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

Author: *Peng Yang*

Email: *pycssrc@qq.com*

Date: *2020/08/20*

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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.

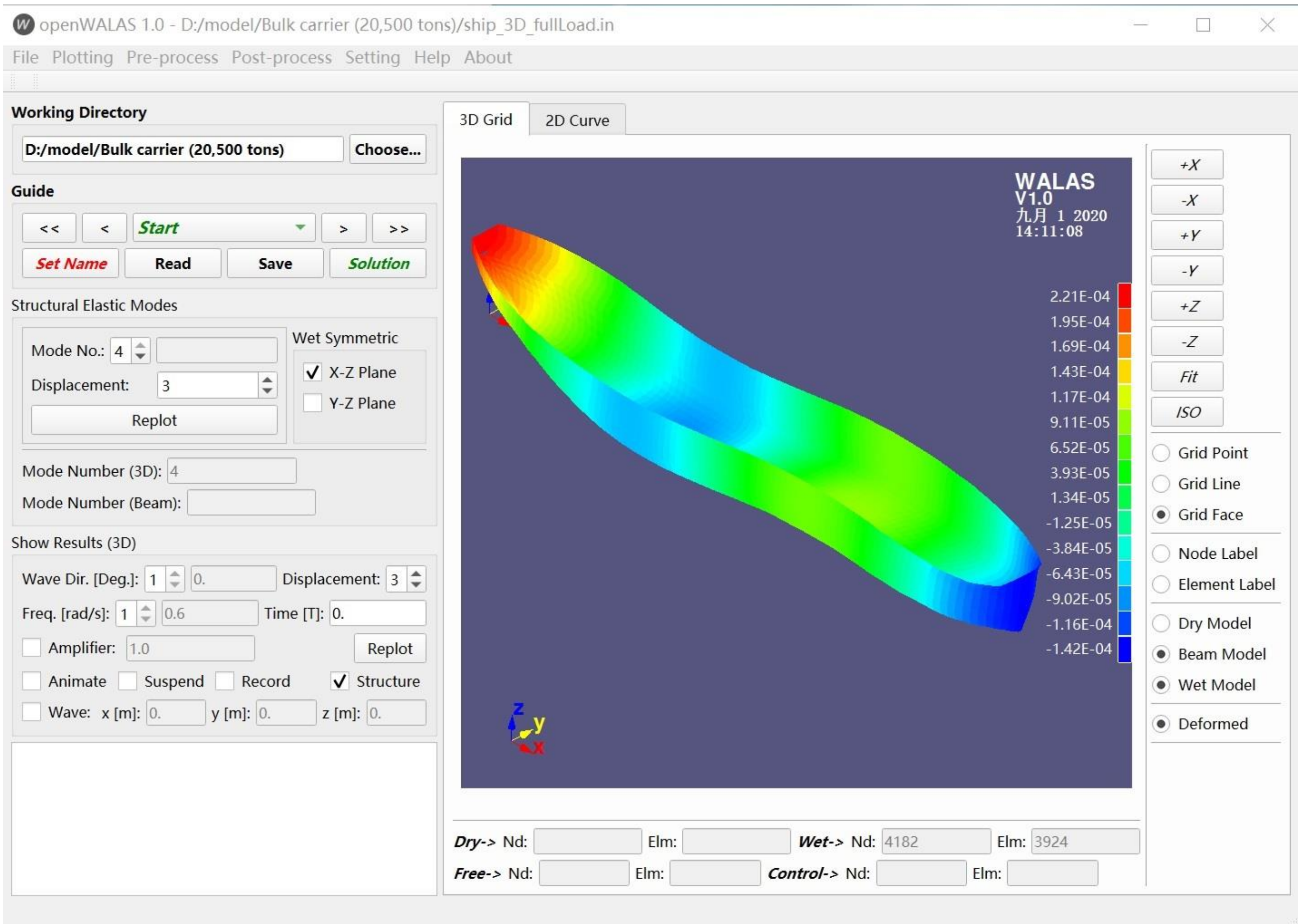

Fig. 1 OpenWALAS GUI

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. Function

OpenWALAS 程序包括船体网格自动划分、船体网格切分、直梁模态分析、横剖面特性计算等功能，以及三维模型显示和二维曲线绘制功能。

1.1.3. Running squence

（一） 方式一：运行 OpenWALAS 界面完成输入参数设置、计算和后处理绘图，在界面中完成一切操作。

（二） 方式二：手动调用

(1) 三维频域模块：OpenWALAS_PRE-> OpenWALAS_FSCM。

(2) 三维间接时域模块：OpenWALAS_PRE-> OpenWALAS_FSCM -> OpenWALAS_TIME_RESP。

(3) 三维直接时域模块：OpenWALAS_PRE -> OpenWALAS_TDGF or OpenWALAS_IORM -> OpenWALAS_TIME_RESP。

1.1.4. Ways of input parameters

本程序输入参数方法有两种：

（1）方式一-窗口界面，见第 3 章；

（2）方式二-文本输入方式，见第**错误!未找到引用源。**章。

1.2. Compiling and development environments

程序语言：C/C++；

程序编译环境：Qt + Eclipse + MinGW（GCC）+gsl；其中 Qt（C++）为 WALAS 的窗口界面开发库，Eclipse 为集成开发环境；minGW（GCC）为 C 语言编译器，gsl 为 C 数值计算库。

开发环境版本：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

本软件适用于 Window XP、Win 7、Win 8、Win 10 等主流 Win 操作系统，发布有 32 位和 64 位程序。

本软件套件同时适用于 Linux、Unix 和 Mac OS 操作系统，发布有 32 位和 64 位程序。

MSC.Patran/Nastran 2005 或更高版本（仅在结构弹性模态分析中需要）。

2. Theoretical fundamental

2.1. Coordinate systems

干结构坐标和湿面元坐标均是：*x* 正方向指向船头，*y* 指向左舷，*z* 指向上，符合右手法则。

干结构坐标系可以与湿面元坐标系不一样，但是要在 case.in 文件中指明。

在程序内部计算和输出结果中，所有的坐标原点均转换到湿坐标原点在静水面投影处（即在内部计算使用参考坐标系）。

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.

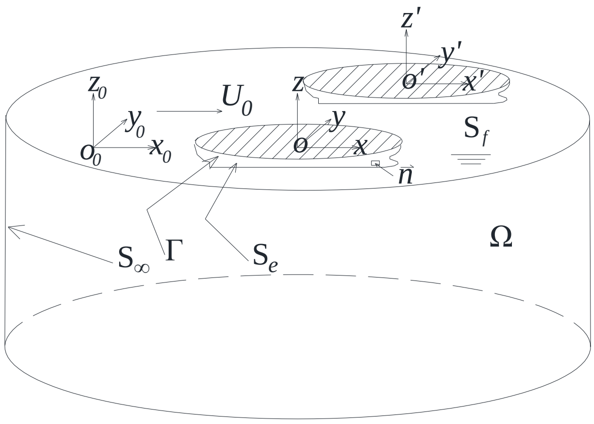

Fig. 2 Sketch of the coordinate systems

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.

$$\begin{cases} x_0 = x + U_0 t, y_0 = y, z_0 = z, \nabla_{x_0} = \nabla_x \\ \left.\frac{\partial}{\partial t}\right|_{x_0} \rightarrow \left.\frac{\partial}{\partial t}\right|_x - U_0 \left.\frac{\partial}{\partial x}\right|_x \end{cases} \quad (1)$$

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.

