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Structural evaluation of offshore wind turbines supported on a jacket using Artificial Neural Networks

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ABSTRACT

Reducing the cost of the support structure of offshore wind turbines is an important objective to promote the development of this technology. In the design stage, the aim is to obtain a structure that verifies the different technical requirements imposed by the regulations and minimizes the amount of material used. In the literature, there are authors who manage to obtain efficient designs by approaching the process as an optimization problem for specific configurations (e.g. [1, 2]). However, introducing structural calculation and verification in an iterative process, such as optimization, considerably increases the computational cost of this process. For this reason, a surrogate model based on Artificial Neural Networks (ANN) is proposed to predict whether a jacket support structure would verify the technical requirements based on the characteristics of the wind turbine and the site.

A dataset is generated to train the ANN. These synthetic data collect the characteristics of the OWT-jacket-foundation system and the site; as well as the result of the technical checks, obtained by means of a finite element structural model. Analysing the confusion matrix of the test data, it is observed that this type of tool allows to establish the technical feasibility of a jacket support structure in a sufficiently precise way. Thus, the computational costs in the pre-design stage can be reduced through the use of Machine Learning techniques, such as ANNs.

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[1] K. Sandal, A. Verbart, and M. Stolpe. Conceptual jacket design by structural optimization. *Wind Energy*, 21(12):1423–1434, 2018.

[2] I. Couceiro, J. París, F. Navarrina, R. Guizán, and I. Colominas. Optimization of Offshore Steel Jackets: Review and Proposal of a New Formulation for Time-Dependent Constraints. *Archives of Computational Methods in Engineering*, pages 1–20, 2019.

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Outline

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Motivation

Structural perspective

- Need to increase the economic profitability of OWTs in deep waters
- Accelerate the jacket substructure design process

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Computational perspective

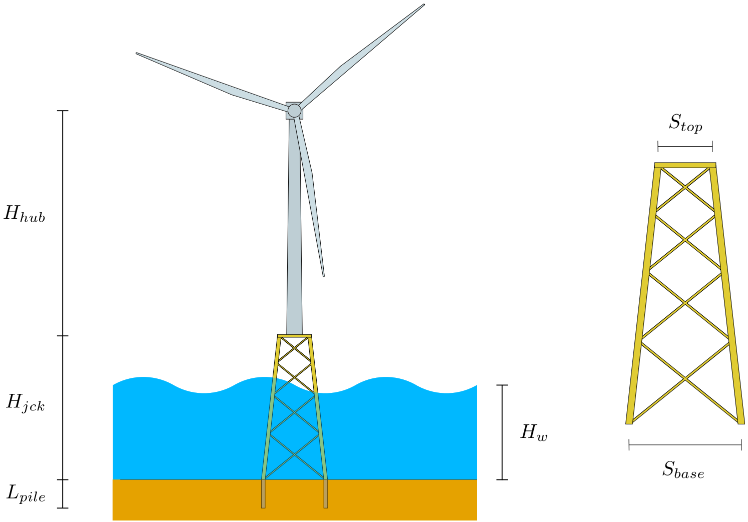
- High computational cost procedure
  - Solving of the continuous domain model if SSI is considered
- High development of Machine learning techniques in recent years

Aims and objectives

Develop a surrogate model based on ANNs capable of determining if the support jacket substructure of an OWT satisfies the necessary technical requirements

