Three-dimensional Analysis Software of Wave Loads and Hydroelasticity

(三维波浪载荷及水弹性响应分析软件)

User’s Manuals

OpenWALAS

（Open *Wa*ve *L*oad *A*nalysis *S*oftware）

Open
WALAS

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Context

1. Software instruction

1.1. Basic information

1.1.1. Introduction

OpenWALAS (***Open Wa**ve **L**oad **A**nalysis **S**oftware*) is a suit of fluid-structural interaction software aiming to numerically calculate the motions, wave loads and hydroelastic responses of marine structures in waves, which is based on three-dimensional potential theory and mode superposition principle of elastic structures. And the velocity and pressure are respectively solved by 3D boundary element method in frequency domain and time domain, considering forward speed, multi-body and nonlinear factors (nonlinear hydrostatic restoring force, nonlinear incident wave exciting force and slamming pressure), as well as the function of eliminating irregular frequencies of floating structures in frequency domain.

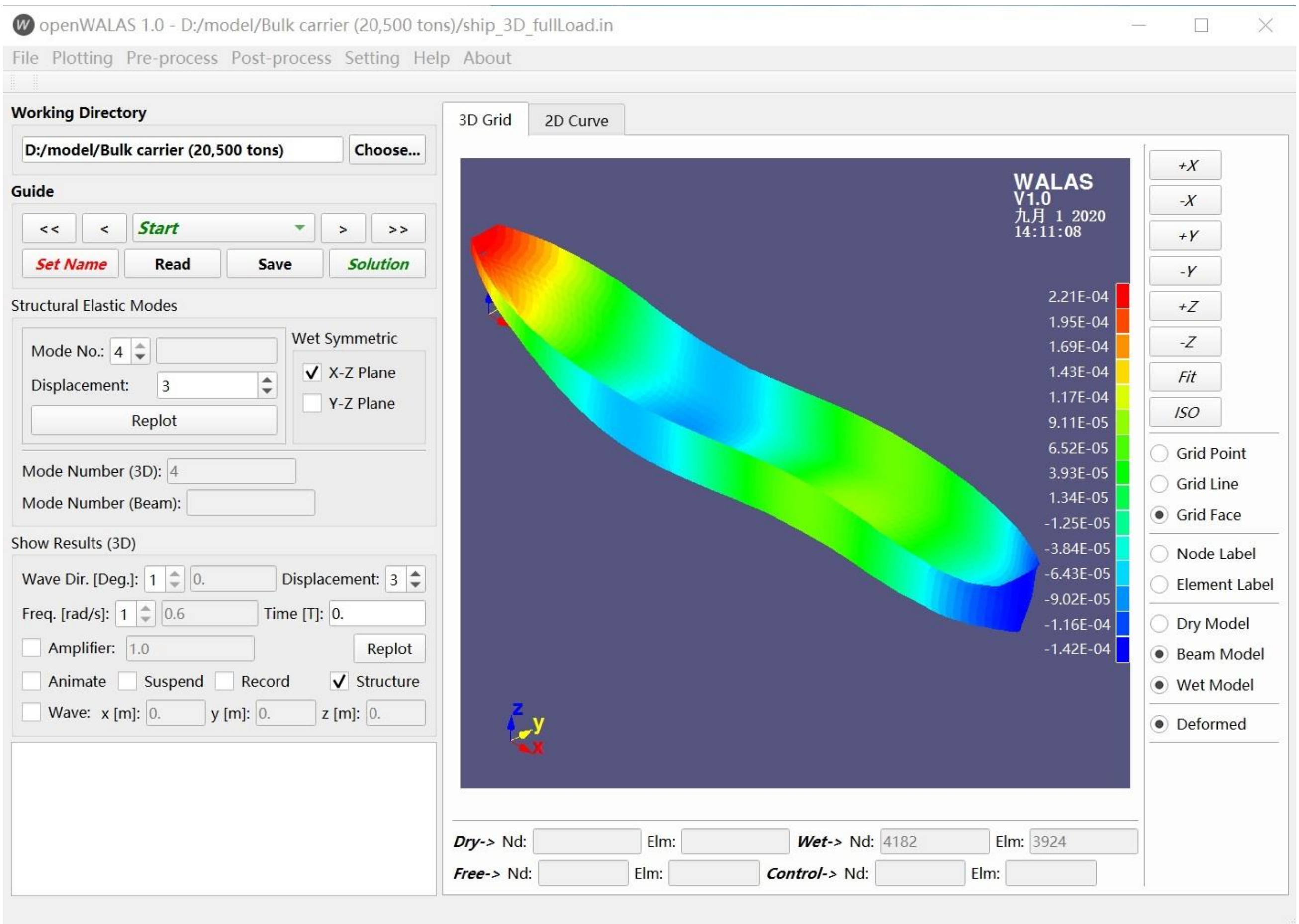

Fig. 1 OpenWALAS GUI

The project of OpenWALAS, maintained by Dr. Peng Yang on GitHub and was built originally for Yang's own research, intends to supply a suit of free (or opensource) software to scientists and engineers all over the world.

OpenWALAS program suit contains the functions of automatic meshing of ship hulls, cut-off hull mesh, straight beam modal analysis, characteristic calculation of transverse section, as well as 3D model display and 2D curve drawing. The software suit contains the GUI program OpenWALAS and five non-GUI core programs: OpenWALAS_PRE, OpenWALAS_FSCM, OpenWALAS_TDGF, OpenWALAS _IORM and OpenWALAS _TIME_RESP.

- OpenWALAS_PRE program for pre-processing, is mainly used to calculate the mode of wetted floating structures from dry modal informtions, in which the structural FEM model is 3D FEM model or beam model.

- 3D calculation and analysis function in time domain: OpenWALAS_TDGF (time domain green's function method, called 'TDGF') and OpenWALAS_IORM（Inner and outer regions matching of Rankine source, called 'IORM' are the core program. The hydrodynamic coefficients are mainly calculated, including impulse response function of radiation potential, impulse response function of diffraction potential, impulse response function of incident potential, impulse response function of wave loads, etc.

- 3D calculation and analysis function in frequency domain: OpenWALAS_FSCM（forward speed correction method in frequency domain, called 'FSCM') is based on the forward speed correction assumption (i.e., low speed and high frequency) in three-dimensional frequency domain, to assess the influence of forward speed. The hydrodynamic coefficients, such as incident wave exciting force, diffraction wave exciting force, added mass and added damping, as well as motions and wave loads, hydroelastic modal responses, wetted surface pressure, and wave height distribution of surrounding flow field are mainly calculated. It also has the function of eliminating irregular frequency by adding a rigid cover on the inner free surface using the extended integral equation.

- OpenWALAS_TIME_RESP is a calculating program of elastic modal responses and wave loads in time domain , which includes the functions of nonlinear incident force, hydrostatic restoring force, slamming force, as well as indirect time-domain method.

1.1.2. Functions

OpenWALAS program includes the functions: automatic division of hull meshes, hull mesh splitting, modal analysis of straight beam, calculation of cross section characteristics, 3D model display and 2D curve drawing.

1.1.3. Running sequence

(a) Method I: run OpenWALAS GUI to complete input parameter setting, calculation and post-processing drawing, and complete all operations in the interface.

(b) Method II: run OpenWALAS non-GUI to complete input parameter setting, calculation.

(i) Three-dimensional frequency-domain calculating module: OpenWALAS_PRE -> OpenWALAS_FSCM.

(ii) Three-dimensional indirect time-domain calculating module: OpenWALAS_PRE-> OpenWALAS_FSCM -> OpenWALAS_TIME_RESP.

(iii) Three-dimensional direct time-domain calculating module: OpenWALAS_PRE -> OpenWALAS_TDGF or OpenWALAS_IORM -> OpenWALAS_TIME_RESP.

1.1.4. Ways of input parameters

There are two ways to input parameters in this program.

(a) First way (GUI), as shown in Chapter 3.

(b) Second way (non-GUI), as shown in Chapter 4.

1.2. Compiling and development environments

Programing language: C/C++.

Compiling environments: Qt + Eclipse + MinGW(GCC) + gsl. Qt (C++) is the development library of the GUI of OpenWALAS. Eclipse is integrated development environment. MinGW (GCC) is the compiler of C language. Gsl is the numerical libraries in C language.

Development environment versions: 1. Qt-5.14.0; 2. MinGW (GCC) - 7.3.0; 3. gsl-2.6; 4. Qwt-6.1.4; 5. Opencv-4.2.0.

1.3. Installation and running environments

The software is suitable for Windows XP, Win 7, Win 8, Win 10 and other mainstream window operating systems with 32-bit or 64-bit versions. Moreover, the software suite is suitable for Linux, UNIX and Mac OS operating systems with 32-bit and 640bit versions.

MSC.Patran/Nastran 2005 or higher version (only required for structural elastic modal analysis).

2. Theoretical fundamental

2.1. Coordinate systems

The dry structure coordinates and wet coordinates are: the positive direction of x axis points to the bow, y axis points to the port side, z axis points up, which obey right-hand rule.

The dry structure coordinate system can be different from the wet coordinate system, defined in files of floating structures (ship.in).

In the internal calculation and output results of the program, all the coordinate origins are converted to the wet coordinate origin at the projection of the still water surface (i.e. the reference coordinate system is used in the internal calculation).

The ships are straightly travelling with constant forward speed U_0. For convenience of presentation, three coordinate systems are established shown in Fig. 2, which are

(1) The space fixed coordinate system $O_0x_0y_0z_0$: the coordinate origin is located at the still water surface, the axis O_0x_0 points to the bow, the axis O_0y_0 points to the port side, and the axis O_0z_0 is upward perpendicular to the still water surface.

(2) The equilibrium coordinate system (also called reference coordinate system) $Oxyz$: the coordinate system moves forward accompanying ship along x axis at constant speed U_0, which coincides with the space fixed coordinate system $O_0x_0y_0z_0$ at the initial moment. And, the axis Ox keeps toward the axis O_0x_0 during ship motion.

(3) The local coordinate system $O'x'y'z'$: this coordinate system is fixed on the hull. When the hull is in the equilibrium position, this coordinate system overlaps with the equilibrium coordinate system. The origin position changes with the translational motion of the hull and the direction changes with the rotation of the hull.

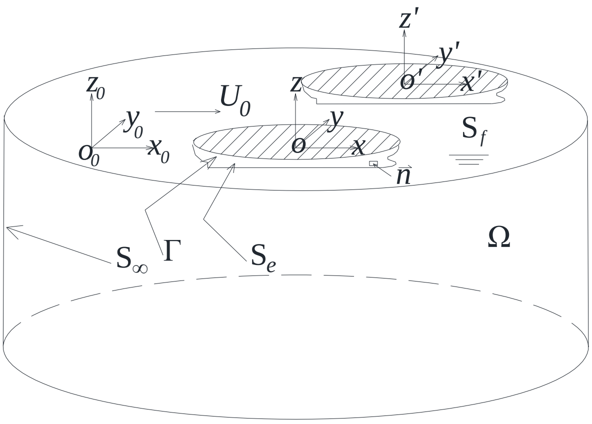

Fig. 2 Sketch of the coordinate systems

The fluid boundary is combined by wetted body surface S_e, free surface S_f, intersection of body surface and free surface Γ, infinite boundary S_∞. Ω denotes the fluid field. $\vec{n}$ denotes the normal direction of body surface towards the inner of ship hull. U_0 denotes forward speed of ship hull.

Both of the space fixed coordinate system and the equilibrium coordinate system obey right-hand rule. There are the following coordinate transformation relations.

$$\begin{cases} x_0 = x + U_0 t, y_0 = y, z_0 = z, \nabla_{x_0} = \nabla_x \\ \left.\dfrac{\partial}{\partial t}\right|_{x_0} \to \left.\dfrac{\partial}{\partial t}\right|_x - U_0 \left.\dfrac{\partial}{\partial x}\right|_x \end{cases} \tag{1}$$

2.2 Wave direction and expression

The definition of wave direction β shown in Fig. 3, 0 degree and 180 degree denote following sea and heading sea, respectively.

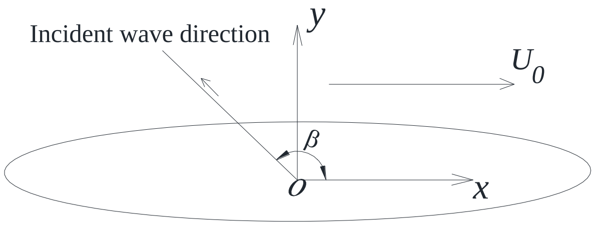

Fig. 3 Sketch of wave direction

The first-order formula of the instantaneous height of the incident wave is

$$\zeta = Ae^{\mathrm{i}k(x\cos\beta + y\sin\beta) - \mathrm{i}\omega t} \tag{2}$$

where the variables A, k and ω denote the wave amplitude, wave number and natural wave frequency, respectively. In addition, $\nu = \omega^2 / \mathrm{g}$ and $k \tanh kh = \nu$.

The first order formula of incident velocity potential Φ_I in the equilibrium coordinate system is

$$\Phi_\mathrm{I} = \mathrm{Re}\left[\phi_\mathrm{I} \mathrm{e}^{-\mathrm{i}\omega t}\right] = \mathrm{Re}\left[\frac{Ag}{\mathrm{i}\omega}\frac{\cosh k(z+h)}{\cosh kh}\mathrm{e}^{\mathrm{i}k(x\cos\beta + y\sin\beta) - \mathrm{i}\omega t}\right] \tag{3}$$

where ϕ_I, h and g denote the amplitude of the incoming potential of fluid, the water depth and the gravitational acceleration constant, respectively.

