Wave Excitation Forces on a Sphere

Description of an Idealized Testcase

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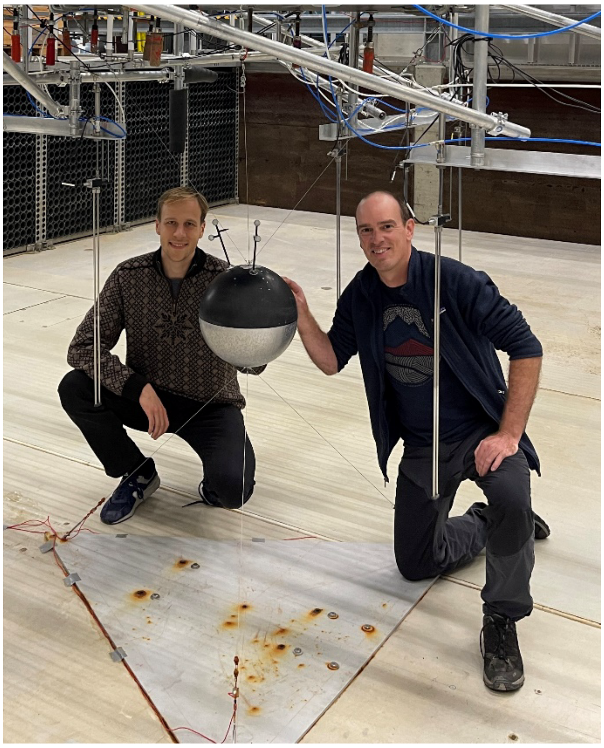

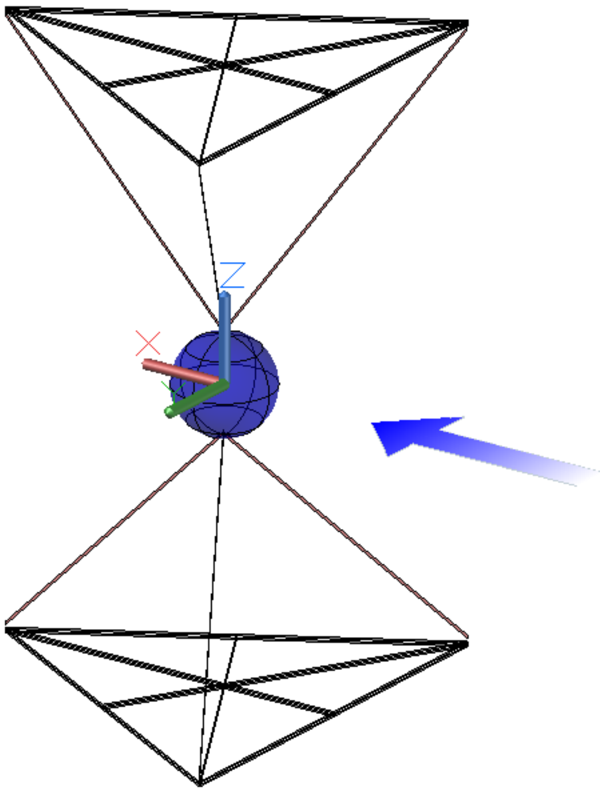

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Contents

Revision Record

Rev.	Date	Description of Change
1	2023 January	Initial issue
2	2023-05-12	Description included of how to compensate *Fz* from numerical models for offset due to buoyancy at calm condition (text added in Section 4).

1 Introduction and Objective

Physical wave basin tests with a focus on uncertainty estimation have been conducted on a fixed sphere subjected to wave loads at Aalborg University as part of the effort of the OES Wave Energy Converters Modelling Verification and Validation (formerly, OES Task 10) working group to increase credibility of numerical modelling of WECs.

The present note defines an idealized testcase formulated to accurately represent the physical tests in a simple way. The testcase consists of a fixed, rigid sphere half submerged in water subjected to regular waves of three different levels of linearity. The objective of the present note is to allow for numerical tests of the idealized testcase. Explanations for the structure and upload of numerical test outputs to a common SharePoint is also included. This allows partners in the OES WEC group for further comparative studies between the models and the physical test data.

