Pontoon Motion Study and Structural Fatigue

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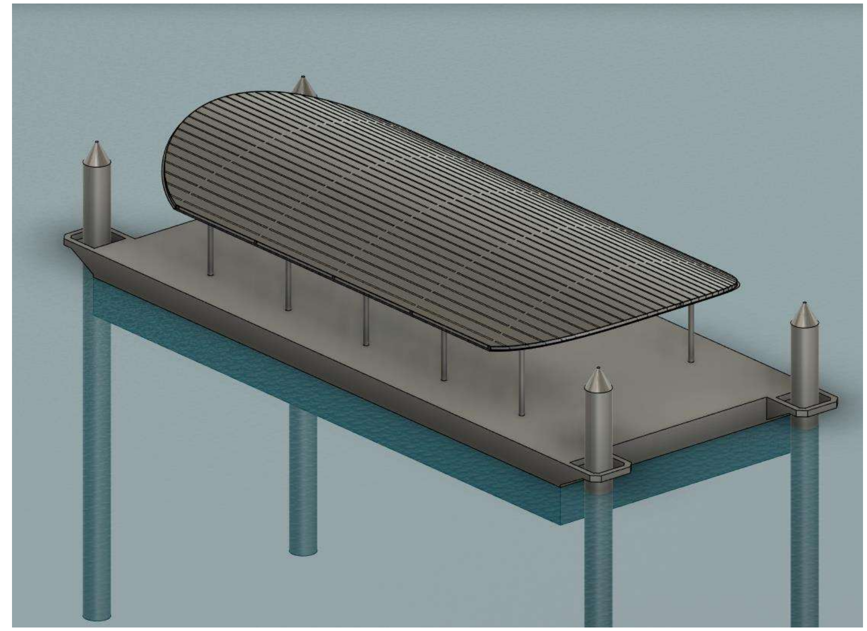
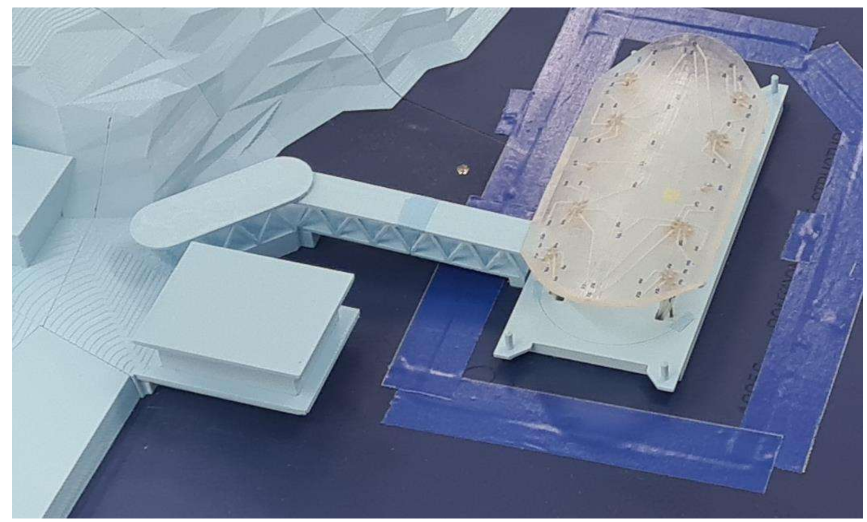
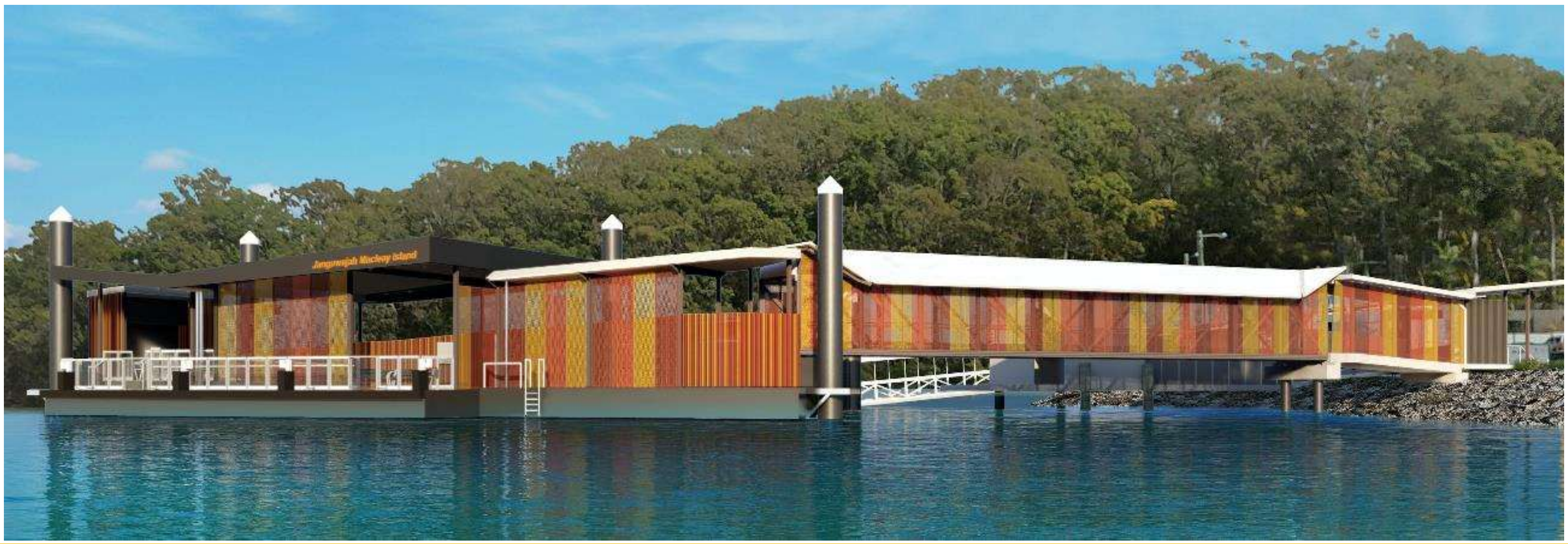
Agenda

