System Reliability Analysis using Monte Carlo based Method and Neural Networks

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Introduction

- This project examines and develops a method for calculating the probability of structural failure by using Monte Carlo simulation and combining it with neural networks approach.
- To assess the validity of this method, a simple concrete beam model with a corrosion crack is built in COMSOL Multiphysics. This type of crack is typically having a constant width and varies in length. The beam is subjected to an external moving load and from the vibration resulting from that load, the crack length can be estimated.
- A second model, of a steel bar reinforced concrete beam, also developed using COMSOL Multiphysics. In this model we calculate the deflection and axial stress. Different actions, e.g., dead load, live load, and wind, are applied to the beam and from deflection measurements, the probability of failure is calculated.

Introduction to Reliability Analysis

- Structural safety or structural reliability analysis aims at calculating the probability of the occurrence of cetin actions that represent the failure of the structure, by creating a probabilistic models of acting loads and resistance of a structural component or system.
  - Gradient based method: In gradient based approaches the performance function is approximated by a linear function in a normalized space at the design point and poor accuracy can result from nonlinear performance functions e.g. the first-order reliability method and the second order reliability method.
  - The simulation techniques have their origin in monte Carlo simulation method. MCS method is time consuming, despite its simplicity this method may become very computationally demanding that it becomes impractical.

Monte Carol Analysis in Reliability Analysis

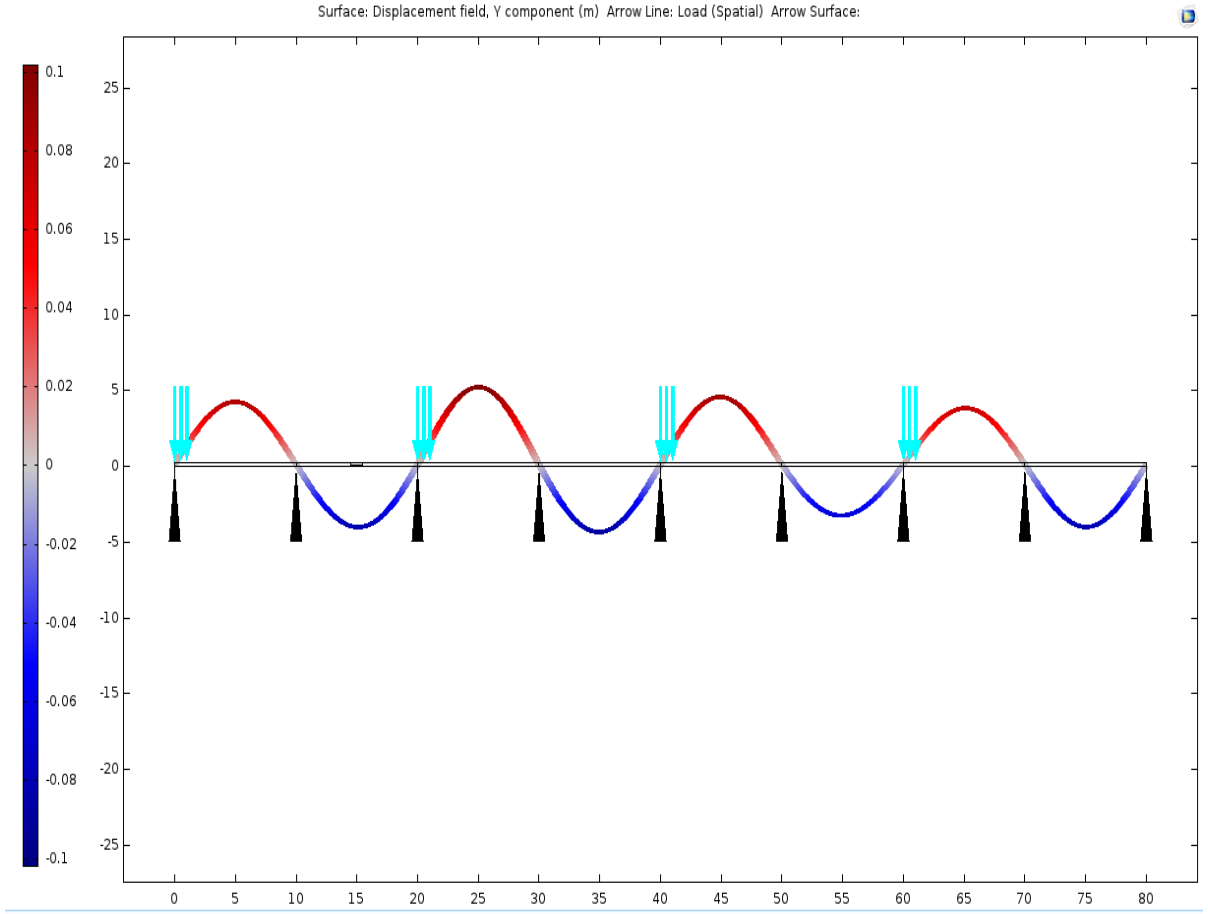
- The Monte Carlo Simulation MCS method is a practical choice for reliability analysis especially when the solution is not attainable and by traditional analytical methods.
- Monte Carlo simulation is a process that relies on random sampling to assign probabilities for different outcomes.
- The mathematical formulation of MCS is simple and straight forward, MCS hasn't had overwhelming acceptance due to the excessive computational effort that is required in dealing with complex problems.
- A well-designed ANN can significantly reduce computational cost of structure response prediction.

