-18-2019 Wed 14:31:06

Camera 04

Hydrodynamic modelling: key findings

Wave climate:

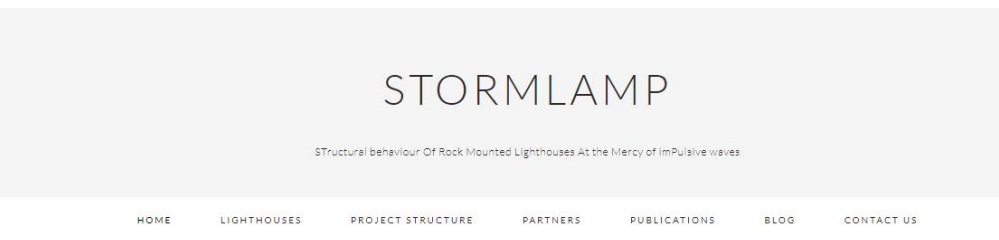
- Fastnet's extreme wave climate shows no statistically significant effects due to the climate change.
- Wolf Rock location has a small increasing trend in wave height but uncertainties due to atmospheric cycles. However, even modest changes in wave loading has implications for structural response.

Individual wave impacts:

- Lighthouses are affected by broken wave impacts - intensity is reduced but duration is increased, compared to directly breaking wave. May cause resonance.
- Wave runup can be 3 x wave height, but difficult to detect automatically due to white water.
- Wave runup and total force increase as the surf similarity parameter decreases, hence there is a dependence on the spectral content of a storm.
- The inverse Bayesian approach allows the reconstruction of incident wave force from measured dynamic force during both laboratory experiments and measured acceleration in the field.
- ***Combined physical and CFD modelling enables us to describe wave loading for a variety of lighthouse geometries.***

Where you can find out more

stormlamp.org.uk



STORMLAMP

STORMLAMP – STructural behaviour Of Rock Mounted Lighthouses At the Mercy of imPulsive waves



STORMLAMP is a research project that is characterising wave loading and structural performance of rock lighthouses. It uses combined field measurements, laboratory studies and analytical and numerical investigations and will support management of lighthouse structural conditions. Specific objectives of the project are to:

SEARCH

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PUBLICATIONS

Brownjohn, J., Raby, A., Bassitt, J., Hudson, E., & Antonini, A. (2017). Modal testing of offshore rock lighthouses around the British Isles. *Procedia Engineering*, 199, 3326–3331. <http://doi.org/10.1016/j.proeng.2017.09.440>

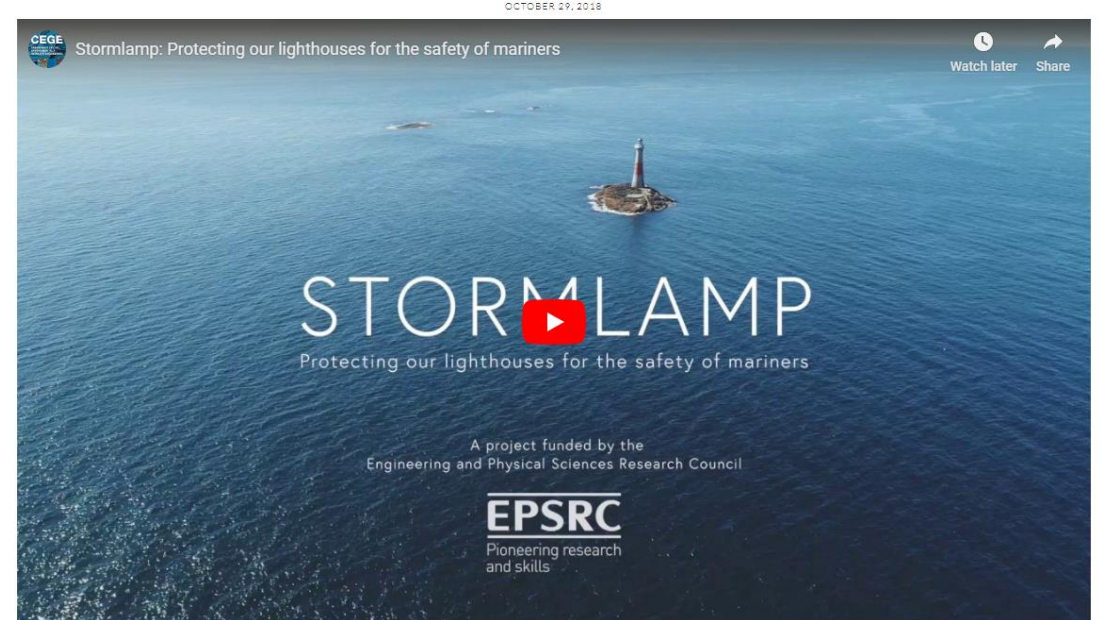
Pappas, A., D'Ayala, D., Antonini, A., Brownjohn, J., & Raby, A. (2017). Numerical modelling of Fastnet lighthouse based on experimental dynamic identification. In *International Conference on Advances in Construction Materials and Systems ICACMS-2017*. Chennai. ([ICACMS 2017 PDF](#))

Antonini, A., Raby, A., Brownjohn, J., Pappas, A., & D'Ayala, D. (2018). Survivability assessment of Fastnet lighthouse. In *36th International Conference on Coastal Engineering ICCE-2018*. Baltimore ([ICCE 2018 PDF](#))

Antonini, A., Raby, A., Caputo, P., Brownjohn, J., Pappas, A., & D'Ayala, D. (2018). An integrated approach for marine structures survivability assessment: the Fastnet lighthouse within the STORMLAMP project. *XXXVI Convegno Nazionale di Idraulica e Costruzioni Idrauliche Ancona, 12-14 September 2018* ([IDRA 2018 PDF](#))

Brownjohn, J., Au S., Wang X., Zhu Z., Raby, A., & Antonini, A. (2018). Bayesian operational modal analysis of offshore rock lighthouses for Structural Health Monitoring. *The 9th European Workshop on Structural Health Monitoring, 10-23 July 2018*. United Kingdom ([EWSHM 2018 PDF](#))

Pappas, A., D'Ayala, D., Antonini, A., & Raby, A. (2018). Rock mounted iconic lighthouses under extreme wave impacts: Limit Analysis and Discrete Element Method. *The 9th International Conference on Computational Methods (ICCM2018) – Rome, Italy*. ([ICCM 2018 PDF](#))



Lighthouses are essential for the safety of mariners in navigating at sea but are they fit for purpose? This film looks at the ongoing research of the STORMLAMP project into the impact of strong waves on lighthouses and how the structure changes.

You can enjoy some breath-taking drone aerial views and videos of the on-site work on rock mounted lighthouses, in peaceful or not so peaceful weather. Alongside with these

Where you can find out more





Wolf Rock
lighthouse

Norströmsgrund
lighthouse



Il Vierge lighthouse

La Jument lighthouse



Morris Island
lighthouse



Gap Rock lighthouse



What you can do to help the project and the University of Plymouth

Key questions for YOU:

1. What aspects are of most interest for international lighthouse authorities?
2. In what ways can the findings change ways of working/thinking e.g. change of maintenance regime, reduction in necessary costs, enabling staff to be kept safe, safeguarding of heritage structures, etc.?

These answers will inform guidance for the UK GLAs and beyond, and assist in the demonstration of our research impact.

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