Seismic Protection of Wind Turbines using vibrating Barriers

This study explores the use of vibrating barriers to reduce the dynamic response of wind turbines under seismic loading either for single wind turbine or a farm of wind turbines.

Literature review and hypothesis

Due to the global warming, the climate summit 2022 recommendation was enforcing all the contributed countries to relies on the clean sources of energy by 2030. Therefore having wind energy become a global trend.

Because of the increasing demand on wind energy, wind turbines became to be embraced in more seismically active parts of the world, so seismic loads are become likely to govern their design[1].

Although the literature on the wind effects on the structural responses of turbines is large,the literature on seismic analysis of turbines is scarce.Also guidelines for the design of such special structures are not explicitly mentioned in current codes of practice[2].

The potential of using vibrating barriers on reducing the dynamic response of structures to seismic loading is one of the promising techniques nowadays.

The Vibrating Barrier is a structure buried in the soil that is able to absorb a significant portion of the dynamic energy arising from the ground motion[3].

Literature review and hypothesis

Cacciola and et al.[4], achieved a significant reduction of the structural response up to 44% on the target monopiled-structure using vibrating barrier (ViBa) implemented in visco-elastic soil.

Ahmed Fady, Moataz A. Mabrouk et al. [5], proposed a new approach of ViBa design to protect the step pyramid of Zoser using Artificial Neural Network (ANN) to optimize the ViBa parameters. The study results showed that the (ANN) optimization approach reduced the peak step pyramid acceleration by 46% compared to 30% using a traditional stochastic approach.

According to the previous literature we claim that using the vibrating barrie we can damp the seismic waves before hitting the wind turbine and this will be a good alternative to control the dynamic response of the wind turbines.

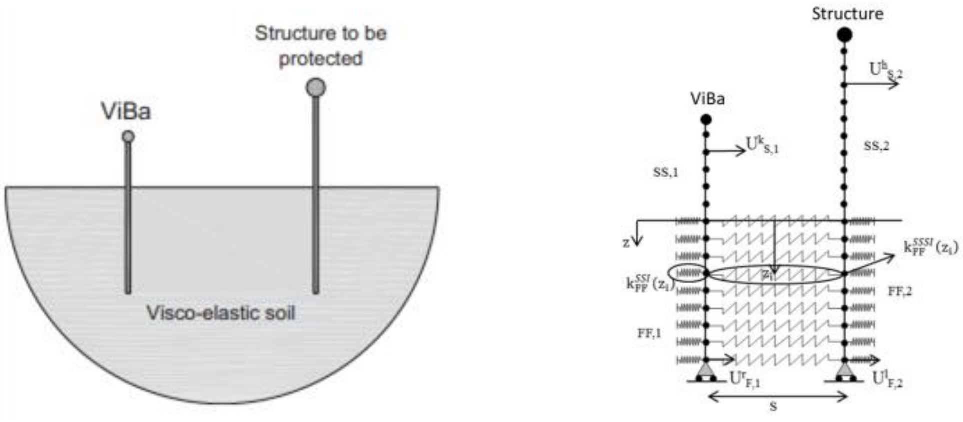


Fig. 1: Basic concept of ViBa _ monopiled structure interaction [4]

Objectives and Methodology

The general objective of this research is to enhance the seismic resilience of wind turbine farms in seismically active regions by introducing an innovative seismic protection strategy using vibrating barriers (ViBa). These barriers will be designed through a novel methodology based on artificial neural networks (ANNs).

The specific objectives are as follows:

1. **Dynamic Response Simulation and Data Generation for (ANNs) training.**

2D and 3D simulations to compute the dynamic response parameters of wind turbines—such as displacement, acceleration. These simulations will include soil–structure interaction and will generate a comprehensive dataset for training and testing the ANN models.

1. **Design of Seismic Protection Strategy Using ViBa.**

Develop a protection strategy that enhances the durability and stability of wind turbines by deploying vibrating barriers. This will be applied to both individual turbines and arrays of turbines within a wind farm setting, considering real site conditions.

