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Wavelet network meta-models for the analysis of slender offshore structures

Aloísio Carlos de Pina, Carl Horst Albrecht, Beatriz Souza Leite Pires de Lima, Breno Pinheiro Jacob *

LAMCSO – Laboratory of Computer Methods and Offshore Systems, PEC/COPPE/UFRJ – Post Graduate Institute of the Federal University of Rio de Janeiro, Civil Engineering Dept., Avenida Pedro Calmon, S/N, Cidade Universitária, Ilha do Fundão, 21941-596 Rio de Janeiro, RJ, Brazil

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ABSTRACT

Mooring lines and risers are crucial components of offshore oil and gas production platforms. The usual design practice requires the use of complex Finite-Element (FE) time-domain simulation tools, to represent their severe nonlinear dynamic behavior. However, such tools may require excessively high computational times; this fact motivates the study of expeditious methods – the so-called *surrogate models* or *meta-models*. In this context, this work presents an approach based on *Wavelet Networks* (WN) – a combination of the feed-forward neural network architecture with the wavelet transform. The goal is to obtain dramatic reductions in processing time, while providing results nearly as good as those from nonlinear dynamic FE methods.

Case studies are presented to evaluate the performance of the model, in terms of accuracy and computational time. Extensive parametric studies are performed to fine-tune the model (in terms of several parameters such as type of wavelet function; number of nodes in the hidden layer; size of the training/validation sets), to find the configuration most suited for the problem at hand. It is shown that the WN-based models proposed in this work are more efficient than ANN models; also, the fine-tuned configuration performs substantially better than the standard configuration with typical values for the parameters.

1. Introduction

The exploitation of offshore oil and gas reserves in deep waters has been performed by floating production systems (FPS), based on moored ships or semi-submersible platforms (Fig. 1). Two of their most important components are the risers and the mooring lines: risers convey oil, gas and other fluids resulting from the production processes, while mooring lines constrain the horizontal motions of the platform, keeping it within a safe operating area.

Mooring lines and risers are very slender structural systems, highly susceptible to dynamic effects from the environmental loads (wave and currents), and also to severe non-linear effects due to the large displacements they undergo [1–3]. They should be designed to comply with safety limits based on parameters of their structural response, such as tensions or stresses; these parameters are defined in terms of time series, usually obtained from complex Finite-Element (FE) time-domain simulation tools.

However, due to several factors the use of such tools may lead to excessively high computational times. Since the environmental loads are non-deterministic, long simulation times must be analyzed to achieve statistical stability of the results (typically 3 h, or 10,800 s). Also, the matrix of loading cases usually defined for the design methodology may include hundreds or thousands of load combinations. Therefore an important line of research consists in developing FE-based computational strategies with improved efficiency for the nonlinear dynamic analysis of structures [4–11], oriented mainly to more advanced stages of design where more accurate results are required [12].

On the other hand, another alternative to obtain expedite solutions is to replace the expensive FE-based solution procedures by simpler methods – the so-called *surrogate models* or *meta-models*. This approach, which may be adequate for the determination of the response parameters of slender structures on preliminary design stages, has been followed on a few previous works, including [13–15] where polynomial models were applied.

Later, the use of surrogate models associated with Artificial Neural Networks (ANN) [16,17,18] has been proposed in [19,20].

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* Corresponding author. Tel./fax: +55 21 2562 8496.
E-mail addresses: aloisiopina@lamcso.coppe.ufrj.br (A.C. de Pina), carl@lamcso.coppe.ufrj.br (C.H. Albrecht), bia@coc.ufrj.br (Beatriz Souza Leite Pires de Lima), breno@lamcso.coppe.ufrj.br (B.P. Jacob).
URL: http://www.lamcso.coppe.ufrj.br (B.P. Jacob).

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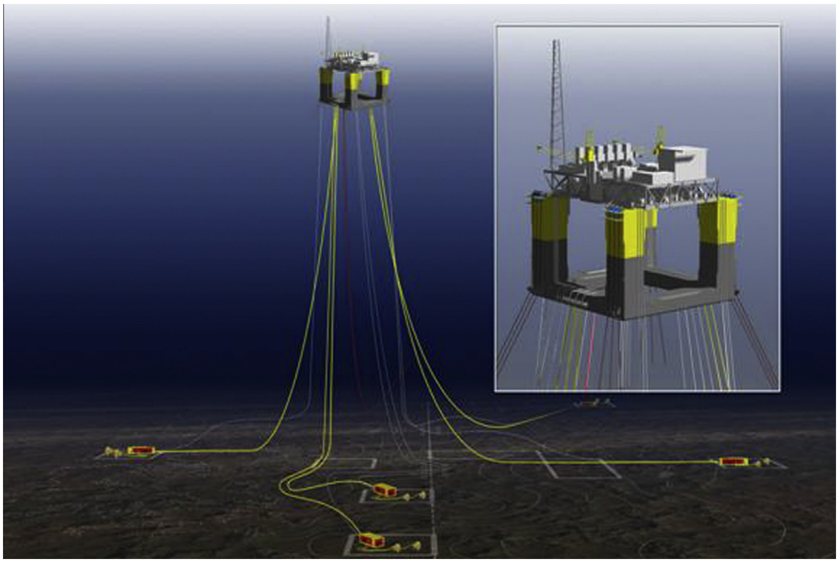