1. Pontoons in Maritime Infrastructure
2. Potential Issues and Symptoms
3. Root Cause Analysis (RCA) of the Failure & Advanced Structural Analysis
4. Physical Modelling (Wave and Wind)
5. Finite Element Modelling (FEA)
6. Fatigue Assessment





Pontoons in Maritime Infrastructure



- By nature, pontoons are in a dynamic setting and important to understand the interaction with environmental actions such as wind and wave
- Pontoons form critical components in maritime infrastructure, particularly in public transport such as ferry terminals
- Ferry terminal been used in many cities such as **Sydney, Brisbane, Perth, San Francisco, New York, London, Stockholm** etc.

United Nations Sustainable Development Goals

Australasian Transport Research Forum 2023 Proceedings
Understanding travelers' satisfaction in ferry services: evidence from Brisbane, Australia - University of Queensland

- Reducing carbon emissions
- Improving commuters' job accessibility
- Enhancing transport resilience and travel experience
- Increasing residential property value
- Facilitating the development of tourism
- Promoting sustainable development

Goal 8 - Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all

Goal 9 – Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

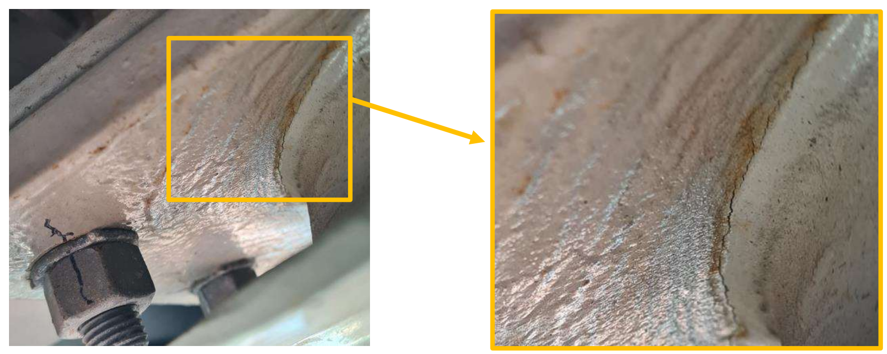
Goal 11 - Make cities and human settlements inclusive, safe, resilient and sustainable

Potential Issue and Symptoms

- Stantec was engaged to inspect ferry terminals (20+ wharves).
- Unique design concept used across the network.
- Inspection noted loose/missing bolts, sheared bolts, and/or weld fractures in the pontoon column and roof connections.
- Pre-mature defects in super-structure connections (min 5-7 years after installation in column base and top).
- Excessive movement in roof at some locations
- Consistent failure pattern at wharves where defects were identified.
- Recurring defects in repaired connections.
- Locations exposed to wind waves and higher marine traffic (not sheltered) exhibit worse conditions.
- Development of defects was gradual – no sudden failure in ultimate loading condition.

Failed Bolted/Welded Base Connection

Failed Top Cap Plate



Crack at Top Cap Plate Weld

Root Cause Analysis & Advanced Structural Assessment

Nature of the Failure

- Under Service Conditions
- Not Limited to a Specific Location
- Failure Due to Cyclic Loading
- Fatigue is Most Likely the Trigger

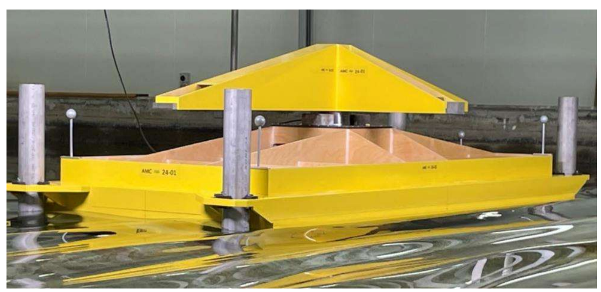
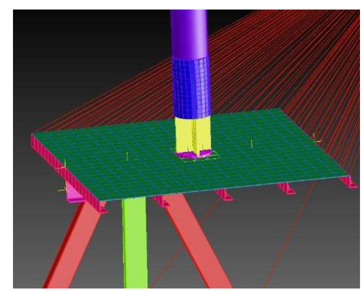
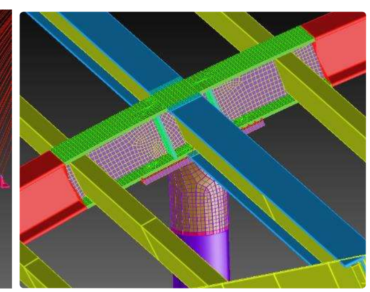
Adequate Geometry , Loading and Boundary Conditions

- Accurate connection details for consideration of nonlinearity effects
- Loading conditions should represent actual service conditions for fatigue assessment.
- Loading derived from physical modelling more suitable than design codes.

