Ship motion numerical model

FOREWORD

This program allows the calculation of the motions of a given type of vessel in response to the wave forces acting on the ship. The frequency response functions are provided by the PDSTRIP (Public Domain Strip Method) program developed by H. Söding and V. Bertram. Time series of motions are then calculated on the basis of these response functions.

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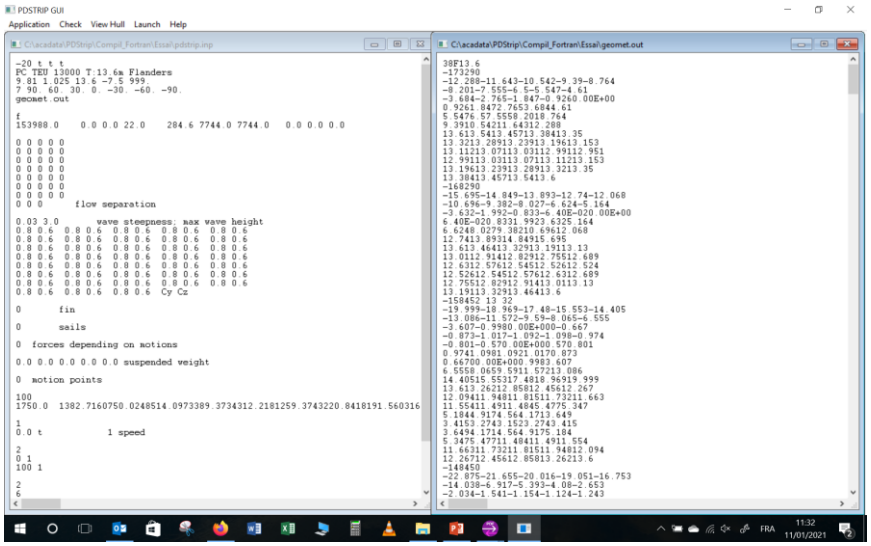
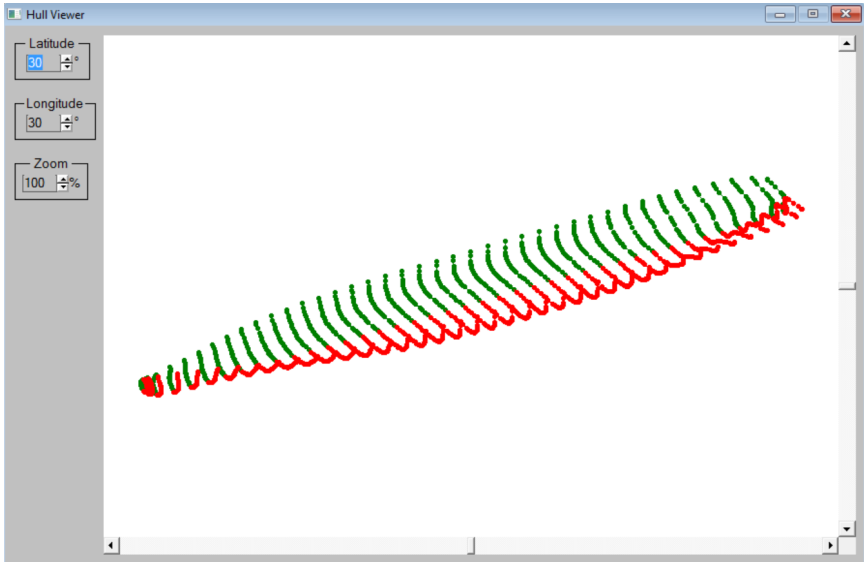
Program PDSTRIP (Public Domain Strip Method*)





PDSTRIP computes from the ship's characteristics (cross-sectional strips of the wetted hull, displacement, position of centre of gravity, radii of gyration…) the following responses:

- RAOs of ship's motions
- Hydrostatic values
- Added masses
- Radiation damping values
- First order wave forces
- Drift forces

Added masses, damping values, wave loads have to be computed on a large frequency range (about 0.05 to 5 rad/s).

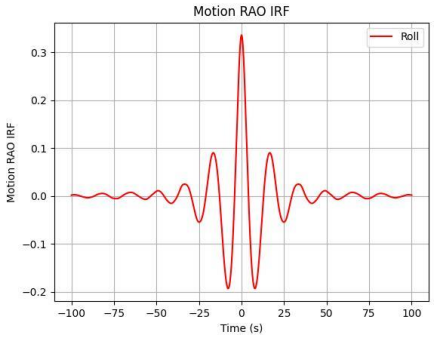
(*) For more information, see: Söding H. and Bertram V., "Program PDSTRIP: Public Domain Strip Method", April 2009

Ship motion numerical model

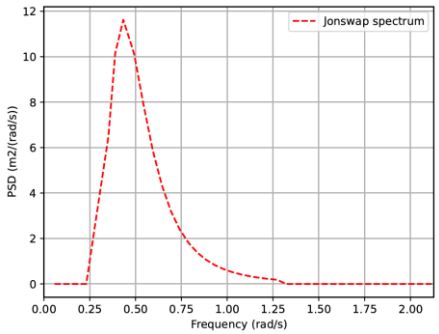
From the RAOs of ship motions, the following elements are obtained:

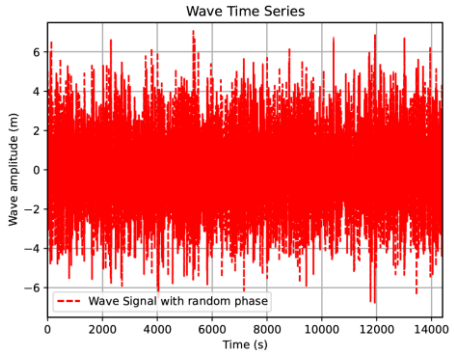
- The impulse response function ("IRF") of motion RAO values
- Random wave and Ship's motion time series according to different options:
  - With random phase, on the basis of Hs, Tp and different spectrum density models (Jonswap, Bretschneider, Torsethaugen, McCormick, OchiHubble, Wallop)
  - With the Fast method, on the basis of Hs, Tp and different spectrum density models (Jonswap, Bretschneider, Torsethaugen, McCormick, OchiHubble, Wallop)
  - With random phase, on the basis of Hs, Tp and a specific density spectrum
  - Other options for wave time series: input as a specific file
- Tables of results (min, max, 1/3, 1/10 values)

Motion RAO IRF

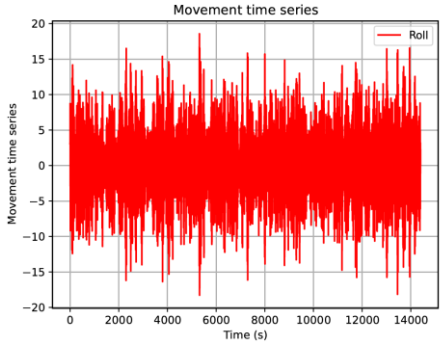


Spectrum density model





Wave time series



Motion time series

Comparison with published model tests

Note: The comparison is always a challenge insofar as when going into the details of things, we realize that some parameters may be missing or are known with a certain approximation. This comparison, even imperfect, however makes it possible to ensure that the numerical model gives results with good orders of magnitude.

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Ultra Large Container Ship (from ref.[1])

Test cases (see details in reference [1]):

- **Partly loaded ULCS (18400 TEU)**
- **Water depth of: 21.3m, 26.6m, 37.5m, deep water**
- **Waves perpendicular to the ship course, with significant wave height between 5.2m and 7.5m and peak period between 11.8s and 14.5s**
- **Wind effect not considered**

References:

- **[1]: MARIN, "Behaviour of an Ultra Large Container Ship in shallow water", Volume 1 – Discussion report, R 31847-1-OB V1.4, June 2020**
- **[2]: MARIN, "Further investigations into the Behaviour of Container Ships in Storms above the Wadden Islands", Summary report, R 32558-1-DIR V1.2, September 2020**

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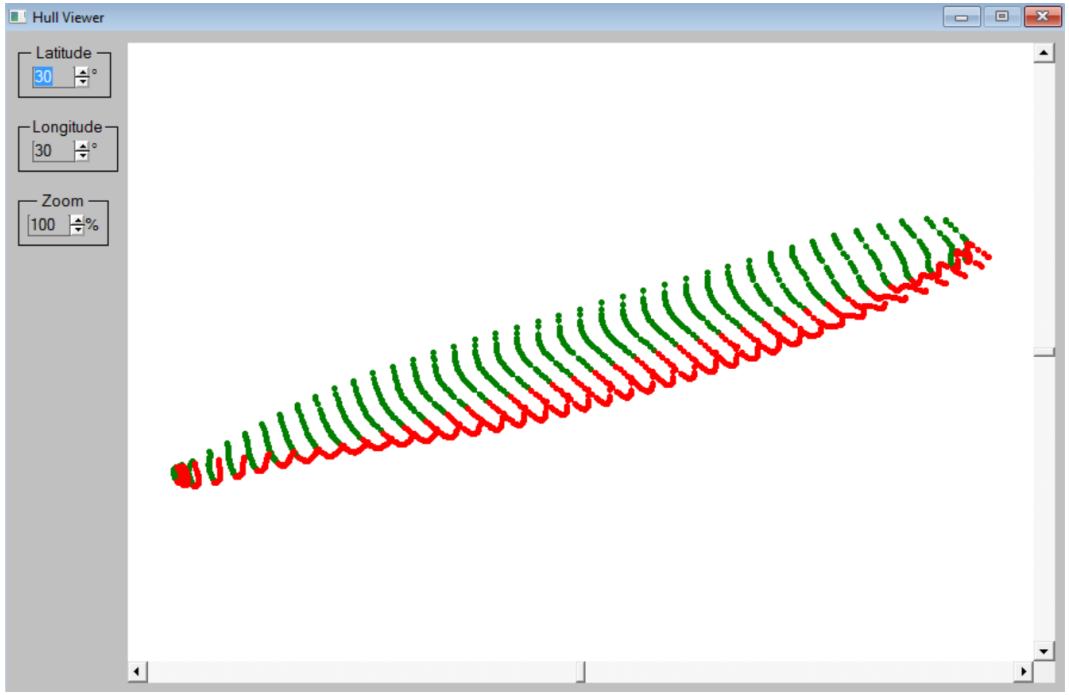
PARTICULARS OF THE ULCS:

- TABLE HEREAFTER GIVES ORIGINAL DATA AND DATA FROM PDSTRIP SCHEMATISATION
- FREQUENCY RANGE FOR CALCULATION: 0.078 – 2.13 RAD/S

Dimensions of ship		
Ship	ULCS	PDSTRIP
Length overall submerged (m)	381.6	381.4
Length between perpendiculars (m)	379.4	383.5
Beam (m)	59	59
Draught (m)	12.3	12.3
Displacement (m3)	183400	180299
Block coefficient	0.66	0.648
Height of Centre of Gravity KG (m)	22.7	23.3 (*)
Longitudinal Centre of Gravity (m)	190.7	190.7
Transverse Metacentric Height GM (m)	9.05	9.05
Roll Radius of Gyration (m)	21.6	21.6
Pitch Radius of Gyration (m)	98.5	98.5
Yaw Radius of Gyration (m)	99.2	99.2
Height of bilge keels (m)	0.4	0.4
Length of bilge keels (m)	104.3	104.3
Water depth (m)	Variable	Variable