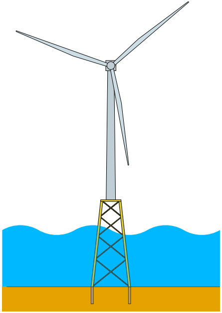
Outline

Problem definition

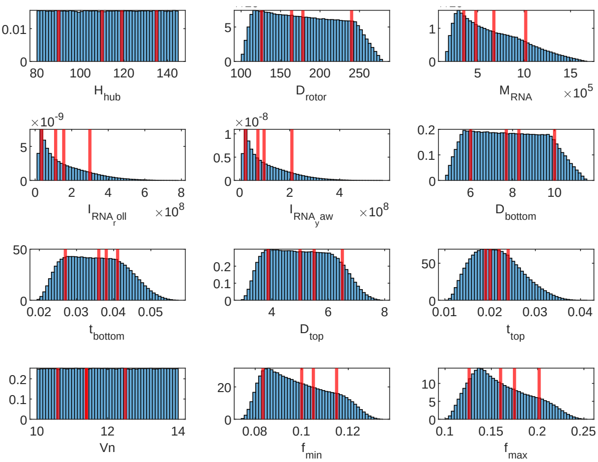


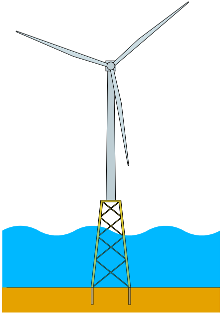
Problem definition - OWT

Variable	Lower limit	Upper limit
Tower height (H_{hub})	80 m	145 m
Rotor diameter (D_{rotor})	$H_{hub}^{1.5} \cdot 0.14$	$H_{hub}^{1.5} \cdot 0.16$
Mass (M_{RNA})	$H_{hub}^{3} \cdot 0.3$	$H_{hub}^{3} \cdot 0.55$
Inertia about roll axis ($I_{RNA,roll}$)	$0.1^2 \cdot H_{hub}^2 \cdot M_{RNA}$	$0.15^2 \cdot H_{hub}^2 \cdot M_{RNA}$
Inertia about yaw axis ($I_{RNA,yaw}$)	$0.6 \cdot I_{RNA,roll}$	$0.75 \cdot I_{RNA,roll}$
Bottom diameter (D_{bottom})	$H_{hub}/16$	$H_{hub}/13$
Bottom thickness (T_{bottom})	$D_{bottom}/250$	$D_{bottom}/200$
Top diameter (D_{top})	$D_{bottom}/1.65$	$D_{bottom}/1.45$
Top thickness (T_{top})	$D_{top}/290$	$D_{top}/190$
Nominal velocity (V_n)	10	14
Rotor speed (min.) (f_{min})	Eq. 1, $a_{tip} \sim U(30, 36)$	
Rotor speed (max.) (f_{max})	Eq. 2, $\psi \sim U(0.1, 0.2)$	



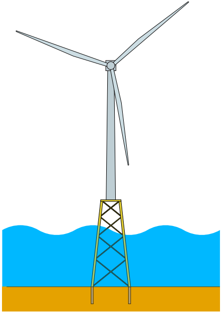
Problem definition - OWT



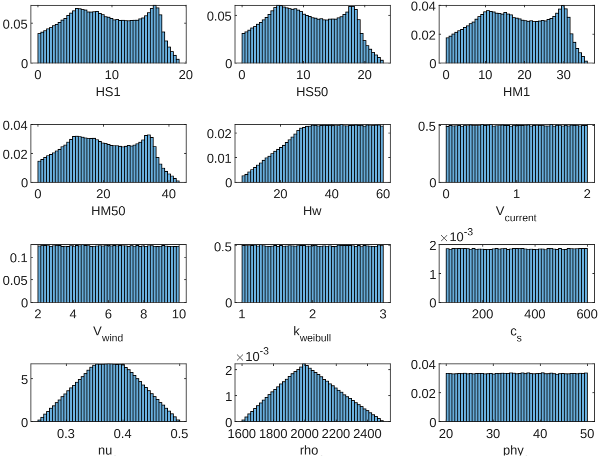


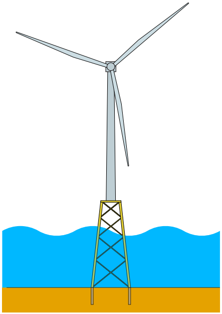
Problem definition - Site conditions

Variable	Lower limit	Upper limit
1-year significant wave (H_{S1})	From eq. 3	
50-year significant wave (H_{S50})	From eq. 3	
1-year maximum wave (H_{M1})	From eq. 4	
50-year maximum wave (H_{M50})	From eq. 4	
Water depth (H_w)	5 m	60 m
Shear wave propagation velocity (c_s)	60 m/s	600 m/s
Soil Poisson's ratio (ν_s)	Eq. 5a	Eq. 5b
Soil density (ρ_s)	Eq. 6a	Eq. 6b
Angle of internal friction (φ_s)	20°	50°



