

HAMBURGISCHE SCHIFFBAU-VERSUCHSANSTALT GMBH

THE HAMBURG SHIP MODEL BASIN

**S 590b / 09**

**Damage Stability Tests with the  
Model of a 200 m RoPax Vessel**

**Final Report Part IIb**

**Customer:  
European Maritime Safety Agency (EMSA)**

**HSVA**

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<b>Abstract:</b>	<p>By order of the European Maritime Safety Agency (EMSA), the survivability of a 200 m RoPax vessel has been investigated in long-crested irregular beam seas in two damage conditions.</p> <p>The main purpose of the present investigation was to ascertain whether the tested ship, designed to comply with the SOLAS 2009 damage stability criteria which have come into force in January 2009, does also fulfil the Stockholm Agreement water on deck criteria.</p> <p>The tests, carried out according to the Directive 2003/25/EC, have shown that the vessel fulfilled the Stockholm Agreement in seaways with significant wave heights less than 4 m in both tested damage conditions. However, significant wave heights between 4 and 5 m lead to several capsizing incidences in Damage Case 1.</p> <p>In order to determine a critical condition for Damage Case 4 a variation of the vessel's floating condition has been taken into consideration. The model did not capsize till it was floating at 1.4 degrees trim and 4 degrees heeling angle off the leakage. In this floating condition the model capsized in all sea conditions, also in seaways having significant wave heights smaller than 4 m.</p> <p>All relevant time histories, the statistical results as well as selected figures and drawings of the model of the 200 m RoPax vessel are shown in Annex A and C.</p>
<b>Keywords:</b>	Damage stability tests, SOLAS 2009, Stockholm Agreement, 200 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 It has superseded the SOLAS 74, as amended up to SOLAS -96/98 Am., hereafter called SOLAS 90, for the same use.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 larger (200 m) RoPax vessel designed according to the rules of the SOLAS 2009. 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 investigations included both, numerical simulations and physical model tests.

The tests have been carried out in HSVA’s large towing tank on 4<sup>th</sup> and 6<sup>th</sup> May 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.

### Model Description

#### 1.1 Main Particulars of the 200 m RoPax Vessel

The main particulars of the investigated vessel (model scale 1:34) and the relevant load conditions are as follows:

Main Data of the Intact Vessel		
	Full Scale	Model
$L_{OA}$ [m]	199.90	5.879
$L_{PP}$ [m]	190.25	5.596
$L_{WL}$ [m]	193.25	5.684
$B_{WL}$ [m]	30.80	0.906
$D$ [m]	22.00	0.647
$T_a$ [m]	6.80	0.200
$T$ [m]	6.80	0.200
$T_f$ [m]	6.80	0.200
$C_B$ [--]	0.56	0.560
$\nabla$ [m <sup>3</sup> ;kg]	22 718	578
$LCB$ [m]	89.96	2.646
$KM$ [m]	18.72	0.550
$KG$ [m]	14.22	0.418
$GM_0$ [m]	4.50	0.132
$KB$ [m]	3.89	0.115
$T_\phi$ [s]	13.1	2.25
$i_{xx}/B_{WL}$ [--]	0.43	0.43
$i_{yy}/L_{PP}$ [--]	0.24	0.24

Damage Case 1		
	Full Scale	Model
$L_{WL}$ [m]	193.25	5.684
$T_a$ [m]	7.93	0.233
$T$ [m]	7.19	0.211
$T_f$ [m]	6.44	0.189
Heel [°]	2.5	2.5
$GM'$ [m]	3.12	0.092
$T_\phi$ [s]	16.2	2.77

Damage Case 4		
	Full Scale	Model
$L_{WL}$ [m]	197.23	5.801
$T_a$ [m]	6.38	0.188
$T$ [m]	9.87	0.290
$T_f$ [m]	13.36	0.393
Heel [°]	1.0	1.0
$GM'$ [m]	1.84	0.054
$T_\phi$ [s]	Not measurable	Not measurable

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 19.

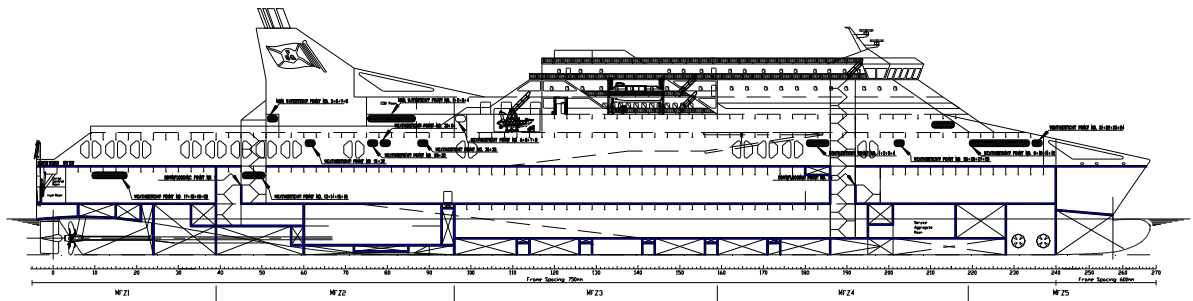


Figure 1: Side view of the 200 m RoPax vessel

## 1.2 Construction of the Model

The 200 m RoPax vessel is a twin screw vessel which has two Ro-Ro cargo holds and a maximum passenger capacity of 542. The ship represents a larger modern RoPax vessel and is therefore well suitable for the present damage stability investigations.

The ship model having an overall length of 5.6 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 5 mm and was built up to a height of 22.00 m above the base line 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.

The long lower cargo hold extends from #<sup>1</sup>96 to #195 and its car deck was modelled at a height of 3 m above the base line. The long lower hold has a double hull so that the maximum width of the hold corresponds to 24 m. The upper car deck extends over almost the whole ship length (from the transom to #240) and was positioned at a height of 9.2 m above the base line. Two variants of the upper cargo hold have been investigated within the model tests. In Damage Case 1 the car deck extended over the whole breadth of the vessel, whereas the upper hold was fitted out with a double hull in Damage Case 4. The double hull extends from #96 to #119 and was due to increase the residual buoyancy in this damage condition. In the parallel part of the ship the double hull has a width of 1.4 m.

Two down flooding points, which can be seen in Figure 9, have been modelled inside the centre casings on the upper car deck. The coordinates of these points are listed in Table 2:

Designation	x-position	y-position	z position
Down flooding Point 1	#45 (33.75 m)	1.60 m to -1.60 m	12.60 m
Down flooding Point 2	#192 (144.00 m)	1.60 m to -1.60 m	12.60 m

**Table 2: Positions of the down flooding points**

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. Those compartments being considered with a permeability of 85% were so small that additional internals were not necessary either.

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<sup>1</sup> #: building frame (frame spacing = 0.75 m)

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

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

Two damage cases, both located on starboard side, have been considered within the model tests. The longitudinal centre of the first damage hole (Damage Case 1) was arranged at #60. The damage length was 8.69 m and had a triangular shape in the horizontal plane with a penetration depth of 6.16 m ( $B/5$ ). The opening angle corresponded to  $55^\circ$ . In the vertical direction the leakage extended to a height of 17 m above the base line.

The longitudinal centre of the second damage hole (Damage Case 4) was arranged at #178. The damage length was also 8.69 m and had a triangular shape in the horizontal plane with a penetration depth of 9.24 m ( $0.3 B$ ). The opening angle corresponded to  $65^\circ$ . In the vertical direction the leakage extended to a height of 17 m above the base line.

In order to simulate the correct roll motion behaviour of the ship the appendages were modelled as well, whereas the rudder dummies provided the lateral area ( $21 \text{ m}^2$  each, including head box), but were not profiled. Two suitable stock propellers (No's. 1087/1088) were chosen having a diameter corresponding to 6.35 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 52.5 m to 112.5 m in front of the aft perpendicular. Following this, the length of the bilge keels (60 m) corresponded to 31.5% of  $L_{PP}$ . The profile height of the bilge keels was 422 mm and their ends were tapered by an angle of  $30^\circ$ .

On the car deck several markings were 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 30<sup>th</sup> building frame.

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

## 1.3 Weight Distribution

### 1.3.1 Intact Ship

Prior to the tests the model was trimmed to the intact load condition corresponding to a draught of 6.8 m on even keel. The initial metacentric height of 4.5 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:

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

in which:

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

$i_{xx}$ : Radius of gyration for roll (**e**xcluding the hydrodynamic added masses)

$T_{\Phi}$ : Natural roll motion period

$g$ : Acceleration due to gravity (= 9.81 m/s<sup>2</sup>)

$GM$ : Metacentric height

1.05: Assumed coefficient for the influence of added mass

For the intact vessel a natural roll motion period  $T_{\Phi} = 13.1$  s was measured. According to the formula shown above, the radius of gyration for roll results in  $0.43 \cdot B_{WL}$  for the dry ship condition.

### 1.3.2 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 metacentric heights for both damage cases were ascertained by inclining tests in calm water.

In Damage Case 1 the GM corresponded to 3.1 m and a natural roll motion period of 16.2 s was measured (see Figure 4). The initial heeling angle was 2.5° towards the damage.

In Damage Case 4 the GM corresponded to 1.84 m. Due to the very high roll damping of the damaged model it was not possible to measure the natural roll motion period reliably. The initial heeling angle of 0.6° towards the damage was increased to 1° according to the IMO Guidelines (Paragraph 3.4 of Appendix of IMO Res.14 of 1995 SOLAS Conf.).

## 2 Measurements

The model of the 200 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 upper 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 8 in Annex A.

Two additional wave probes were used for measuring the wave elevation, one near the model 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.



## 3 Model Tests

A test series of 35 test runs was performed with the model of the 200 m RoPax vessel.

### 3.1 Tested Seaways

The model tests were carried out in long-crested irregular seaways defined by both, the JONSWAP spectrum (Joint North Sea Wave Project) and the ITTC spectrum (International Towing Tank Conference). Both spectra are characterized by the parameters significant wave height  $H_s$  and the peak period  $T_p$ , but have different enhancement factors,  $\gamma$ . 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 3.68 to 6.69 m. The seaways with JONSWAP spectra had peak periods corresponding to  $4\sqrt{H_s}$ , whereas the seaways with ITTC spectrum had peak periods corresponding to  $6\sqrt{H_s}$ .

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

The actual seaway spectra were calculated from the time histories of each test run. In Annex D 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 reflections. Taking this into account the desired spectra were satisfactorily modelled in the tests.

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

## 3.2 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 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.

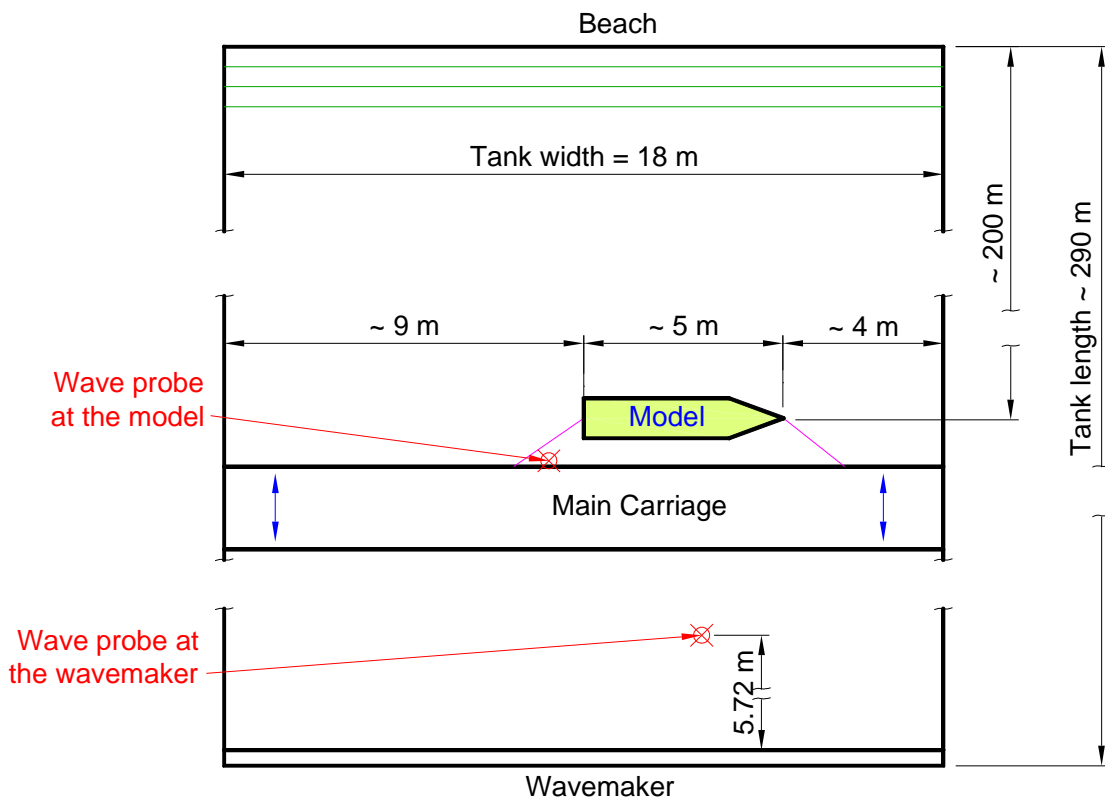


Figure 2: Sketch of the test arrangement

## 4 Data Handling and Analysis

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

### 4.2 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 25 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.

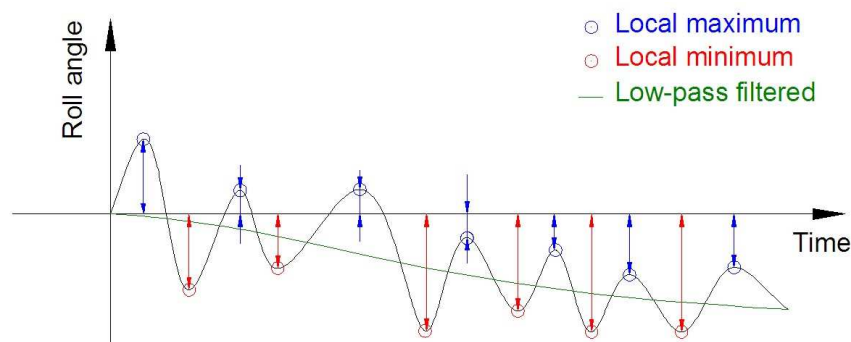


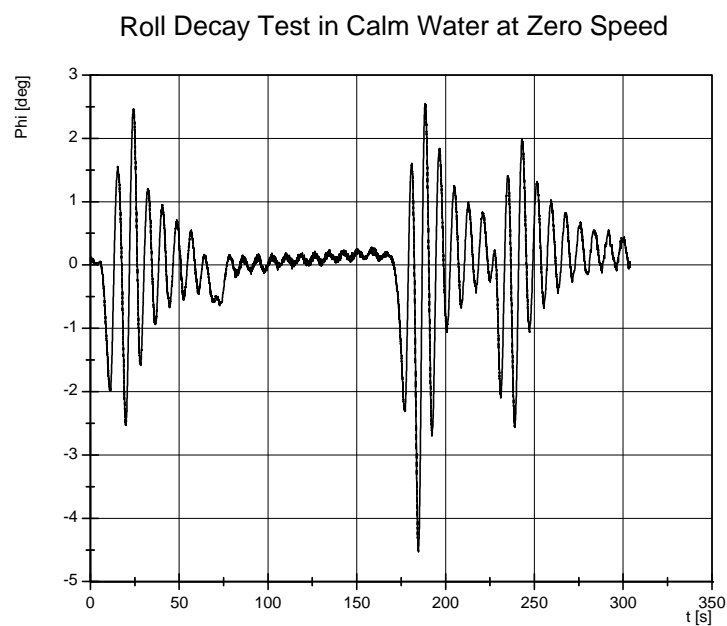
Figure 3: Statistical analysis of the roll motion

## 5 Test Results

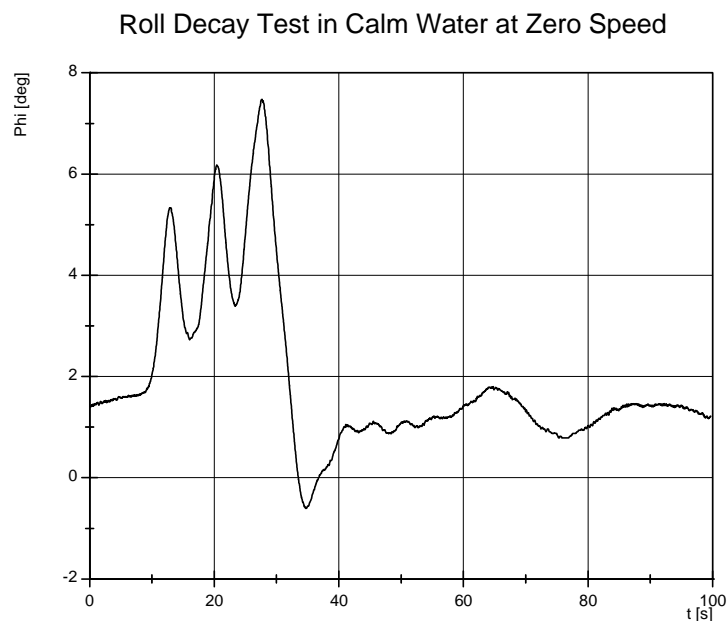
### 5.1 Roll Decay Test in Calm Water

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,  $T_\phi = 16.2$  s)**



**Figure 5: Roll decay test in calm water (Damage Case 4).**

## 5.2 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 indicates whether the vessel fulfilled the survival criteria of the guidelines or not.

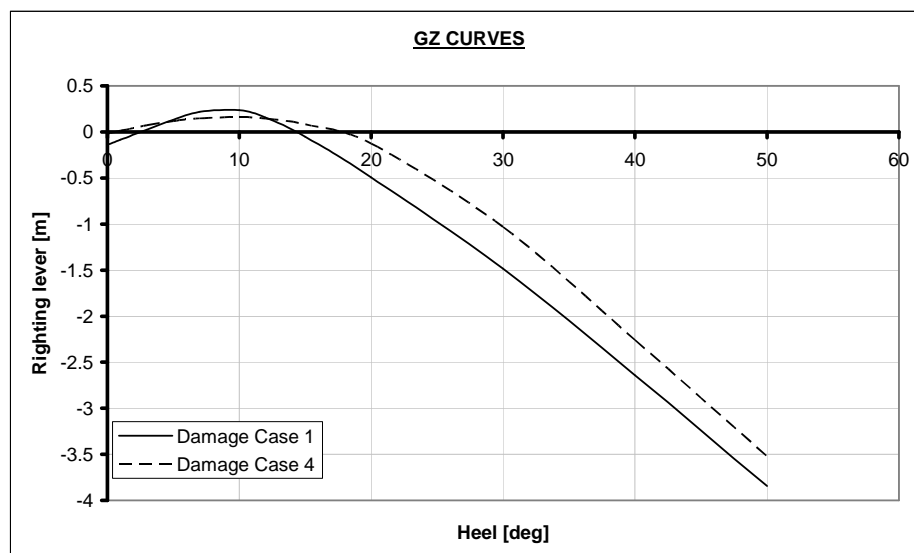


Figure 6: GZ curves for both damage cases

Damage Case 1						
Run-No.	GZ,max [m]	Range [deg]	Hs [m]	Tp [s]	$\gamma$	Survived*
1	0.248	14.5	3.97	12.0	1.0	YES
2	0.248	14.5	4.01	12.0	1.0	YES
3	0.248	14.5	4.02	12.0	1.0	YES
4	0.248	14.5	4.03	12.0	1.0	YES
5	0.248	14.5	4.46	12.0	1.0	NO
6	0.248	14.5	4.87	12.2	1.0	NO
7	0.248	14.5	4.32	11.6	1.0	NO
8	0.248	14.5	3.81	8.4	3.3	YES
9	0.248	14.5	3.73	8.4	3.3	YES
10	0.248	14.5	4.51	8.6	3.3	YES
11	0.248	14.5	4.77	8.7	3.3	NO
12	0.248	14.5	4.99	8.9	3.3	NO
13	0.248	14.5	4.58	8.6	3.3	NO
14	0.248	14.5	4.65	8.6	3.3	YES
15	0.248	14.5	4.65	8.6	3.3	NO

Table 3: Survival of the damaged vessel in Damage Case 1

Damage Case 4						
Run-No.	GZ,max [m]	Range [deg]	Hs [m]	Tp [s]	$\gamma$	Survived*
16	0.162	17.9	3.90	11.8	1.0	YES
17	0.162	17.9	3.75	11.6	1.0	YES
18	0.162	17.9	4.64	12.3	1.0	YES
19	0.162	17.9	4.62	12.2	1.0	YES
20	0.162	17.9	4.64	12.3	1.0	YES
21	0.162	17.9	3.73	8.3	3.3	YES
22	0.162	17.9	4.35	8.4	3.3	YES
23	0.162	17.9	4.31	8.4	3.3	YES
24	0.162	17.9	4.30	8.4	3.3	YES
25	0.162	17.9	4.38	8.4	3.3	YES
26	0.162	17.9	6.50	10.2	3.3	YES
27	0.162	17.9	6.69	11.1	3.3	YES
28	0.162	17.9	4.39	8.5	3.3	YES
29	0.162	17.9	5.60	10.3	3.3	YES
30	0.162	17.9	6.64	11.1	3.3	YES
* 31	0.162	17.9	4.21	8.3	3.3	NO
32	0.162	17.9	3.91	8.3	3.3	NO
33	0.162	17.9	3.70	8.3	3.3	NO
34	0.162	17.9	3.68	8.3	3.3	NO
35	0.162	17.9	3.78	8.3	3.3	NO

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

\* Change of floating condition

## 5.3 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 (see Figure 3)
- $A_{max}$  lower bound Local minimum single amplitudes (see Figure 3)
- $T_m$  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.

## 6 Conclusion

By order of the European Maritime Safety Agency (EMSA), damage stability tests have been carried out with the model of a 200 m RoPax vessel.

The main objective of the investigations 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 5.6 m and a hull thickness of 5 mm has been built including all relevant internals and structural details. The tests were carried out in HSVA's large towing tank on 4<sup>th</sup> and 6<sup>th</sup> May 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, both located on starboard, have been considered within the model tests.

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.

All tests have been documented on video. Three camera views can be seen on the video, one showing the whole model and two showing the interior of the cargo hold from fore and aft.

The tests, carried out according to the Directive 2003/25/EC, have shown that the vessel fulfilled the Stockholm Agreement in seaways with significant wave heights less than 4 m in both tested damage conditions. However, significant wave heights between 4 and 5 m lead to several capsizing incidences in Damage Case 1.

In order to determine a critical condition for Damage Case 4 a variation of the vessel's floating condition has been taken into consideration. The model did not capsize till it was floating at 1.4 degrees trim and 4 degrees heeling angle off the leakage. In this floating condition the model capsized in all sea conditions, also in seaways having significant wave heights smaller than 4 m. The reason for these capsizing incidents was that in this condition the water could accumulate on the car deck without draining off again.

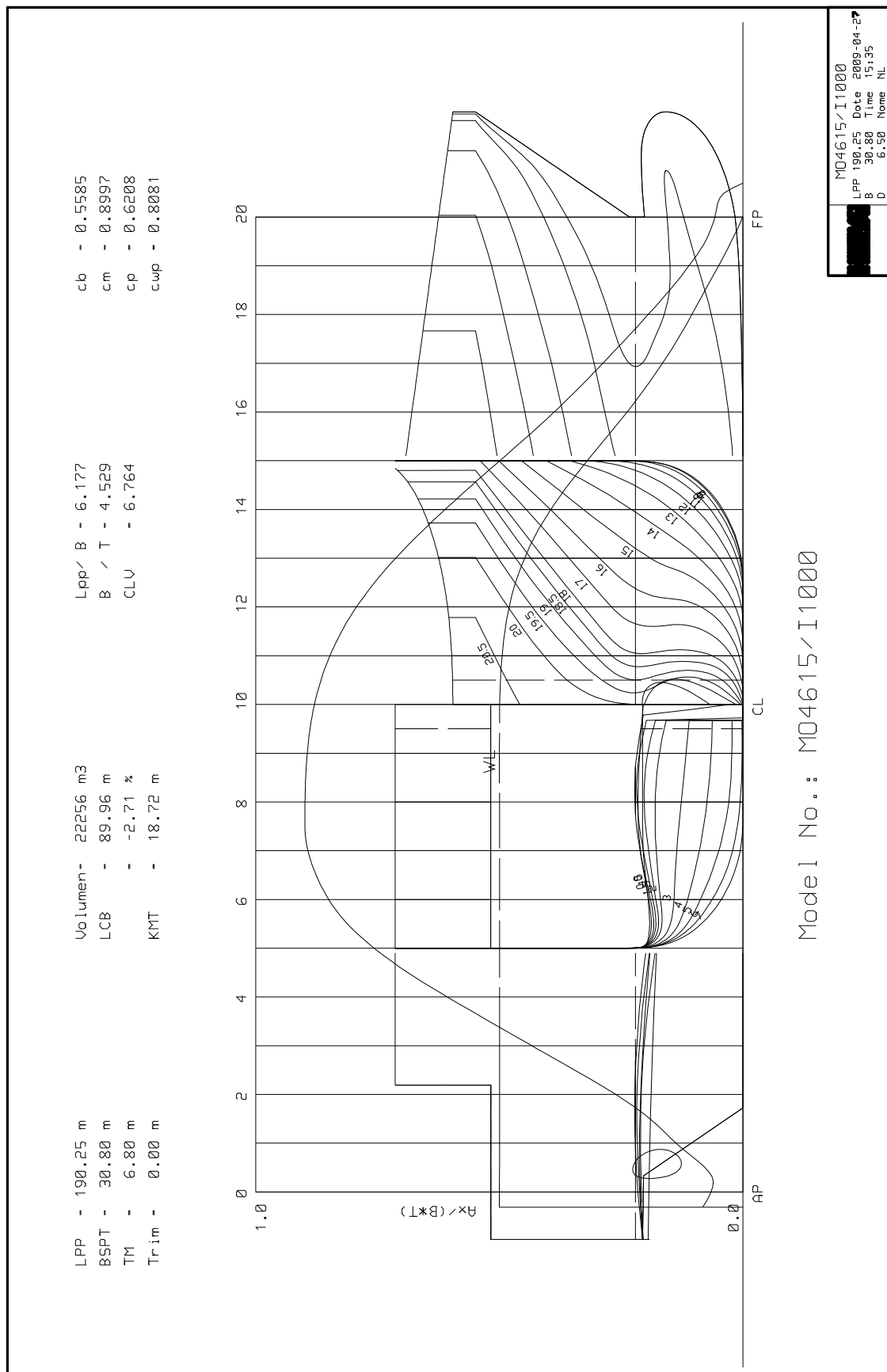


## 7 List of Symbols

$L_{OA}$	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
$\nabla$	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
$T_\Phi$	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
$\#$	Building frame
$GZ$	Righting lever of the ship
$f_s$	Residual freeboard
$g$	Acceleration due to gravity
$H_s$	Significant wave height
$T_P$	Peak period
$\gamma$	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)
$\zeta_{wp1..n}$	Wave elevation at the wave probes on the car deck (statistics)

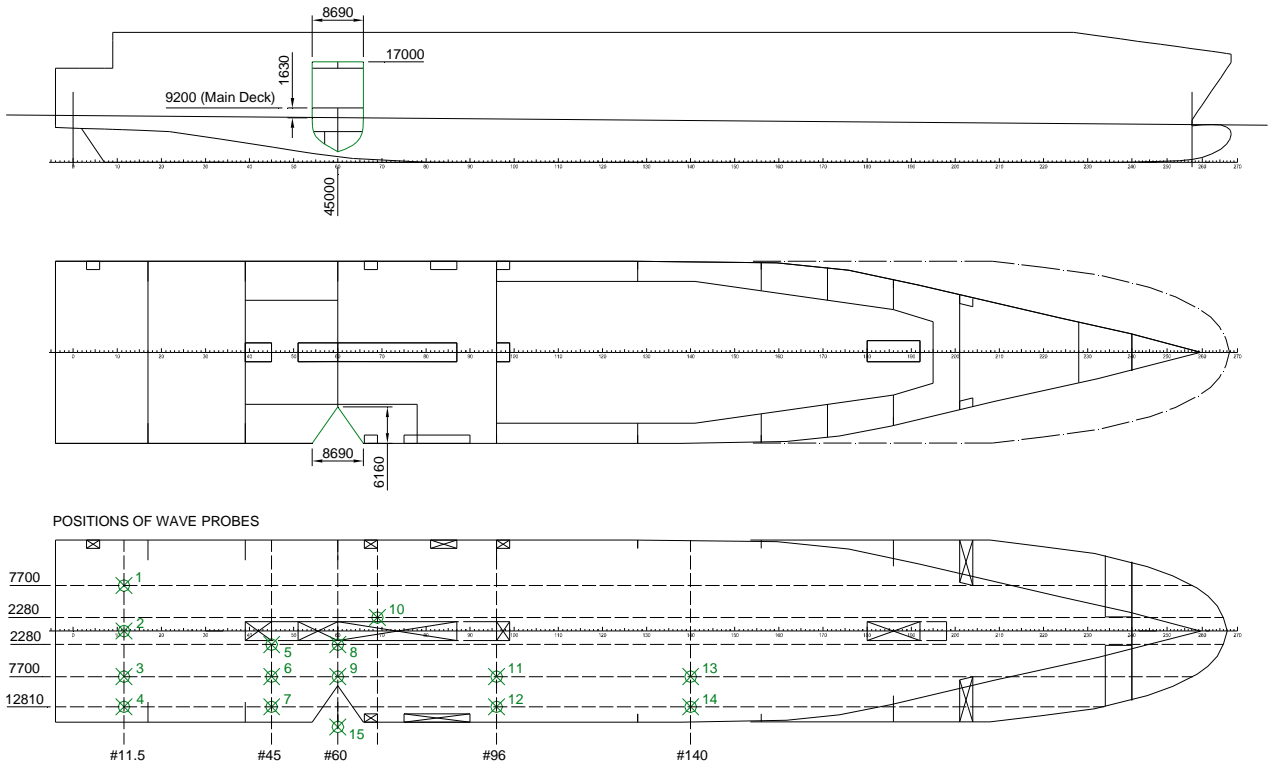
# **Annex A**

## ***Drawings and Photographs***



**Figure 7: Body plan / contour of stem and stern frame**

## DAMAGE CASE 1



## DAMAGE CASE 4

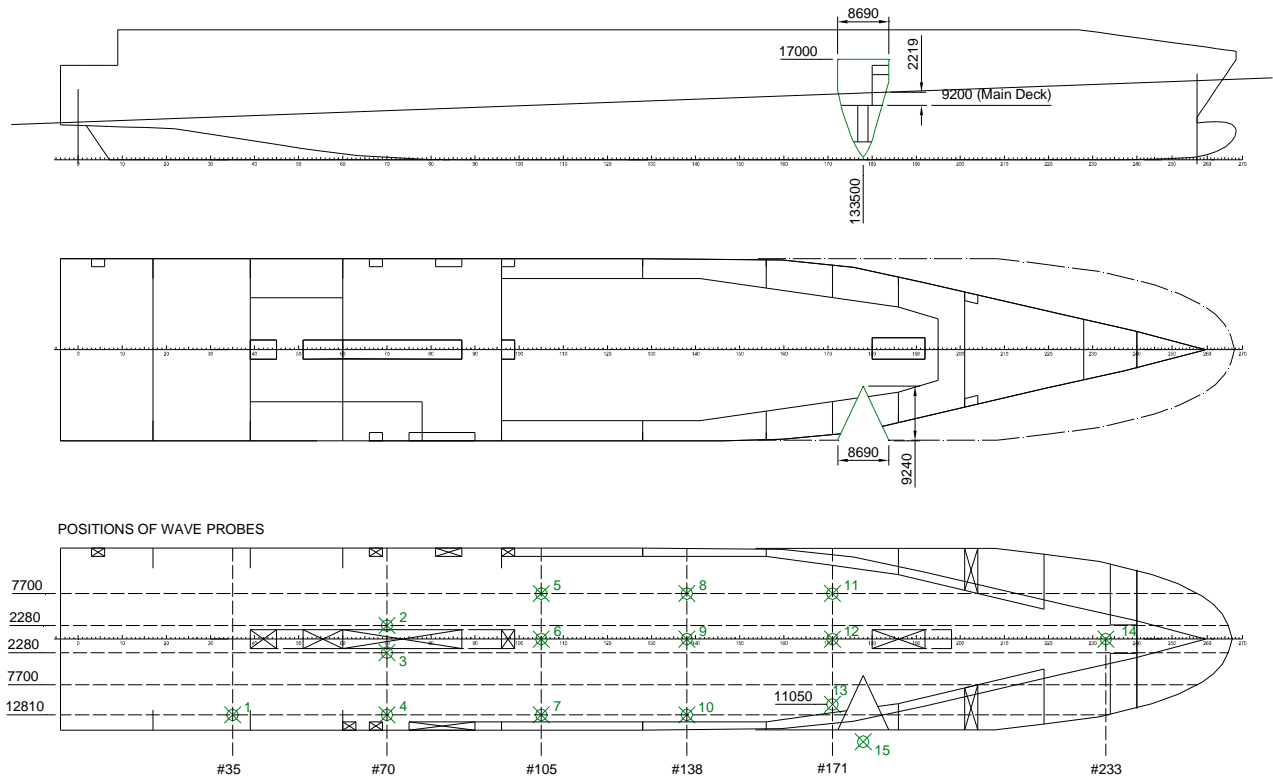
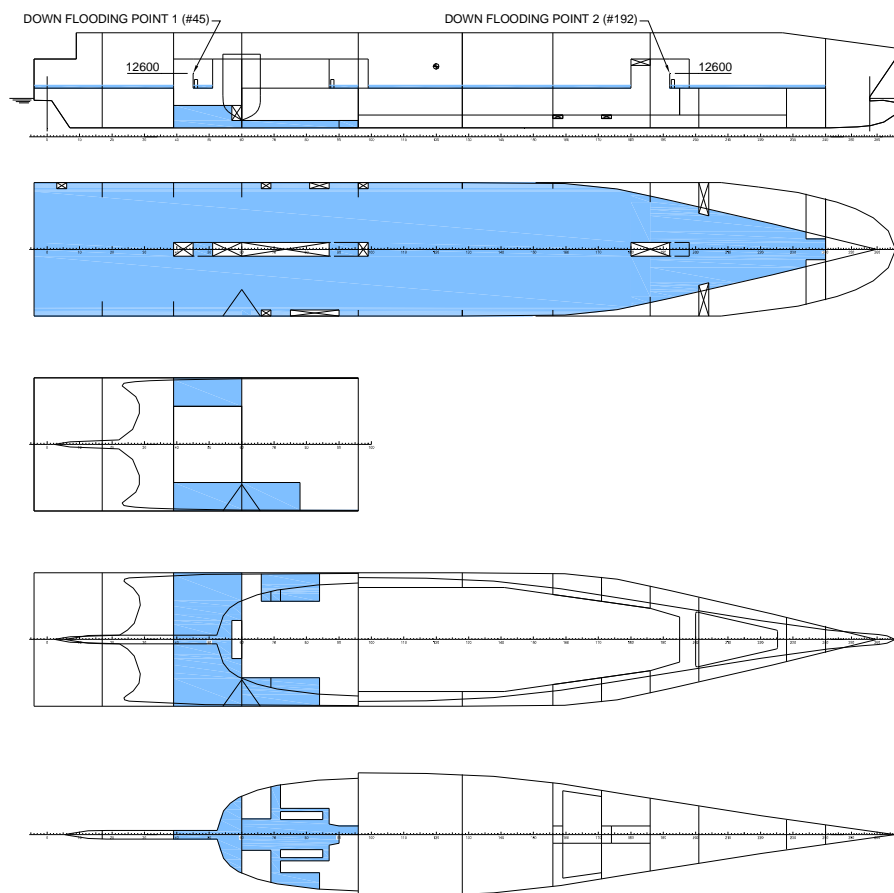


Figure 8: Dimensions of the damage holes and positions of the wave probes on the car deck

## DAMAGE CASE 1



## DAMAGE CASE 4

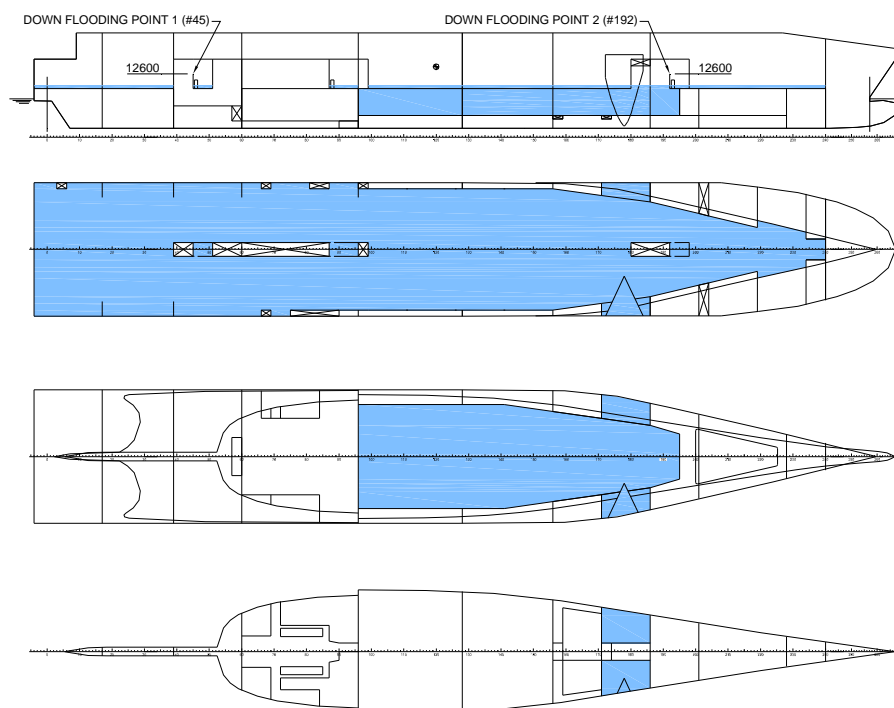
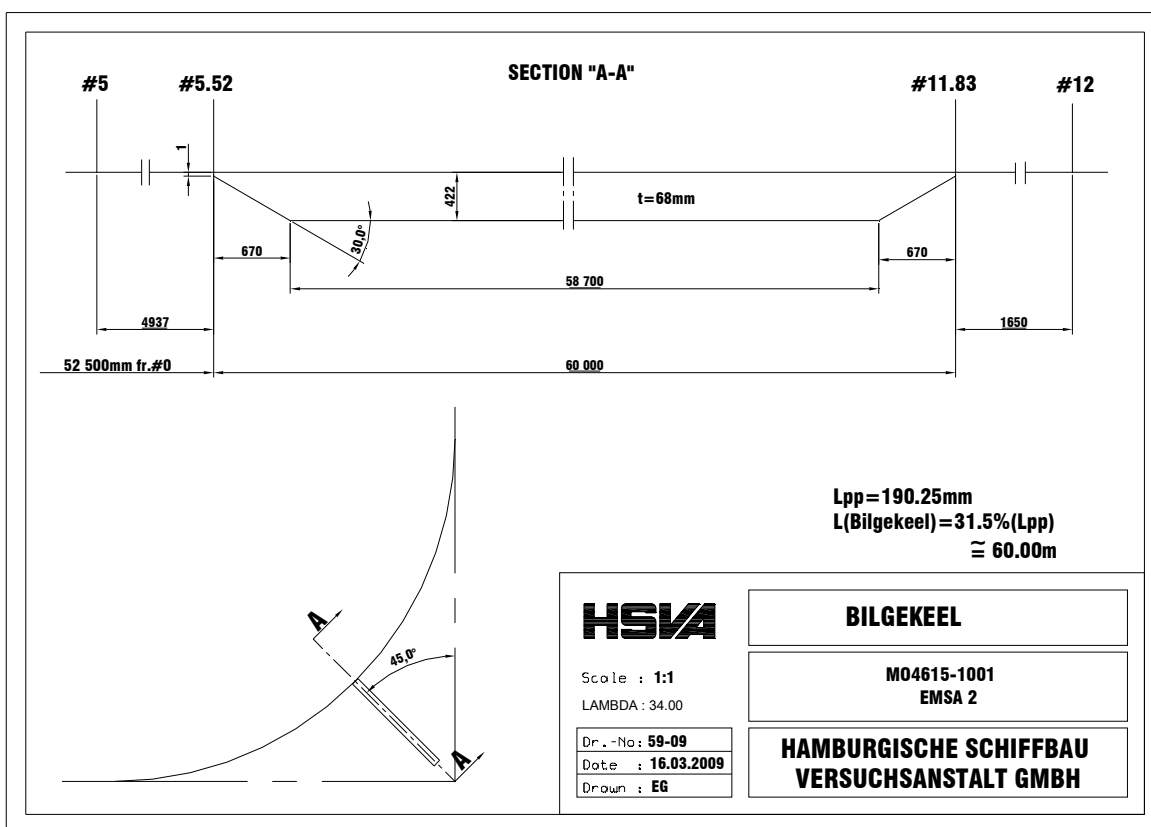


Figure 9: Flooded compartments



**Figure 10: Bilge keel arrangement**



**Figure 11: Void 8; engine & electric workshop etc. (#39 to #60)**



**Figure 12: Tanks below the tank top (#60 to #96)**



**Figure 13: Tanks below the tank top (#160 to #186)**



**Figure 14: Engine room floor (#60 to #96)**



**Figure 15: Engine room; void 7; purifier plant 2**



**Figure 16: Lower hold, view from aft (#96 to #195)**





**Figure 17: Lower hold, void 3 & void 4**



**Figure 18: Aft appendages of the model**



Figure 19: Leakage of Damage Case 1



Figure 20: Leakage of Damage Case 4

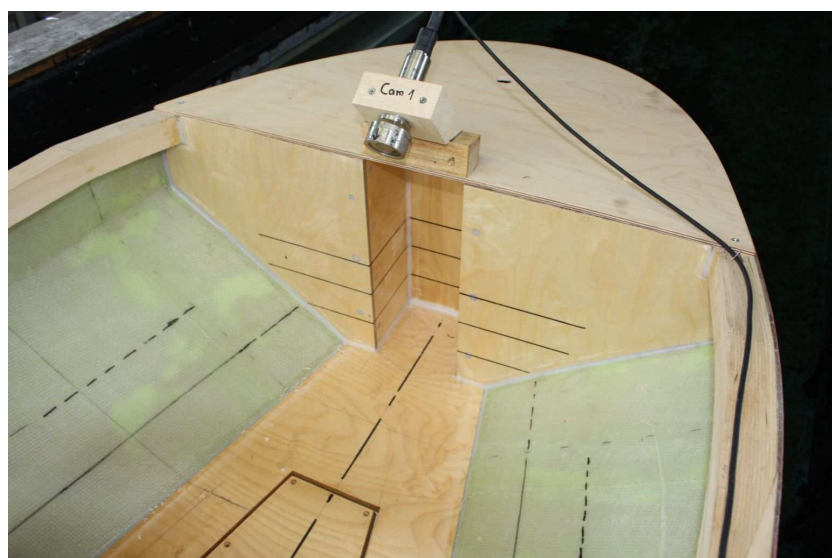
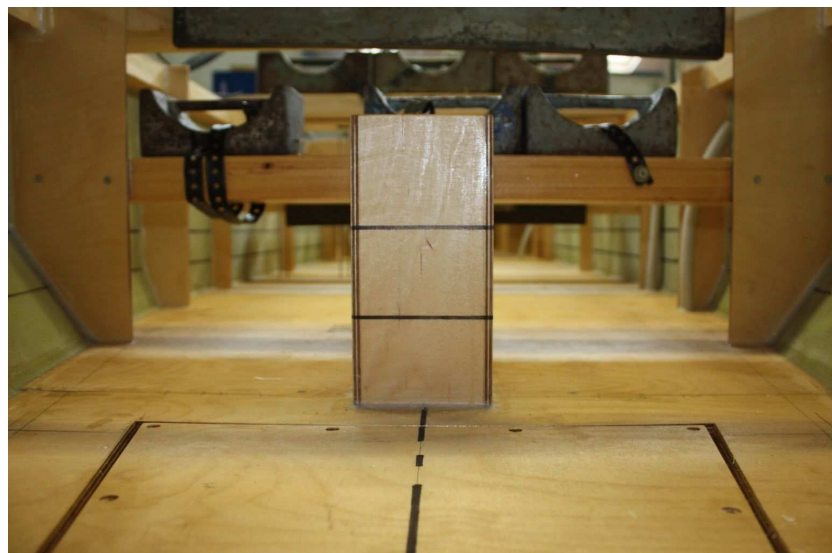
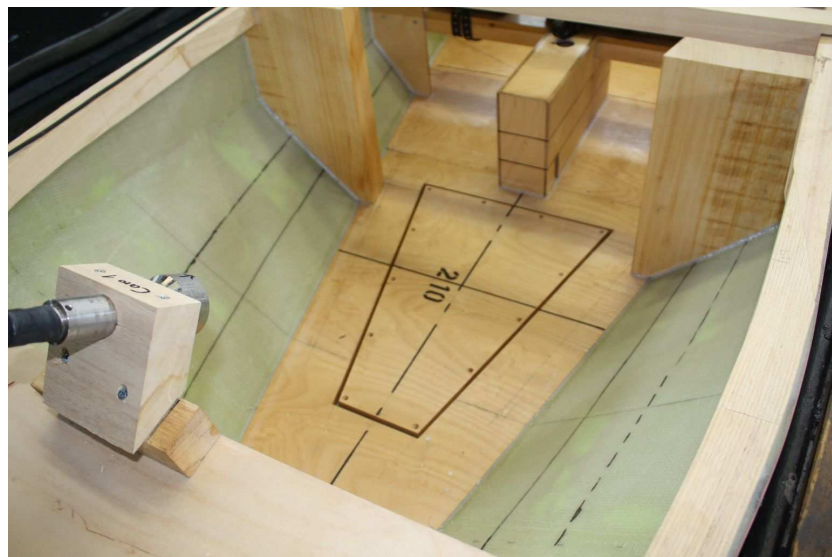
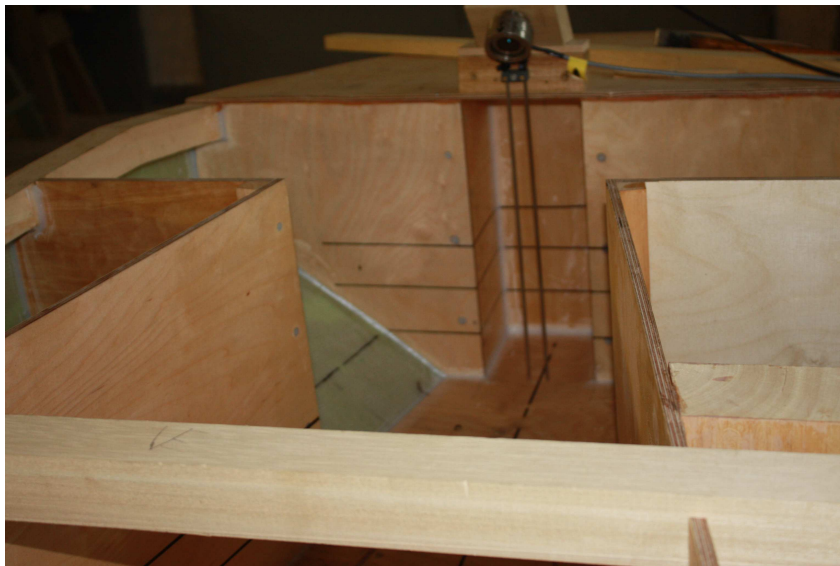
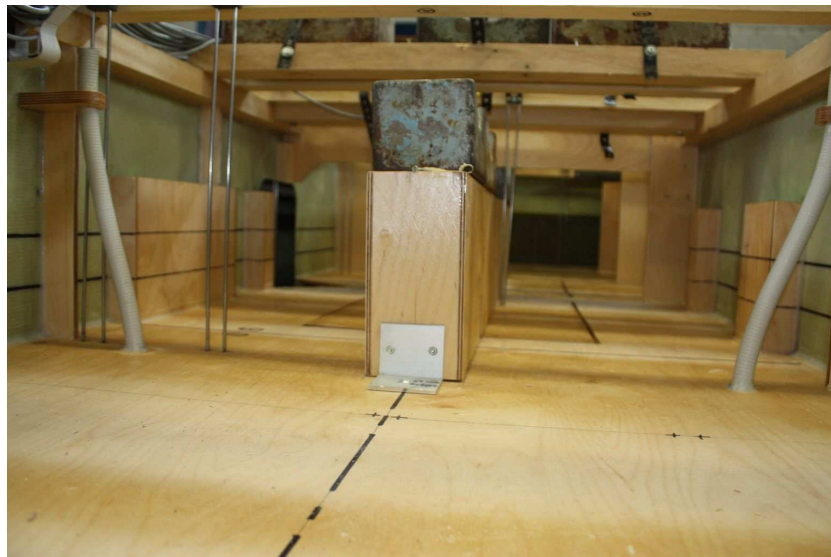


Figure 21: Main deck (forward part without double hull)





**Figure 22: Main deck (forward part with double hull)**

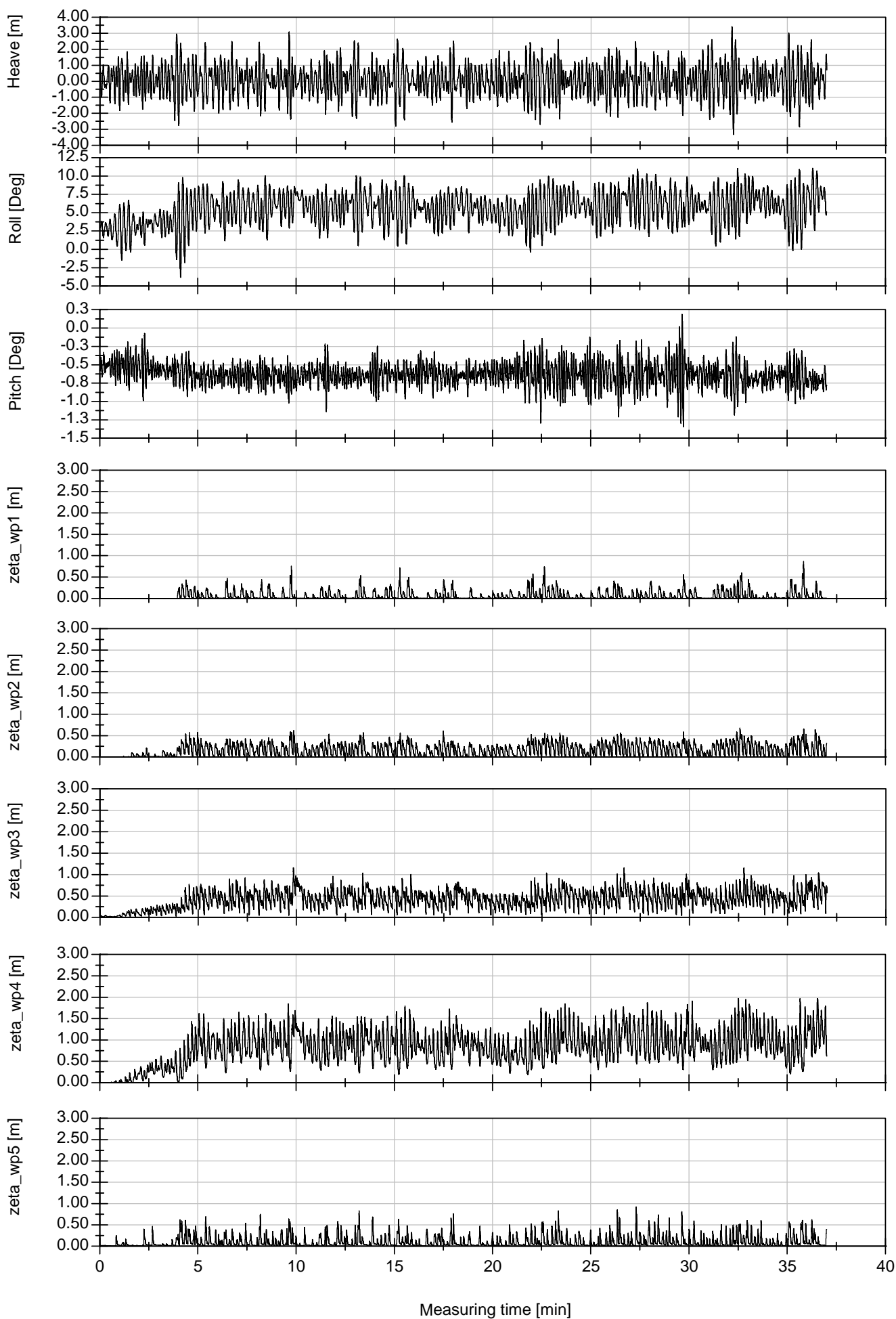


**Figure 23: Main deck (aft part)**

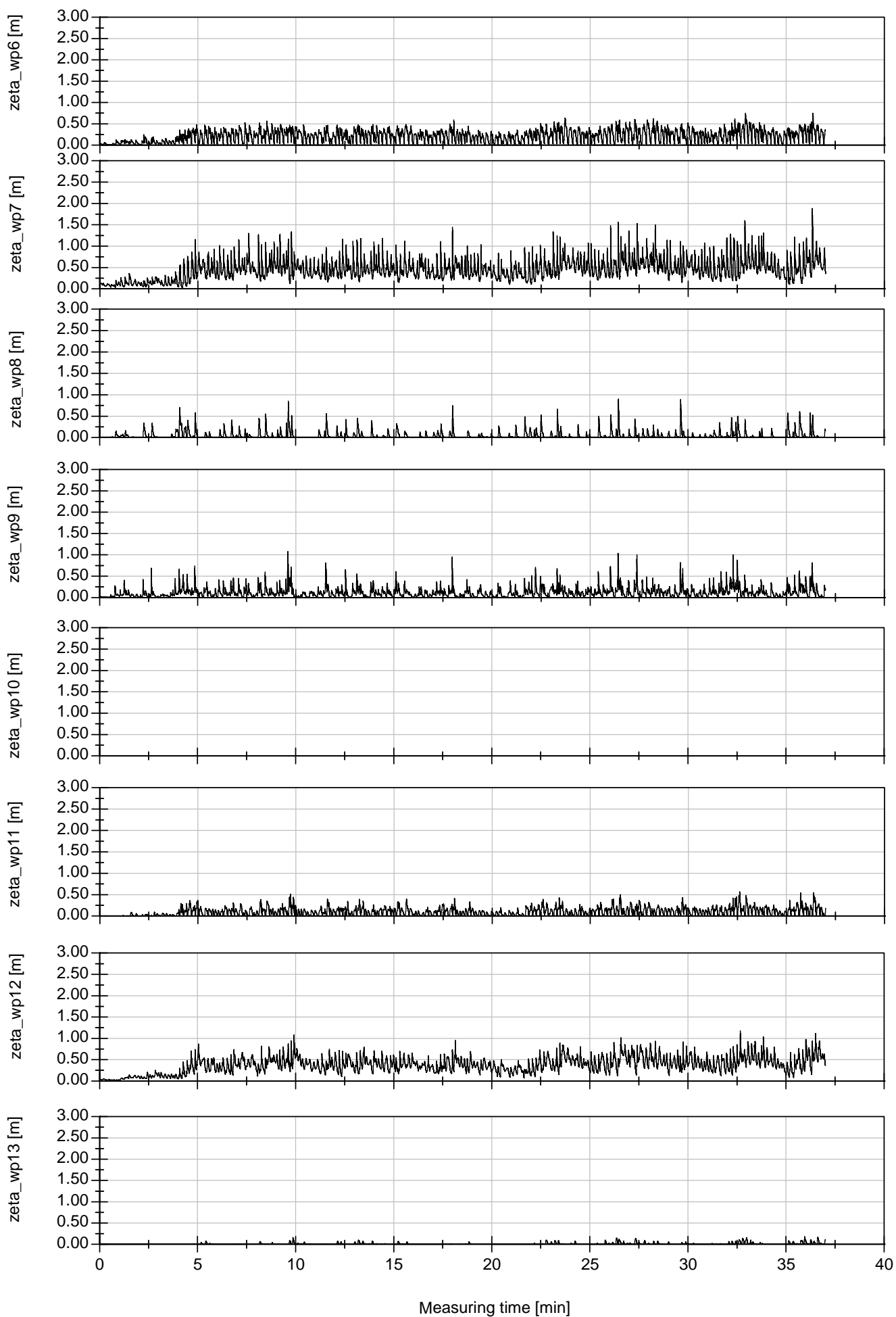
# **Annex B**

## ***Time Histories***

Run-No. 1 / Damage Case 1 /  $H_s = 3.97$  m /  $T_p = 12.0$  s /  $\Gamma = 1.0$

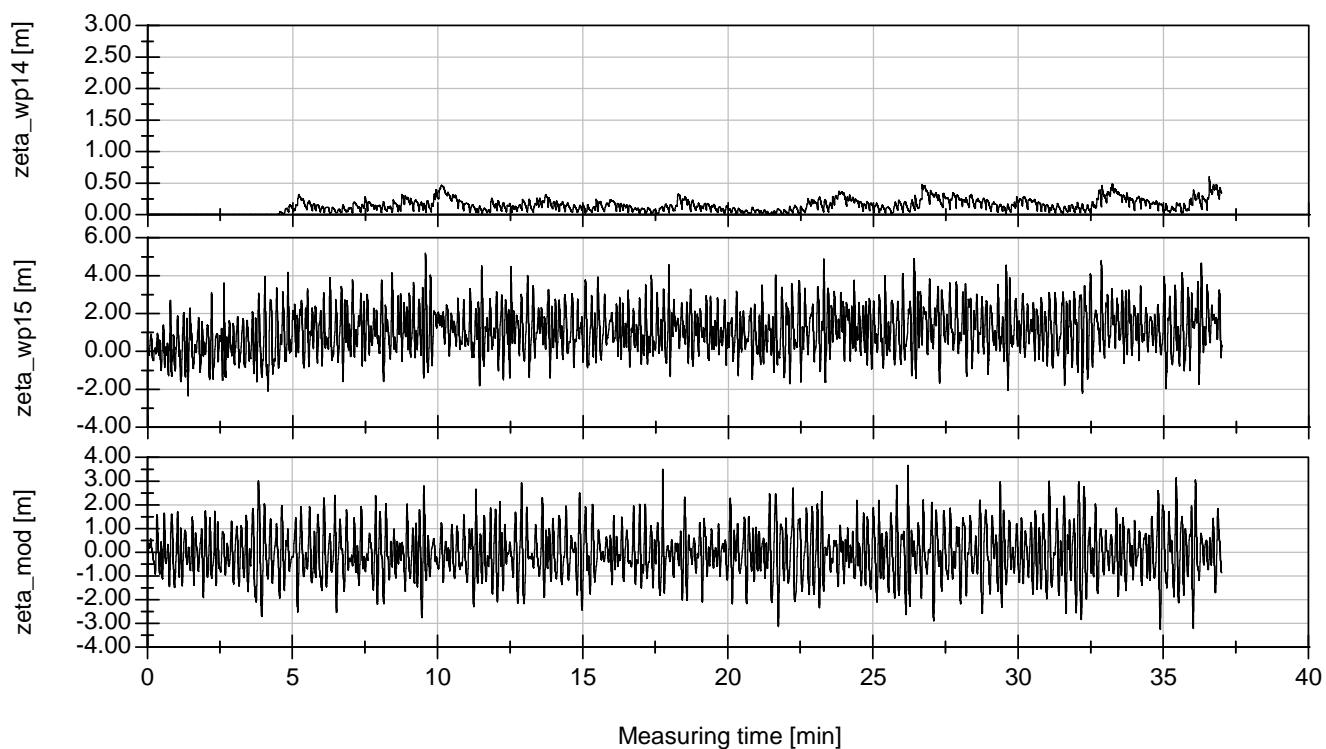


Run-No. 1 / Damage Case 1 /  $H_s = 3.97$  m /  $T_p = 12.0$  s /  $\Gamma = 1.0$

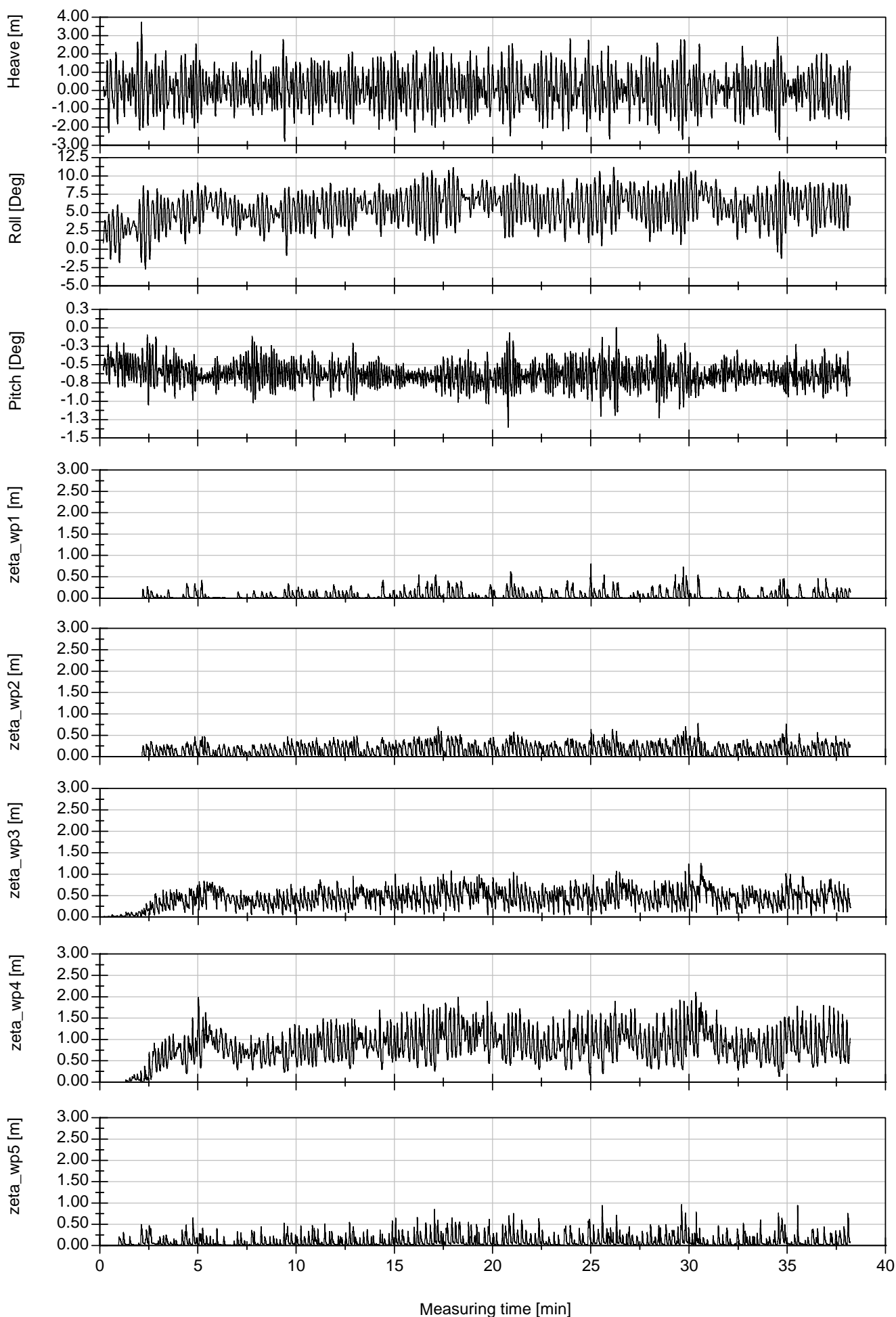




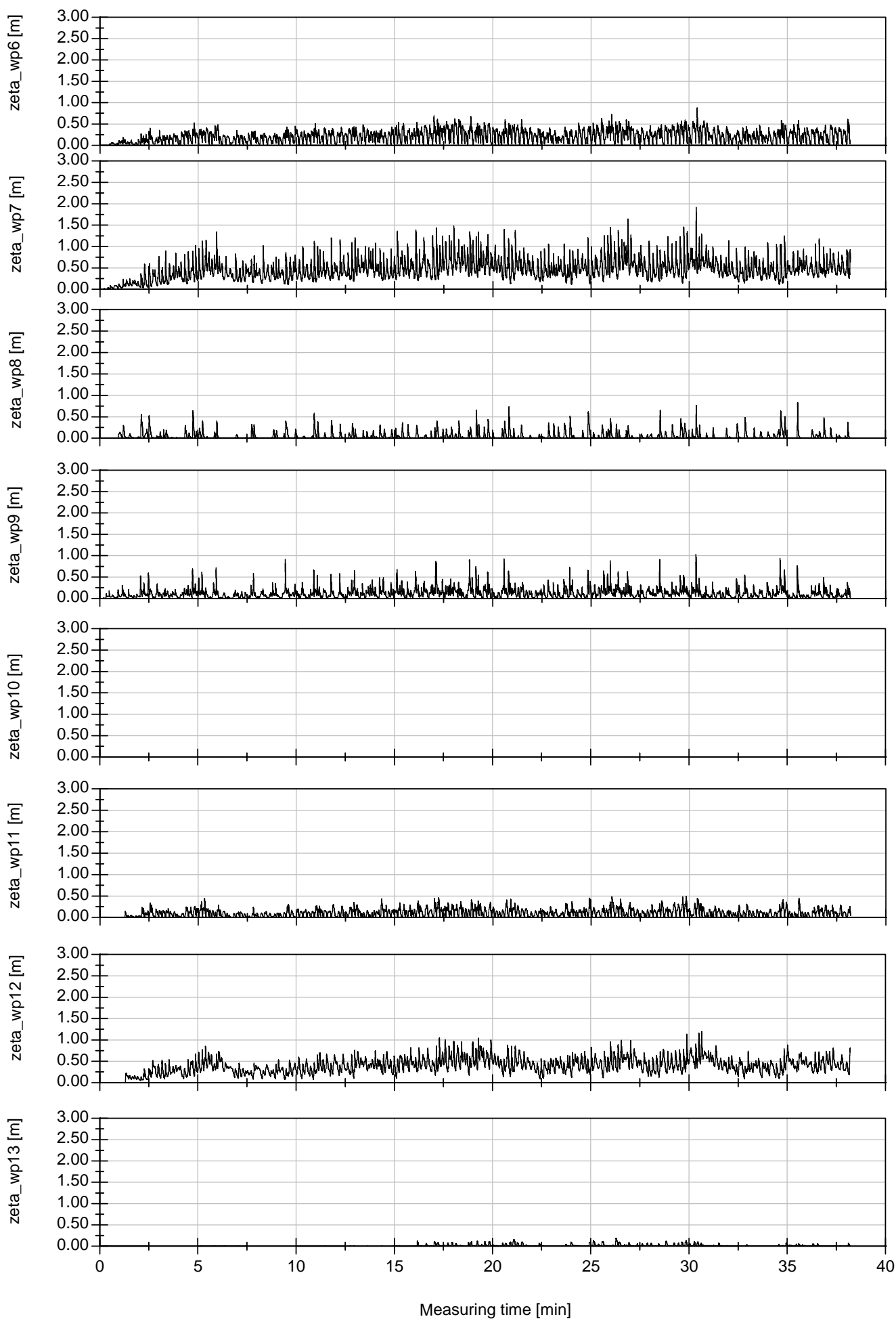
Run-No. 1 / Damage Case 1 /  $H_s = 3.97$  m /  $T_p = 12.0$  s /  $\Gamma = 1.0$



