Technische Universität Braunschweig

Leichtweiß-Institute for Hydraulic Engineering and Water Resources
Department of Hydromechanics and Coastal Engineering

Dynamic Response of Jacket Structures to Breaking and Non-breaking Waves: Yesterday, Today, Tomorrow

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Contents

- **Practical position of the problem (Yesterday)**
  - Application of jacket structures in offshore industry
  - Available prediction models for breaking wave loads on jacket structures
  - Physical modelling of wave loads on jacket structures

- **Contribution of the PhD study to enhance knowledge (Today)**
  - Motivation and objectives
  - Slamming load formulae for breaking waves on jacket structures
  - Total breaking and non-breaking wave loads on jacket structures
  - Dynamic response of a full-scale jacket structure to breaking waves

- **Need for further research and development (Tomorrow)**
  - No theory to predict breaking and broken wave characteristics
  - Applicability and validity range of Morison equation
  - Wave slamming loads on moveable/deformable slender piles
  - Effect of neighbouring members on the wave loading of a member of the jacket

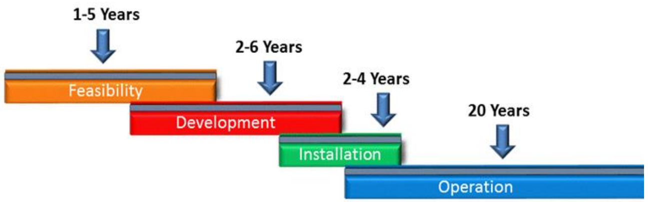
Jacket platforms in oil and gas industry

- Offshore jacket platforms are successfully used in oil and gas industry
- Jacket platforms are widely installed in the Persian Gulf, the Gulf of Mexico, Nigeria, and California shorelines (Sadeghi, 2012)

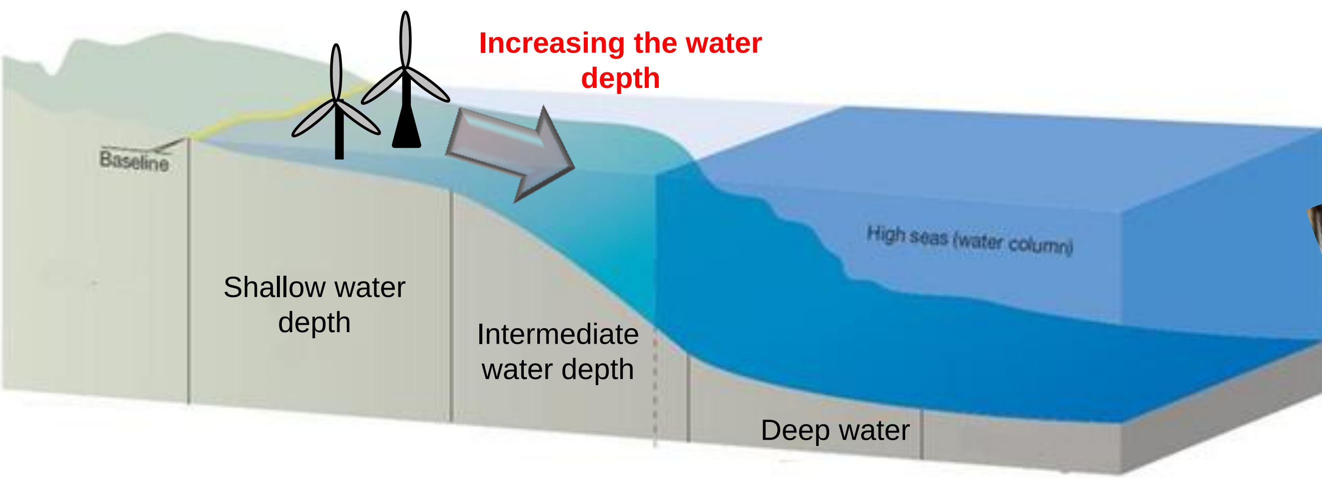
- 150 template platforms belonging to Iran and more than130 template platforms belonging to Arabian countries are installed in the Persian Gulf

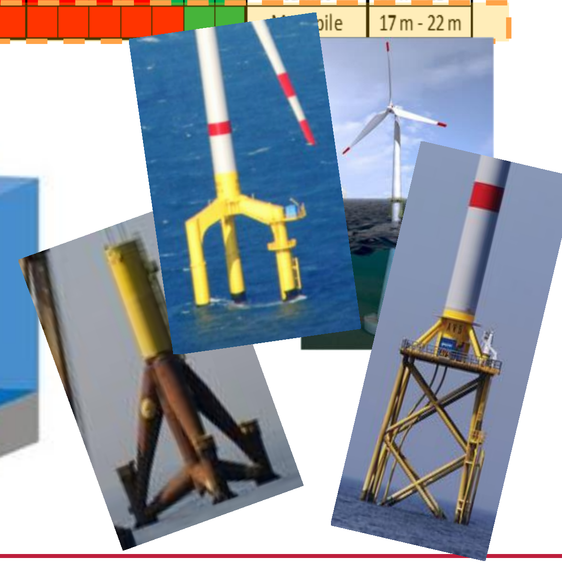
Jacket structures in offshore wind industry

Most operating wind farms have been built using gravity based and monopile foundations:



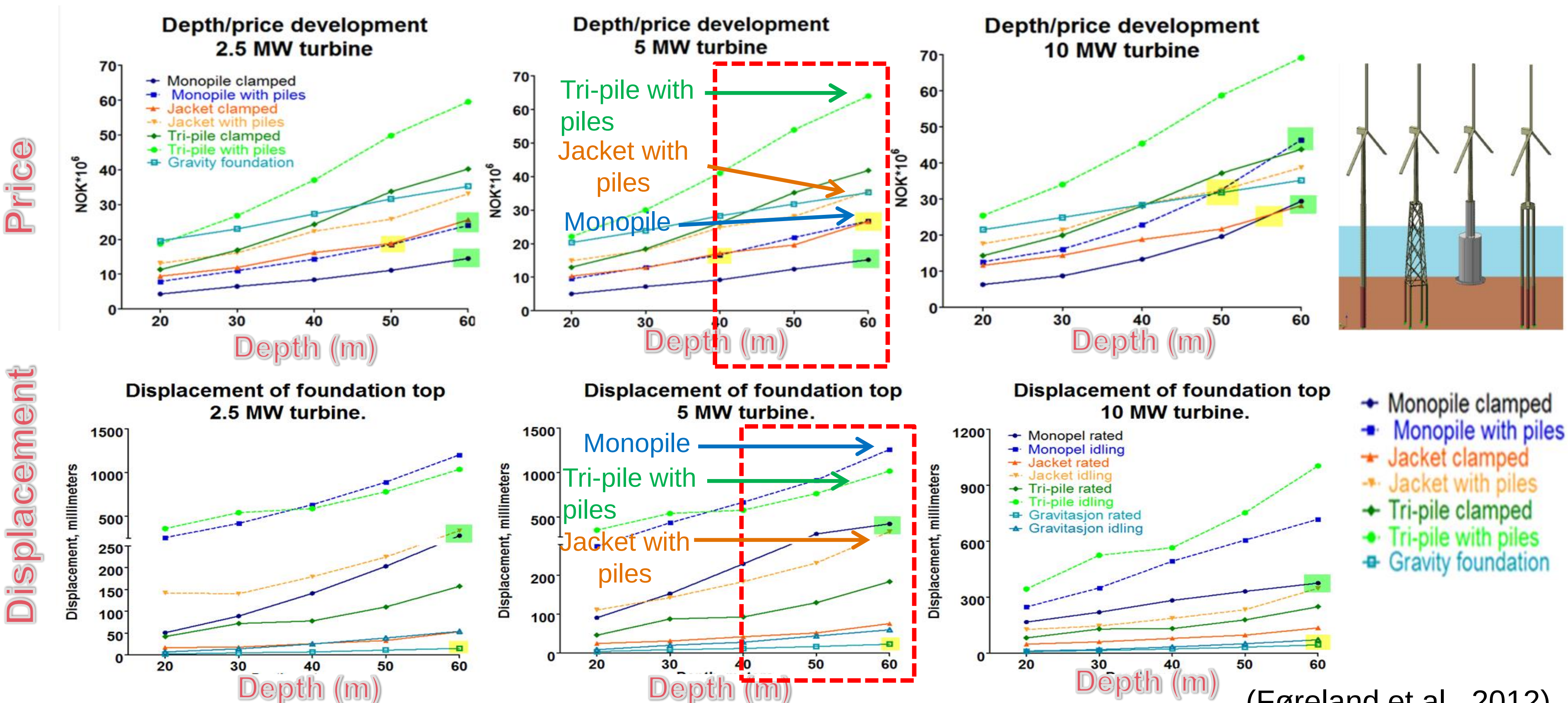
Project	Country	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	Foundation	Water Depth
Horns Rev	Denmark																		Monopile	6 m - 14 m
Nysted	Denmark																		Gravity Base	6 m - 10 m
Scroby Sands	UK																		Monopile	0 m - 8 m
OWEZ	Netherland																		Monopile	15 m - 18 m
C-Power Phase I	Belgium																		Gravity Base	12 m - 28 m
Liligrund	Sweden																		Gravity Base	4 m - 8 m
Prinses Amaliawindpark	Netherland																		Monopile	19 m - 24 m
Alpha Ventus	Germany																		Jacket & Tripod	33 m - 45 m
Belwind I	Belgium																		Monopile	20 m - 37 m
Greater Gabbard	UK																		Monopile	20 m - 32 m
Sheringham Shoal	UK																		Monopile	15 m - 22 m
C-Power Phase 2	Belgium																		Jacket	12 m - 28 m
Butendiek	Germany																		[illegible]pile	17 m - 22 m





