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REVIEW PAPER

# State-of-Art: Artificial Intelligence Models Era in Modeling Beam Shear Strength

Zainab Al-Khafaji,*,[1] Salim Heddam,[2] Sungwon Kim,[3] Decroly Djoubissié Denouwé,[4] Aissa Bouaissi,[5] Reem Sabah Mohammad,[6] Sameh Yehia,[7] Ammar Ali Hussein,[8] and Ahmed W. Al Zand[1]

[1]Department of Civil Engineering, Universiti Kebangsaan Malaysia (UKM), 43600 Bangi, Selangor, Malaysia
[2]Faculty of Science, Agronomy Department, Hydraulics Division, Laboratory of Research in Biodiversity Interaction Ecosystem and Biotechnology, University 20 Août 1955, Route El Hadaik, BP 26, Skikda, Algeria
[3]Department of Railroad Construction and Safety, Engineering, Dongyang University, Yeongju 36040, Republic of Korea
[4]Laboratoire Eco-Matériaux et Habitats Durables (LEMHaD), Institut International d'ingénierie de l'Eau et de l'Environnement (Institut 2iE), 1 Rue de la science, 01 BP 594 Ouagadougou 01, BurkinaFaso
[5]School of Engineering, University of Plymouth, Plymouth PL4 8AA, UK
[6]Petroleum-Gas University of Ploieşti, Bucharest Blvd, no.39, Romania
[7]Faculty of Engineering, Suez University, Suez, Egypt
[8]Faculty of Economics and Management, University of Sfax, Sfax, Tunisia
*Corresponding author. Email: zainabcivil90@gmail.com

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**Abstract**

The computer aided models have received much attention in the recent years for solving diverse civil engineering applications. In the current review, the applications of artificial intelligence (AI) methodologies in modeling beam shear strength are presented. The review is attempted to give an insightful version for AI models progression in modeling diverse shear strength of structure beams types. Several essential components are surveyed and summarized including, the types of the applied AI models, the input parameters used for the development, types of the additive material, number of the modelled dataset, performance metrics, sources of the modelled data and data availability. Based on the reported literature, several significant core aspects on the AI model's implementation are assessed and discussed scientifically. Future research directions are presented with respect to the exhibited literature review.

**Keywords:** Beam shear strength; artificial intelligence; review; parametric analysis; structure design.

## 1. Introduction

Shear strengthening of Reinforced Concrete (RC) beams has received relatively little study compared to flexural strengthening, which has received the majority of attention [1]. Structures with brittle failure to shear force are particularly harmful. This is mostly caused by the sudden, unexpected structural collapse mechanism caused by shear. Shear force is the primary force experienced by deep beams, with a shear span to effective depth proportion (a/d) of less than two [2]. In both analytical approach and design, the behaviours of a deep beam exposed to vertical static stress vary dramatically from those of the narrow beam.

Because of the fast and brittle fracture of reinforced concrete (RC) beams caused by shear action and the absence of logical design formulas in building regulations, the behaviour and design of RC beams under shear remain a source of worry for structural engineers. Concerns about the outdated shear design methodology at the time were highlighted by the partial collapse of the Wilkins Air

Force Depot building in Ohio in 1955 [3], which was brought on by the shear failure of RC beams. In order to avoid such unexpected failures, design code techniques have been developed and tightened since then.

Researchers are currently debating the shear modes of failure, the resistant mechanism at cracked phases, and the function of different factors [4], [5]. Additionally, investigations on the defining characteristics that influence the shear strength of RC beams have been conducted [6]–[9]. These criteria involve beam size and form, reinforcing quantity, shear-span/effective-depth proportion, and material strength. The standard method utilized in most studies to estimate how these characteristics affect an RC beam's shear strength begins with an expected version of the practical or analytical formula [10]. A regression analysis utilizing experimental data is then performed to identify the unknown coefficients needed to fit the test data into the formula [11]. The shear strength of RC beams may be predicted using various models. However, a comparative analysis of these models [9] has shown that they are only useful for understanding the experimental data utilized for their calibration. The variations in the variables employed and the specifics of the trials might be to blame for this disagreement.