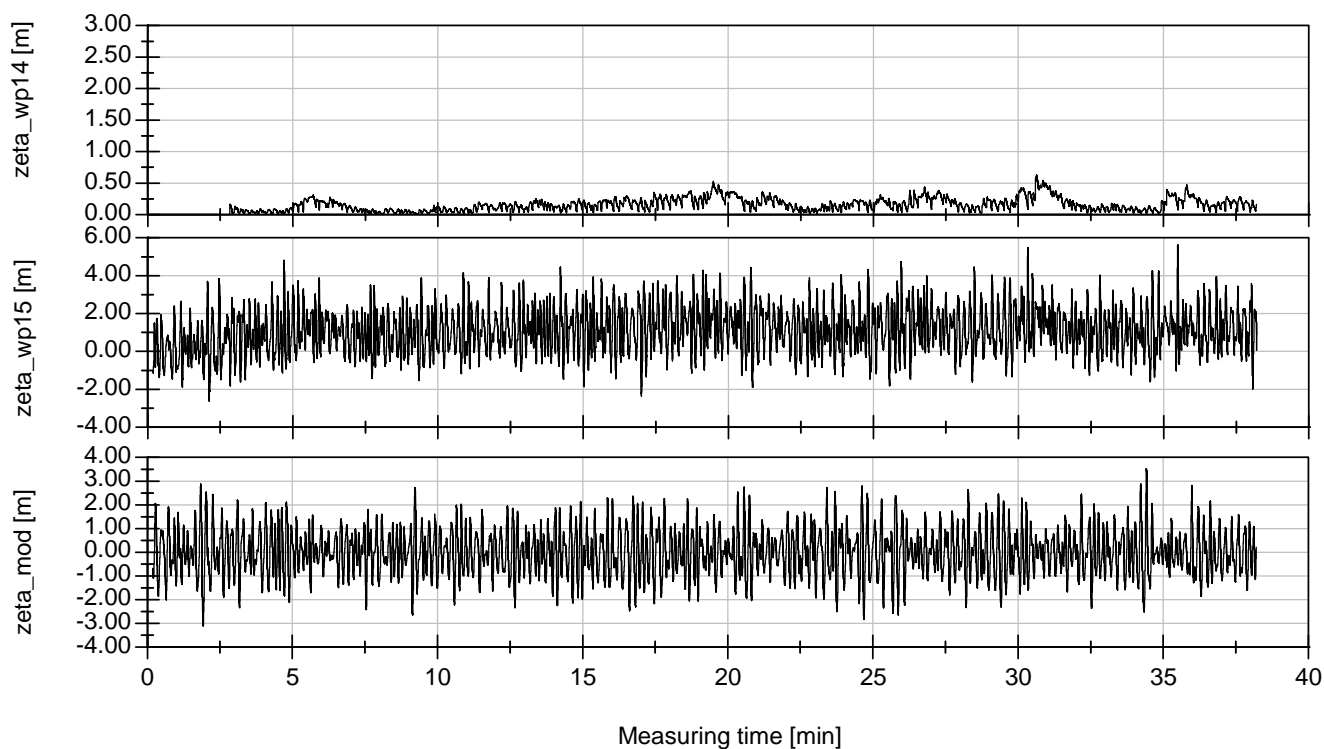
Run-No. 2 / Damage Case 1 /  $H_s = 4.01$  m /  $T_p = 12.0$  s /  $\Gamma = 1.0$



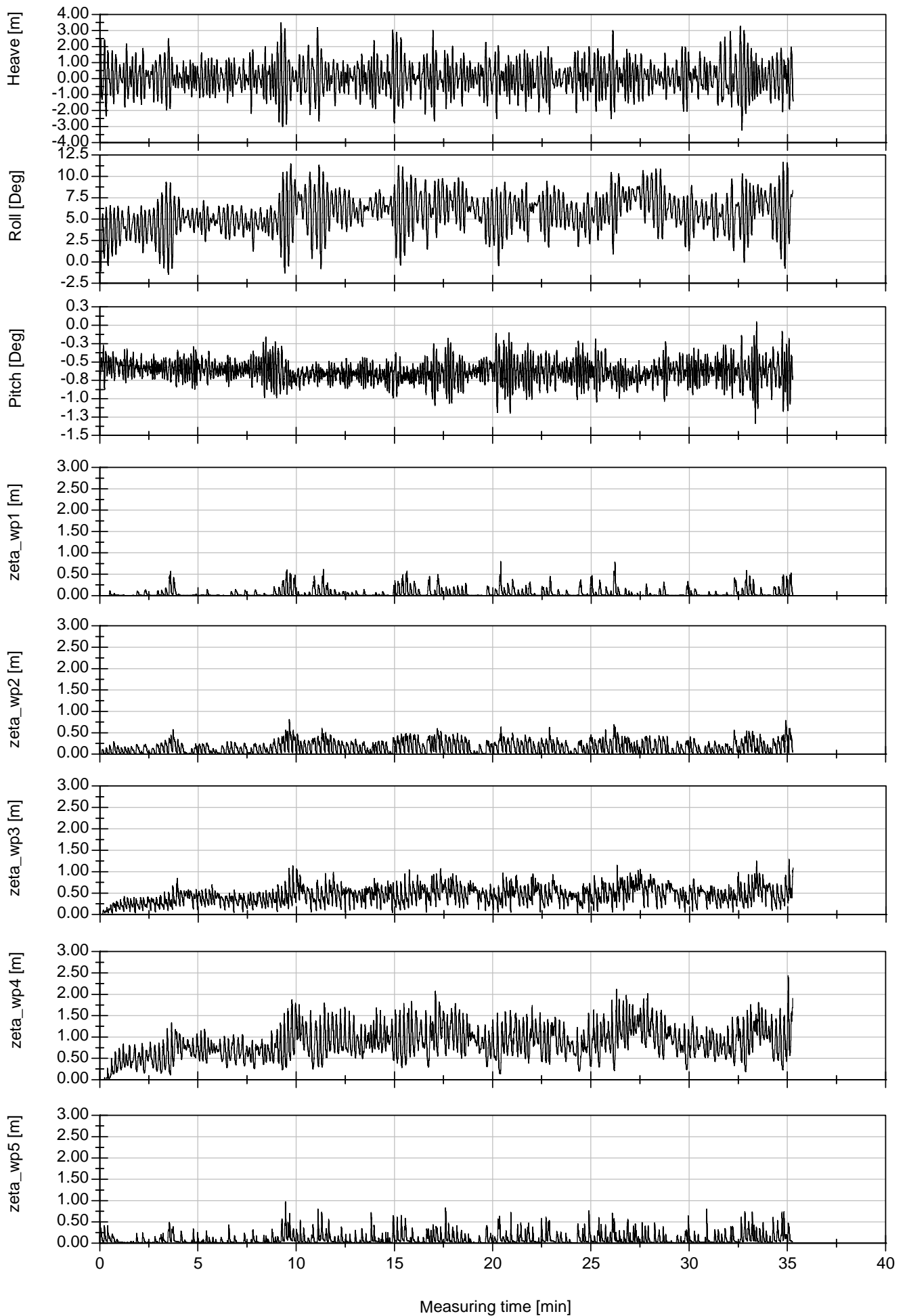
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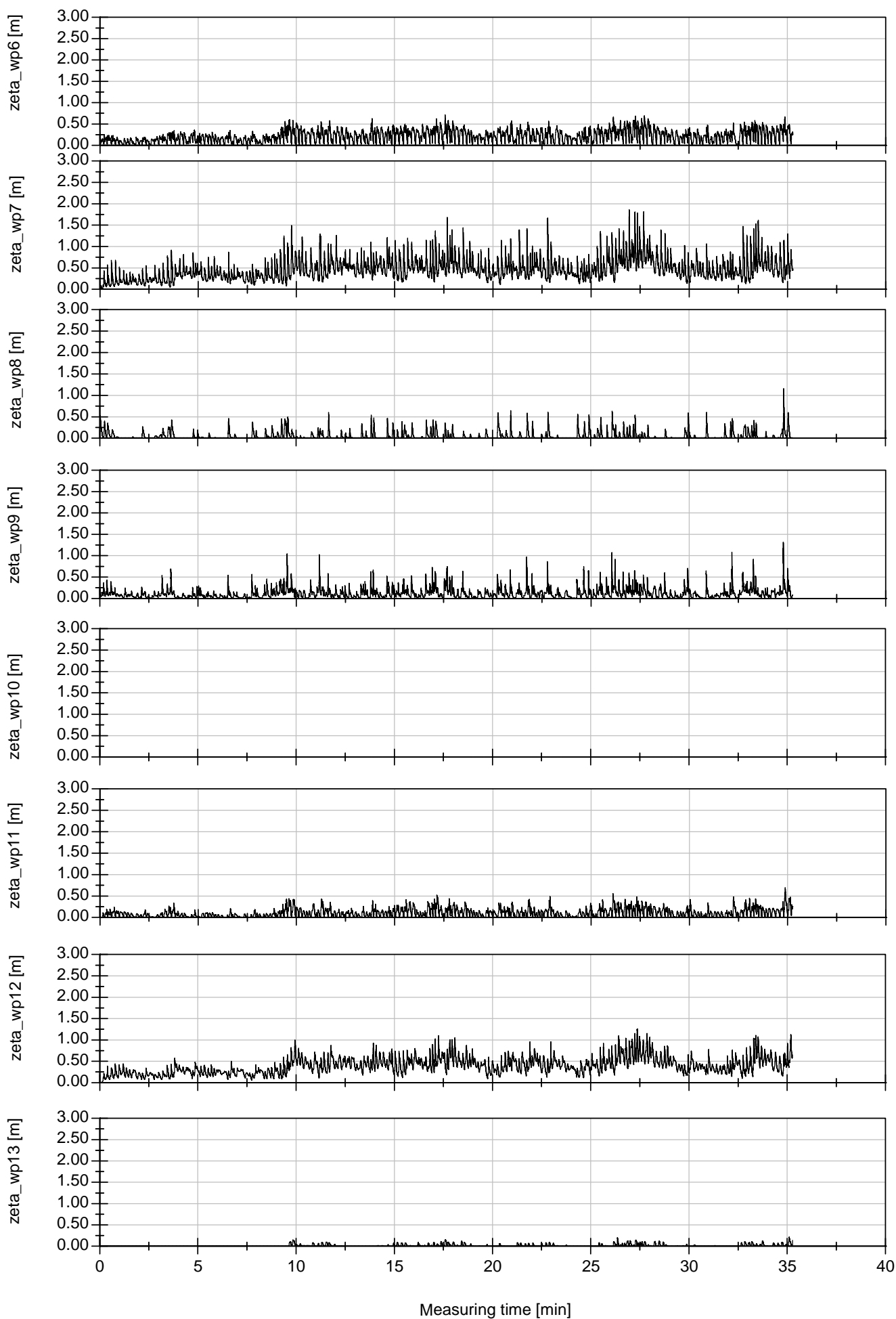
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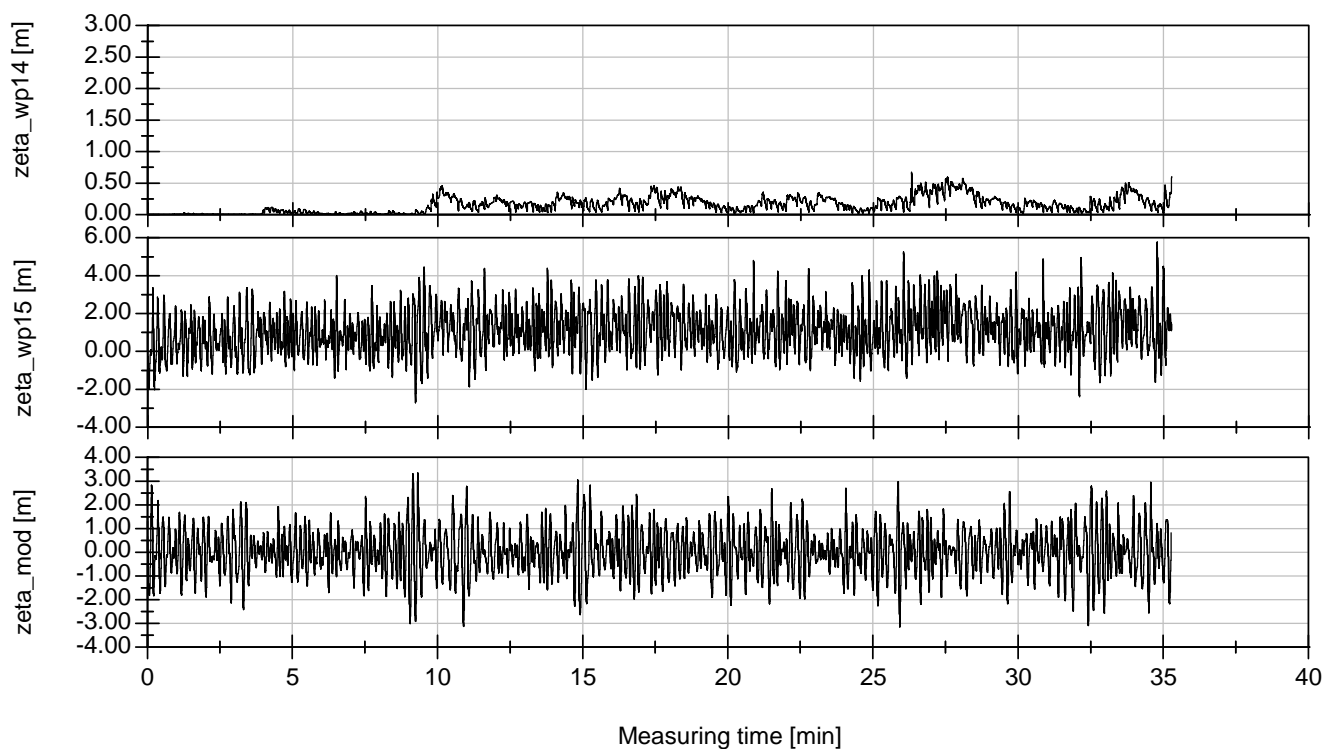
Run-No. 3 / Damage Case 1 /  $H_s = 4.02$  m /  $T_p = 12.0$  s /  $\Gamma = 1.0$



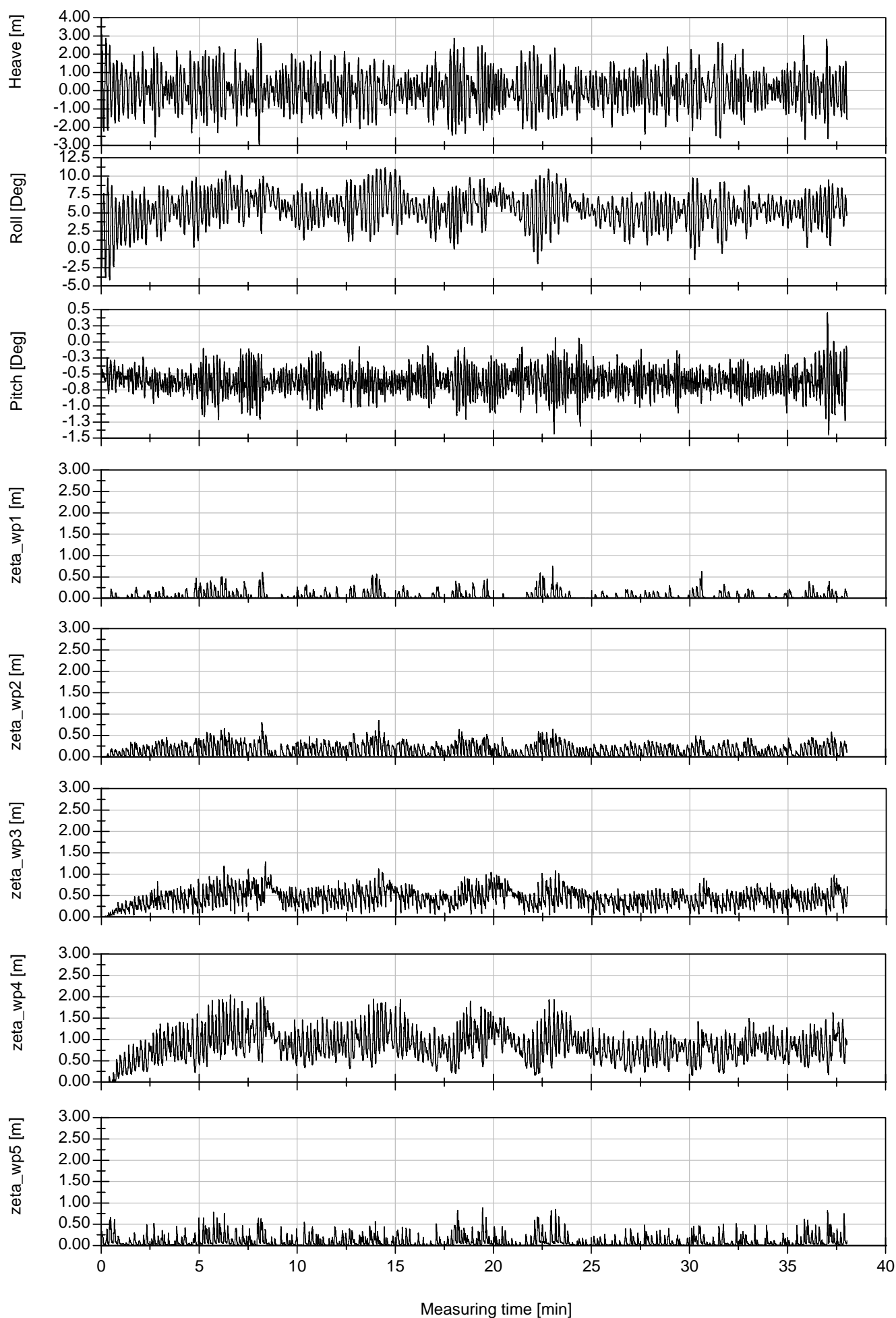
Run-No. 3 / Damage Case 1 /  $H_s = 4.02$  m /  $T_p = 12.0$  s /  $\Gamma = 1.0$



Run-No. 3 / Damage Case 1 /  $H_s = 4.02$  m /  $T_p = 12.0$  s /  $\Gamma = 1.0$

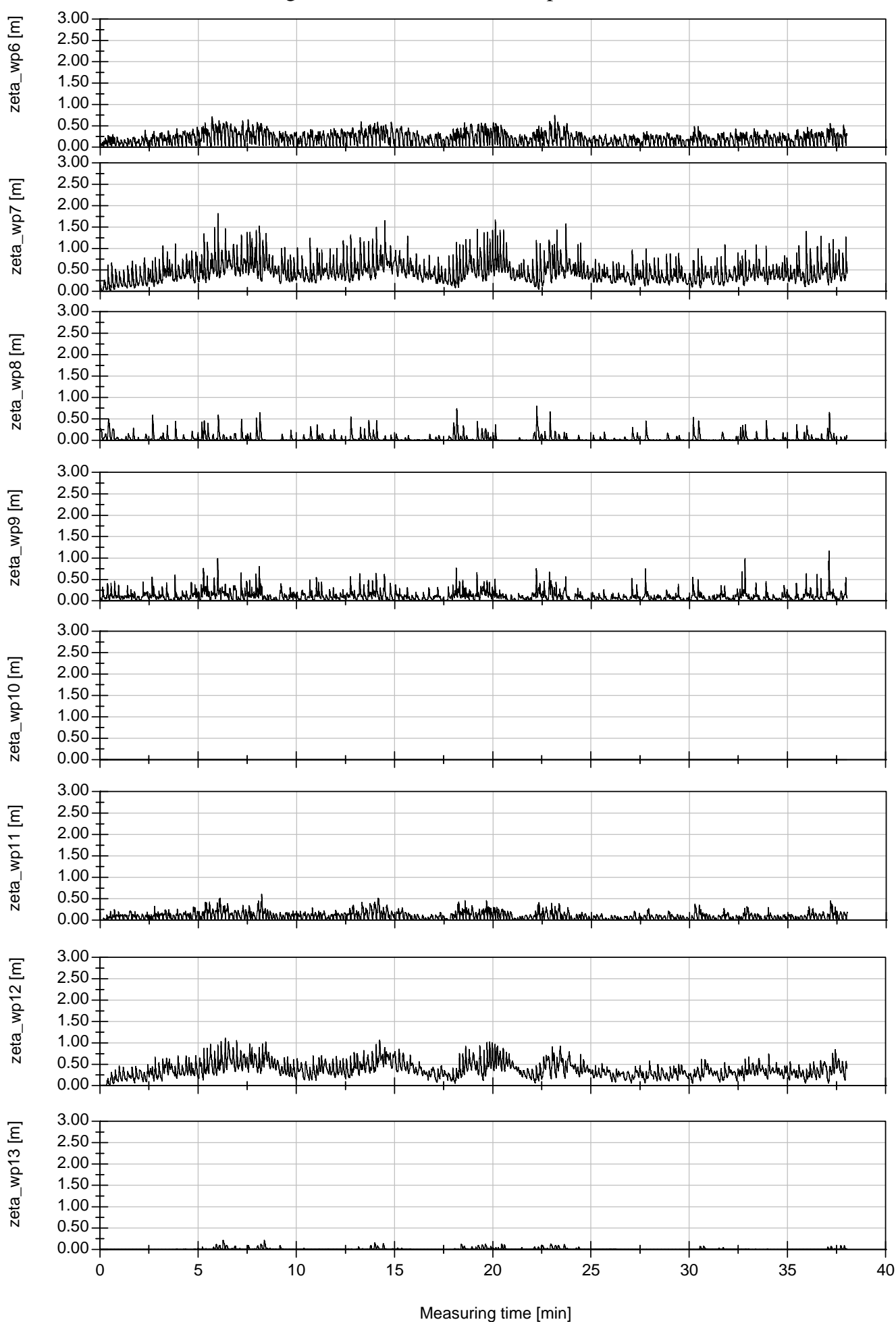


Run-No. 4 / Damage Case 1 /  $H_s = 4.03$  m /  $T_p = 12.0$  s /  $\Gamma = 1.0$

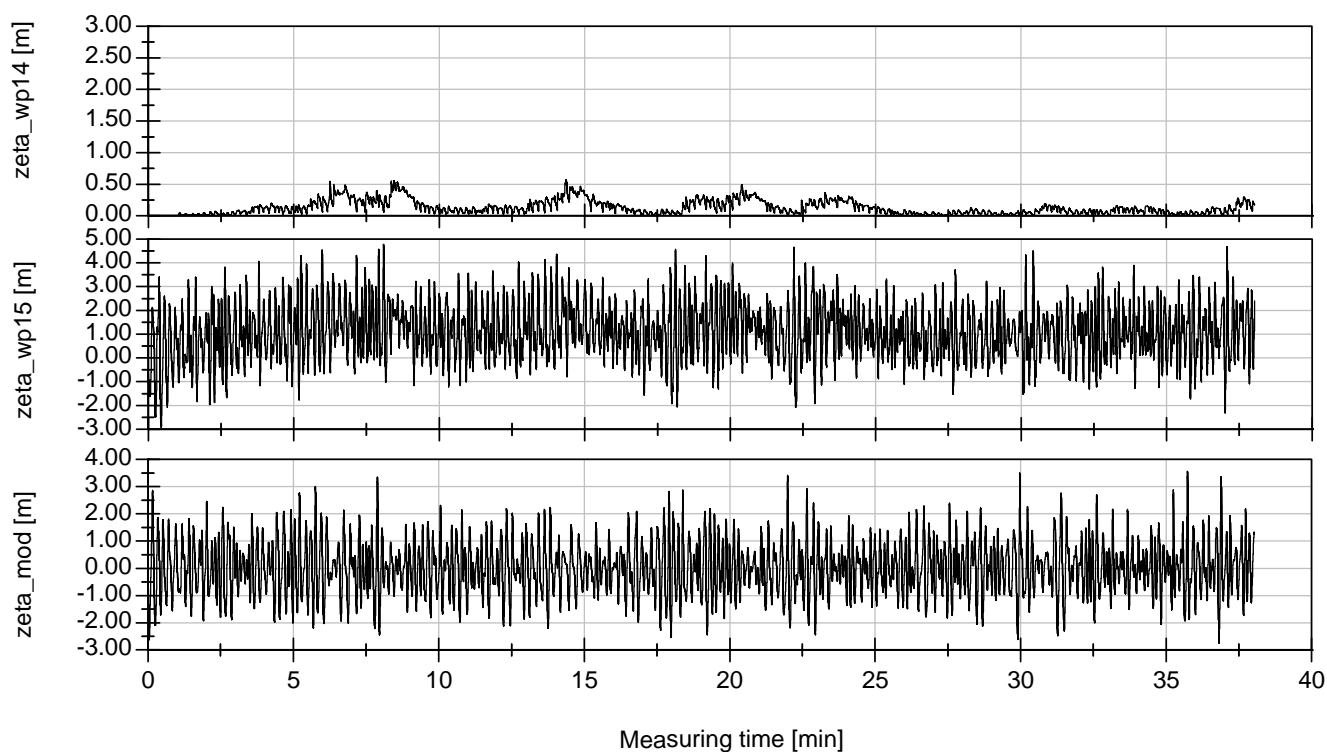




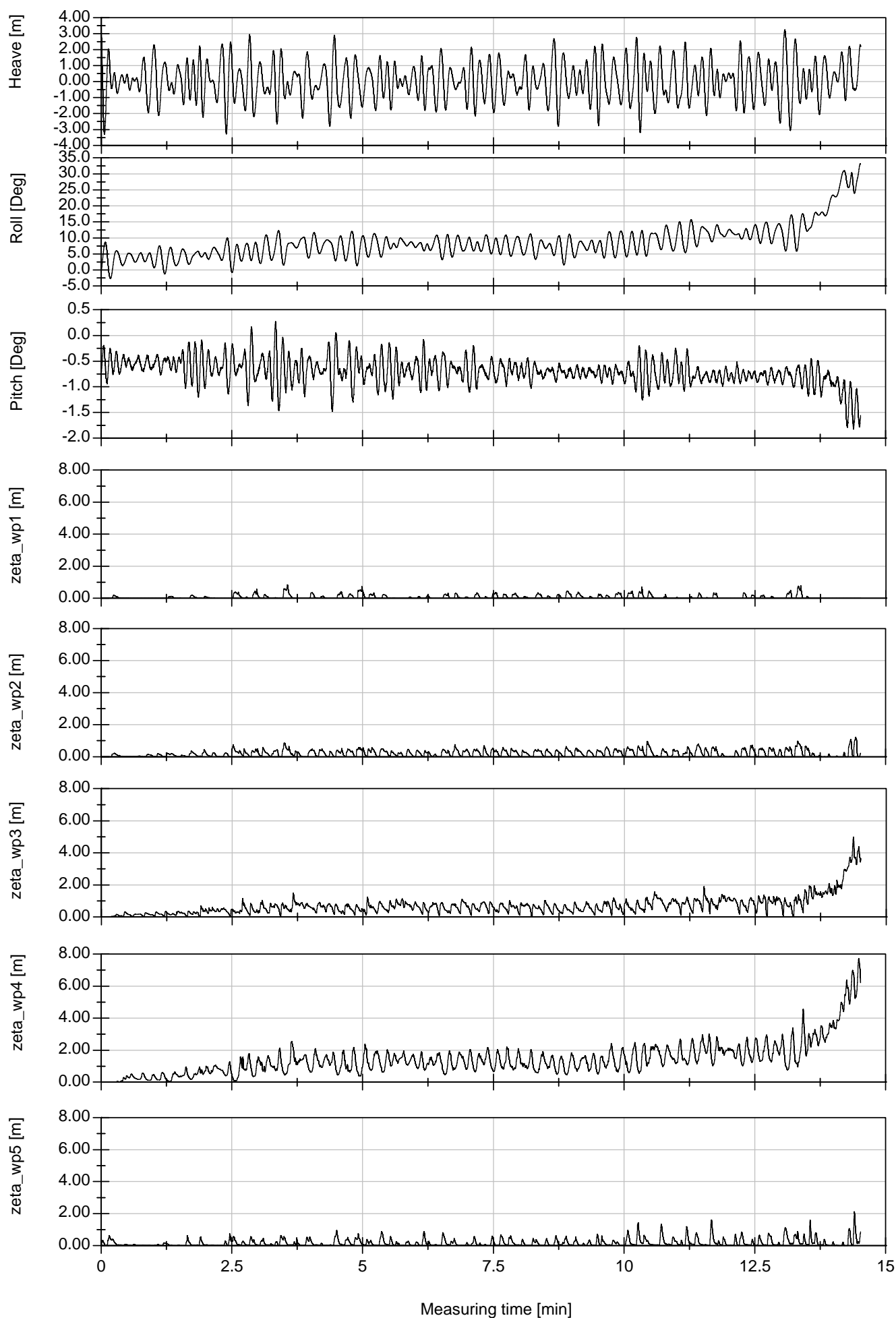
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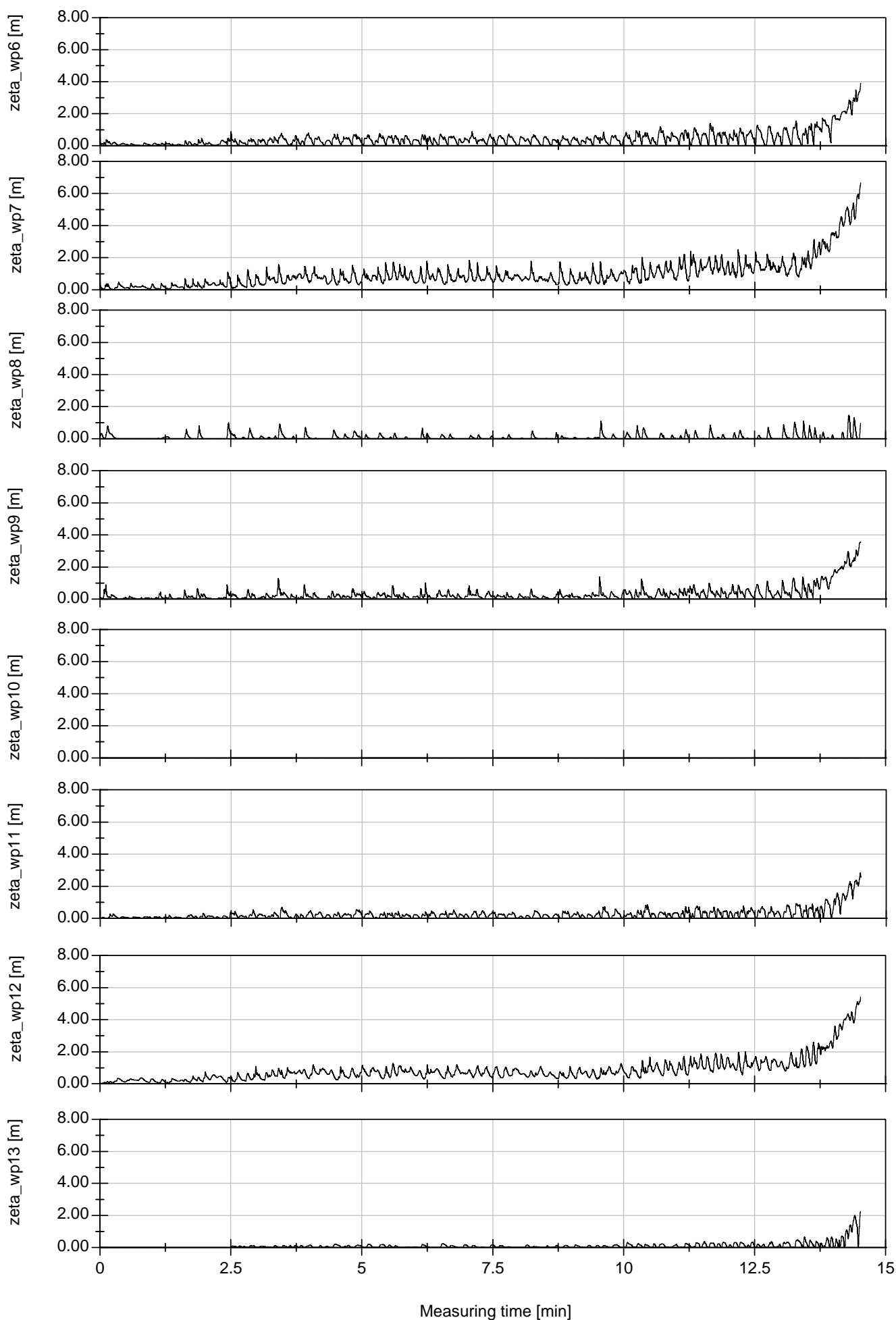
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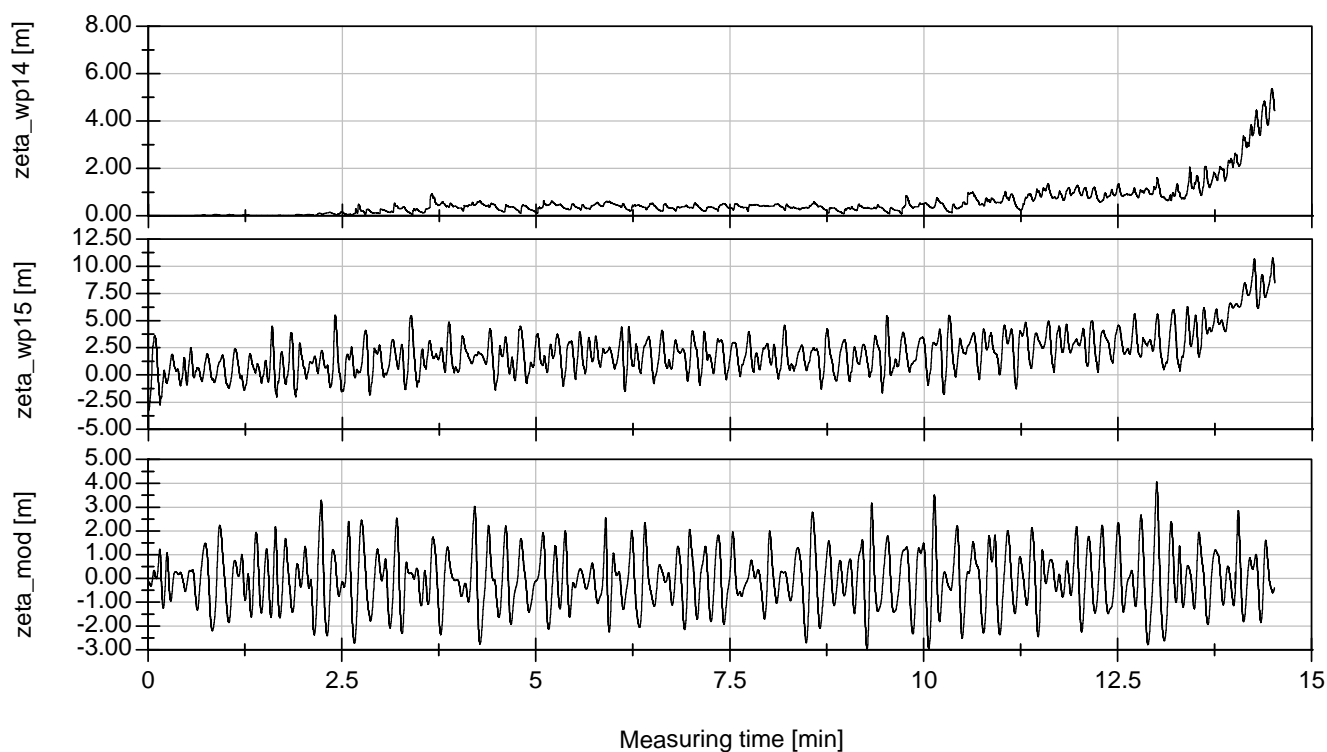
Run-No. 5 / Damage Case 1 /  $H_s = 4.46$  m /  $T_p = 12.0$  s /  $\Gamma = 1.0$



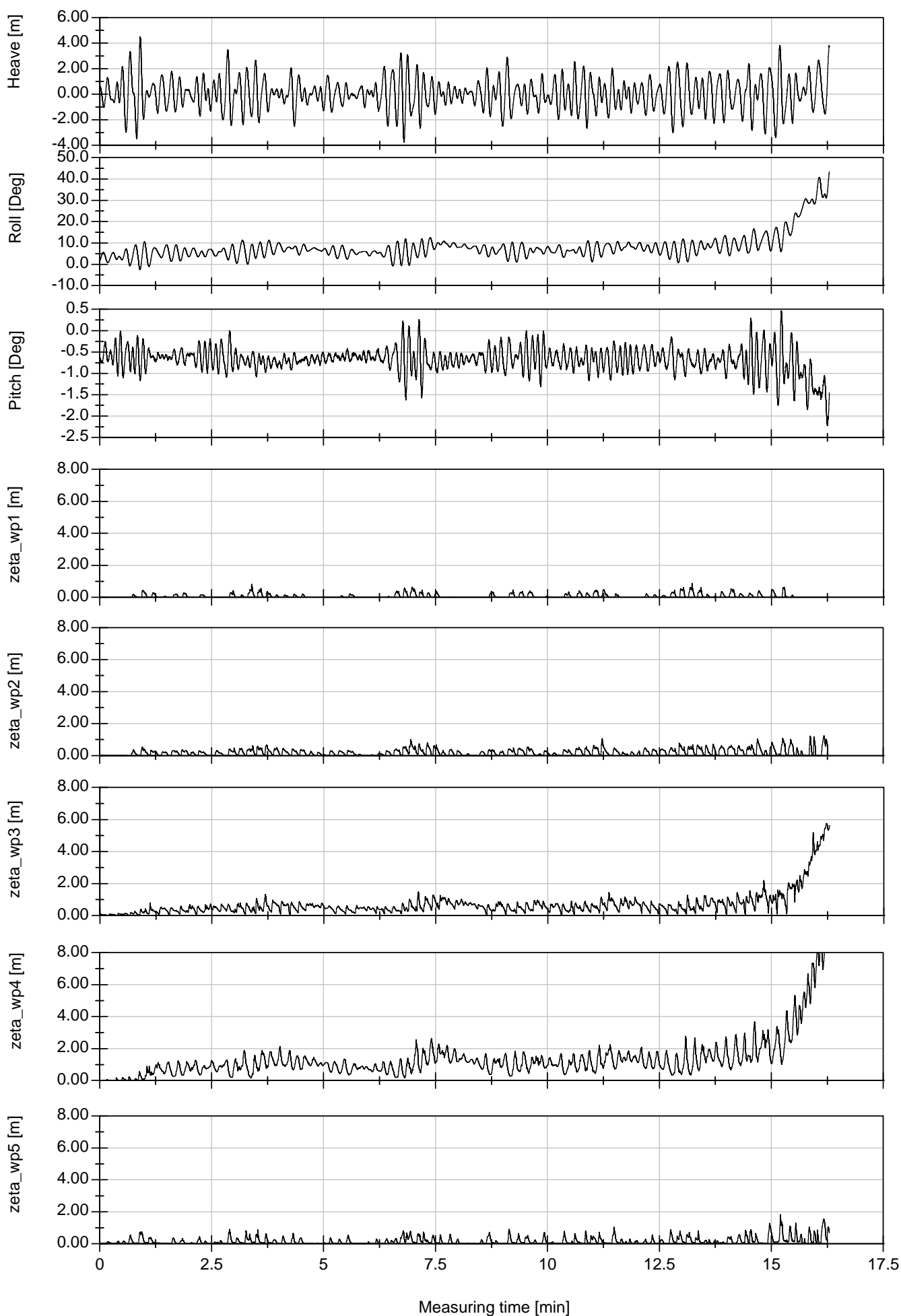
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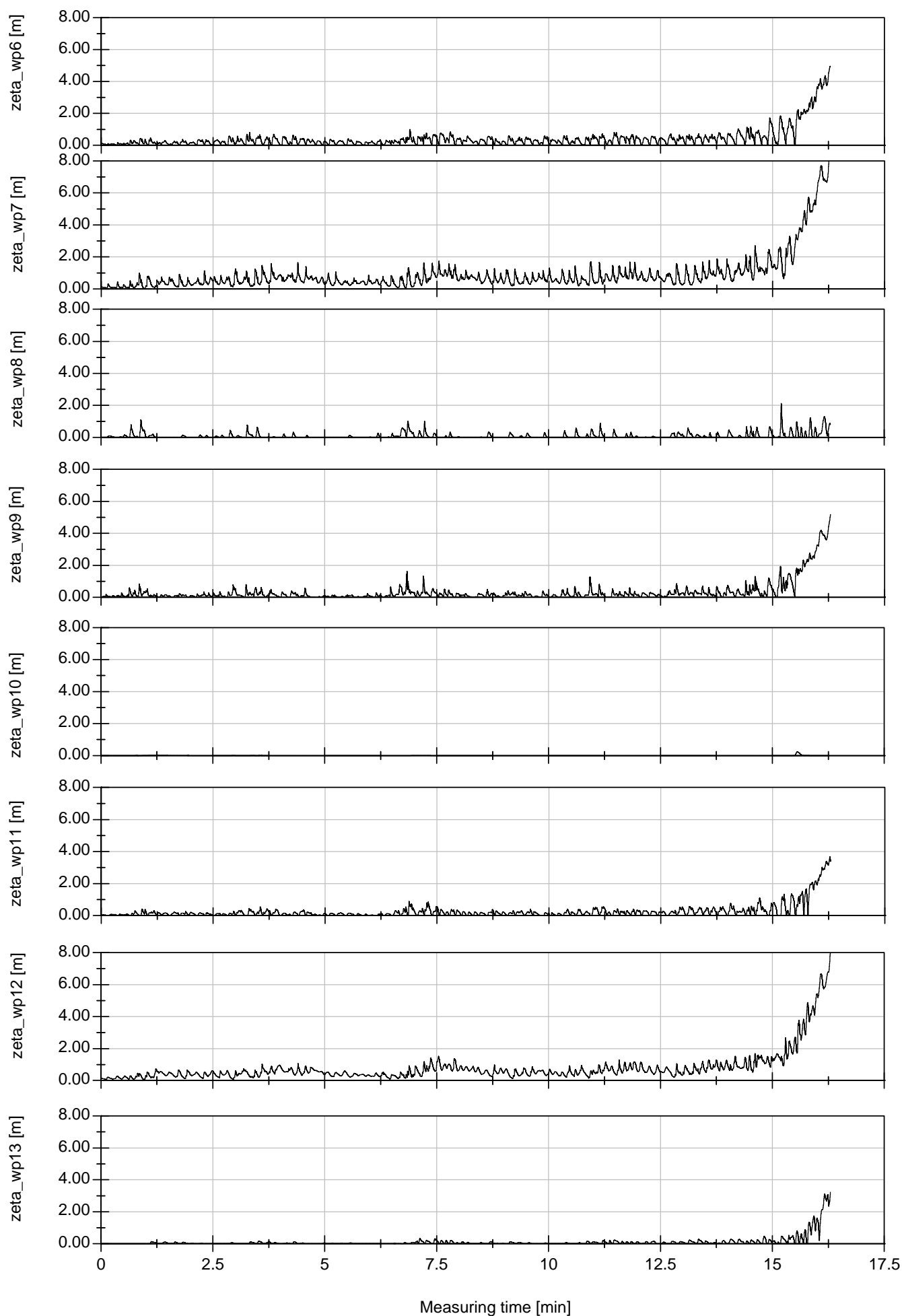
Run-No. 5 / Damage Case 1 /  $H_s = 4.46$  m /  $T_p = 12.0$  s /  $\Gamma = 1.0$



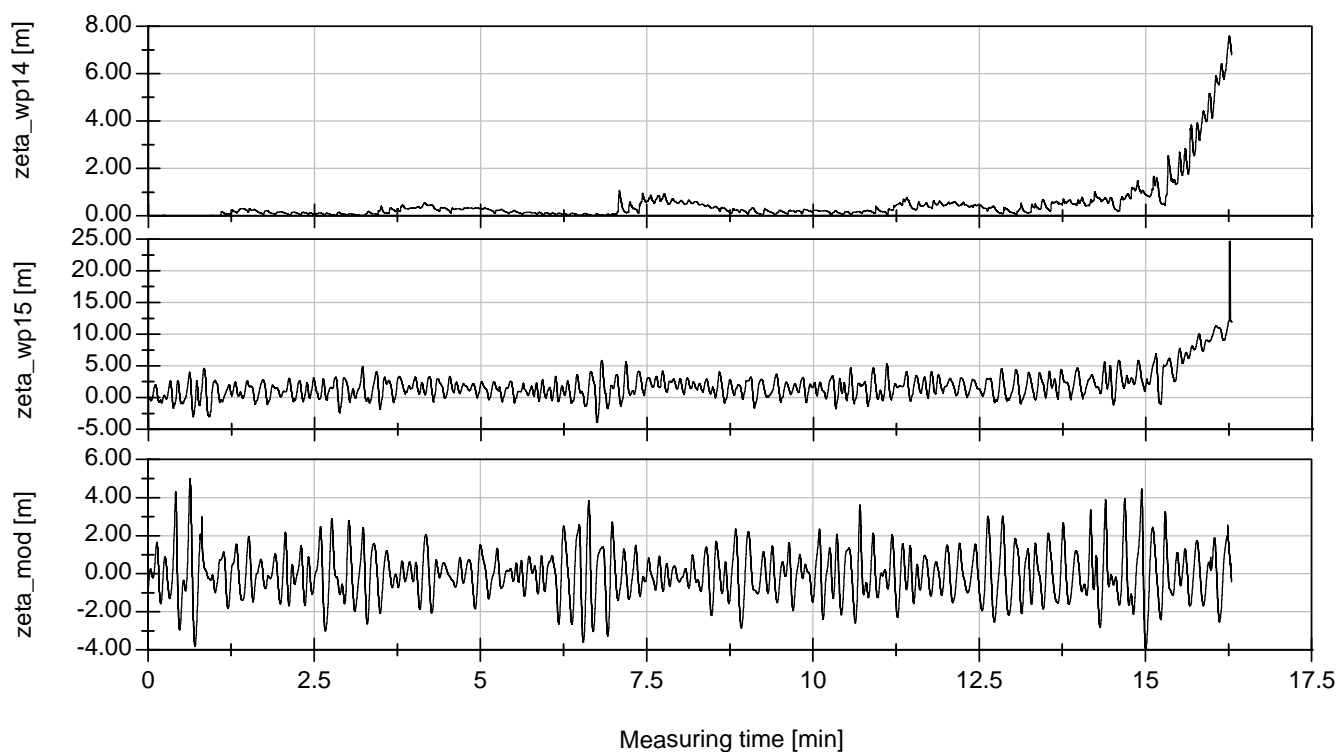
Run-No. 6 / Damage Case 1 /  $H_s = 4.87$  m /  $T_p = 12.2$  s /  $\Gamma = 1.0$



Run-No. 6 / Damage Case 1 /  $H_s = 4.87$  m /  $T_p = 12.2$  s /  $\Gamma = 1.0$

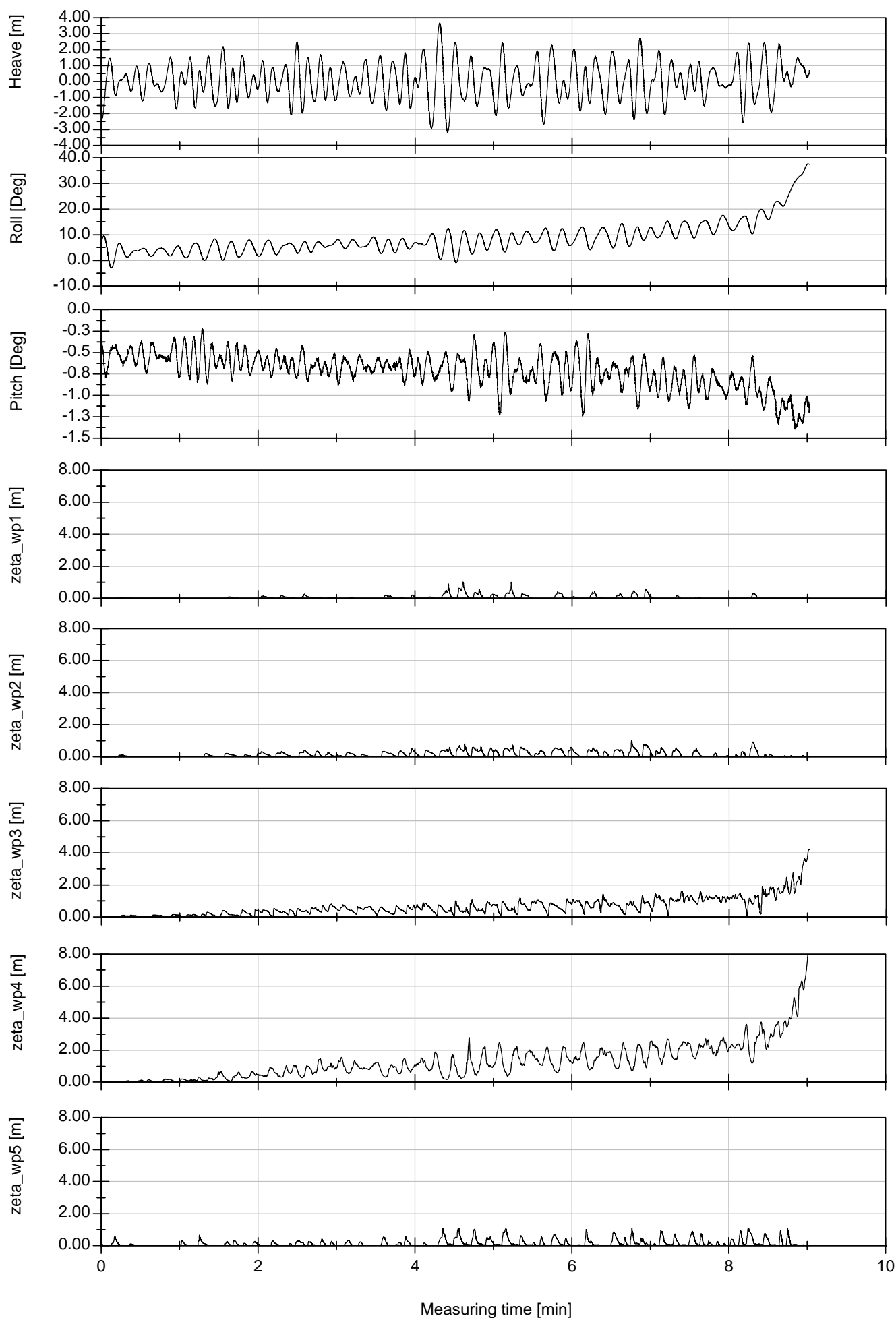


Run-No. 6 / Damage Case 1 /  $H_s = 4.87$  m /  $T_p = 12.2$  s /  $\Gamma = 1.0$

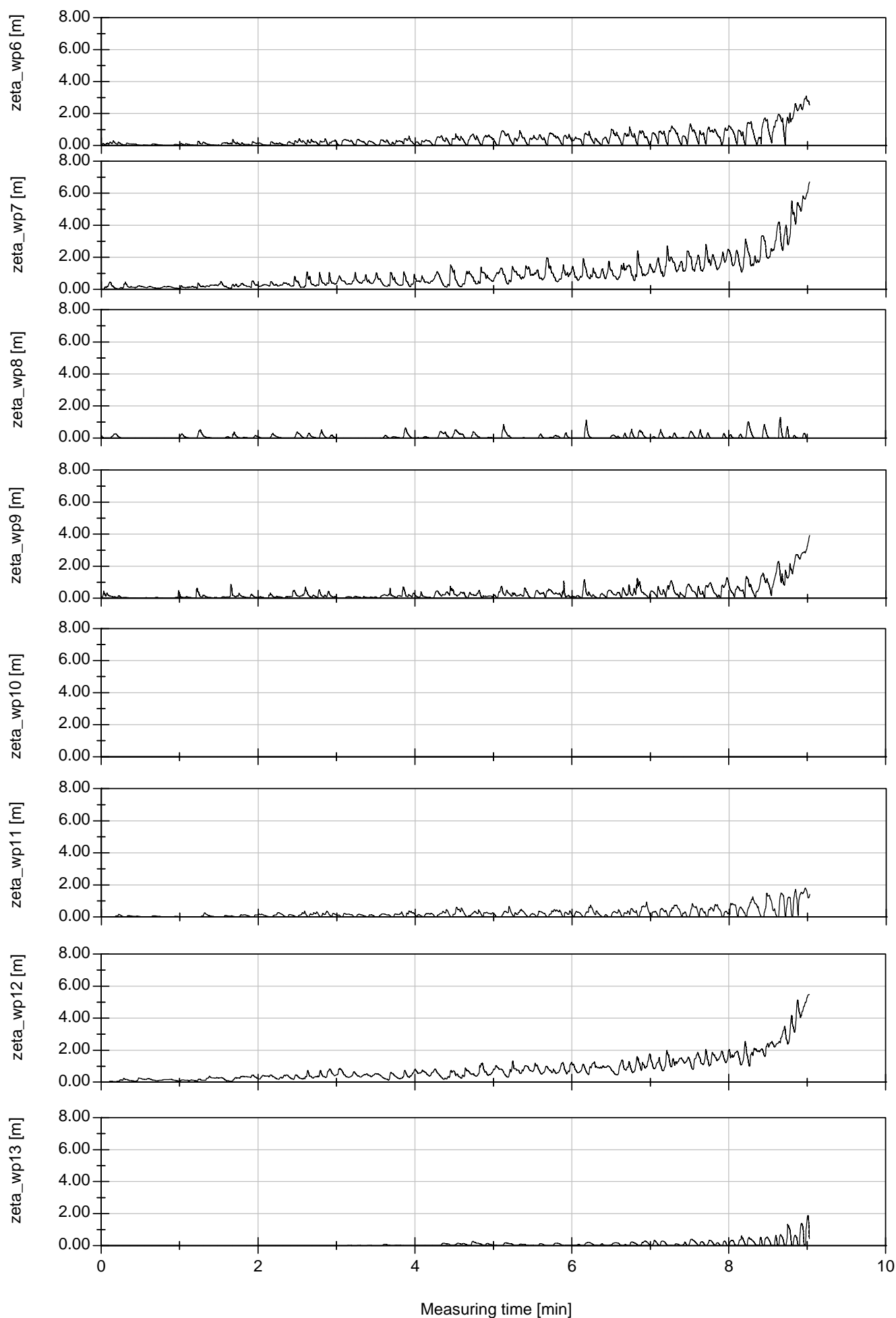




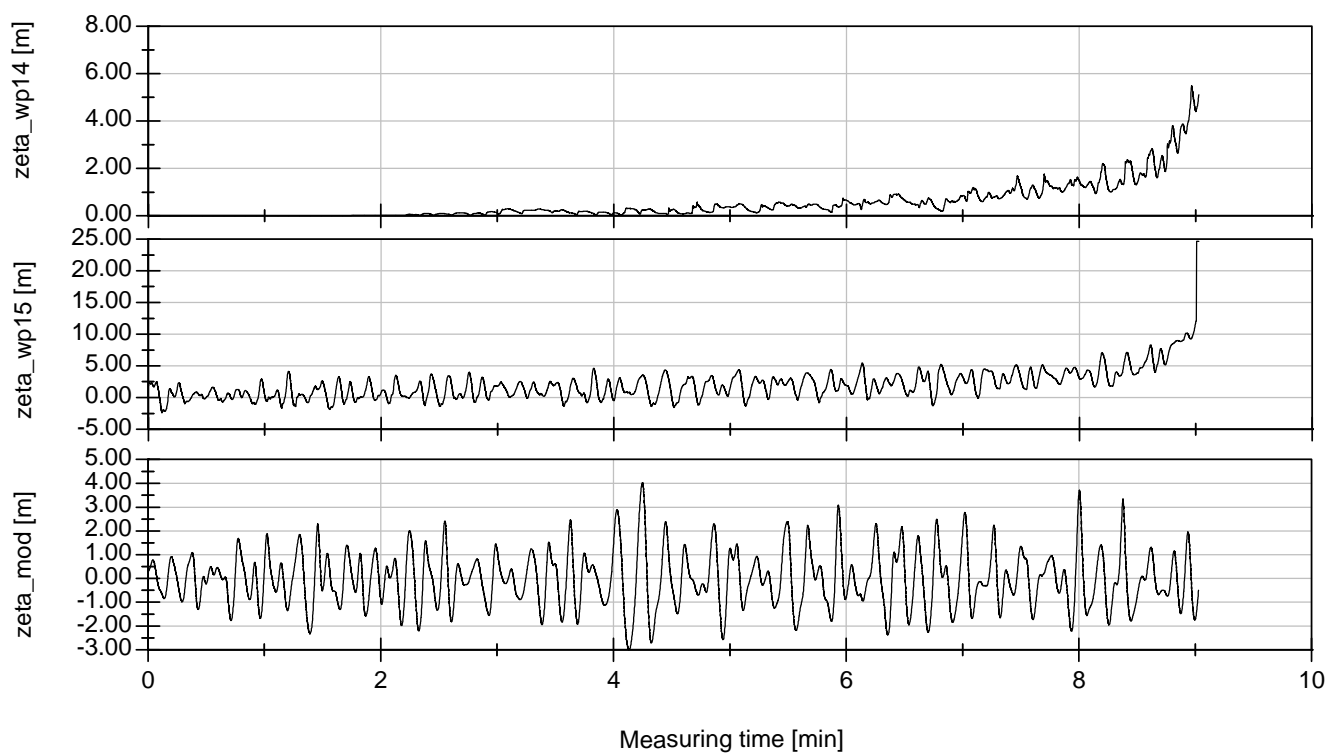
Run-No. 7 / Damage Case 1 /  $H_s = 4.32$  m /  $T_p = 11.6$  s /  $\Gamma = 1.0$



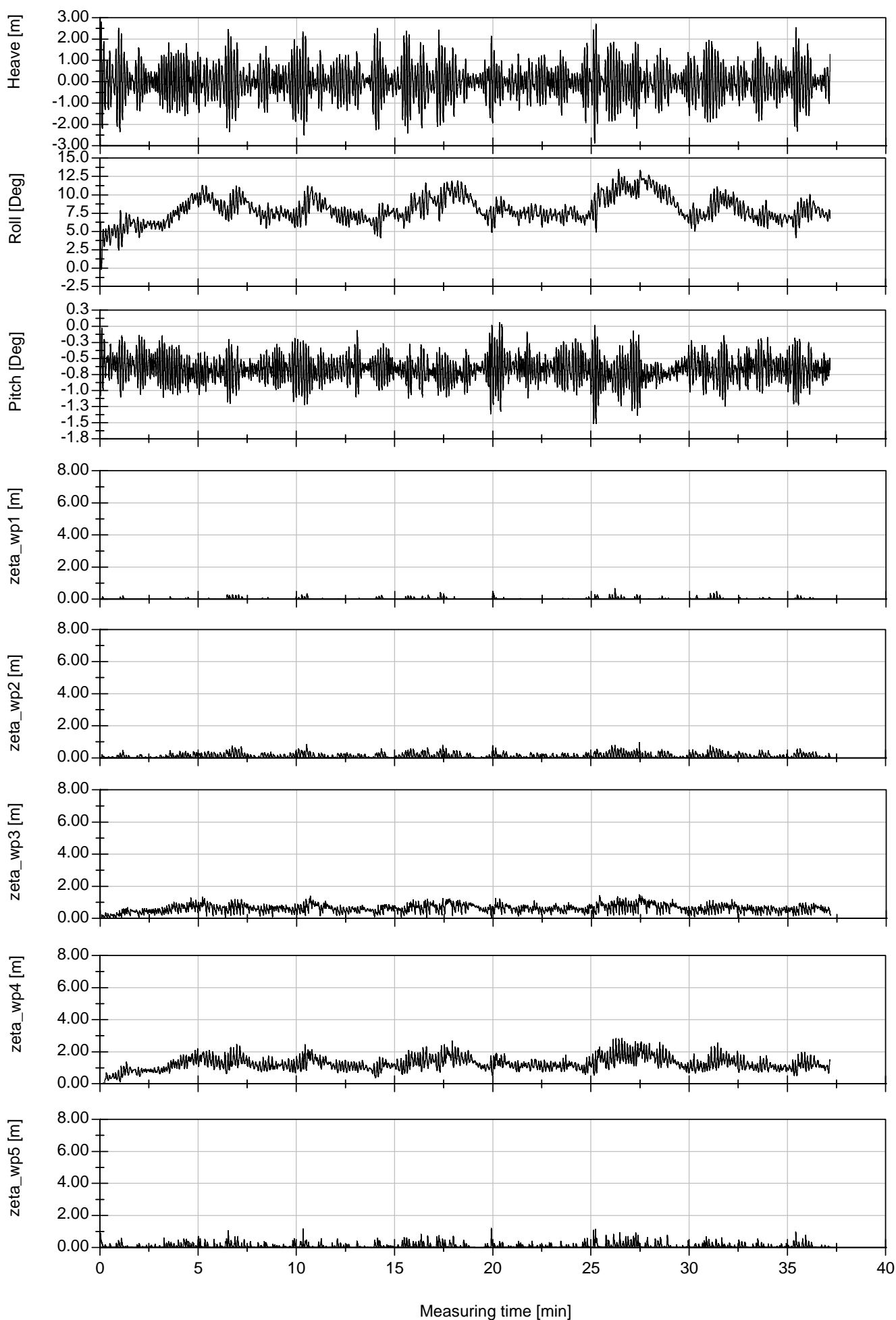
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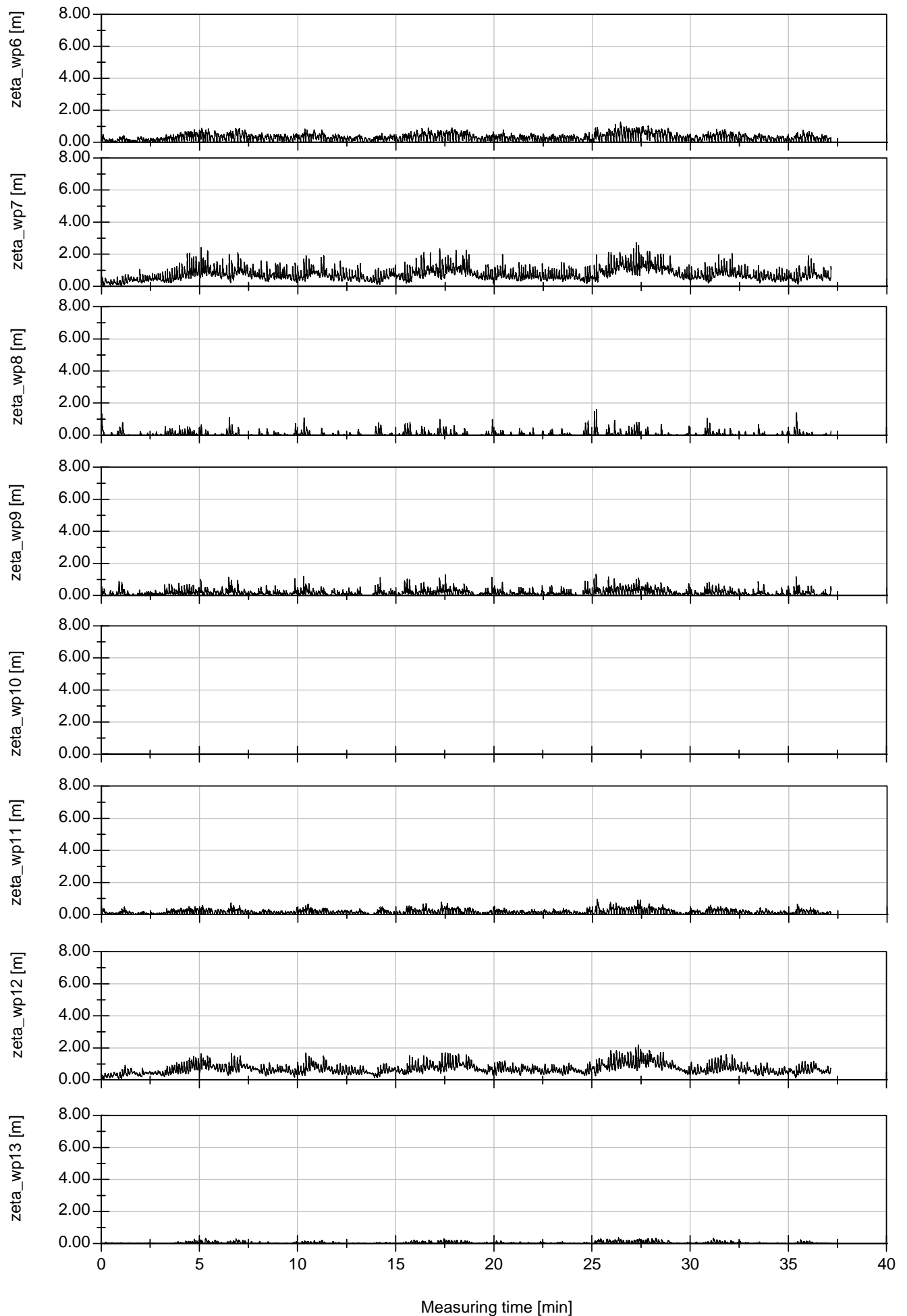
Run-No. 7 / Damage Case 1 /  $H_s = 4.32$  m /  $T_p = 11.6$  s /  $\Gamma = 1.0$