If the reader is not familiar with the previous work on building benchmark datasets from fluid-structure-interaction tests on the sphere under OES Task 10 it is recommended to start out with the following:

1) Become familiar with the background and intention of the sphere studies of the OES working group. For the current study, a similar procedure as the decay tests completed as the first part of the *Kramer Sphere Cases* will be followed [1].
2) Become familiar with the status and plans of the work, e.g., by reading the presentations from the OES Task 10 Webinar on 2022-11-17 [2], 2023-01-26 [3], and 2023-05-12 [4].

2 Description of Numerical Tests

An excel sheet with the filename “Description of numerical tests.xlsx” is located in the root of the shared file folder on the NREL SharePoint (“*Files -> ProjectV_SphereCases -> Excitation force*”, location is further described in Section 5). As shown in Table 1 the first column is defining a “Model name”. The model name must be the same as the sub-folder under which the numerical simulation results are stored. If an institution is uploading results from two different models, then more lines are added to the table, and the model names are given a running number, e.g., “AAU1” and “AAU2”.

Descriptions of numerical models should be included. Examples of relevant contents (from the sphere decay paper) are included in Table 1.

Table 1. Description of numerical models.

Model name	Institution	Author	Framework	Description	Computational effort for one wave condition [Core Hours]
AAU	Aalborg University	Jacob Andersen	OpenFOAM-v1912	3D URANS model. Incompressible, isothermal. Volume of fluid method. Two vertical symmetry planes. Reflective side walls. Mesh morphing using SLERP method. Cell count of 6 9 M cells. No turbulence model. Second-order accurate in time and space. CFL criterion of 0.5.	~3000
UoP	Plymouth University	Edward Ransley	OpenFOAM 5.0	3D URANS model. Incompressible, isothermal. Volume of fluid. Two vertical symmetry planes. Reflective side walls. Mesh morphing using SLERP method. Cell count of ~12 M cells. No turbulence model. CFL criterion of 0.5.	
NREL	National Renewable Energy Lab.	Thanh Toan Tran	STAR-CCM+ 13.06	3D URANS model. Incompressible, isothermal. Volume of fluid. Two vertical symmetry planes. Cell count of 6 M cells. Mesh morphing with one DOF. k-Omega SST turbulence model. Second-order accurate in time and space. CFL criterion of 0.5. Max. time step of 0.1 ms.	
Text with red letters are just examples for inspiration (taken from the decay paper), and must be updated for the current runs.					

3 Description of File Names for Numerical Test Datasets

One regular wave run should correspond to one data file. The file name must contain the model name and the name of the wave in the following order:

“Model name”_“Wave condition”

A file created by Aalborg University with the model name AAU for the wave named R01, should thus be given the file name “AAU_R01.txt”.

4 Data and File Format for Uploaded Numerical Test Datasets

The dataset should consist of time series of the surface elevation η and the resulting force $[F_x, F_y, F_z]$ (and potentially resulting moment $[M_x, M_y, M_z]$). Surface elevation is the incident, regular wave measured at the location of sphere centre (without the sphere). The format of the files must be ASCII with 8 columns having the contents described in Table 2. Samples are given in the rows. Sampling frequency can be variable, or may be fixed, e.g., to 50 Hz.

The dataset should include data for two wave periods (2*T*), with the centre 1 period intended for the main comparison between data. Time series are aligned by the centre wave crest, i.e., $\max(\eta)$, at which time is set to *t* = 0. The adjacent wave crests will thus approximately align with *t* = -*T* and *t* = *T* in a similar way as the data presented in Figure 5. The first and last half wave period of the time series will not be considered in the main comparison but will only be used for qualitative comparison in figures. Any transient initial conditions included in the raw simulation data must be removed before storing the data file that is handed in.

The column headers may be omitted. Files may contain less force components, e.g., only *Fx* (in which case the file would have only 3 columns), but in this case the header must be given.

Table 2. Description of numerical data files. As indicated the time must go from –T to T, with the wave crest appearing at time t = -T, t = 0 and t = T.

time [s]	eta [m]	Fx [N]	Fy [N]	Fz [N]	Mx [Nm]	My [Nm]	Mz [Nm]
-T	crest						
…	…						
0	crest						
…	…						
T	crest						

Forces must be referred to the centre of the sphere with the waves propagating in the positive x-direction. Further info on the coordinate system is given in Section 6.