Objectives and Methodology

3. Development of ANN-Based Design tool

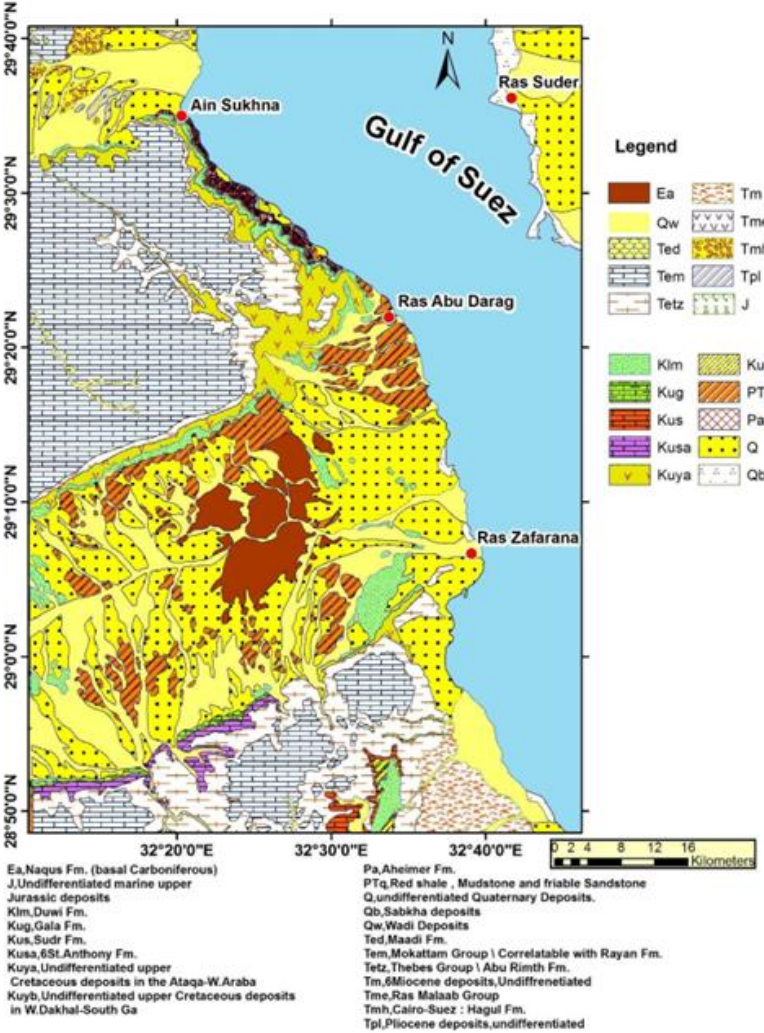
Build a customizable software tool based on artificial neural networks for the optimal design of ViBa systems tailored to different wind turbine configurations. This tool will allow engineers to generate site-specific designs without affecting the primary turbine structure.

4. Structural Evaluation and Reliability Assessment

Apply efficient analysis methods to evaluate the dynamic performance and reliability of the turbine structures under seismic excitation. This includes analyzing random response behavior and assessing system-level reliability in realistic scenarios, study cases Zaafarana and Gabal el zeit wind Farms.

Objectives and methodology

Fig. (2): Location and geological map of the Zafarana region [6].



Objectives and methodology

Fig. (3): (a) Layout of Zafarana wind Farms [6].

(b) Layout of the Expansion area of Gabal El Zeit wind Farms including 11 wind farms in this location [6].

Numerical model setup & validation

To achieve the first objective 2d finite element model was developed and validated as shown in figure 4. The turbine dimensions, and material properties for the soil and turbine were as follows:

- Tower: Height = 60 m
- Tower is a cylindrical steel shell
- Average outer diameter: 3.8 m, thickness: 35 mm
- Young's modulus: 210 GPa
- Mass density: 7850 kg/m3
- Blades: Hollow rectangular box sections
- Average dimensions: 3 m by 0.8 m, thickness 18 mm
- Young's modulus: 65 GPa
- Mass density: 2100 kg/m3
- Blade length: 30 m
- Lumped Hub and Nacelle mass: 70,000 kg
- Soil: Plain- Strain finite elements was used
- Young's modulus: 90000 KN/m2
- Mass density: 20 kN/m3
- Poisson's ratio : 0.3