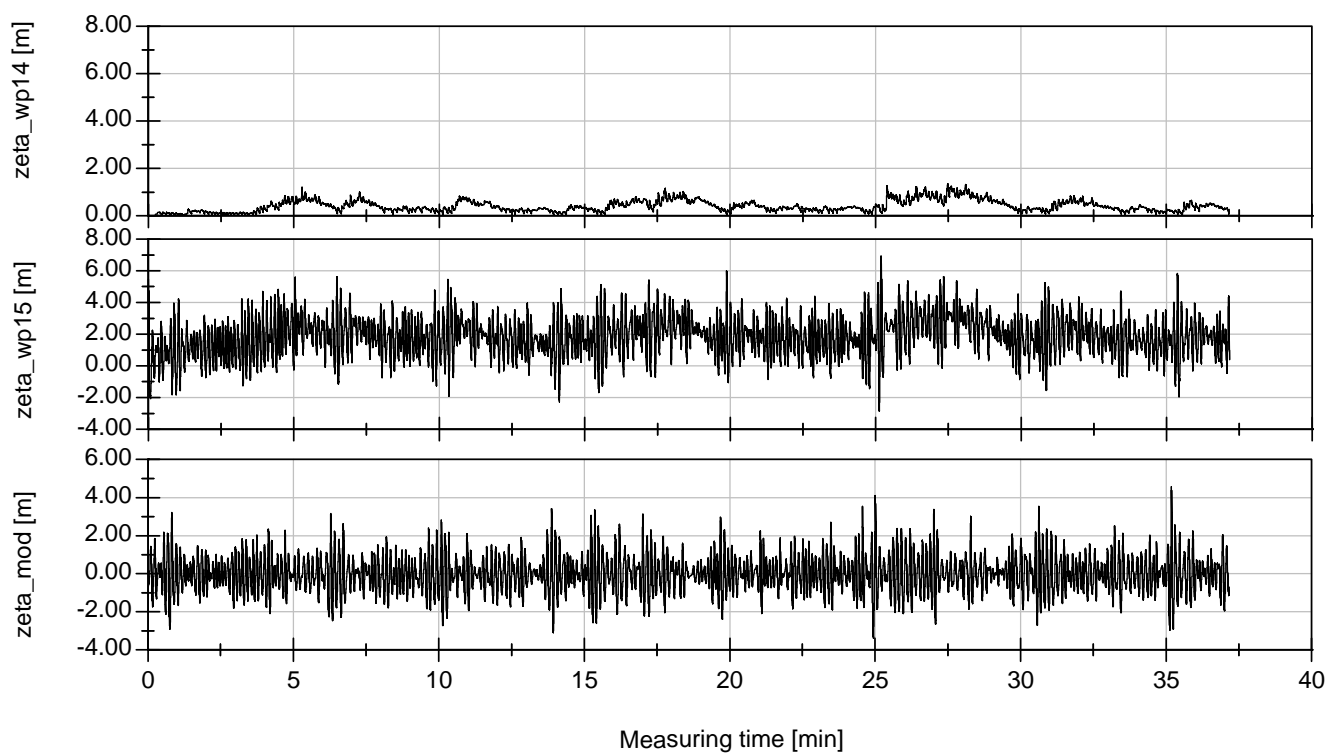
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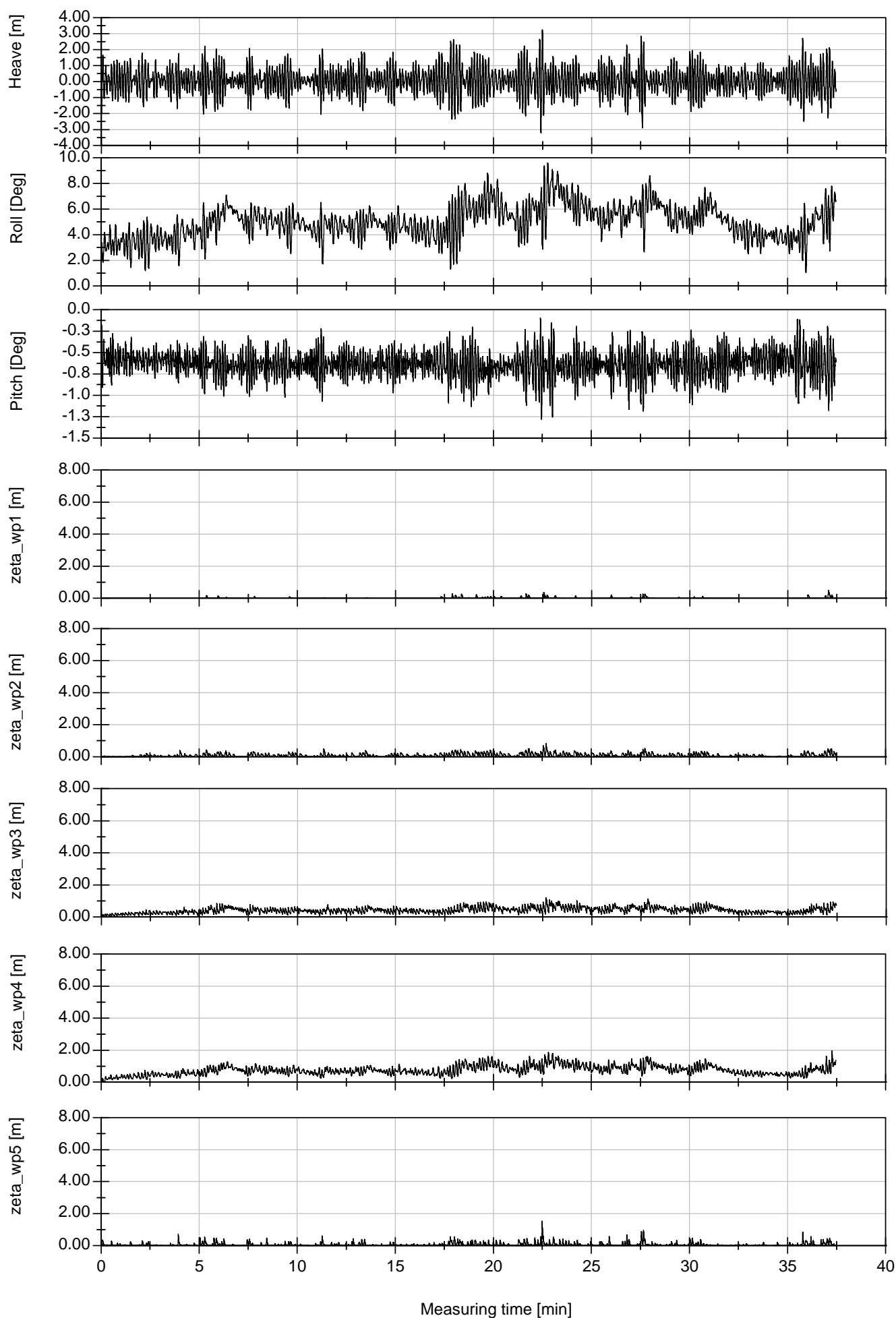
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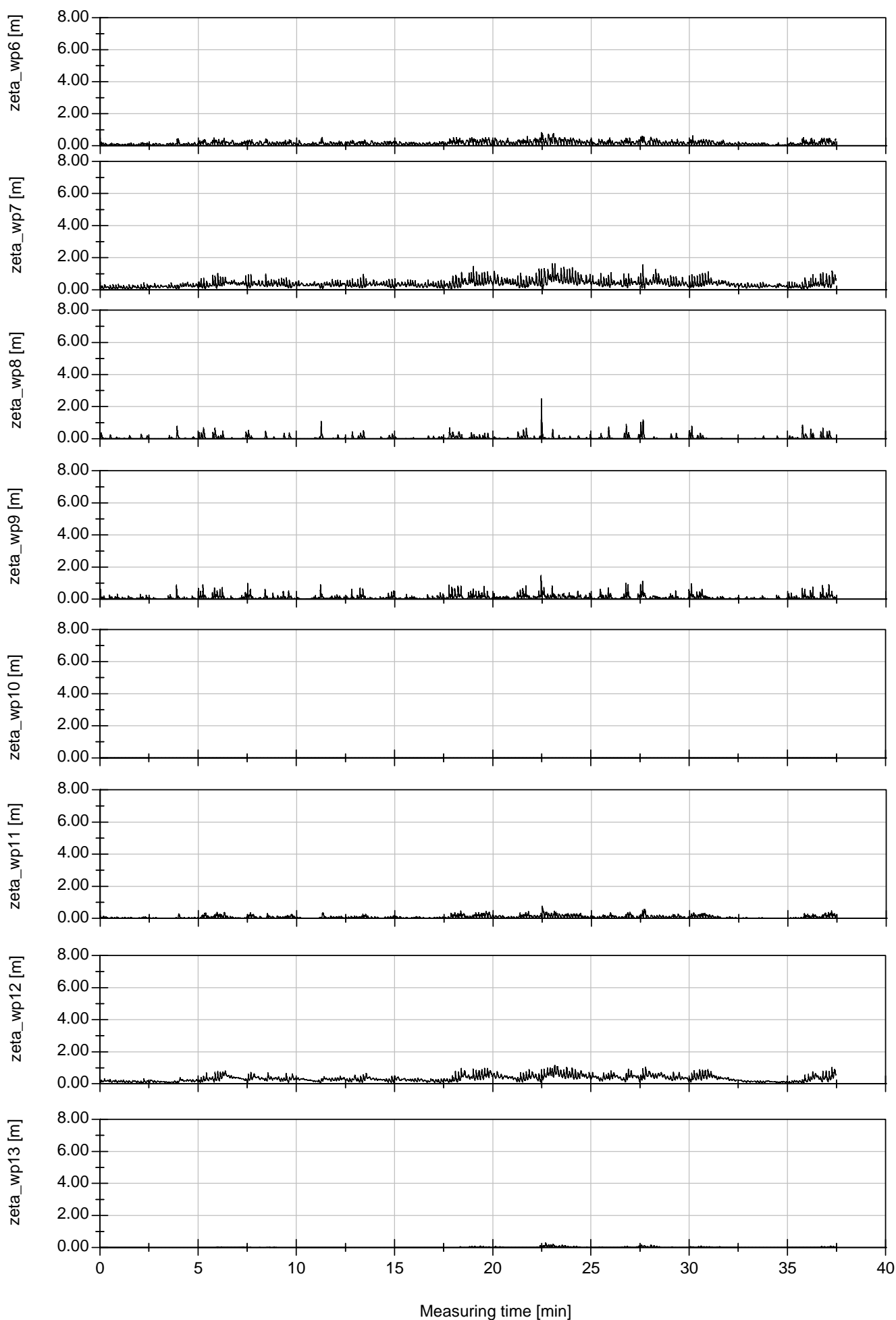
Run-No. 8 / Damage Case 1 /  $H_s = 3.81$  m /  $T_p = 8.4$  s /  $\Gamma = 3.3$



Run-No. 9 / Damage Case 1 /  $H_s = 3.73$  m /  $T_p = 8.4$  s /  $\Gamma = 3.3$

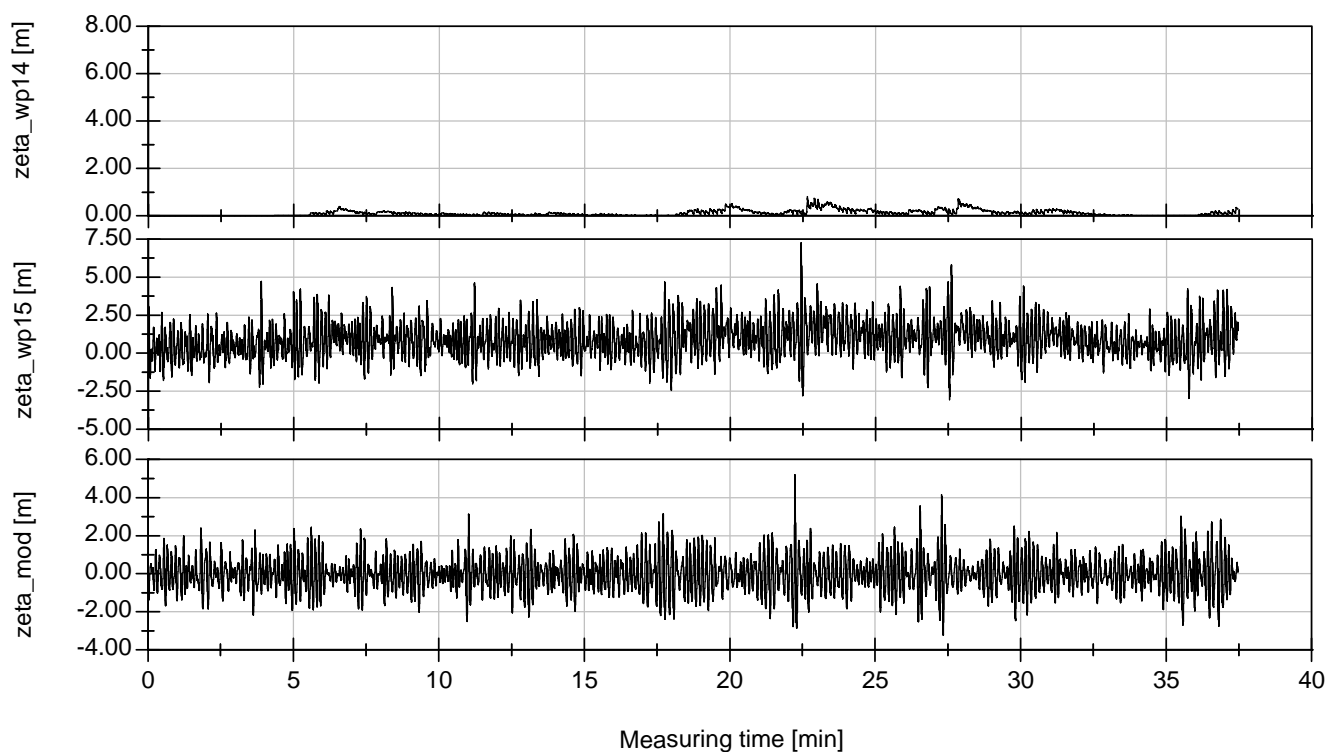


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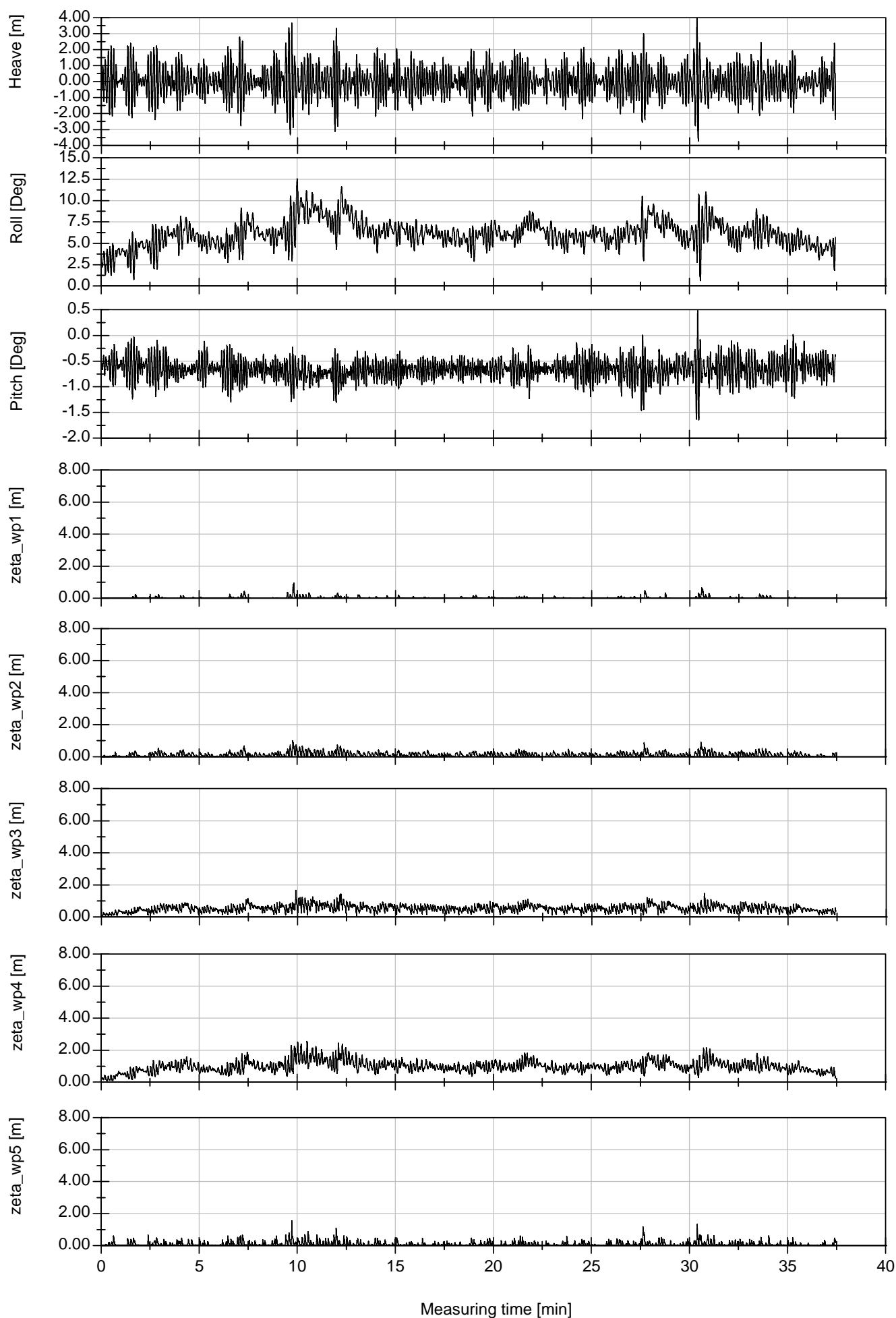




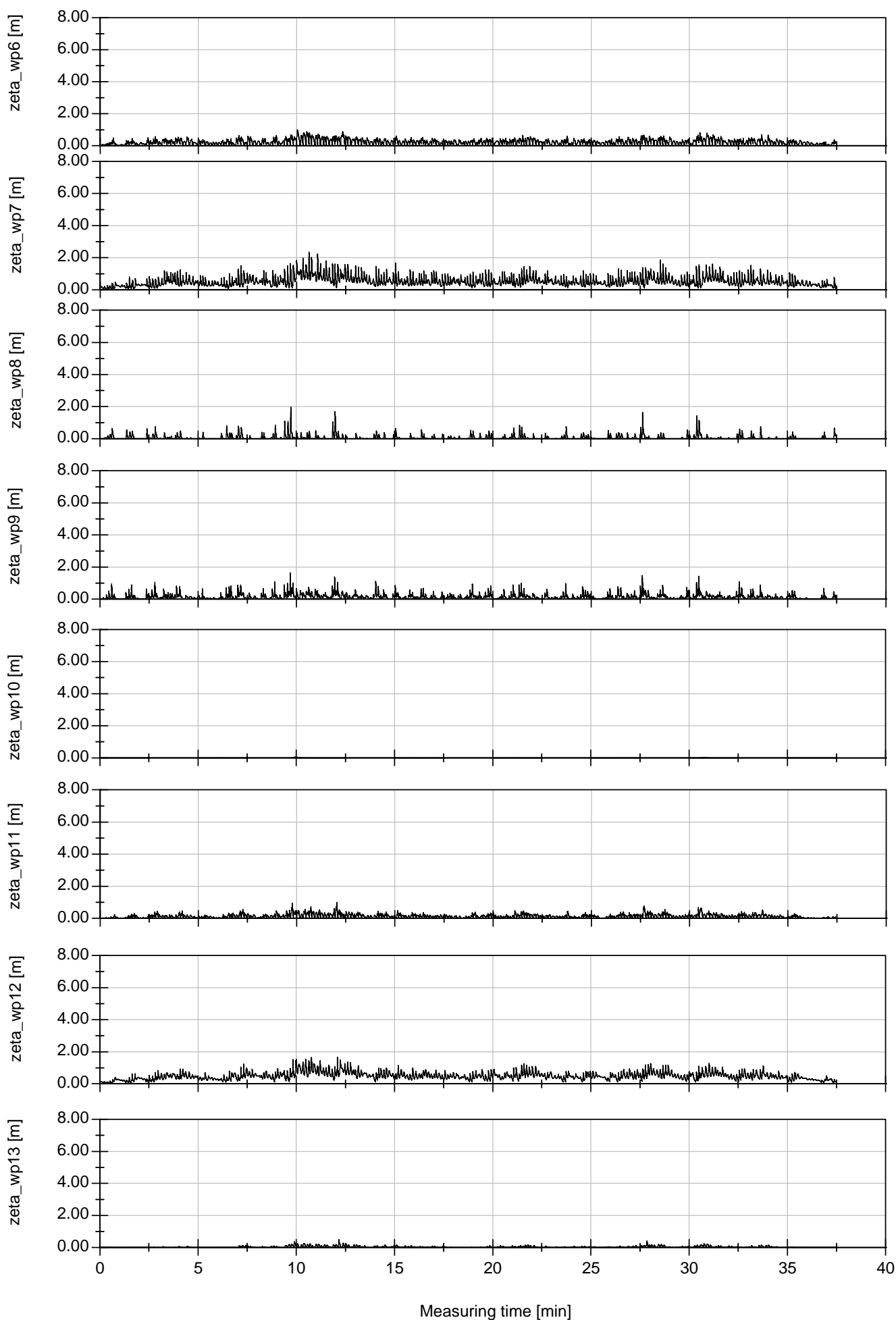
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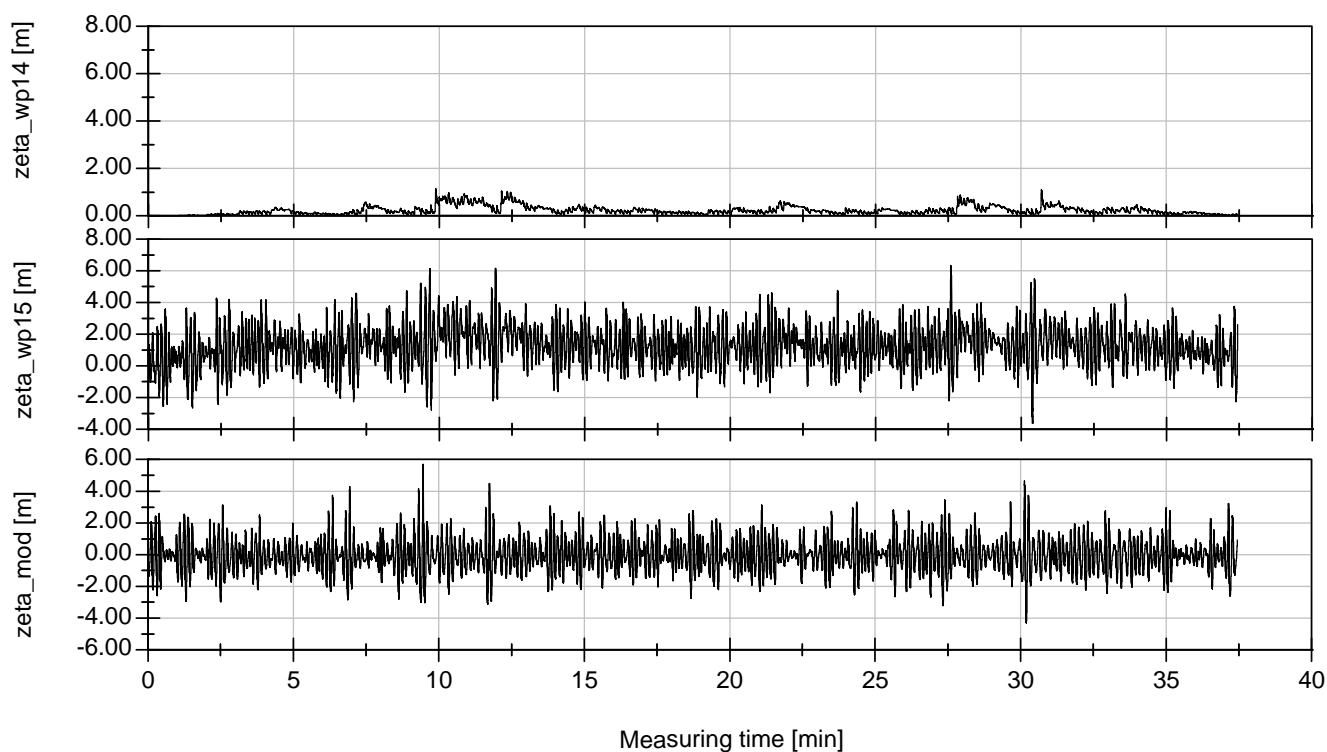
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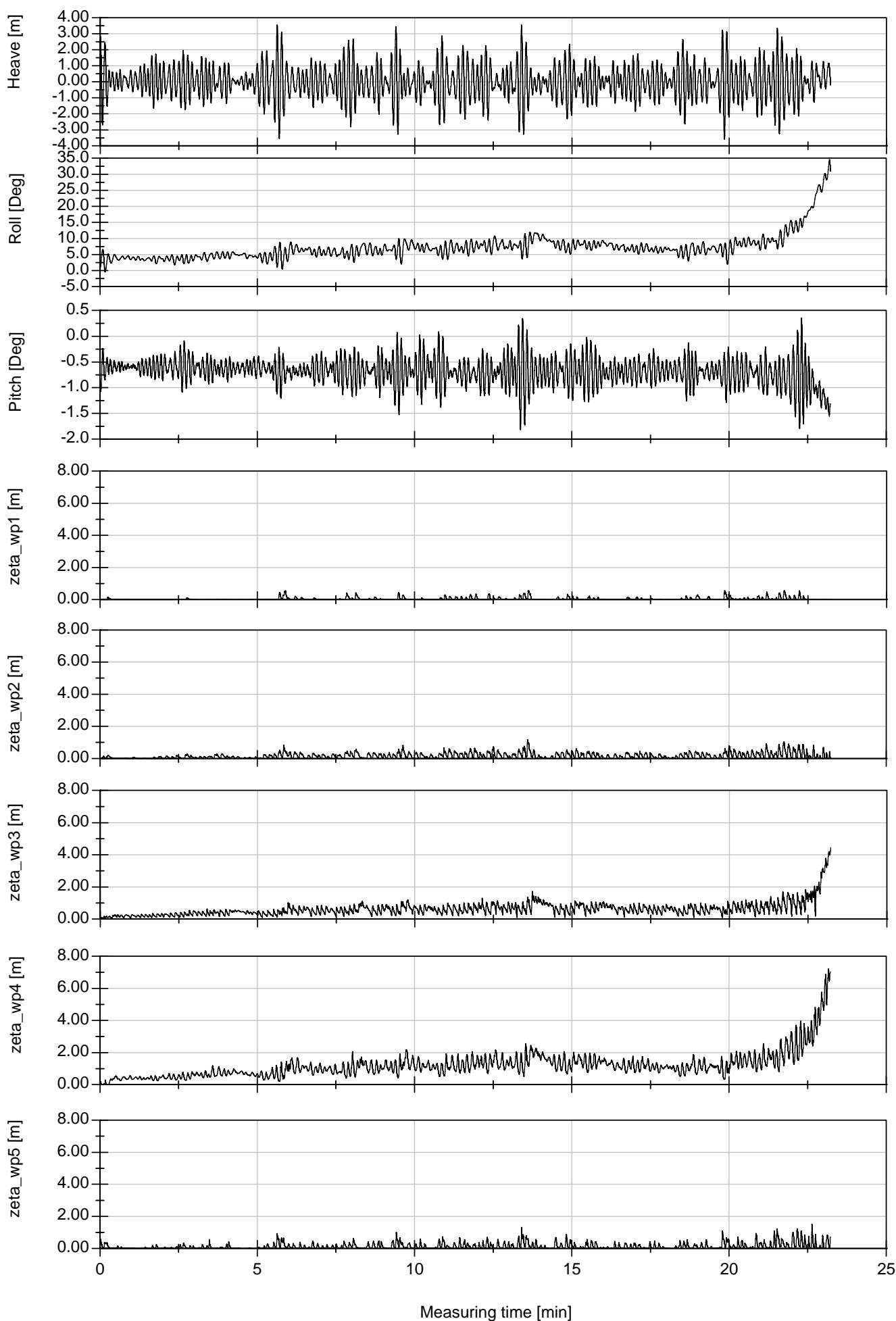
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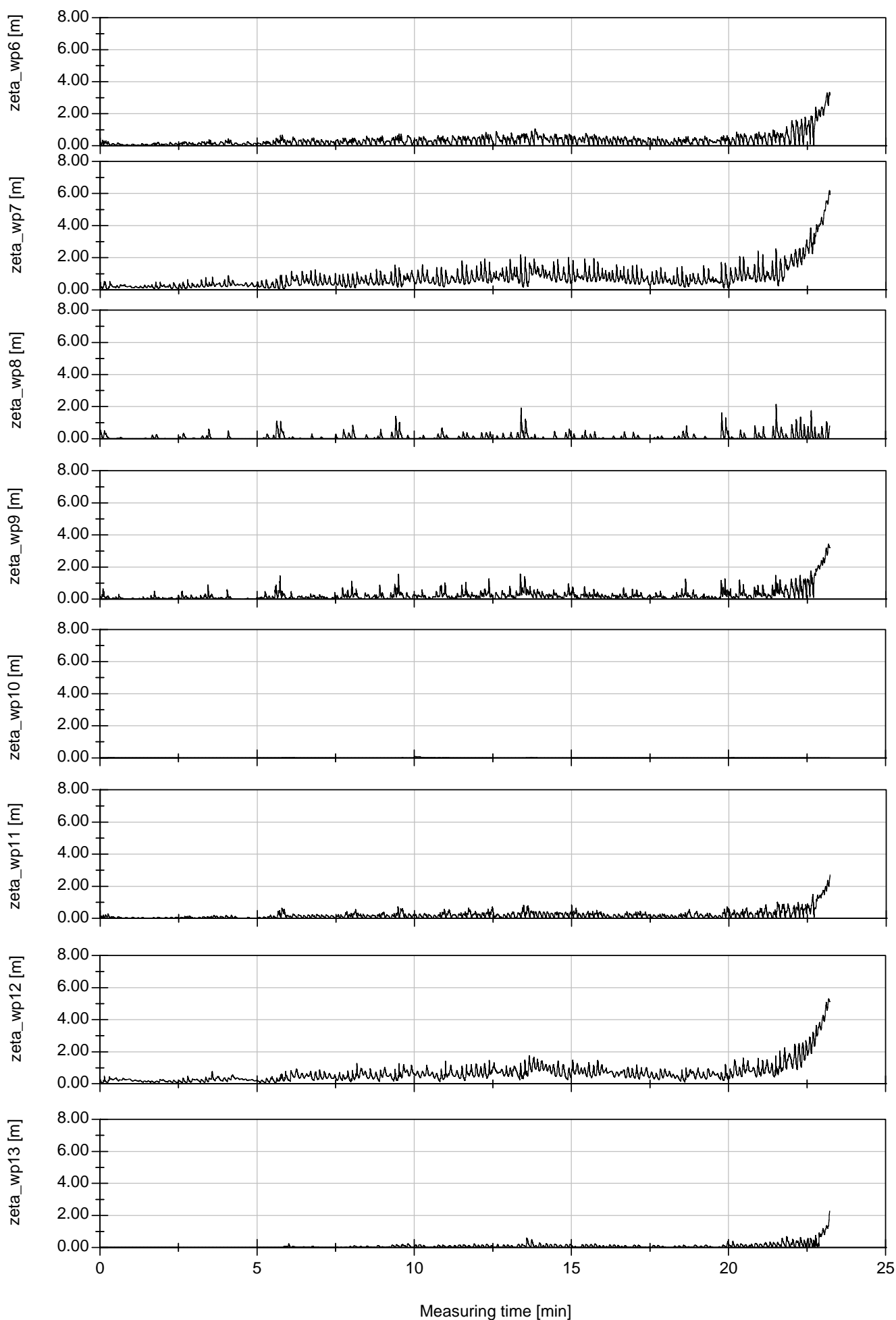
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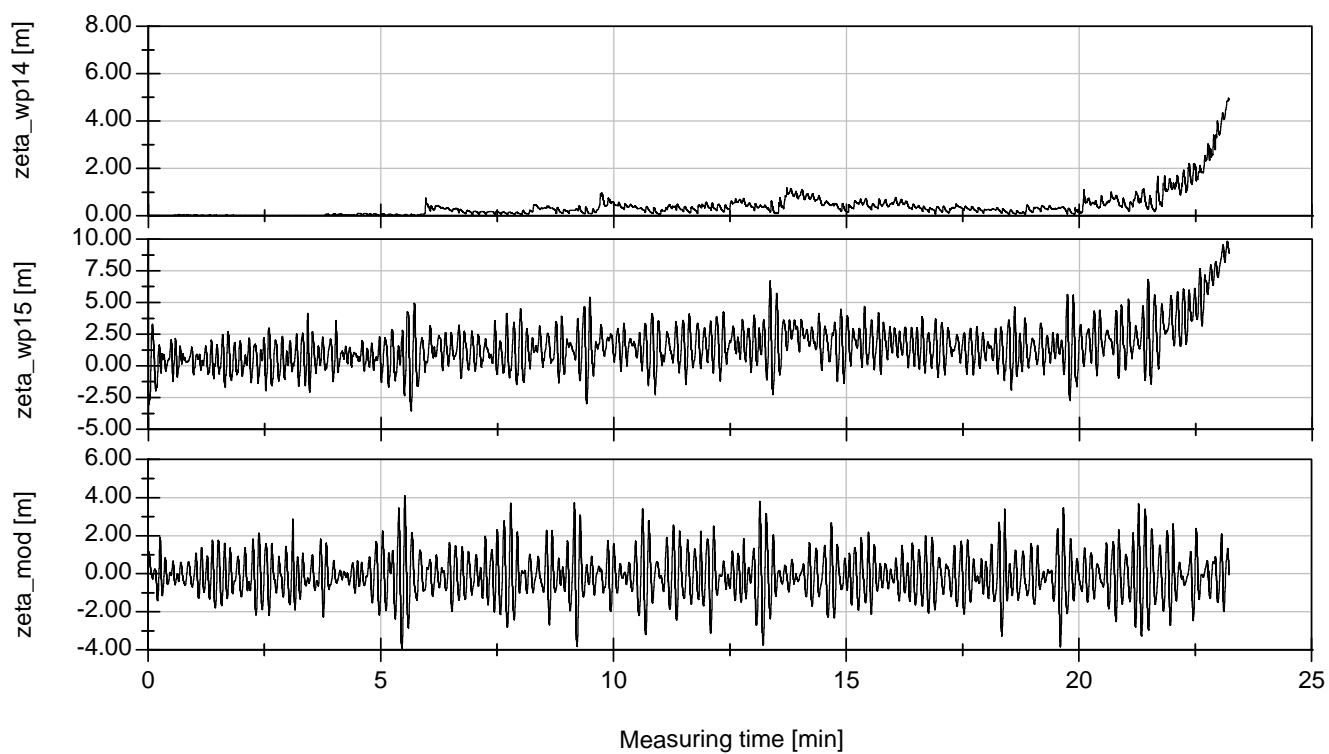
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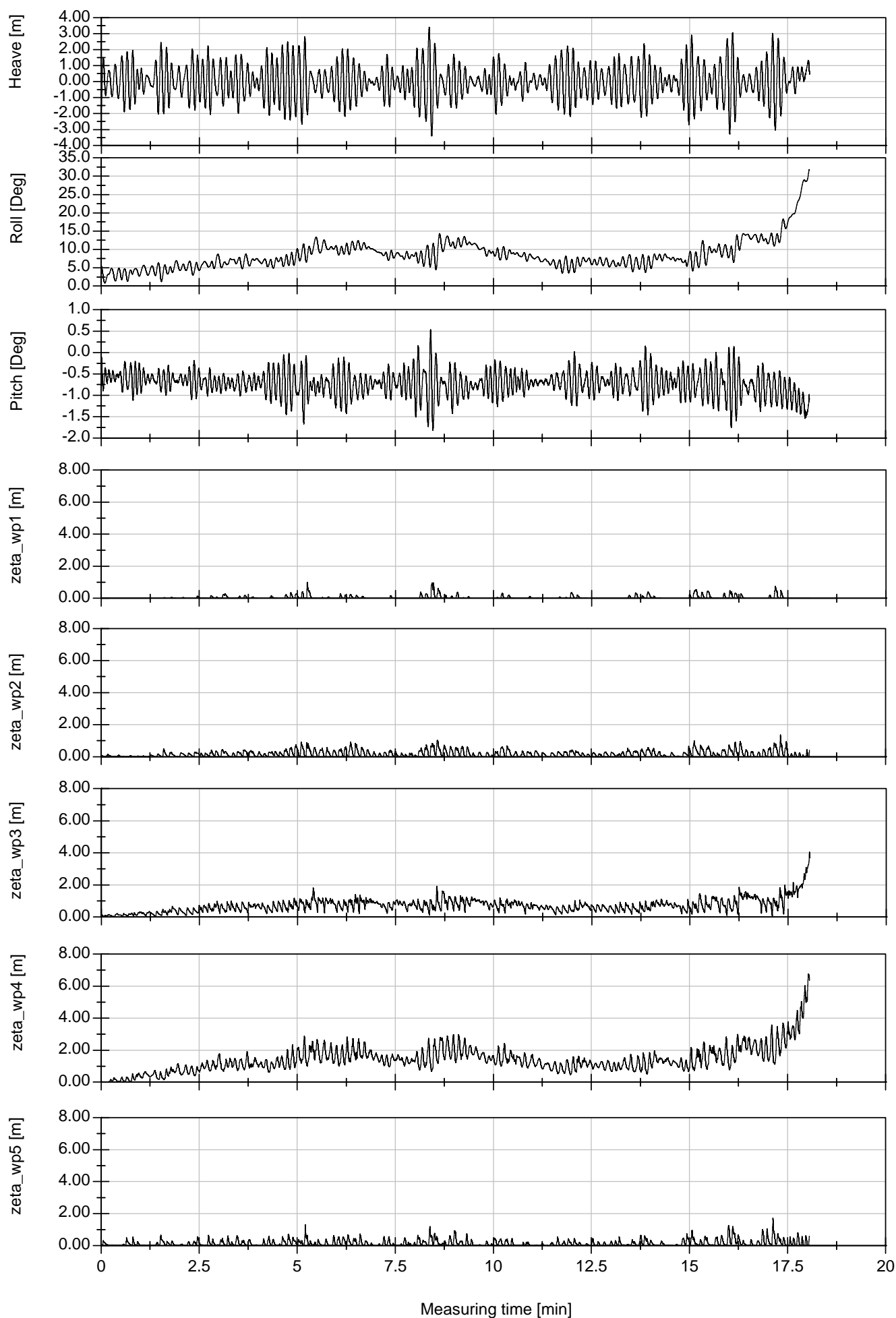
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Run-No. 11 / Damage Case 1 /  $H_s = 4.77$  m /  $T_p = 8.7$  s /  $\Gamma = 3.3$

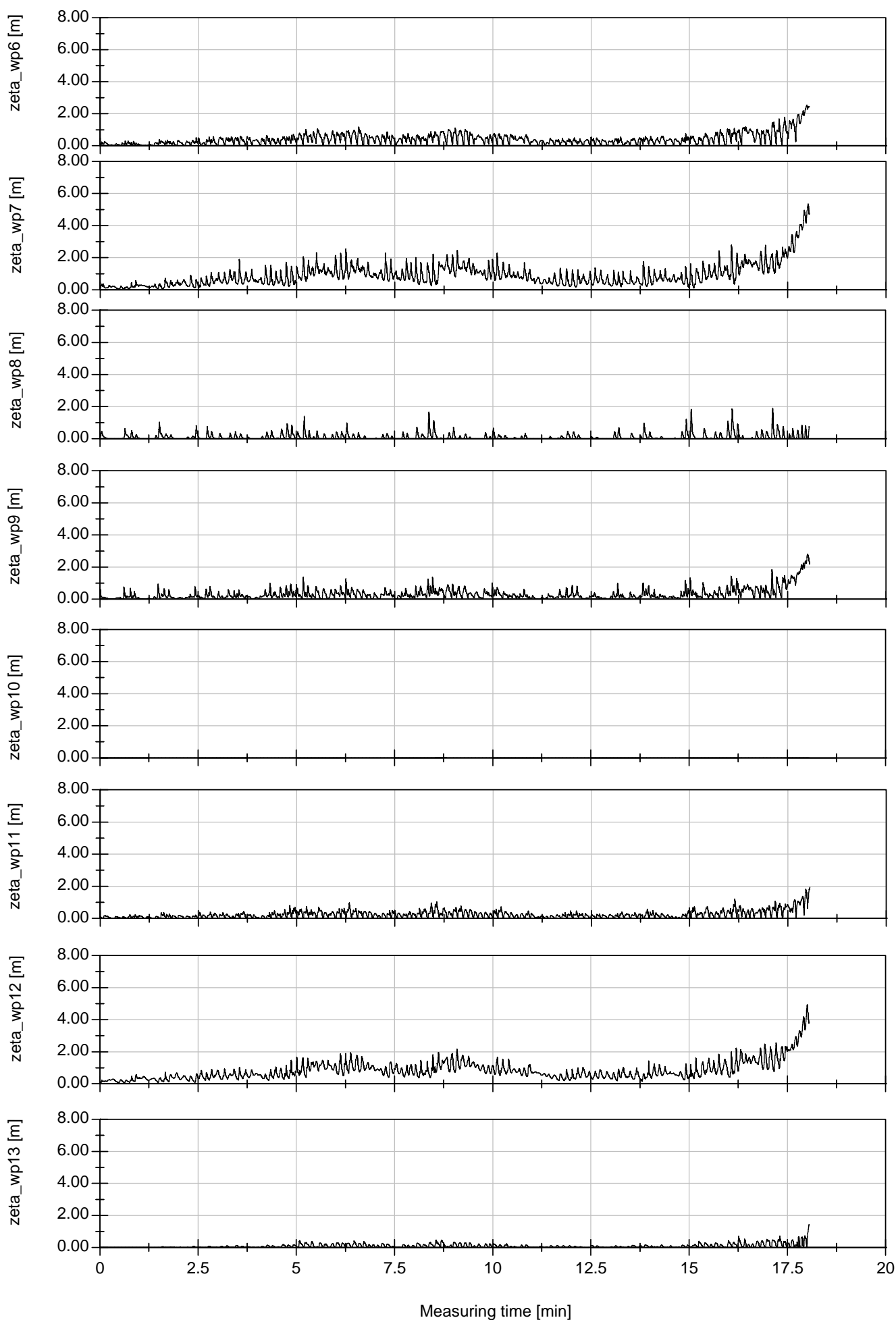


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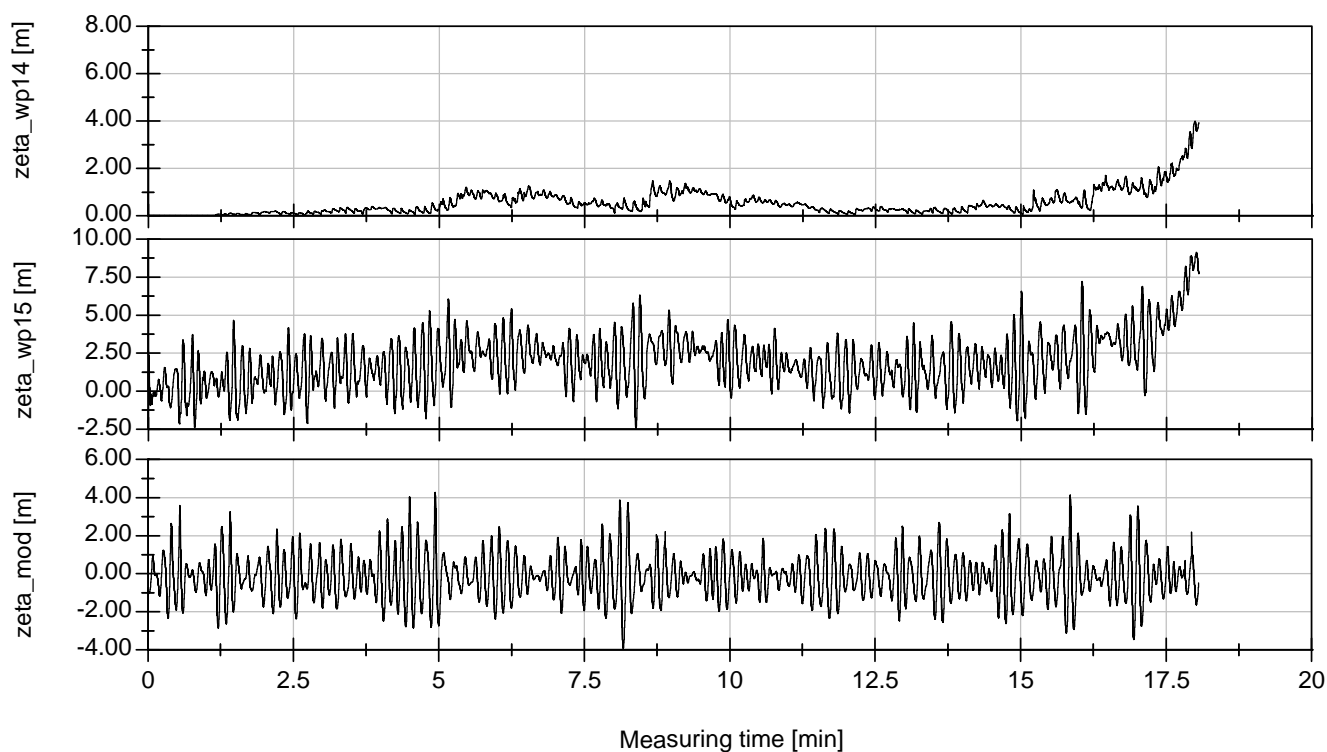




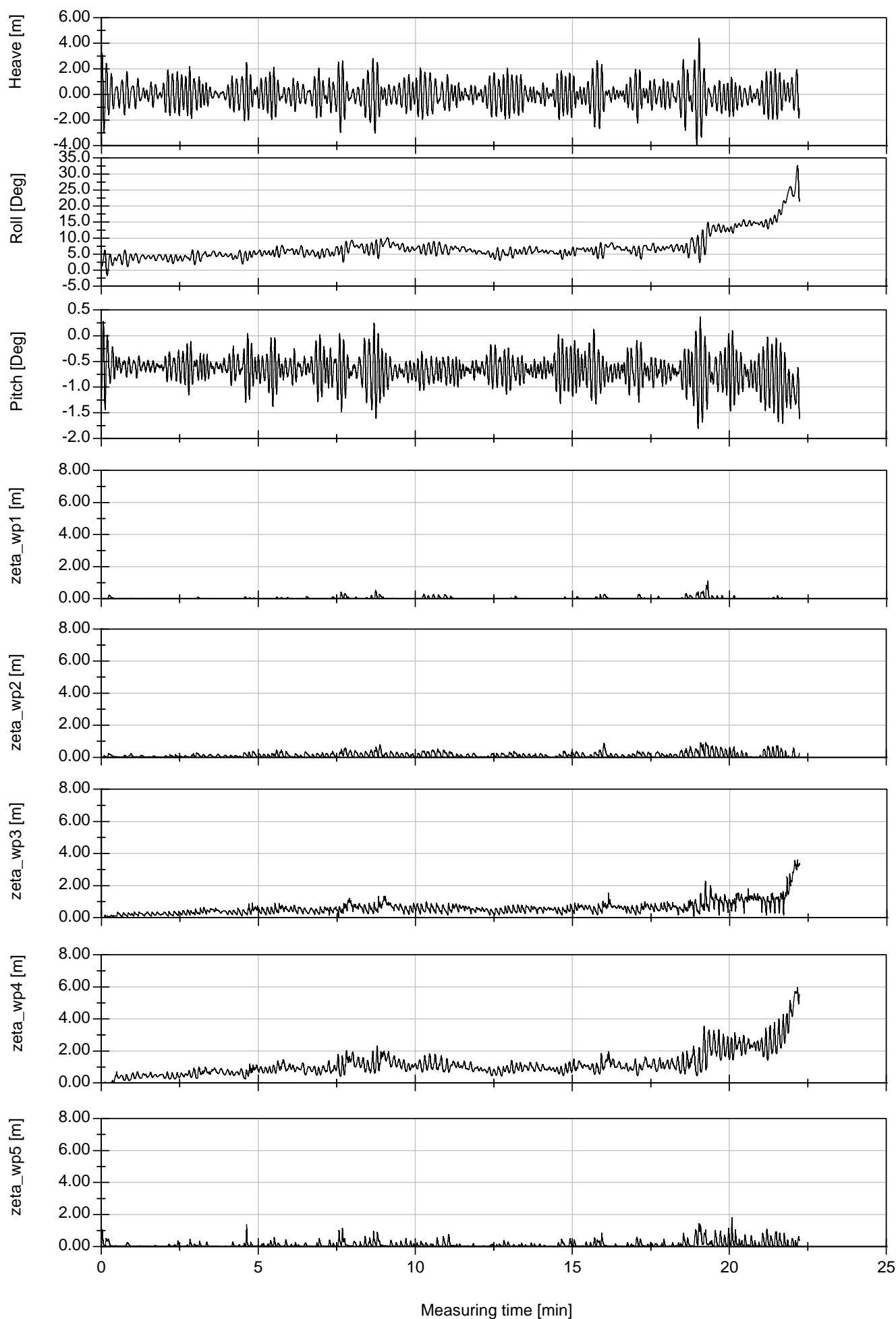
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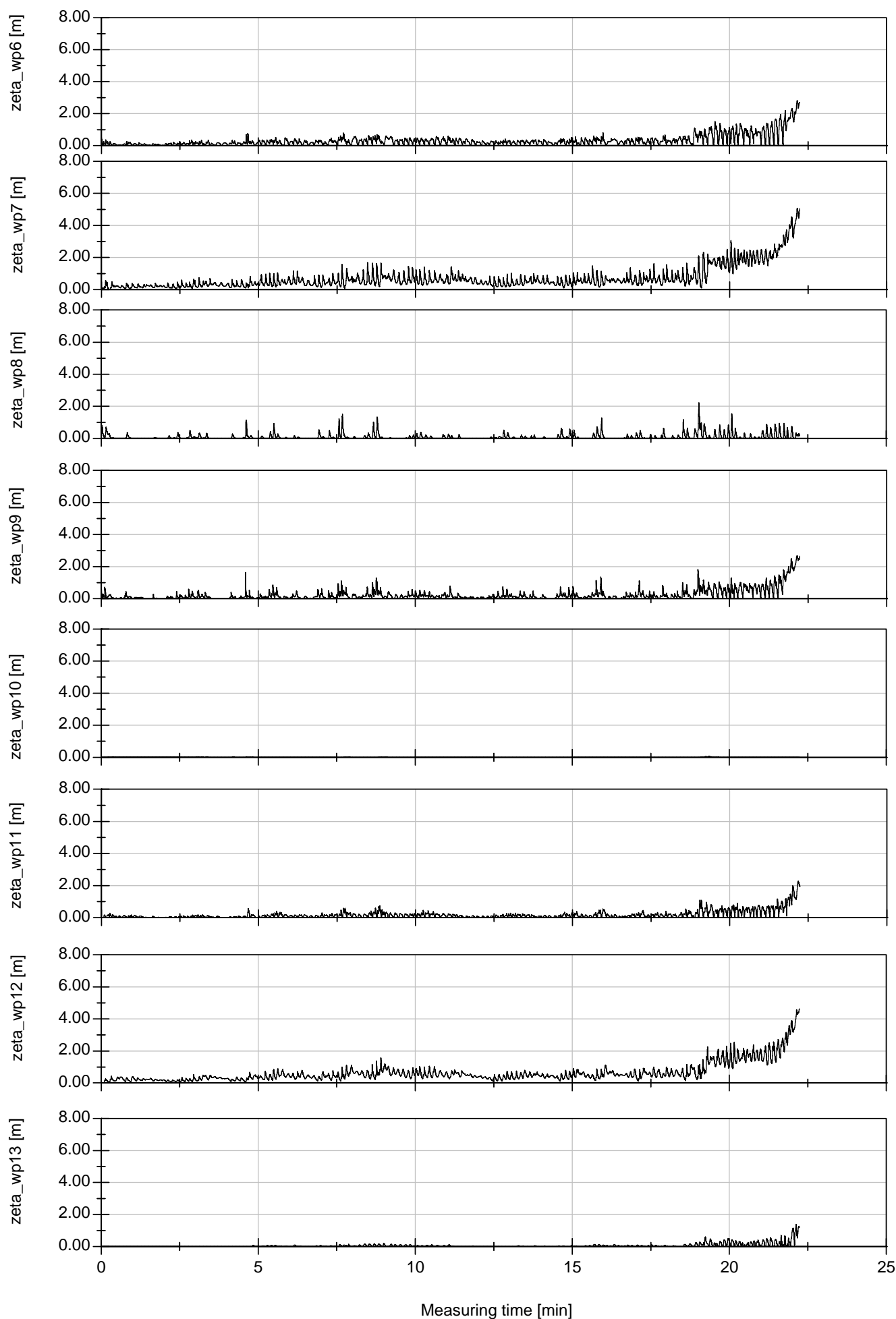
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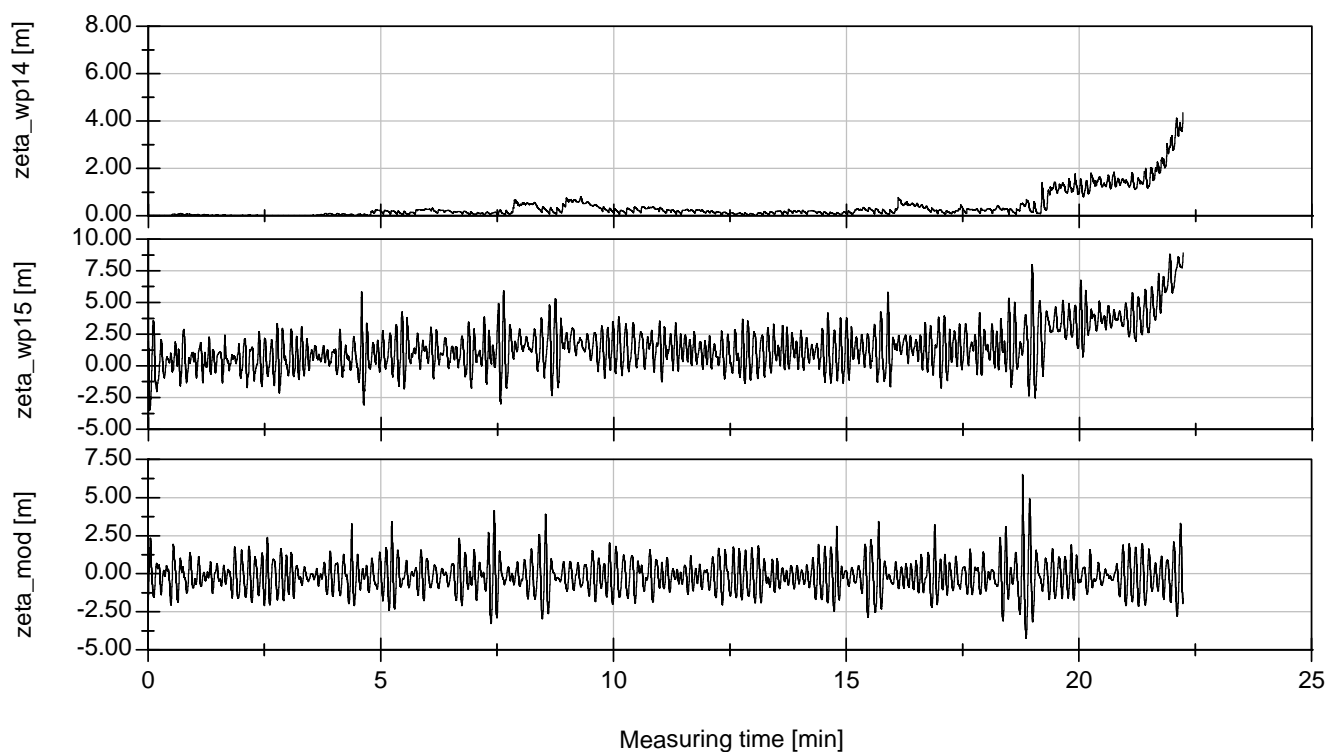
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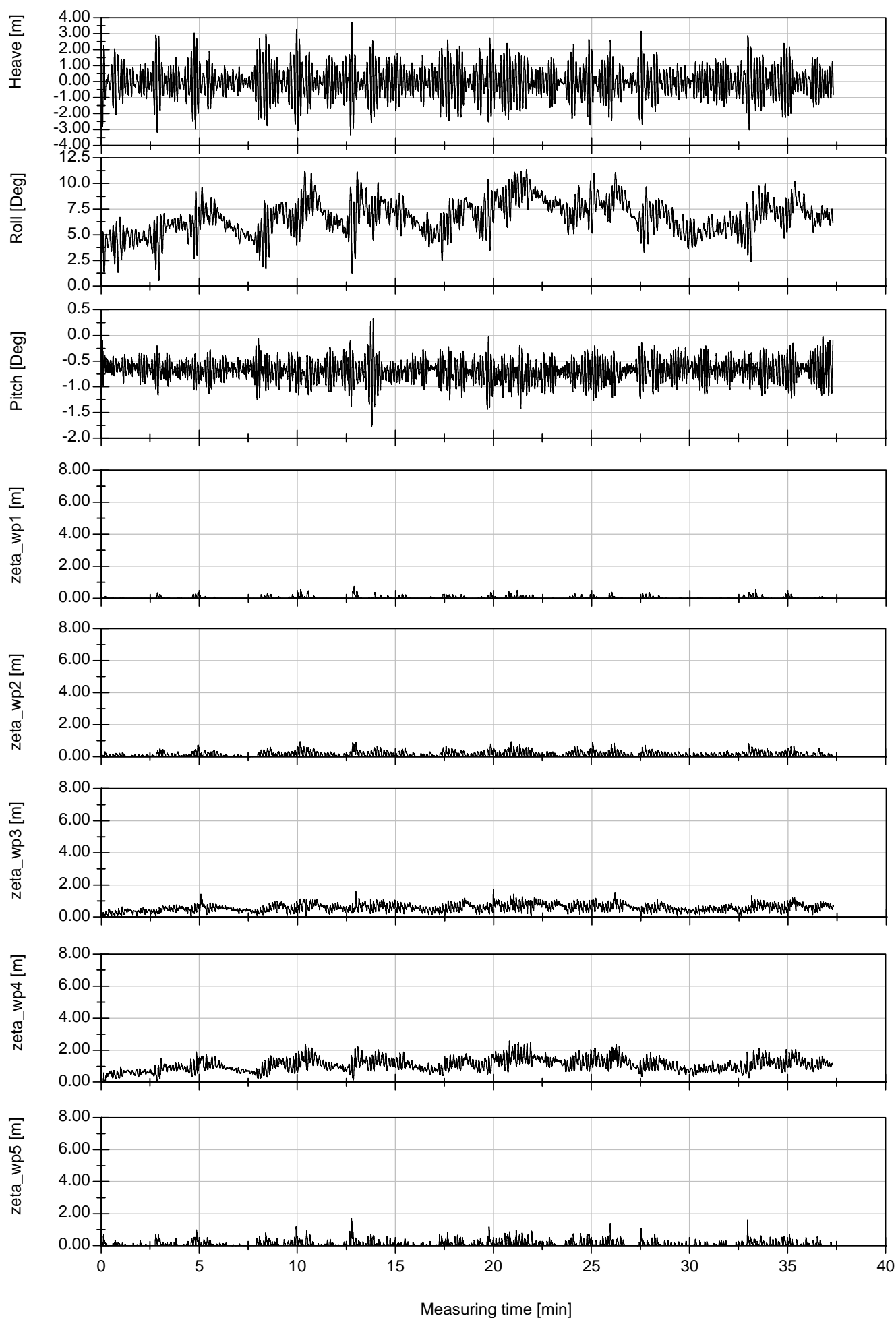
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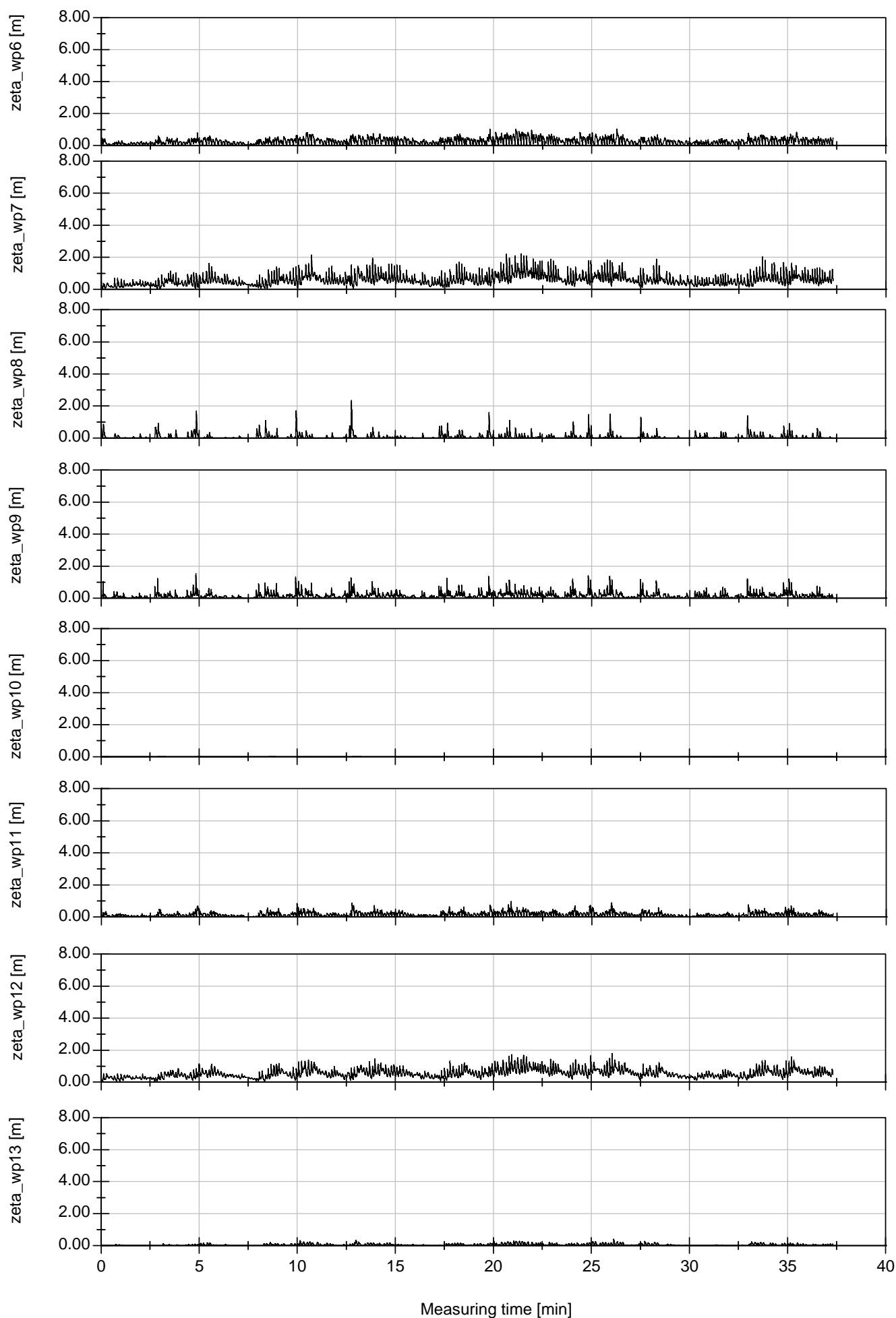
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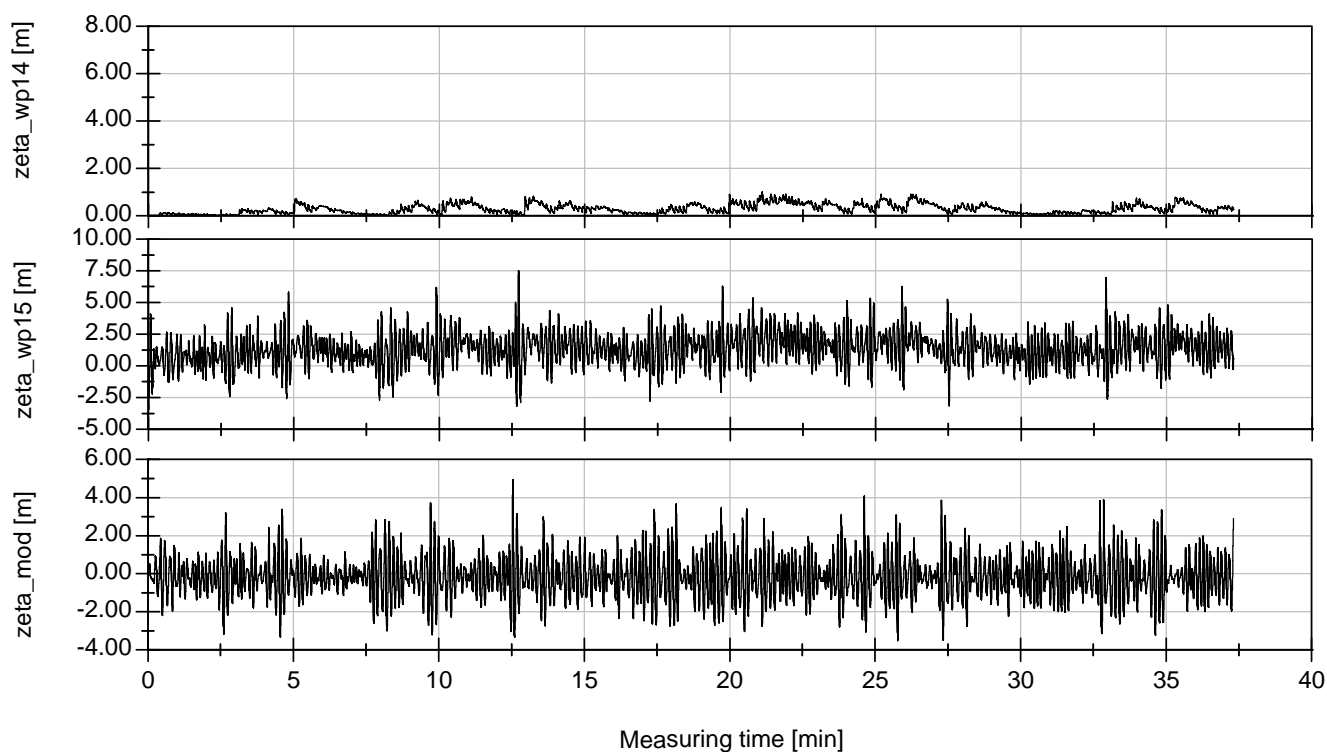
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Run-No. 14 / Damage Case 1 /  $H_s = 4.65$  m /  $T_p = 8.6$  s /  $\Gamma = 3.3$