The vertical force *Fz* must be given without the static constant offset due to buoyancy when initially at rest in calm water. Vertical forces from numerical models that outputs the total (dynamic + buoyancy) hydrodynamic force must be compensated for this offset by subtracting the buoyancy force when the sphere is at rest in calm water (initial condition). The buoyancy offset value may be found by selecting the first value of the vertical force from the numerical model, where the water is stagnant. As a check, this offset should correspond approximately to the analytical value, which is 69.3 N (1/2*4/3*pi*0.15^3*998.2*9.82 = 69.3 N).

Note that *Fy*, *Mx* and *Mz* approximately will be zero as the waves are long-crested and propagating in the x-direction. Most likely, only comparisons for *Fx* and *Fz* will be presented in the paper.

4.1 Example of a data file

An example of a data file is given in Figure 1 with the data plotted in Figure 2. The file name is "FPP1_R01.txt", which has a file size of 10.9 kB. The file is for the model name *FPP1* and the wave is *R01*. *FPP1* is a linear model, and *R01* is the most linear wave condition with *T* = 1.14 s and *H* = 18.1 mm (conditions given in Table 3 and Table 4).

For this file it was chosen to use scientific notation with 4 digits, use tabulated data, and store the file using UTF-8 encoding. The following is noted:

- The first sample is for *time* = -1.14 s, which can be seen to correspond to *time* = *-T.*
- The second sample has *time* = -1.12 s, i.e., the time step is 0.02 s corresponding to a sampling frequency of 50 Hz.
- The first value of the wave is *eta* = 9.05e-3 m, i.e., the wave crest is 9.05 mm for this linear model run, which corresponds to a wave height of 2*9.05 mm = 18.1 mm. It is seen that this value agrees with the wave height of *R01*.
- The values of *Fy*, *Mx* and *Mz* are zero as expected.

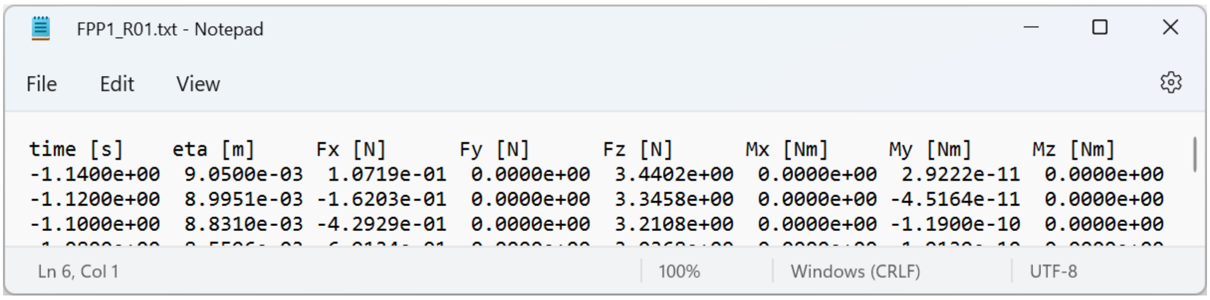

Figure 1. First few lines of a data-file, example for FPP1_R01.