Fixed-bottom offshore structures for higher water depth

Comparative study of different fixed-bottom offshore structures for fabrication costs and their dynamic response to non-breaking waves (Føreland et al., 2012)

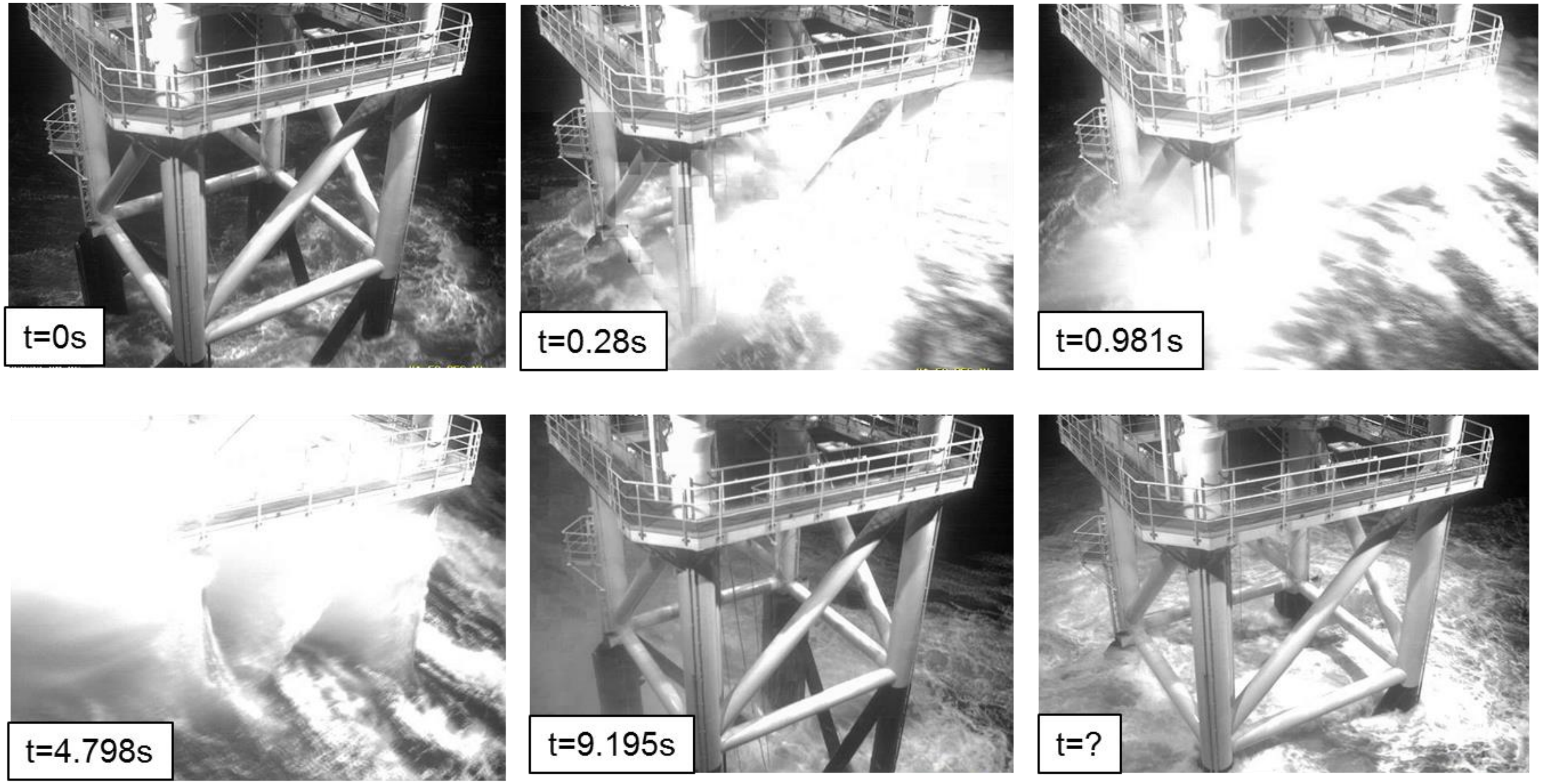


(Føreland et al., 2012)

Breaking wave on a jacket platform

Jackets structures are frequently under extreme loads caused by breaking waves

Breaking wave on the FINO jacket structure



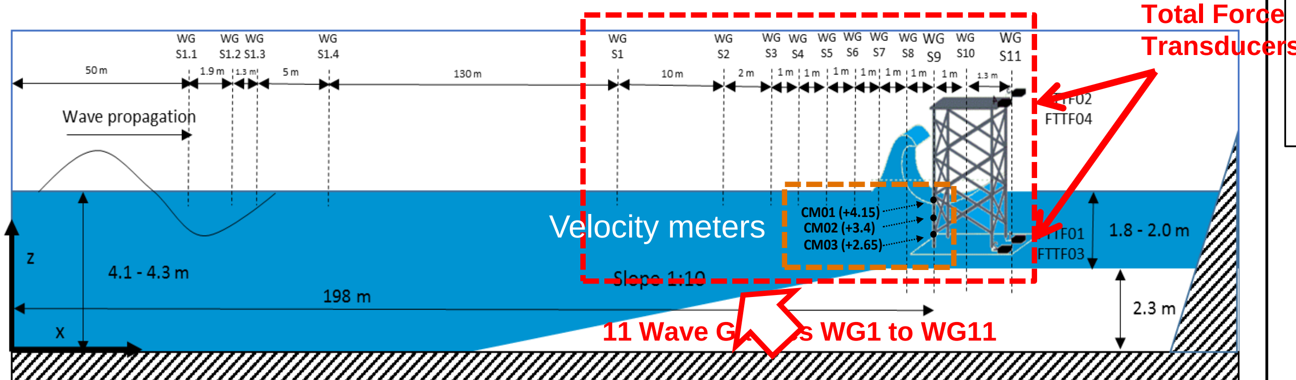
(Germanischer Lloyd, 2009)

Extreme wave loads might cause considerable damage to the structure members and endanger the overall stability of the structure

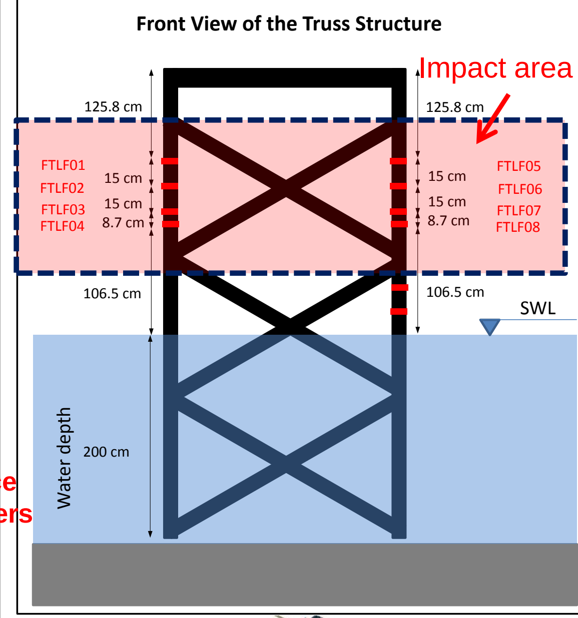
Laboratory tests on a truss structure under breaking waves

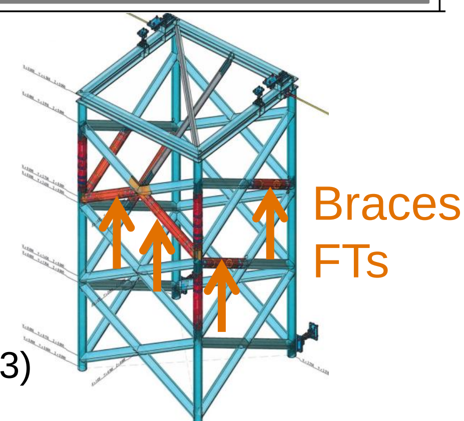
a) wave generation in the large scale wave flume

b) Incident wave approaching the truss structure



c) The model set-up in the large scale wave flume





GWK Tests: large scale model tests in Hannover in frame of the WaveSlam project (2013)