Finite Element Analysis and Post Processing

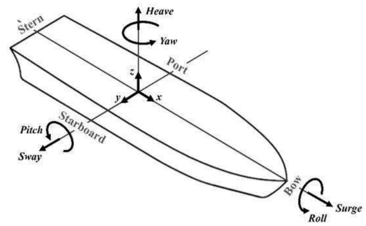
- Nonlinear geometry and materials
- Transient dynamic loading cases

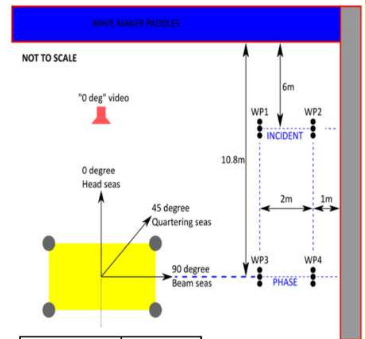


Wave Modelling

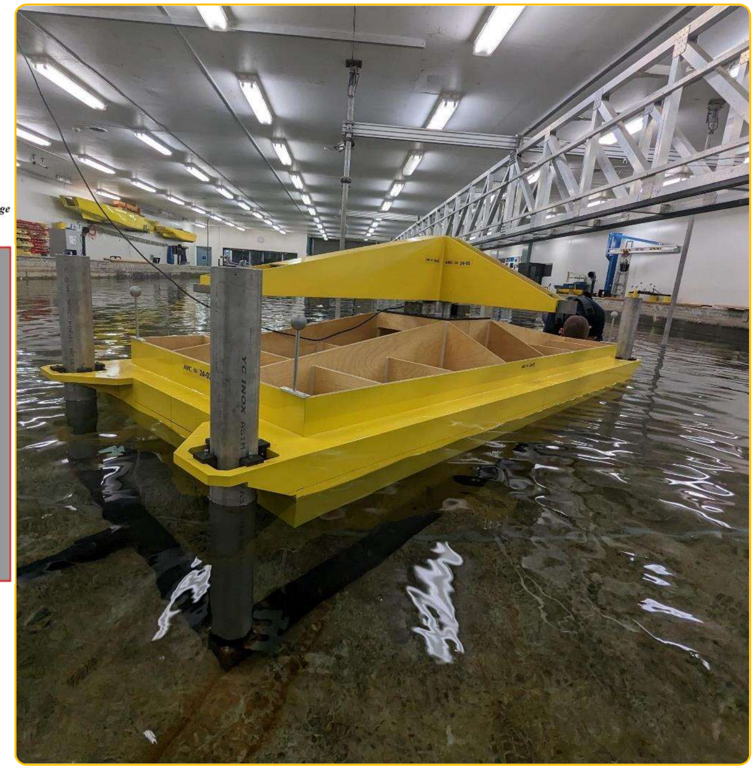
- Physical modelling presents the best method to replicate operational loading scenarios.
- Model built and tested in Australian Maritime College (AMC) wave basin
- Model Scale is 1:10, accurate desired mass and inertial properties for the pontoon and roof structures
- Details like pile guide, gap, roof mass, draft etc. include in assessment
- Wave Scenarios were defined according to project wave climate (wind and swell waves, ferry wake)
- 6 pontoon motions were recorded (3x translational , 3x rotational)





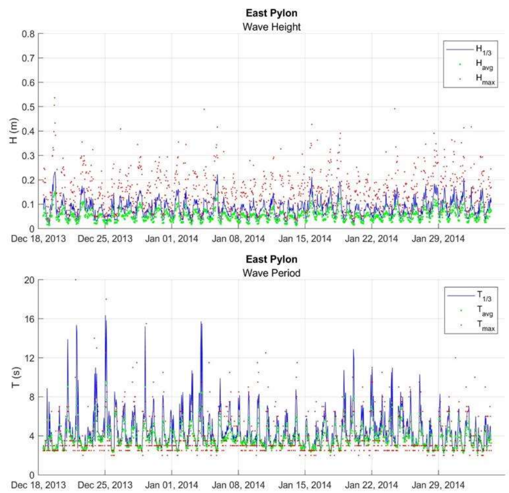
Type	Factor
Force	λ^3
Moment	λ^4
Energy	λ^4
Length	λ
Time	$\sqrt{\lambda}$

Froude scaling factor = λ=10

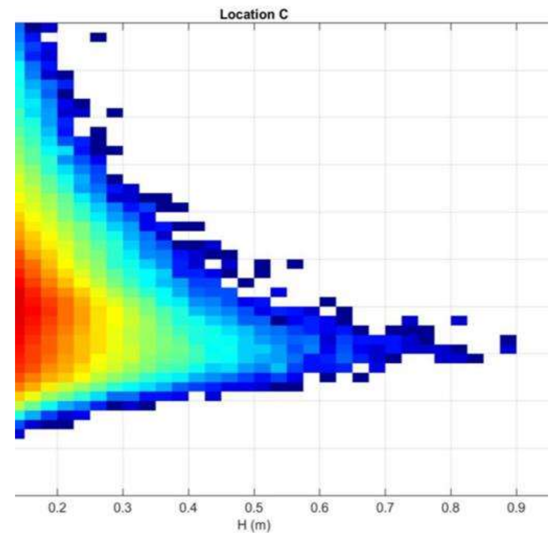


Wave Modelling
Met-Ocean

- Coastal team and AMC provided insight regarding the wave climate .
- Majority of wave due to wind waves (local waves) and ferry wake
- The wind wave has period ranging from 3sec to 4 sec
- Swell wave could have period to 8sec, however was not the frequent case in the area
- Frey wake depends on the vessel type , ranging from 2sec to 6 sec
- Wave data was recorded at 3 locations over 7 weeks period
- In testing schedule, different wave height (0.3m, 0.5m) and period (2-8 sec) at 3 different orientations (beam sea, head sea, quartering sea)
- Regular and irregular cases were tested.



