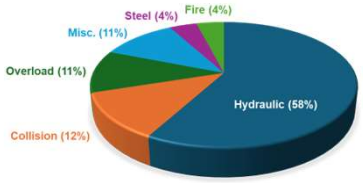
Bridge Scour Depth Prediction using Ensemble Machine Learning Models

Peter Damilola Ogunjinmi, Woubishet Zewdu Taffese, Genda Chen

Department of Civil, Architectural and Environmental Engineering

Introduction & Motivation

- Bridge scour, which refers to the erosion of sediment around the foundation of a bridge structure, is the leading cause of bridge failures in the United States.
- It accounts for approximately 58% of bridge failures attributed to hydraulic factors.
- Accurately predicting bridge scour depth is crucial to ensure the structural integrity, resilience, and safety of bridges.



Causes of bridge failure in the United States (1966 -2005)

Collapse of Schoharie Creek Bridge in New York due to scour (1987)

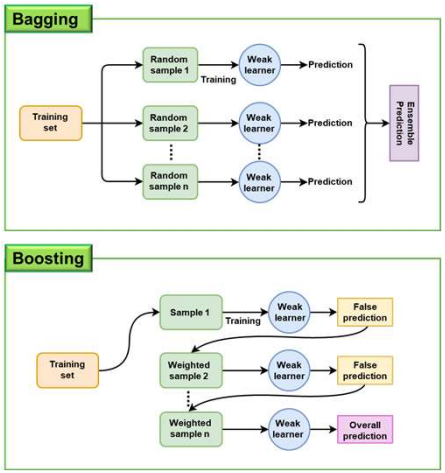
Objective of study

This study aims to advance the prediction of bridge scour depth by harnessing the power of ensemble machine learning (ML) models.

Methodology

Ensemble ML Models

- Ensemble models combine multiple base ML models to make predictions.
- The aggregation of diverse models leads to more accurate and robust results.
- Bagging and boosting ensemble ML approaches were considered in this study due to their effectiveness in reducing variance and bias, respectively.



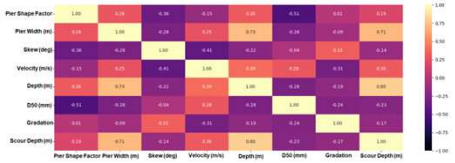
Ensemble ML techniques: Bagging & Boosting

Dataset Description & Preprocessing

- The dataset consists of 237 instances of bridge pier scour measurements.
- Before model fitting and training, the dataset was split into two subsets: 80% for training and 20% for testing.
- In addition, the dataset was normalized to enhance faster convergence.

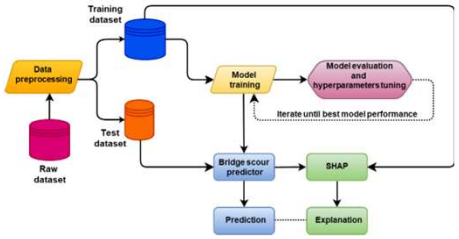
	Pier Shape Factor	Pier width (m)	Skew (deg)	Velocity (m/s)	Depth (m)	D_{50} (mm)	Gradation	Scour depth (m)
Min	0.70	0.30	0.00	0.00	0.20	0.12	1.20	0.10
Mean	0.98	1.56	9.27	1.53	4.31	17.97	3.73	1.12
Std.	0.20	1.18	18.36	0.82	3.90	25.13	3.14	1.33
Max	1.30	5.50	85.00	4.50	22.50	95.00	21.80	7.70

Note: *Pier Shape factor = 1.3 for square pier;1 for round pier; 0.7 for sharp pier*



Correlation coefficients of the variables

Model Development & Training



Workflow for ensemble ML model development

- A Deep Neural Network (DNN), linear regression model, and eight ensemble ML models were employed to predict bridge scour depth.
- The DNN comprises 1 input layer with 7 neurons and 3 hidden layers with 20, 50, 30 neurons; Rectified Linear Unit (ReLU) activation functions were applied between its layers, and it was trained for 500 epochs using Adam optimizer.
- Hyperparameters for ensemble models were optimized via grid search, and 10-fold cross-validation was employed to minimize training bias.

Results

Performance of the ML Models

Feature importance & SHAP analysis based on CatBoost model

Conclusion

This study proposed an ensemble ML approach for predicting bridge scour depth. All the ensemble models outperformed the linear regression and DNN models, with CatBoost yielding the best performance (R^2 = 0.853).

References

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