3. Introduction of OpenWALAS GUI

3.1. Main GUI

3.1.1. Set working directory

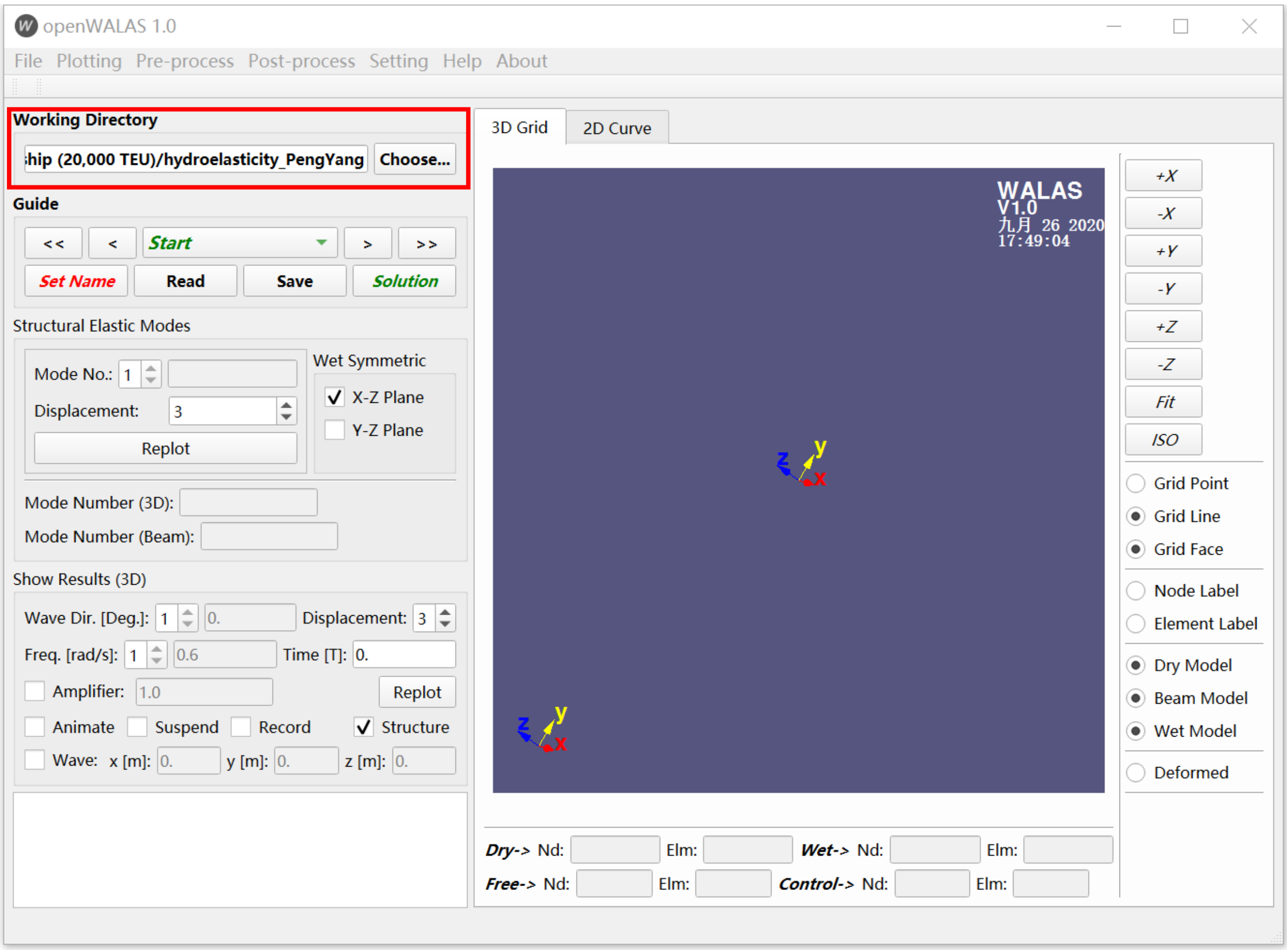

Fig. 4 Working directory

3.1.2. Set a file name of floating structures

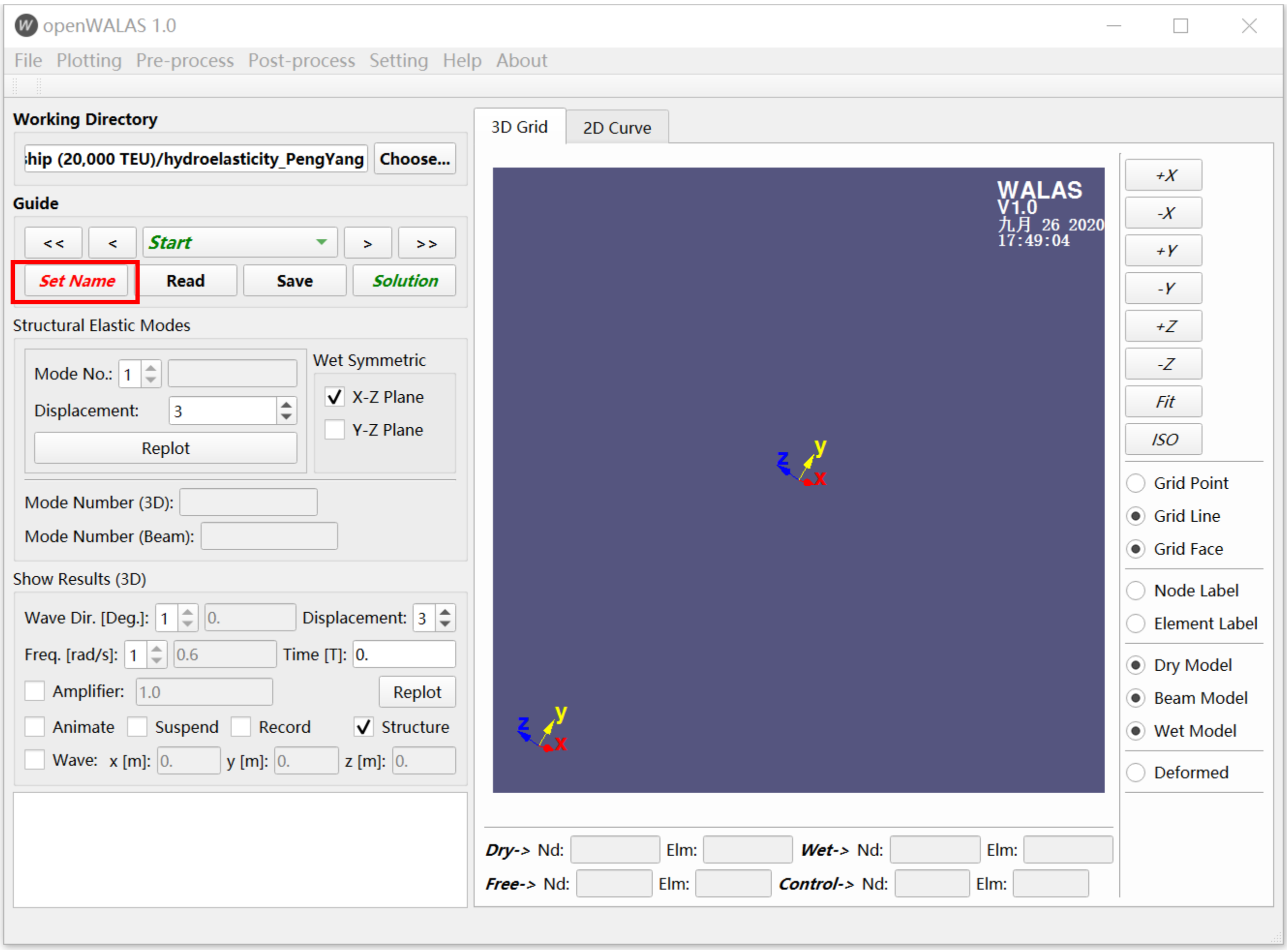

Fig. 5 File name

3.1.3. Show dry model

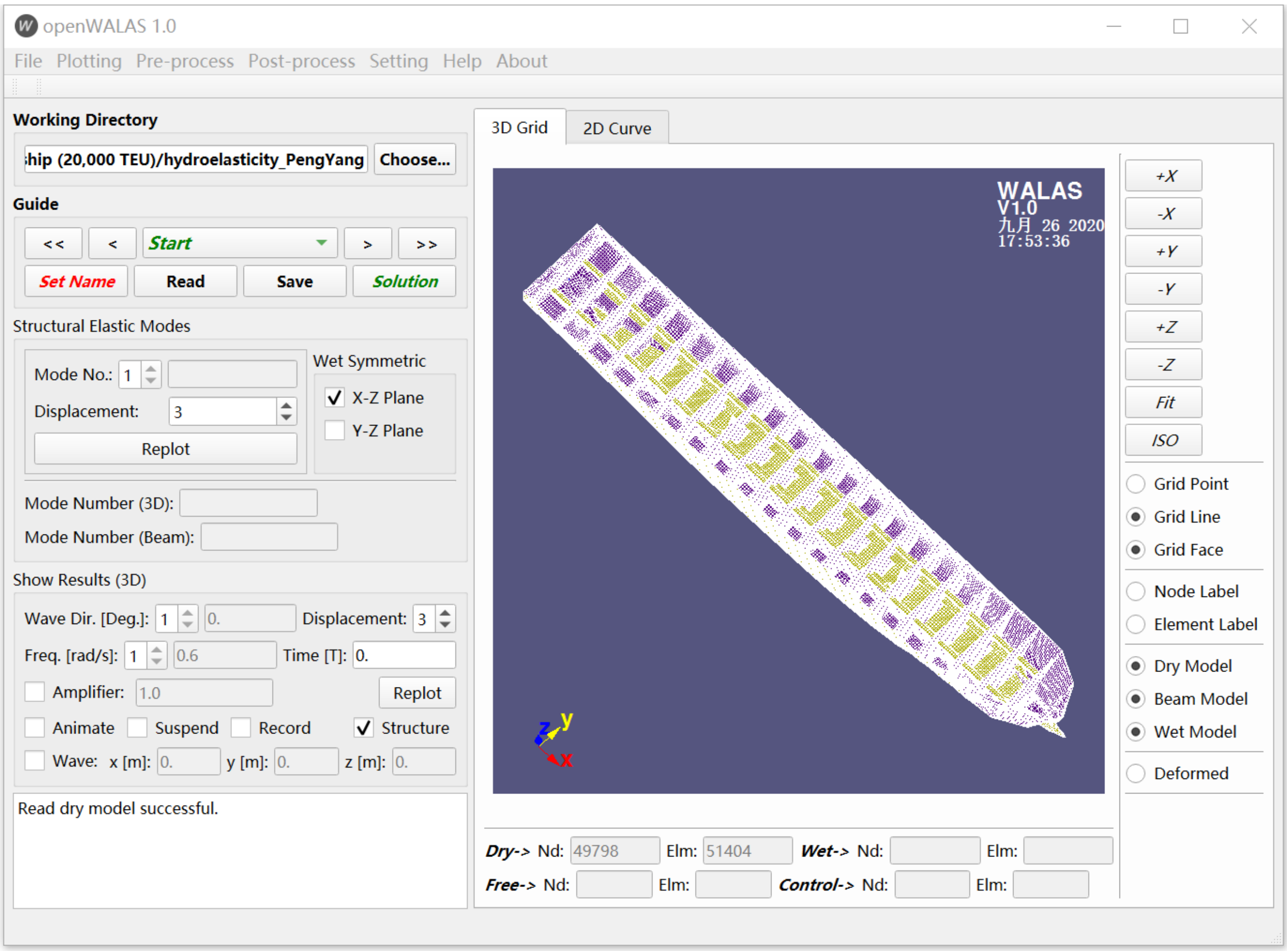

Fig. 6 3D FEM model

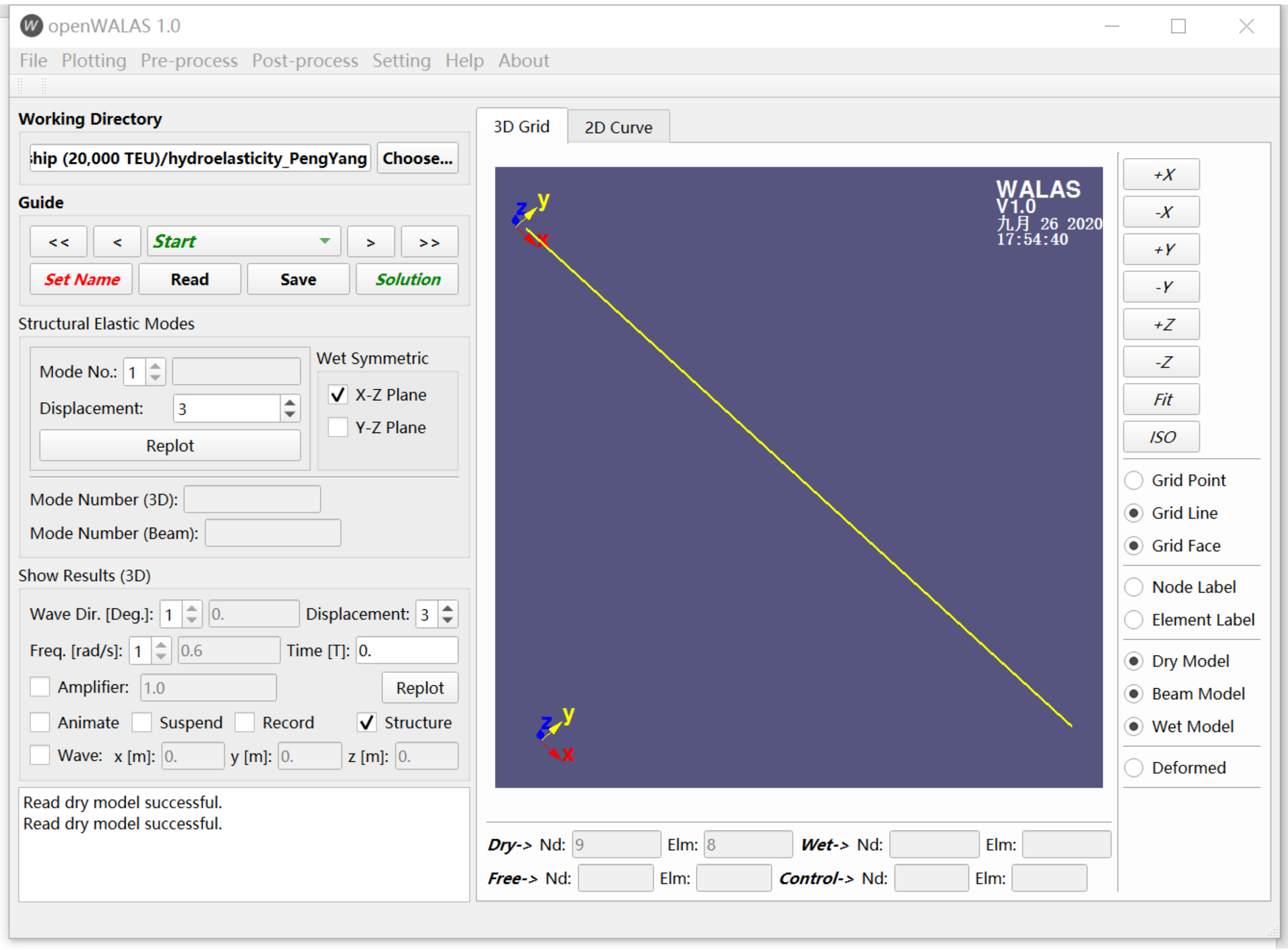

Fig. 7 1D beam model

3.1.4. Show wet model

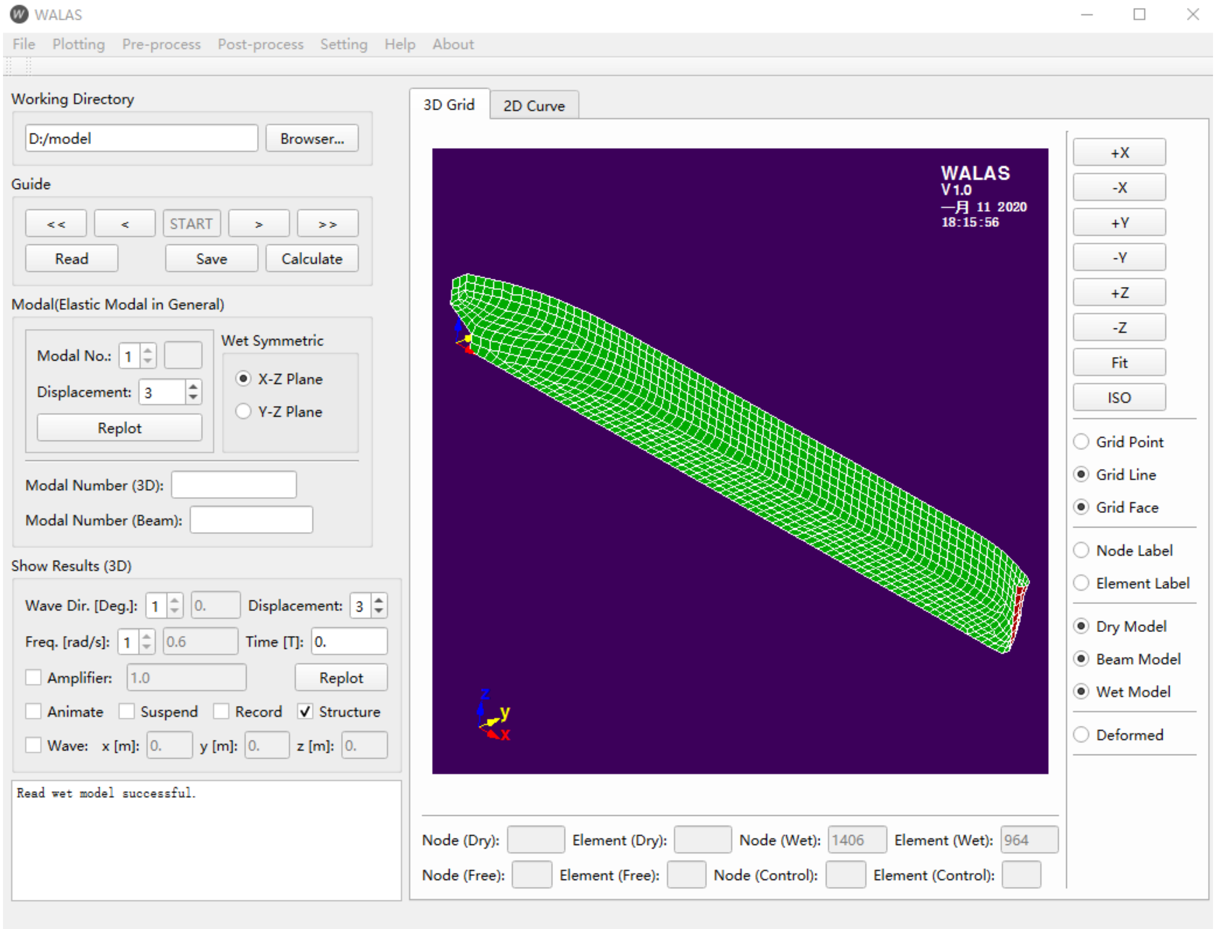

Fig. 8 3D wet model

3.1.5. Show free surface model

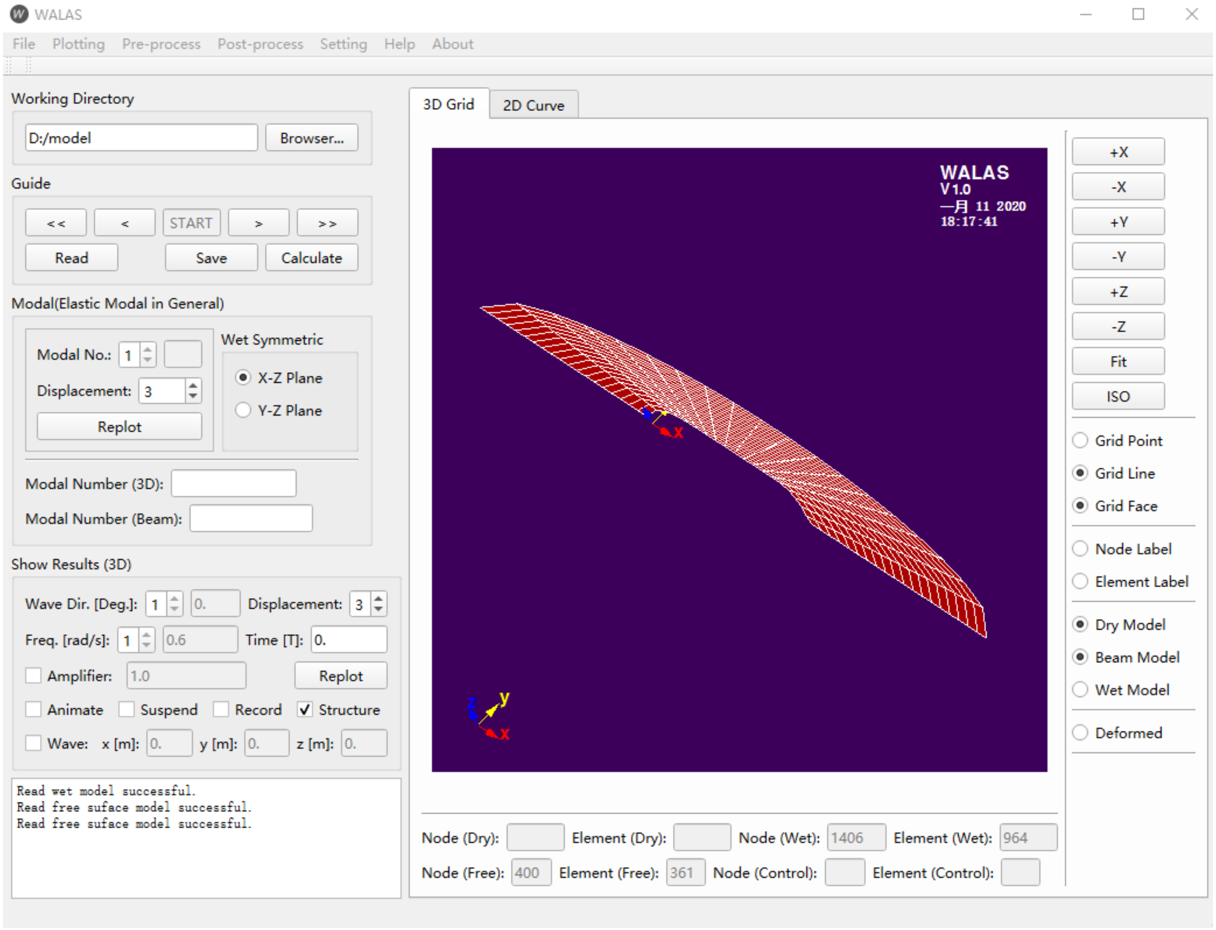

Fig. 9 Meshes on free surface

3.1.6. Show control surface model

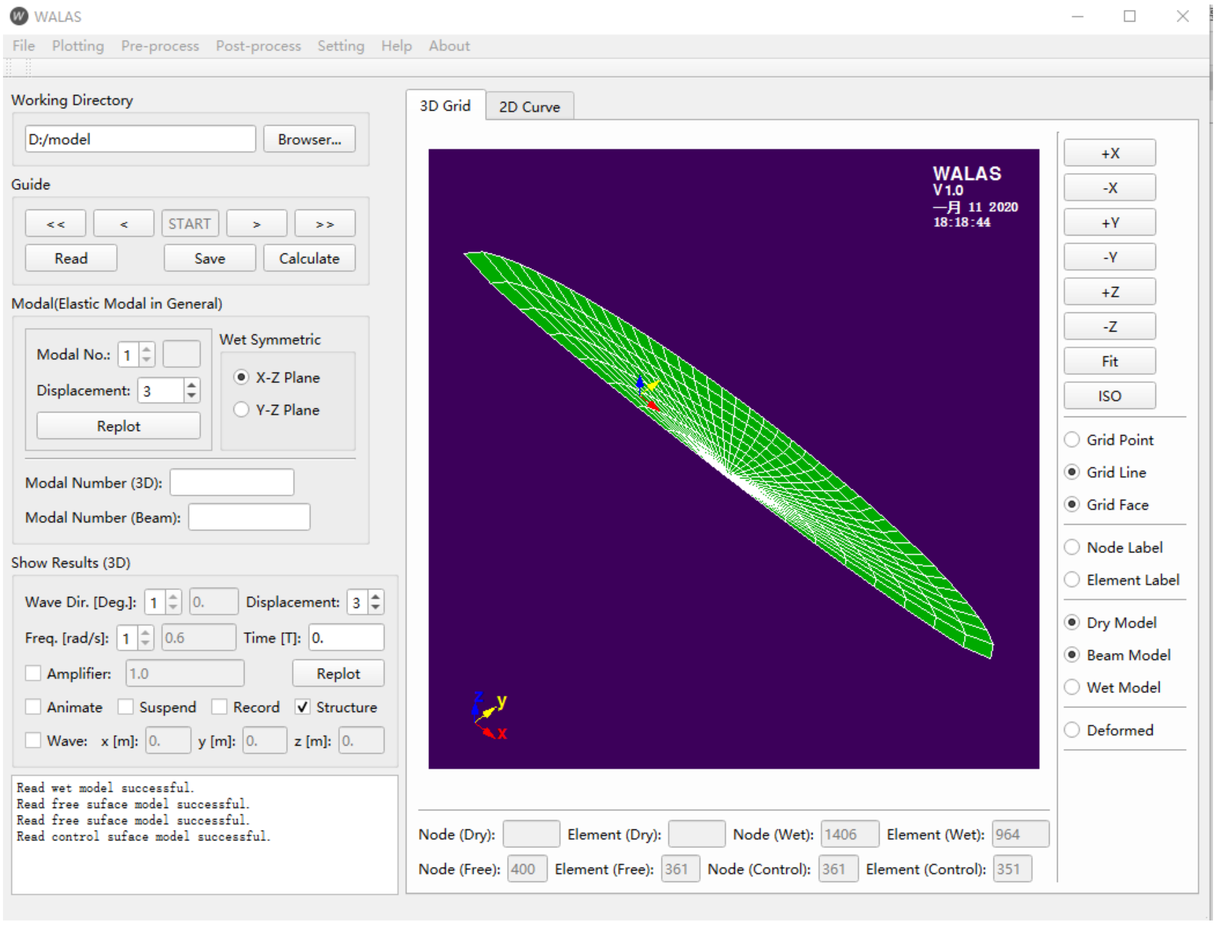

Fig. 10 Meshes on control surface

3.1.7. Show modes of dry models

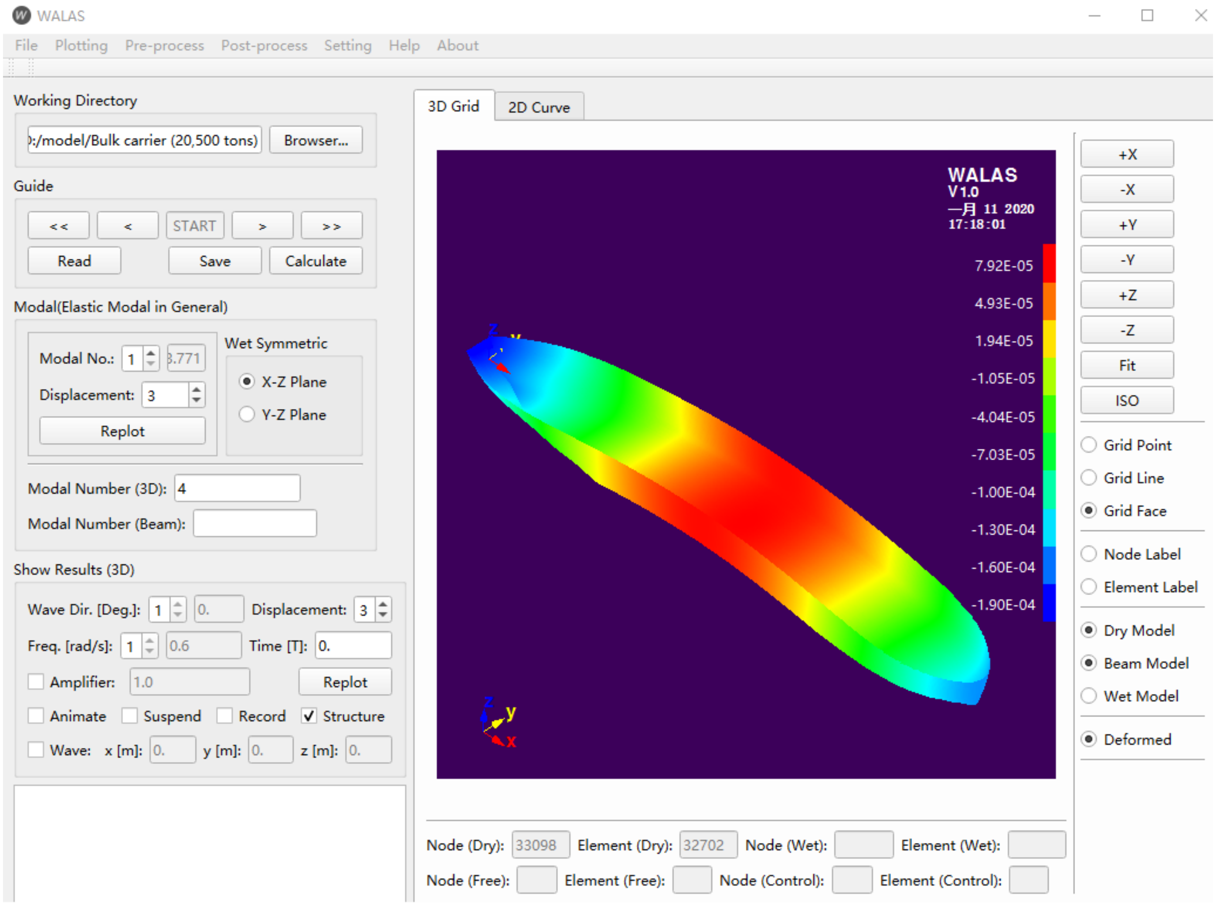

Fig. 11 3D FEM model

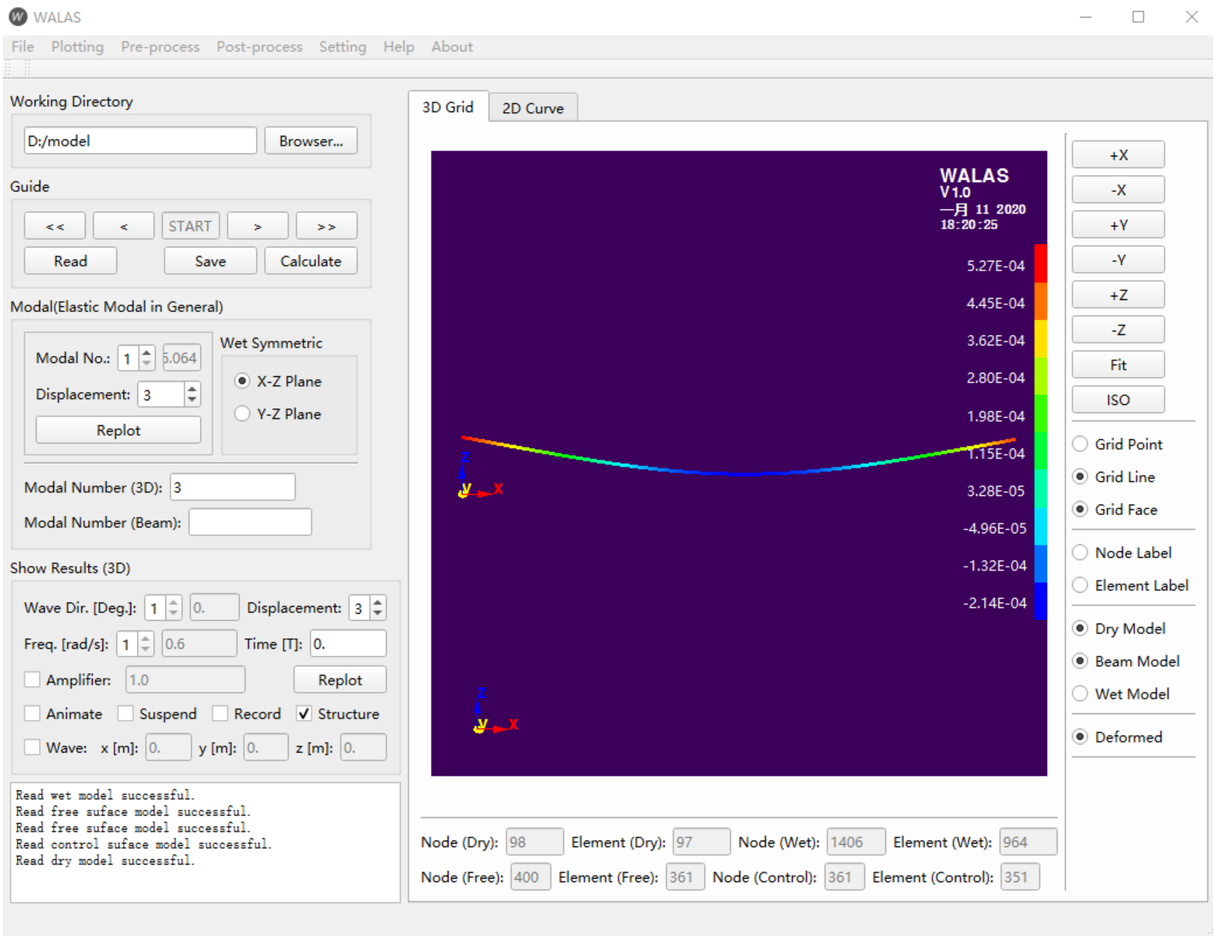

Fig. 12 1D beam model

3.1.8. Show modes of wet models

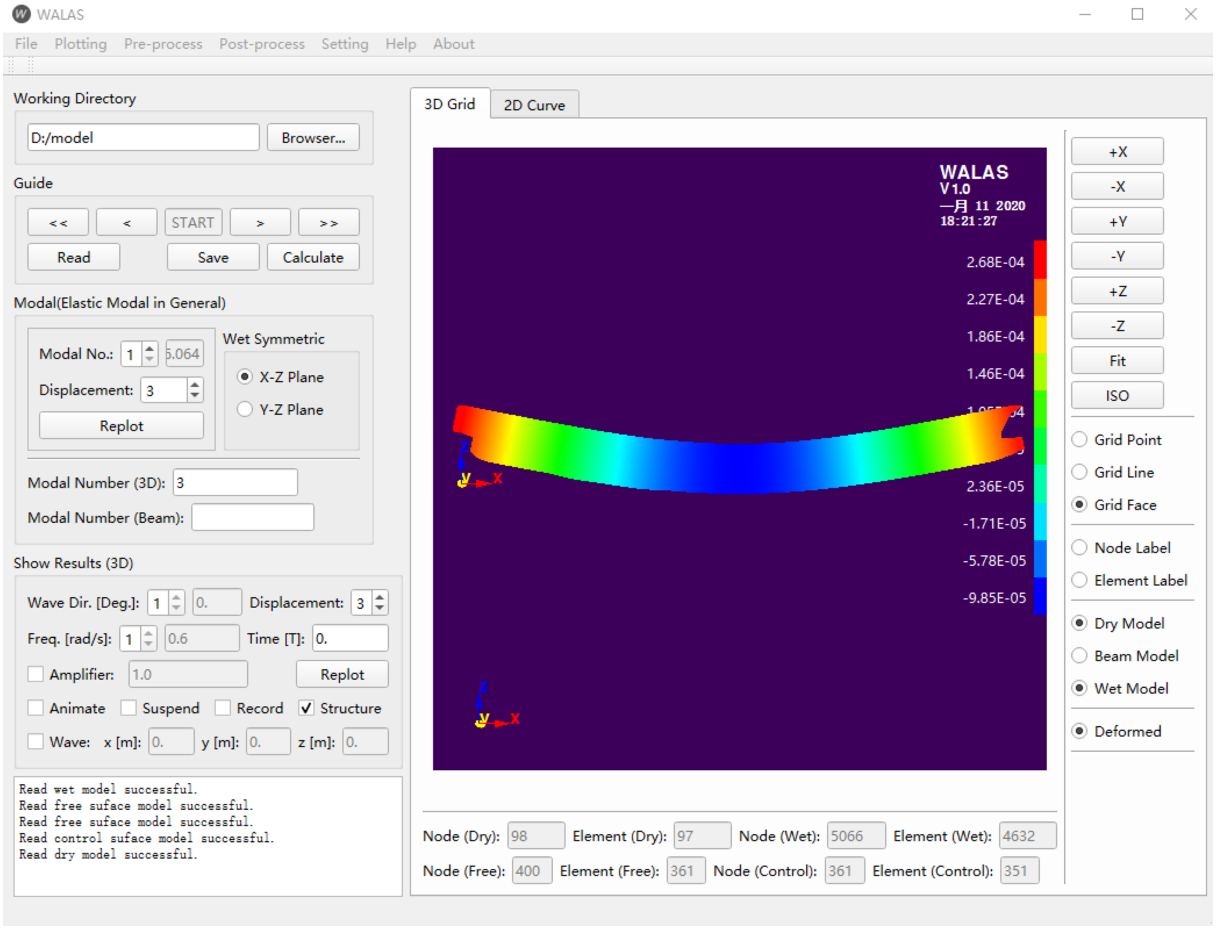

Fig. 13 3D wet model

3.2. Pre-process

3.2.1. Grid meshing

(1) Meshing on ship hull

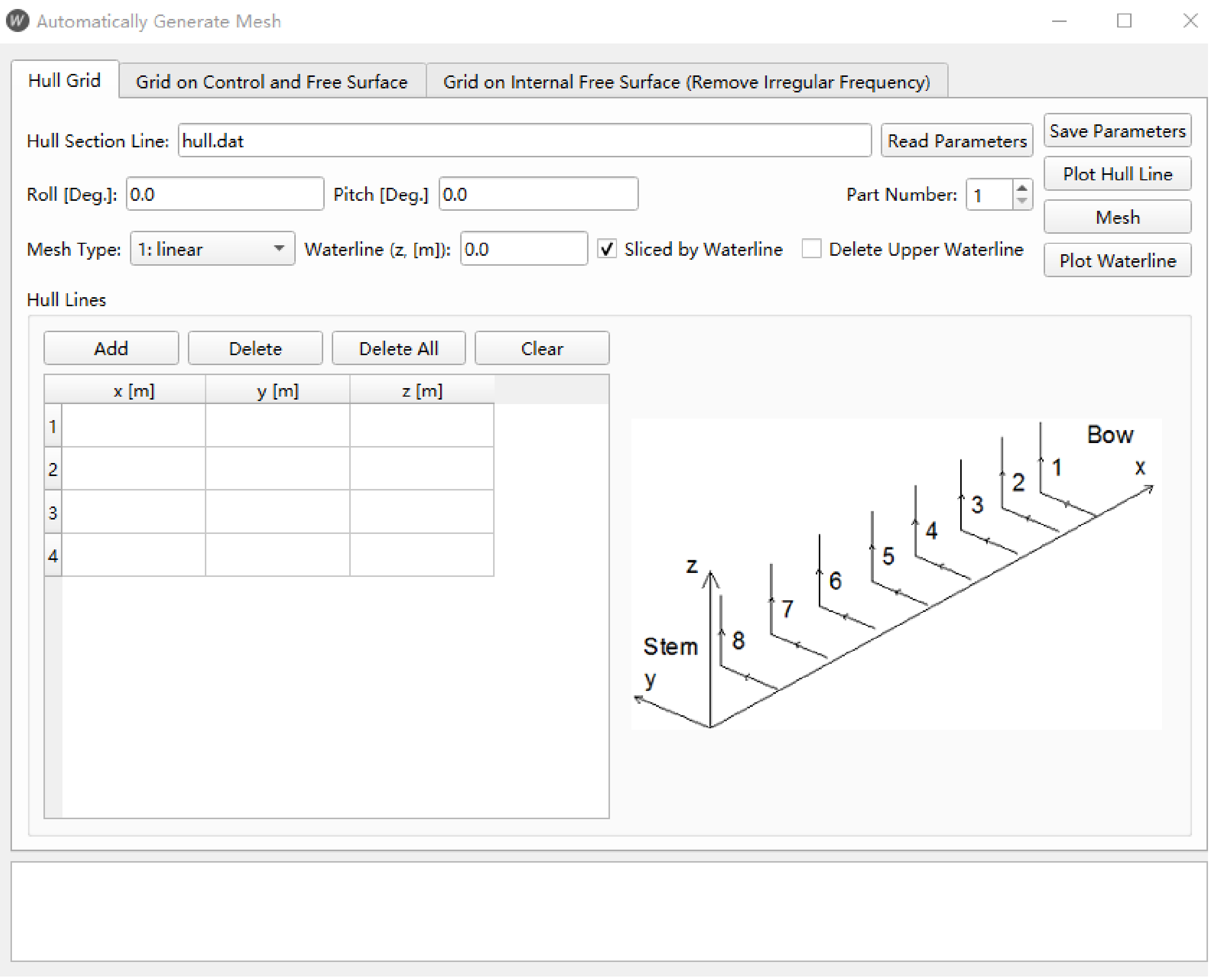

Fig. 14 Meshing on ship hulls

(2) Meshing on free surface and control surface

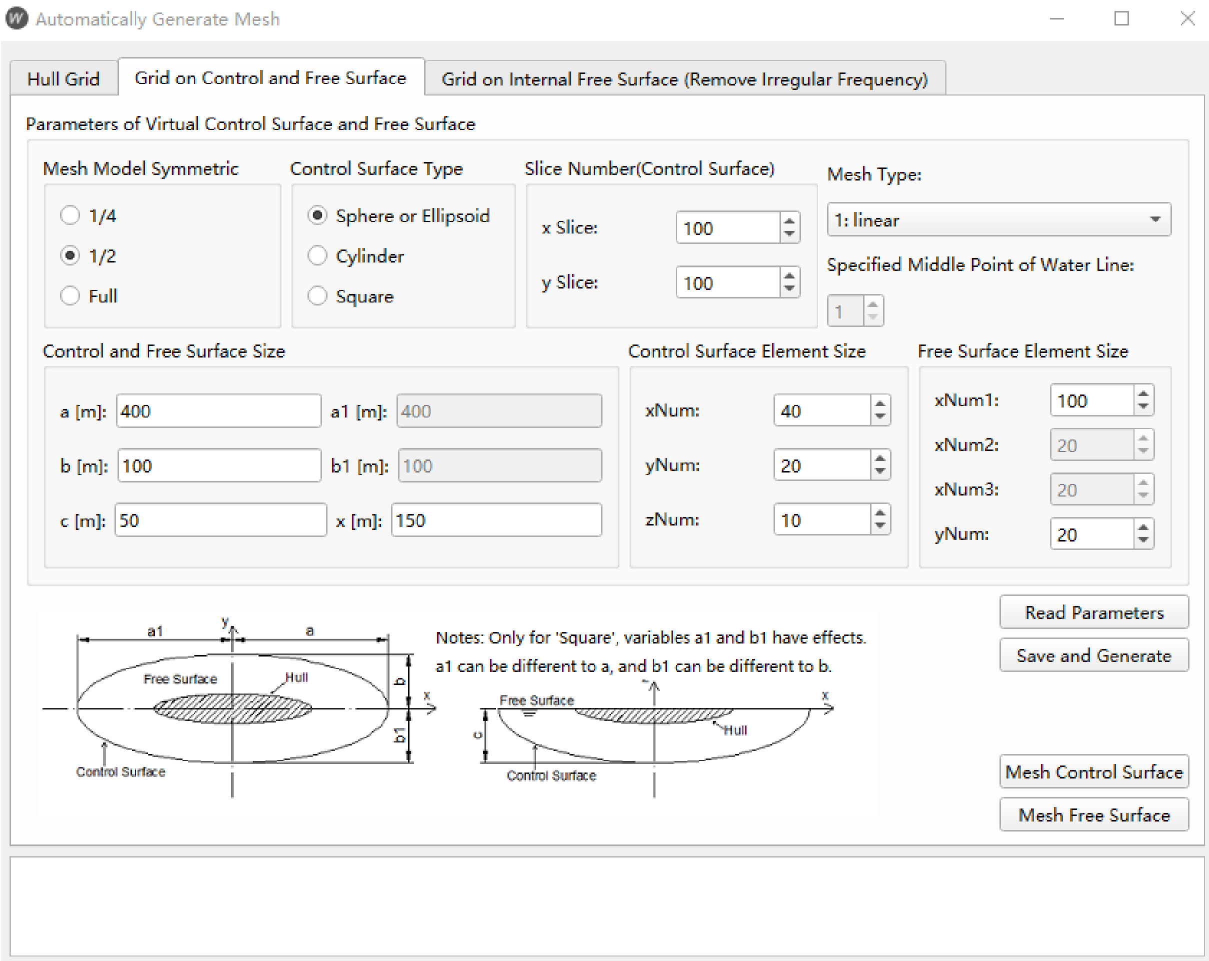

Fig. 15 Meshing on free surface and control surface

(3) Meshing on internal free surface

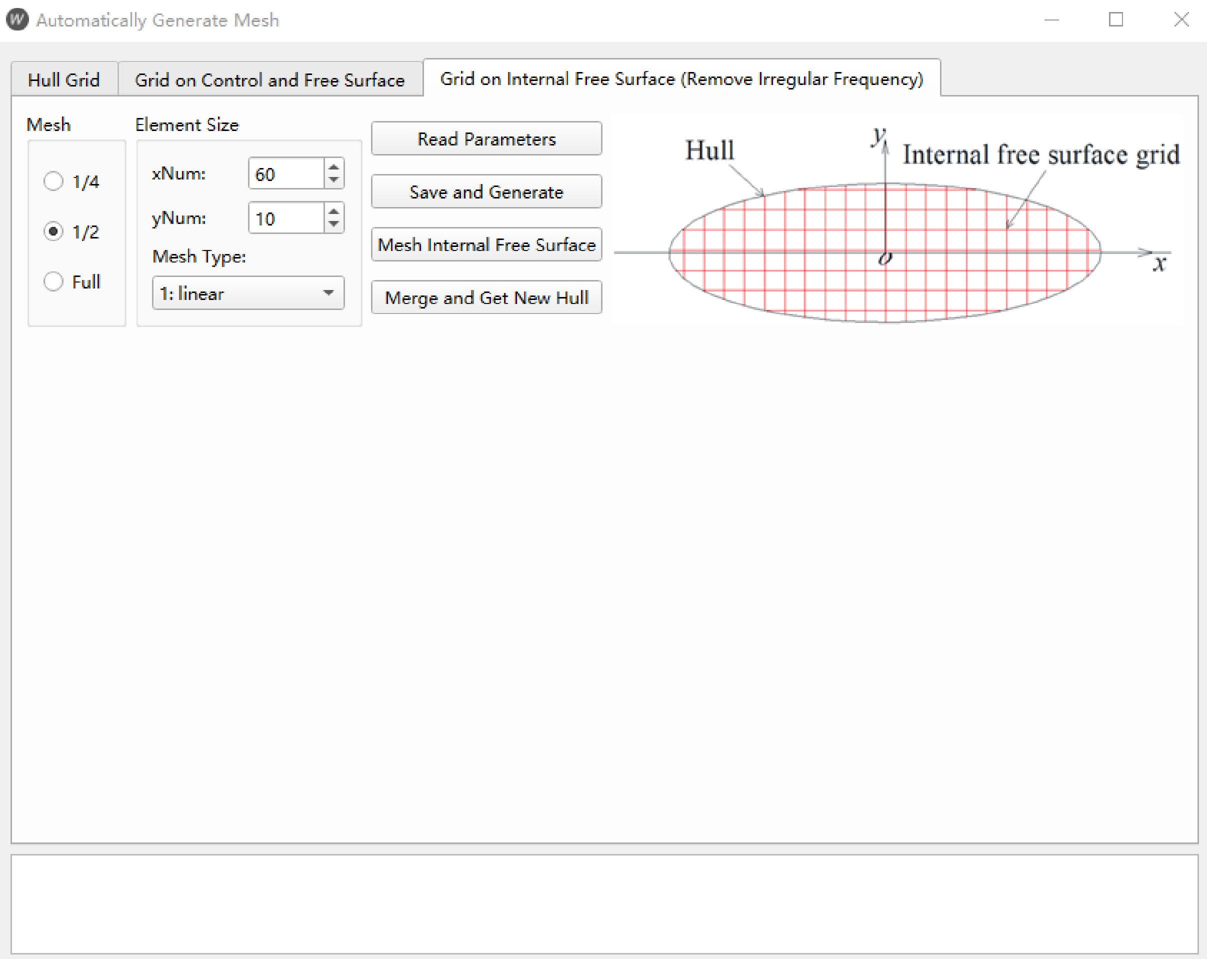

Fig. 16 Meshing on internal free surface

3.2.2. Splitting grid

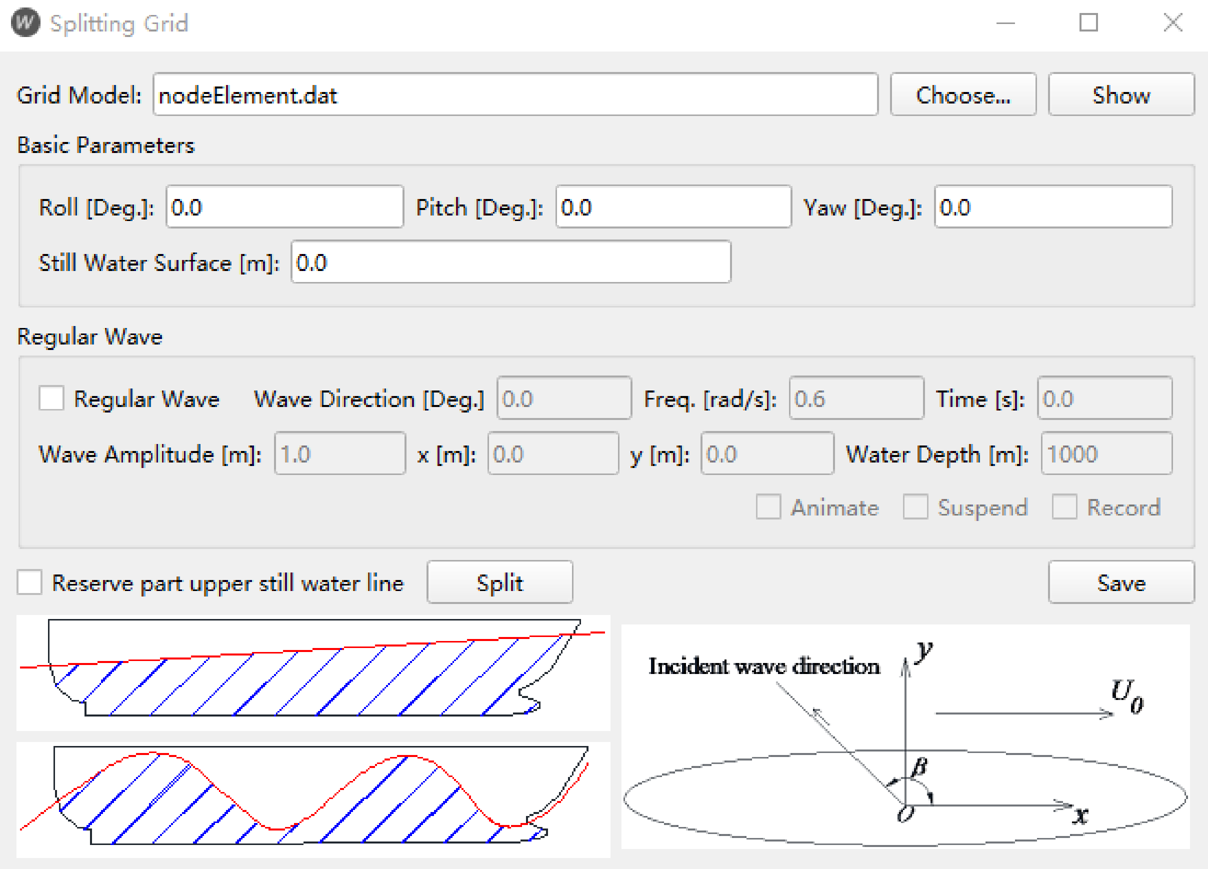

Fig. 17 Splitting grid

3.2.3. Natural frequency prediction of uniform straight beam

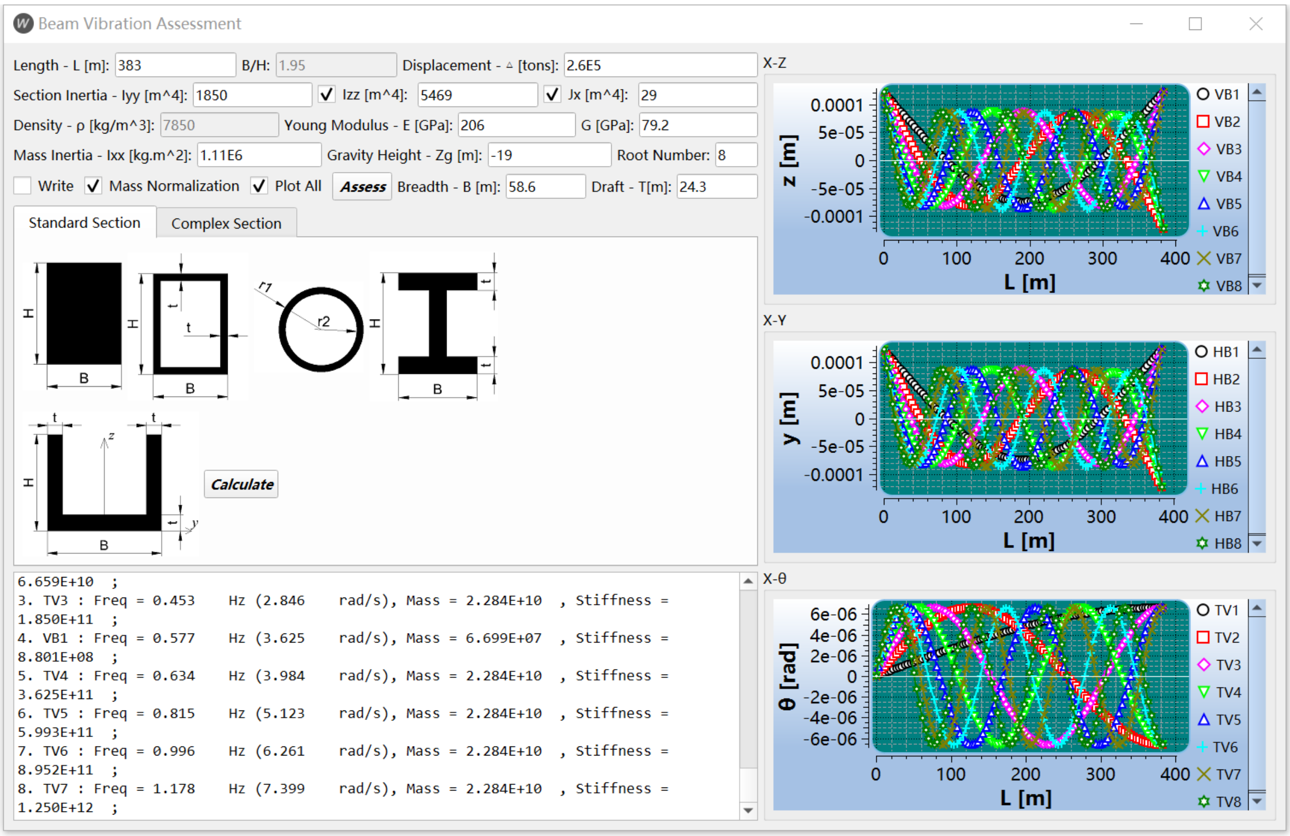

Fig. 18 Natural frequency prediction

3.3. Input parameters

3.3.1. Step 1 (dry model and wet model from .bdf and .f06 files of Patran)

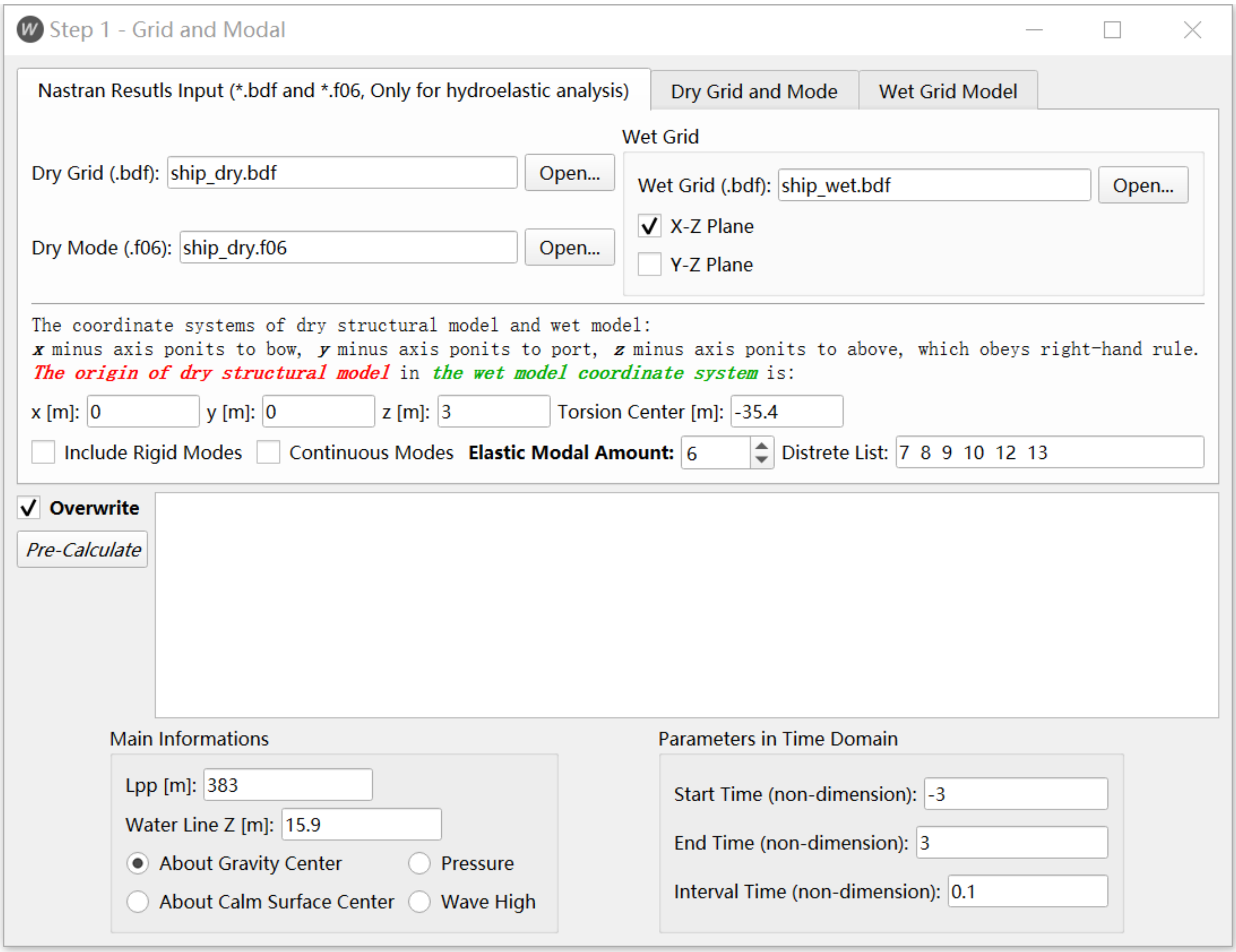

Fig. 19 Step 1

3.3.2. Step 2 (gravity center and Inertia)

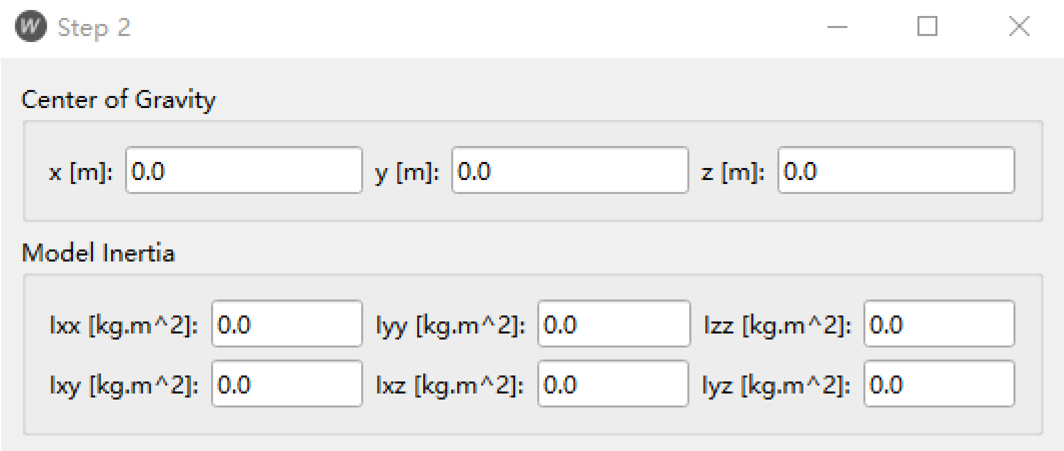

Fig. 20 Step 2

3.3.3. Step3 (forward speed, fluid density, gravity acceleration and water depth)

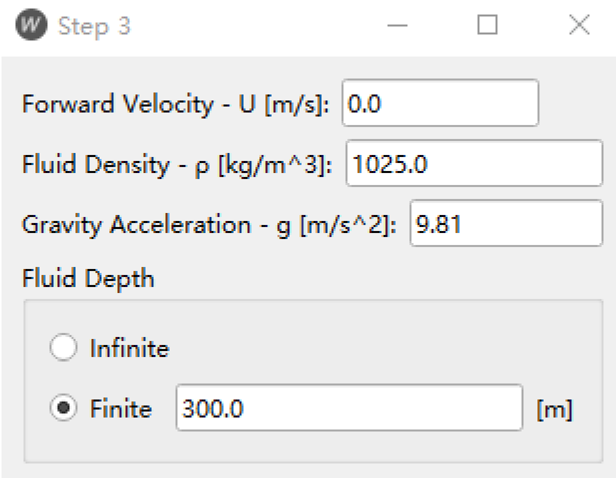

Fig. 21 Step 3

3.3.4. Step4 (wave frequencies and periods)

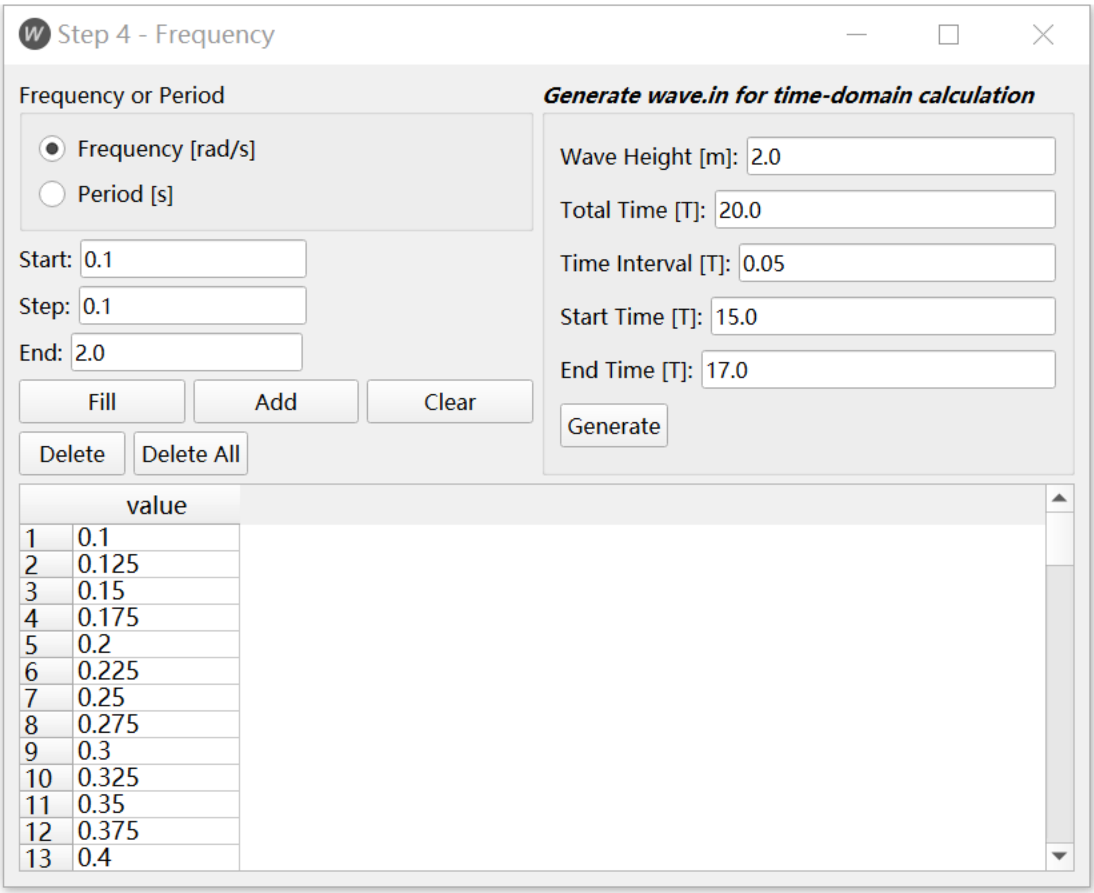

Fig. 22 Step 4

3.3.5. Step5 (wave directions)

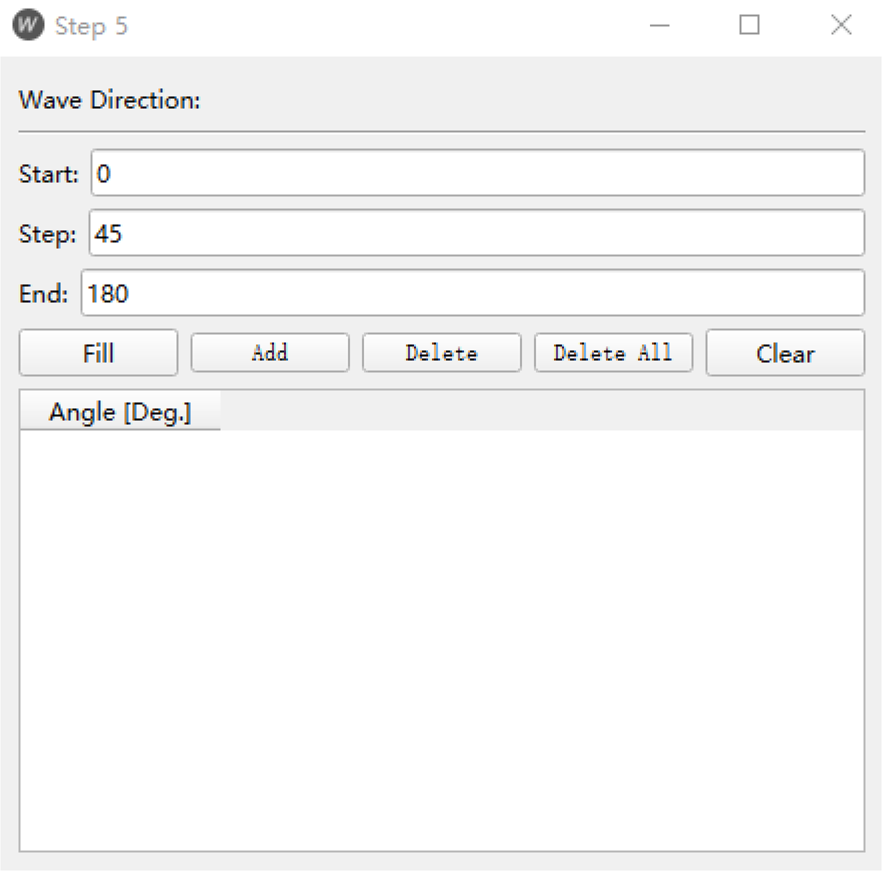

Fig. 23 Step 5

3.3.6. Step6 (interpolation and artificial damping coefficient)