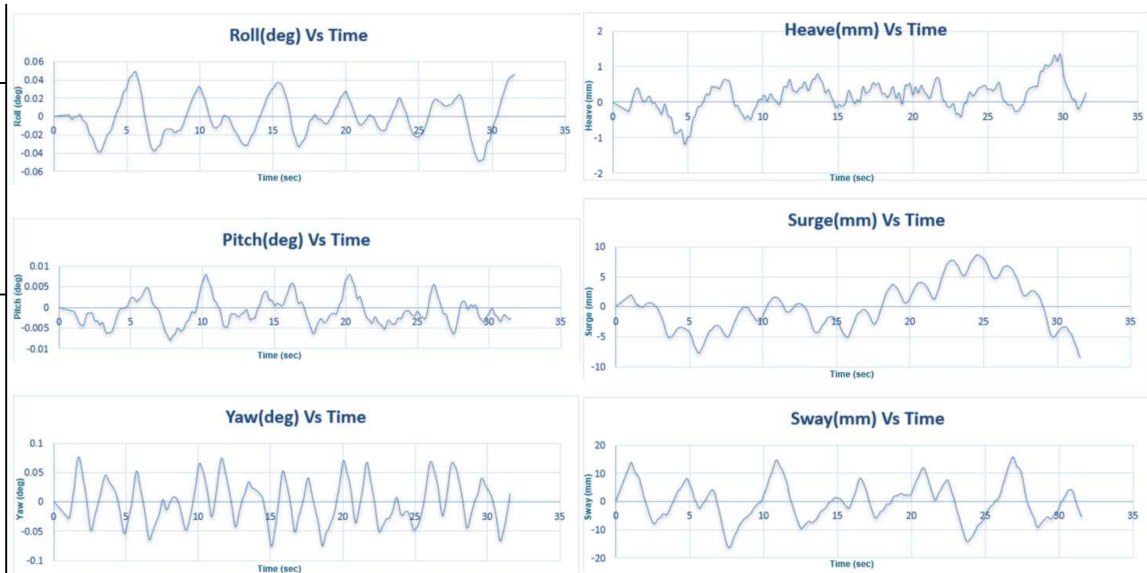
Recorded wave data- period & height

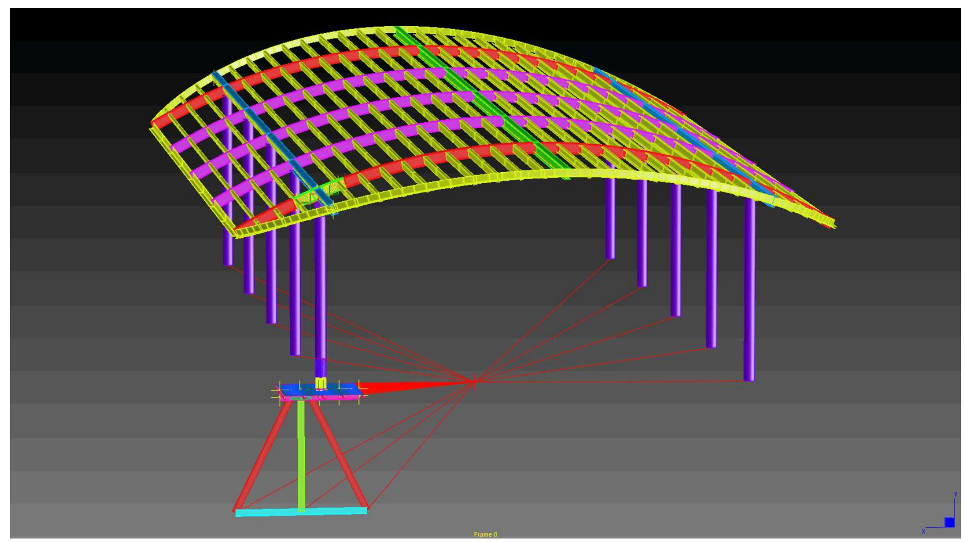


Intensity of wave height distribution

Wave Modelling

- Sensitivity checks were conducted to ensure the pontoon's response (pile gap, decay test)
- Results exported as a scaled time series of data. (motion response vs time)
- Pontoon displacements for 6 DOF at CoG then used to drive the FE model.
- All motions were scaled to represent the actual pontoon response to wave climate
- Time-series were used as loading input for structural model
- The structural model were run for different wave scenarios to determine the stress in components such as bolts, welds, and plates