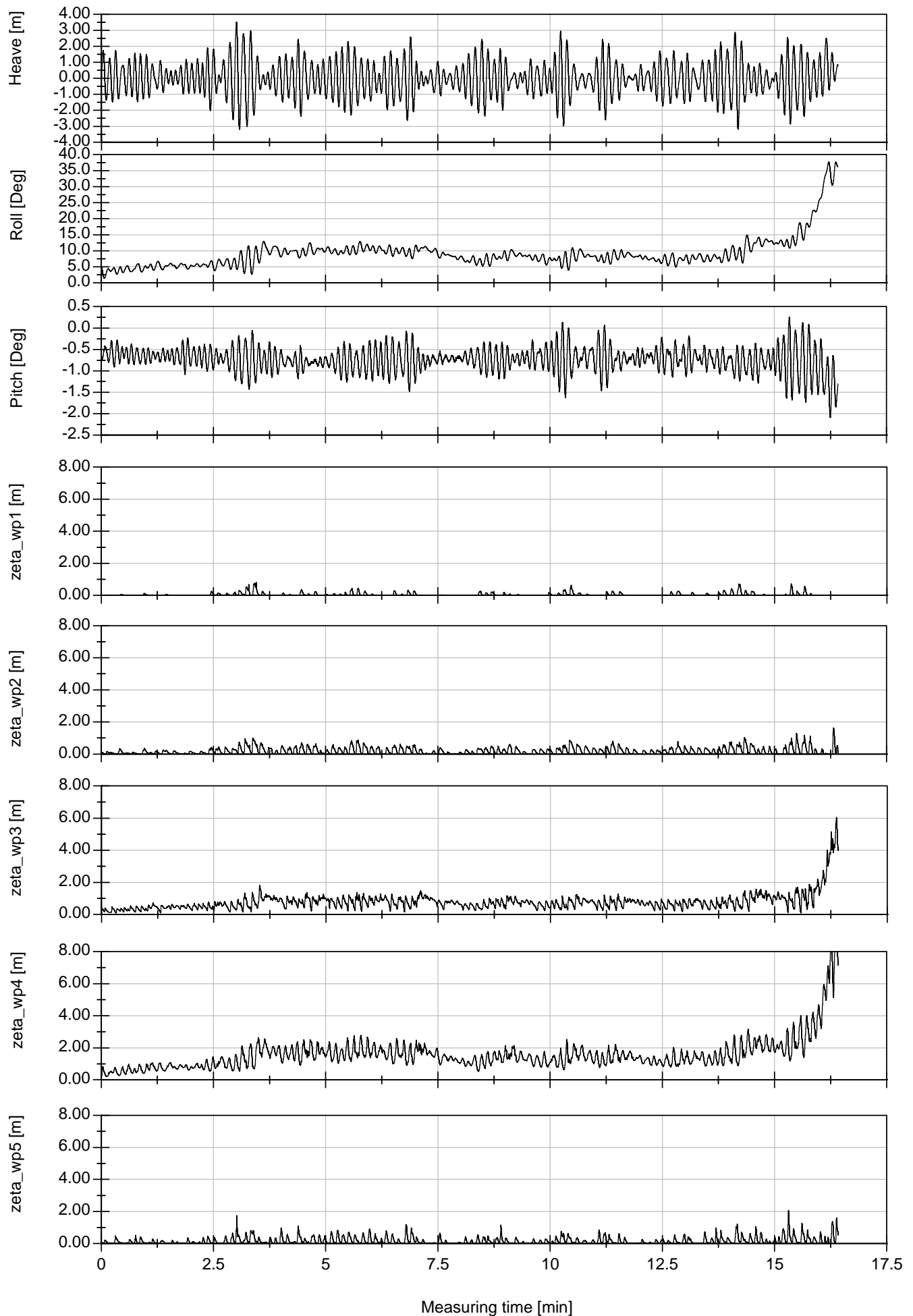


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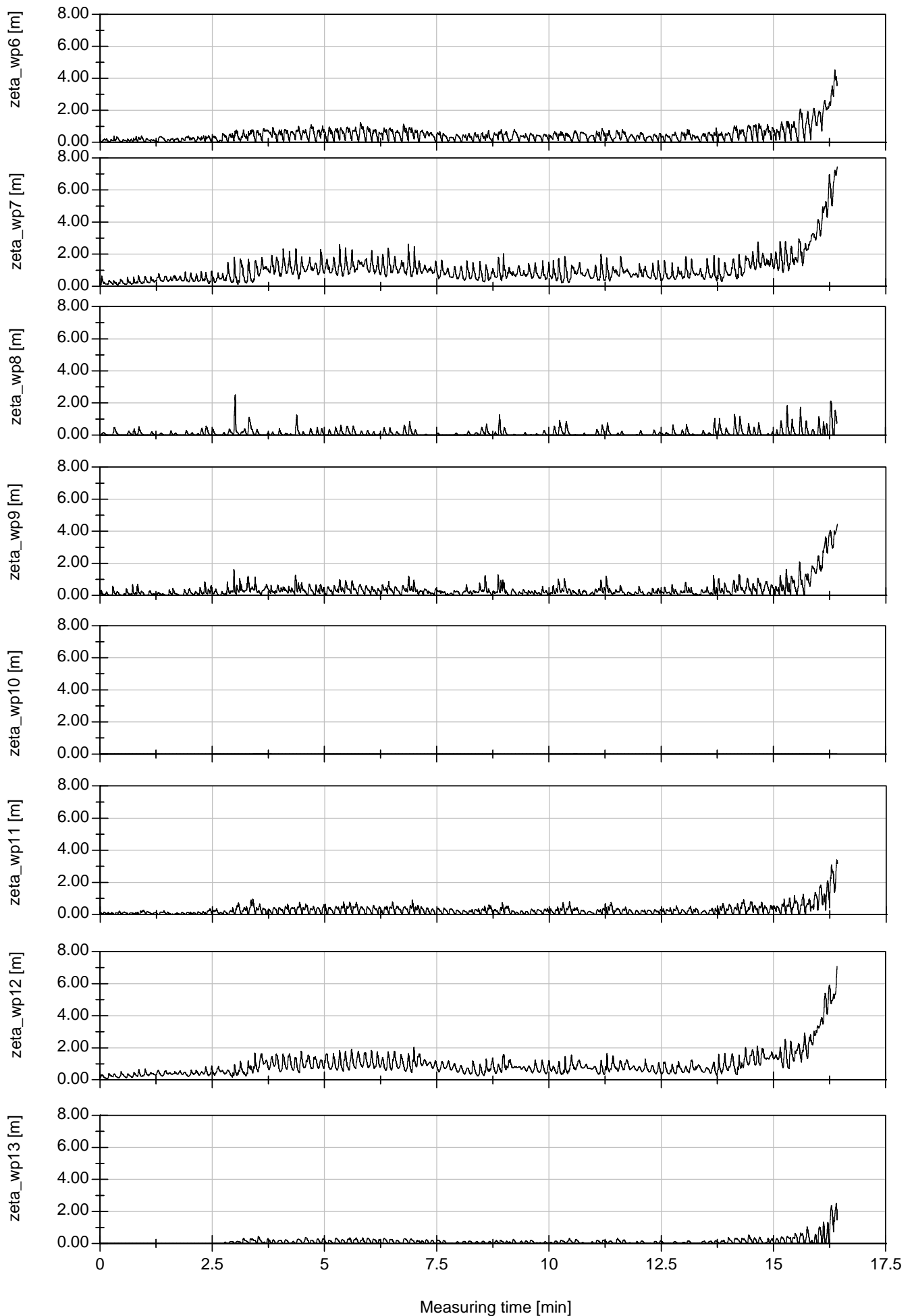




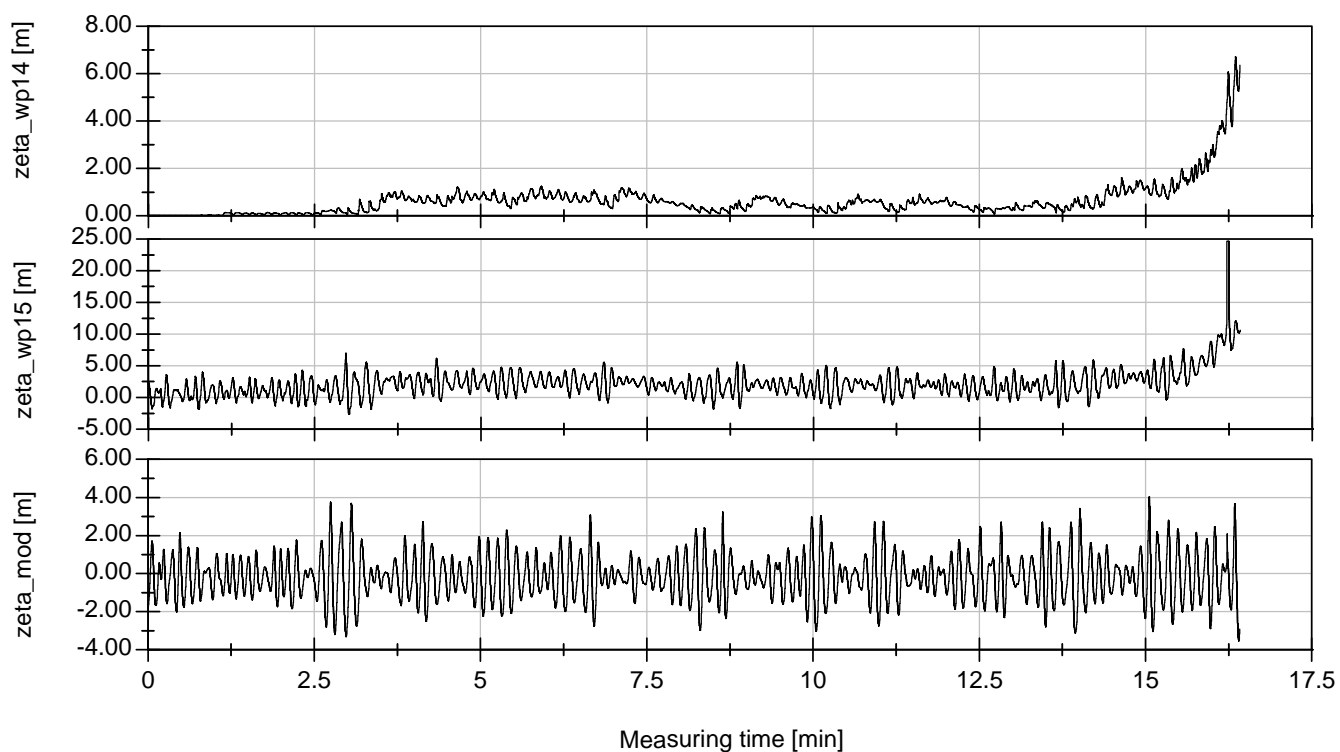
Run-No. 15 / Damage Case 1 /  $H_s = 4.65$  m /  $T_p = 8.6$  s /  $\Gamma = 3.3$



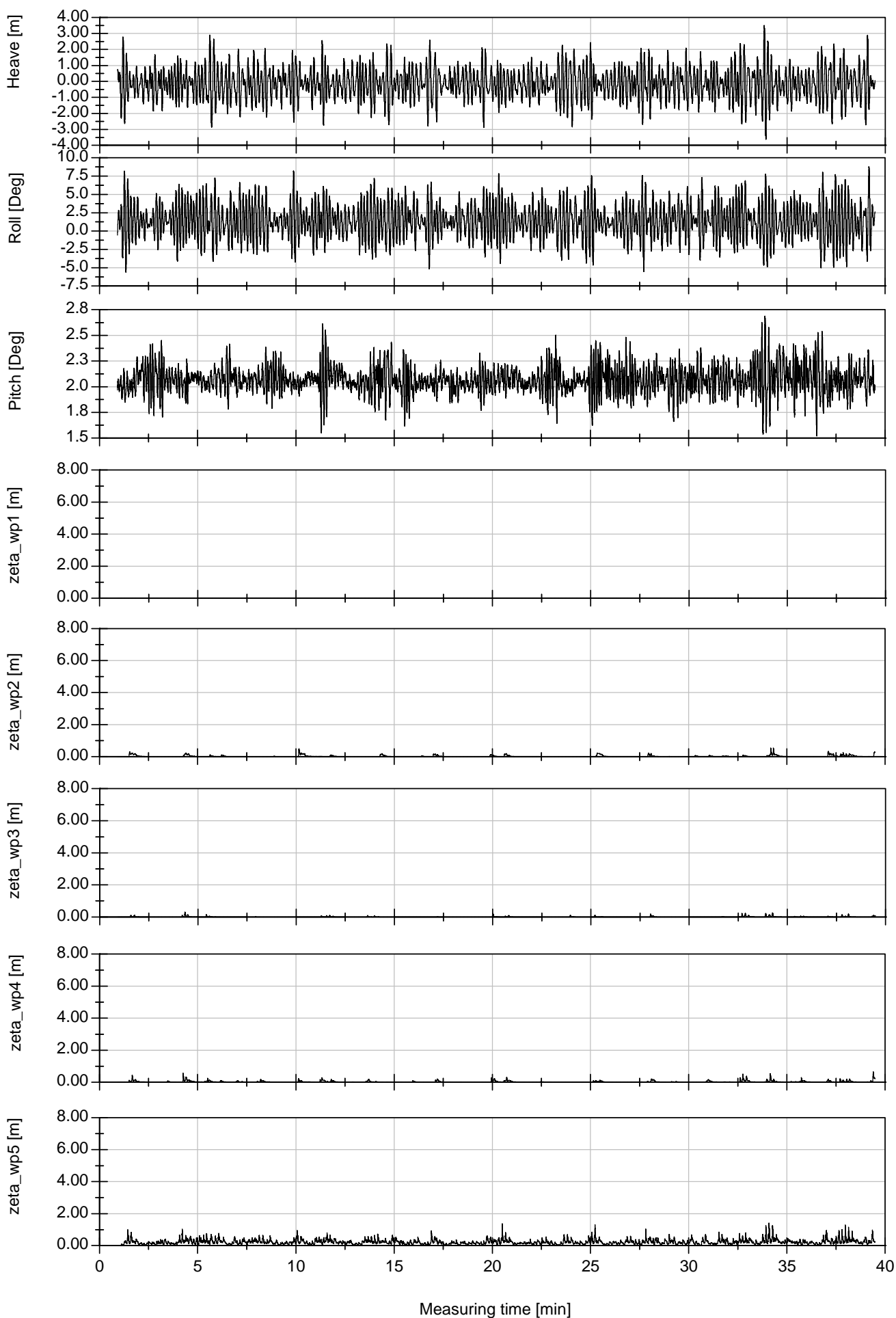
Run-No. 15 / Damage Case 1 /  $H_s = 4.65$  m /  $T_p = 8.6$  s /  $\Gamma = 3.3$



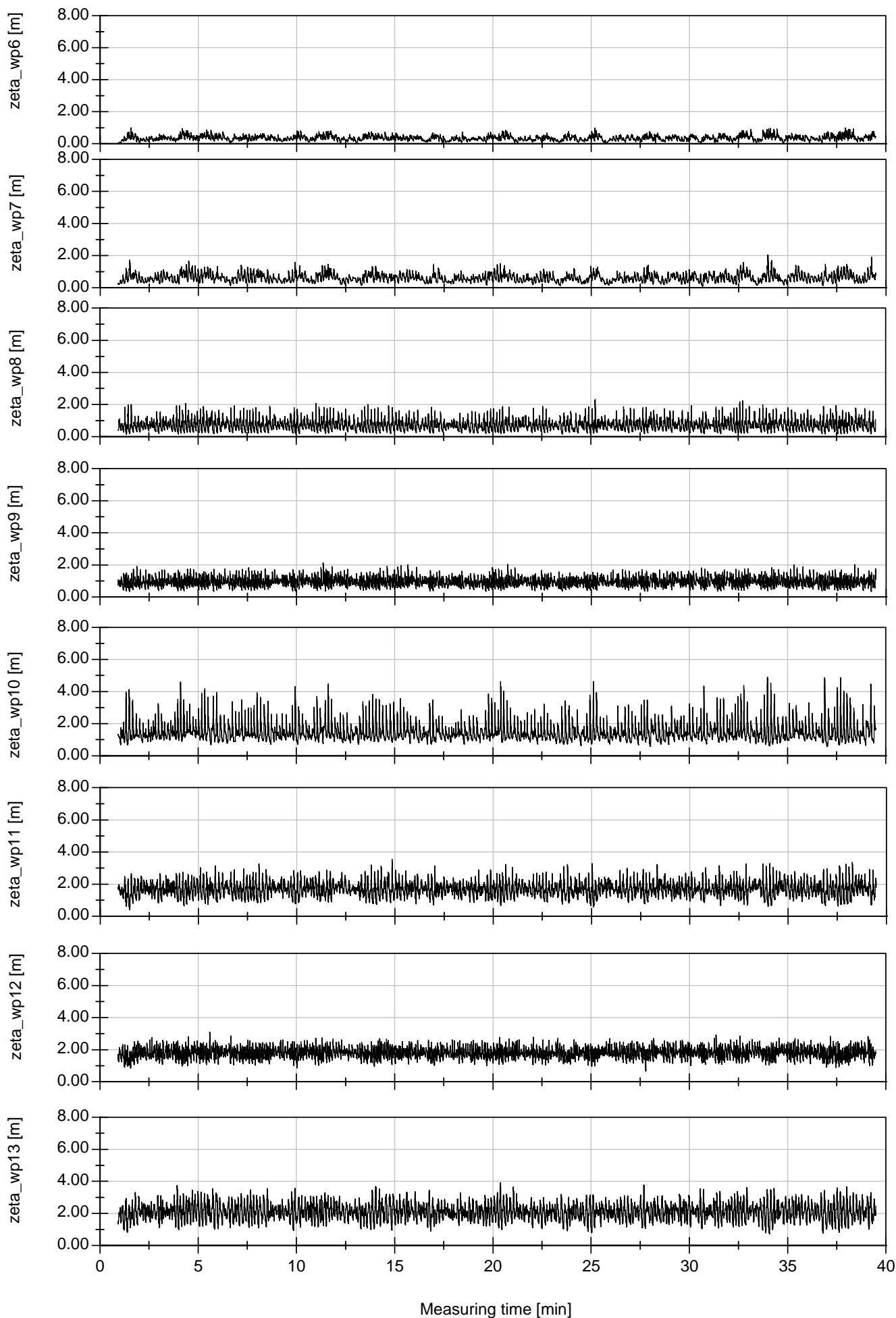
Run-No. 15 / Damage Case 1 /  $H_s = 4.65$  m /  $T_p = 8.6$  s /  $\Gamma = 3.3$



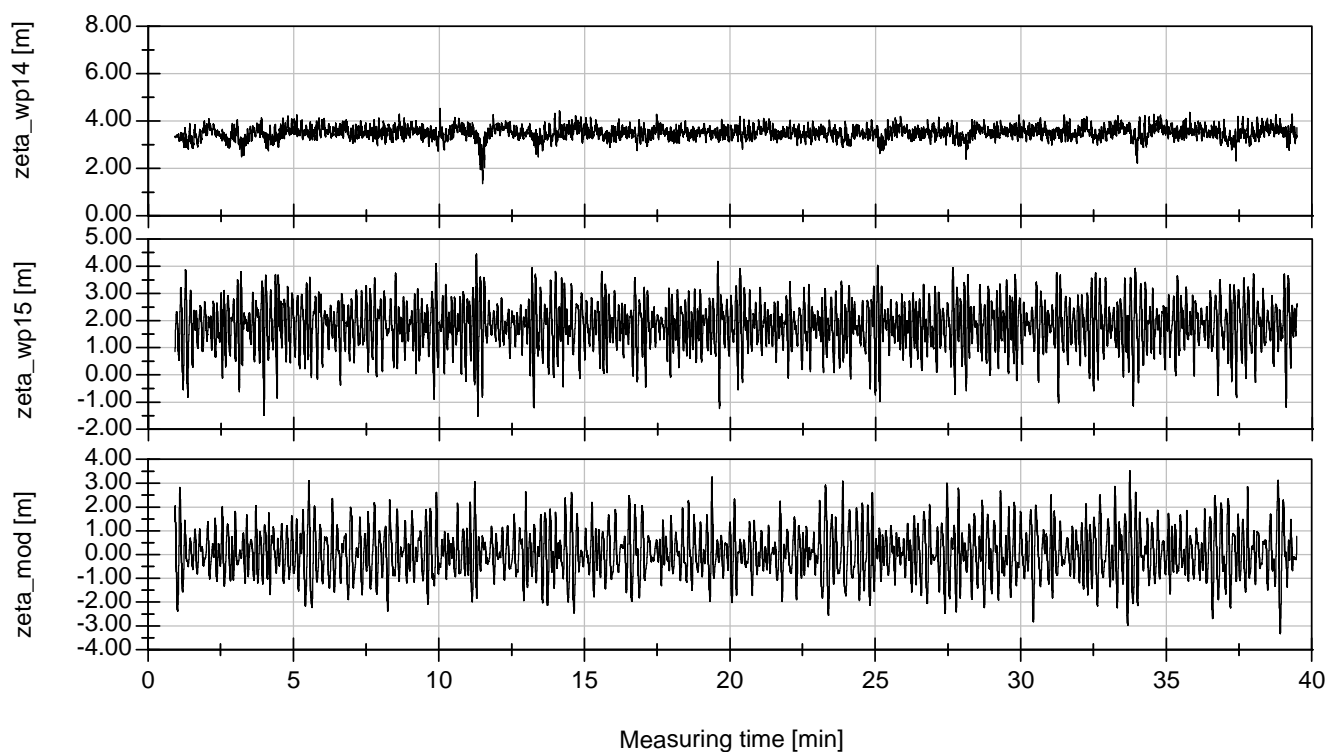
Run-No. 16 / Damage Case 4 /  $H_s = 3.90$  m /  $T_p = 11.8$  s /  $\Gamma = 1.0$



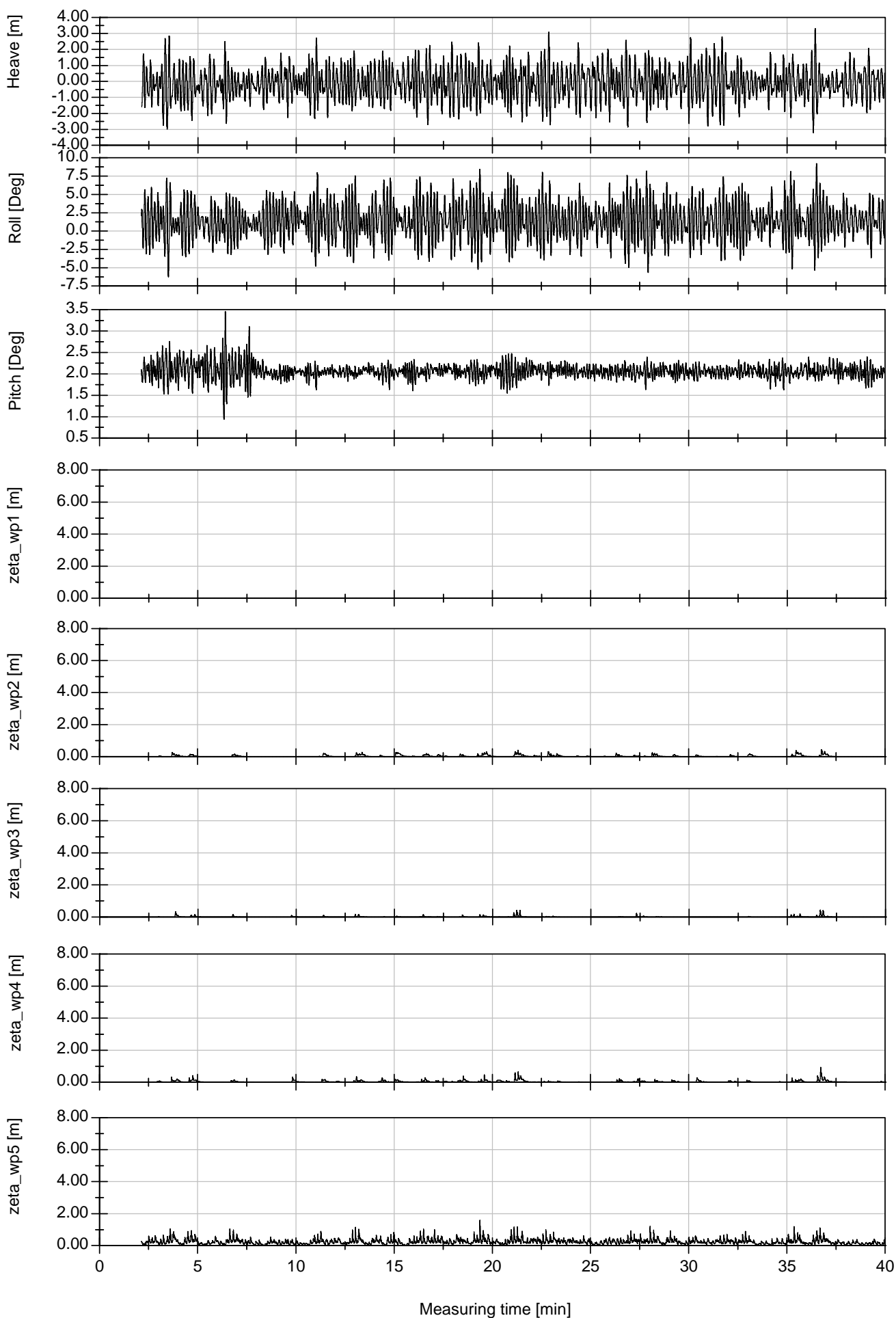
Run-No. 16 / Damage Case 4 /  $H_s = 3.90$  m /  $T_p = 11.8$  s /  $\Gamma = 1.0$



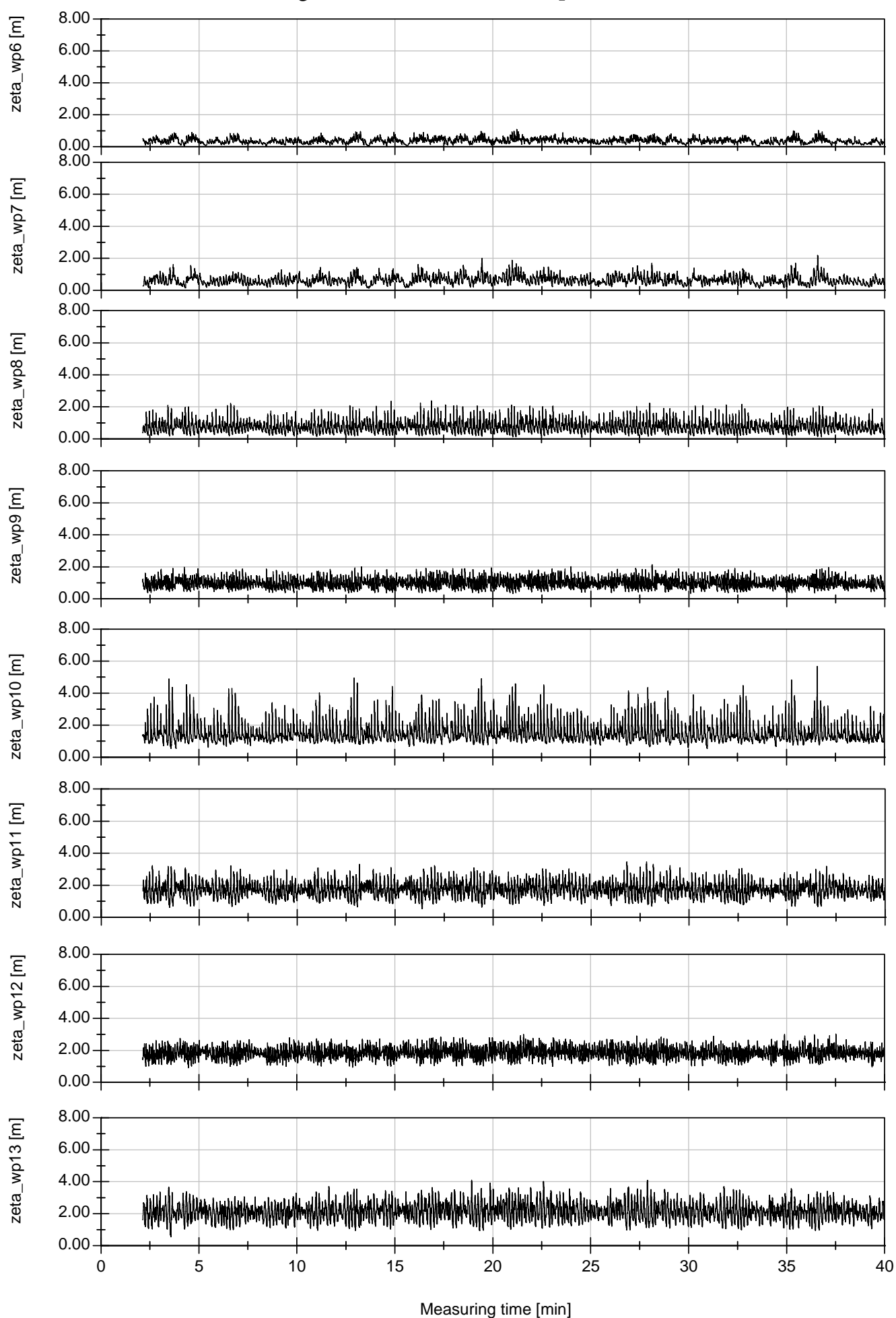
Run-No. 16 / Damage Case 4 /  $H_s = 3.90$  m /  $T_p = 11.8$  s /  $\Gamma = 1.0$



Run-No. 17 / Damage Case 4 /  $H_s = 3.75$  m /  $T_p = 11.6$  s /  $\Gamma = 1.0$

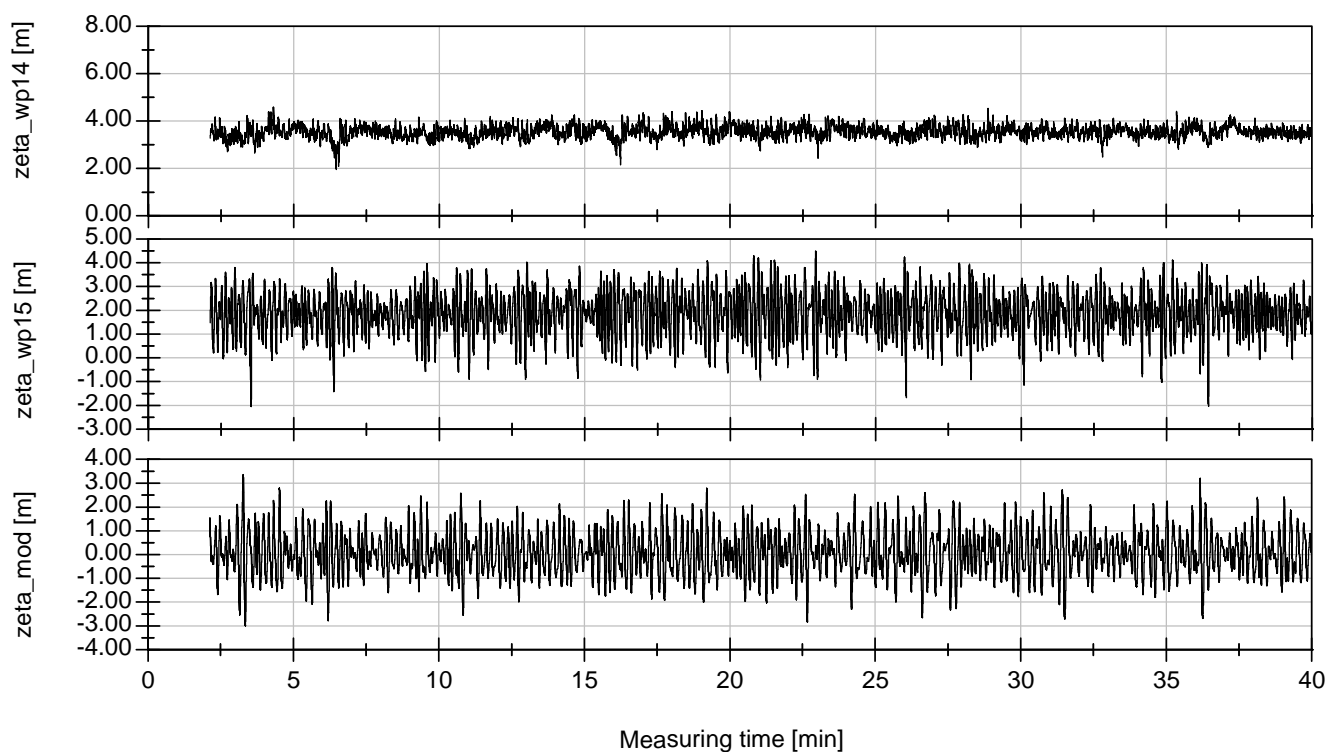


Run-No. 17 / Damage Case 4 /  $H_s = 3.75$  m /  $T_p = 11.6$  s /  $\Gamma = 1.0$

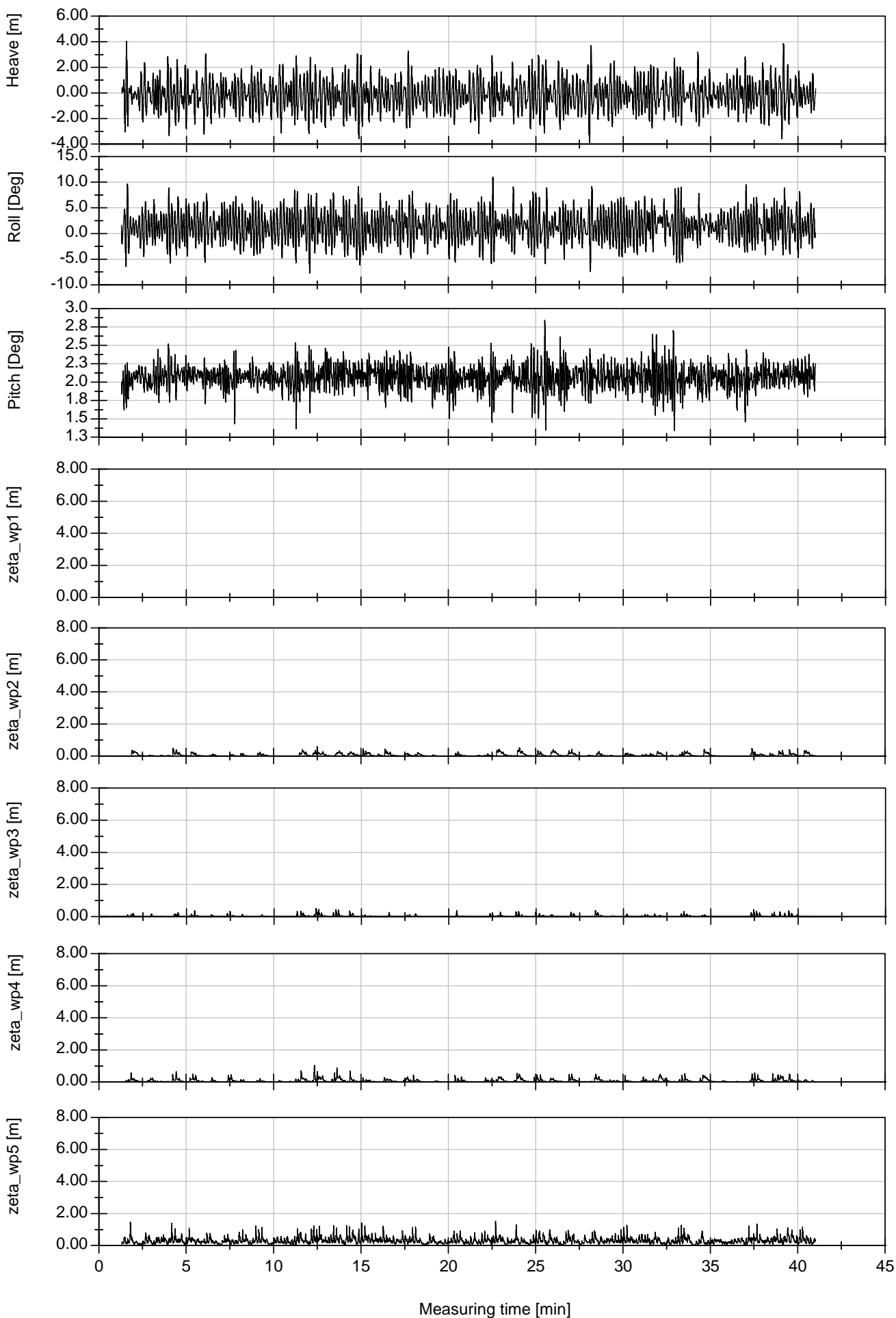




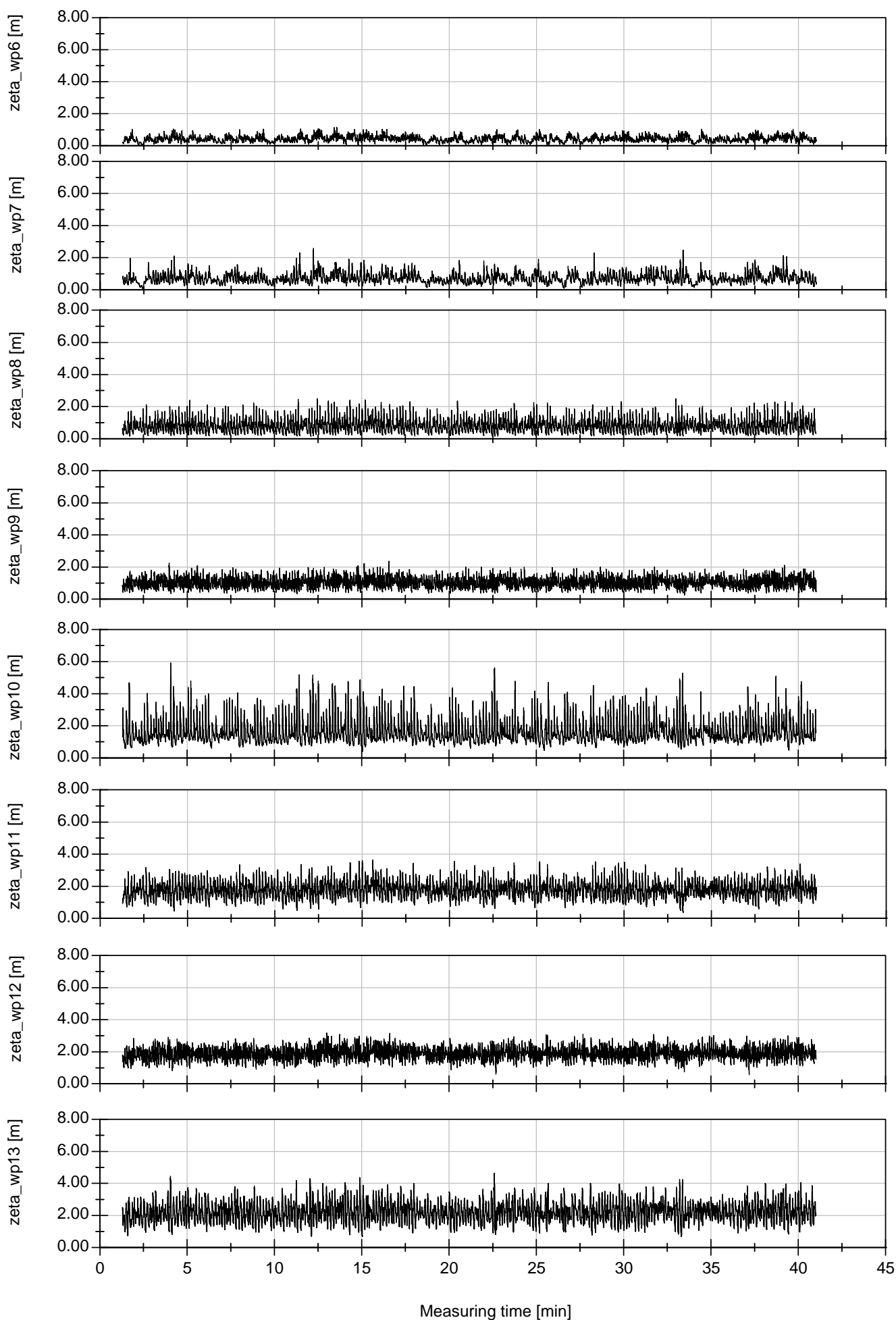
Run-No. 17 / Damage Case 4 /  $H_s = 3.75$  m /  $T_p = 11.6$  s /  $\Gamma = 1.0$



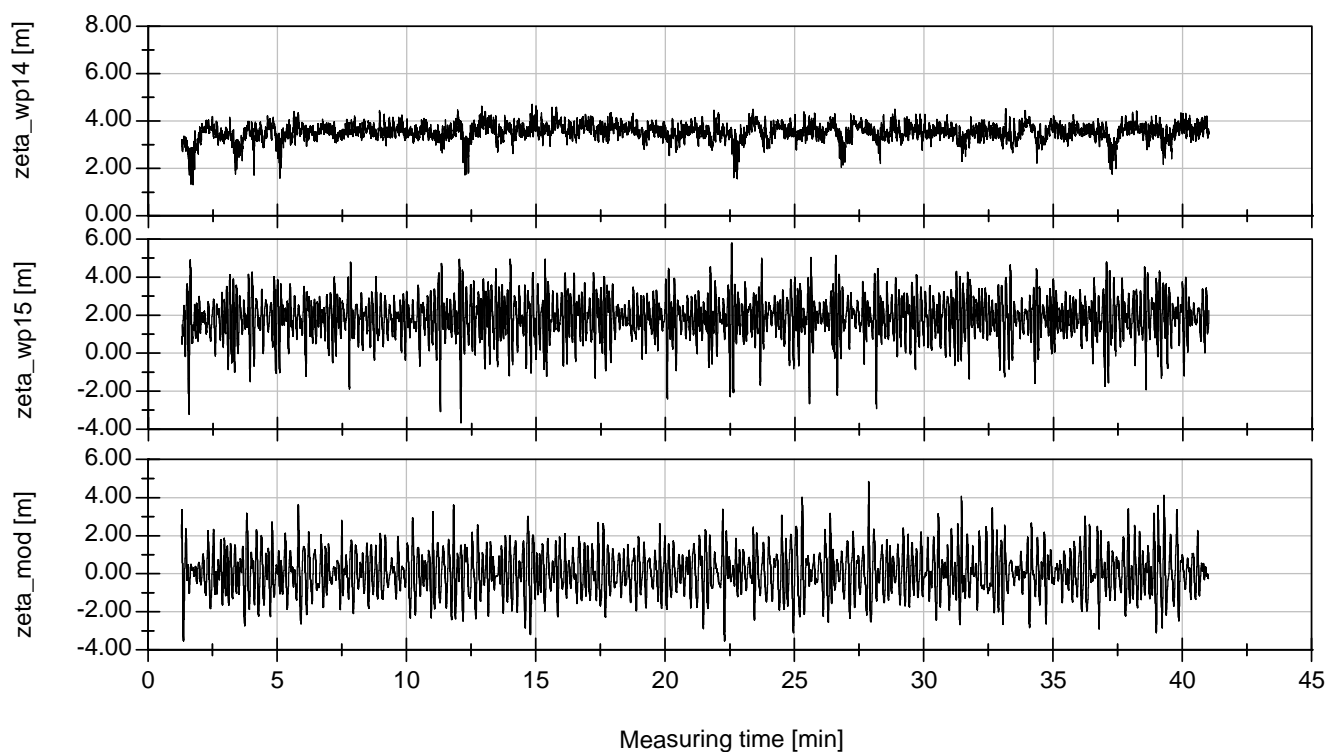
Run-No. 18 / Damage Case 4 /  $H_s = 4.64$  m /  $T_p = 12.3$  s /  $\Gamma = 1.0$



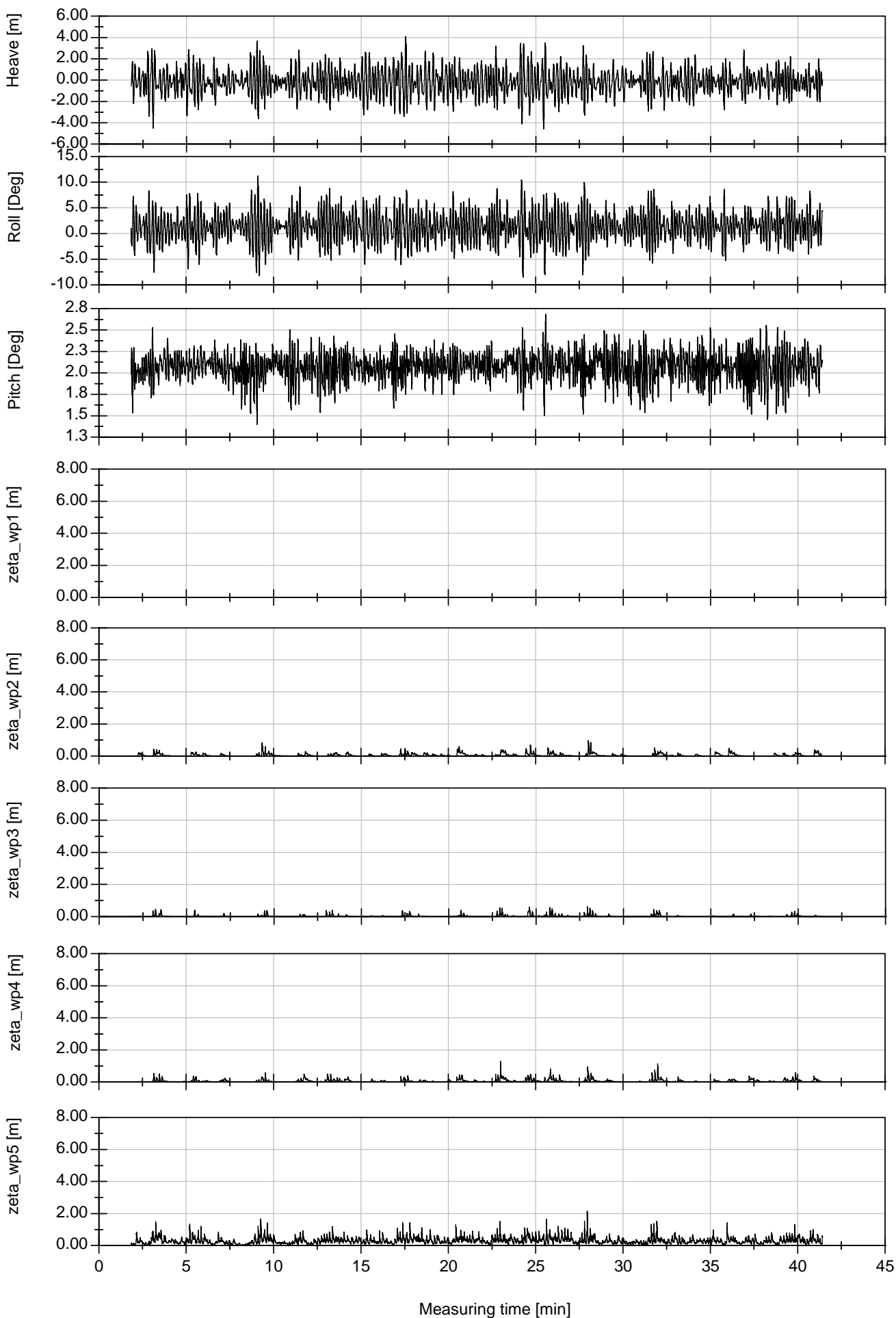
Run-No. 18 / Damage Case 4 /  $H_s = 4.64$  m /  $T_p = 12.3$  s /  $\Gamma = 1.0$



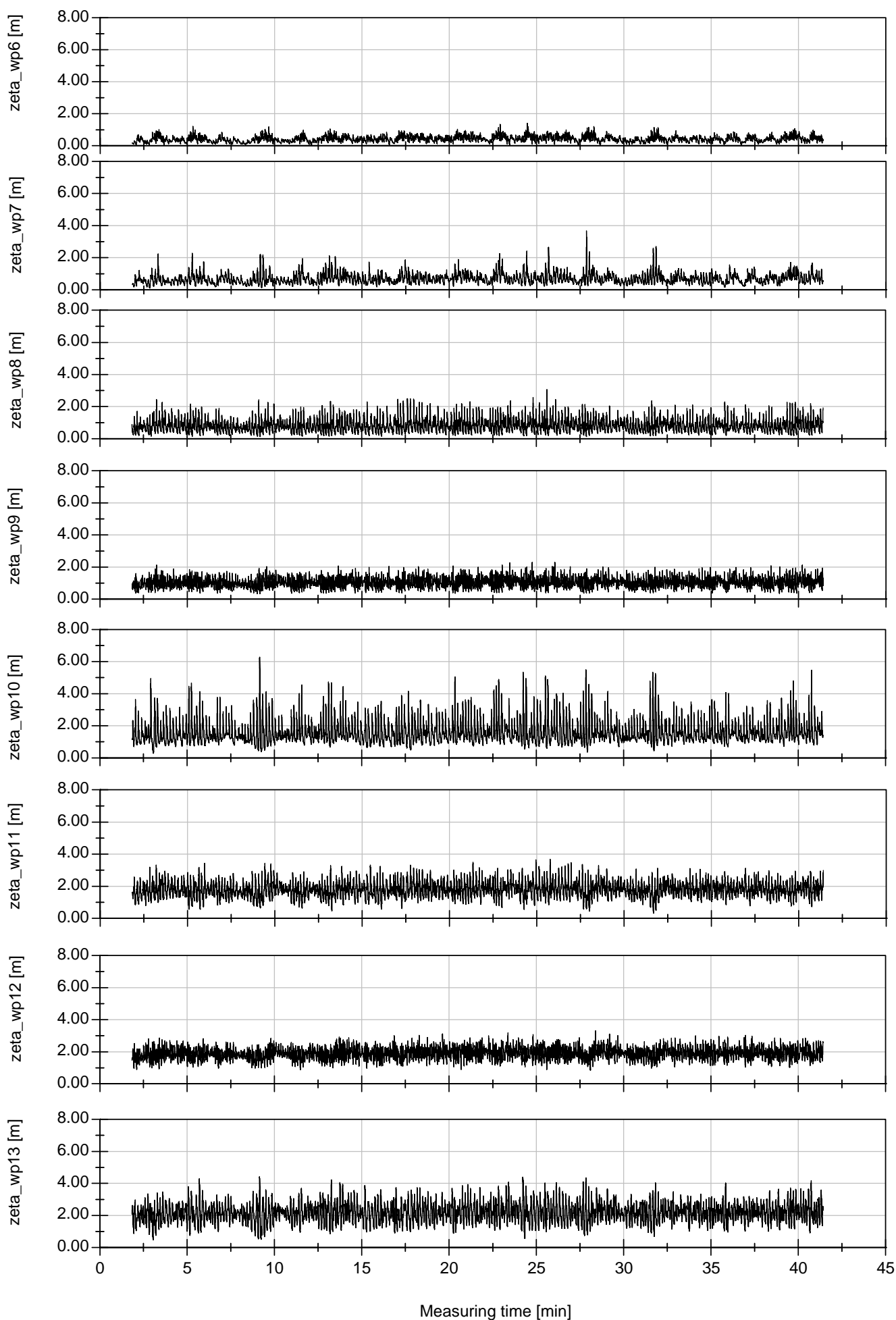
Run-No. 18 / Damage Case 4 /  $H_s = 4.64$  m /  $T_p = 12.3$  s /  $\Gamma = 1.0$



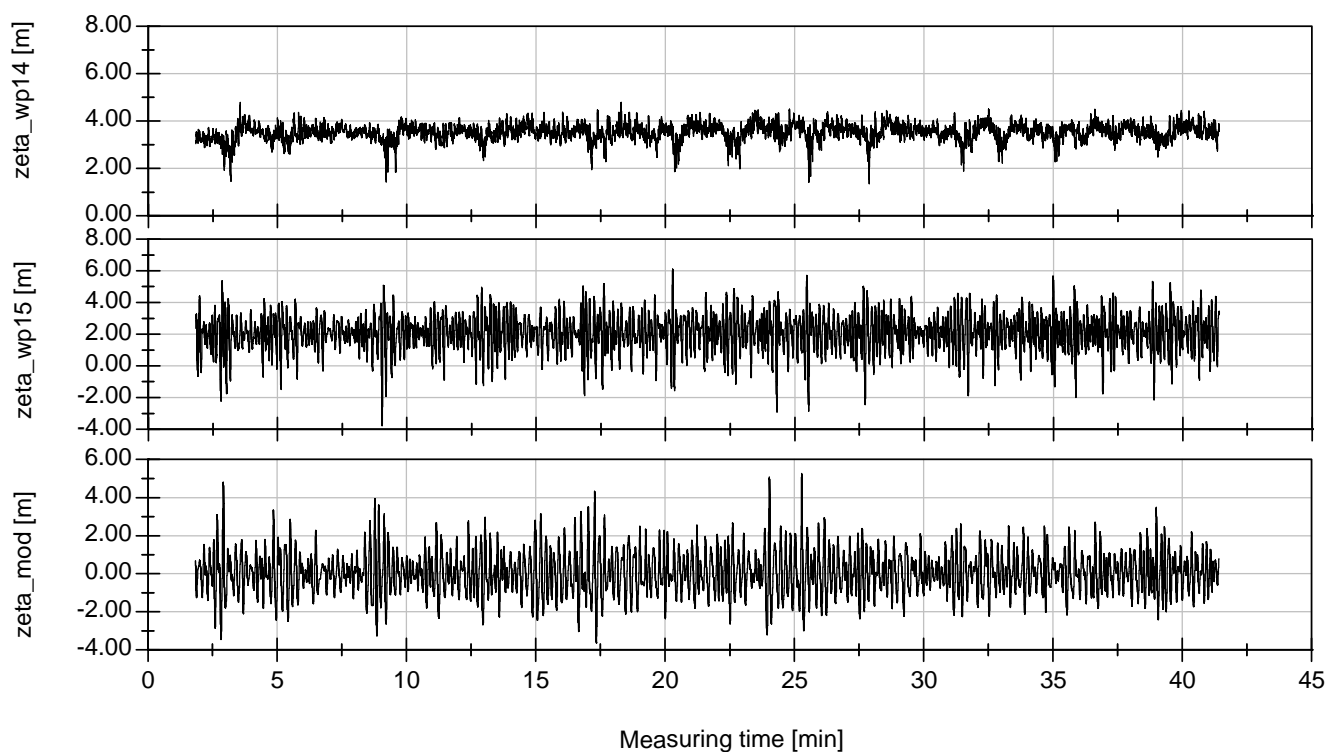
Run-No. 19 / Damage Case 4 /  $H_s = 4.62$  m /  $T_p = 12.2$  s /  $\Gamma = 1.0$



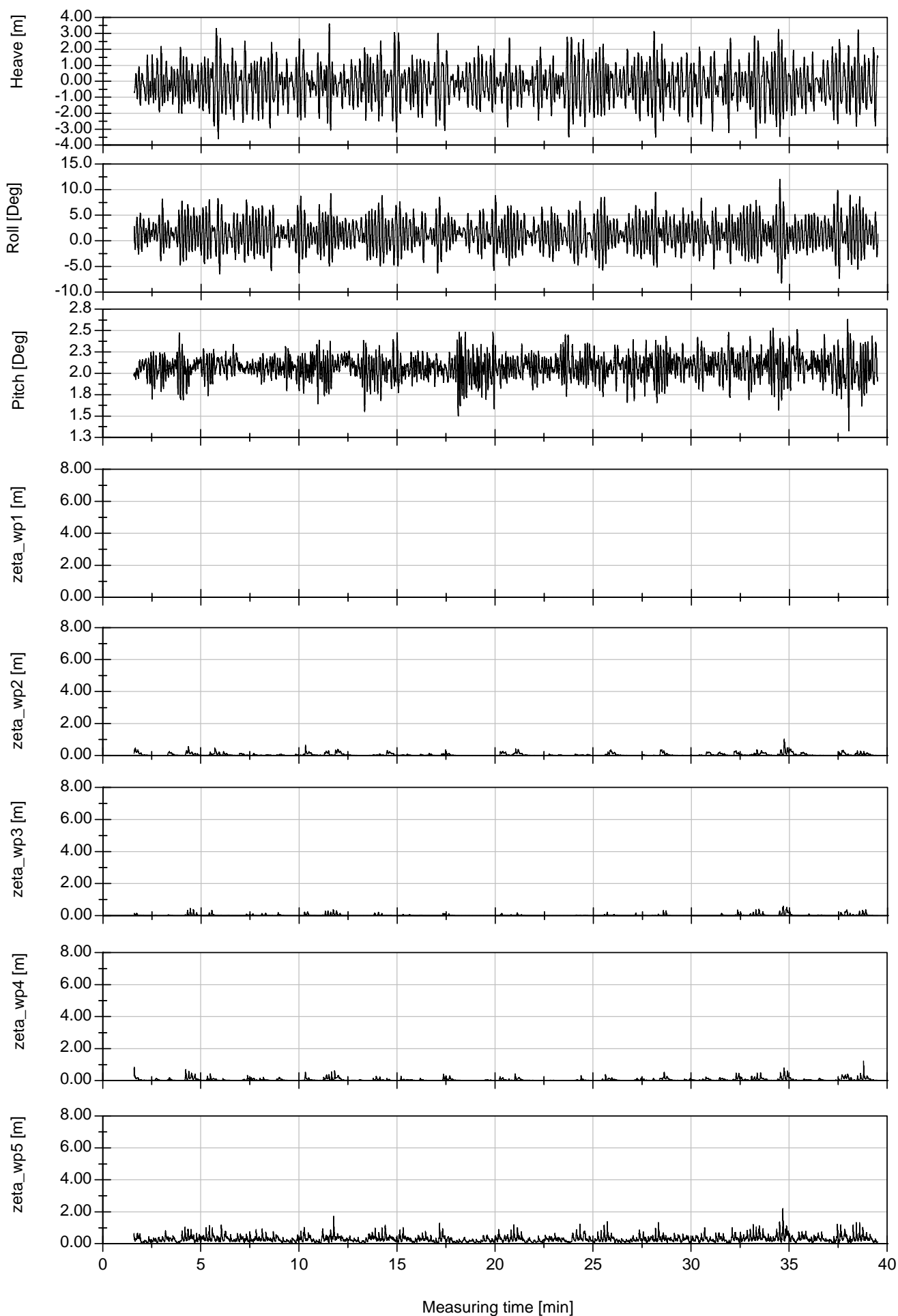
Run-No. 19 / Damage Case 4 /  $H_s = 4.62$  m /  $T_p = 12.2$  s /  $\Gamma = 1.0$



Run-No. 19 / Damage Case 4 /  $H_s = 4.62$  m /  $T_p = 12.2$  s /  $\Gamma = 1.0$