Neural Networks in Structural Reliability Analysis

- Artificial Neural network is a mapping mechanism that simulates the ability of a biological neuron network by interconnecting many simple neurons.
- A well trained NN can provide the correlation or the mathematical relationship between multidimensional input output data.
- In this research a multi layer feed-forward neural network structure is used, it consists of 3 layers and each layer consists of several neurons.
- The input of the neural network are the variables that control the structure's strength, while the output is the sate of the structure.

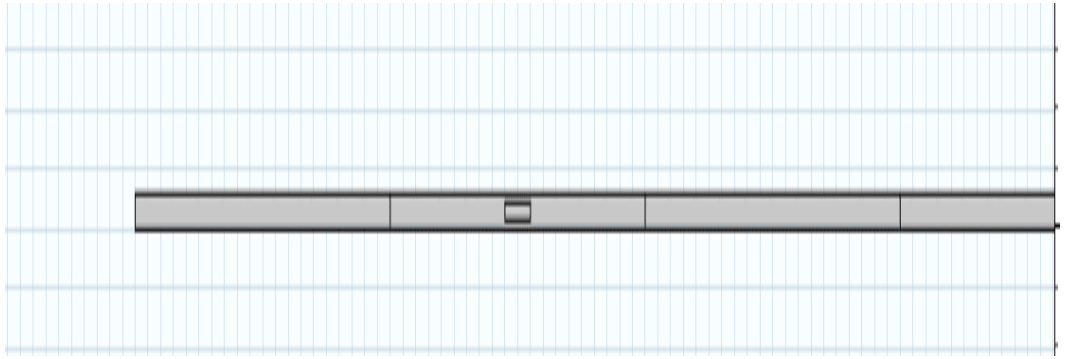
Example 1: Simple Concrete beam

- The designed model is based on a prebuilt COMSOL model called “Beam with Traveling Load”
- The model is of a simple bridge like structure with a moving load on top.
- The displacement vs time is recorded at four positions along the structure.