(*) KG slightly changed to obtain a more appropriate GM value



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Vessels tested at MARIN: ULCS, Panamax and Feeder
(FROM REF.[1])

TEST CASES (SEE DETAILS IN REFERENCE [2]):

- LOADED PANAMAX SHIP
- WATER DEPTH OF: 21.3M, 26.6M, 37.5M
- WAVES PERPENDICULAR TO THE SHIP COURSE, WITH SIGNIFICANT WAVE HEIGHT BETWEEN 5.2M AND 7.5M AND PEAK PERIOD BETWEEN 10.2S AND 13.2S
- WIND EFFECT NOT CONSIDERED

REFERENCE:

- [2]: MARIN, "FURTHER INVESTIGATIONS INTO THE BEHAVIOUR OF CONTAINER SHIPS IN STORMS ABOVE THE WADDEN ISLANDS", SUMMARY REPORT, R 32558-1-DIR V1.2, SEPTEMBER 2020

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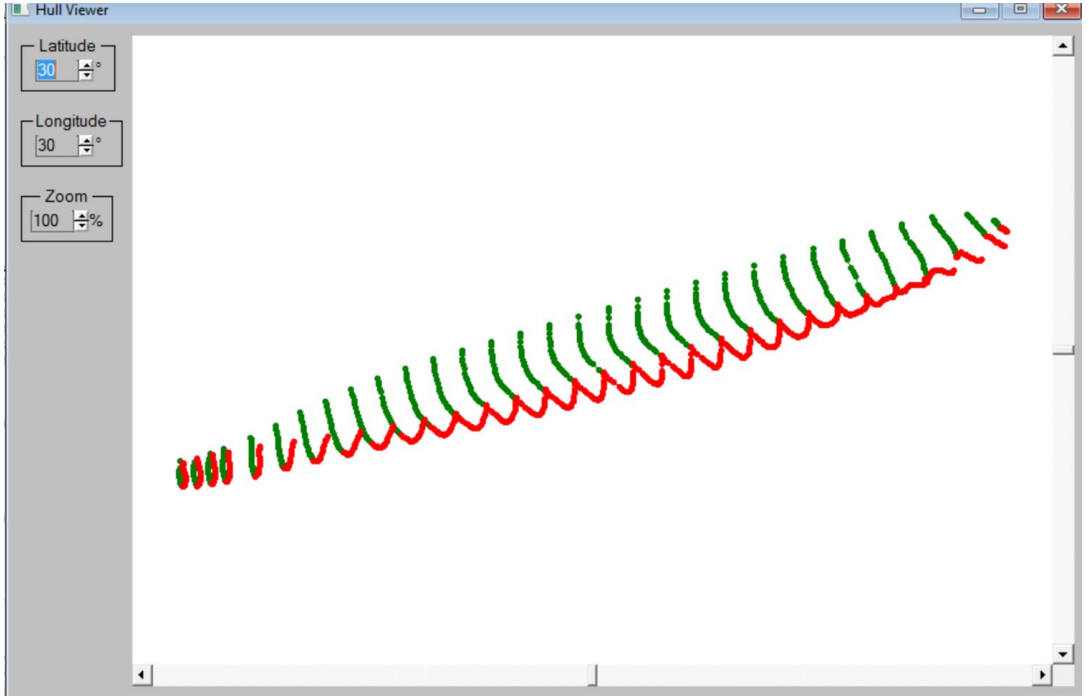
Particulars of the Panamax ship:

- Table hereafter gives original data and data from PDSTRIP schematisation
- Frequency range for calculation: 0.078 – 2.13 rad/s

Dimensions of ship		
Ship	Panamax	PDSTRIP
Length overall (m)	?	289.4
Length between perpendiculars (m)	278	278
Beam (m)	32.2	32.2
Draught (m)	12.2	12.2
Displacement (m3)	70324	70634
Block coefficient	0.63	0.631
Height of Centre of Gravity KG (m)	?	12.4
Longitudinal Centre of Gravity (m)	134.8	134.1
Transverse Metacentric Height GM (m)	1 or 2.5	1 or 2.5
Roll Radius of Gyration (m)	?	13.2(*)
Pitch Radius of Gyration (m)	?	72.3
Yaw Radius of Gyration (m)	?	72.3
Height of bilge keels (m)	0.4	0.4
Length of bilge keels (m)	77.5	77.5
Water depth (m)	Variable	Variable

(*) Roll radius of gyration adapted to obtain a natural roll period of 18.4s with a GM value of 2.5m at a water depth of 21.3m



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Uncertain inputs and differences:

- Body plan used for the ULCS is not exactly the same as used for the model tests. The body plans for the panama and feeder ships were not known and for these two ships, some information was lacking, such as radii of gyration, vertical position of centre of gravity, amidships and prismatic coefficients,…
- All the calculations carried out with long-crested waves, as the results of model tests were given for short-crested waves. According to the model tests, in comparison with short-crested waves, long-crested waves show an increase of approximately 30% for sway and heave motions and a slight increase of maximum 9% in roll response.
- Model tests at zero speed were performed with the model restrained fore and aft by means of soft springs. The characteristics of the soft spring set-up were chosen in such a way that the influence on the ship motions was reduced to a minimum.
- The references provide only a summary of the findings of the complete studies. Details of the wave conditions reproduced in the basin (such as wave time series, spectral shapes…) were not known.
- Results of the roll decay tests for the ships were not known. The damping from the bilge keel was then obtained in the PDSTRIP calculations according to the characteristics of the bilge keel (position, span, chord) and also to the different coefficients (especially for the cross-flow resistance) given in the following reference: Saad B., “Development of a practical tool to determine the hull damping of modern ship hull forms”, Master thesis EMSHIP, Ref. 159652-1-2009-1-BE-ERA MUNDUS-EMMC, February 2014

