HAMBURGISCHE SCHIFFBAU-VERSUCHSANSTALT GMBH

THE HAMBURG SHIP MODEL BASIN

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Damage Stability Tests with the Model of an 80 m RoPax Vessel

Final Report Part IIa

Customer:
European Maritime Safety Agency (EMSA)

HSVA

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Abstract:

By order of the European Maritime Safety Agency (EMSA), the survivability of an 80 m RoPax vessel has been investigated in long-crested irregular beam seas in two damage conditions.

The main purpose of the present investigation was to ascertain whether the tested ship, designed to comply with the SOLAS 2009 damage stability criteria, does also fulfil the Stockholm Agreement water on deck criteria.

The tests have shown that the Damage Case 1 in which the leakage was within the area of the engine room lead to capsize incidences in several sea conditions. However, Damage Case 4 comprising a leakage that extended over two compartments amidships turned out to be uncritical, even in waves higher than 4 m. In fact, the vessel did neither capsize after changing the initial heeling angle from 1° towards the leakage to 1° to the opposite side. As a second modification the forward trim of the model was reduced by 27%. Although both changes led to larger heeling angles the vessel survived all test runs in this condition.

All relevant time histories, the statistical results as well as selected figures and drawings of the model of the 80 m RoPax vessel are shown in Annex A and C.

Keywords: Damage stability tests, SOLAS 2009, Stockholm Agreement, 80 m RoPax vessel, irregular beam seas, two damage cases

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1 Introduction

In January 2009, the new harmonised probabilistic rules for ship subdivision, released in the IMO Res.MSC.216(82) [SOLAS 2009], have become mandatory. It has superseded the SOLAS 74, as amended up to SOLAS -96/98 Am., hereafter called SOLAS 90, for the same use.

One of the main aspects of the new guidelines is the probabilistic concept which implies the idea that two different ships having the same Attained Index feature the same safety standard so that no special treatments of single compartments are necessary. In addition to collision damages, emphasis is put on bottom leakages due to grounding.

Similar to the SOLAS 90 an Attained Index “A” resulting from the sum of all investigated damage conditions is calculated. This Attained Index must not be smaller than the Required Index “R”. For the Required Index the SOLAS 2009 specifies formulae depending on the type of ship that are based on statistical evaluations of existing vessels investigated within the IMO’s framework of HARDER project. The R-Index is defined as the minimum safety level.

Besides the probabilistic concept of damage stability the SOLAS 2009 implicates some more modifications to the previous rules. Some of the important issues are listed below:

- The extension of the collision damage has to be considered up to at least B/2 and not only in the space of the B/5 margin line as specified in SOLAS 90.
- The 1, 2 or 3 subdivision damage (max damage length of 11 m) is replaced by the maximum damage length of 60 m.
- The distance between the bulkheads can be optionally defined.
- Some of the calculated damage cases may not fulfil the survival criteria, whereas the SOLAS 90 specifies the KG,max in dependence of the critical damage case.

By order of the European Maritime Safety Agency (EMSA), damage stability investigations have been performed for a small (80 m) RoPax vessel designed according to the rules of the SOLAS 2009. The investigations included both, numerical simulations and physical model tests. The main purpose of the damage stability investigations was to find out if this ship does also comply with the water on deck criteria of the Stockholm Agreement (SOLAS 90).

The tests have been carried out in HSVA’s large towing tank on 23 and 24 February 2009. The model was trimmed to one initial load condition and has been prepared for two different damage cases. The tests have been carried out in different long-crested irregular beam sea conditions according to the Directive 2003/25/EC.

2 Model Description

2.1 Main Particulars of the 80 m RoPax Vessel

The main particulars of the investigated vessel (model scale 1:16) and the relevant load conditions are as follows:

Main Data of the Intact Vessel		
	Full Scale	**Model**
L_{OA} [m]	79.20	4.950
L_{PP} [m]	73.60	4.600
L_{WL} [m]	76.00	4.750
B_{WL} [m]	16.00	1.000
D [m]	5.50	0.344
T_a [m]	4.09	0.256
T [m]	4.09	0.256
T_f [m]	4.09	0.256
C_B [--]	0.520	0.520
∇ [m³;kg]	2502	611
LCB [m]	35.13	2.196
KM [m]	9.42	0.589
KG [m]	7.78	0.486
GM_0 [m]	1.64	0.102
KB [m]	2.38	0.149
$T\phi$ [s]	11.1	2.77
i_{xx}/B_{WL} [--]	0.42	0.42
i_{yy}/L_{PP} [--]	0.24	0.24

Damage Case 1		
	Full Scale	**Model**
L_{WL} [m]	76.00	4.750
T_a [m]	4.99	0.312
T [m]	4.57	0.286
T_f [m]	4.15	0.260
Heel [°]	-1.0	-1.0
GM' [m]	1.64	0.103
T_ϕ [s]	12.2	3.04

Damage Case 4		
	Full Scale	**Model**
L_{WL} [m]	76.49	4.781
T_a [m]	4.45	0.278
T [m]	5.24	0.327
T_f [m]	6.02	0.376
Heel [°]	1.0	1.0
GM' [m]	1.52	0.095
T_ϕ [s]	13.4	3.34

Table 1: Main particulars of the vessel in the relevant test conditions

The abbreviations used above are explained separately in the List of Symbols on page 20.

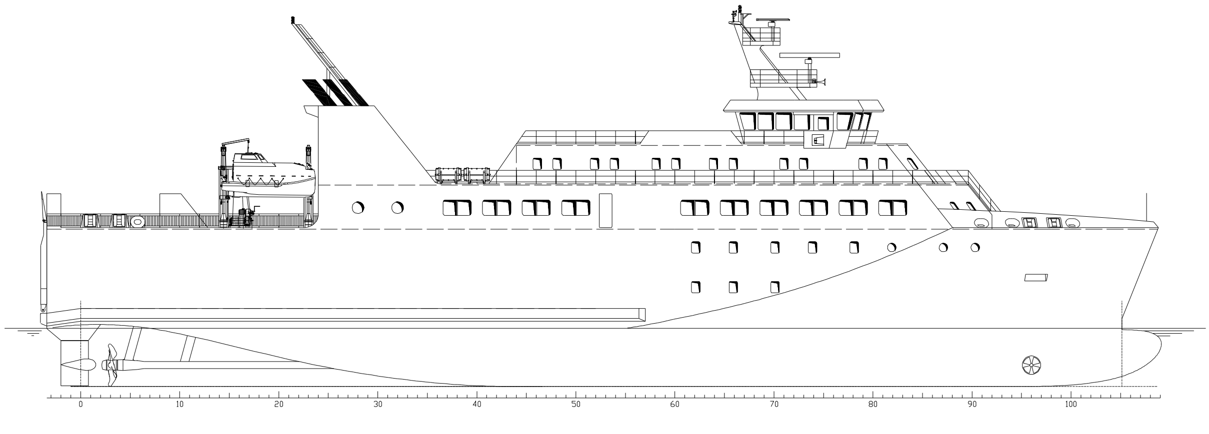


Figure 1: Side view of the 80 m RoPax vessel

2.2 *Construction of the Model*

The ship model having an overall length of 5 m has been built from reinforced plastics according to the hull lines provided by Flensburger Schiffbaugesellschaft GmbH (FSG). The hull of the model has a mean thickness of *4 mm* and was built up to a total height of 14.20 m in full scale dimension.

All relevant internal structures like tanks, decks, bulkheads etc. were made from plywood and positioned according to the general arrangement plan delivered by FSG.

As the damages of interest were not located in the forward part of the vessel (accommodation area) the internal structures were just modelled up to building frame 64 (44.80 m in front of AP). Inside the model of the 80 m RoPax vessel a double bottom extending from building frame 40 (28 m in front of AP) to building frame 64 (44.80 m in front of AP) was arranged at a height of 1.40 m above the base line. The engine room has a tween deck at a height of 2.20 m above the base line. This deck has a centre opening of 6 m x 10 m in length and width. The car deck extending from the transom to building frame 60 was modelled at height at 5.50 m above the base line.

All compartments between the transom and building frame 64 have been modelled so that the model has 6 bulkheads at the building frames 4, 16, 24, 40, 52 and 64. For constructional reasons two web frames were installed in the fore ship. On the car deck longitudinal side walls were arranged on each side at 5.80 m out of the centre line. The decks between the hull and longitudinal walls were modelled at a height of 8.30 m.

The necessary wall thickness of the internal arrangements reduced the permeability of the flooded spaces by approximately 5% depending on the size of the rooms. For this reason, further adjustments of the permeability were not necessary for most of the flooded spaces. For those compartments being considered with a permeability of 85% additional internals have been arranged.

For the damaged compartments without funnel and ventilation systems or emergency exits, air pipes were provided so that the residual air of the flooded rooms could escape.

It has been decided that the car deck should be considered as having watertight boundaries at the transom, hull and front bulkhead in order to avoid the flooding of the relative complicated accommodations in front of the cargo hold during the numerical and experimental simulations. In fact, the flooding of the accommodation area was thought to have almost no influence on the capsizing behaviour of the vessel.

Non-watertight doors were considered as openings in the walls.

Two damage cases were investigated within the model tests. The first damage (Damage Case 1) was arranged on port side in the area of the engine room. The longitudinal centre of the leakage was 20.36 m in front of the aft perpendicular. The damage length was 5.20 m and had a trapezoidal shape in the horizontal plane with a penetration depth of 2.20 m. The opening angle corresponded to 56°. In the vertical direction the leakage extended to a height of 11.80 m above the base line.

The second damage (Damage Case 4) had the same extensions as the first damage, but was located on starboard side with its longitudinal centre at 36.40 m in front of the aft perpendicular. In addition to the car deck this leakage involved two compartments of the double bottom (Void Spaces 6 and 5) and two compartments above the tank top (Pump Room/Main Switchboard and Sewage Plant/AC Chillers Room/Engine Control Room).

In order to ensure the correct roll motion behaviour of the ship the appendages were modelled as well, whereas the rudder dummies provided the correct lateral area (9.5 m² each, including head box), but were not profiled. Two suitable stock propellers (No's. 1087/1088) were chosen having regard to the proper diameter (D_P = 3.00 m). The propeller shafts were supported by two V-brackets each. In addition, the model was fitted out with one pair of bilge keels extending from 22.40 m to 44.80 m in front of the aft perpendicular. Following this, the length of the bilge keels corresponds to 30% of L_{PP}. The profile height of the bilge keels corresponded to 0.42 m. The ends of the bilge keels were tapered by an angle of 30°.

On the car deck several markings have been used to subdivide the deck into rectangular fields in order to visualise the water accumulation on the car deck. One longitudinal line has been drawn on the vessel's centre line. Transversal lines have been provided on each tenth building frame.

Annex A contains a couple of drawings and photographs showing the above-described details of the model.

2.3 Weight Distribution

2.3.1 Intact Ship

Prior to the tests in the damage conditions the model was trimmed to one intact load condition on a draught of 4.09 m without trim. The initial metacentric height of 1.64 m was ascertained by an inclining test in calm water. The radius of gyration for pitch was $0.24 \cdot L_{PP}$.

The natural roll motion period of the fully equipped model was measured during a roll decay test in calm water at zero speed. By using the following formula, the radius of gyration for roll can be estimated:

$$i_{xx,AM} = T_\Phi \cdot \frac{\sqrt{g \cdot GM}}{2 \cdot \pi} \qquad \text{or} \qquad i_{xx} = \frac{T_\Phi \cdot \sqrt{g \cdot GM}}{2 \cdot \pi \cdot 1.05}$$

in which:

$i_{xx,AM}$: Radius of gyration for roll (**in**cluding the hydrodynamic added masses)

i_{xx}: Radius of gyration for roll (**ex**cluding the hydrodynamic added masses)

T_Φ: Natural roll motion period

g: Acceleration due to gravity (= 9.81 m/s²)

GM: Metacentric height

1.05: Assumed coefficient for the influence of added mass

For the intact vessel a natural roll motion period T_ϕ of 11.1 s was measured. According to the formula shown above, the radius of gyration for roll results in $0.42 \cdot B_{WL}$ for the dry ship condition.

2.3.2 Damage Cases 1 and 4

After having cut the leakages the floating condition of the model was ascertained and compared with the data determined from the hydrostatic calculations. The floating condition of the physical model and of the hydrostatic calculations fitted very well. The liquid metacentric heights were ascertained by inclining tests in calm water.

In both damage cases the tests began with an initial heeling angle of 1° towards the side of the leakage. This heeling angle was adjusted by moving one ballast weight from one side to the other.

A natural roll motion period of 12.2 s (see Figure 4) was measured for Damage Case 1. In Damage Case 4 the natural roll motion period corresponded to 13.3 s (see Figure 5).

3 Measurements

The model of the 80 m RoPax vessel was equipped with an optical measuring system which measured the roll, pitch and heave motions of the model.

Fourteen wave probes have been arranged in order to determine the water level in the relevant areas of the car deck. One further wave probe measured the water elevation directly in front of the hull opening. The positions of the wave probes can be seen in Figure 9 in Annex A.

Two additional wave probes were used for measuring the wave elevation, one near the model (zeta_mod) and one close to the wave generator as required by the guidelines.

Three video cameras have been used during the model tests. Two cameras showing the front and aft view of the cargo hold were installed on the model and one camera was positioned on the main carriage to record the overall view of the model.

4 Model Tests

A test series of 35 test runs was performed with the model of the 80 m RoPax vessel. Due to technical problems on the second testing day the signals of some wave probes could not be measured during the remaining test runs. It has been decided to disconnect the wave probes located most aft because the vessel had forward trim and most of the water on deck accumulated in the forward part of the cargo hold.

4.1 Tested Seaways

The model tests were carried out in long-crested irregular seaways defined by both, the JONSWAP spectrum (**Jo**int **N**orth **S**ea **Wa**ve **P**roject) and the ITTC spectrum (**I**nternational **T**owing **T**ank **C**onference). Both spectra are characterized by the parameters significant wave height H_s and the peak period T_p, but have different enhancement factors, γ. For the seaways with JONSWAP spectrum the enhancement factor has been set to 3,3. The seaways with ITTC spectrum were defined with an enhancement factor corresponding to 1,0.

The model was tested in several sea conditions with significant heights from 2.42 to 4.52 m. The seaways with JONSWAP spectra had peak periods corresponding to $4 \cdot \sqrt{H_s}$, whereas the seaways with ITTC spectrum had peak periods corresponding to $6 \cdot \sqrt{H_s}$.

The control signals for the wave generator were composed for five different seaway realisations.

The actual seaway spectra were calculated from the time histories of each test run. In the Annex a comparison of the spectra determined from the measurements at two locations (one near to the wave generator and the other near to the model) and the theoretical spectra is shown in Cartesian diagrams. The spectra derived from the measurements in the vicinity of the model were converted to the earth-fixed coordinate system considering the mean drifting speed of the model.

The comparison of the corresponding spectra shows some unavoidable scatter in the measurements, for example due to reflection. Taking this into account the desired spectra were satisfactorily modelled in the tests.

In cases of short measuring times due to capsizing incidences this comparison between actual and theoretical seaway spectra can not be seen as reliable because the measurements do not cover the whole spectrum.

For the H_s and T_p values used within this report the wave probe near the wave maker has been used since there were no disturbances due to reflections etc.

4.2 Test Arrangement

The seakeeping tests were performed in HSVA's large towing tank which measures 300 x 18 x 5.6 metres in length, width and water depth.

During all runs the free-drifting model was positioned in beam seas (90° encounter angle) with the leakage facing the incoming waves. In order to maintain the heading of the model two soft ropes fastened at the stem and transom at a height of 6.76 m, i.e. between the position of KG and the damaged water line, were used.

The measured signals of the wave probes inside the model were transmitted to the measuring system on the main carriage.

During the tests the main carriage followed the model so that the cables were almost hanging vertically above the model and did not influence its motions to a measurable extent.

In order to minimise wave reflections the model was positioned at a distance of about 90 m from the wave maker so that there was a remaining distance of about 200 m between the model and the beach at the other end of the tank.

Figure 2 shows a principle sketch of the test arrangement.

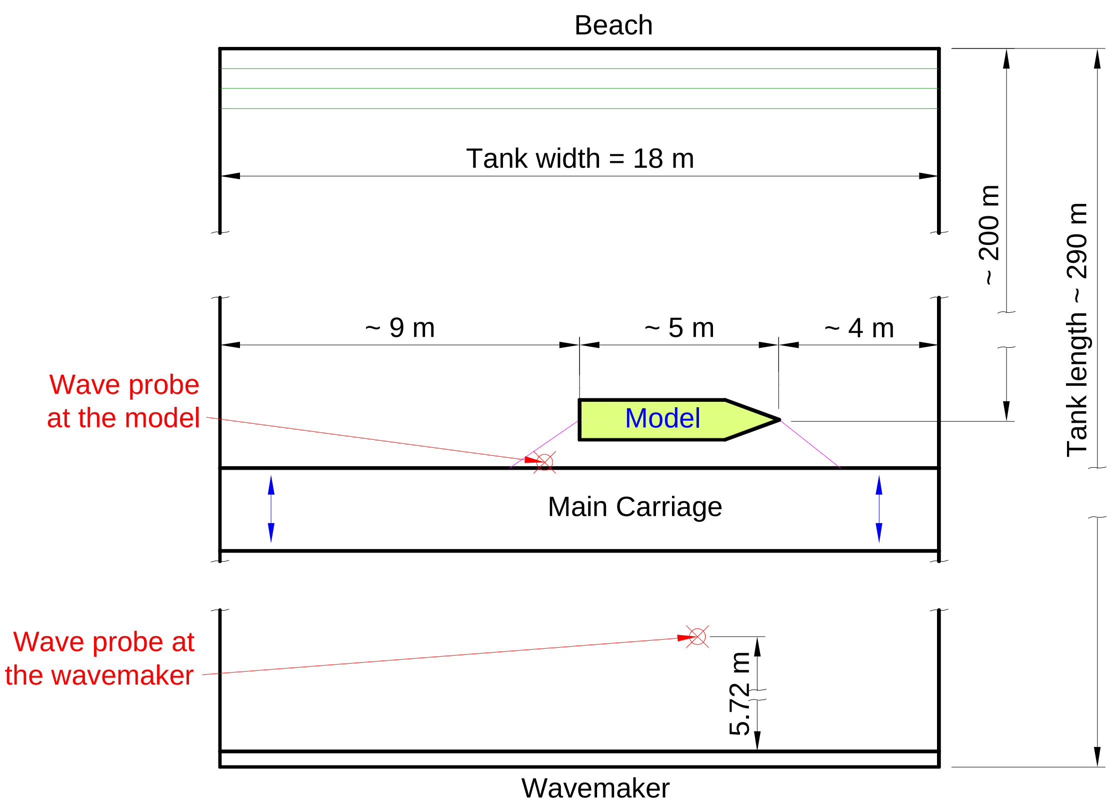


Figure 2: Sketch of the test arrangement

5 Data Handling and Analysis

5.1 Data Recording

The analogue ship motion data was transferred to the measuring system on the main carriage. This data was digitally recorded at a sampling rate of 100 Hz in model scale. The signals of the wave probes were recorded on HSVA's measuring system at a logging frequency of 100 Hz and signal filtering at 20 Hz using a Butterworth filter.

All relevant data and analysis results were converted to full-scale values according to Froude's law of similarity.

5.2 Data Analysis

In terms of a statistical analysis (see chapter E.3) several statistical values were determined. Positive and negative amplitude values are given separately in order to point out the non-linear characteristics of the investigated responses.

According to Figure 17 in Annex E the definition of the positive direction for the determined ship motions and accelerations are as follows:

Response	Positive Direction
Pitch angle	Bow down
Roll angle	Starboard side down
Heave motion	Up
Wave elevation	Up (wave crest)

For the roll motion a special treatment was necessary because the roll angle did not oscillate around zero. First, the time history of roll has been low-pass filtered and stored separately. The resulting filtered data has been used in order to find the local maximum and minimum values. For the determination of the statistical values the local maximum and minimum values have been referred to zero. This procedure is exemplified in the figure below.

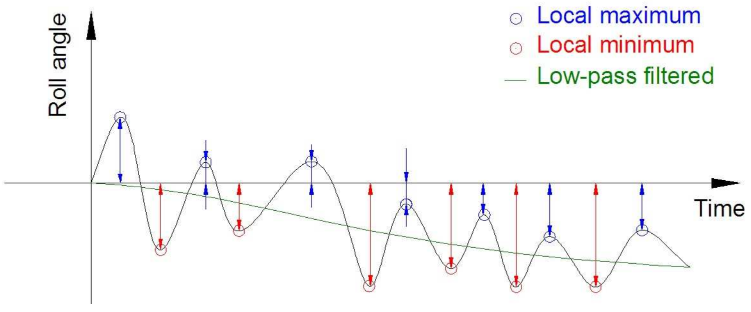


Figure 3: Statistical analysis of the roll motion

6 Test Results

6.1 Roll Decay Test in Calm Water

For each load condition a roll decay test was performed in calm water at zero speed. In the course of this test, the model was first excited to roll. After releasing the model, the decaying roll motions were recorded.

The time histories of the roll decay tests can be seen below.

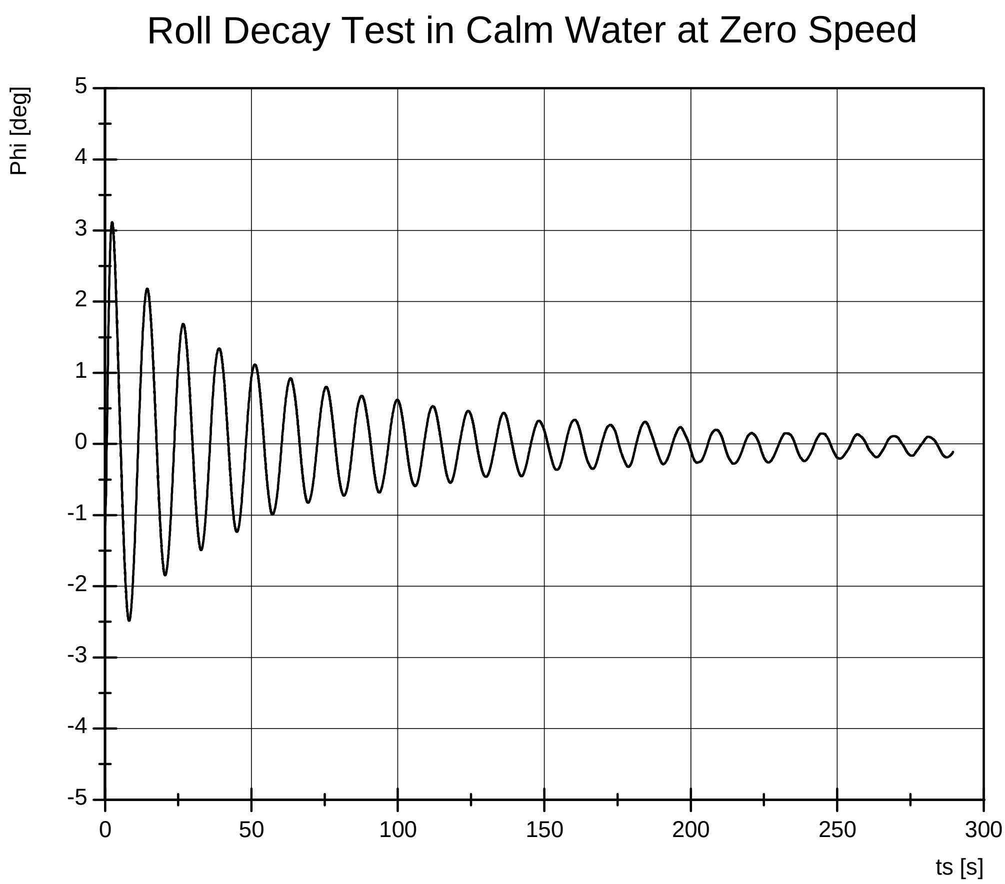


Figure 4: Roll decay test in calm water (Damage Case 1, T_{ϕ} = 12.2 s)

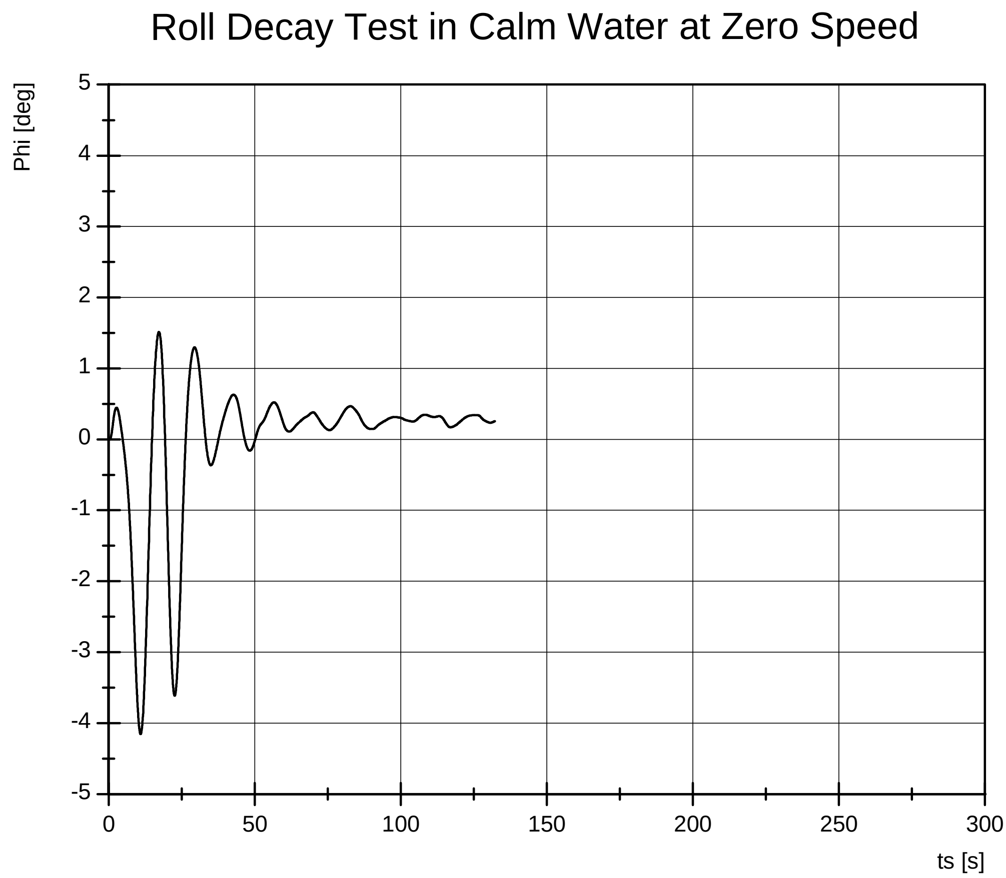


Figure 5: Roll decay test in calm water (Damage Case 4, T_ϕ = 13.3 s)

As can be seen from the figures above the roll motion is much more damped in Damage Case 4 than in the first case.

6.2 Survival Criteria

Paragraph 5 of the Appendix of Directive 2003/25/EC, Annex I, as amended, defines the survival criteria as follows:
"The model should be considered as surviving if a stationary state is reached for the successive test runs as required in paragraph 4.3. The model should be considered as capsized if angles of roll of more than 30° to the vertical axis or steady (average) heel greater than 20° for a period longer than three minutes full-scale occur, even if a stationary state is reached."

The criteria quoted above have been laid down on 18 February 2005. HSVA has taken the survival criteria according to Paragraph 4 of the Appendix of Directive 2003/25/EC, Annex I from 17 May 2003 as basis. In this version the survival criteria are defined as follows:
"The ship should be considered as surviving if a stationary state is reached for the successive test runs as required in paragraph 3.3, provided that angles of roll of more than 30° against the vertical axis, occurring more frequently than in 20% of the rolling cycles or steady heel greater than 20° should be taken as capsizing events even if a stationary state is reached."

However, in the present model tests the interpretation of the survival criteria according to the version from 18 February 2005 would have led to identical results, as the 30° criterion was not decisive.

Below the curves of the vessel's righting levers are shown for both damage cases (calm water). In addition, the limits of the GZ curves are listed in tables together with the measured significant wave heights. The last column <survived*> indicates whether the vessel fulfilled the survival criteria of the guidelines or not.

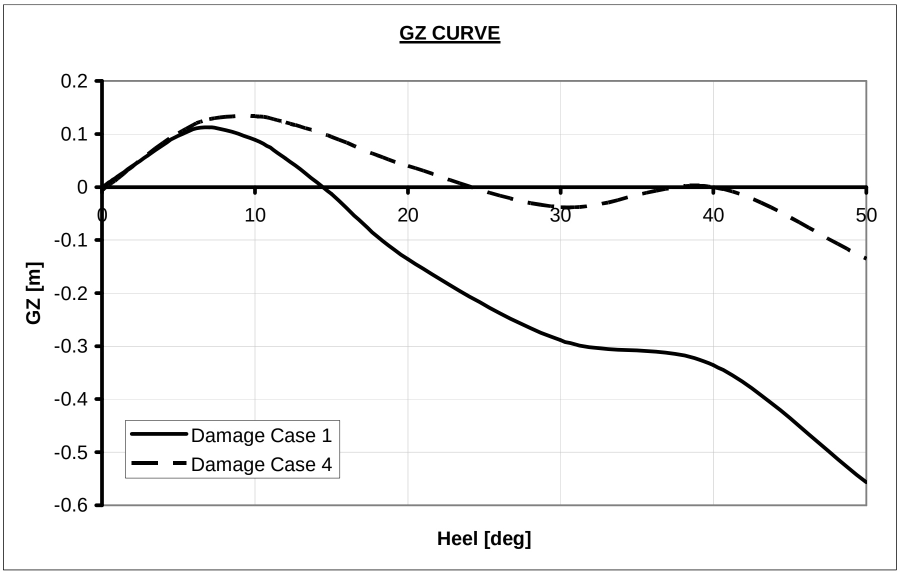


Figure 6: GZ curve for both damage cases

Damage Case 1							
Run-No.	GZ,max [m]	Range [deg]	Hs [m]	Tp [s]	γ	Survived*	Capsize after 30min
1	0.113	15.0	4.21	12.3	1.0	YES	
2	0.113	15.0	4.33	12.5	1.0	YES	X
3	0.113	15.0	4.36	12.5	1.0	YES	X
4	0.113	15.0	4.23	12.3	1.0	YES	
5	0.113	15.0	4.19	12.3	1.0	NO	
6	0.113	15.0	3.24	7.7	3.3	NO	
7	0.113	15.0	3.36	7.5	3.3	NO	
8	0.113	15.0	3.20	7.2	3.3	NO	
9	0.113	15.0	3.23	7.3	3.3	NO	
10	0.113	15.0	3.63	7.8	3.3	NO	
11	0.113	15.0	2.63	6.8	3.3	YES	
12	0.113	15.0	3.01	7.7	3.3	YES	X
13	0.113	15.0	2.99	6.9	3.3	NO	
14	0.113	15.0	2.92	6.8	3.3	YES	X
15	0.113	15.0	2.97	6.9	3.3	NO	

Table 2: Survival of the damaged vessel in Damage Case 1

The column <survived*> refers to the survival criteria defined by the Directive 2003/25/EC, whereas the column <Capsize after 30 min> indicates the cases where the model capsized after 30 minutes (the Directive requires a minimum measuring time of 30 minutes in full scale time).

Damage Case 4						
Run-No.	GZ,max [m]	Range [deg]	Hs [m]	Tp [s]	γ	Survived*
16	0.136	24.0	4.16	12.2	1.0	YES
17	0.136	24.0	4.15	12.2	1.0	YES
18	0.136	24.0	4.20	12.3	1.0	YES
19	0.136	24.0	4.18	12.3	1.0	YES
20	0.136	24.0	4.10	12.2	1.0	YES
21	0.136	24.0	4.35	8.3	3.3	YES
22	0.136	24.0	4.36	8.4	3.3	YES
23	0.136	24.0	4.38	8.4	3.3	YES
24	0.136	24.0	4.38	8.4	3.3	YES
25	0.136	24.0	4.35	8.3	3.3	YES
26	0.136	24.0	4.35	8.3	3.3	YES
27	0.136	24.0	4.38	8.4	3.3	YES
28	0.136	24.0	4.47	8.5	3.3	YES
29	0.136	24.0	4.35	8.3	3.3	YES
30	0.136	24.0	4.36	8.3	3.3	YES
31	0.136	24.0	4.34	8.3	3.3	YES
32	0.136	24.0	4.40	8.4	3.3	YES

Table 3: Survival of the damaged vessel in Damage Case 4

6.3 Results of Measurements (Annex C)

The results of the statistical analysis for the full-scale vessel are compiled in Annex C. The tables show the performed test program in detail.

Below the header, showing the test conditions, the statistical results can be seen for all measured values.

The abbreviations used in the tables are explained below:

- A_{sig} — Mean value of the one-third highest absolute single amplitudes measured during the test runs (absolute significant single amplitudes)
- A_{sig} +/- — Mean value of the one-third highest positive/negative single amplitudes measured during the test runs (positive and negative significant single amplitudes)
- A_{max} +/- — Maximum positive/negative single amplitude measured during the test runs

For the roll motion the following abbreviations can be seen in the statistics:

- $A_{sig\ upper\ bound}$ — Mean value of the one-third highest local maximum single amplitudes
- $A_{sig\ lower\ bound}$ — Mean value of the one-third highest local minimum single amplitudes
- $A_{max\ upper\ bound}$ — Local maximum single amplitudes
- $A_{max\ lower\ bound}$ — Local minimum single amplitudes
- T_m — Mean rolling period

The given maximum values are realisations of a randomly distributed variable. In case of exposure times longer than the measuring times during the tests, higher extreme values become more probable, whereas the significant values are much more stable.

7 Conclusion

By order of the European Maritime Safety Agency (EMSA), damage stability tests have been carried out with the model of an 80 m RoPax vessel.

The main objective of the investigations performed was to verify whether the vessel designed according to the new damage stability guidelines, which have come into force in January 2009, does also comply with the SOLAS 90 Water on Deck Criteria (Stockholm Agreement).

For the tests one model with an overall length of 5 m and a hull thickness of 4 mm has been built including all relevant internals and structural details. The tests were carried out in HSVA's large towing tank on 23rd and 24th February 2009. The free drifting model was positioned in long-crested irregular beam seas (90° encounter angle) with the damage hole facing the incoming waves. Two damage cases have been considered within the model tests of which the first extended over one compartment whereas the second damage hole involved two compartments.

The measurements included the heave, pitch and roll motions of the model and the water elevation at fourteen positions inside the cargo hold. One wave probe measured the water level directly in front of the hull opening. The wave elevations at the wave generator and in the vicinity of the model were measured by two additional wave probes.

The results of the tests have shown that the vessel did not fulfil the survival criteria of the Directive 2003/25/EC at eight test runs, all being performed in Damage Case 1. In damage Case 4 the vessel survived in all test conditions even though considerable amounts of water entered the car deck. The change of the initial heeling angle from 1.0 degree towards the leakage to 1.1 degree to the opposite side plus reducing the forward trim did not lead to any capsizing incidences.

8 List of Symbols

L_{OA}	Length over all
L_{PP}	Length between perpendiculars
L_{WL}	Length in waterline
B_{WL}	Breadth in waterline
D	Depth to main deck
T_a	Draught at the aft perpendicular
T	Mean draught (at $L_{PP}/2$)
T_f	Draught at the fore perpendicular
C_B	Block coefficient
∇	Displacement volume
LCB	Longitudinal centre of buoyancy
KM	Height of the initial metacentre above the keel
KG	Height of the centre of gravity above the keel (Vertical centre of gravity)
GM_0	Initial metacentric height
GM’	Metacentric height in the damage condition
KB	Vertical centre of buoyancy
T_Φ	Natural roll motion period of the ship
i_{xx}	Radius of gyration for roll
i_{yy}	Radius of gyration for pitch
AP	Aft perpendicular
FP	Fore perpendicular
GZ	Righting lever of the ship
f_s	Residual freeboard
g	Acceleration due to gravity
H_s	Significant wave height
T_P	Peak period
γ	Enhancement factor of the seaway spectrum
$A_{sig+/-}$	Mean of the 1/3 highest positive / negative values
$A_{max+/-}$	Maximum positive / negative values
zeta _mod	Wave elevation in the vicinity of the model
zeta _wp1..n	Wave elevation at the wave probes on the car deck (time histories)
$\zeta_{wp1 \ldots n}$	Wave elevation at the wave probes on the car deck (statistics)

Annex A

Drawings and Photographs

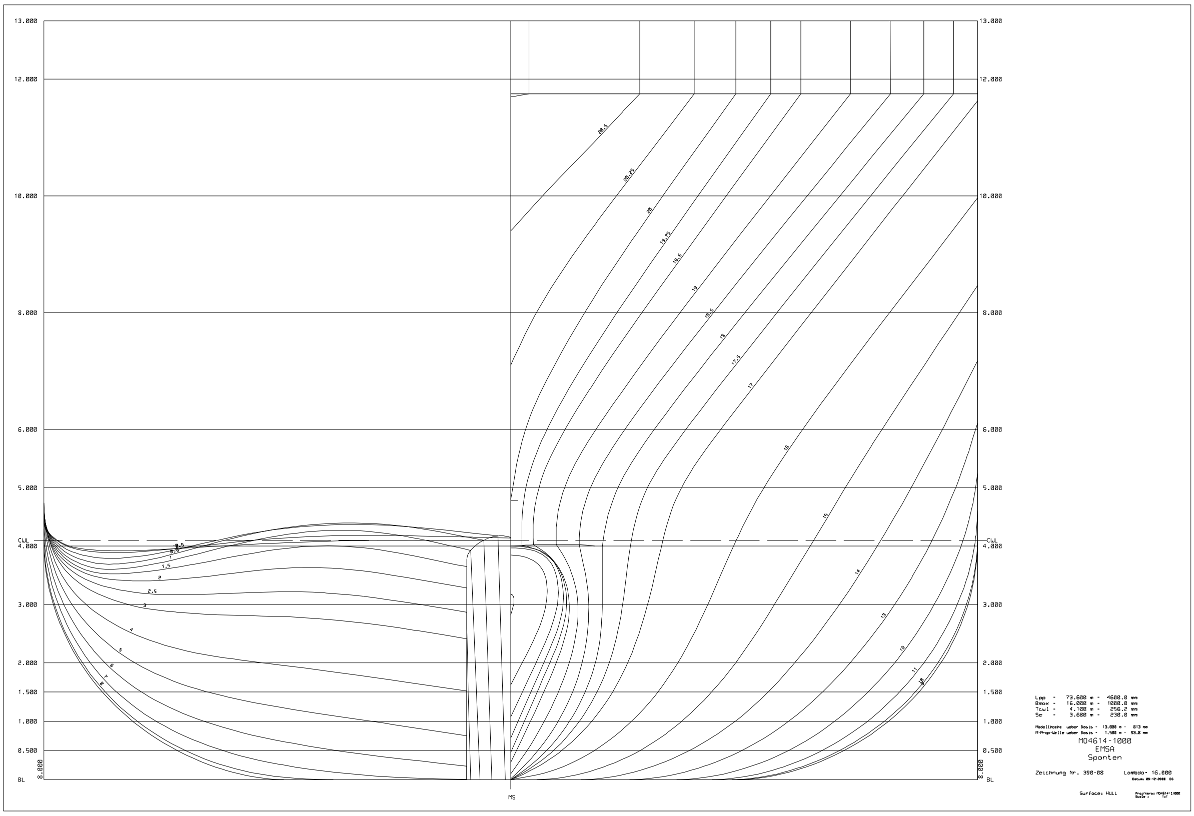


Figure 7: Body plan

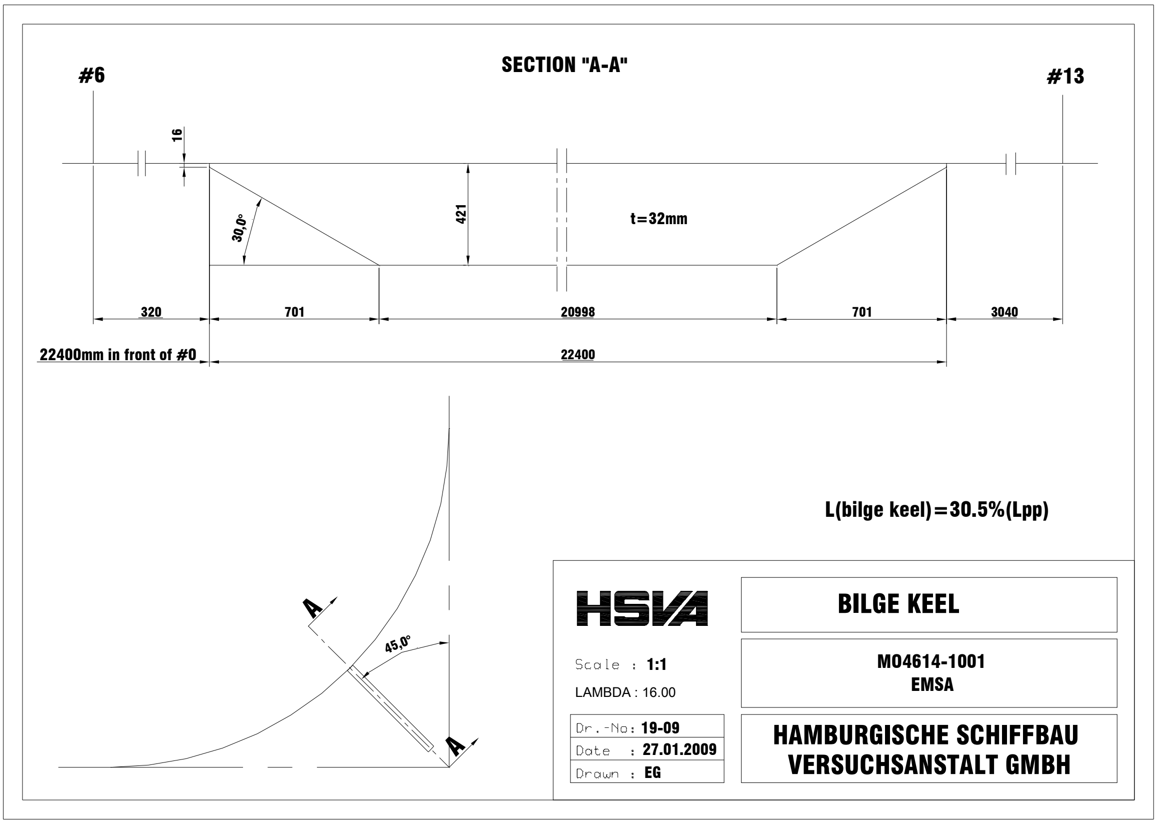


Figure 8: Bilge keel arrangement

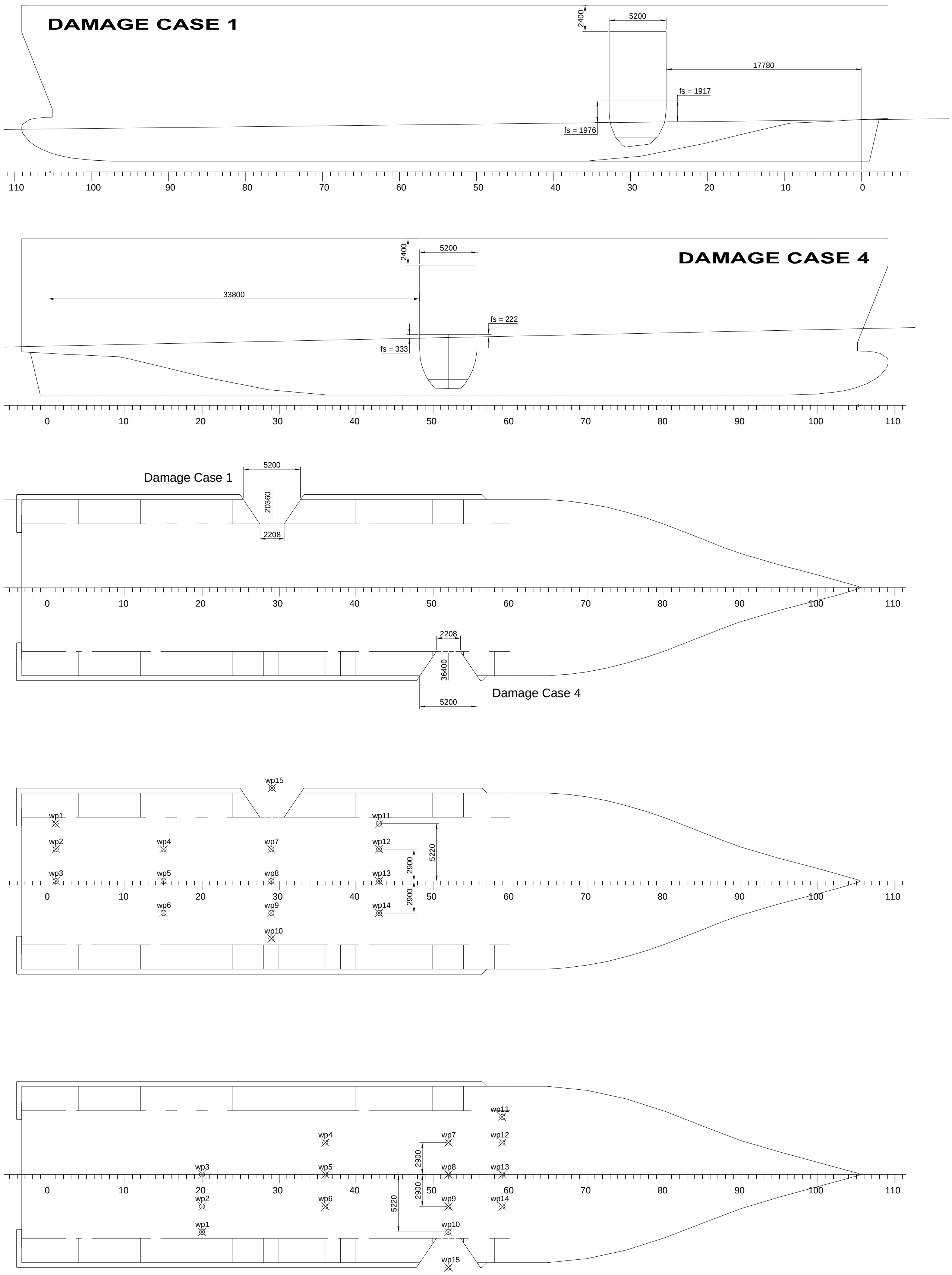
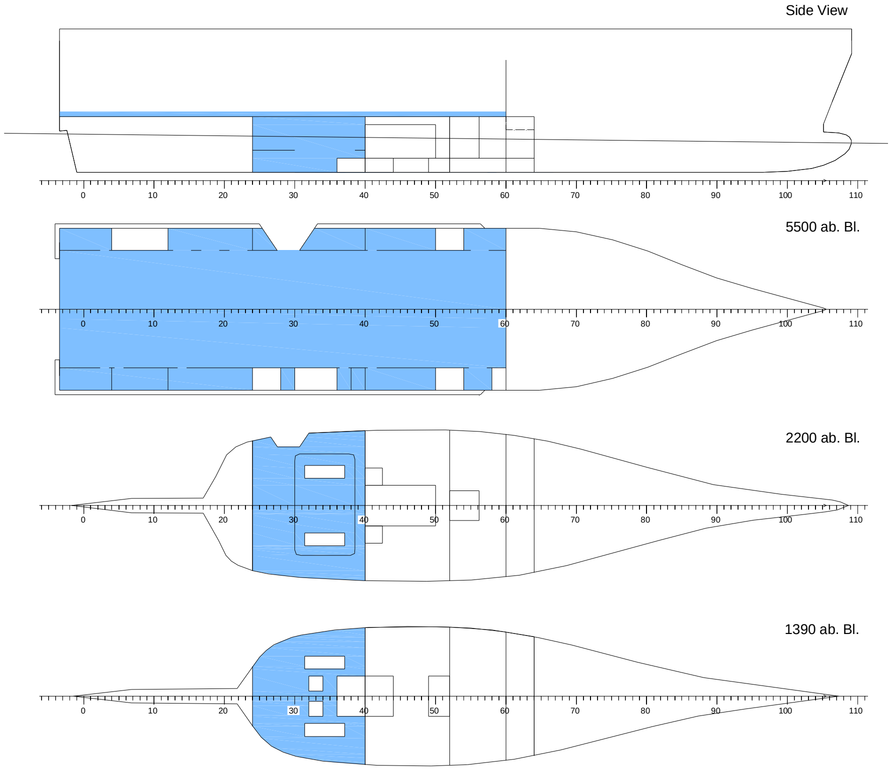


Figure 9: Dimensions of the damage holes and positions of the wave probes on the car deck

