OpenMOOR v 0.1 User Guide

Lin Chen, Biswajit Basu

[a] *School of Engineering, Trinity College Dublin, Dublin 2, Ireland*

Abstract

OpenMOOR is an **Open** source program for simulating **MOOR**ing systems in ocean renewable energy applications, including floating offshore wind turbine, wave energy devices and also other moored structures. The source code is available via GitHub.

This user guide describes how to compile **OpenMOOR** as a standalone application or a dynamically linked library and how to use it to solve the static and dynamic problems of a multi-cable mooring system when subjected to current effect and forced motion resulting from the moored structures. The platform (moored structure/device) is considered as a rigid body with motion defined at a reference point. The mooring cable model is able to include bending stiffness, torsional stiffness, the seabed effect, and nonuniform current effect. The statics/dynamics of each cable is solved using a spatial-time difference method and parallel computing is implemented to handle multiple cables efficiently.

Contents

Email addresses: `l.chen.tj@gmail.com or chenl1@tcd.ie` (Lin Chen), `basub@tcd.ie` (Biswajit Basu)

1. Problem description

Ocean wave and wind are two promising sources for renewable energy. The mooring system is the key component of this type of structures for harvesting ocean wave and wind energy. A typical mooring system is composed of multiple cables, each of which is of strong nonlinearity and requires careful treatment in numerical simulation. **OpenMOOR** is designed as an open framework to simulate multi-cable mooring systems in ocean renewable energy applications.

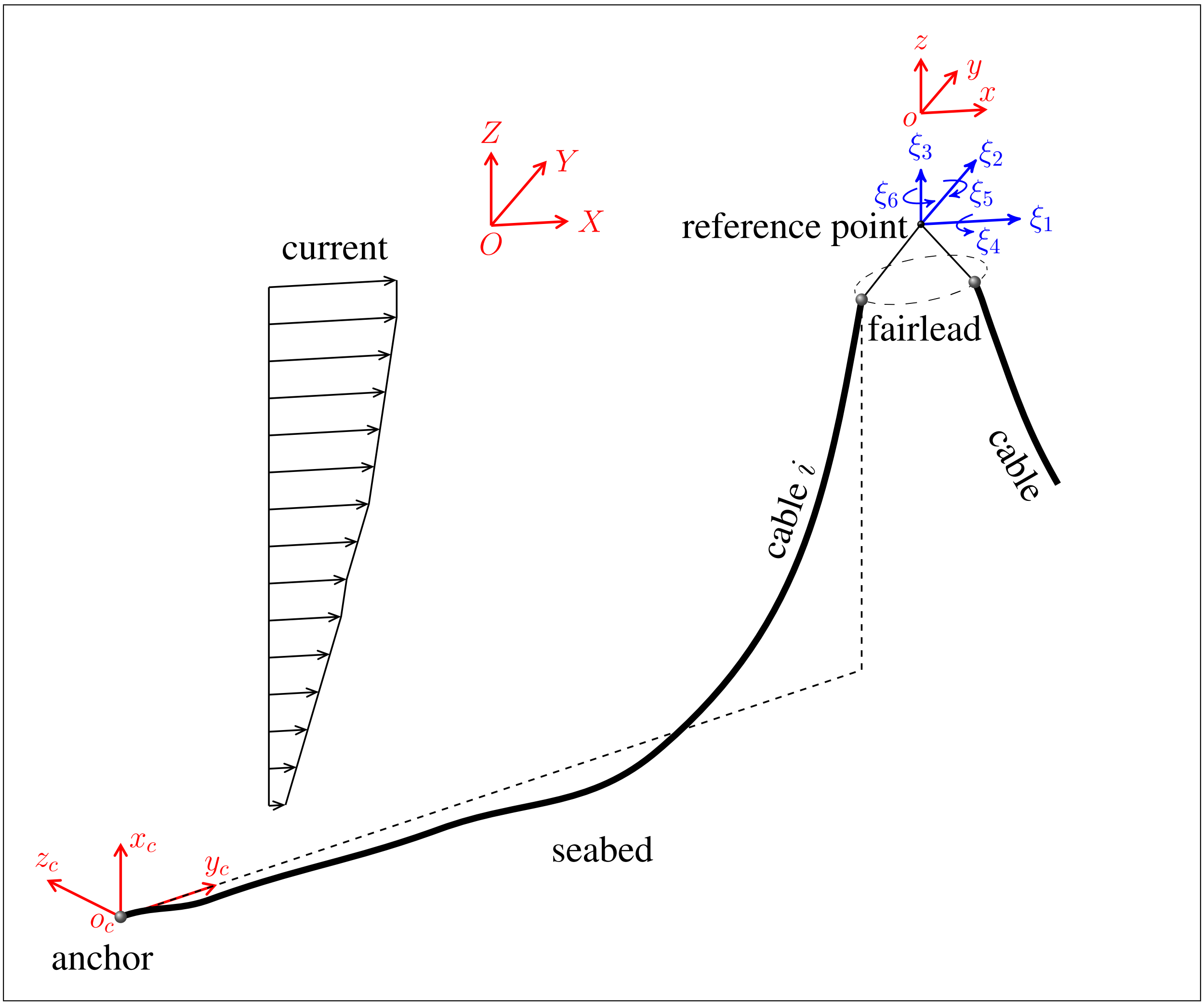

Figure 1: Illustration of a mooring system with multiple cables and the coordinate systems