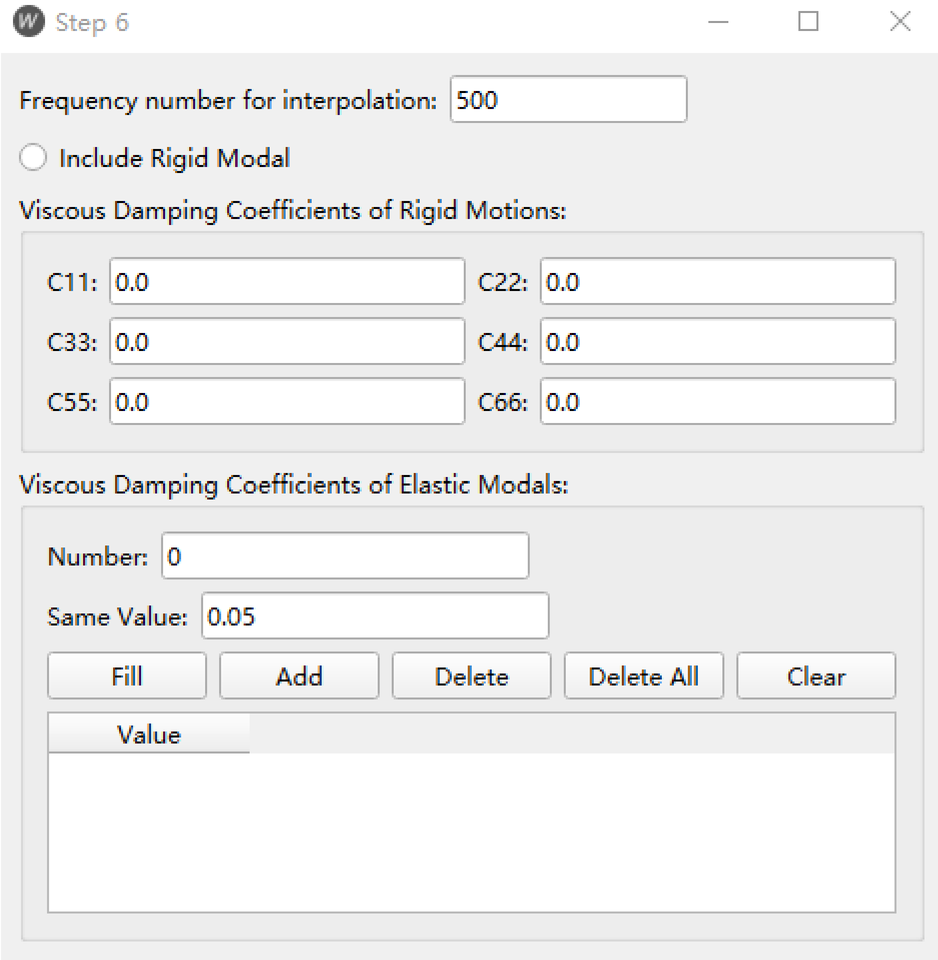

Fig. 24 Step 6

3.3.7. Step7 (mass distribution and section positions for wave load calculation)

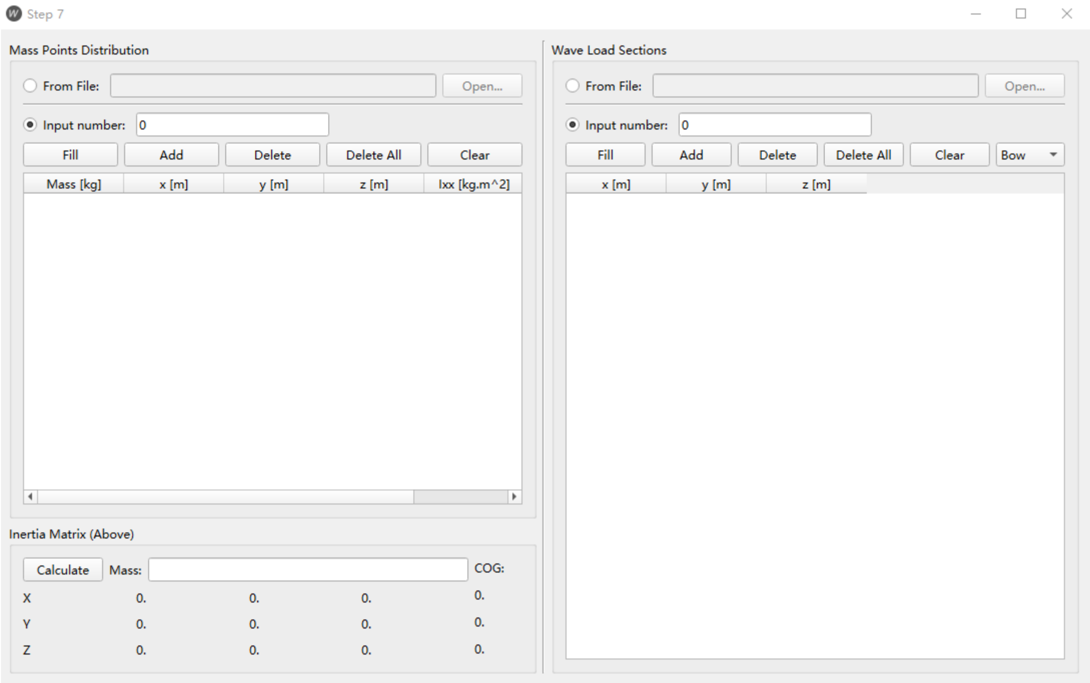

Fig. 25 Step 7

3.4. Solution

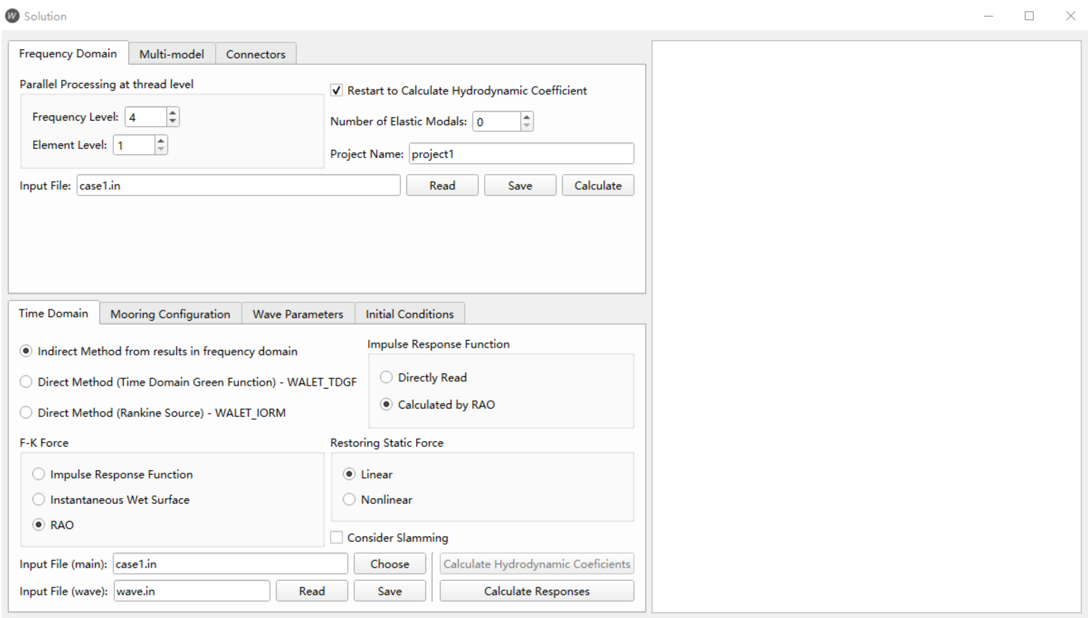

Fig. 26 Solution type

3.5. Post-process and show results

3.5.1. Basic information

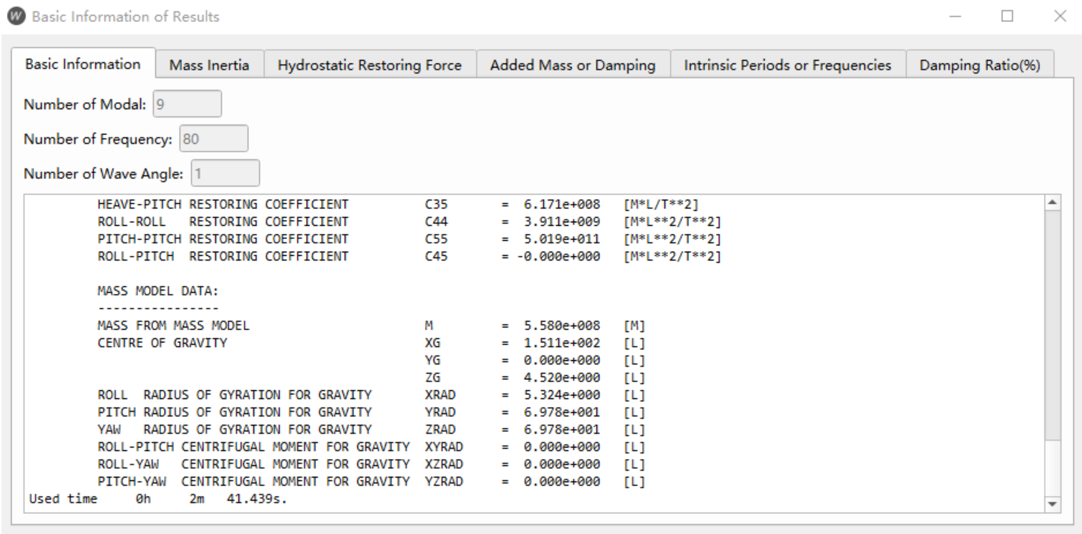

Fig. 27 Basic information

3.5.2. Results in frequency domain

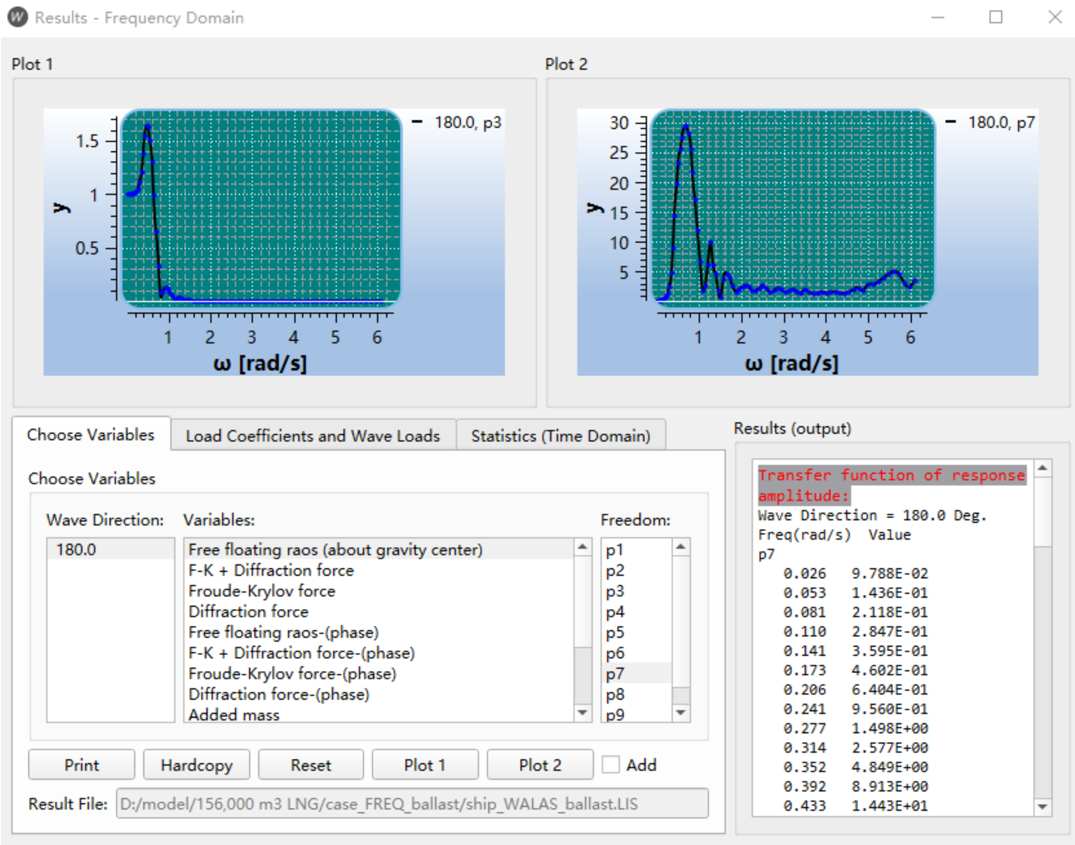

Fig. 28 Results in frequency domain

3.5.3. Results in time domain

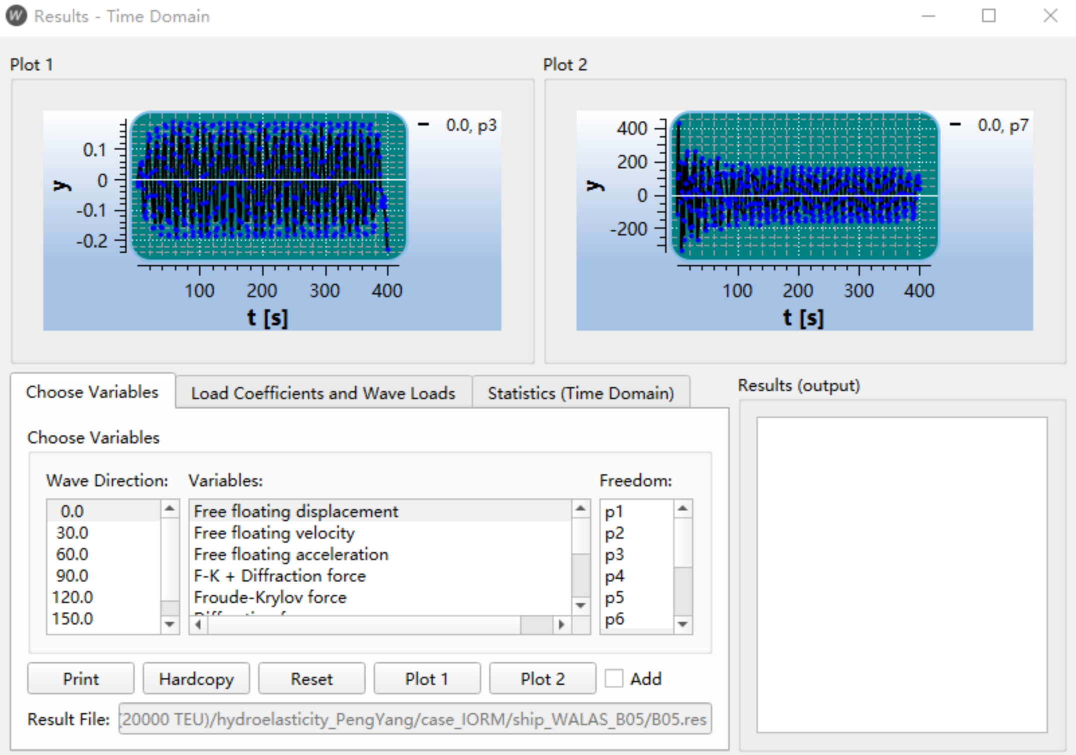

Fig. 29 Results in time domain

3.5.4. Predictions in short-term

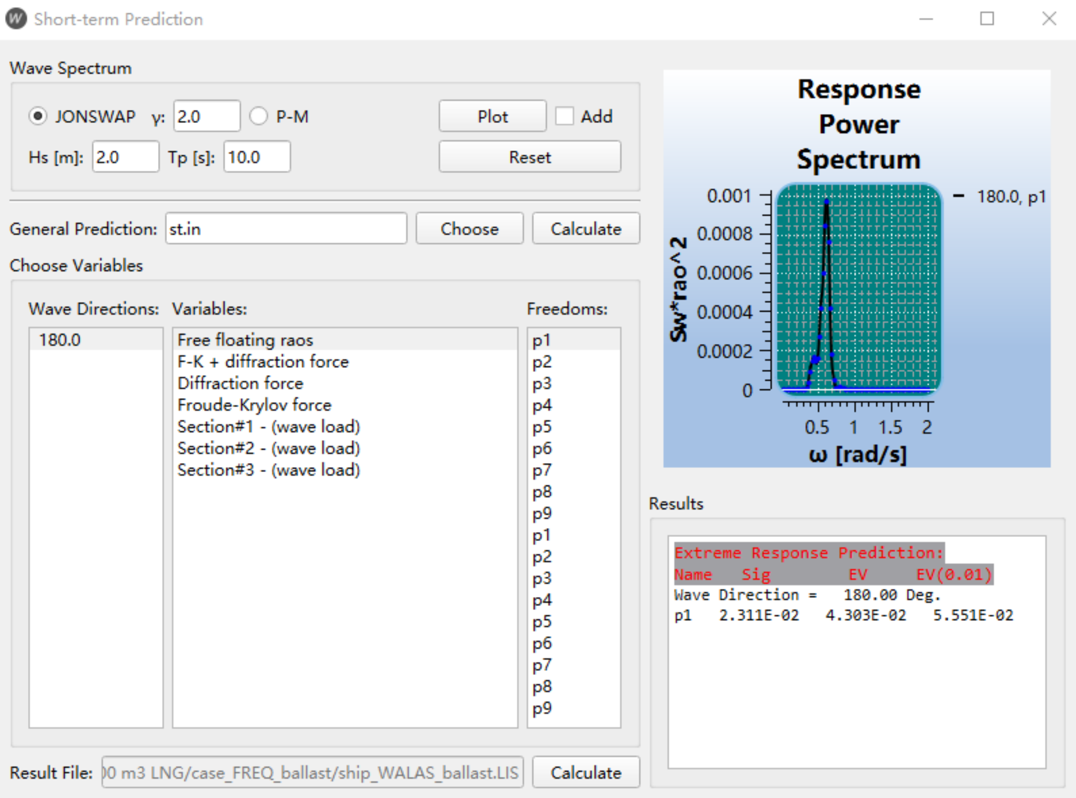

Fig. 30 Prediction in short-term

3.5.5. Predictions in long-term and fatigue analysis

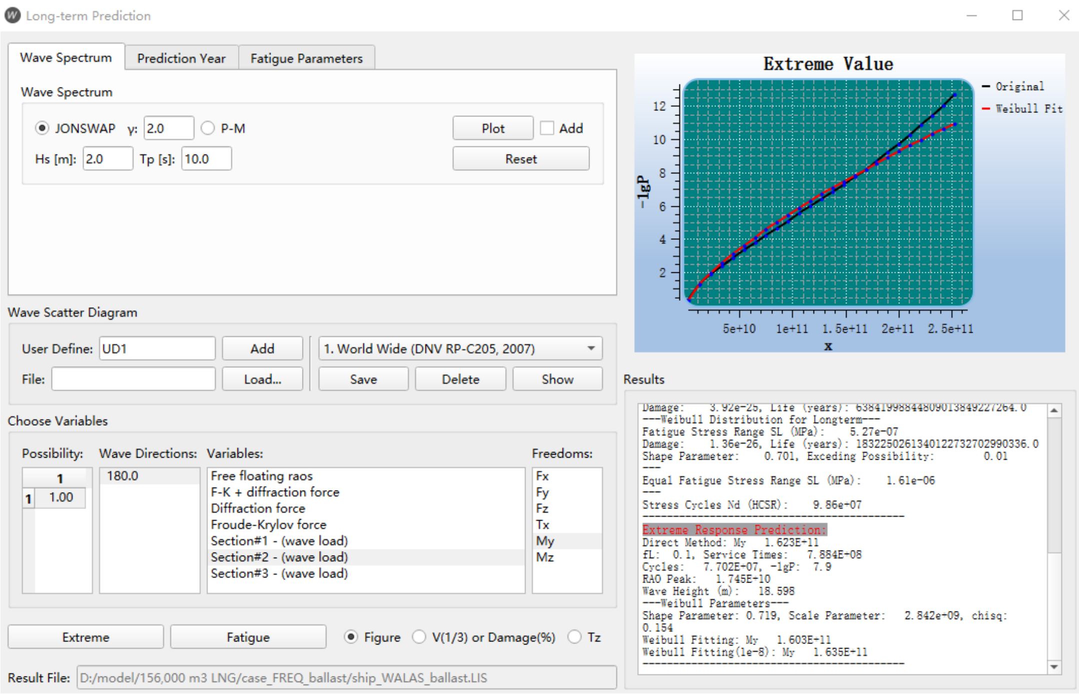

Fig. 31 Prediction in long-term

3.6. Basic definitions

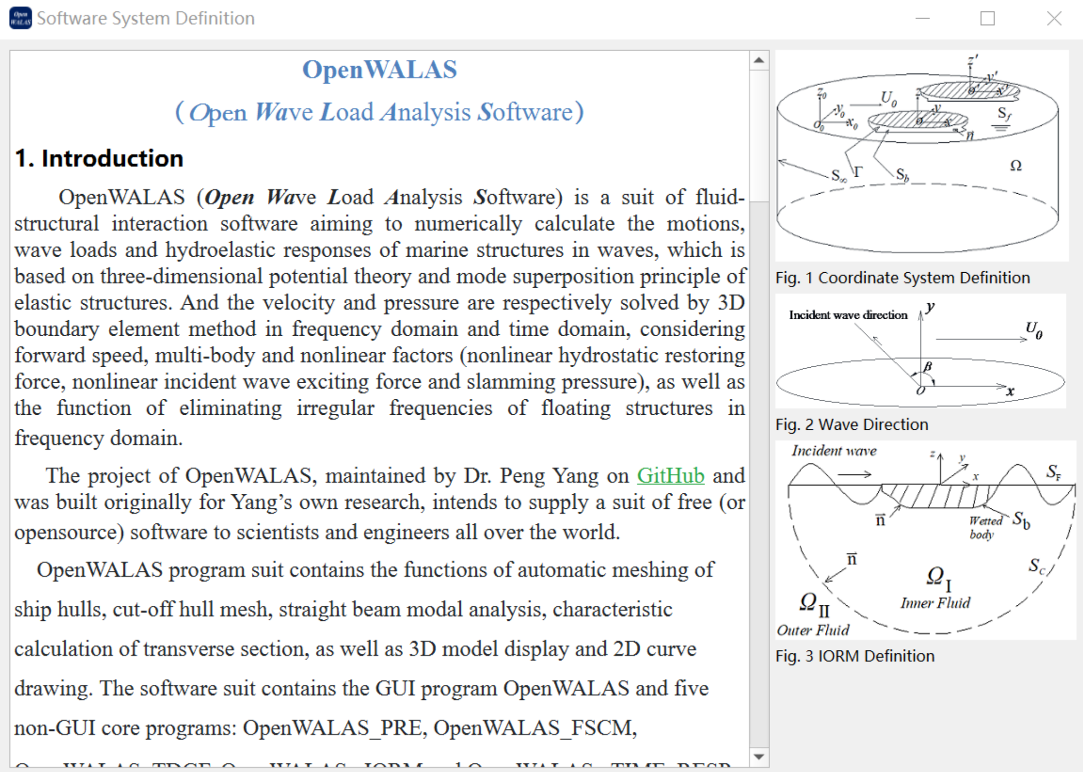

Fig. 32 Basic definition

4. Introduction of OpenWALAS non-GUI

4.1. Running sequences

1. Pre-process: *OpenWALAS_PRE.exe case.ini 0(or 1)*

2. Solution

   (a) *OpenWALAS_FSCM.exe case.ini*;

   (b) *OpenWALAS_TDGF.exe case.ini*;

   (c) *OpenWALAS_IORM.exe case.ini*;

   (d) *OpenWALAS_TIME_RESP.exe case.ini wave.in*;

3. Post-process: *OpenWALAS_POST.exe case.ini 1 Y Y Y*

There are five input files: *case.ini*, *ship1.in*, *ship_wet.bdf*, *ship_dry.bdf*, *ship.f06*.

4.2. Main input file of different cases (case.ini)

The file of input parameters mainly includes the control parameters of the program and does not need to be modified frequently.

4.2.1. Identity of input file

JOB WALAS MULTI

4.2.2. Parameters of parallel calculation

threadNumFreq threadNumElem

threadNumFreq: thread number for parallel process (frequency parallel)

threadNumElem: thread number for parallel process (element parallel)

4.2.3. Control parameters of hydrodynamic coupling among floating structures

STRCNUM startCoupleNo

STRCNUM: module number

startCoupleNo: module No. of starting coupling

4.2.4. Control parameters of structural modes

modalNum wetDryFlag restartFlag dampFlag_con

modalNum: modal number, including rigid and elastic modes