There are many methods by which shear force is conveyed in reinforced concrete members [12]–[14]. The shear resistance of uncracked concrete in the compression zone, the interlocking action of aggregates along the rough concrete surfaces on either side of the crack [15], and the dowel action of the longitudinal reinforcement all contribute to carrying shear force for thin beams with a/d greater than 2.0 to 3.0. For relatively short beams, however, arch action primarily resists shear force following the breakdown of beam action. According to test findings, the concrete strength, longitudinal steel proportion, shear span-to-depth ratio, and effective depth are the key determinants of the shear strength of reinforced concrete beams without web reinforcement. Of course, variables like the max aggregate size, bar diameter, and flexural crack spacing exhibit minor contributions. The shear strength forecast models that are now in use incorporate some of these basic components, but the impacts of these elements are calculated differently in each model.

It is well known that the shear failure of strengthened concrete beams devoid of web reinforcement is a classic instance of brittle failure and exhibits a considerable size impact. Reinhardt [16] first used fracture mechanics to forecast shear strength in 1981. He examined the scant test data for shear failure based on linear elastic fracture mechanics. It was later shown that the nonlinear failure mechanism seems to be a better fit to characterise the brittle collapses of concrete structures because the size impact predicted by linear elastic fracture mechanics is too severe in the case of concrete. Meanwhile, Bazant [8] provided a straightforward and approximative size impact rule based on nonlinear fracture mechanics. Bazant's size impact rule is in good correlation with test findings, according to much research [8], [17]–[19]. Nevertheless, there is a significant inconsistency between the test results and the prediction made by Bazant's rule, especially for large-sized specimens. Kim and Eo [20] have developed a modified Bazant's size impact rule to lessen the disparity.

The brittle and sudden nature of the shear failure of RC beams made it a major concern [21]. Hence, conventional steel stirrups have been found as effective shear reinforcements that can prevent the sudden failure of concretes and improve the shear capacity [22]. However, some challenges face the integration of stirrups in thin, congested, and irregular sections [23]. One of the problems is related to the placement of concrete in the spacing between stirrups due to the available small gap and this can lead to the presence of voids in the resulting concrete [24]. Furthermore, the use of conventional stirrups requires a great human effort that increases construction costs. Hence, steel fibers have received considerable attention as the alternative material in recent years due to their ability to provide the required shear reinforcement when used in sufficient quantities [25]. The use of steel fiber reinforced concrete (SFRC) in the construction industry has been associated with many advantages; for instance, the study by [25] noted the ability of fibers to improve shear resistance by reducing the width of cracks and facilitation of the diagonal transfer of the tensile stresses. The shrinking behavior and post-cracking toughness of concretes can also be improved using fibers [26]; the inclusion of fiber into concretes has also been reported to enhance the dowel resistance due to the improvement of the tensile strength of the concrete in the splitting plane along with the reinforcements [27]. A fiber volume fraction of 1% has been reported by [27] to be sufficient for the control of shear failure transition from the catastrophic mode to the controlled ductile failure mode. Considering these advantages of steel fibers, the ACI building code has permitted the minimal replacement of stirrups with steel fibers in concrete structures [28]. Therefore, the shear capacity of SFRC must be accurately determined even though it is not an easy process due to the complex nature of the shear transfer mechanisms in SFRC beams, as well as the orientation of the fiber at the crack interface [26]. Currently, the shear strength of SFRC beams is mainly determined using empirical models that involve statistical experimental data analysis. The study by [29] developed an equation that accounts for the tensile strength of concrete and the shear span-to-depth ratio while linking the tensile and compressive concrete strengths with Wright's formula [30]. Kwak et al. [31] performed 12 tests on SFRC beams when developing a relationship that accommodates the effect of fiber inclusion using Zsutty's equation for RC beams [32]. The introduced empirical formulations over the literature are associated with several limitations and thus the development of advanced computer aided models were the reliable alternative methodologies for the beam shear strength determination.