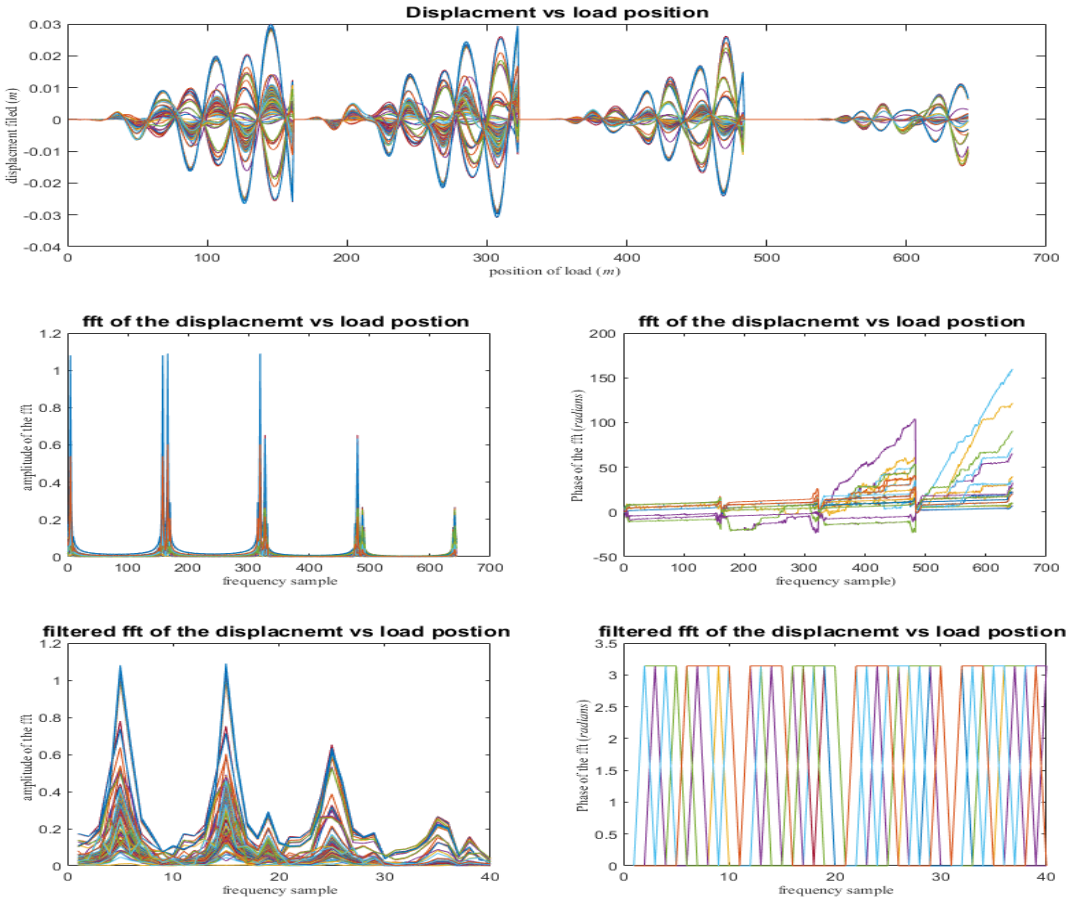
Introducing a Crack

- A crack is introduced in the second beam, the crack's height, 15cm, is half of the beams' height
- Using the parameter sweep tool the crack's length is set from 1 cm to 100 cm with 1 cm intervals
- The goal is for the designed ANN model to predict the crack size from the displacement data



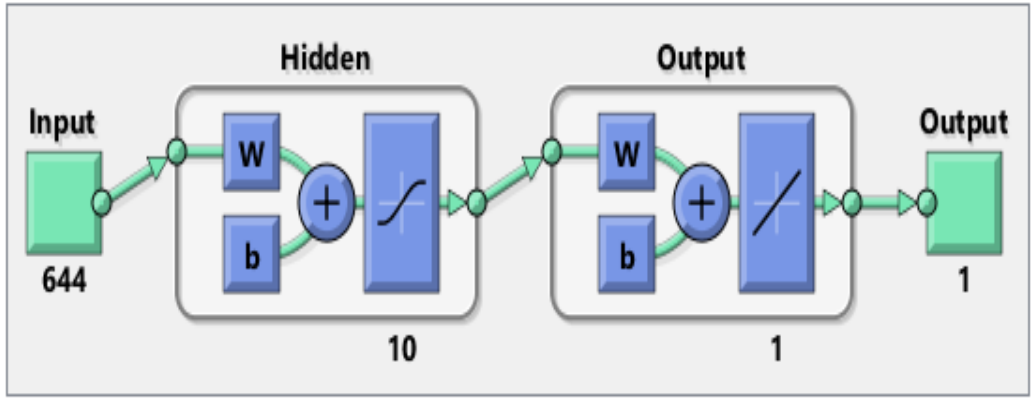
Effect of Crack Size on Displacement

- The top plot in the next figure shows the displacement vs the position of the load.
- The second plot show the Fourier transformation of the displacement data.
- As the amplitude of Fourier transformation is concentrated in the first few frequency samples, the final plot filters the first 10 samples of the Fourier transformed data.