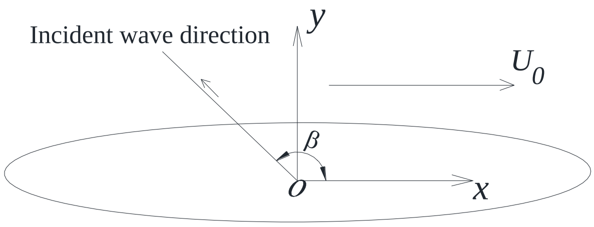

Fig. 3 Sketch of wave direction

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

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

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

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

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

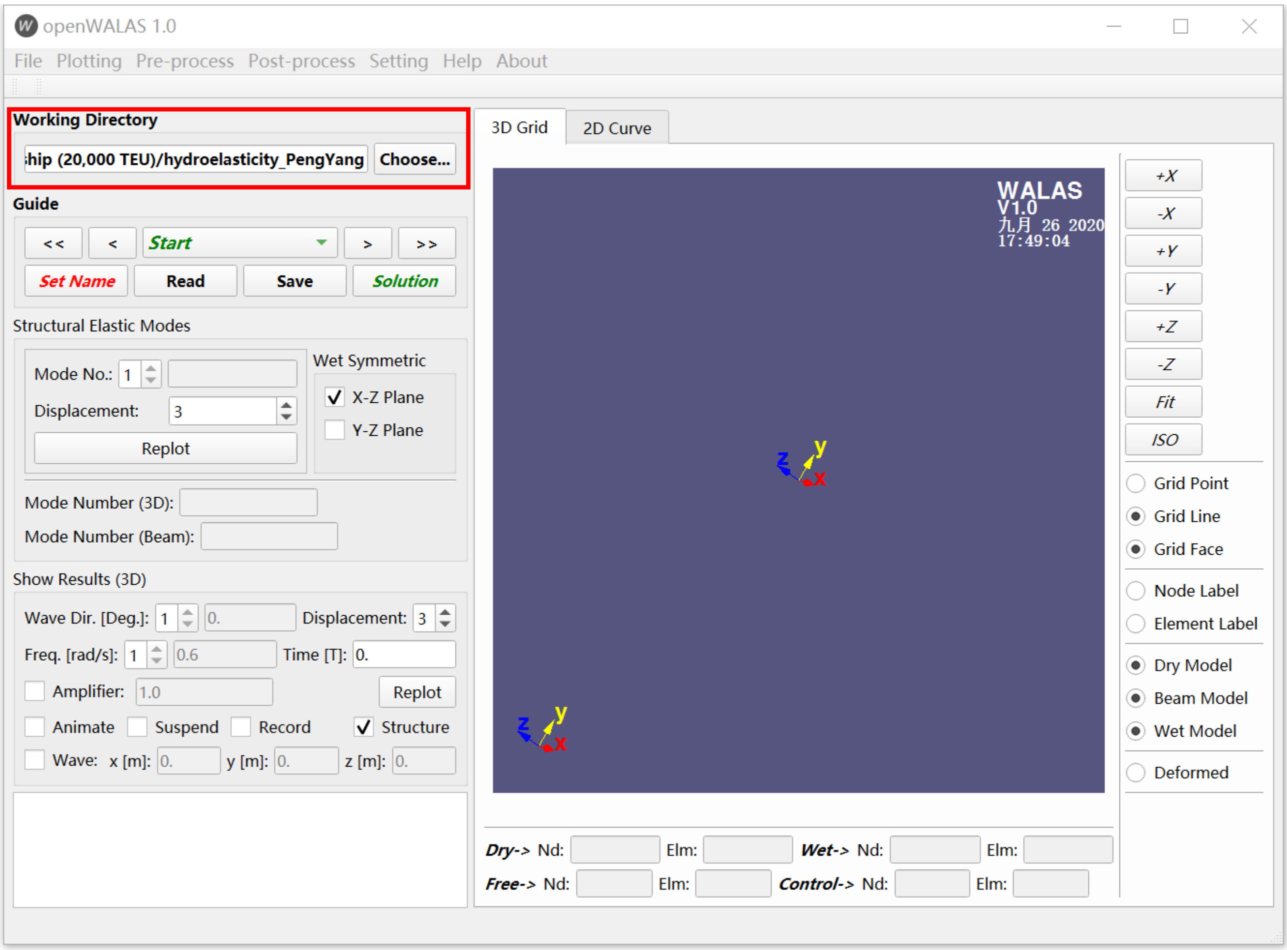

Fig. 4 Working directory

3.1.2. Set a file name of floating structures

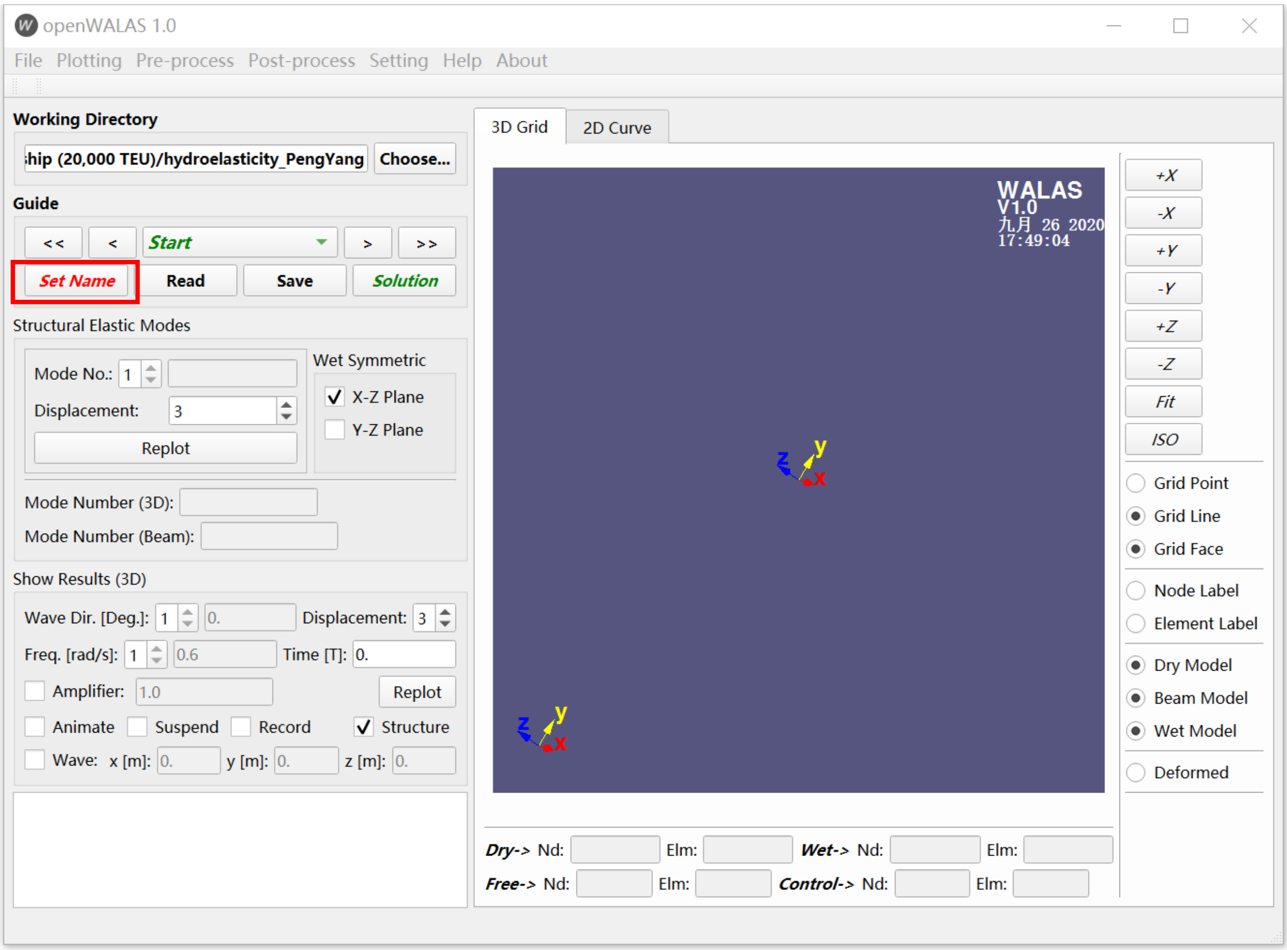

Fig. 5 File name

3.1.3. Show dry model

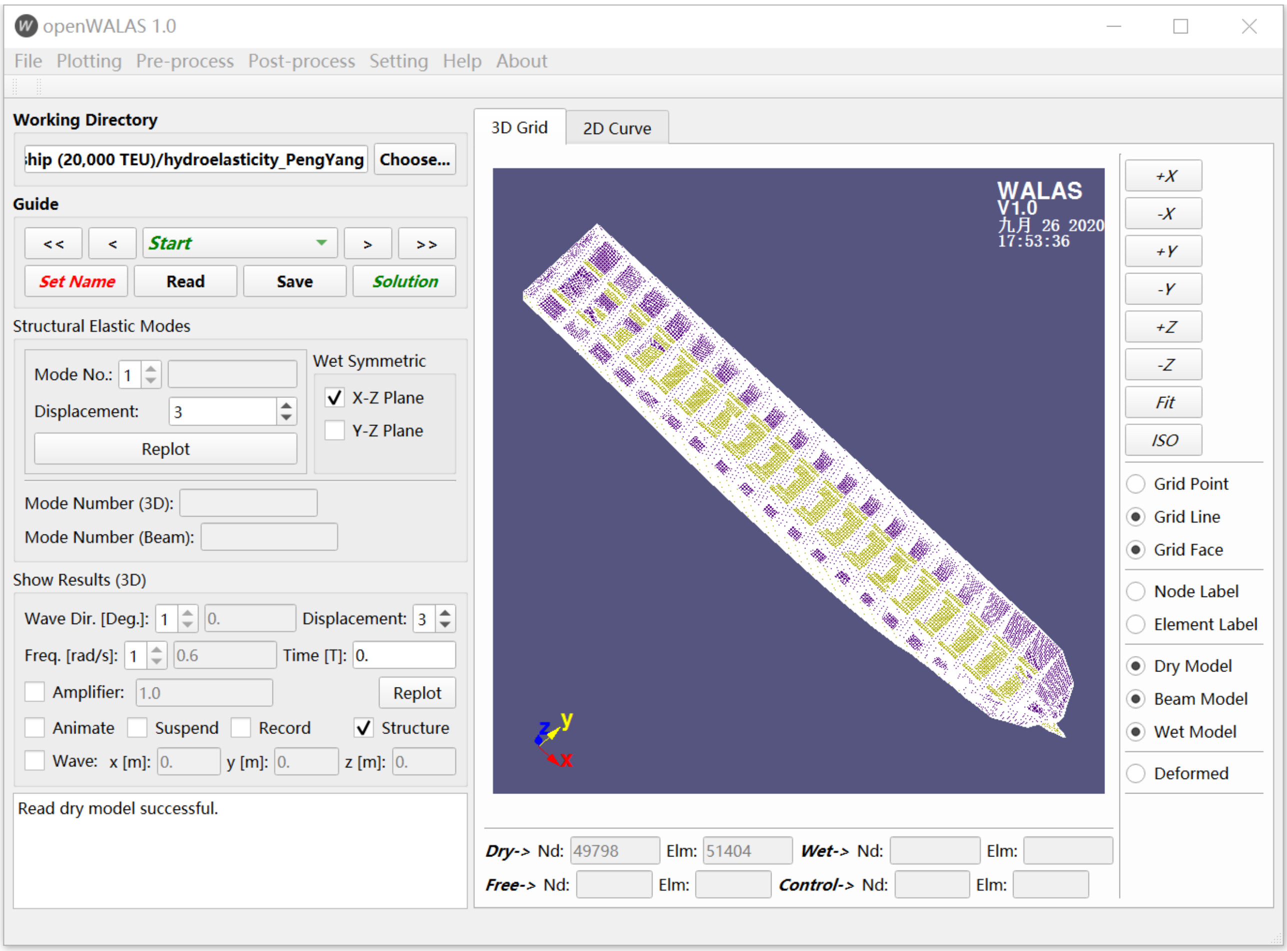

