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Programme Area: Marine

Project: PerAWAT

Title: SpecWec Beta Release

Abstract:

The purpose of this deliverable is to describe the beta release of the SpecWEC software tool. As the SpecWEC tool is a modification of the existing TOMAWAC ocean spectral wave model that includes a representation of wave energy converters, the document describes the changes that were made to the TOMAWAC base model to create the SpecWEC tool. These changes were broken down into four core elements: representation of Wave Energy Converter (WEC) performance, input of WEC parameters, specification of WEC location, and output of WEC parameters. The document also includes full documentation of the test cases which were carried out to verify the functionality of each core element, and describes the verification of the SpecWEC tool, including four test cases which were run to demonstrate the successful integration of the four core elements. User instructions for the beta release are included. These include a description of how the user can create an executable from the provided files; create their own source term subroutine for the representation of WEC performance, or use one of the two provided source term subroutines (which have a simple linear frequency/directional dependence on the spectral wave energy of a point absorber representation); and run the tool, including the preparation of input files necessary to run the two provided source term subroutines.

Context:

The Performance Assessment of Wave and Tidal Array Systems (PerAWaT) project, launched in October 2009 with £8m of ETI investment. The project delivered validated, commercial software tools capable of significantly reducing the levels of uncertainty associated with predicting the energy yield of major wave and tidal stream energy arrays. It also produced information that will help reduce commercial risk of future large scale wave and tidal array developments.

Queen's University Belfast

SpecWec Beta Release

WG1 WP2 D3

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Contents

Executive Summary

The purpose of this deliverable is to describe the beta release of the SpecWEC software tool. The document begins with an introduction, which includes a discussion of the scope of the document, the relationship of this deliverable to other deliverables, and a statement of the acceptance criteria for this deliverable. As the SpecWEC tool is a modification of the existing TOMAWAC ocean spectral wave model that includes a representation of wave energy converters, the next portion of the document describes the changes that were made to the TOMAWAC base model to create the SpecWEC tool. These changes were broken down into four core elements: representation of WEC performance (described in Section 2), input of WEC parameters (described in Section 3), specification of WEC location (described in Section 4), and output of WEC parameters (described in Section 5). Each of these four sections details what changes were made to the TOMAWAC model source code, describes any new subroutines which were written for SpecWEC, and also includes test cases which were carried out to verify the functionality of each core element. The full documentation of these test cases can be found in Section 8, the appendix of this document. Section 6 of this document describes the verification of the SpecWEC tool, including four test cases which were run to demonstrate the successful integration of the four core elements. Finally, Section 7 contains user instructions for the beta release. This section begins with a description of how the user can create an executable from the provided files. It then details how the user can create their own source term subroutine for the representation of WEC performance, or use one of the two provided source term subroutines (which have a simple linear frequency/directional dependence on the spectral wave energy of a point absorber representation). Finally, this section includes instructions for running the tool, including the preparation of input files necessary to run the two provided source term subroutines.

1 Introduction

1.1 Scope of Document

The goal of WG1 WP2 of the PerAWaT program is to modify an existing spectral wave model to allow representation of wave energy converters. The previous deliverables (WG1 WP2 D1 and WG1 WP2 D2) presented the plans for the representation of a wave energy converter and the implementation of that representation, respectively. In WG1 WP2 D2, justification was given for the choice of the TOMAWAC (TELEMAC based Operational Model Addressing Wave Action Computation) spectral wave model for development as part of this project. This deliverable documents the changes that were made to the TOMAWAC source code in order to produce the SpecWec tool. It also provides verification of those changes, demonstrating that the code is performing as required. Validation of the representation of wave energy converters (WECs) in TOMAWAC will be provided in two subsequent deliverables (WG1WP2 D4 and D5) which will compare SpecWec output with both linear models and wave tank testing. The development of SpecWec was divided into four separate components: representation of WEC performance, input of WEC parameters, specification of WEC location, and output of WEC performance. In the following, the code modification and verification is described for each component. Finally, user instructions are provided for the SpecWec beta release.

1.2 Relationship to other deliverables

This deliverable documents the application of the representation and implementation plans developed in WG1 WP2 D1 and WG1 WP2 D2. The beta release of the SpecWec code documented in this deliverable will be followed in two deliverables (WG1 WP2 D4 and WG1 WP2 D5) with the validation of this code through comparison with both nonlinear models and wave tank testing.

1.3 Acceptance Criteria

The acceptance criteria for this deliverable are as follows:

1. Release delivered as executable file and source code for production of model output
2. Model capable of representing Point Absorber WEC.

In addition to the source code and executable files which have been provided, this document describes the changes that were made to the TOMAWAC source code and the point absorber representation that was produced.

2 Core Element 1: Representation of WEC performance

2.1 Modifications made to TOMAWAC source code

Spectral wave models solve the wave action conservation equation, which is essentially an energy conservation equation; wave action is defined as wave energy divided by frequency, a quantity which is conserved even in the presence of a background current. A wave energy converter can be incorporated into a spectral wave model by representing the wave energy converter as a source/sink of wave action that can be dependent on frequency, direction, and the incoming wave field. In order to make the SpecWec tool as flexible as possible, the calculation of the WEC source term strength takes place in a subroutine which is incorporated as a dynamic link library. Therefore, the SpecWec user can write their own subroutine (*wecsource.f90*) and compile it into a .dll file, thereby maintaining the confidentiality of the specifications of their device.

Because the WEC representation occurs in a separate dynamic link library file, the changes to the TOMAWAC source code are minimal. There were two objectives of these changes: first, to create a flag which allows the user to turn on and off the WEC subroutine, and second, to incorporate the call to the WEC source term subroutine. In order to create a flag that controls the use of the WEC subroutine, the TOMAWAC dictionary file was modified to include a new keyword (CONSIDERATION OF WECs) that can be used in the TOMAWAC steering file (a text file which controls each TOMAWAC simulation). The main TOMAWAC program *wac.f* was modified to include a logical variable where true indicates the source term subroutine will be called and false indicates it will not. The value of this variable is set using the value that is read in from the steering file. Finally, this variable is passed to the TOMAWAC subroutine which computes all of the wave action source terms, *semimp.f*. This subroutine was also modified to contain the call to the dynamic link library which does the actual WEC source term calculation.

2.2 Sample WEC source term subroutines provided with SpecWec

The WEC source term subroutine may contain any calculations the user required, as long as it follows the form defined here. Fundamentally the WEC source term must define the change in the action density due to the presence of the WEC. The arguments for the source term subroutine as called by TOMAWAC are fixed, and the subroutine must alter two specific variables which contain the source term strength in the model. Three sample source term subroutines are provided as guidance for development of suitable WEC source subroutines: a shell subroutine, a linear frequency/direction dependent source term subroutine, and a point absorber subroutine.

Currently the WEC source terms do not contain an element to represent the radiated wave energy. However, whilst calculation of the strength of the radiated wave source term is somewhat complex, fundamentally it is simple to include with the WEC source term structure developed.

2.2.1 Shell subroutine

This subroutine is provided as a template for the user to modify to include their own WEC representation. It contains the minimum code needed for the WEC source term subroutine; it does not have an actual WEC representation. However, critically it defines the available inputs and necessary outputs required by the WEC source term subroutine. Within these input/output constraints the user may do whatever is necessary to determine the WEC performance and impact on wave action density. This may include equations to solve the hydrodynamics and/or look-up tables as appropriate. The following two sub-sections described provide some guidance on the form that a subroutine may take; however, in general the structure of the sub-routine is left to the discretion of the user..

2.2.2 Simplified linear frequency/direction dependent source term

This subroutine contains a simple representation of a WEC in which the amount of energy removed by the WEC is dependent on both the frequency and direction of the wave: $\boldsymbol{S}(\boldsymbol{\omega},\boldsymbol{\theta}) = \boldsymbol{C}(\boldsymbol{\omega})\boldsymbol{D}(\boldsymbol{\theta})\boldsymbol{E}(\boldsymbol{\omega},\boldsymbol{\theta})$**,** where $\boldsymbol{S}(\boldsymbol{\omega},\boldsymbol{\theta})$ is the WEC source term strength, $\boldsymbol{E}(\boldsymbol{\omega},\boldsymbol{\theta})$ is the spectral energy density, $\boldsymbol{C}(\boldsymbol{\omega})$ is a frequency dependent coefficient, and $\boldsymbol{D}(\boldsymbol{\theta})$ is the directional dependent coefficient. For a specific wave energy converter, the frequency dependent coefficient is dependent on the specific device geometry, as well as the power take-off settings with which the device is operating. For a linear single degree of freedom system it can relatively easily be shown that the percentage of maximum energy extraction, $\boldsymbol{C(\omega)}$, depends on the ratio of the frequency to natural frequency, **υ**, the ratio of the inertial and radiation forces, **μ**, and the ratio of the applied to radiation damping, **λ**.

$$\boldsymbol{C(\omega) = \frac{4\lambda}{\mu^2(1/\nu - \nu)^2 + (1+\lambda)^2}}$$

The user can set the values of **υ, μ,** and **λ** to match the design of their particular device. The directional dependent coefficient is simply related to the cosine squared of the wave direction: $\boldsymbol{D(\theta) = cos^2(\theta - \theta_0)}$**,** where $\boldsymbol{\theta_0}$ is the incoming wave direction. Of course in actuality the values of these variables will be frequency dependent, but this model is provided as the simplest form that may be considered as representative of a WEC.

