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A Hybrid Data-Driven and Physics-Based Approach for Shear Capacity Estimation of Steel Fiber Reinforced Concrete Beams

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Abstract

Estimation of shear strength of steel fiber reinforced concrete (SFRC) beams is difficult because of the complex nonlinear interactions between fiber, geometry, and reinforcements. In this study, the hybrid machine learning (ML) and finite element analysis (FEA) method are utilized for estimating the load-carrying capacity (Pmax) of SFRC beams. A database of 257 SFRC beams was collected from literature and was pre-processed. Seven ML methods, including Decision Tree, AdaBoost, Linear Regression, k-Nearest Neighbors, Random Forest, Stochastic Gradient Descent, and Gradient Boosting, were applied on the database through the k-fold cross-validation technique. The best model was selected as Gradient Boosting due to $R^2 > 0.93$. By conducting SHAP analysis, longitudinal reinforcement ratio, height of the beam, and shear span-to-depth ratio were found to be the most important parameters. Using nonlinear FEA in Abaqus, the results of ML models were validated by comparing them with experimental and simulation results ($\Delta \approx 4.79\%$ and $\Delta \approx 0.14\%$, respectively). Through parametric studies, the positive influence of the volume fraction of fibers and reinforcement ratio and negative influence of shear span-to-depth ratio were determined. The suggested ML-FEA approach can be considered accurate and efficient for practical SFRC shear design.

Keywords: Fiber Reinforced Concrete; Abaqus; FEA; Machine Learning.

1. Introduction

The use of steel fiber reinforced concrete (SFRC) in the last decades has gained an increasing interest to improve the performance of concrete beams [1]. SFRC improves the tensile strength and shrinkage crack resistance performance [2]. The use of SFRC enhances the overall structural performance of concrete beams by increasing their shear strength and ductility as compared to regular reinforced concrete [3, 4]. The presence of randomly distributed steel fibers across the cracks effectively bridges the cracks, thus making the structure highly tough and energy absorbing. Therefore, SFRC is best applicable in beam, slab, pavement, and tunnel lining designs, where shear plays a crucial role in the overall structural behavior [5, 6].

In the last decades, significant research has been done globally regarding the behavior of SFRC beams subjected to four-point loading. It has been observed that the incorporation of steel fibers significantly increases the flexural strength of concrete beams [7]. Although the compressive strength of FRC is less affected by the presence of fibers, the failure model of FRC can be considered ductile [8]. The incorporation of steel fibers significantly delays the formation and

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