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Shear strength of RC deep beam predicted by support vector regression

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ABSTRACT

Numerous design equations have been developed to forecast the shear strength of reinforced concrete (RC) deep beams. However, some of them showed widely scattered and conservative predictions due to the complexity of the shear characteristics of RC deep beams. Thus, this study introduced a computational method, namely support vector regression (SVR) to assess the shear strength of RC deep beams. The hyperparameters of the SVR algorithm were tuned through the Bayesian search approach. A database of 320 test results was collected from the existing studies for the validation of the SVR model. The predictions by the SVR model were compared with those obtained from mechanical-driven models. Based on the SVR model, a parametric study was performed.

1. INTRODUCTION

Many experimental studies have been carried out to inspect the structural performance of deep beams. A literature review indicated that the RC deep beams are usually failed in shear than flexure, which could cause a catastrophic deterioration without warning (Oh and Shin, 2001; Rao et al., 2007). Also, various mechanical-driven models for the shear strength of deep beams have been developed. Nonetheless, some of these existing models might yield a large scatter and some bias in their evaluations. This is due to the complex behaviors of the shear mechanism of deep beams, which could not be merged into one theoretical model. Consequently, reliability and robustness in the shear strength prediction of deep beams is still a challenging assignment.

In recent years, machine learning (ML) techniques have proliferated and promptly become a surge in research fields related to material and structural engineering. This is because the ML models could reduce the scatter and bias of the prediction results; have well-archived experimental data as well as data obtained from numerical

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simulations; and have significantly advanced computing capabilities. In this study, the SVR model was utilized to forecast the shear strength of deep beams. To achieve the accurate predictions, the hyperparameters of the SVR model were optimized using the Bayesian search method and an experimental database of 320 specimens. Based on the developed model, the influences of input parameters on the shear strength of deep beams were investigated.

2. DEVELOPMENT OF MACHINE LEARNING-BASED MODEL

2.1 Support vector regression (SVR)

Support vector regression (SVR) is an application of a support vector machine (SVM), which was developed by Vapnik et al. (1996), for the regression process to find a predictive equation that can fit all sample points and minimizes the variance. The resulting SVR algorithm for the regression fitting function can be expressed as follows:

$$f\left(x\right)=\sum_{i=1}^{n}\alpha_i K\left(X,x_i\right)+b \tag{1}$$

where α_i is the Lagrange multipliers; b is the “bias” term; and $K\left(X,x_i\right)$ is the kernel function. The kernel function could be linear, polynomial, radial basis function (rbf), or hyperbolic tangent. Fig. 1 illustrates the graphical structure of the SVR algorithm.

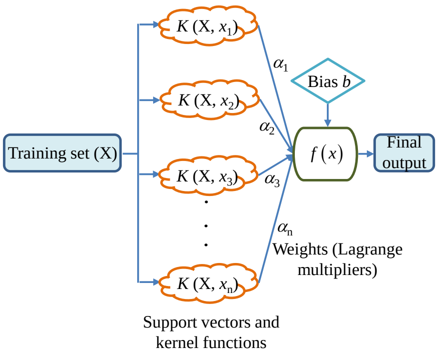

Fig. 1 Graphical structure of SVR algorithm

2.2 Bayesian search approach

To improve the performance of the SVR model, its hyperparameters including ‘C’, ‘gamma’, ‘epsilon’, and ‘degree’ need to be optimized. In this study, Bayesian search, which is an informed search method based on Bayes’ theorem, was utilized in combination with 10-fold cross-validation to obtain the optimal hyperparameters. The Bayesian algorithm could optimize its parameter selection in each round according to the previous round score. Therefore, instead of randomly choosing the next set of parameters, the algorithm optimizes the choice to achieve the best parameter set.

2.3 Database

A total of 320 test results acquired from the existing studies were used. The test parameters included beam height (h), effective depth (d), beam width (b_w), shear span

(a), effective length-to-depth ratio (L/d), shear span-to-depth ratio (a/d), longitudinal tension and compression reinforcement ratios (ρ_{lt} and ρ_{lc}) and its yield strength (f_{yl}), horizontal web reinforcement ratio (ρ_h) and its yield strength (f_{yh}), vertical web reinforcement ratio (ρ_v) and its yield strength (f_{yv}), and concrete compressive strength (f_c') were used as input variables. While the measured shear strength $V_{u,\exp}$ was used as an output variable. Fig. 2 shows the histogram of the output variable.