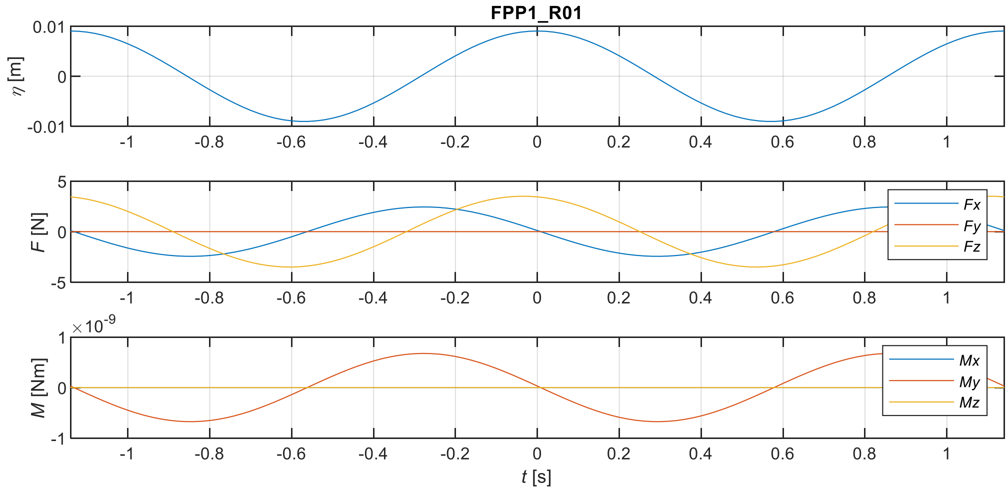

Figure 2. Plot of the example data in FPP1_R01.

5 Procedure for Uploading Numerical Test Datasets

When uploading numerical test datasets, the following procedure must be used:

1) Complete the numerical tests using the inputs described in this note.
2) Generate output datasets from the numerical tests complying with Table 2. Recall that the submitted files must contain only data from two fully developed waves (2*T*).
3) Get access to the NREL share. To get access please ask the responsible person at NREL, who currently is Thanh Toan Tran, ThanhToan.Tran@nrel.gov
4) Browse the NREL fileshare to find the location for the numerical test datasets (Files -> ProjectV_SphereCases -> Excitation force -> Idealized Testcase), see Figure 3.
5) Update the Excel file on the NREL fileshare (Table 1). Include a new line in the sheet with the information for your model.
6) Make a subfolder for your datasets within "Idealized Testcase" and upload files to the subfolder. Make sure the model name given in the Excel file is the same as the name of the subfolder.

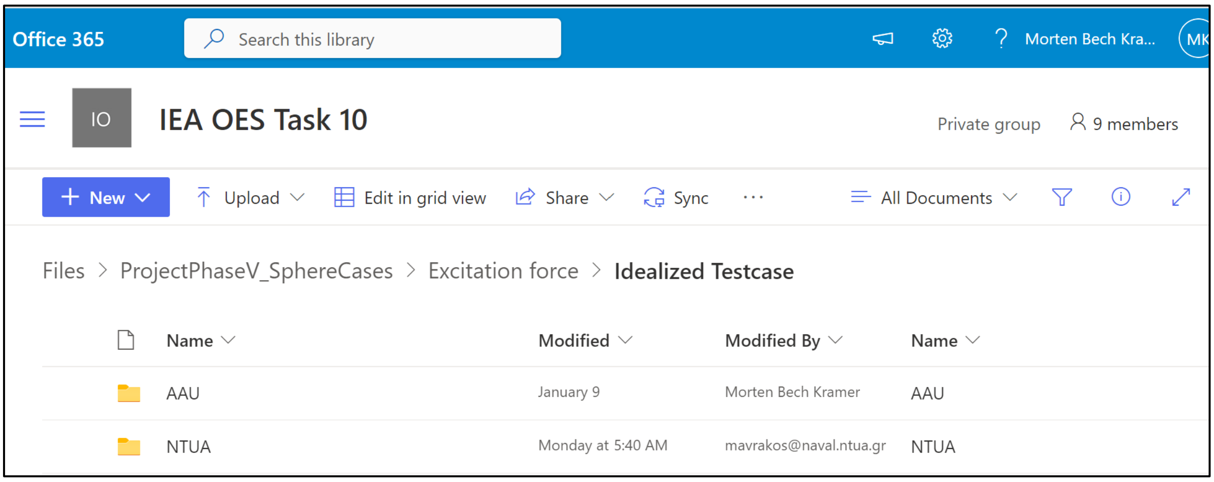

Figure 3. Screendump from NREL Sharepoint fileshare showing the folder used for the current data.

6 Coordinate System

The sphere is fixed between an air and a water phase with the equator coinciding with the still water level. A fixed global Cartesian coordinate system is defined from the still water level; the *xy*-plane coincides with the plane of the free water surface, and the *z*-axis is vertical oriented upwards towards the air phase; see Figure 4. Waves are propagating in the positive direction of *x*.