DAMAGE CASE 1



DAMAGE CASE 4

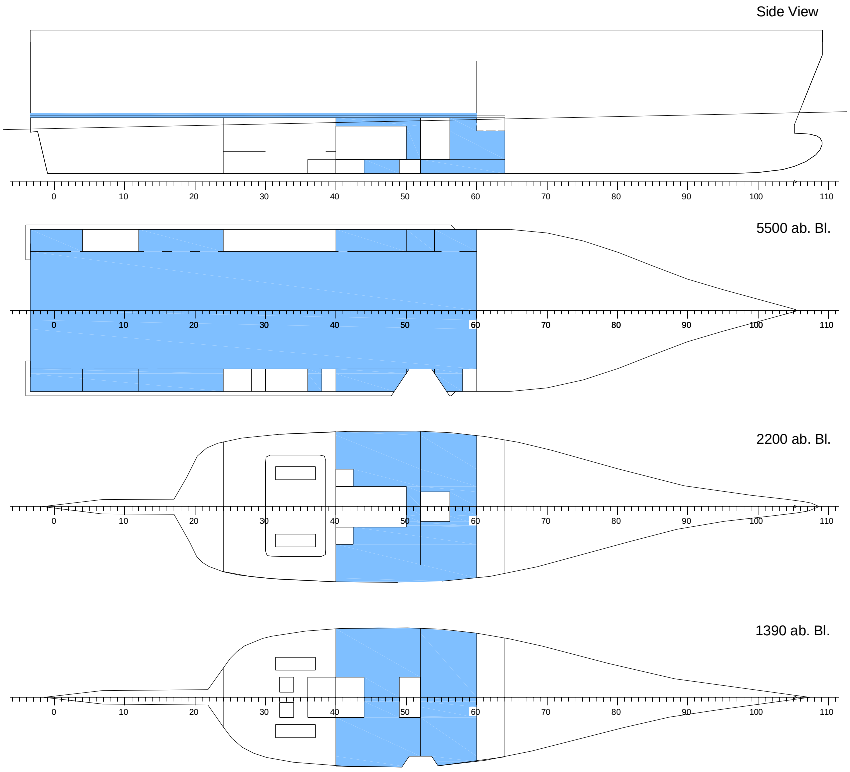


Figure 10: Flooded compartments

Figure 11: Model manufacture

Figure 12: Rudder and propeller arrangement

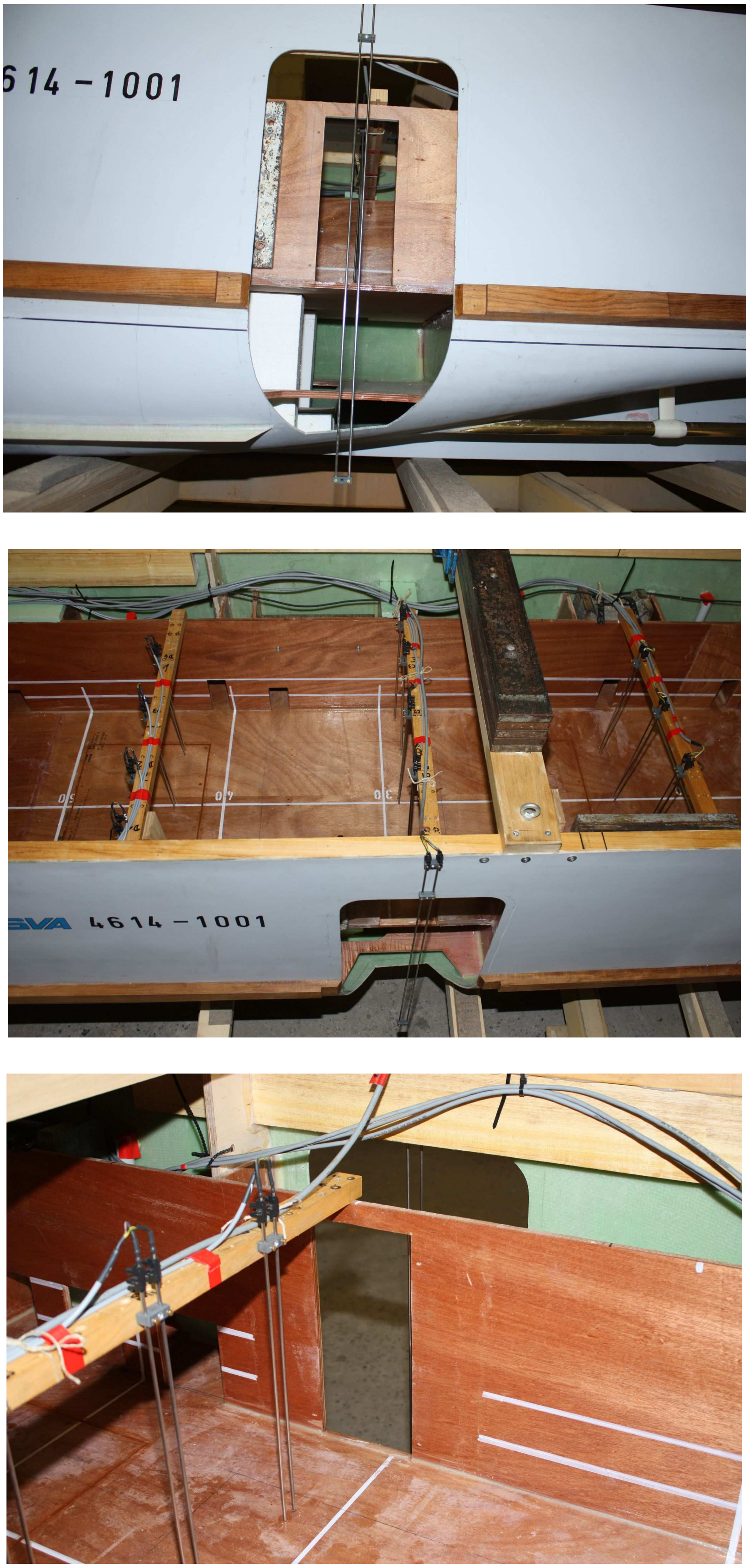


Figure 13: Leakage of Damage Case 1

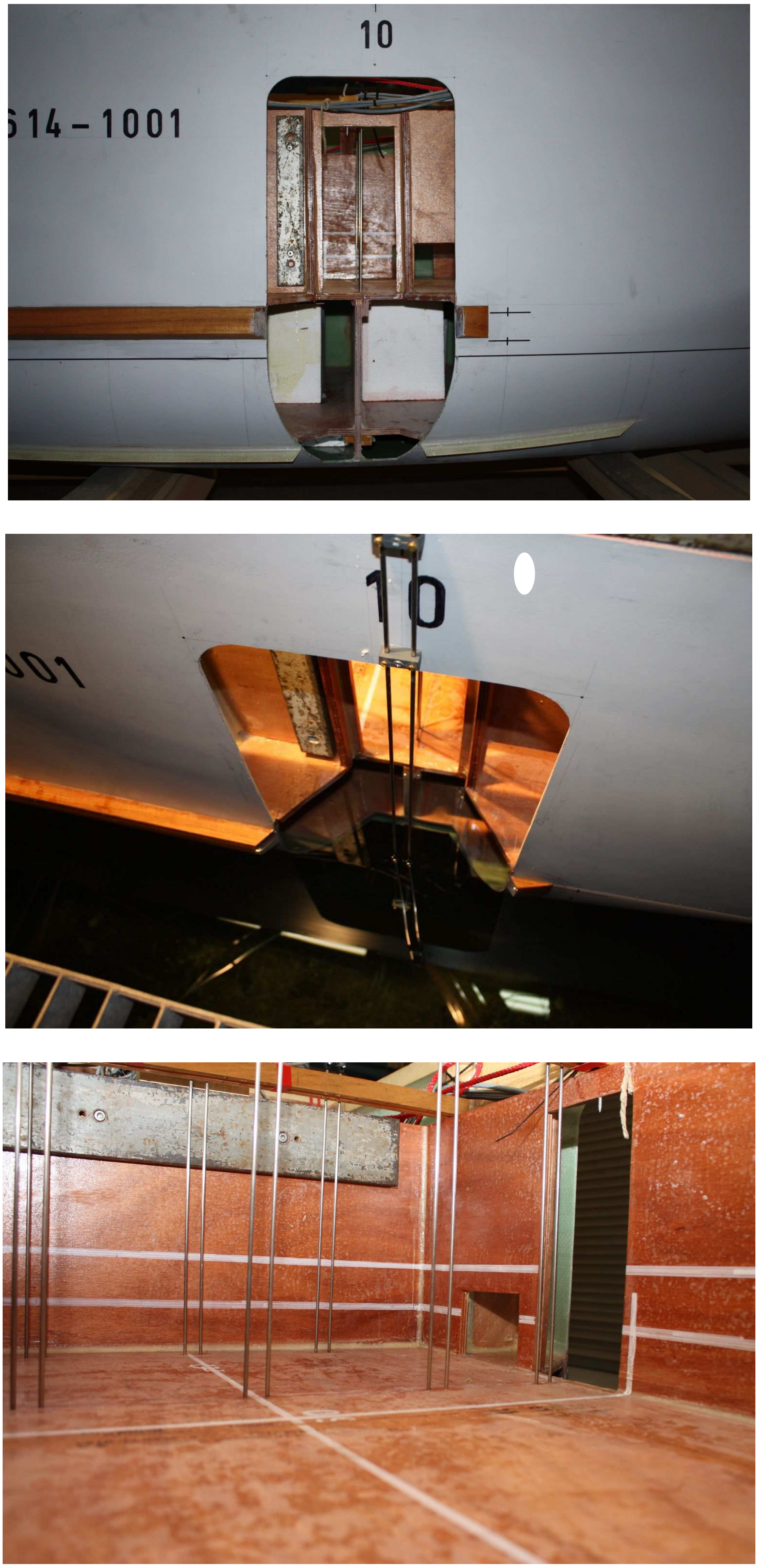


Figure 14: Leakage of Damage Case 4

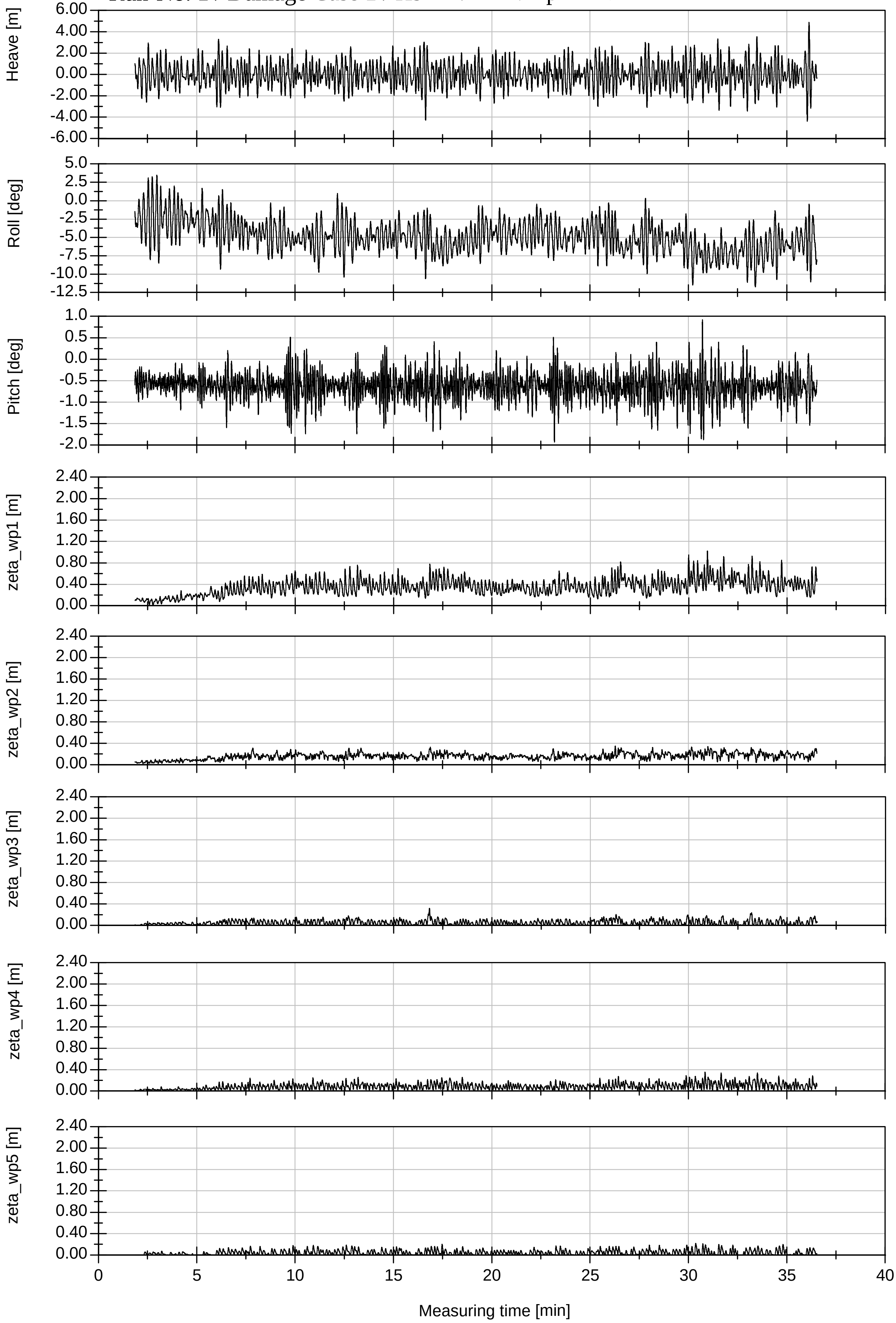
Figure 15: Wave probes inside the hold

Annex B

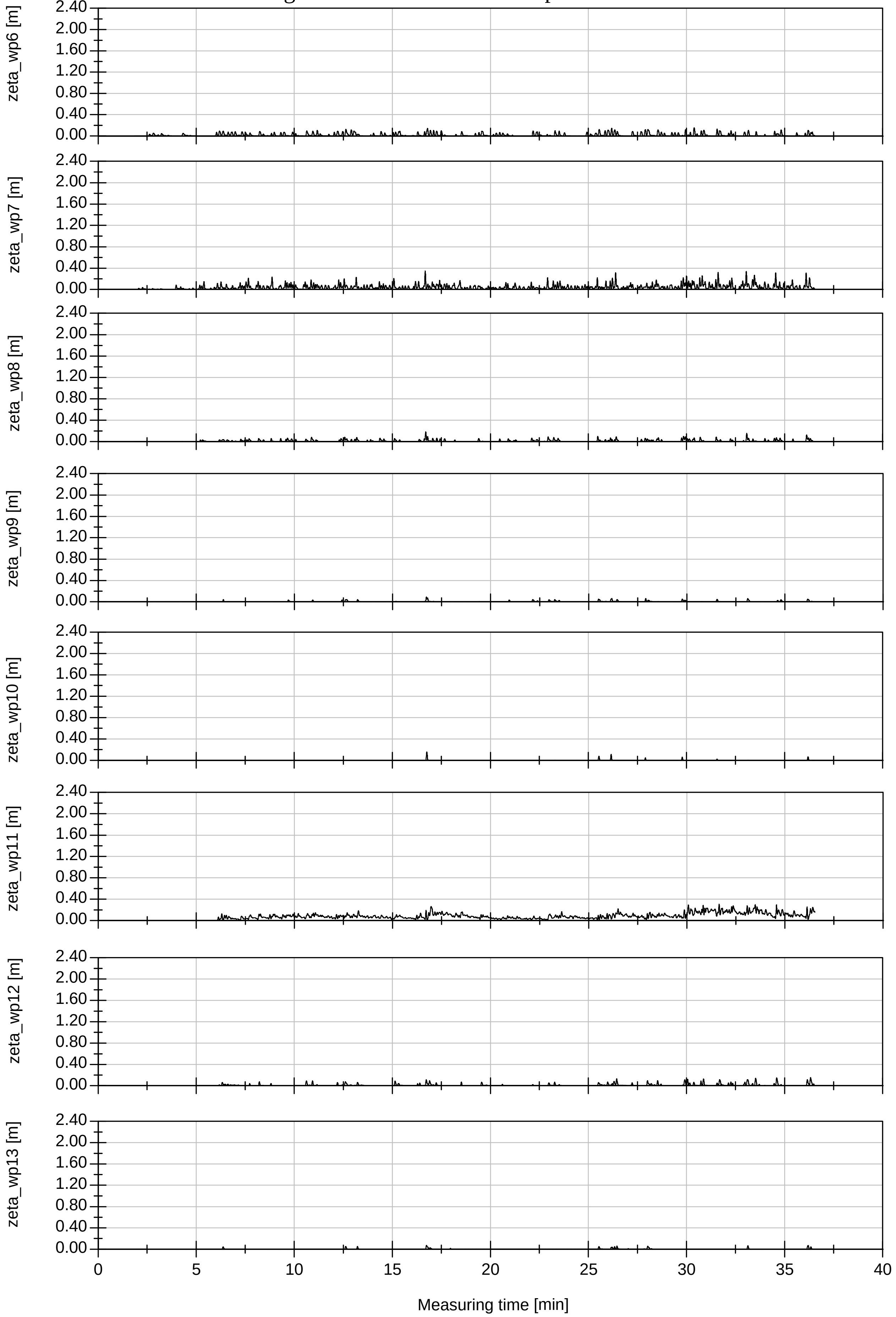
Time Histories

(Full Scale Values)

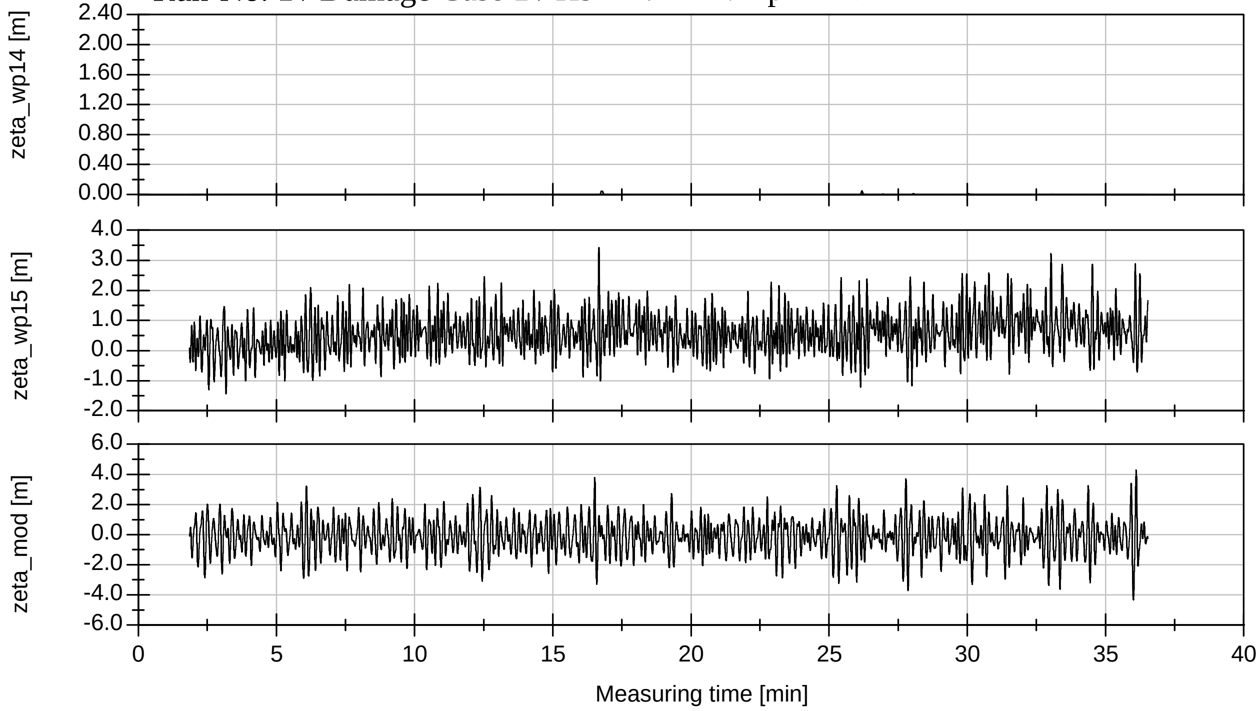
Run-No. 1 / Damage Case 1 / Hs = 4.21 m / Tp = 12.3 s / Gamma = 1.0



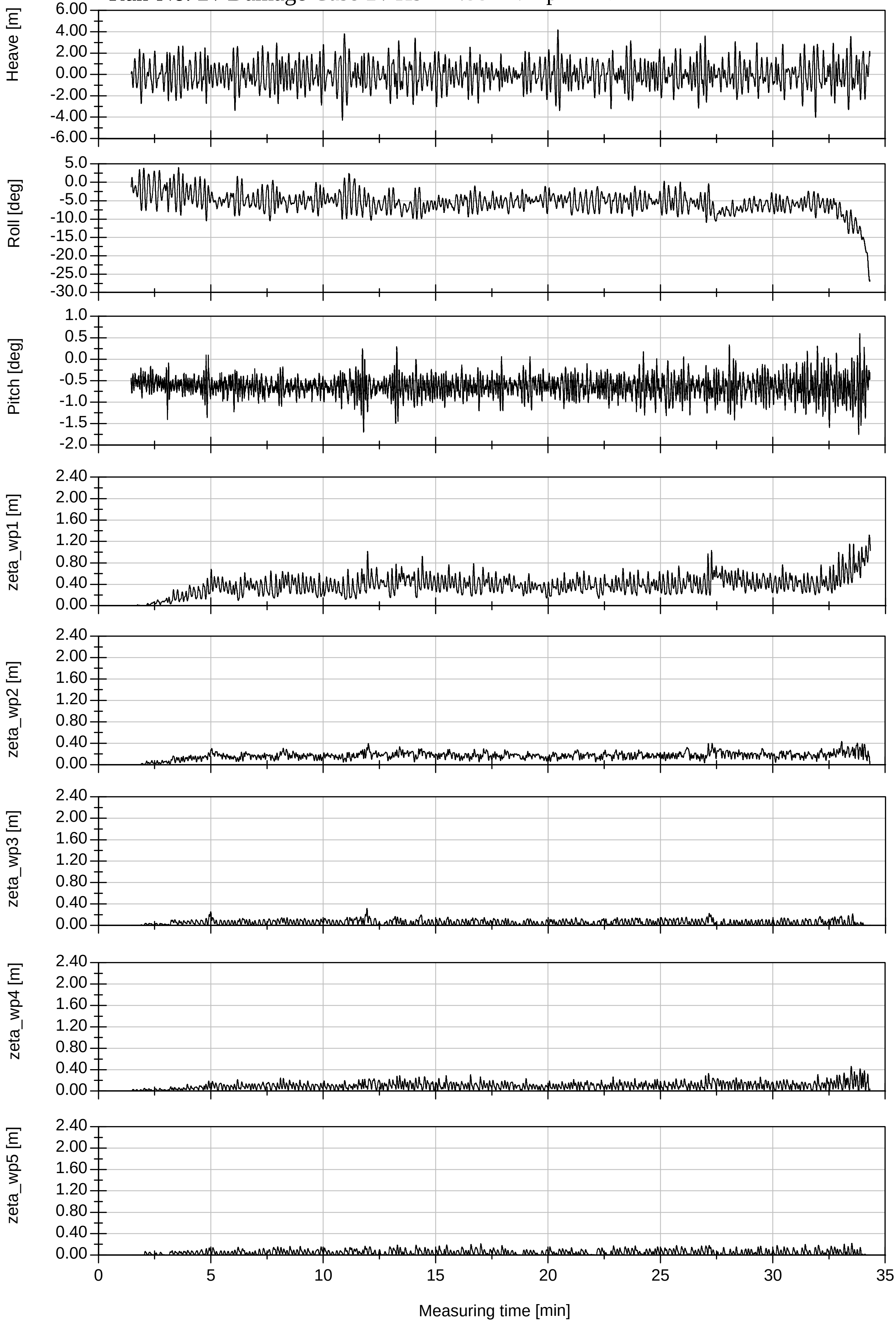
Run-No. 2 / Damage Case 1 / Hs = 4.33 m / Tp = 12.5 s / Gamma = 1.0



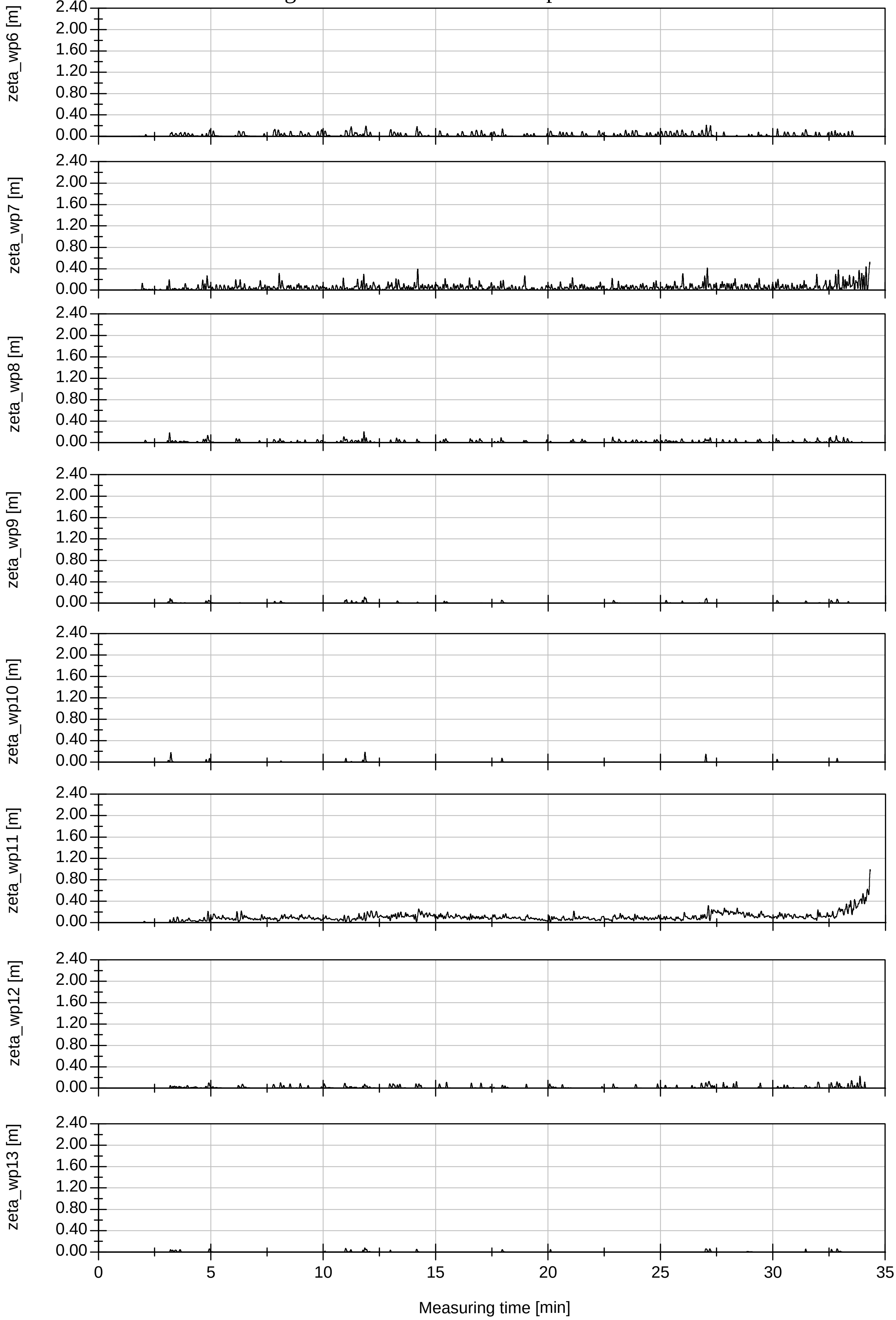
Run-No. 1 / Damage Case 1 / Hs = 4.21 m / Tp = 12.3 s / Gamma = 1.0



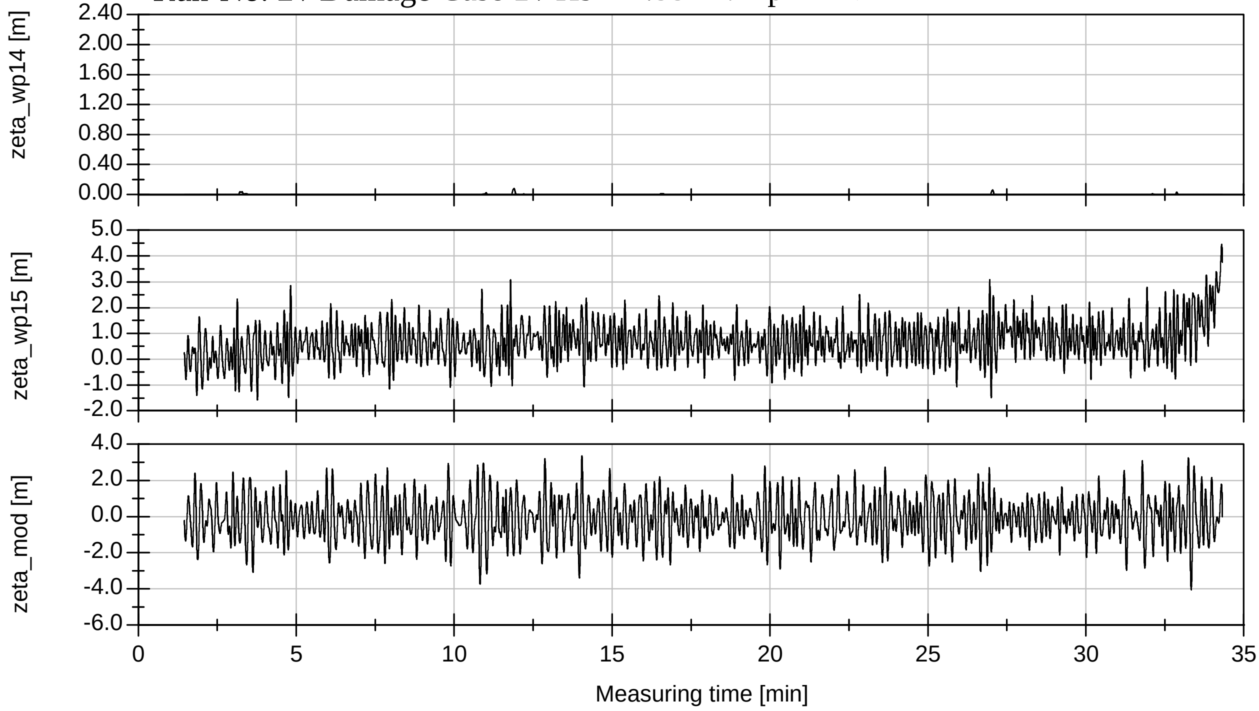
Run-No. 2 / Damage Case 1 / Hs = 4.33 m / Tp = 12.5 s / Gamma = 1.0



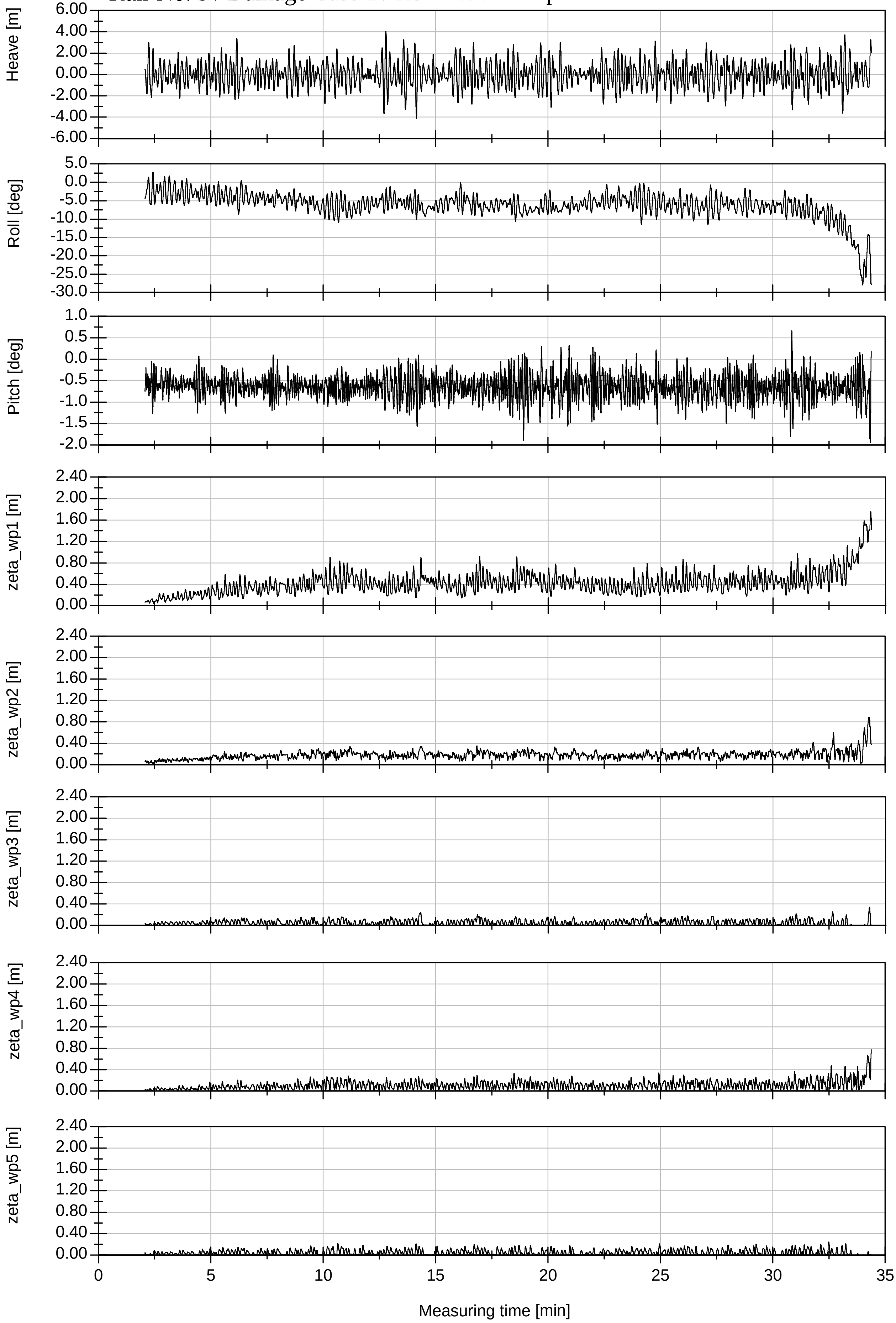
Run-No. 2 / Damage Case 1 / Hs = 4.33 m / Tp = 12.5 s / Gamma = 1.0



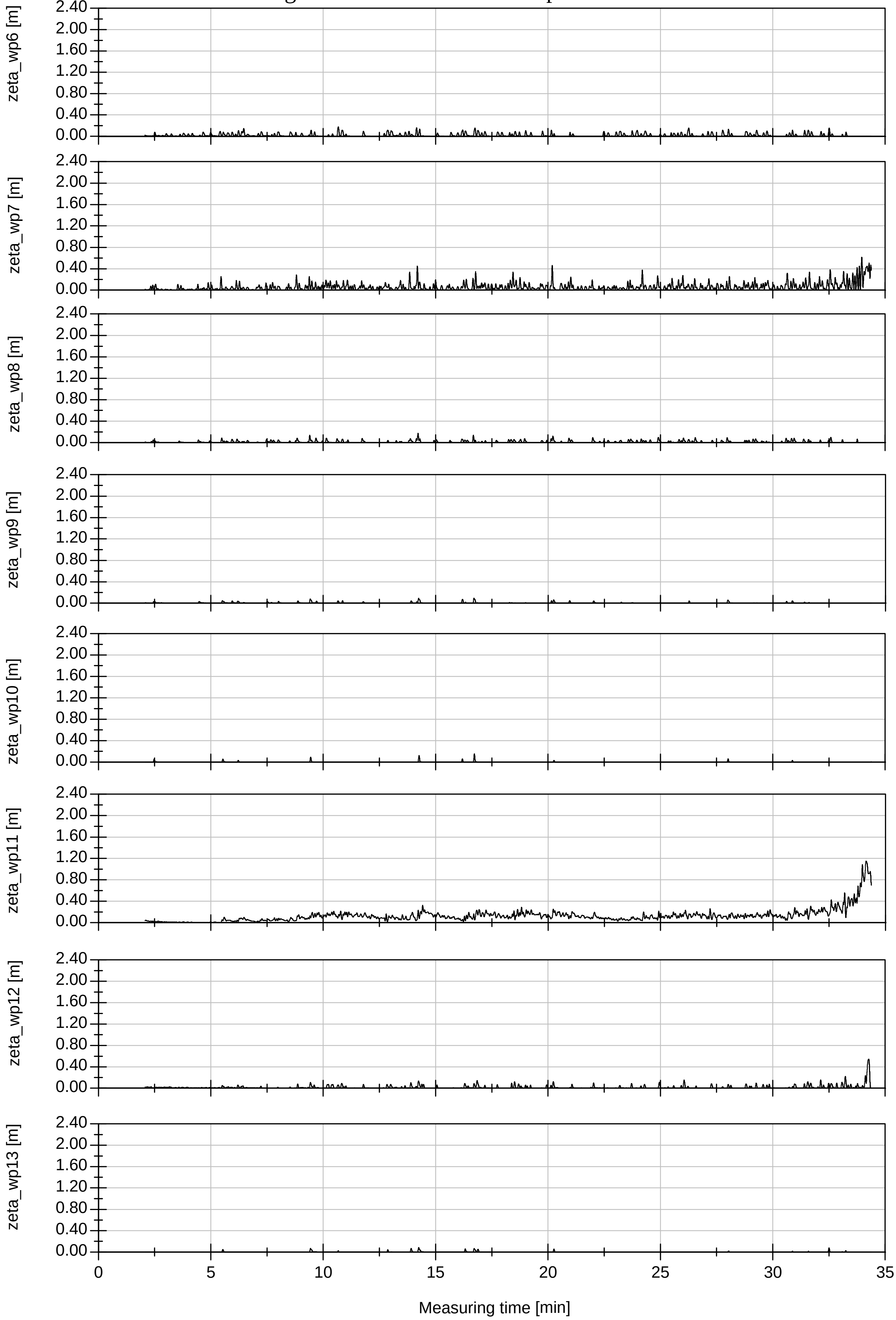
Run-No. 2 / Damage Case 1 / Hs = 4.33 m / Tp = 12.5 s / Gamma = 1.0



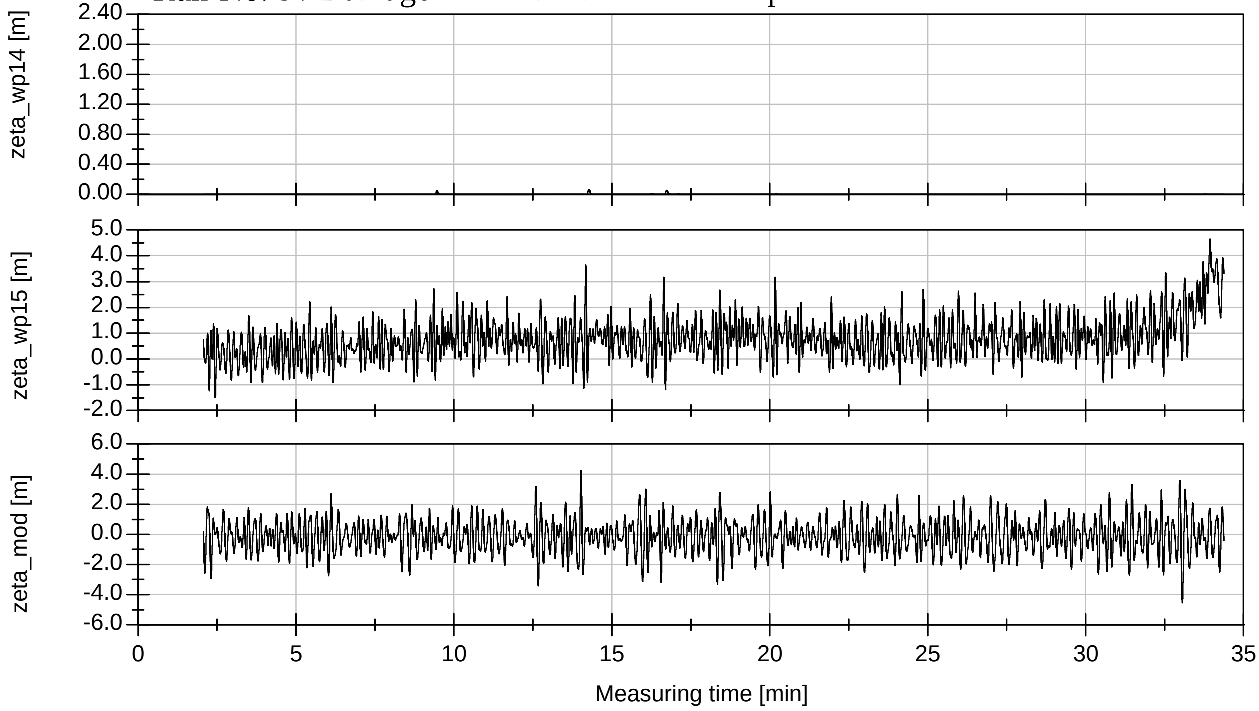
Run-No. 3 / Damage Case 1 / Hs = 4.36 m / Tp = 12.5 s / Gamma = 1.0



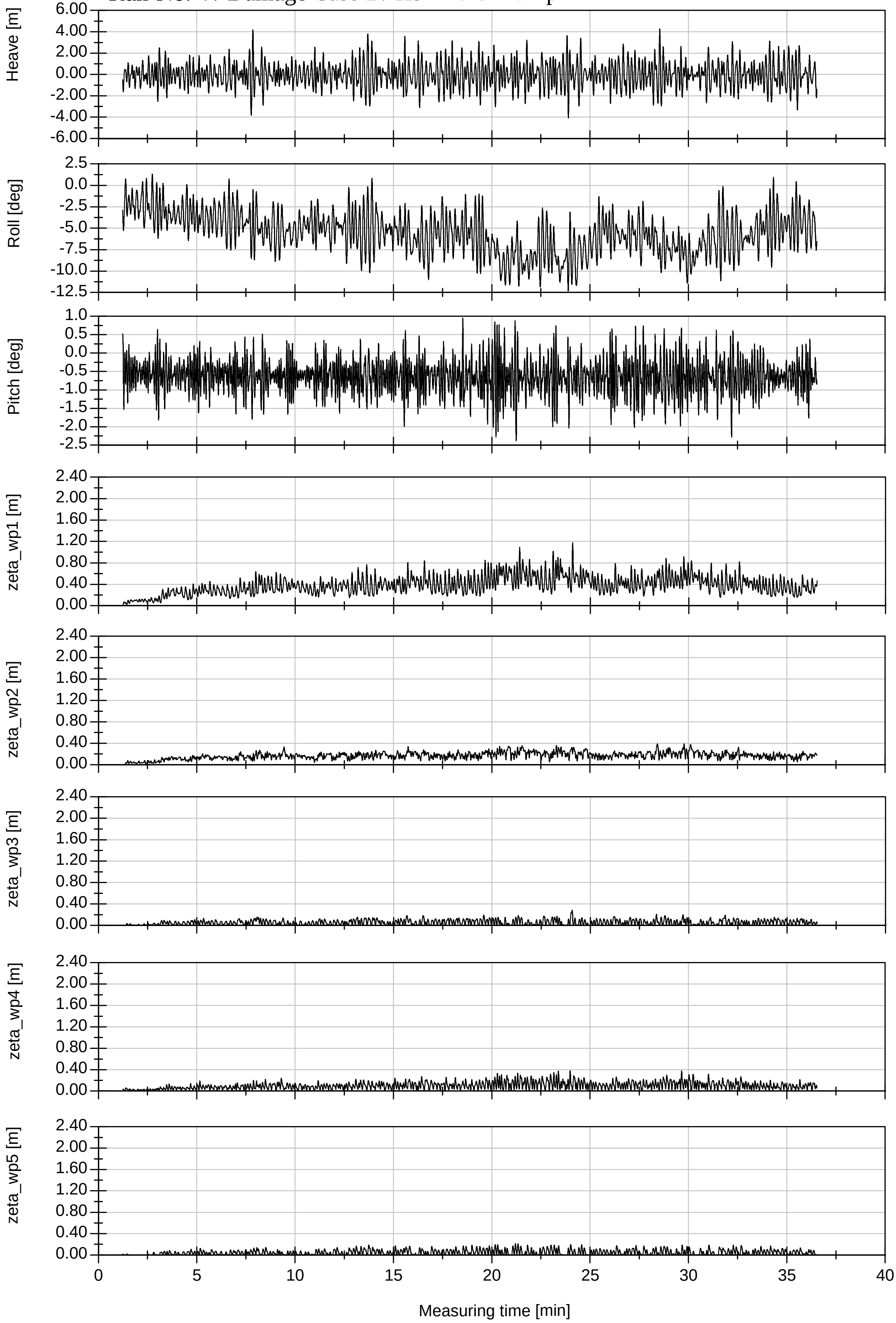
Run-No. 3 / Damage Case 1 / Hs = 4.36 m / Tp = 12.5 s / Gamma = 1.0



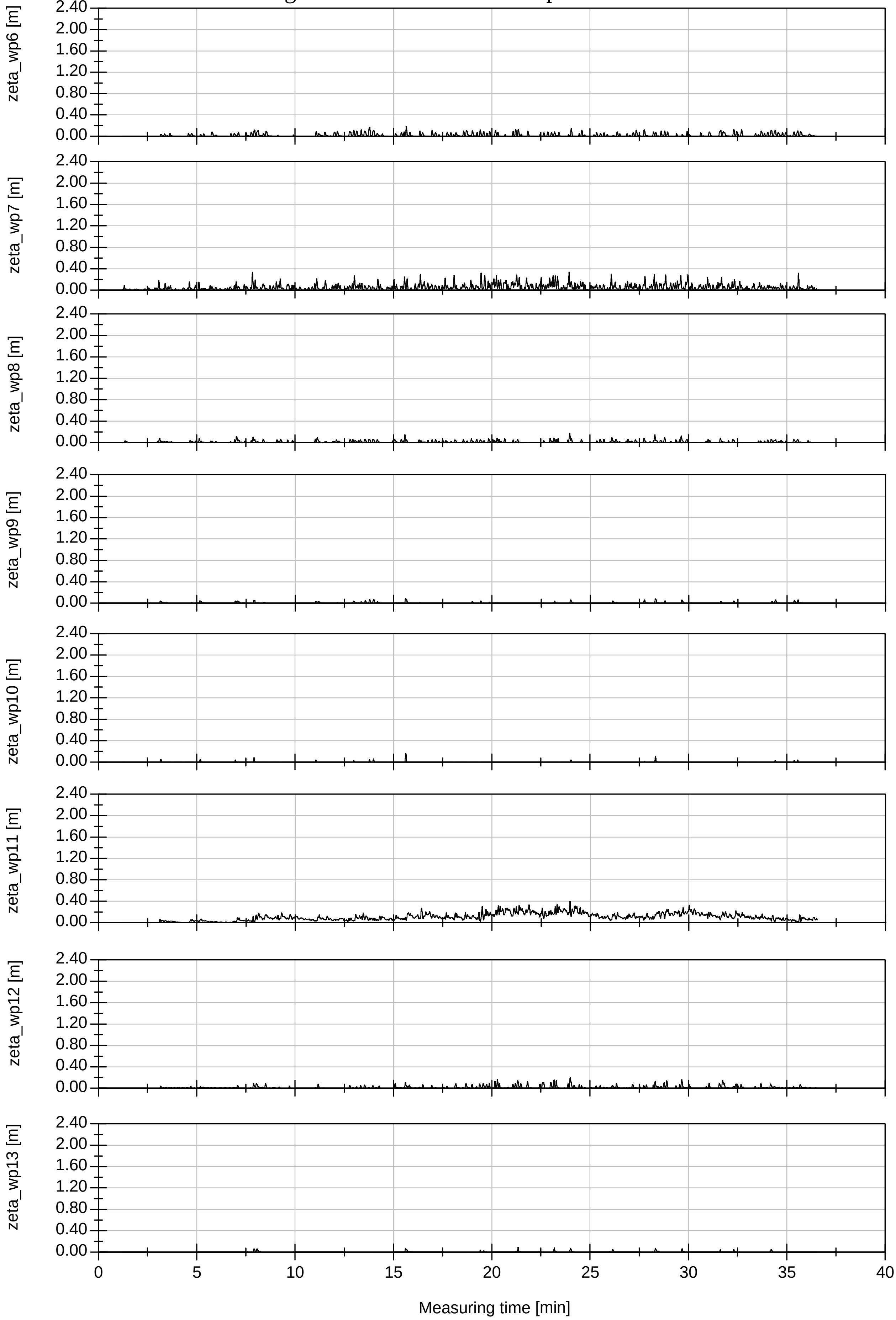
Run-No. 3 / Damage Case 1 / Hs = 4.36 m / Tp = 12.5 s / Gamma = 1.0



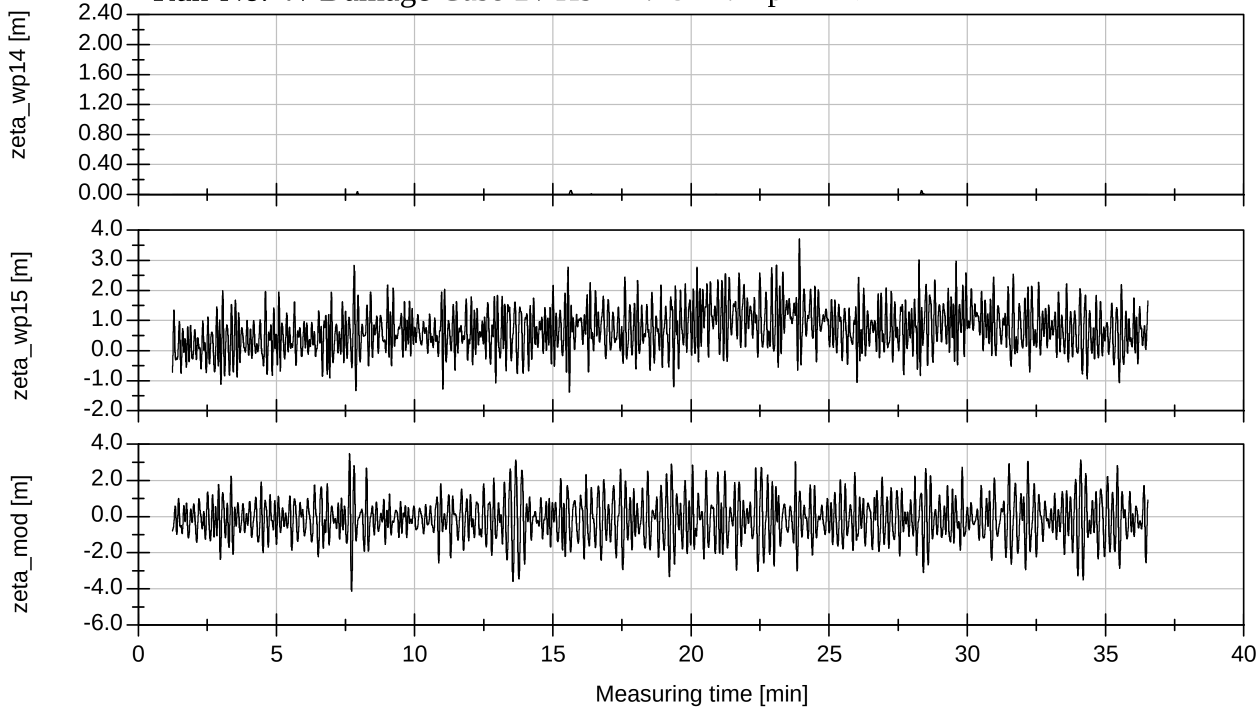
Run-No. 4 / Damage Case 1 / Hs = 4.23 m / Tp = 12.3 s / Gamma = 1.0



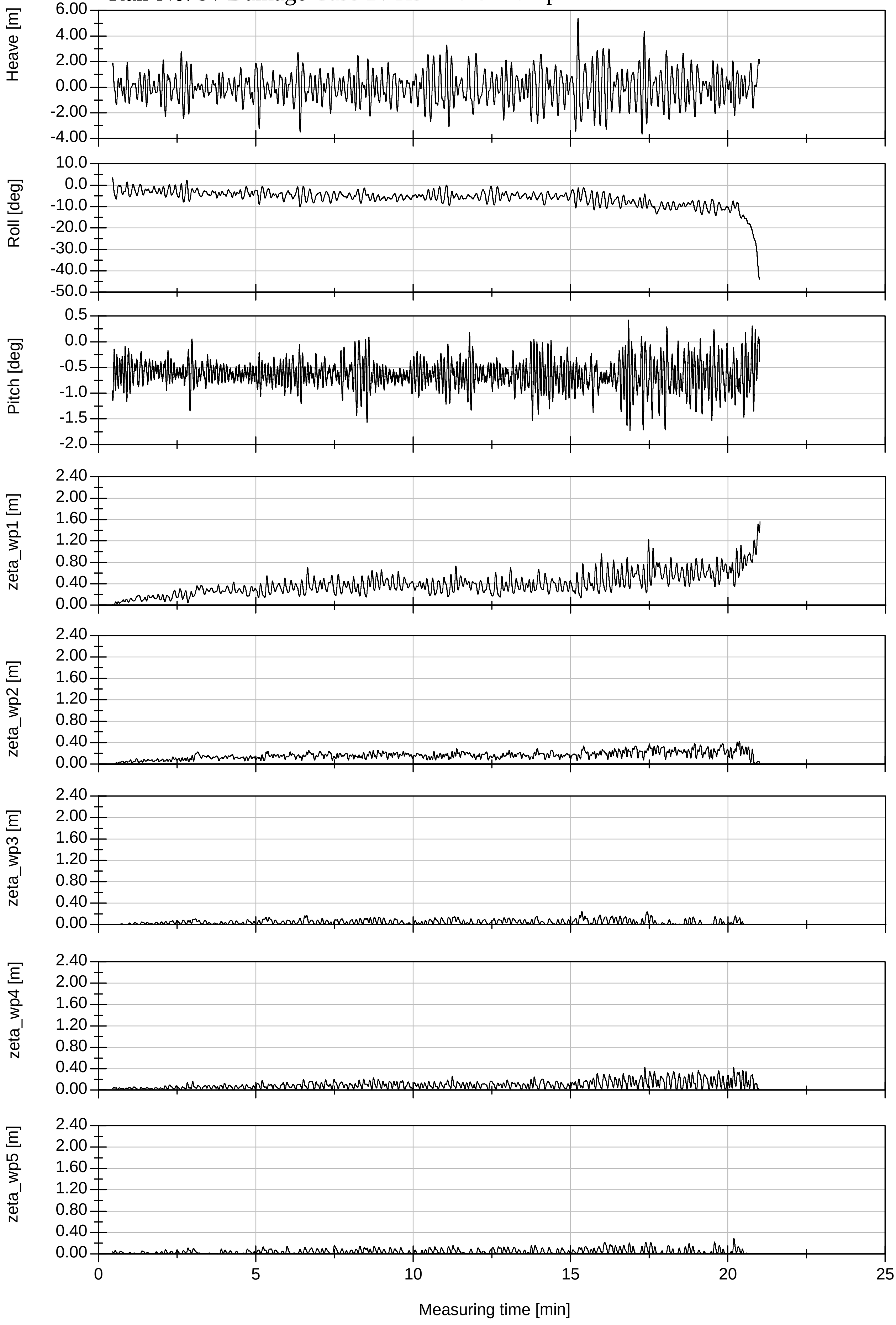
Run-No. 4 / Damage Case 1 / Hs = 4.23 m / Tp = 12.3 s / Gamma = 1.0



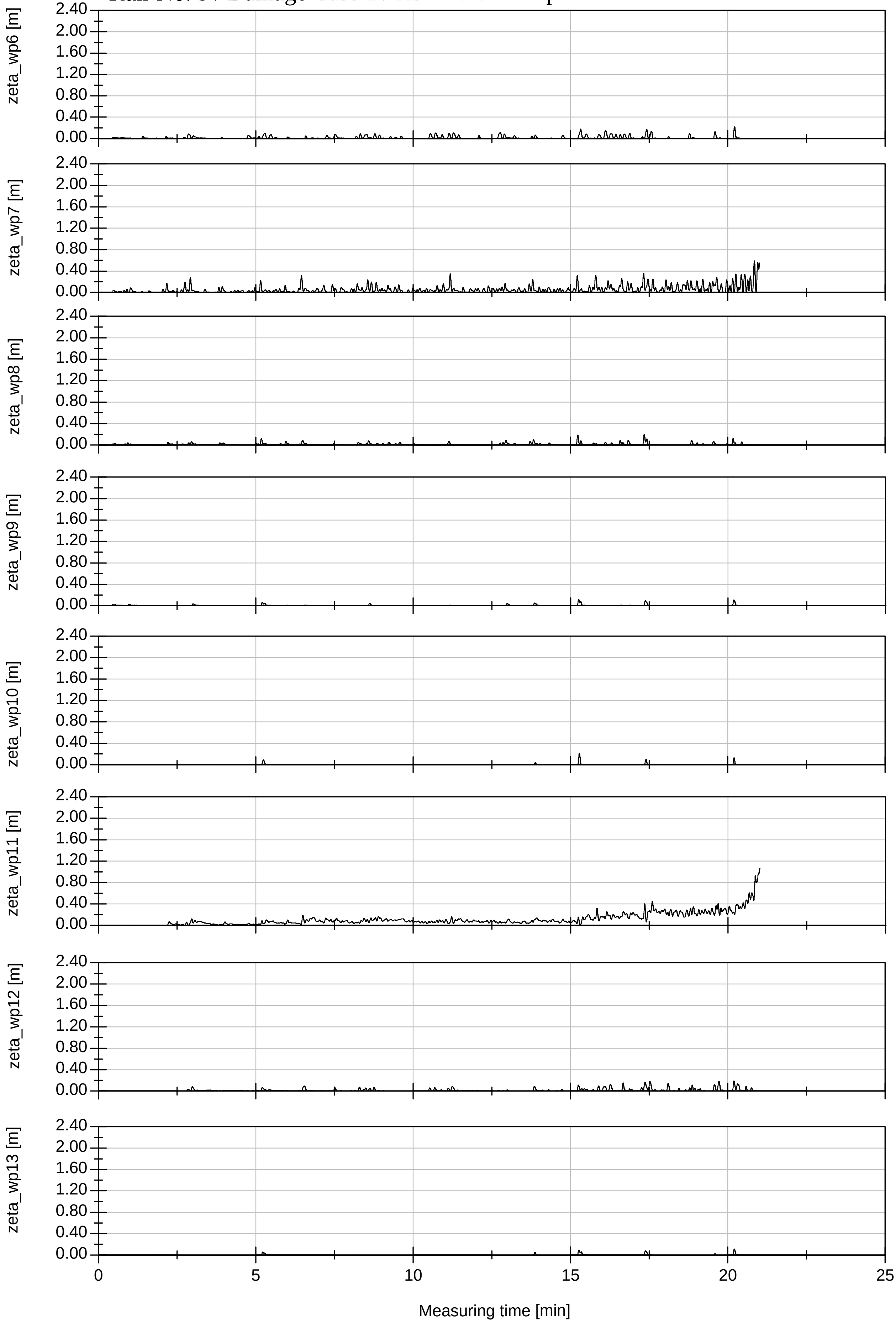
Run-No. 4 / Damage Case 1 / Hs = 4.23 m / Tp = 12.3 s / Gamma = 1.0



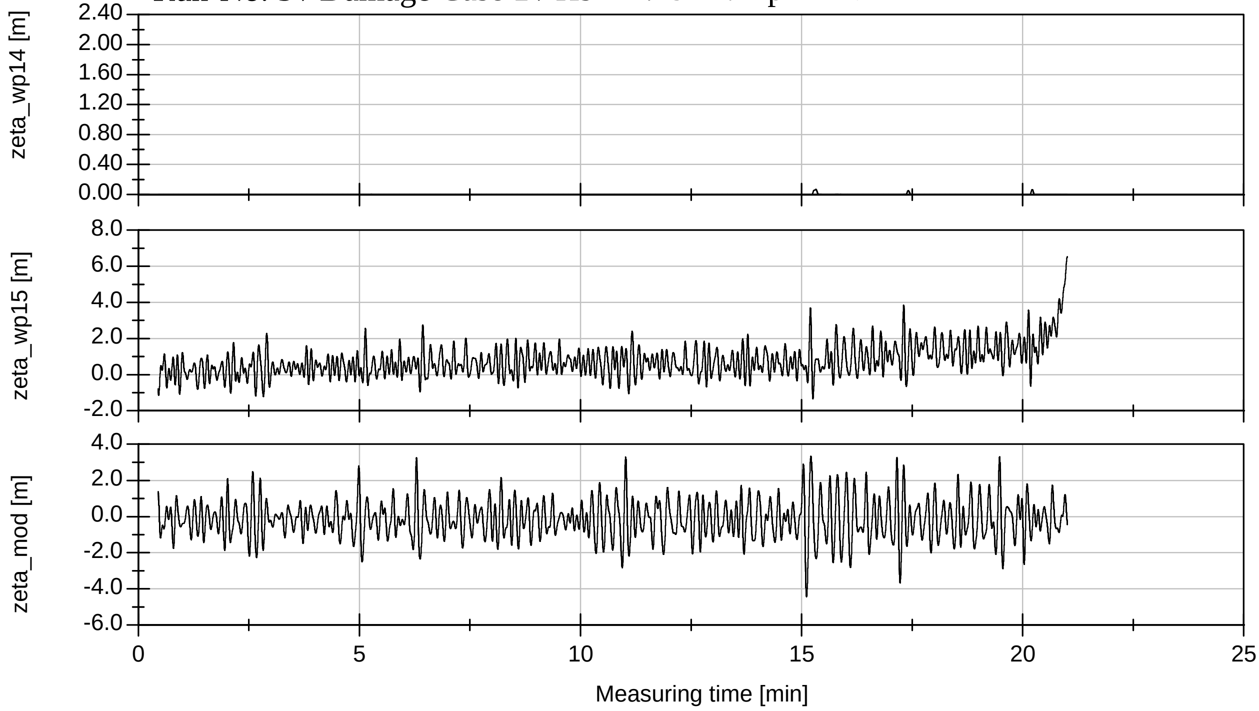
Run-No. 5 / Damage Case 1 / Hs = 4.19 m / Tp = 12.3 s / Gamma = 1.0