wetDryFlag: nodes of connectors from wet model or dry model; 0 – wet model, 1 – dry model. If there are elastic modes, the flag must be 1 (dry model).

restartFlag: Whether restart to calculate hydrodynamic coefficients, 0 – No, 1 – Yes.

dampFlag_con： ratio or coefficients for artificial damping, 0 - ratio, 1: coefficients.

4.2.5. Input parameters and file name of different floating structures

file[n]

x[n] y[n] z[n]

FIXED

Damp1 Damp2 Damp3 ……

Note：

file[n]: enclosed in double quotation marks.

x[n] y[n] Rz[n]：(*x*, *y*) denotes the vector of moving in X-Y plane. Rz denotes rotation degree about z axis based on the gravity center of floating structures (unit: degree)

FIXED: whether fixed of the floating structures, 0 - No, 1 – Yes.

Damp[n]: ration or coefficients, determined by 'DampFlag', means six rigid modes and ElasNum elastic modes.

4.2.6. Connector definition

CONNUM

strcNo1 pointNo1 strcNo2 pointNo2 stiff1 stiff2 stiff3 stiff4 stiff5 stiff6

CONNUM: number of connectors

strcNo1, strcNo2: No. of floating structures

pointNo1, pointNo2: Node No

stiff1 stiff2 stiff3 stiff4 stiff5 stiff6: the stiffness of translation and rotation

4.3. Input parameters of floating structures (shipX.in)

File of parameters (the most important files), including the information of models.

4.3.1. Identity

JOB WALAS

4.3.2. File name of wet grid model

Enclosed in double quotation marks

4.3.3. File name of dry grid model

Enclosed in double quotation marks

4.3.4. Modal shapes of nodes of dry model

Enclosed in double quotation marks

4.3.5. Modal shapes of elements of wet model

Enclosed in double quotation marks

4.3.6. Information of dudx of wet model

Enclosed in double quotation marks

4.3.7. Characteristic parameters

Lpp SwlHeight ISOFLAG NORMALFLAG ORIGINFLAG PRESFlag WHPFlag nonTimeStart nonTimeEnd nonDt

Lpp: perpendicular length

SwlHeight: height of still water surface relative to wet coordinate system

ISOFLAG: symmetrical flag of wet model, 0 – no symmetry, 1 - Bilateral symmetry, 2 – two symmetrical planes about Y-Z plane and X-Z plane

NORMALFLAG: normal flag of wet model, 1 – point to internal of ship hull, -1 - point to external fluid. For Rankine source method (IORM), the normal vectors of free surface and virtual control surface are consistent with ship hull.