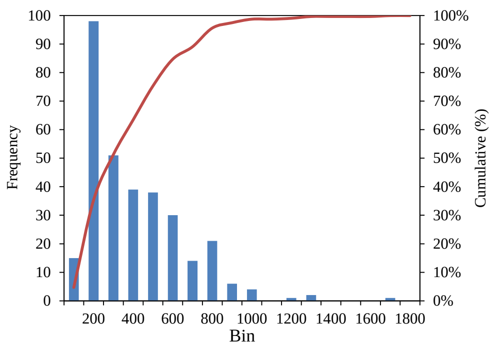

Fig. 2 Histogram of output variable

3. PREDICTION PERFORMANCE OF SVR MODEL

After tuning with Bayesian search, the optimal values of the hyperparameters are as follows: C = 3209, degree = 1, gamma = 0.0246, and epsilon = 0.01. Fig. 3 compares the predictions by the SVR model with test results. As expected, SVR model produced highly accurate predictions: the R^2 and RMSE for the training dataset were 0.965 and 44.434 kN, and 0.918 and 75.453 kN for the testing dataset. For the entire dataset, the mean, COV, R^2, and RMSE of $V_{u,\exp}/V_{u,\text{pre}}$ were 1.015, 0.173, 0.955, and 52.136 kN. For comparison, the model developed by Russo et al. was recalled. It was found that with the use of Russo et al.'s model, the mean, COV, R^2, and RMSE of $V_{u,\exp}/V_{u,\text{pre}}$ were 1.376, 0.228, 0.874, and 122.875 kN. This means the SVR model could exhibit better predictions than Russo et al.'s model.

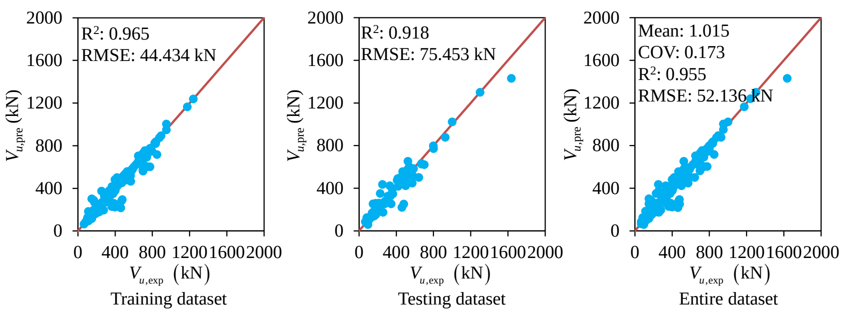

Fig. 3 Shear strength predicted by SVR model

To examine the effects of design variables on the shear strength of deep beams, a parametric study was performed using the SVR model and Russo et al.'s model. As shown in Fig. 4, two models showed similar trends. It was also found that the effective depth, beam width, shear span-to-depth ratio, tension reinforcement ratio, and compressive concrete strength have strong influences on the shear strength of deep beams (see Fig. 4).

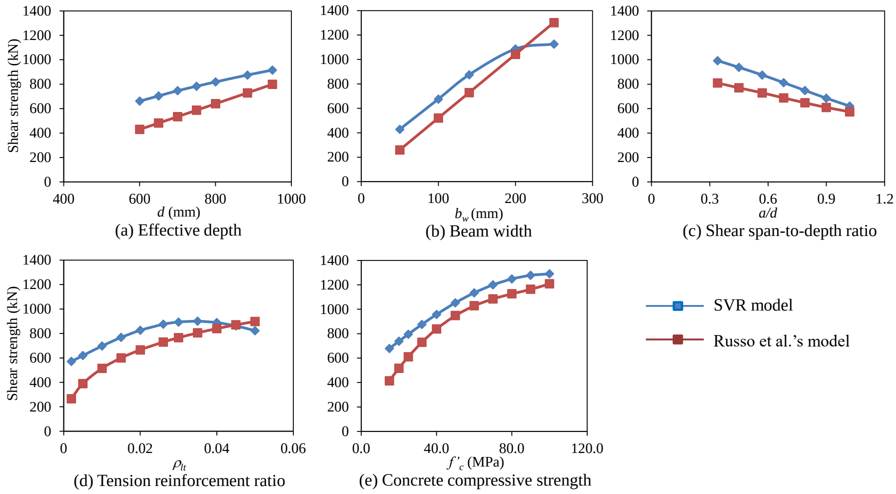

Fig. 4 Parametric study

4. CONCLUSIONS

This study optimizes SVR model using Bayesian search approach to predict the shear strength of RC deep beams. The predictions by the SVR model with the optimal hyperparameters agreed well with the test results. The parametric study indicated that the effective depth, beam width, shear span-to-depth ratio, longitudinal tension reinforcement ratio, and compressive concrete strength have strong effects on the shear strength of deep beams.

ACKNOWLEDGEMENT

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