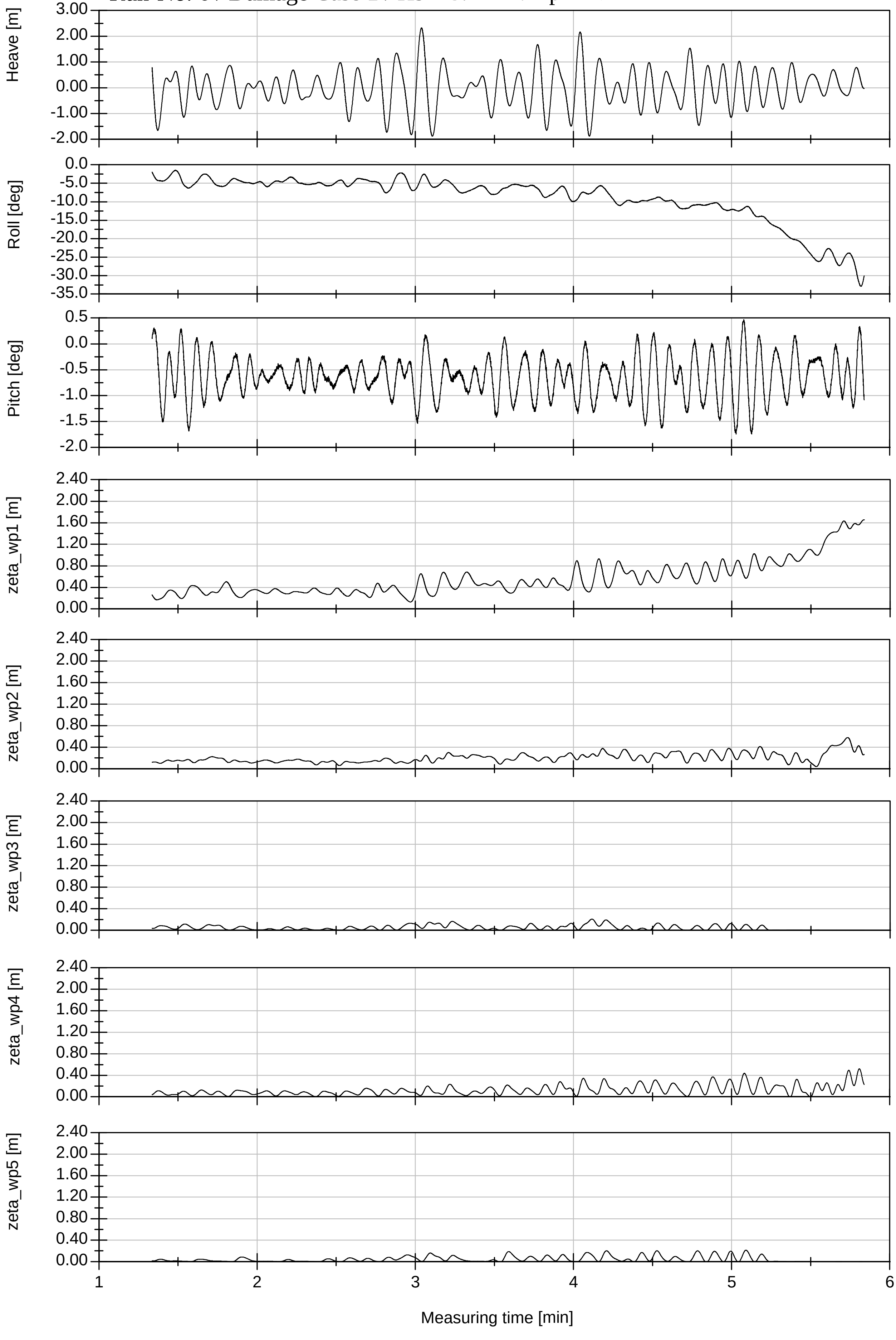
Run-No. 5 / Damage Case 1 / Hs = 4.19 m / Tp = 12.3 s / Gamma = 1.0



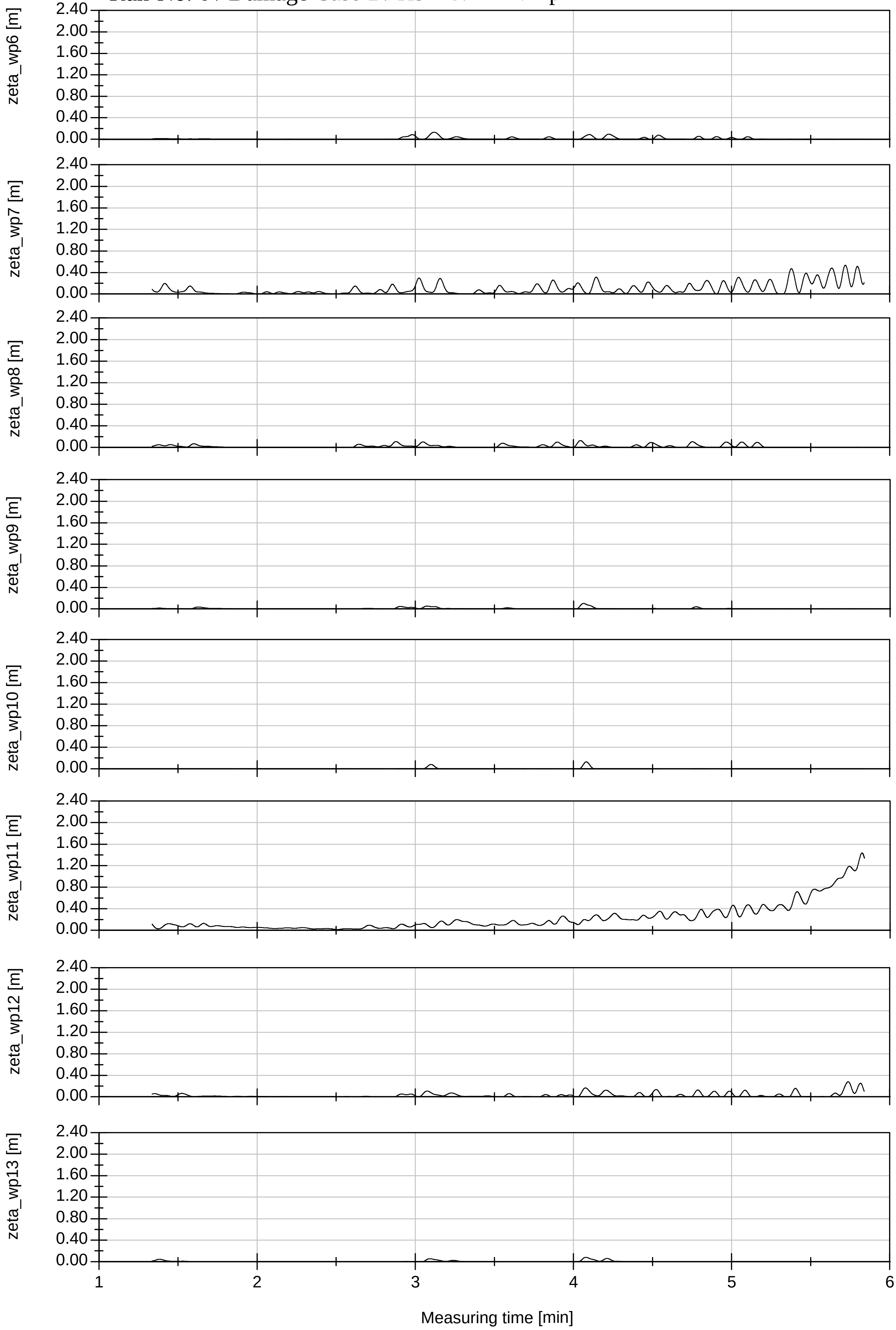
Run-No. 5 / Damage Case 1 / Hs = 4.19 m / Tp = 12.3 s / Gamma = 1.0

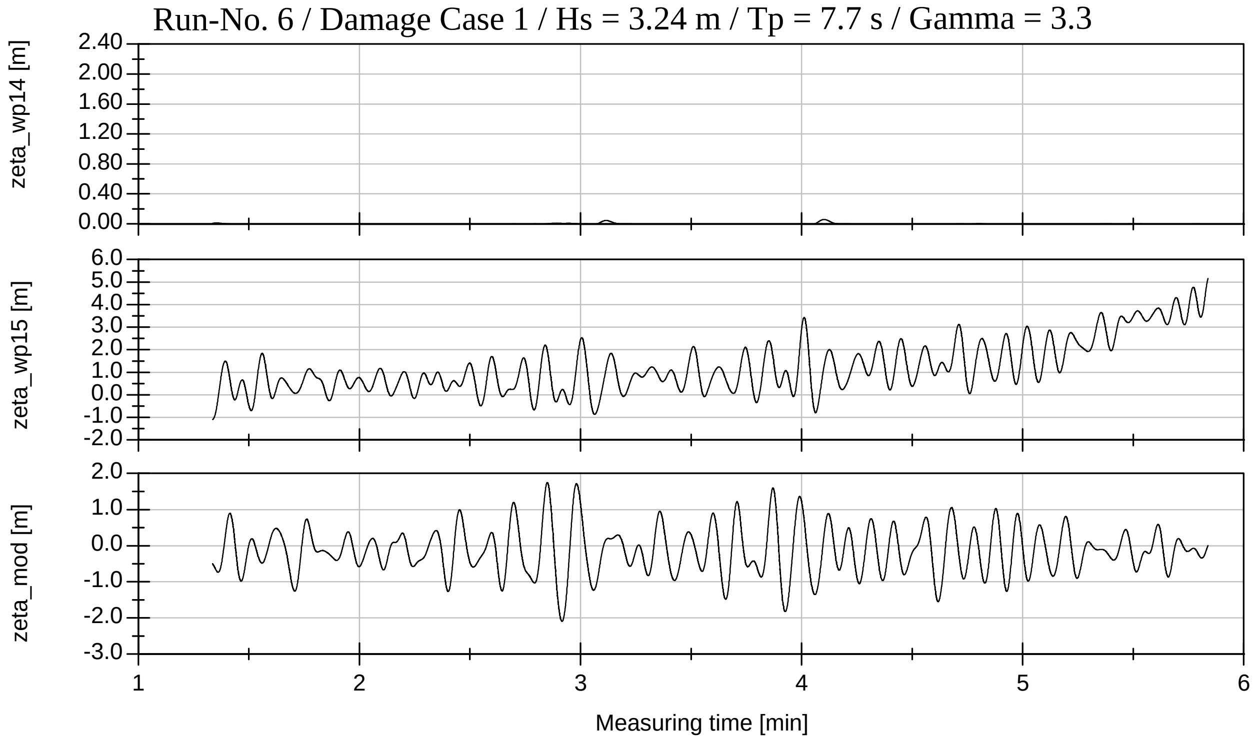


Run-No. 6 / Damage Case 1 / Hs = 3.24 m / Tp = 7.7 s / Gamma = 3.3

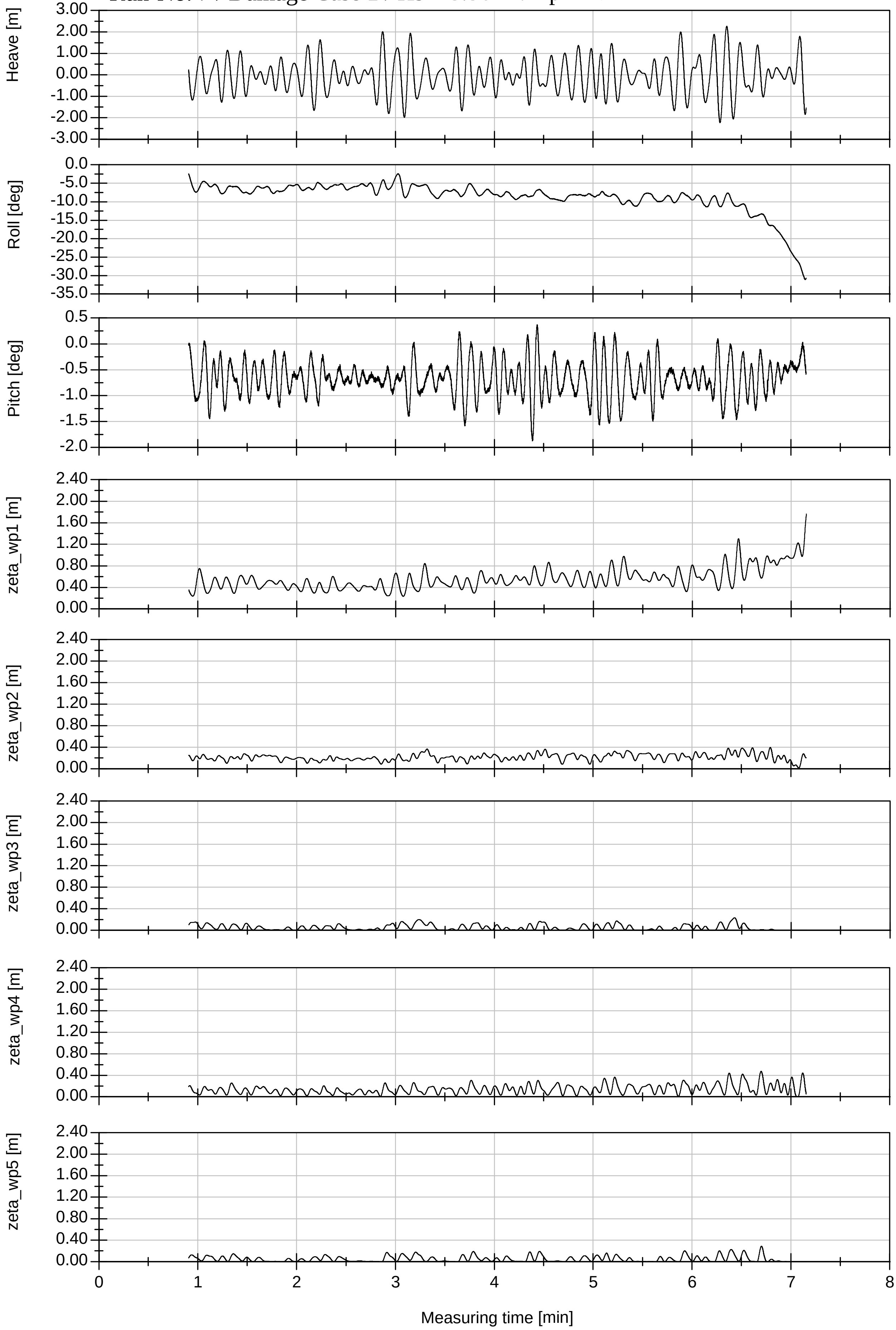


Run-No. 6 / Damage Case 1 / Hs = 3.24 m / Tp = 7.7 s / Gamma = 3.3

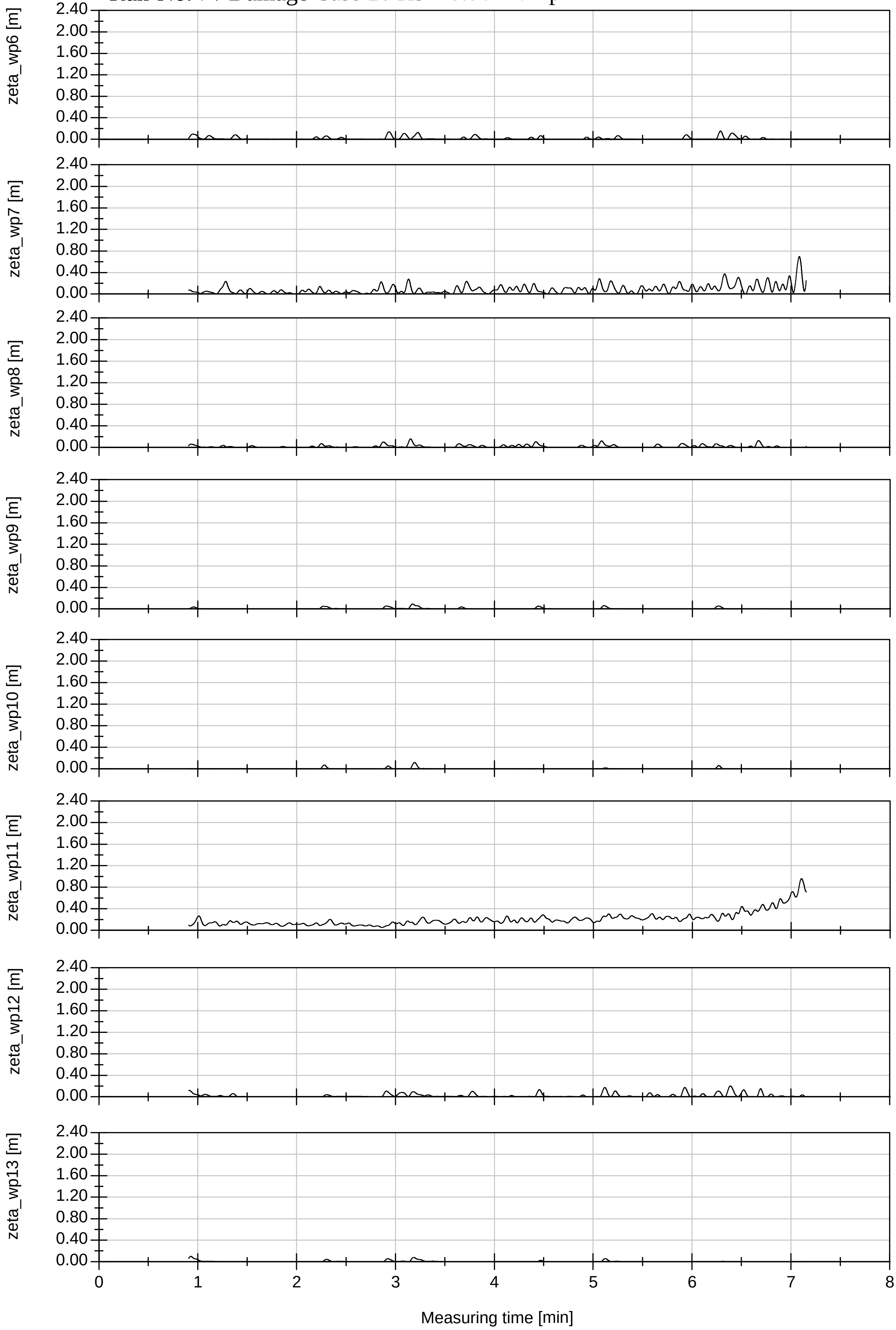



Run-No. 6 / Damage Case 1 / Hs = 3.24 m / Tp = 7.7 s / Gamma = 3.3
zeta_wp14 [m]
2.40
2.00
1.60
1.20
0.80
0.40
0.00
zeta_wp15 [m]
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
zeta_mod [m]
2.0
1.0
0.0
-1.0
-2.0
-3.0
1
2
3
4
5
6
Measuring time [min]

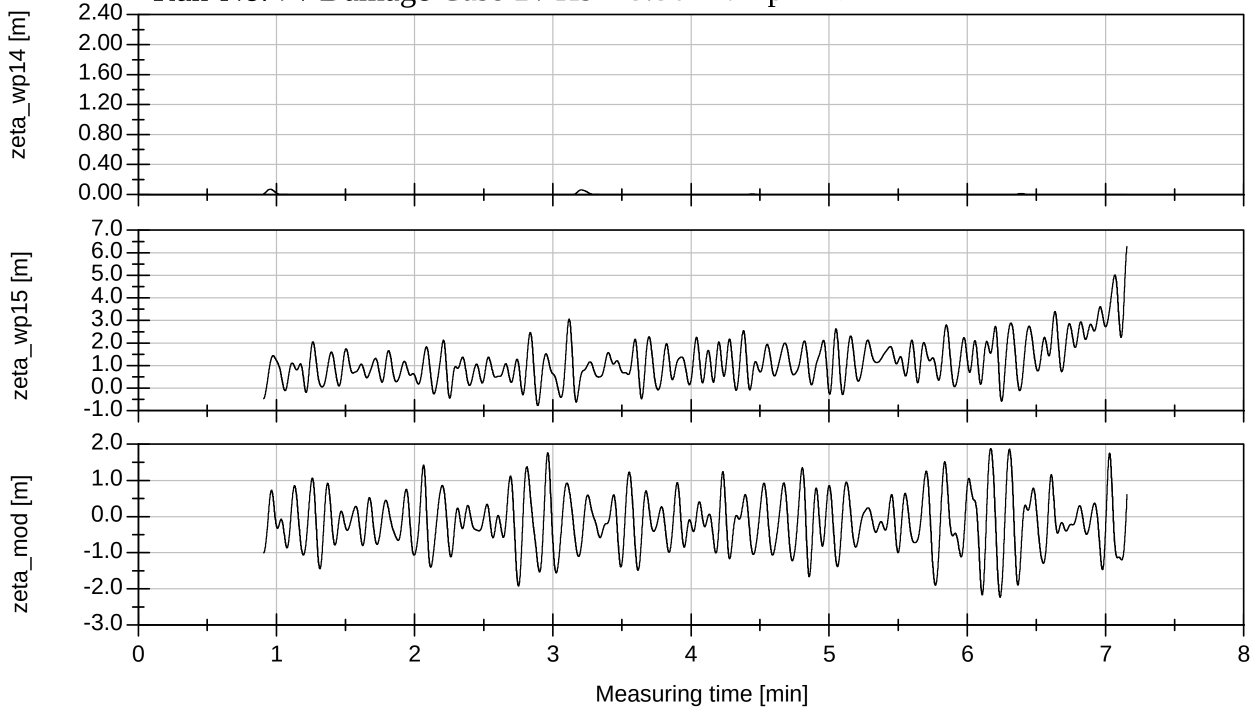
Run-No. 7 / Damage Case 1 / Hs = 3.36 m / Tp = 7.5 s / Gamma = 3.3



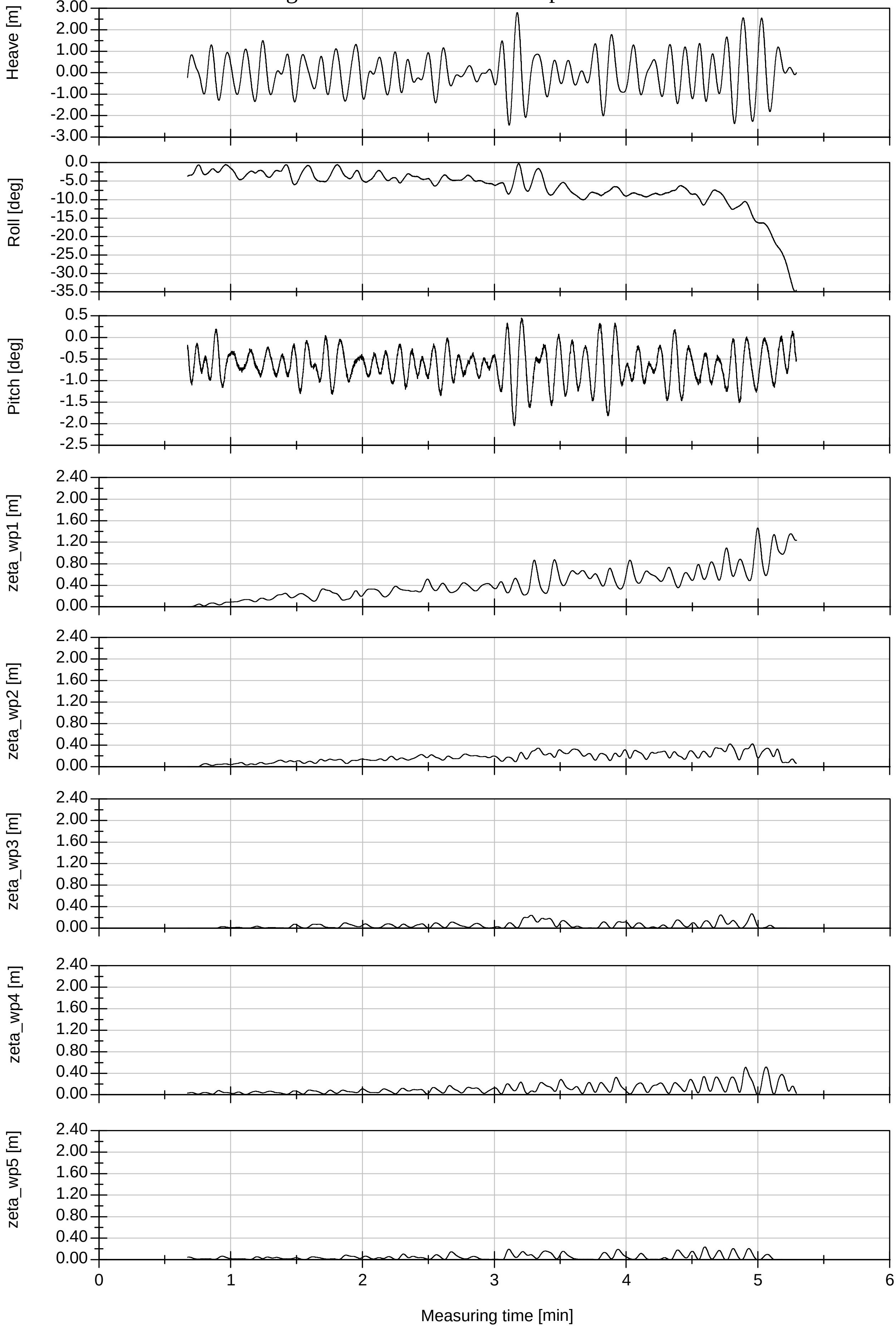
Run-No. 7 / Damage Case 1 / Hs = 3.36 m / Tp = 7.5 s / Gamma = 3.3



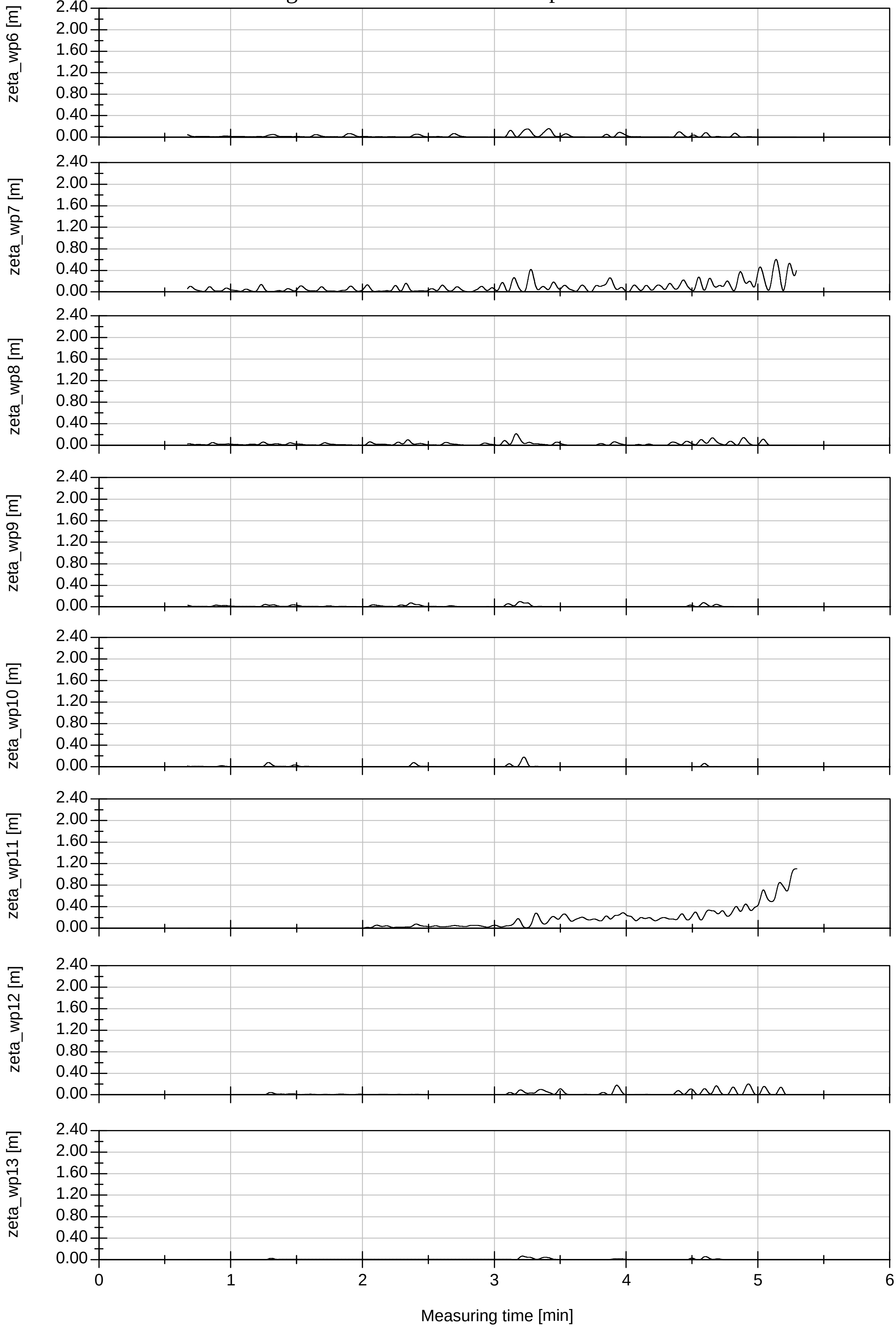
Run-No. 7 / Damage Case 1 / Hs = 3.36 m / Tp = 7.5 s / Gamma = 3.3



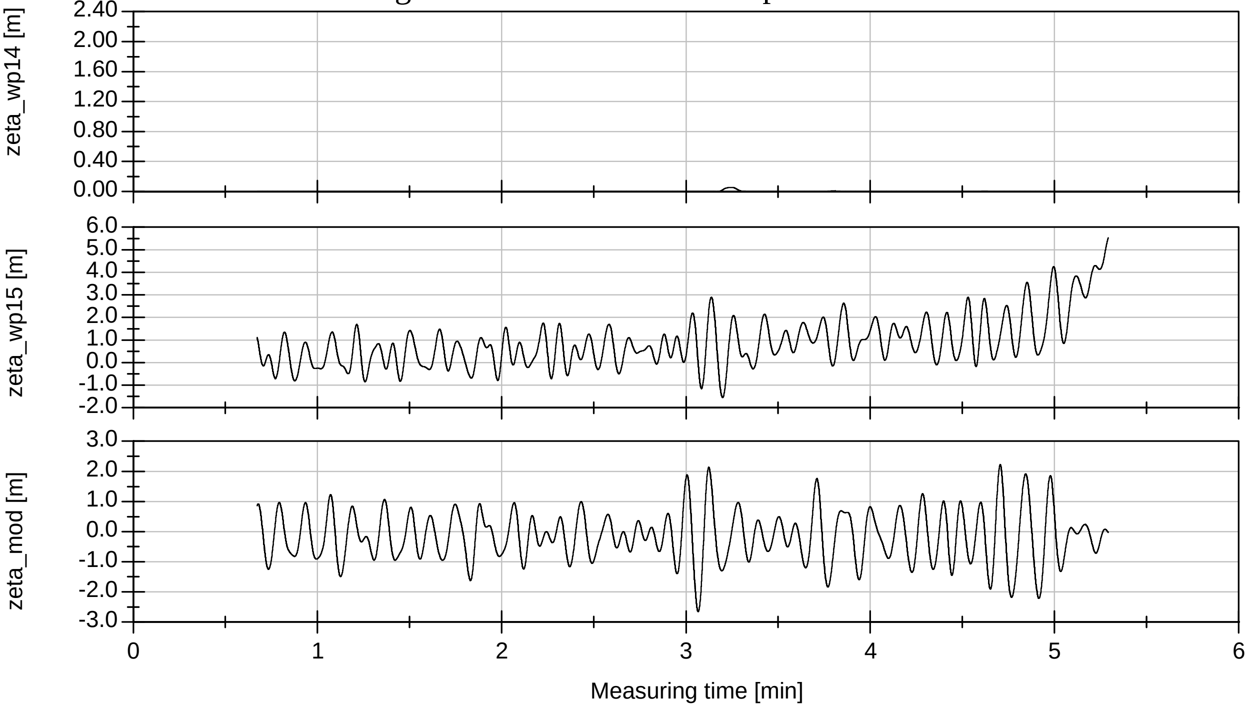
Run-No. 8 / Damage Case 1 / Hs = 3.20 m / Tp = 7.2 s / Gamma = 3.3



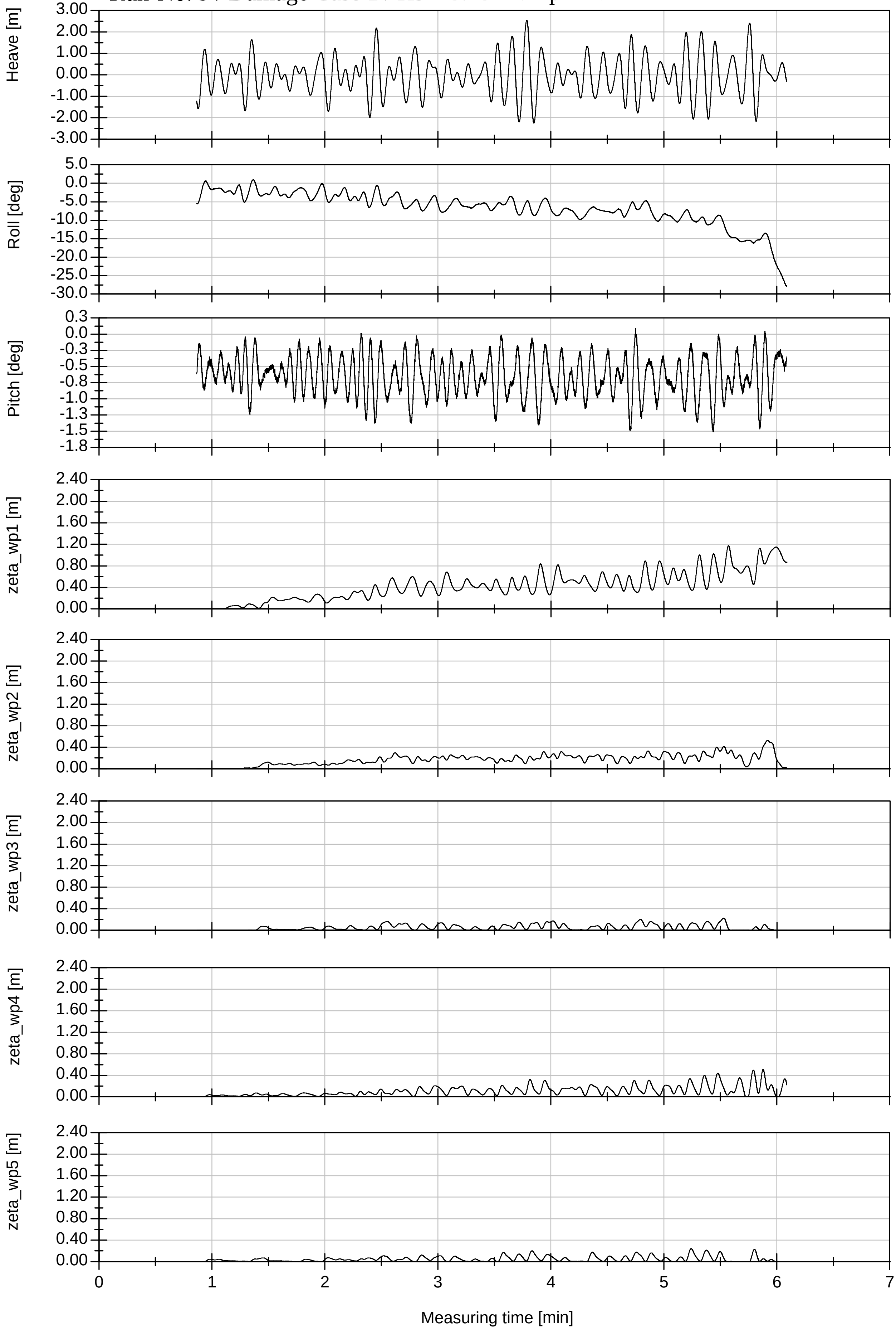
Run-No. 8 / Damage Case 1 / Hs = 3.20 m / Tp = 7.2 s / Gamma = 3.3



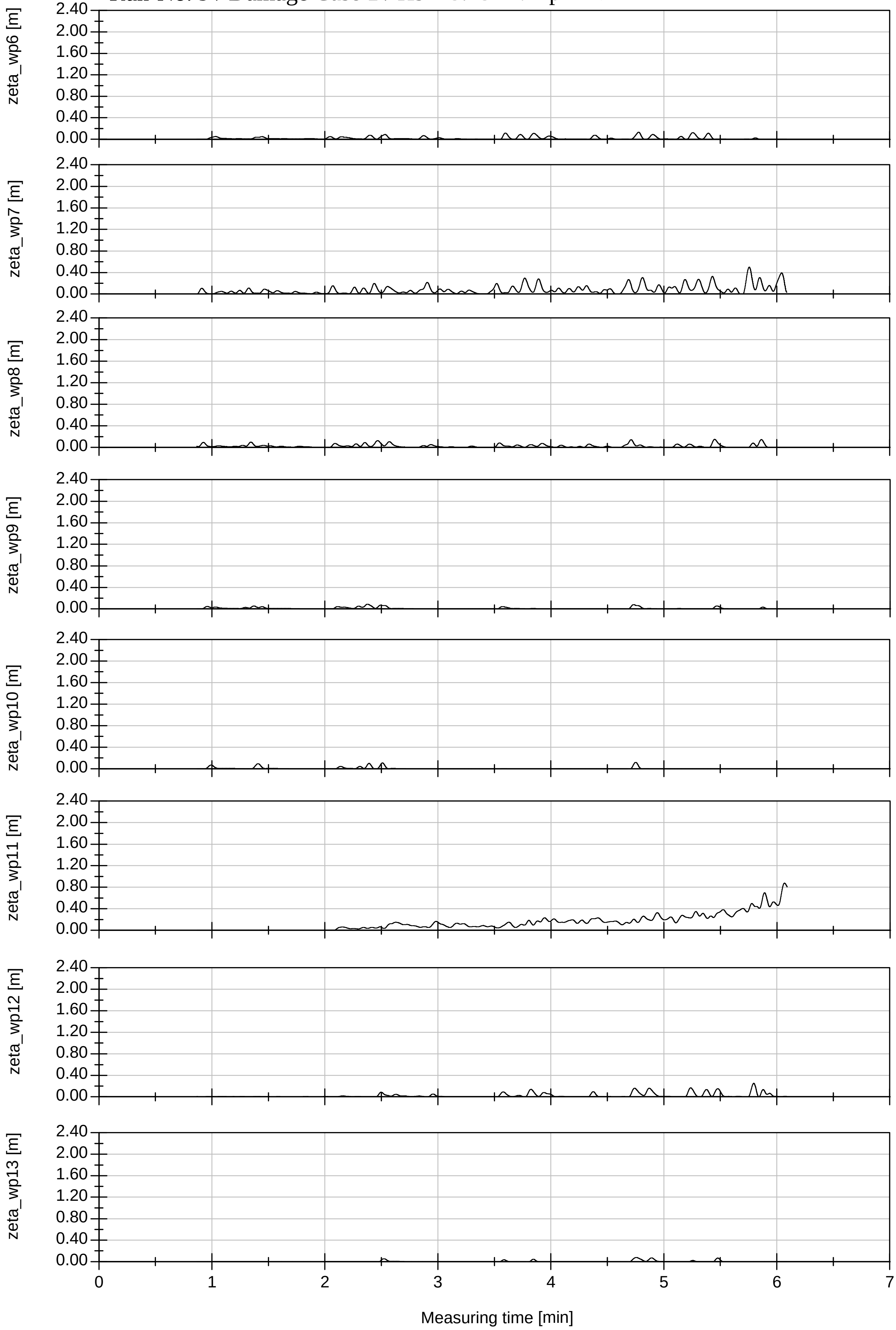
Run-No. 8 / Damage Case 1 / Hs = 3.20 m / Tp = 7.2 s / Gamma = 3.3



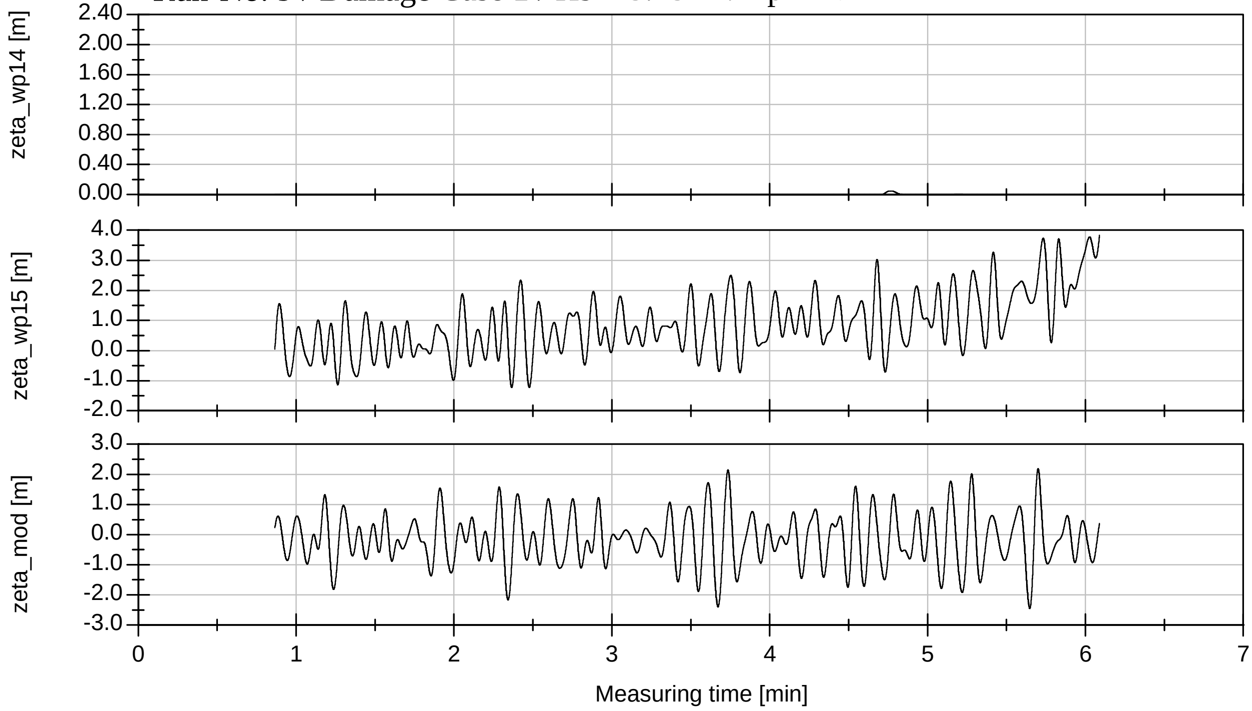
Run-No. 9 / Damage Case 1 / Hs = 3.23 m / Tp = 7.3 s / Gamma = 3.3



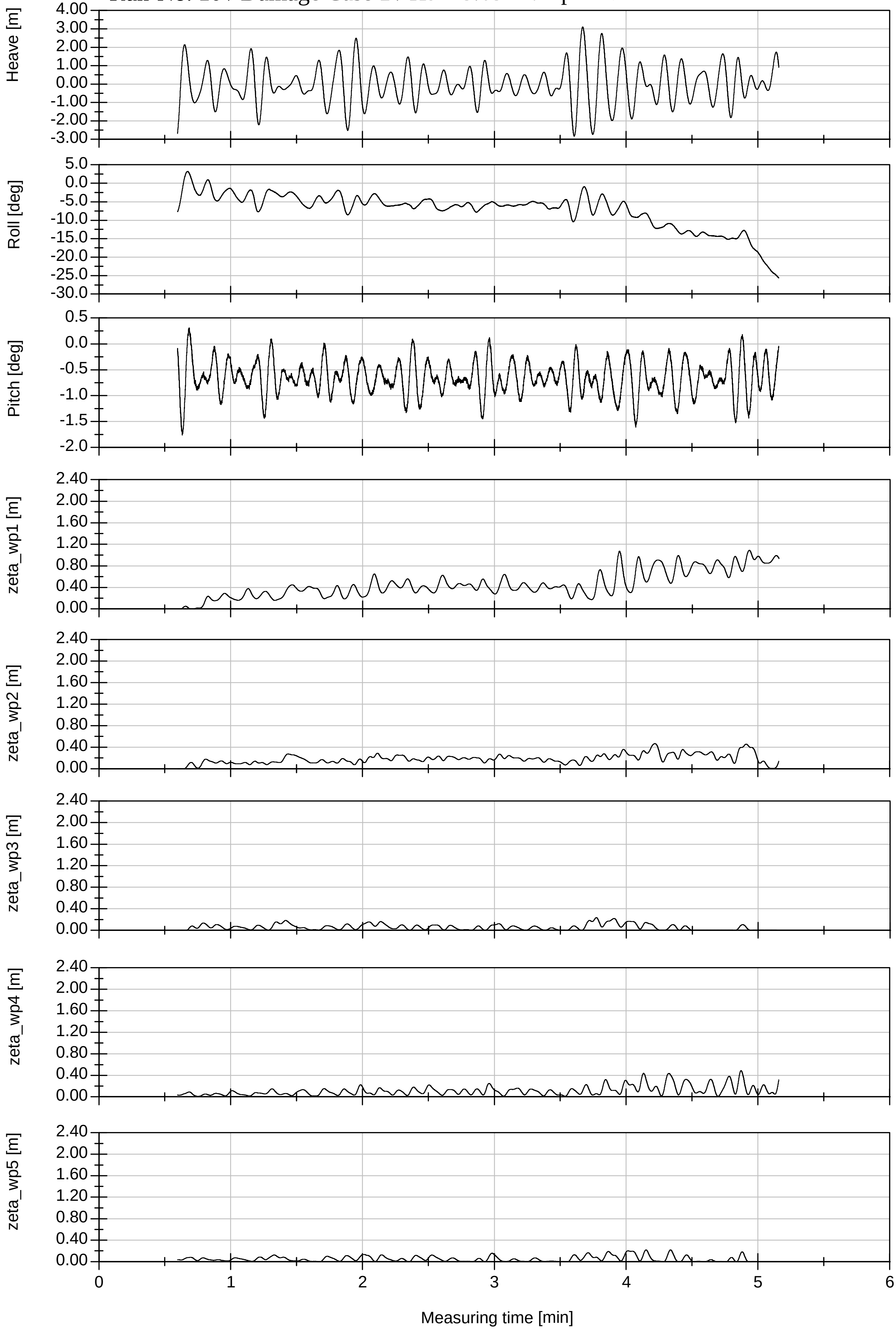
Run-No. 9 / Damage Case 1 / Hs = 3.23 m / Tp = 7.3 s / Gamma = 3.3



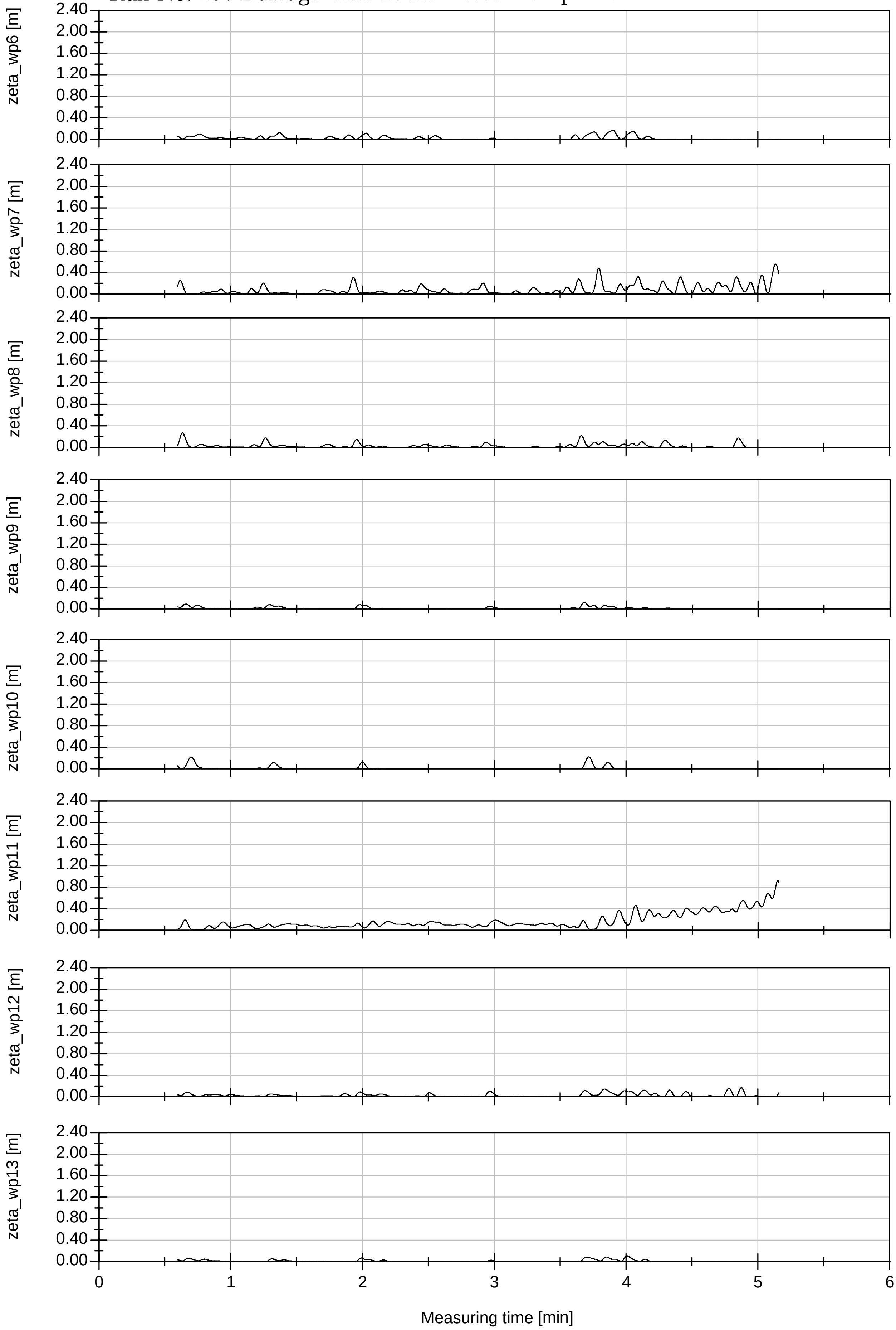
Run-No. 9 / Damage Case 1 / Hs = 3.23 m / Tp = 7.3 s / Gamma = 3.3



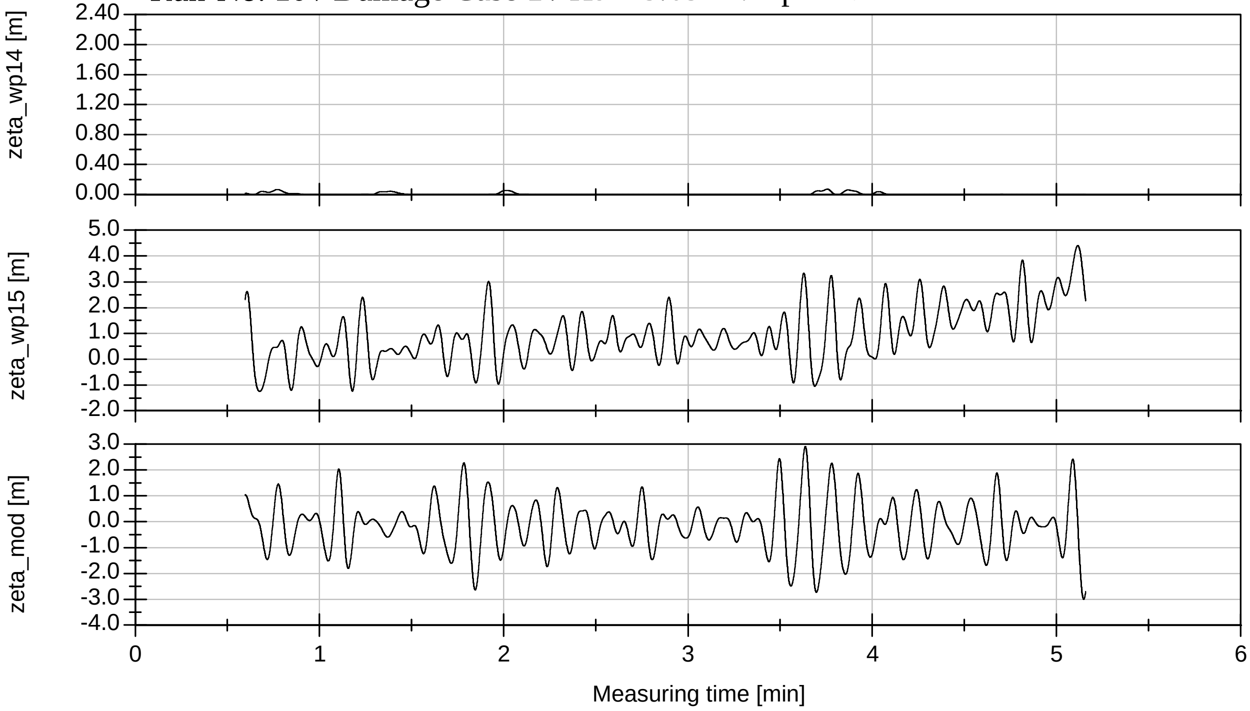
Run-No. 10 / Damage Case 1 / Hs = 3.63 m / Tp = 7.8 s / Gamma = 3.3



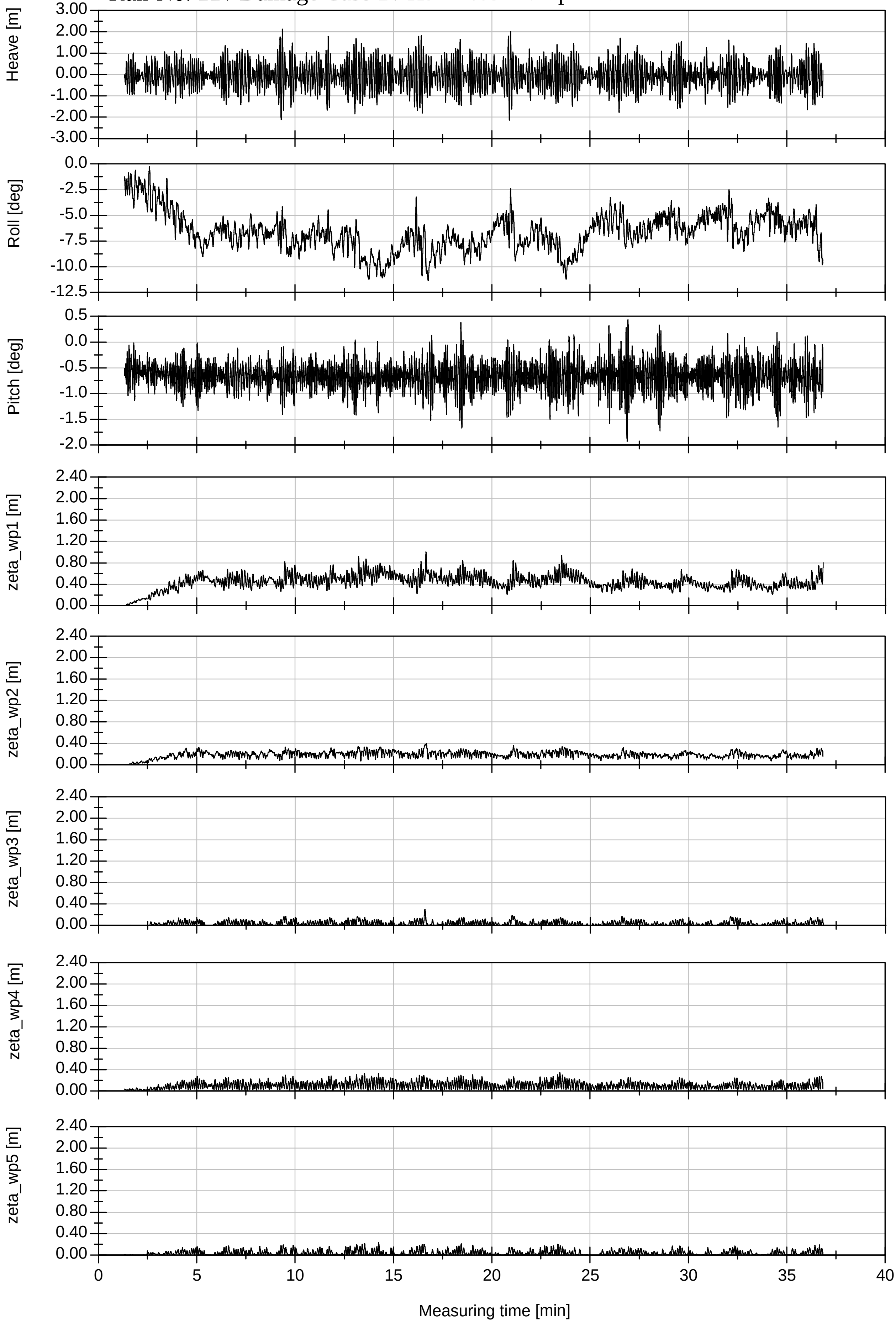
Run-No. 10 / Damage Case 1 / Hs = 3.63 m / Tp = 7.8 s / Gamma = 3.3