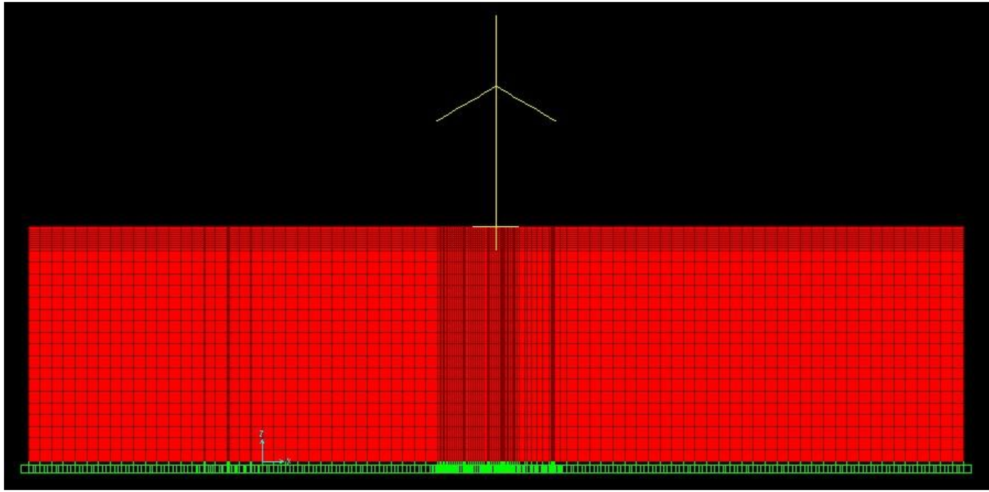


Fig. 4: 2D FEM for the wind turbine and surrounding soil

Numerical model setup & validation

Table (1): The developed model vs. the reference paper modal eigenfrequency (Hz) comparison

mode	Reference [2]	The generated model
1	0.57	0.59
2	1.41	1.03
3	1.54	1.44
4	3.61	3.95
5	4.20	4.145

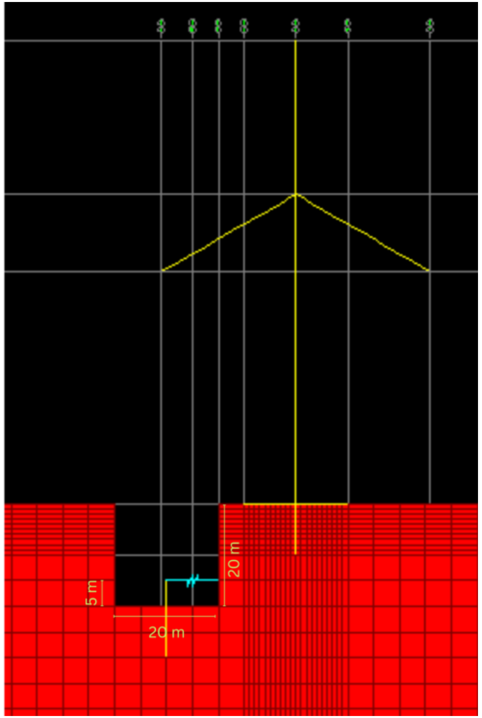


Fig. 5: 2D turbine model with ViBa

Numerical model setup & validation

To validate the proposed concept, several models with different VIBA parameters were conducted. Figure (6) shows the reduction in the hub acceleration after using VIBA. To generate the training dataset for the ANNs a visual basic for application (VBA) program was used to generate the training dataset.