Large scale laboratory tests (GWK tests) – Front View

(WaveSlam project, 2013)

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Objectives

Generation of a knowledge base for a better understanding of the physical processes associated with non-breaking, near-breaking and breaking waves on jacket support structures of wind turbines and the associated dynamic response:

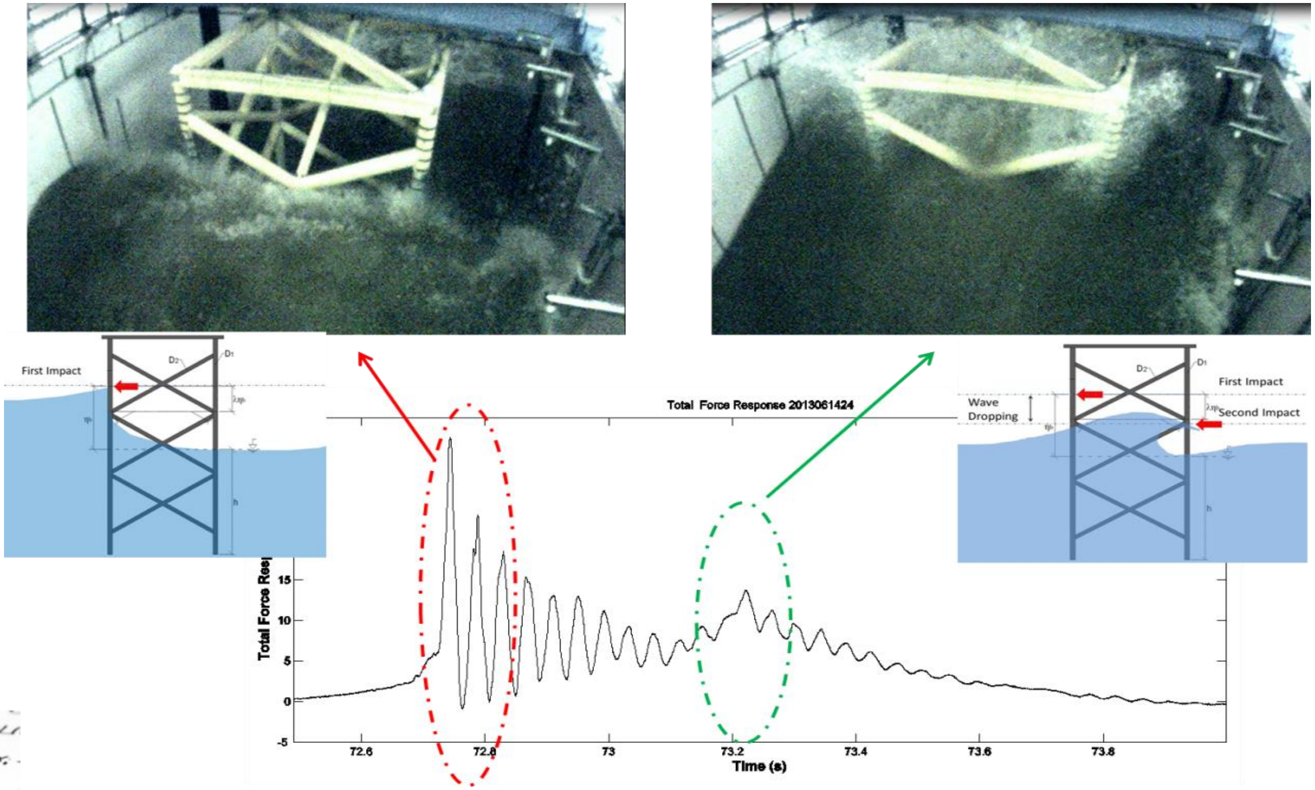
- Provide simple formulae for the prediction of wave loads caused by breaking waves on the front and rear faces of jacket structures as well as on the entire structure
- Improve the understanding of the process involved in the pile-soil interaction for jacket structures under extreme breaking and nonbreaking wave load events.
- Identify the most relevant parameters affecting the dynamic response of jacket structures under breaking and non-breaking wave loads considering pile-soil interaction.

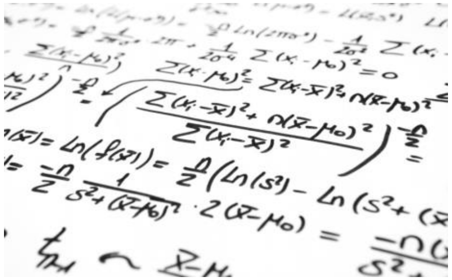
Analysis of GWK tests

Two Impacts on the structure

First Impact: Breaking wave on the front face

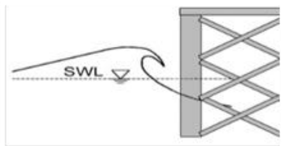
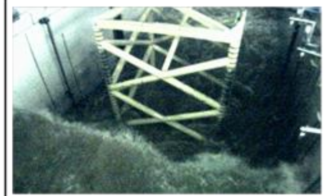
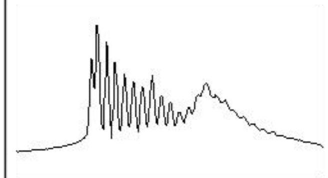
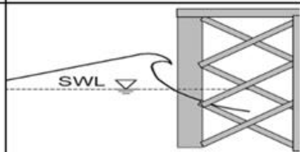
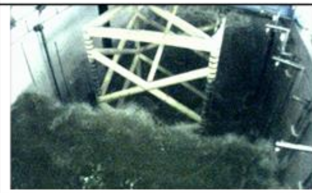
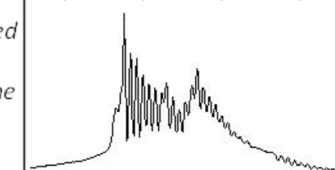
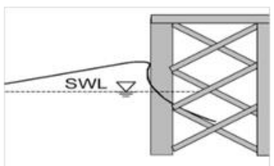
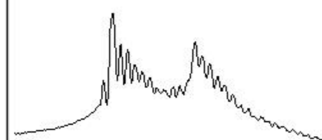
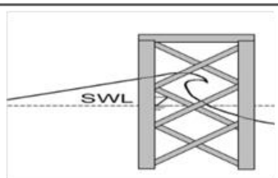
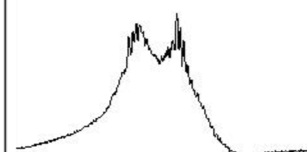
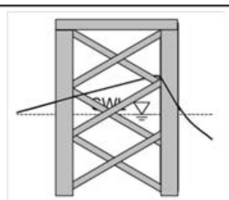
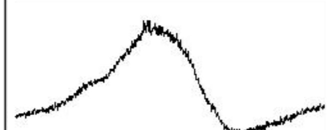
Second Impact: Broken wave on the rear face



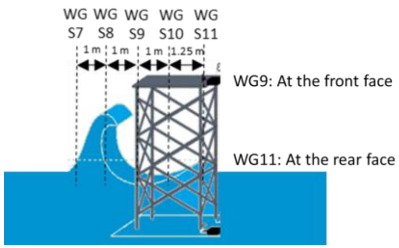


✓ Provide formulae to predict both impact loads on the front and rear faces

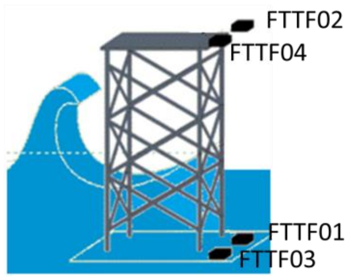
Classification of breaking waves on the truss structure

Loading Case	Definition Sketch	Experiments	Description	Schematic Signal
Load Case 1 Wave breaking far in front of the structure			*Breaker tongue impinges the structure when reaching the trough →broken wave at the structure*	
Load Case 2 Wave breaking in front of the structure			*Breaker tongue inclined →breaking wave at the structure*	
Load Case 3 Wave breaking just at the structure			*Breaker tongue formed at the front face →partial breaking wave*	
Load Case 4 Wave breaking within the structure			*Breaker tongue formed between the first and the second face of the truss structure →partial breaking wave*	
Load Case 5 Wave breaking behind the structure			*Breaker tongue formed behind the structure →non-breaking wave*	

Incipient wave breaking location:

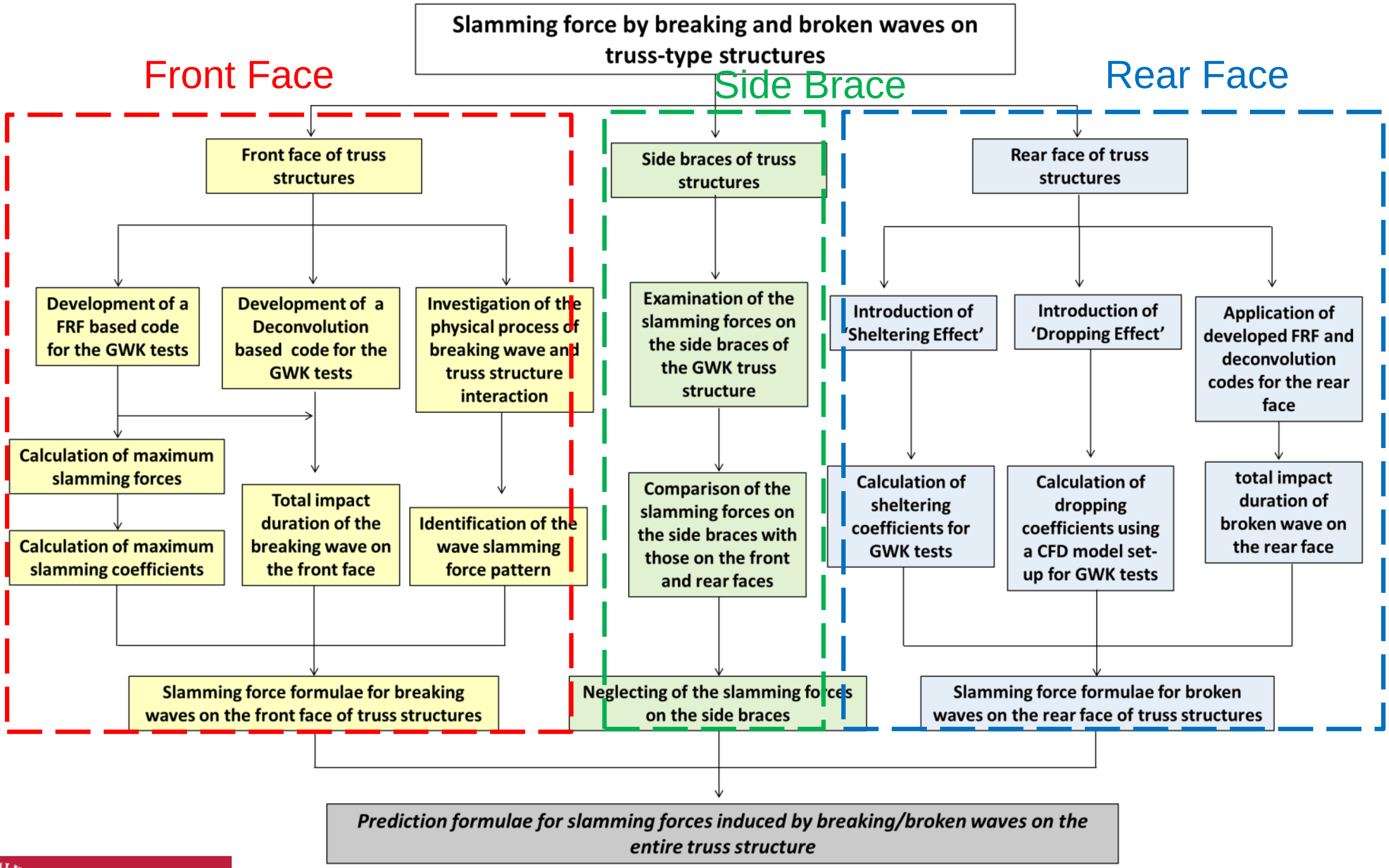


Total Force Response TFR:



Total Force Response = FTTF01 + FTTF02 + FTTF03 + FTTF04

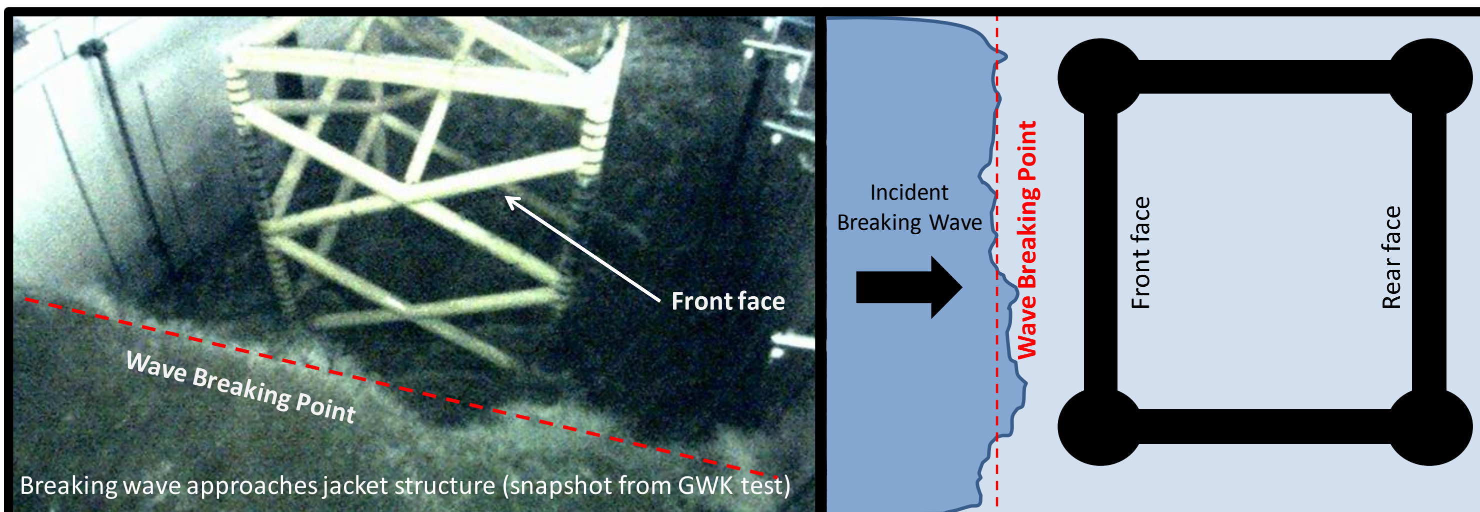
Methodology for formulae to predict slamming forces by breaking/broken waves on entire jacket structure



Breaking wave on the *front face* of the truss structure

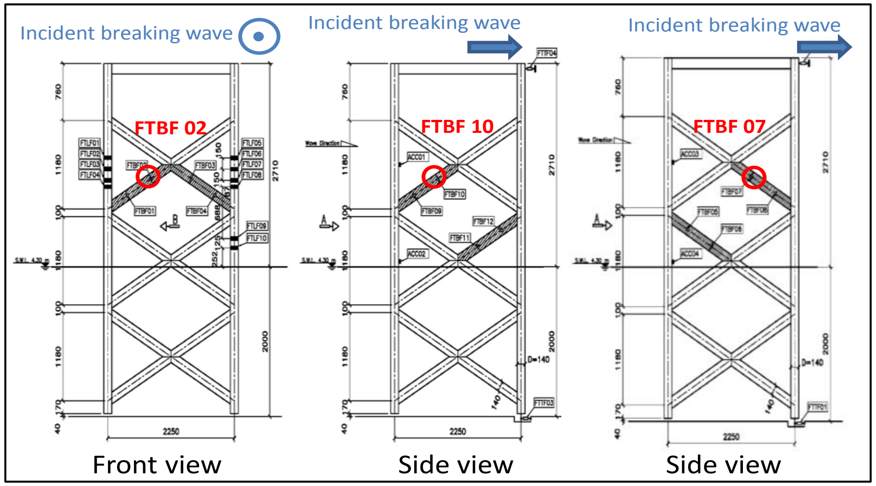
Maximum slamming forces on the front face of the truss structure are calculated

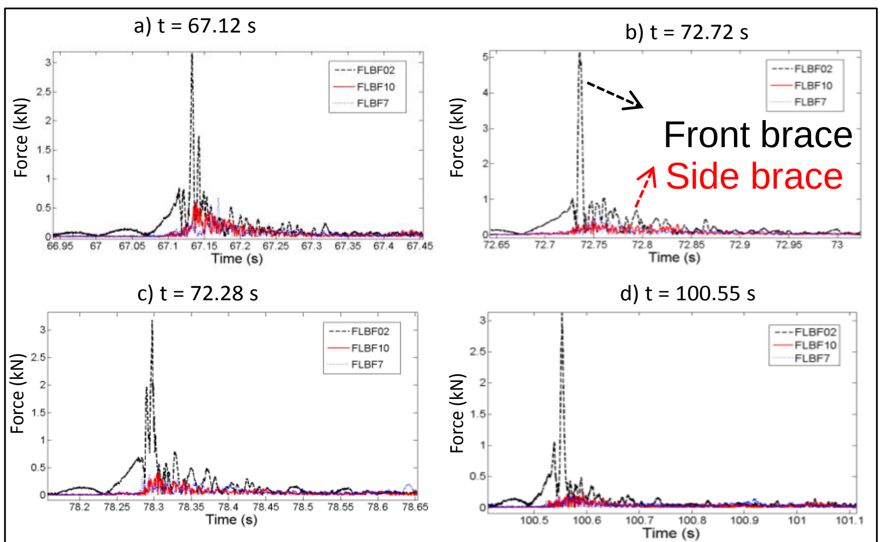
Slamming force model	Wave crest height η_b(m)	Impact area λ (m)	Maximum slamming force on the front face (kN)	Maximum slamming coefficient	Impact duration
Present study	1.44	0.66	12.0	1.63	0.0209
Goda (1966)		0.58	21.6	Π	0.0135
Wienke & Oumeraci (2005)		0.66	49.7	2π	0.0055
Campbell-Weynberg (1980)		0.72	44.3	5.15	0.135