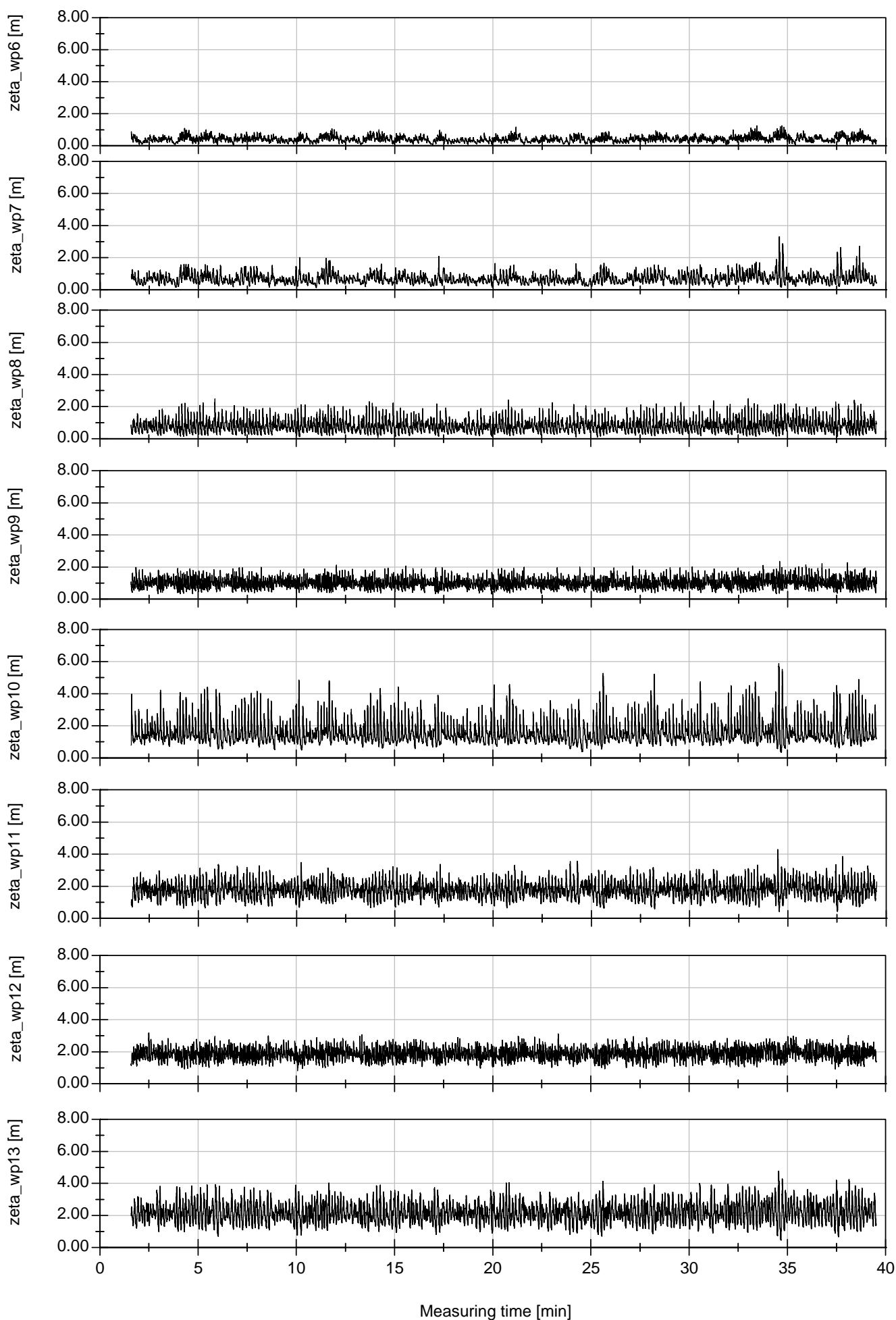


Run-No. 20 / Damage Case 4 /  $H_s = 4.64$  m /  $T_p = 12.3$  s /  $\Gamma = 1.0$

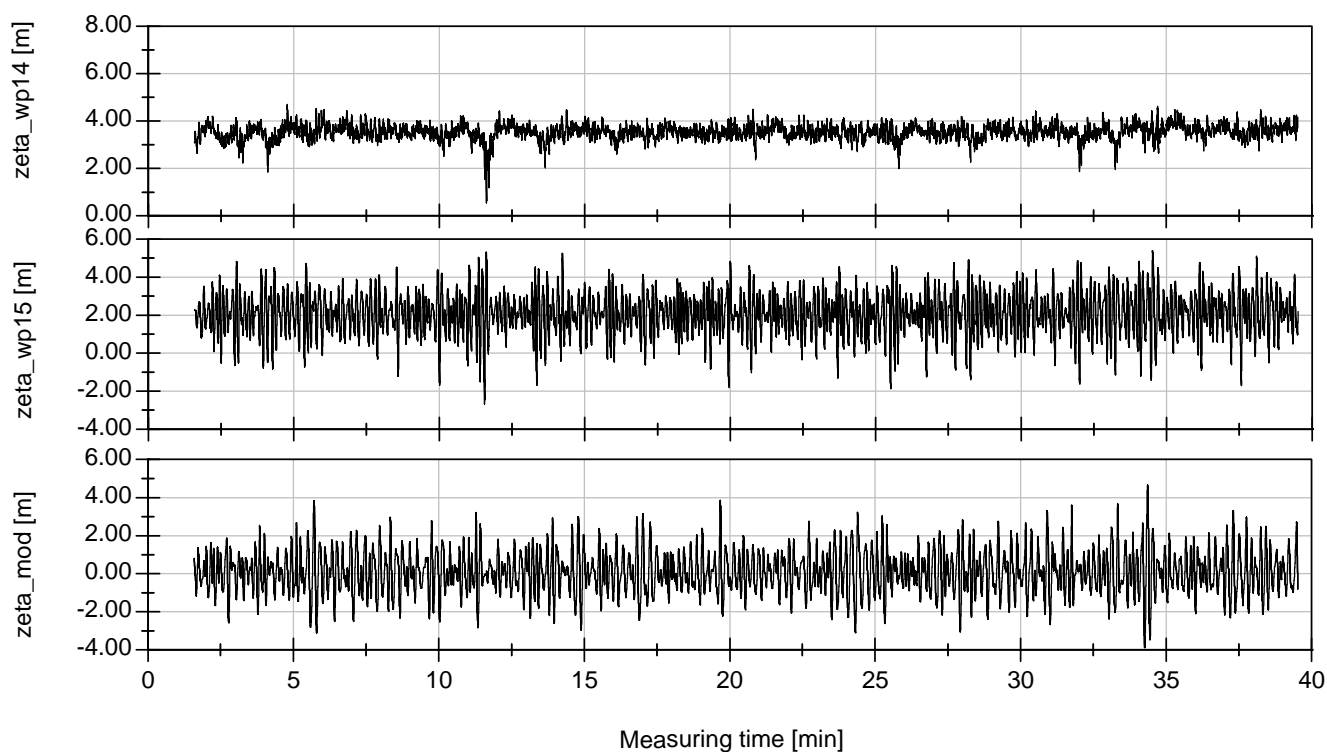




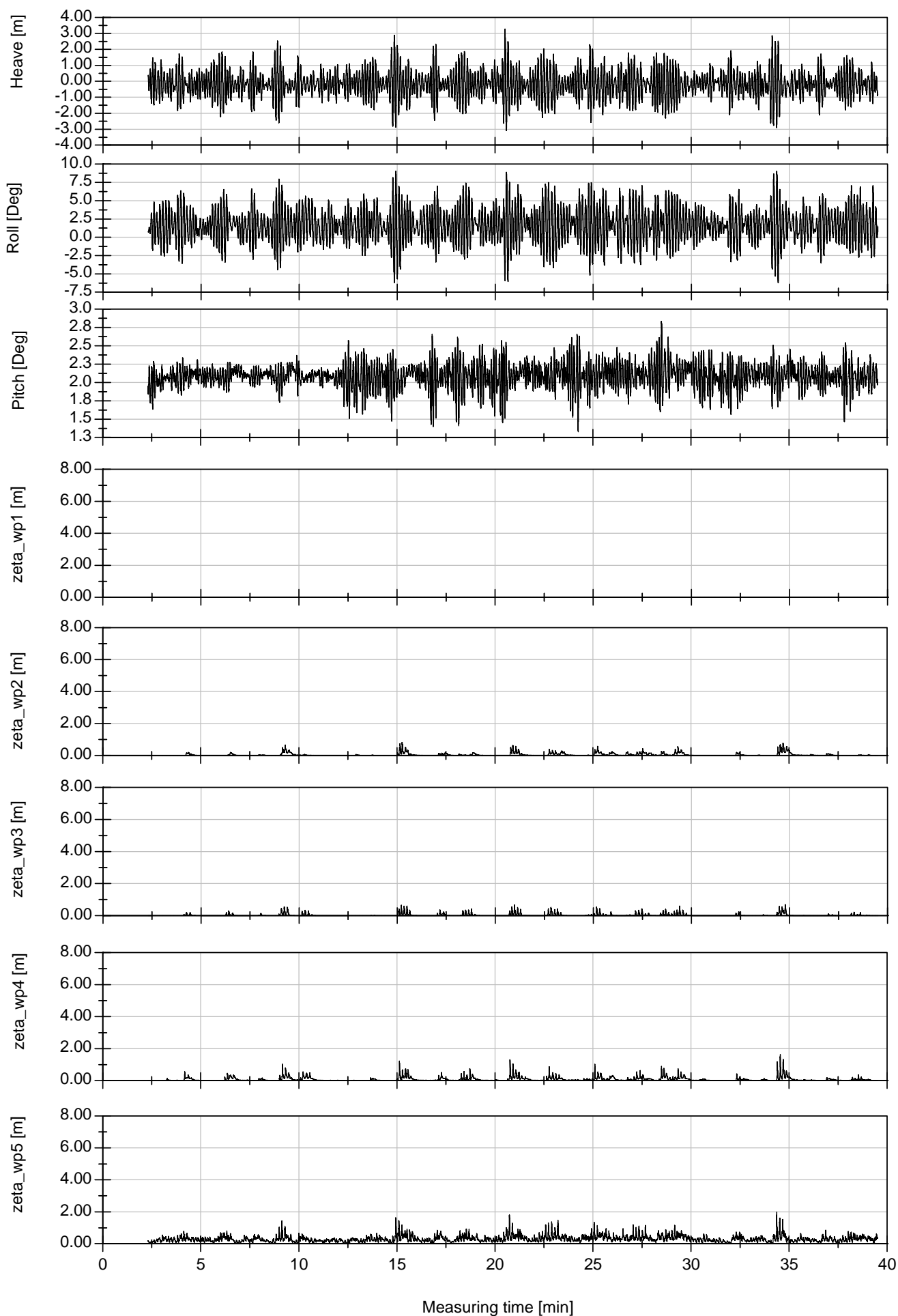
Run-No. 20 / Damage Case 4 /  $H_s = 4.64$  m /  $T_p = 12.3$  s /  $\Gamma = 1.0$



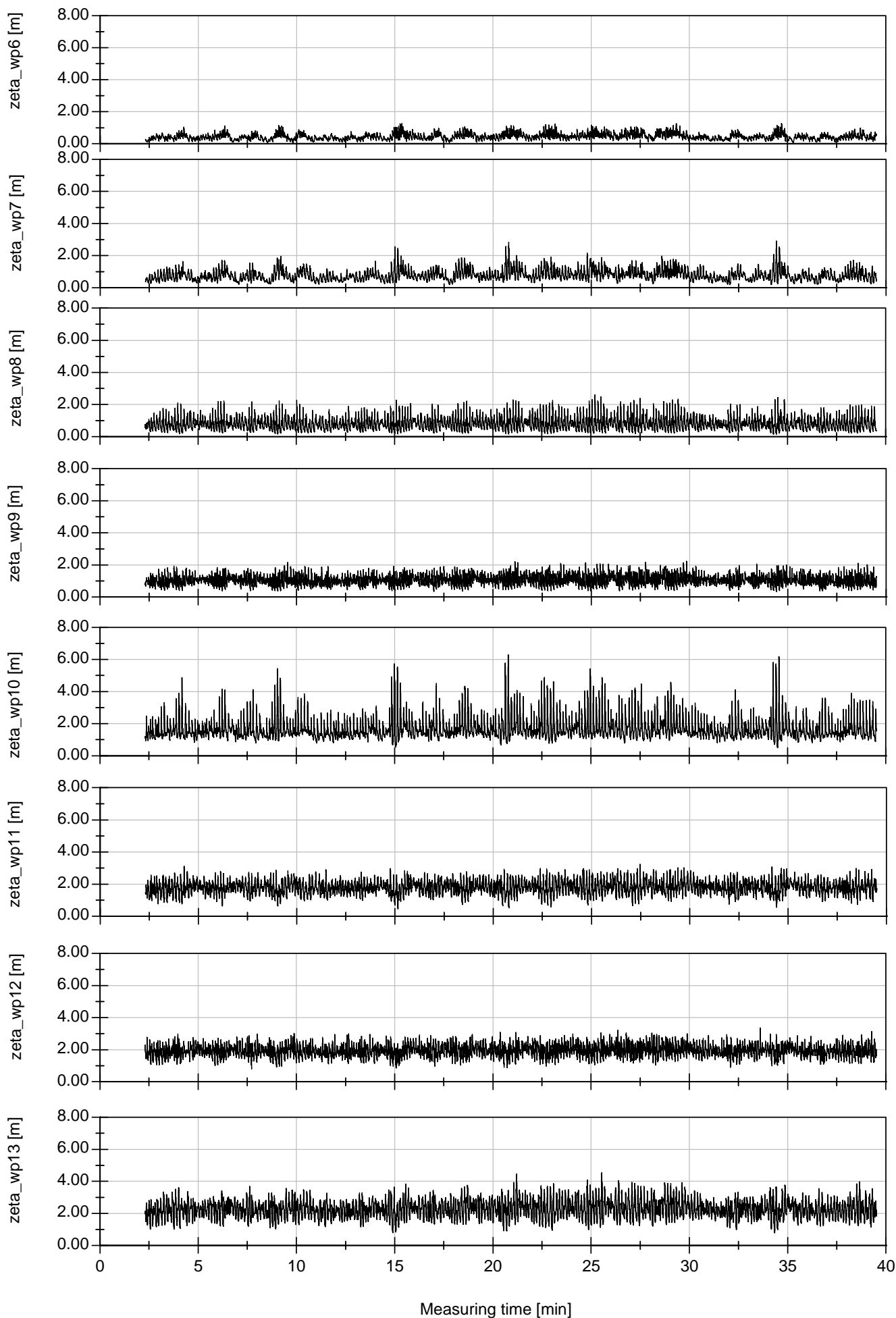
Run-No. 20 / Damage Case 4 /  $H_s = 4.64$  m /  $T_p = 12.3$  s /  $\Gamma = 1.0$



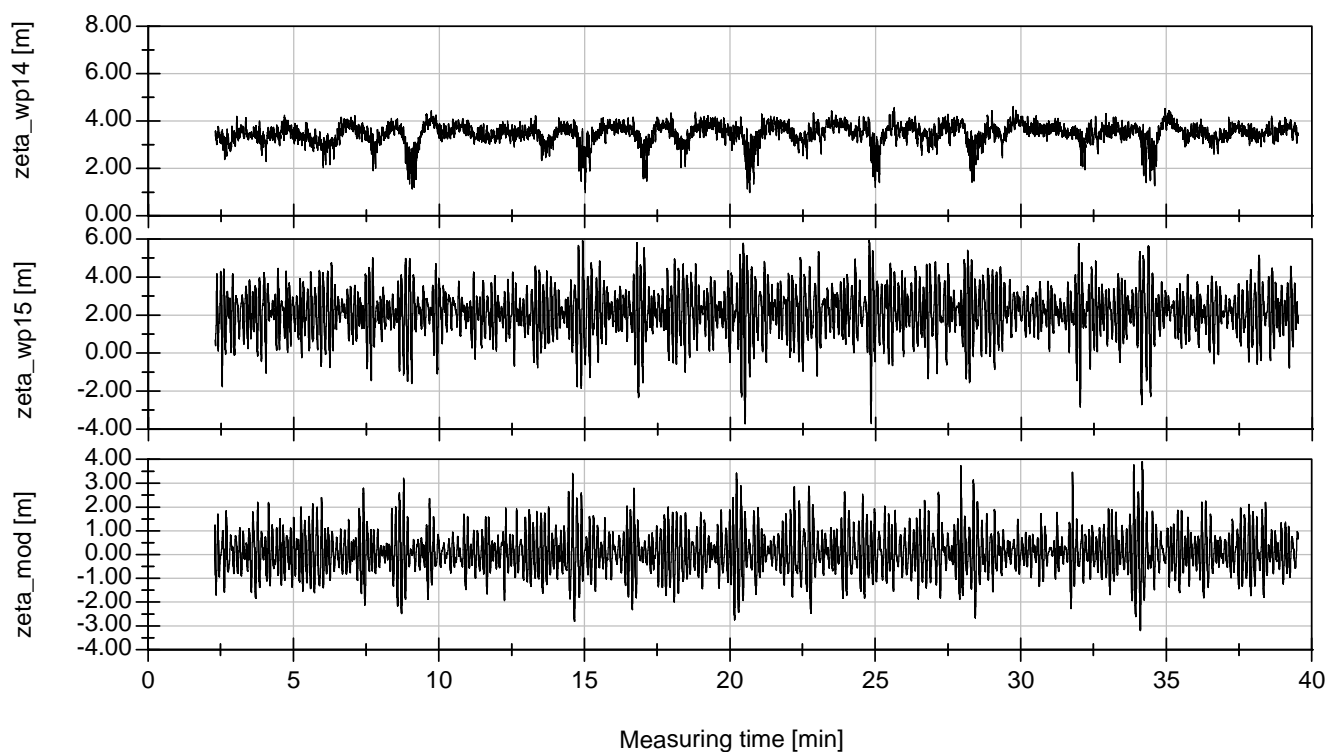
Run-No. 21 / Damage Case 4 /  $H_s = 3.73$  m /  $T_p = 8.3$  s /  $\Gamma = 3.3$



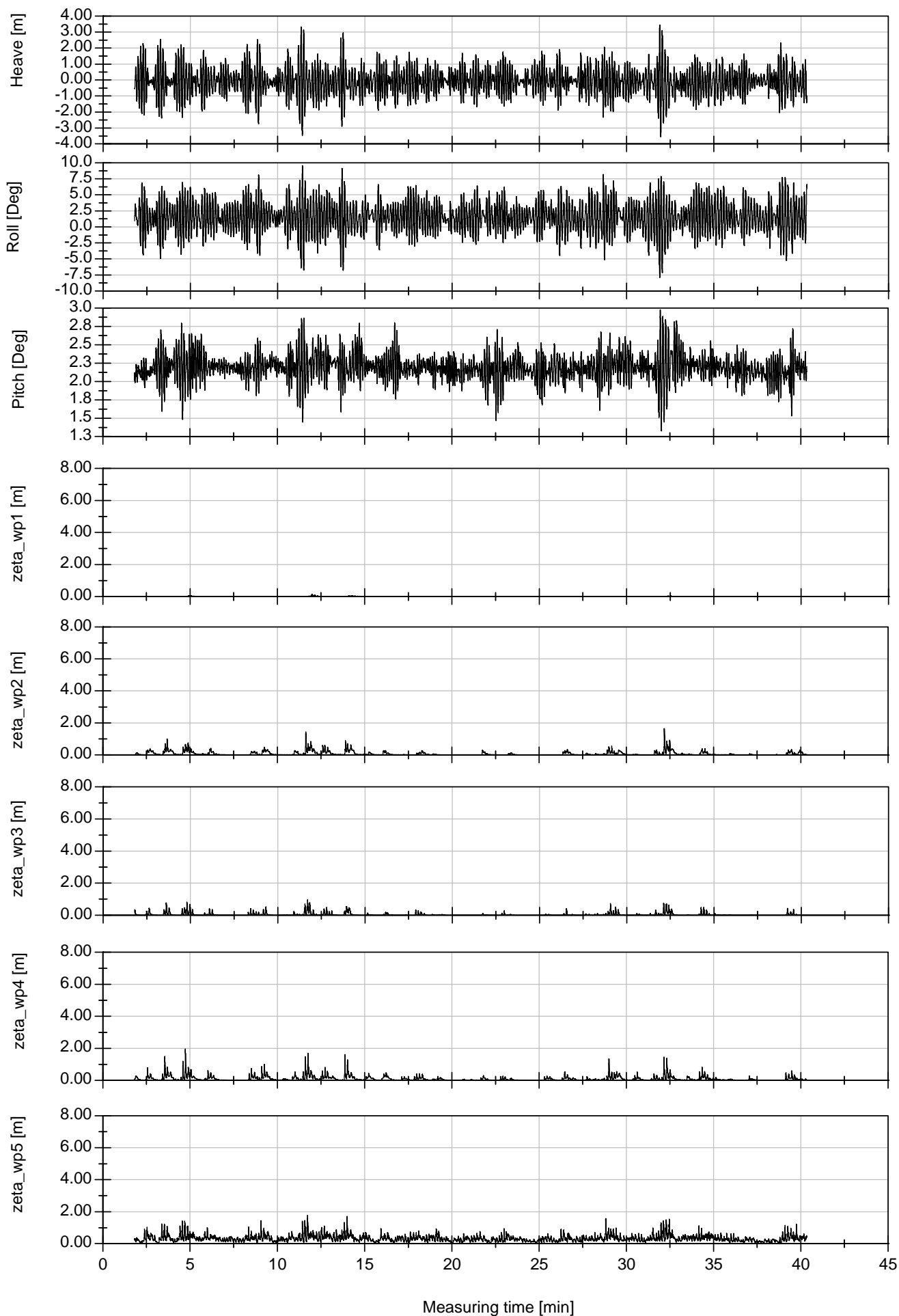
Run-No. 21 / Damage Case 4 /  $H_s = 3.73$  m /  $T_p = 8.3$  s /  $\Gamma = 3.3$



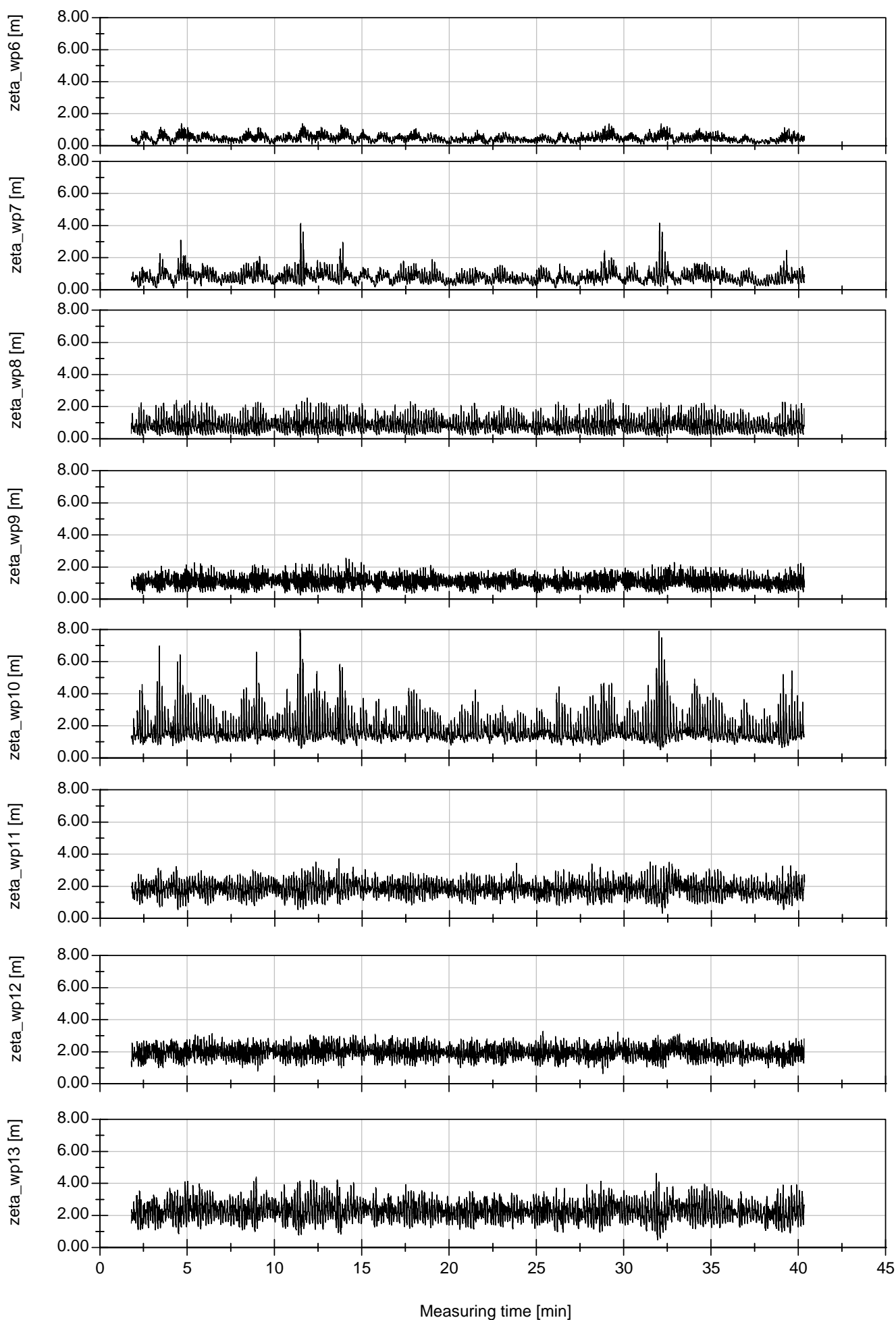
Run-No. 21 / Damage Case 4 /  $H_s = 3.73$  m /  $T_p = 8.3$  s /  $\Gamma = 3.3$



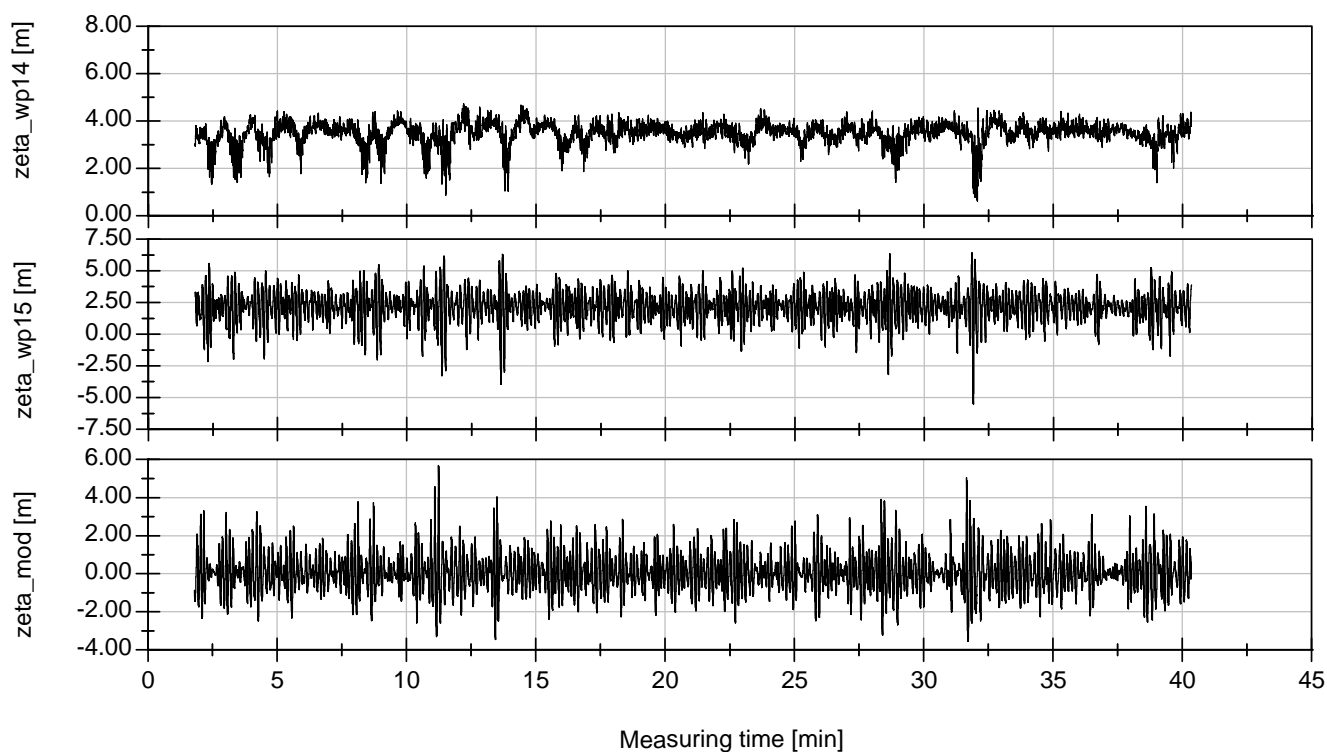
Run-No. 22 / Damage Case 4 /  $H_s = 4.35$  m /  $T_p = 8.4$  s /  $\Gamma = 3.3$



Run-No. 22 / Damage Case 4 /  $H_s = 4.35$  m /  $T_p = 8.4$  s /  $\Gamma = 3.3$

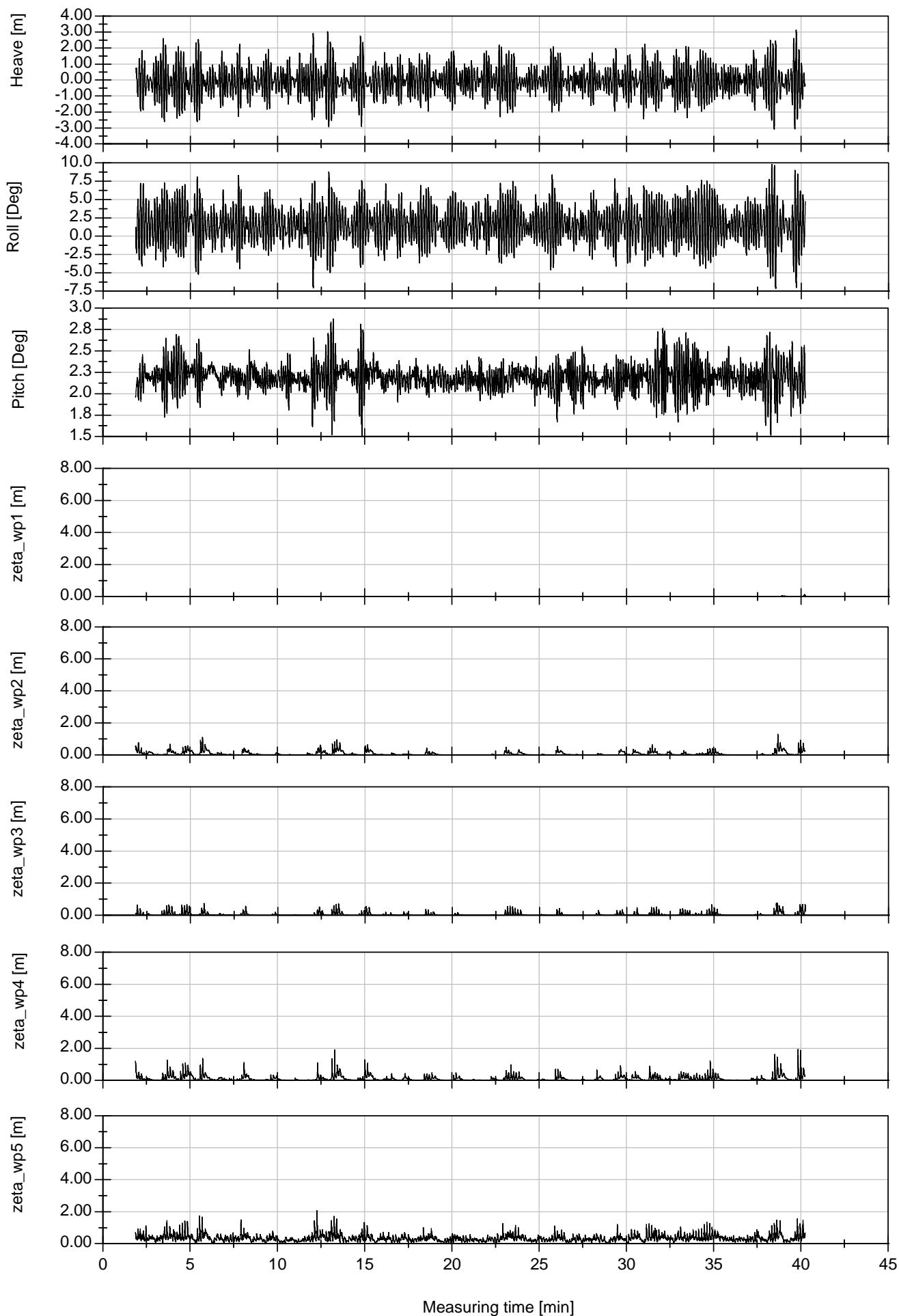


Run-No. 22 / Damage Case 4 /  $H_s = 4.35$  m /  $T_p = 8.4$  s /  $\Gamma = 3.3$

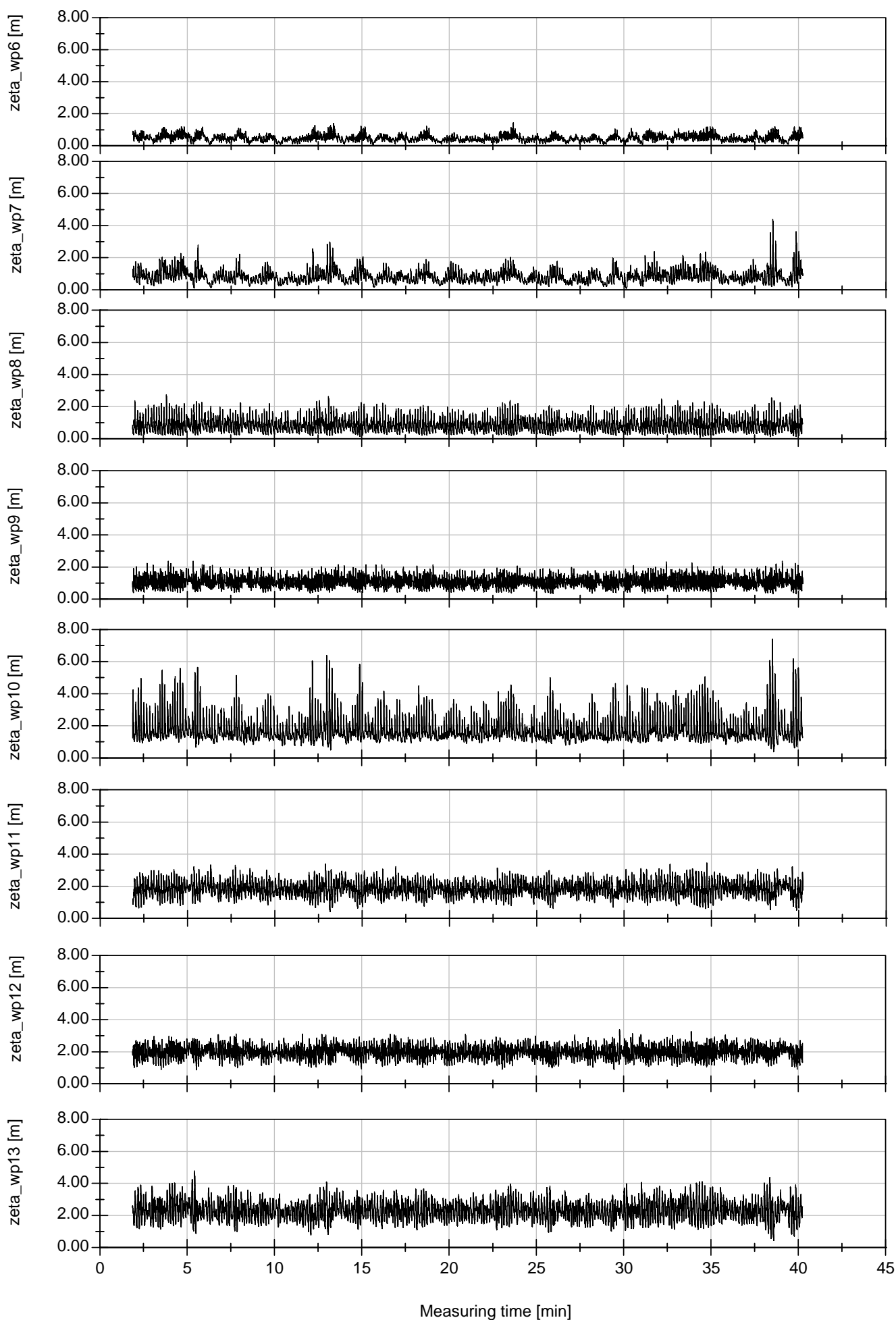




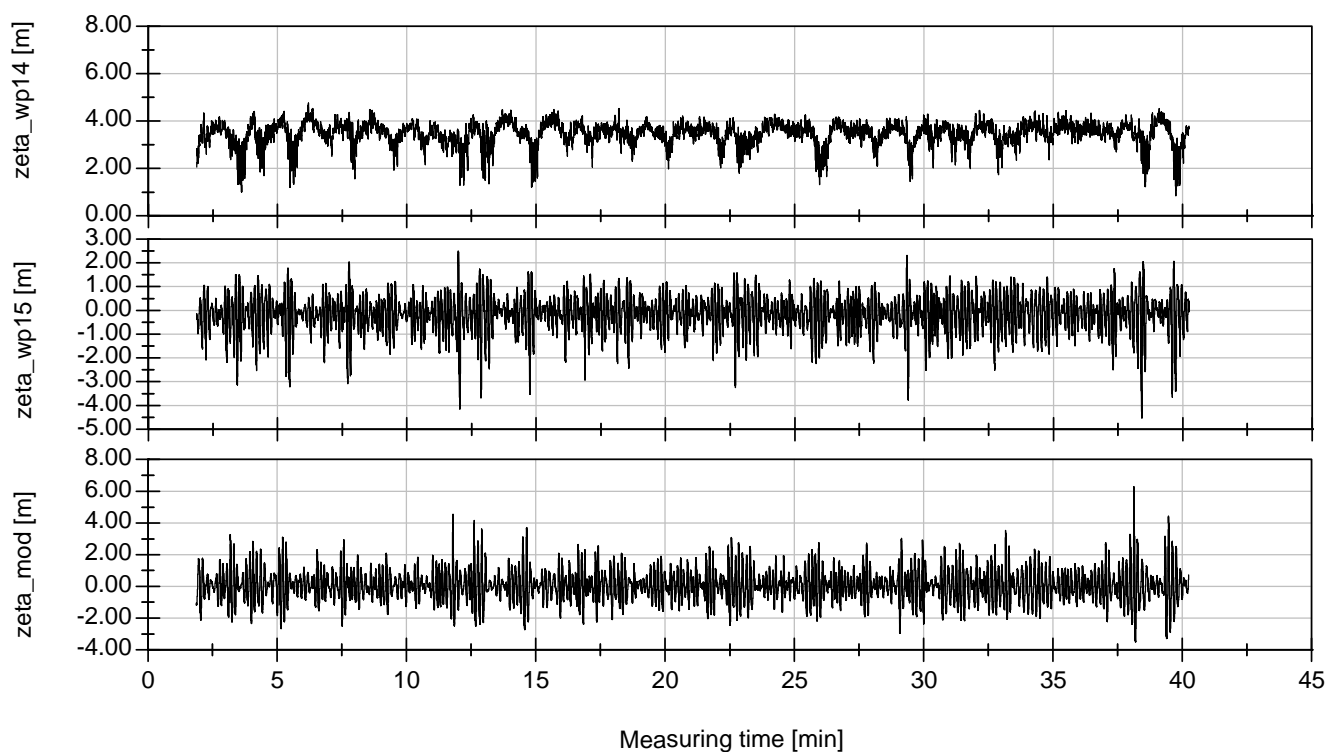
Run-No. 23 / Damage Case 4 /  $H_s = 4.31$  m /  $T_p = 8.4$  s /  $\Gamma = 3.3$



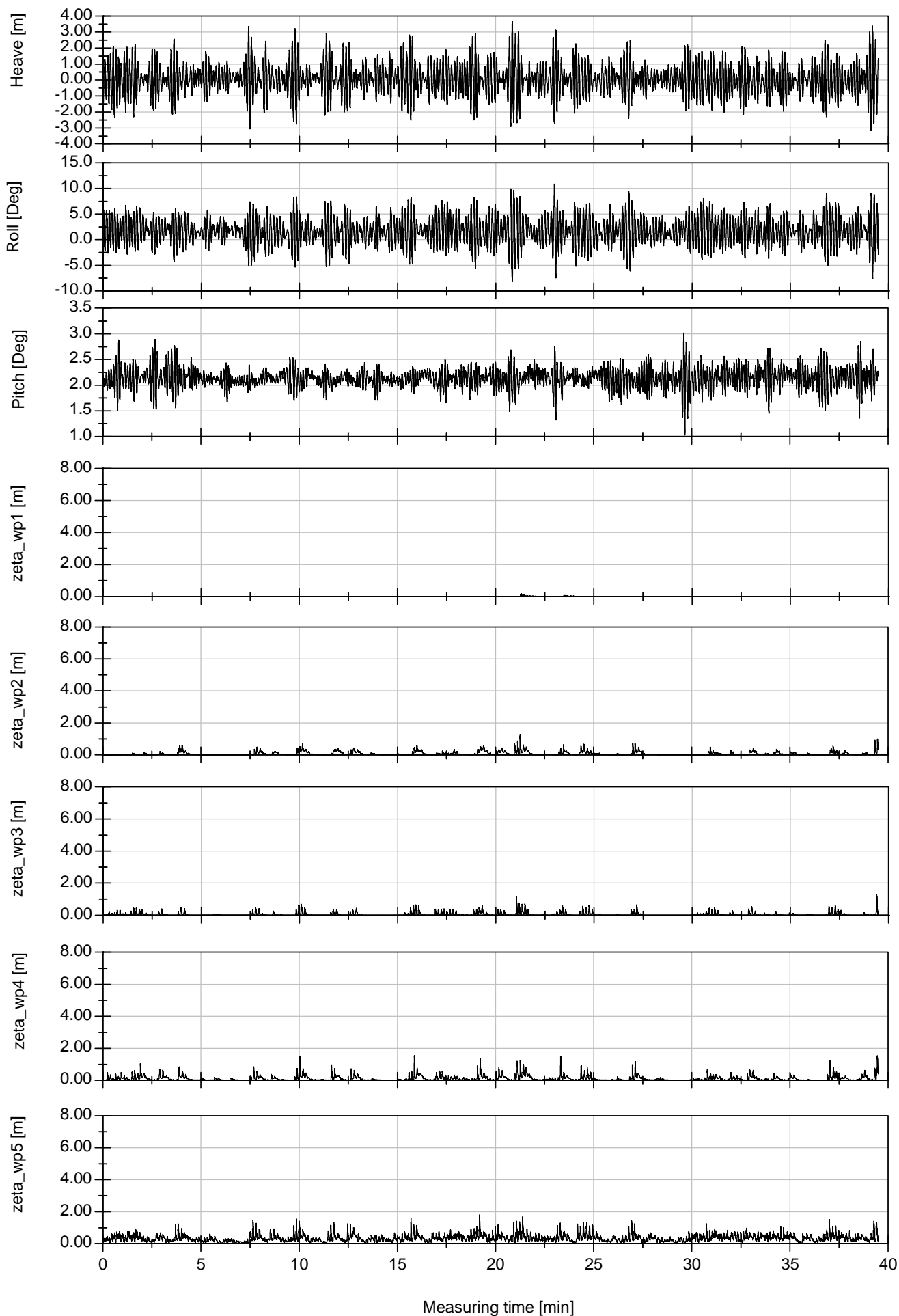
Run-No. 23 / Damage Case 4 /  $H_s = 4.31$  m /  $T_p = 8.4$  s /  $\Gamma = 3.3$



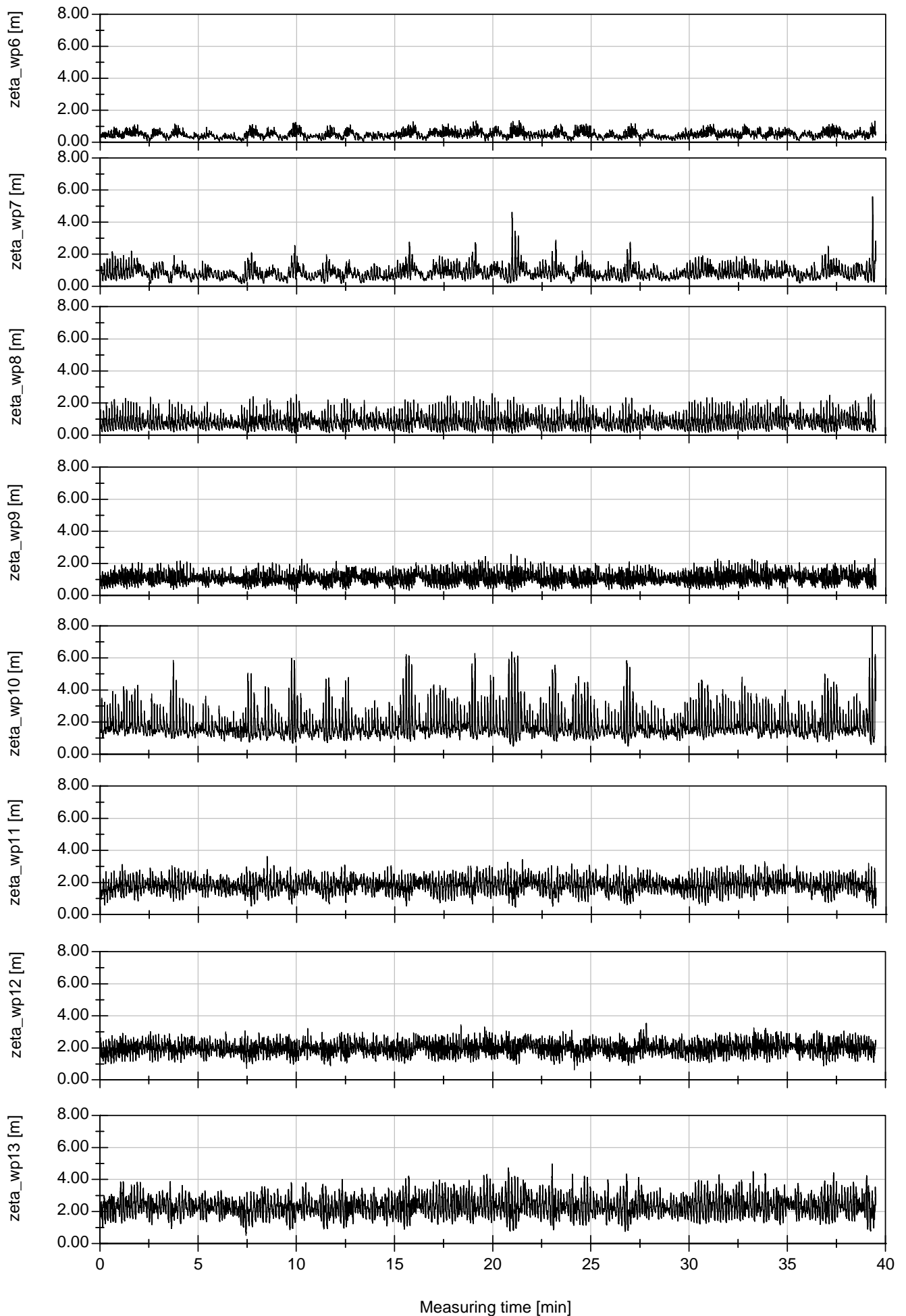
Run-No. 23 / Damage Case 4 /  $H_s = 4.31$  m /  $T_p = 8.4$  s /  $\Gamma = 3.3$



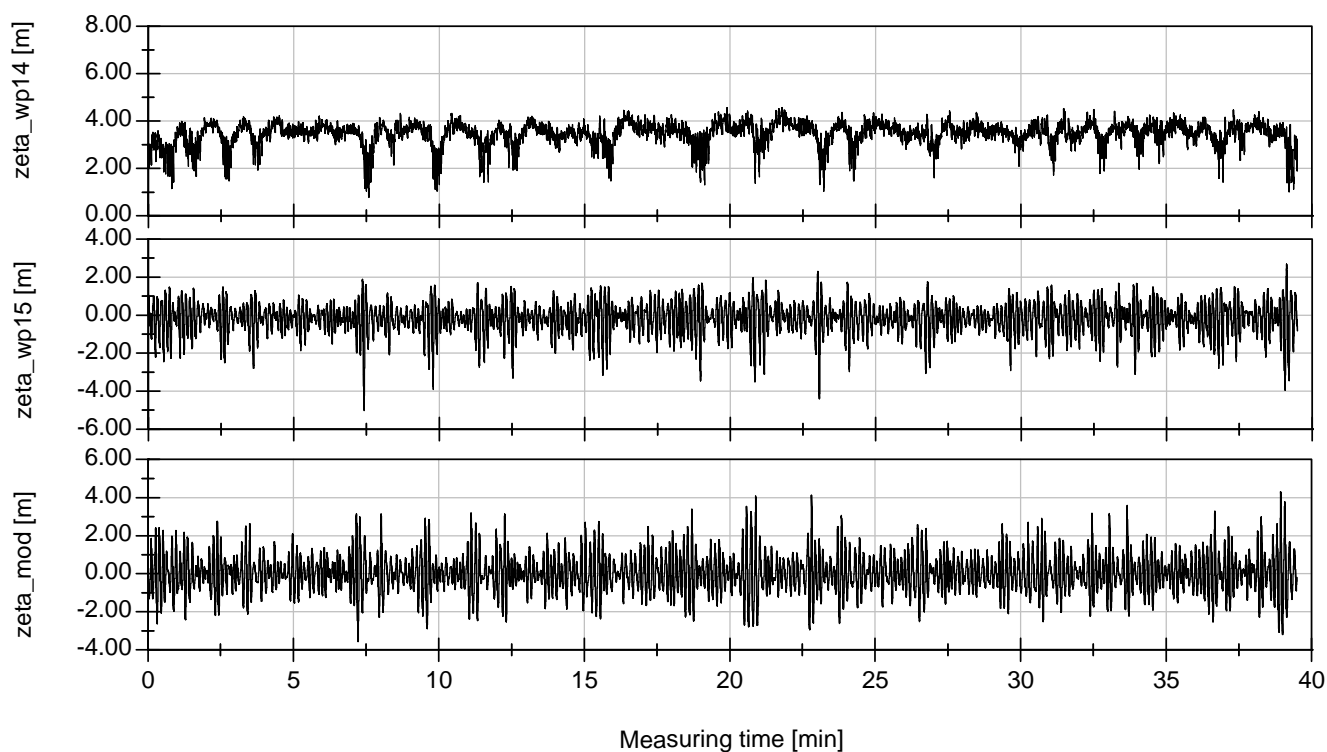
Run-No. 24 / Damage Case 4 /  $H_s = 4.30$  m /  $T_p = 8.4$  s /  $\Gamma = 3.3$



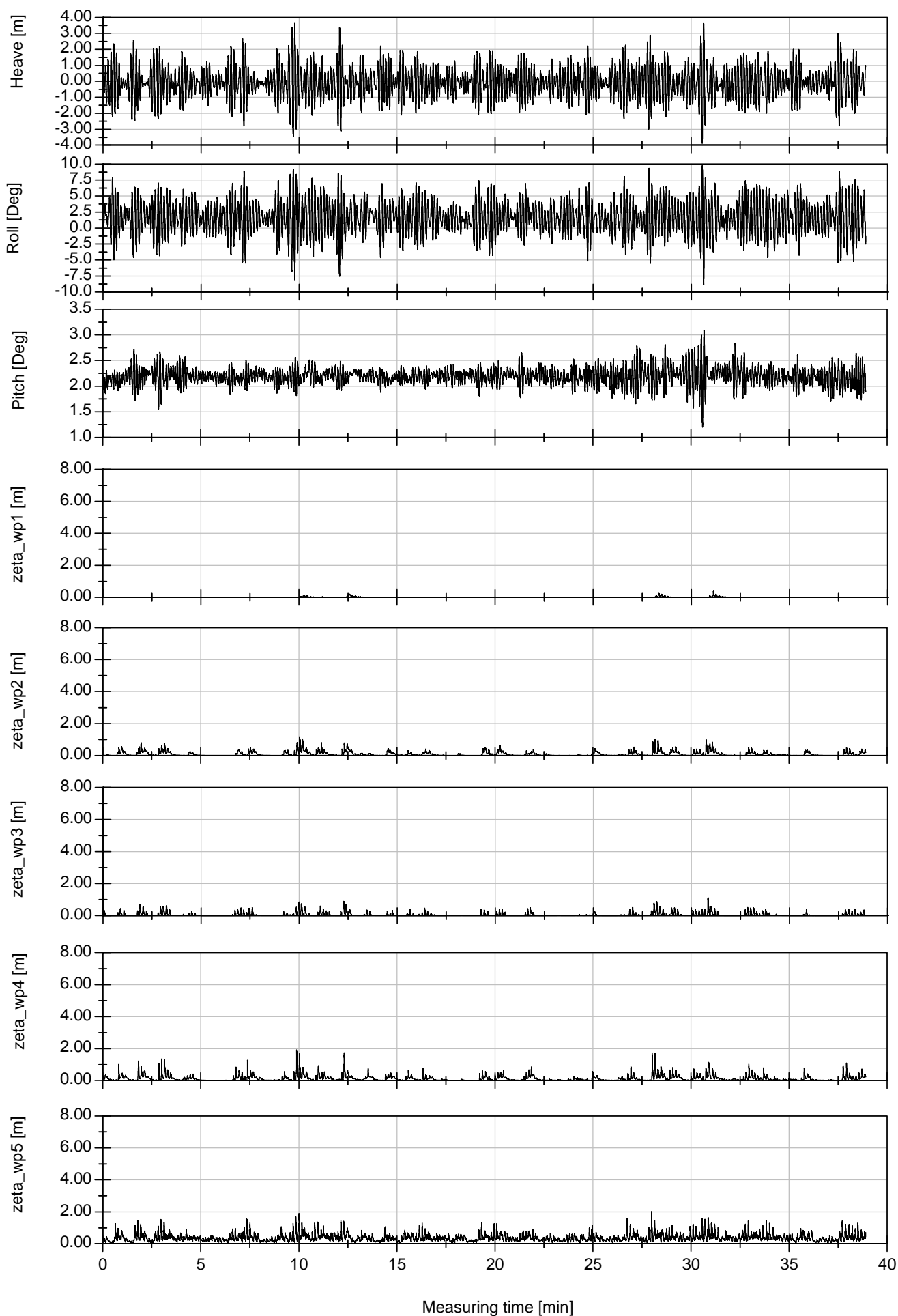
Run-No. 24 / Damage Case 4 /  $H_s = 4.30$  m /  $T_p = 8.4$  s /  $\Gamma = 3.3$



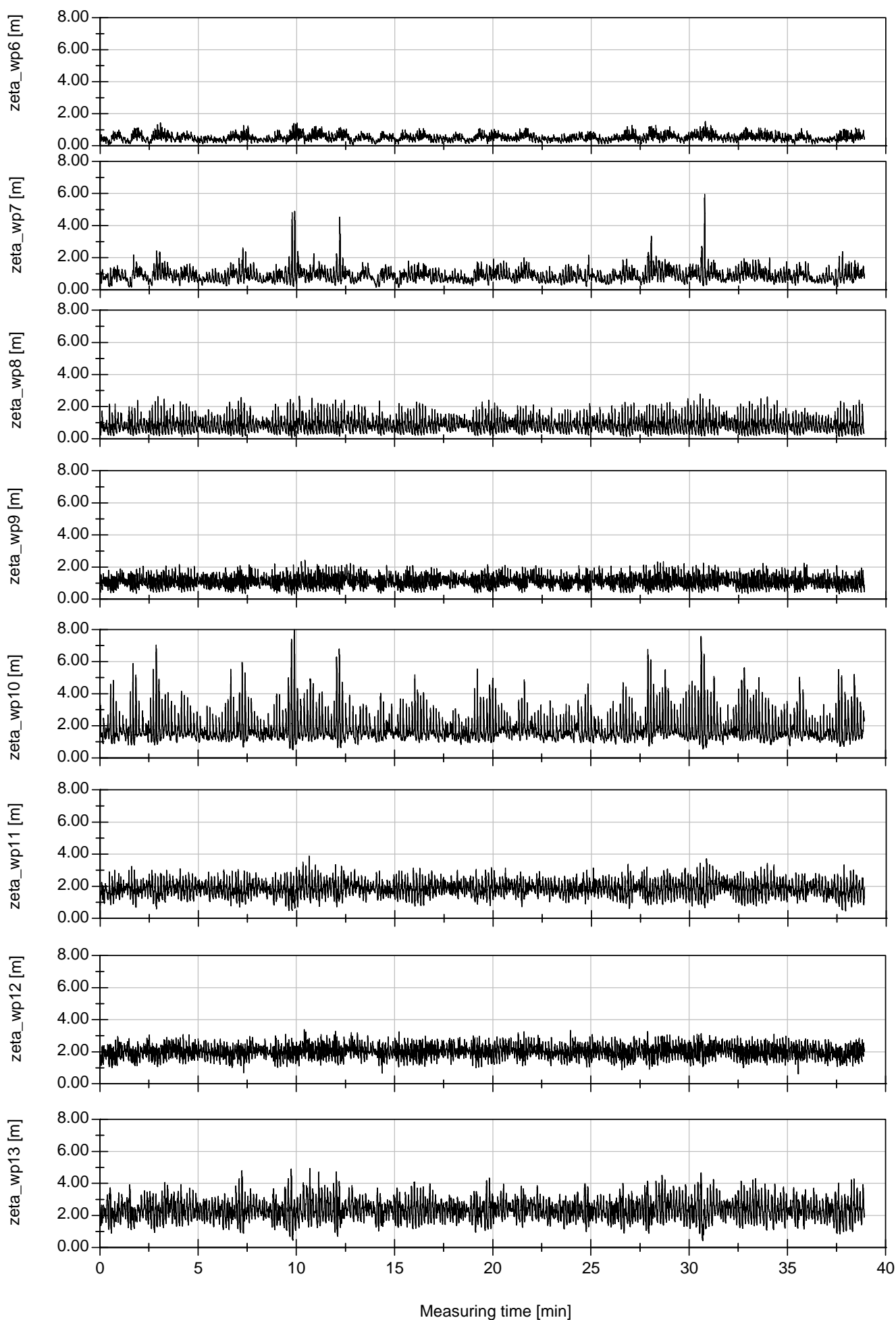
Run-No. 24 / Damage Case 4 /  $H_s = 4.30$  m /  $T_p = 8.4$  s /  $\Gamma = 3.3$



Run-No. 25 / Damage Case 4 /  $H_s = 4.38$  m /  $T_p = 8.4$  s /  $\Gamma = 3.3$

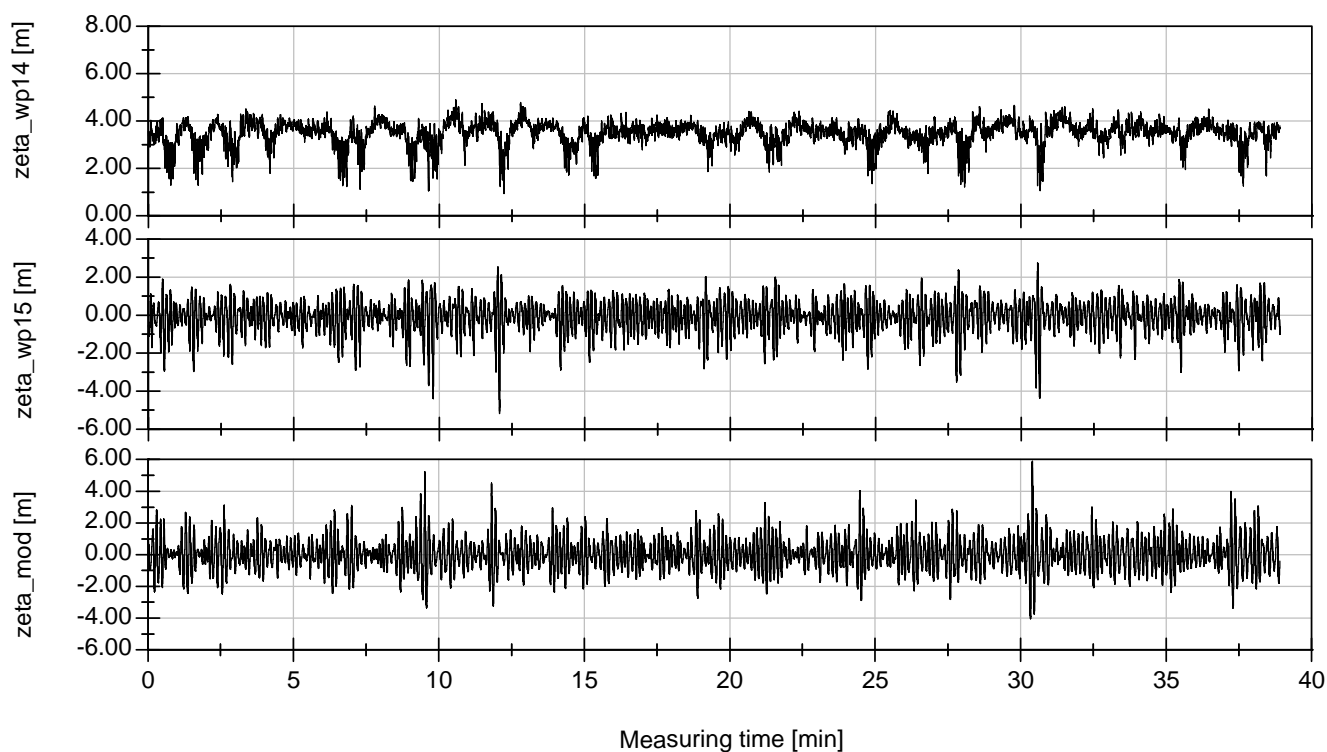


Run-No. 25 / Damage Case 4 /  $H_s = 4.38$  m /  $T_p = 8.4$  s /  $\Gamma = 3.3$

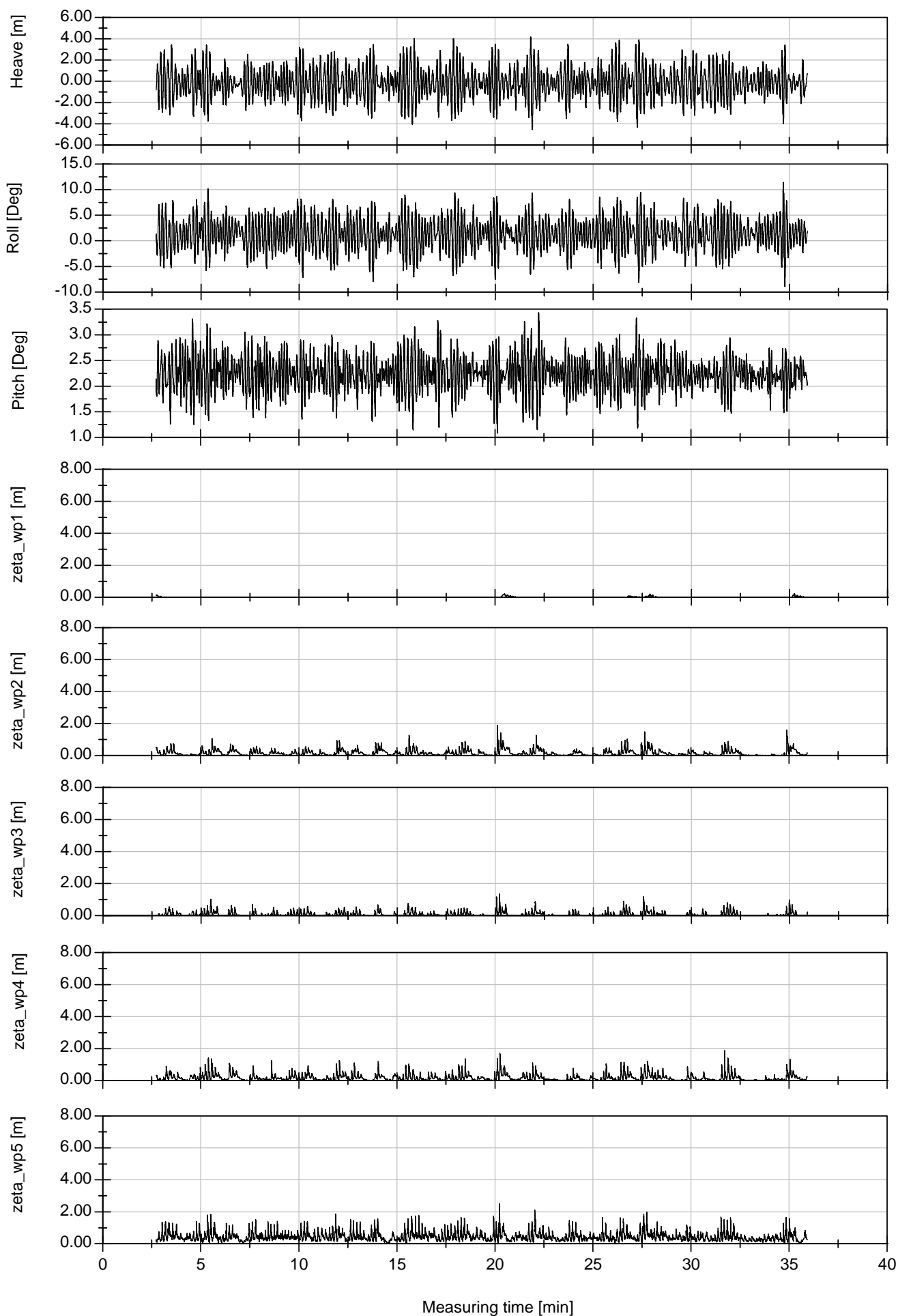




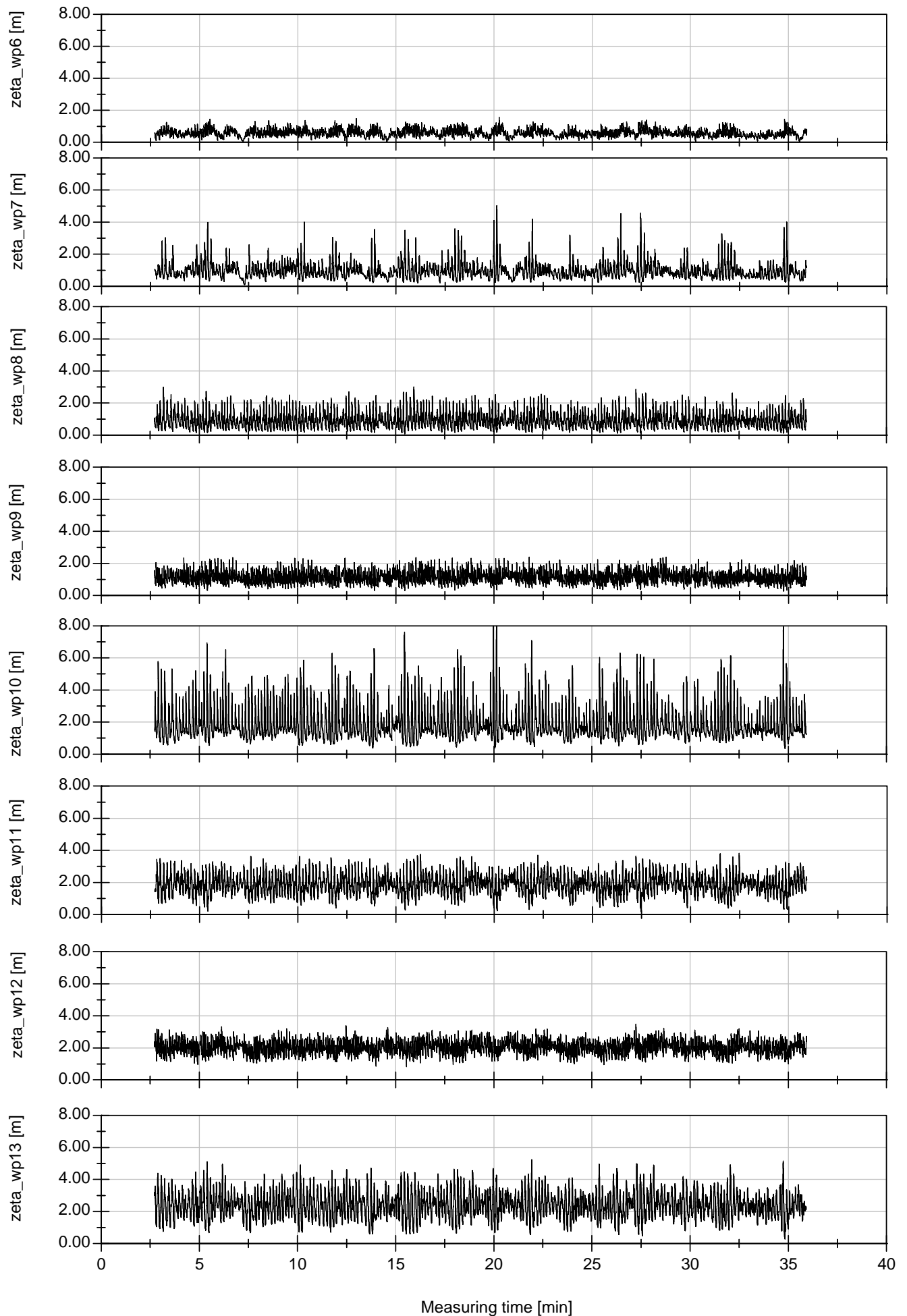
Run-No. 25 / Damage Case 4 /  $H_s = 4.38$  m /  $T_p = 8.4$  s /  $\Gamma = 3.3$