Fig. 6 3D FEM model

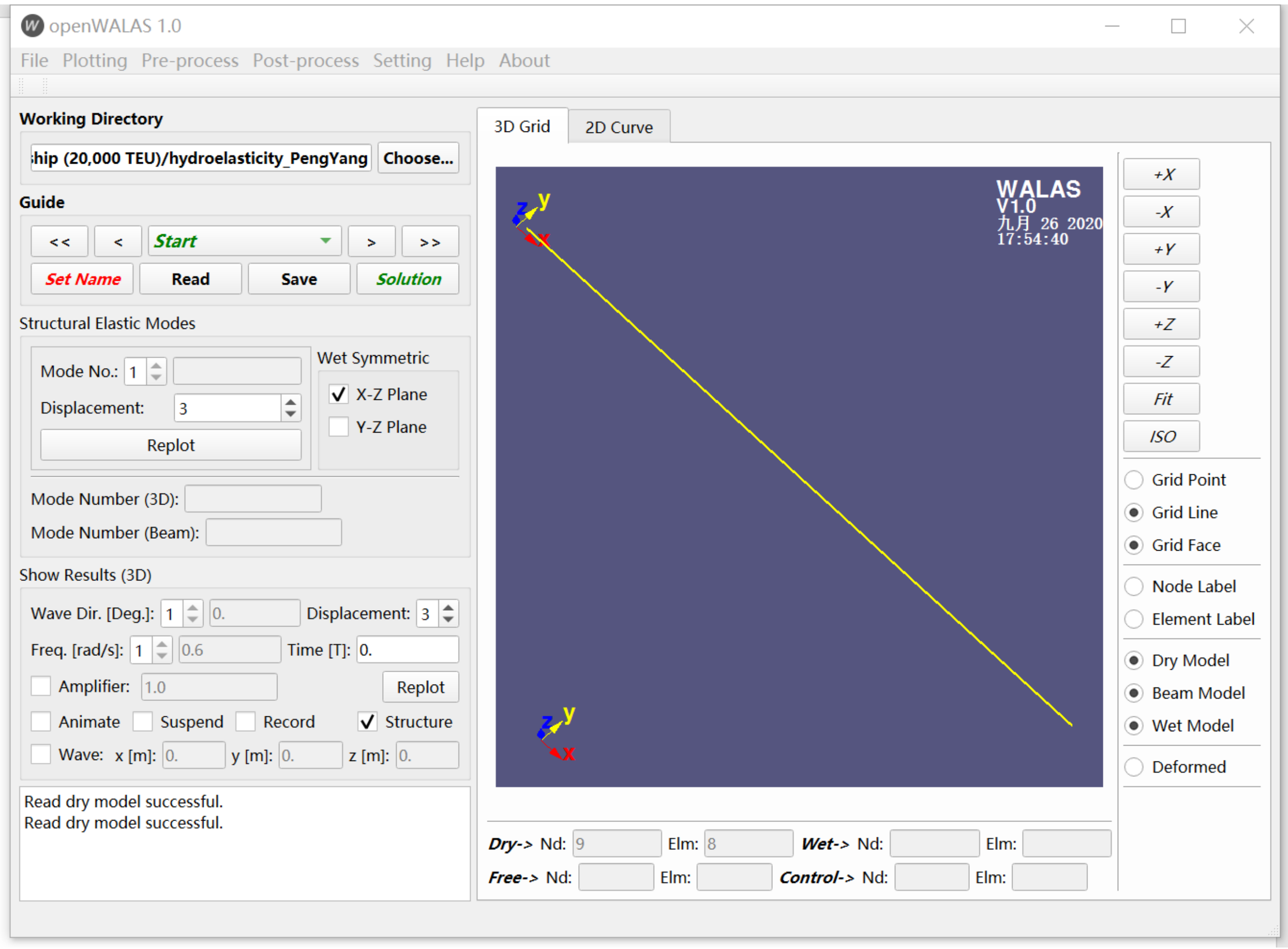

Fig. 7 1D beam model

3.1.4. Show wet model

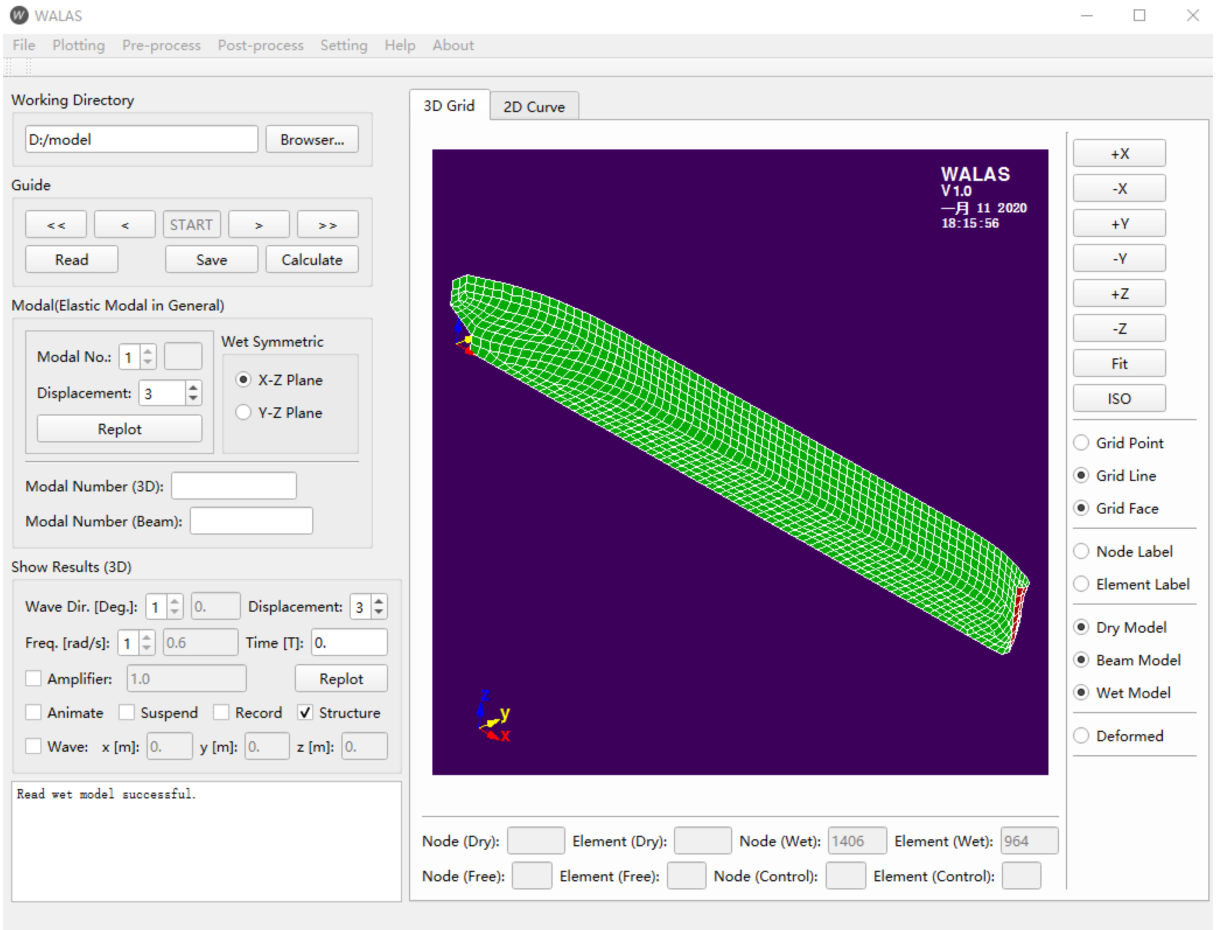

Fig. 8 三维湿模型

3.1.5. Show free surface model

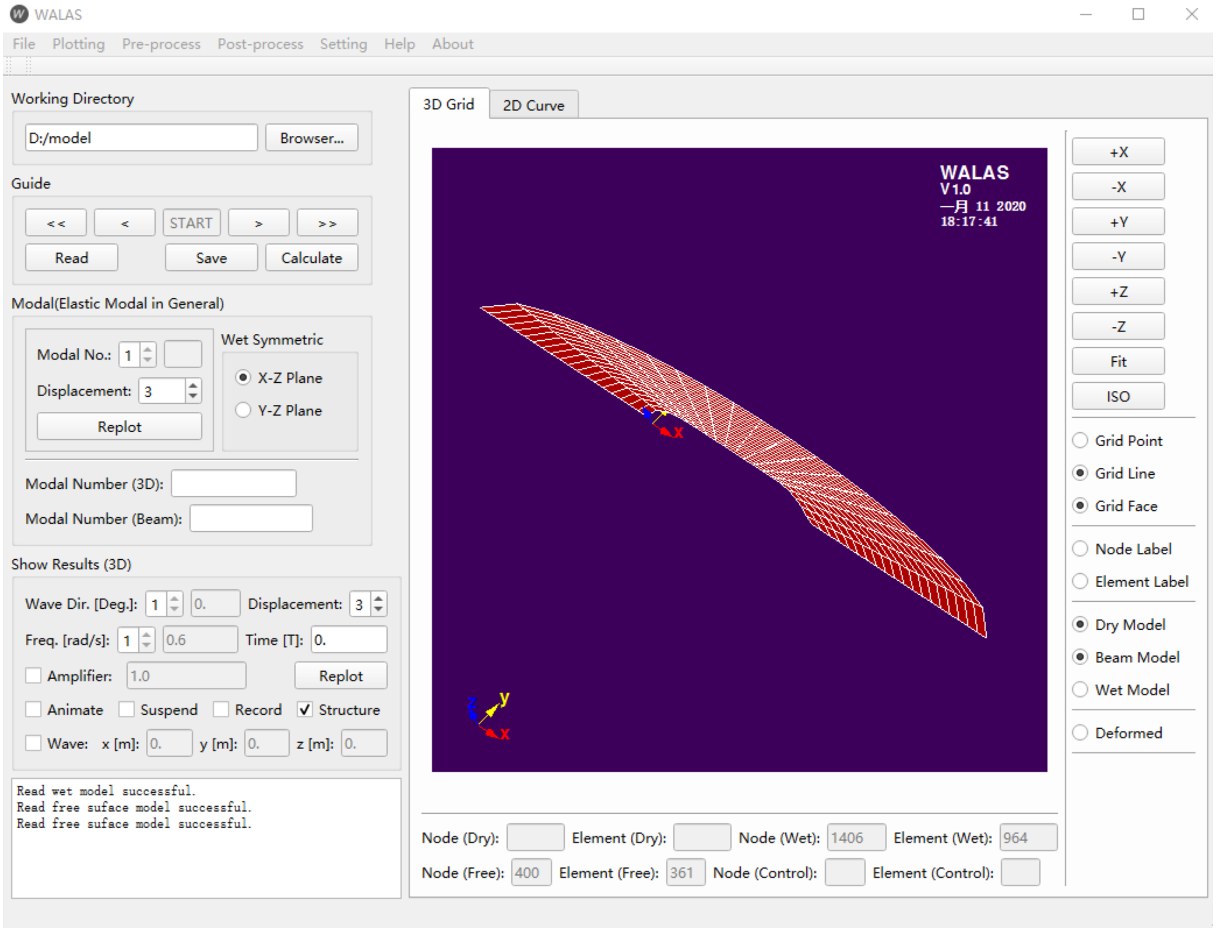

Fig. 9 自由面网格

3.1.6. Show control surface model

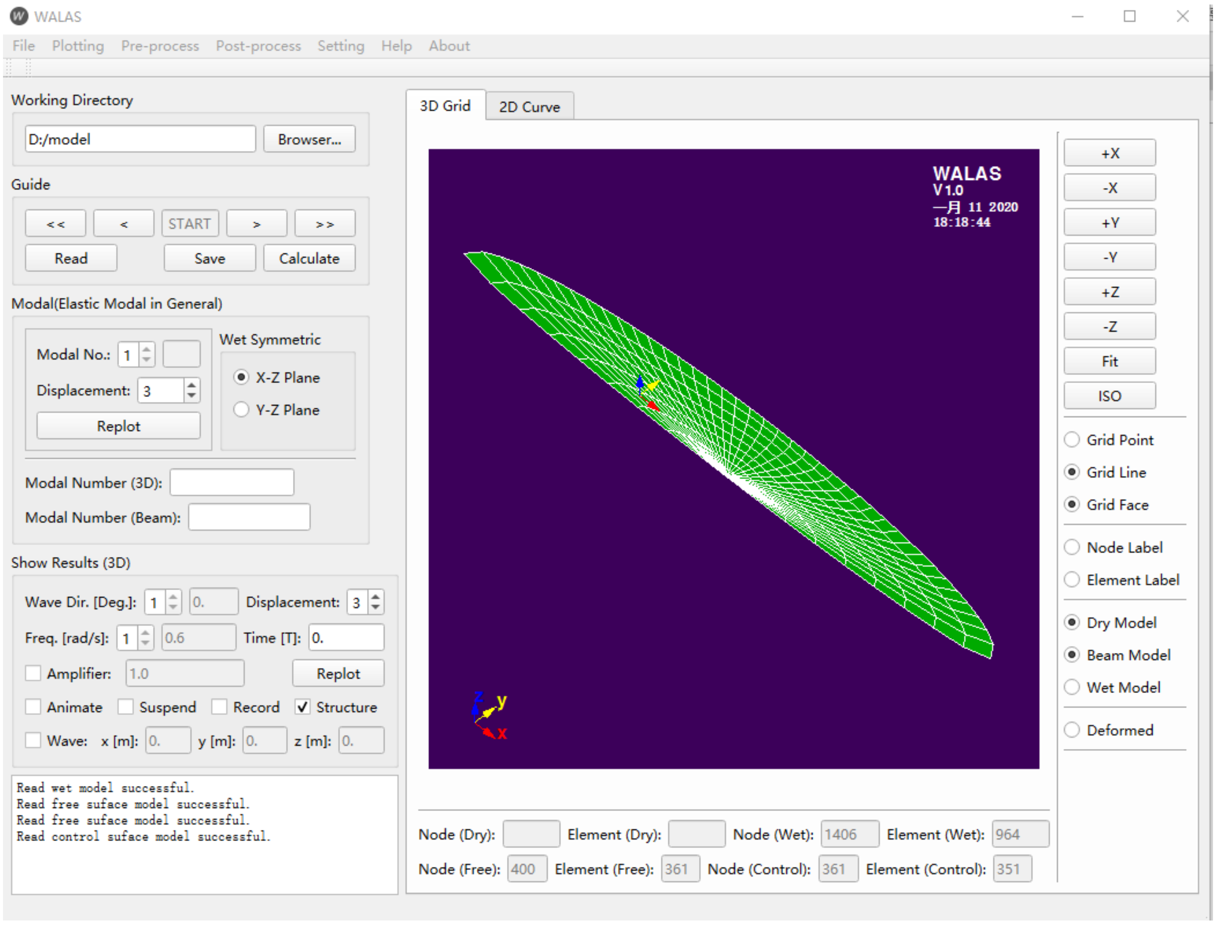

Fig. 10 控制面网格

3.1.7. Show modes of dry models

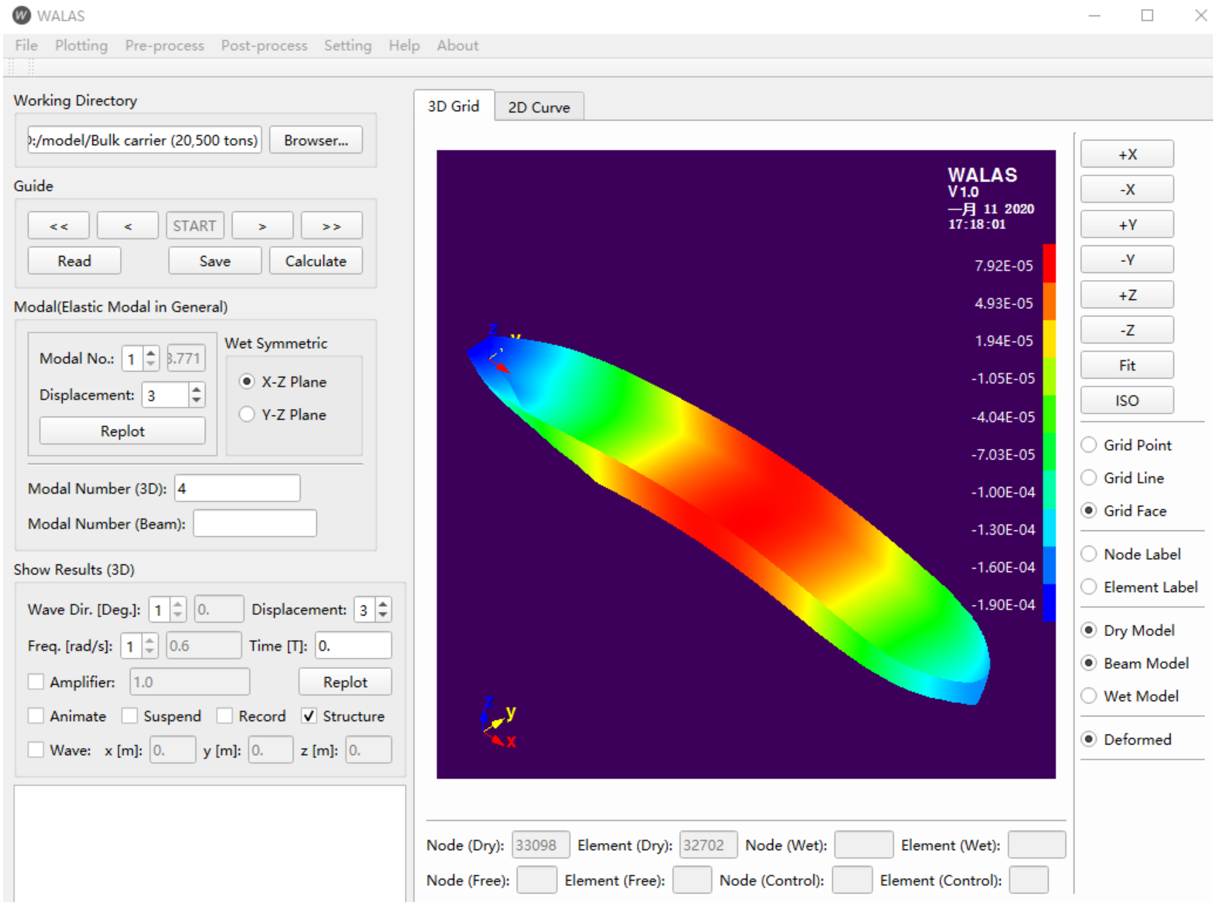

Fig. 11 三维结构 FEM 模型

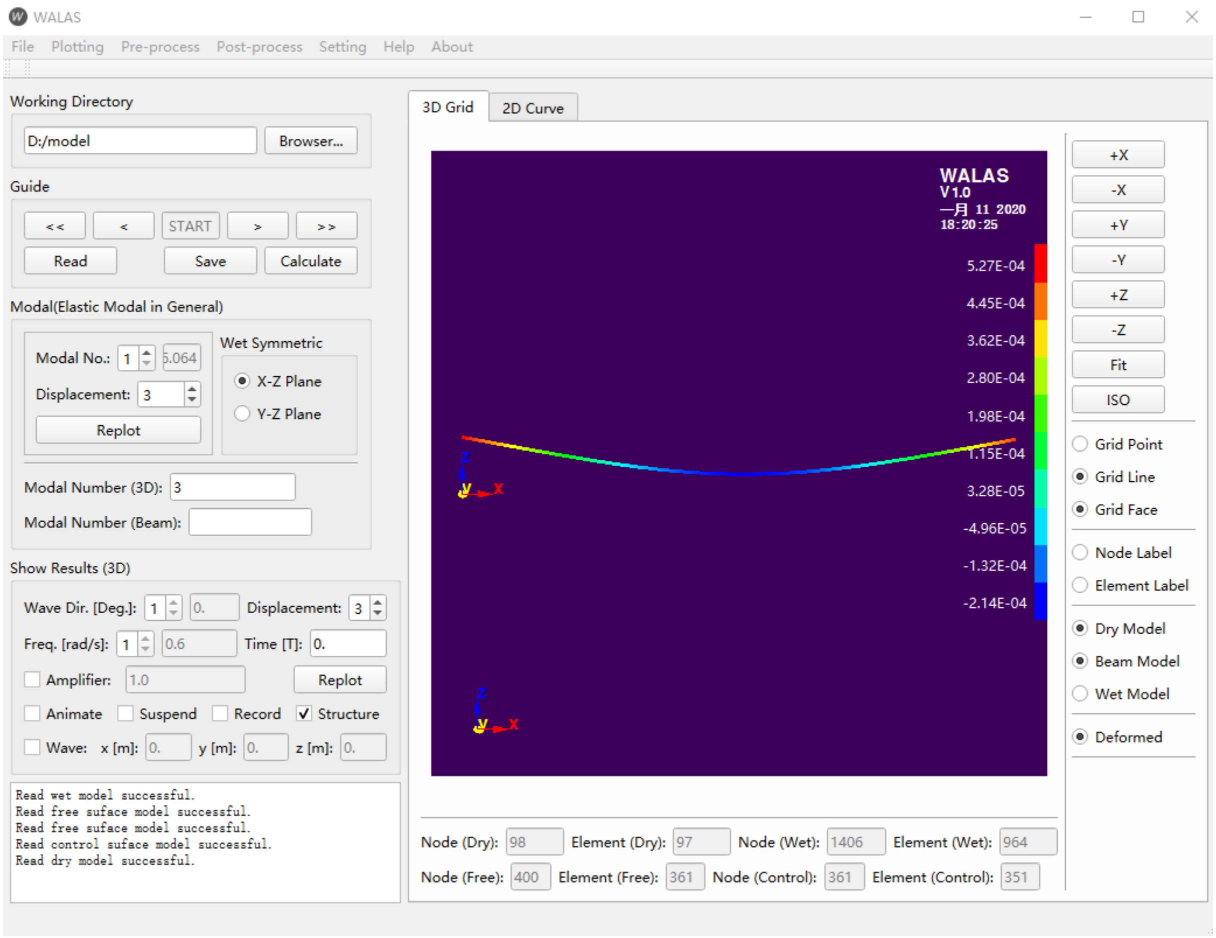

Fig. 12 Beam FEM 模型

3.1.8. Show modes of wet models

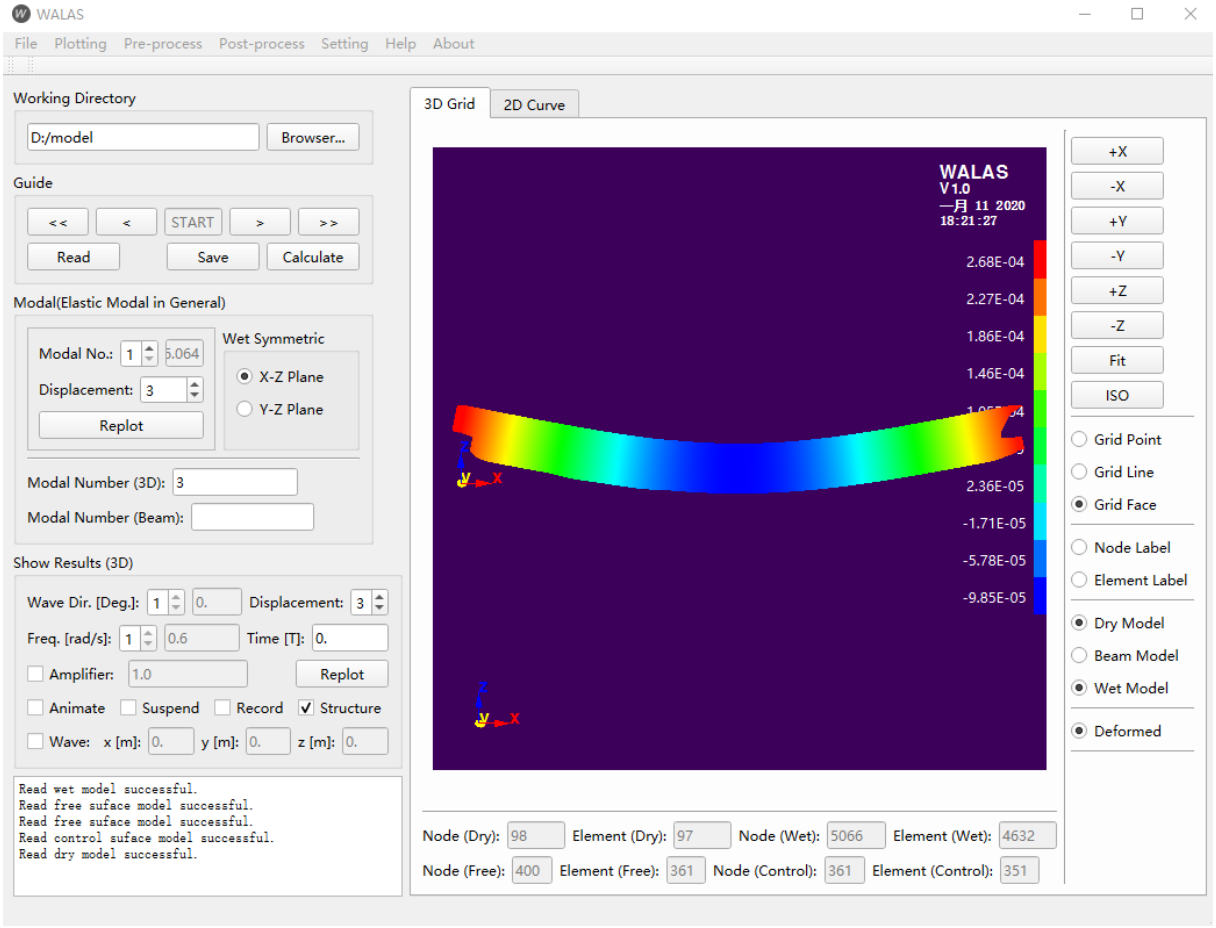

Fig. 13 湿模型

3.2. Pre-process