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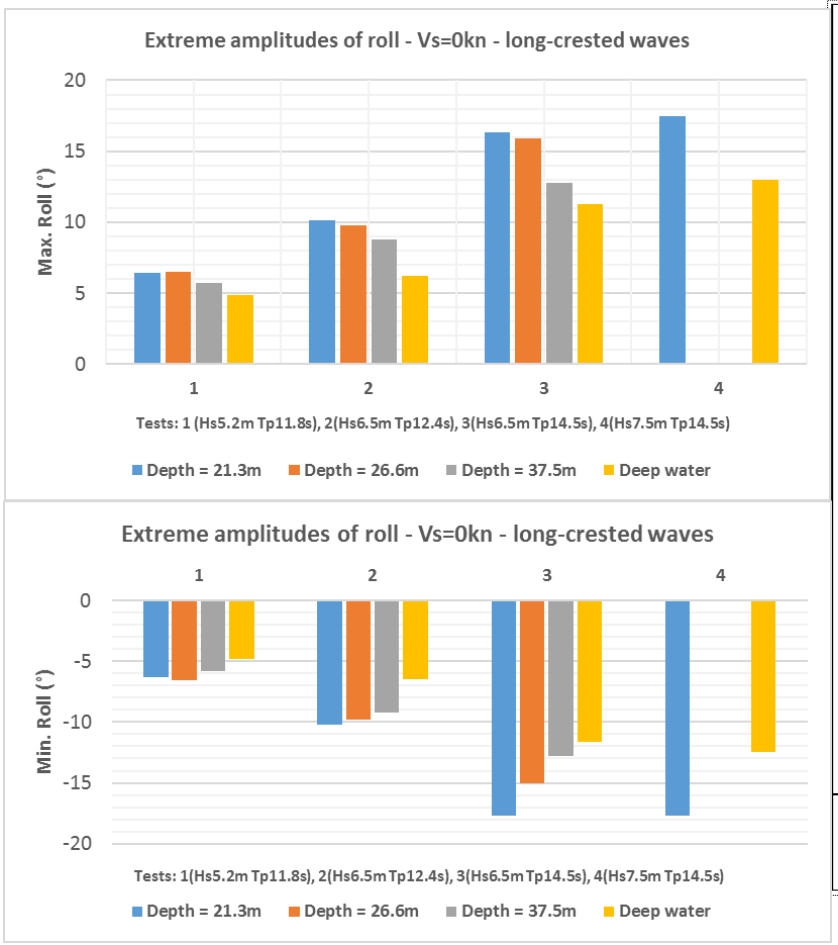
ULCS - Roll Motions

Measured minimum and maximum roll motions are presented in ref.[1]. In the following figures, are shown the calculated minimum and maximum roll motions in comparison with the scale model tests results. Although long-crested waves show a slight increase of maximum 9% in roll response in comparison with short-crested waves, no correction was applied to the calculated values.



***PDSTRIP* numerical results**

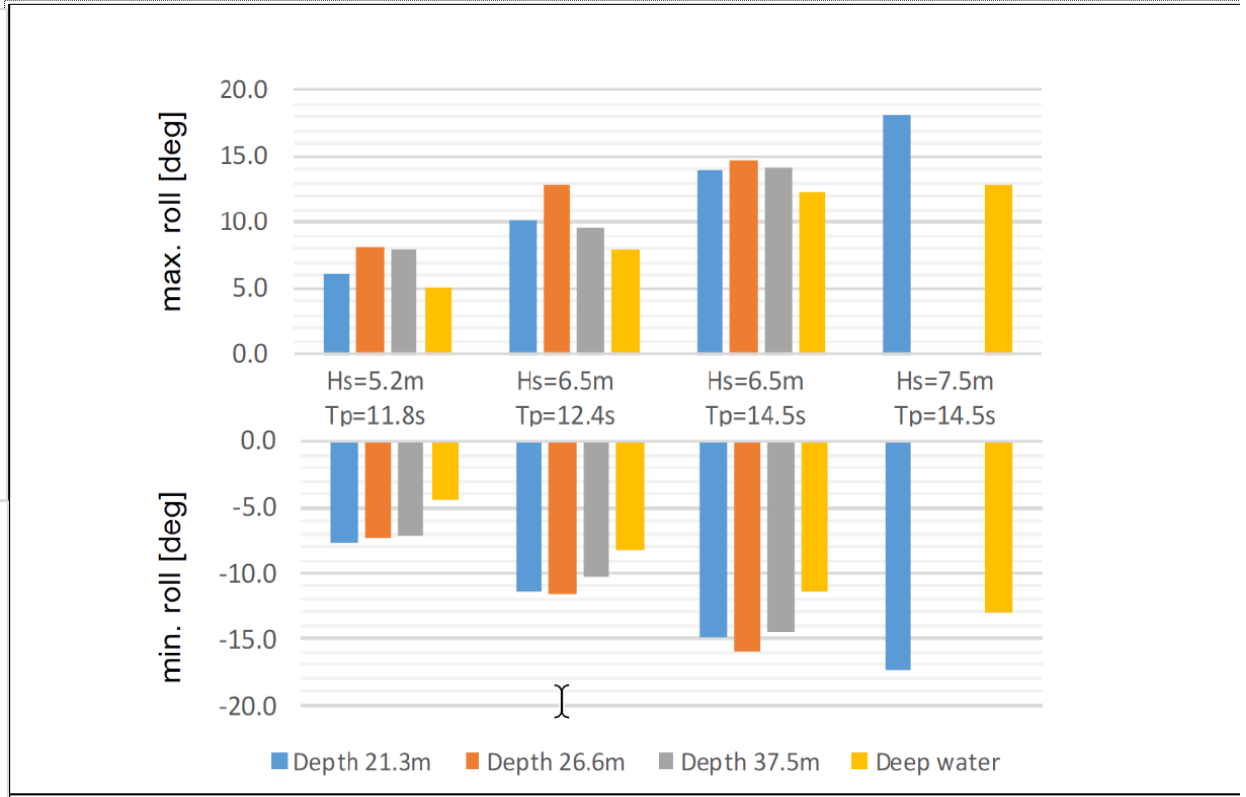


Figure 46: Extreme amplitudes of roll Vs = 0 kn, short-crested waves (Source MARIN)