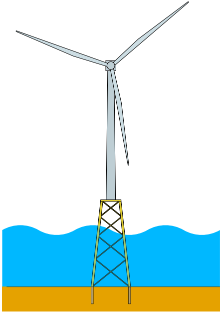
Problem definition - Site conditions



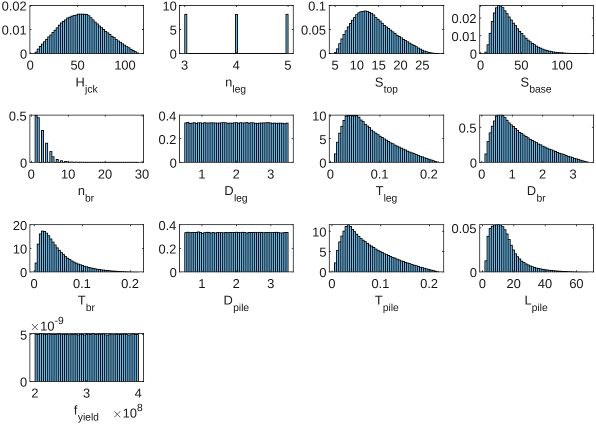


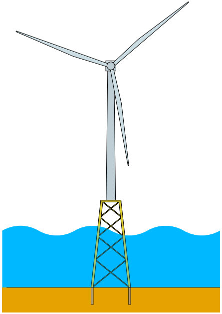
Problem definition - Jacket

Variable	Lower limit	Upper limit
Height (H_{jck})	H_w	$1.9 \cdot H_w$
Number of legs (n_{leg})	3	5
Top leg spacing (S_{top})	D_{bottom}	$2.5 \cdot D_{bottom}$
Base leg spacing (S_{base})	Eq. 7, $\alpha_{leg} \sim U\left(60^\circ, 90^\circ\right)$	
Number of bracing levels (n_{br})	Eq.8, $\beta = 70^\circ$	Eq. 8, $\beta = 30^\circ$
Leg diameter (D_{leg})	0.5 m	3.5 m
Leg thickness (T_{leg})	$D_{leg}/64$	$D_{leg}/16$
Bracing diameter (D_{br})	$D_{leg}/5$	D_{leg}
Bracing thickness (T_{br})	$D_{br}/64$	$D_{br}/16$
Yield strength (f_{yield})	$200 \cdot 10^6$	$400 \cdot 10^6$



Problem definition - Jacket





Problem definition - Verifications

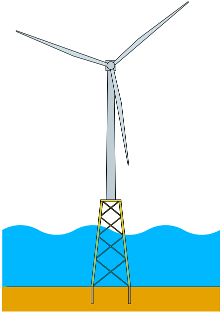
Option 1

Global check

Option 2

Partial checks

- Fundamental frequency
- Platform rotation
- ULS in pile
- ULS in legs
- ULS in braces
- Minimum pile thickness
- Minimum platform height
- Geometry of unions



Dataset generation

Input data generation

Generation of uniform random data between limits

- Site conditions
- Wind turbine
- Jacket

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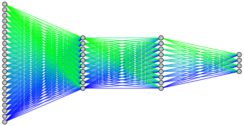
Output data generation - Structural model

- Finite element method
- SSI is implemented by impedance functions obtained from a continuum model
- All requirements are checked

Surrogate model generation



Surrogate model

- Define number of hidden layers
- Define number of neurons per hidden layers
- Train model using the train dataset
- Cross-entropy loss function:
  $\text{Loss} = \sum_{i=1}^{n} (y_i \log \widehat{y_i} + (1 - y_i) \log(1 - \widehat{y_i}))$
- Correction of unbalanced data

Outline

Dataset information

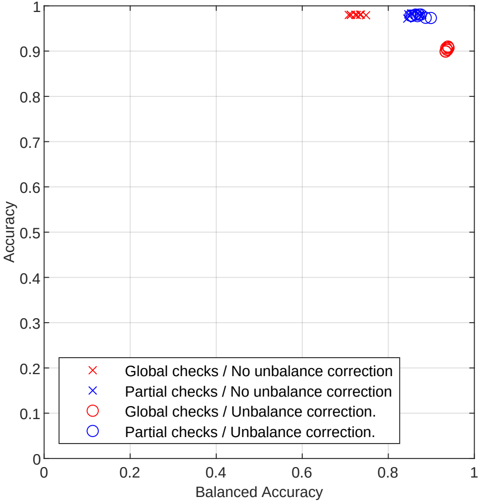
Size:

- Train dataset: 100.000 cases
- Test dataset: 50.000 cases

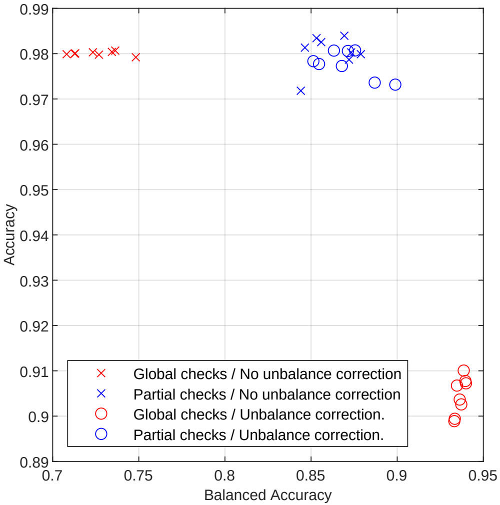
Unbalanced dataset:

- Positive cases (verifies all checks): 2.28%
- Negative cases (not verifies all checks): 97.72%