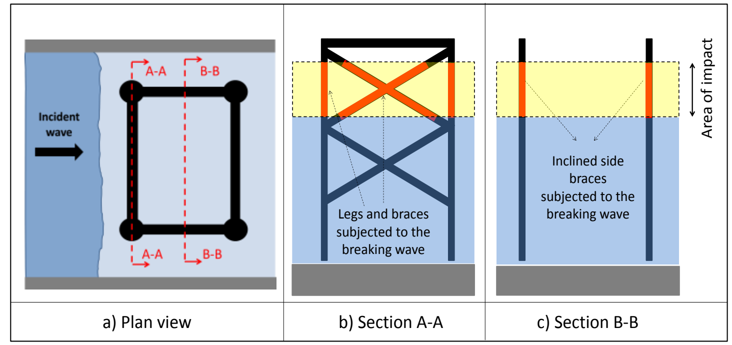
Breaking wave approaches jacket structure (snapshot from GWK test)

Breaking wave on *side braces* of the truss structure

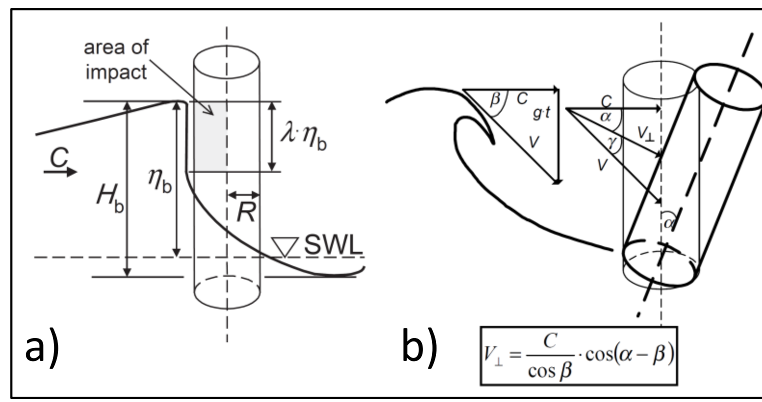




(i)The area of impact on the side braces is much smaller compared to the area of impact for the front and the rear faces



(ii)The inclination of the side braces

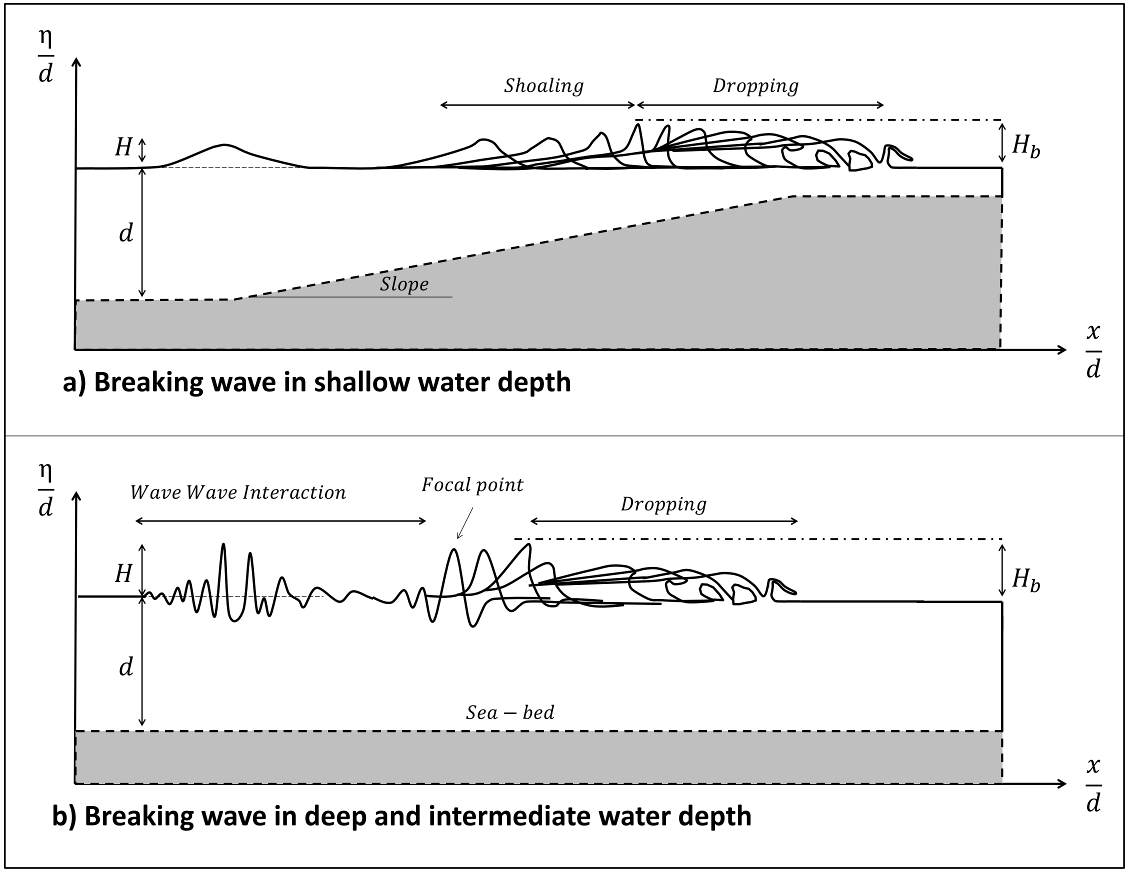


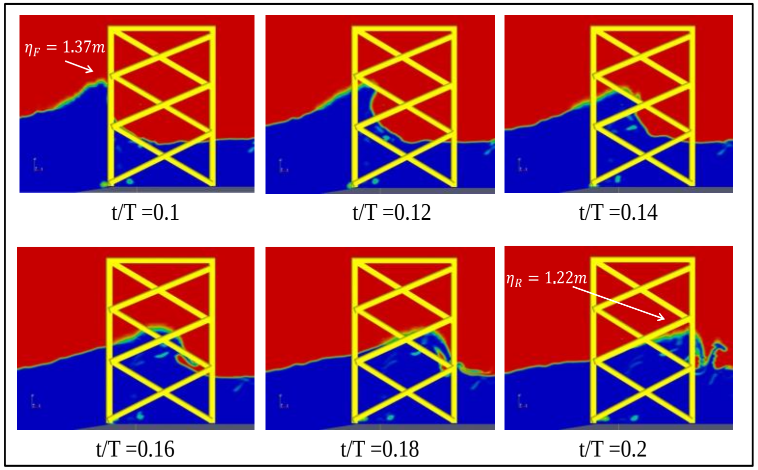
(iii) Sheltering effects

(modified from Wienke & Oumeraci, 2001)

Broken wave on the *rear face* of the truss structure (Dropping Effect)

(i) Dropping effect: After incipient wave breaking location, the wave crest height decreases gradually





Dropping Coefficient:

$$\gamma_D = \frac{\eta_R}{\eta_F}$$

where η_F and η_R are respectively the breaking and broken wave crest heights at the front and the rear faces of the truss structure

Broken wave on the *rear face* of the truss structure (Sheltering Effect)

(ii) Sheltering effect:

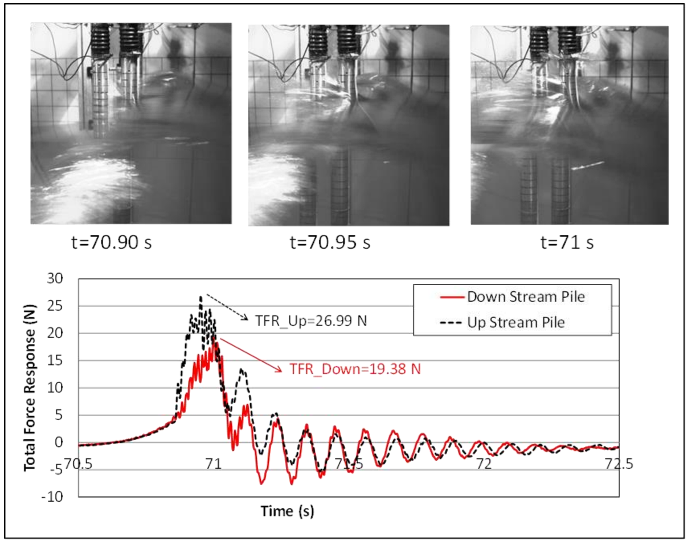
(WaveSlam project, 2013)

When the breaking wave strikes members of the jacket structure on the front face, the water splashes. The breaking wave reaches the rear face of the structure as a broken wave causing a second impact. In general, the second impact is significantly affected by the first impact.