Note: tests in waves of height 7.5m were only performed for depths 21.3m and deep water.

Scale model tests results (from ref.[1])

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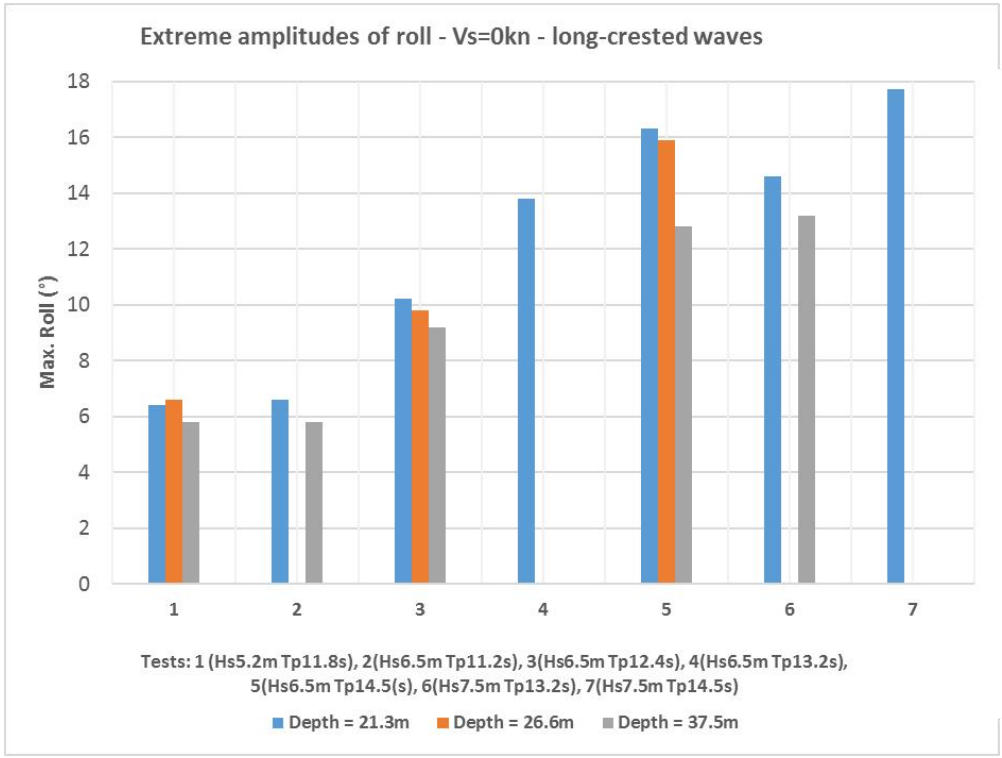
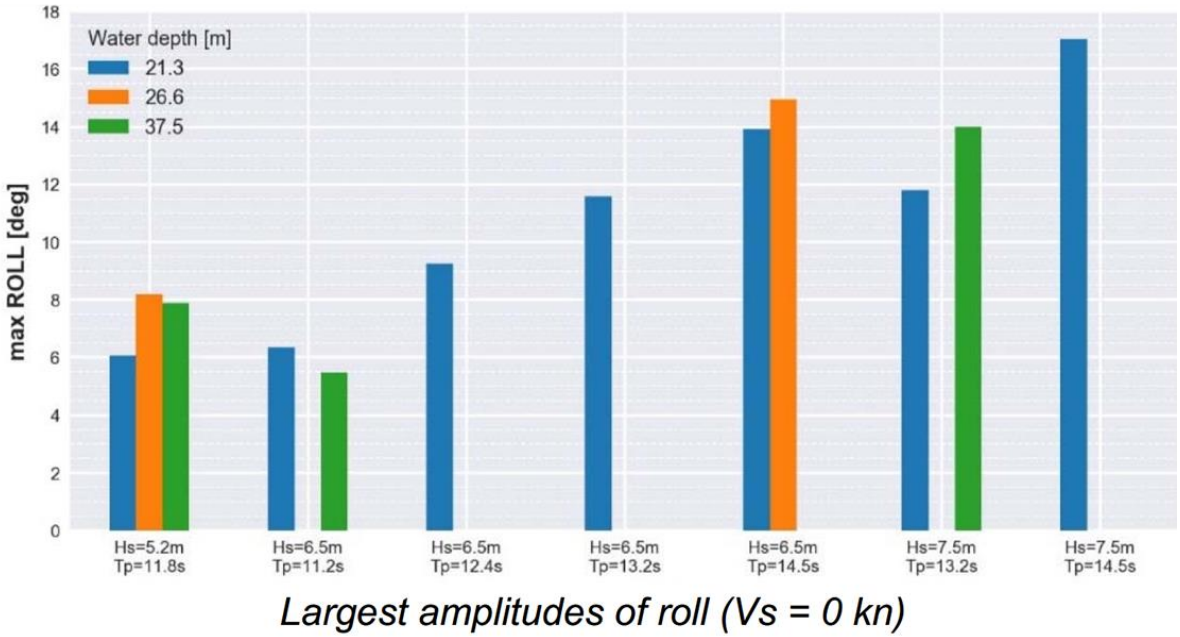
ULCS - Roll Motions

Measured maximum roll motions are also presented in ref.[2]. In the following figures, are shown the calculated maximum roll motions in comparison with the scale model tests results. Although long-crested waves show a slight increase of maximum 9% in roll response in comparison with short-crested waves, no correction was applied to the calculated values.