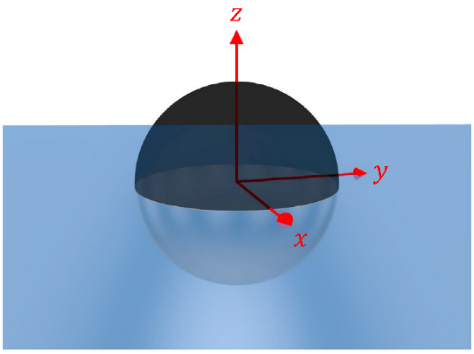

Figure 4. Fixed global coordinate system.

7 Testcase Characteristics

Values for the testcase is given in Table 3. Most parameters are the same as used for the decay testcase [1], for example the water depth, density and viscosity. The seabed is horizontal. The wave conditions for the three regular cases called R01, R05 and R12 are explained further in the following section.

Table 3: Testcase characteristics.

	Parameter	Value	Standard Uncertainty	Unit	ISO Type
Testcase values	Diameter of sphere	300	0.1	mm	B
	Acceleration due to gravity	9.82	0.003	m/s^2	B
	Density of water	998.2	0.4	kg/m^3	B
	Water depth	900	1	mm	B
	Wave conditions	R01) $T,H = 1.140,\ 18.1$ R05) $T,H = 0.880,\ 56.1$ R12) $T,H = 1.420,\ 261.1$	To be included in the paper	s, mm	A
Additional values	Temperature of air and water	20	2	°C	B
	Kinematic viscosity of water	$1.0 \cdot 10^{-6}$	$0.1 \cdot 10^{-6}$	m^2/s	B
	Density of air	1.20	0.012	kg/m^3	B
	Kinematic viscosity of air	$15.1 \cdot 10^{-6}$	$0.2 \cdot 10^{-6}$	m^2/s	B
	Surface tension water-air	0.07	0.004	N/m	B
	Mass of sphere	7056	1	g	B
	Centre of gravity	(0.0, 0.0, −34.8)	(0.1, 0.1, 0.1)	mm	B
	Moments of inertia of the sphere model; $I = \{I_{xx}, I_{yy}, I_{zz}, I_{xy}, I_{xz}, I_{yz}\}$	$\{98251, 98254, 73052, 0, 10, 0\} \cdot 10^3$	$\{37, 37, 1, 0, -77, 96\} \cdot 10^3$	gmm^2	B

8 Details about the Wave Conditions

The incident waves on the fixed sphere are regular and long-crested (2-D). Three wave conditions are used termed R01, R05 and R12, respectively, see Figure 5 for a plot of the measured surface elevation. R01 is the lowest and least steep wave, whereas R12 is the highest and steepest wave. R05 is an intermediate condition. R01 is a rather linear wave, where linear wave theory is expected to apply well, whereas R12 is a highly non-linear wave in which overtopping of the sphere is taking place.

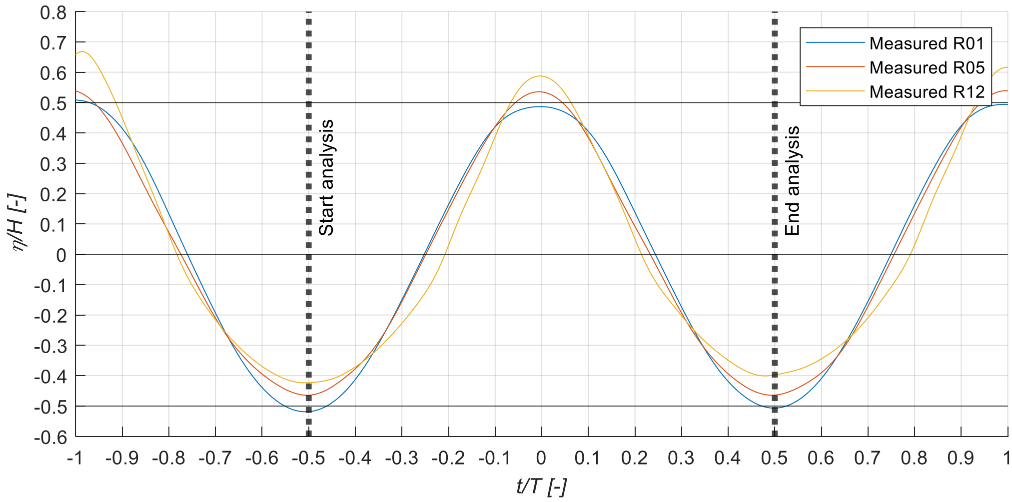

Figure 5. Measured wave for the three case studies. Each curve represents the average from 5 tests.