1.1. Statics/dynamics of multi-cable mooring system

A typical mooring system with multiple cables are illustrated in Fig. 1. The platform is often modeled as a rigid body with motion defined at a reference point (e.g. center of gravity) in a fixed coordinate system as (x, y, z), as shown in the figure. For the convenience of solving single cable dynamics, a fixed Cartesian coordinate is defined as (x_c, y_c, z_c) for each cable with origin at the cable seabed anchor and the $x_c - y_c$ plane is in the vertical plane defined by the anchor location and initial (or static) fairlead location and axis x_c is pointing upwards.

There are two basic problems for analyzing the mooring systems:

i. Static problem: to determine the static configuration of the mooring cables and the platform. In general, it is a coupled problem considering the varied current effects on cables.

ii. Dynamic problem: (given static/initial condition) to determine the mooring load to the platform with respect to the reference point in response to platform motions.

The cable static/dynamic problem is a two-point boundary-valued problems. In both the aforementioned problems, the fairlead end conditions are coupled for all the cables through the rigid body motions of the platform. **OpenMOOR** solves the coupled static problems using a dynamic relaxation method (another method – shooting for static problem is also offered but will not be explained). Therefore, only the dynamic problem will be briefly introduced here. When the platform is moving, for each time step, the displacement and velocity of the platform at the reference point are fed to **OpenMOOR**. Each includes six components associated with the platform motion in x, y and z directions and platform roll, pitch and yaw rotation, respectively. The mooring analysis then carries out the following steps:

i. obtain current fairlead position relative to the platform reference point and the velocity at each fairlead in (x, y, z);
ii. obtain fairlead velocity for each cable in the corresponding cable coordinate system (x_c, y_c, z_c) by axis rotation;
iii. solve cable state for the given fairlead velocity for each cable and obtain the fairlead forces in cable coordinate system. For a detailed method on solving single cable dynamics, one can refer to [1];
iv. obtain fairlead forces in platform coordinate system and compute the moments due to fairlead forces with respect to the reference point by the cross-product of fairlead forces and relative fairlead position; and
v. assemble the mooring load by summing the fairlead forces and moments over all the cables and return six components associated with platform motion in translating directions (x, y, z) and rotations (roll, pitch and yaw).

1.2. Introduction of solving single mooring cable mechanics

The mooring cable is considered to be anchored at seabed and may have part grounded on the seabed. The other end of the cable is connected to the fairlead which can move when subjected to excitations.