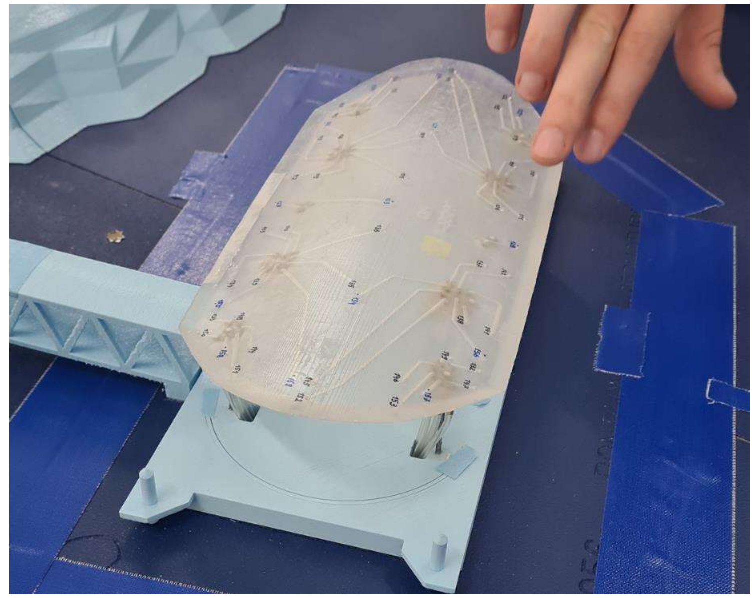
Wind Modelling

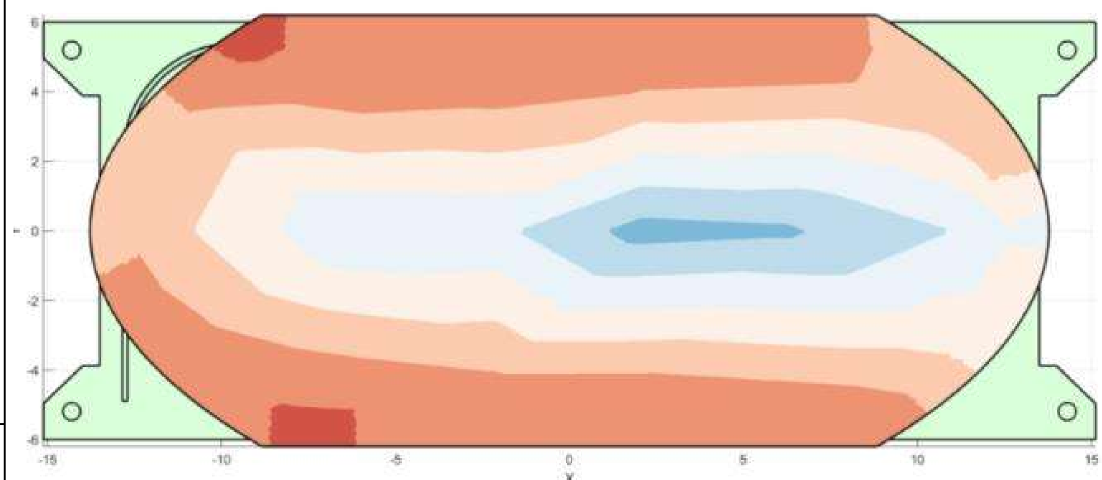
- Wind loading from operational cases to contribute to fatigue damage.
- Wind pressures from building codes and standards or obtained from analytical methods (CFD) not as accurate as physical testing for complex geometries.
- Wind tunnel testing of a 1:100 scale proximity model was completed by CPP Wind Engineering Consultants.
- Accurate proximity model relevant to the case study was constructed using 3D printing techniques..
- Wind testing was completed for 360 degrees in 10-degree increments.

Wind Modelling

CPP Wind Engineering Consultants (CPP)

- Pressure measurements taken across the model to form tributary pressure areas.
- Pressure areas calibrated with the developed FE model through extraction of structural coefficients.
- Structural coefficients allow identification of instantaneous loading cases that maximise structural response in these target elements.
- Subsequent full-scale external pressure time histories were then applied to the structural coefficients from the FE model to derive component-level structural response.





Finite Element Modelling

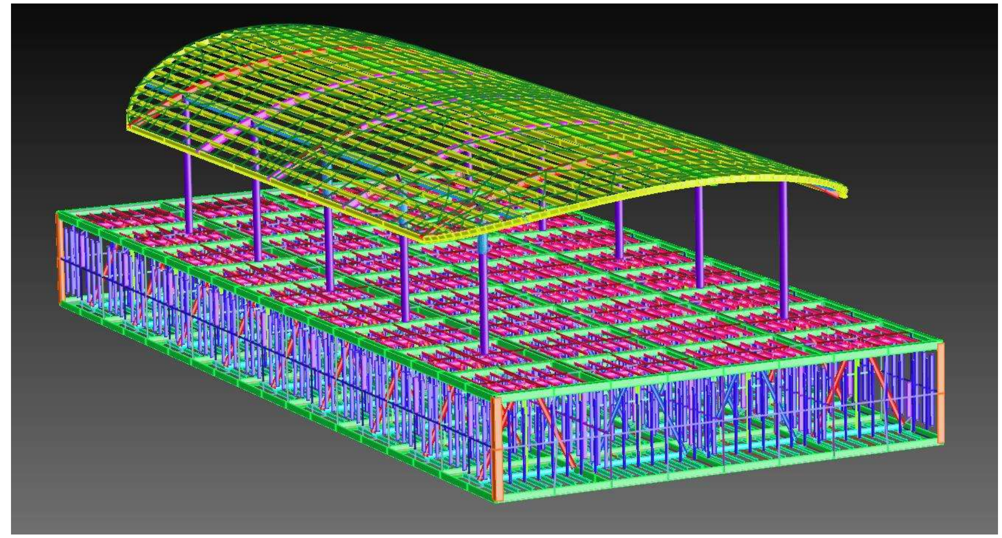
- Development of detailed holistic model was completed with Strand7 and allows for checking of boundary conditions set in optimized models.