Wave heights and periods are given in Table 4. All the conditions are shown in the Le Mehaute diagram in Figure 6, where the three selected conditions are indicated by larger markers.

Table 4. Wave period and height for the 3 regular wave cases.

Case	*T* [s]	*H* [m]
R01	1.140	0.0181
R05	0.880	0.0561
R12	1.420	0.2611

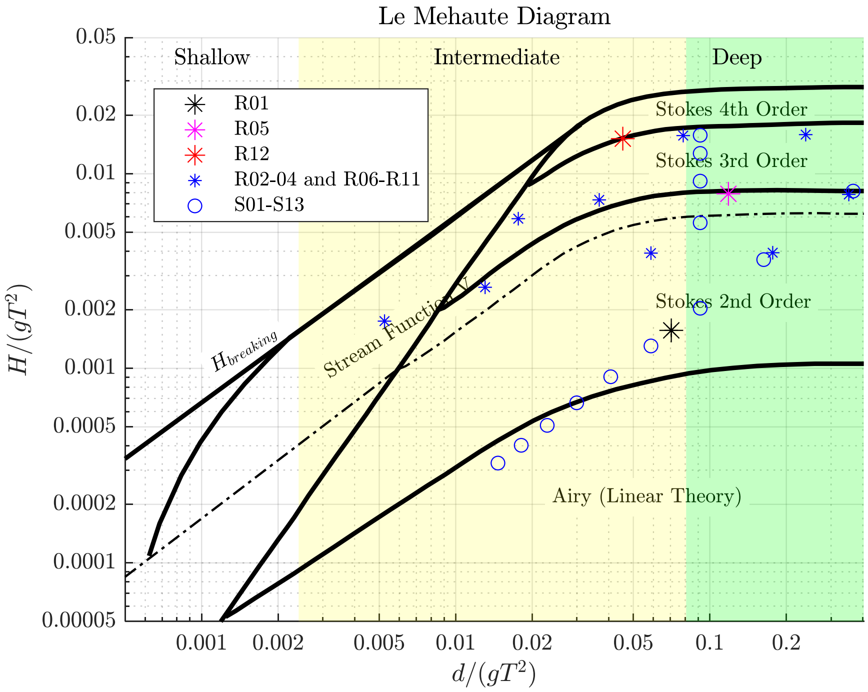

Figure 6. Le Mehaute diagram for actual regular wave conditions. The selected waves R01, R05 and R12 are highlighted.

8.1 Figures of measured wave surface elevation VS theory

In the idealized testcase, incident waves are described from the wave parameters *H* and *T.* Figures 7 and 8 underline how surface elevation time series from the physical wave basin tests are well-represented by using appropriate wave theories.

The normalised time series are plotted in Figure 7 and the actual time series with the dimensional units are given in Figure 8 (same data in both figures). From the acquired signals of the water surface elevation the measured wave height is calculated as the distance from the measured wave crest (t = 0) to the average of the two measured neighbouring wave troughs. The calculated crest and trough level is shown in Figure 7 by a horizontal line. The corresponding surface elevation by using Airy theory (linear theory) and stream function theory is indicated in the figures by the dashed curves to shown how the signals compare to the measurements.