2.2.3 Point absorber source term

The point absorber WEC source term subroutine has a more sophisticated representation of the energy absorbed by a point absorber WEC. This subroutine solves for the frequency dependent displacement of a point absorber based on the exciting wave force generated from the TOMAWAC spectral energy density:

$$\boldsymbol{I = \frac{K}{-\omega^2(M + A) + i\omega(B + \Lambda) + C}}$$

where $\boldsymbol{I}$ is the WEC displacement, $\boldsymbol{K}$ is the exciting force, $\boldsymbol{M}$ is the mass of the body, $\boldsymbol{A}$ is the frequency dependent added mass, $\boldsymbol{B}$ is the frequency dependent damping coefficient, $\boldsymbol{\Lambda}$ is the power takeoff coefficient, and $\boldsymbol{C}$ is the hydrostatic coefficient. Using this displacement, the power is then calculated as: $\boldsymbol{P(\omega) = \frac{1}{2}Re(K\omega I) - \frac{1}{2}(B + \Lambda)\omega^2 I^2}$. Because this power is the amount of energy removed from the waves by the wave energy converter it is the WEC source term strength, $\boldsymbol{S(\omega) = P(\omega)}$**.** The calculation of the displacement and power is done at each time step for each frequency. This particular representation is not dependent on direction due to the symmetrical shape of a point absorber.

2.3 Verification of core element functionality

Verification of the representation of WEC performance core element was designed to demonstrate that the sample source term subroutines provided with the SpecWEC tool are correctly solving the equations for source term strength which are described in the previous two sections. To achieve this aim, the two source term subroutines were recreated as Matlab subroutines. The Fortran SpecWEC and Matlab subroutines were run with the same parameters and the results for power absorption were compared. Five different test cases with varying incoming waves are described in detail in Section 8.1 of this document. The Fortran and Matlab subroutines had identical results for all the test cases for both source term subroutines. Validation of the representation of WEC performance in SpecWEC will take place through comparison with both wave tank analysis and other numerical models and will be presented in the next two deliverables of this work package.

3 Core Element 2: Input of WEC parameters

3.1 Modifications made to TOMAWAC source code

The source term representation of a WEC may be dependent on many different parameters. Some of these parameters could be the same for each device; parameters concerning the geometry of the device would fall under this category. Other parameters may be different for each device, for example power takeoff settings which may vary in order to maximize the energy output of the array as a whole. It is also possible that some parameters could be dependent on frequency, direction, and/or time. Because the kinds of parameters needed for the WEC source term are so variable and dependent on the specific device being represented, the input of WEC parameters is incorporated into the user-produced dynamic link library instead of being hardwired into the TOMAWAC program. This allows the user to tailor the input of WEC parameters to their specific needs. The method for inputting WEC parameters developed for the two provided source term examples is described in the next section and could be used by a new user as a starting point for their code.

3.2 Input of WEC parameters in provided source term subroutines

For the simplified linear and point absorber subroutines provided with the beta release, there are two defined kinds of parameters: those that are the same for each device (homogeneous WEC parameters) and those that vary by device (heterogeneous WEC parameters). These parameters are read in from an input text (ASCII) file called *wecinfo.txt* which contains the number of input parameters, number of output variables, location of the WECs, and the values of the input parameters. The information is then used to calculate the source term strength of the WECs at each time step. More information about the specific parameters required for each subroutine is provided in the user instructions section of this document.

3.3 Verification of core element functionality

Verification of the input of WEC parameters core element is designed to show that the parameters required for the calculation of energy absorption contained in a user created file are being read in correctly by the SpecWEC tool, and that the tool is capable of notifying the user that the input file is incomplete. Four test cases which represent the testing of the two provided source term subroutines for these two functionalities are described in detail in Section 8.2 of this document. Through comparison of initial input files and screen shots taken during the running of the SpecWEC tool, it is shown that WEC parameters are being read into the model correctly and that error messages are produced when the input files for the two subroutines are incomplete.

4 Core Element 3: Specification of WEC location

4.1 Specification of WEC location in provided source term subroutines

One of the novel aspects in the SpecWec representation of WECs in a spectral wave model is the sub-grid scale parameterization that is used. Each WEC is implemented as a source/sink of wave energy at a single computational node, which allows the waves to flow between the devices; this offers a distinct advantage over the previous representations of wave farms as large obstacles which can only transmit a percentage of the incoming energy. Because the source term strength for each WEC is calculated by the user in the WEC dynamic link library, the specification of which mesh grid points are designated to be the location of WECs is also done by the user in the dynamic link library. It is possible for the user to either choose nodes from a mesh that has already been designed or potentially design a mesh with nodes specifically at the desired locations for the WECs. The simplified linear and point absorber WEC representations each allow for both of these possibilities.

In the sample subroutines provided, location of the WECs can be entered into the input file *wecinfo.txt* in one of two formats. If the user chooses to create a computational mesh in which nodes are located exactly at each WEC location, then it is possible to enter those node numbers directly into the input file. However, if this is not the case, then the user can enter the desired (x,y) coordinates of the WECs, and the closest computational node will be found automatically. This is achieved by finding the node at the minimum distance to the entered coordinates. In the output file, the x and y coordinates of each WEC location are recorded, which allows the user to check that the actual location of the WEC is within reasonable range of the required coordinates.

4.2 Verification of core element functionality

Verification of the specification of WEC location consists of three test cases which show that SpecWEC is capable of reading in WEC location information in the form of either computational node numbers or (x,y) positions. One of these test cases also demonstrates that the user will be warned if more than one WEC has been placed on the same computational node. The verification is carried out through comparison of model input files with screen shots of the model as it is running, and each test case is described in detail in Section 8.3 of this document. Because the specification of WEC location is identical in the two provided source term subroutines, only one of the subroutines was tested.

5 Core Element 4: Output of WEC performance

5.1 Output of WEC performance in provided source term subroutines

The TOMAWAC spectral wave model has the capability to produce two different kinds of output files: a two-dimensional results file, and a spectral results file. The two-dimensional results file consists of a variable chosen by the user (such as significant wave height or mean direction of the wave field) which is output on the two dimensional spatial grid at a time interval set by the user. The spectral results file contains the directional spectra of wave action at specific spatial positions which have been designated by the user, along with the time interval for output. In addition to these outputs which can be used to describe the wave climate, a SpecWec user will want to have the ability to output variables concerning the operation of the WECs themselves. Because these variables can be totally dependent on the source term representation of the WEC used, it is left to the user to incorporate this capability into the dynamic link library they create. For the simplified linear and point absorber representations provided with the beta release, the amount of power absorbed by each WEC is summed over direction and written out at each time step for all computational frequencies to the file *wecout.txt*.

5.2 Verification of core element functionality

Verification of the output of WEC performance is designed to show that both of the provided source term subroutines are capable of correctly documenting the WEC energy absorption in an external text file. This verification also demonstrates that this external output text file created by SpecWEC can be read into Matlab. Comparison of screen shots during the running of SpecWEC with the external output file, as well as screen shots of Matlab, are used to demonstrate these functionalities of SpecWEC. These test cases are described in detail in Section 8.4 of this document.

6 Verification of SpecWec

After all of the individual core elements of SpecWEC were verified individually, a few test cases of the full SpecWEC tool were run in order to demonstrate that these core elements have been integrated together properly. This verification of SpecWEC is intended to show that the results of the SpecWEC tool are reasonable and that the tool runs with no problems or errors. Further validation of the model and specifically the representations of WECs in SpecWEC will occur through comparison between numerical models and also wave tank data, and will be reported in two subsequent deliverables.

For each of the two provided source term subroutines, two test cases were carried out. All of the cases had a 4 km square domain in which the incoming waves were a Jonswap spectrum with significant wave height of 4 meters and a peak period of 10 seconds. The first test case consisted of an array of 40 WECs (4 rows of 10) in which the simplified linear source term subroutine was used to represent the WEC energy absorption, Figure 1.

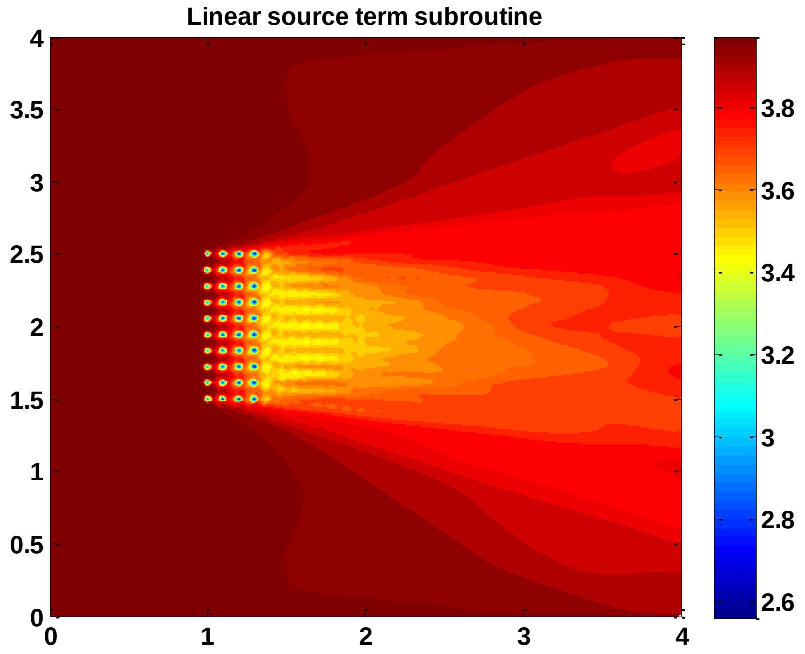


Figure 1: Significant wave height (m) for test case 1.