In order to forecast the shear strength of both FRP-reinforced concrete elements with and without stirrups, group method of data handling networks (GMDH) is used and tested [33], [34]. There are a total of 12 significant geometrical and mechanical characteristics taken into account as input parameters for the GMDH. New models are created for two scenarios with and without shear reinforcement using two readily accessible, recently gathered extensive datasets of 112 and 175 data samples, respectively. A number of codes of practise are compared to the suggested GMDH models. The same datasets are also used to create an artificial neural network (ANN) model and an ANFIS-based model to further evaluate GMDH. The statistical error parameters are used to assess the correctness of the created models. The findings demonstrate that the GMDH outperforms previous models and may be utilised as a useful and successful tool for shear strength forecasting of members with and without stirrups. Additionally, parametric and sensitivity studies are used to assess the relative weight and effect of input factors on the forecast of the shear capacity of reinforced concrete components.

It was worth to survey the Scopus database for the adopted research on beam shear strength modeling using the development of machine learning models. 205 keywords were majorly recognized over the literature as reported in Figure 1a. Based on the several clusters generated in accordance with the VOSviewer algorithm software, this research domain is getting more interesting than before and multiple aspects related to the concrete properties, dimensional design, concrete additive materials, modeling algorithm types, etc. Figure 1b indicates that more research were adopted recently and concerning the types of the fiber reinforcement, the diverse variant of the data mining models, material bond strength, types of structure and others. Figure 1c explains the globalization interest popularity for the studied beam shear strength prediction. United states, China and Vietnam were the majorly devoted more attention on this problem investigation. However, nearly 30 other countries were having interest in studying this problem. The current survey was introduced due to the missing of such a review research over the literature. It is very essential to introduce the current review with the motive to have an insightful vision for AI progression in modeling diverse shear strength of structure beams types. The goals of this review are (i) to recognize the adopted AI models over the literature for solving the beam shear strength, (ii) to identify the significant of the utilized parameters "geometric, concrete properties and etc." on the beam shear determination, (iii) to survey the various types of the additive material targeted to enhance the concrete properties, (iv) to understand the influence of the dataset span on the modeling procedure, (v) to spot the data availability over the literature and finally (vi) to check the performance metrics were used for the modeling evaluation. Hence, based on the reported literature, numerous core aspects were assessed and discussed scientifically. Future research directions are presented with respect to the exhibited literature review.

## 2. Beam Shear Strength Literature Review Using AI Models

### 2.1 Artificial Neural Network Model (ANN)

The brain systems of humans are greatly simplified in ANN models. Artificial neurons are computational units that are similar to the neurons found in the biological nervous system [35]. The output, hidden, and input layers make up the majority of the ANN model. A signal connects every neuron in the nth layer to the neurons in the $(n + 1)$-th layer. A weight is given to each link. Every input might well be multiplied by its appropriate weight to determine the output. To obtain the finalized ANN output, the output is processed by an activation function [36].

Various technical and scientific challenges could benefit from the application of the ANN. As a result, the ANN has several applications [37], including picture compression, signal processing, differential formulas, medical diagnostics, stock market forecasting, and function approximation [38]–[41].

Biological neural networks are consistent with ANN models [42]. They are made up of the top layer, any hidden layers, and the bottom layer [43]. The input layer is on the top layer, while the output layer is on the bottom layer. There are nodes known as neurons in each layer of an ANN. A node is a network building component that utilizes a sum and transfer function to handle data. The number of neurons in the hidden layer affects how well the ANN predicts outcomes; while this isn't always the case, studies show that having more neurons improves how closely model outputs resemble training data. To represent a dataset using learning methods, the ANN model is trained. Because ANN models just need input data and do not divulge the transfer functions, they are entirely black box models [44]. Even nonlinear, piecewise, discontinuous, and other types of connections may be accommodated by them. Training, validation, and testing points may be separated out of the experimental dataset. The learning process may benefit from the validation and training points, whereas the testing points may be utilized to assess the model's capacity for prediction after the learning phase [45].

Building energy efficiency and consumption activities often make use of neural network technology [46]. The responsibilities of predicting the load on air conditioning systems, electricity usage, and analysis of energy use are where ANN are first utilized [47]. Additionally, thermal insulation qualities of materials and the heat and thermal insulation of building walls are studied using neural networks [48]. The study and optimization of HVAC control systems, as well as the quick prediction of non-uniform indoor pollutant concentration, are two tasks in which neural networks are utilized [49].