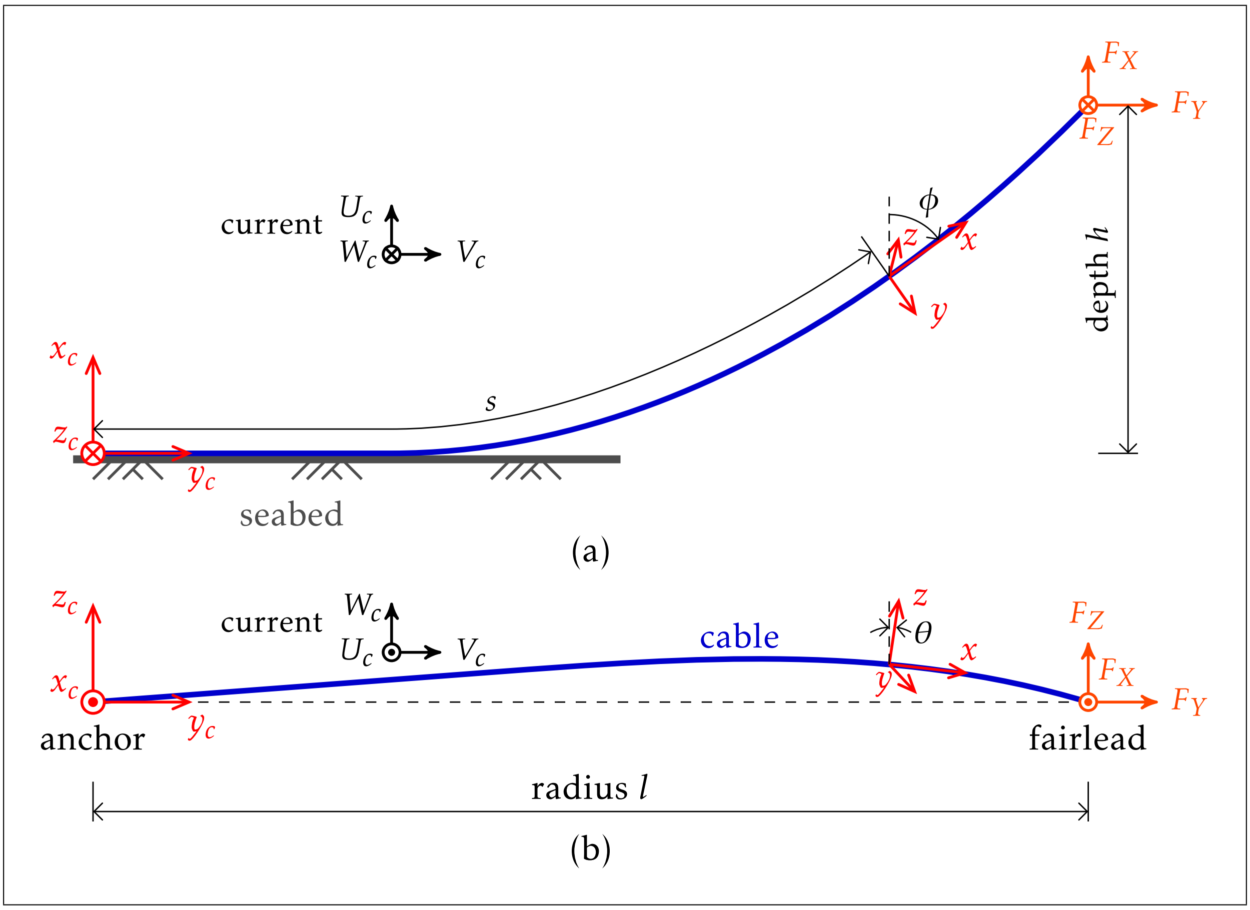

Figure 2: Coordinate system for describing mooring cable mechanics

The mooring cable mechanics formulated in a moving Lagrangian reference frame is followed herein [2, 1, 3, 4]. The Lagrangian reference frame is defined by the *cable arc length coordinate* s along the unstretched length starting from the anchor, and the *Euler angles* (ϕ, θ) or the *Quaternion* $(\beta_0, \beta_1, \beta_2, \beta_3)$. The cable state is described respectively by

$$\text{Euler angle formulation: } \varepsilon, S_n, S_b, u, v, w, \phi, \theta, \kappa_2, \kappa_3$$
$$\text{Quaternion formulation: } \varepsilon, S_n, S_b, u, v, w, \beta_0, \beta_1, \beta_2, \beta_3, \kappa_1, \kappa_2, \kappa_3$$

where ε = strain, S_n, S_b = shear forces in normal and binormal directions, u, v, w cable velocities in tangential, normal and binormal directions, κ_1 = torsional deformation (always zero in present consideration since no torsional load is considered), κ_2, κ_3 = out-of-plane and in-plane curvatures. *The quaternion formulation is not implemented in the present version.*

In addition to using the equations derived in [2, 1, 3, 4], the structural damping of the mooring cable is considered by $F_d = \beta EA\dot{\varepsilon}$ where β is a coefficient with unit (s/m) and EA = cable axial stiffness.

1.3. Finite difference solver for a single cable

The implemented program is using center finite difference for spatial discretization and generalized-α method for temporal discretization, as described in [5, 6, 7].

2. Compiling OpenMOOR

OpenMOOR can be compiled as a standalone application or a dynamically linked library (DLL) to be used in Matlab. The following folders and files provided in the source code folder are required for compiling (the root folder is named moor):

- moor/include: subfolder including open source libraries used by **OpenMOOR**;
- moor/src: subfolder including **OpenMOOR** source code;
- moor/doxygen: subfolder including files used in generating the documentation and for saving the generated documents;
- moor/test: subfolder including input files for demonstration of the compiled application and for saving output files;
- moor/CMakeLists.txt: file for using CMake [8] to generate makefile for compiling;
- moor/moorconfig.h.in: file for version information and option setting in compiling;
- moor/doxygenconfig: configuration file for using Doxygen [9] to generate the documentation from **OpenMOOR** source code.

OpenMOOR is written in C++ using the following three three main library. Besides, OpenMP is used for parallel computing using multiple cores.

- Eigen [10]: a C++ template library for linear algebra: matrices, vectors, numerical solvers, and related algorithms;
- boost/odeint-v2 [11, 12]: for time integration in optimizing the node distribution for tracing cable-seabed touchdown point [4].
- rapidxml-1.13 [13]: for handling input using xml files.

Designed to be a cross-platform simulation tool, a *CMakeLists.txt* file is provided for compiling **OpenMOOR**. To compile **OpenMOOR** as a standalone application at line 22 of *CMakeLists.txt* the variable OpenMOOR_API needs to be set to 0 and when it is set to 1 to a DLL will be compiled. The *CMakeLists.txt* has been tested on macOS 10.12.6 and a win64 system.

2.1. Compiling using CMake on macOS

There are two simple steps for using CMake in terminal to compile **OpenMOOR** on a macOS:

i. Open terminal on mac, as use *cd* to set openmo as the current directory, then type (g++ compiler need to be installed)
cmake -DCMAKE_CXX_COMPILER=g++-6 CMakeLists.txt
After successful running of this script, the files for compiling should be generated, particularly the *Makefile* should be in the main folder;

ii. After step i. and set the main as current directory again, then type
make
and if successful the compiling procedure is completed.