It can be seen that each WEC is represented individually, which allows energy to pass through the array. Each successive WEC row encounters less energy than the one before it, and the energy behind the array is diminished. The wave energy begins to increase again further downstream due to the directional spreading of the waves. Similar results are achieved when the point absorber source term subroutine is used, Figure 2.

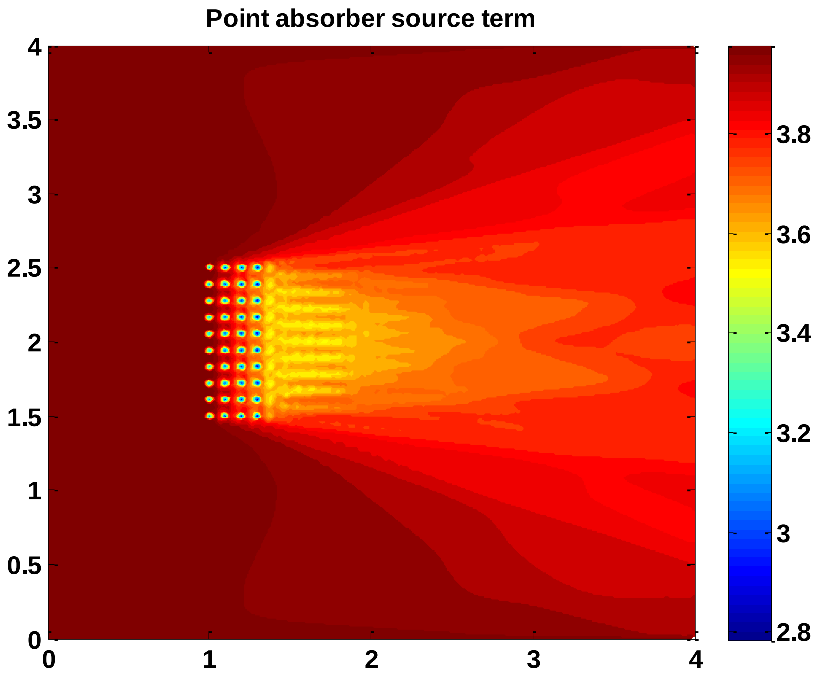


Figure 2: Significant wave height (m) for test case 2.

The remaining two test cases were of a similar design as those presented above, except that 8 of the WECs in the middle of the array were turned off. This demonstrates the ability of the model to control each WEC individually. It would also be possible to represent a WEC with a different source term subroutine, to model the presence of different kinds of WECs in one array. For the test case of incomplete WEC array with the simplified linear source term subroutine, it can be seen that the reduction in significant wave height behind the array is smaller than the full array case, as expected, Figure 3.

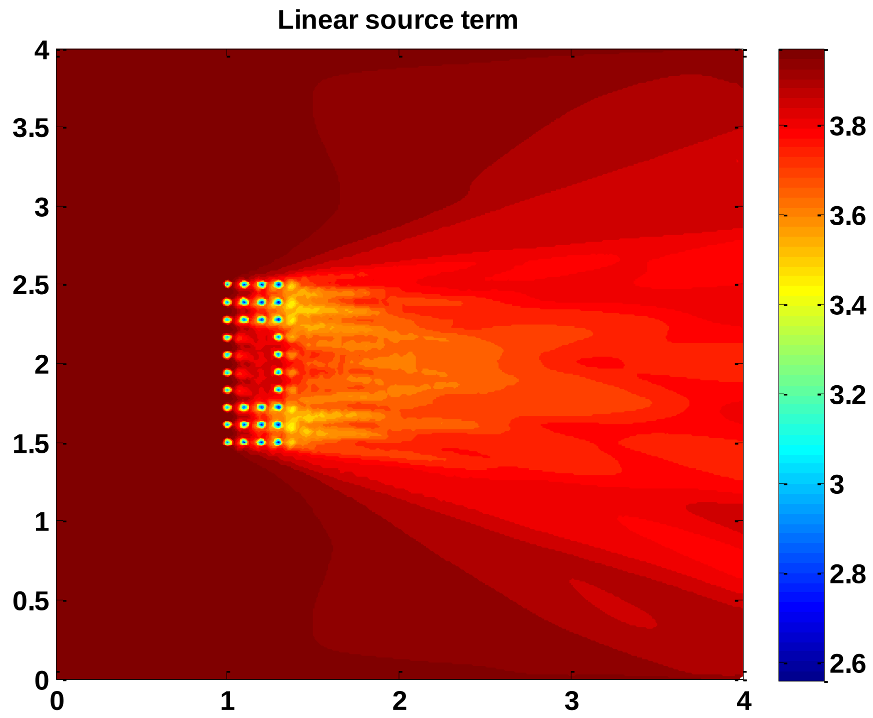


Figure 3: Significant wave height (m) for test case 3.

Similar results are achieved when the point absorber subroutine is used, Figure 4.

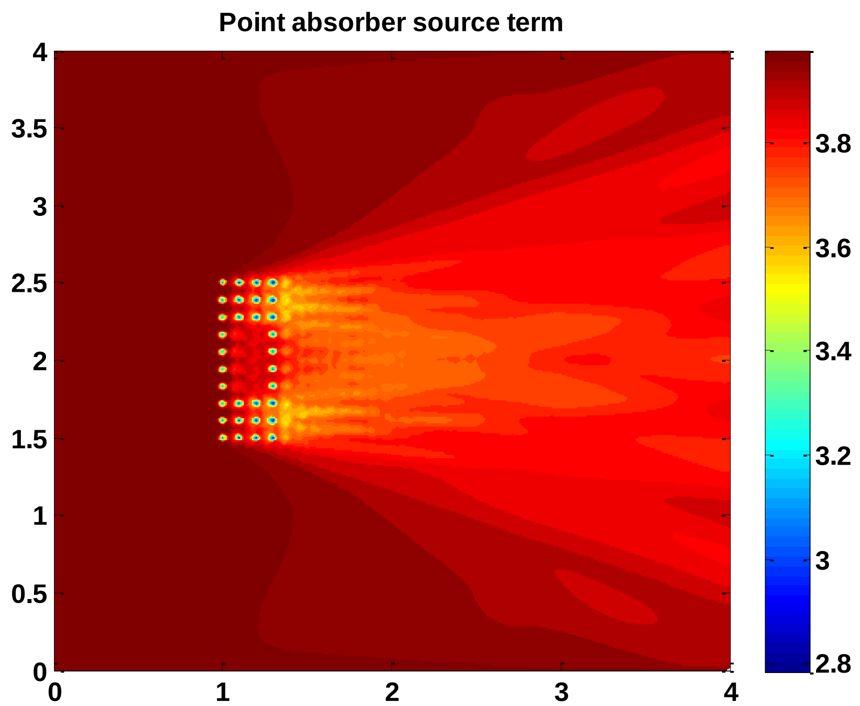


Figure 4: Significant wave height (m) for test case 4.

The results of the four test cases presented here demonstrate that the SpecWEC model can be run and produce qualitatively sensible results, showing that the integration of the core elements has been carried out successfully.

7 Beta Release User Instructions

7.1 Creating the SpecWec executable

SpecWec is a modification of the TOMAWAC spectral wave model that is an open source model produced by EDF. The SpecWec modification allows the spectral wave model to represent the effect of wave energy converters on the surface wave spectrum. The exact nature of the representation can be determined by the SpecWec user. This section contains the instructions for using the SpecWec beta release. It does not contain instructions for running the base TOMAWAC model- these can be found on the EDF website: http://www.opentelemac.org/.

The SpecWec beta release includes four file folders:

1. *tomawac source code* : contains the source Fortran files for the modified TOMAWAC model and the compiled object files for those same Fortran files
2. *tomawac libraries:* contains some library files needed to run TOMAWAC
3. *WEC subroutines*: contains three sample subroutines for the representation of wave energy converters in TOMAWAC.
4. *runtime*: contains two files needed for running SpecWec

Executable files named SpecWec.exe are located in the WEC subroutine folders for the simplified linear and point absorber subroutines. These executables can be run as they are (with the required input files) without requiring any linking. The user can also create an executable file from these provided files in order to run the model, and if they wish they can also incorporate their own source term subroutine by writing a dynamic link library for the representation of WECs and including in the executable. The executable file can then be run using TOMAWAC-standard input files as well as any additional user required files to obtain SpecWec results.

In order to create the TOMAWAC executable, the user must use a Fortran linker/compiler to link together the following items:

1. All of the object files in the *tomawac source code/object files* folder
2. All of the library files in the *tomawac libraries* folder
3. The *WECSOURCE.lib* file that corresponds to the user-chosen WEC source term dynamic link library. For example, if the user wishes to use the provided point absorber source term subroutine, they must include the file *WECSOURCE.lib* found in the *WEC subroutines/point absorber* folder.