ORIGINFLAG: 0 denotes origin of the internal calculating coordinate system is the project of the origin of wet model on still water surface, 1 – denotes origin is gravity center.

PRESFlag: whether calculate pressure on ship hull, 0 – No, 1 – Yes.

WHPFlag: whether calculate wave height of the specific points in fluid filed, 0 – No, 1 – Yes.

nonTimeStart: nondimensional starting time.

nonTimeEnd: nondimensional end time.

nonDt: nondimensional interval time.

4.3.8. Coordinates of gravity center

Xg Yg Zg

Relative to wet coordinate system

Xg: *x* value

Yg: *y* value

Zg: *z* value

4.3.9. Mass inertia

Ixx Iyy Izz Ixy Ixz Iyz

Relative to gravity center

Ixx: about *x* axis.

Iyy: about *y* axis

Izz: about *z* axis

Ixy: in x-y plane.

Ixz: in x-z plane

Iyz: in y-z plane

4.3.10. Position of dry coordinate origin in wet coordinate system

Dryx Dryy Dryz Tz

Dryx: *x* value

Dryy: *y* value

Dryz: *z* value

Tz：torsional center (or shear center) about neutral axis of vertical bending (only works in Beam model)

4.3.11. Forward speed, density and acceleration of gravity

Vel Rho G

Forward speed, density of fluid, gravity acceleration.

4.3.12. Water depth

DepthFlag Depth

DepthFlag: flag of water depth, 0 – finite water depth, 1 – infinite water depth

Depth: water depth, only works in finite water depth case

4.3.13. Frequencies or periods

FreqFlag FreqNum

[FreqStar tFreqEnd] [Freq1 Freq2 Freq3 ……] *(six in a row)*

FreqFlag: flag of frequencies, 0 - continuous values, 1 - discrete values

FreqNum: number of frequencies

FreqStart: starting value, only works when FreqFlag is 0.

FreqEnd: end value, only works when FreqFlag is 0.

Freq[n]: values, only works when FreqFlag is 1.

4.3.14. Wave directions

DirFlag DirNum

[DirStart DirEnd] [Dir1 Dir2 Dir3 ……] *(six in a row)*

DirFlag: flag of wave directions, 0 - continuous values, 1 - discrete values

DirNum: number of wave directions

DirStart: starting value, only works when DirFlag is 0

DirEnd: end value, only works when DirFlag is 0.

Dir[n]: values, only works when DirFlag is 1.

4.3.15. Number of frequencies for interpolation

MoreFreqNum