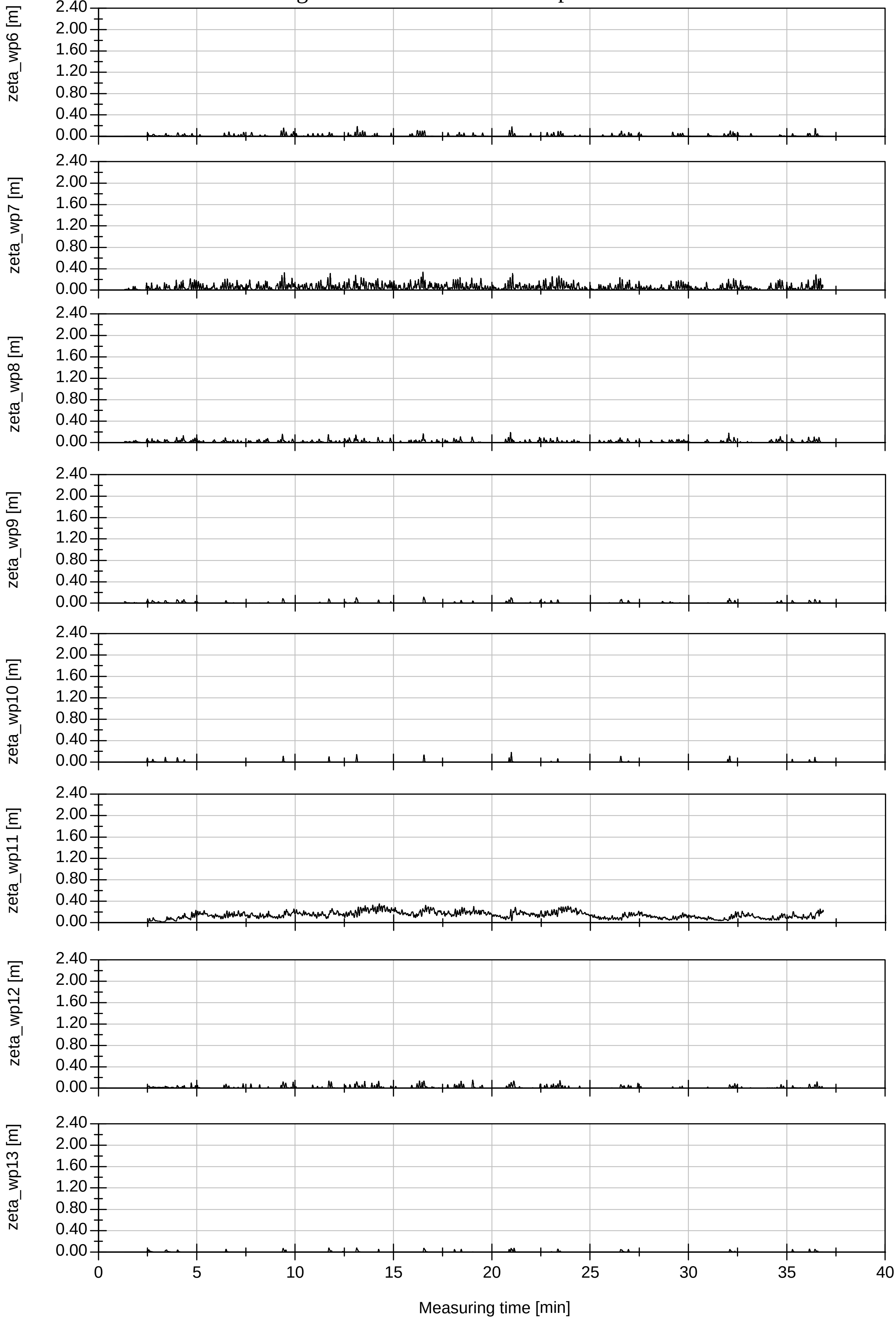
Run-No. 10 / Damage Case 1 / Hs = 3.63 m / Tp = 7.8 s / Gamma = 3.3



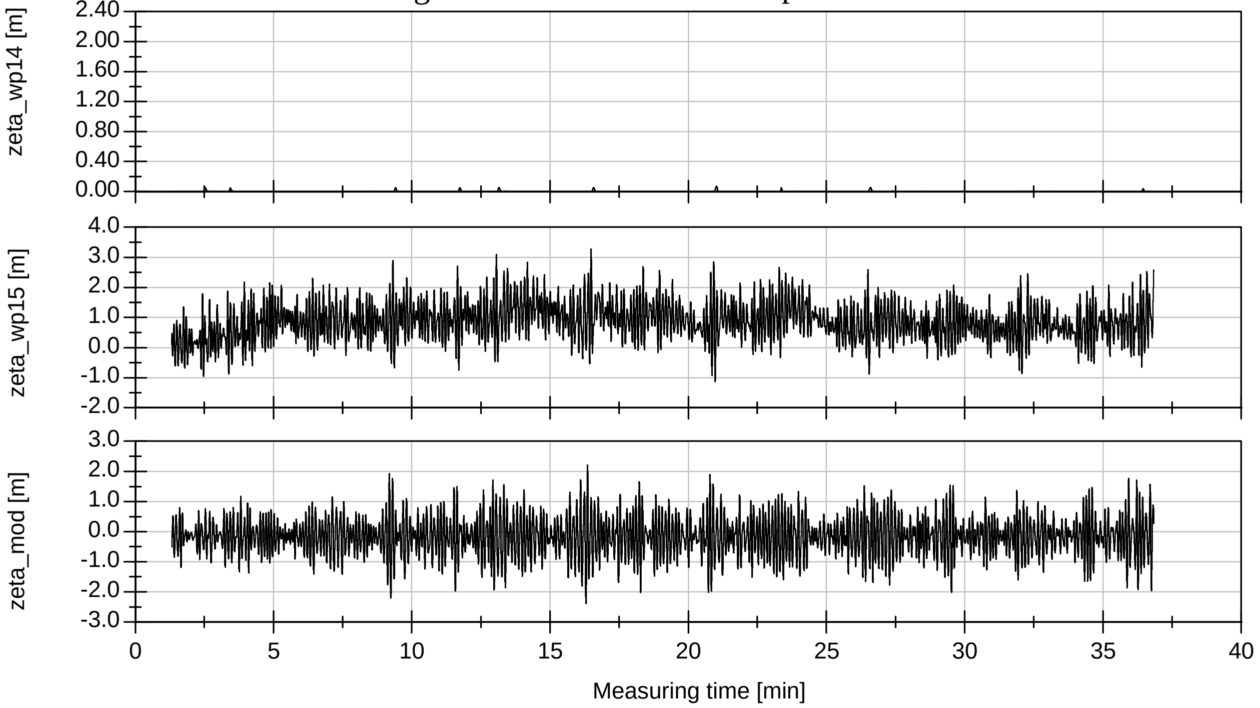
Run-No. 11 / Damage Case 1 / Hs = 2.63 m / Tp = 6.8 s / Gamma = 3.3



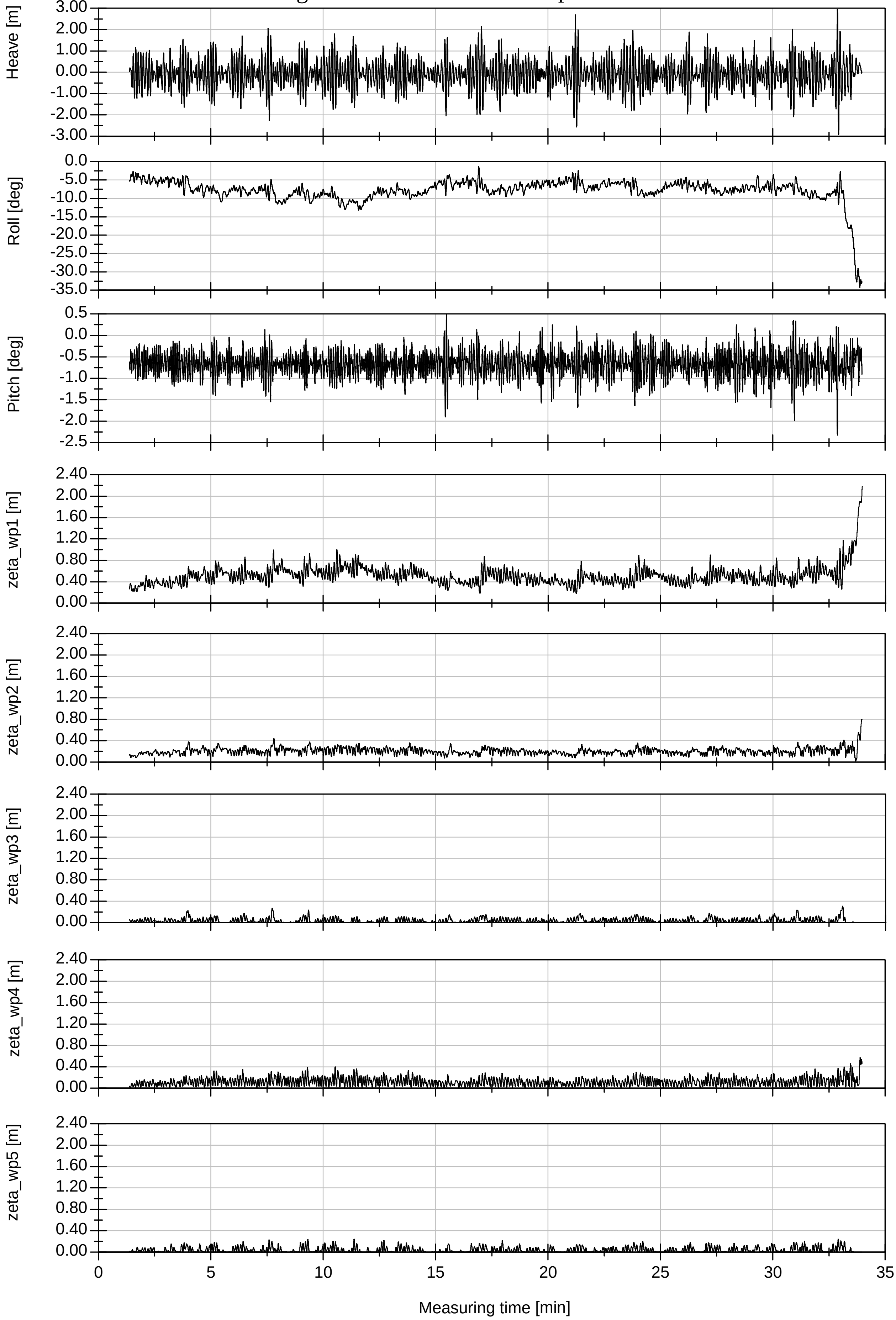
Run-No. 11 / Damage Case 1 / Hs = 2.63 m / Tp = 6.8 s / Gamma = 3.3



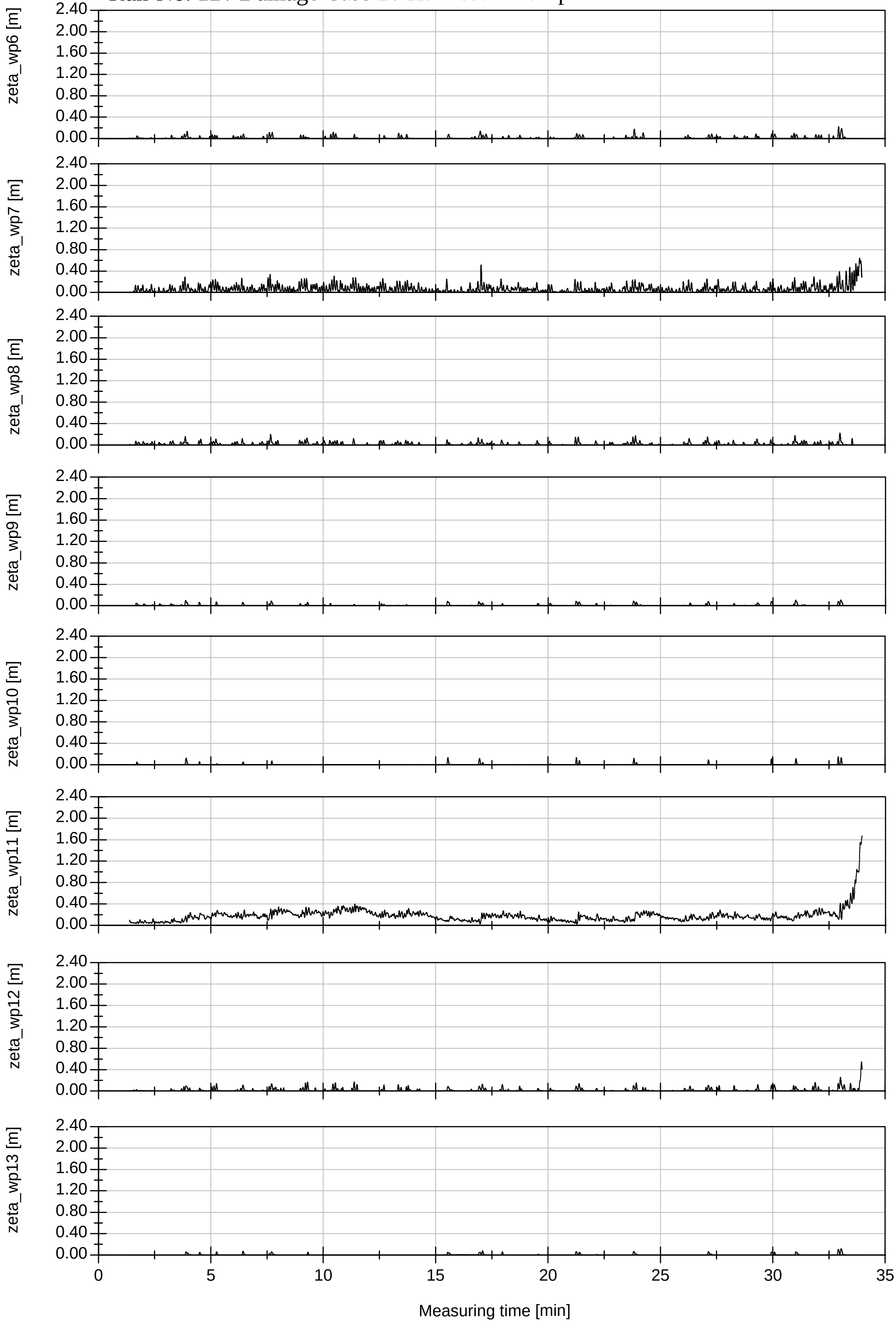
Run-No. 11 / Damage Case 1 / Hs = 2.63 m / Tp = 6.8 s / Gamma = 3.3



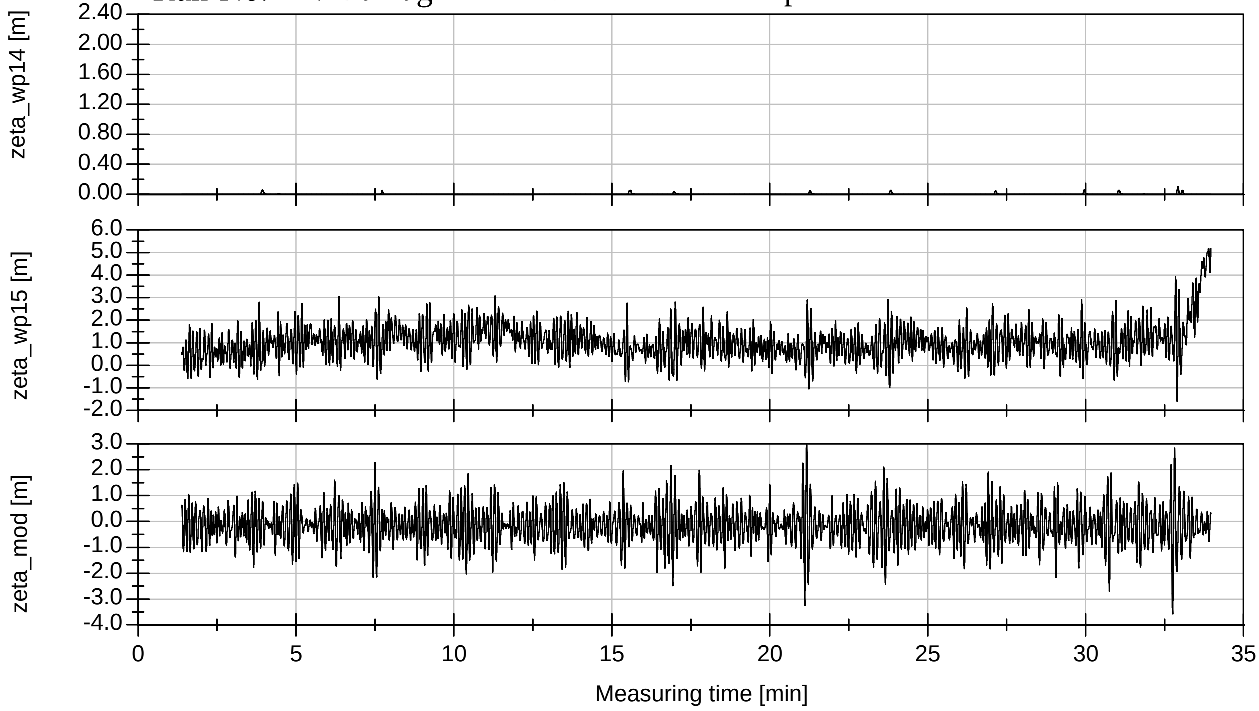
Run-No. 12 / Damage Case 1 / Hs = 3.01 m / Tp = 6.9 s / Gamma = 3.3



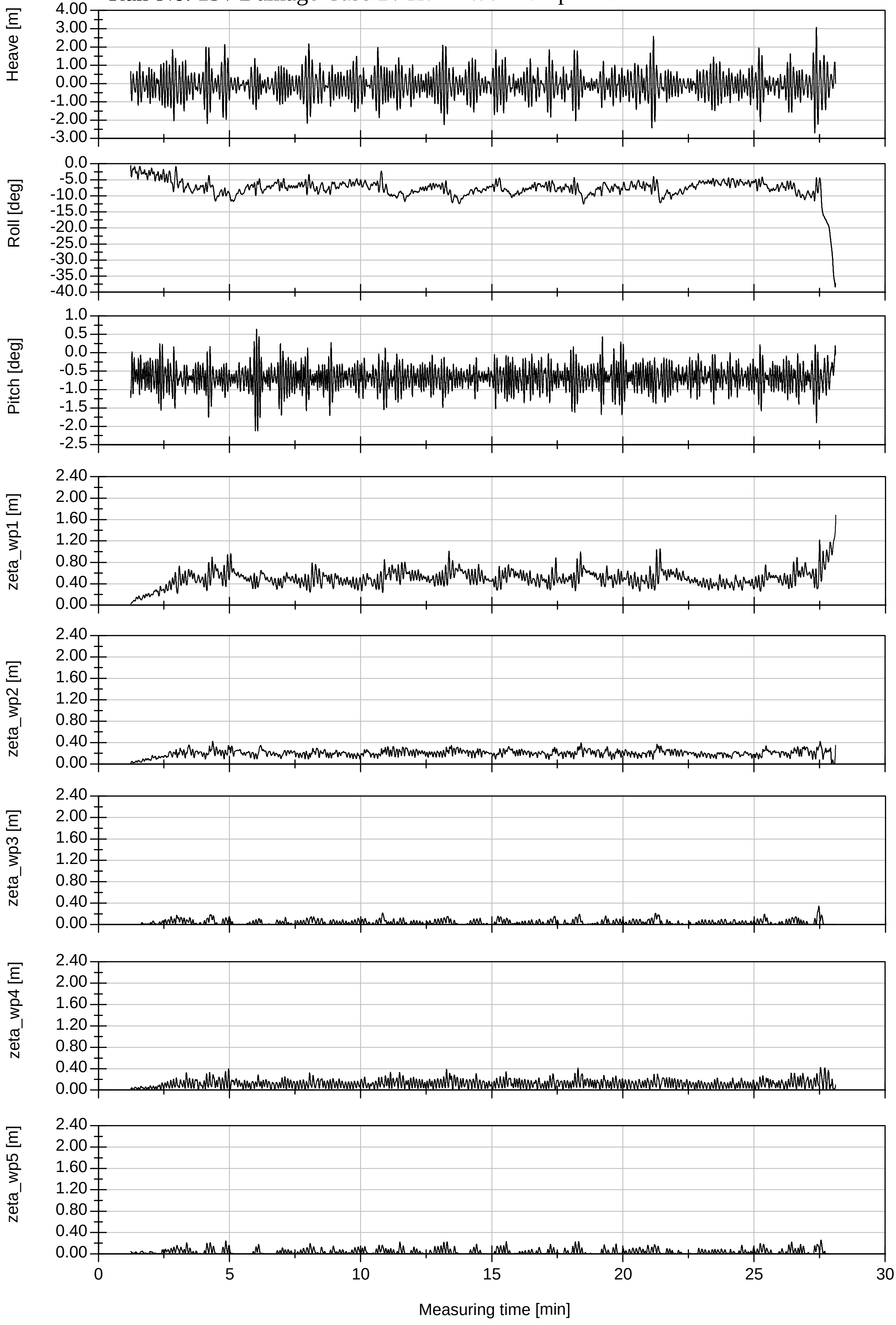
Run-No. 12 / Damage Case 1 / Hs = 3.01 m / Tp = 6.9 s / Gamma = 3.3



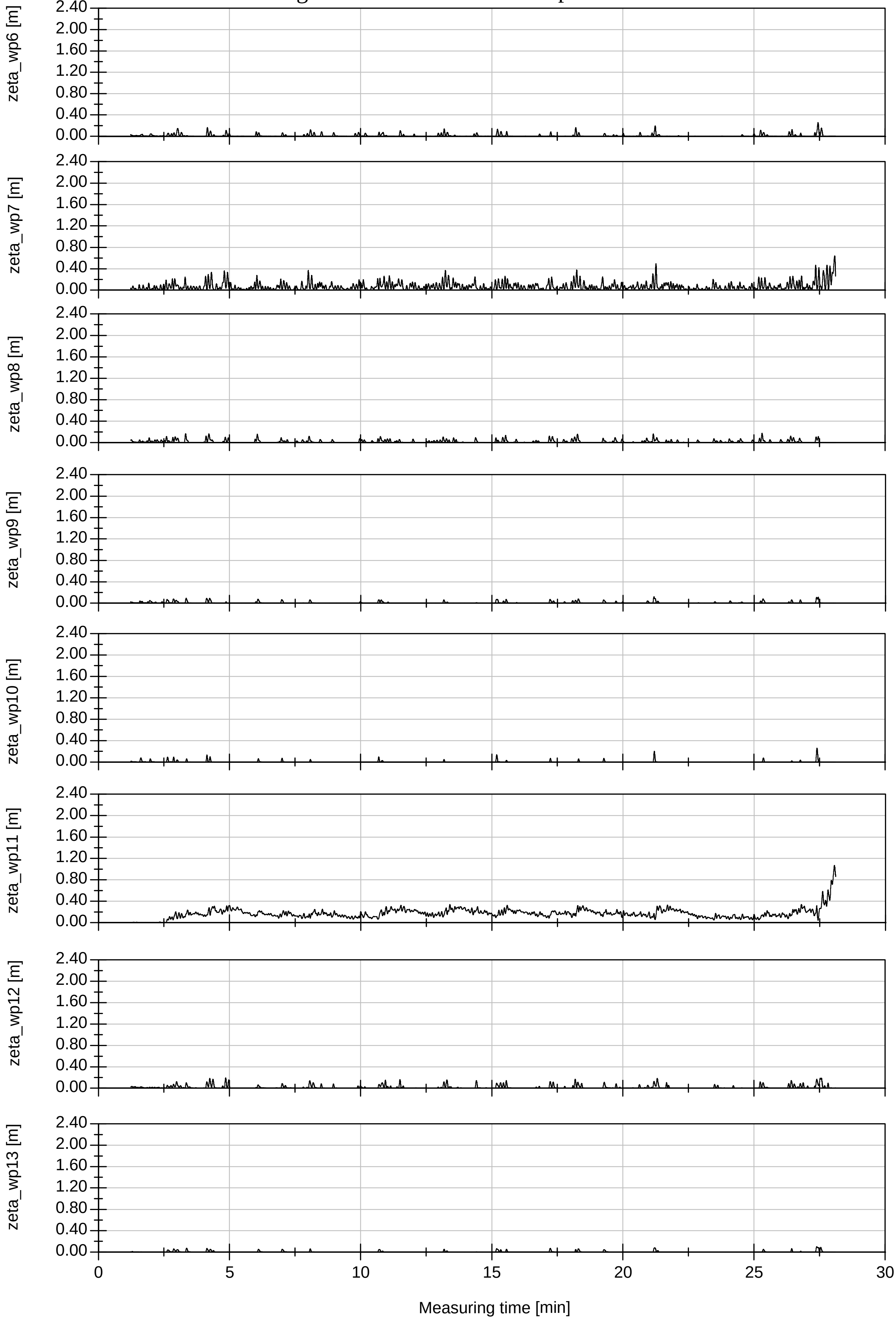
Run-No. 12 / Damage Case 1 / Hs = 3.01 m / Tp = 6.9 s / Gamma = 3.3



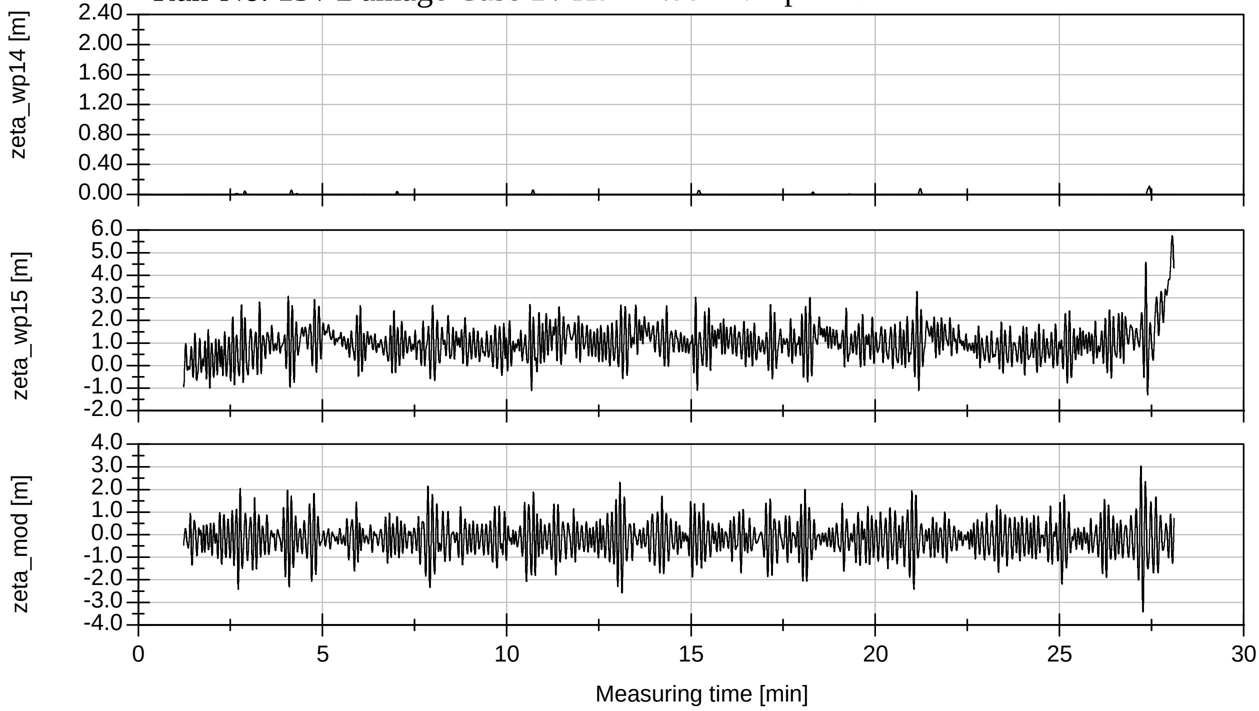
Run-No. 13 / Damage Case 1 / Hs = 2.99 m / Tp = 6.9 s / Gamma = 3.3



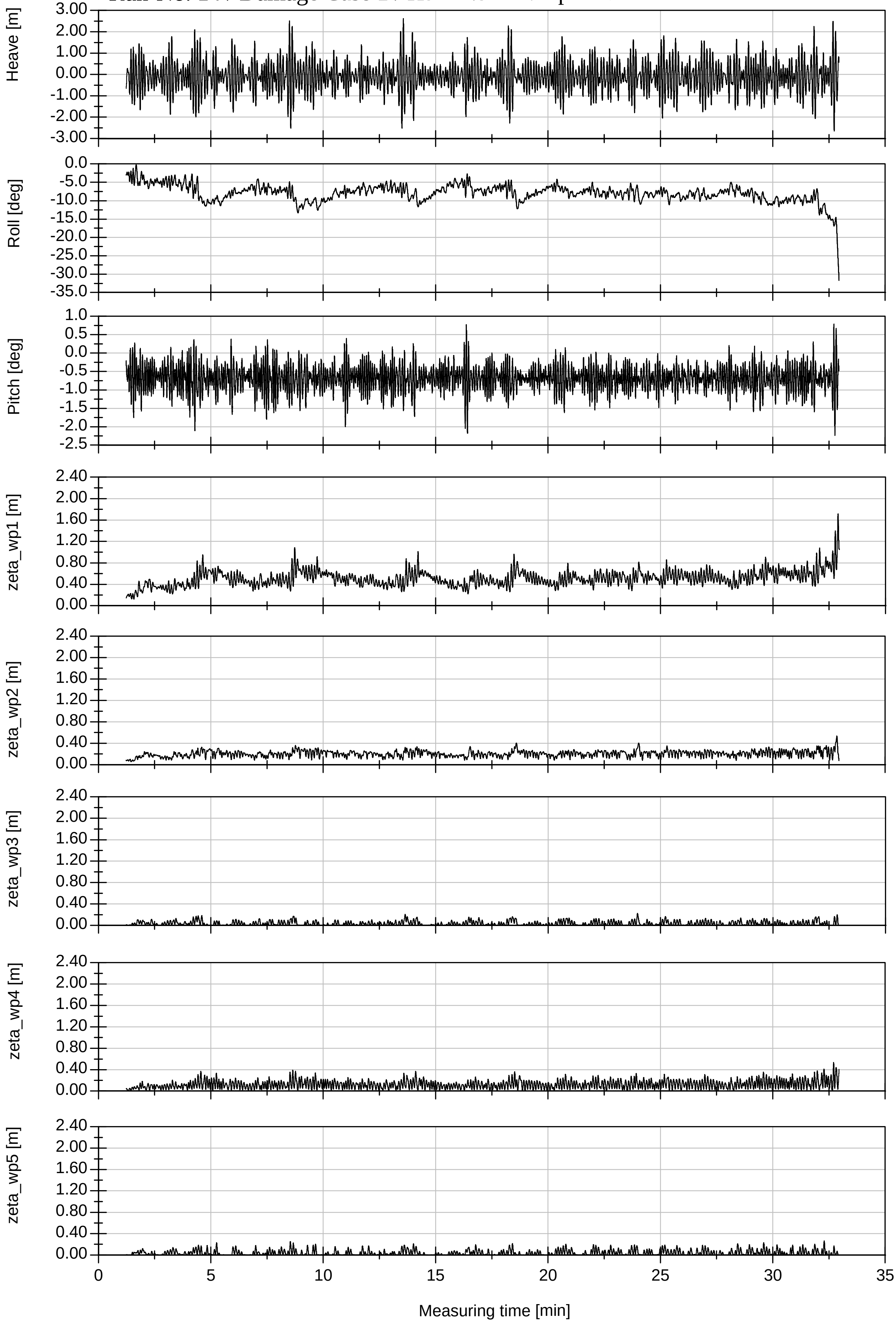
Run-No. 13 / Damage Case 1 / Hs = 2.99 m / Tp = 6.9 s / Gamma = 3.3



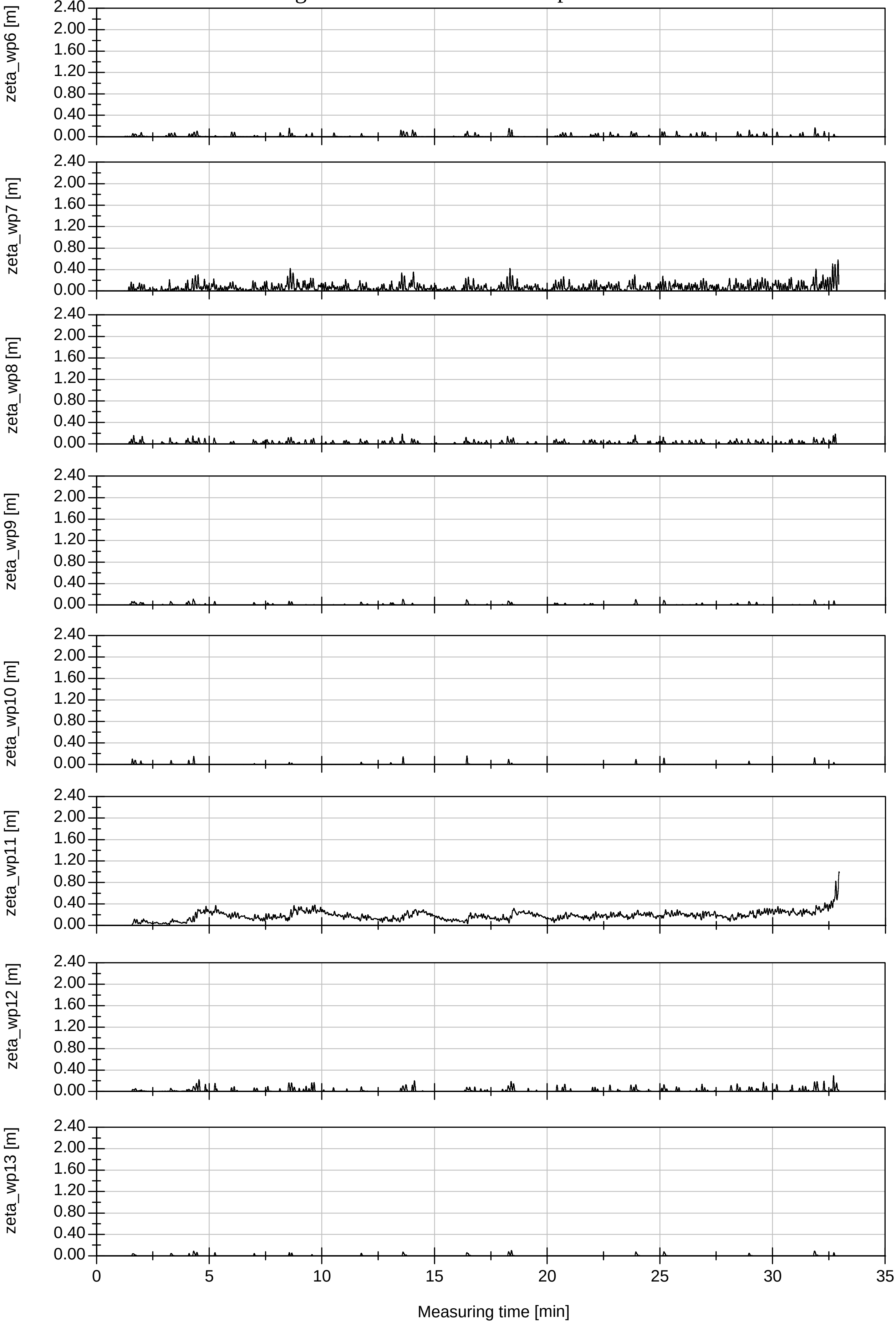
Run-No. 13 / Damage Case 1 / Hs = 2.99 m / Tp = 6.9 s / Gamma = 3.3



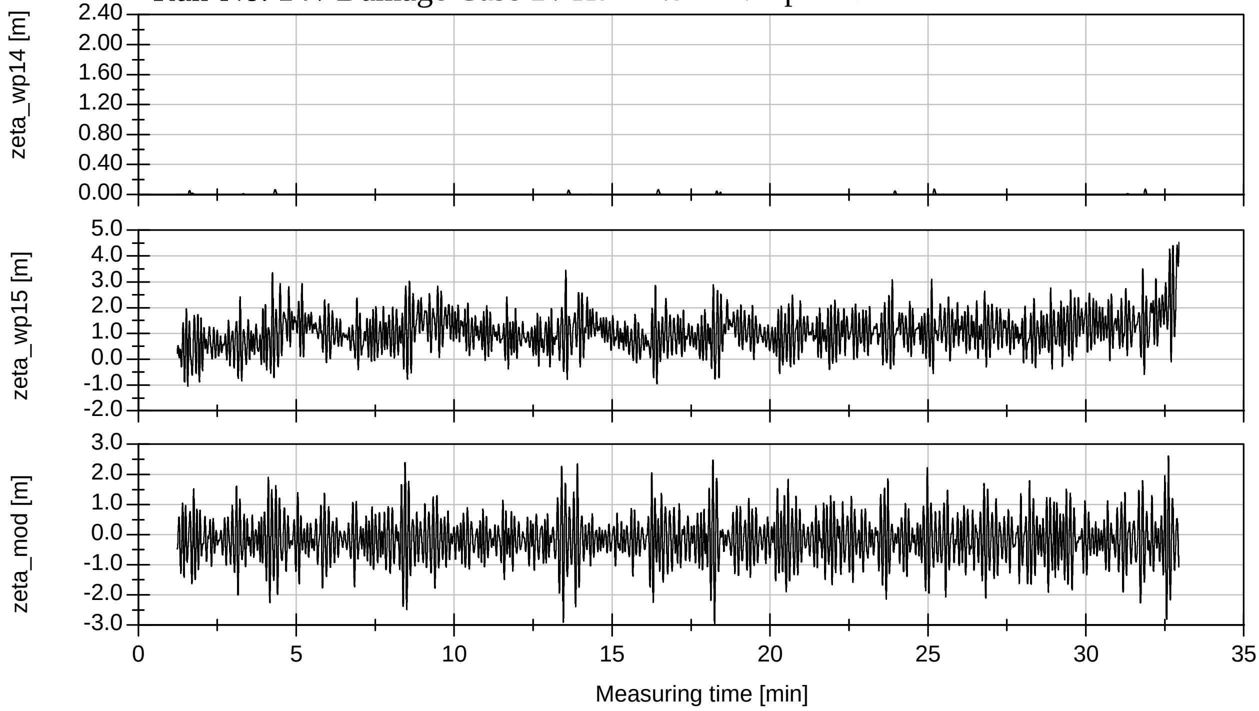
Run-No. 14 / Damage Case 1 / Hs = 2.92 m / Tp = 6.8 s / Gamma = 3.3



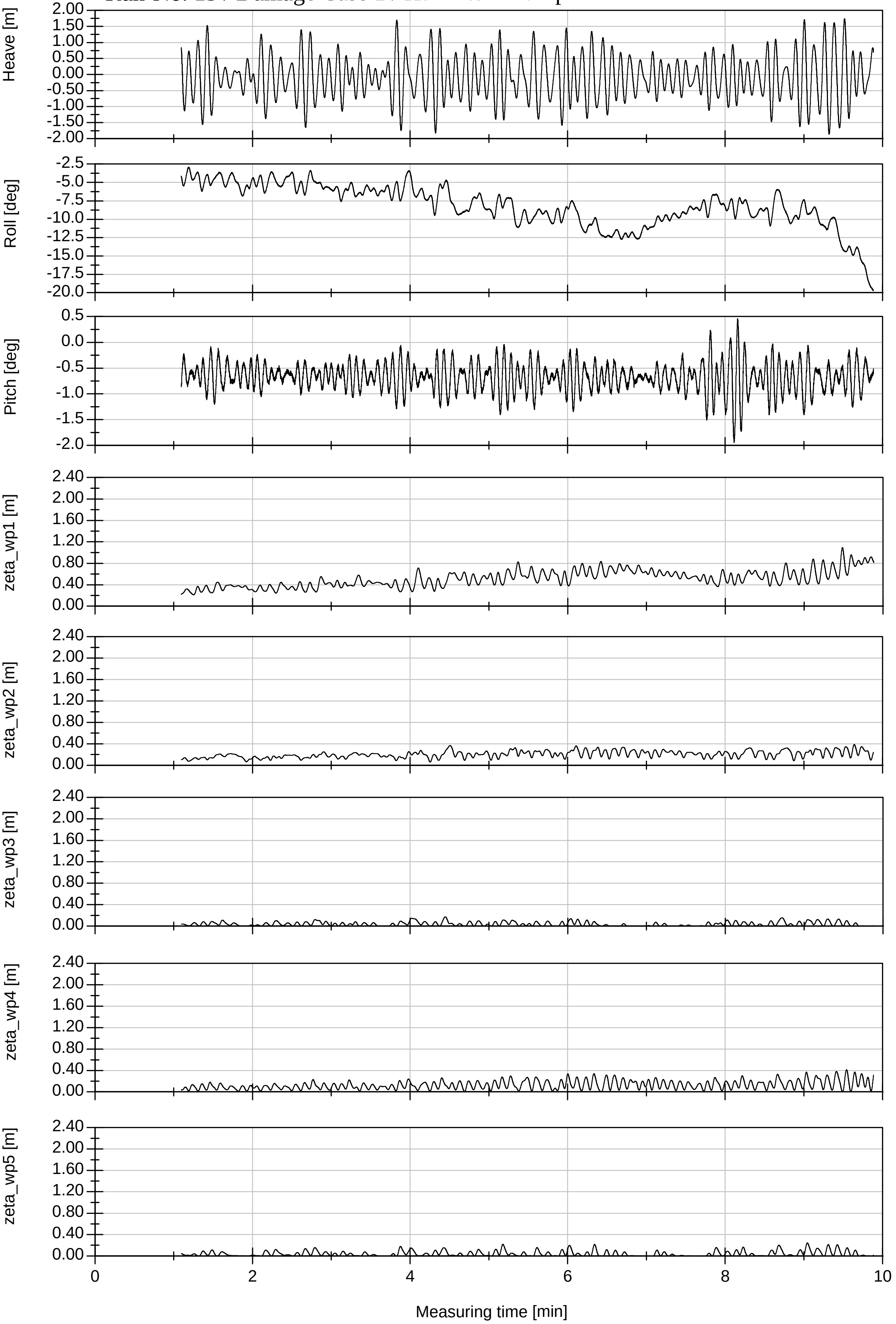
Run-No. 14 / Damage Case 1 / Hs = 2.92 m / Tp = 6.8 s / Gamma = 3.3



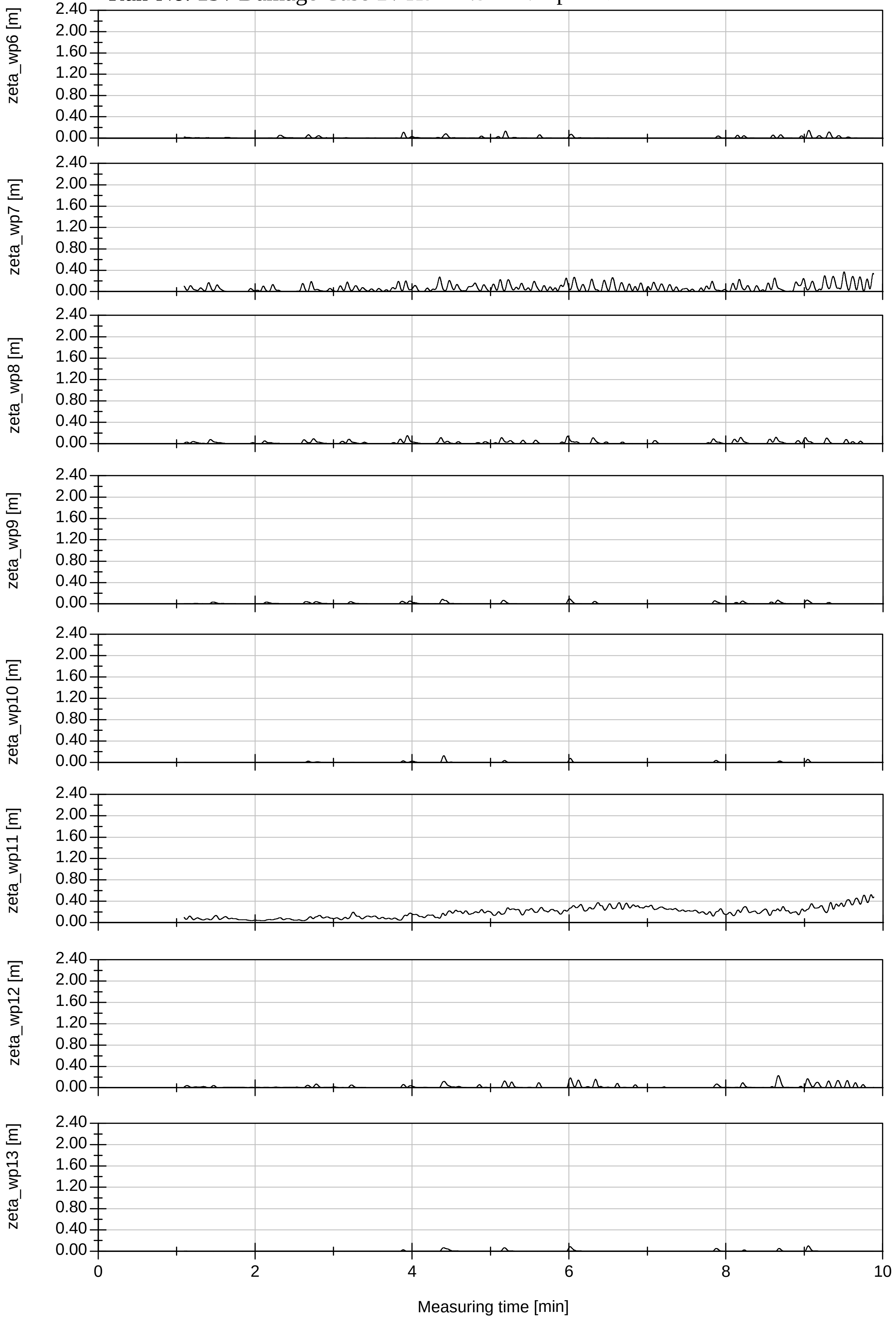
Run-No. 14 / Damage Case 1 / Hs = 2.92 m / Tp = 6.8 s / Gamma = 3.3



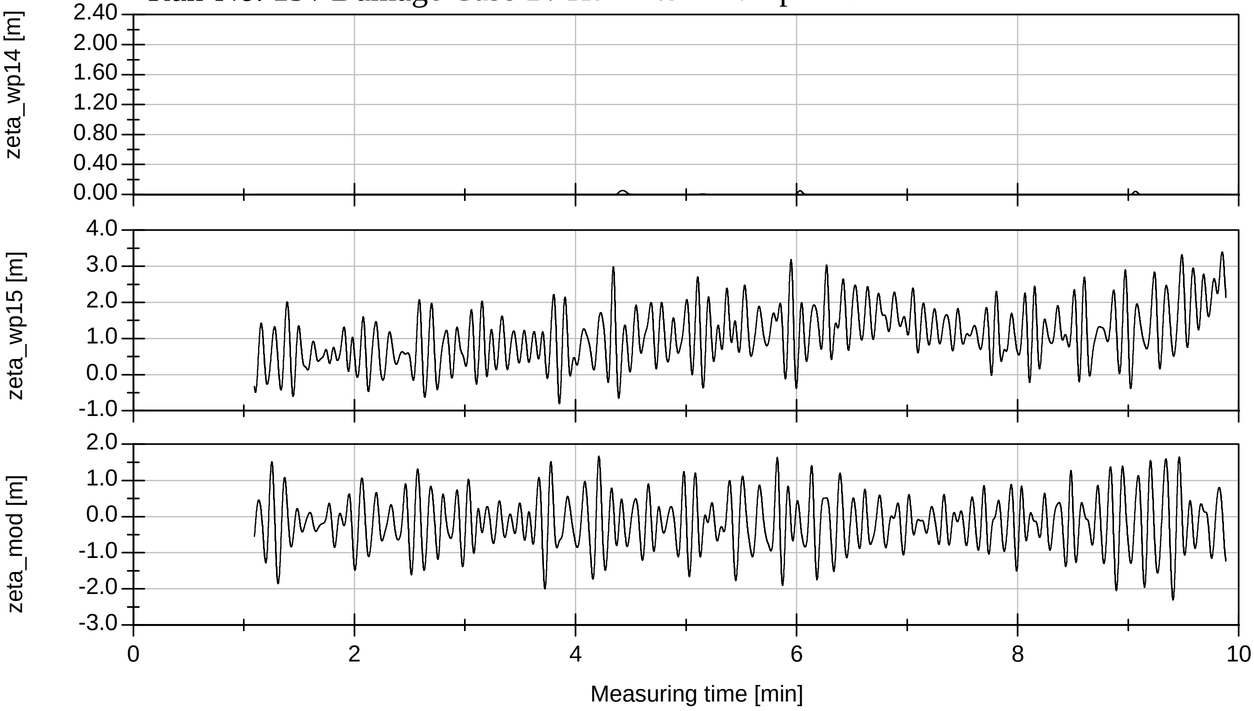
Run-No. 15 / Damage Case 1 / Hs = 2.97 m / Tp = 6.9 s / Gamma = 3.3



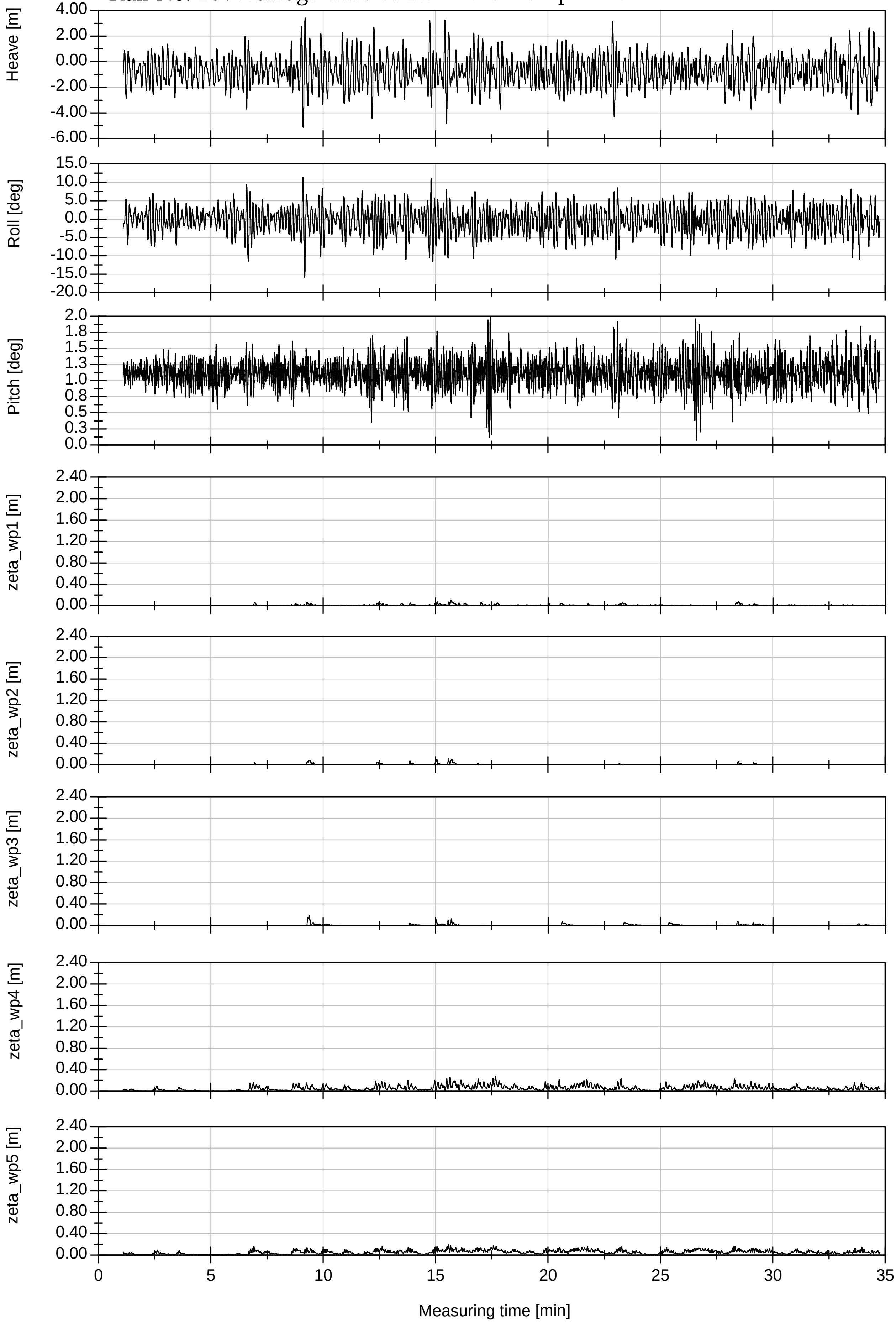
Run-No. 15 / Damage Case 1 / Hs = 2.97 m / Tp = 6.9 s / Gamma = 3.3



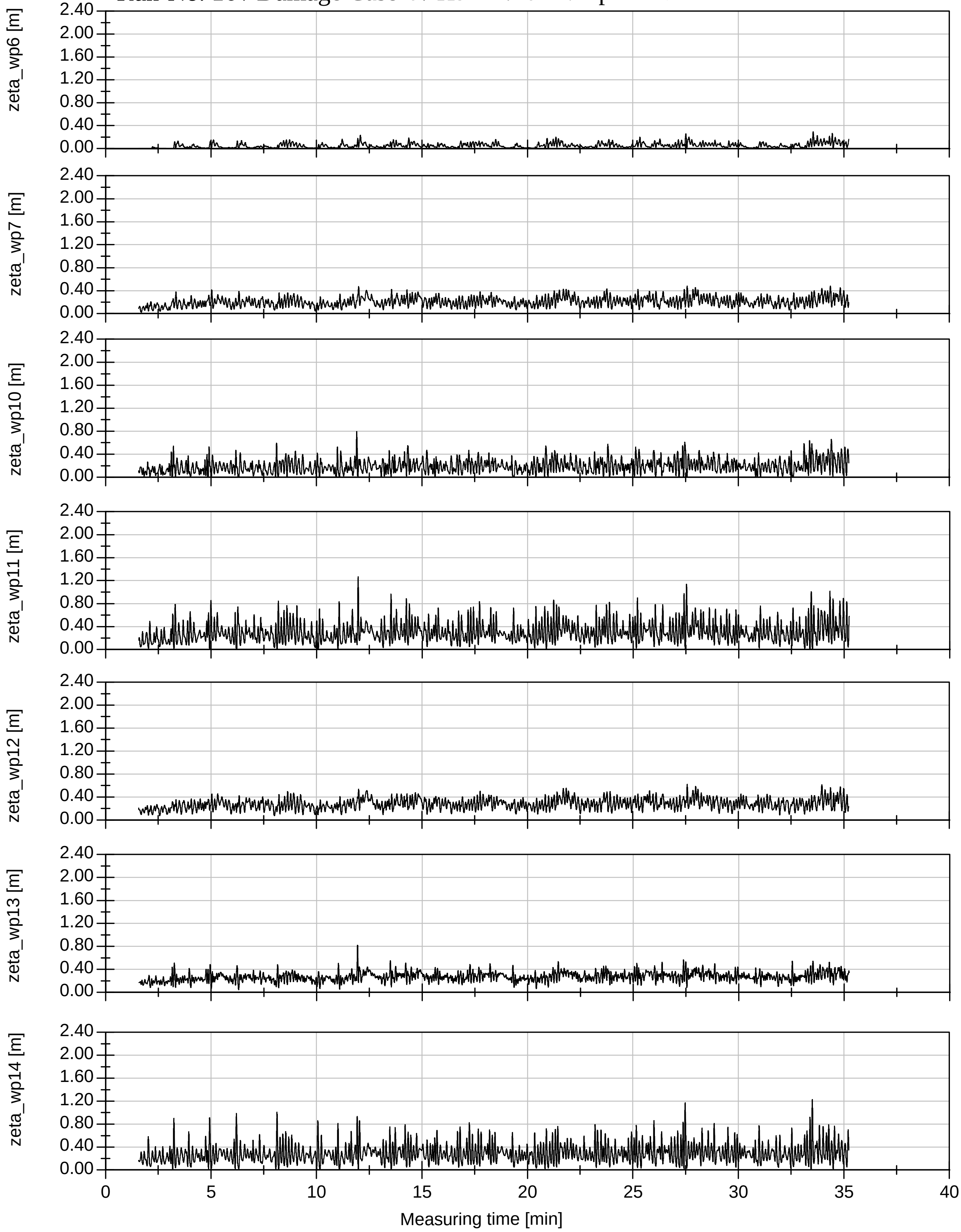
Run-No. 15 / Damage Case 1 / Hs = 2.97 m / Tp = 6.9 s / Gamma = 3.3