Please note that when performing this linking step to create the TOMAWAC executable, it is useful to use the TOMAWAC linker options in order for the model to work properly. These can be found in the TOMAWAC model documentation. In particular, the stack size must be set to 61708864. For the Intel Visual Fortran compiler, the linking statement that creates the executable includes the following segment: */link /stack:61708864*.

7.2 Writing your own WEC source term subroutine

As stated above, the user can write their own WEC source term subroutine containing any calculations they require. However, the arguments for the source term subroutine are fixed, and this is why is it suggested that the user use the provided shell subroutine as a starting point for their new subroutine. The shell script contains the necessary subroutine definition as well as the code required to make the subroutine into a dynamic link library. The variables which make up the argument of the subroutine are described in detail in the shell script.

There are two variables which are particularly important: *TSTOT* and *TSDER*. These are the variables containing the source term strength for the TOMAWAC calculation and they must be modified with the WEC source term strength. Please note that they cannot be written over; instead the WEC source term strength must be added to them. If *S* is the WEC source term strength, then the subroutine must contain a statement which looks like: *TSTOT = TSTOT+S*. The two variables are known as the total source term strength (*TSTOT*) and the partial source term strength (*TSDER)*. There are two source term strength variables because of the way in which TOMAWAC calculates the various ocean energy source terms. The source terms are assumed to be dependent on the wave energy density spectrum, and the *TSDER* variable represents the source term strength after a derivative with respect to that energy spectrum has been taken. A full explanation of these variables can be found in

Section 6.3 of the TOMAWAC manual. The simplest way to deal with these two variables as far as WEC source term strength is concerned is to set the *TSTOT* variable to the total calculated WEC source term strength and not to modify the *TSDER* variable.

Once the source term subroutine has been written, it must be compiled with a Fortran compiler as a dynamic link library; this process should create two necessary files which have the same names regardless of what the Fortran file is called. One is the *WECSOURCE.dll* file used at runtime and the other is the *WECSOURCE.lib* file which is linked into the SpecWec executable.

7.3 Running SpecWec

Once the executable has been created, SpecWec can be run. There are several files which need to be present with specific names in the directory in which SpecWec is to be run. These include:

1. *CONFIG*: a file found in the *runtime* folder of the beta release
2. *WACDICO*: the TOMAWAC library file, found in the *runtime* folder of the beta release
3. *WACCAS*: the case or steering file for the TOMAWAC model run, written by the user as per the TOMAWAC instructions. In order for the SpecWec tool to be activated, the *CONSIDERATION OF WECs* key word in the case file must be set to *1,YES,* or *TRUE*.
4. *WACGEO*: the geometry file containing information about the mesh, created by the user as per the TOMAWAC instructions
5. *WACCLI*: the boundary conditions file, created by the user as per the TOMAWAC instructions
6. *WECSOURCE.dll*: the dynamic link library containing the WEC source term strength subroutine
7. *Any additional files required by the WECSOURCE subroutine*: for example the point absorber and simplified linear subroutines require an additional input file called *wecinfo.txt*.

7.3.1 Using the simplified linear subroutine

If the user wishes to implement the simplified linear subroutine, they can either use the provided executable file or link in the *WECSOURCE.lib* file found in the *WEC Subroutines/linear* folder of the beta release during the creation of the executable. Then, one additional text file must be created to input information about the WECs to SpecWec. This file must be called *wecinfo.txt*, and must contain certain information in the correct order. However, this information can be separated by comments (denoted by the "!" symbol to the left of any comments). The information required, in order is:

Number of WECs			
WEC location format	Note: (1 for nodes, 2 for (x,y) positions)		
WEC orientation ($\boldsymbol{\theta_0}$) in radians			
Number of output variables	Note: (must be equal to the number of computational frequencies)		
Number of WEC parameters (ALWAYS 3)			
WEC location	**μ** (ratio of the inertial and radiation forces)	**λ** (ratio of the applied to radiation damping)	Natural frequency of the WEC

See Section 2.2.2 of this document for a detailed description of the parameters **λ, μ,** and $\boldsymbol{\theta_0}$. For example, if there is one WEC located at node 100 with a WEC orientation of 0 radians, **μ** and **λ** values of 1, a natural frequency of .1 Hz, and the computation has 30 frequency points, then the input file will look as follows:

```
! Number of WECs
1
!WEC Location format
1
! Incoming wave direction
```

```
0
! Number of output variables
30
! Number of WEC parameters
3
! List of WEC location and parameters
100   1   1   0.1
```

Once this input file has been written, it should be placed in the running directory for SpecWec with the other SpecWec input files and then the model can be run. There will be one output file generated specifically by this subroutine, in addition to any standard TOMAWAC output requested by the user. This output file, *wecout.txt* contains the following information printed out at each time step:

Node number	X location of node	Y node location	Energy absorbed at first frequency	....	Energy absorbed at last frequency

The amount of energy absorbed by each WEC is summed over all directions and then reported for each frequency at each time step.

7.3.2 Using the point absorber subroutine

If the user wishes to implement the point absorber subroutine, they can use the provided executable or link in the *WECSOURCE.lib* file found in the *WEC Subroutines/point absorber* folder of the beta release during the creation of the executable. Then, one additional text file must be created to input information about the WECs to SpecWec. This file must be called *wecinfo.txt*, and must contain certain information in the correct order. However, this information can be separated by comments (denoted by !). The information required, in order is:

Number of WECs			
WEC location format	Note: (1 for nodes, 2 for (x,y) positions)		
Hydrostatic Stiffness (**C**)			
Body Mass (**M**)			

Number of output variables (must be equal to the number of computational frequencies)			
Number of WEC parameters (ALWAYS 4)			
WEC location			
Added mass (**A**) for the first computational frequency	Added damping (**B**) for the first computational frequency	Exciting force (**K**) for the first computational frequency	Power takeoff (**Λ**) for the first computational frequency
Added mass (**A**) for the second computational frequency	Added damping (**B**) for the second computational frequency	Exciting force (**K**) for the second computational frequency	Power takeoff (**Λ**) for the second computational frequency
…	…	…	…
Added mass (**A**) for the last computational frequency	Added damping (**B**) for the last computational frequency	Exciting force (**K**) for the last computational frequency	Power takeoff (**Λ**) for the last computational frequency

Once this input file has been written, it should be placed in the running directory for SpecWec with the other SpecWec input files and then the model can be run. There will be one output file generated specifically by this subroutine, in addition to any standard TOMAWAC output requested by the user. This output file, *wecout.txt* contains the following information printed out at each time step:

Node number	X location of node	Y node location	Energy absorbed at first frequency	....	Energy absorbed at last frequency

The amount of energy absorbed by each WEC is summed over all directions and then reported for each frequency at each time step.

8 Appendix: Verification test cases

8.1 Verification of Core Element 1

8.1.1 Test case #1.1

Core element of SpecWEC tested
Representation of WEC performance
Specific SpecWEC functionality tested
Ability of the simplified linear and the point absorber source term subroutines to calculate energy absorption correctly
Description of test case
The energy absorption by a single WEC represented by the source terms described in Sections 2.2.2 and 2.2.3 is calculated for an incoming wave climate characterized as a JONSWAP spectrum with a significant wave height of 4 meters and a peak period of 8 seconds. The calculation is carried out using both the Fortran subroutines that are part of SpecWEC and equivalent Matlab subroutines which were written for comparison purposes.
Results of test case
The energy absorption by a single WEC in both the Fortran and Matlab subroutines is integrated over all computational directions and reported here as a function of frequency. It can be seen that the Fortran and Matlab subroutines obtain the same results.

Frequency	Linear Fortran power absorption	Linear Matlab power absorption	Point absorber Fortran power absorption	Point absorber Matlab power absorption
0.0400	0	0	0	0

0.0440	0	0	0	0
0.0490	0	0	0	0
0.0540	0	0	0	0
0.0600	0	0	0	0
0.0660	0	0	0	0
0.0730	0.0770	0.0770	0.0040	0.0040
0.0810	1.6910	1.6910	0.0980	0.0980
0.0900	11.6500	11.6500	0.6850	0.6850
0.1000	35.2960	35.2960	1.8810	1.8810
0.1100	62.4800	62.4800	3.5100	3.5100
0.1220	76.8750	76.8750	3.7230	3.7230
0.1340	73.5560	73.5560	3.6490	3.6490
0.1490	59.0020	59.0020	2.4900	2.4900
0.1650	41.8600	41.8600	1.4070	1.4070
0.1820	27.2710	27.2710	0.7180	0.7180
0.2010	16.6650	16.6650	0.3230	0.3230
0.2230	9.6780	9.6780	0.1190	0.1190
0.2460	5.4530	5.4530	0.0440	0.0440
0.2730	2.9720	2.9720	0.0120	0.0120
0.3020	1.5920	1.5920	0.0030	0.0030
0.3340	0.8380	0.8380	0.0010	0.0010
0.3690	0.4390	0.4390	0	0
0.4080	0.2250	0.2250	0	0
0.4520	0.1150	0.1150	0	0
0.5000	0.0590	0.0590	0	0

8.1.2 Test case #1.2

Core element of SpecWEC tested
Representation of WEC performance
Specific SpecWEC functionality tested
Ability of the simplified linear and the point absorber source term subroutines to calculate energy absorption correctly
Description of test case
The energy absorption by a single WEC represented by the source terms described in

Sections 2.2.2 and 2.2.3 is calculated for an incoming wave climate characterized as a JONSWAP spectrum with a significant wave height of 4 meters and a peak period of 9 seconds. The calculation is carried out using both the Fortran subroutines that are part of SpecWEC and equivalent Matlab subroutines which were written for comparison purposes.