After compiling the application will be in /bin folder or the DLL (libMoorApi.dylib) should be found in the /lib folder.

2.2. Compiling using CMake on windows

With CMake installed, open the cmake-gui.exe and set "where is the source code" to *.../moor* and set "where to build the binaries" also to *.../moor*. Two steps again are needed:

i. Click Configure and when configuration is completed click Generate. In testing, the community version of Visual Studio 15 2017 was used as the generator.

ii. After step i., open the generated MSVS project *OpenMOOR.sln* and then *Build Solution*.

When successful, the application or the DLL (MoorApi.dll) will be in moor/bin folder.

2.3. Generating documentation using Doxygen

Download Doxygen and then set the root moor folder as the current directory then in the terminal run the doxygen:
.../doxygen doxygenconfig
and then the documentation should be generated in moor/doxygen folder. This only has been tested on macOS while it should be done in a similar way on windows.

3. Running OpenMOOR

*3.1. Using **OpenMOOR** as a standalone application*

For use the standalone application **OpenMOOR**.exe (or **OpenMOOR** on macOS platform), a *Setting.xml* (don't change the file name) file is needed and has to be put in the same folder where the **OpenMOOR** application is located. For running **OpenMOOR** using the input files provided in the folder moor/test, just copy **OpenMOOR**.exe to this folder. The working folder and other input files are defined in the Setting.xml file.

3.1.1. Input file: Setting.xml

Currently, the **OpenMOOR** can do both static and dynamic analysis and for static analysis two methods are offered. In total, three types of analyses can be done, i.e.

- Shooting: when choosing shooting analysis, the options for shooting needs to be properly set, following the example file as in Fig. 3.
- Dynamic relaxation method: when choosing this analysis, the options for relaxation need to be properly set, following the example file as in Fig. 3
- Forced motion analysis: the excitation file providing the excitation time histories needs to be specified.

All the parameters are self-explanatory in the example setting file shown in Fig. 3. Note that the mooring input file has to be defined in XML format and the path of this file is given relative to the folder where *Setting.xml* is saved. The folder where the input file is placed is the working folder and the output results will be saved in this folder.

```xml
<?xml version="1.0" encoding="utf-8"?>
<setting id="OpenMOORSetting" date="2018/02/23">
    <simulationtype note="forcedmotion/shooting/relaxation">shooting</simulationtype>
    <mooringinputfile note="relative to current folder">OC3/CaseOC3.xml</mooringinputfile>
    <platformsaveflag note="if not a zero it is recoganized as true">1</platformsaveflag>
    <forcedmotion note="forced motion at the platform reference point.">
        <timehistory note="first line is the header">excite5.dat</timehistory>
    </forcedmotion>
    <relaxation>
        <platformvelocitytolerance>0.01</platformvelocitytolerance>
        <cablevelocitytolerance>0.01</cablevelocitytolerance>
        <stoptime>200</stoptime>
        <timestep>0.02</timestep>
        <platformmass note="rowwise 6x6 matrix for relaxation">8e6 0 0 0 0 0 0 8e6 0 0 0 0 0 0 8e6 0 0 0
        <platformdamping note="rowwise 6x6 matrix for relaxation">1e5 0 0 0 0 0 0 1e5 0 0 0 0 0 0 2e5 0 0
        <platformhydrostaticstiffness note="rowwise 6x6 hydrostatic matrix">0 0 0 0 0 0 0 0 0 0 0 0 0 0 3
        <platformotherload note="6x1 vector, e.g buoyancy">0 0 1.601672e6 0 0 0</platformotherload>
    </relaxation>
    <shooting
        <fairleadpositiontolerance xc="0.05" yc="0.05" zc="0.01"/>
        <fairleadforcerelaxationfactor>0.1</fairleadforcerelaxationfactor>
        <fairleadpositioniterationlimit>100</fairleadpositioniterationlimit>
        <platformpositioniterationlimit>100</platformpositioniterationlimit>
        <platformdisplacementtolerance note="averaged">1e-3</platformdisplacementtolerance>
        <platformdisplacementrelaxationfactor>0.1</platformdisplacementrelaxationfactor>
        <cableoutofplanestiffness note="approximation value">1000</cableoutofplanestiffness>
        <platformhydrostaticstiffness note="rowwise 6x6 hydrostatic matrix">0 0 0 0 0 0 0 0 0 0 0 0 0 0 3
        <platformotherload note="6x1 vector, e.g buoyancy">0 0 1.601672e6 0 0 0</platformotherload>
    </shooting>
</setting>
```