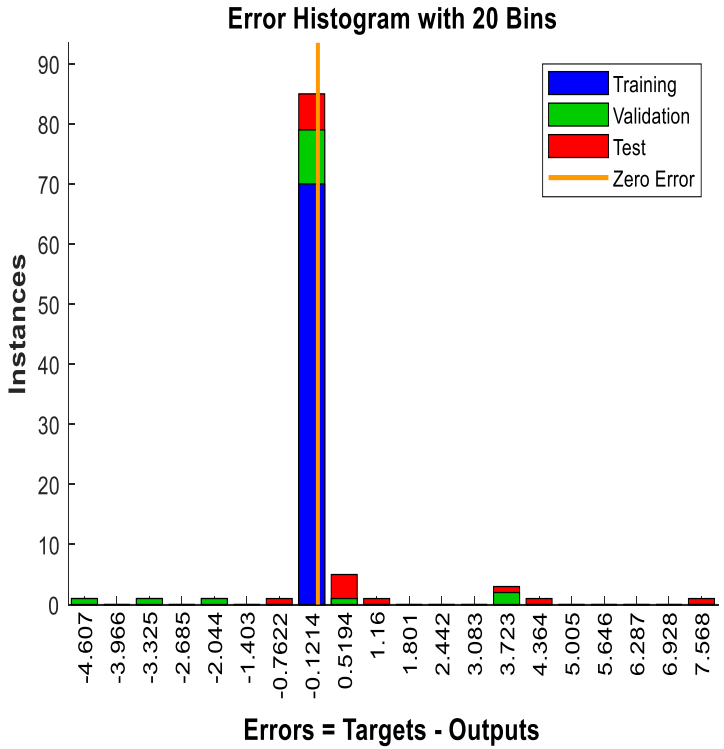
Fitting the Data with a Neural Network

- The designed network is a three-layer feed forward network with one hidden layer.
- The input is 644 * 100 matrix: 644 elements for each of the 100 crack sizes. The output is the crack size
- The output is the crack size