Results of test case

The energy absorption by a single WEC in both the Fortran and Matlab subroutines is integrated over all computational directions and reported here as a function of frequency. It can be seen that the Fortran and Matlab subroutines obtain the same results.

Frequency	Linear Fortran power absorption	Linear Matlab power absorption	Point absorber Fortran power absorption	Point absorber Matlab power absorption
0.0400	0	0	0	0
0.0440	0	0	0	0
0.0490	0	0	0	0
0.0540	0	0	0	0
0.0600	0	0	0	0
0.0660	0.1420	0.1420	0.0080	0.0080
0.0730	2.5160	2.5160	0.1410	0.1410
0.0810	14.9730	14.9730	0.8690	0.8690
0.0900	42.4250	42.4250	2.4960	2.4960
0.1000	71.6570	71.6570	3.8190	3.8190
0.1100	85.7270	85.7270	4.8170	4.8170
0.1220	81.1880	81.1880	3.9320	3.9320
0.1340	65.2220	65.2220	3.2360	3.2360
0.1490	46.5590	46.5590	1.9650	1.9650
0.1650	30.5590	30.5590	1.0270	1.0270
0.1820	18.9010	18.9010	0.4980	0.4980
0.2010	11.1570	11.1570	0.2160	0.2160
0.2230	6.3270	6.3270	0.0780	0.0780
0.2460	3.5140	3.5140	0.0280	0.0280
0.2730	1.8940	1.8940	0.0070	0.0070
0.3020	1.0080	1.0080	0.0020	0.0020
0.3340	0.5300	0.5300	0	0
0.3690	0.2760	0.2760	0	0
0.4080	0.1410	0.1410	0	0

0.4520	0.0720	0.0720	0	0
0.5000	0.0370	0.0370	0	0

8.1.3 Test case #1.3

Core element of SpecWEC tested
Representation of WEC performance
Specific SpecWEC functionality tested
Ability of the simplified linear and the point absorber source term subroutines to calculate energy absorption correctly
Description of test case
The energy absorption by a single WEC represented by the source terms described in Sections 2.2.2 and 2.2.3 is calculated for an incoming wave climate characterized as a JONSWAP spectrum with a significant wave height of 4 meters and a peak period of 10 seconds. The calculation is carried out using both the Fortran subroutines that are part of SpecWEC and equivalent Matlab subroutines which were written for comparison purposes.
Results of test case
The energy absorption by a single WEC in both the Fortran and Matlab subroutines is integrated over all computational directions and reported here as a function of frequency. It can be seen that the Fortran and Matlab subroutines obtain the same results.

Frequency	Linear Fortran power absorption	Linear Matlab power absorption	Point absorber Fortran power absorption	Point absorber Matlab power absorption
0.0400	0	0	0	0
0.0440	0	0	0	0
0.0490	0	0	0	0
0.0540	0.0020	0.0020	0	0
0.0600	0.1610	0.1610	0.0080	0.0080
0.0660	2.7930	2.7930	0.1500	0.1500
0.0730	15.9730	15.9730	0.8980	0.8980
0.0810	44.6800	44.6800	2.5940	2.5940

0.0900	76.2370	76.2370	4.4850	4.4850
0.1000	92.2370	92.2370	4.9160	4.9160
0.1100	88.2140	88.2140	4.9570	4.9570
0.1220	71.9360	71.9360	3.4840	3.4840
0.1340	52.3000	52.3000	2.5950	2.5950
0.1490	34.9270	34.9270	1.4740	1.4740
0.1650	21.9230	21.9230	0.7370	0.7370
0.1820	13.1640	13.1640	0.3470	0.3470
0.2010	7.6160	7.6160	0.1480	0.1480
0.2230	4.2630	4.2630	0.0520	0.0520
0.2460	2.3470	2.3470	0.0190	0.0190
0.2730	1.2580	1.2580	0.0050	0.0050
0.3020	0.6670	0.6670	0.0010	0.0010
0.3340	0.3480	0.3480	0	0
0.3690	0.1820	0.1820	0	0
0.4080	0.0920	0.0920	0	0
0.4520	0.0470	0.0470	0	0
0.5000	0.0240	0.0240	0	0

8.1.4 Test case #1.4

Core element of SpecWEC tested
Representation of WEC performance
Specific SpecWEC functionality tested
Ability of the simplified linear and the point absorber source term subroutines to calculate energy absorption correctly
Description of test case
The energy absorption by a single WEC represented by the source terms described in Sections 2.2.2 and 2.2.3 is calculated for an incoming wave climate characterized as a JONSWAP spectrum with a significant wave height of 4 meters and a peak period of 11 seconds. The calculation is carried out using both the Fortran subroutines that are part of SpecWEC and equivalent Matlab subroutines which were written for comparison purposes.
Results of test case

The energy absorption by a single WEC in both the Fortran and Matlab subroutines is integrated over all computational directions and reported here as a function of frequency. It can be seen that the Fortran and Matlab subroutines obtain the same results.

Frequency	Linear Fortran power absorption	Linear Matlab power absorption	Point absorber Fortran power absorption	Point absorber Matlab power absorption
0.0400	0	0	0	0
0.0440	0	0	0	0
0.0490	0	0	0	0
0.0540	0.1320	0.1320	0.0070	0.0070
0.0600	2.4020	2.4020	0.1200	0.1200
0.0660	14.8260	14.8260	0.7940	0.7940
0.0730	43.0440	43.0440	2.4210	2.4210
0.0810	76.2640	76.2640	4.4270	4.4270
0.0900	95.7730	95.7730	5.6340	5.6340
0.1000	94.6880	94.6880	5.0470	5.0470
0.1100	79.0950	79.0950	4.4440	4.4440
0.1220	58.9240	58.9240	2.8540	2.8540
0.1340	40.3260	40.3260	2.0010	2.0010
0.1490	25.8620	25.8620	1.0910	1.0910
0.1650	15.8030	15.8030	0.5310	0.5310
0.1820	9.3180	9.3180	0.2450	0.2450
0.2010	5.3310	5.3310	0.1030	0.1030
0.2230	2.9620	2.9620	0.0360	0.0360
0.2460	1.6190	1.6190	0.0130	0.0130
0.2730	0.8640	0.8640	0.0030	0.0030
0.3020	0.4580	0.4580	0.0010	0.0010
0.3340	0.2390	0.2390	0	0
0.3690	0.1250	0.1250	0	0
0.4080	0.0630	0.0630	0	0
0.4520	0.0320	0.0320	0	0
0.5000	0.0170	0.0170	0	0

8.1.5 Test case #1.5

Core element of SpecWEC tested

Representation of WEC performance
Specific SpecWEC functionality tested
Ability of the simplified linear and the point absorber source term subroutines to calculate energy absorption correctly
Description of test case
The energy absorption by a single WEC represented by the source terms described in Sections 2.2.2 and 2.2.3 is calculated for an incoming wave climate characterized as a JONSWAP spectrum with a significant wave height of 4 meters and a peak period of 12 seconds. The calculation is carried out using both the Fortran subroutines that are part of SpecWEC and equivalent Matlab subroutines which were written for comparison purposes.
Results of test case
The energy absorption by a single WEC in both the Fortran and Matlab subroutines is integrated over all computational directions and reported here as a function of frequency. It can be seen that the Fortran and Matlab subroutines obtain the same results.