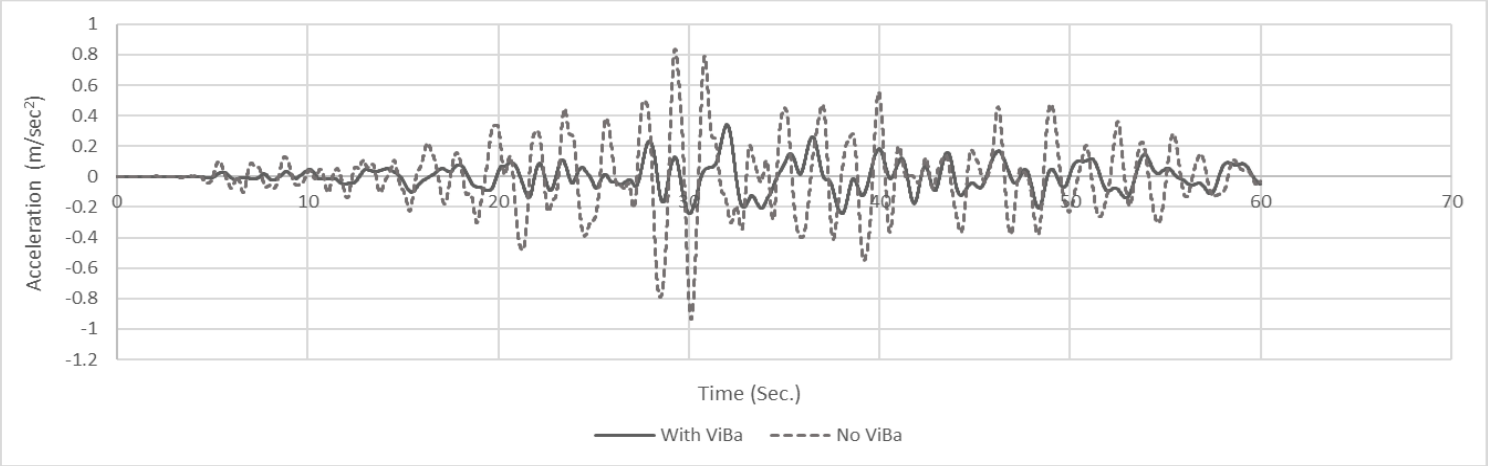


Fig. 6: Effect of ViBa on wind turbine seismic response

Numerical model setup & validation

10500 model was generated and solved, then their result were extracted and combined with the earthquakes parameters to form the training dataset. The models were generated by changing VIBA parameters with the following criteria:
-Distances vary between 15, 25, and 35 meters from the turbine tower base.
-ViBa masses are assumed between 300 KN and 30000 KN.
-Stiffness is assumed to cover frequency range between 0.1 and 24 Hz

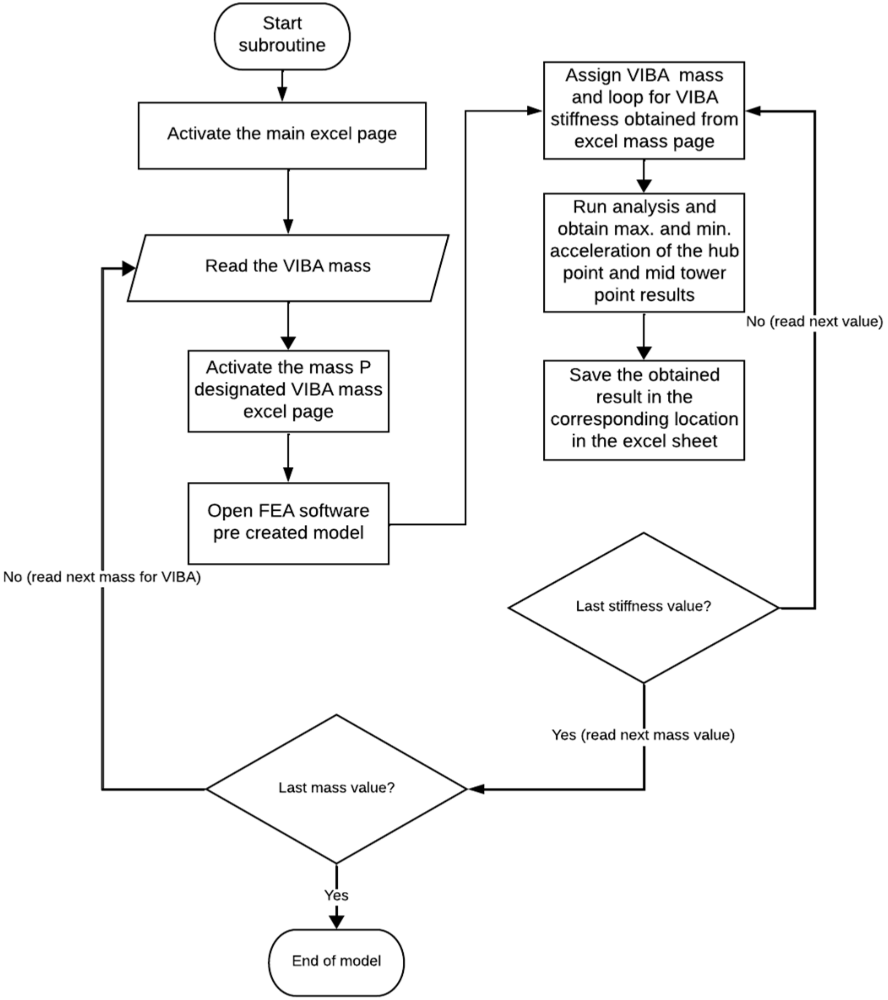


Fig. 7: Flowchart of data generation code

Numerical model setup & validation

To test and enhance the quality of the used dataset, a CHAID algorithm was used to determine the significance of each parameter in training data as shown in (Figure 5)