PDSTRIP numerical results

Scale model tests results (from ref.[2])

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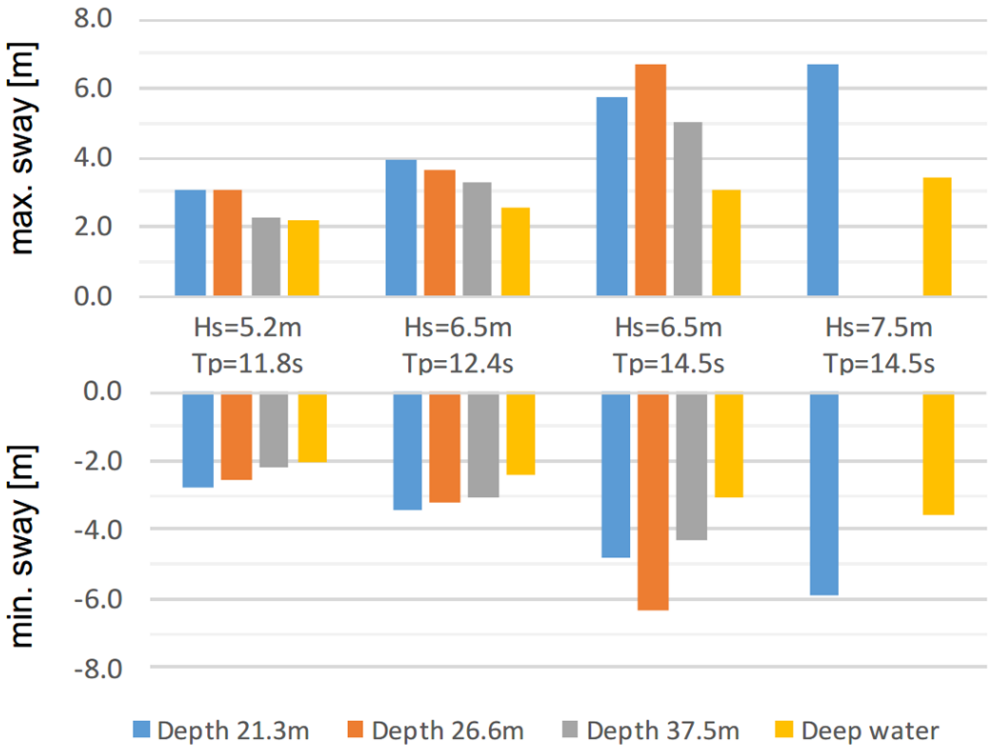
ULCS – SWAY MOTIONS

MEASURED MINIMUM AND MAXIMUM SWAY MOTIONS ARE PRESENTED IN REF.[1]. IN THE FOLLOWING FIGURES, ARE SHOWN THE CALCULATED MINIMUM AND MAXIMUM SWAY MOTIONS IN COMPARISON WITH THE SCALE MODEL TESTS RESULTS. ALTHOUGH LONG-CRESTED WAVES SHOW AN INCREASE OF APPROXIMATELY 30% IN SWAY RESPONSE IN COMPARISON WITH SHORT-CRESTED WAVES, A CORRECTION WAS APPLIED ACCORDINGLY TO THE CALCULATED VALUES.

PDSTRIP NUMERICAL RESULTS



Extreme amplitudes of wave-frequency sway
Vs = 0 kn, short-crested waves.

SCALE MODEL TESTS RESULTS (FROM REF.[1])

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ULCS

Comments on the results obtained for the ULCS:

- ***Roll motions:***
  - ***As per the scale model tests, the ship shows the largest roll motion in waves of peak period 14.5s. In beam waves of significant height 6.5m and peak period 14.5s, the ship exhibits also with the numerical model a rolling behaviour with amplitudes up to 16 deg. When the wave height is increased to 7.5m, the roll amplitudes reach also 17° to 18° with the numerical model. Nevertheless, with the scale model, the water depth of 26.6m shows the largest roll amplitudes from all tested depths as with the mathematical model, the water depth of 21.3m is noted to yield highest rolling behaviour from all four water depths with a decrease in motion observed in deeper waters.***
- ***Sway motions:***
  - ***As per the scale model tests, the sway motion is largest in the shallowest condition and lowest in deep water. It is also found to increase with wave height and wave peak period. Slightly highest values are found with the mathematical model in comparison with the scale model tests for the peak period 14.5s.***