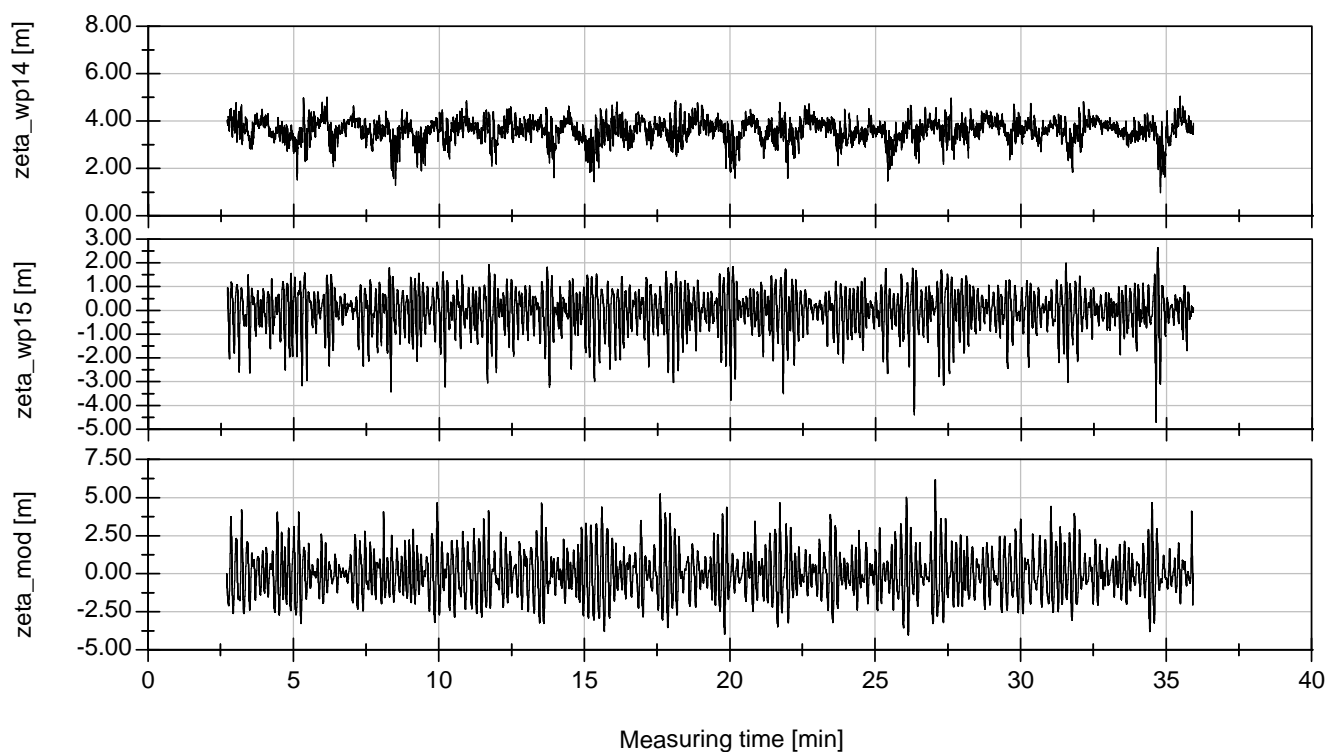
Run-No. 26 / Damage Case 4 /  $H_s = 6.50$  m /  $T_p = 10.2$  s /  $\Gamma = 3.3$



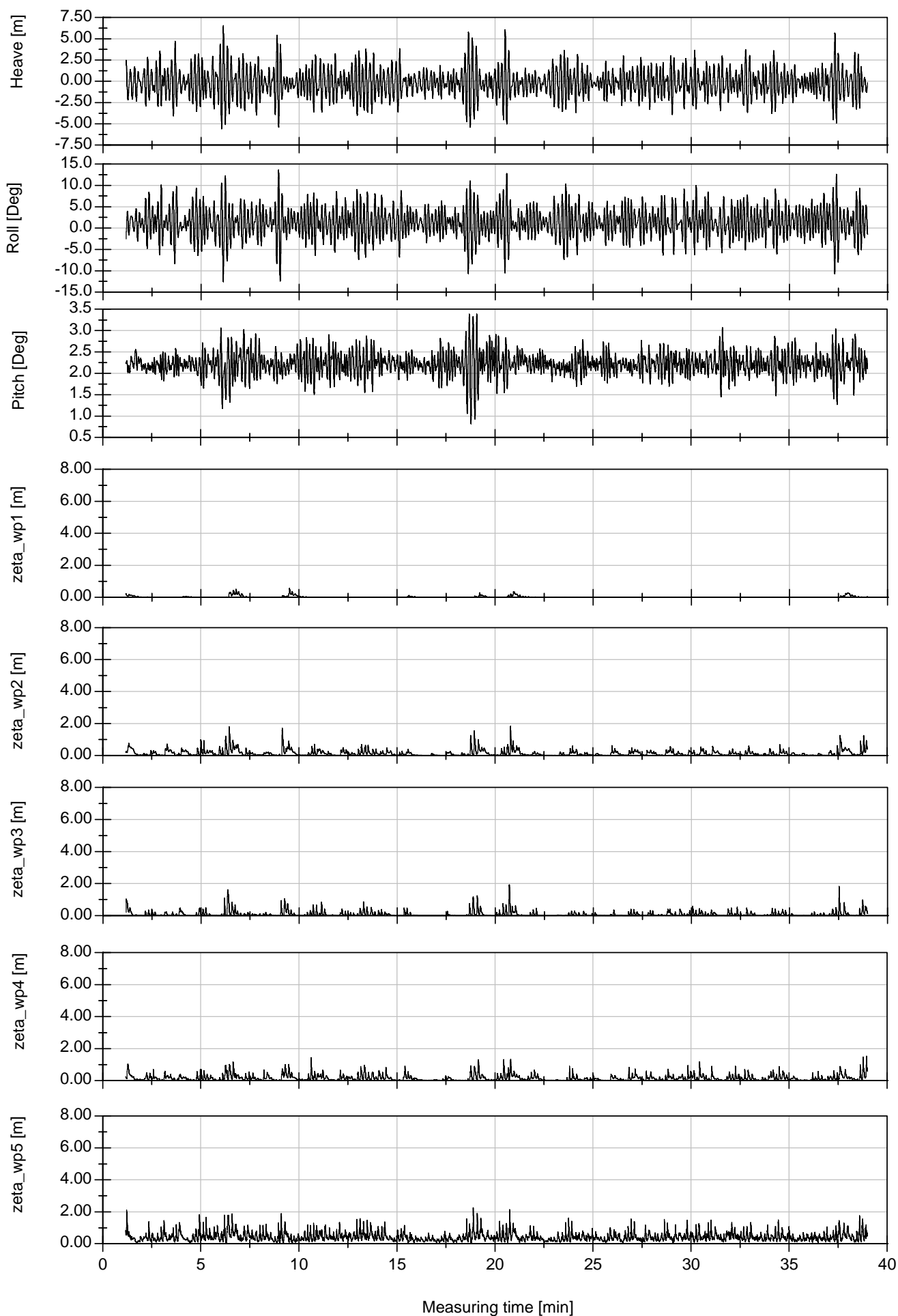
Run-No. 26 / Damage Case 4 /  $H_s = 6.50$  m /  $T_p = 10.2$  s /  $\Gamma = 3.3$



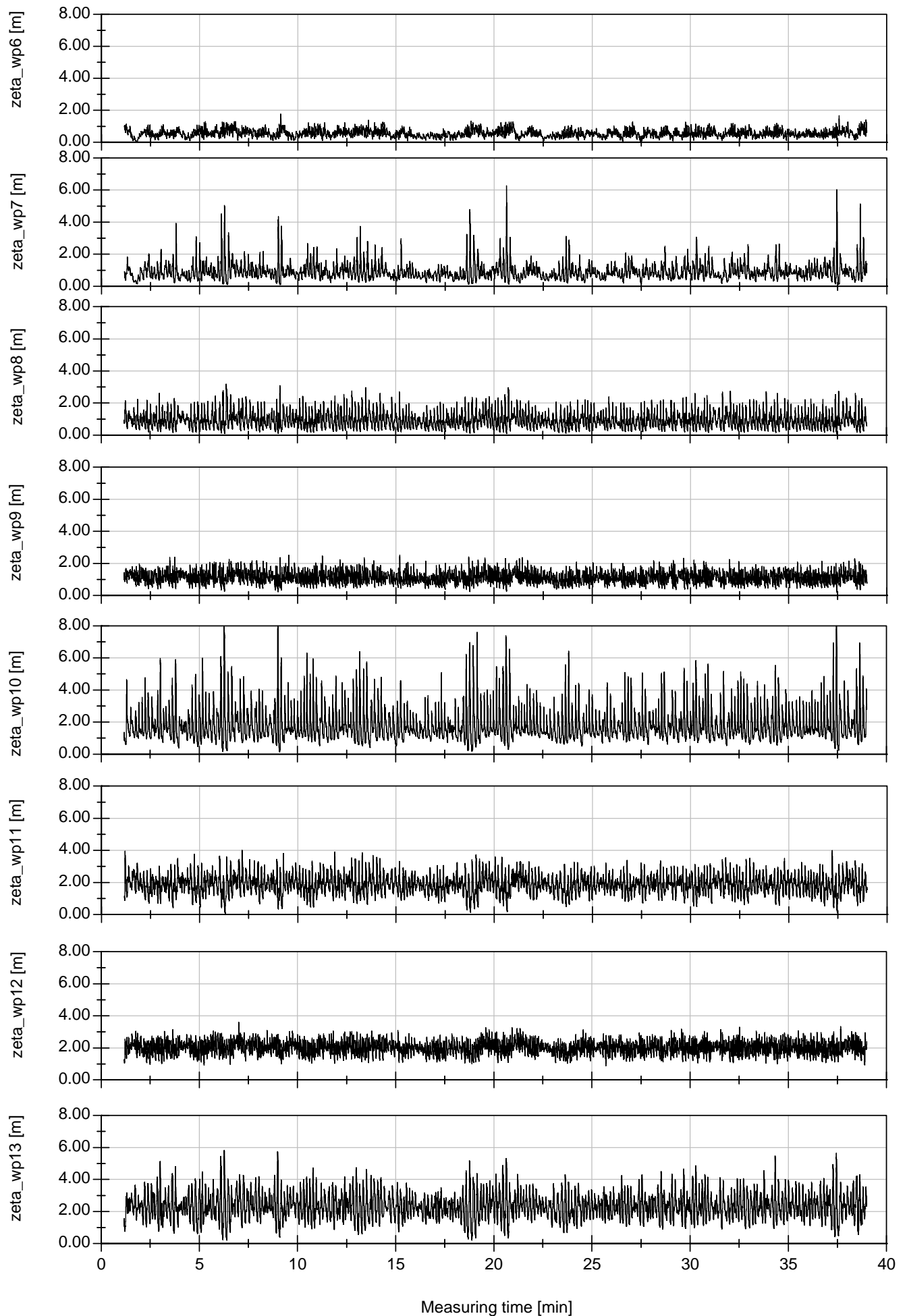
Run-No. 26 / Damage Case 4 /  $H_s = 6.50$  m /  $T_p = 10.2$  s /  $\Gamma = 3.3$



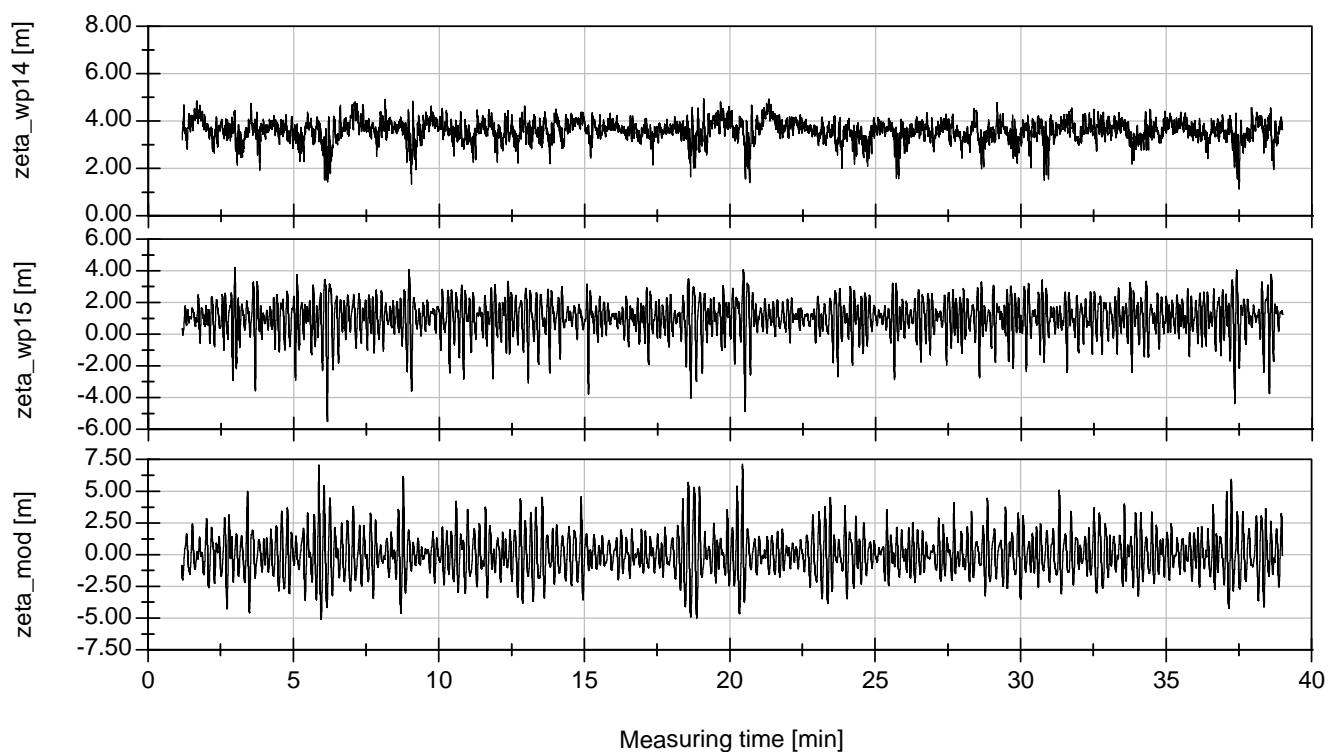
Run-No. 27 / Damage Case 4 /  $H_s = 6.69$  m /  $T_p = 11.1$  s /  $\Gamma = 3.3$



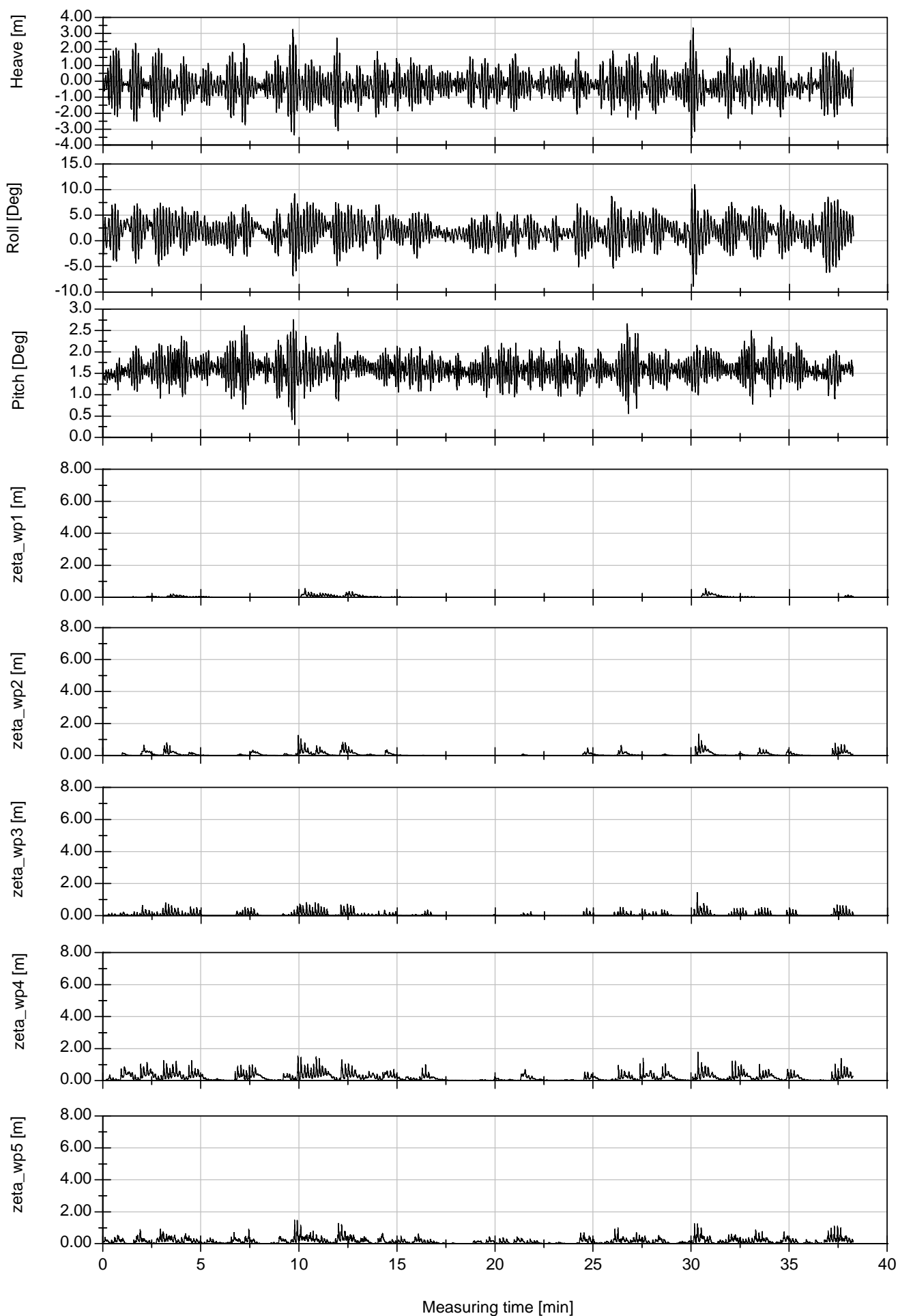
Run-No. 27 / Damage Case 4 /  $H_s = 6.69$  m /  $T_p = 11.1$  s /  $\Gamma = 3.3$



Run-No. 27 / Damage Case 4 /  $H_s = 6.69$  m /  $T_p = 11.1$  s /  $\Gamma = 3.3$

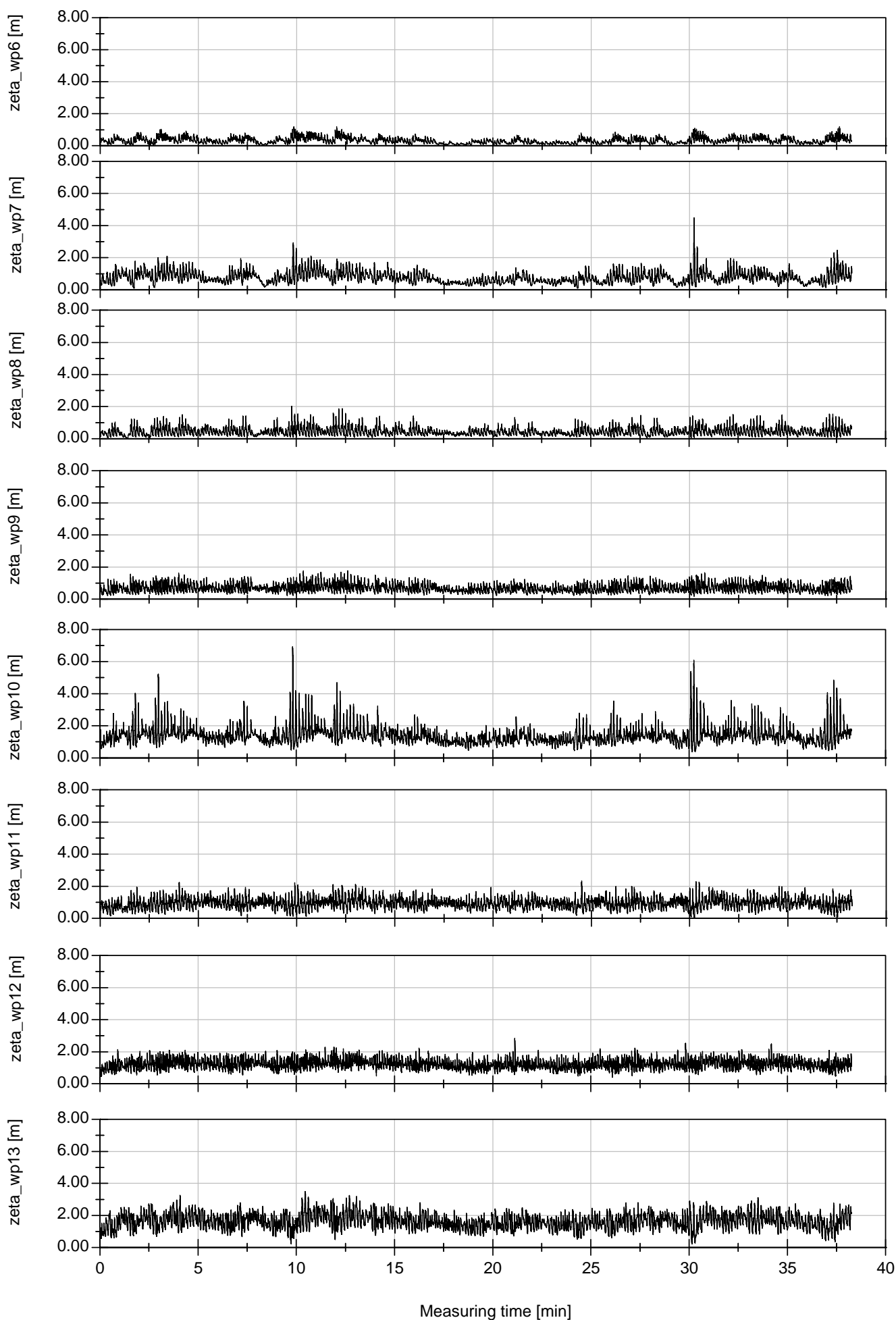


Run-No. 28 / Damage Case 4 /  $H_s = 4.39$  m /  $T_p = 8.5$  s /  $\Gamma = 3.3$

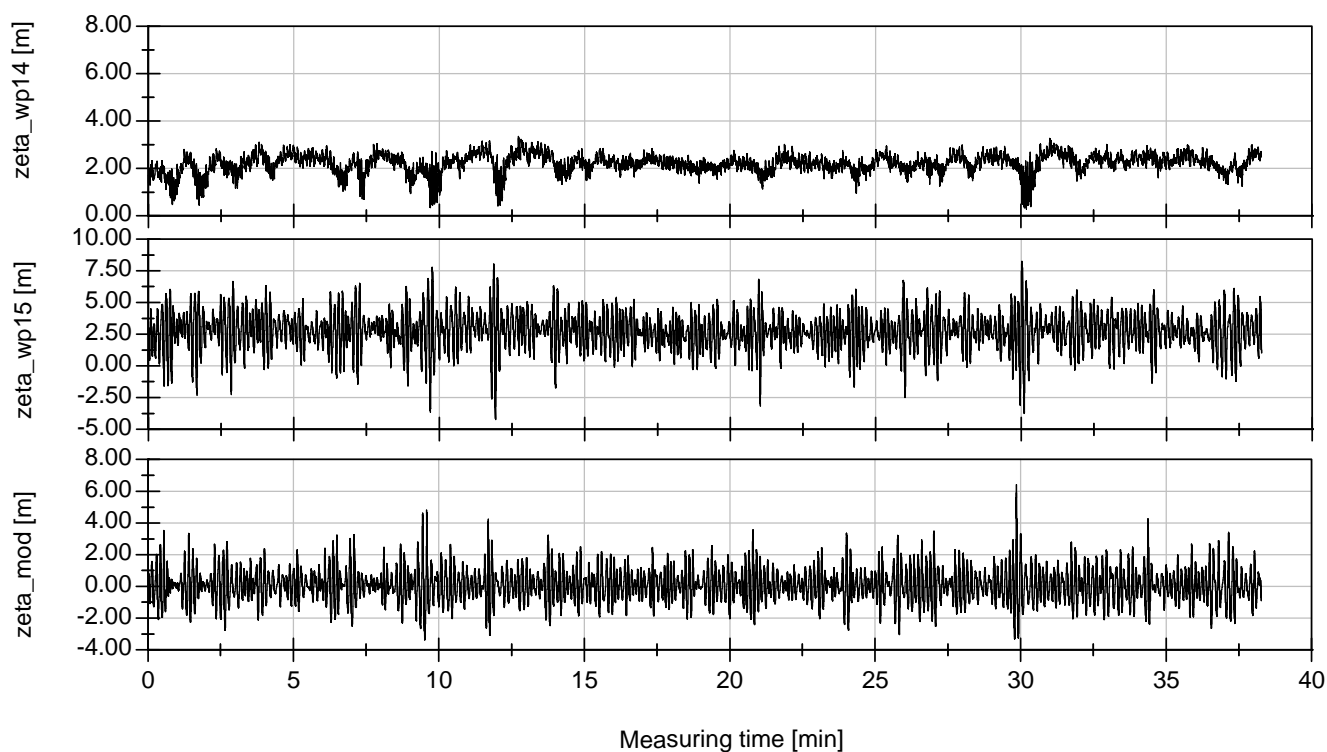




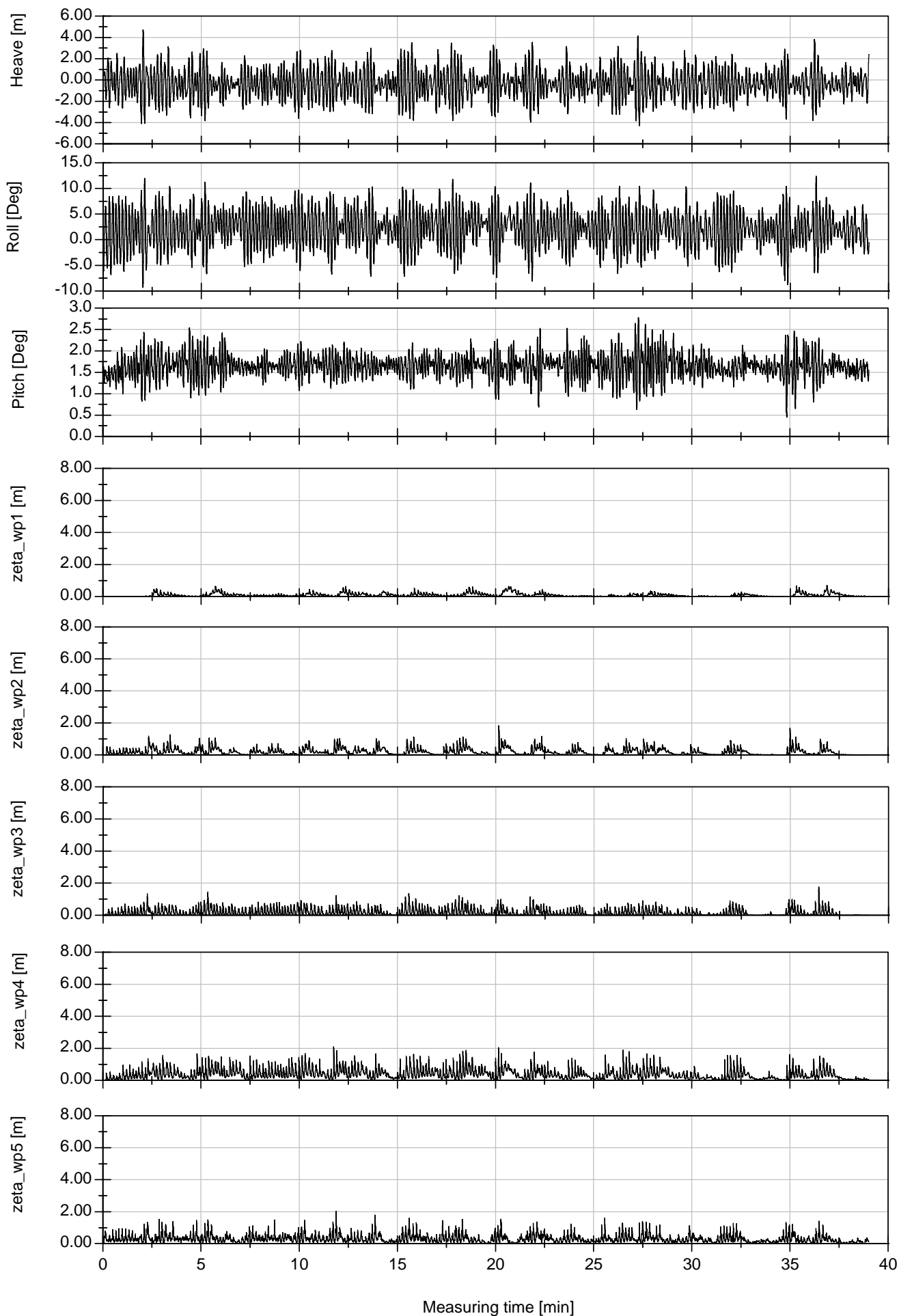
Run-No. 28 / Damage Case 4 /  $H_s = 4.39$  m /  $T_p = 8.5$  s /  $\Gamma = 3.3$



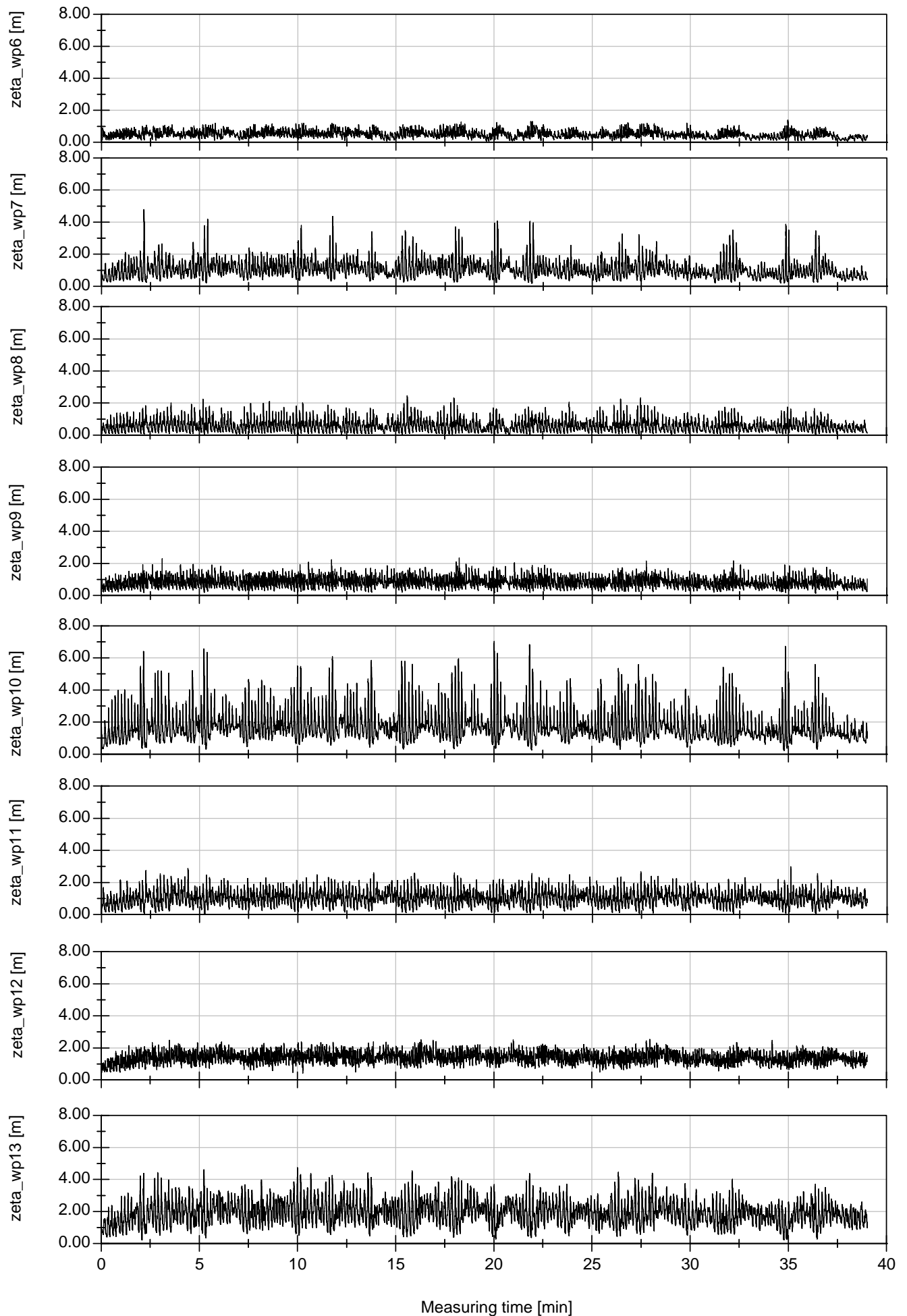
Run-No. 28 / Damage Case 4 /  $H_s = 4.39$  m /  $T_p = 8.5$  s /  $\Gamma = 3.3$



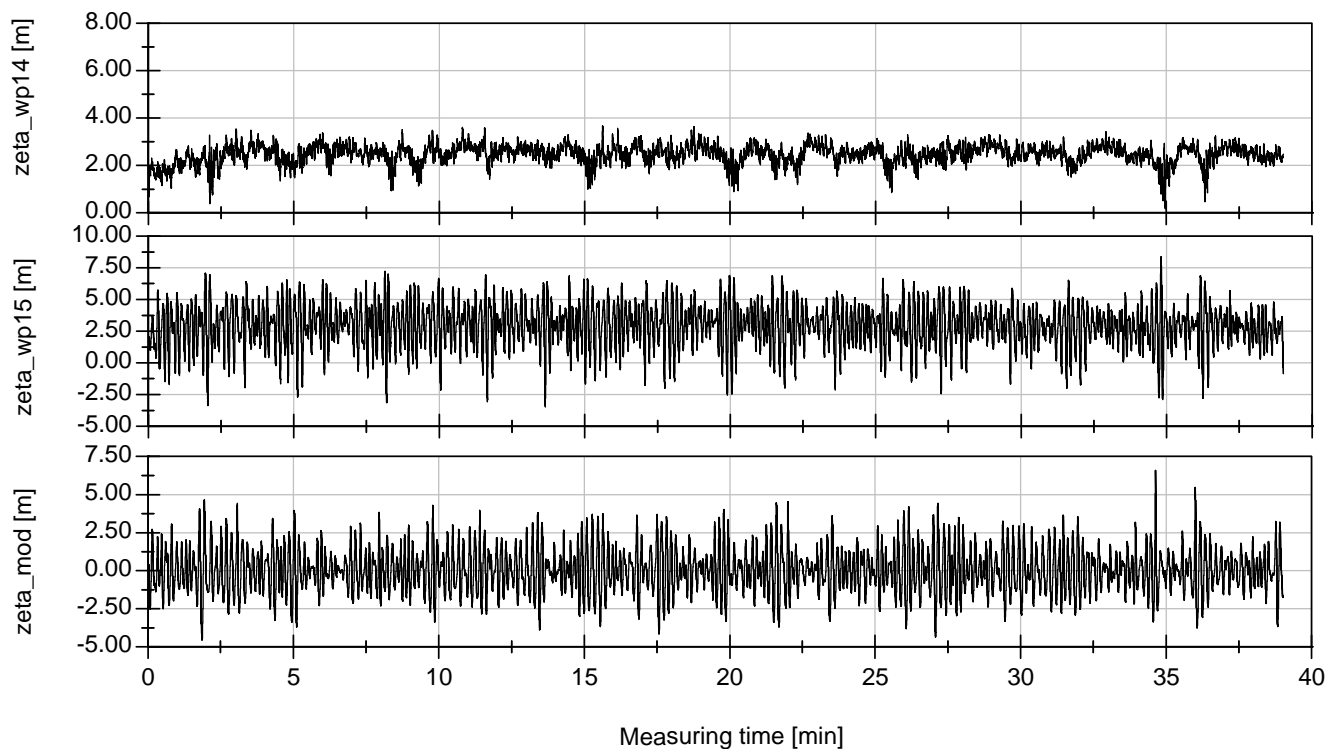
Run-No. 29 / Damage Case 4 /  $H_s = 5.60$  m /  $T_p = 10.3$  s /  $\Gamma = 3.3$



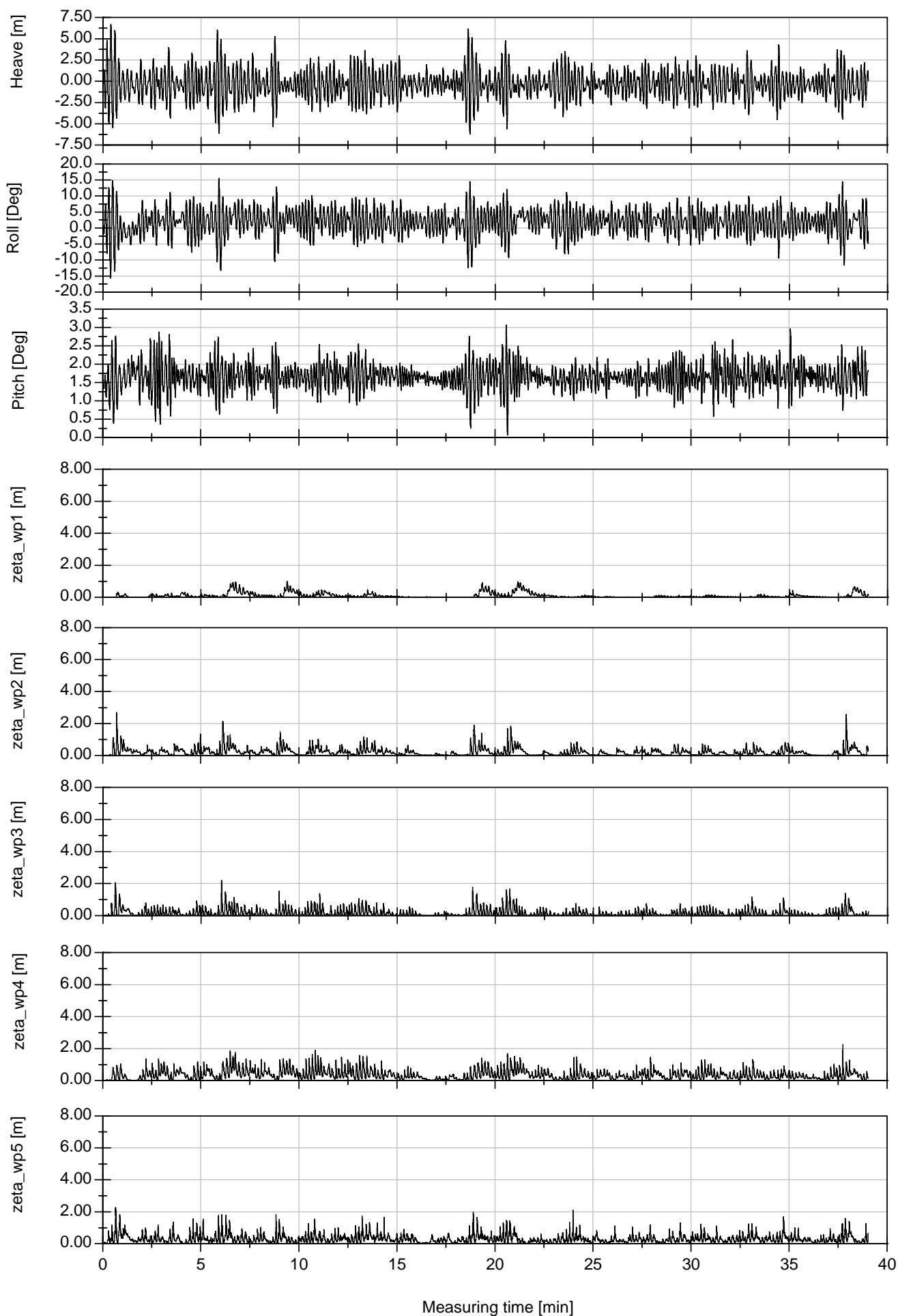
Run-No. 29 / Damage Case 4 /  $H_s = 5.60$  m /  $T_p = 10.3$  s /  $\Gamma = 3.3$



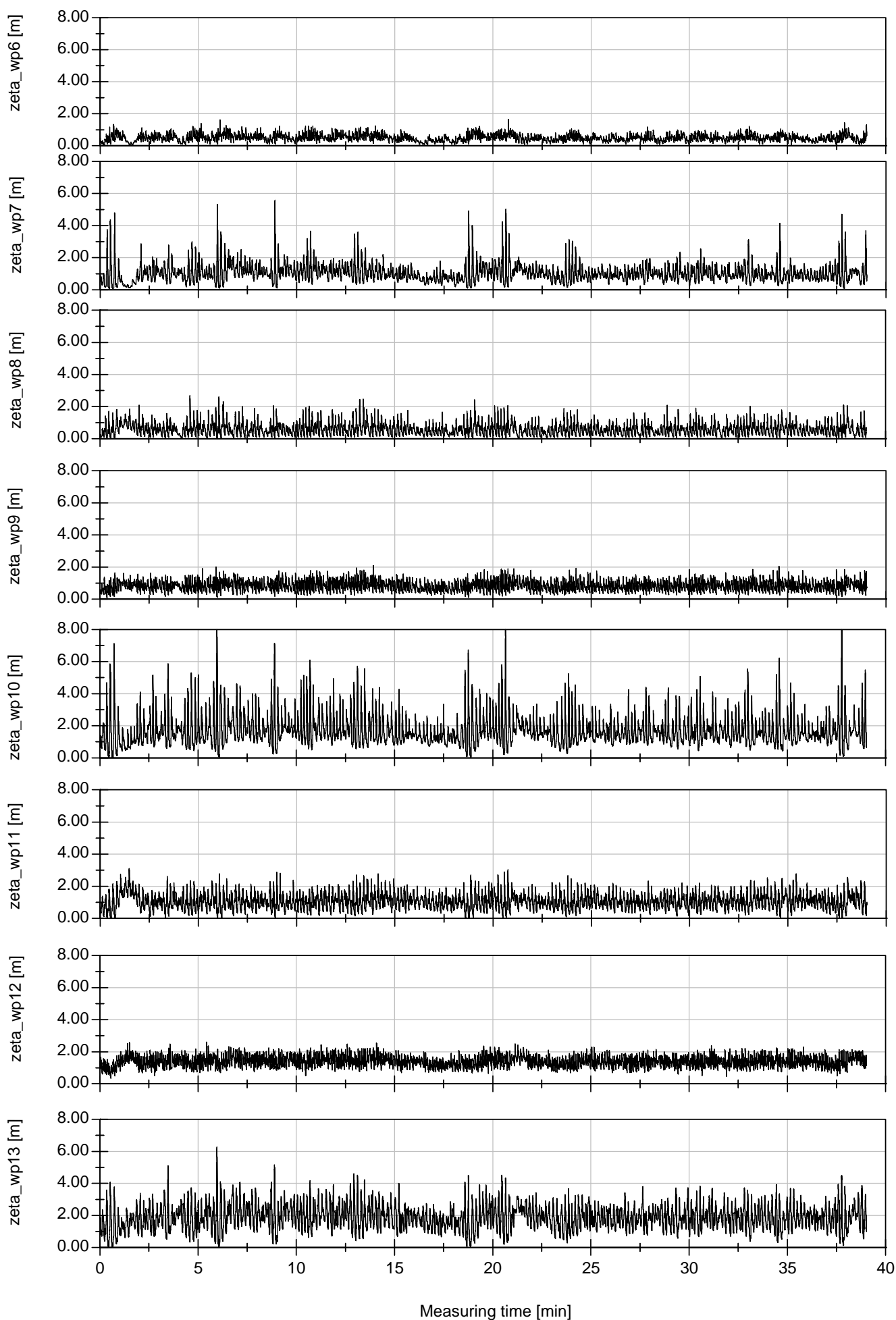
Run-No. 29 / Damage Case 4 /  $H_s = 5.60$  m /  $T_p = 10.3$  s /  $\Gamma = 3.3$



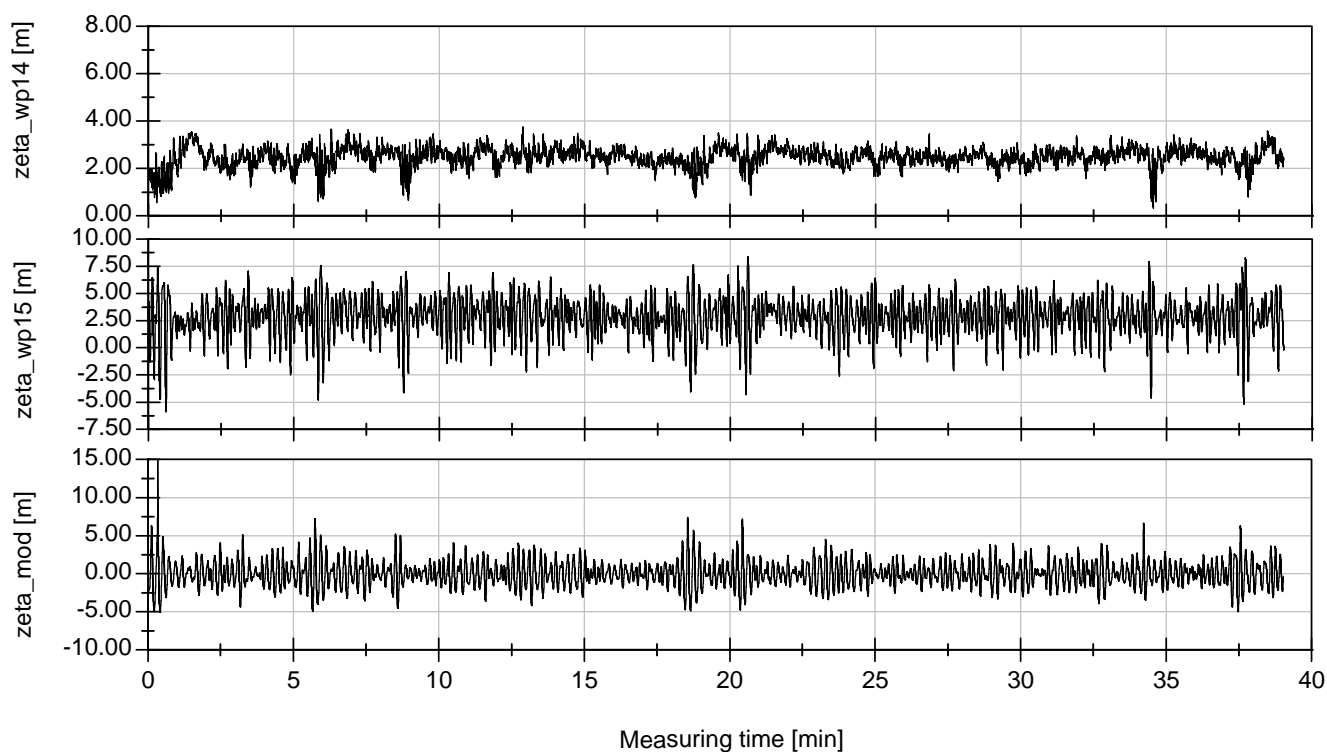
Run-No. 30 / Damage Case 4 /  $H_s = 6.64$  m /  $T_p = 11.1$  s /  $\Gamma = 3.3$



Run-No. 30 / Damage Case 4 /  $H_s = 6.64$  m /  $T_p = 11.1$  s /  $\Gamma = 3.3$

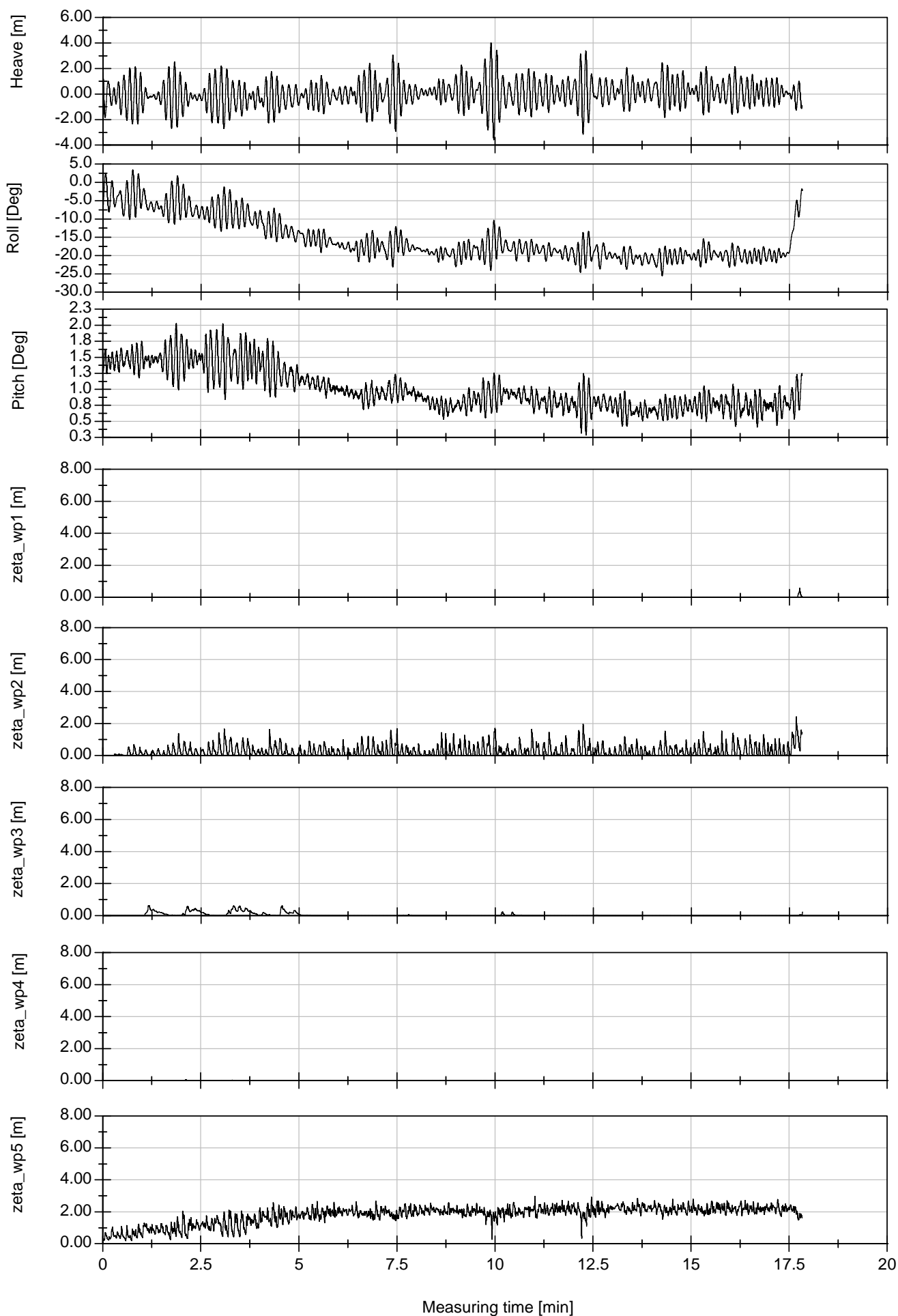


Run-No. 30 / Damage Case 4 /  $H_s = 6.64$  m /  $T_p = 11.1$  s /  $\Gamma = 3.3$

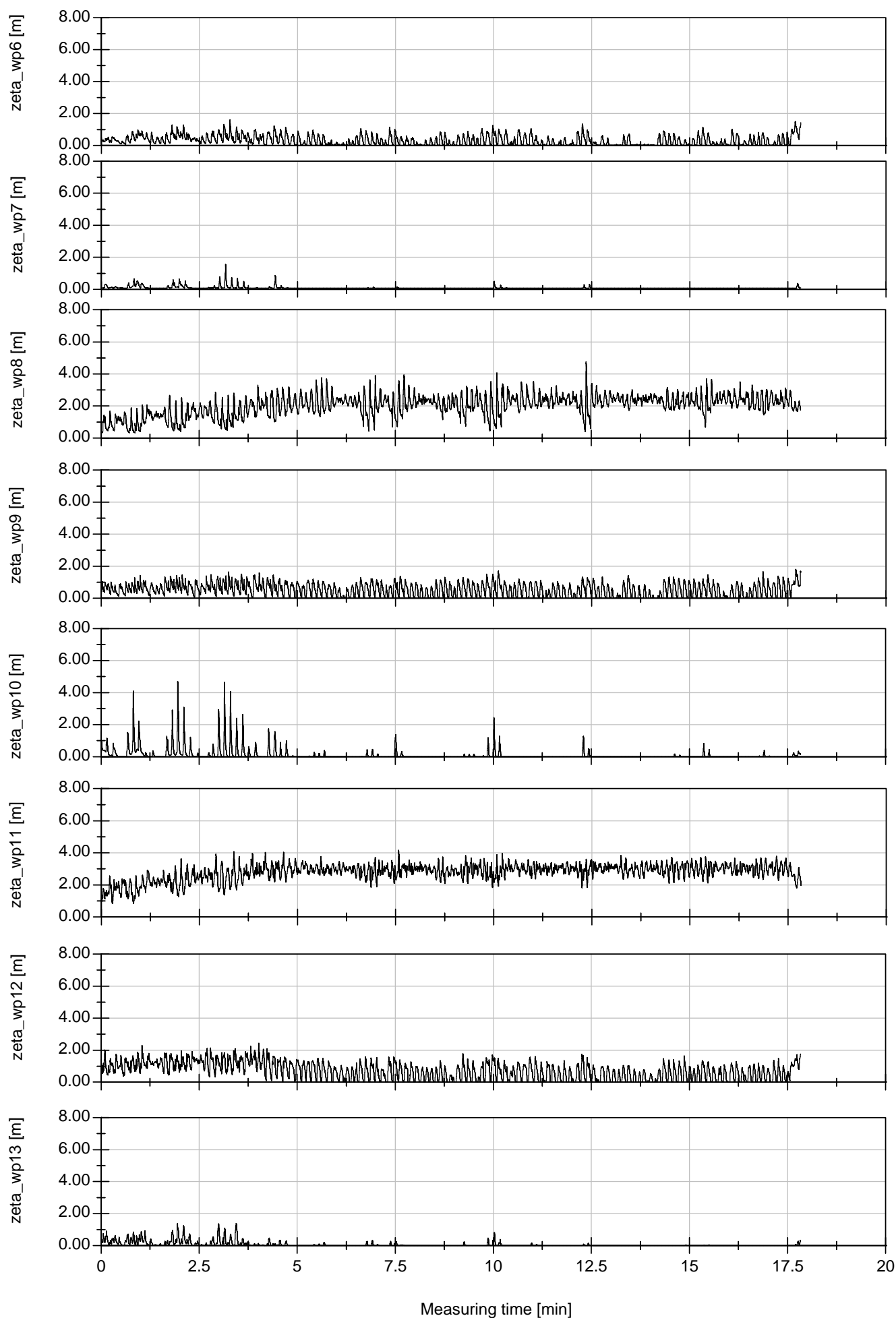




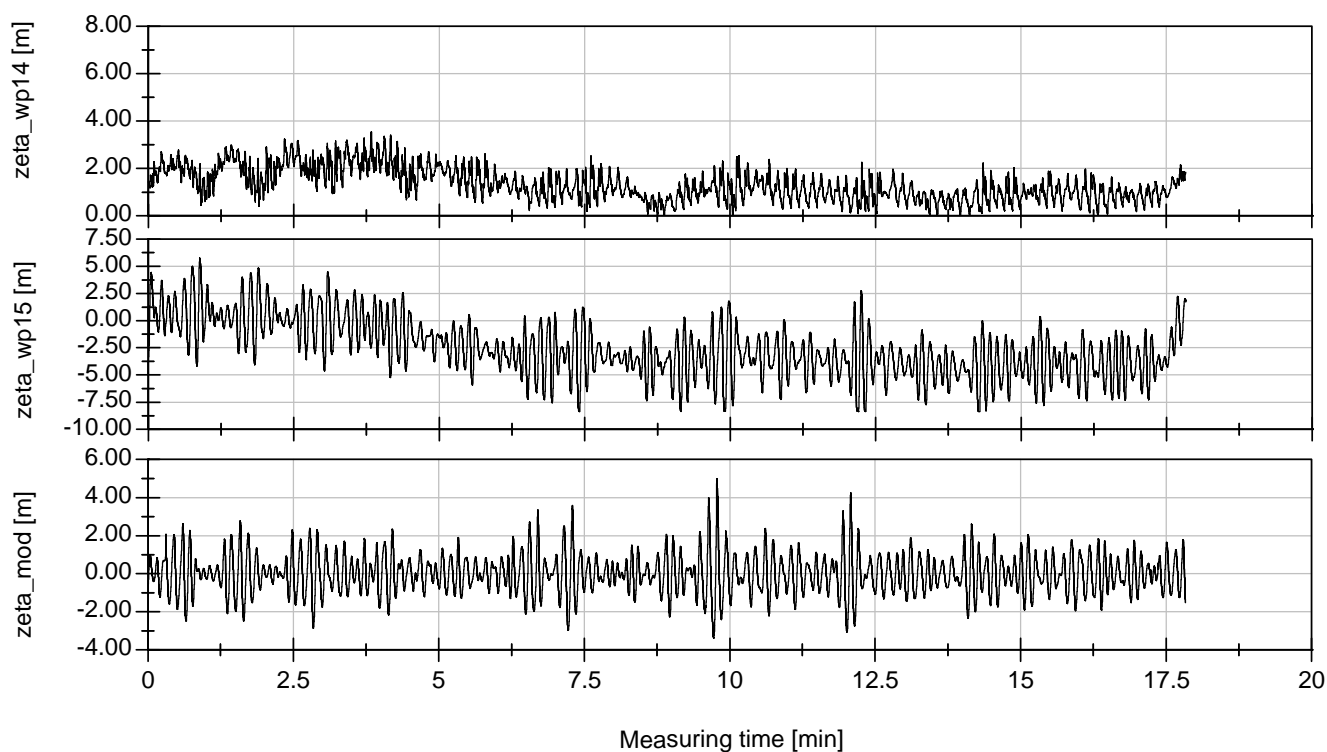
Run-No. 31 / Damage Case 4 /  $H_s = 4.21$  m /  $T_p = 8.3$  s /  $\Gamma = 3.3$



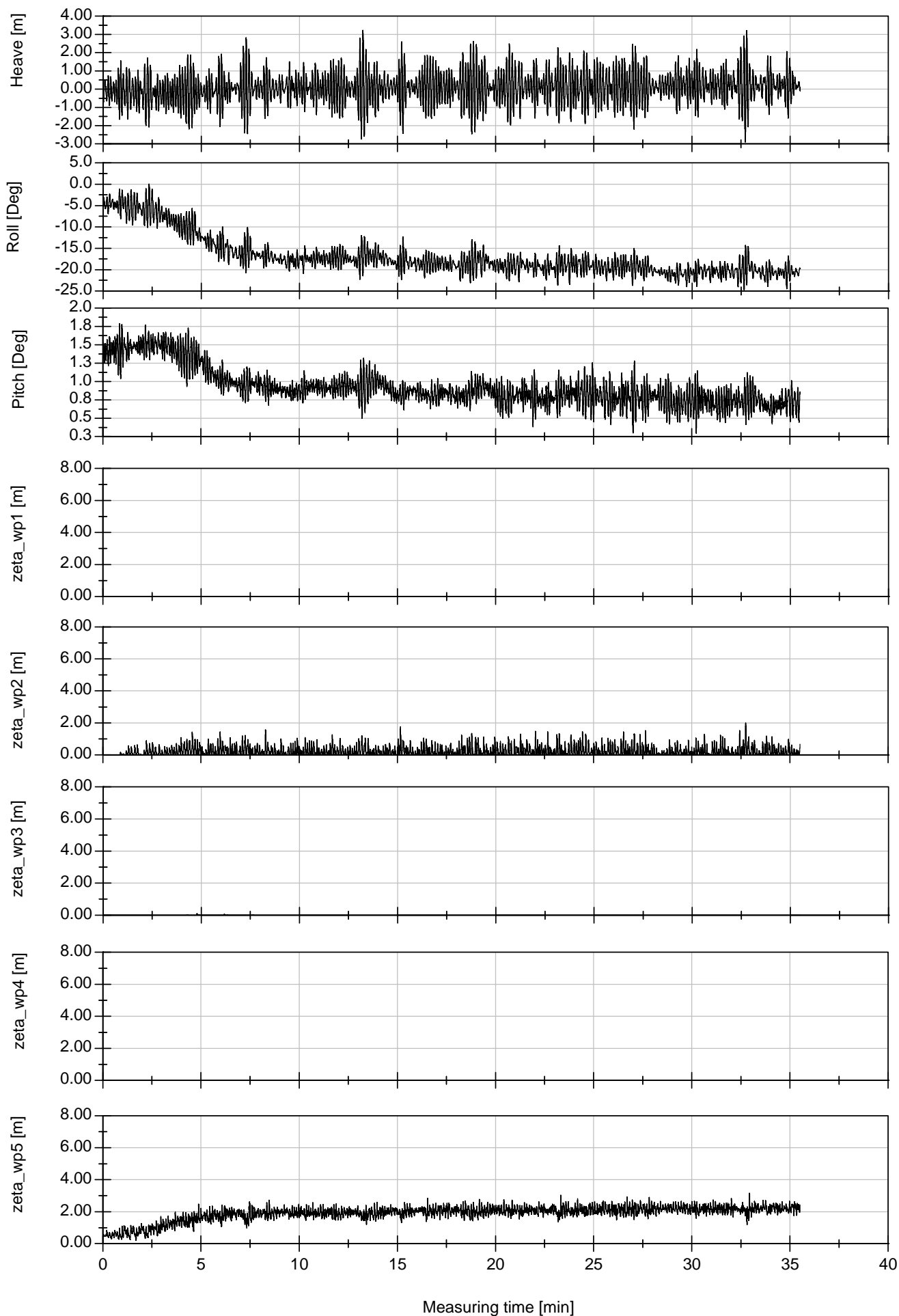
Run-No. 31 / Damage Case 4 /  $H_s = 4.21$  m /  $T_p = 8.3$  s /  $\Gamma = 3.3$