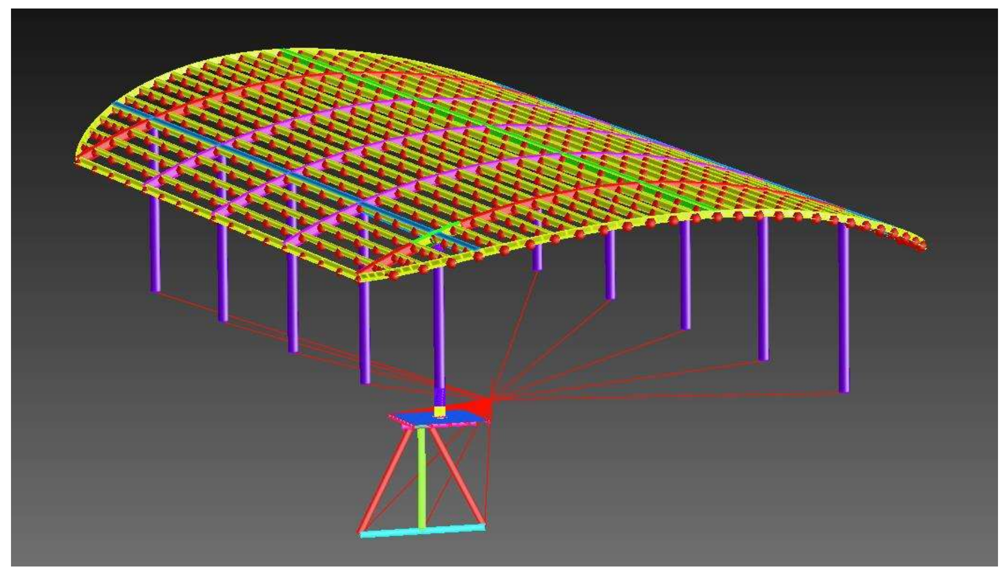
13,249 nodes + 3,986 beams + 7,781 plates

↓

8,716 nodes + 1,190 beams + 7,792 plates

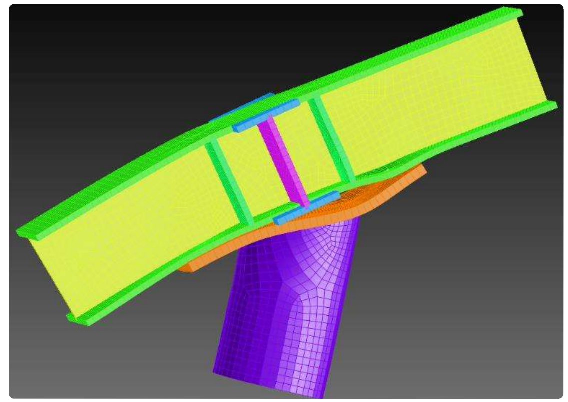
- Optimised models may then focus on accurate stresses to be examined in target elements.
- Targeted roof connections modelled using plate elements – Quad 4 mesh.
- Loading inputs from physical modelling data need to be run with Strand7's nonlinear transient dynamic solver.



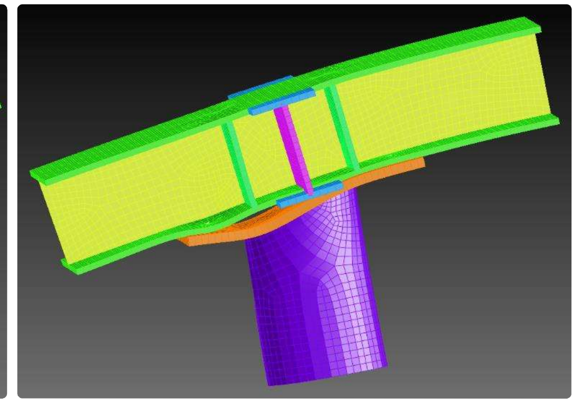


FE Model Nonlinearity

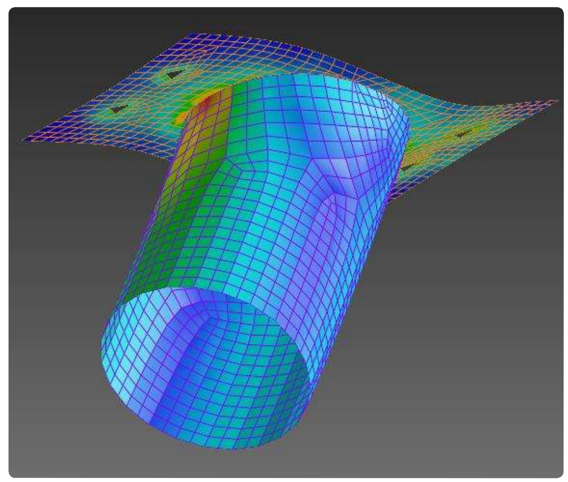
- Replication of true structural behaviour of bolted connections and other nonlinear responses is critical to obtaining correct results from the FE model.
- Bolts allow for loading in shear and tension, but compression is taken by the plate-to-plate contact.
- Stress distribution is not uniform.
- Necessary to allow for detachment of bolted faces – modelling of compression-only Gap elements.
- Material nonlinearity included in the model to allow for accurate prediction of yield failure.
- This structural behaviour is critical in development of bolt stresses as well as welded connection stresses.