However, there are currently no logical and simple-to-use formulae accessible in design software that correctly anticipate the shear strength of RC beams with transverse reinforcement. Therefore, utilizing data from previous trials, the current research investigates the viability of employing ANNs to predict the shear strength of beams with transverse reinforcement. By definition, an ANN is a network of linked processing units that may be taught to translate an input data into a desired output [50]. ANNs may be a useful tool to forecast the shear strengths of RC beams failing in shear since the shear behavior of these beams is affected by a number of complicated characteristics and the experimental data that are accessible were dispersed [51], [52].

The preparation of rational shear design formulas that use these theories seems to be very complex because there are predictable and unpredictable factors that are interdependent, despite the fact that several rational truss model theories have been suggested over the past 20 years, including the MCFT [53] and the RA-STM [54], to forecast the deformation and strength properties of shear

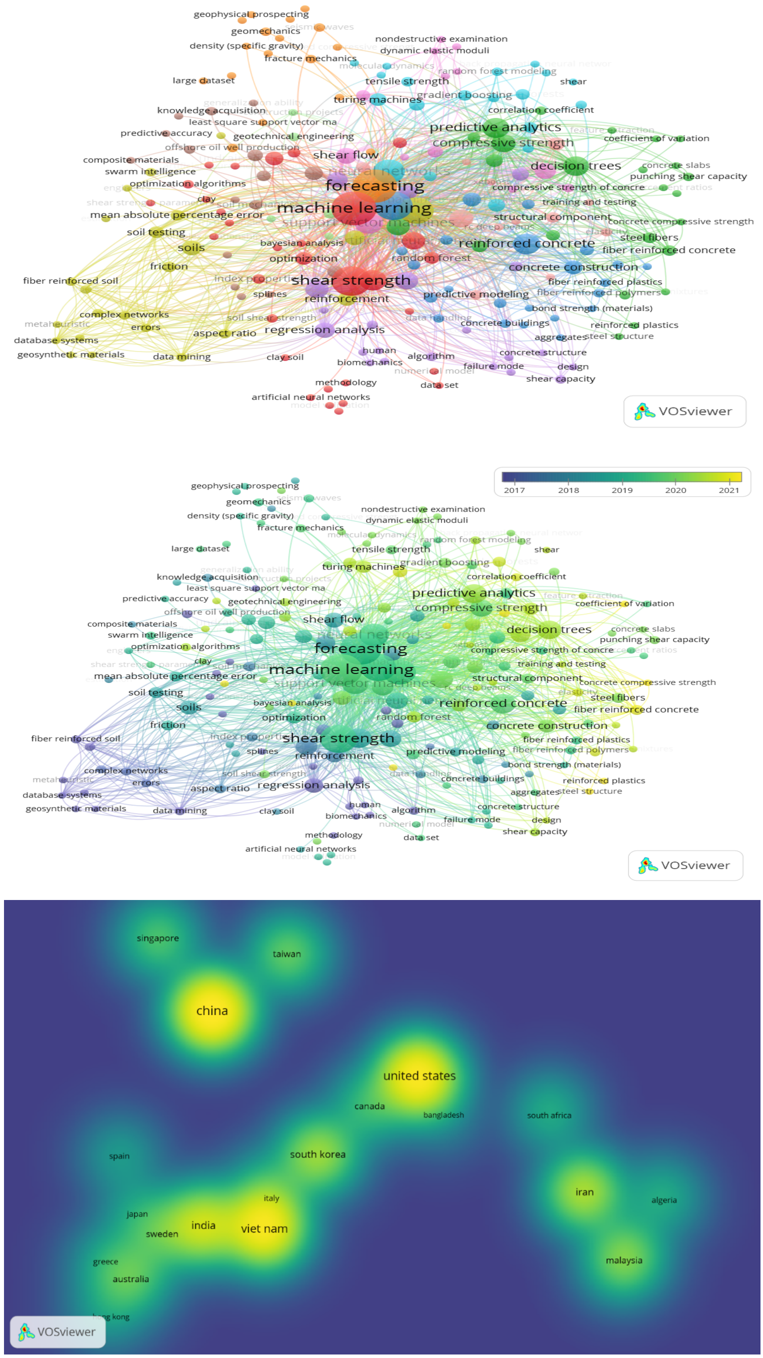


**Figure 1:** *a) The identified main keywords over the literature based on Scopus database related to beam shear strength prediction using AI model and the countries where the research were adopted. b) and c) The diversity of the countries has interest in modeling.*