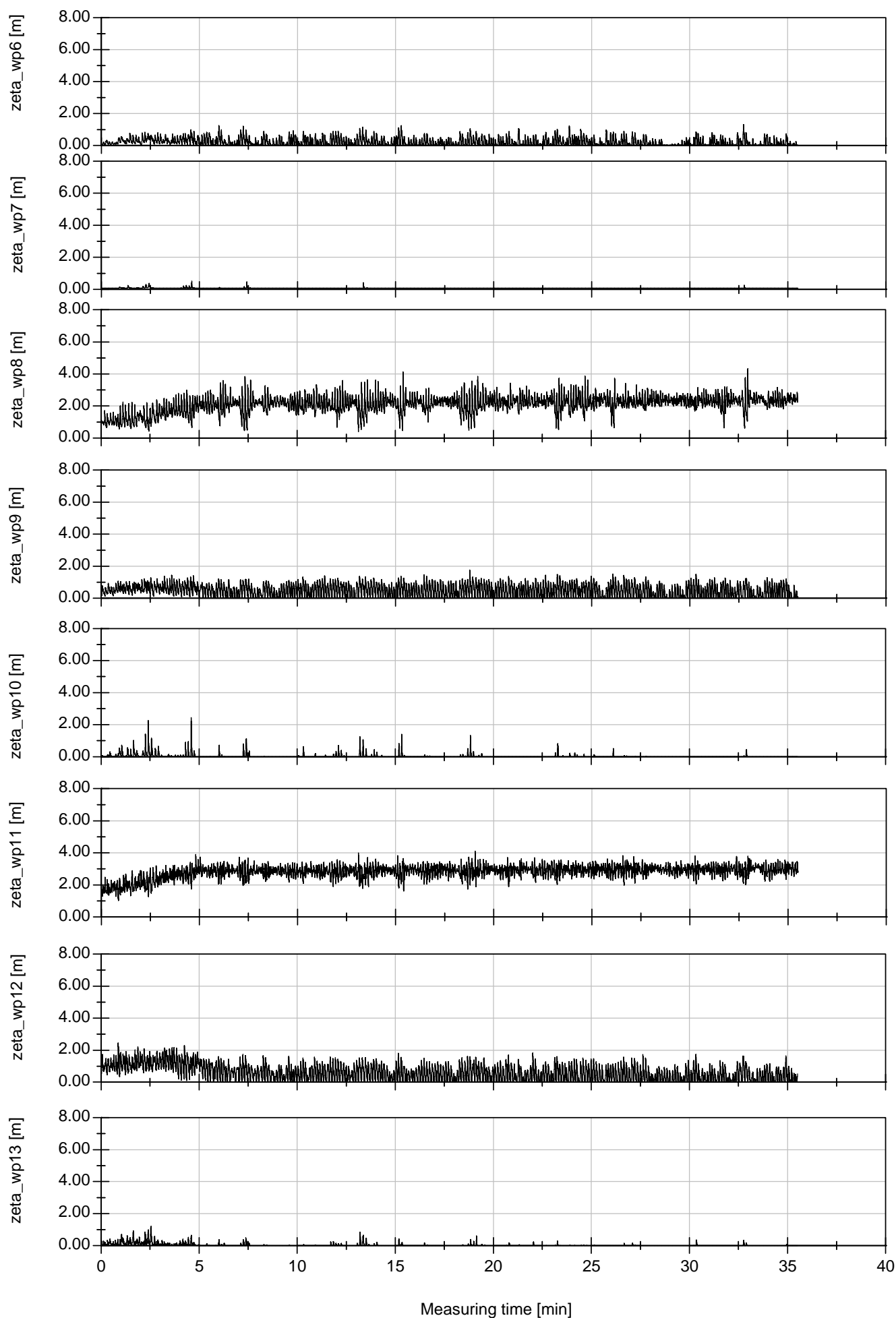
Run-No. 31 / Damage Case 4 /  $H_s = 4.21$  m /  $T_p = 8.3$  s /  $\Gamma = 3.3$



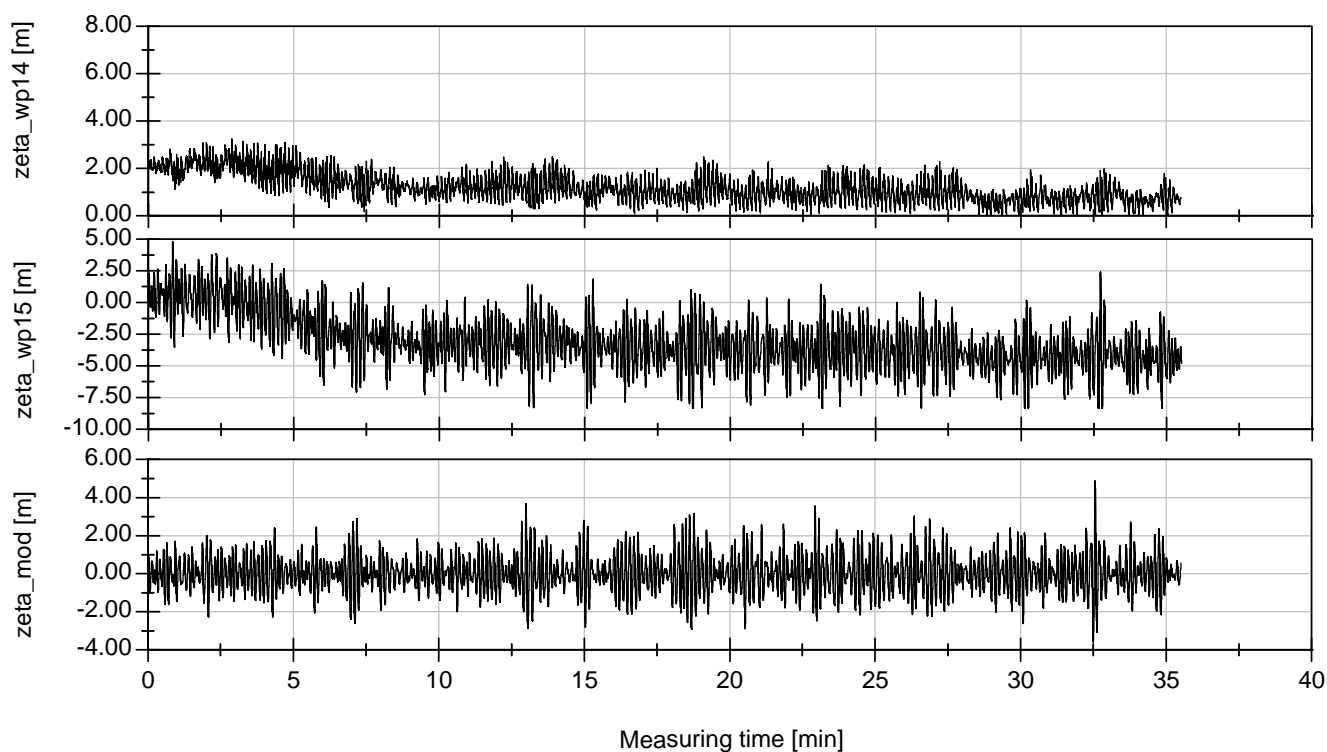
Run-No. 32 / Damage Case 4 /  $H_s = 3.91$  m /  $T_p = 8.3$  s /  $\Gamma = 3.3$



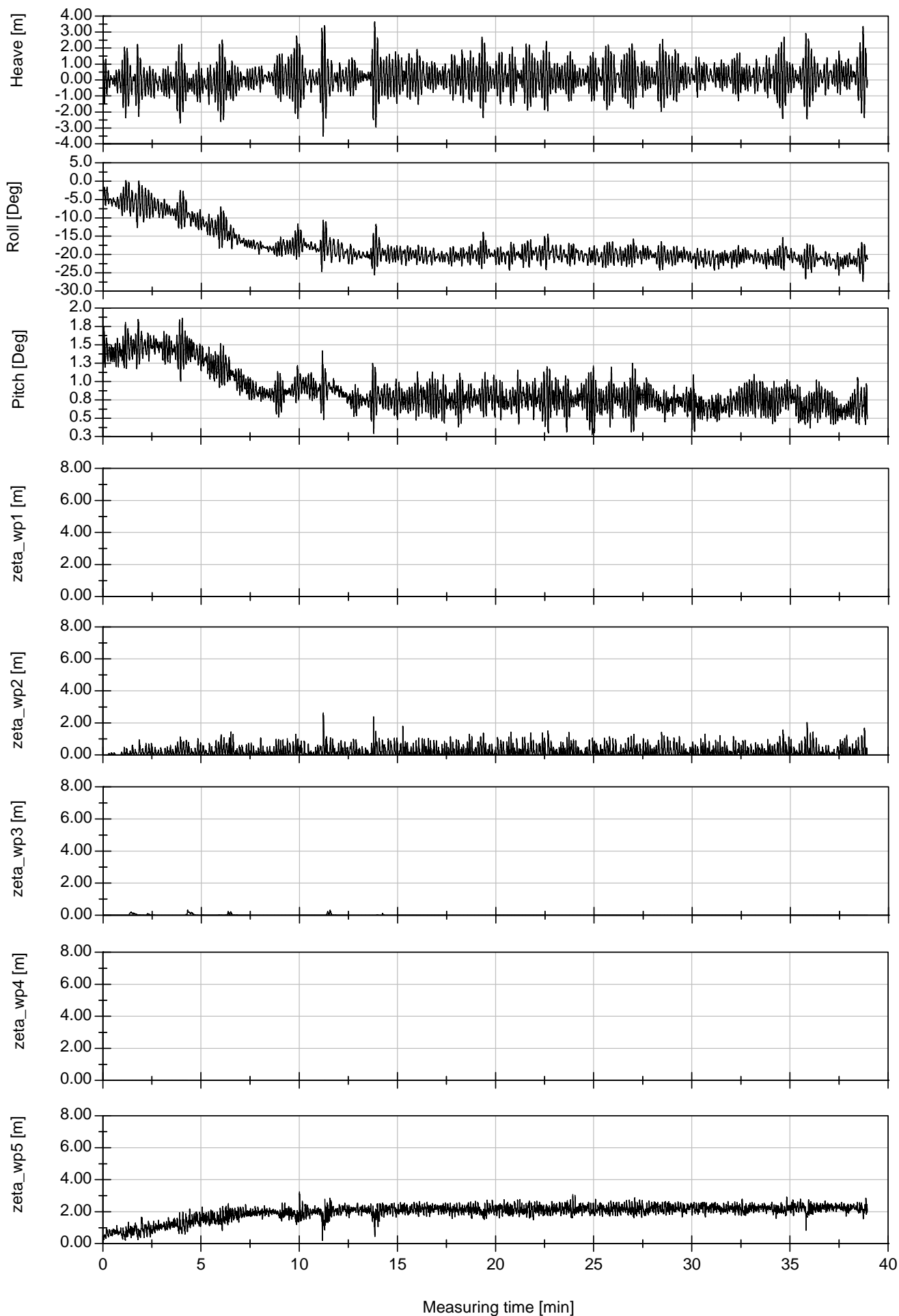
Run-No. 32 / Damage Case 4 /  $H_s = 3.91$  m /  $T_p = 8.3$  s /  $\Gamma = 3.3$



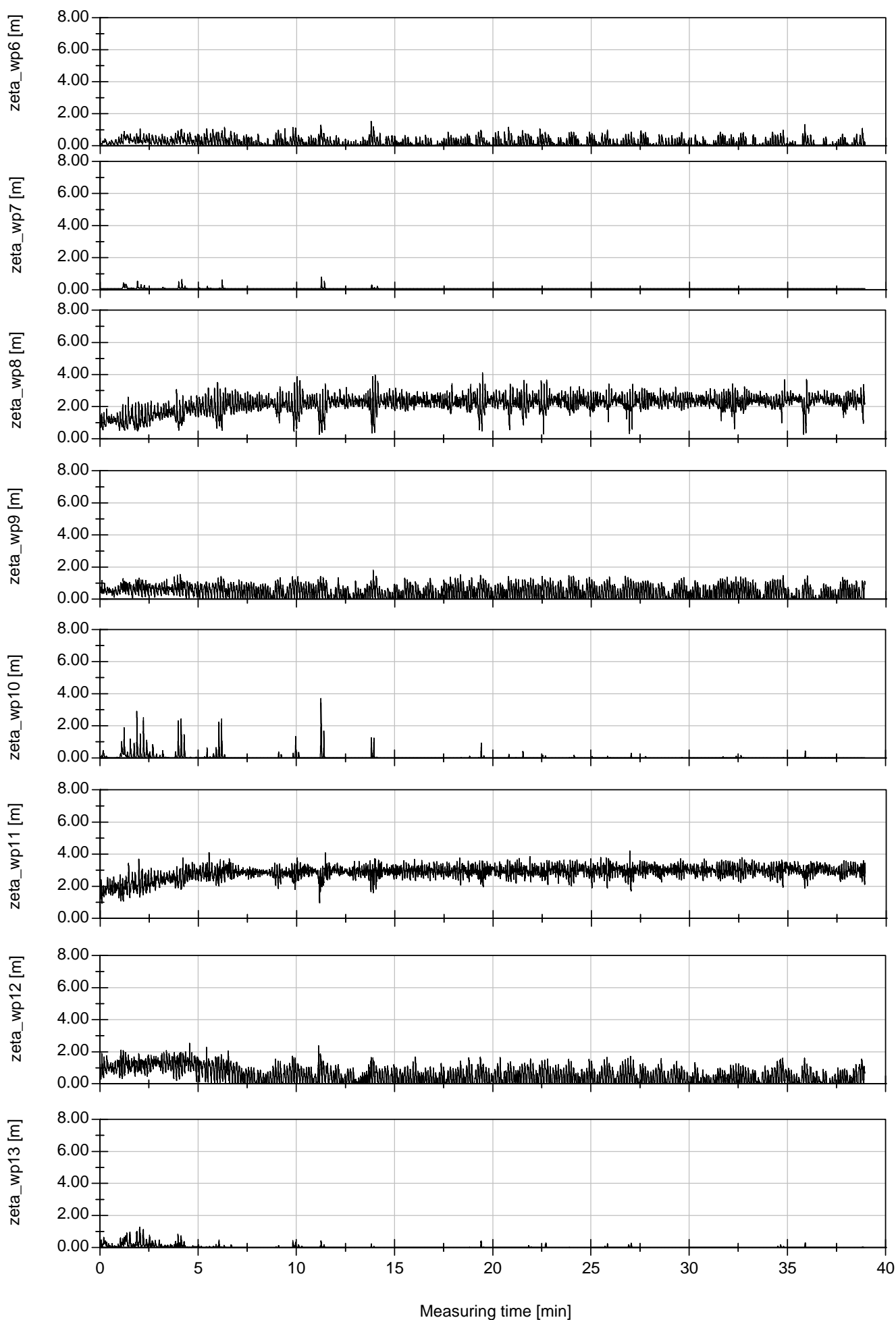
Run-No. 32 / Damage Case 4 /  $H_s = 3.91$  m /  $T_p = 8.3$  s /  $\Gamma = 3.3$



Run-No. 33 / Damage Case 4 /  $H_s = 3.70$  m /  $T_p = 8.3$  s /  $\Gamma = 3.3$

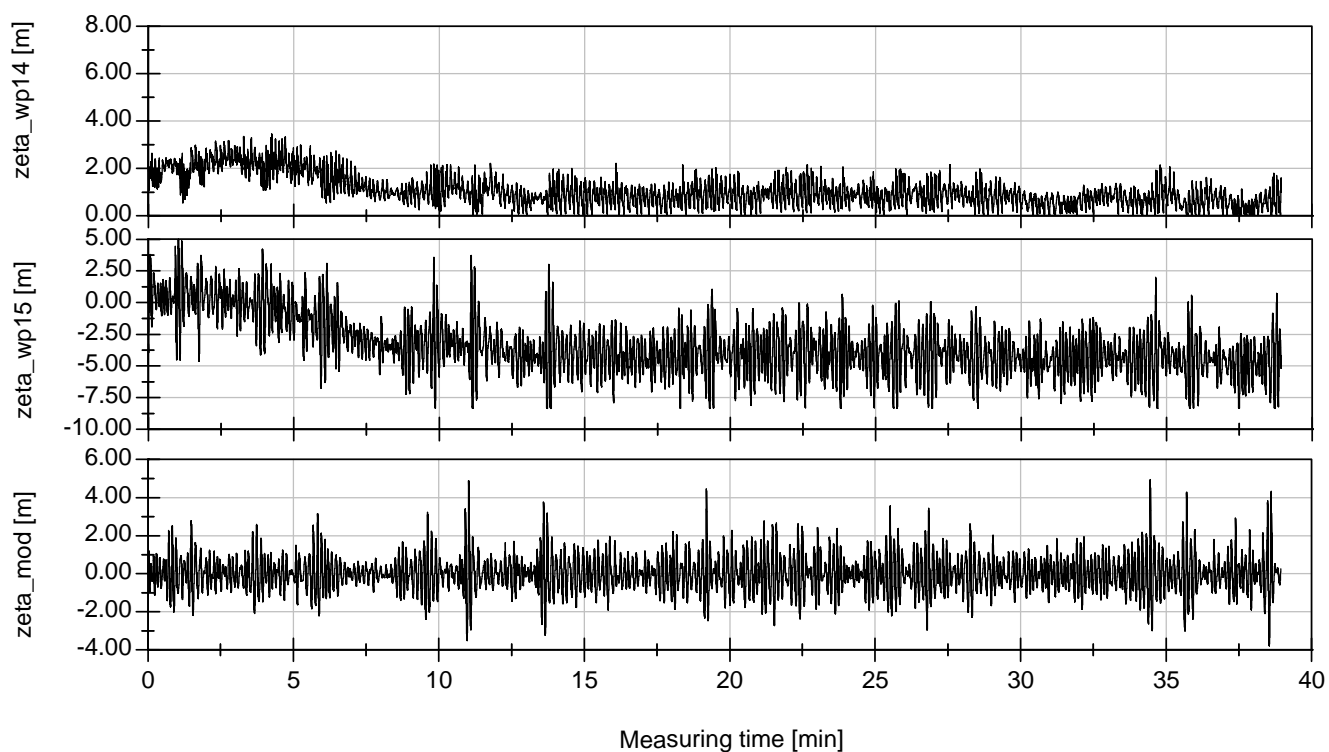


Run-No. 33 / Damage Case 4 /  $H_s = 3.70$  m /  $T_p = 8.3$  s /  $\Gamma = 3.3$

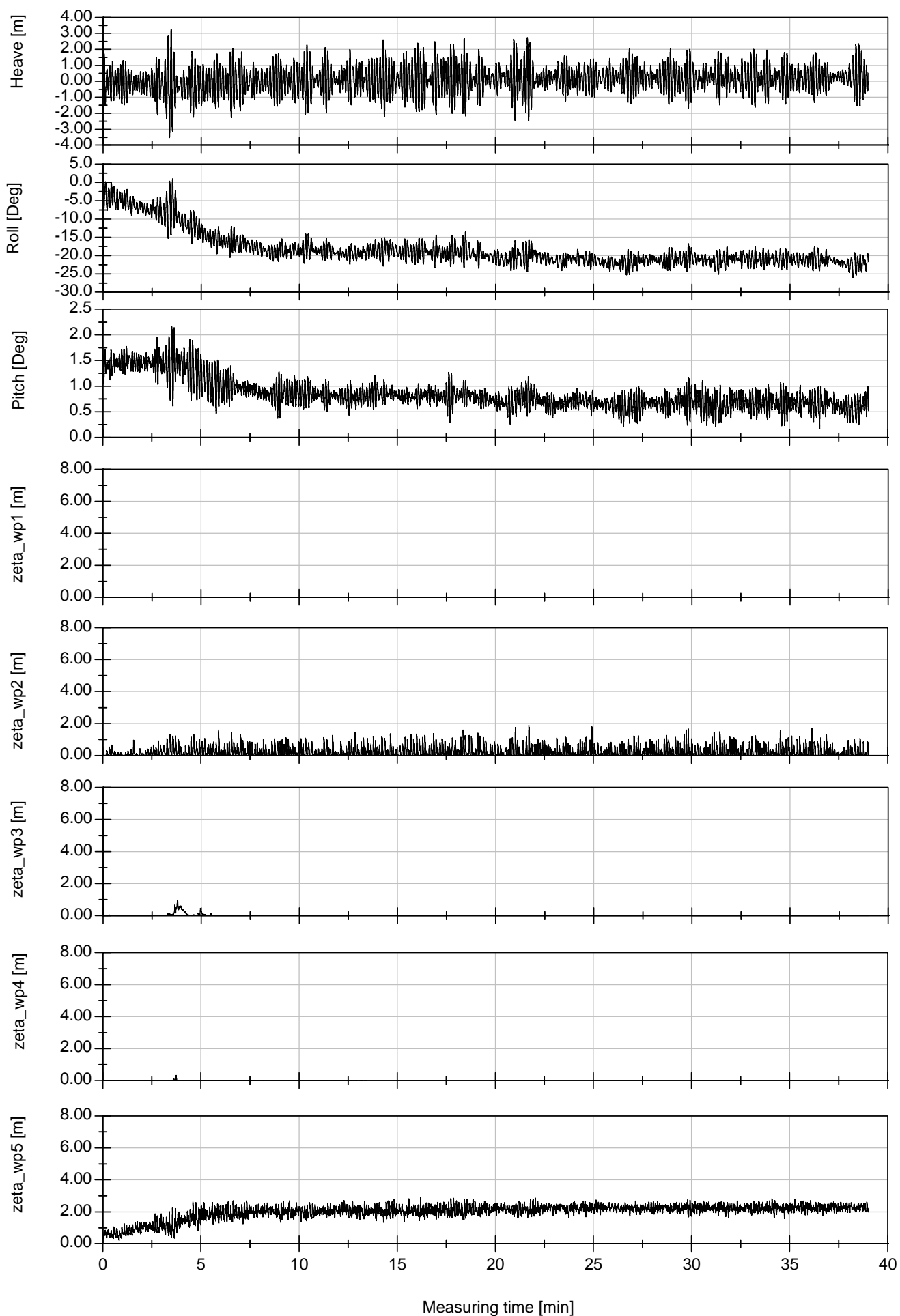




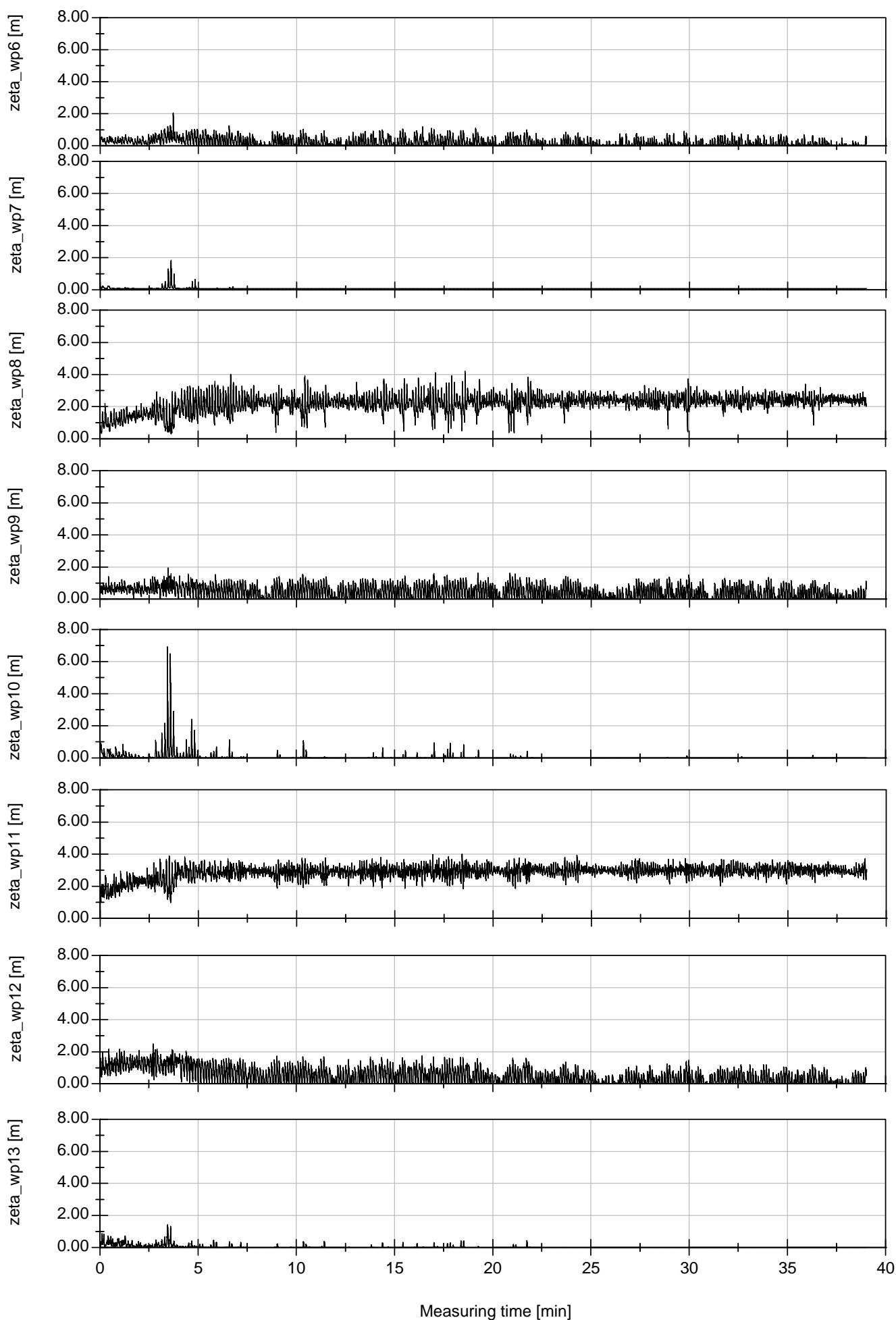
Run-No. 33 / Damage Case 4 /  $H_s = 3.70$  m /  $T_p = 8.3$  s /  $\Gamma = 3.3$



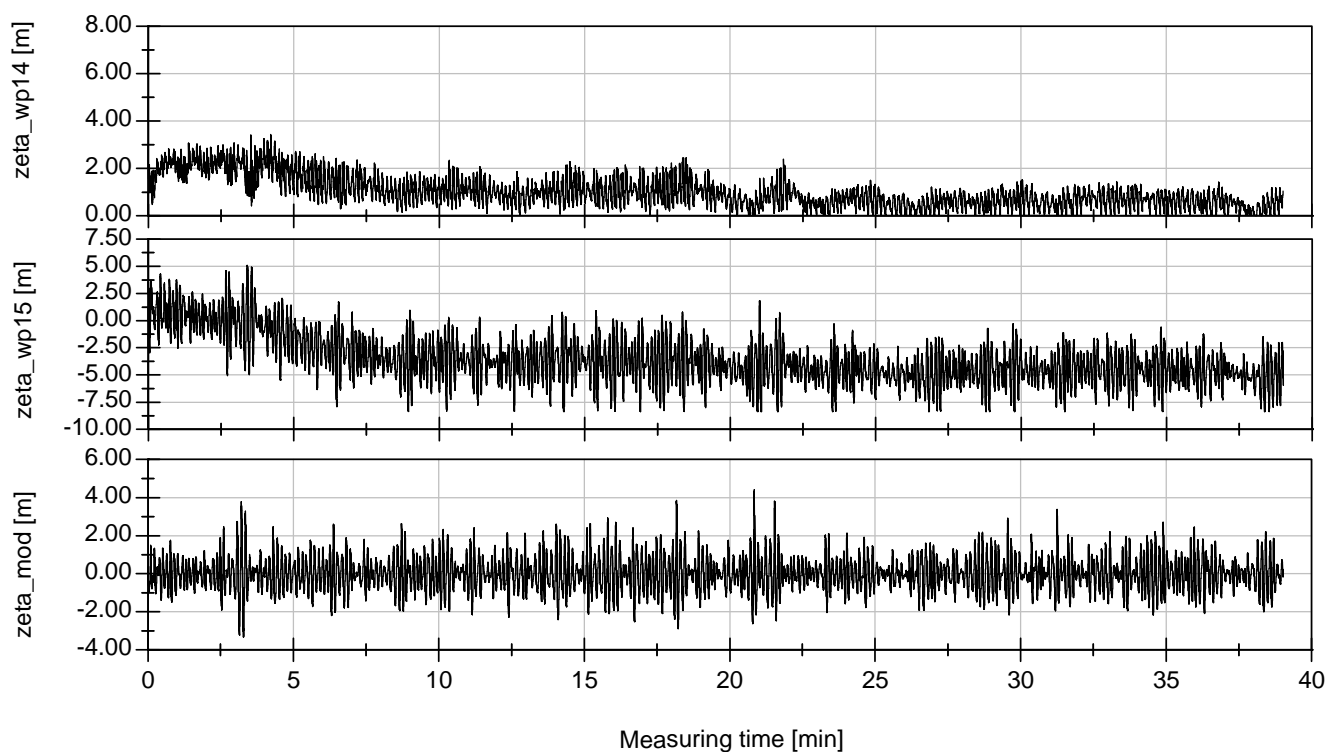
Run-No. 34 / Damage Case 4 /  $H_s = 3.68$  m /  $T_p = 8.3$  s /  $\Gamma = 3.3$



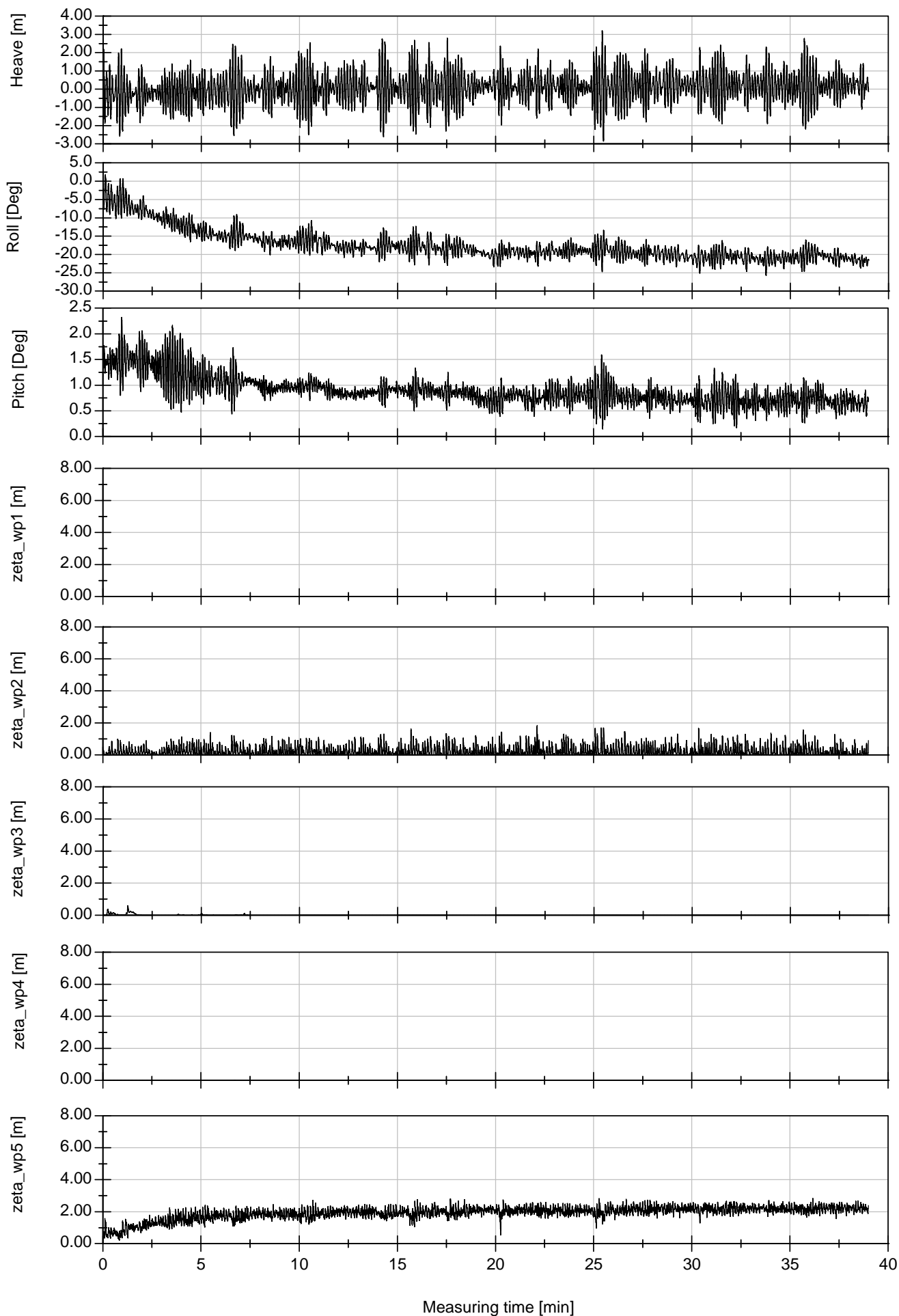
Run-No. 34 / Damage Case 4 /  $H_s = 3.68$  m /  $T_p = 8.3$  s /  $\Gamma = 3.3$



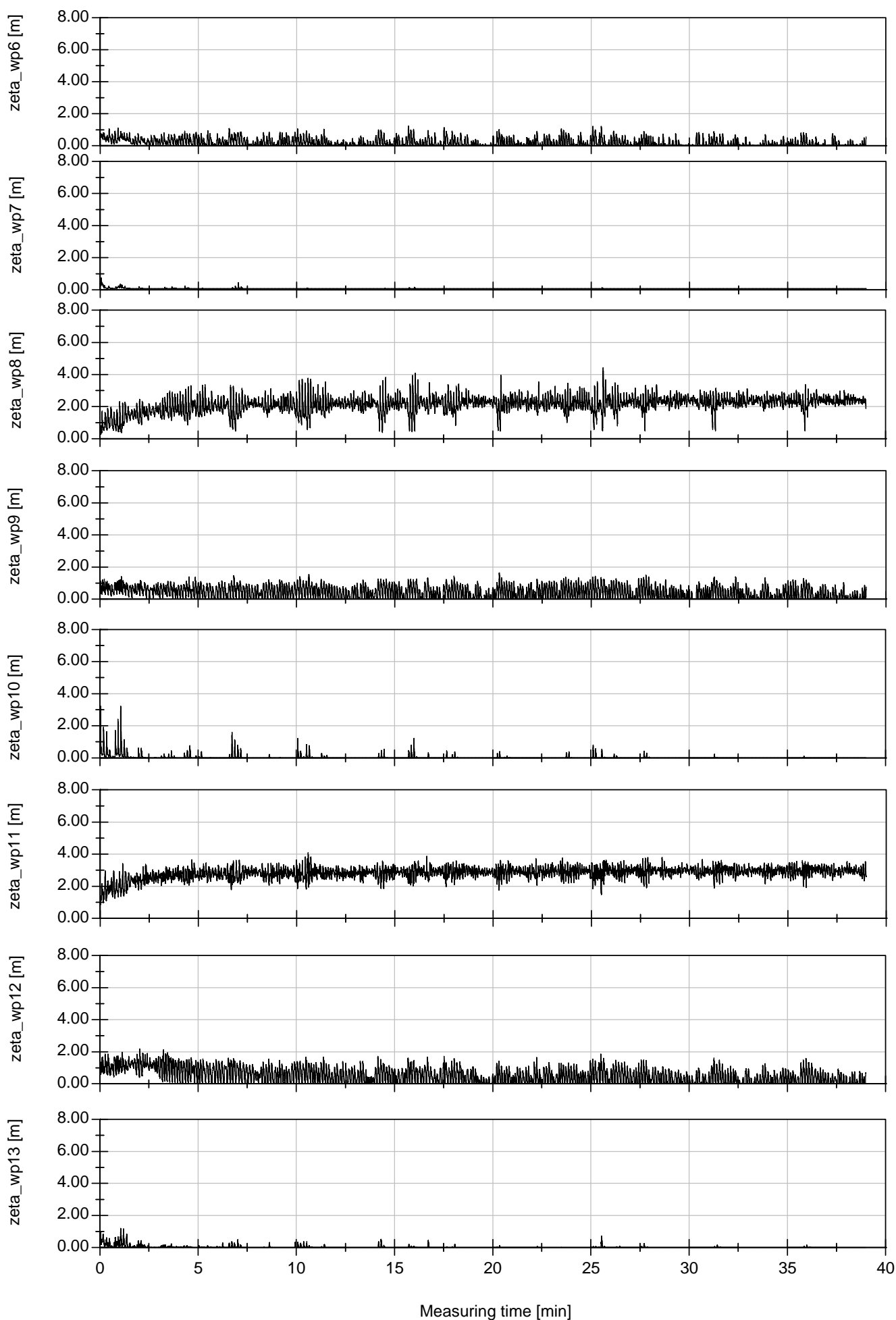
Run-No. 34 / Damage Case 4 /  $H_s = 3.68$  m /  $T_p = 8.3$  s /  $\Gamma = 3.3$



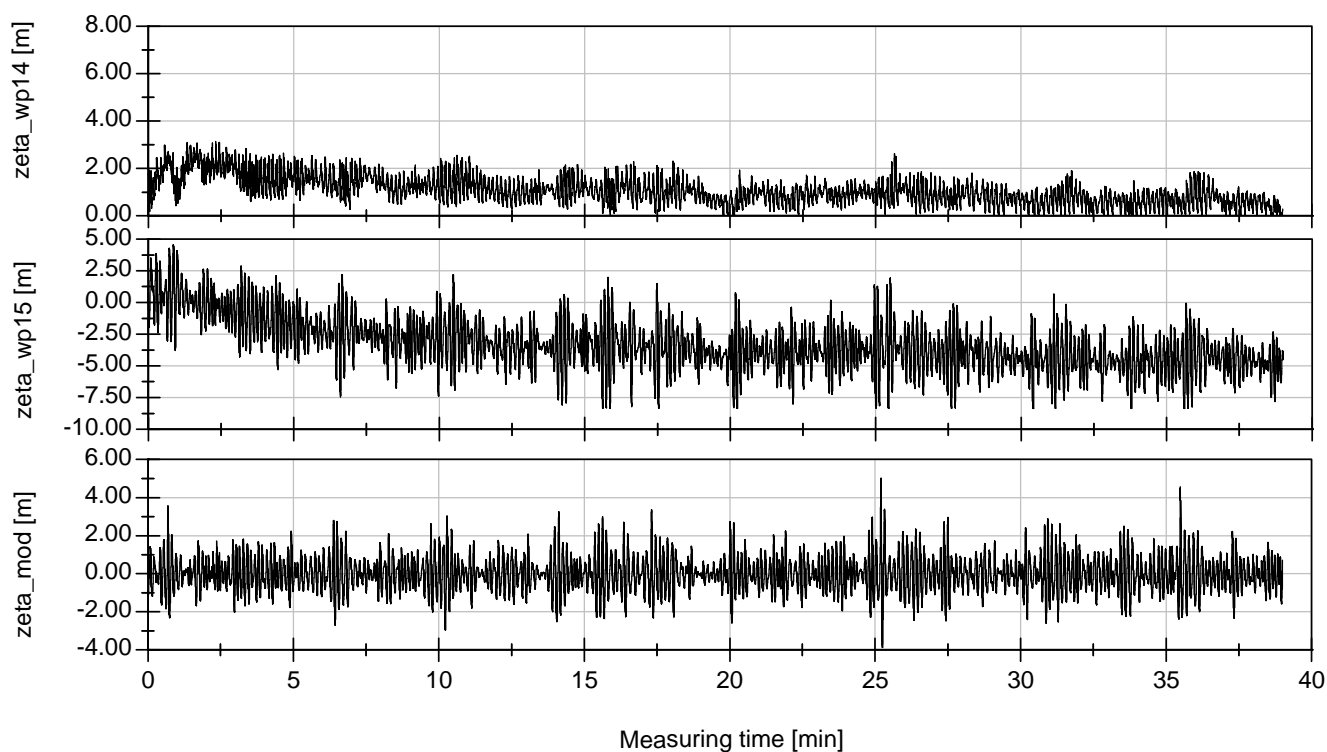
Run-No. 35 / Damage Case 4 /  $H_s = 3.78$  m /  $T_p = 8.3$  s /  $\Gamma = 3.3$



Run-No. 35 / Damage Case 4 /  $H_s = 3.78$  m /  $T_p = 8.3$  s /  $\Gamma = 3.3$



Run-No. 35 / Damage Case 4 /  $H_s = 3.78$  m /  $T_p = 8.3$  s /  $\Gamma = 3.3$



# **Annex C**

## ***Statistical Results***



Damage Case		1				
Run-No.		1	2	3	4	5
Survived (EU Directive)		YES	YES	YES	YES	NO
Comments						
Initial draught		7.19				
Initial heeling angle		2.5				
Initial trim angle		-0.4				
Seaway spectrum		ITTC				
Realisation		1	2	3	4	1
$H_s$		3.97	4.01	4.02	4.03	4.46
$T_p$		12.0	12.0	12.0	12.0	12.0
Measuring time		37.0	38.0	35.3	38.0	14.5
Heave	$A_{sig}$	1.98	1.95	1.95	1.95	2.33
	$A_{sig+}$	1.96	1.97	1.95	1.99	2.31
	$A_{sig-}$	-1.99	-1.94	-1.94	-1.92	-2.34
	$A_{max+}$	3.36	3.64	3.44	2.98	3.23
	$A_{max-}$	-3.39	-2.88	-3.30	-3.05	-3.33
Final draught (30 min)		7.19	7.19	7.19	7.19	-
Roll	$A_{sig}$ upper bound	9.51	9.5	9.8	9.4	14.0
	$A_{sig}$ lower bound	1.15	1.2	1.1	0.9	1.8
	$A_{max}$ upper bound	11.07	11.2	11.7	11.1	18.2
	$A_{max}$ lower bound	-3.84	-2.7	-1.4	-4.2	-2.7
	$T_m$	12.6	12.8	12.7	12.4	12.4
Final heel (30 min)		6.0	5.6	5.7	5.2	-
Pitch	$A_{sig}$	0.34	0.3	0.3	0.4	0.5
	$A_{sig+}$	0.34	0.3	0.3	0.4	0.5
	$A_{sig-}$	-0.34	-0.3	-0.3	-0.4	-0.5
	$A_{max+}$	0.82	0.6	0.7	1.1	1.0
	$A_{max-}$	-0.72	-0.7	-0.7	-0.8	-0.8
Final trim (30 min)		-0.7	-0.6	-0.6	-0.6	-
$\zeta_{wp1}$	$A_{sig+}$	0.49	0.49	0.53	0.51	0.57
	$A_{max+}$	0.87	0.81	0.81	0.76	0.84
$\zeta_{wp2}$	$A_{sig+}$	0.51	0.51	0.51	0.50	0.74
	$A_{max+}$	0.68	0.78	0.81	0.85	1.23
$\zeta_{wp3}$	$A_{sig+}$	0.89	0.89	0.91	0.89	1.47
	$A_{max+}$	1.16	1.26	1.25	1.30	2.09
$\zeta_{wp4}$	$A_{sig+}$	1.70	1.72	1.72	1.68	2.84
	$A_{max+}$	1.97	2.11	2.44	2.04	4.57
$\zeta_{wp5}$	$A_{sig+}$	0.62	0.60	0.64	0.60	1.04
	$A_{max+}$	0.92	0.97	0.97	0.88	2.13
$\zeta_{wp6}$	$A_{sig+}$	0.52	0.54	0.54	0.51	1.06
	$A_{max+}$	0.75	0.88	0.72	0.75	1.72
$\zeta_{wp7}$	$A_{sig+}$	1.19	1.20	1.28	1.24	2.15
	$A_{max+}$	1.89	1.92	1.86	1.82	3.16
$\zeta_{wp8}$	$A_{sig+}$	0.67	0.57	0.56	0.60	0.94
	$A_{max+}$	0.90	0.77	1.16	0.80	1.45
$\zeta_{wp9}$	$A_{sig+}$	0.65	0.63	0.72	0.62	1.05
	$A_{max+}$	1.08	1.03	1.32	1.17	1.43
$\zeta_{wp10}$	$A_{sig+}$	-	-	-	-	-
	$A_{max+}$	-	-	-	-	-
$\zeta_{wp11}$	$A_{sig+}$	0.37	0.38	0.41	0.37	0.76
	$A_{max+}$	0.57	0.49	0.69	0.61	1.58
$\zeta_{wp12}$	$A_{sig+}$	0.85	0.86	0.91	0.86	1.87
	$A_{max+}$	1.18	1.20	1.26	1.12	2.67
$\zeta_{wp13}$	$A_{sig+}$	-	-	-	-	-
	$A_{max+}$	-	-	-	-	-
$\zeta_{wp14}$	$A_{sig+}$	0.35	0.39	0.48	0.41	1.44
	$A_{max+}$	0.49	0.63	0.68	0.57	2.09
$\zeta_{wp15}$	$A_{sig+}$	2.53	2.57	2.56	2.46	2.82
	$A_{sig-}$	-2.30	-2.26	-2.21	-2.23	-3.36
	$A_{max+}$	4.08	4.52	4.65	3.68	4.25
	$A_{max-}$	-3.46	-3.75	-3.82	-4.04	-4.83

Table 3: Statistical Results of ship motions and wave probe measurements

Damage Case		1				
Run-No.		6	7	8	9	10
Survived (EU Directive)		NO	NO	YES	YES	YES
Comments						
Initial draught		7.19				
Initial heeling angle		2.5				
Initial trim angle		-0.4				
Seaway spectrum		ITTC		JONSWAP		
Realisation		2	3	1	2	1
$H_s$		4.87	4.32	3.81	3.73	4.51
$T_p$		12.2	11.6	8.4	8.4	8.6
Measuring time		16.3	9.0	37.2	37.5	37.4
Heave	$A_{sig}$	2.48	2.20	1.68	1.66	1.88
	$A_{sig+}$	2.46	2.23	1.69	1.67	1.91
	$A_{sig-}$	-2.49	-2.20	-1.67	-1.65	-1.84
	$A_{max+}$	4.49	3.61	2.81	3.20	4.00
	$A_{max-}$	-3.80	-3.25	-2.88	-3.28	-3.73
Final draught (30 min)		-	-	7.19	7.19	7.19
Roll	$A_{sig}$ upper bound	12.39	14.7	10.9	7.3	8.7
	$A_{sig}$ lower bound	1.06	0.8	5.3	2.6	3.4
	$A_{max}$ upper bound	19.93	20.0	13.5	9.6	12.6
	$A_{max}$ lower bound	-2.62	-2.9	-0.2	1.0	0.6
	$T_m$	12.5	13.2	9.9	10.6	10.6
Final heel (30 min)		-	-	7.1	4.8	4.8
Pitch	$A_{sig}$	0.57	0.4	0.4	0.3	0.4
	$A_{sig+}$	0.60	0.4	0.4	0.3	0.4
	$A_{sig-}$	-0.54	-0.4	-0.4	-0.3	-0.4
	$A_{max+}$	1.15	0.5	0.7	0.5	1.2
	$A_{max-}$	-1.17	-0.5	-0.8	-0.6	-1.0
Final trim (30 min)		-	-	-0.7	-0.7	-0.7
$\zeta_{wp1}$	$A_{sig+}$	0.60	0.88	0.43	-	0.55
	$A_{max+}$	0.90	1.02	0.68	-	0.97
$\zeta_{wp2}$	$A_{sig+}$	0.84	0.71	0.56	0.42	0.50
	$A_{max+}$	1.25	1.04	0.97	0.84	1.01
$\zeta_{wp3}$	$A_{sig+}$	1.43	1.41	1.10	0.82	0.99
	$A_{max+}$	2.51	1.91	1.48	1.22	1.68
$\zeta_{wp4}$	$A_{sig+}$	2.75	2.68	2.20	1.34	1.75
	$A_{max+}$	5.33	3.76	2.85	1.87	2.57
$\zeta_{wp5}$	$A_{sig+}$	0.98	0.97	0.73	0.63	0.64
	$A_{max+}$	1.83	1.09	1.20	1.54	1.55
$\zeta_{wp6}$	$A_{sig+}$	0.87	1.20	0.77	0.49	0.61
	$A_{max+}$	1.84	1.97	1.27	0.83	1.00
$\zeta_{wp7}$	$A_{sig+}$	1.83	2.30	1.82	1.05	1.40
	$A_{max+}$	3.42	3.35	2.72	1.65	2.37
$\zeta_{wp8}$	$A_{sig+}$	0.96	0.78	0.87	0.88	0.89
	$A_{max+}$	2.13	1.29	1.61	2.49	1.98
$\zeta_{wp9}$	$A_{sig+}$	1.05	1.13	0.81	0.82	0.92
	$A_{max+}$	1.95	2.29	1.34	1.48	1.65
$\zeta_{wp10}$	$A_{sig+}$	-	-	-	-	-
	$A_{max+}$	-	-	-	-	-
$\zeta_{wp11}$	$A_{sig+}$	0.78	0.99	0.52	0.39	0.47
	$A_{max+}$	1.67	1.72	0.96	0.78	1.00
$\zeta_{wp12}$	$A_{sig+}$	1.59	1.85	1.49	0.87	1.12
	$A_{max+}$	3.84	2.55	2.19	1.16	1.67
$\zeta_{wp13}$	$A_{sig+}$	-	-	-	-	-
	$A_{max+}$	-	-	-	-	-
$\zeta_{wp14}$	$A_{sig+}$	1.33	1.90	1.02	0.55	0.66
	$A_{max+}$	2.83	2.83	1.35	0.81	1.15
$\zeta_{wp15}$	$A_{sig+}$	2.59	2.71	2.59	2.52	2.65
	$A_{sig-}$	-3.26	-3.38	-2.57	-2.24	-2.59
	$A_{max+}$	5.01	5.04	5.06	6.33	5.10
	$A_{max-}$	-5.85	-4.43	-4.71	-3.98	-4.88

Table 3: Statistical Results of ship motions and wave probe measurements

Damage Case		1				
Run-No.		11	12	13	14	15
Survived (EU Directive)		NO	NO	NO	YES	NO
Comments						
Initial draught		7.19				
Initial heeling angle		2.5				
Initial trim angle		-0.4				
Seaway spectrum		JONSWAP				
Realisation		1	2	3	1	2
$H_s$		4.77	4.99	4.58	4.65	4.65
$T_p$		8.7	8.9	8.6	8.6	8.6
Measuring time		23.2	18.1	22.2	37.3	16.4
Heave	$A_{sig}$	2.14	2.15	1.96	2.00	2.14
	$A_{sig+}$	2.12	2.15	1.98	2.00	2.15
	$A_{sig-}$	-2.14	-2.13	-1.95	-2.01	-2.13
	$A_{max+}$	3.55	3.40	4.38	3.74	3.53
	$A_{max-}$	-3.59	-3.41	-3.95	-3.33	-3.19
Final draught (30 min)		-	-	-	7.19	-
Roll	$A_{sig}$ upper bound	10.53	12.3	11.0	9.6	12.3
	$A_{sig}$ lower bound	2.89	3.6	3.0	3.6	4.4
	$A_{max}$ upper bound	16.26	18.3	19.0	11.3	18.8
	$A_{max}$ lower bound	-0.42	0.8	-1.6	0.5	1.5
	$T_m$	10.7	11.4	10.8	10.9	11.0
Final heel (30 min)		-	-	-	5.9	-
Pitch	$A_{sig}$	0.54	0.6	0.6	0.4	0.6
	$A_{sig+}$	0.53	0.6	0.6	0.4	0.6
	$A_{sig-}$	-0.55	-0.6	-0.6	-0.5	-0.6
	$A_{max+}$	1.04	1.3	1.0	1.0	1.0
	$A_{max-}$	-1.13	-1.1	-1.1	-1.1	-1.4
Final trim (30 min)		-	-	-	-0.7	-
$\zeta_{wp1}$	$A_{sig+}$	0.50	0.65	0.64	0.51	0.61
	$A_{max+}$	0.58	1.00	1.12	0.76	0.81
$\zeta_{wp2}$	$A_{sig+}$	0.71	0.77	0.60	0.62	0.81
	$A_{max+}$	1.18	1.36	0.92	0.94	1.63
$\zeta_{wp3}$	$A_{sig+}$	1.27	1.30	1.22	1.08	1.37
	$A_{max+}$	2.05	1.91	2.28	1.69	2.20
$\zeta_{wp4}$	$A_{sig+}$	2.34	2.73	2.44	1.95	2.76
	$A_{max+}$	4.83	3.77	4.30	2.57	4.69
$\zeta_{wp5}$	$A_{sig+}$	0.85	0.81	0.97	0.78	0.97
	$A_{max+}$	1.53	1.73	1.82	1.71	2.07
$\zeta_{wp6}$	$A_{sig+}$	0.88	1.01	0.98	0.69	1.09
	$A_{max+}$	1.86	1.79	2.21	1.05	2.13
$\zeta_{wp7}$	$A_{sig+}$	1.91	2.14	1.84	1.61	2.19
	$A_{max+}$	3.87	2.79	3.08	2.22	2.96
$\zeta_{wp8}$	$A_{sig+}$	1.13	1.02	1.10	0.98	1.10
	$A_{max+}$	2.15	1.92	2.22	2.36	2.51
$\zeta_{wp9}$	$A_{sig+}$	1.10	1.07	1.10	0.94	1.08
	$A_{max+}$	1.76	1.85	1.82	1.55	2.09
$\zeta_{wp10}$	$A_{sig+}$	-	-	-	-	-
	$A_{max+}$	-	-	-	-	-
$\zeta_{wp11}$	$A_{sig+}$	0.71	0.76	0.71	0.54	0.88
	$A_{max+}$	1.51	1.38	1.18	0.96	2.10
$\zeta_{wp12}$	$A_{sig+}$	1.62	1.84	1.66	1.28	1.86
	$A_{max+}$	3.22	2.55	2.80	1.80	2.91
$\zeta_{wp13}$	$A_{sig+}$	-	-	-	-	-
	$A_{max+}$	-	-	-	-	-
$\zeta_{wp14}$	$A_{sig+}$	1.38	1.36	1.65	0.78	1.47
	$A_{max+}$	2.21	2.07	2.03	1.01	2.64
$\zeta_{wp15}$	$A_{sig+}$	2.76	3.02	2.61	2.75	2.95
	$A_{sig-}$	-3.06	-3.30	-3.05	-2.62	-3.31
	$A_{max+}$	5.24	5.30	6.45	6.18	5.49
	$A_{max-}$	-5.14	-4.37	-5.05	-4.55	-4.85

Table 3: 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]	9.87				
Initial heeling angle	[deg]	1.0				
Initial trim angle	[deg]	2.1				
Seaway spectrum		ITTC				
Realisation		1	2	1	2	3
H <sub>s</sub>	[m]	3.90	3.75	4.64	4.62	4.64
T <sub>p</sub>	[s]	11.8	11.6	12.3	12.2	12.3
Measuring time	[min]	38.6	37.8	39.7	39.6	37.9
Heave	A <sub>sig</sub>	1.97	2.01	2.37	2.42	2.35
	A <sub>sig+</sub>	1.98	2.02	2.43	2.46	2.34
	A <sub>sig-</sub>	-1.96	-2.00	-2.31	-2.39	-2.34
	A <sub>max+</sub>	3.64	3.44	4.19	4.24	3.78
	A <sub>max-</sub>	-3.49	-3.08	-3.73	-4.41	-3.45
	Final draught (30 min)	9.87	10.15	10.17	10.17	10.07
Roll	A <sub>sig</sub> upper bound	6.19	6.3	7.2	7.1	7.1
	A <sub>sig</sub> lower bound	-3.37	-3.5	-4.2	-4.4	-4.2
	A <sub>max</sub> upper bound	8.77	9.2	11.0	11.2	12.0
	A <sub>max</sub> lower bound	-5.64	-6.3	-7.7	-8.5	-8.2
	T <sub>m</sub>	10.0	10.0	9.9	10.0	9.9
	Final heel (30 min)	1.2	1.1	1.4	1.3	1.2
Pitch	A <sub>sig</sub>	0.30	0.3	0.3	0.3	0.3
	A <sub>sig+</sub>	0.31	0.4	0.3	0.3	0.3
	A <sub>sig-</sub>	-0.29	-0.3	-0.4	-0.4	-0.3
	A <sub>max+</sub>	0.62	1.4	0.8	0.6	0.6
	A <sub>max-</sub>	-0.55	-1.1	-0.7	-0.7	-0.7
	Final trim (30 min)	2.1	2.0	2.0	2.0	2.1
ζ <sub>wp1</sub>	A <sub>sig+</sub>	-	-	-	-	-
	A <sub>max+</sub>	-	-	-	-	-
ζ <sub>wp2</sub>	A <sub>sig+</sub>	0.48	0.39	0.48	0.62	0.52
	A <sub>max+</sub>	0.55	0.41	0.61	0.98	1.04
ζ <sub>wp3</sub>	A <sub>sig+</sub>	-	-	0.49	0.57	0.49
	A <sub>max+</sub>	-	-	0.51	0.62	0.59
ζ <sub>wp4</sub>	A <sub>sig+</sub>	0.47	0.75	0.65	0.72	0.69
	A <sub>max+</sub>	0.58	0.94	1.03	1.28	1.23
ζ <sub>wp5</sub>	A <sub>sig+</sub>	0.81	0.86	1.03	1.06	1.03
	A <sub>max+</sub>	1.42	1.60	1.54	2.15	2.21
ζ <sub>wp6</sub>	A <sub>sig+</sub>	0.74	0.75	0.86	0.88	0.86
	A <sub>max+</sub>	0.97	1.05	1.14	1.39	1.22
ζ <sub>wp7</sub>	A <sub>sig+</sub>	1.24	1.25	1.52	1.52	1.49
	A <sub>max+</sub>	1.97	2.13	2.53	3.61	3.25
ζ <sub>wp8</sub>	A <sub>sig+</sub>	1.75	1.86	1.98	2.03	1.97
	A <sub>max+</sub>	2.32	2.38	2.50	3.05	2.50
ζ <sub>wp9</sub>	A <sub>sig+</sub>	1.65	1.70	1.78	1.80	1.79
	A <sub>max+</sub>	2.13	2.14	2.37	2.30	2.37
ζ <sub>wp10</sub>	A <sub>sig+</sub>	3.63	3.69	4.06	3.99	3.94
	A <sub>max+</sub>	4.87	5.67	5.92	6.28	5.87
ζ <sub>wp11</sub>	A <sub>sig+</sub>	2.82	2.83	2.98	2.95	2.96
	A <sub>max+</sub>	3.54	3.47	3.66	3.68	4.30
ζ <sub>wp12</sub>	A <sub>sig+</sub>	2.54	2.61	2.70	2.69	2.67
	A <sub>max+</sub>	3.12	3.04	3.17	3.32	3.17
ζ <sub>wp13</sub>	A <sub>sig+</sub>	3.25	3.33	3.60	3.56	3.60
	A <sub>max+</sub>	3.90	4.09	4.62	4.40	4.77
ζ <sub>wp14</sub>	A <sub>sig+</sub>	4.04	4.08	4.17	4.16	4.13
	A <sub>max+</sub>	4.52	4.58	4.70	4.79	4.71
ζ <sub>wp15</sub>	A <sub>sig+</sub>	1.63	1.72	2.13	2.16	2.11
	A <sub>sig-</sub>	-1.96	-2.05	-2.63	-2.63	-2.45
	A <sub>max+</sub>	2.63	2.63	3.92	4.03	3.33
	A <sub>max-</sub>	-3.34	-3.92	-5.55	-5.85	-4.76

Table 6: 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			9.87				
Initial heeling angle			1.0				
Initial trim angle			2.1				
Seaway spectrum			JONSWAP				
Realisation			1	1	2	3	4
$H_s$			3.73	4.35	4.31	4.30	4.38
$T_p$			8.3	8.4	8.4	8.4	8.4
Measuring time			37.2	38.5	38.4	39.5	38.9
Heave	$A_{sig}$	[m]	1.74	1.76	1.88	2.01	1.95
	$A_{sig+}$	[m]	1.78	1.79	1.93	2.06	2.01
	$A_{sig-}$	[m]	-1.71	-1.72	-1.84	-1.96	-1.90
	$A_{max+}$	[m]	3.45	3.53	3.21	3.61	3.77
	$A_{max-}$	[m]	-2.91	-3.47	-2.99	-3.19	-3.79
	Final draught (30 min)	[m]	9.87	9.87	9.87	9.87	9.87
Roll	$A_{sig}$ upper bound	[deg]	6.35	6.3	6.6	7.0	6.7
	$A_{sig}$ lower bound	[deg]	-3.03	-3.3	-3.4	-3.6	-3.7
	$A_{max}$ upper bound	[deg]	9.03	9.6	9.8	10.9	9.7
	$A_{max}$ lower bound	[deg]	-6.20	-7.9	-7.2	-8.0	-8.9
	$T_m$	[s]	9.0	9.3	9.2	9.0	9.1
	Final heel (30 min)	[deg]	1.7	1.1	1.2	1.4	1.6
Pitch	$A_{sig}$	[deg]	0.38	0.4	0.3	0.4	0.4
	$A_{sig+}$	[deg]	0.35	0.4	0.3	0.4	0.4
	$A_{sig-}$	[deg]	-0.40	-0.4	-0.3	-0.4	-0.4
	$A_{max+}$	[deg]	0.75	0.8	0.7	0.9	0.9
	$A_{max-}$	[deg]	-0.76	-0.9	-0.7	-1.1	-1.0
	Final trim (30 min)	[deg]	2.1	2.2	2.2	2.2	2.2
$\zeta_{wp1}$	$A_{sig+}$	[m]	-	-	-	-	-
	$A_{max+}$	[m]	-	-	-	-	-
$\zeta_{wp2}$	$A_{sig+}$	[m]	0.69	0.96	0.84	0.76	0.85
	$A_{max+}$	[m]	0.82	1.67	1.31	1.29	1.14
$\zeta_{wp3}$	$A_{sig+}$	[m]	0.60	0.70	0.64	0.62	0.66
	$A_{max+}$	[m]	0.70	0.96	0.76	1.18	1.12
$\zeta_{wp4}$	$A_{sig+}$	[m]	1.00	1.22	1.24	1.02	1.13
	$A_{max+}$	[m]	1.62	1.97	1.93	1.56	1.93
$\zeta_{wp5}$	$A_{sig+}$	[m]	0.96	0.98	1.09	1.07	1.16
	$A_{max+}$	[m]	1.98	1.78	2.09	1.82	2.03
$\zeta_{wp6}$	$A_{sig+}$	[m]	0.95	0.96	0.98	1.01	1.03
	$A_{max+}$	[m]	1.25	1.36	1.41	1.33	1.50
$\zeta_{wp7}$	$A_{sig+}$	[m]	1.62	1.73	1.83	1.83	1.87
	$A_{max+}$	[m]	2.84	4.10	4.34	5.53	5.88
$\zeta_{wp8}$	$A_{sig+}$	[m]	1.98	2.06	2.06	2.12	2.16
	$A_{max+}$	[m]	2.60	2.54	2.74	2.57	2.78
$\zeta_{wp9}$	$A_{sig+}$	[m]	1.79	1.88	1.89	1.91	1.94
	$A_{max+}$	[m]	2.23	2.56	2.38	2.59	2.44
$\zeta_{wp10}$	$A_{sig+}$	[m]	3.98	4.33	4.37	4.43	4.64
	$A_{max+}$	[m]	6.29	8.76	7.40	8.08	9.31
$\zeta_{wp11}$	$A_{sig+}$	[m]	2.72	2.89	2.87	2.84	2.96
	$A_{max+}$	[m]	3.25	3.72	3.47	3.64	3.89
$\zeta_{wp12}$	$A_{sig+}$	[m]	2.76	2.77	2.78	2.83	2.86
	$A_{max+}$	[m]	3.37	3.29	3.40	3.54	3.39
$\zeta_{wp13}$	$A_{sig+}$	[m]	3.49	3.60	3.60	3.74	3.83
	$A_{max+}$	[m]	4.53	4.62	4.78	4.96	4.93
$\zeta_{wp14}$	$A_{sig+}$	[m]	4.08	4.15	4.12	4.13	4.18
	$A_{max+}$	[m]	4.61	4.72	4.75	4.57	4.89
$\zeta_{wp15}$	$A_{sig+}$	[m]	2.41	2.35	1.42	1.48	1.48
	$A_{sig-}$	[m]	-2.81	-2.87	-1.88	-2.05	-2.07
	$A_{max+}$	[m]	3.79	4.27	2.66	2.87	2.83
	$A_{max-}$	[m]	-5.87	-7.69	-4.37	-4.84	-5.11