Frequency	Linear Fortran power absorption	Linear Matlab power absorption	Point absorber Fortran power absorption	Point absorber Matlab power absorption
0.0400	0	0	0	0
0.0440	0	0	0	0
0.0490	0.0760	0.0760	0.0040	0.0040
0.0540	1.7130	1.7130	0.0940	0.0940
0.0600	11.9230	11.9230	0.5970	0.5970
0.0660	38.3670	38.3670	2.0550	2.0550
0.0730	72.4910	72.4910	4.0770	4.0770
0.0810	96.1810	96.1810	5.5840	5.5840
0.0900	99.4640	99.4640	5.8510	5.8510
0.1000	86.5450	86.5450	4.6130	4.6130
0.1100	66.3540	66.3540	3.7280	3.7280
0.1220	46.6790	46.6790	2.2610	2.2610
0.1340	30.7470	30.7470	1.5250	1.5250
0.1490	19.2190	19.2190	0.8110	0.8110
0.1650	11.5500	11.5500	0.3880	0.3880
0.1820	6.7330	6.7330	0.1770	0.1770

0.2010	3.8210	3.8210	0.0740	0.0740
0.2230	2.1140	2.1140	0.0260	0.0260
0.2460	1.1520	1.1520	0.0090	0.0090
0.2730	0.6150	0.6150	0.0020	0.0020
0.3020	0.3250	0.3250	0.0010	0.0010
0.3340	0.1690	0.1690	0	0
0.3690	0.0870	0.0870	0	0
0.4080	0.0450	0.0450	0	0
0.4520	0.0230	0.0230	0	0
0.5000	0.0110	0.0110	0	0

8.2 Verification of Core Element 2

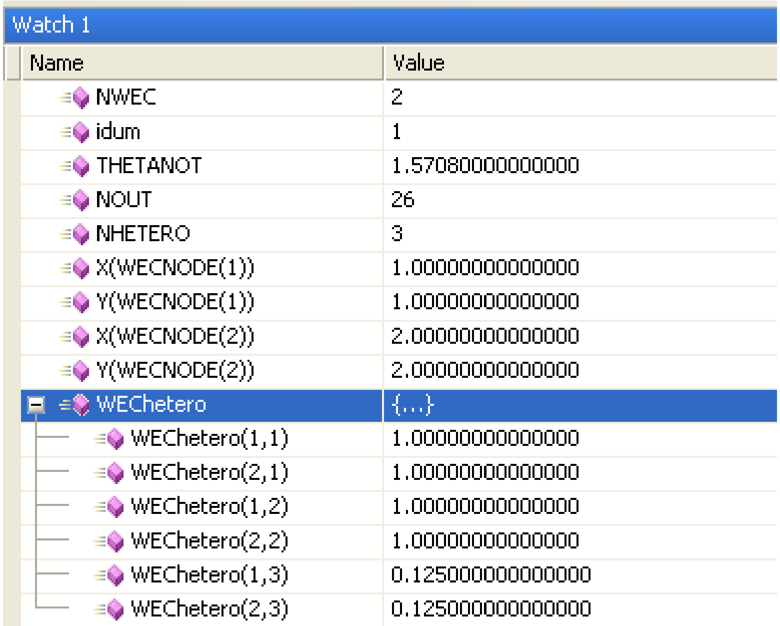
8.2.1 Test case #2.1

Core element of SpecWEC tested
Input of WEC parameters
Specific SpecWEC functionality tested
Ability of SpecWEC to read in parameters for simplified linear source term subroutine correctly
Description of test case
The SpecWEC tool is run with a sample input file and the tool is paused during runtime. The input parameter file is then compared with the variables that have been read in to the SpecWEC tool.
Results of test case
The input parameter file is as follows:

```
!----------------------------------------------------------------
! Number of WECs
       2
!----------------------------------------------------------------
! Location format indicator (1 for nodes, 2 for x,y coordinates)
       1
!----------------------------------------------------------------
! Primary direction of incoming wave field
       1.5708
!----------------------------------------------------------------
! Number of output variables
       26
!----------------------------------------------------------------
```

```
! Number of heterogeneous WEC parameters
        3
!--------------------------------------------------------------
! Node number/ x-y coordinates // mu // lambda // natural frequency
       1                       1.0     1.0         0.125
       2                       1.0     1.0         0.125
```

The following screen shot shows the parameters after they have been read in correctly by the SpecWEC tool:



Watch 1

Name	Value
NWEC	2
idum	1
THETANOT	1.57080000000000
NOUT	26
NHETERO	3
X(WECNODE(1))	1.00000000000000
Y(WECNODE(1))	1.00000000000000
X(WECNODE(2))	2.00000000000000
Y(WECNODE(2))	2.00000000000000
WEChetero	{...}
WEChetero(1,1)	1.00000000000000
WEChetero(2,1)	1.00000000000000
WEChetero(1,2)	1.00000000000000
WEChetero(2,2)	1.00000000000000
WEChetero(1,3)	0.125000000000000
WEChetero(2,3)	0.125000000000000

Here NWEC represents the number of WECs, idum is the location format indicator, THETANOT is the primary direction of the incoming wave field, NOUT is the number of output variables, NHETERO is the number of heterogeneous WEC parameters, X,Y are the x and y positions of the WECs, and WEChetero contains the three WEC parameters listed in the input file as mu, lambda, and the natural frequency.

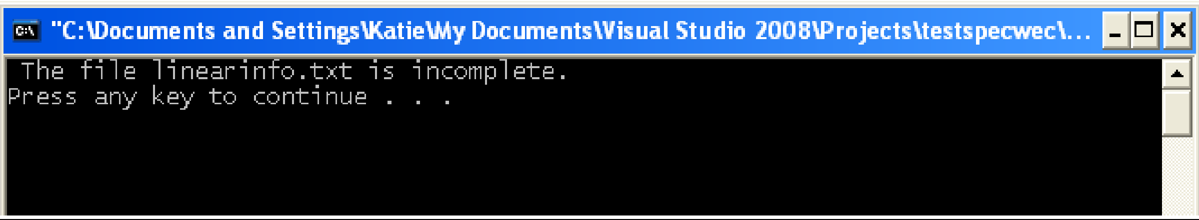
8.2.2 Test case #2.2

Core element of SpecWEC tested
Input of WEC parameters
Specific SpecWEC functionality tested
Ability of SpecWEC to notify user when input file for the simplified linear source term subroutine is incomplete.
Description of test case
The SpecWEC tool is run with a sample incomplete input file. The resulting error which is printed to the screen is recorded below.
Results of test case

The incomplete input parameter file is as follows:

```
!----------------------------------------------------------------
! Number of WECs
        2
!----------------------------------------------------------------
! Location format indicator (1 for nodes, 2 for x,y coordinates)
        1
!----------------------------------------------------------------
! Primary direction of incoming wave field
        1.5708
!----------------------------------------------------------------
! Number of output variables
        26
!----------------------------------------------------------------
! Number of heterogeneous WEC parameters
        3
!----------------------------------------------------------------
! Node number/ x-y coordinates // mu // lambda // natural frequency
       1                        1.0      1.0         0.125
       2                        1.0      1.0
```

The screen shot of the warning given to the user when SpecWEC is run with the incomplete parameter file:



8.2.3 Test case #2.3

Core element of SpecWEC tested
Input of WEC parameters
Specific SpecWEC functionality tested
Ability of SpecWEC to read in parameters for point absorber source term subroutine correctly
Description of test case
The SpecWEC tool is run with a sample input file and the tool is paused during runtime. The input parameter file is then compared with the variables that have been read in to the SpecWEC tool.
Results of test case

The input parameter file is as follows:

```
!-----------------------------------------------------------------
! Number of WECs
      1
!-----------------------------------------------------------------
! Location format indicator (1 for nodes, 2 for x,y coordinates)
       1
!-----------------------------------------------------------------
! Hydrostatic Stiffness
       481
!-----------------------------------------------------------------
! Body Mass
       5
!-----------------------------------------------------------------
! Number of output variables
       26
!-----------------------------------------------------------------
! Number of heterogeneous input WEC parameters (device-specific)
       4
!-----------------------------------------------------------------
! Node number/ x-y coordinates
      1
!--------------------------------------------------------------------
! WEC heterogeneous parameters
    3.1385    1.6017  465.9798    0.1000
    3.0979    1.7369  456.5170    0.1000
    3.0531    1.8865  446.0482    0.1000
    3.0034    2.0519  434.4667    0.1000
    2.9485    2.2349  421.6540    0.1000
    2.8878    2.4374  407.4793    0.1000
    2.8185    2.6645  391.7021    0.1000
    2.7352    2.9144  373.2981    0.1000
    2.6472    3.1659  351.4135    0.1000
    2.5615    3.4154  326.4599    0.1000
    2.4604    3.6342  296.6260    0.1000
    2.3583    3.7897  263.5812    0.1000
    2.2580    3.8150  227.1886    0.1000
    2.1704    3.6433  189.9308    0.1000
    2.1048    3.2463  152.7255    0.1000
    2.0724    2.6596  118.0682    0.1000
    2.0843    1.9636   86.0797    0.1000
    2.1220    1.2932   60.4699    0.1000
    2.1754    0.7919   40.8792    0.1000
    2.2326    0.3897   24.4836    0.1000
    2.2818    0.1930   14.6491    0.1000
    2.3197    0.0645    7.4501    0.1000
    2.3420    0.0288    3.8838    0.1000
    2.3632         0    0.9204    0.1000
    2.3763         0    0.5930    0.1000
    2.3908         0    0.2308    0.1000
```

The following screen shot shows the parameters after they have been read in correctly by the SpecWEC tool:

Watch 1

Name	Value
NWEC	1
idum	1
HYDRO	481.000000000000
MASS	5
NOUT	26
NHETERO	4
WECNODE	{...}
WECNODE(1)	1
WEChetero	{...}
WEChetero(1,1)	3.13850000000000
WEChetero(2,1)	3.09790000000000
WEChetero(3,1)	3.05310000000000
WEChetero(4,1)	3.00340000000000
WEChetero(5,1)	2.94850000000000
WEChetero(6,1)	2.88780000000000
WEChetero(7,1)	2.81850000000000
WEChetero(8,1)	2.73520000000000
WEChetero(9,1)	2.64720000000000
WEChetero(10,1)	2.56150000000000
WEChetero(11,1)	2.46040000000000
WEChetero(12,1)	2.35830000000000
WEChetero(13,1)	2.25800000000000
WEChetero(14,1)	2.17040000000000
WEChetero(15,1)	2.10480000000000
WEChetero(16,1)	2.07240000000000
WEChetero(17,1)	2.08430000000000
WEChetero(18,1)	2.12200000000000
WEChetero(19,1)	2.17540000000000
WEChetero(20,1)	2.23260000000000
WEChetero(21,1)	2.28180000000000
WEChetero(22,1)	2.31970000000000
WEChetero(23,1)	2.34200000000000
WEChetero(24,1)	2.36320000000000
WEChetero(25,1)	2.37630000000000
WEChetero(26,1)	2.39080000000000