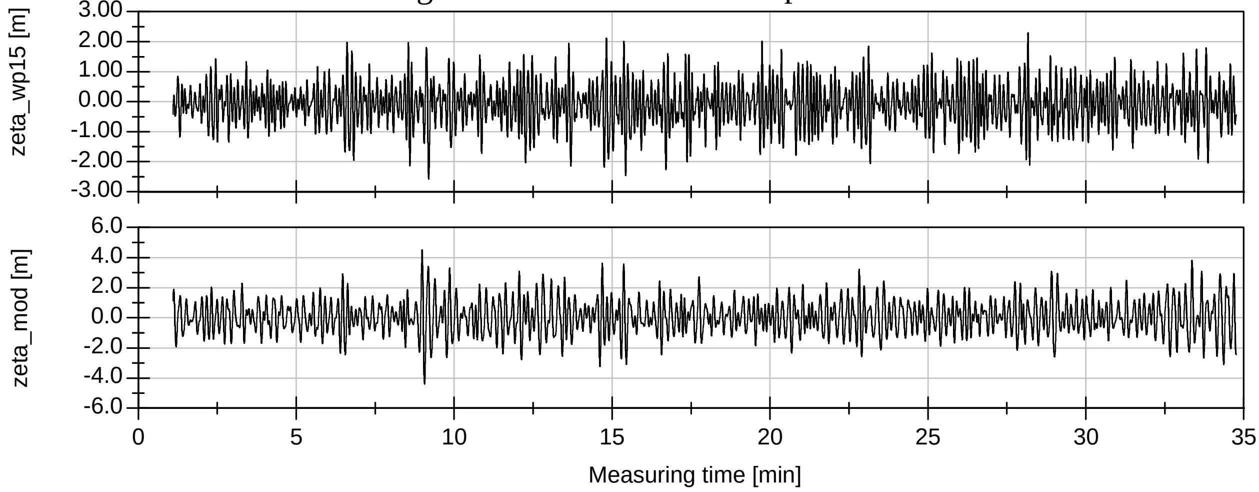
Run-No. 16 / Damage Case 4 / Hs = 4.16 m / Tp = 12.2 s / Gamma = 1.0



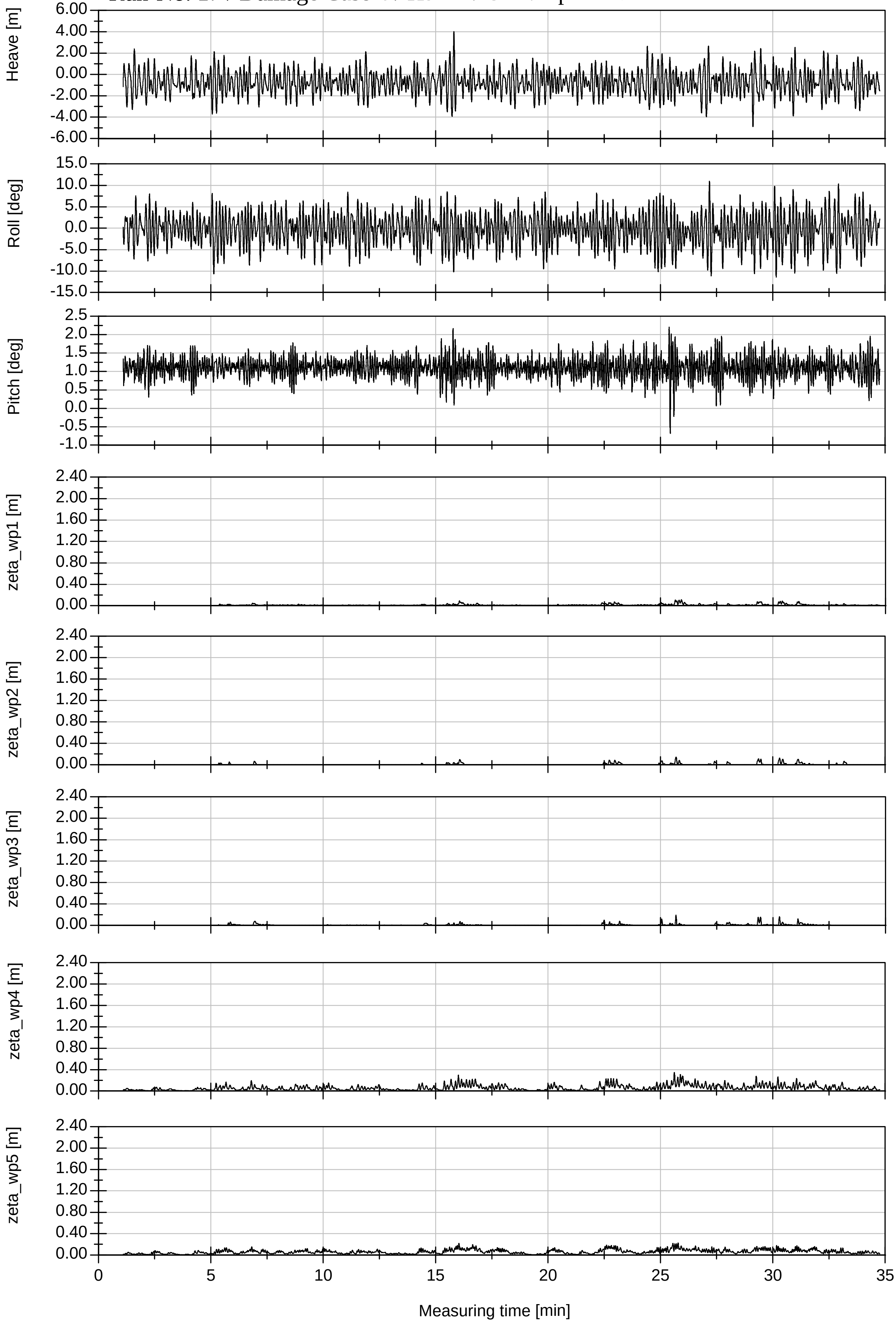
Run-No. 16 / Damage Case 4 / Hs = 4.16 m / Tp = 12.2 s / Gamma = 1.0



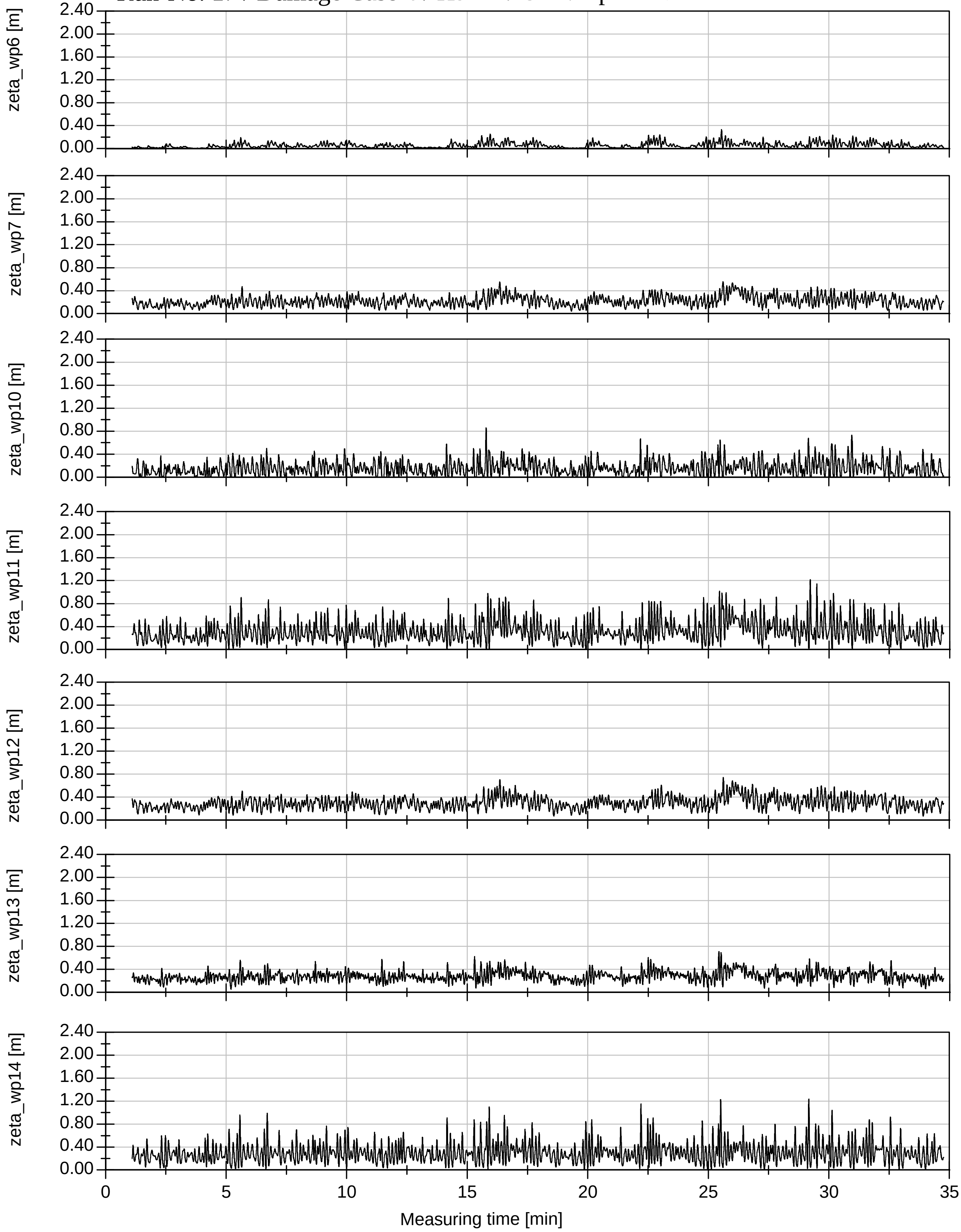
Run-No. 16 / Damage Case 4 / Hs = 4.16 m / Tp = 12.2 s / Gamma = 1.0



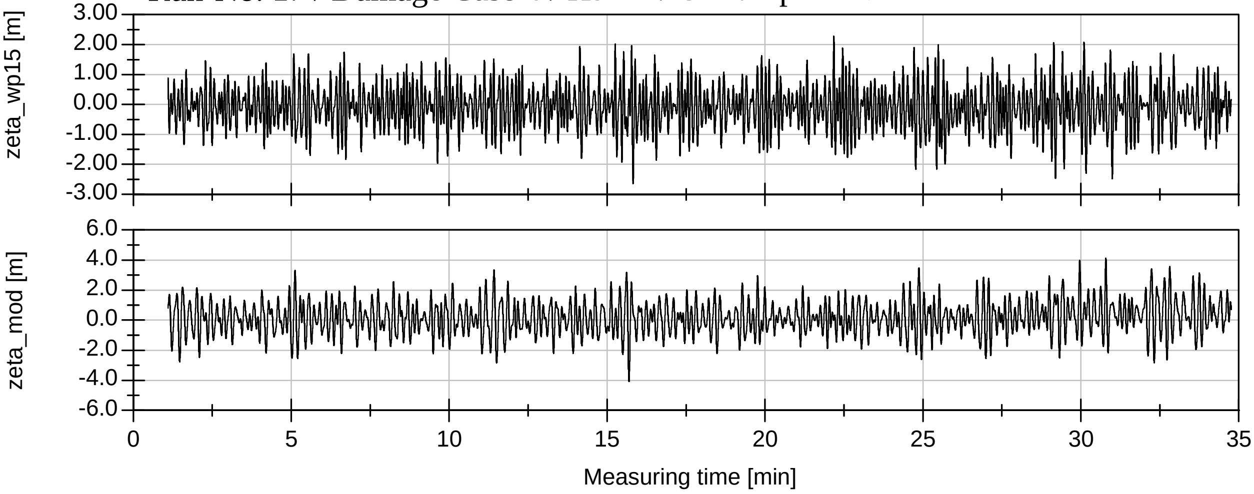
Run-No. 17 / Damage Case 4 / Hs = 4.15 m / Tp = 12.2 s / Gamma = 1.0



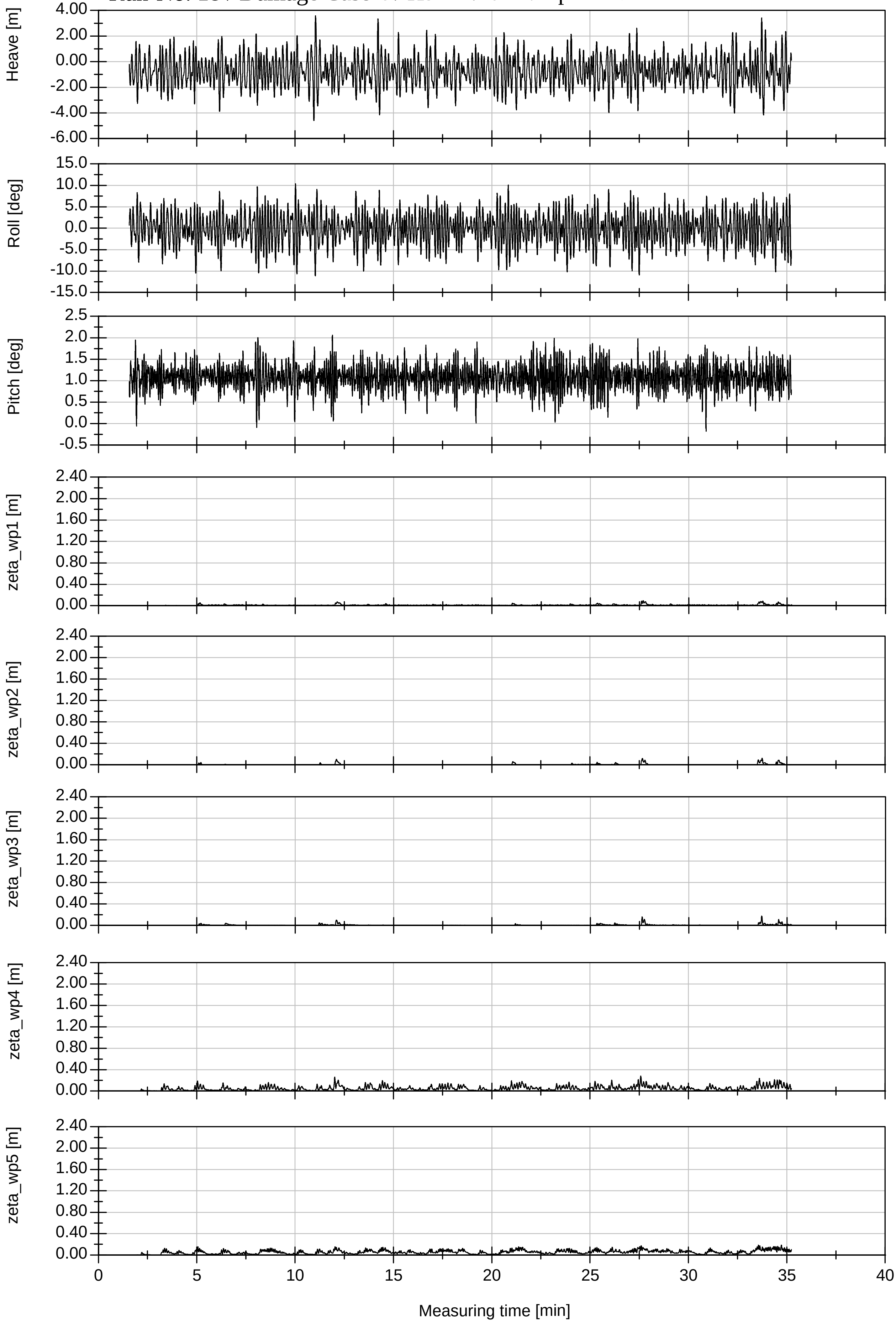
Run-No. 17 / Damage Case 4 / Hs = 4.15 m / Tp = 12.2 s / Gamma = 1.0



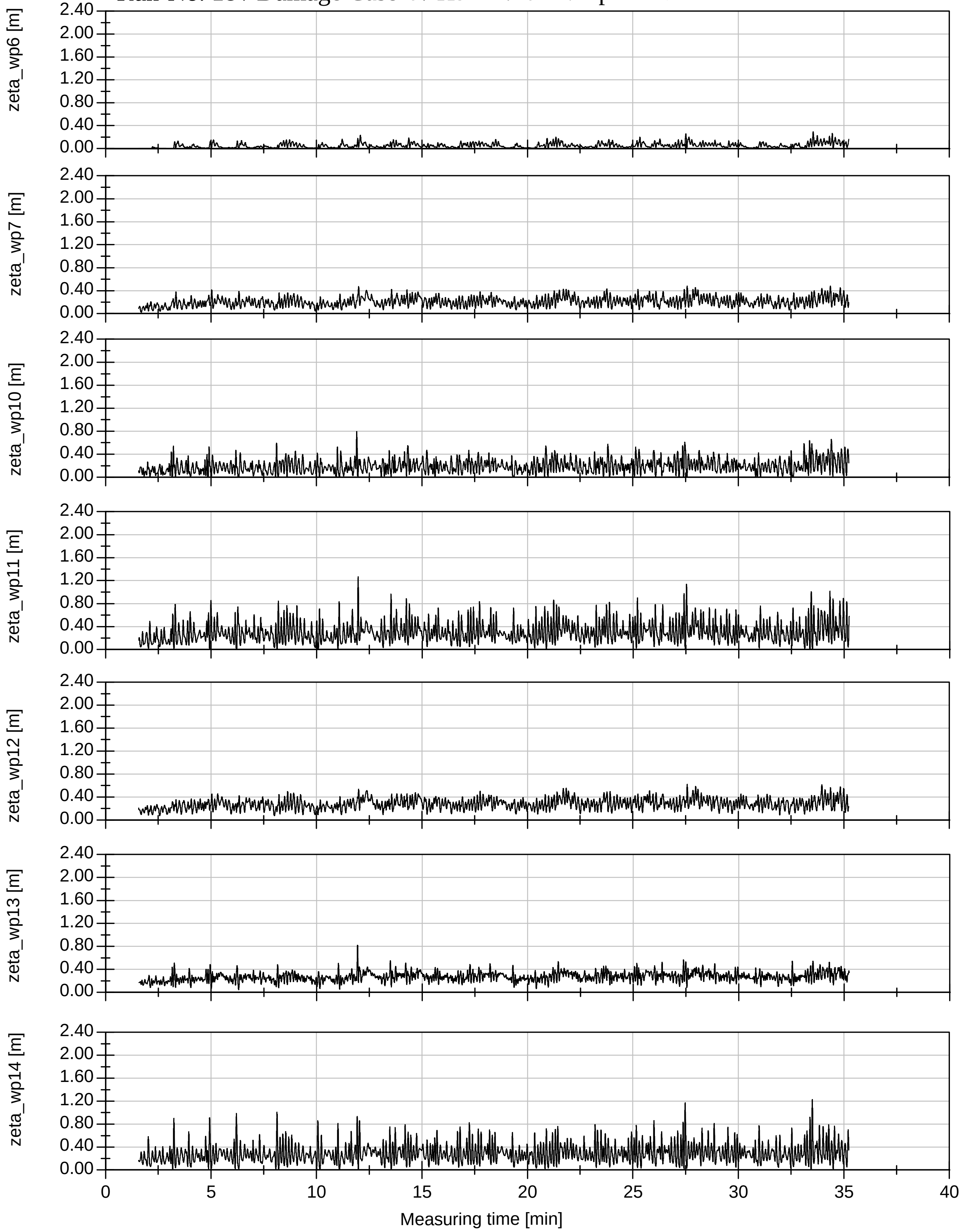
Run-No. 17 / Damage Case 4 / Hs = 4.15 m / Tp = 12.2 s / Gamma = 1.0

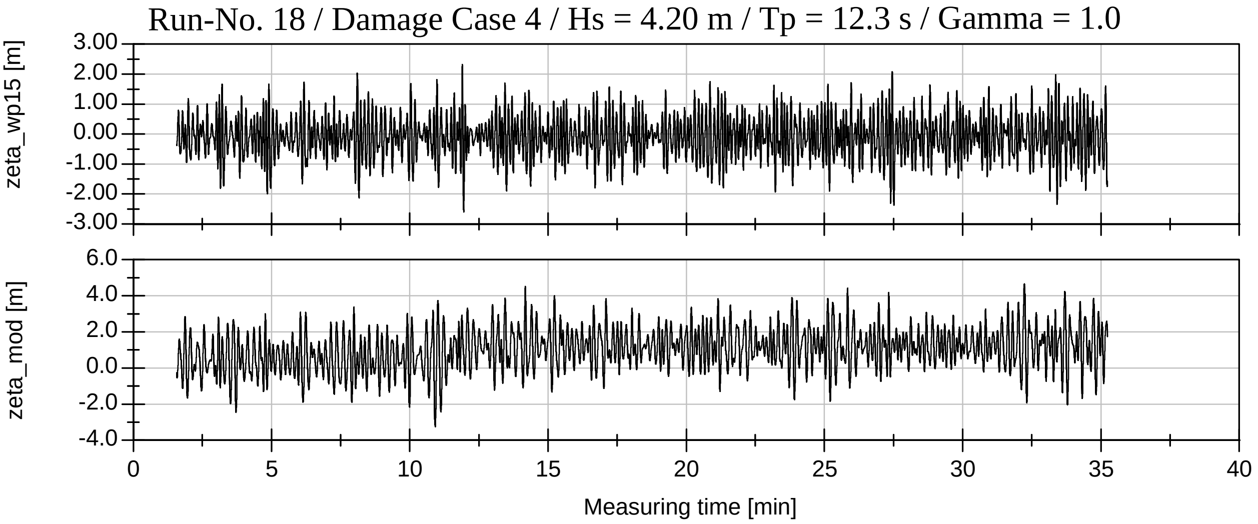


Run-No. 18 / Damage Case 4 / Hs = 4.20 m / Tp = 12.3 s / Gamma = 1.0

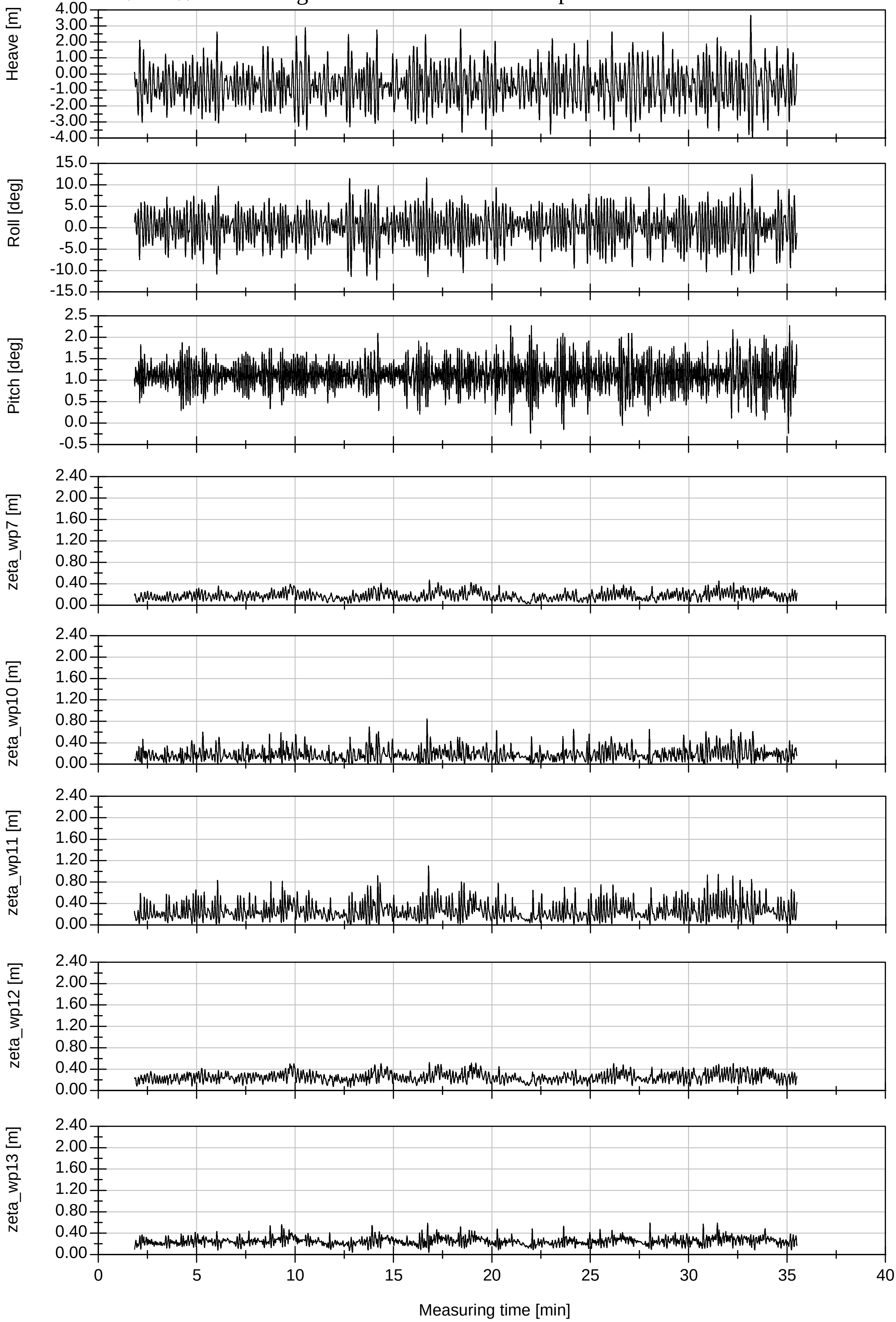


Run-No. 18 / Damage Case 4 / Hs = 4.20 m / Tp = 12.3 s / Gamma = 1.0

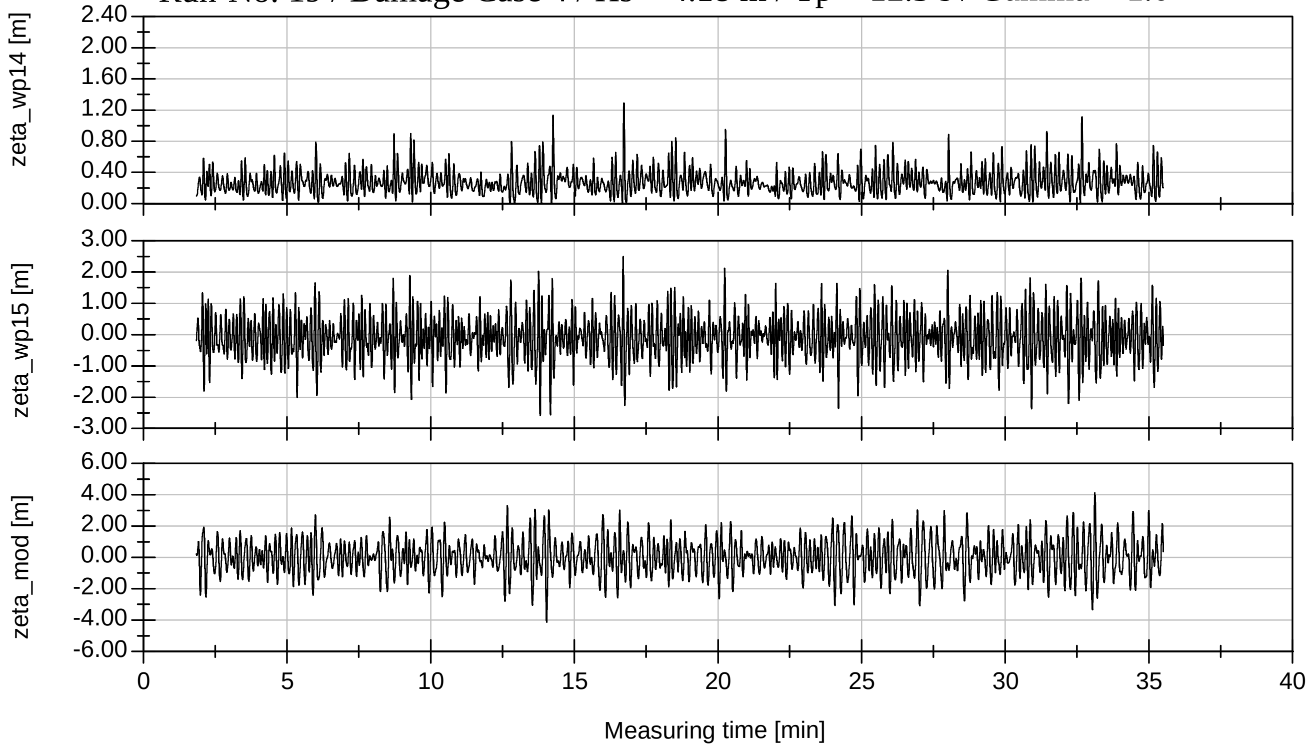



Run-No. 18 / Damage Case 4 / Hs = 4.20 m / Tp = 12.3 s / Gamma = 1.0
zeta_wp15 [m]
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
zeta_mod [m]
6.0
4.0
2.0
0.0
-2.0
-4.0
0
5
10
15
20
25
30
35
40
Measuring time [min]

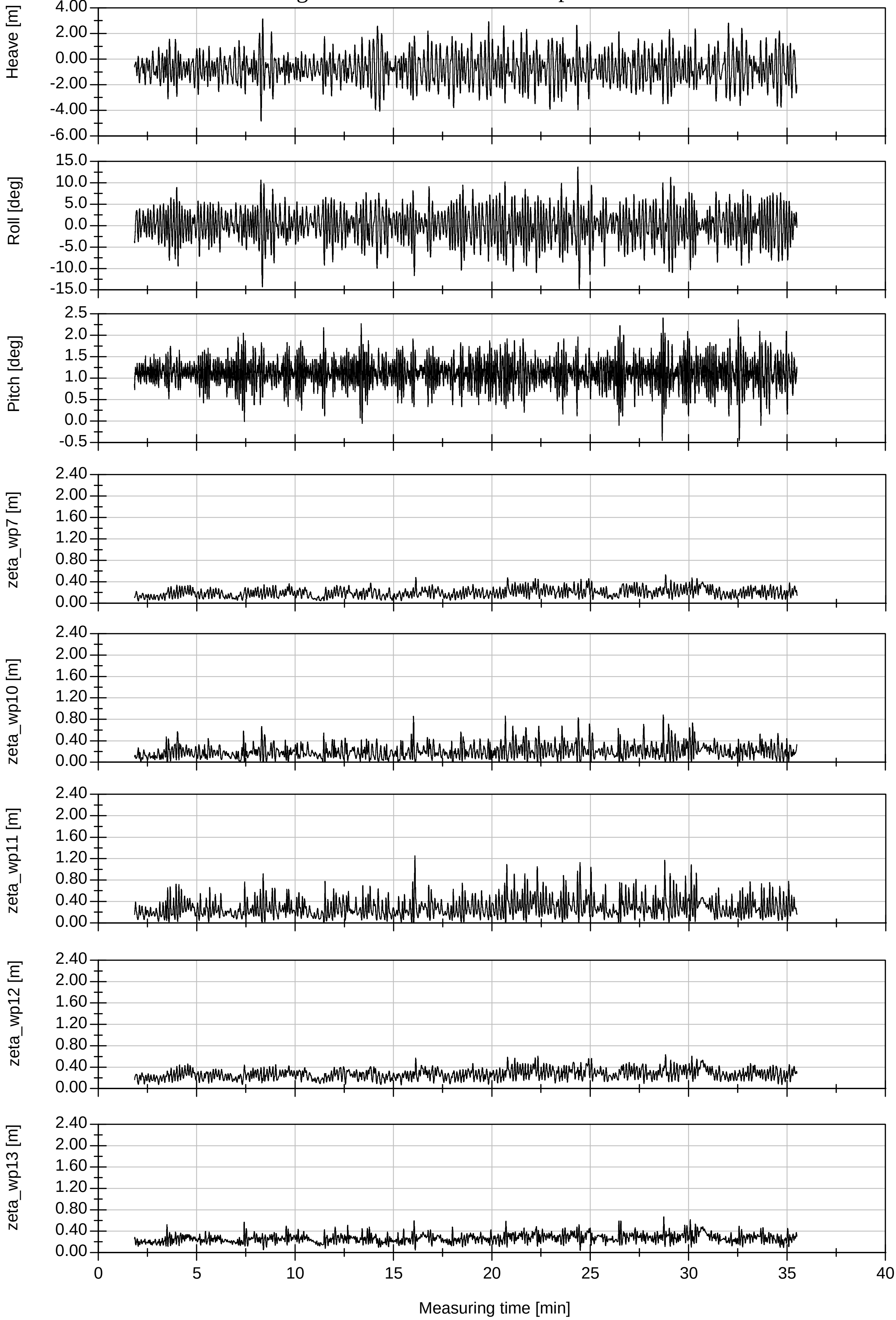
Run-No. 19 / Damage Case 4 / Hs = 4.18 m / Tp = 12.3 s / Gamma = 1.0

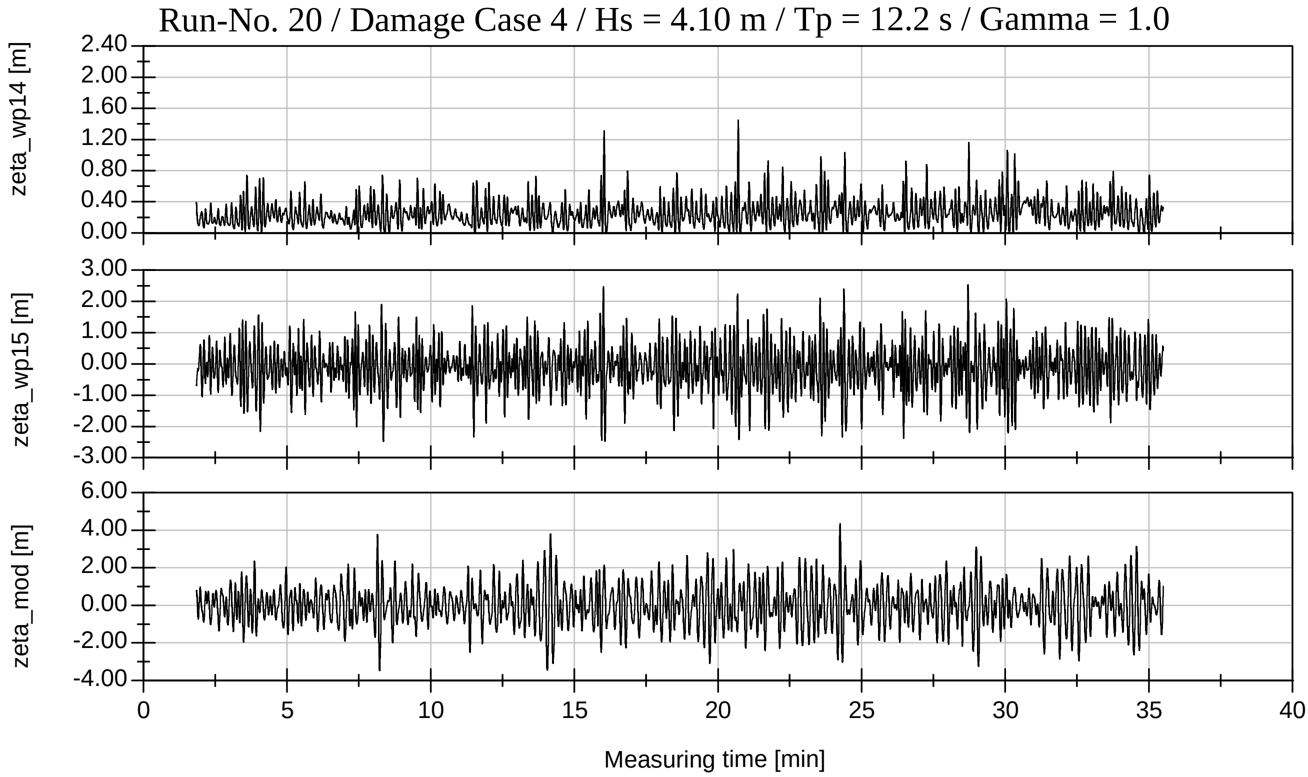


Run-No. 19 / Damage Case 4 / Hs = 4.18 m / Tp = 12.3 s / Gamma = 1.0

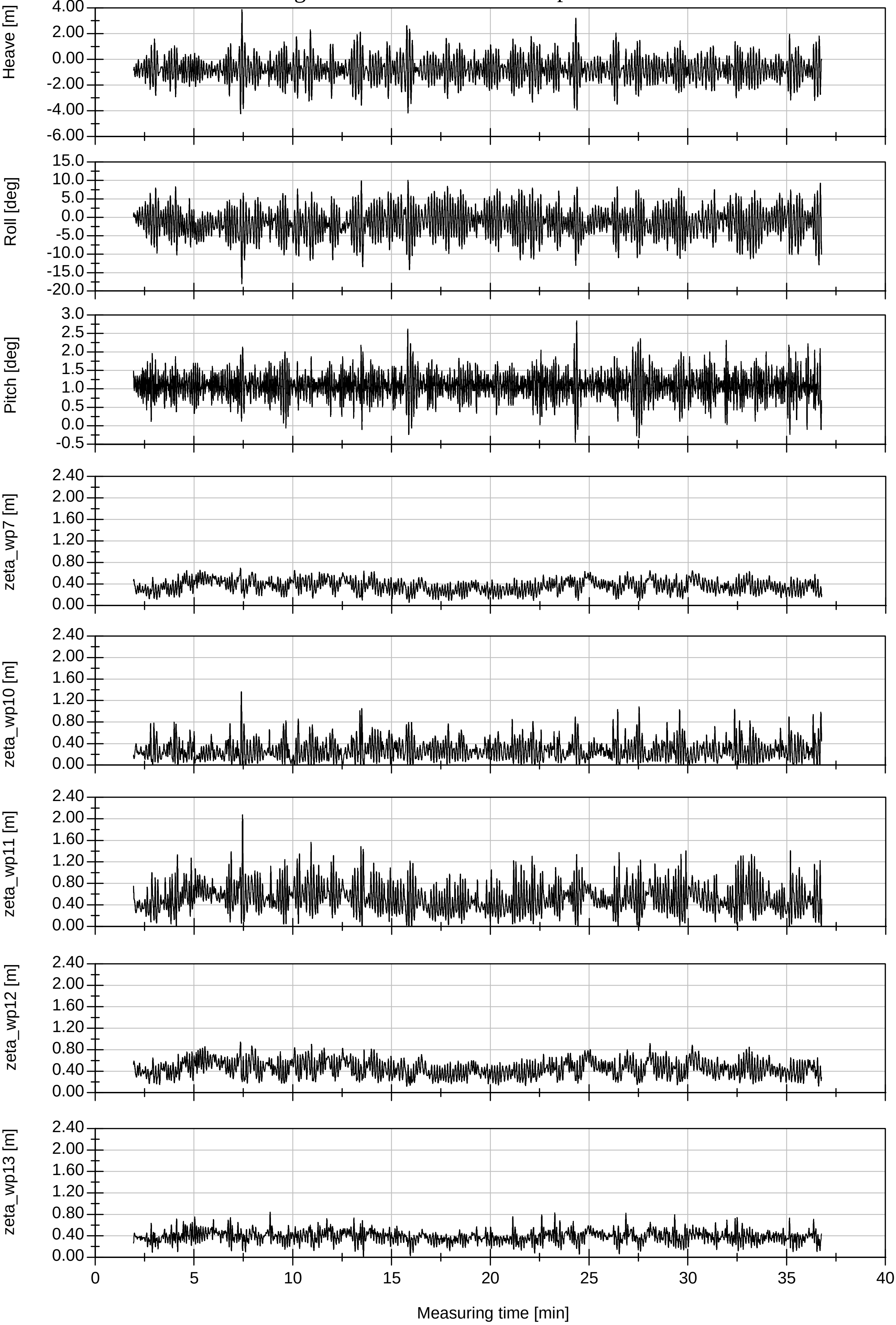


Run-No. 20 / Damage Case 4 / Hs = 4.10 m / Tp = 12.2 s / Gamma = 1.0

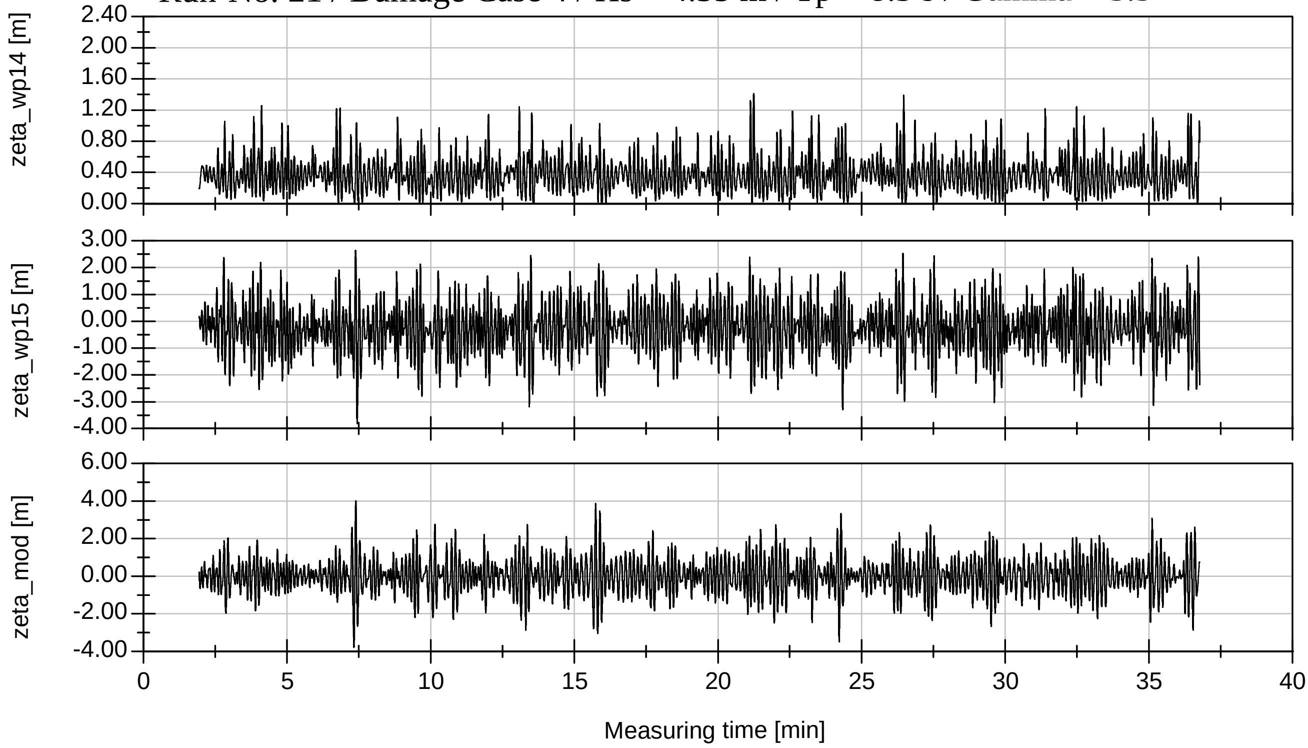



Run-No. 20 / Damage Case 4 / Hs = 4.10 m / Tp = 12.2 s / Gamma = 1.0
zeta_wp14 [m]
2.40
2.00
1.60
1.20
0.80
0.40
0.00
zeta_wp15 [m]
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
zeta_mod [m]
6.00
4.00
2.00
0.00
-2.00
-4.00
0
5
10
15
20
25
30
35
40
Measuring time [min]

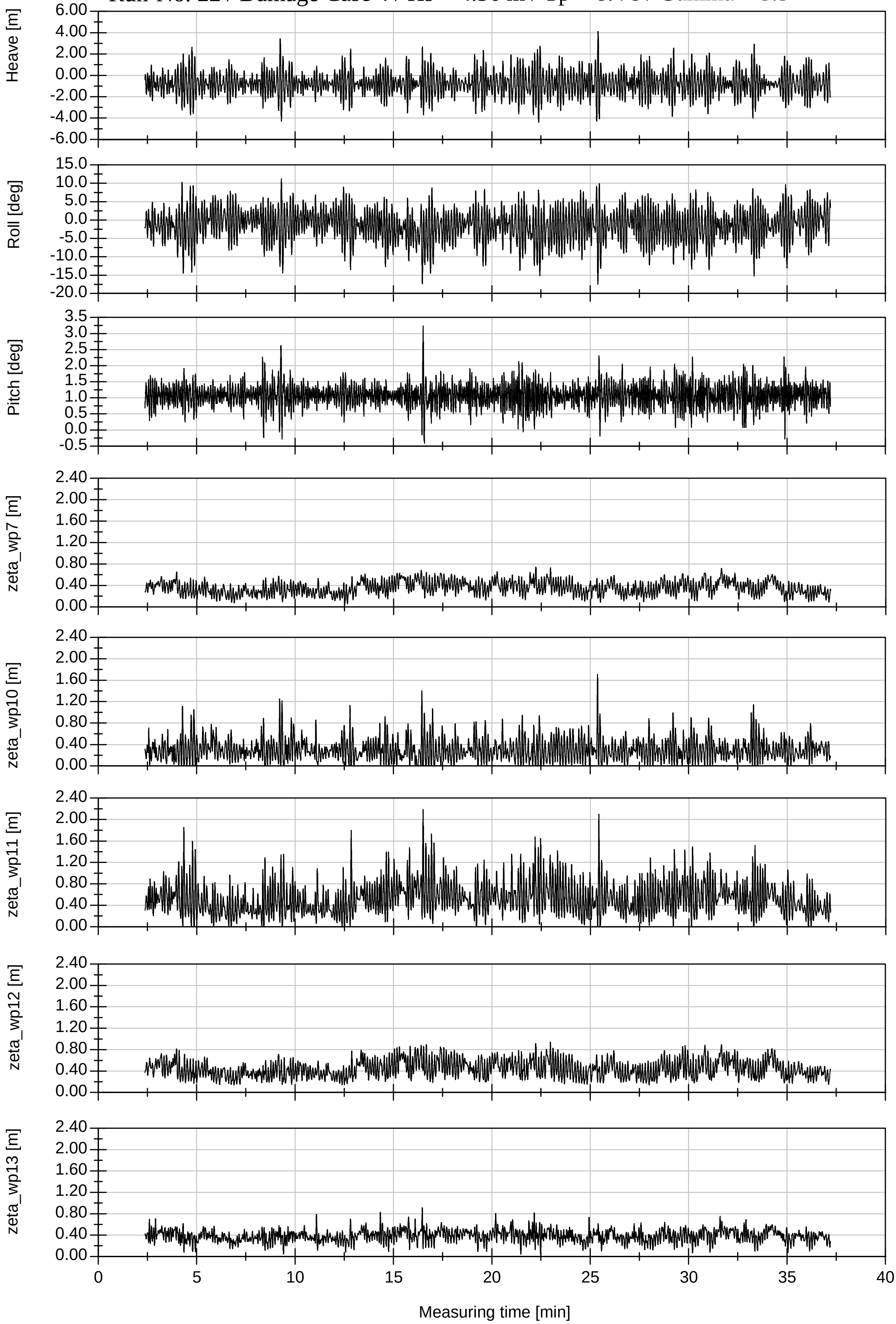
Run-No. 21 / Damage Case 4 / Hs = 4.35 m / Tp = 8.3 s / Gamma = 3.3



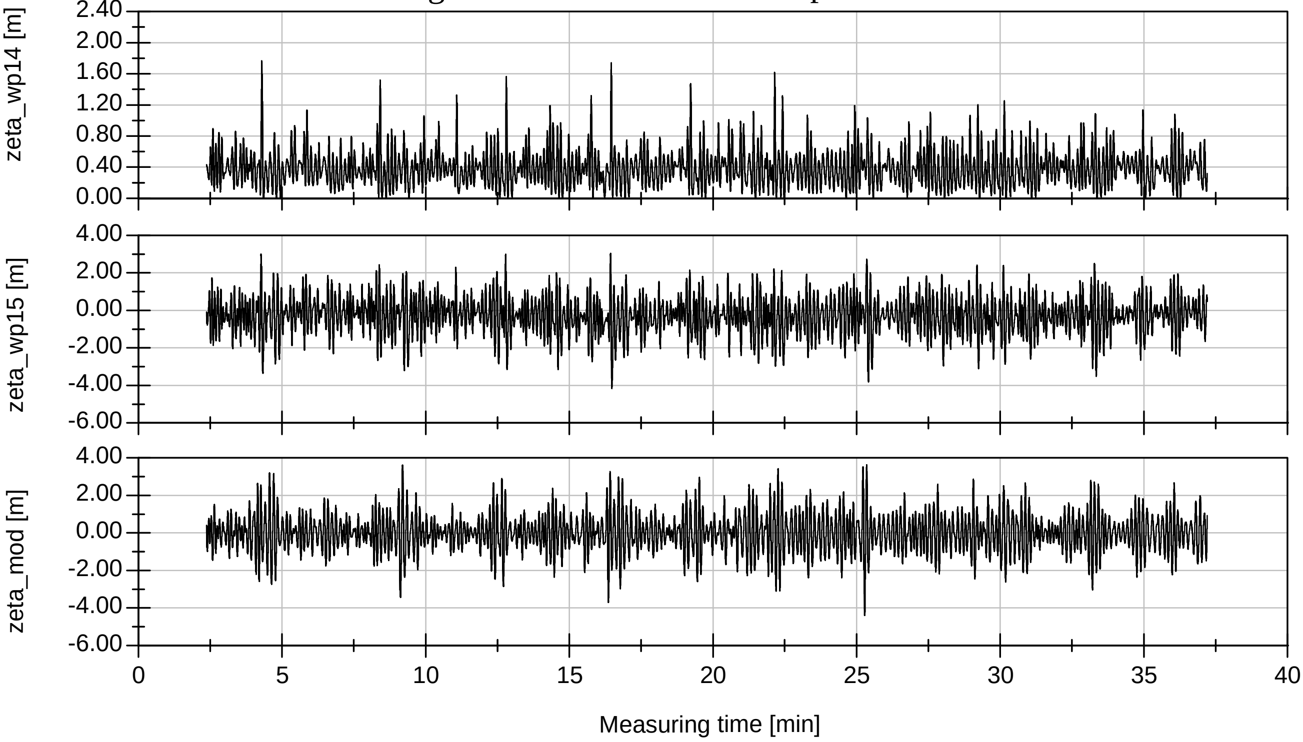
Run-No. 21 / Damage Case 4 / Hs = 4.35 m / Tp = 8.3 s / Gamma = 3.3



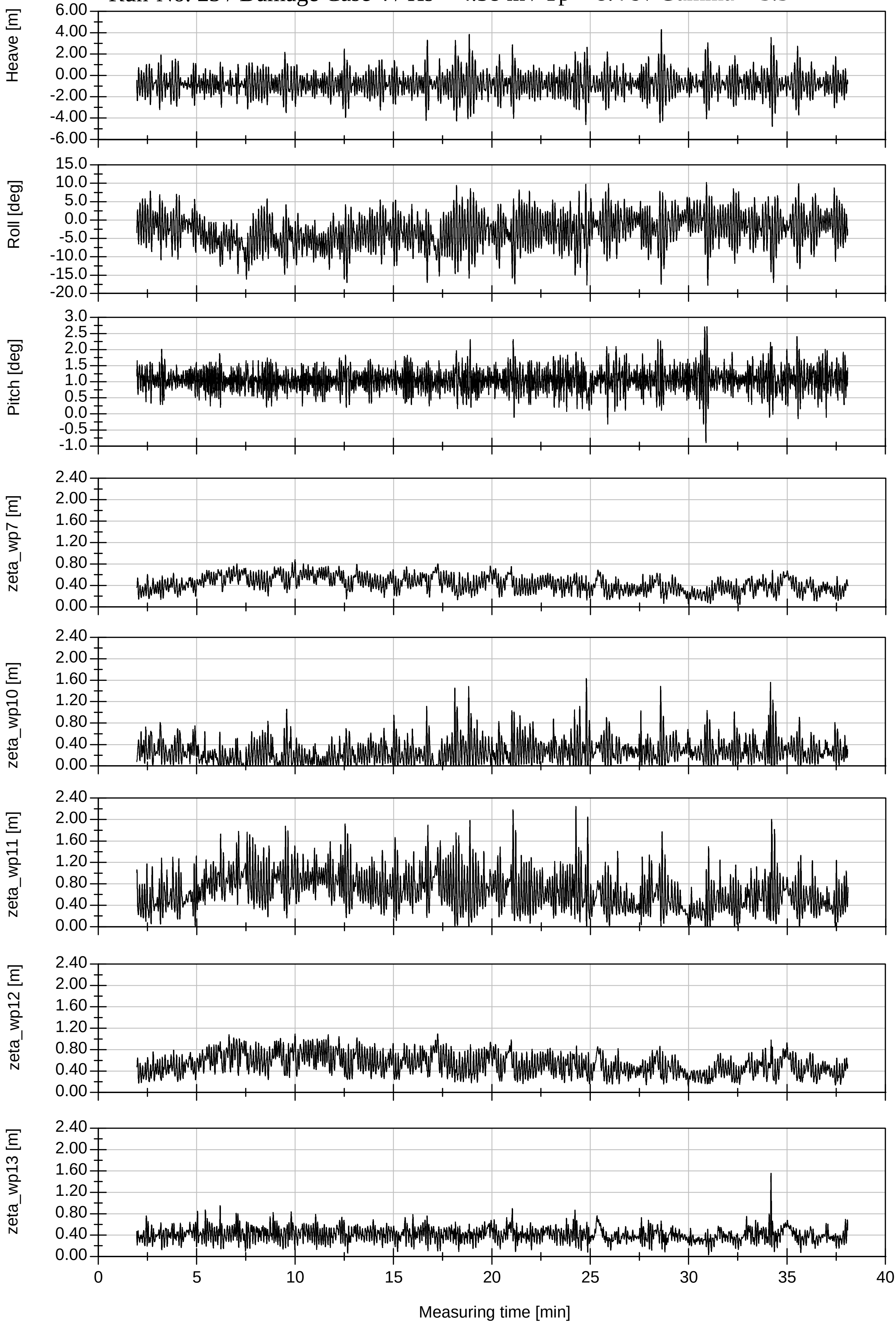
Run-No. 22 / Damage Case 4 / Hs = 4.36 m / Tp = 8.4 s / Gamma = 3.3