3.2.1. Grid meshing

(1) Meshing on ship hull

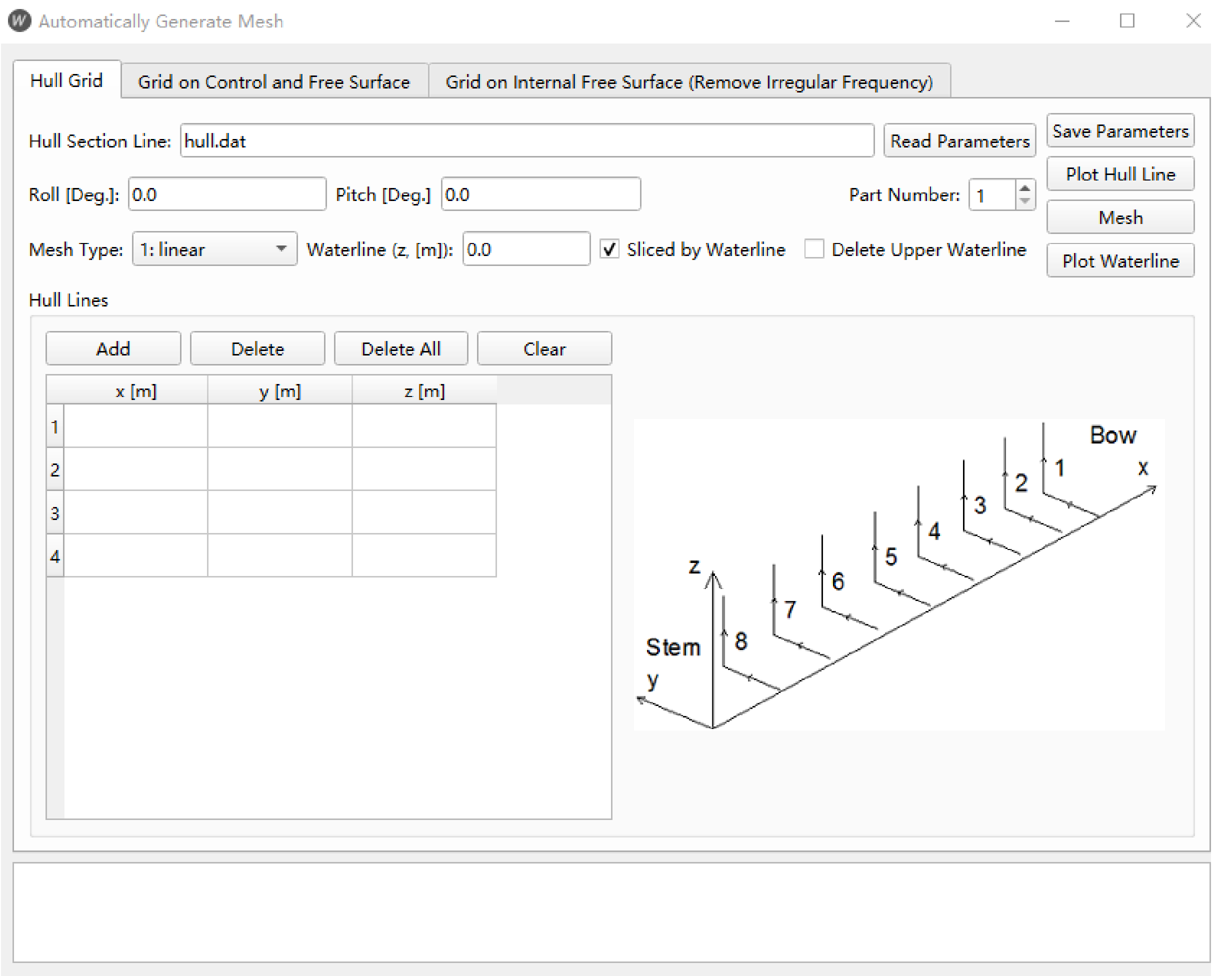

Fig. 14 Grid on ships

（2）Meshing on free surface and control surface

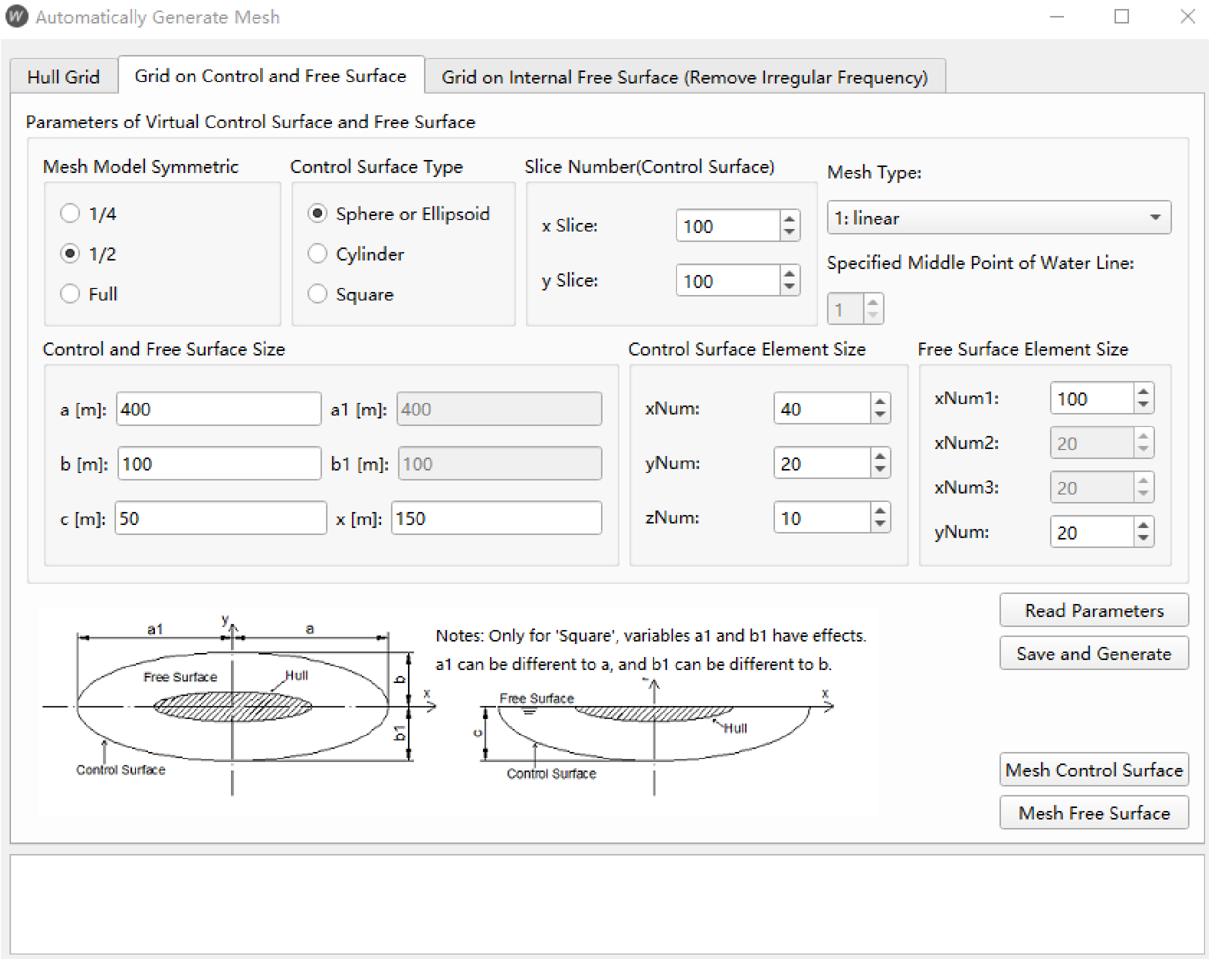

Fig. 15 自由面和控制面

（3）划分内部自由面网格

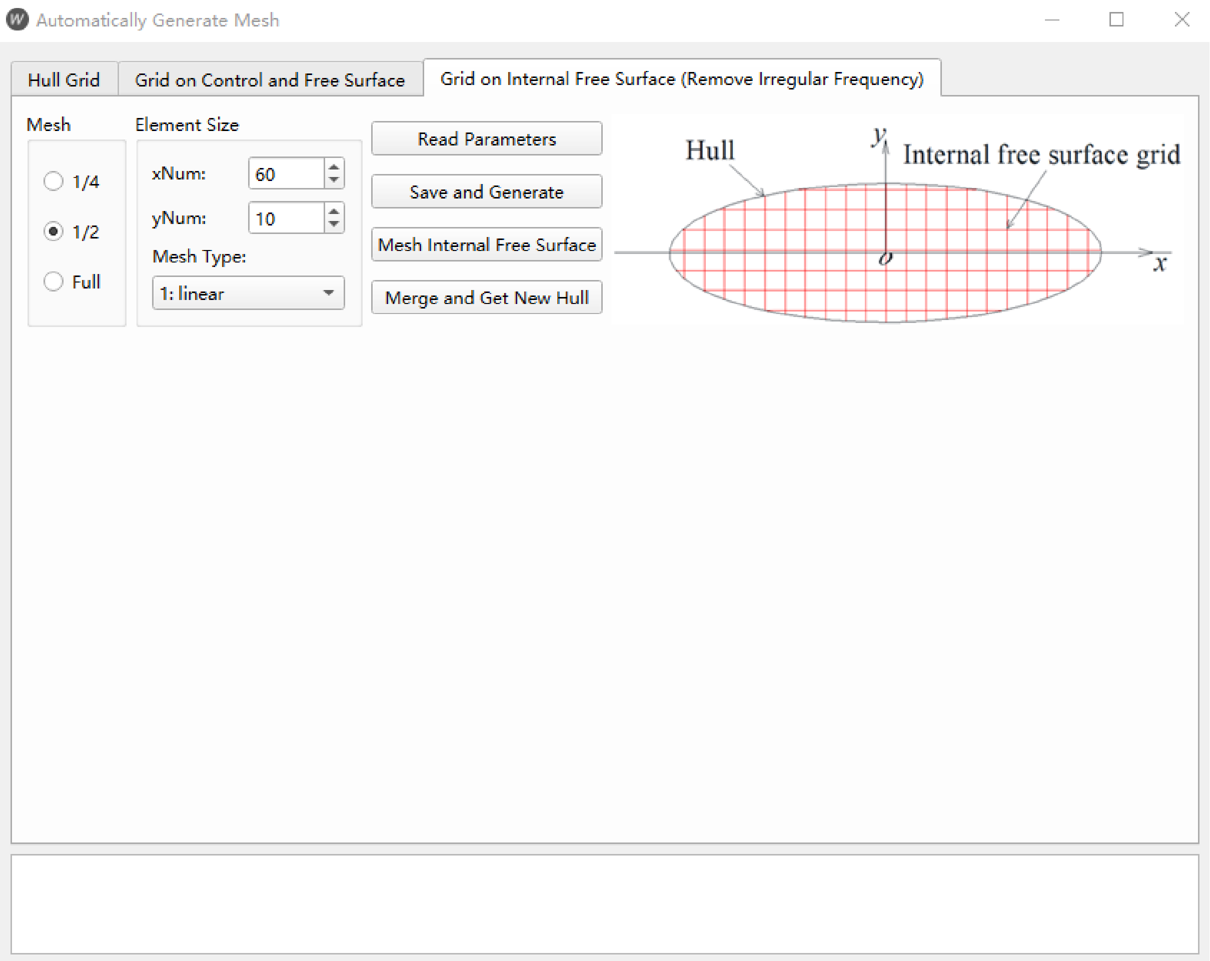
Automatically Generate Mesh
Hull Grid
Grid on Control and Free Surface
Grid on Internal Free Surface (Remove Irregular Frequency)
Mesh
1/4
1/2
Full
Element Size
xNum:
60
yNum:
10
Mesh Type:
1: linear
Read Parameters
Save and Generate
Mesh Internal Free Surface
Merge and Get New Hull
Hull
y
Internal free surface grid
o
x