elements. Thus, the equilibrium requirements of the straightforward 45-v-truss model theory put forward by Ritter and Morsch at the start of the 20th century serve as the foundation for the majority of shear design formulas. Most design standards, including the ACI building code, employ these equations after they have been statistically updated to take into account the impact of flexure and the longitudinal reinforcement proportion on the RC beams shear strength [55]. The formulae only calculate an RC beam's shear strength as the sum of its shear strength from concrete alone and its shear reinforcement alone. Once compared to actual findings, it was shown that the RC beams shear strength estimated to use these straightforward formulas was quite conservative. This was mostly due to the formulas' presumption that there is no interactions between shear resisting mechanisms, which conflicts with the results of several studies [56], [57]. To anticipate the shear strengths and behavior of shear-dominant structures, many rational truss model theories were created. Table 1 presents the adopted literature on the implementation of neural network models for share strength prediction of beam concrete.

By definition, an ANN is a network with connections between its inputs and outputs, whose connections are made up of neurons. A neural network's primary computing abilities are its capacity to learn functional correlations from instances and to use self-organization to find patterns data. Many researches have been done over the last 20 years to use ANNs to forecast the shear strength of RC components. In order to test and train their ANN against 176 RC beams with shear reinforcement, Mansour et al. [58] constructed an ANN. Goh [59] looked into whether neural networks could be used to assess the ultimate strength of deep RC beams exposed to shear and came to the conclusion that the assumptions made by neural networks were more accurate than those made by traditional formulas. Utilizing 111 deep beam tests, Sanad and Saka [60] also investigated the application of ANN approaches to forecast the ultimate shear strength of reinforced concretes deep beams. In order to forecast the shear strength of typical and great strength concrete beams without and with shear reinforcement, Cladera and Mari [61] used ANNs. Depending on a parametric research carried out using ANNs, Cladera and Mari have created novel formulations for beams without and with shear reinforcement [62]. Utilizing an ANN, Oreta [63] carried out a size impact research on the shear strength of RC beams without shear reinforcement. Additional research into the application of ANNs for RC beams without shear reinforcement was conducted by Jung et al. [64] and Seleemah [65]. The shear capacity of FRP reinforced concrete beams and steel-fibre reinforced concrete beams have both been effectively predicted using ANNs. Le et al. [66] used ANN to forecast the axial load capacity of steel tube columns filled with concrete and found that ANN had more accuracy than the present code formulas. The maximum axial load of concrete-filled steel pipes was predicted using Asteris et al. [67] unique hybrid predictive model, which combines balancing composite movement optimization and ANN. In order to forecast the unconfined compressive strength of granite using non-destructive texts, Armaghani et al. [68] employed ANN. Additionally, ANNs have been employed in structural damages evaluation [69], and to predict additional concrete parameters including tensile strength and compressive strength.

In 2006, predicting the shear strength capacity of steel fiber reinforced concrete (SFRC) beams was done theoretically using an ANN models [70]. Where two models were developed using enormous data collected from the existing experimental results for construct and validate these ANN models. The typical architecture of building the ANN model presented in Figure 2a and the process of neuron is shown in Figure 2b. The effects of varied parameters on the shear strength of the SFRC beams were considered such as the span-depth ratio, concrete compressive strength, length-depth ratio, and steel fiber contained ratio. The validation of the proposed ANN models was confirmed since achieved accurate prediction results compared to the existing tested results by others.