Figure 3: Example of *Setting.xml* file

3.1.2. *Input file: Mooring parameters and solving options*

The mooring input file is composed of 9 sessions

- Constants: including gravitational acceleration, water density and water depth.
- Platform: the initial platform position and orientation, six degree of freedom of the reference point and the mooring load will be calculated with respect to this point.
- Connections: anchor and fairlead positions. For fairlead it is the initial position.
- Cables: the parameters include the number of nodes to be used for spatial discretization, associated current definition and solver chosen for solving the problem, the index of the connections at the two cable ends. For considering cable with varied properties along the cable, the cable can be defined as multiple segments and each segment is associated with a group of structural, hydrodynamic and seabed properties. The initial state if available can be provided for initialization, and if provided the node number will be ignored.
- Structural properties: multiple properties can be defined for one cable.
- Hydrodynamic properties: multiple properties can be defined for one cable.
- Seabed properties: multiple properties can be defined for one cable.
- Currents: multiple current profiles can be defined for different cables. Each cable is associated with one current profile. The profile index is defined in the cable session. The parameters include the number of current data points, the order for polynomial fitting of nonuniform current profile, and the current data file which should be also in the working folder.
- Solvers: each cable is associated with one solver. The solver index in defined is the cable session.

The number of properties, solvers and currents should be consistent with the followed definition of the respective property, solver and current. If no initial state file is provided, the catenary solution will be used for initialization.

As shown in Fig. 4, it is the input file defined based on the mooring system of Hywind OC3. For analyzing other mooring systems, it is recommended to modify this file according to the target system.

3.1.3. *Input file: initial state file*

The initial state file should be saved in the same folder as the mooring system definition file. This file has a line of header and the cable nodal state is provided row by row. An example file is shown in Fig. 5.

3.1.4. *Input file: current profile*

The current velocities are given in discrete points in global coordinate system (x, y, z). In the present version, the velocities in three directions are only considered as functions of the vertical coordinate (z). The velocities will be fitted using polynomials with the order specified in the current session of the mooring input file and then the fitted polynomial functions are used for evaluating the current velocities when the cable nodes are in motion. One example current file is shown in Fig. 6.

3.1.5. *Input file: forced motion*

For forced motion analysis, the time histories of the forced velocity at the platform reference point should be supplied along with the time. One example is given as in Fig. 7.

3.1.6. *Output files*

The output files will be saved in the work folder. For the three types analysis, the output platform state and cable state file names are prefixed by *s_*, *r_*, *f_* respectively.

subfolder named as *shooting*, *relaxing*, or *dynamics* needs to be created before simulation. *Otherwise, the output files are not to be saved*. The output file including *platform_state.dat* which appending the platform state row by row. If in the mooring input, the option *saveflag* in cables session is set to 1, for each time or iteration step (for shooting analysis), a file will be created saving the cable state. The cable state file has the same format as the initial state file for cable.

3.2. *Using **OpenMOOR** as a dynamically linked library*

If **OpenMOOR** is compiled as a DLL, the *moorapi.h* needs to be copied to the same folder where the DLL file is placed. Note for macOS the generated DLL would be *libopenmo.dylib* and for windows it would be *openmo.dll*. In this version, the DLL is for dynamic coupled analysis of the platform of the mooring system and hence the Setting.xml is not needed and the full path of the mooring input file needs to be fed to the when initializing the dll in Matlab. A example file for using the dll in Matlab is provided as below. If an error occurs in using the dll file, an *openmoor.log* will be created saving the error message for correct the input file.

```matlab
% Example to use libMoorApi in Matlab on MacOS
freq = 0.2;
time = 0:0.02:10/freq;
time_step = time(2:end) - time(1:end-1);
n_time = length(time);
displacement = zeros(n_time,6);
velocity = displacement;
mooring_load = zeros(n_time,6);
mooring_load_ptr = libpointer('doublePtr', mooring_load(1,:));
direction_id = 1;
amplitude = 2*pi*freq*1;

for j=1:n_time
    % Let the cable start from zero displacements
    if (time(j)<1/freq/2)
        velocity(j, direction_id)=-0.5*amplitude*sin(2.0*pi*freq*time(j));
    else
        velocity(j, direction_id)= -amplitude*sin(2.0*pi*freq*time(j));
    end
    if j >= 2
        displacement(j, direction_id) = displacement(j-1,1) + ...
```

```
                (time(j)-time(j-1))*velocity(j, 1);
    end
end

% Load library
loadlibrary('libMoorApi','moorapi.h');

%% Initialization.
input_file = 'CaseOC3.xml';
calllib('libMoorApi','initialize',input_file);

%% Time stepping.
tic
for j = 2:n_time
    calllib('libMoorApi','update', mooring_load_ptr, displacement(j,:)', ...
        velocity(j,:)', time(j), time_step(j-1), 1.0);
    % Cable state is saved every 1 s.
    mooring_load(j,:) = mooring_load_ptr.value;
    % Check fairlead force if desired.
    % calllib('libMoorApi','get_cable_fairlead_force',0);
end
toc
%% Finish simulation and clear variables.
% Clear memory
calllib('libMoorApi','finish');
unloadlibrary('libMoorApi');
```


4. Acknowledgment

In developing the code, we have referred to WHOI cable v2 manual [14] and the Ph.D. dissertation by D.V. Phan [15] for solving mooring mechanics. The code from the Numerical recipes book [5] has been referred to in developing the solver in this code. The code for polyfit from this link is used for fitting current velocity.

