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

   $F=BottmStiff \times dz^2$ in [N/m^2]

   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.

2. 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	

	Mooring restoring force [N]	
OtherState%F_Lines(LEG,J)		

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.

3. 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
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    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.