Number of frequencies for interpolation, using spline interpolation hydrodynamic coefficient, wave excitation force, and then to solve the modal principal coordinate response results

4.3.16. Number of elastic modes

RigidFlag ElasFlag ElasNum

[Elas1 Elas2 Elas3 Elas4 Elas5 ……]

RigidFlag: flag of rigid modes, 0 – the rigid modes are not included in the modal shape files and automatic generated by programs, suggested value; 1 - Yes

ElasFlag: flag of elastic modes, 0 – continuous modal No, 1 – discrete No.

ElasNum: number of elastic modes

Elas[n]: values, only works for ElasFlag = 1.

4.3.17. Artificial damping coefficients

DampFlag1 DampFlag2

Damp1 Damp2 Damp3 ……

DampFlag1: flag of damping, 0 – ratio, 0 - coefficients

DampFlag2: flag of damping, 0 – same value, 1 – different values

Damp[n]: values

4.3.18. Mass points for wave loading calculations

massPointNum

mass[n] x[n] y[n] z[n] Ixx[n]

……

massPointNum: number of mass points, 0 – not calculate wave loads.

mass[n]: mass of each point

x[n] y[n] z[n]: coordinate about wet model

Ixx[n]: the mass inertia about *x* axis.

4.3.19. Section definitions of wave loads

secNum waveLoadSymbol

x [n] y[n] z[n]

secNum: section number of wave loads

x[n] y[n] z[n]: coordinate of calculating origin

waveLoadSymbol: flag of integral for wave loads, -1: bow, 1 - stern

4.4. Wave parameters of time-domain calculation (wave.in)

Example:

```
0       0       0       0
0
5e+05   5e+06   0       0       0       1e+10
20
"B01"
0       2       62.832
3       1200    800     900
6
```

```
0           0
0           0
0           0
0           0
0           0
0           0
"B02"
0           2           31.416
3        1500       1000       1100
6
0           0
0           0
0           0
0           0
0           0
0           0
"B03"
0           2           20.944
2         800        650        750
6
0           0
0           0
0           0
0           0
0           0
0           0
```

4.4.1. IPL, FKI, NONLSTF, SLM

IPL: flag of impulse response function, 0 – directly read, 1 – calculated by added mass and added damping in frequency domain

FKI: flag of incident wave exciting force, 0 – impulse response function (linear wave force）, 1 – directly pressure integral in time domain (nonlinear wave force), 2 – interpolation by the results of transfer function in frequency domain.