References

[1] A. A. Tjavaras, Q. Zhu, Y. Liu, M. S. Triantafyllou, D. K. P. Yue, The mechanics of highly-extensible cables, Journal of Sound and Vibration 213 (4) (1998) 709–737. doi:10.1006/jsvi.1998.1526.

[2] A. A. Tjavaras, The dynamics of highly extensible cables, Thesis (1996).

[3] J. I. Gobat, The dynamics of geometrically compliant mooring systems, Thesis (2000).

[4] J. I. Gobat, M. A. Grosenbaugh, Time-domain numerical simulation of ocean cable structures, Ocean Engineering 33 (10) (2006) 1373–1400. doi:10.1016/j.oceaneng.2005.07.012.

[5] W. H. Press, S. A. Teukolsky, W. T. Vetterling, B. P. Flannery, Numerical Recipes in C: The art of scientific computing Second Edition, Cambridge university press, 2007.

[6] J. Gobat, M. Grosenbaugh, Application of the generalized-α method to the time integration of the cable dynamics equations, Comput. Methods Appl. Mech. Eng. 190 (37-38) (2001) 4817–4829.

[7] J. I. Gobat, M. A. Grosenbaugh, M. S. Triantafyllou, Generalized-α time integration solutions for hanging chain dynamics, Journal of engineering mechanics 128 (6) (2002) 677–687.

[8] Kitware, Cmake, https://cmake.org.

[9] D. van Heesch, Doxygen, https://www.doxygen.org.

[10] G. Guennebaud, B. Jacob, et al., Eigen v3, http://eigen.tuxfamily.org (2010).

[11] Boost, Boost C++ Libraries, http://www.boost.org/ (2015).

[12] K. Ahnert, M. Mulansky, odeint, http://www.odeint.com (2012).

[13] M. Kalicinski, Rapidxml, http://rapidxml.sourceforge.net (2009).

[14] J. I. Gobat, M. A. Grosenbaugh, Whoi cable v2. 0: Time domain numerical simulation of moored and towed oceanographic systems, Report, Woods Hole Oceanographic Institution (2000).
[15] D. V. Phan, Numerical study on vortex-induced vibration of slender flexible structure using finite difference method and wake oscillator model, Thesis (2014).

```xml
<?xml version="1.0" encoding="utf-8"?>
<case id="OC3" date="2018/02/22">
    <constants note="still water level is at z=0 m">
        <gravitationalacceleration unit="N/kg">9.80655</gravitationalacceleration>
        <waterdensity unit="kg/m^3">1025</waterdensity>
        <waterdepth unit="m" note="positive">320</waterdepth>
    </constants>
    <platform note="rigid body, motion & force defined w.r.t. a reference point">
        <position x="0" y="0" z="-89.92" roll="0" pitch="0" yaw="0" note="initial"/>
    </platform>
    <connections number="2">
        <connection id="0" type="anchor" x="853.87" y="0" z="-320" note="initial position"/>
        <connection id="1" type="fairlead" x="5.2" y="0" z="-70" note="position"/>
    </connections>
    <cables number="1">
        <cable id="0">
            <initialstatefile note="use catenary if not provided"></initialstatefile>
            <icurrent>0</icurrent>
            <isolver>0</isolver>
            <nodenumber note="ignored if valid initial state found">20</nodenumber>
            <segmentlength>902.2</segmentlength>
            <istructproperty>0</istructproperty>
            <ihydroproperty>0</ihydroproperty>
            <iseabedproperty>0</iseabedproperty>
            <iconnection note="indexes of two end points">0 1</iconnection>
            <saveflag>1</saveflag>
        </cable>
    </cables>
    <structuralproperties number="1">
        <structuralproperty id="0">
            <diameter unit="m">0.09</diameter>
            <unitlengthmass unit="kg/m">77.7066</unitlengthmass>
            <unitlengthweight unit="N/m">698.094</unitlengthweight>
            <axialstiffness unit="N">3.84243E+08</axialstiffness>
            <bendingstiffness unit="N*m^2">3.8E+02</bendingstiffness>
            <torsionalstiffness unit="N*m^2">0</torsionalstiffness>
            <dampingcoefficient unit="s/m">0.1E-04</dampingcoefficient>
        </structuralproperty>
    </structuralproperties>
    <hydroproperties number="1">
        <hydroproperty id="0">
            <addedmasscoefficient tangential="0" normal="1" binormal="1"/>
            <dragcoefficient tangential="0" normal="1.6" binormal="1.6"/>
        </hydroproperty>
    </hydroproperties>
    <currents number="1">
        <current id="0">
            <polyorder note="used for polyfit the data">1</polyorder>
            <profilefile>current.dat</profilefile>
        </current>
    </currents>
    <seabedproperties number="1">
        <seabedproperty id="0">
            <dampingcoefficient>0</dampingcoefficient>
            <stiffnesscoefficient>1.0</stiffnesscoefficient>
        </seabedproperty>
    </seabedproperties>
    <solvers number="1">
        <solver id="0">
            <iterationnumberlimit>400</iterationnumberlimit>
            <convergencetolerance>1e-8</convergencetolerance>
            <initialrelaxationfactor>1.0</initialrelaxationfactor>
            <relaxationincreasefactor>1.02</relaxationincreasefactor>
            <relaxationdecreasefactor>1.1</relaxationdecreasefactor>
            <lambdainfinity>-0.5</lambdainfinity>
        </solver>
    </solvers>
</case>
```