Watch 1

Name	Value
WEChetero(1,2)	1.60170000000000
WEChetero(2,2)	1.73690000000000
WEChetero(3,2)	1.88650000000000
WEChetero(4,2)	2.05190000000000
WEChetero(5,2)	2.23490000000000
WEChetero(6,2)	2.43740000000000
WEChetero(7,2)	2.66450000000000
WEChetero(8,2)	2.91440000000000
WEChetero(9,2)	3.16590000000000
WEChetero(10,2)	3.41540000000000
WEChetero(11,2)	3.63420000000000
WEChetero(12,2)	3.78970000000000
WEChetero(13,2)	3.81500000000000
WEChetero(14,2)	3.64330000000000
WEChetero(15,2)	3.24630000000000
WEChetero(16,2)	2.65960000000000
WEChetero(17,2)	1.96360000000000
WEChetero(18,2)	1.29320000000000
WEChetero(19,2)	0.791900000000000
WEChetero(20,2)	0.389700000000000
WEChetero(21,2)	0.193000000000000
WEChetero(22,2)	6.450000000000000D-002
WEChetero(23,2)	2.880000000000000D-002
WEChetero(24,2)	0.000000000000000D+000
WEChetero(25,2)	0.000000000000000D+000
WEChetero(26,2)	0.000000000000000D+000
WEChetero(1,3)	465.979800000000
WEChetero(2,3)	456.517000000000
WEChetero(3,3)	446.048200000000
WEChetero(4,3)	434.466700000000
WEChetero(5,3)	421.654000000000
WEChetero(6,3)	407.479300000000
WEChetero(7,3)	391.702100000000
WEChetero(8,3)	373.298100000000
WEChetero(9,3)	351.413500000000

Watch 1

Name	Value
WEChetero(10,3)	326.459900000000
WEChetero(11,3)	296.626000000000
WEChetero(12,3)	263.581200000000
WEChetero(13,3)	227.188600000000
WEChetero(14,3)	189.930800000000
WEChetero(15,3)	152.725500000000
WEChetero(16,3)	118.068200000000
WEChetero(17,3)	86.0797000000000
WEChetero(18,3)	60.4699000000000
WEChetero(19,3)	40.8792000000000
WEChetero(20,3)	24.4836000000000
WEChetero(21,3)	14.6491000000000
WEChetero(22,3)	7.45010000000000
WEChetero(23,3)	3.88380000000000
WEChetero(24,3)	0.920400000000000
WEChetero(25,3)	0.593000000000000
WEChetero(26,3)	0.230800000000000
WEChetero(1,4)	0.100000000000000
WEChetero(2,4)	0.100000000000000
WEChetero(3,4)	0.100000000000000
WEChetero(4,4)	0.100000000000000
WEChetero(5,4)	0.100000000000000
WEChetero(6,4)	0.100000000000000
WEChetero(7,4)	0.100000000000000
WEChetero(8,4)	0.100000000000000
WEChetero(9,4)	0.100000000000000
WEChetero(10,4)	0.100000000000000
WEChetero(11,4)	0.100000000000000
WEChetero(12,4)	0.100000000000000
WEChetero(13,4)	0.100000000000000
WEChetero(14,4)	0.100000000000000
WEChetero(15,4)	0.100000000000000
WEChetero(16,4)	0.100000000000000
WEChetero(17,4)	0.100000000000000
WEChetero(18,4)	0.100000000000000
WEChetero(19,4)	0.100000000000000
WEChetero(20,4)	0.100000000000000
WEChetero(21,4)	0.100000000000000
WEChetero(22,4)	0.100000000000000
WEChetero(23,4)	0.100000000000000
WEChetero(24,4)	0.100000000000000
WEChetero(25,4)	0.100000000000000
WEChetero(26,4)	0.100000000000000

Here NWEC represents the number of WECs, idum is the location format indicator, HYDRO is the hydrostatic stiffness, MASS is the mass of the device, NOUT is the number of output variables, NHETERO is the number of heterogeneous WEC parameters, WECNODE is the WEC node number, and WEChetero contains the frequency dependent parameters listed in the input file.

8.2.4 Test case #2.4

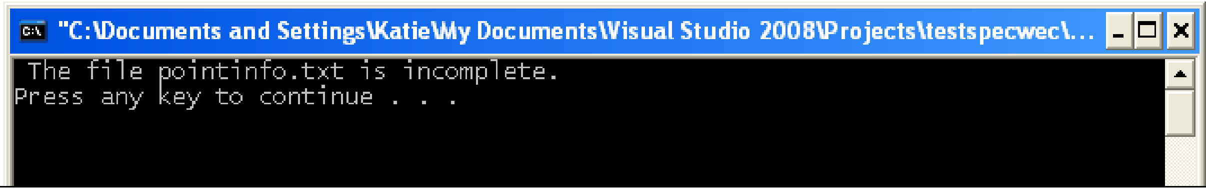
Core element of SpecWEC tested
Input of WEC parameters
Specific SpecWEC functionality tested
Ability of SpecWEC to notify user when input file for the point absorber source term subroutine is incomplete.
Description of test case
The SpecWEC tool is run with a sample incomplete input file. The resulting error which is printed to the screen is recorded below.
Results of test case

The incomplete input parameter file is as follows:

```
!---------------------------------------------------------------
! Number of WECs
       1
!---------------------------------------------------------------
! Location format indicator (1 for nodes, 2 for x,y coordinates)
        1
!---------------------------------------------------------------
! Hydrostatic Stiffness
        481
!---------------------------------------------------------------
! Body Mass
        5
!---------------------------------------------------------------
! Number of output variables
        26
!---------------------------------------------------------------
! Number of heterogeneous input WEC parameters (device-specific)
        4
!---------------------------------------------------------------
! Node number/ x-y coordinates
       1
!------------------------------------------------------------------
! WEC heterogeneous parameters
    3.1385    1.6017  465.9798    0.1000
    3.0979    1.7369  456.5170    0.1000
    3.0531    1.8865  446.0482    0.1000
    3.0034    2.0519  434.4667    0.1000
    2.9485    2.2349  421.6540    0.1000
    2.8878    2.4374  407.4793    0.1000
    2.8185    2.6645  391.7021    0.1000
    2.7352    2.9144  373.2981    0.1000
    2.6472    3.1659  351.4135    0.1000
    2.5615    3.4154  326.4599    0.1000
    2.4604    3.6342  296.6260    0.1000
    2.3583    3.7897  263.5812    0.1000
    2.2580    3.8150  227.1886    0.1000
```

```
     2.1704      3.6433    189.9308      0.1000
     2.1048      3.2463    152.7255      0.1000
     2.0724      2.6596    118.0682      0.1000
     2.0843      1.9636     86.0797      0.1000
     2.1220      1.2932     60.4699      0.1000
     2.1754      0.7919     40.8792      0.1000
     2.2326      0.3897     24.4836      0.1000
     2.2818      0.1930     14.6491      0.1000
     2.3197      0.0645      7.4501      0.1000
     2.3420      0.0288      3.8838      0.1000
     2.3632           0      0.9204      0.1000
     2.3763           0      0.5930      0.1000
     2.3908           0      0.2308
```

The screen shot of the warning given to the user when SpecWEC is run with the incomplete parameter file:



8.3 Verification of Core Element 3

8.3.1 Test case #3.1

Core element of SpecWEC tested

Location of WEC parameters

Specific SpecWEC functionality tested

The ability of the SpecWEC tool to read in the WEC location as node numbers.

Description of test case

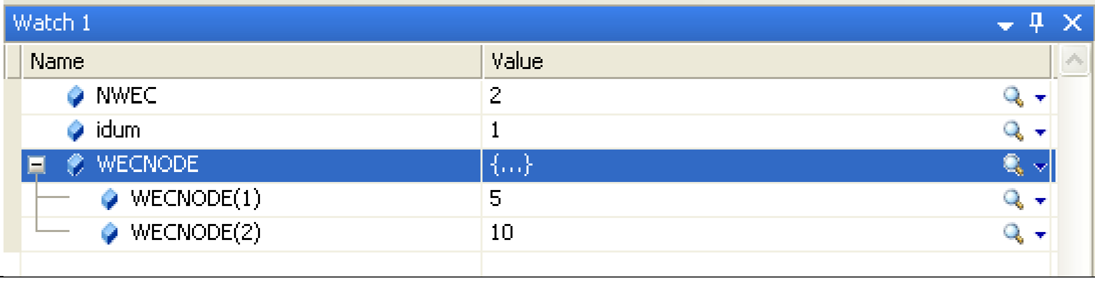
The SpecWEC tool is run with the input parameter file specifying the WEC location in node number.