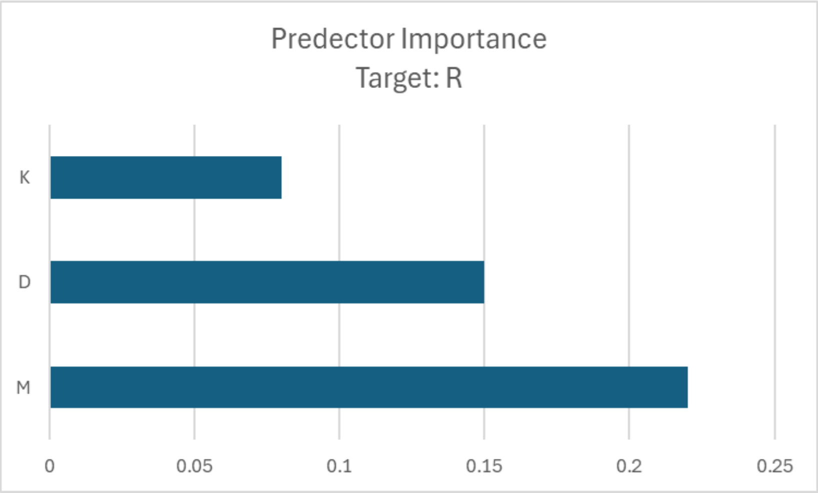


Fig 8: Importance factor of VIBA parameters using CHAID algorithm.

The Developed ANN

Sequential feedforward neural network model was developed. This network was designed to process multi-source input data through a modular architecture, enabling it to extract and learn complex relationships within the dataset using Tensorflow library. A genetic Algorithm was executed to predict the optimum architecture of the neural network using the previously generated dataset. Figure (8) shows the neural network optimized architecture.