Fig. 16 内部自由面

3.2.2. Splitting grid

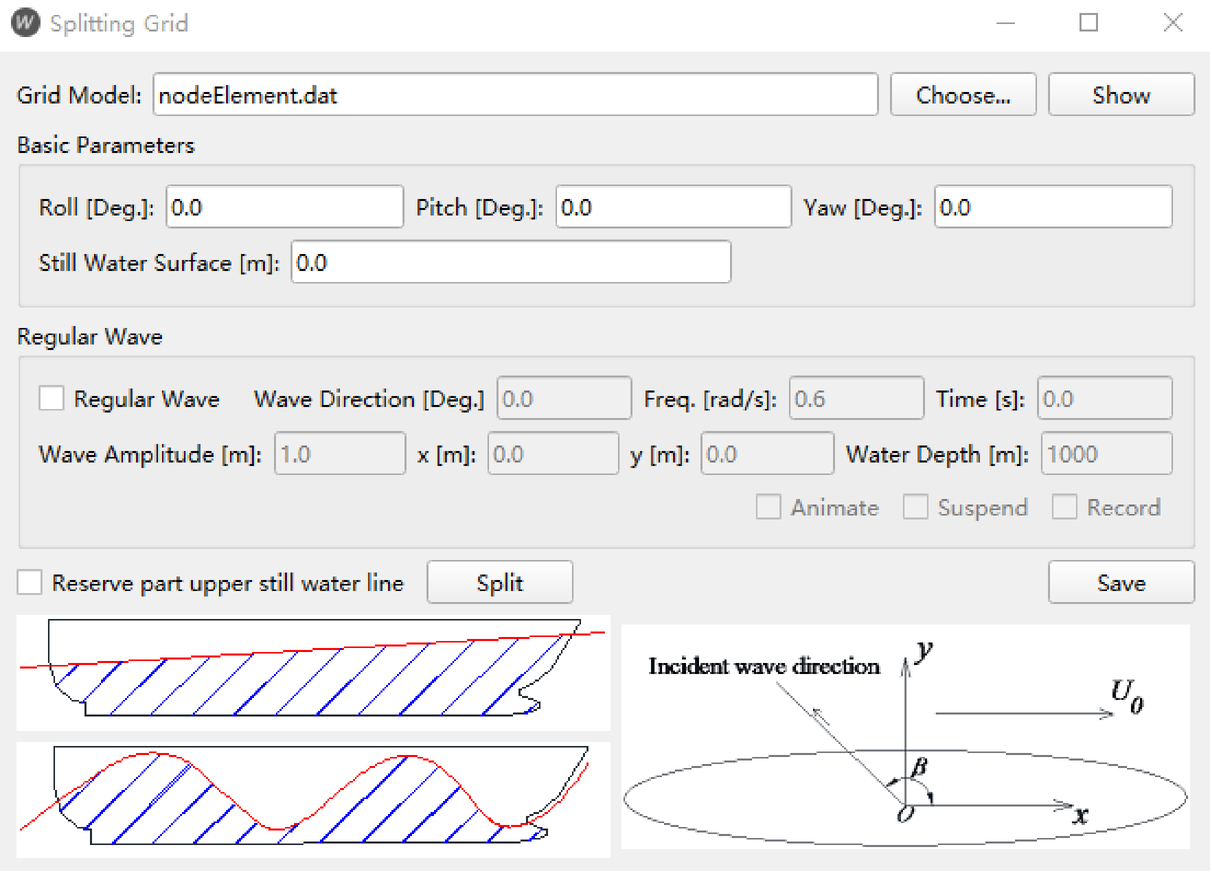

Fig. 17 Splitting grid

3.2.3. Natural frequency prediction of uniform straight beam

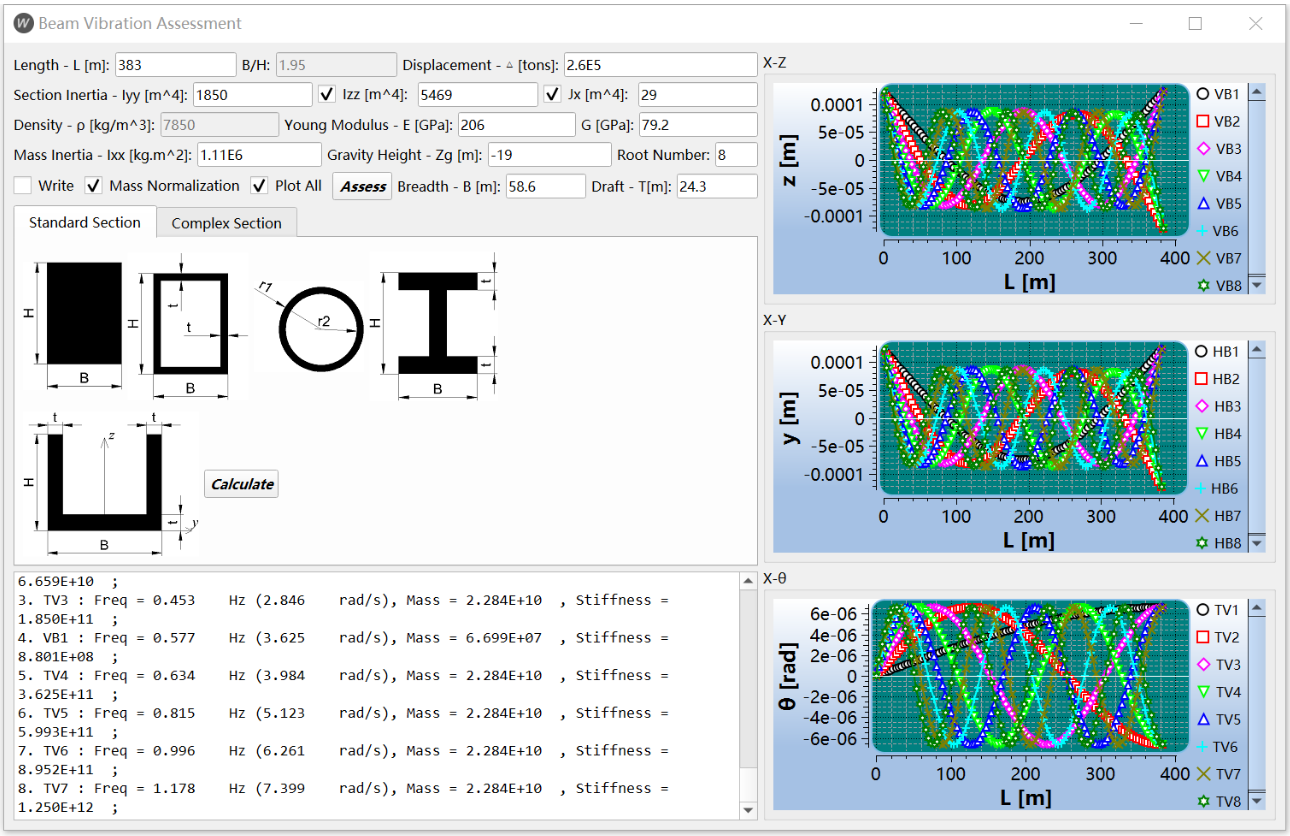

Fig. 18 Natural frequency prediction

3.3. Input parameters

3.3.1. Step 1-以 Patran 的.bdf 和.f06 文件作为湿面元和干面元输入

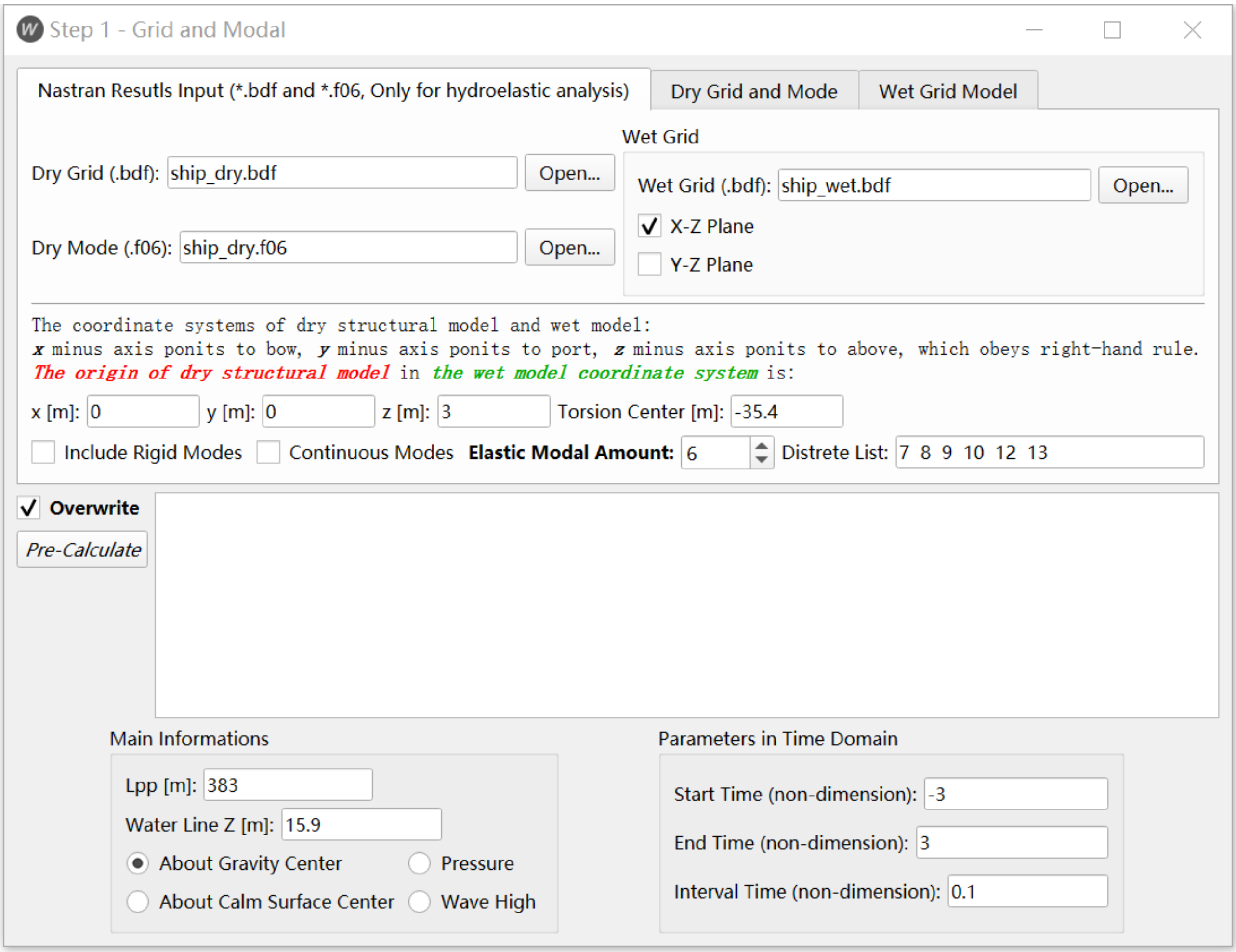

Fig. 19 Step 1

3.3.2. Step 2-重心和惯性矩

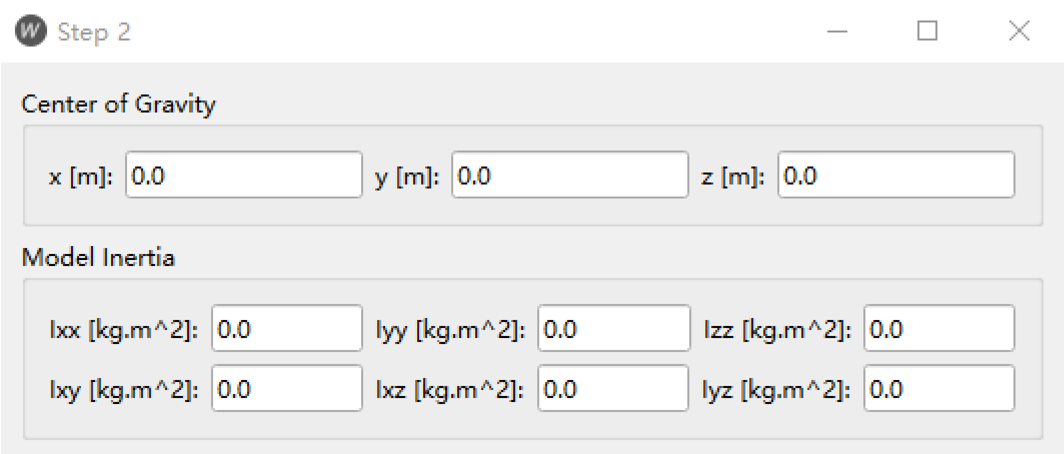

Fig. 20 Step 2

3.3.3. Step3-航速、流体密度、重力加速度和水深

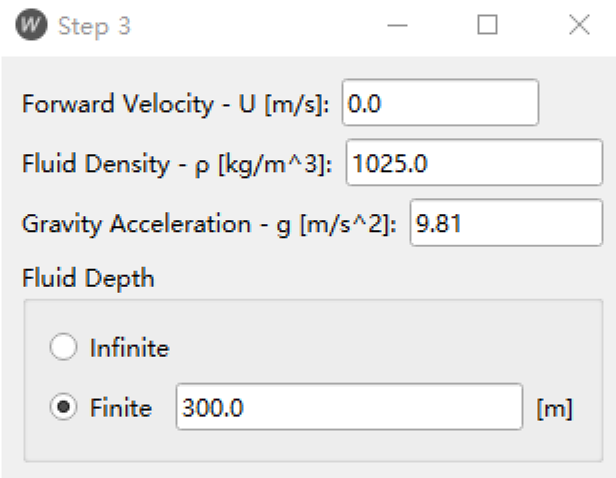

Fig. 21 Step 3

3.3.4. Step4-波浪频率或周期

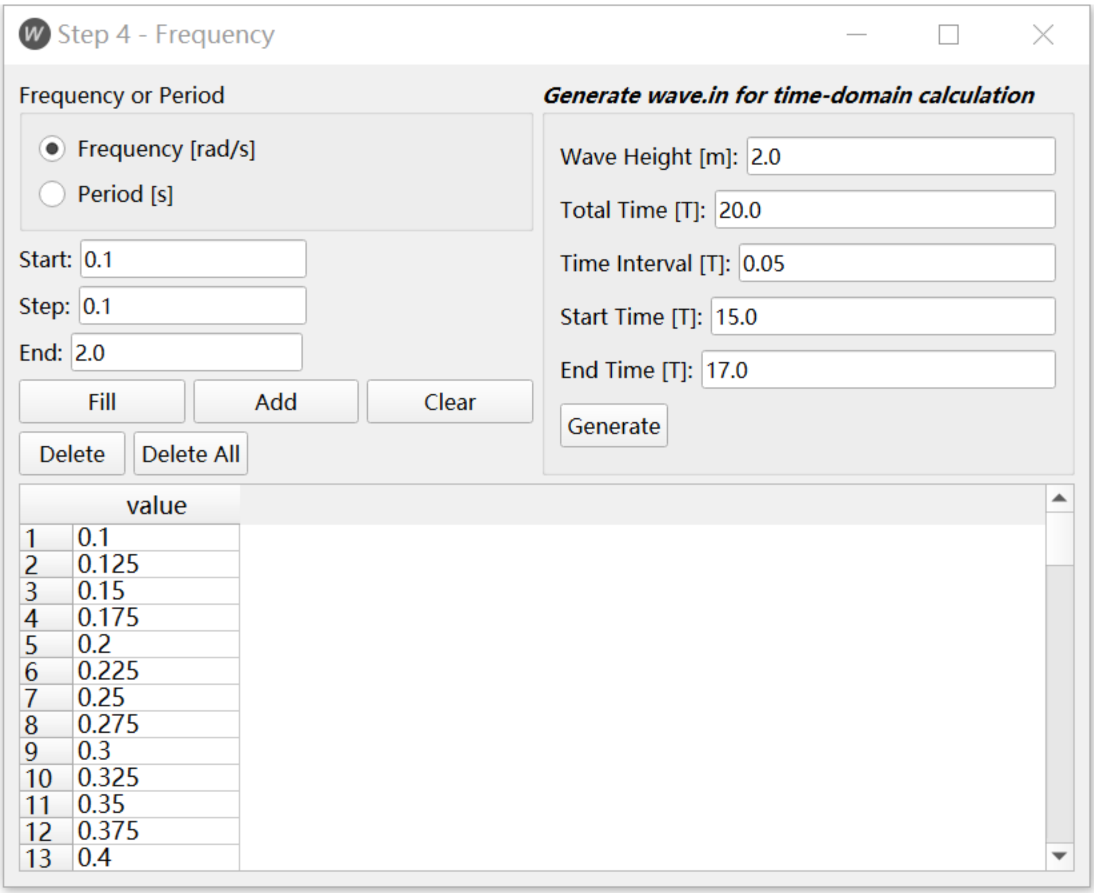

Fig. 22 Step 4

3.3.5. Step5-浪向

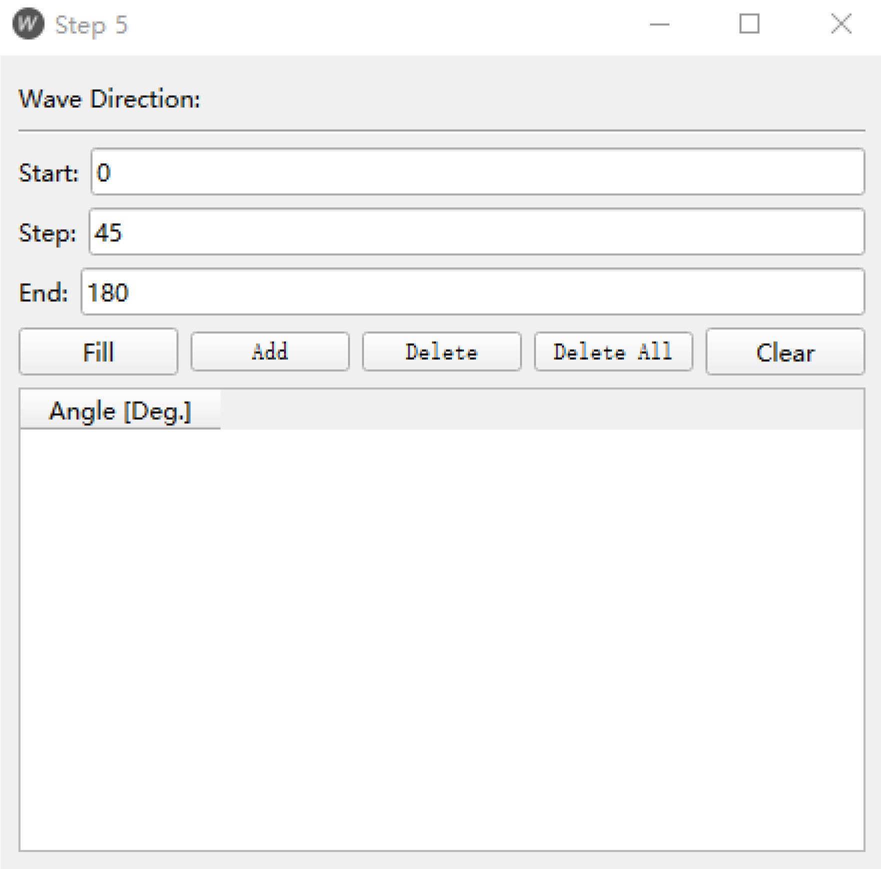

Fig. 23 Step 5

3.3.6. Step6-插值频率点和人工粘性系数

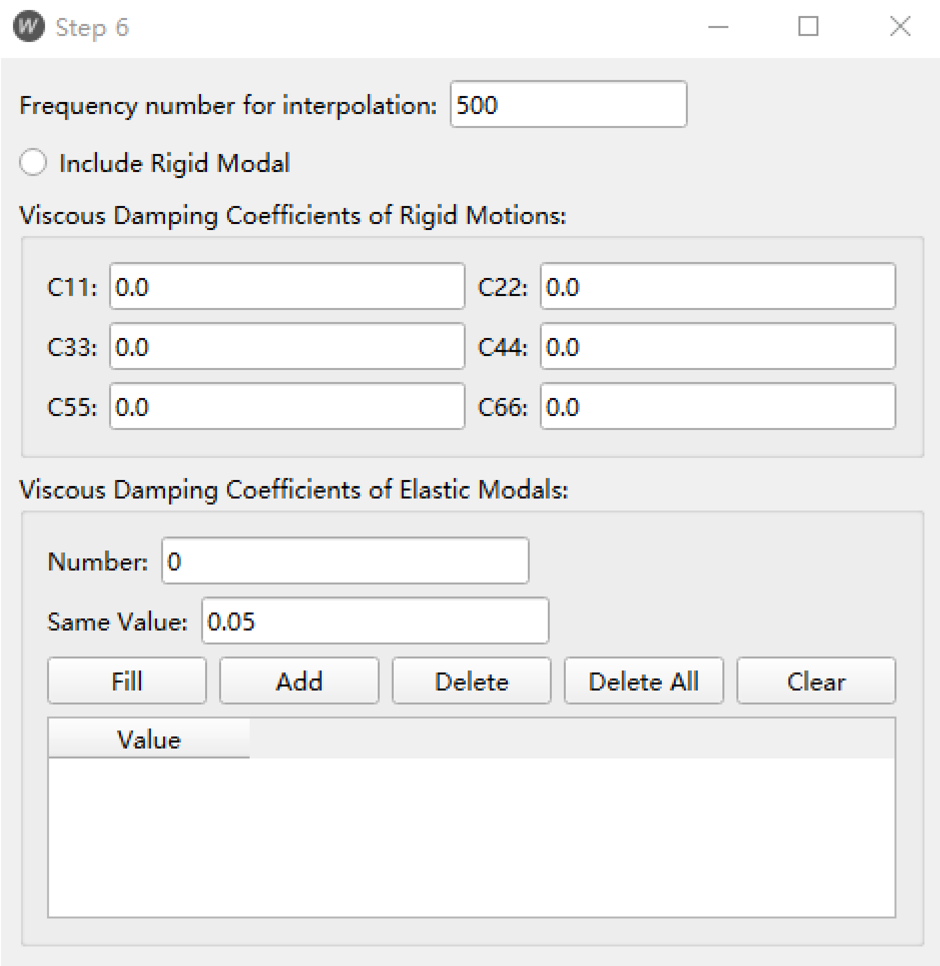

Fig. 24 Step 6

3.3.7. Step7-重量分布（用于载荷计算）和载荷剖面

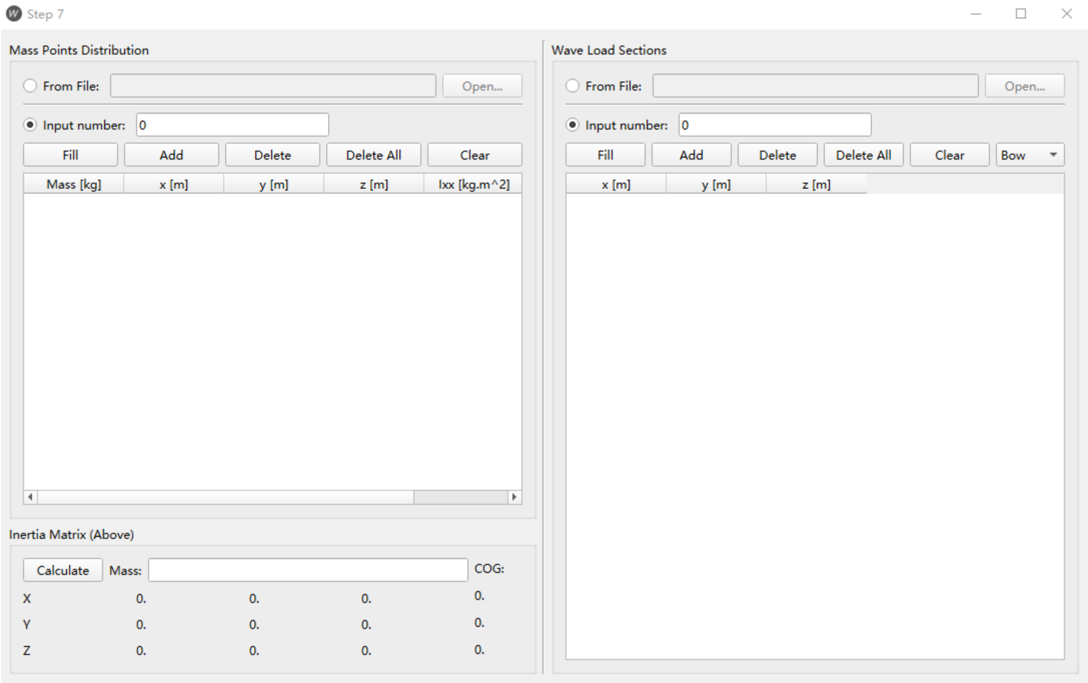

Fig. 25 Step 7

3.4. Solution

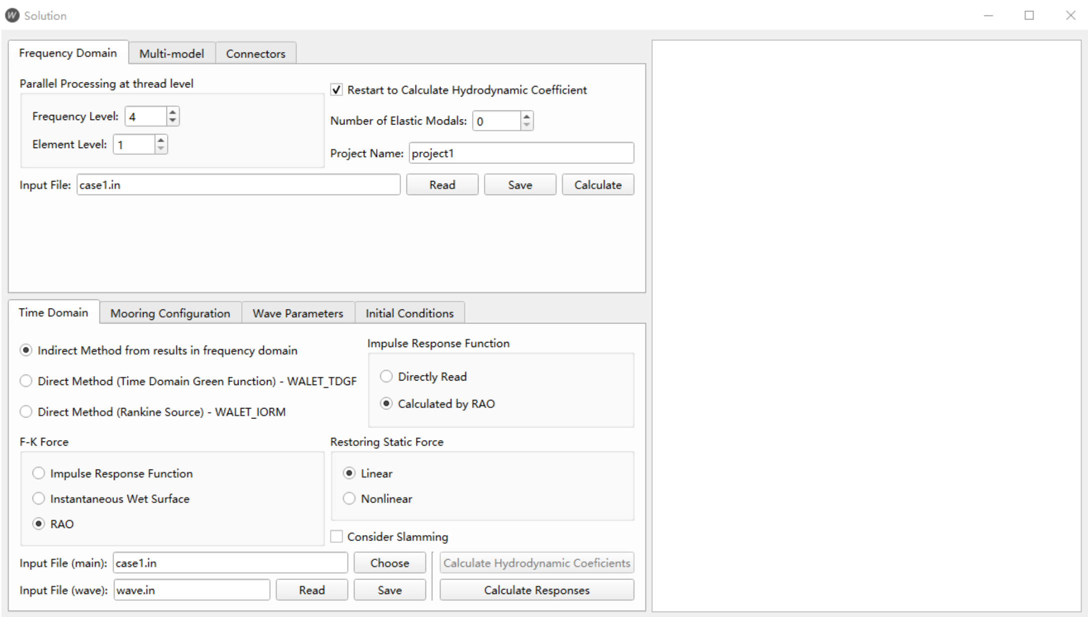

Fig. 26 Solution type

3.5. Post-process and show result

3.5.1. Basic informations

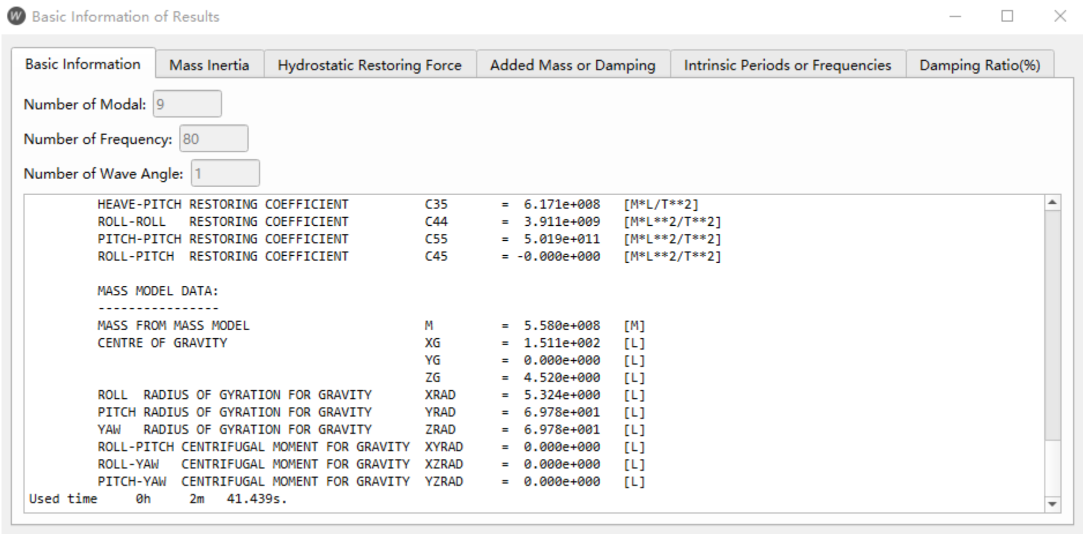

Fig. 27 基本结果

3.5.2. Results in frequency domain

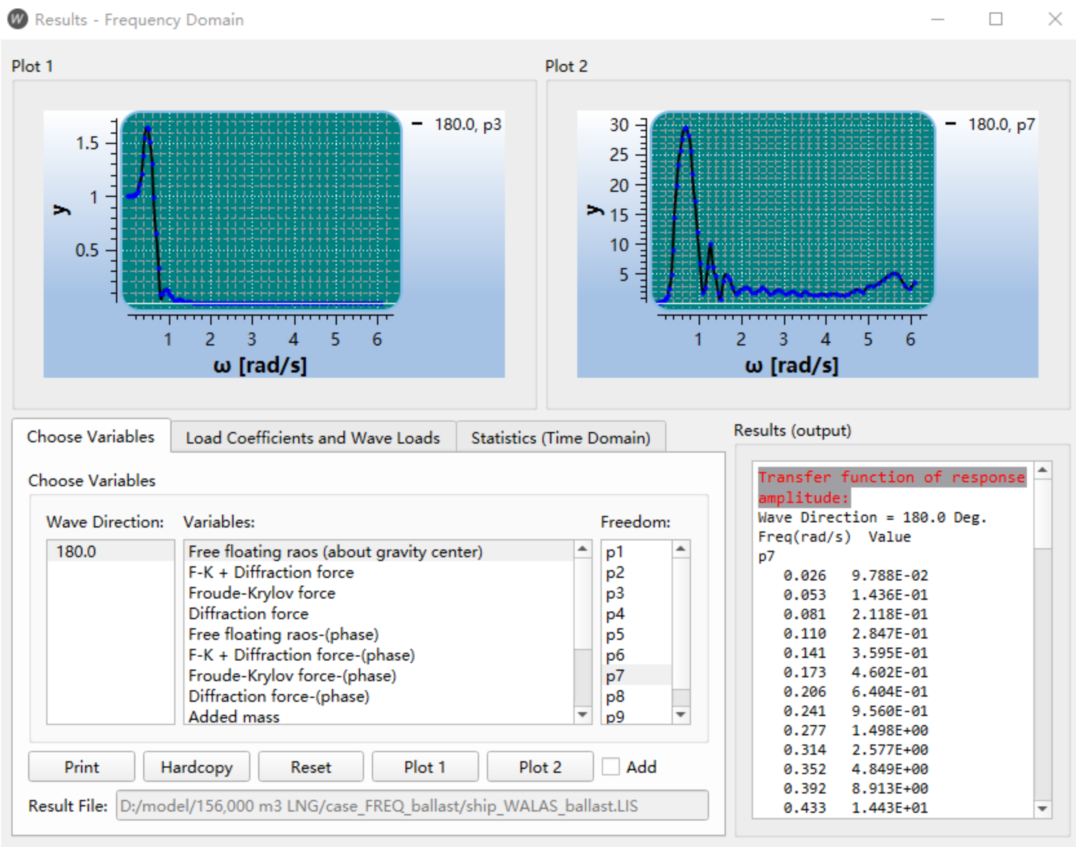

Fig. 28 Results in frequency domain

3.5.3. Results in time domain

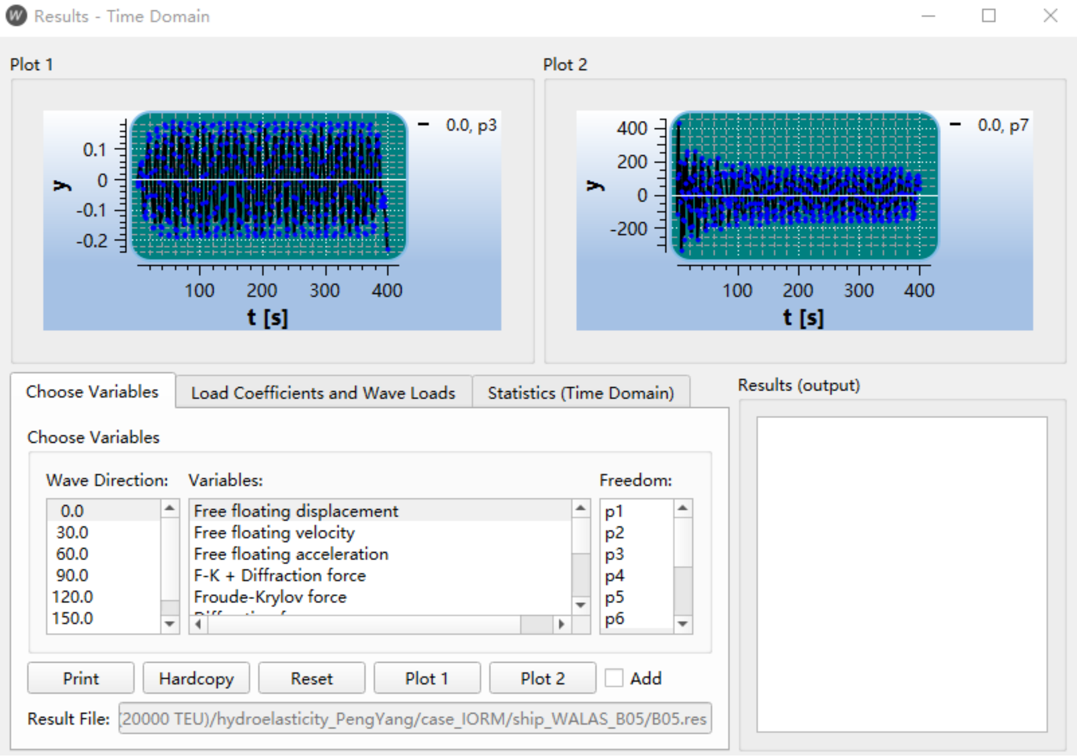

Fig. 29 results in time domain

3.5.4. Predictions in short-term

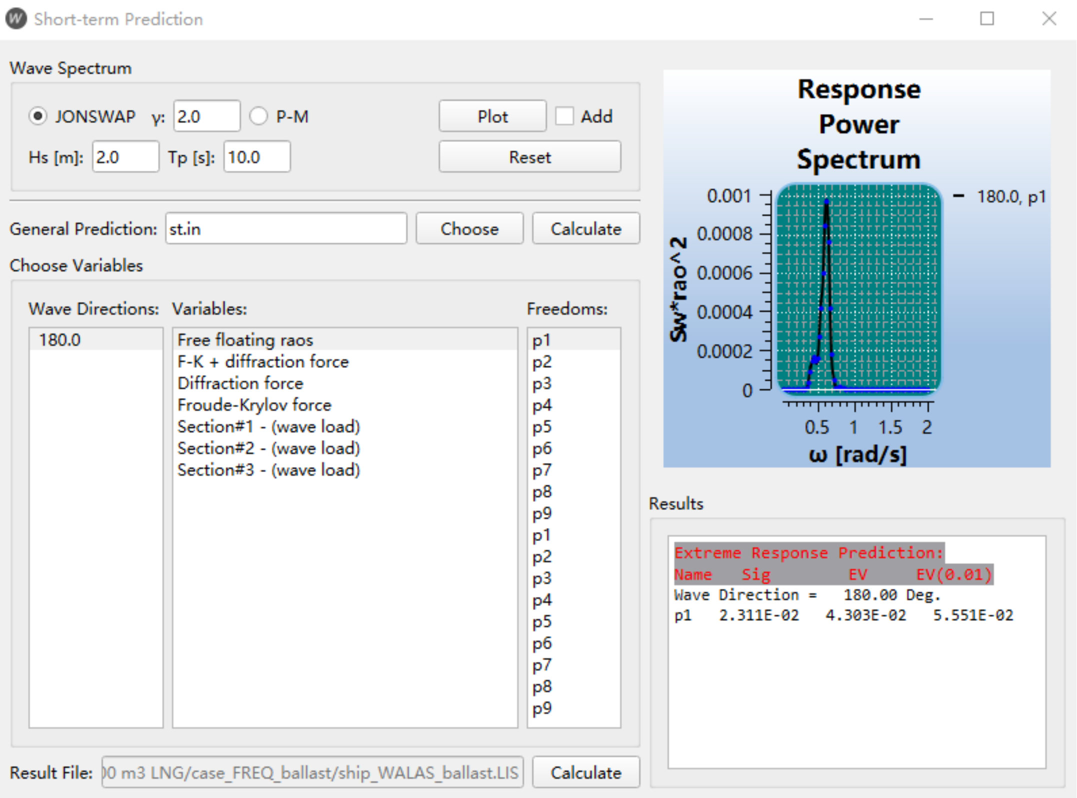

Fig. 30 Prediction in short-term

3.5.5. Predictions in long-term and fatigue analysis

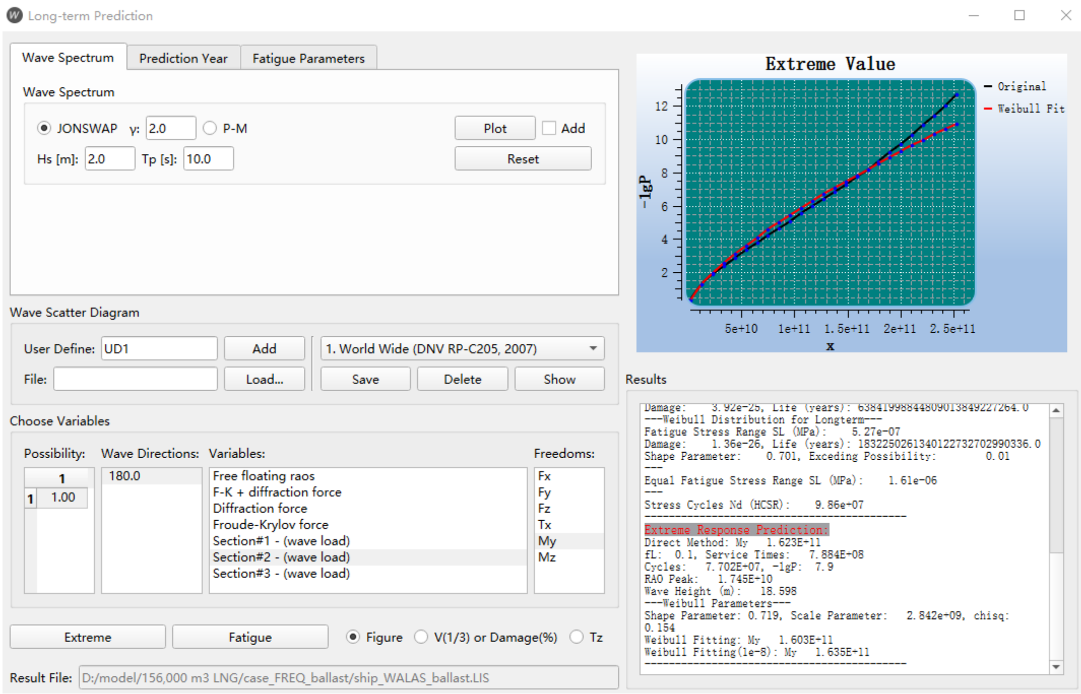

Fig. 31 Prediction in long-term

3.6. Basic definitions

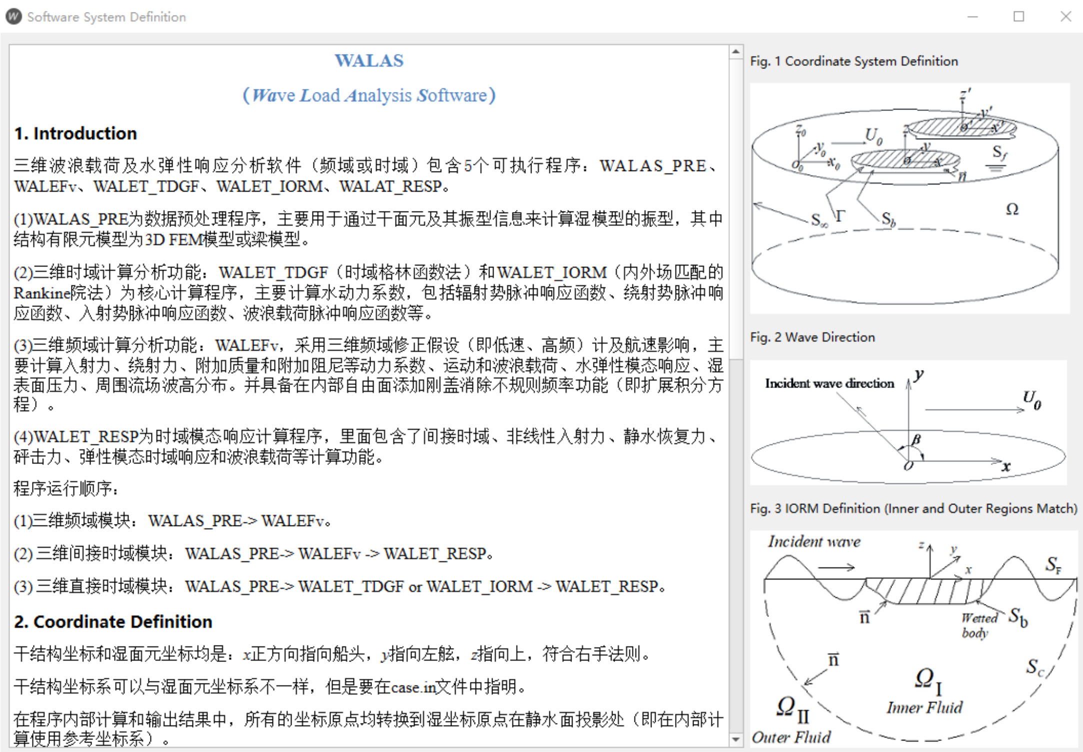

Fig. 32 Basic definition

4. Instruction of input files

四个输入文件：case.ini，ship1.in，ship_wet.bdf，ship_dry.bdf，ship.f06。

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

输入参数的文件，主要包括程序的控制参数，不需要经常修改。

4.1.1. Identity of input file

JOB WALAS MULTI

4.1.2. Parameters of parallel calculation

threadNumFreq threadNumElem

threadNumFreq：线程并行数量（频率并行）

threadNumElem：线程并行数量（单元并行）