Table 6: 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			9.87		9.87		
Initial heeling angle			1.0		1.0		
Initial trim angle			2.1		1.4		
Seaway spectrum			JONSWAP				
Realisation			1	1	1	1	1
H <sub>s</sub>			6.50	6.69	4.39	5.60	6.64
T <sub>p</sub>			10.2	11.1	8.5	10.3	11.1
Measuring time			33.2	37.8	38.3	39.0	39.0
Heave	A <sub>sig</sub>	[m]	2.94	3.31	1.76	2.73	3.32
	A <sub>sig+</sub>	[m]	3.02	3.37	1.79	2.78	3.39
	A <sub>sig-</sub>	[m]	-2.88	-3.21	-1.72	-2.66	-3.23
	A <sub>max+</sub>	[m]	4.33	6.74	3.60	5.06	7.03
	A <sub>max-</sub>	[m]	-4.37	-5.40	-3.31	-3.91	-5.86
	Final draught (30 min)	[m]	9.87	9.87	10.27	10.23	10.37
Roll	A <sub>sig</sub> upper bound	[deg]	7.43	8.1	6.7	9.0	9.4
	A <sub>sig</sub> lower bound	[deg]	-5.00	-5.6	-3.2	-5.2	-6.0
	A <sub>max</sub> upper bound	[deg]	11.44	13.6	11.0	12.4	15.5
	A <sub>max</sub> lower bound	[deg]	-8.94	-12.6	-8.9	-9.3	-15.7
	T <sub>m</sub>	[s]	9.9	10.0	9.7	10.2	10.8
	Final heel (30 min)	[deg]	1.0	1.1	1.6	1.3	1.4
Pitch	A <sub>sig</sub>	[deg]	0.70	0.5	0.6	0.6	0.7
	A <sub>sig+</sub>	[deg]	0.69	0.5	0.6	0.6	0.7
	A <sub>sig-</sub>	[deg]	-0.71	-0.5	-0.6	-0.6	-0.7
	A <sub>max+</sub>	[deg]	1.20	1.2	1.2	1.1	1.4
	A <sub>max-</sub>	[deg]	-1.15	-1.4	-1.3	-1.2	-1.6
	Final trim (30 min)	[deg]	2.2	2.2	1.5	1.6	1.7
ζ <sub>wp1</sub>	A <sub>sig+</sub>	[m]	-	0.45	0.43	0.51	0.67
	A <sub>max+</sub>	[m]	-	0.59	0.55	0.73	1.00
ζ <sub>wp2</sub>	A <sub>sig+</sub>	[m]	1.02	1.04	0.93	1.02	1.25
	A <sub>max+</sub>	[m]	1.89	1.86	1.37	1.84	2.71
ζ <sub>wp3</sub>	A <sub>sig+</sub>	[m]	0.73	0.91	0.68	0.87	0.96
	A <sub>max+</sub>	[m]	1.35	1.92	1.44	1.76	2.21
ζ <sub>wp4</sub>	A <sub>sig+</sub>	[m]	1.14	0.94	1.16	1.50	1.35
	A <sub>max+</sub>	[m]	1.88	1.44	1.79	2.10	2.25
ζ <sub>wp5</sub>	A <sub>sig+</sub>	[m]	1.47	1.37	0.88	1.23	1.31
	A <sub>max+</sub>	[m]	2.51	2.25	1.49	2.03	2.27
ζ <sub>wp6</sub>	A <sub>sig+</sub>	[m]	1.11	1.08	0.80	1.01	1.01
	A <sub>max+</sub>	[m]	1.55	1.73	1.17	1.36	1.63
ζ <sub>wp7</sub>	A <sub>sig+</sub>	[m]	2.49	2.45	1.69	2.51	2.54
	A <sub>max+</sub>	[m]	4.97	6.21	4.42	4.74	5.51
ζ <sub>wp8</sub>	A <sub>sig+</sub>	[m]	2.28	2.27	1.28	1.68	1.76
	A <sub>max+</sub>	[m]	3.01	3.18	2.01	2.46	2.70
ζ <sub>wp9</sub>	A <sub>sig+</sub>	[m]	2.03	1.97	1.35	1.63	1.58
	A <sub>max+</sub>	[m]	2.40	2.53	1.77	2.35	2.10
ζ <sub>wp10</sub>	A <sub>sig+</sub>	[m]	5.48	5.36	3.05	4.83	4.80
	A <sub>max+</sub>	[m]	8.41	8.66	6.93	7.03	9.34
ζ <sub>wp11</sub>	A <sub>sig+</sub>	[m]	3.27	3.28	1.74	2.18	2.26
	A <sub>max+</sub>	[m]	3.83	4.02	2.35	2.99	3.11
ζ <sub>wp12</sub>	A <sub>sig+</sub>	[m]	2.91	2.89	1.92	2.12	2.13
	A <sub>max+</sub>	[m]	3.50	3.61	2.84	2.54	2.62
ζ <sub>wp13</sub>	A <sub>sig+</sub>	[m]	4.25	4.24	2.61	3.67	3.70
	A <sub>max+</sub>	[m]	5.23	5.82	3.47	4.73	6.27
ζ <sub>wp14</sub>	A <sub>sig+</sub>	[m]	4.41	4.34	2.81	3.13	3.14
	A <sub>max+</sub>	[m]	5.04	4.94	3.35	3.66	3.75
ζ <sub>wp15</sub>	A <sub>sig+</sub>	[m]	1.47	1.94	2.82	3.17	3.14
	A <sub>sig-</sub>	[m]	-2.30	-2.86	-3.31	-4.01	-4.34
	A <sub>max+</sub>	[m]	2.67	3.20	5.51	5.42	5.54
	A <sub>max-</sub>	[m]	-4.67	-6.52	-6.98	-6.41	-8.77

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

Damage Case			4				
Run-No.			31	32	33	34	35
Survived (EU Directive)			NO	NO	NO	NO	NO
Comments							
Initial draught			9.87				
Initial heeling angle			-4.0				
Initial trim angle			1.4				
Seaway spectrum			JONSWAP				
Realisation			1	1	2	3	4
H <sub>s</sub>			4.21	3.91	3.70	3.68	3.78
T <sub>p</sub>			8.3	8.3	8.3	8.3	8.3
Measuring time			17.8	35.5	38.9	39.0	39.0
Heave	A <sub>sig</sub>	[m]	2.11	1.77	1.79	1.72	1.80
	A <sub>sig+</sub>	[m]	2.11	1.80	1.81	1.73	1.81
	A <sub>sig-</sub>	[m]	-2.08	-1.75	-1.76	-1.72	-1.78
	A <sub>max+</sub>	[m]	3.99	3.15	3.54	3.16	3.12
	A <sub>max-</sub>	[m]	-3.61	-2.98	-3.64	-3.63	-2.93
Final draught (30 min)			-	-	-	-	-
Roll	A <sub>sig</sub> upper bound	[deg]	-5.63	-9.8	-10.5	-10.9	-10.7
	A <sub>sig</sub> lower bound	[deg]	-22.57	-22.3	-23.4	-23.5	-22.7
	A <sub>max</sub> upper bound	[deg]	3.45	0.0	0.2	1.0	1.7
	A <sub>max</sub> lower bound	[deg]	-25.55	-24.7	-27.4	-26.1	-25.8
	T <sub>m</sub>	[s]	9.1	8.6	9.0	8.8	8.7
Final heel (30 min)			-	-	-	-	-
Pitch	A <sub>sig</sub>	[deg]	0.47	0.4	0.4	0.4	0.5
	A <sub>sig+</sub>	[deg]	0.41	0.2	0.2	0.4	0.5
	A <sub>sig-</sub>	[deg]	-0.50	-0.4	-0.4	-0.5	-0.5
	A <sub>max+</sub>	[deg]	1.03	0.4	0.5	1.3	1.4
	A <sub>max-</sub>	[deg]	-0.71	-0.6	-0.6	-0.7	-0.7
Final trim (30 min)			-	-	-	-	-
ζ <sub>wp1</sub>	A <sub>sig+</sub>	[m]	-	-	-	-	-
	A <sub>max+</sub>	[m]	-	-	-	-	-
ζ <sub>wp2</sub>	A <sub>sig+</sub>	[m]	1.33	1.12	1.16	1.20	1.14
	A <sub>max+</sub>	[m]	2.43	2.00	2.64	1.91	1.84
ζ <sub>wp3</sub>	A <sub>sig+</sub>	[m]	0.62	-	-	0.85	0.52
	A <sub>max+</sub>	[m]	0.63	-	-	0.97	0.60
ζ <sub>wp4</sub>	A <sub>sig+</sub>	[m]	-	-	-	-	-
	A <sub>max+</sub>	[m]	-	-	-	-	-
ζ <sub>wp5</sub>	A <sub>sig+</sub>	[m]	2.57	2.57	2.61	2.60	2.54
	A <sub>max+</sub>	[m]	2.97	3.18	3.26	2.92	2.85
ζ <sub>wp6</sub>	A <sub>sig+</sub>	[m]	1.03	0.84	0.85	0.87	0.84
	A <sub>max+</sub>	[m]	1.57	1.29	1.50	2.03	1.21
ζ <sub>wp7</sub>	A <sub>sig+</sub>	[m]	0.88	-	-	1.37	0.18
	A <sub>max+</sub>	[m]	1.50	-	-	1.78	0.20
ζ <sub>wp8</sub>	A <sub>sig+</sub>	[m]	3.35	3.22	3.15	3.22	3.16
	A <sub>max+</sub>	[m]	4.77	4.31	4.12	4.21	4.43
ζ <sub>wp9</sub>	A <sub>sig+</sub>	[m]	1.36	1.26	1.28	1.31	1.22
	A <sub>max+</sub>	[m]	1.71	1.77	1.82	1.96	1.66
ζ <sub>wp10</sub>	A <sub>sig+</sub>	[m]	3.24	1.39	2.29	2.93	1.78
	A <sub>max+</sub>	[m]	4.68	2.44	3.71	6.92	3.21
ζ <sub>wp11</sub>	A <sub>sig+</sub>	[m]	3.65	3.50	3.56	3.56	3.46
	A <sub>max+</sub>	[m]	4.19	4.11	4.22	4.01	4.11
ζ <sub>wp12</sub>	A <sub>sig+</sub>	[m]	1.80	1.69	1.64	1.64	1.56
	A <sub>max+</sub>	[m]	2.44	2.46	2.53	2.49	2.18
ζ <sub>wp13</sub>	A <sub>sig+</sub>	[m]	1.07	0.68	0.87	0.83	0.95
	A <sub>max+</sub>	[m]	1.38	1.21	1.27	1.41	1.20
ζ <sub>wp14</sub>	A <sub>sig+</sub>	[m]	2.68	2.46	2.46	2.41	2.35
	A <sub>max+</sub>	[m]	3.54	3.24	3.46	3.44	3.14
ζ <sub>wp15</sub>	A <sub>sig+</sub>	[m]	4.75	3.50	3.56	3.55	3.66
	A <sub>sig-</sub>	[m]	-4.97	-4.16	-4.17	-4.11	-4.04
	A <sub>max+</sub>	[m]	8.35	6.92	8.43	8.68	7.41
	A <sub>max-</sub>	[m]	-5.80	-5.31	-4.93	-4.77	-5.06

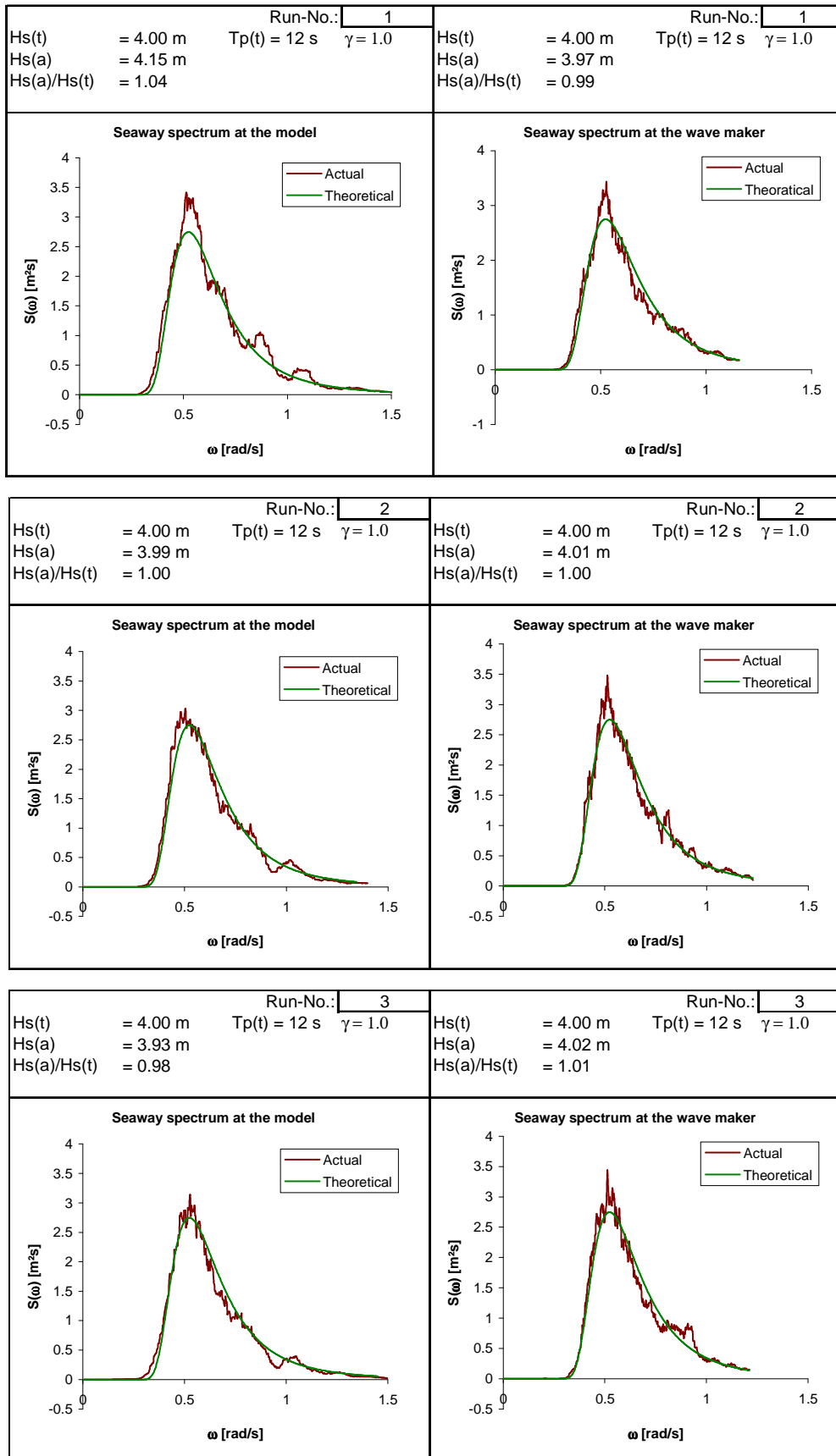
Table 6: Statistical Results of ship motions and wave probe measurements

# **Annex D**

## ***Seaway Spectra***

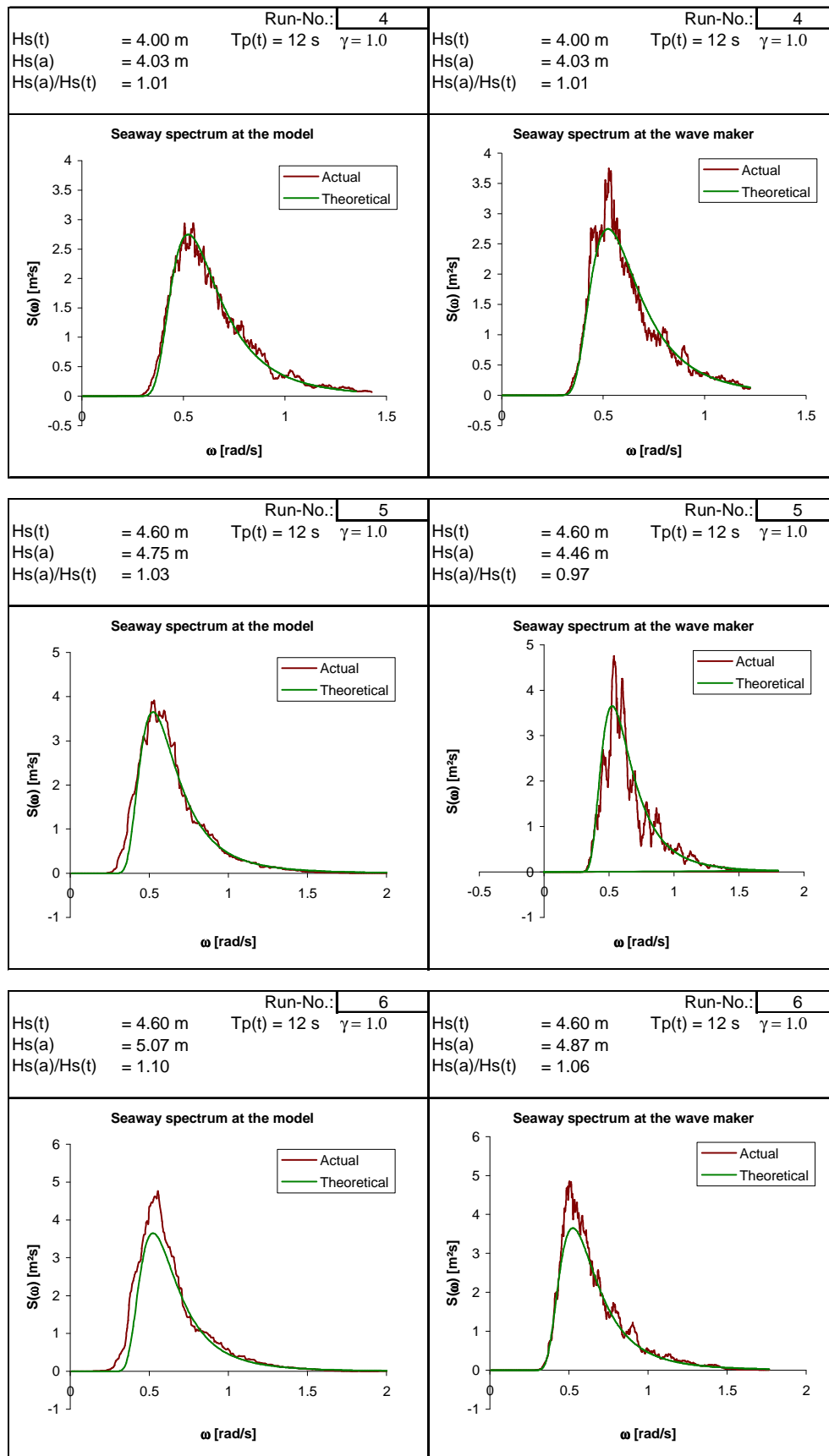
**The positions of the wave probes related to the sea spectra are shown in Figure 2**





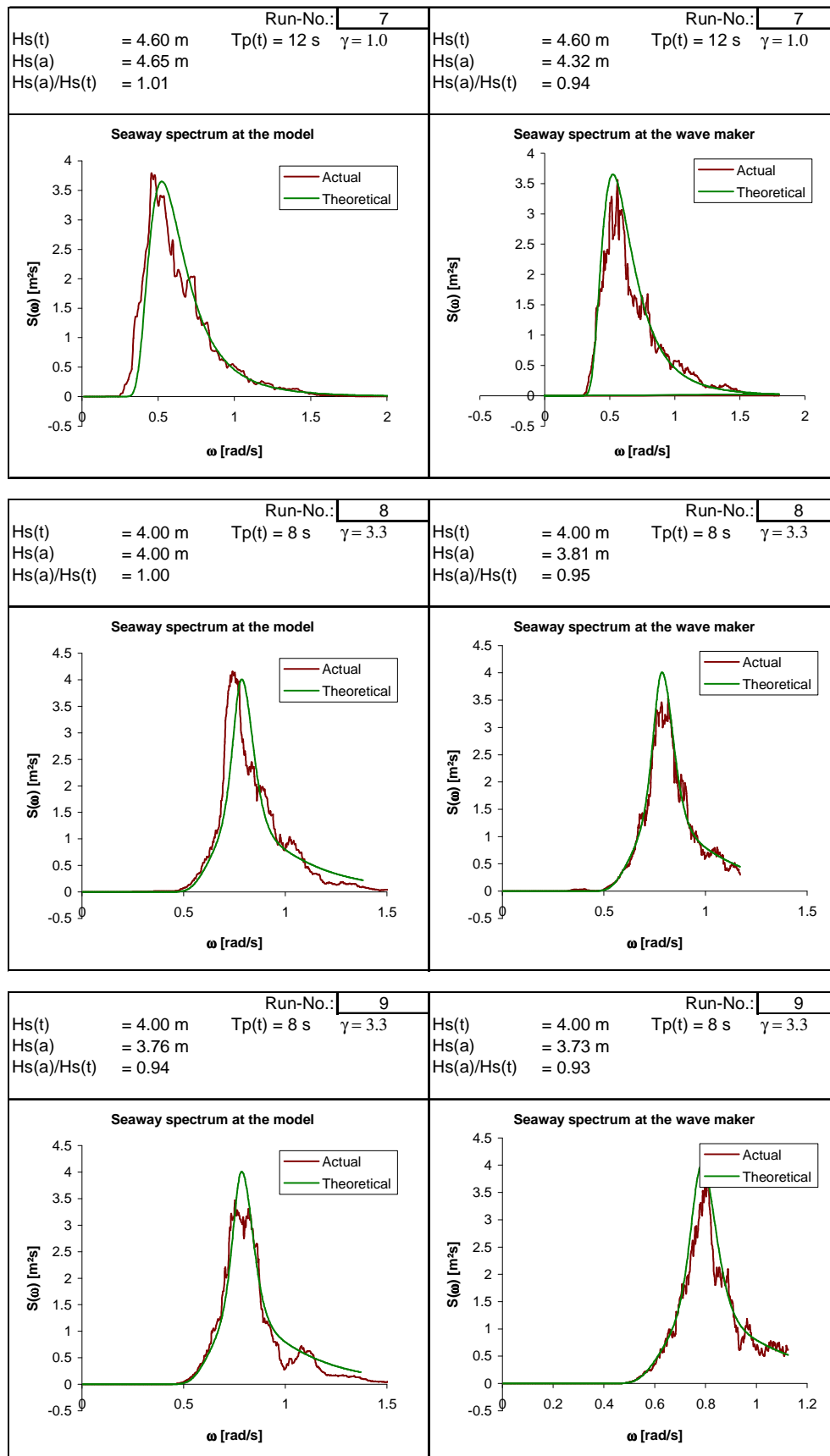
Hs(a): actual significant wave height

Hs(t): theoretical significant wave height



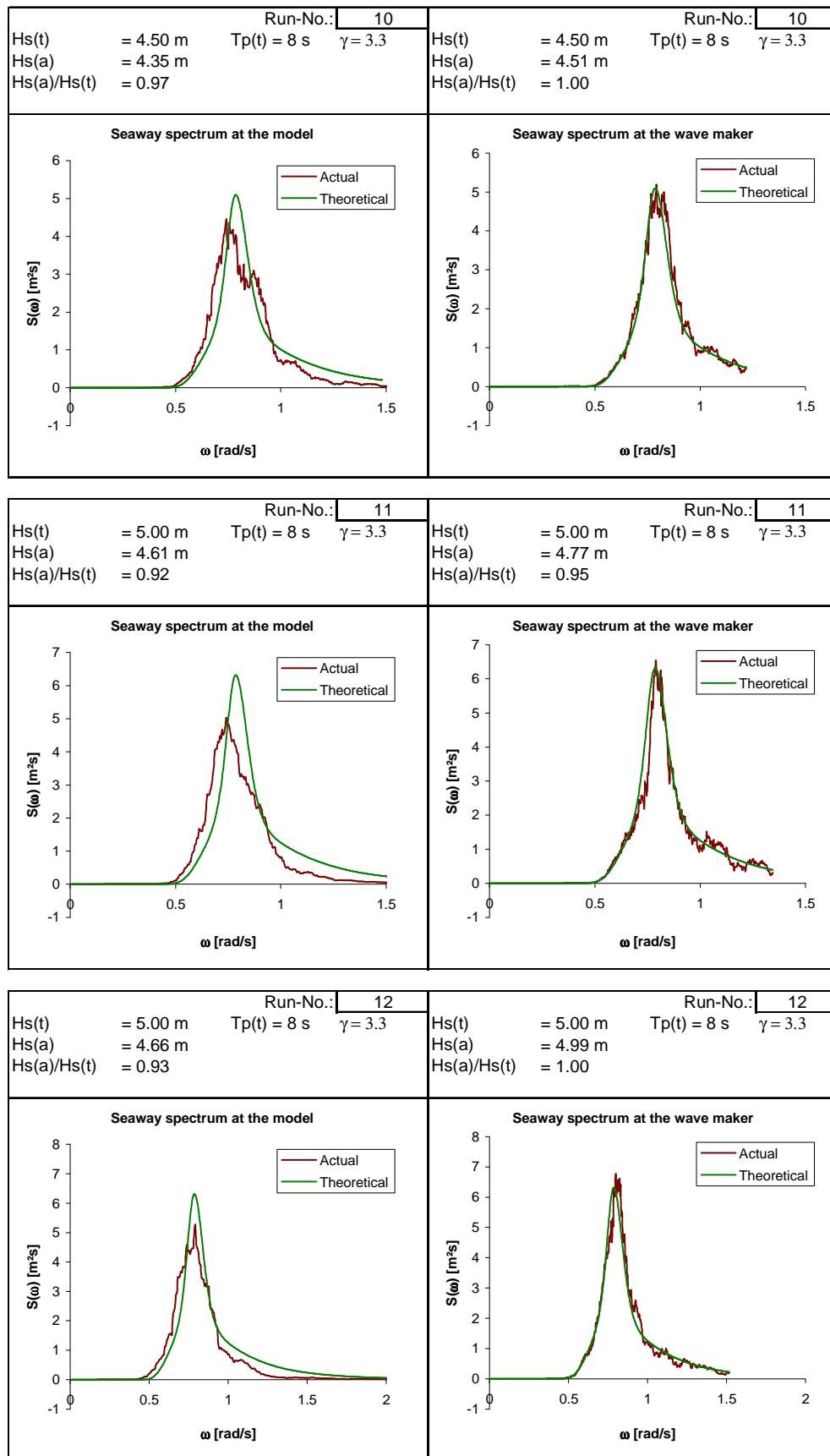
Hs(a): actual significant wave height

Hs(t): theoretical significant wave height



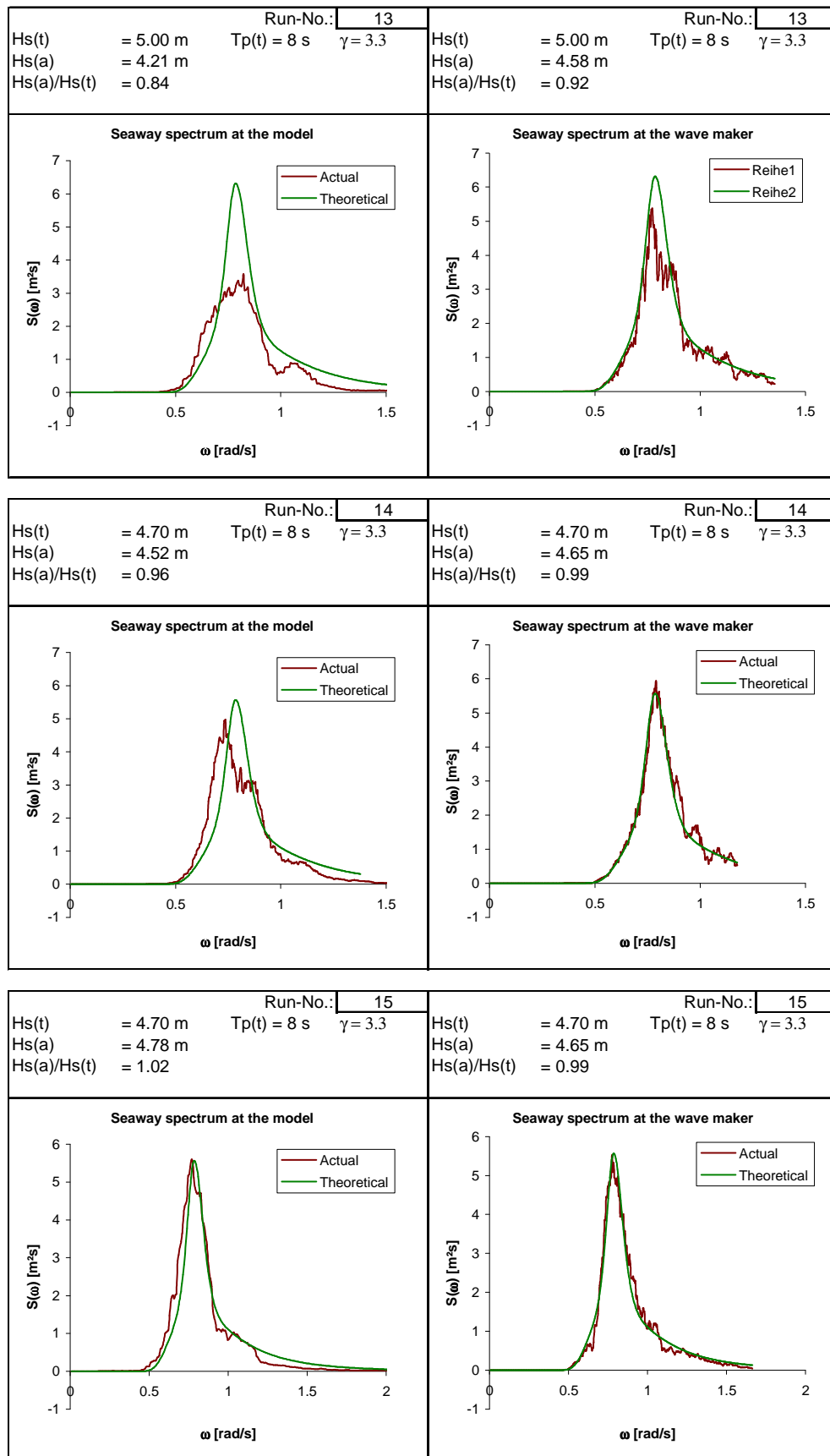
Hs(a): actual significant wave height

Hs(t): theoretical significant wave height



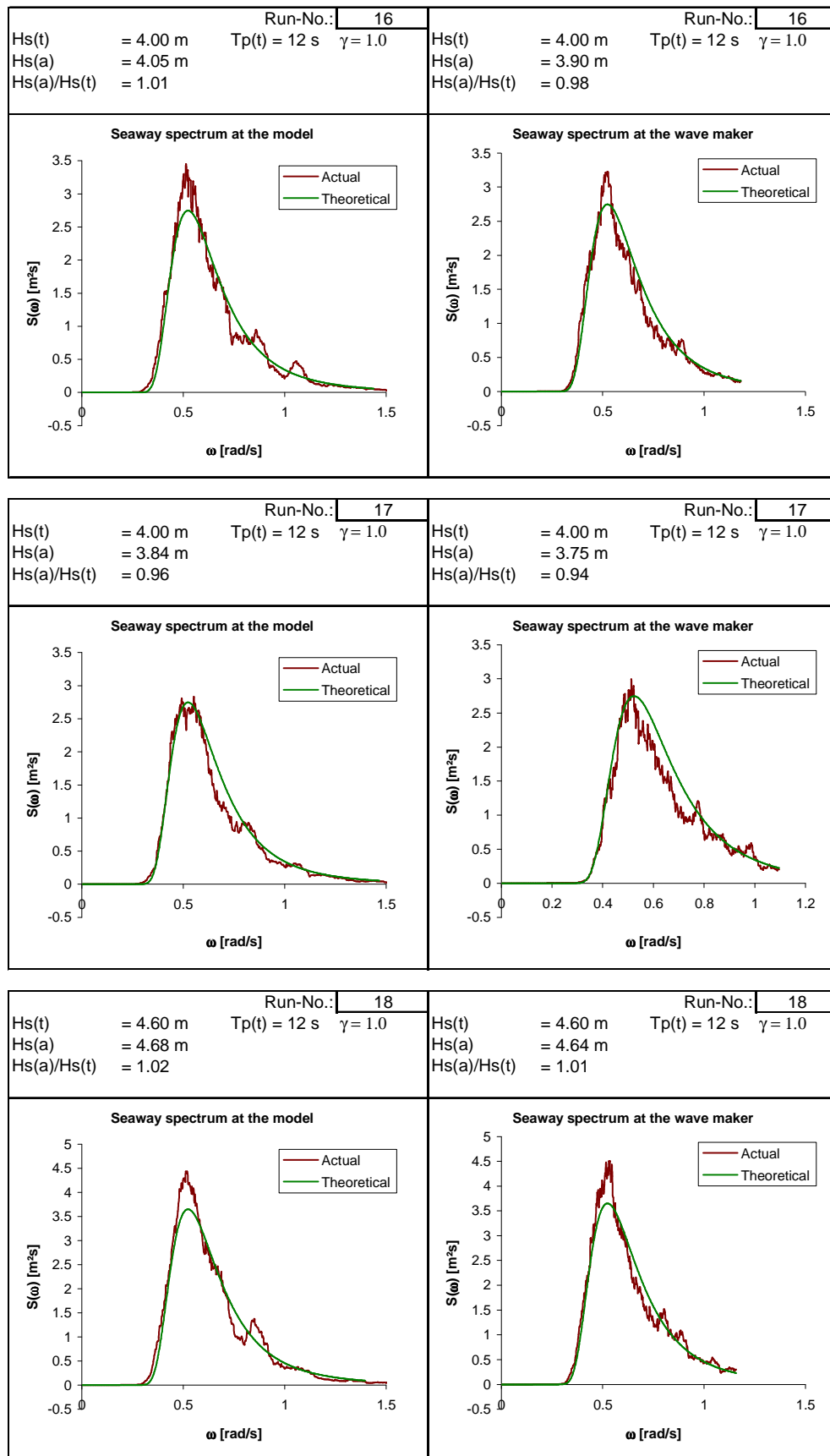
Hs(a): actual significant wave height

Hs(t): theoretical significant wave height



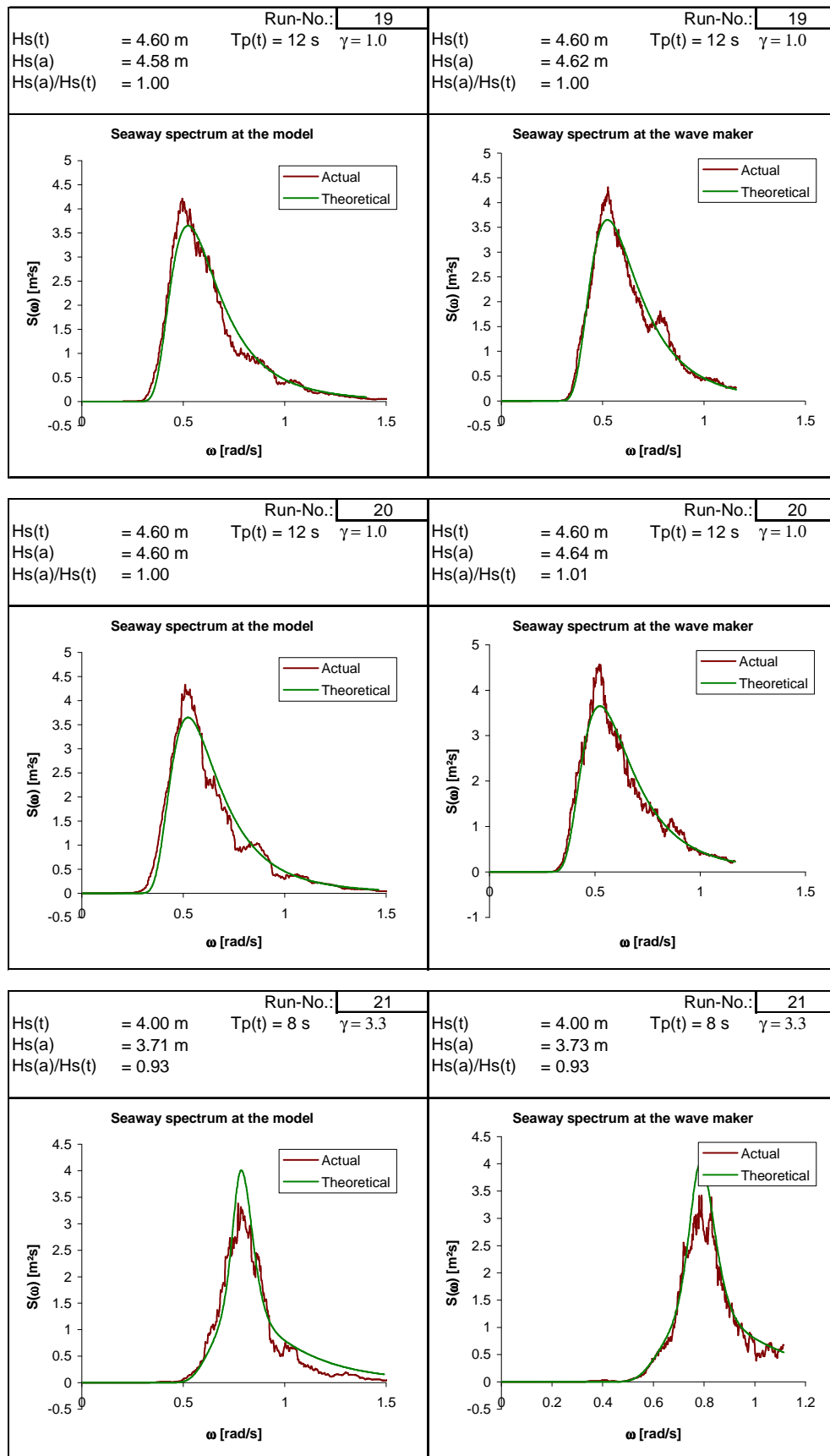
Hs(a): actual significant wave height

Hs(t): theoretical significant wave height



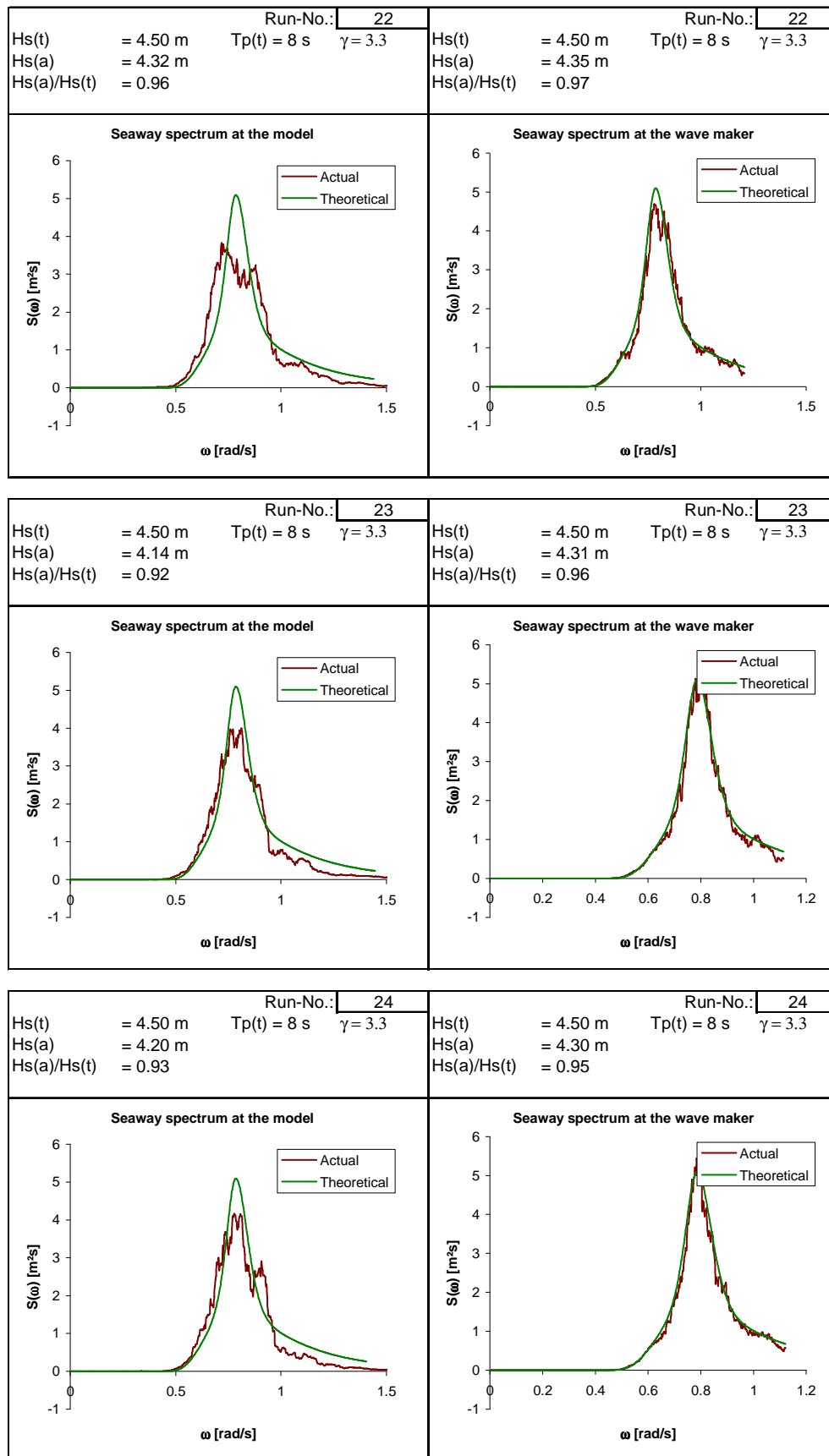
Hs(a): actual significant wave height

Hs(t): theoretical significant wave height



Hs(a): actual significant wave height

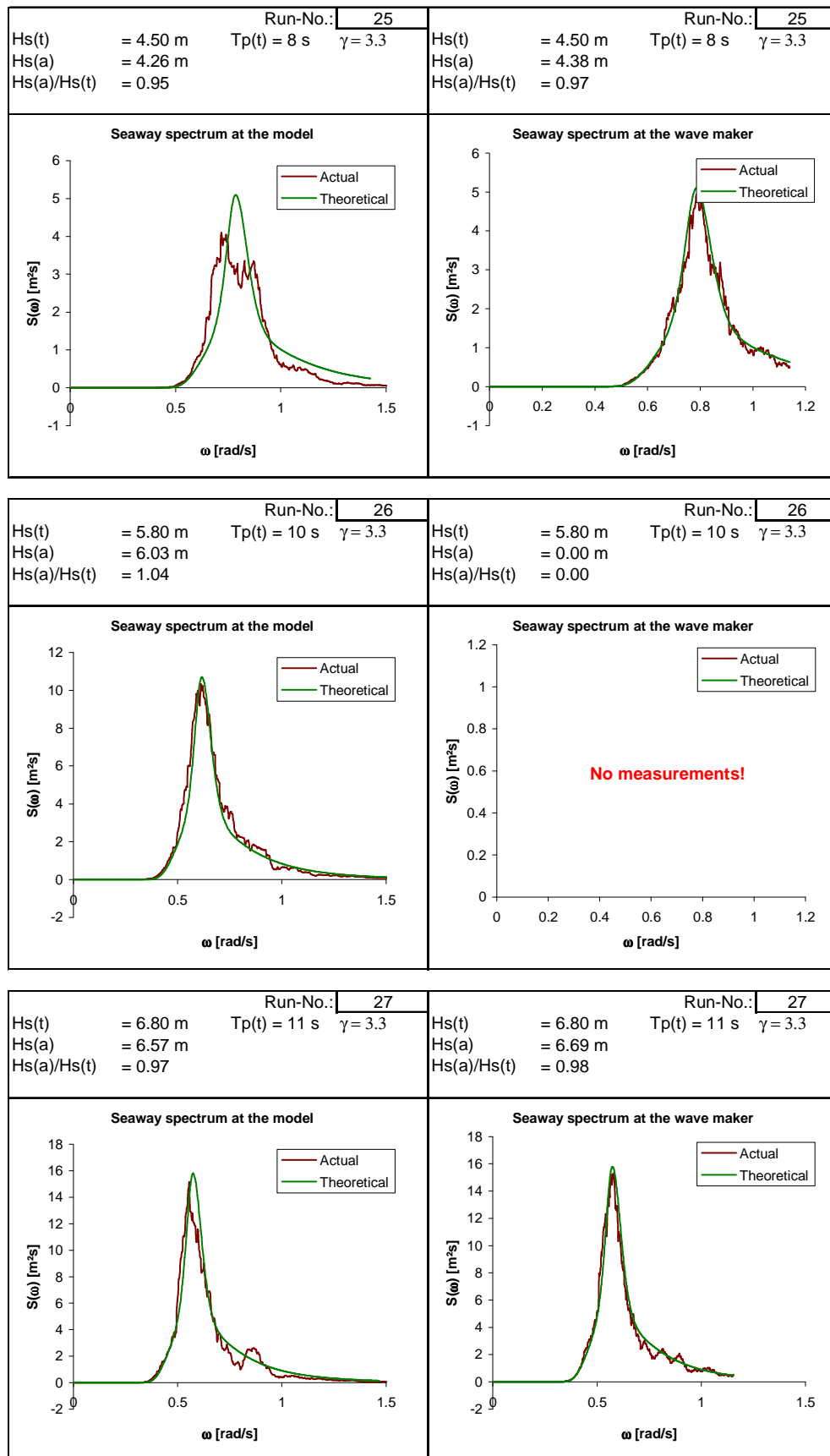
Hs(t): theoretical significant wave height



Hs(a): actual significant wave height

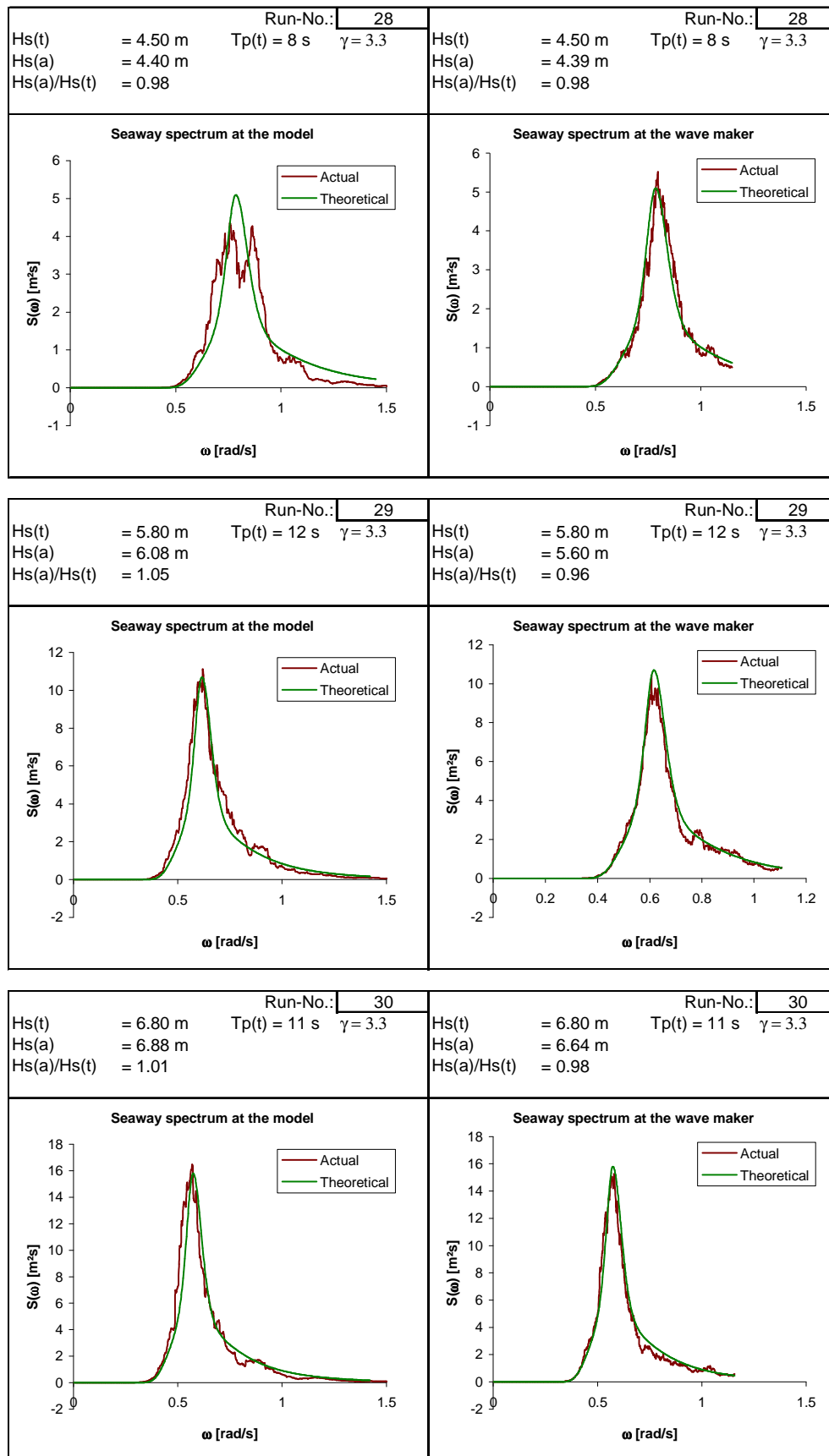
Hs(t): theoretical significant wave height





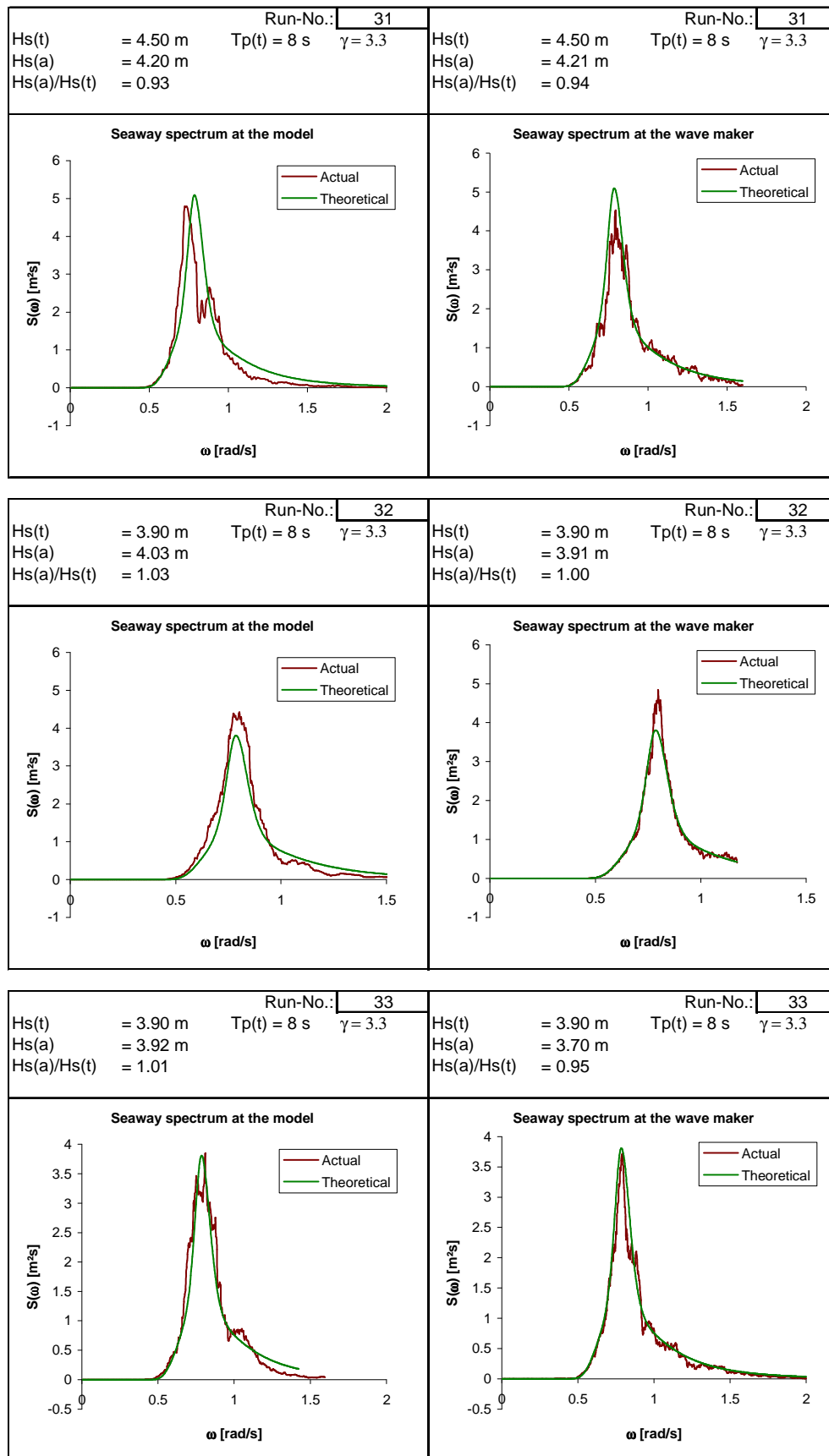
Hs(a): actual significant wave height

Hs(t): theoretical significant wave height



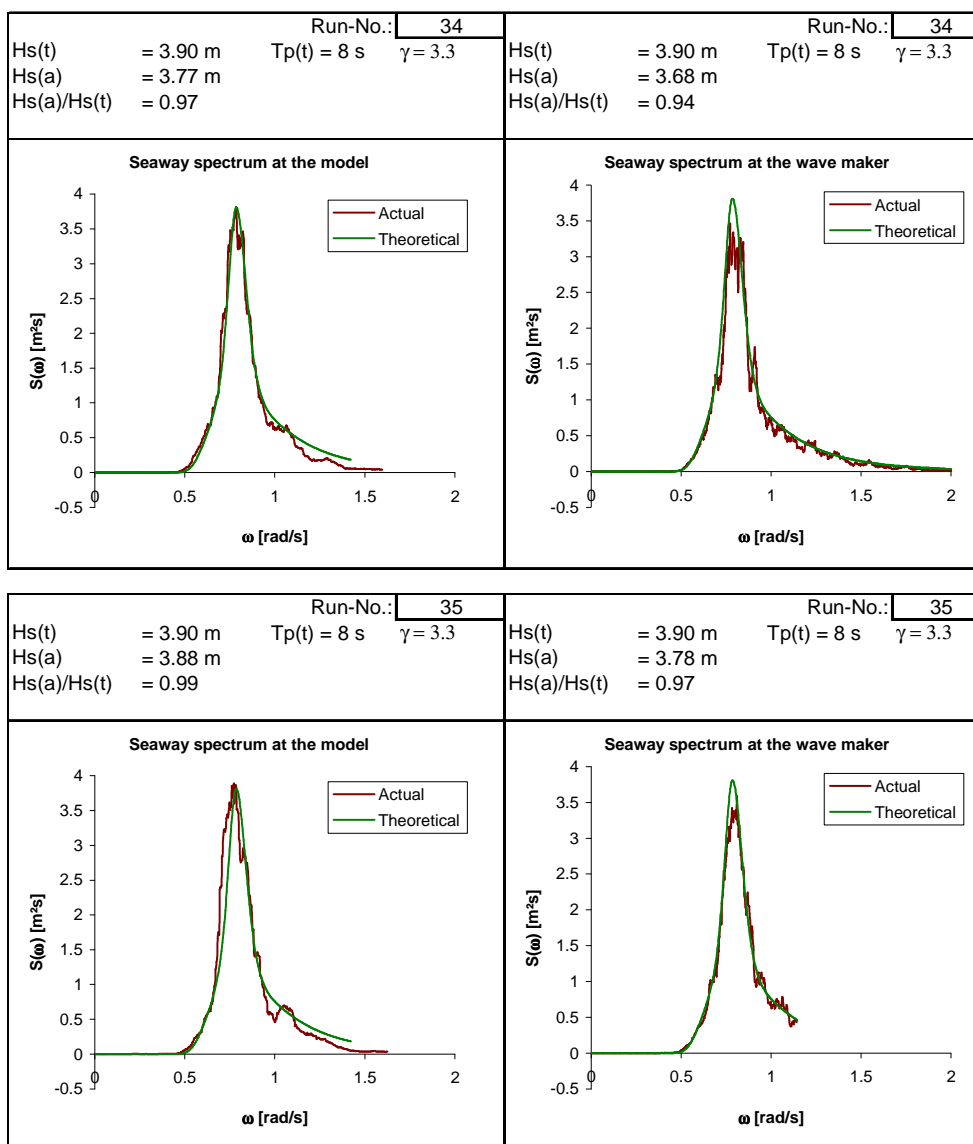
Hs(a): actual significant wave height

Hs(t): theoretical significant wave height



Hs(a): actual significant wave height

Hs(t): theoretical significant wave height



Hs(a): actual significant wave height

Hs(t): theoretical 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.

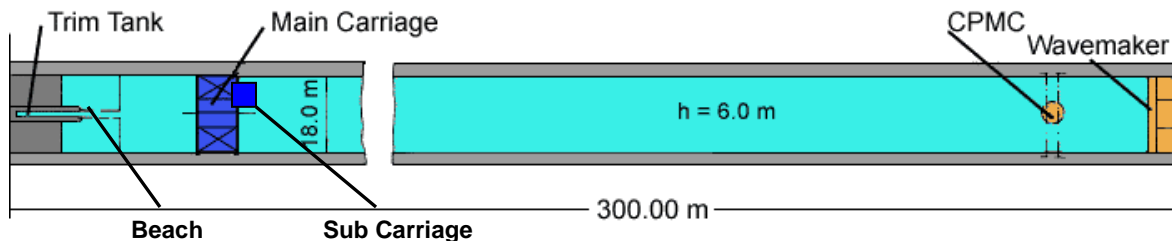


Figure 24: Principle view of the Large Towing Tank

## E.2 Definitions

### E.2.1 Ship Coordinate System

The coordinate system, used for the present seakeeping tests, is shown in Figure 25. It is valid for the steady state of the vessel. The origin has been

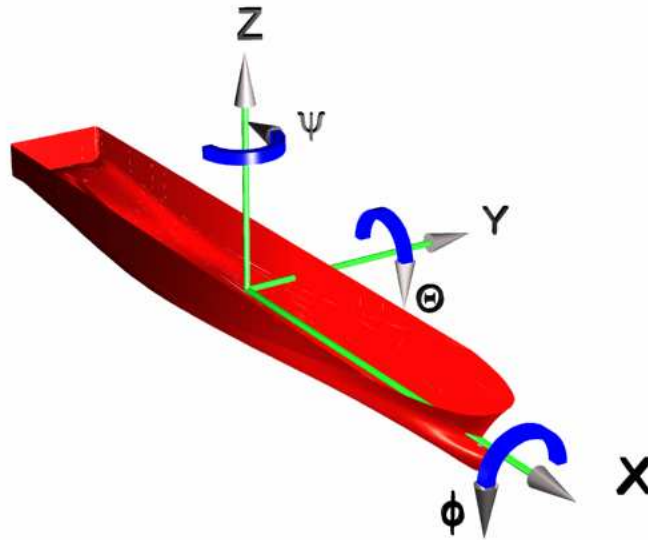


Figure 25: Ship coordinate system

### E.2.2 Encounter Angle $\mu$

The encounter angle  $\mu$  of the vessel is defined as the angle between the ship's heading and the direction of the wave propagation. It is  $0^\circ$  in stern seas and  $180^\circ$  in head seas. The angle  $\mu$  is illustrated in Figure 26.

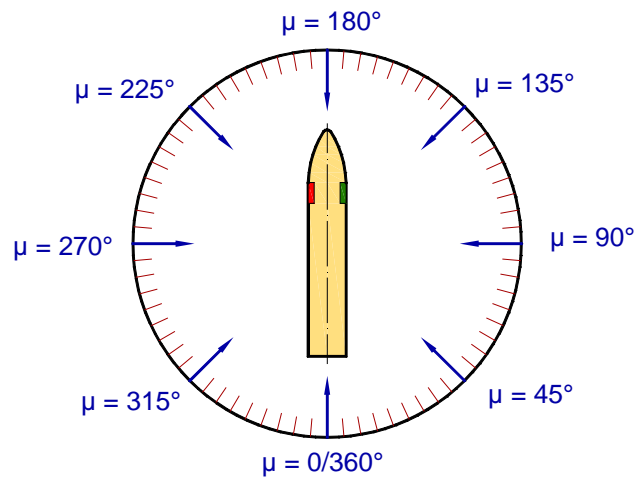
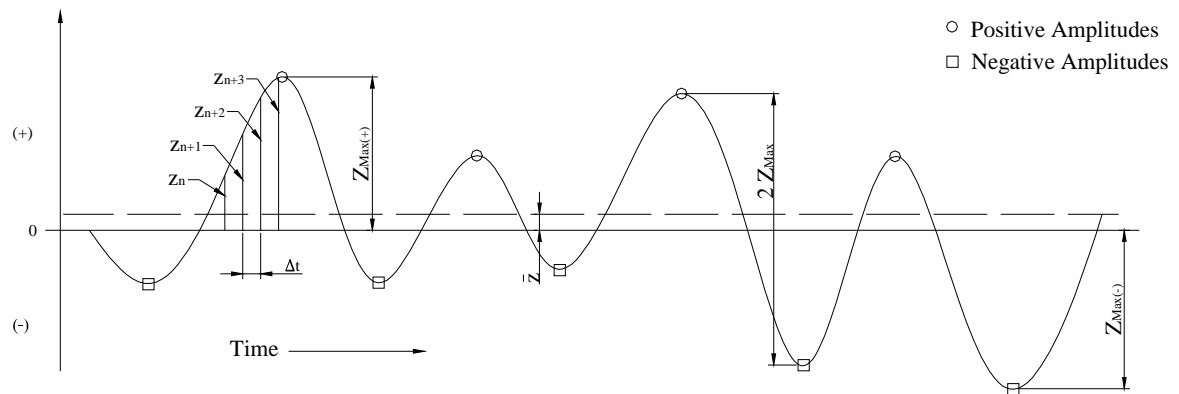


Figure 26: Encounter angle  $\mu$

## 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 27.



**Figure 27: General time record**

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

a. *Mean value:*

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

N: Number of samples

b. *Standard deviation:*

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

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:*

$Z_{sig +} \Rightarrow$  Mean of the one-third largest positive amplitudes

g. *Negative significant single amplitude:*

$Z_{sig -} \Rightarrow$  Mean of the one-third largest negative amplitudes

h. *Mean significant single amplitude:*

$Z_{sig \text{ mean}} \Rightarrow$  Mean value of the positive and negative significant single amplitude

i. *Significant double amplitude:*

$2 Z_{sig} \Rightarrow$  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.	$\gamma$	Hs [m]	Tp [s]
10	10	10	1	5	1.0	3.97	12.0
7	7	7	2	2	1.0	4.01	12.0
8	8	8	3	3	1.0	4.02	12.0
9	9	9	4	4	1.0	4.03	12.0
11	11	11	5	6	1.0	4.46	12.0
12	12	12	6	7	1.0	4.87	12.2
13	13	13	7	8	1.0	4.32	11.6
14	14	14	8	9	3.3	3.81	8.4
15	15	16	9	11	3.3	3.73	8.4
17	17	18	10	13	3.3	4.51	8.6
18	18	19	11	14	3.3	4.77	8.7
19	19	20	12	15	3.3	4.99	8.9
20	20	21	13	16	3.3	4.58	8.6
21	21	22	14	17	3.3	4.65	8.6
22	22	23	15	18	3.3	4.65	8.6
26	26	26	16	19	1.0	3.9	11.8
27	27	27	17	20	1.0	3.75	11.6
28	28	28	18	21	1.0	4.64	12.3
29	29	29	19	22	1.0	4.62	12.2
31	31	32	20	24	1.0	4.64	12.3
30	30	31	21	23	3.3	3.73	8.3
33	33	33	22	25	3.3	4.35	8.4
34	34	34	23	26	3.3	4.31	8.4
35	35	35	24	27	3.3	4.3	8.4
36	36	36	25	28	3.3	4.38	8.4
37	37	---	26	29	3.3		
38	38	38	27	30	3.3	6.69	11.1
42	42	42	28	31	3.3	4.39	8.5
43	43	43	29	32	3.3	5.6	10.3
44	44	44	30	33	3.3	6.64	11.1
46	46	46	31	34	3.3	4.21	8.3
47	47	47	32	35	3.3	3.91	8.3
48	48	48	33	36	3.3	3.7	8.3
49	49	49	34	37	3.3	3.68	8.3
50	50	50	35	38	3.3	3.78	8.3

**Table 11: Correlation of Measuring and Video**