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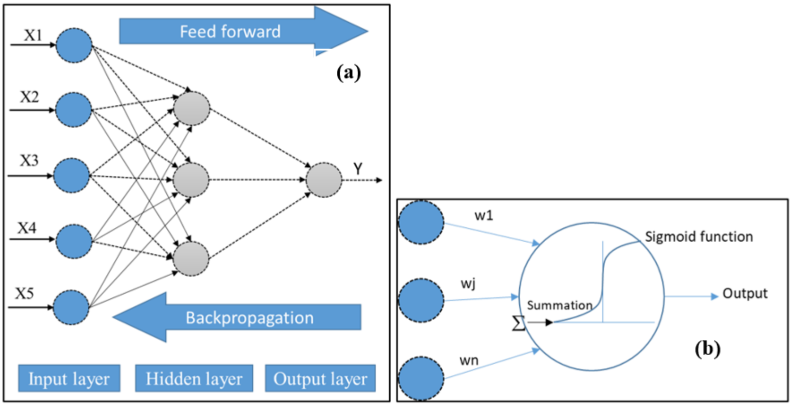


**Figure 2:** *The typical architecture of multilayer feed forward neural network, a) Network architecture; b) Processing neuron [70].*

The ultimate shear strength capacity of SFRC corbel without steel stirrups was estimated by developing an ANN model [71]. Figure 3 presents the typical shear failure of SFRC corbel without stirrups. The algorithm called Lavenberg–Marquardt was chosen for build the proposed ANN model using the MATLAB program. Compared to the most available test results and those obtained using the existing models, the proposed ANN model in this study was fairly satisfied the prediction values. After the validity of the proposed model was confirmed, the effects of further parametric studies were investigated on the failure and strength capacity of the SFRC corbel without stirrups.

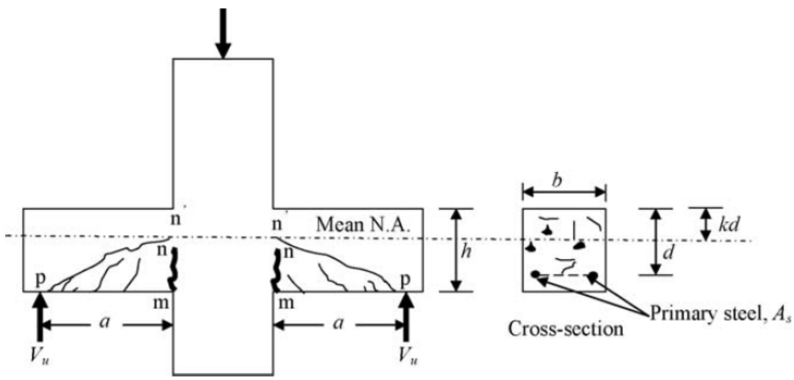


**Figure 3:** *Typical cracks at shear failure of SFRC corbel without steel stirrups [71].*

An ANN model was proposed to predicting the shear strength capacity of RC beams externally wrapped with fibre reinforced polymer (FRP) sheets [72]. In addition to the effects shear span-to-depth ratio, the proposed model considered the effect of varied strengthening configurations. Figures 4a and 4b showed some of the failure mode of the tested RC beams strengthened with FRP sheets (beams with T and Rectangular cross-section). In Addition to the results of tested specimens in this study, additional results of 84 RC beams that obtained from existing studies were all used to train and verify the proposed ANN model. The validity of the model was sufficiently confirmed among the existing code standards such as the American guideline (ACI 440.2R), Federation for Structural Concrete (fib14), Italian National Research Council (CNR-DT 200), Australian guideline (CIDAR), and Canadian guideline (CHBDC) for verification.