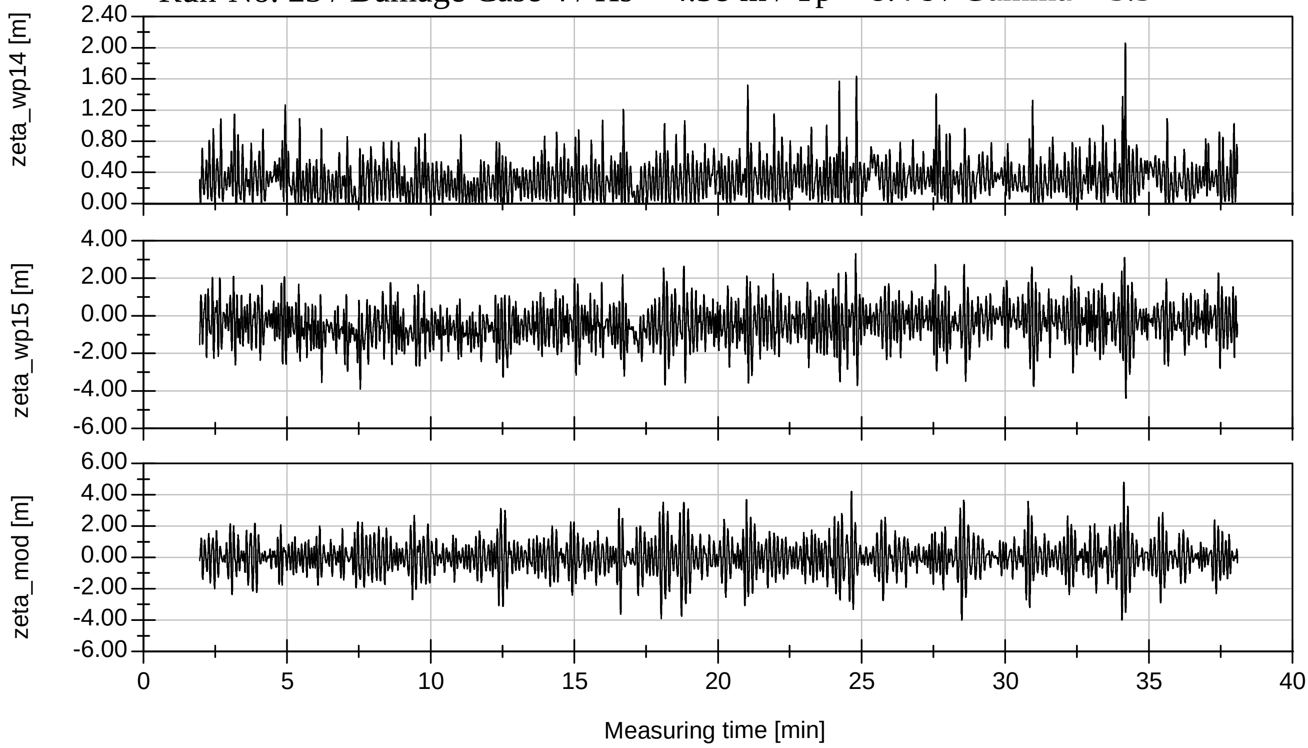
Run-No. 22 / Damage Case 4 / Hs = 4.36 m / Tp = 8.4 s / Gamma = 3.3



Run-No. 23 / Damage Case 4 / Hs = 4.38 m / Tp = 8.4 s / Gamma = 3.3

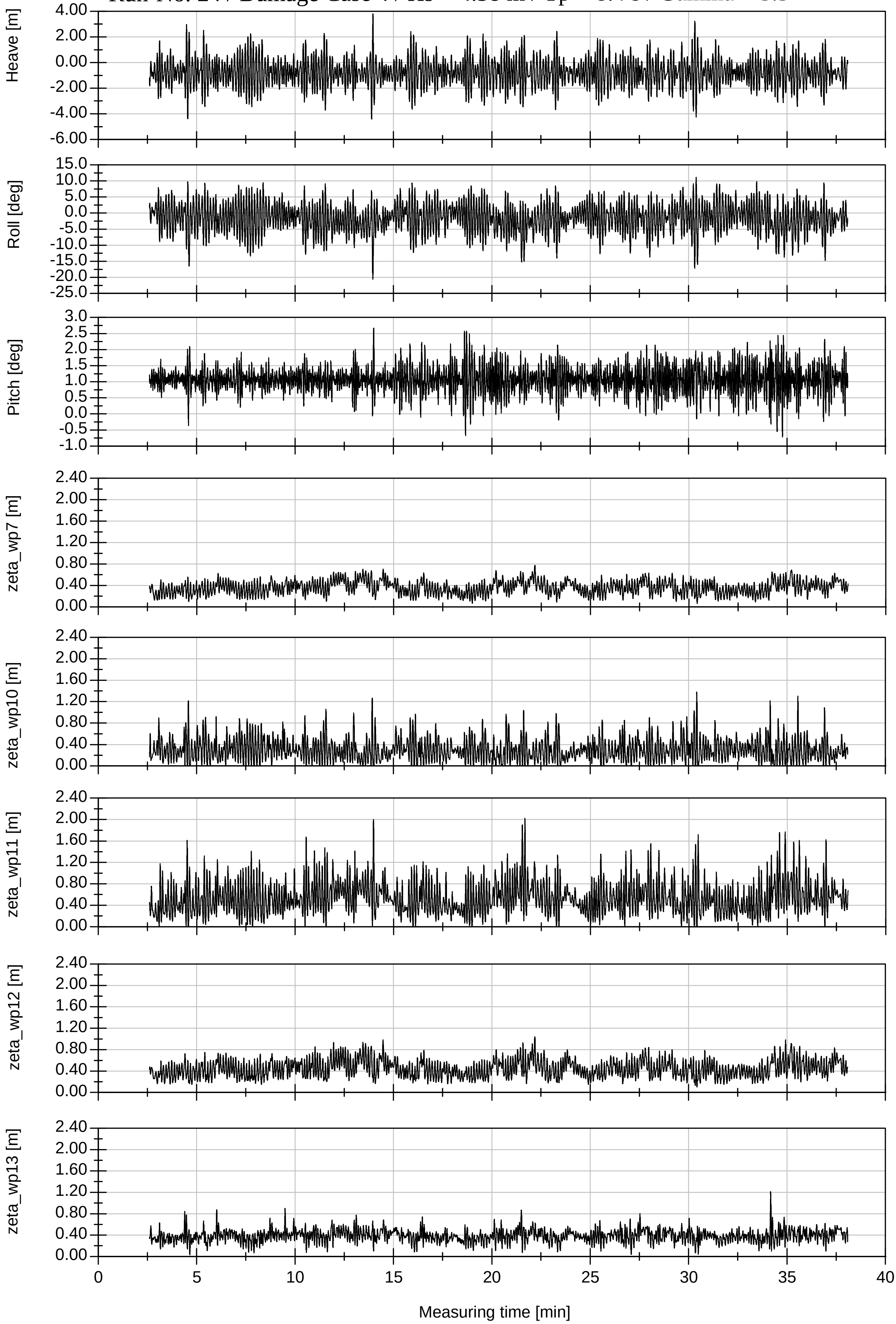


Run-No. 23 / Damage Case 4 / Hs = 4.38 m / Tp = 8.4 s / Gamma = 3.3

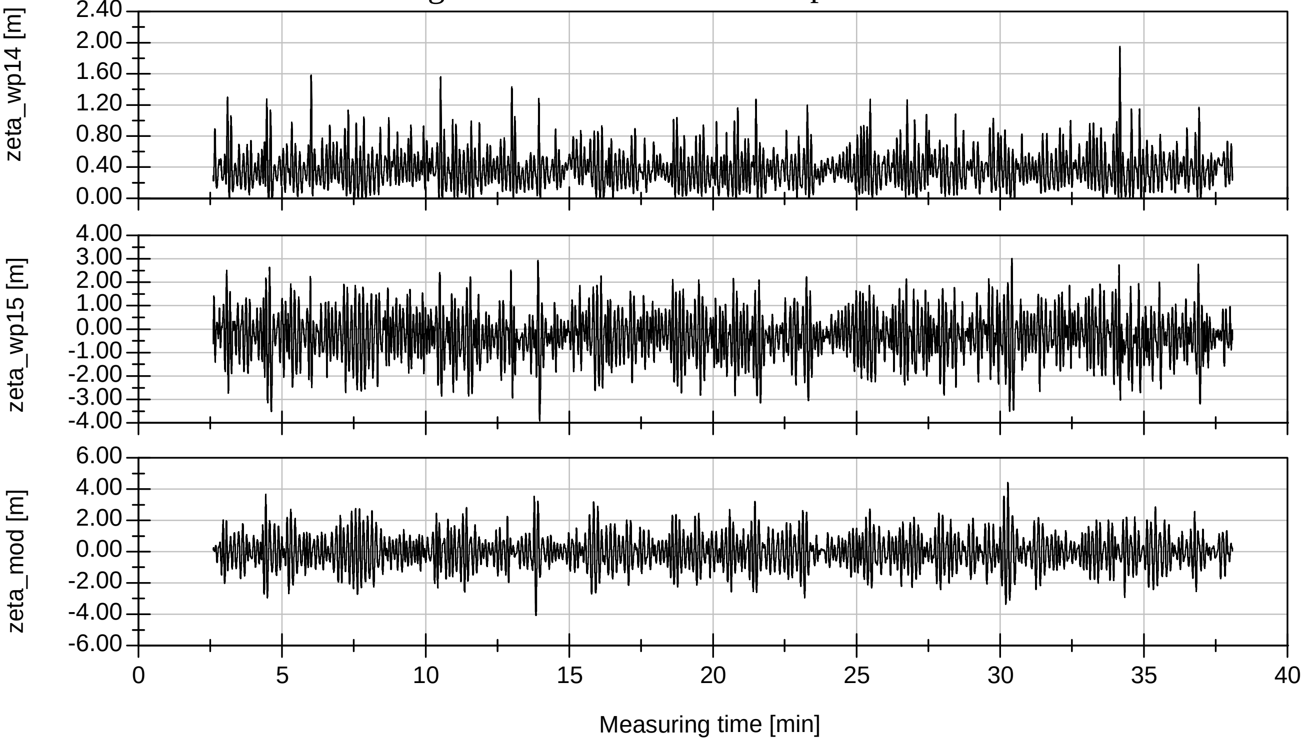


EMSA - 80 m RoPax Vessel

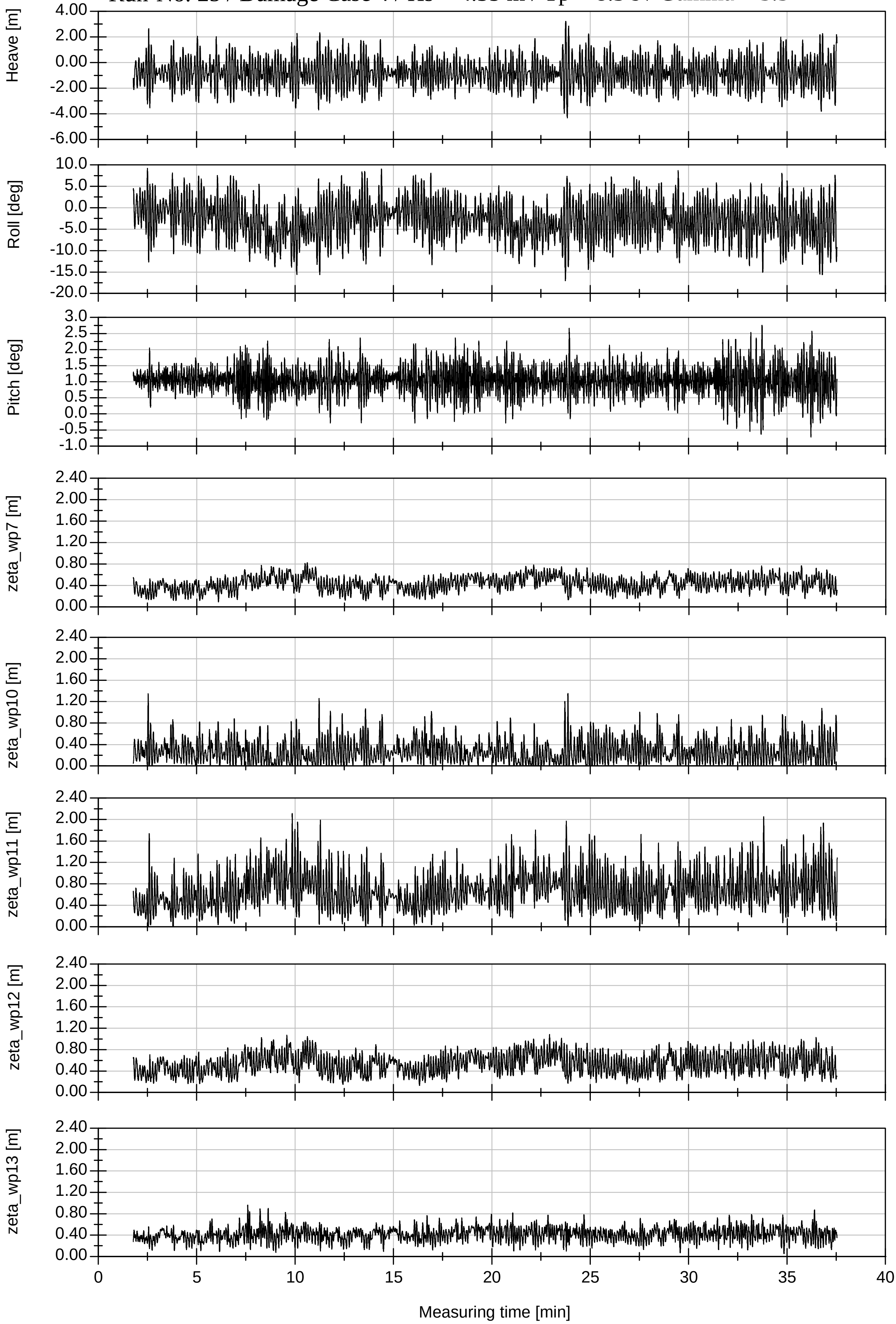
Run-No. 24 / Damage Case 4 / Hs = 4.38 m / Tp = 8.4 s / Gamma = 3.3



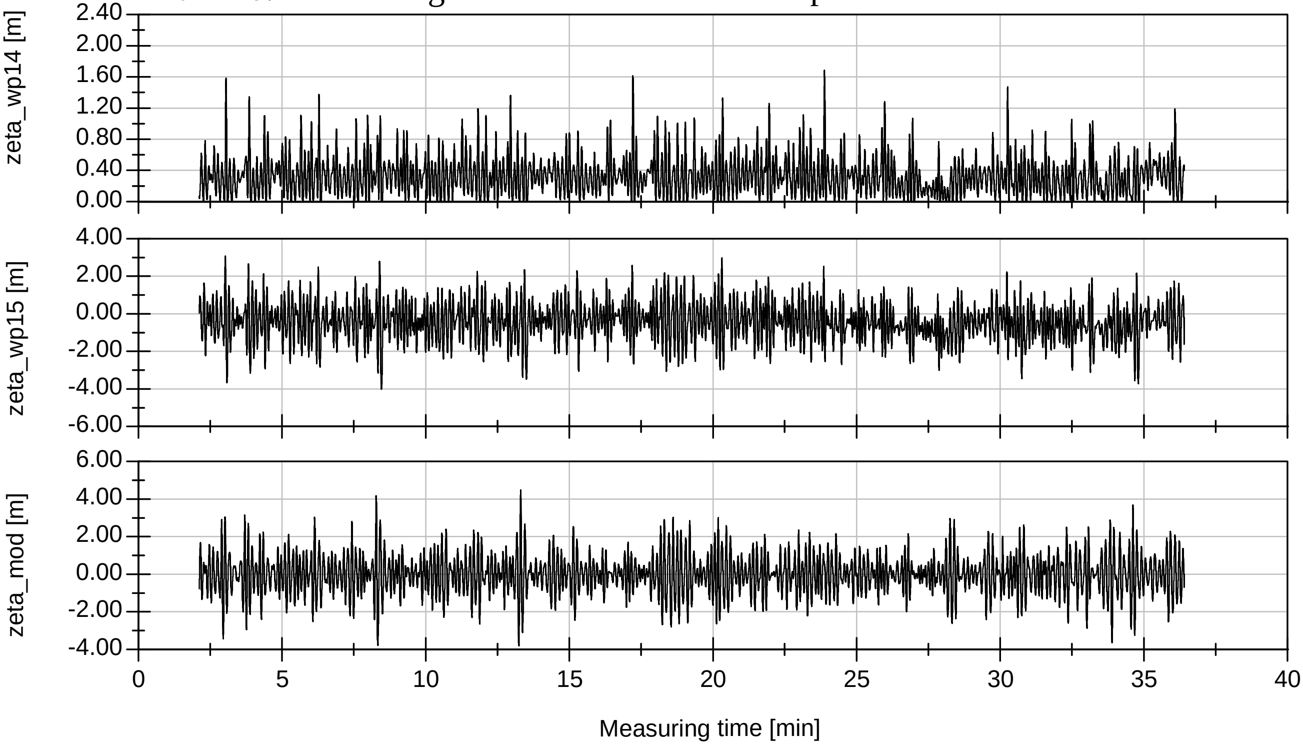
Run-No. 24 / Damage Case 4 / Hs = 4.38 m / Tp = 8.4 s / Gamma = 3.3



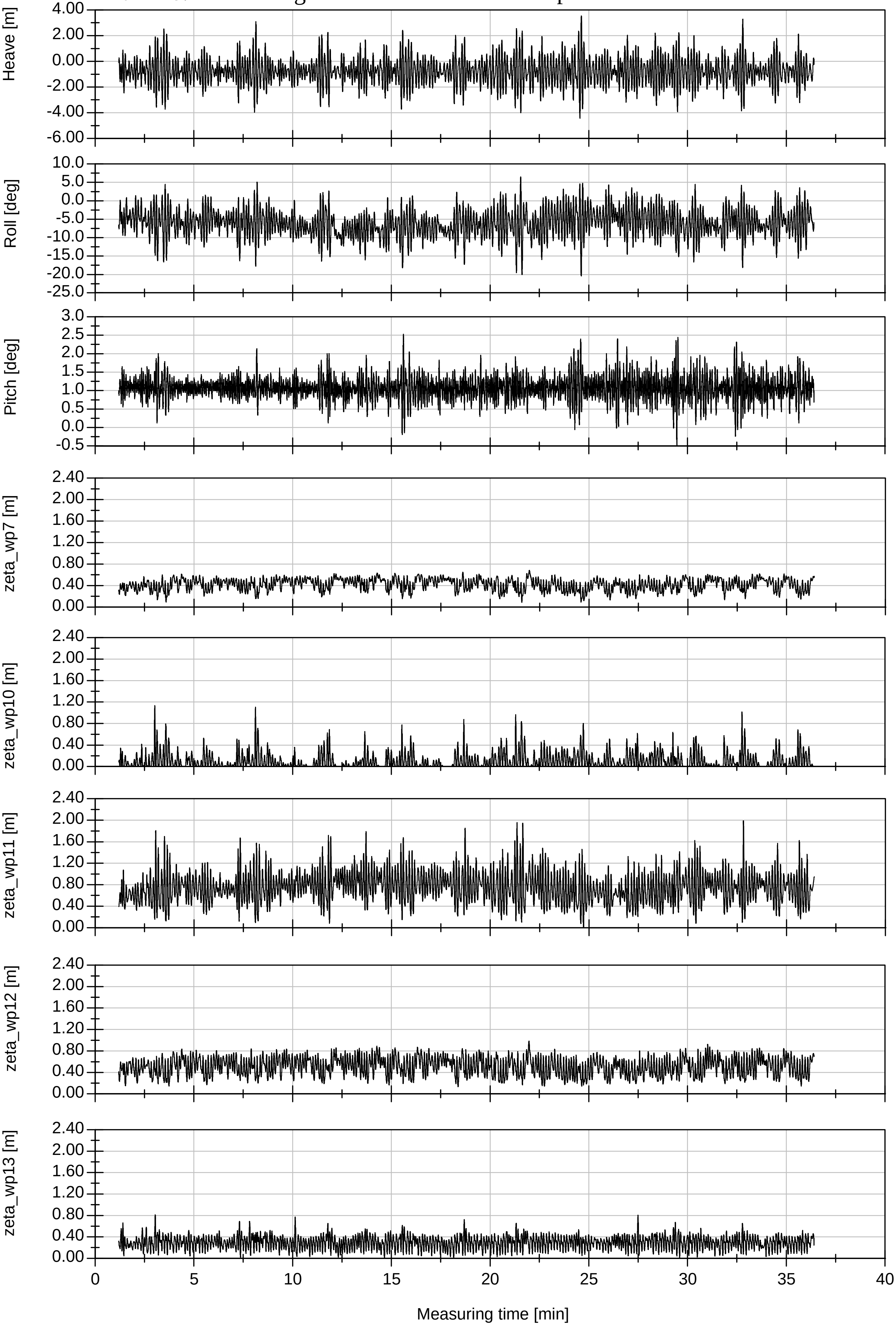
Run-No. 25 / Damage Case 4 / Hs = 4.35 m / Tp = 8.3 s / Gamma = 3.3



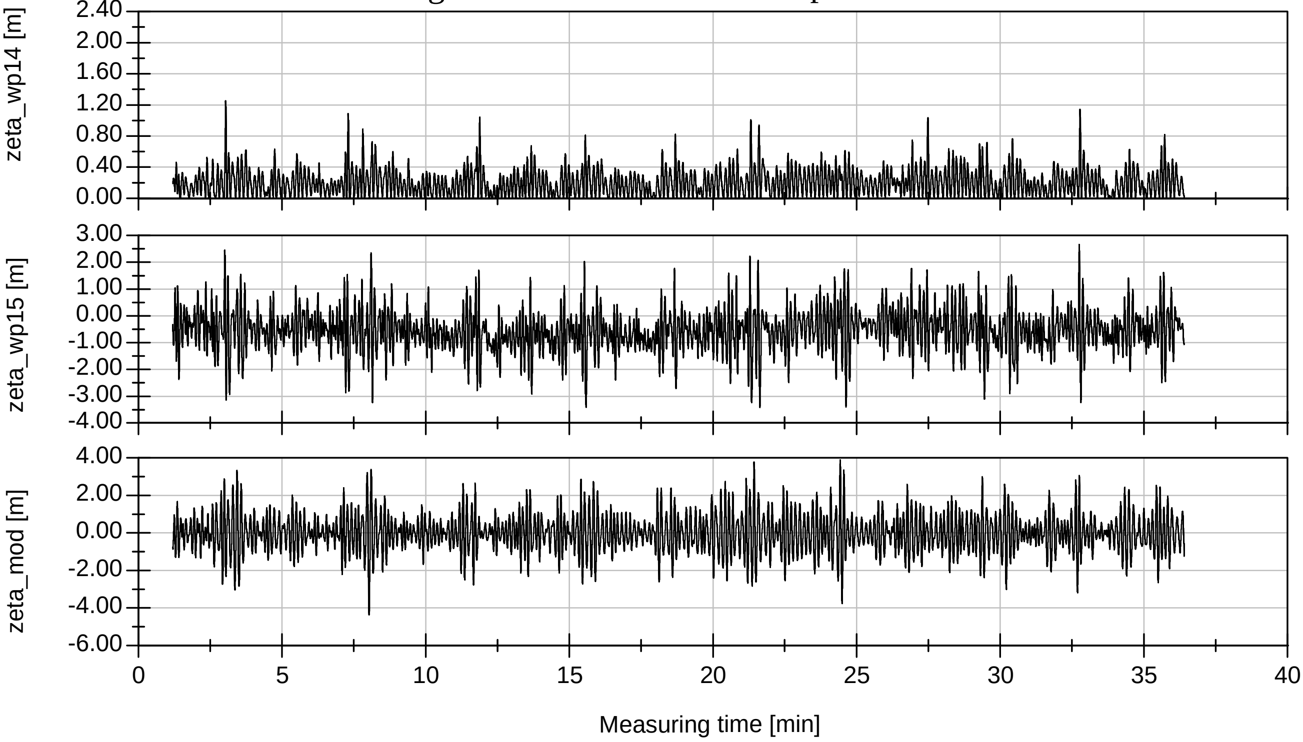
Run-No. 25 / Damage Case 4 / Hs = 4.35 m / Tp = 8.3 s / Gamma = 3.3



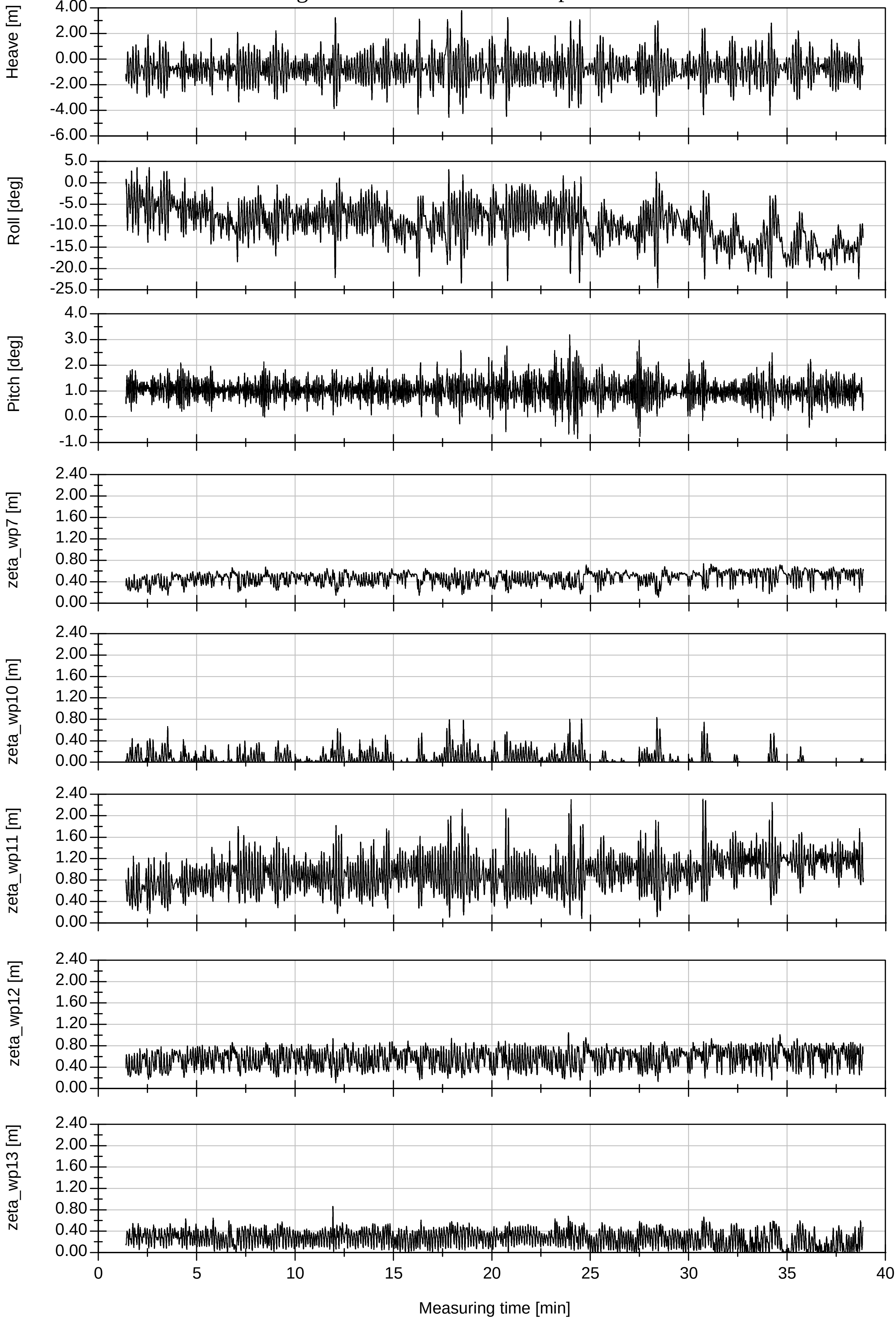
Run-No. 26 / Damage Case 4 / Hs = 4.35 m / Tp = 8.3 s / Gamma = 3.3



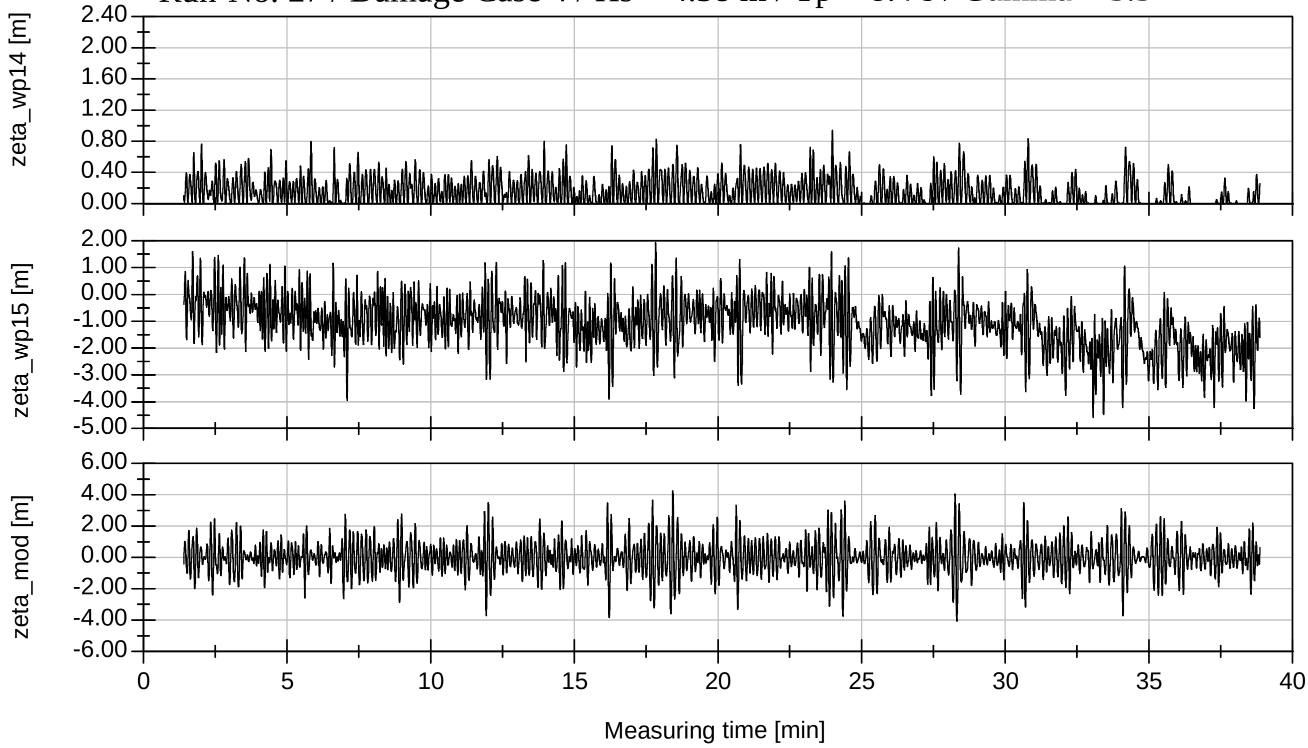
Run-No. 26 / Damage Case 4 / Hs = 4.35 m / Tp = 8.3 s / Gamma = 3.3

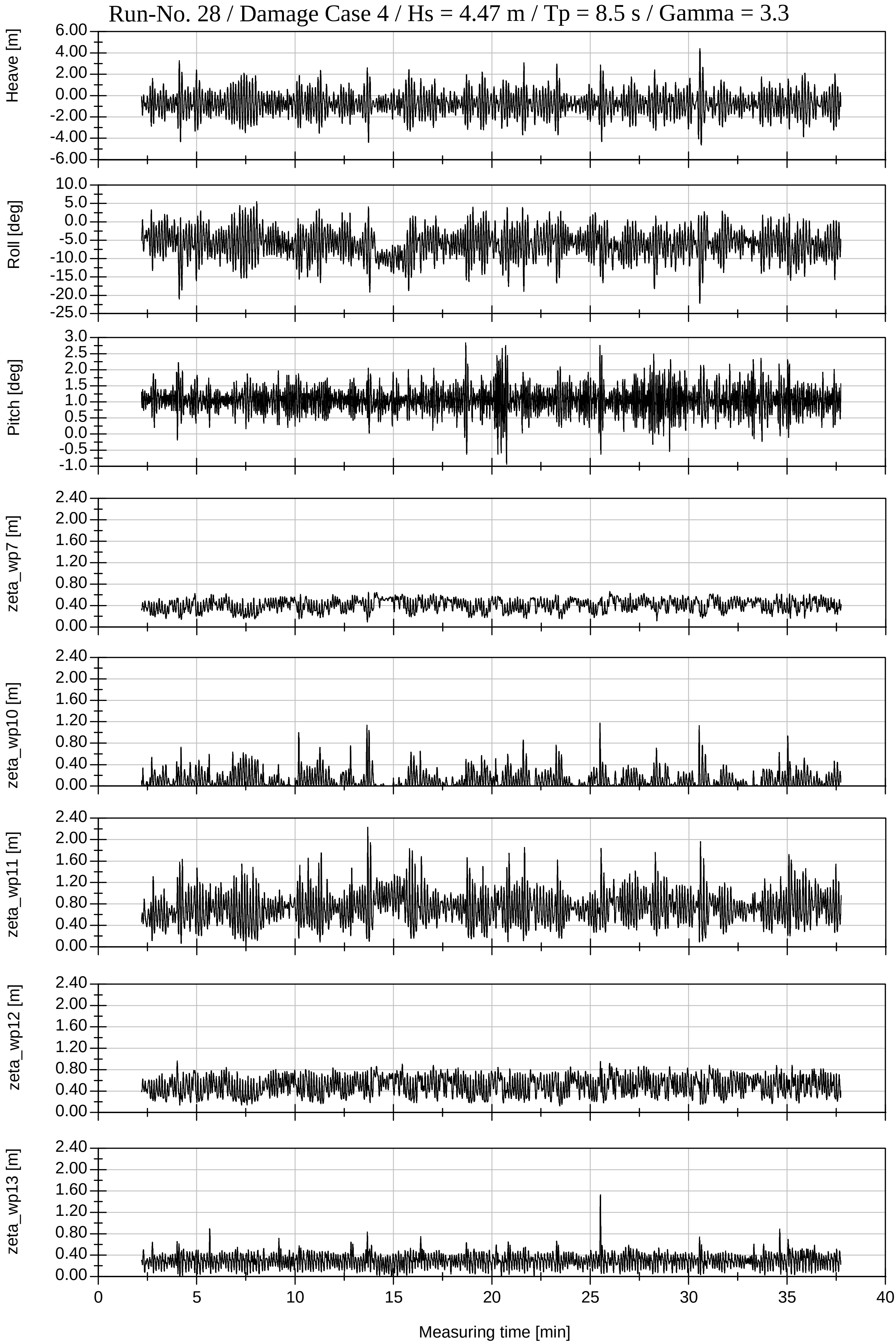


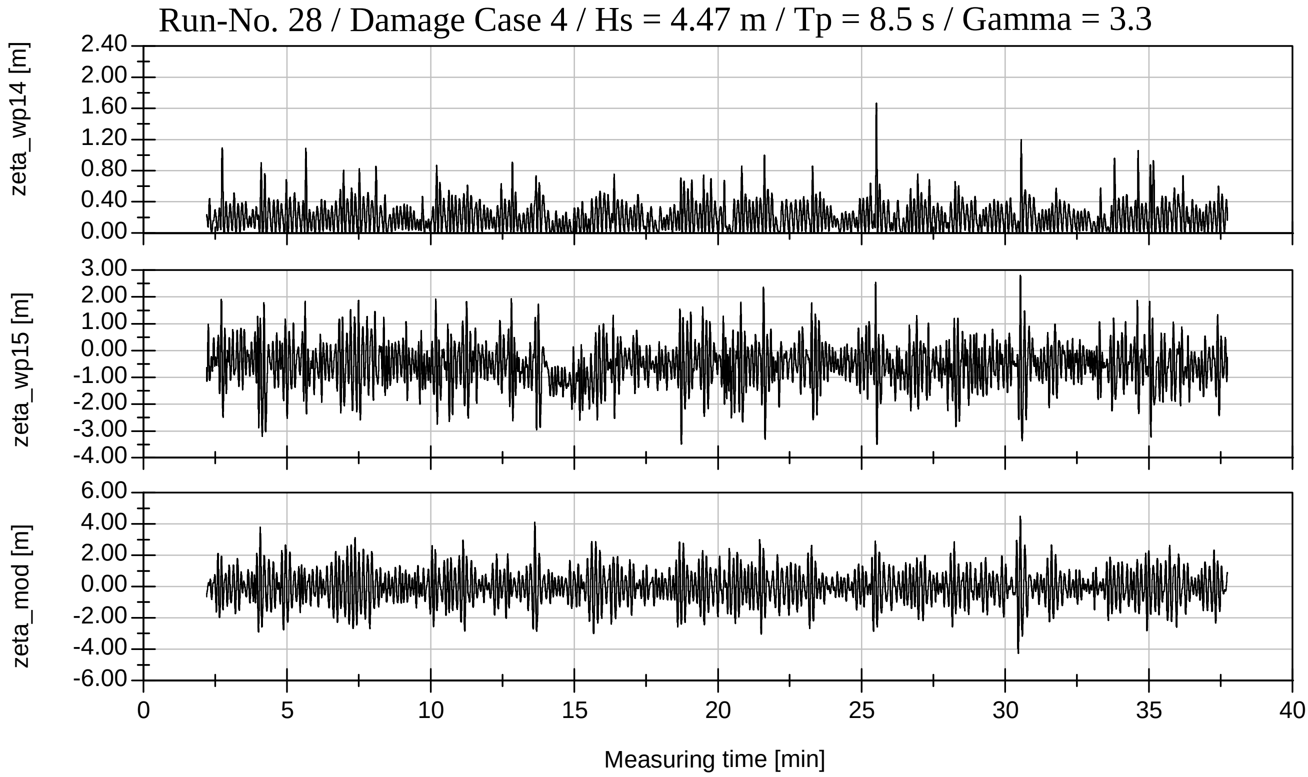
Run-No. 27 / Damage Case 4 / Hs = 4.38 m / Tp = 8.4 s / Gamma = 3.3



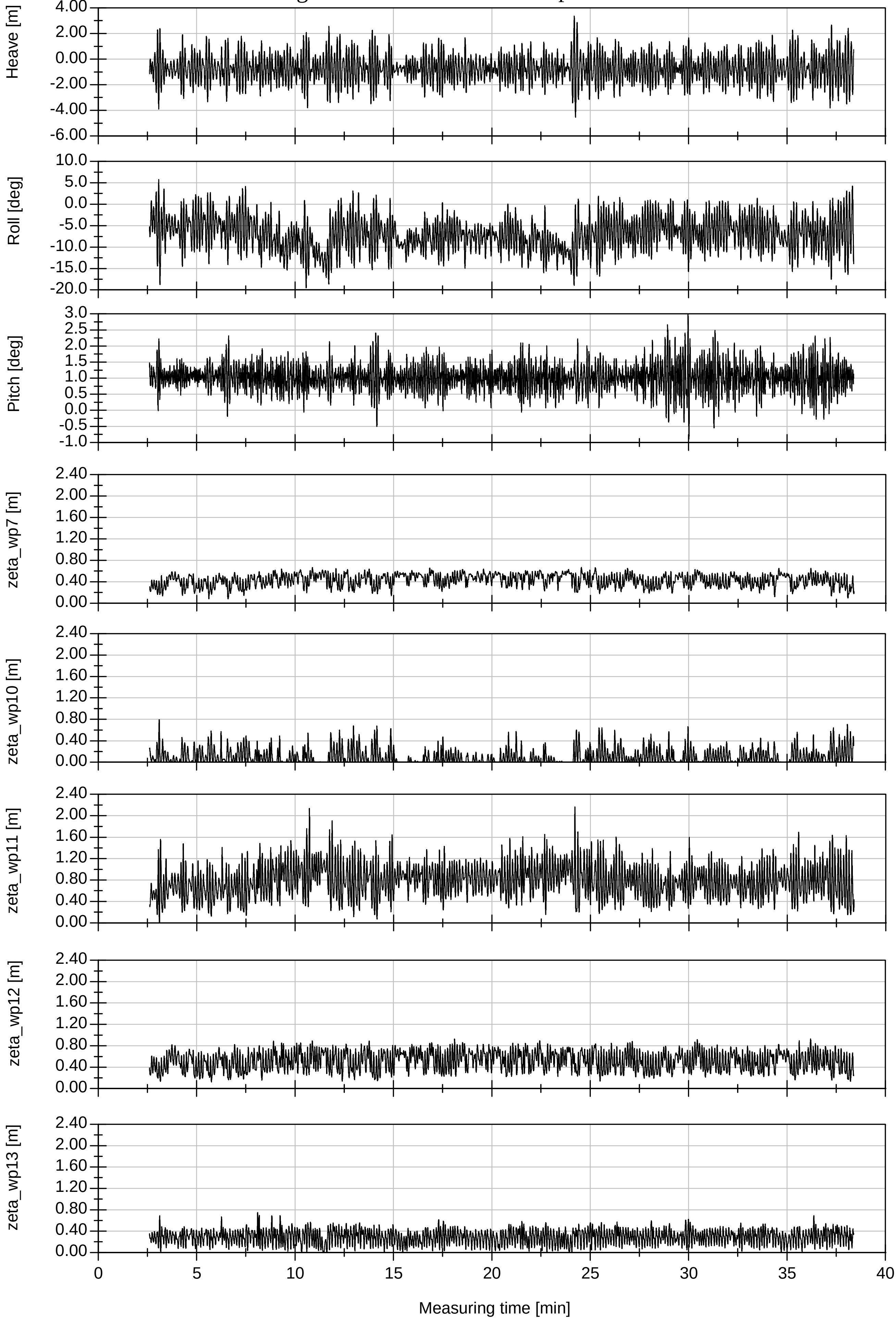
Run-No. 27 / Damage Case 4 / Hs = 4.38 m / Tp = 8.4 s / Gamma = 3.3



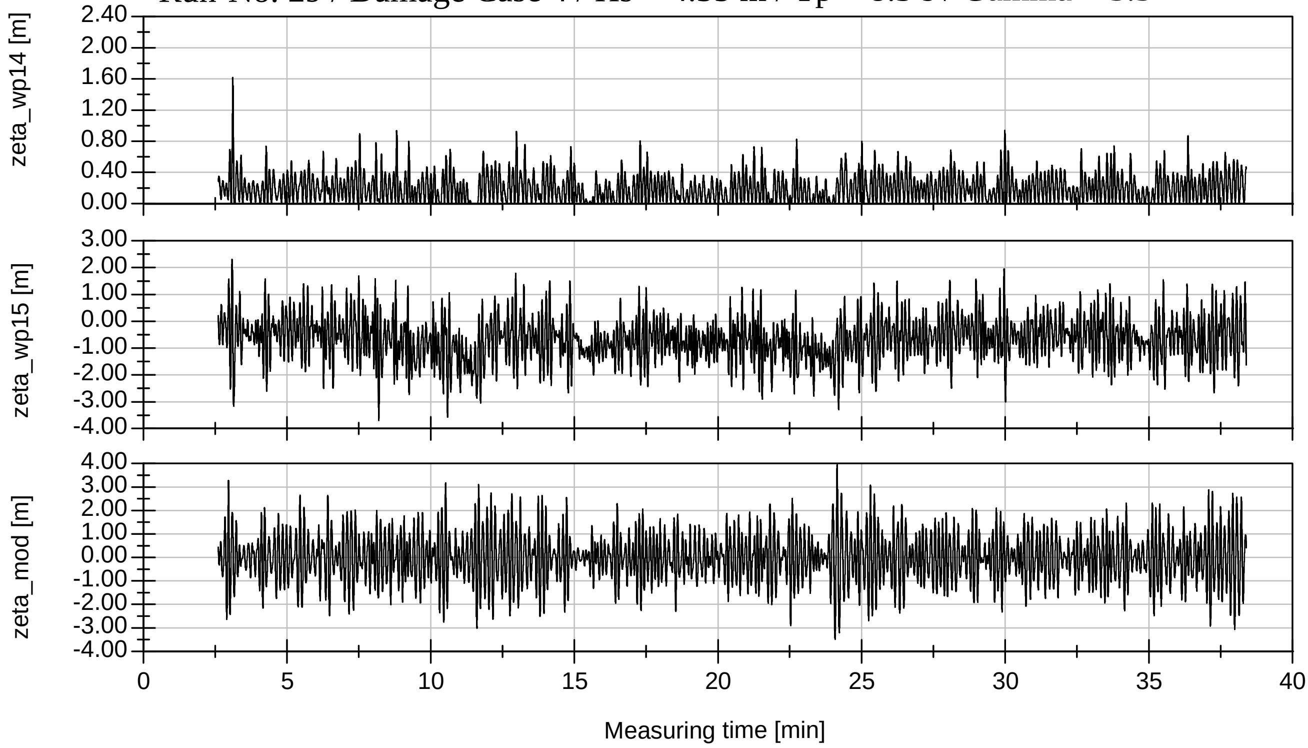

Run-No. 28 / Damage Case 4 / Hs = 4.47 m / Tp = 8.5 s / Gamma = 3.3
Heave [m]
Roll [deg]
Pitch [deg]
zeta_wp7 [m]
zeta_wp10 [m]
zeta_wp11 [m]
zeta_wp12 [m]
zeta_wp13 [m]
Measuring time [min]


Run-No. 28 / Damage Case 4 / Hs = 4.47 m / Tp = 8.5 s / Gamma = 3.3
zeta_wp14 [m]
2.40
2.00
1.60
1.20
0.80
0.40
0.00
zeta_wp15 [m]
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
zeta_mod [m]
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
0
5
10
15
20
25
30
35
40
Measuring time [min]

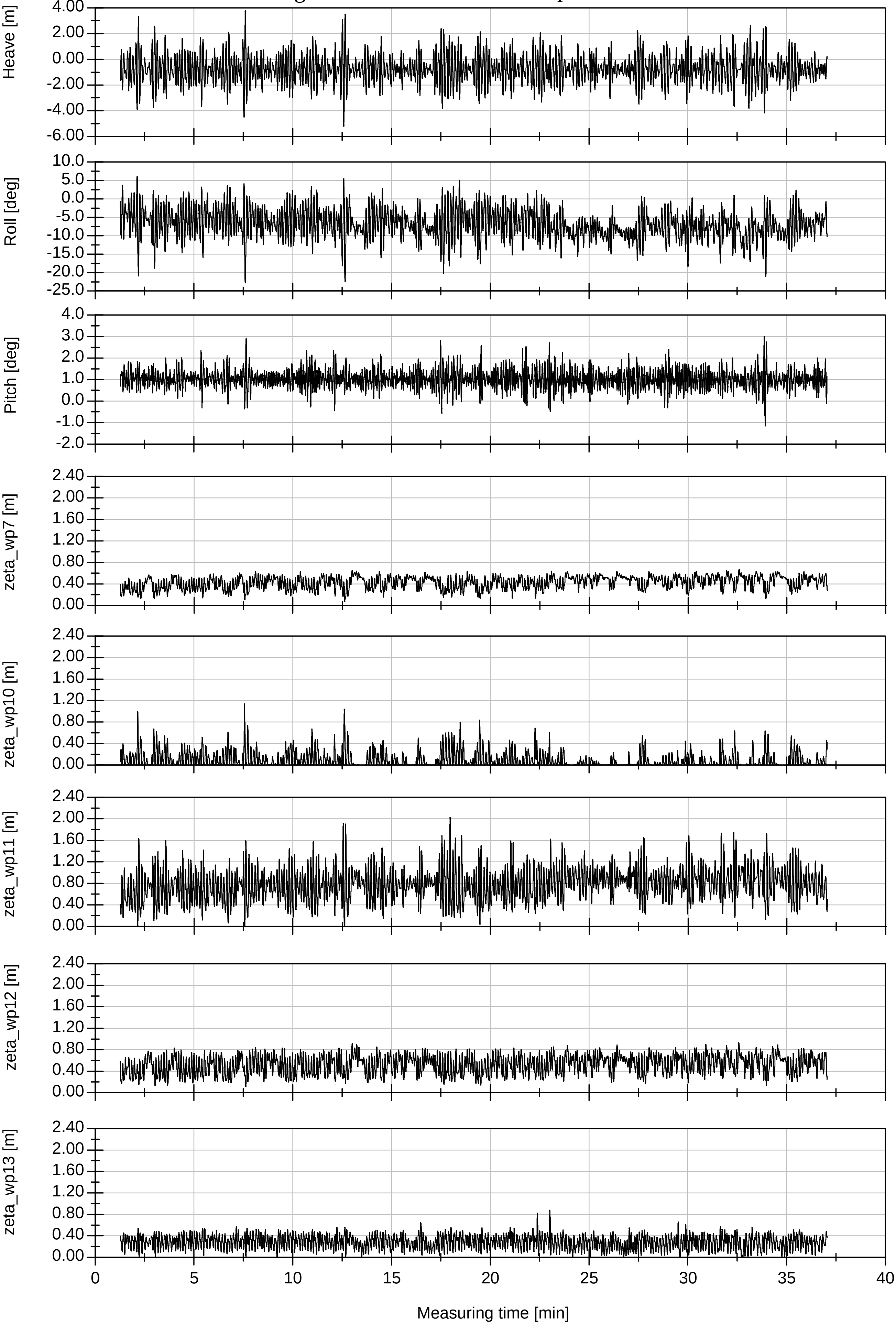
Run-No. 29 / Damage Case 4 / Hs = 4.35 m / Tp = 8.3 s / Gamma = 3.3

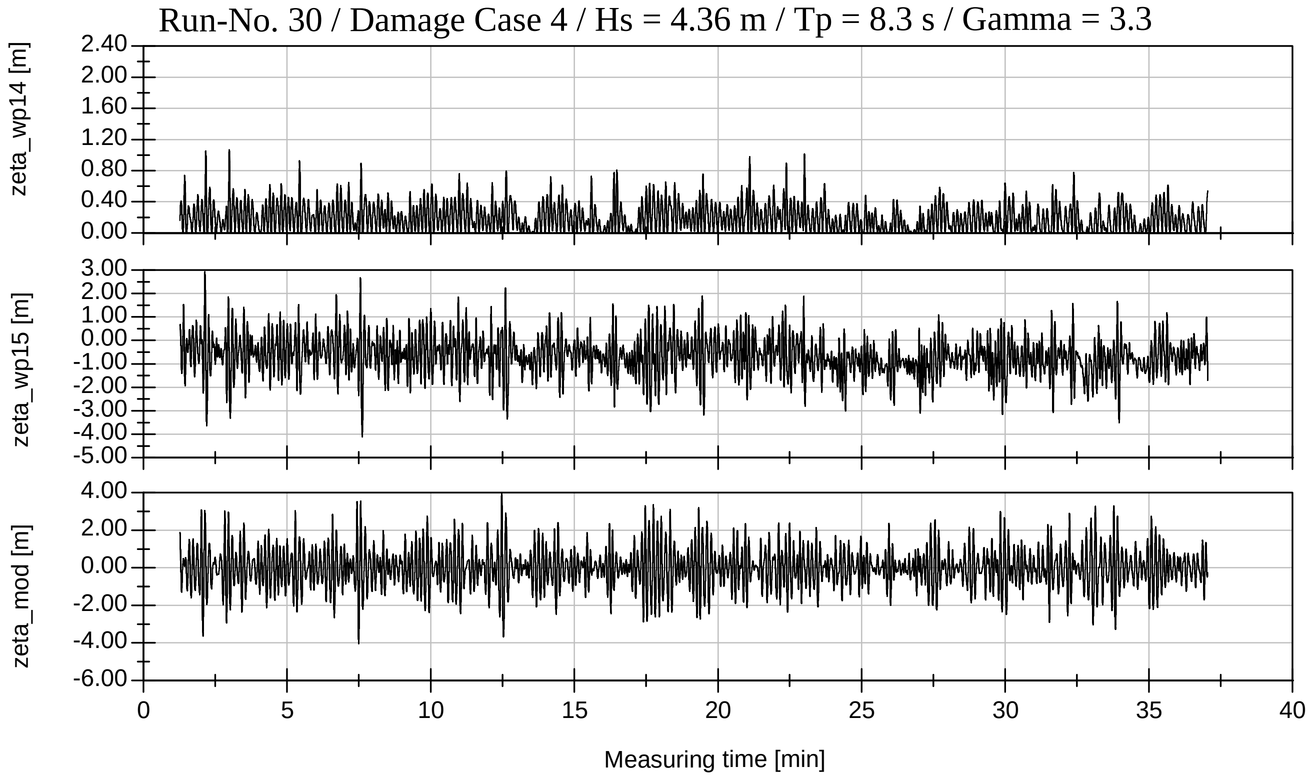


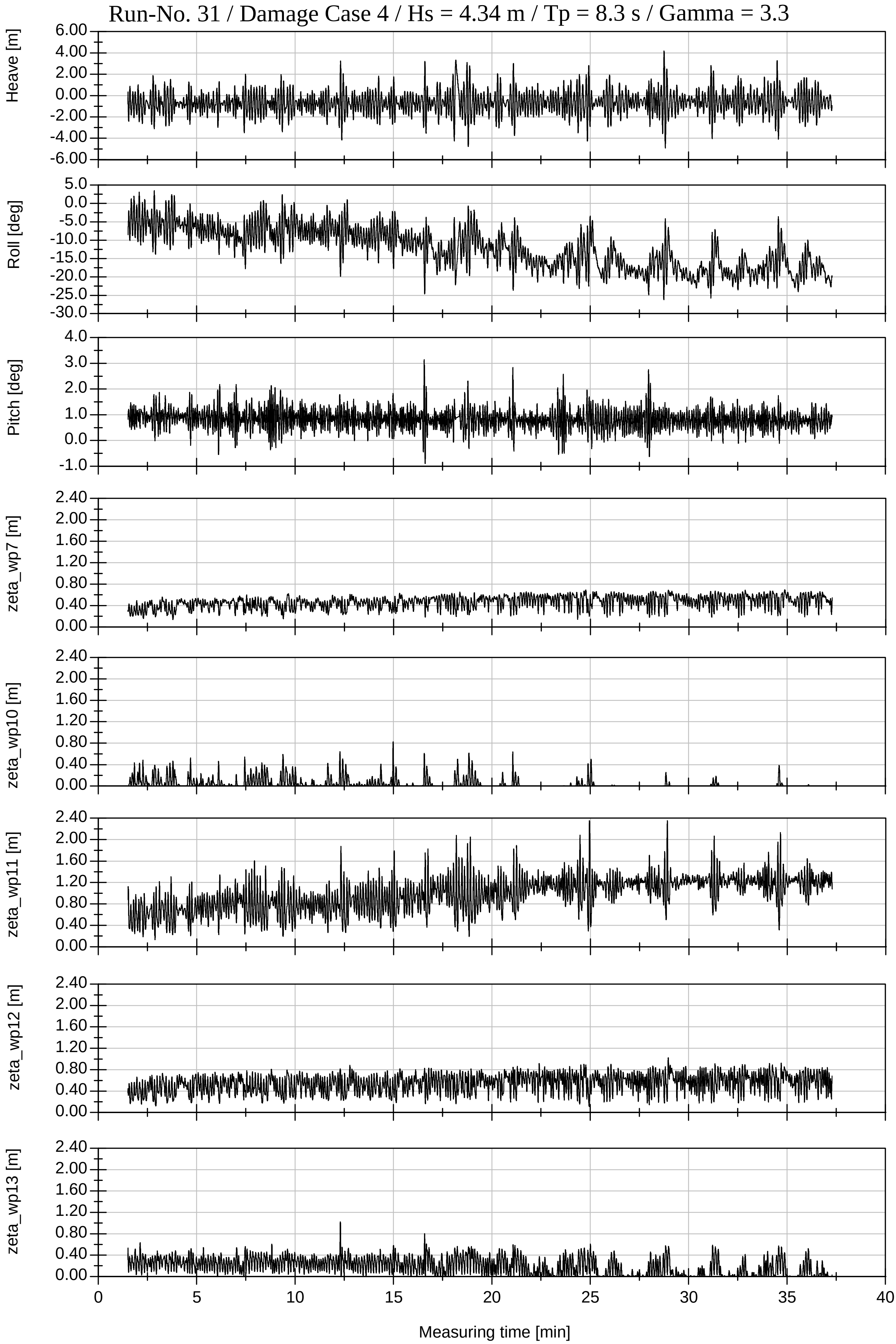
Run-No. 29 / Damage Case 4 / Hs = 4.35 m / Tp = 8.3 s / Gamma = 3.3