4.1.3. Control parameters of hydrodynamic coupling among floating structures

STRCNUM startCoupleNo

STRCNUM：模块数量

startCoupleNo：开始耦合模块编号

4.1.4. Control parameters of structural modes

modalNum wetDryFlag restartFlag dampFlag_con

modalNum：模态数量(包括刚体和弹性体模态)

wetDryFlag：连接器节点来自湿面元或干面元；0:湿面元，1:干面元，含有弹性模态时必须为来自干面元

restartFlag：是否重新计算水动力系数，0：否，1：Yes

dampFlag_con：人工粘性阻尼为阻尼比还是阻尼系数；0:damping ratio, 1: coefficient

4.1.5. Input parameters and file name of different floating structures

file[n]

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

FIXED

Damp1 Damp2 Damp3 ……

Note：

file[n]：以双引号括住

x[n] y[n] Rz[n]：(*x*, *y*)为浮体需要移动的向量，Rz 以当前浮体重心为旋转点绕 z 轴旋转角度（单位：度）

FIXED：浮体是否固定，0：No, 1: Yes

Damp[n]：阻尼比或阻尼系数（由 DampFlag 决定，包含 6 个刚体模态+ElasNum 个弹性模态）

4.1.6. Connector definition

CONNUM

strcNo1 pointNo1 strcNo2 pointNo2 stiff1 stiff2 stiff3 stiff4 stiff5 stiff6

CONNUM：连接器数量

strcNo1、strcNo2：浮体编号

pointNo1、pointNo2：节点编号

stiff1 stiff2 stiff3 stiff4 stiff5 stiff6：平动和转动方向的刚度

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

参数输入文件（最重要的文件），主要包括模型信息。

4.2.1. Identity

JOB WALAS

4.2.2. File name of wet grid model

以双引号括住

4.2.3. File name of dry grid model

以双引号括住

4.2.4. Modal shapes of nodes of dry model

以双引号括住

4.2.5. Modal shapes of elements of wet model

以双引号括住

4.2.6. Information of dudx of wet model

以双引号括住

4.2.7. Characteristic parameters

Lpp SwlHeight ISOFLAG NORMALFLAG ORIGINFLAG PRESFlag WHPFlag nonTimeStart nonTimeEnd nonDt

Lpp：特征长度，一般取浮体垂线间长；

SwlHeight：静水线高度（相对于湿面元坐标系）；

ISOFLAG：浮体湿面元对称标志，无对称面为 0，左右对称为 1，两个对称面取 2

NORMALFLAG：湿面元法向标志，方向朝船体内部为 1，外部为-1；对 Rankine 源（IORM）方法中自由面和虚拟控制面的网格法向也是与船体一致，同时指向内场流体，或者外部。

ORIGINFLAG：0 表示以湿坐标系中坐标原点之上静水面点为原点，1 表示以重心为原点

PRESFlag：是否计算物面压力的标志，0 表示不计算，1 表示计算

WHPFlag：是否计算波高标志，0 表示不计算，1 表示计算

nonTimeStart：无量纲化起始时间

nonTimeEnd：无量纲化结束时间

nonDt: 无量纲化时间间隔

4.2.8. Coordinates of gravity center

Xg Yg Zg

相对于湿面元坐标系

Xg：重心坐标 x 坐标

Yg：重心坐标 y 坐标

Zg：重心坐标 z 坐标

4.2.9. Mass inertia

Ixx Iyy Izz Ixy Ixz Iyz

相对于重心

Ixx：绕 x 轴主惯性矩

Iyy：绕 y 轴主惯性矩

Izz：绕 z 轴主惯性矩