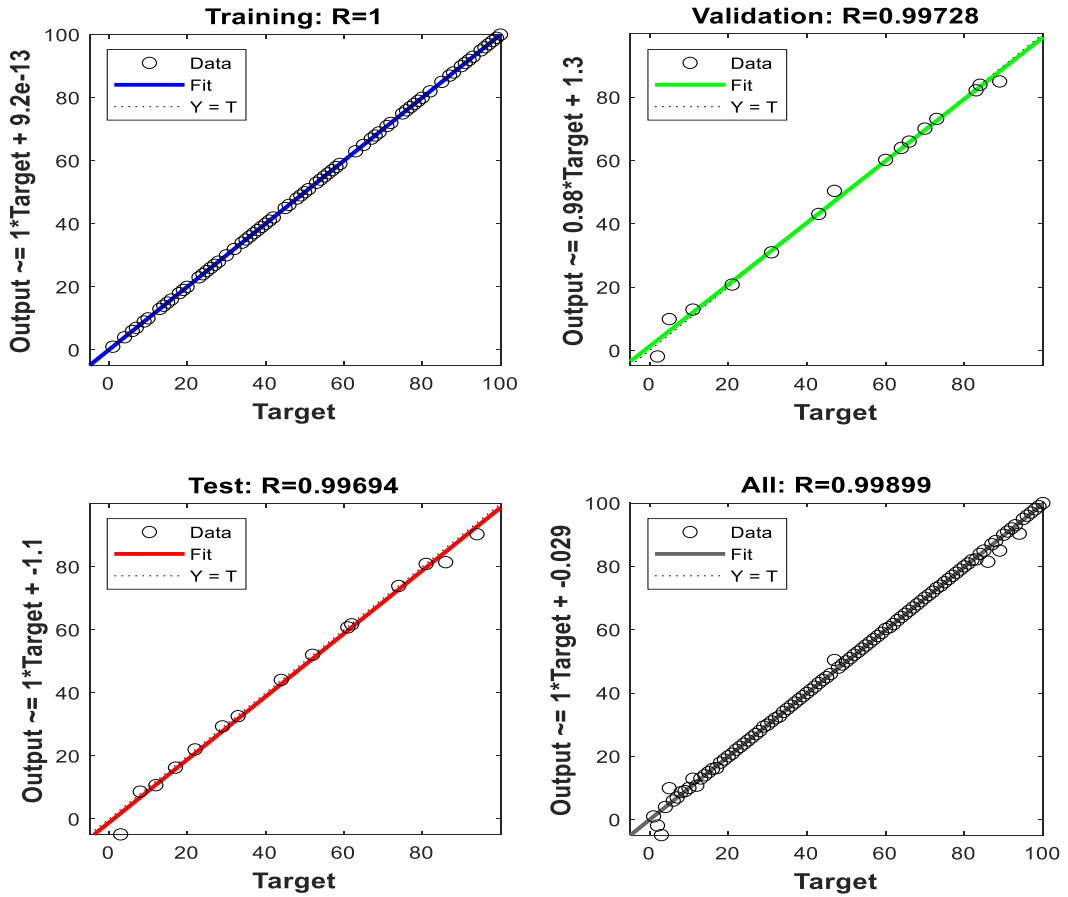
Training the Network (Error Histogram)

- The error histogram graph, is useful in analyzing the outliners, or data points that perform significantly worse than most of the data.
- In this example we can see that if wee took the accepted error levels as values between 1 and -1, we can approximate 9 outliers.
- By analyzing those samples, we can see if those data are different than the rest or does the network need to collect more data on each sample, or if another training algorithm would produce better results.



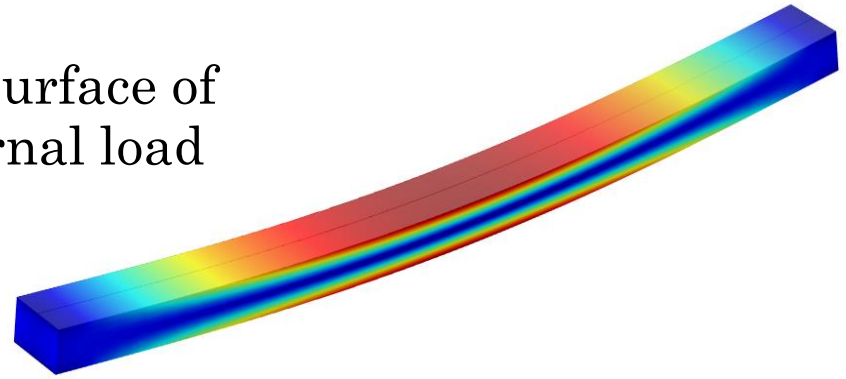
Training the Network (Regression Plot)

- The regression plot displays the network outputs with respect to targets for training validation and testing.
- For a perfect fit, the data should be along the 45-degree line where the network output is equal to the target.
- In this example the fit is reasonably good with regression value (R), the correlation between outputs and targets, of over 0.99



Example 2: Steel Bar Reinforced Concrete Beam

- The designed model is based on a prebuilt COMSOL model called “Concrete Beam with Reinforcement Bars”.
- The model is that of a concrete block modeled using the solid mechanics interface, and steel bars modeled using the Truss interface.
- In this model the deflection along the top surface of the concrete beam due to gravity and external load is calculated.