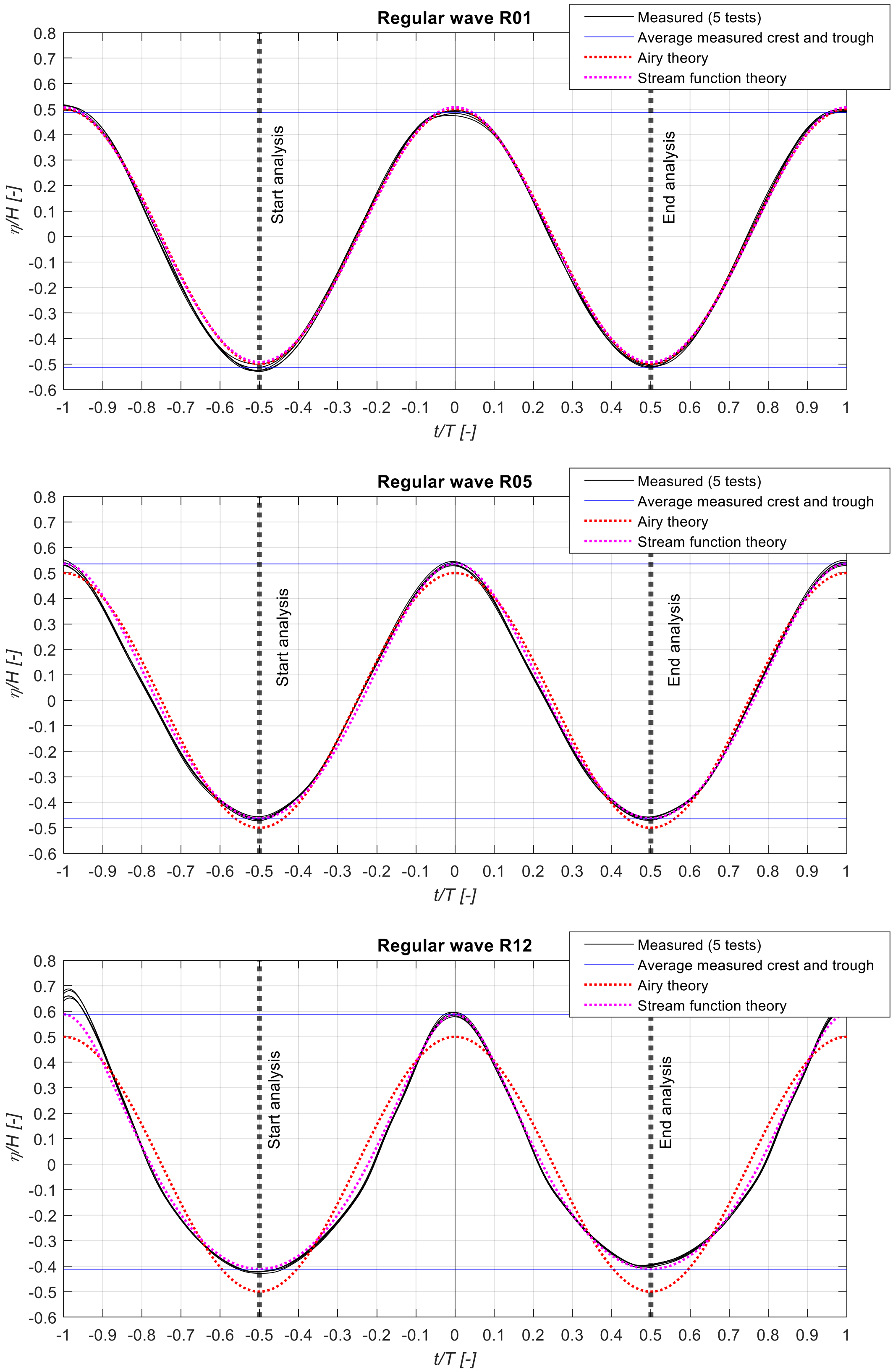

Figure 7. Measured wave compared to simulated waves using linear and stream function formulations. Normalised axes.