Sheltering coefficient:

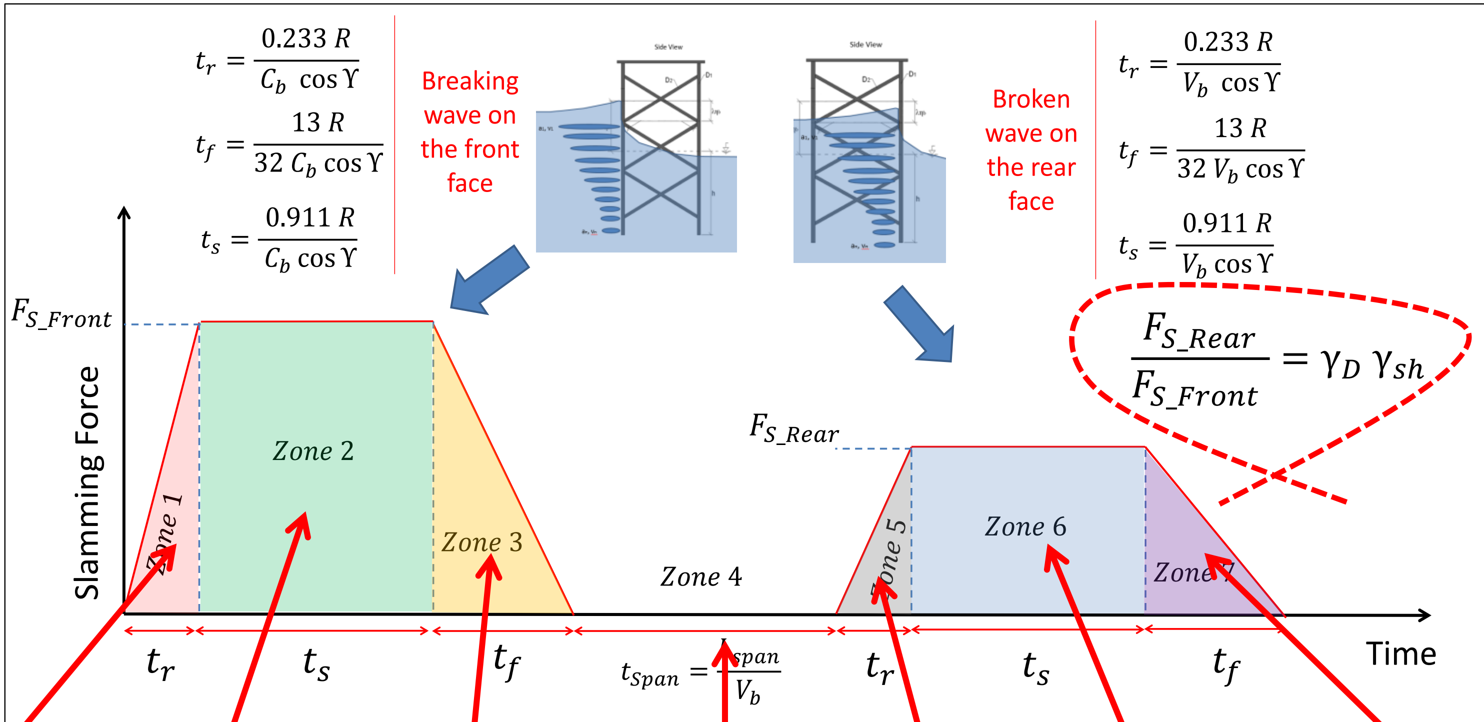
$$\gamma_{sh} = \frac{C_{sR}}{C_{sF}}$$

Where C_{sR} and C_{sF} are maximum slamming force coefficient on the rear and the front faces of the truss structure, respectively



(Bonakdar, 2014)

Slamming formulae for breaking waves on jacket structures



Zone 1: Time required for the impact force to rise from zero to its max value

Zone 2: Successive impacts caused by local impact forces on the front face of the truss structure

Zone 3: Time required for the impact force to decrease (fall) from its max value to zero

Zone4: Time required for the *broken* wave to travel from the front face to the rear face

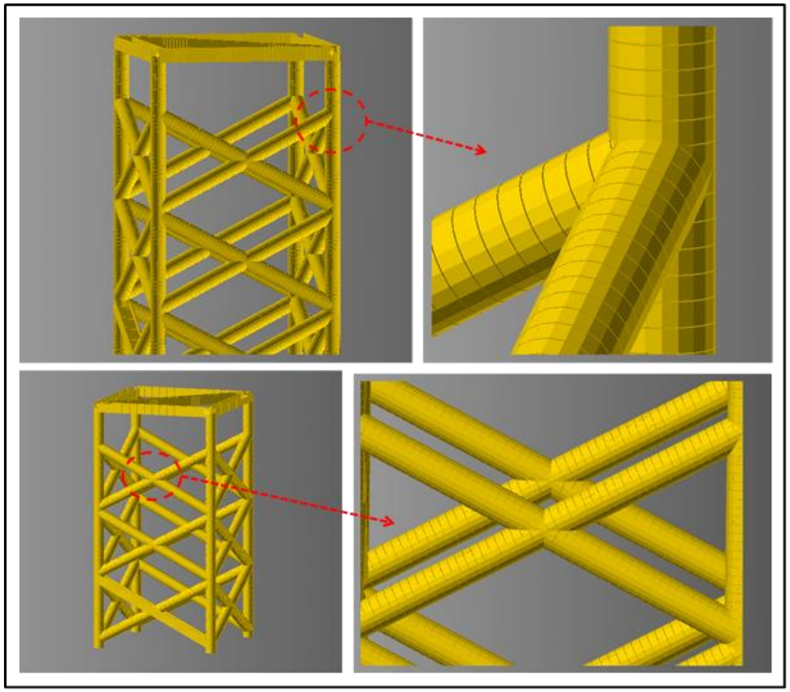
Zone 5: Time required for the impact force to rise from zero to its max value

Zone 6: Successive impacts caused by local impact forces on the rear face of the truss structure

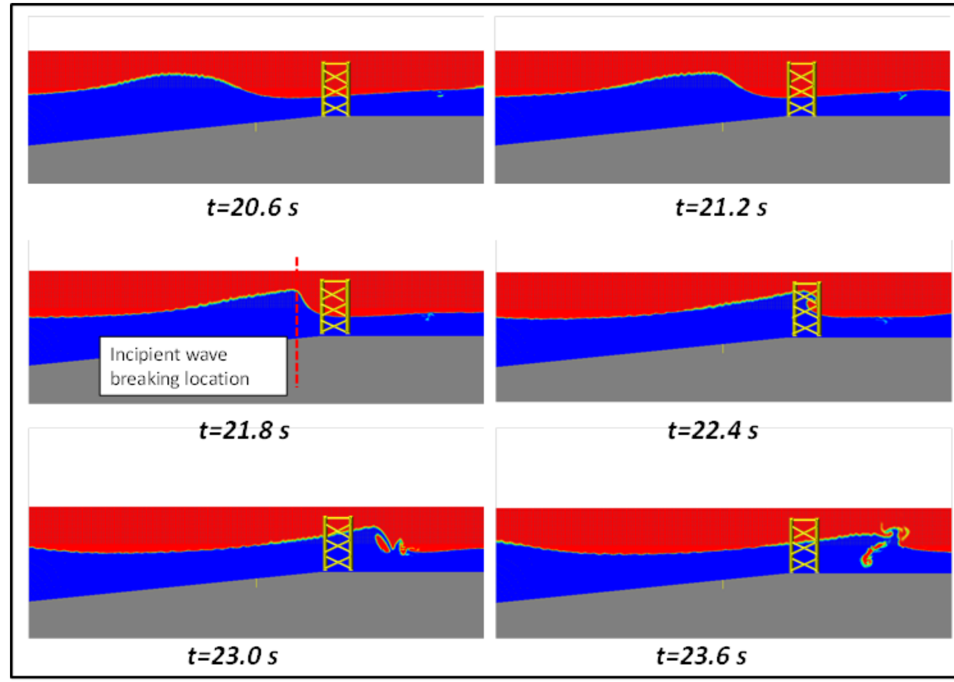
Zone 7: Time required for the impact force to decrease (fall) from its max value to zero