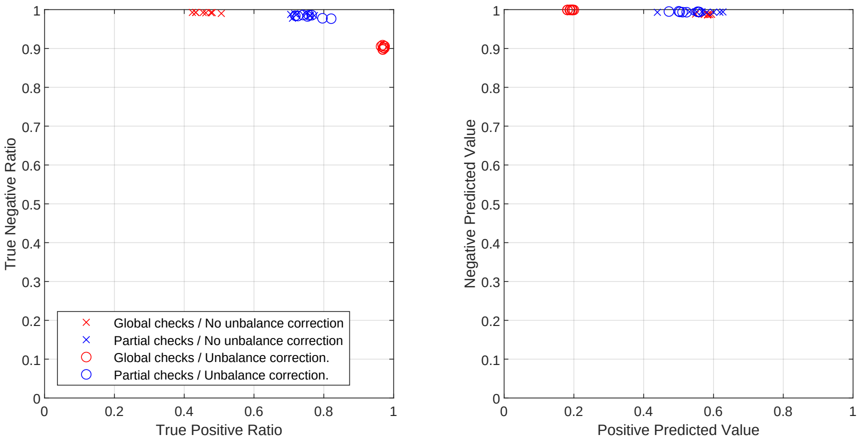
Model precision



Model precision



Ratio analysis



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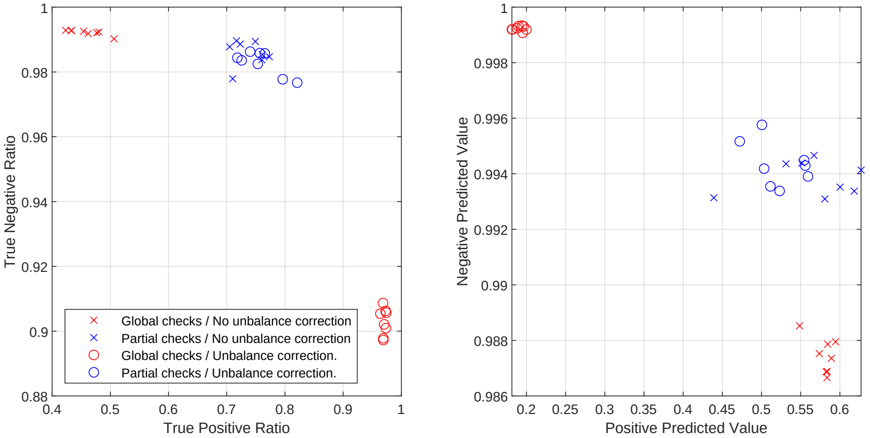
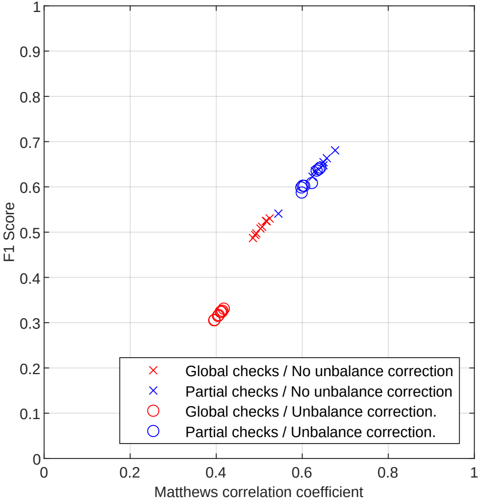
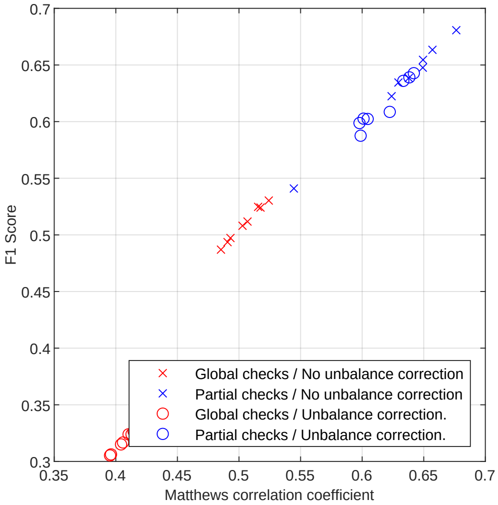


Global analysis statistic



Global analysis statistic



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Conclusions

Architecture

- The stochastic processes involved in the generation and training of ANNs produce differences between the same architecture cases
- In this problem, the performance of the network depends more on the training strategy used than on the number of parameters

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- The stochastic processes involved in the generation and training of ANNs produce differences between the same architecture cases
- In this problem, the performance of the network depends more on the training strategy used than on the number of parameters

Surrogate model evaluation

- Network performance varies greatly depending on the statistic used
- Depending on the application, the training strategy that best suits the task can be selected

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