Figure 4: Example of input file: *CaseOC3.xml* (one cable)

s (m)	epsilon (-)	S_n (N)	S_b (N)	u (m/s)	v (m/s)	w (m/s)	phi (rad)	theta (rad)	kappa_2 (-)	kappa_3 (-)
0.000000E+00	1.923131E-03	-0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.570796E+00	0.000000E+00	0.000000E+00	0.000000E+00
3.752039E+01	1.923131E-03	-0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.570796E+00	0.000000E+00	0.000000E+00	0.000000E+00
7.504079E+01	1.923131E-03	3.427233E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.570796E+00	0.000000E+00	0.000000E+00	0.000000E+00
1.125612E+02	1.923131E-03	2.805714E-04	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.570796E+00	0.000000E+00	0.000000E+00	-6.807076E-05
1.381075E+02	1.922770E-03	7.945123E-04	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.566503E+00	0.000000E+00	0.000000E+00	-4.683422E-04
1.542103E+02	1.923118E-03	3.423386E-04	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.551290E+00	0.000000E+00	0.000000E+00	-9.439130E-04
1.903719E+02	1.925521E-03	-3.334841E-06	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.517170E+00	0.000000E+00	0.000000E+00	-9.419090E-04
2.249968E+02	1.929915E-03	-5.653017E-06	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.484616E+00	0.000000E+00	0.000000E+00	-9.376649E-04
2.585576E+02	1.936116E-03	-7.666078E-06	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.453235E+00	0.000000E+00	0.000000E+00	-9.317067E-04
2.912200E+02	1.943970E-03	-9.541572E-06	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.422915E+00	0.000000E+00	0.000000E+00	-9.242273E-04
3.230980E+02	1.953344E-03	-1.127384E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.393585E+00	0.000000E+00	0.000000E+00	-9.154063E-04
3.542881E+02	1.964125E-03	-1.286022E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.365182E+00	0.000000E+00	0.000000E+00	-9.054064E-04
3.848789E+02	1.976222E-03	-1.430017E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.337648E+00	0.000000E+00	0.000000E+00	-8.943745E-04
4.149504E+02	1.989555E-03	-1.559654E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.310927E+00	0.000000E+00	0.000000E+00	-8.824423E-04
4.445720E+02	2.004058E-03	-1.675320E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.284972E+00	0.000000E+00	0.000000E+00	-8.697278E-04
4.738076E+02	2.019677E-03	-1.777380E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.259738E+00	0.000000E+00	0.000000E+00	-8.563374E-04
5.027151E+02	2.036365E-03	-1.866420E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.235182E+00	0.000000E+00	0.000000E+00	-8.423673E-04
5.313451E+02	2.054083E-03	-1.943108E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.211270E+00	0.000000E+00	0.000000E+00	-8.279041E-04
5.597434E+02	2.072798E-03	-2.007952E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.187968E+00	0.000000E+00	0.000000E+00	-8.130262E-04
5.879538E+02	2.092484E-03	-2.061612E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.165246E+00	0.000000E+00	0.000000E+00	-7.978052E-04
6.160139E+02	2.113116E-03	-2.104835E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.143075E+00	0.000000E+00	0.000000E+00	-7.823057E-04
6.439581E+02	2.134675E-03	-2.138275E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.121433E+00	0.000000E+00	0.000000E+00	-7.665871E-04
6.718174E+02	2.157143E-03	-2.162564E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.100297E+00	0.000000E+00	0.000000E+00	-7.507033E-04
6.996217E+02	2.180508E-03	-2.178345E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.079646E+00	0.000000E+00	0.000000E+00	-7.347038E-04
7.273971E+02	2.204757E-03	-2.186643E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.059463E+00	0.000000E+00	0.000000E+00	-7.186335E-04
7.551674E+02	2.229880E-03	-2.190380E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.039729E+00	0.000000E+00	0.000000E+00	-7.025291E-04
7.829703E+02	2.255883E-03	-2.182939E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.020421E+00	0.000000E+00	0.000000E+00	-6.863854E-04
8.109758E+02	2.282906E-03	-2.094028E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	1.001423E+00	0.000000E+00	0.000000E+00	-6.702521E-04
8.391365E+02	2.310889E-03	-1.770111E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.827753E-01	0.000000E+00	0.000000E+00	-6.552220E-04
8.635919E+02	2.335828E-03	-2.204102E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.669481E-01	0.000000E+00	0.000000E+00	-6.455722E-04
8.692869E+02	2.341719E-03	-4.196578E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.633110E-01	0.000000E+00	0.000000E+00	-6.376111E-04
8.729355E+02	2.345509E-03	-2.391336E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.609905E-01	0.000000E+00	0.000000E+00	-6.351808E-04
8.758579E+02	2.348554E-03	-2.211783E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.591372E-01	0.000000E+00	0.000000E+00	-6.334469E-04
8.783675E+02	2.351175E-03	-2.168548E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.575496E-01	0.000000E+00	0.000000E+00	-6.319968E-04
8.806016E+02	2.353513E-03	-2.148954E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.561392E-01	0.000000E+00	0.000000E+00	-6.307206E-04
8.826349E+02	2.355645E-03	-2.137763E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.548581E-01	0.000000E+00	0.000000E+00	-6.295664E-04
8.845134E+02	2.357619E-03	-2.130428E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.536765E-01	0.000000E+00	0.000000E+00	-6.285044E-04
8.862679E+02	2.359465E-03	-2.125146E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.525747E-01	0.000000E+00	0.000000E+00	-6.275152E-04
8.879200E+02	2.361206E-03	-2.121076E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.515388E-01	0.000000E+00	0.000000E+00	-6.265857E-04
8.894860E+02	2.362858E-03	-2.117774E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.505583E-01	0.000000E+00	0.000000E+00	-6.257062E-04
8.909779E+02	2.364435E-03	-2.114989E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.496255E-01	0.000000E+00	0.000000E+00	-6.248694E-04
8.924054E+02	2.365945E-03	-2.112568E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.487341E-01	0.000000E+00	0.000000E+00	-6.240698E-04
8.937762E+02	2.367397E-03	-2.110413E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.478791E-01	0.000000E+00	0.000000E+00	-6.233027E-04
8.950965E+02	2.368797E-03	-2.108460E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.470567E-01	0.000000E+00	0.000000E+00	-6.225645E-04
8.963716E+02	2.370151E-03	-2.106663E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.462633E-01	0.000000E+00	0.000000E+00	-6.218523E-04
8.976057E+02	2.371463E-03	-2.104990E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.454963E-01	0.000000E+00	0.000000E+00	-6.211636E-04
8.988027E+02	2.372736E-03	-2.103418E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.447532E-01	0.000000E+00	0.000000E+00	-6.204960E-04
8.999656E+02	2.373975E-03	-2.101930E-05	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.440320E-01	0.000000E+00	0.000000E+00	-6.198480E-04
9.010972E+02	2.375182E-03	-1.046686E-02	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.433309E-01	0.000000E+00	0.000000E+00	-6.192178E-04
9.022000E+02	2.376358E-03	-0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	9.426484E-01	0.000000E+00	0.000000E+00	0.000000E+00

