An Alternative Methodology for Static 3D Nonlinear Hanging Mooring Lines Analysis

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ABSTRACT

Strings are slender bodies having the properties that they cannot withstand compression nor bending or torsion. This particular model is largely used in static and quasi-static mooring studies to deal with chains and some wire ropes. Several methodologies are available to solve the catenary equation such as analytical and finite elements solvers which both present advantages and limitations. Analytical methodology benefits from strong accuracy, simplicity of modeling but limited application cases to standard catenary shapes. On the other hand, finite element methods (FEMs) cover a wider application field by introducing more physics but request a specific attention when setting up the model and adjusting numerical parameters to reach a required precision.

The present paper describes an alternative methodology based on shooting method, offering a compromise between the accuracy of analytical computation and the general application field of FEMs, keeping the approach and implementation simple.

In this paper the hanging mooring line is modeled as a nonlinear extensible elastic string handling only traction along the centerline. The two point boundary value problem (TPBVP) static equations are reminded with the introduction of 3D external distributed loads. The TPBVP is then solved iteratively as a succession of initial value problems (IVPs) using the shooting method. The multi-shooting method is also introduced to deal with multi-material segments and line assemblies. Three validation cases based on analytical formulations are presented in this paper.

KEY WORDS: 3D; nonlinear; mooring; static; shooting method.

INTRODUCTION

Undersea cables and mooring lines static studies remain an important subject of simulation in offshore field whether for steady-state analysis or dynamic simulation initialization. In order to get the static equilibrium of mooring lines, two approaches exist based either on dynamic equations – such as dynamic relaxation – or on TPBVP static equations. The TPBVP for strings is constituted of a set of ordinary differential equations (ODEs) associated with two boundary conditions at segment extremities. In order to solve such problem, several well-known dedicated techniques exist such as: difference methods, variational methods, colocation methods, shooting methods, etc.

The shooting method consists in transforming the TPBVP into a succession of IVPs and solve iteratively - through continuous integration - by adapting the missing part of the initial unknowns. From (Stoer, 2002), this method is very well suited for the study of nonlinear TPBVPs when unknown fields depending on a single integrated parameter have to be accurately described. General applications studies on elastic slender bodies can be found in (Villaggio, 2005) and (Antman, 2005).

The shooting method has previously been introduced in the offshore field by (De Zoysa, 1978) and completed by (Friswell, 1995) to analyze three-dimensional steady-state configuration of underwater flexible cable problem. Application cases were developed for the resolution of the line profile and tension under gravity and current loads on a single cable linking a surface vessel to a buggy at seabed, and single line towing configurations.

(Masciola, 2012) adapted the shooting method to lumped mass cable models using discretized solution fields and discussed about the good convergence of the shooting method.

This paper reminds the boundary value problem for the static continuous nonlinear ordinary differential equations of strings. It describes how to solve this problem using a single shooting method on the example of a single segment under its own weight. The multiple shooting method is introduced in order to increase the application range of the single shooting method for offshore practical case of line assemblies. For this purpose a three catenary line assembly is taken as example.

Finally the shooting method as presented is confronted to the classical velaria problem where more than one solution exists.

TPBVP EQUATION

This paper deals with string theory (Antman, 2005), (Villaggio, 2005) which makes the following assumptions:

(i) a configuration of the string is defined as a set of material points (sections) having the geometrical property to be a curve in \( \mathbb{R}^3 \),

(ii) the string has the mechanical property to be ‘perfectly flexible’, withstanding only stretch deformations (i.e. deformations only along the centerline)

(iii) geometrical and mechanical functions defining the string are sufficiently regular to be derivated accordingly.