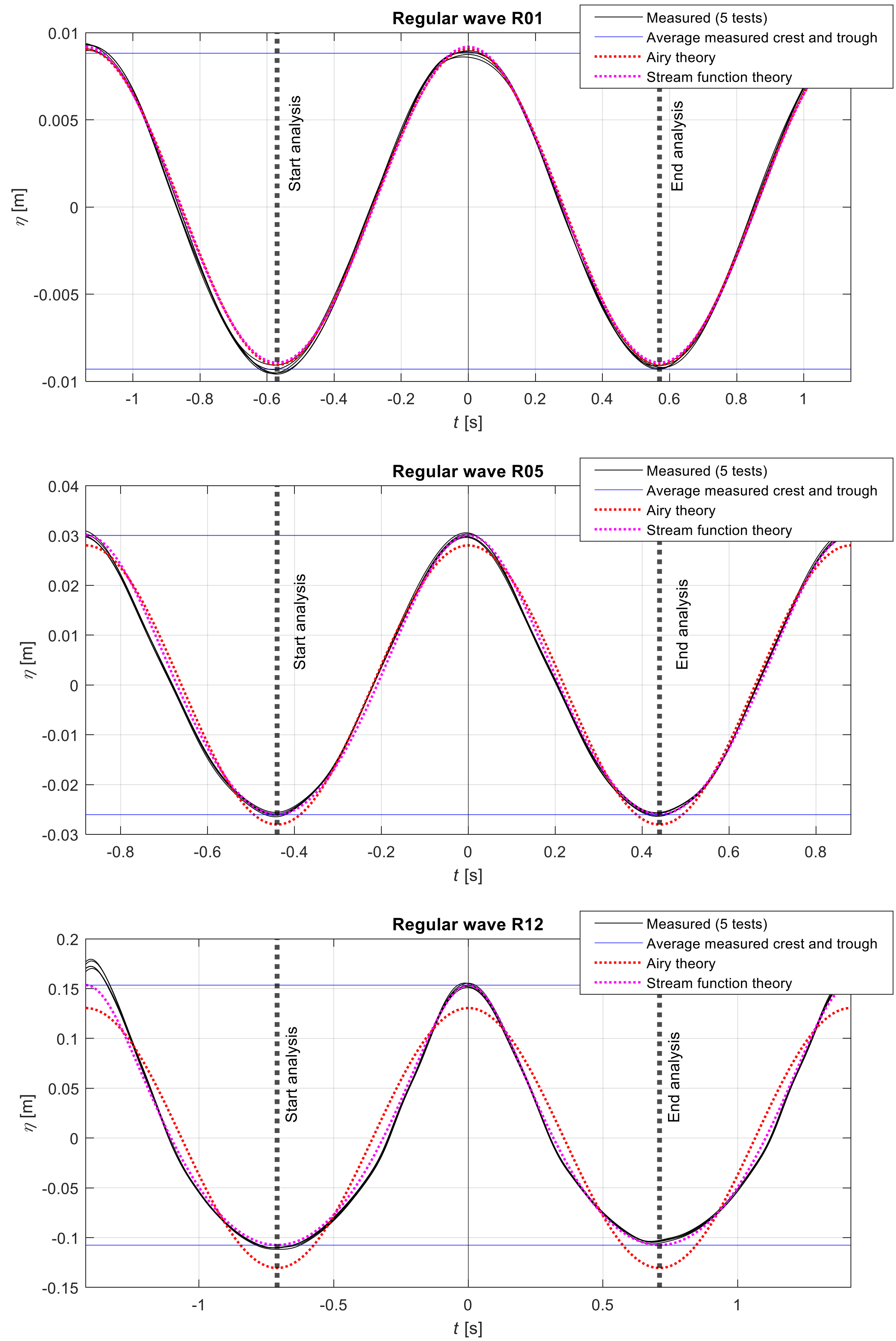

Figure 8. Measured wave compared to simulated waves using linear and stream function formulations.

9 References

[1] Kramer, M. B., Andersen, J., Thomas, S., Bendixen, F., Bingham, H., Read, R., Holk, N., Ransley, E., Brown, S., Yu, Y-H., Tran, T. T., Davidson, J., Horvath, C., Janson, C. E., Nielsen, K., & Eskilsson, C. (2021). *Highly Accurate Experimental Heave Decay Tests with a Floating Sphere: A Public Benchmark Dataset for Model Validation of Fluid-Structure Interaction*. Energies, 14(2), [269]. https://doi.org/10.3390/en14020269

[2] Kramer, M. B., Andersen, J. (2022). *Sphere Excitation Tests*. Presentation from OES Task 10 Webinar, 2022-11-17.

[3] Kramer, M. B., Andersen, J. (2023). *Definition of an Idealized Testcase for the Sphere Excitation Tests*. Presentation from OES Task 10 Webinar, 2023-01-26.

[4] Kramer, M. B., Andersen, J. (2023). *Update on the Sphere Excitation Test Cases*. Presentation from OES Task 10 Webinar, 2023-05-11.