CFD and CSD models for the GWK tests

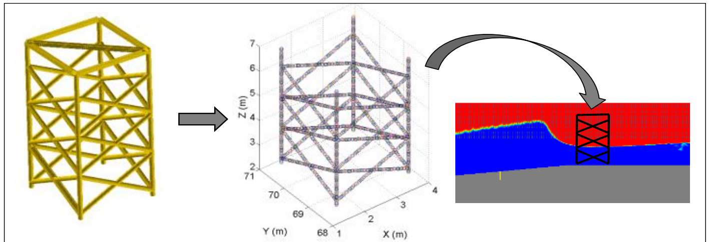
CSD model



CFD model



Discretized



a) Discretization of the CSD model

b) Defined Nodes

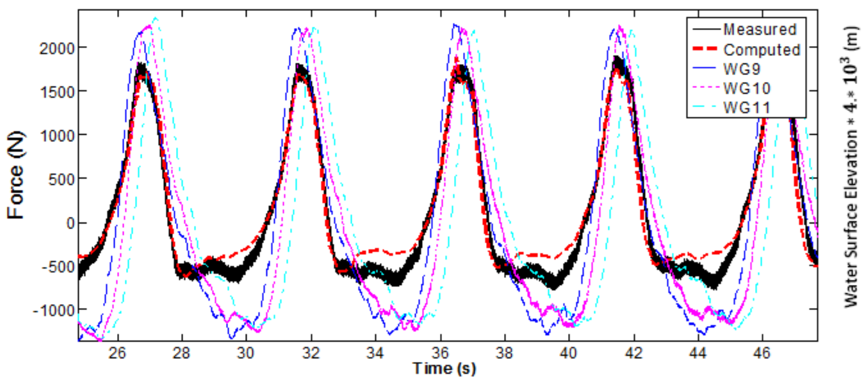
c) Importing the Nodes in the CFD model

Imported

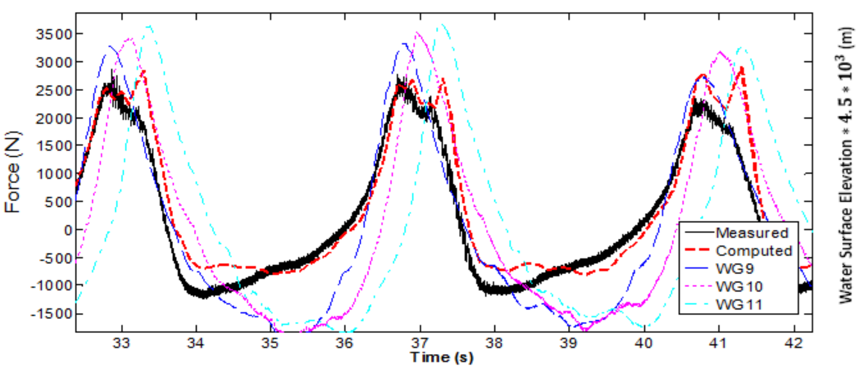
Application of developed approach to reproduce selected wave tests on the GWK truss structure

Non-breaking Waves

a) Test no. 2013061709 (H=0.75 m, T=4.9 s, d=4.3m)

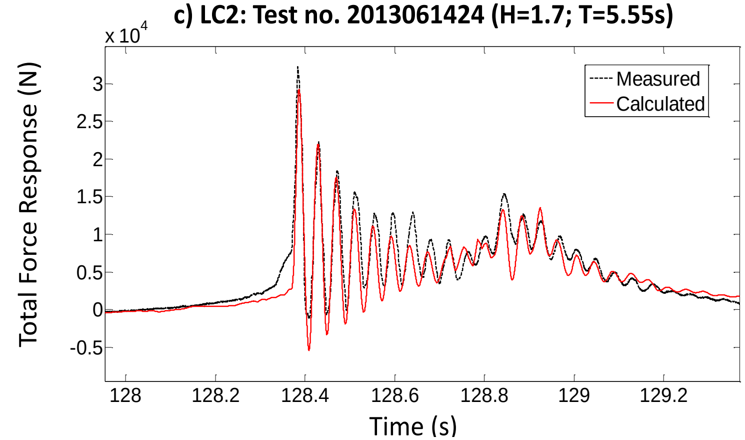


b) Test no. 2013061818 (H=1 m, T=4.0 s, d=4.3m)

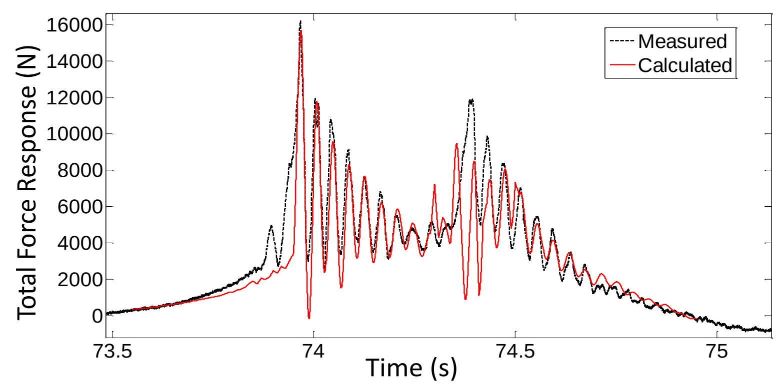


Breaking Waves

c) LC2: Test no. 2013061424 (H=1.7; T=5.55s)

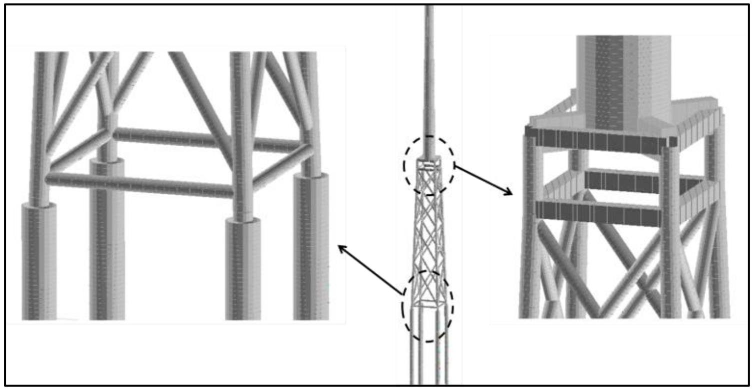


d) LC3: Test no. 2013061402 (H=1.5; T=4.6s)



Application of developed slamming formulae to a full scale jacket

- **A CSD model for OC4 jacket structure with pile foundation model in 50m water depth**
- **A CFD model for different waves approaching the OC4 jacket structure**



Dynamic response of the OC4 jacket structure with pile-soil foundation to breaking wave loads

Wave

(i) Breaking wave load cases (Load cases 1, 2, 3, 4 & 5) *
(ii) Wave slamming force models (e.g. Wienke, Goda, Armand, Campbell, etc.) *

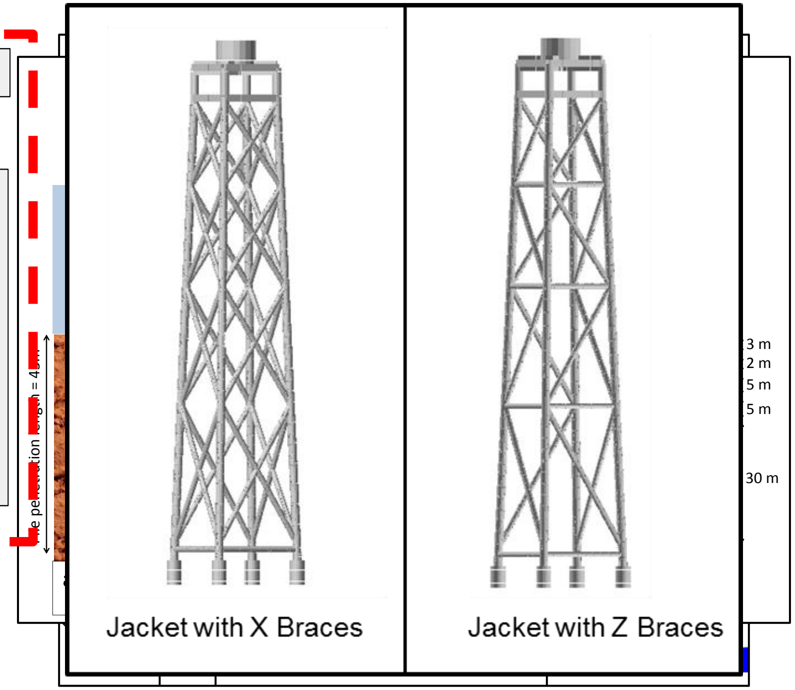
Pile and soil

Effect of:
(i) Soil type (Clay & Sand)**
(ii) Soil non-linearity (Linear & nonlinear soil models)**
(iii) Scour **
(iv) Pile group **