Figure 5: Example of cable initial state file.

X (m)	Y (m)	Z (m)	U_c (m/s)	V_c (m/s)	W_c (m/s)
0.000000E+00	0.000000E+00	0.000000E+00	-1.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00	0.000000E+00	-0.800000E+02	-1.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00	0.000000E+00	-1.600000E+02	-1.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00	0.000000E+00	-2.400000E+02	-1.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00	0.000000E+00	-3.200000E+02	-1.000000E+00	0.000000E+00	0.000000E+00

Figure 6: Example of current data file.

```
t (s)         U_X (m/s)     U_Y (m/s)     U_Z (m/s)     U_Roll (rad/s) U_Pitch (rad/s) U_Yaw (rad/s)
0.000000E+00 -0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
2.000000E-02 -1.578970E-02  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
4.000000E-02 -3.156944E-02  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
6.000000E-02 -4.732923E-02  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
8.000000E-02 -6.305913E-02  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
1.000000E-01 -7.874919E-02  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
1.200000E-01 -9.438952E-02  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
1.400000E-01 -1.099702E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
1.600000E-01 -1.254815E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
1.800000E-01 -1.409135E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
2.000000E-01 -1.562565E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
2.200000E-01 -1.715008E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
2.400000E-01 -1.866367E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
2.600000E-01 -2.016548E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
2.800000E-01 -2.165455E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
3.000000E-01 -2.312995E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
3.200000E-01 -2.459073E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
3.400000E-01 -2.603599E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
3.600000E-01 -2.746479E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
3.800000E-01 -2.887625E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
4.000000E-01 -3.026948E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
4.200000E-01 -3.164358E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
4.400000E-01 -3.299770E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
4.600000E-01 -3.433097E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
4.800000E-01 -3.564256E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
5.000000E-01 -3.693164E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
5.200000E-01 -3.819739E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
5.400000E-01 -3.943901E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
5.600000E-01 -4.065573E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
5.800000E-01 -4.184676E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
6.000000E-01 -4.301136E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
6.200000E-01 -4.414880E-01  0.000000E+00  0.000000E+00  0.000000E+00   0.000000E+00    0.000000E+00
```

Figure 7: Example of velocity time history file for forced motion analysis.