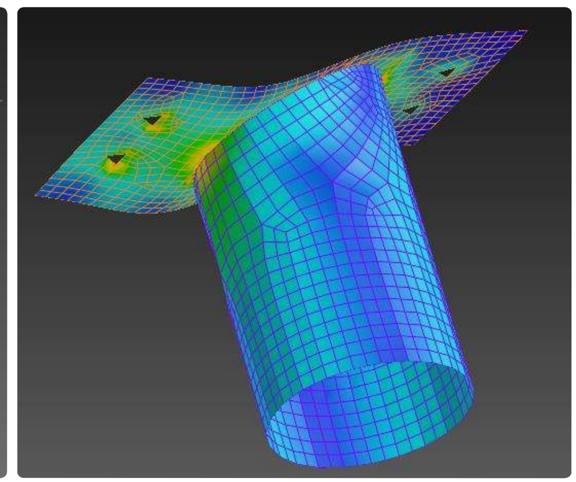


Column cap plate/roof beam connection (top)



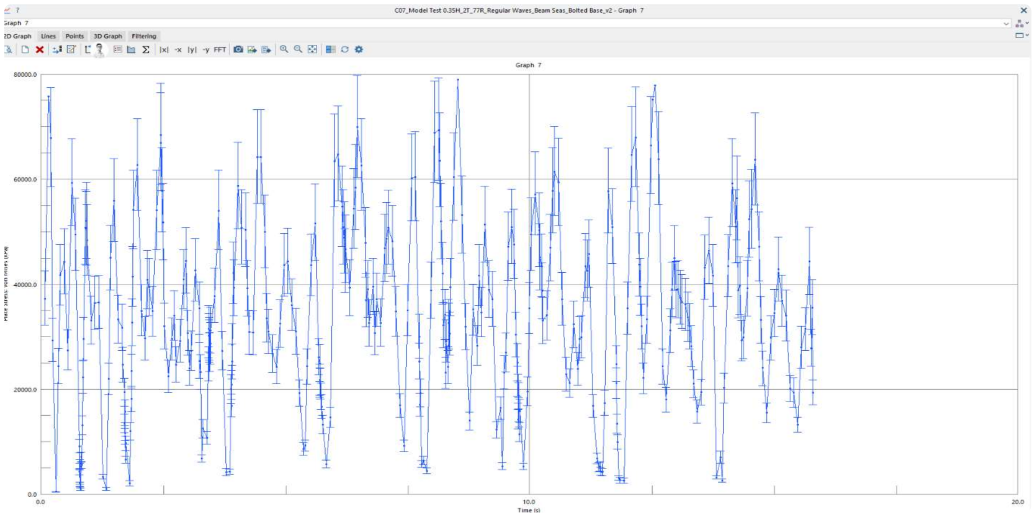
Column cap plate/roof beam connection (top)

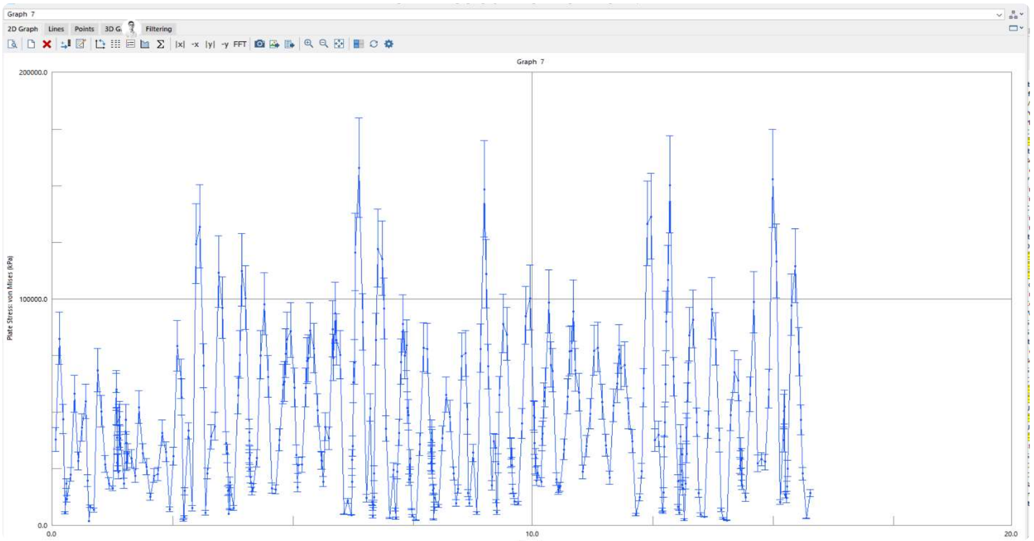




FE Model Response

- The low-damped response of the modelled roof to excitation from wave loading can be seen visually in the model results.
- Model results show that the low-damped nature creates ongoing oscillation at the structure's natural frequency regardless of the period of incoming waves.
- Comparison of component stresses at the top of a roof column between 0.35m waves at 2 second period versus 6 second period.
- Lack of sufficient damping in the system will contribute heavily to fatigue damage.