NONLSTF: 0 – linear hydrostatic restoring force, 1 – nonlinear.

SLM: 0 – not considering slamming effects, 1 – Yes.

4.4.2. MRL，moorPointFixedNum, wetDryFlag

MRL: flag of mooring, 0 – directly six springs of linear stiffness

moorPointFixedNum: number of mooring points

wetDryFlag: type of mooring points, 0 – from wet model, 1 – from dry model. If including elastic modes, must be 1.

4.4.3. caseNum

caseNum: number of cases

```
"B01"
0          2          62.832
3       1200     800     900
6
0          0
0          0
0          0
0          0
0          0
0          0
```

4.5. Definition of slamming areas (slm.in)

This file is a slamming parameter file for calculating whipping response in time domain.

Standard format:

```
X1    x2
No
```

Point1

Point2

…

PointN

Explanation:

X1: from stern to x1, considering slamming

X2: from x2 to bow, considering slamming

No: the number of wet elements to output slamming pressure (the number of the following elements follows the principle of sequential numbering from 1, which is not the element number in node-element file and is the number of full model)

Point1: element #1

Point2: element #2

Point3: element #3

Example:

50 330

3

147

148

149

4.6. Definition of slamming pressures (flareSlm.ini)

This file is the calculation formula of slamming pressure. There is a default slamming pressure calculation formula (Stavovy & Chuang) in the program. If the file does not exist, the default calculation formula in the program will be used.

Standard format:

No

x1 y1

x2 y2

x3 y3

…

xn   yn

4.7. Modal informations of dry model in Patran/Nastran (ship.f06)

This file is the result file of MSC / NASTRAN calculation, and saves the node modal information of dry model.

4.8. Dry model in Patran/Nastran (ship_dry.bdf)

The file is saved from the finite element model, which saves the node and element information of dry structure panel. This file is used for OpenWALAS_PRE program and ship_ wet.bdf. The modal information of wet model is calculated from ship.f06.