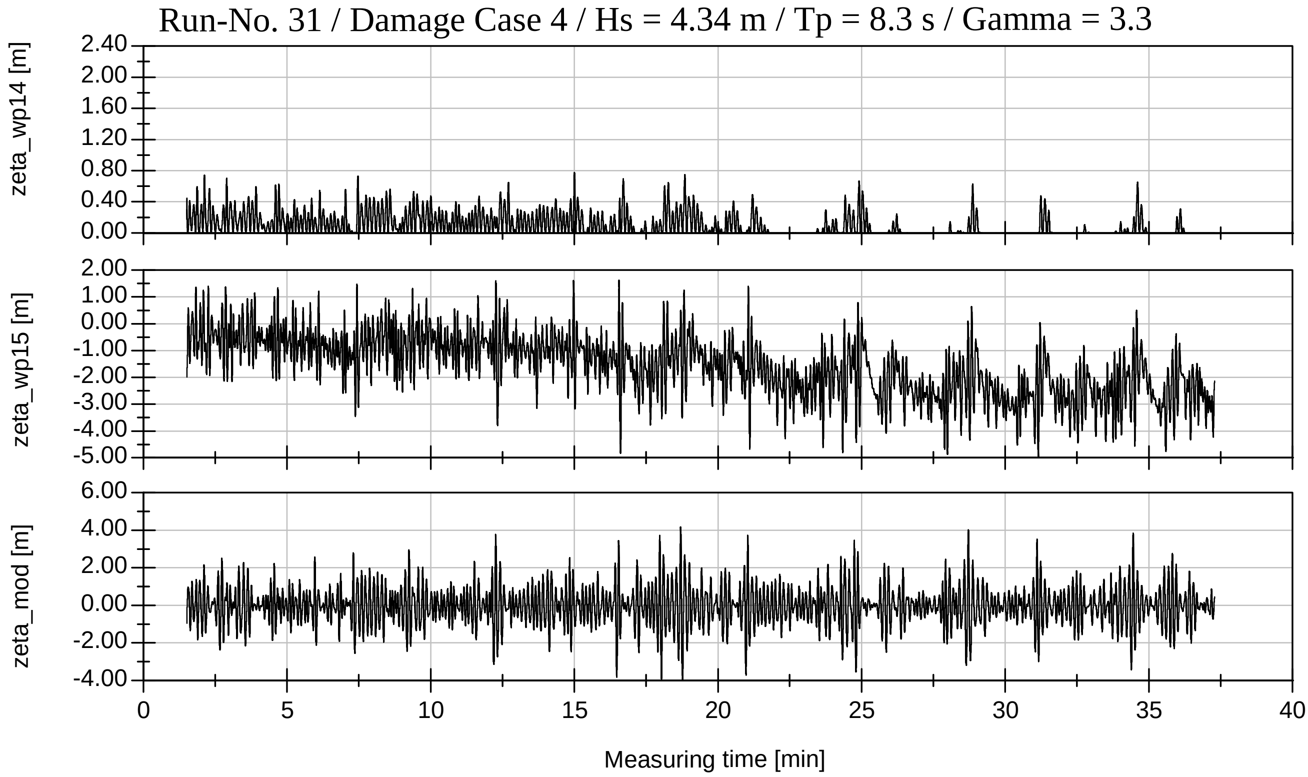


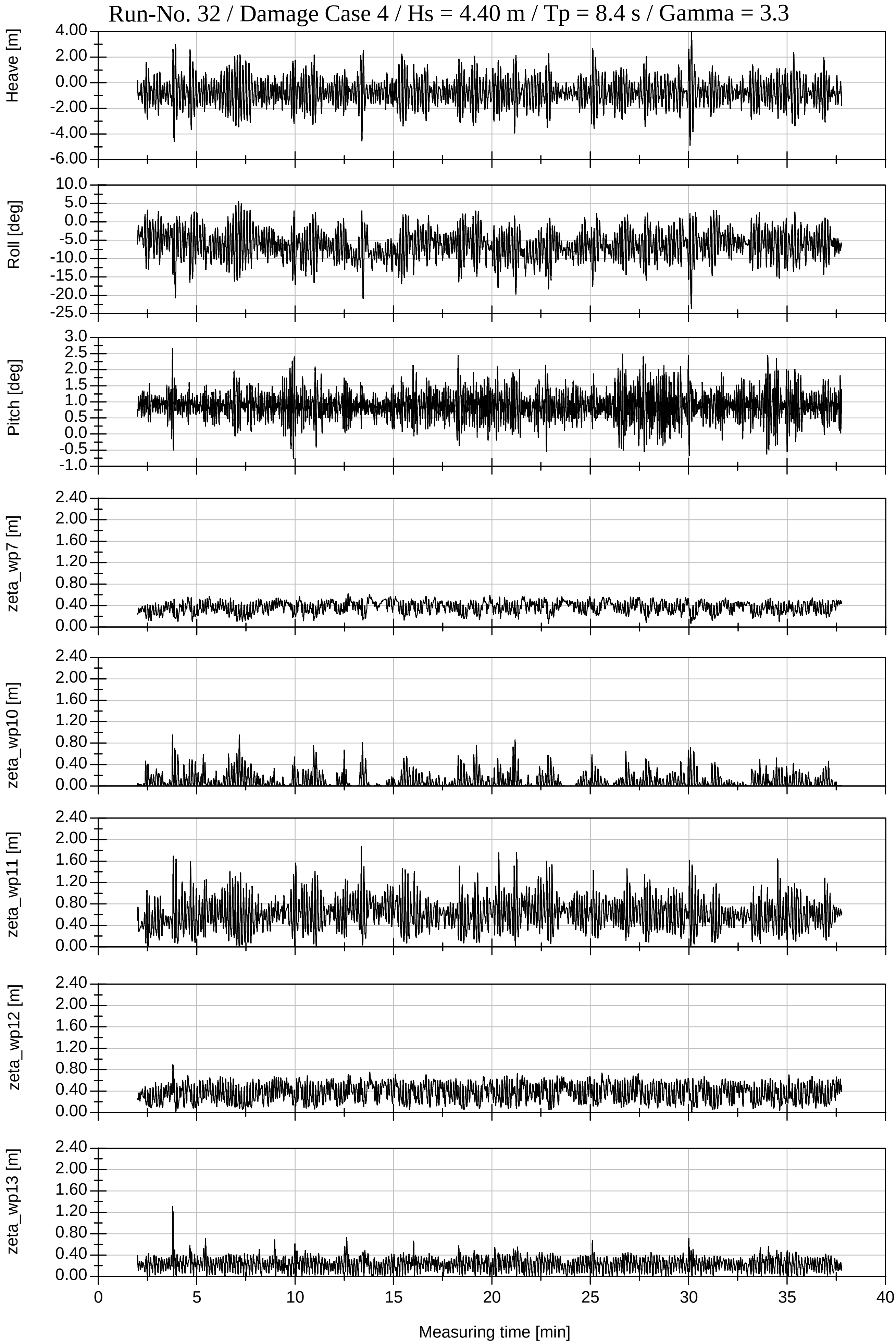
Run-No. 30 / Damage Case 4 / Hs = 4.36 m / Tp = 8.3 s / Gamma = 3.3



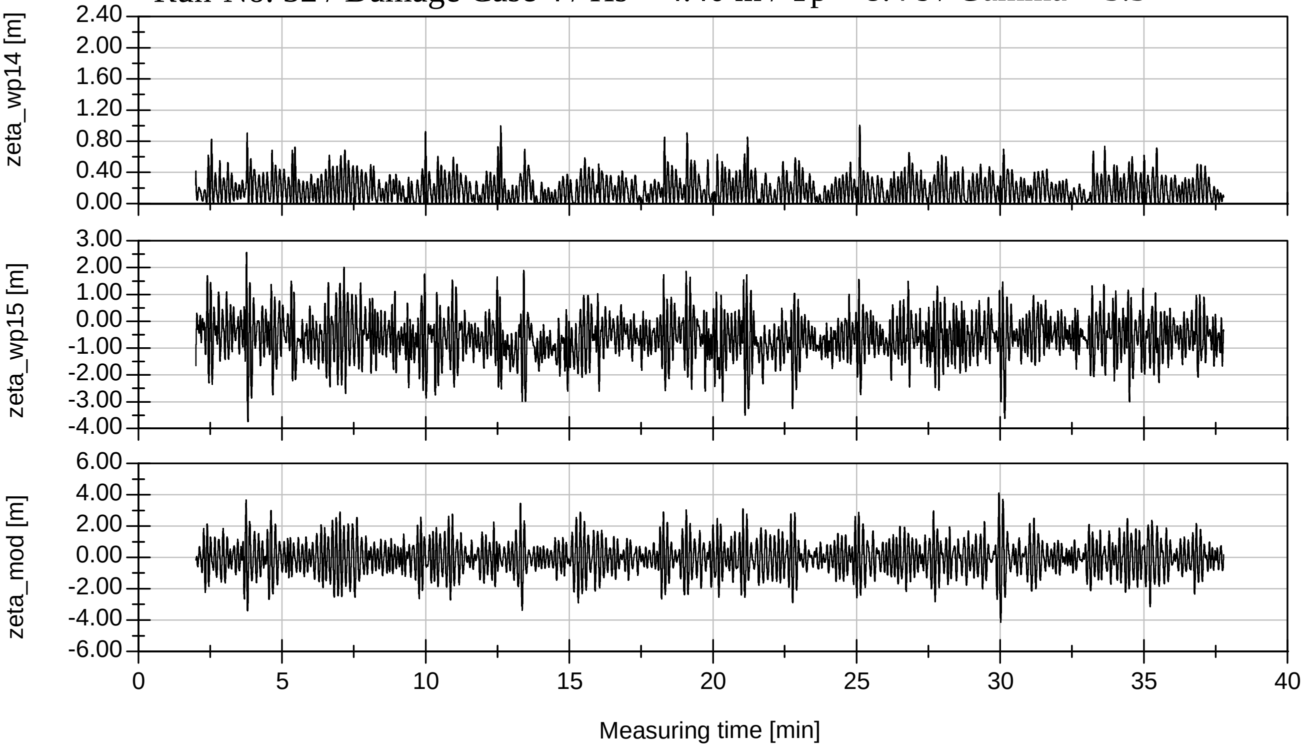

Run-No. 30 / Damage Case 4 / Hs = 4.36 m / Tp = 8.3 s / Gamma = 3.3
zeta_wp14 [m]
2.40
2.00
1.60
1.20
0.80
0.40
0.00
zeta_wp15 [m]
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
zeta_mod [m]
4.00
2.00
0.00
-2.00
-4.00
-6.00
0
5
10
15
20
25
30
35
40
Measuring time [min]


Run-No. 31 / Damage Case 4 / Hs = 4.34 m / Tp = 8.3 s / Gamma = 3.3
Heave [m]
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
Roll [deg]
5.0
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
Pitch [deg]
4.0
3.0
2.0
1.0
0.0
-1.0
zeta_wp7 [m]
zeta_wp10 [m]
zeta_wp11 [m]
zeta_wp12 [m]
zeta_wp13 [m]
2.40
2.00
1.60
1.20
0.80
0.40
0.00
0
5
10
15
20
25
30
35
40
Measuring time [min]


Run-No. 31 / Damage Case 4 / Hs = 4.34 m / Tp = 8.3 s / Gamma = 3.3
zeta_wp14 [m]
2.40
2.00
1.60
1.20
0.80
0.40
0.00
zeta_wp15 [m]
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
zeta_mod [m]
6.00
4.00
2.00
0.00
-2.00
-4.00
0
5
10
15
20
25
30
35
40
Measuring time [min]


Run-No. 32 / Damage Case 4 / Hs = 4.40 m / Tp = 8.4 s / Gamma = 3.3
Heave [m]
4.00
2.00
0.00
-2.00
-4.00
-6.00
Roll [deg]
10.0
5.0
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
Pitch [deg]
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
zeta_wp7 [m]
zeta_wp10 [m]
zeta_wp11 [m]
zeta_wp12 [m]
zeta_wp13 [m]
2.40
2.00
1.60
1.20
0.80
0.40
0.00
0
5
10
15
20
25
30
35
40
Measuring time [min]

Run-No. 32 / Damage Case 4 / Hs = 4.40 m / Tp = 8.4 s / Gamma = 3.3



Annex C

Test Results

(Full Scale Values)

Damage Case		[--]	1				
Run-No.		[--]	1	2	3	4	5
Survived (EU Directive)		[--]	YES	YES	YES	YES	NO
Comments		[--]		Capsize after 33 min	Capsize after 33 min		Capsize after 21 min
Initial draught		*[m]*	*4.57*				
Initial heeling angle		*[deg]*	*-1.0*				
Initial trim angle		*[deg]*	*-0.7*				
Seaway spectrum		[--]	ITTC				
Realisation		[--]	1	2	3	4	5
H_s		[m]	4.21	4.33	4.36	4.23	4.19
T_p		[s]	12.3	12.5	12.5	12.3	12.3
Measuring time		[min]	34.7	32.9	32.3	35.3	20.6
Heave	A_{sig}	[m]	2.32	2.41	2.27	2.32	2.41
	A_{sig+}	[m]	2.37	2.45	2.30	2.38	2.42
	A_{sig-}	[m]	-2.28	-2.36	-2.23	-2.26	-2.39
	A_{max+}	[m]	4.89	4.19	4.02	4.28	5.38
	A_{max-}	[m]	-4.36	-4.29	-4.14	-4.09	-3.66
Final draught (30 min)		*[m]*	*4.57*	*4.57*	*4.57*	*4.57*	-
Roll	$A_{sig\ upper\ bound}$	[deg]	-0.48	-0.2	-1.1	-1.0	-0.8
	$A_{sig\ lower\ bound}$	[deg]	-8.86	-9.5	-10.5	-9.9	-10.7
	$A_{max\ upper\ bound}$	[deg]	3.40	3.9	2.7	1.3	2.2
	$A_{max\ lower\ bound}$	[deg]	-11.71	-15.6	-27.8	-12.2	-15.2
	T_m	[s]	12.2	12.1	12.0	12.1	12.1
Final heel (30 min)		*[deg]*	*-7.5*	*-7.3*	*-7.7*	*-8.3*	-
Pitch	A_{sig}	[deg]	1.08	1.0	1.1	1.3	1.0
	A_{sig+}	[deg]	-0.03	-0.2	-0.1	0.2	-0.1
	A_{sig-}	[deg]	-1.25	-1.1	-1.2	-1.5	-1.2
	A_{max+}	[deg]	0.82	0.4	0.6	0.8	0.3
	A_{max-}	[deg]	-1.83	-1.6	-1.9	-2.3	-1.6
Final trim (30 min)		*[deg]*	*-1.3*	*-1.3*	*-1.4*	*-1.3*	-
ζ_{wp1}	A_{sig+}	[m]	0.69	0.76	0.77	0.76	0.85
	A_{max+}	[m]	1.02	1.32	1.27	1.18	1.52
ζ_{wp2}	A_{sig+}	[m]	0.26	0.28	0.30	0.28	0.29
	A_{max+}	[m]	0.35	0.44	0.89	0.39	0.42
ζ_{wp3}	A_{sig+}	[m]	0.15	0.15	0.15	0.15	0.14
	A_{max+}	[m]	0.32	0.32	0.34	0.28	0.25
ζ_{wp4}	A_{sig+}	[m]	0.22	0.25	0.27	0.25	0.28
	A_{max+}	[m]	0.36	0.46	0.67	0.38	0.42
ζ_{wp5}	A_{sig+}	[m]	0.16	0.16	0.17	0.16	0.16
	A_{max+}	[m]	0.22	0.22	0.24	0.21	0.29
ζ_{wp6}	A_{sig+}	[m]	0.11	0.12	0.11	0.11	0.11
	A_{max+}	[m]	0.16	0.21	0.18	0.18	0.21
ζ_{wp7}	A_{sig+}	[m]	0.18	0.20	0.25	0.21	0.25
	A_{max+}	[m]	0.35	0.44	0.62	0.34	0.59
ζ_{wp8}	A_{sig+}	[m]	0.08	0.09	0.08	0.08	0.09
	A_{max+}	[m]	0.18	0.20	0.17	0.18	0.20
ζ_{wp9}	A_{sig+}	[m]	0.04	0.05	0.05	0.05	0.05
	A_{max+}	[m]	0.09	0.12	0.09	0.09	0.12
ζ_{wp10}	A_{sig+}	[m]	0.01	0.03	0.02	0.02	0.02
	A_{max+}	[m]	0.16	0.19	0.15	0.16	0.22
ζ_{wp11}	A_{sig+}	[m]	0.20	0.22	0.27	0.24	0.33
	A_{max+}	[m]	0.31	0.63	1.09	0.40	0.93
ζ_{wp12}	A_{sig+}	[m]	0.09	0.10	0.11	0.10	0.11
	A_{max+}	[m]	0.15	0.22	0.55	0.20	0.19
ζ_{wp13}	A_{sig+}	[m]	0.02	0.03	0.02	0.02	0.01
	A_{max+}	[m]	0.07	0.08	0.09	0.09	0.11
ζ_{wp14}	A_{sig+}	[m]	0.00	0.01	0.00	0.00	0.00
	A_{max+}	[m]	0.05	0.08	0.06	0.06	0.07
ζ_{wp15}	A_{sig+}	[m]	2.00	2.16	2.36	2.18	2.46
	A_{sig-}	[m]	-0.65	-0.66	-0.61	-0.62	-0.60
	A_{max+}	[m]	3.42	3.27	4.65	3.71	4.21
	A_{max-}	[m]	-1.44	-1.58	-1.49	-1.38	-1.33

Table 4: Statistical Results of ship motions and wave probe measurements

Damage Case		[--]	1				
Run-No.		[--]	6	7	8	9	10
Survived (EU Directive)		[--]	NO	NO	NO	NO	NO
Comments		[--]	Capsize after 5 min	Capsize after 6 min	Capsize after 5 min	Capsize after 5 min	Capsize after 4 min
Initial draught		*[m]*	*4.57*				
Initial heeling angle		*[deg]*	*-1.0*				
Initial trim angle		*[deg]*	*-0.7*				
Seaway spectrum		[--]	JONSWAP				
Realisation		[--]	1	2	3	4	5
H_s		[m]	3.24	3.36	3.20	3.23	3.63
T_p		[s]	7.7	7.5	7.2	7.3	7.8
Measuring time		[min]	4.5	6.2	4.6	5.2	4.6
Heave	A_{sig}	[m]	1.48	1.57	1.71	1.78	2.06
	A_{sig+}	[m]	1.37	1.61	1.71	1.77	2.02
	A_{sig-}	[m]	-1.51	-1.56	-1.70	-1.78	-2.00
	A_{max+}	[m]	2.32	2.26	2.80	2.55	3.10
	A_{max-}	[m]	-1.88	-2.23	-2.44	-2.24	-2.83
Final draught (30 min)		*[m]*	-	-	-	-	-
Roll	$A_{sig\ upper\ bound}$	[deg]	-2.91	-4.6	-0.7	-0.5	-0.9
	$A_{sig\ lower\ bound}$	[deg]	-14.90	-10.8	-10.0	-10.5	-10.7
	$A_{max\ upper\ bound}$	[deg]	-1.54	-2.4	-0.5	0.9	3.2
	$A_{max\ lower\ bound}$	[deg]	-27.17	-14.3	-12.6	-15.8	-14.3
	T_m	[s]	13.5	12.9	13.6	12.0	9.8
Final heel (30 min)		*[deg]*	-	-	-	-	-
Pitch	A_{sig}	[deg]	1.25	1.2	1.2	1.1	1.1
	A_{sig+}	[deg]	0.08	0.0	0.0	-0.2	-0.1
	A_{sig-}	[deg]	-1.40	-1.3	-1.4	-1.2	-1.3
	A_{max+}	[deg]	0.35	0.2	0.4	-0.1	0.2
	A_{max-}	[deg]	-1.61	-1.7	-1.9	-1.4	-1.6
Final trim (30 min)		*[deg]*	-	-	-	-	-
ζ_{wp1}	A_{sig+}	[m]	0.98	0.90	0.94	0.96	0.95
	A_{max+}	[m]	1.63	1.31	1.47	1.17	1.09
ζ_{wp2}	A_{sig+}	[m]	0.37	0.33	0.33	0.34	0.34
	A_{max+}	[m]	0.58	0.39	0.42	0.53	0.47
ζ_{wp3}	A_{sig+}	[m]	0.14	0.16	0.18	0.16	0.17
	A_{max+}	[m]	0.21	0.23	0.27	0.23	0.24
ζ_{wp4}	A_{sig+}	[m]	0.36	0.34	0.33	0.35	0.35
	A_{max+}	[m]	0.52	0.48	0.52	0.51	0.49
ζ_{wp5}	A_{sig+}	[m]	0.20	0.19	0.19	0.19	0.18
	A_{max+}	[m]	0.21	0.29	0.24	0.24	0.22
ζ_{wp6}	A_{sig+}	[m]	0.09	0.11	0.11	0.11	0.13
	A_{max+}	[m]	0.13	0.15	0.16	0.13	0.16
ζ_{wp7}	A_{sig+}	[m]	0.38	0.29	0.35	0.30	0.31
	A_{max+}	[m]	0.54	0.70	0.60	0.50	0.48
ζ_{wp8}	A_{sig+}	[m]	0.11	0.09	0.11	0.12	0.17
	A_{max+}	[m]	0.13	0.16	0.21	0.15	0.27
ζ_{wp9}	A_{sig+}	[m]	0.05	0.07	0.07	0.07	0.09
	A_{max+}	[m]	0.10	0.09	0.10	0.09	0.12
ζ_{wp10}	A_{sig+}	[m]	0.06	0.08	0.10	0.11	0.21
	A_{max+}	[m]	0.13	0.12	0.18	0.12	0.22
ζ_{wp11}	A_{sig+}	[m]	0.49	0.41	0.45	0.40	0.44
	A_{max+}	[m]	0.76	0.96	0.85	0.70	0.55
ζ_{wp12}	A_{sig+}	[m]	0.17	0.14	0.15	0.16	0.14
	A_{max+}	[m]	0.28	0.20	0.20	0.25	0.17
ζ_{wp13}	A_{sig+}	[m]	0.06	0.06	0.04	0.06	0.09
	A_{max+}	[m]	0.08	0.08	0.07	0.08	0.11
ζ_{wp14}	A_{sig+}	[m]	0.04	0.03	0.01	0.01	0.07
	A_{max+}	[m]	0.06	0.07	0.06	0.05	0.07
ζ_{wp15}	A_{sig+}	[m]	3.25	2.81	2.78	2.62	2.86
	A_{sig-}	[m]	-0.37	-0.24	-0.71	-0.77	-0.88
	A_{max+}	[m]	4.78	5.02	4.26	3.74	3.85
	A_{max-}	[m]	-0.86	-0.77	-1.55	-1.23	-1.25

Table 5: Statistical Results of ship motions and wave probe measurements

Damage Case		[--]	1				
Run-No.		[--]	11	12	13	14	15
Survived (EU Directive)		[--]	YES	YES	NO	YES	NO
Comments		[--]		Capsize after 33 min	Capsize after 28 min	Capsize after 33 min	Capsize after 10 min
Initial draught		*[m]*	*4.57*				
Initial heeling angle		*[deg]*	*-1.0*				
Initial trim angle		*[deg]*	*-0.7*				
Seaway spectrum		[--]	JONSWAP				
Realisation		[--]	1	1	2	3	4
H_s		[m]	2.63	3.01	2.99	2.92	2.97
T_p		[s]	6.8	7.7	6.9	6.8	6.9
Measuring time		[min]	35.5	32.6	26.9	31.7	8.8
Heave	A_{sig}	[m]	1.24	1.37	1.43	1.45	1.37
	A_{sig+}	[m]	1.20	1.31	1.38	1.38	1.29
	A_{sig-}	[m]	-1.26	-1.42	-1.47	-1.51	-1.43
	A_{max+}	[m]	2.13	2.95	3.07	2.62	1.74
	A_{max-}	[m]	-2.14	-2.91	-2.70	-2.64	-1.86
Final draught (30 min)		*[m]*	*4.57*	*4.57*	-	-	-
Roll	$A_{sig\ upper\ bound}$	[deg]	-3.77	-4.3	-4.1	-4.4	-4.0
	$A_{sig\ lower\ bound}$	[deg]	-9.00	-10.0	-10.1	-10.5	-11.5
	$A_{max\ upper\ bound}$	[deg]	-0.29	-1.4	-0.8	-0.2	-3.0
	$A_{max\ lower\ bound}$	[deg]	-11.28	-18.1	-17.1	-14.9	-14.8
	T_m	[s]	10.4	10.8	11.7	11.0	11.6
Final heel (30 min)		*[deg]*	*-7.0*	*-8.5*	-	-	-
Pitch	A_{sig}	[deg]	1.04	1.1	1.1	1.2	1.1
	A_{sig+}	[deg]	-0.19	-0.2	-0.1	-0.1	-0.2
	A_{sig-}	[deg]	-1.16	-1.2	-1.2	-1.3	-1.2
	A_{max+}	[deg]	0.28	0.3	0.4	0.6	0.2
	A_{max-}	[deg]	-1.71	-2.1	-1.9	-2.1	-1.7
Final trim (30 min)		*[deg]*	*-1.4*	*-1.3*	-	-	-
ζ_{wp1}	A_{sig+}	[m]	0.70	0.77	0.77	0.79	0.81
	A_{max+}	[m]	1.01	1.17	1.22	1.72	1.09
ζ_{wp2}	A_{sig+}	[m]	0.28	0.31	0.30	0.30	0.32
	A_{max+}	[m]	0.40	0.56	0.42	0.54	0.38
ζ_{wp3}	A_{sig+}	[m]	0.13	0.13	0.14	0.13	0.12
	A_{max+}	[m]	0.30	0.31	0.35	0.22	0.17
ζ_{wp4}	A_{sig+}	[m]	0.25	0.28	0.27	0.29	0.31
	A_{max+}	[m]	0.35	0.46	0.42	0.54	0.41
ζ_{wp5}	A_{sig+}	[m]	0.16	0.17	0.17	0.17	0.18
	A_{max+}	[m]	0.23	0.24	0.26	0.26	0.24
ζ_{wp6}	A_{sig+}	[m]	0.09	0.09	0.11	0.09	0.09
	A_{max+}	[m]	0.19	0.22	0.26	0.17	0.14
ζ_{wp7}	A_{sig+}	[m]	0.20	0.25	0.26	0.24	0.25
	A_{max+}	[m]	0.34	0.64	0.64	0.58	0.37
ζ_{wp8}	A_{sig+}	[m]	0.09	0.11	0.11	0.11	0.11
	A_{max+}	[m]	0.19	0.22	0.18	0.19	0.15
ζ_{wp9}	A_{sig+}	[m]	0.06	0.08	0.08	0.07	0.07
	A_{max+}	[m]	0.12	0.11	0.12	0.11	0.10
ζ_{wp10}	A_{sig+}	[m]	0.06	0.06	0.10	0.05	0.07
	A_{max+}	[m]	0.18	0.15	0.26	0.16	0.13
ζ_{wp11}	A_{sig+}	[m]	0.26	0.31	0.31	0.30	0.36
	A_{max+}	[m]	0.35	1.05	1.07	0.83	0.51
ζ_{wp12}	A_{sig+}	[m]	0.10	0.12	0.14	0.14	0.14
	A_{max+}	[m]	0.15	0.26	0.19	0.30	0.23
ζ_{wp13}	A_{sig+}	[m]	0.04	0.04	0.06	0.05	0.07
	A_{max+}	[m]	0.08	0.12	0.10	0.10	0.10
ζ_{wp14}	A_{sig+}	[m]	0.01	0.02	0.02	0.01	0.03
	A_{max+}	[m]	0.07	0.10	0.11	0.07	0.05
ζ_{wp15}	A_{sig+}	[m]	2.15	2.46	2.37	2.42	2.56
	A_{sig-}	[m]	-0.30	-0.25	-0.35	-0.23	-0.25
	A_{max+}	[m]	3.28	5.19	4.58	4.41	3.32
	A_{max-}	[m]	-1.14	-1.59	-1.29	-1.05	-0.81

Table 6: Statistical Results of ship motions and wave probe measurements

Damage Case		[--]	4				
Run-No.		[--]	16	17	18	19	20
Survived (EU Directive)		[--]	YES	YES	YES	YES	YES
Comments		[--]					
Initial draught		*[m]*	*5.24*				
Initial heeling angle		*[deg]*	*1.0*				
Initial trim angle		*[deg]*	*1.2*				
Seaway spectrum		[--]	ITTC				
Realisation		[--]	1	2	3	4	5
H_s		[m]	4.16	4.15	4.20	4.18	4.10
T_p		[s]	12.2	12.2	12.3	12.3	12.2
Measuring time		[min]	33.7	33.7	33.7	33.7	33.7
Heave	A_{sig}	[m]	2.61	2.50	2.61	2.55	2.57
	A_{sig+}	[m]	1.67	1.51	1.67	1.61	1.65
	A_{sig-}	[m]	-2.96	-2.90	-2.97	-2.87	-2.98
	A_{max+}	[m]	3.41	4.02	3.58	3.67	3.14
	A_{max-}	[m]	-5.14	-4.87	-4.59	-4.00	-4.84
Final draught (30 min)		*[m]*	*6.24*	*5.99*	*5.94*	*6.15*	*5.88*
Roll	$A_{sig\ upper\ bound}$	[deg]	6.16	6.6	6.8	6.9	7.1
	$A_{sig\ lower\ bound}$	[deg]	-7.71	-7.9	-7.5	-7.5	-7.7
	$A_{max\ upper\ bound}$	[deg]	11.23	10.8	10.2	12.3	13.2
	$A_{max\ lower\ bound}$	[deg]	-15.73	-11.2	-11.0	-11.9	-14.6
	T_m	[s]	10.8	10.6	10.8	10.8	10.9
Final heel (30 min)		*[deg]*	*0.2*	*0.4*	*0.6*	*1.1*	*0.5*
Pitch	A_{sig}	[deg]	1.42	1.5	1.5	1.6	1.6
	A_{sig+}	[deg]	1.51	1.6	1.6	1.7	1.7
	A_{sig-}	[deg]	0.72	0.6	0.5	0.5	0.5
	A_{max+}	[deg]	1.89	2.1	2.0	2.2	2.2
	A_{max-}	[deg]	0.23	-0.4	0.0	-0.1	-0.3
Final trim (30 min)		*[deg]*	*2.3*	*2.3*	*2.3*	*2.3*	*2.3*
ζ_{wp1}	A_{sig+}	[m]	0.04	0.07	0.05	-	-
	A_{max+}	[m]	0.09	0.11	0.09	-	-
ζ_{wp2}	A_{sig+}	[m]	0.01	0.03	0.02	-	-
	A_{max+}	[m]	0.11	0.14	0.12	-	-
ζ_{wp3}	A_{sig+}	[m]	0.06	0.10	0.07	-	-
	A_{max+}	[m]	0.18	0.19	0.18	-	-
ζ_{wp4}	A_{sig+}	[m]	0.17	0.20	0.17	-	-
	A_{max+}	[m]	0.27	0.35	0.28	-	-
ζ_{wp5}	A_{sig+}	[m]	0.13	0.15	0.13	-	-
	A_{max+}	[m]	0.19	0.23	0.19	-	-
ζ_{wp6}	A_{sig+}	[m]	0.15	0.18	0.16	-	-
	A_{max+}	[m]	0.28	0.33	0.29	-	-
ζ_{wp7}	A_{sig+}	[m]	0.39	0.41	0.38	0.34	0.37
	A_{max+}	[m]	0.54	0.56	0.48	0.47	0.53
ζ_{wp8}	A_{sig+}	[m]	-	-	-	-	-
	A_{max+}	[m]	-	-	-	-	-
ζ_{wp9}	A_{sig+}	[m]	-	-	-	-	-
	A_{max+}	[m]	-	-	-	-	-
ζ_{wp10}	A_{sig+}	[m]	0.42	0.45	0.45	0.47	0.51
	A_{max+}	[m]	0.75	0.86	0.80	0.85	0.88
ζ_{wp11}	A_{sig+}	[m]	0.77	0.79	0.76	0.68	0.76
	A_{max+}	[m]	1.22	1.22	1.27	1.10	1.25
ζ_{wp12}	A_{sig+}	[m]	0.50	0.51	0.47	0.43	0.46
	A_{max+}	[m]	0.72	0.74	0.62	0.53	0.63
ζ_{wp13}	A_{sig+}	[m]	0.43	0.46	0.43	0.40	0.43
	A_{max+}	[m]	0.88	0.71	0.82	0.59	0.67
ζ_{wp14}	A_{sig+}	[m]	0.70	0.75	0.72	0.68	0.70
	A_{max+}	[m]	1.08	1.23	1.23	1.29	1.45
ζ_{wp15}	A_{sig+}	[m]	1.32	1.40	1.35	1.31	1.37
	A_{sig-}	[m]	-1.49	-1.55	-1.47	-1.50	-1.62
	A_{max+}	[m]	2.31	2.28	2.33	2.50	2.53
	A_{max-}	[m]	-2.58	-2.64	-2.60	-2.58	-2.48

Table 7: Statistical Results of ship motions and wave probe measurements

Damage Case		[--]	4				
Run-No.		[--]	21	22	23	24	25
Survived (EU Directive)		[--]	YES	YES	YES	YES	YES
Comments		[--]					
Initial draught		*[m]*	*5.24*				
Initial heeling angle		*[deg]*	*1.0*				
Initial trim angle		*[deg]*	*1.2*				
Seaway spectrum		[--]	JONSWAP				
Realisation		[--]	1	2	3	4	5
H_s		[m]	4.35	4.36	4.38	4.38	4.35
T_p		[s]	8.3	8.4	8.4	8.4	8.3
Measuring time		[min]	34.8	36.1	35.5	35.8	34.3
Heave	A_{sig}	[m]	2.55	2.53	2.49	2.52	2.59
	A_{sig+}	[m]	1.57	1.48	1.47	1.40	1.52
	A_{sig-}	[m]	-2.97	-2.89	-2.87	-2.87	-2.97
	A_{max+}	[m]	4.13	4.29	3.81	3.22	3.88
	A_{max-}	[m]	-4.39	-4.78	-4.42	-4.32	-5.33
Final draught (30 min)		*[m]*	*6.13*	*6.10*	*6.08*	*6.12*	*6.10*
Roll	$A_{sig\ upper\ bound}$	[deg]	6.47	5.6	6.8	5.4	6.0
	$A_{sig\ lower\ bound}$	[deg]	-10.34	-11.6	-10.5	-11.4	-11.5
	$A_{max\ upper\ bound}$	[deg]	10.85	9.8	10.7	8.9	10.0
	$A_{max\ lower\ bound}$	[deg]	-17.12	-17.6	-20.2	-16.7	-21.1
	T_m	[s]	9.8	9.4	9.6	9.6	9.4
Final heel (30 min)		*[deg]*	*-1.6*	*1.0*	*0.1*	*-2.7*	*-2.7*
Pitch	A_{sig}	[deg]	1.52	1.5	1.6	1.6	1.7
	A_{sig+}	[deg]	1.65	1.7	1.8	1.8	1.9
	A_{sig-}	[deg]	0.48	0.5	0.3	0.2	0.2
	A_{max+}	[deg]	2.98	2.7	2.5	2.6	3.2
	A_{max-}	[deg]	-0.25	-0.7	-0.5	-0.5	-1.2
Final trim (30 min)		*[deg]*	*2.3*	*2.3*	*2.2*	*2.3*	*2.3*
ζ_{wp1}	A_{sig+}	[m]	-	-	-	-	-
	A_{max+}	[m]	-	-	-	-	-
ζ_{wp2}	A_{sig+}	[m]	-	-	-	-	-
	A_{max+}	[m]	-	-	-	-	-
ζ_{wp3}	A_{sig+}	[m]	-	-	-	-	-
	A_{max+}	[m]	-	-	-	-	-
ζ_{wp4}	A_{sig+}	[m]	-	-	-	-	-
	A_{max+}	[m]	-	-	-	-	-
ζ_{wp5}	A_{sig+}	[m]	-	-	-	-	-
	A_{max+}	[m]	-	-	-	-	-
ζ_{wp6}	A_{sig+}	[m]	-	-	-	-	-
	A_{max+}	[m]	-	-	-	-	-
ζ_{wp7}	A_{sig+}	[m]	0.59	0.69	0.59	0.68	0.68
	A_{max+}	[m]	0.75	0.88	0.78	0.82	0.79
ζ_{wp8}	A_{sig+}	[m]	-	-	-	-	-
	A_{max+}	[m]	-	-	-	-	-
ζ_{wp9}	A_{sig+}	[m]	-	-	-	-	-
	A_{max+}	[m]	-	-	-	-	-
ζ_{wp10}	A_{sig+}	[m]	0.79	0.81	0.79	0.80	0.83
	A_{max+}	[m]	1.71	1.63	1.38	1.35	1.36
ζ_{wp11}	A_{sig+}	[m]	1.26	1.47	1.27	1.49	1.45
	A_{max+}	[m]	2.19	2.25	2.02	2.12	2.23
ζ_{wp12}	A_{sig+}	[m]	0.77	0.91	0.78	0.90	0.90
	A_{max+}	[m]	0.94	1.10	1.04	1.08	1.05
ζ_{wp13}	A_{sig+}	[m]	0.60	0.67	0.62	0.66	0.68
	A_{max+}	[m]	0.91	1.56	1.21	0.96	1.44
ζ_{wp14}	A_{sig+}	[m]	0.98	0.90	0.98	0.98	0.96
	A_{max+}	[m]	1.77	2.06	1.95	1.50	1.69
ζ_{wp15}	A_{sig+}	[m]	1.70	1.57	1.72	1.59	1.63
	A_{sig-}	[m]	-2.34	-2.46	-2.31	-2.47	-2.46
	A_{max+}	[m]	3.05	3.31	3.01	3.39	3.07
	A_{max-}	[m]	-4.16	-4.39	-3.91	-3.81	-4.02

Table 8: Statistical Results of ship motions and wave probe measurements

Damage Case		[--]	4				
Run-No.		[--]	26	27	28	29	30
Survived (EU Directive)		[--]	YES	YES	YES	YES	YES
Comments		[--]					
Initial draught		*[m]*	*5.24*				
Initial heeling angle		*[deg]*	*-1.1*				
Initial trim angle		*[deg]*	*1.2*				
Seaway spectrum		[--]	JONSWAP				
Realisation		[--]	1	2	3	4	5
H_s		[m]	4.35	4.38	4.47	4.35	4.36
T_p		[s]	8.3	8.4	8.5	8.3	8.3
Measuring time		[min]	35.2	37.5	35.5	35.8	35.8
Heave	A_{sig}	[m]	2.48	2.48	2.56	2.50	2.53
	A_{sig+}	[m]	1.45	1.49	1.53	1.48	1.52
	A_{sig-}	[m]	-2.86	-2.85	-2.93	-2.88	-2.92
	A_{max+}	[m]	3.54	3.79	4.41	3.37	3.78
	A_{max-}	[m]	-4.45	-4.54	-4.64	-4.56	-5.22
Final draught (30 min)		*[m]*	*6.12*	*6.00*	*6.20*	*6.09*	*6.14*
Roll	$A_{sig\ upper\ bound}$	[deg]	1.34	-1.4	1.3	0.7	0.9
	$A_{sig\ lower\ bound}$	[deg]	-13.45	-17.5	-13.9	-14.3	-14.3
	$A_{max\ upper\ bound}$	[deg]	6.06	3.3	5.1	5.3	5.6
	$A_{max\ lower\ bound}$	[deg]	-20.07	-24.2	-22.0	-19.3	-22.6
	T_m	[s]	9.8	10.4	9.7	9.9	9.7
Final heel (30 min)		*[deg]*	*-5.4*	*-9.3*	*-5.3*	*-6.2*	*-7.1*
Pitch	A_{sig}	[deg]	1.49	1.6	1.6	1.6	1.6
	A_{sig+}	[deg]	1.64	1.8	1.8	1.8	1.8
	A_{sig-}	[deg]	0.51	0.3	0.4	0.3	0.3
	A_{max+}	[deg]	2.39	2.9	2.7	2.8	2.8
	A_{max-}	[deg]	-0.29	-0.6	-0.6	-0.7	-0.9
Final trim (30 min)		*[deg]*	*2.3*	*2.2*	*2.3*	*2.1*	*2.3*
ζ_{wp1}	A_{sig+}	[m]	-	-	-	-	-
	A_{max+}	[m]	-	-	-	-	-
ζ_{wp2}	A_{sig+}	[m]	-	-	-	-	-
	A_{max+}	[m]	-	-	-	-	-
ζ_{wp3}	A_{sig+}	[m]	-	-	-	-	-
	A_{max+}	[m]	-	-	-	-	-
ζ_{wp4}	A_{sig+}	[m]	-	-	-	-	-
	A_{max+}	[m]	-	-	-	-	-
ζ_{wp5}	A_{sig+}	[m]	-	-	-	-	-
	A_{max+}	[m]	-	-	-	-	-
ζ_{wp6}	A_{sig+}	[m]	-	-	-	-	-
	A_{max+}	[m]	-	-	-	-	-
ζ_{wp7}	A_{sig+}	[m]	0.59	0.63	0.58	0.60	0.59
	A_{max+}	[m]	0.68	0.74	0.66	0.67	0.68
ζ_{wp8}	A_{sig+}	[m]	-	-	-	-	-
	A_{max+}	[m]	-	-	-	-	-
ζ_{wp9}	A_{sig+}	[m]	-	-	-	-	-
	A_{max+}	[m]	-	-	-	-	-
ζ_{wp10}	A_{sig+}	[m]	0.53	0.46	0.55	0.49	0.53
	A_{max+}	[m]	1.14	0.84	1.18	0.80	1.14
ζ_{wp11}	A_{sig+}	[m]	1.41	1.61	1.41	1.46	1.43
	A_{max+}	[m]	1.99	2.31	2.23	2.16	2.03
ζ_{wp12}	A_{sig+}	[m]	0.81	0.85	0.80	0.82	0.81
	A_{max+}	[m]	0.98	1.05	0.96	0.93	0.93
ζ_{wp13}	A_{sig+}	[m]	0.52	0.53	0.55	0.53	0.51
	A_{max+}	[m]	0.81	0.87	1.53	0.75	0.88
ζ_{wp14}	A_{sig+}	[m]	0.61	0.56	0.64	0.63	0.61
	A_{max+}	[m]	1.26	0.94	1.66	1.62	1.07
ζ_{wp15}	A_{sig+}	[m]	1.11	0.67	1.13	1.03	1.05
	A_{sig-}	[m]	-2.13	-2.94	-2.20	-2.29	-2.31
	A_{max+}	[m]	2.66	1.93	2.82	2.31	2.94
	A_{max-}	[m]	-3.43	-4.59	-3.50	-3.70	-4.11

Table 9: Statistical Results of ship motions and wave probe measurements

Damage Case		[--]	4		-
Run-No.		[--]	31	32	
Survived (EU Directive)		[--]	YES	YES	-
Comments		[--]			-
Initial draught		*[m]*	*5.24*		-
Initial heeling angle		*[deg]*	*-1.1*		-
Initial trim angle		*[deg]*	*0.9*		-
Seaway spectrum		[--]	JONSWAP		-
Realisation		[--]	2	3	-
H_s		[m]	4.34	4.40	-
T_p		[s]	8.3	8.4	-
Measuring time		[min]	35.8	35.8	-
Heave	A_{sig}	[m]	2.41	2.47	-
	A_{sig+}	[m]	1.52	1.46	-
	A_{sig-}	[m]	-2.75	-2.84	-
	A_{max+}	[m]	4.19	3.97	-
	A_{max-}	[m]	-4.92	-4.91	-
Final draught (30 min)		*[m]*	*5.83*	*6.14*	-
Roll	$A_{sig\ upper\ bound}$	[deg]	-2.27	1.1	-
	$A_{sig\ lower\ bound}$	[deg]	-21.02	-14.1	-
	$A_{max\ upper\ bound}$	[deg]	3.16	5.2	-
	$A_{max\ lower\ bound}$	[deg]	-26.00	-23.4	-
	T_m	[s]	10.5	9.6	-
Final heel (30 min)		*[deg]*	*-18.0*	*-5.7*	-
Pitch	A_{sig}	[deg]	1.35	1.5	-
	A_{sig+}	[deg]	1.52	1.7	-
	A_{sig-}	[deg]	0.16	0.1	-
	A_{max+}	[deg]	2.89	2.4	-
	A_{max-}	[deg]	-0.73	-0.6	-
Final trim (30 min)		*[deg]*	*2.0*	*2.1*	-
ζ_{wp1}	A_{sig+}	[m]	-	-	-
	A_{max+}	[m]	-	-	-
ζ_{wp2}	A_{sig+}	[m]	-	-	-
	A_{max+}	[m]	-	-	-
ζ_{wp3}	A_{sig+}	[m]	-	-	-
	A_{max+}	[m]	-	-	-
ζ_{wp4}	A_{sig+}	[m]	-	-	-
	A_{max+}	[m]	-	-	-
ζ_{wp5}	A_{sig+}	[m]	-	-	-
	A_{max+}	[m]	-	-	-
ζ_{wp6}	A_{sig+}	[m]	-	-	-
	A_{max+}	[m]	-	-	-
ζ_{wp7}	A_{sig+}	[m]	0.64	0.53	-
	A_{max+}	[m]	0.70	0.62	-
ζ_{wp8}	A_{sig+}	[m]	-	-	-
	A_{max+}	[m]	-	-	-
ζ_{wp9}	A_{sig+}	[m]	-	-	-
	A_{max+}	[m]	-	-	-
ζ_{wp10}	A_{sig+}	[m]	0.44	0.52	-
	A_{max+}	[m]	0.82	0.96	-
ζ_{wp11}	A_{sig+}	[m]	1.57	1.29	-
	A_{max+}	[m]	2.36	1.88	-
ζ_{wp12}	A_{sig+}	[m]	0.83	0.65	-
	A_{max+}	[m]	1.02	0.90	-
ζ_{wp13}	A_{sig+}	[m]	0.51	0.47	-
	A_{max+}	[m]	1.02	1.31	-
ζ_{wp14}	A_{sig+}	[m]	0.51	0.58	-
	A_{max+}	[m]	0.78	1.00	-
ζ_{wp15}	A_{sig+}	[m]	0.52	1.02	-
	A_{sig-}	[m]	-3.76	-2.22	-
	A_{max+}	[m]	1.63	2.56	-
	A_{max-}	[m]	-4.96	-3.74	-

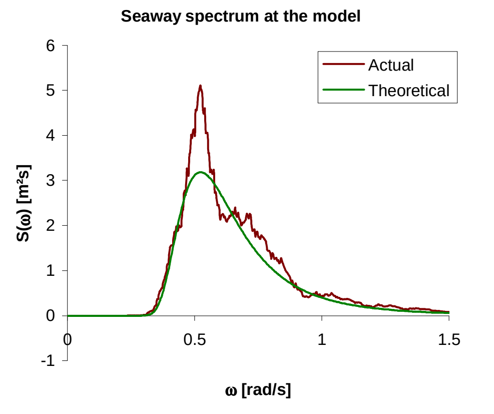
Table 10: Statistical Results of hip motions and wave probe measurements

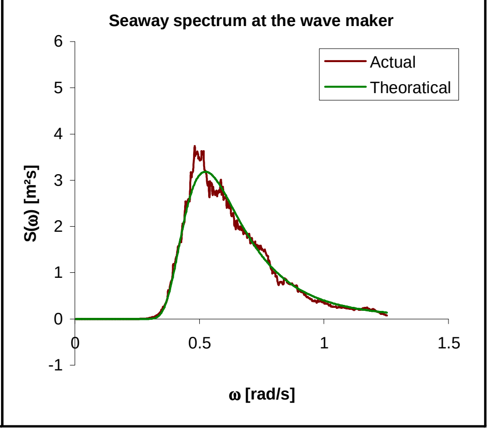
Annex D

Seaway Spectra

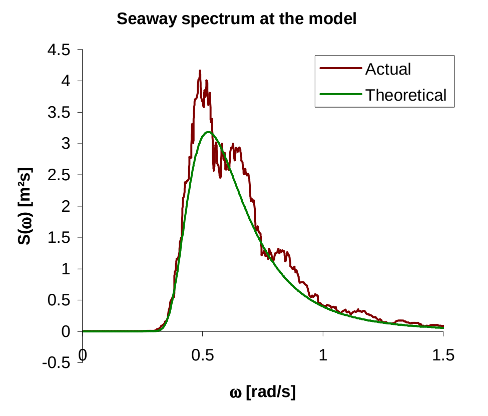
The positions of the wave probes related to the sea spectra are shown in Figure 2

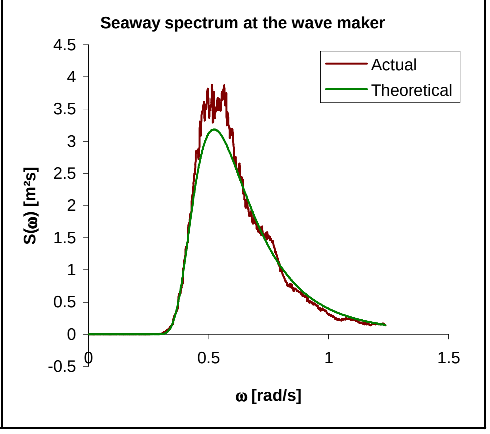
Run-No.: 1				Run-No.: 1			
Hs(t)	= 4.30 m	Tp(t) = 12 s	γ = 1.0	Hs(t)	= 4.30 m	Tp(t) = 12 s	γ = 1.0
Hs(a)	= 4.66 m			Hs(a)	= 4.21 m		
Hs(a)/Hs(t)	= 1.08			Hs(a)/Hs(t)	= 0.98		



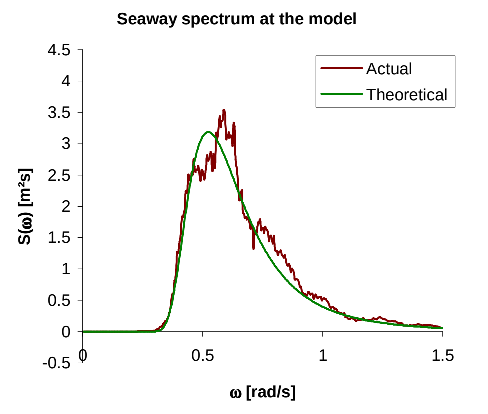


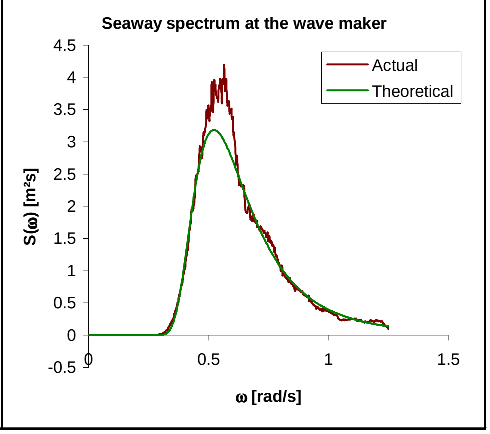
Run-No.: 2				Run-No.: 2			
Hs(t)	= 4.30 m	Tp(t) = 12 s	γ = 1.0	Hs(t)	= 4.30 m	Tp(t) = 12 s	γ = 1.0
Hs(a)	= 4.64 m			Hs(a)	= 4.33 m		
Hs(a)/Hs(t)	= 1.08			Hs(a)/Hs(t)	= 1.01		





Run-No.: 3				Run-No.: 3			
Hs(t)	= 4.30 m	Tp(t) = 12 s	γ = 1.0	Hs(t)	= 4.30 m	Tp(t) = 12 s	γ = 1.0
Hs(a)	= 4.45 m			Hs(a)	= 4.36 m		
Hs(a)/Hs(t)	= 1.04			Hs(a)/Hs(t)	= 1.01		

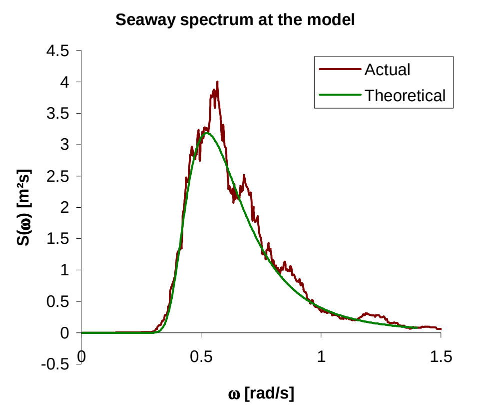


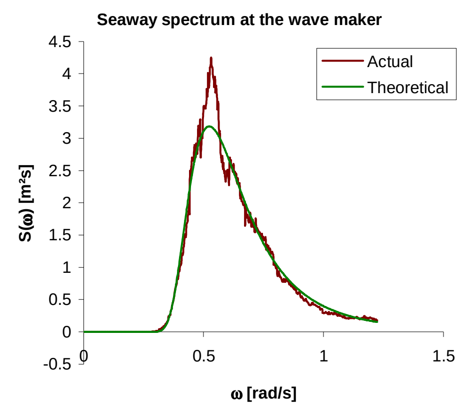


Hs(a): **a**ctual significant wave height

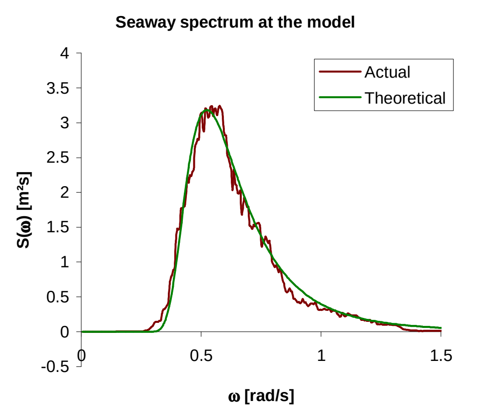
Hs(t): **t**heoretical significant wave height

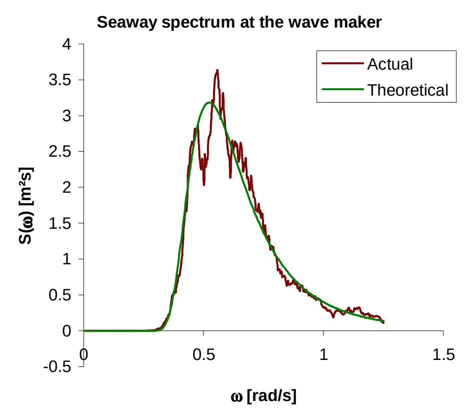
		Run-No.:	4			Run-No.:	4
Hs(t)	= 4.30 m	Tp(t) = 12 s	γ = 1.0	Hs(t)	= 4.30 m	Tp(t) = 12 s	γ = 1.0
Hs(a)	= 4.52 m			Hs(a)	= 4.23 m		
Hs(a)/Hs(t)	= 1.05			Hs(a)/Hs(t)	= 0.98		



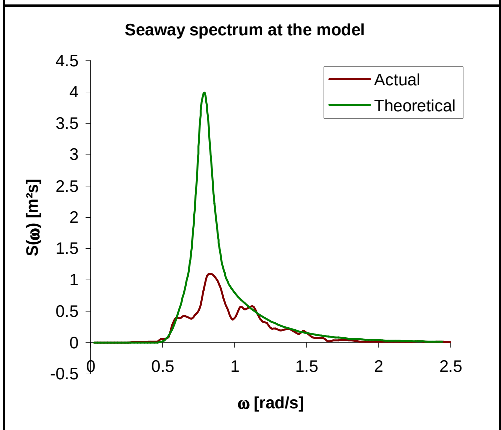


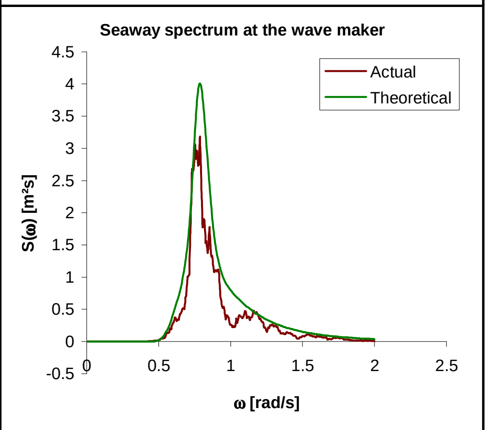
		Run-No.:	5			Run-No.:	5
Hs(t)	= 4.30 m	Tp(t) = 12 s	γ = 1.0	Hs(t)	= 4.30 m	Tp(t) = 12 s	γ = 1.0
Hs(a)	= 4.22 m			Hs(a)	= 4.19 m		
Hs(a)/Hs(t)	= 0.98			Hs(a)/Hs(t)	= 0.98		





		Run-No.:	6			Run-No.:	6
Hs(t)	= 4.00 m	Tp(t) = 8 s	γ = 3.3	Hs(t)	= 4.00 m	Tp(t) = 8 s	γ = 3.3
Hs(a)	= 2.76 m			Hs(a)	= 3.24 m		
Hs(a)/Hs(t)	= 0.69			Hs(a)/Hs(t)	= 0.81		

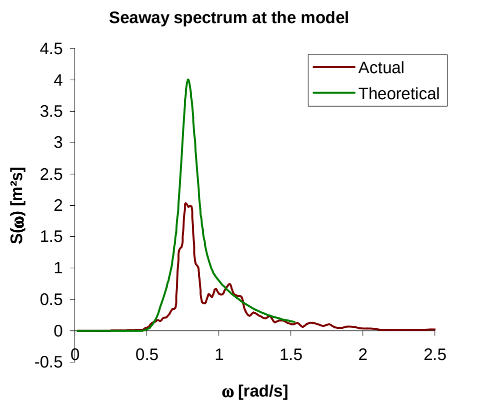




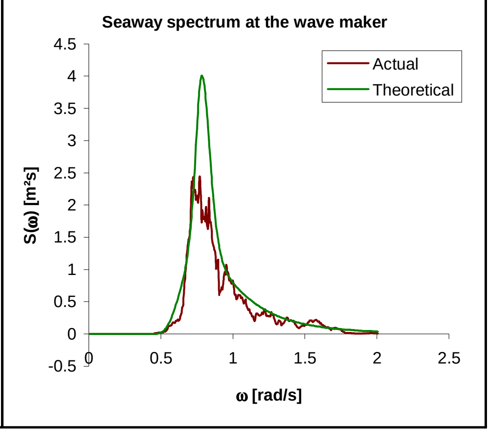
Hs(a): **a**ctual significant wave height

Hs(t): **t**heoretical significant wave height

Run-No.: 7			
Hs(t)	= 4.00 m	Tp(t) = 8 s	γ = 3.3
Hs(a)	= 3.08 m		
Hs(a)/Hs(t)	= 0.77		

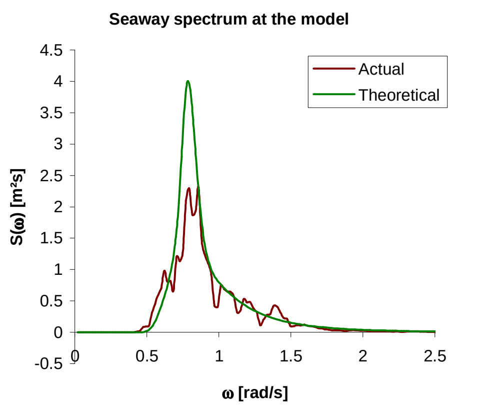


Run-No.: 7			
Hs(t)	= 4.00 m	Tp(t) = 8 s	γ = 3.3
Hs(a)	= 3.36 m		
Hs(a)/Hs(t)	= 0.84		

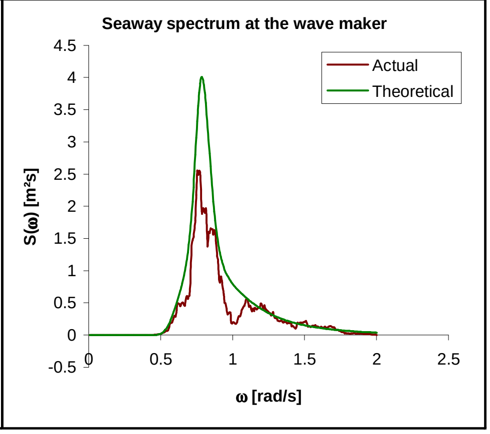


For run No. 8 there are no measurements!