Ixy：关于 xy 平面惯性矩

Ixz：关于 xz 平面惯性矩

Iyz：关于 yz 平面惯性矩

4.2.10. Position of dry coordinate origin in wet coordinate system

Dryx Dryy Dryz Tz

Dryx：干结构坐标系原点的 x 坐标

Dryy：干结构坐标系原点的 y 坐标

Dryz：干结构坐标系原点的 z 坐标

Tz：剖面扭心（或剪心）相对于垂向弯曲中和轴位置（Beam 模型中起作用）

4.2.11. Forward speed, density and acceleration of gravity

Vel Rho G

航速向前为正

4.2.12. Water depth

DepthFlag Depth

DepthFlag：水深标志，有限水深为 0，无限水深为 1

Depth：水深，只在水深标志位 0 时起作用

4.2.13. Frequencies or periods

FreqFlag FreqNum

[FreqStar tFreqEnd] [Freq1 Freq2 Freq3 ……] *(6 个一行)*

FreqFlag: 频率标志，为 0 表示后面的频率连续间隔取值，1 表示离散数值

FreqNum：频率个数

FreqStart：频率起始值，只在 FreqFlag 为 0 时存在

FreqEnd：频率结束值，只在 FreqFlag 为 0 时存在

Freq[n]：频率数值，只在 FreqFlag 为 1 时存在

4.2.14. Wave directions

DirFlag DirNum

[DirStart DirEnd] [Dir1 Dir2 Dir3 ……] *(6 个一行)*

DirFlag: 浪向标志，为 0 表示后面的浪向连续间隔取值，1 表示离散数值

DirNum：浪向个数

DirStart：浪向起始值，只在 DirFlag 为 0 时存在

DirEnd：浪向结束值，只在 DirFlag 为 0 时存在

Dir[n]：浪向数值，只在 DirFlag 为 1 时存在

4.2.15. Number of frequencies for interpolation

MoreFreqNum

利用样条插值水动力系数、波浪激励力，然后求解模态主坐标响应结果

4.2.16. Number of elastic modes

RigidFlag ElasFlag ElasNum

[Elas1 Elas2 Elas3 Elas4 Elas5 ……]

RigidFlag：刚体模态标志，为 0 表示干结构节点和湿面元文件中不包含刚体模态，而由程序自动生成刚体模态，一般取此值；为 1 表示干结构节点和湿面元文件中包含刚体模态

ElasFlag：弹性模态标志，为 0 表示后面的模态数量取前 ElasNum 个弹性模态

ElasNum：弹性模态数量

Elas[n]：第 n 个模态，仅在 ElasFlag 取 1 时存在

4.2.17. Artificial damping coefficients

DampFlag1 DampFlag2

Damp1 Damp2 Damp3 ……

DampFlag1：阻尼标志 1，为 0 表示后面的值是阻尼比，为 1 表示是阻尼系数

DampFlag2：阻尼标志 2，为 0 表示所有模态的阻尼一样（后面只需填写 Damp1），为 1 表示不一样

Damp[n]：阻尼比或阻尼系数（由 DampFlag 决定，包含 6 个刚体模态+ElasNum 个弹性模态）

4.2.18. Mass points for wave loading calculations

massPointNum

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

……

massPointNum：质量点个数，不计算载荷填 0

mass[n]：质量点的质量

x[n] y[n] z[n]：质量点的坐标

Ixx[n] 绕 x 轴惯性矩

4.2.19. Section definitions of wave loads

secNum waveLoadSymbol

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

secNum：载荷剖面数量

x[n] y[n] z[n]：载荷剖面的计算原点

waveLoadSymbol：波浪载荷积分是考虑船尾部分还是船艏部分，-1：船艏，1：船艉

4.3. 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

