**FEAM Dynamic Mooring Module User’s Guide**

The FEAM mooring module input file contains the information about mooring system (element definition, material property, platform-mooring coupling, and mooring line boundary conditions)

The input data are dimensional and standard unit systems are used (meters, kg, Newton and second for SI system).

In the FEAM input file, the x and y axis define a horizontal plane and z axis is positive upward. The origins of the global coordinate systems are located on the mean water surface with the corresponding axis parallel to each other. All the information related to the mooring system is defined with respect to the global coordinate system. In the following sections, all the input and output data are given in global coordinate except those specified otherwise.

1. **Input Data**

The input data can be divided into two groups. The first group of data contains general information needed in the program and is listed as follows

**DT**: Communication interval for module

**NumLines**: The total number of mooring lines

**NumElem**: The total number of elements per line. All elements are equal in length.

**MaxIter**: The maximum number of iterations for finding static equilibrium position of lines. In most cases, 100 is enough.

**Eps**: Static iteration tolerance.

The second group of data contains all the properties of mooring lines including material properties, geometry, boundary conditions. This group of data should be prepared for every line. In other words, one should repeat this group of input data for NumLines times, where NumLines is the total number of lines as defined in group one.

**LEAStiff**: The axial stiffness (Young’s modulus cross sectional area of the line) in [N]

**LMassDen**: The mass per unit length of the element in [kg/m]

**LDMassDen**: The displaced mass per unit length if the element is in water (LDMassDen =0 if the element is in air) in [kg/m]

**LUnstrLen**: The unstretched line length in [m]

**BottmStiff**: The stiffness coefficient of the foundation. In the program, the elastic foundation is modeled as a continuous quadratic spring foundation to support the lines, i.e. the relation between the vertical support force *F* and the vertical deformation *dz* is *F=BottmStiff ⅹ dz2* in [N/m2]

**LRadAnch**: The anchor point radius in [m]

**LAngAnch**: The anchor point angle in [deg]

**LDpthAnch**: The anchor point depth in [m]

**LRadFair**: The fairlead point radius in [m]

**LAngFair**: The fairlead point angle in [deg]

**LDrftFair**: The fairlead point draft in [m]

**Tension**: is the pretension at the fairlead point. This input affects axial deformation of the element in the analysis. For example, in a TLP analysis, if the stretch of the tether caused by the net buoyancy force is already included in the initial element length (LUnstrLen), one needs to set the ‘Tension’ as the actual static pretension so that any axial deformation in the calculation is caused only by dynamic tension

**XSpringStiff, YSpringStiff, ZSpringStiff**: The linear spring stiffness between mooring line top and platform fairlead along x, y and z direction respectively in [N/m]. The user can vary the stiffness to simulate different types of connections. It is recommended that the values of stiffness should be about 100~1,000 times higher than the axial (stretch) stiffness (LEAStiff) of the lines.

1. **Subroutines and internal variables**

The subroutines inside the FEAM module are explained in this section.

**FEAM\_Init**: In this subroutine, the input file data are loaded and initial line stiffness matrix is made. Then it calls ‘FEAM\_Solve’ to find the static equilibrium of line position.

**FEAM\_UpdateStates**: This subroutine updates the states variables by calling ‘FEAM\_Solve’. Since p%DYN = true in this subroutine, ‘FEAM\_Solve’ compute the dynamic equation of motion of lines. The current fairlead positions in global coordinate system are fed into ‘FEAM\_Solve’. In addition, this subroutine saves the current position of fairlead into ‘OtherState%FAST\_FPA’ in order to use numerical integration of the next time step.

**FEAM\_CalcOutput**: This subroutine calculates outputs. The outputs in this subroutine are listed below.

|  |  |  |
| --- | --- | --- |
| **Name** | **Description** | **Index** |
| OtherState%FAIR\_T(LEG) | Fairlead tension [N] | LEG : Line number |
| OtherState%ANCH\_T(LEG) | Anchor tension [N] |
| OtherState%FAIR\_ANG(LEG,I) | Unit tangent vector component of fairlead angle | LEG : Line number  I : Direction (x,y,z) |
| OtherState%ANCH\_ANG(LEG,I) | Unit tangent vector component of anchor angle |
| OtherState%Line\_Coordinate(LEG,I,J) | Line element coordinate | LEG : Line number  I : Node number  J : Direction (x,y,z) |
| OtherState%Line\_Tangent(LEG,I,J) | Line element tangent vector at nodes |
| OtherState%F\_Lines(LEG,J) | Mooring restoring force [N] |

**FEAM\_Solve**: If p%DYN = false, this subroutine calculate the initial static configuration of lines. Otherwise, it solves the dynamic equation of motion of lines.