Results of test case

The input parameter file specification of node location is as follows:

```
!---------------------------------------------------------------
! Number of WECs
        2
!---------------------------------------------------------------
! Location format indicator (1 for nodes, 2 for x,y coordinates)
        1
!---------------------------------------------------------------
! Node number/ x-y coordinates
       5
       10
```

The following screen shot shows the WEC node numbers after they have been read into the SpecWEC tool correctly.



8.3.2 Test case #3.2

Core element of SpecWEC tested

Location of WEC parameters

Specific SpecWEC functionality tested

The ability of the SpecWEC tool to read in the WEC location as (x,y) positions.

Description of test case

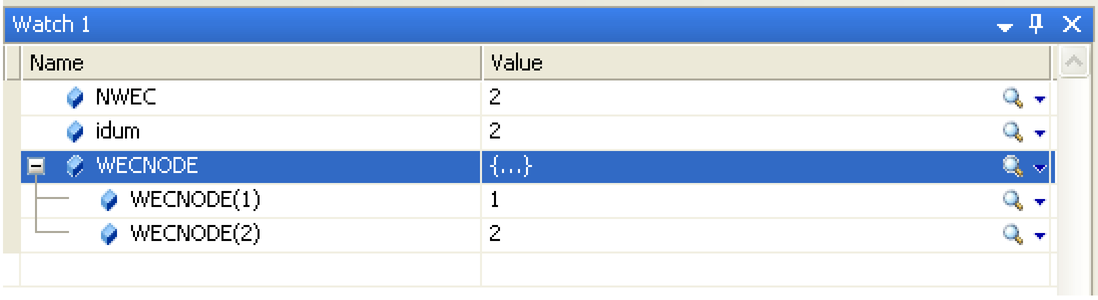
The SpecWEC tool is run with the input parameter file specifying the WEC location in (x,y) position. The simple grid for the test case consists of only 2 nodes: 1 located at (x,y) position (1,1) and 2 located at (x,y) position (2,2).

Results of test case

The input parameter file specification of node location is as follows:

```
!---------------------------------------------------------------
! Number of WECs
      2
!---------------------------------------------------------------
! Location format indicator (1 for nodes, 2 for x,y coordinates)
      2
!---------------------------------------------------------------
! Node number/ x-y coordinates
     1  1
     2  2
```

The following screen shot shows the WEC node numbers after they have been read into the SpecWEC tool correctly.



8.3.3 Test case #3.3

Core element of SpecWEC tested

Location of WEC parameters

Specific SpecWEC functionality tested

The ability of the SpecWEC tool to inform the user when two WECs have been placed on the same computational node when reading in the WEC location as (x,y) positions.

Description of test case

The SpecWEC tool is run with the input parameter file specifying the WEC location in (x,y) position. The simple grid for the test case consists of only 2 nodes: 1 located at (x,y) position (1,1) and 2 located at (x,y) position (2,2).

Results of test case

The input parameter file specification of node location is as follows:

```
!---------------------------------------------------------------
! Number of WECs
        2
!---------------------------------------------------------------
! Location format indicator (1 for nodes, 2 for x,y coordinates)
        2
!---------------------------------------------------------------
! Node number/ x-y coordinates
       1  1
       1.1  1.1
```

The following screen shot shows the warning which is provided to users after the two WECs have been placed on the same computational node.

8.4 Verification of Core Element 4

8.4.1 Test case #4.1

Core element of SpecWEC tested

Output of WEC parameters

Specific SpecWEC functionality tested

The ability of the SpecWEC tool to output the (x,y) position and power absorption for a single WEC as calculated by the simplified linear source term subroutine.

Description of test case

The SpecWEC tool is run for a single WEC with the simplified linear source term subroutine activated. A screen shot of the power absorption and location values for the WEC is compared with the output file produced by SpecWEC.

Results of test case

The following screen shot shows the values of the power absorption and location of the WEC during the SpecWEC computation:

Watch 1

Name	Value
X(WECNODE(1))	1.00000000000000
Y(WECNODE(1))	1.00000000000000
WECout	{...}
WECout(1,1)	0.000000000000000D+000
WECout(1,2)	0.000000000000000D+000
WECout(1,3)	7.642282577438722D-002
WECout(1,4)	1.71291823374384
WECout(1,5)	11.9229340902302
WECout(1,6)	38.3673423841448
WECout(1,7)	72.4907839991843
WECout(1,8)	96.1810461523502
WECout(1,9)	99.4639840176297
WECout(1,10)	86.5447200583659
WECout(1,11)	66.3544488751858
WECout(1,12)	46.6790166855465
WECout(1,13)	30.7470718701211
WECout(1,14)	19.2192228040487
WECout(1,15)	11.5503664584974
WECout(1,16)	6.73290279853252
WECout(1,17)	3.82069997537351
WECout(1,18)	2.11352311438649
WECout(1,19)	1.15150374978617
WECout(1,20)	0.615445914026465
WECout(1,21)	0.324631218270687
WECout(1,22)	0.169347600974392
WECout(1,23)	8.679042439978399D-002
WECout(1,24)	4.498919581682364D-002
WECout(1,25)	2.313440128387801D-002
WECout(1,26)	1.146831528787163D-002

The following table contains the output file which is obtained from the SpecWEC run:

Node number
1
X position
1.000
Y position

	1.000	
	Power absorption	
	0.000	
	0.000	
	0.076	
	1.713	
	11.923	
	38.367	
	72.491	
	96.181	
	99.464	
	86.545	
	66.354	
	46.679	
	30.747	
	19.219	
	11.550	
	6.733	
	3.821	
	2.114	
	1.152	
	0.615	
	0.325	
	0.169	
	0.087	
	0.045	
	0.023	
	0.011	

8.4.2 Test case #4.2

Core element of SpecWEC tested
Output of WEC parameters
Specific SpecWEC functionality tested
The ability of the SpecWEC tool to output the (x,y) position and power absorption for a single WEC as calculated by the point absorber source term subroutine.
Description of test case
The SpecWEC tool is run for a single WEC with the point absorber source term subroutine activated. A screen shot of the power absorption and location values for the WEC is compared with the output file produced by SpecWEC.

Results of test case

The following screen shot shows the values of the power absorption and location of the WEC during the SpecWEC computation:

Watch 1

Name	Value
X(WECNODE(1))	1.00000000000000
Y(WECNODE(1))	1.00000000000000
WECout	{...}
WECout(1,1)	0.000000000000000D+000
WECout(1,2)	0.000000000000000D+000
WECout(1,3)	3.830104609591637D-003
WECout(1,4)	9.407816957786398D-002
WECout(1,5)	0.596865119240717
WECout(1,6)	2.05499525985438
WECout(1,7)	4.07687551779815
WECout(1,8)	5.58352179755527
WECout(1,9)	5.85096072177755
WECout(1,10)	4.61265285249597
WECout(1,11)	3.72818541442203
WECout(1,12)	2.26091690082311
WECout(1,13)	1.52538143237668
WECout(1,14)	0.810956992044251
WECout(1,15)	0.388087640383561
WECout(1,16)	0.177365161180903
WECout(1,17)	7.408402501059767D-002
WECout(1,18)	2.594351056127793D-002
WECout(1,19)	9.328203970967452D-003
WECout(1,20)	2.430539868769778D-003
WECout(1,21)	6.418491090529420D-004
WECout(1,22)	1.214435383104410D-004
WECout(1,23)	2.431152921416663D-005
WECout(1,24)	1.038418538468258D-006
WECout(1,25)	3.207723649474074D-007
WECout(1,26)	3.137735037716268D-008

The following table contains the output file which is obtained from the SpecWEC run:

Node number
1
X position
1.000
Y position
1.000
Power absorption
0.000
0.000
0.004

	0.094	
	0.597	
	2.055	
	4.077	
	5.584	
	5.851	
	4.613	
	3.728	
	2.261	
	1.525	
	0.811	
	0.388	
	0.177	
	0.074	
	0.026	
	0.009	
	0.002	
	0.001	
	0.000	
	0.000	
	0.000	
	0.000	
	0.000	

8.4.3 Test case #4.3

Core element of SpecWEC tested
Output of WEC parameters
Specific SpecWEC functionality tested
The ability for the output files created by SpecWEC to be read into the post-processing tool Matlab.
Description of test case

The output file from a SpecWEC run is read into Matlab and a screen shot of the data in Matlab is compared to the input file.

Results of test case

The following table contains the output file which is obtained from the SpecWEC run:

Node number
1
X position
1.000
Y position
1.000
Power absorption
0.000
0.000
0.004
0.094
0.597
2.055
4.077
5.584
5.851
4.613
3.728
2.261
1.525
0.811
0.388
0.177
0.074
0.026
0.009
0.002

0.001
0.000
0.000
0.000
0.000
0.000

The following screen shot shows the output file being read in and displayed in Matlab, where it can be seen to be the same as the above output file.

Command Window

```
>> load('pointout.txt')
>> pointout

pointout =

  Columns 1 through 8

    1.0000    1.0000    1.0000         0         0    0.0040    0.0940    0.5970

  Columns 9 through 16

    2.0550    4.0770    5.5840    5.8510    4.6130    3.7280    2.2610    1.5250

  Columns 17 through 24

    0.8110    0.3880    0.1770    0.0740    0.0260    0.0090    0.0020    0.0010

  Columns 25 through 29

         0         0         0         0         0
```