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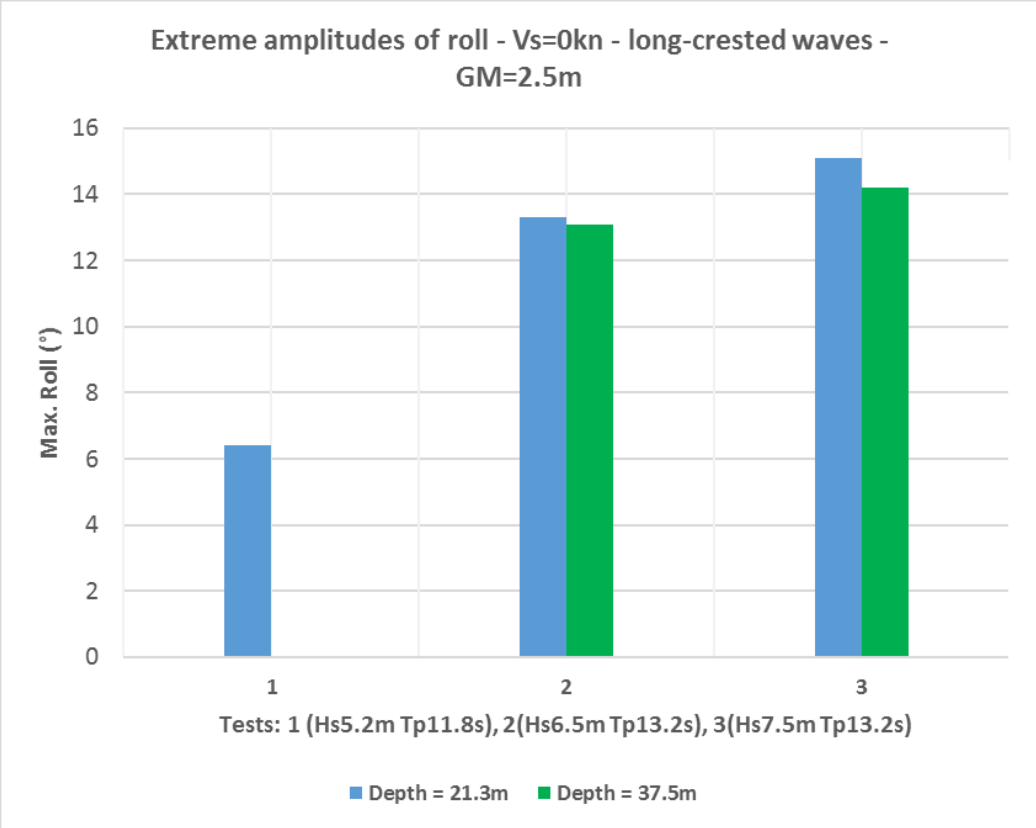
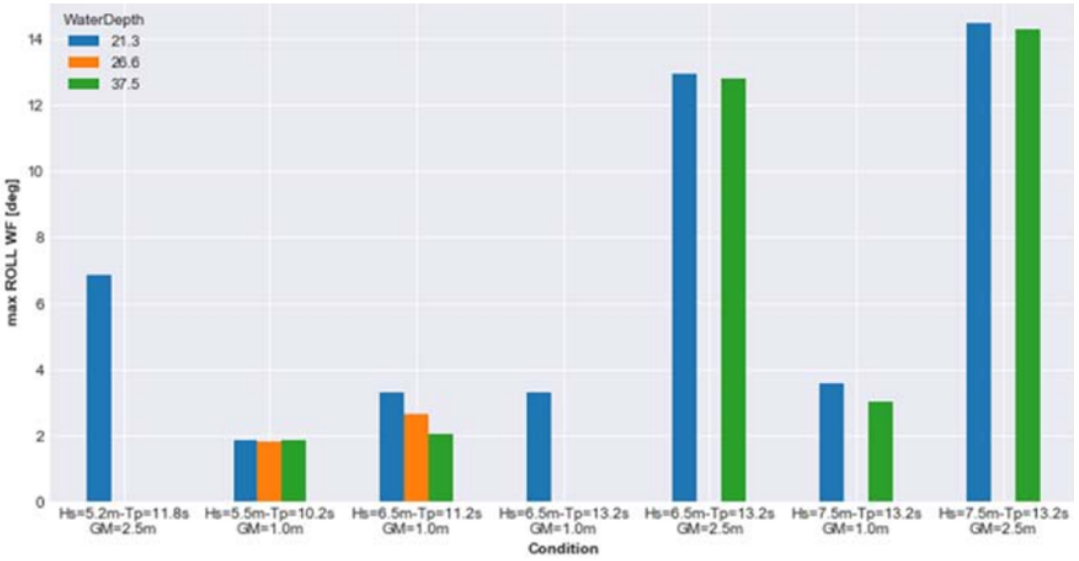
PANAMAX SHIP - ROLL MOTIONS

MEASURED MAXIMUM ROLL MOTIONS ARE ALSO PRESENTED IN REF.[2]. IN THE FOLLOWING FIGURES, ARE SHOWN THE CALCULATED MAXIMUM ROLL MOTIONS IN COMPARISON WITH THE SCALE MODEL TESTS RESULTS. ALTHOUGH LONG-CRESTED WAVES SHOW A SLIGHT INCREASE OF MAXIMUM 9% IN ROLL RESPONSE IN COMPARISON WITH SHORT-CRESTED WAVES, NO CORRECTION WAS APPLIED TO THE CALCULATED VALUES. THE SCALE MODEL WAS TESTED WITH GM VALUES OF 2.5M AND 1M.



PDSTRIP NUMERICAL RESULTS



Largest amplitudes of roll (Vs = 0 kn)

SCALE MODEL TESTS RESULTS (FROM REF.[2])