Run-No.: 9			
Hs(t)	= 4.00 m	Tp(t) = 8 s	γ = 3.3
Hs(a)	= 3.55 m		
Hs(a)/Hs(t)	= 0.89		

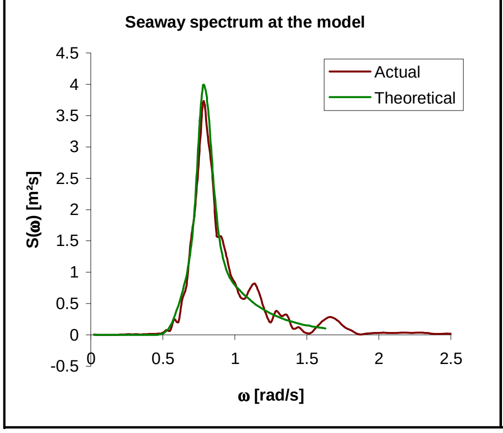


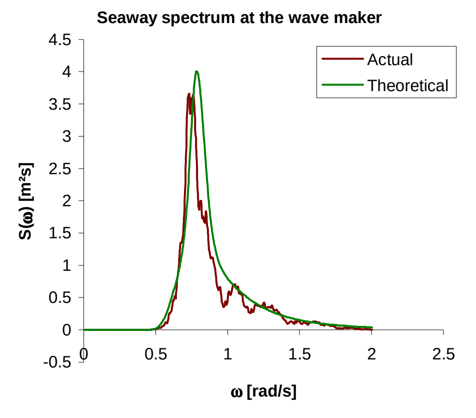
Run-No.: 9			
Hs(t)	= 4.00 m	Tp(t) = 8 s	γ = 3.3
Hs(a)	= 3.23 m		
Hs(a)/Hs(t)	= 0.81		



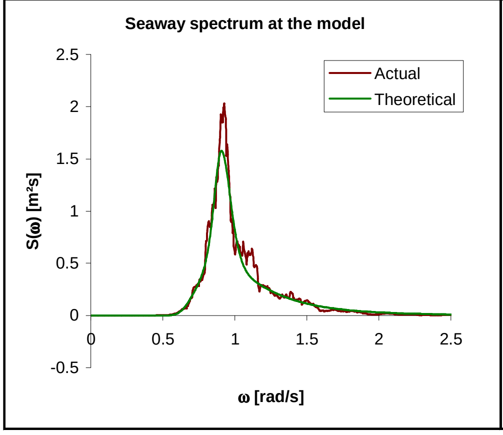
Hs(a): **a**ctual significant wave height
Hs(t): **t**heoretical significant wave height

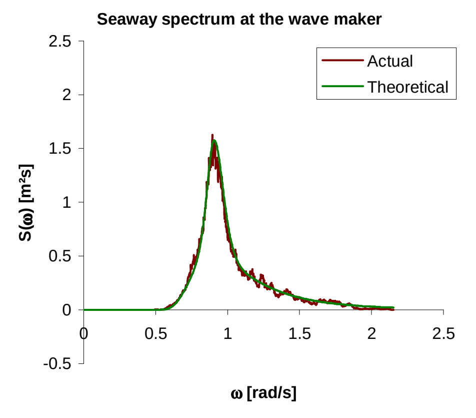
Run-No.: 10				Run-No.: 10			
Hs(t)	= 4.00 m	Tp(t) = 8 s	γ = 3.3	Hs(t)	= 4.00 m	Tp(t) = 8 s	γ = 3.3
Hs(a)	= 4.01 m			Hs(a)	= 3.63 m		
Hs(a)/Hs(t)	= 1.00			Hs(a)/Hs(t)	= 0.91		



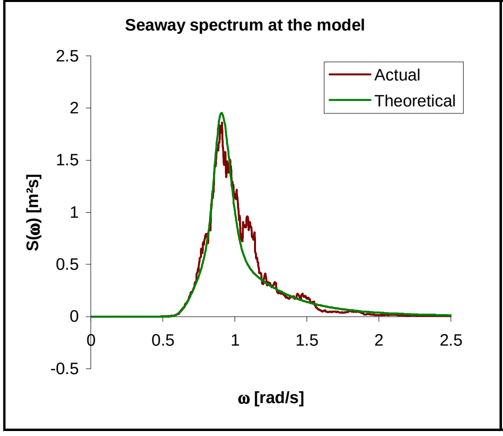


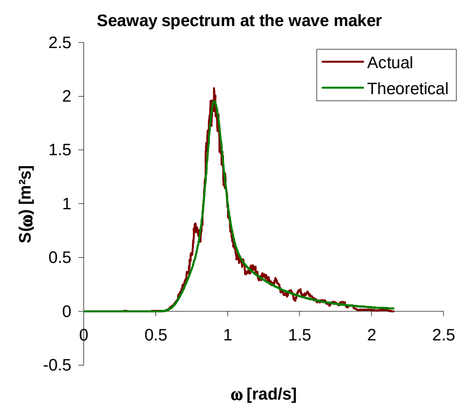
Run-No.: 11				Run-No.: 11			
Hs(t)	= 2.70 m	Tp(t) = 7 s	γ = 3.3	Hs(t)	= 2.70 m	Tp(t) = 7 s	γ = 3.3
Hs(a)	= 2.79 m			Hs(a)	= 2.63 m		
Hs(a)/Hs(t)	= 1.03			Hs(a)/Hs(t)	= 0.97		





Run-No.: 12				Run-No.: 12			
Hs(t)	= 3.00 m	Tp(t) = 7 s	γ = 3.3	Hs(t)	= 3.00 m	Tp(t) = 7 s	γ = 3.3
Hs(a)	= 3.07 m			Hs(a)	= 3.01 m		
Hs(a)/Hs(t)	= 1.02			Hs(a)/Hs(t)	= 1.00		



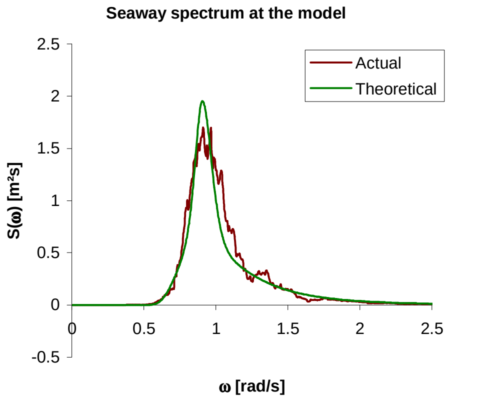


Hs(a): **a**ctual significant wave height

Hs(t): **t**heoretical significant wave height

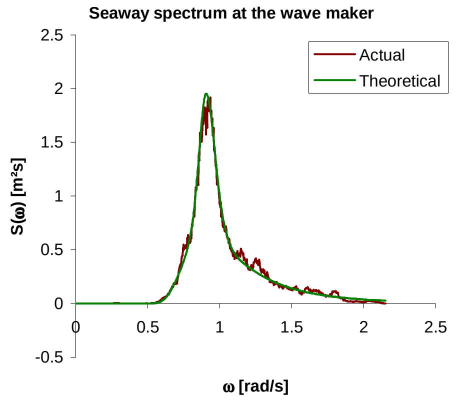
Run-No.: 13

Hs(t) = 3.00 m Tp(t) = 7 s γ = 3.3
Hs(a) = 3.12 m
Hs(a)/Hs(t) = 1.04



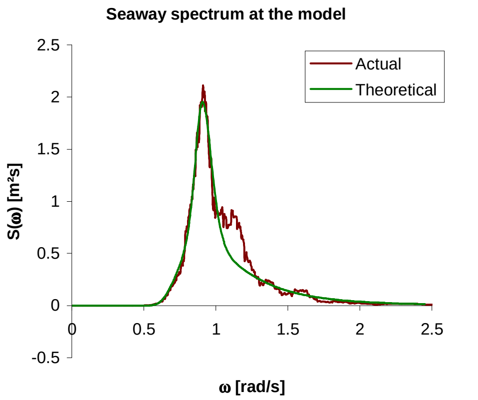
Run-No.: 13

Hs(t) = 3.00 m Tp(t) = 7 s γ = 3.3
Hs(a) = 2.99 m
Hs(a)/Hs(t) = 1.00



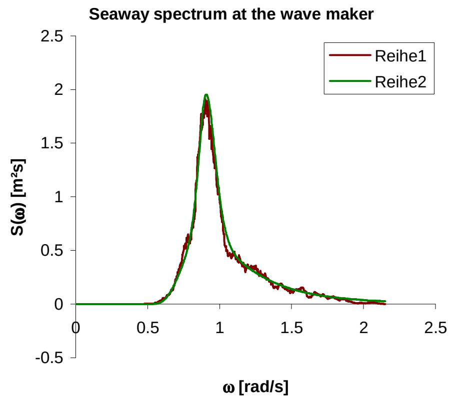
Run-No.: 14

Hs(t) = 3.00 m Tp(t) = 7 s γ = 3.3
Hs(a) = 3.12 m
Hs(a)/Hs(t) = 1.04



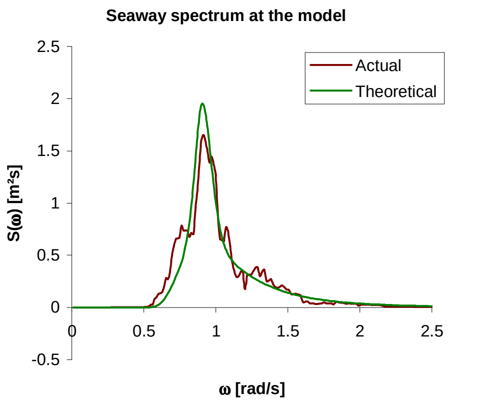
Run-No.: 14

Hs(t) = 3.00 m Tp(t) = 7 s γ = 3.3
Hs(a) = 2.92 m
Hs(a)/Hs(t) = 0.97



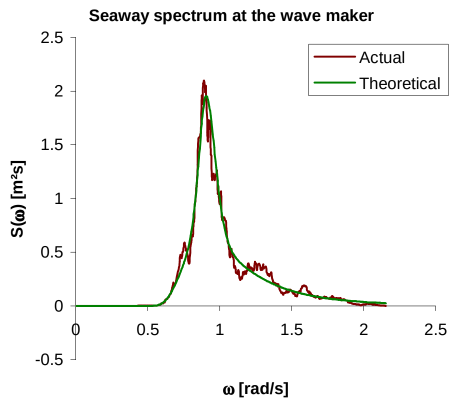
Run-No.: 15

Hs(t) = 3.00 m Tp(t) = 7 s γ = 3.3
Hs(a) = 3.03 m
Hs(a)/Hs(t) = 1.01



Run-No.: 15

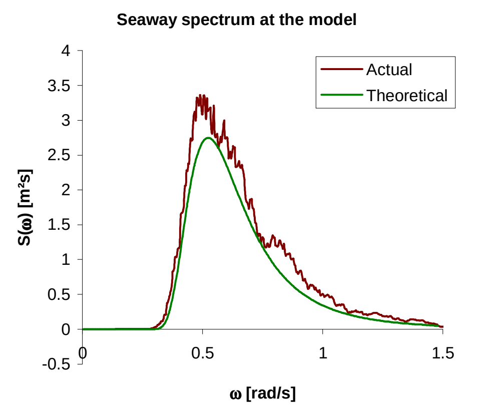
Hs(t) = 3.00 m Tp(t) = 7 s γ = 3.3
Hs(a) = 2.97 m
Hs(a)/Hs(t) = 0.99

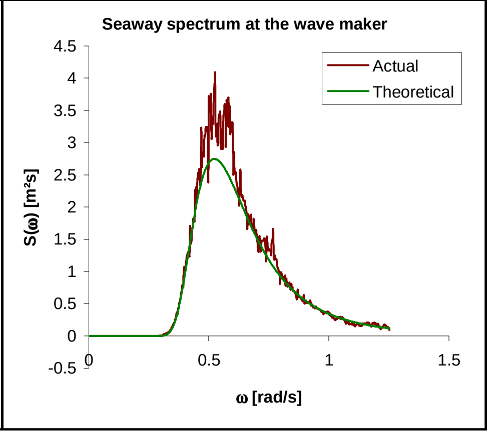


Hs(a): **a**ctual significant wave height

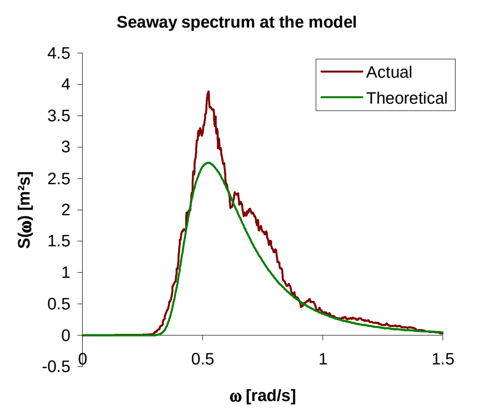
Hs(t): **t**heoretical significant wave height

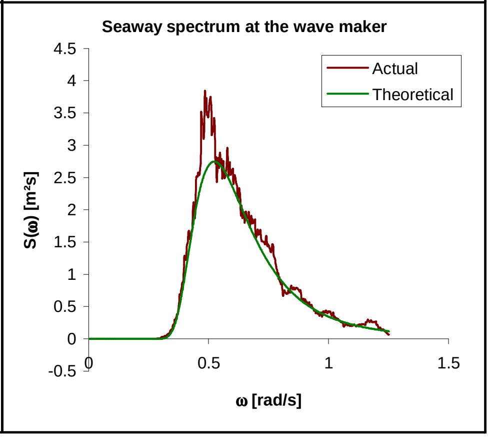
			Run-No.:	16				Run-No.:	16
Hs(t)	= 4.00 m	Tp(t) = 12 s	γ = 1.0		Hs(t)	= 4.00 m	Tp(t) = 12 s	γ = 1.0	
Hs(a)	= 4.46 m				Hs(a)	= 4.16 m			
Hs(a)/Hs(t)	= 1.11				Hs(a)/Hs(t)	= 1.04			



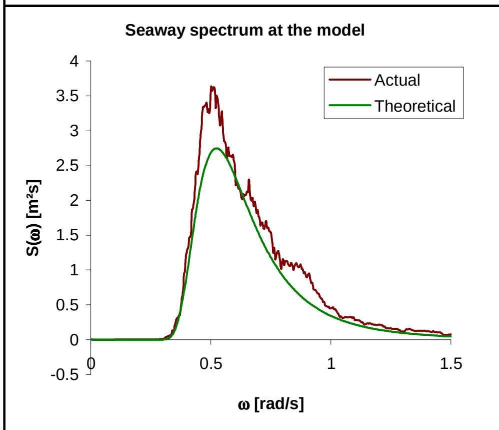


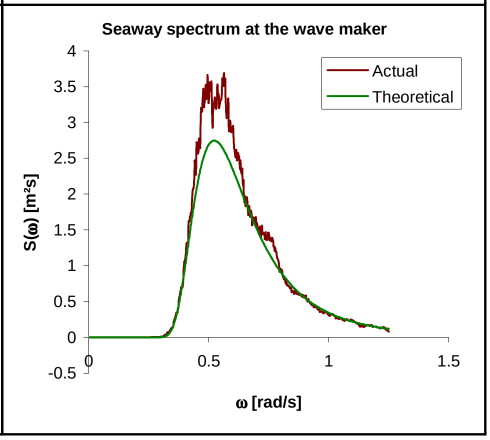
			Run-No.:	17				Run-No.:	17
Hs(t)	= 4.00 m	Tp(t) = 12 s	γ = 1.0		Hs(t)	= 4.00 m	Tp(t) = 12 s	γ = 1.0	
Hs(a)	= 4.41 m				Hs(a)	= 4.15 m			
Hs(a)/Hs(t)	= 1.10				Hs(a)/Hs(t)	= 1.04			





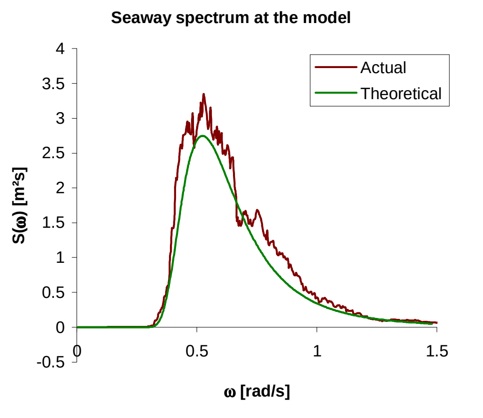
			Run-No.:	18				Run-No.:	18
Hs(t)	= 4.00 m	Tp(t) = 12 s	γ = 1.0		Hs(t)	= 4.00 m	Tp(t) = 12 s	γ = 1.0	
Hs(a)	= 4.43 m				Hs(a)	= 4.20 m			
Hs(a)/Hs(t)	= 1.11				Hs(a)/Hs(t)	= 1.05			

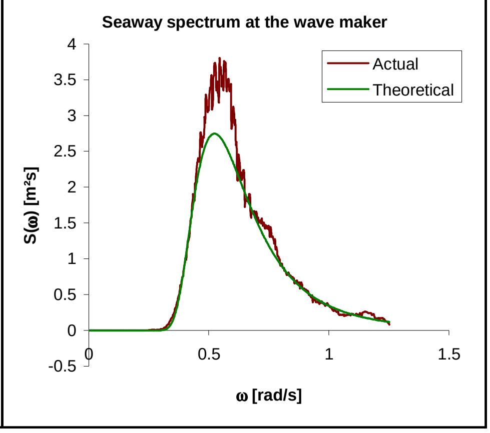




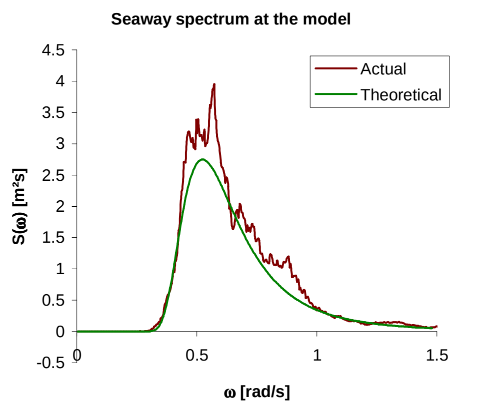
Hs(a): **a**ctual significant wave height
Hs(t): **t**heoretical significant wave height

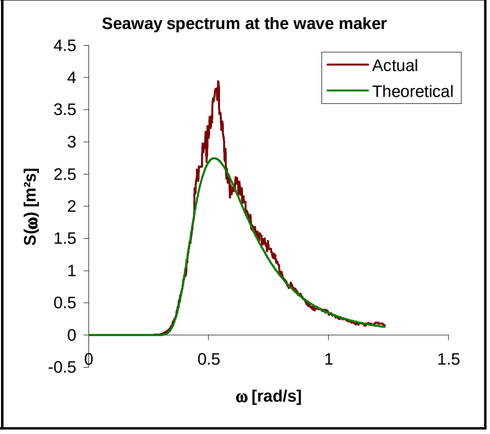
		Run-No.:	19			Run-No.:	19
Hs(t)	= 4.00 m	Tp(t) = 12 s	γ = 1.0	Hs(t)	= 4.00 m	Tp(t) = 12 s	γ = 1.0
Hs(a)	= 4.40 m			Hs(a)	= 4.18 m		
Hs(a)/Hs(t)	= 1.10			Hs(a)/Hs(t)	= 1.05		



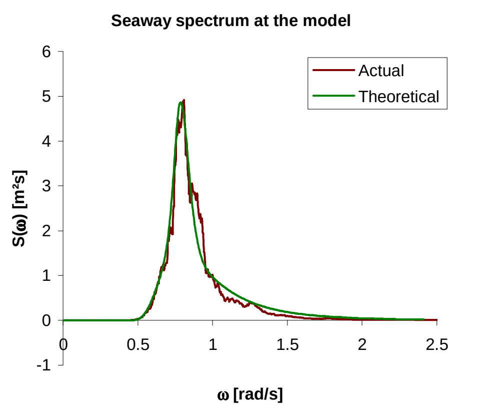


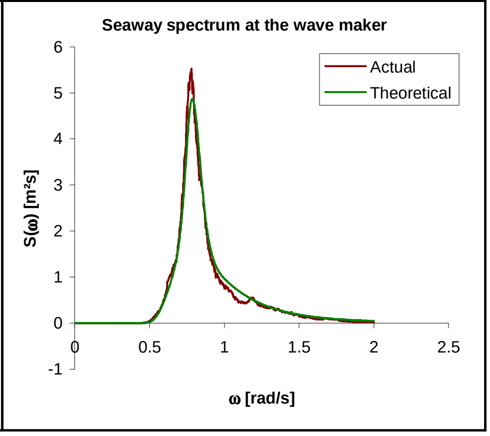
		Run-No.:	20			Run-No.:	20
Hs(t)	= 4.00 m	Tp(t) = 12 s	γ = 1.0	Hs(t)	= 4.00 m	Tp(t) = 12 s	γ = 1.0
Hs(a)	= 4.40 m			Hs(a)	= 4.10 m		
Hs(a)/Hs(t)	= 1.10			Hs(a)/Hs(t)	= 1.03		





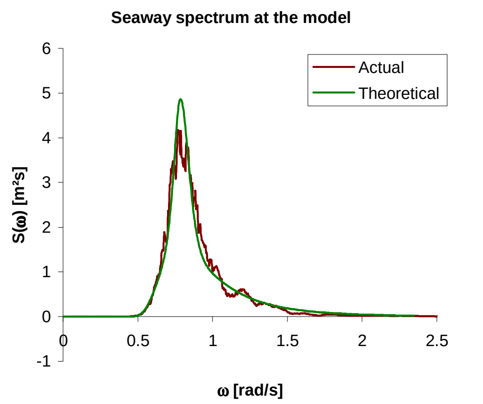
		Run-No.:	21			Run-No.:	21
Hs(t)	= 4.40 m	Tp(t) = 8 s	γ = 3.3	Hs(t)	= 4.40 m	Tp(t) = 8 s	γ = 3.3
Hs(a)	= 4.26 m			Hs(a)	= 4.35 m		
Hs(a)/Hs(t)	= 0.97			Hs(a)/Hs(t)	= 0.99		

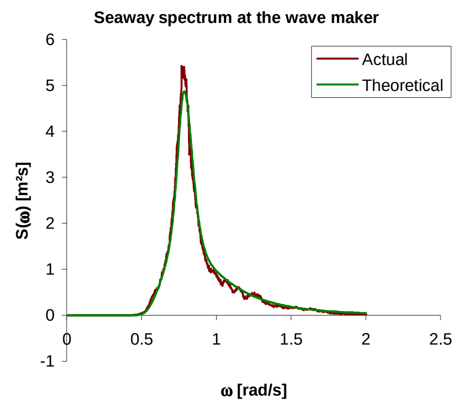




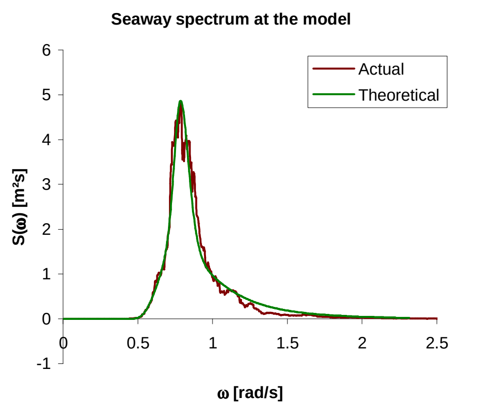
Hs(a): **a**ctual significant wave height
Hs(t): **t**heoretical significant wave height

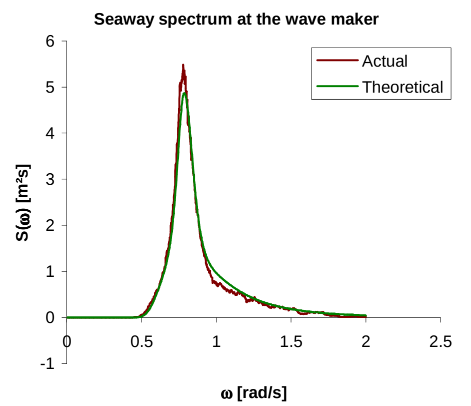
			Run-No.:	22				Run-No.:	22
Hs(t)	= 4.40 m	Tp(t) = 8 s		γ = 3.3	Hs(t)	= 4.40 m	Tp(t) = 8 s		γ = 3.3
Hs(a)	= 4.39 m				Hs(a)	= 4.36 m			
Hs(a)/Hs(t)	= 1.00				Hs(a)/Hs(t)	= 0.99			



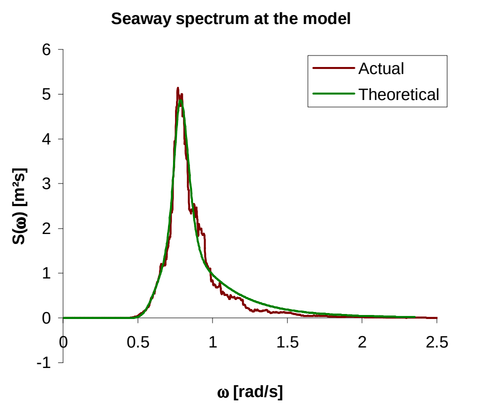


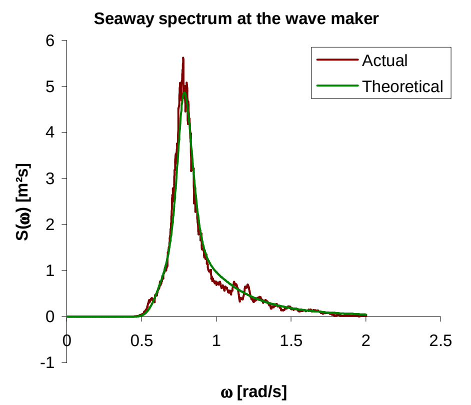
			Run-No.:	23				Run-No.:	23
Hs(t)	= 4.40 m	Tp(t) = 8 s		γ = 3.3	Hs(t)	= 4.40 m	Tp(t) = 8 s		γ = 3.3
Hs(a)	= 4.40 m				Hs(a)	= 4.38 m			
Hs(a)/Hs(t)	= 1.00				Hs(a)/Hs(t)	= 0.99			





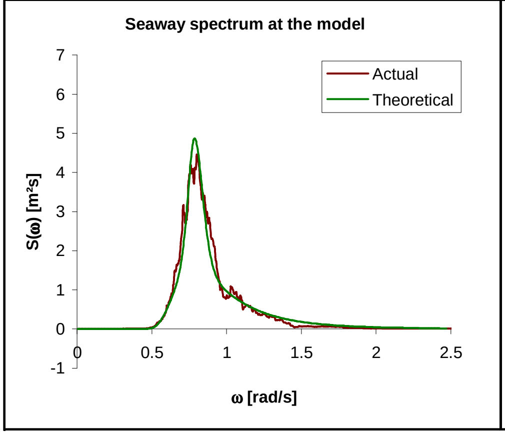
			Run-No.:	24				Run-No.:	24
Hs(t)	= 4.40 m	Tp(t) = 8 s		γ = 3.3	Hs(t)	= 4.40 m	Tp(t) = 8 s		γ = 3.3
Hs(a)	= 4.24 m				Hs(a)	= 4.38 m			
Hs(a)/Hs(t)	= 0.96				Hs(a)/Hs(t)	= 1.00			



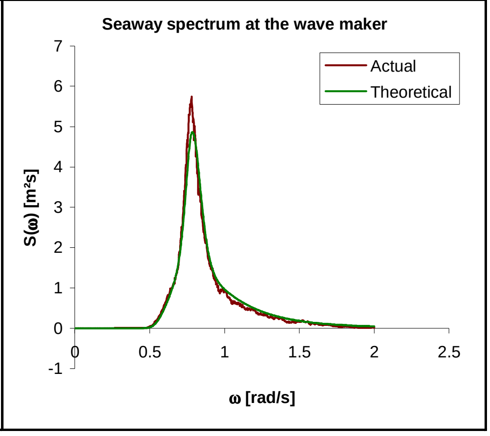


Hs(a): **a**ctual significant wave height
Hs(t): **t**heoretical significant wave height

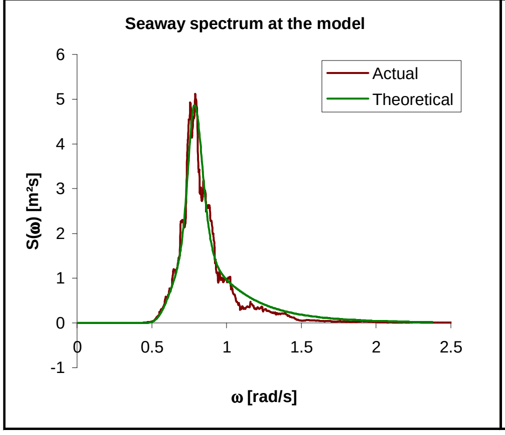
Run-No.: 25		Tp(t) = 8 s	γ = 3.3
Hs(t)	= 4.40 m		
Hs(a)	= 4.43 m		
Hs(a)/Hs(t)	= 1.01		



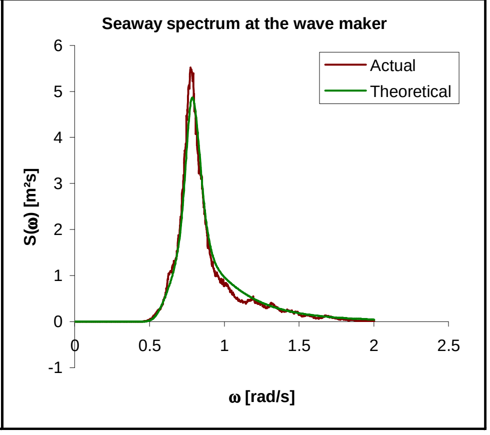
Run-No.: 25		Tp(t) = 8 s	γ = 3.3
Hs(t)	= 4.40 m		
Hs(a)	= 4.35 m		
Hs(a)/Hs(t)	= 0.99		



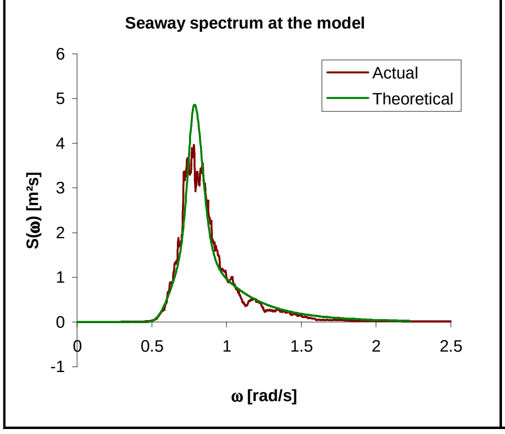
Run-No.: 26		Tp(t) = 8 s	γ = 3.3
Hs(t)	= 4.40 m		
Hs(a)	= 4.26 m		
Hs(a)/Hs(t)	= 0.97		



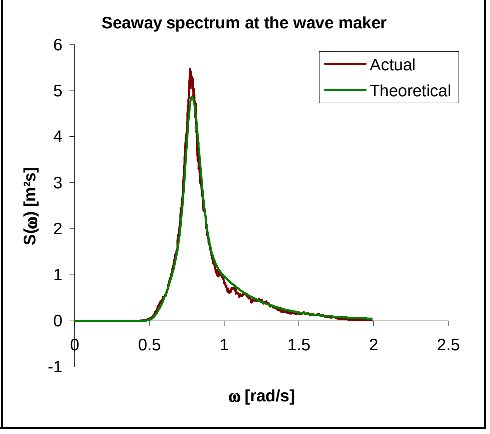
Run-No.: 26		Tp(t) = 8 s	γ = 3.3
Hs(t)	= 4.40 m		
Hs(a)	= 4.35 m		
Hs(a)/Hs(t)	= 0.99		



Run-No.: 27		Tp(t) = 8 s	γ = 3.3
Hs(t)	= 4.40 m		
Hs(a)	= 4.29 m		
Hs(a)/Hs(t)	= 0.98		

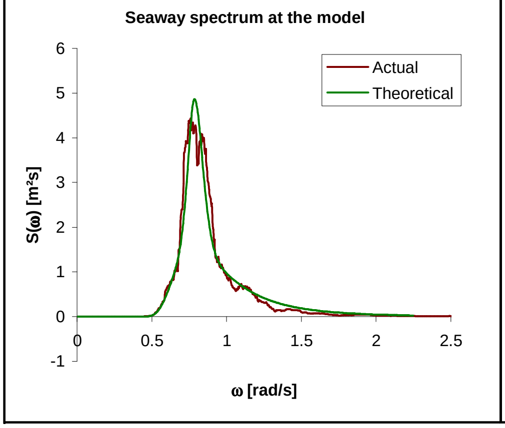


Run-No.: 27		Tp(t) = 8 s	γ = 3.3
Hs(t)	= 4.40 m		
Hs(a)	= 4.38 m		
Hs(a)/Hs(t)	= 0.99		

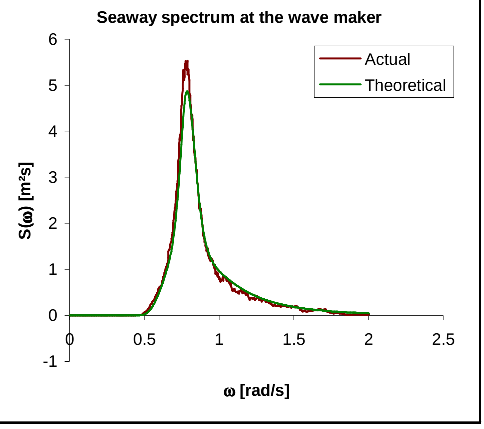


Hs(a): **a**ctual significant wave height
Hs(t): **t**heoretical significant wave height

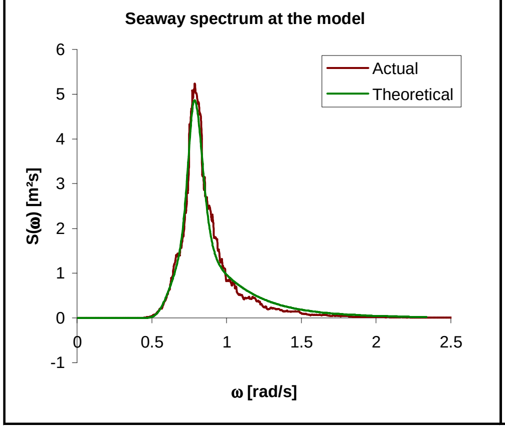
Run-No.: 28			
Hs(t)	= 4.40 m	Tp(t) = 8 s	γ = 3.3
Hs(a)	= 4.44 m		
Hs(a)/Hs(t)	= 1.01		



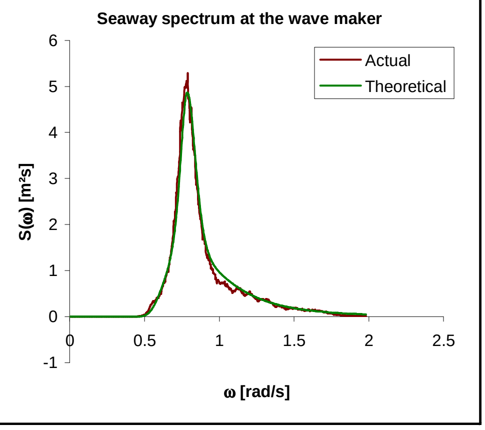
Run-No.: 28			
Hs(t)	= 4.40 m	Tp(t) = 8 s	γ = 3.3
Hs(a)	= 4.47 m		
Hs(a)/Hs(t)	= 1.01		



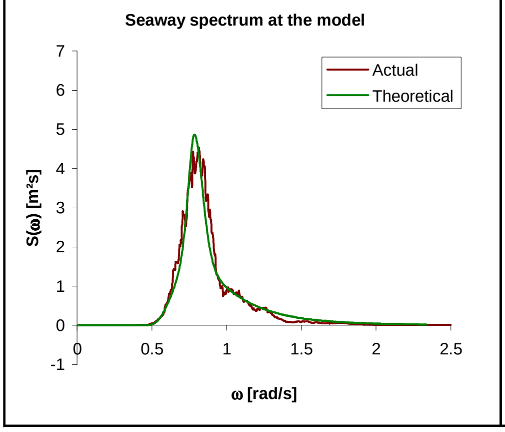
Run-No.: 29			
Hs(t)	= 4.40 m	Tp(t) = 8 s	γ = 3.3
Hs(a)	= 4.36 m		
Hs(a)/Hs(t)	= 0.99		



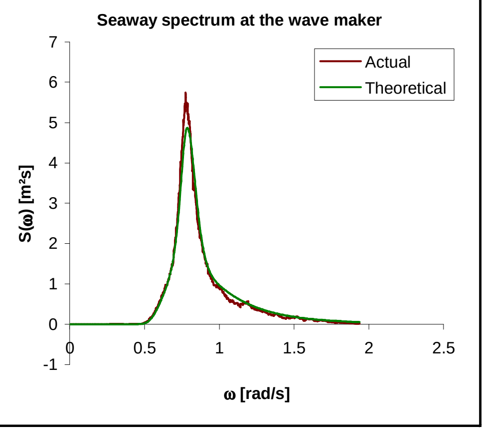
Run-No.: 29			
Hs(t)	= 4.40 m	Tp(t) = 8 s	γ = 3.3
Hs(a)	= 4.35 m		
Hs(a)/Hs(t)	= 0.99		



Run-No.: 30			
Hs(t)	= 4.40 m	Tp(t) = 8 s	γ = 3.3
Hs(a)	= 4.46 m		
Hs(a)/Hs(t)	= 1.01		

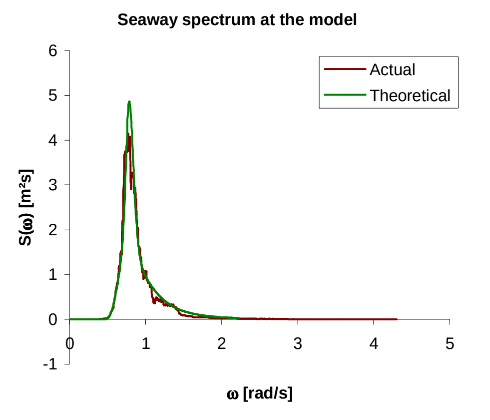


Run-No.: 30			
Hs(t)	= 4.40 m	Tp(t) = 8 s	γ = 3.3
Hs(a)	= 4.36 m		
Hs(a)/Hs(t)	= 0.99		

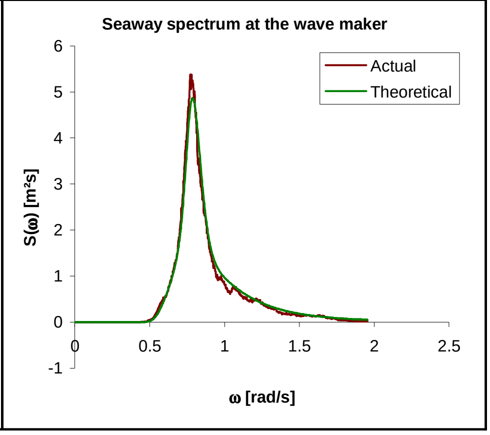


Hs(a): **a**ctual significant wave height
Hs(t): **t**heoretical significant wave height

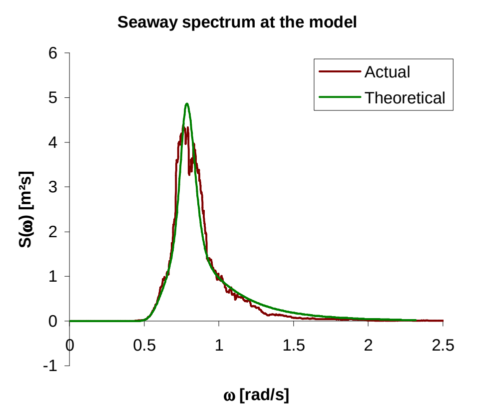
Hs(t)	= 4.40 m	Tp(t) = 8 s	γ = 3.3	Run-No.: 31
Hs(a)	= 4.29 m			
Hs(a)/Hs(t)	= 0.98			



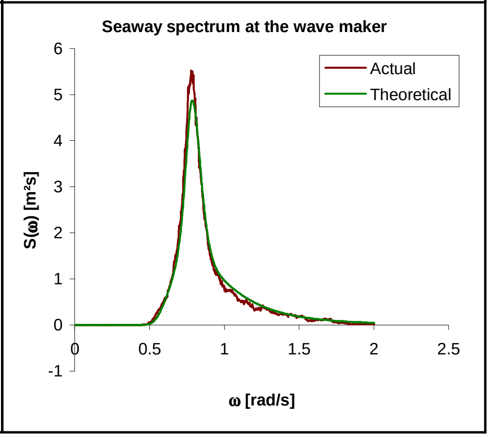
Hs(t)	= 4.40 m	Tp(t) = 8 s	γ = 3.3	Run-No.: 31
Hs(a)	= 4.34 m			
Hs(a)/Hs(t)	= 0.99			



Hs(t)	= 4.40 m	Tp(t) = 8 s	γ = 3.3	Run-No.: 32
Hs(a)	= 4.39 m			
Hs(a)/Hs(t)	= 1.00			



Hs(t)	= 4.40 m	Tp(t) = 8 s	γ = 3.3	Run-No.: 32
Hs(a)	= 4.40 m			
Hs(a)/Hs(t)	= 1.00			



Hs(a): **a**ctual significant wave height
Hs(t): **t**heoretical significant wave height

Annex E

General Information

E.1 Test Facilities

All seakeeping tests are performed in the large towing tank of the HSVA, which measures 300 x 18 x 5.6 m in length, width and water depth.

The towing tank is equipped with a hydraulically operated double flap wave generator at one end of the tank. The wave generator extends over the full width of the model basin. At the other end a beach absorbs the waves. Regular waves and irregular long-crested seas according to several spectral shapes can be simulated. Significant wave heights up to 0.45 m with a belonging modal wave period of 2.25 s can be realized.

The towing tank is equipped with a main carriage that is guided by longitudinal rails located at both sides of the tank. The main carriage is able to follow the model in the longitudinal direction of the tank. In addition, a sub carriage is connected at the front of the main carriage. This sub carriage can move transversally to the tank and maintain the relative distance to the model. The sketch below shows the tank arrangement.

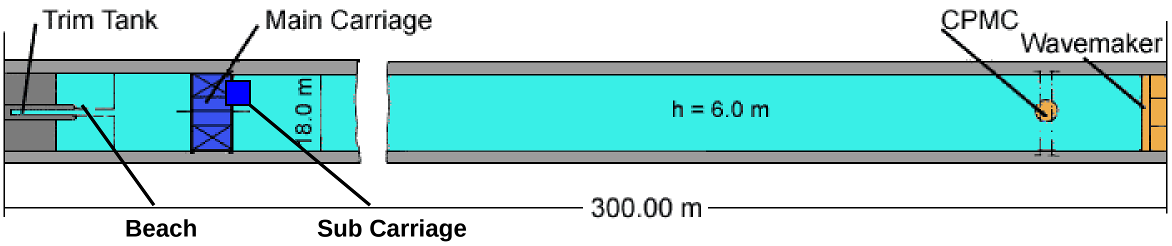


Figure 16: Principle view of the Large Towing Tank

E.2 Definitions

E.2.1 Ship Coordinate System

The coordinate system, used for the present seakeeping tests, is shown in Figure 17. It is valid for the steady state of the vessel. The origin has been

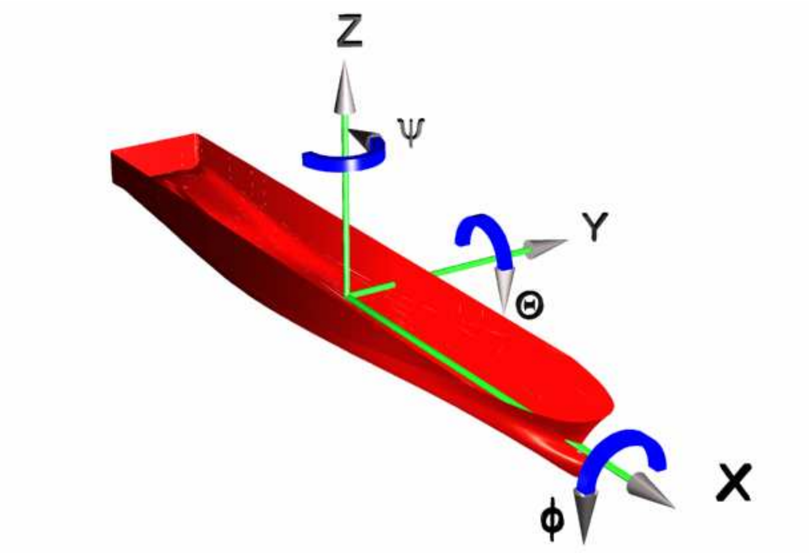


Figure 17: Ship coordinate system

E.2.2 Encounter Angle μ

The encounter angle **μ** of the vessel is defined as the angle between the ship's heading and the direction of the wave propagation. It is 0° in stern seas and 180° in head seas. The angle **μ** is illustrated in Figure 18.

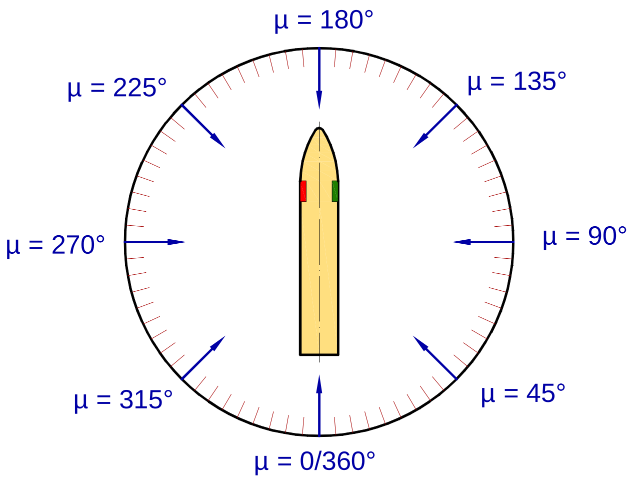


Figure 18: Encounter angle μ

E.3 Statistical Analysis

In a statistical analysis the significant single amplitudes (the mean value of the one-third highest amplitudes) and the maximum single amplitudes were determined from the time records of ship motions and accelerations that were measured during the test runs. As an example, a time record of a general measurement signal is shown in Figure 19.

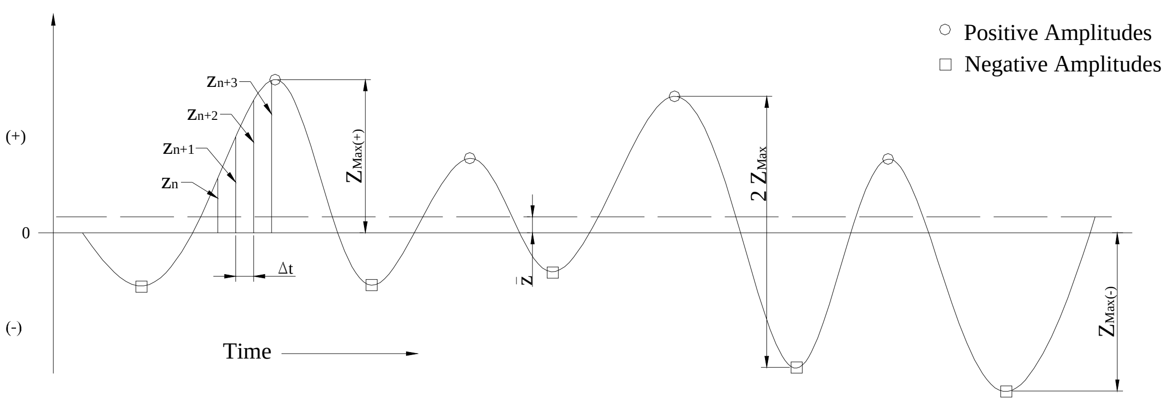


Figure 19: General time record

The statistical values of interest are listed in the items *a.* to i.:

a. *Mean value:*

$$\bar{z} = \frac{1}{N} \cdot \sum_{n=1}^{N} z_n \qquad (2)$$

N: Number of samples

b. *Standard deviation:*

$$\sigma_z = \sqrt{\frac{1}{N} \cdot \sum_{n=1}^{N} (z_n - \bar{z})^2} \qquad (3)$$

c. *Maximum positive amplitude:*

$Z_{Max\,(+)}$ (highest crest to zero value)

d. *Maximum negative amplitude:*

$Z_{Max\,(-)}$ (highest trough to zero value)

e. *Maximum double amplitude:*

2 Z_{Max} (highest trough to crest value)

f. *Positive significant single amplitude:*

Z_{sig} + => Mean of the one-third largest positive amplitudes

g. *Negative significant single amplitude:*

Z_{sig} - => Mean of the one-third largest negative amplitudes

h. *Mean significant single amplitude:*

Z_{sig} mean => Mean value of the positive and negative significant single amplitude

i. *Significant double amplitude:*

2 Z_{sig} => Mean of the one-third highest double amplitude

Please note that the statistical analysis of the fluctuating motion responses is related to the mean value of the time series. Therewith, the absolute value of positive amplitudes is the sum of the mean value of the time series and the positive single amplitudes as found in the statistical analysis. In a similar way absolute negative amplitudes are derived by subtracting the negative single amplitudes from the mean value of the time series.

Annex F

Correlation of Measuring and Video

Meas.-No.	Seaway-No. at model	Seaway-No. at wave maker	Run-No.	Video-No.	γ	Hs [m]	Tp [s]
10	10	10	1	3	1.0	4.21	12.3
11	11	11	2	4	1.0	4.33	12.5
12	12	12	3	5	1.0	4.36	12.5
13	13	13	4	6	1.0	4.23	12.3
14	14	14	5	7	1.0	4.19	12.3
15	15	15	6	8	3.3	3.24	7.7
16	16	16	7	9	3.3	3.36	7.5
17	17	---	8	10	3.3	3.20	7.2
18	18	18	9	11	3.3	3.23	7.3
19	19	19	10	12	3.3	3.63	7.8
20	20	20	11	13	3.3	2.63	6.8
21	21	21	12	14	3.3	3.01	7.7
22	22	22	13	15	3.3	2.99	6.9
23	23	23	14	16	3.3	2.92	6.8
24	24	24	15	17	3.3	2.97	6.9
27	27	27	16	18	1.0	4.16	12.2
28	28	28	17	19	1.0	4.15	12.2
29	29	29	18	20	1.0	4.20	12.3
31	31	31	19	21	1.0	4.18	12.3
32	32	32	20	22	1.0	4.10	12.2
34	34	34	21	24	3.3	4.35	8.3
35	35	35	22	25	3.3	4.36	8.4
36	36	36	23	26	3.3	4.38	8.4
37	37	37	24	27	3.3	4.38	8.4
38	38	38	25	28	3.3	4.35	8.3
40	40	40	26	29	3.3	4.35	8.3
41	41	41	27	30	3.3	4.38	8.4
42	42	42	28	31	3.3	4.47	8.5
43	43	43	29	32	3.3	4.35	8.3
44	44	44	30	33	3.3	4.36	8.3
47	47	47	31	34	3.3	4.34	8.3
48	48	48	32	35	3.3	4.40	8.4

Table 10: Correlation of Measuring and Video