**Element**: This subroutine fills out the mass, stiffness and force matrix of one line element. The forces acting on the element include gravity, seabed quadratic spring and hydrodynamic force from Morison equation. The hydrodynamic force on one line element of length ‘p%Elength’ should be inserted into ‘OtherState%FORCE’. The details of key variables are tabulated below.

|  |  |  |
| --- | --- | --- |
| **Name** | **Description** | **Remark** |
| OtherState%U(1,1) | X Coordinate of 1st end |  |
| OtherState%U(2,1) | Y Coordinate of 1st end |  |
| OtherState%U(3,1) | Z Coordinate of 1st end |  |
| OtherState%U(1,3) | X Coordinate of 2nd end |  |
| OtherState%U(2,3) | Y Coordinate of 2nd end |  |
| OtherState%U(3,3) | Z Coordinate of 2nd end |  |
| OtherState%U(1,2) | X component of direction cosine of 1st end |  |
| OtherState%U(2,2) | Y component of direction cosine of 1st end |  |
| OtherState%U(3,2) | Z component of direction cosine of 1st end |  |
| OtherState%U(1,4) | X component of direction cosine of 2nd end |  |
| OtherState%U(2,4) | Y component of direction cosine of 2nd end |  |
| OtherState%U(3,4) | Z component of direction cosine of 2nd end |  |
| OtherState%FORCE(1) | Hydrodynamic Force of 1st end in X in [N] |  |
| OtherState%FORCE(2) | Hydrodynamic Moment of 1st end in X in [Nm] |  |
| OtherState%FORCE(3) | Hydrodynamic Force of 1st end in Y in [N] |  |
| OtherState%FORCE(4) | Hydrodynamic Moment of 1st end in Y in [Nm] |  |
| OtherState%FORCE(5) | Hydrodynamic Force of 1st end in Z in [N] |  |
| OtherState%FORCE(6) | Hydrodynamic Moment of 1st end in Z in [Nm] |  |
| OtherState%FORCE(7) | Reserved for residue force input |  |
| OtherState%FORCE(8) | Reserved for residue force input |  |
| OtherState%FORCE(9) | Hydrodynamic Force of 2nd end in X in [N] |  |
| OtherState%FORCE(10) | Hydrodynamic Moment of 2nd end in X in [Nm] |  |
| OtherState%FORCE(11) | Hydrodynamic Force of 2nd end in Y in [N] |  |
| OtherState%FORCE(12) | Hydrodynamic Moment of 2nd end in Y in [Nm] |  |
| OtherState%FORCE(13) | Hydrodynamic Force of 2nd end in Z in [N] |  |
| OtherState%FORCE(14) | Hydrodynamic Moment of 2nd end in Z in [Nm] |  |
| OtherState%FORCE(15) | Reserved for residue force input |  |

All the above coordinates and forces should be written with respect to the global coordinate system at current simulation time ‘t’. The ‘u%HydroForceLineMesh’ variable contains the information of the line coordinate inside ‘position’

**Couple**: This subroutine calculates the spring connector force and stiffness coefficients between line ends and platform. The right hand side ‘RHSR’ should be calculated based on both the previous fairlead position and the current fairlead position for numerical integrations. This is why ‘FEAM\_Solve’ always calls ‘Couple’ subroutine twice.

**Solve**: This is a generic subroutine for solving systems of equations using Gauss elimination.

1. **Example**

In this section, OC3-Hywind spar mooring lines are modeled using FEAMooing module.

---------------------- FAST MOORING FILE --------------------------------------

NREL 5.0 MW offshore baseline floating platform input properties for the OC3-Hywind spar-buoy.