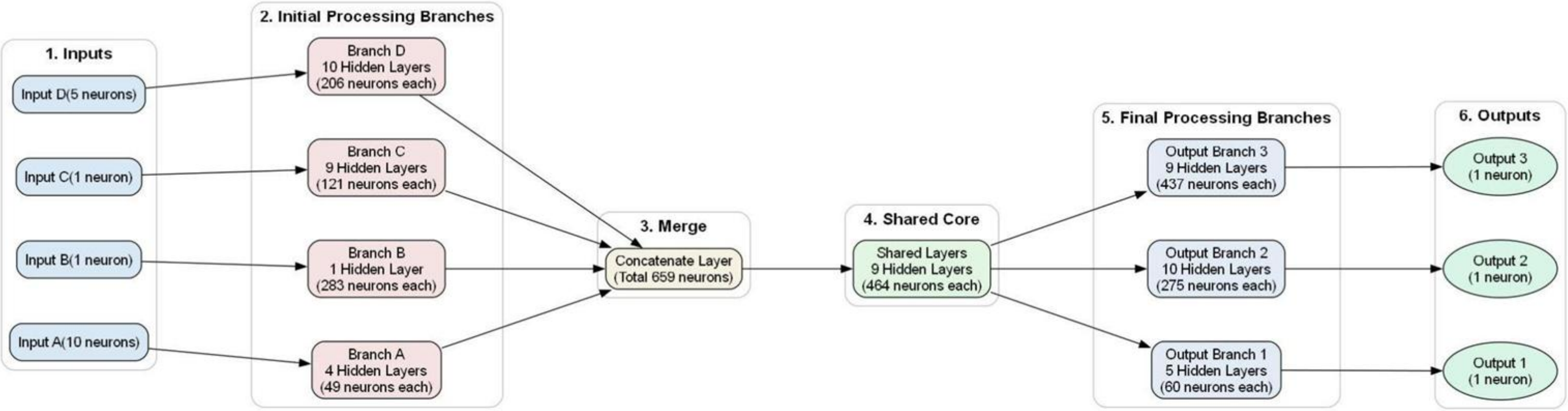


Fig. 9: Schematic of the used Sequential Neural Network

Stage (1) Results and Discussion

The network was trained using Aqaba and Dahshour earthquakes, and tested using 5 different earthquakes including Elaqaba and Dahshour. The earthquakes was chosen to be different in intensity, time length, and magnitude, then they was scaled according to guidelines of ASCE 7 to match the seismic zone of the turbine. After testing, the VIBA design with the highest response reduction was tested using another 2 different earthquakes to verify its reduction capabilities, then the VIBA design with the highest reduction was chosen as the optimum design of the VIBA for the case study turbine. Different cases of the training to testing ratio was examined (60:40, 70:30, and 90:10) to refine the learning curve. The 60:40 ratio showed the highest reduction for the turbins hub.

The results (Table 2,3,4) shows reduction in the response about 47% in terms of acceleration at the turbine hub point.

K: ViBa stiffness	EQ1: Aqaba EQ
M_{ViBa}: Mass of ViBa	EQ2: Dahshour 1992 EQ
$M_{Turbine}$: Lumped mass of turbine hub and nassell	EQ3: El Centro EQ
d: Distance from Turbine tower	EQ4: Kobe EQ
	EQ5: Cornith EQ

Table 3: (60 : 40) % of dataset training to testing ratio resultsfor the first 5 earthquakes

Targeted reduction	Actual reduction EQ1	Actual reduction EQ2	Actual reduction EQ3	Actual reduction EQ4	Actual reduction EQ5
40%	-10.16	70.45	99.99	66.88	45.04
50%	-25.41	75.43	44.05	53.54	47.05
60%	43.75	-5.51	73.93	25.18	47.99
70%	32.67	7.86	40.71	33.51	51.13
80%	4.85	82.48	-1.02	-4.68	45.10
90%	59.41	84.32	13.98	70.53	44.34

Table 3: (70 : 30) % of dataset training to testing ratio resultsfor the first 5 earthquakes

Targeted reduction	Actual reduction EQ1	Actual reduction EQ2	Actual reduction EQ3	Actual reduction EQ4	Actual reduction EQ5
40%	70.22	-14	59.99	-837.6	-213.35
50%	54.57	29.45	71.09	-584.73	-115.69
60%	28.24	60.97	18.72	-313.62	13.91
70%	27.42	69.13	56.16	-32.195	36.52
80%	67.79	65.51	47.29	45.97	54.43
90%	24.79	55.87	43.09	7.52	63.73

Table 3: Testing results in terms of turbine hub acceleration reduction for the choosen design (based on 60:40 % results)

	Response Red. for EQ1 %	Response Red. for EQ2	Response Red. for EQ3	Response Red. for EQ4	Response Red. for EQ5
$(K, M_{ViBa,} d)_{60}$ EQ1 (23929.16, 87626528, 11.63)	<u>32.1</u>	<u>44.91</u>	<u>46.72</u>	<u>7.54</u>	<u>22.28</u>
$(K, M_{ViBa,} d)_{60}$ EQ2 (10255.33, 86929336, 13.54)	28.84	47.6	36.73	4.72	19.2
$(K, M_{ViBa,} d)_{60}$ EQ3 22373.91,77526752, 26.14)	27.03	0.023	41.2	-37.33	1.73
$(K, M_{ViBa,} d)_{60}$ EQ4 25624.38, 212704496, 45.26)	21.59	-22.22	<u>61.67</u>	-29.5	1.07
$(K, M_{ViBa,} d)_{60}$ EQ5 (38915.95, 298855552, 56.61)	-15.12	-23.66	4.87	-44.42	-7.64

Further work

- Complete the design testing criteria as descriped in the previous section (using the optimun design resulted from the prvious step of testing to design the VIBA to resist 2 new earthquakes never seen before by the network).
- Repete the design testing criteria with multi VIBA - single turbine conditions.
- Repete the design testing criteria with multi VIBA - single turbine conditions in 3D.
- Use the design testing criteria with multi VIBA - multi turbineconditions (Zaafarana and Gabal Elzeit wind farms).
- Structural Evaluation of the turbine.

References

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Thank you