For convenience, it can be directly copied from the. BDF file of ship.f06, or re-extracted from the finite element model of the dry structure (only the elements on the surface of the floating body should be kept, and the number must be kept unchanged). The. BDF file corresponding to ship.f06 saves all the nodes of the modal calculation.

4.9. Wet model in Patran/Nastran (ship_wet.bdf)

The file saves the node and element information of wet surface element. Because the dimension of dry structure surface element is smaller than that of wet surface element, it is necessary to make wet surface element file again, but the surface element model of both can be maintained.

5. Output instruction

5.1. Hydrodynamic coefficients in frequency domain (binary format)

case.hyd, including wave exciting forces, added mass, added damping, hydrostatic restoring matrix.

5.2. Hydrodynamic coefficients in time domain (binary format)

impulse.hyd, inducing the impulse response functions of incident wave exciting forces (Fkr), diffraction exciting forces (Fdr) and radiation potential (Krs).

5.3. Results in frequency domain (text format)

(1) case.LIS, including overall basic information

(2) ship1.LIS, basic information and results for each floating structures.

5.4. Results in time domain (text format)

(1) ship1_TIM.LIS, basic information in time domain.

(2) ship1_t2f.LIS, results of transfer function by time-domain programs.

5.5. 3D models of wet model

(1) XX_ internal_nodeElement.plt: Tecplot format, the elements above still water are removed.

(2) nodeElement_coupled.plt: Tecplot format, the coupled models.

(3) nodeElement_all.plt: Tecplot format, including all models.

(4) whole.DXF, XX_ original_nodeElement.DXF: Autocad format, full model, the elements above still water are reserved.

6. Other useful tools

The interface between OpenWALAS and Patran or ANSYS are built by the tools as follows, which are in directory of "tools" in OpenWALAS.

1. createElem(ansys)
2. createhull(ansys)
3. createElem(patran)
4. createhull(patran)
5. getModal(ansys)
6. getNodeElement(ansys)
7. bdf2WALAS – transfer grid model form .bdf file of Patran to OpenWALAS

And the "shorterm" program is for response prediction in short-term sea states.

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