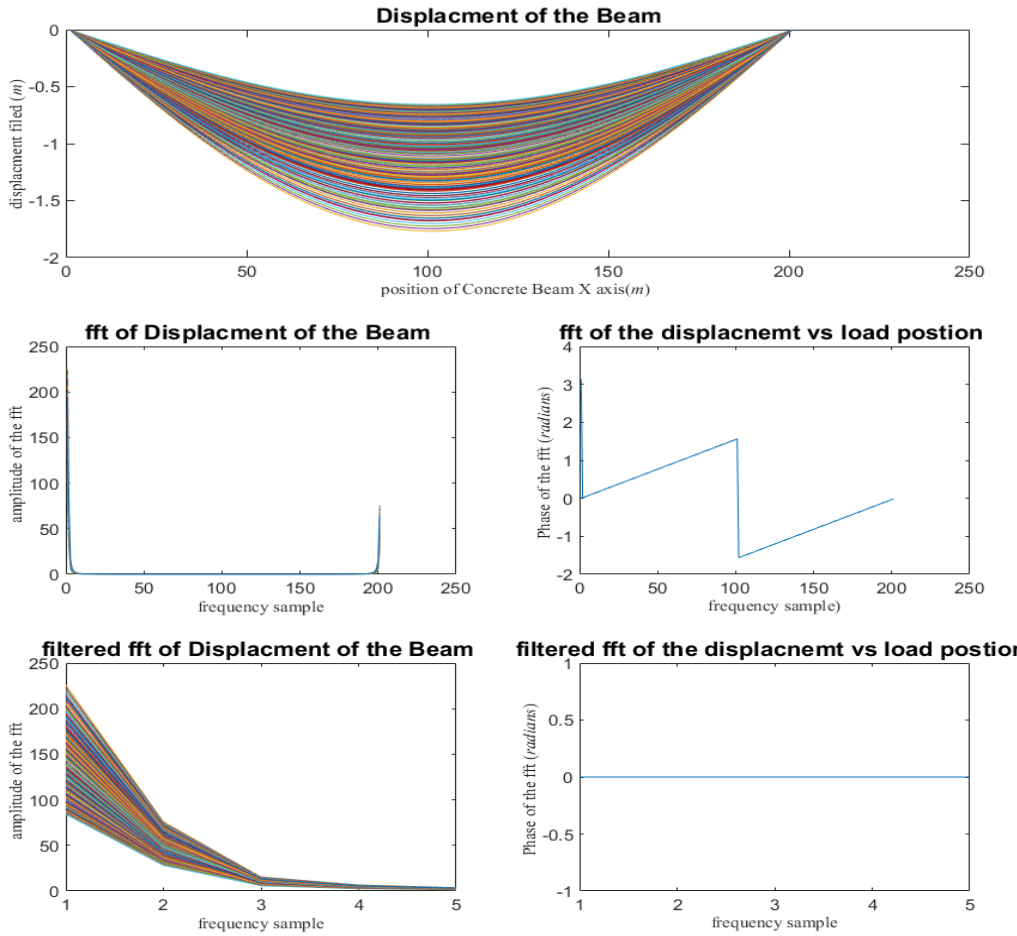
Probabilistic model

- To detect the probability of failure of the structure, the strength of the structure is defined by several random variables (table below)

Variable	Unit	Probabilistic distribution	Mean value	Standard Deviation
Concrete beam Height	mm	Normal	200	10.5
Steel Bar Diameter	Mm	Normal	10	0.5
Force Area	[N/m^2]	Normal/Lognormal	2e4	2e3
Concrete Young's Modulus	GPa	Lognormal	25	12
Steel Young's Modulus	GPa	Lognormal	200	120

Simulation Results

- The top plot in the next figure shows the displacement along different points on the concrete beam.
- The variations in the random variables that control the probabilistic model, produce small variations in the displacement.
- Those results are not suitable to use in a NN.
- Different combination of variables should be tested.



Conclusion

- In recent years Monte Carlo Simulation along with Neural network have been used in preforming structure's Reliability analysis.
- Generally Reliability analysis and calculating the probability of failure are computationally intensive process.
- In the first example considered (simple concrete beam) MCS was preformed along with a NN to describe the structural behavior of the model due to an introduced crack.
- In the second example (steel bar reinforced concrete beam) the developed methodology shows that the correlation between the random variables and the displacement is not sufficient for a NN to be trained.

References

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Thank you