---------------------- SIMULATION CONTROL --------------------------------------

False Echo - Echo input data to <RootName>.ech (flag)

0.01 DT - Communication interval for controllers (s)

3 NumLines - Number of lines

20 NumElem - Total number of elements per line

9.81 Gravity - Gravitational acceleration (m/s^2)

1025.0 WtrDens - Water density (kg/m^3)

100 MaxIter - Maximum number of static iterations

1e-4 Eps - Static iteration tolerance

---------------------- MOORING LINES 1 -------------------------------------------

384.243E6 LEAStiff - Axial stiffness

77.7 LMassDen - Mass per unit length of the element

6.47 LDMassDen - Displaced mass per unit length of the element

902.2 LUnstrLen - Unstretched length

1.0E4 BottmStiff - Seabed stiffness

855.574 LRadAnch

0.0 LAngAnch

320.0 LDpthAnch

4.7 LRadFair

0.0 LAngFair

70.0 LDrftFair

9.7E5 Tension - Initial top tension

1.0E10 XSpringStiff - The linear spring stiffness in x-direction between mooring & platform

1.0E10 YSpringStiff - The linear spring stiffness in y-direction between mooring & platform

1.0E10 ZSpringStiff - The linear spring stiffness in z-direction between mooring & platform

---------------------- MOORING LINES 2 -------------------------------------------

384.243E6 LEAStiff - Axial stiffness

77.7 LMassDen - Mass per unit length of the element

6.47 LDMassDen - Displaced mass per unit length of the element

902.2 LUnstrLen - Unstretched length

1.0E4 BottmStiff - Seabed stiffness

855.574 LRadAnch

120.0 LAngAnch

320.0 LDpthAnch

4.7 LRadFair

120.0 LAngFair

70.0 LDrftFair

9.7E5 Tension - Initial top tension

1.0E10 XSpringStiff - The linear spring stiffness in x-direction between mooring & platform

1.0E10 YSpringStiff - The linear spring stiffness in y-direction between mooring & platform

1.0E10 ZSpringStiff - The linear spring stiffness in z-direction between mooring & platform

---------------------- MOORING LINES 3 -------------------------------------------

384.243E6 LEAStiff - Axial stiffness

77.7 LMassDen - Mass per unit length of the element

6.47 LDMassDen - Displaced mass per unit length of the element

902.2 LUnstrLen - Unstretched length

1.0E4 BottmStiff - Seabed stiffness

855.574 LRadAnch

240.0 LAngAnch

320.0 LDpthAnch

4.7 LRadFair

240.0 LAngFair

70.0 LDrftFair

9.7E5 Tension - Initial top tension

1.0E10 XSpringStiff - The linear spring stiffness in x-direction between mooring & platform

1.0E10 YSpringStiff - The linear spring stiffness in y-direction between mooring & platform

1.0E10 ZSpringStiff - The linear spring stiffness in z-direction between mooring & platform

---------------------- OUTPUT --------------------------------------------------

True SumPrint - Print summary data to <RootName>.fsm (flag) (currently unused)

1 OutFile - Switch to determine where output will be placed

True TabDelim - Use tab delimiters in text tabular output file? (flag) (currently unused)

"ES10.3E2" OutFmt - Format used for text tabular output (except time). Resulting field should be 10 characters. (quoted string) (currently unused)

5 TStart - Time to begin tabular output (s) (currently unused)

OutList - The next line(s) contains a list of output parameters.

END of input file (the word "END" must appear in the first 3 columns of this last OutList line)

In this example, three mooring lines are modeled. The angle between each line is 120 degrees, and the radius of anchor position is 855.574m. The initial pretension of the mooring lines are set to 9.7e5N per line and its direction is tangent to the end of the line element. The pretensions are used to find the initial equilibrium position of floating platform. If this pretension is too small, the initial equilibrium position will be greater than MWL for example. The linear spring stiffness between mooring line end and fairlead is 1.0e10 N/m for all x, y and z direction.

*LRadAnch*

*LDrftFair*

*LRadFair*

*LAngAnch*

*LAngFair*

*y*

*x*

*LRadAnch*