Structure

Effect of:
(i) Legs and braces diameter *
(ii) Geometry of the structure (x and z braces)*
(iii) Top side mass (RNA and concrete block masses) *

** Comparative Study
* Parameter Study



Jacket under breaking wave loads

Dynamic response of the OC4 jacket structure to a breaking wave

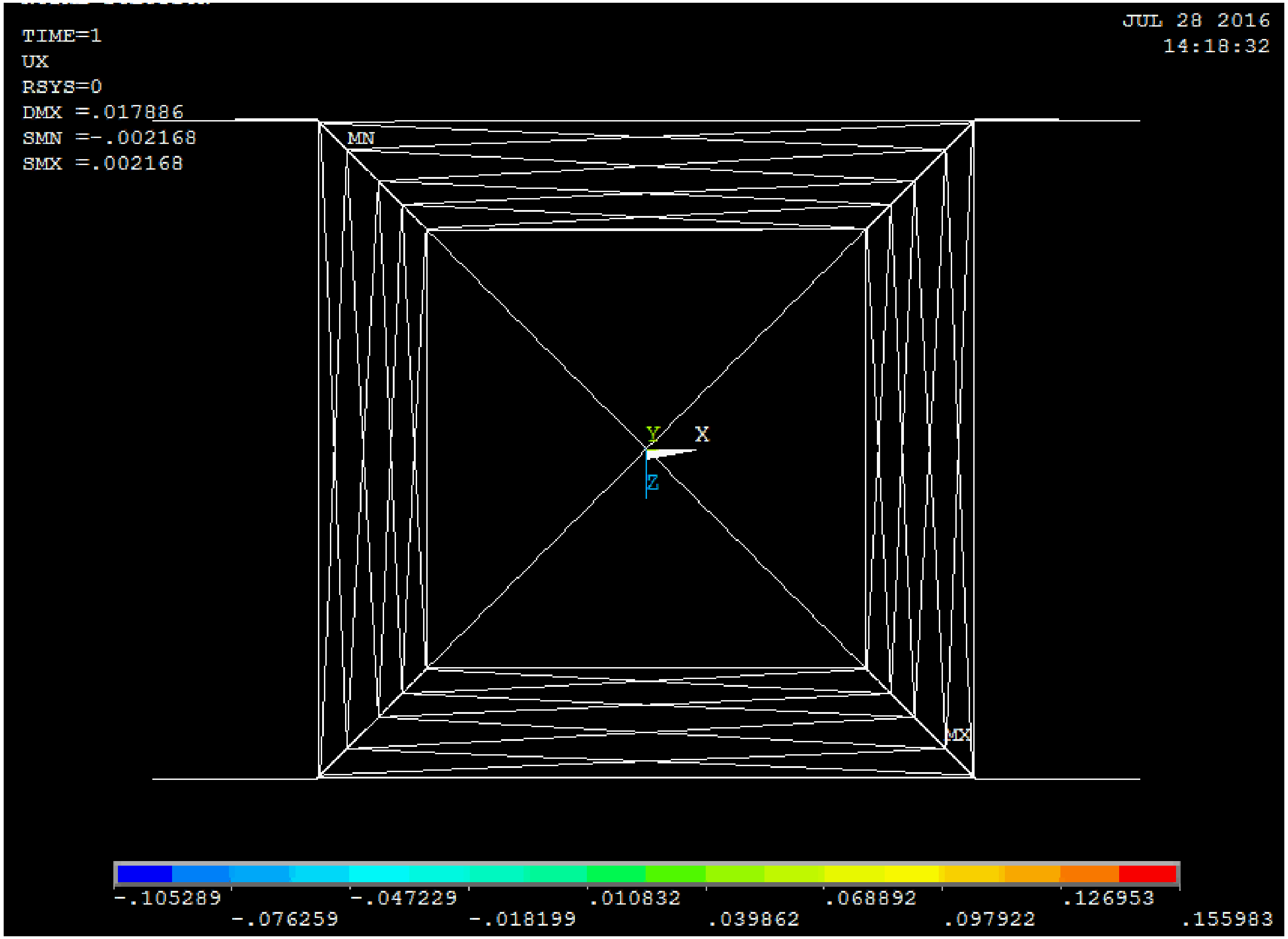
H=10 m

T=10 s

d=50 m

Impact on the front face at t=2.66s

Impact on the rear face at t=3.9s



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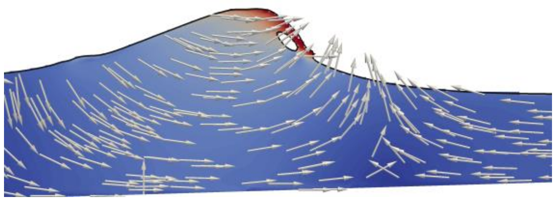
Need for further research and development (1)

(i) Wave characteristics of breaking and broken waves

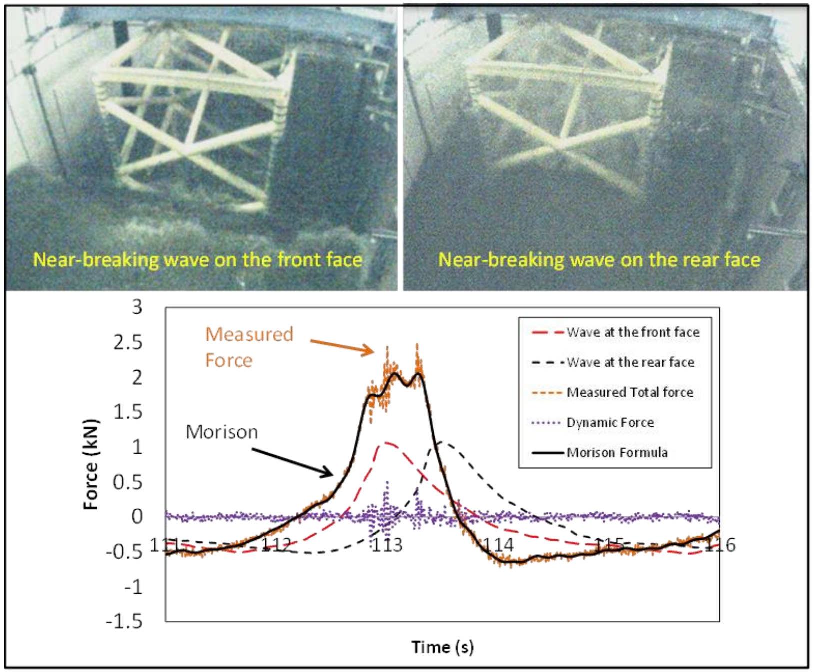


(reef3d.wordpress.com)

Lack of reliable model for the prediction of water surface elevation and wave kinematics of the breaking, broken and post-breaking waves

(ii) Validity range and applicability of Morison Equation

It is not fully clear when the Morison equation can be applied for the calculation of wave loads on jacket structures. The applicability and the validity range of the Morison equation become questionable with increasing wave non-linearity

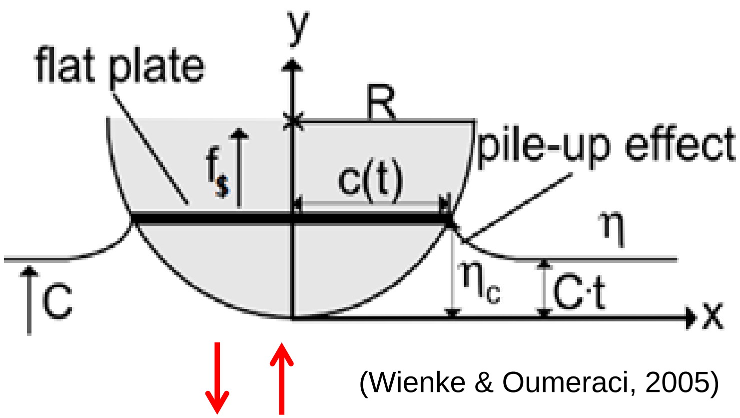


H=1.1m, T=4s, d=4.3m

Need for further research and development (2)

(iii) Wave slamming force on flexible/moveable piles

the available slamming models for the prediction of slamming forces on single piles (e.g. Wienke & Oumeraci, 2005; Goda, 1966; etc) are developed with the assumption that the structure is rigid. Consideration of moveable/flexible/deformable slender piles might affect the process involved in the interaction of breaking wave and slender piles



(Wienke & Oumeraci, 2005)

Moveable body???

Deformable body???

(iv) Effect of neighbouring members on the wave loading of a member of the jacket

The lack of a proper understanding of the effect of neighbouring members on the wave loading of a member of the jacket structure. Since the members of the jacket structures are closely spaces, the wave load on a single slender pile is significantly affected by the neighbouring piles and can thus not be calculated by the commonly applied formulae for a single isolated pile.

Thank You for Your Attention

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