4.3.1. IPL, FKI, NONLSTF, SLM

IPL: 脉冲响应函数标志，0：直接读取；1：通过频域中附加阻尼和质量计算

FKI: 入射波浪力标志，0：采用脉冲响应函数（即线性波浪力），1：直接在时域里面进行压力面积分（即非线性波浪力）

NONLSTF：非线性静水力标志，0：线性，1：非线性

SLM：砰击力标志，0：不考虑；1：考虑砰击

4.3.2. MRL，moorPointFixedNum, wetDryFlag

MRL：系泊力标志，0：表示直接采用 6 个刚度线性弹簧刚度

moorPointFixedNum：系泊点数量

wetDryFlag：系泊点类型标志

4.3.3. caseNum

caseNum：工况数量

"B01"

0 2 62.832

3 1200 800 900

6

0 0

0 0

0 0

0 0

0 0

0 0

4.4. Definition of slamming areas (slm.in)

该文件为在时域中计算颤振响应的砰击参数文件。

标准格式如下：

X1 x2

No

Point1

Point2

…

PointN

解释如下：

X1：从船艉到 x1 考虑砰击

X2：从 x2 到船艏考虑砰击

No：要输出砰击压力的湿单元数量（后面的单元序号遵从单元号从 1 按顺序连续编号原则，非 nodeElement 文件中的单元编号，且为全模型编号）

Point1：单元#1

Point2：单元#2

Point3：单元#3

例子：

50 330

3

147

148

149

4.5. Definition of slamming pressures (flareSlm.ini)

该文件为砰击压力计算公式。程序内部有默认砰击压力计算公式（Stavovy & Chuang），如果该文件不存在，则采用程序内部默认计算公式。

标准格式：

No

x1　y1

x2　y2

x3　y3

…

xn　yn

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

该文件为 MSC/Nastran 计算的结果文件，保存了干面元节点模态信息。

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

该文件为从有限元模型中保存的文件，保存着干结构面元节点和单元信息。该文件用于 WALAF_PRE 程序中与 ship_wet.bdf 匹配，从 ship.f06 中计算出湿面元的模态信息。

为了方便可以直接从 ship.f06 的.bdf 文件中复制过来，也可以从干结构有限元模型中重新提取（只保留浮体表面的单元，**切忌**保存编号不变），而 ship.f06 对应的.bdf 文件保存了模态计算时所有节点的。

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

该文件保存了湿面元的节点和单元信息。因为一般是干结构面元尺寸小于湿面元，因此要重新制作湿面元文件，但是也可以保持两者的面元模型一样。

5. Output instruction

5.1. Hydrodynamic coefficients in frequency domain (binary format)

case.hyd，包括了波浪力、附加质量和附加阻尼、恢复力矩阵等。

5.2. Hydrodynamic coefficients in time domain (binary format)

impulse.hyd，包括了入射波浪力 Fkr、绕射波浪力 Fdr 和辐射效应脉冲响应函数 Krs。

5.3. Results in frequency domain (text format)

（1）case.LIS 总体基本信息结果

（2）ship1.LIS-各模块结果

5.4. Results in time domain (text format)

（1）ship1_TIM.LIS-时域总体基本信息结果

（2）ship1_t2f.LIS-时域程序获得的频域结果或传递函数结果

5.5. 3D models of wet model

（1）nodeElement_walas.plt：Tecplot 格式，水线以上面元删除。

（2）whole.DXF，nodeElement_walas.DXF：Autocad 格式，全模型（对称后，不删除水线上面元）。

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