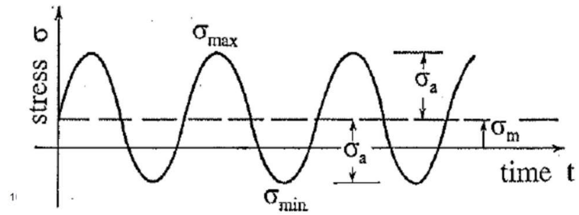


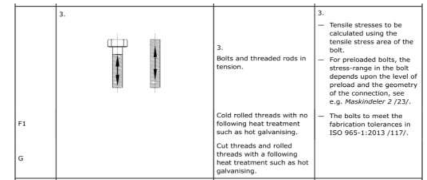
Fatigue Assessment

- A component, which fails through yielding at a high constant (unfluctuating) load, may fail under a substantially smaller fatigue load
- S-N approach, which relates stress cycles (N) to stress range (S)

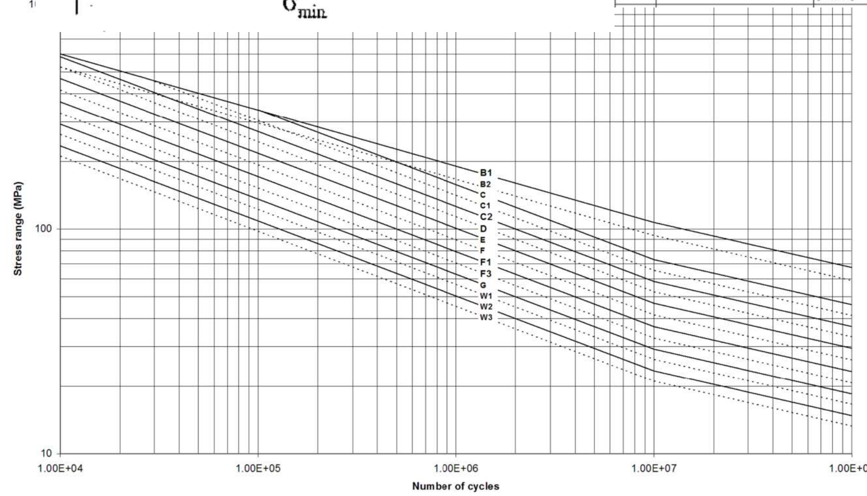
DNV-C203 was selected to assess the fatigue life :

- DNV's approach aligns well with marine structures that are exposed mainly to wind and wave loading.
- The code provides recommendations for stress concentration and hot-spot stress calculations based on FEA.
- Stress cycle were calculated according to coastal engineering input and ferry fleet data.
- The Palmgren-Miner rule was used to evaluate fatigue strength. (accumulative damage)
- The S-N curves are thus associated with approximate 97% probability of survival





	3.	3. Bolts and threaded rods in tension.	3. — Tensile stresses to be calculated using the tensile stress area of the bolt. — For preloaded bolts, the stress-range in the bolt depends upon the level of preload and the geometry of the connection, see e.g. *Maskindeler 2* /23/.
F1		Cold rolled threads with no following heat treatment such as hot galvanising.	— The bolts to meet the fabrication tolerances in ISO 965-1:2013 /117/.
G		Cut threads and rolled threads with a following heat treatment such as hot galvanising.	



COLUMN BASE PLATE BOLT_ ACCUMULATED DAMAGE

Case	Fatigue Stress Range, S (Mpa)	Estimated Annual Stress Cycles	Expected Design life, years	Total Stress Cycles (N)	Cycles to Fail	Damage
Quartering Seas, Regular,0.175H,3T	51	136,000	3.5	476,000	1.9E+06	0.253
Beam Seas, Regular,0.35H,6T	230	0	3.5	0	2.1E+04	0.000
Quartering Seas, Regular,0.35H,3T	110	9,900	3.5	34,650	1.9E+05	0.184
Quartering Seas, Regular,0.5H,4T	170	240	3.5	840	5.1E+04	0.017
Quartering Seas, Irregular, 0.3H,4T	90	14,850	3.5	51,975	3.4E+05	0.152
Quartering Seas, Regular, 0.35H,2T	70	87,776	3.5	307,216	7.3E+05	0.421
					Accumulated Damage	**1.026**

Conclusions	Recommendations
Fatigue was the main cause for connection pre-mature failure, proved through FEA and physical modelling.	Stress range must be controlled in all structures mounted on supports (roof, control rooms, equipment etc.) to increase the fatigue strength of the connections.
Non-linearity affects the stress distribution in model and must be considered.	Detailing in structural components is important: • Pre-tensioned bolts to off-set the stress range. • Double nuts (or lock nut) arrangement to avoid losing pre-tensioned force in bolt. • Structural frame bracing.
Corrosion contributes to the fatigue damage, particularly at base connection.	Material selection to consider resistance to corrosion (for example stainless steel instead of carbon steel).
Wind loading has some effects, though these were not dominant in fatigue assessment.	Redundancy in primary connections (such as baseplate bolt size) should be considered.
Wave loading due to ferry wake has considerable impact on fatigue.	Additional damping (mechanical systems) can be introduced into the structural system.

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Thank you

Questions?