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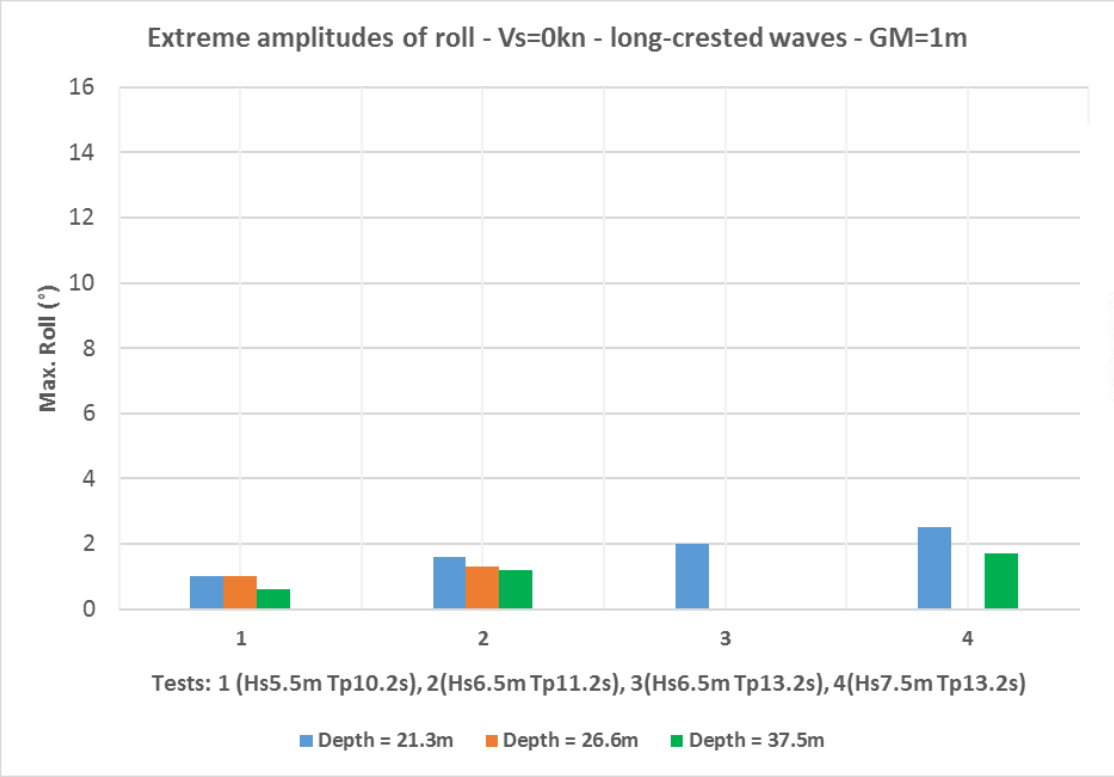
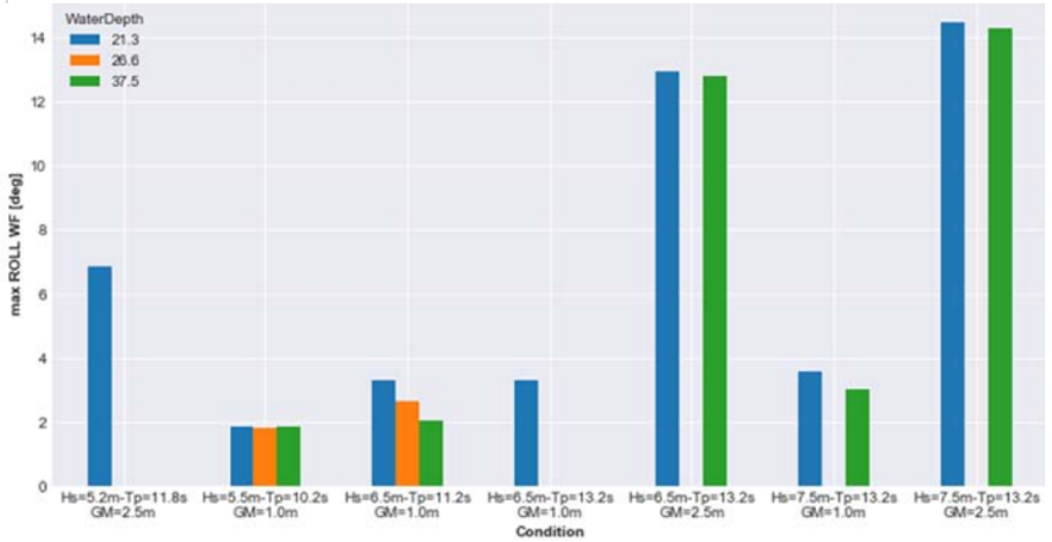
PANAMAX SHIP - ROLL MOTIONS

MEASURED MAXIMUM ROLL MOTIONS ARE ALSO PRESENTED IN REF.[2]. IN THE FOLLOWING FIGURES, ARE SHOWN THE CALCULATED MAXIMUM ROLL MOTIONS IN COMPARISON WITH THE SCALE MODEL TESTS RESULTS. ALTHOUGH LONG-CRESTED WAVES SHOW A SLIGHT INCREASE OF MAXIMUM 9% IN ROLL RESPONSE IN COMPARISON WITH SHORT-CRESTED WAVES, NO CORRECTION WAS APPLIED TO THE CALCULATED VALUES. THE SCALE MODEL WAS TESTED WITH GM VALUES OF 2.5M AND 1M.



PDSTRIP NUMERICAL RESULTS



Largest amplitudes of roll (Vs = 0 kn)

SCALE MODEL TESTS RESULTS (FROM REF.[2])

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PANAMAX SHIP

COMMENTS ON THE RESULTS OBTAINED FOR THE PANAMAX SHIP:

- ***ROLL MOTIONS:***
  - ***AS PER THE SCALE MODEL TESTS, UNDER THE HIGHER GM CONDITION, THE SHIP IS MORE SENSITIVE TO DIRECT ROLL EXCITATION. WITH THE MATHEMATICAL MODEL, A MAXIMUM AMPLITUDE OF 15° IS ALSO OBSERVED IN BEAM WAVES OF SIGNIFICANT HEIGHT 7.5M. AT THE LOWER GM (1M), THE ROLL RESPONSE WITH THE MATHEMATICAL MODEL IS ALSO VERY LOW AND LOWER THAN THE SCALE MODEL ROLL MOTION.***