Fig. 1. Semi-submersible platform.

The application of a simple backpropagation ANN was presented in [19], comprising an "exogenous" method where time series of line tensions are estimated using the time series of known platform motions, with the ANN trained by a short initial window of the tensions that result from a FE simulation with these motions prescribed at the top of the line. In [20] the ANN-based approach was extended by considering a more complex surrogate model, where an ANN is associated to a Nonlinear AutoRegressive model with eXogenous inputs (NARX); differently from the previous purely exogenous models, the NARX model of [20] relates the present value of the desired tension time series not only to present and past values of the exogenous series (i.e. platform motions) but also to past values of the desired series itself.

Now, this work considers a different (and hopefully more efficient) approach, by devising new meta-models based on *Wavelet Networks* (WNs) [21]. WNs, also referred as "wavelet neural networks" or "wavenets" for short, are combinations of the feed-forward neural network architecture with the wavelet transform. The first works related to the synthesis and application of wavelet networks were published in the first half of the 1990s, including for instance [22–24]. The use of WNs has been increasing in the last years, for different applications such as time series prediction; system identification; optimization; approximation and classification of non-linear functions (see [25–31,21] and the references therein). Still, relatively few works can be found related to the application of WNs for offshore engineering problems, including for instance [32,33].

Here the WN concept is used to obtain a computational tool to replace expensive FE-based methods for the analysis and design of slender offshore structures such as mooring lines and risers. The tool should present dramatic reductions in processing time, while providing results nearly as good as those from FE methods; the goal is to obtain a meta-model still more efficient than the presented in [20] that was based on standard ANNs. Considering that surrogate models in general may be strongly problem-dependent, extensive parametric studies are performed to fine-tune the models, to find the configuration most suited for the problem at hand (in terms of choice of wavelet function; number of wavelons/neurons in the hidden layer; size of the training/validation sets, amongst other parameters).

The remainder of this paper is organized as follows: Initially, Section 2 presents a brief overview of the main characteristics of the ANN as implemented in [20]. Next, Section 3 presents the definition of wavelet functions, and introduces the basic expressions used to assemble the wavelet network. Section 4 then presents the procedures for the assembly of the different ANN-based and WN-based surrogate models, and Section 5 presents case studies to assess these models. Based on the results obtained, final remarks and conclusions are presented in Section 6.

2. Artificial Neural Network (ANN)

The inspiration for devising ANNs derived from the observation of biological learning systems composed by complex networks of interconnected simple units. Each unit receives a number of inputs and produces one output only, which becomes input to other units. On biological neural networks, the *neurons* are the units responsible for reception, processing and transmission of signals; on ANNs, these tasks are performed by an artificial model of a neuron, such as the McCulloch–Pitts neuron [34] (Fig. 2). Upon receiving a given number of inputs x_i, $i = 1, N$, firstly it calculates a linear combination of these inputs using synaptic weights w_i to generate the *weighted input* z. Next, it provides an output y via an *activation function* $f(z)$ that must present increasing monotonic behavior over a determined range of values for z, and assume a constant value outside this range. Several types of activation functions can be used [16], including the *logistic function* defined by the following expression (with a parameter α that modifies the derivative in the neighborhood of $z = 0$, to adjust the transition "speed"):

$$y = f(z) = \frac{1}{1 + e^{-\alpha z}} \tag{1}$$

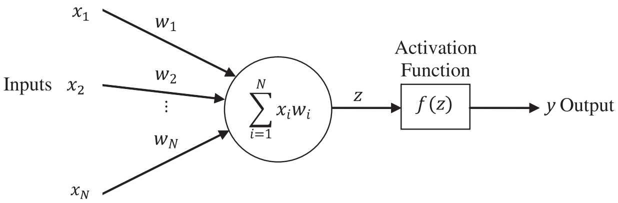

Fig. 2. McCulloch–Pitts neuron.