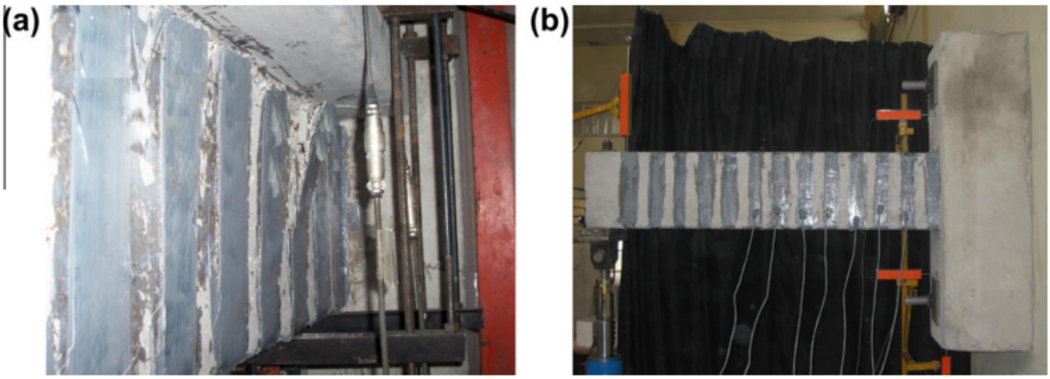


**Figure 4:** *Failure mode of RC beams bonded with FRP, a) T-section, b) Rectangular-section [72].*

The database of 430 results obtained from the literature are used to generate a ANN model to theoretically predict the shear strength capacity of the SFRC beams without steel stirrups [73] that presented in Figure 5. Compared to the available empirical and existing code expressions, the proposed ANN model in this study achieved the best prediction accuracy since it is considered a wide range of parameters. The proposed model help the designers for initially predicting the proper parameters of the SFRC beams before proceed with experimental approach.

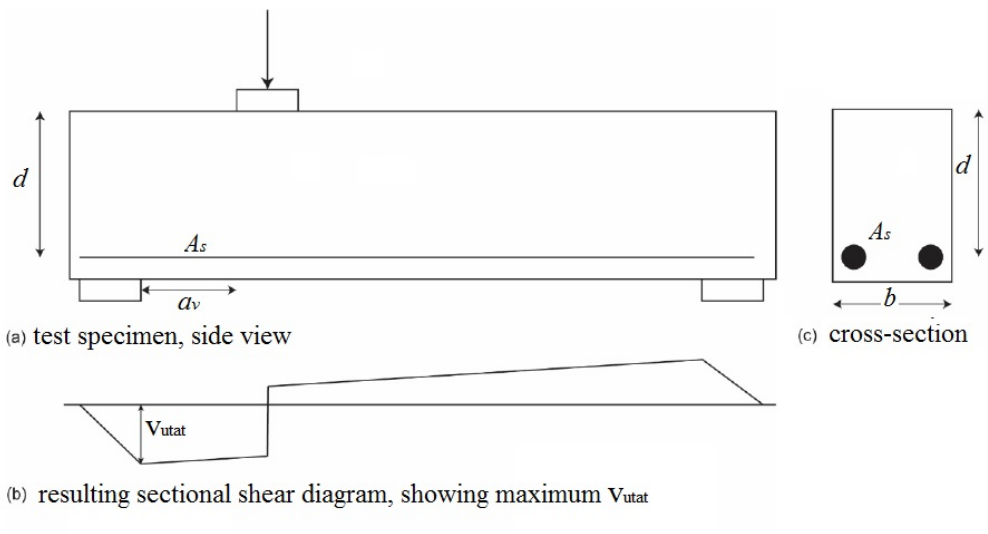


**Figure 5:** *Geometry and loading scenario of RC beam without stirrups [73].*

**Table 1:** *The established literature review research on the beam shear strength prediction using the feasibility of artificial neural network.*

| Research | Applied models | Input parameters | Output parameter | Type of additive | Number of modeled datasets | Performance metrics | Source of the dataset | Research provide their dataset |
|---|---|---|---|---|---|---|---|---|
| [70] | ANN | $V_f, l_f/d_f, F, \rho, d, f_c$ | V | Steel fiber | 85, 70 sets training, 15 sets testing | Mean, median, SD | [27], [74]–[81] | Yes |
| [82] | ANN | $V_f$, $l_f/d_f$, $\rho$, $d$, $f_{ck}$, $a/d$ | V | Steel fiber | 43, 34 sets training, 9 sets testing | Compared observed data with predicted data, sensitivity analysis | [75]–[77], [80], [83] | Yes |
| [71] | ANN | $f_c$, $d$, $b_w$, $a/d$, $\rho_t$, $v_f$, $l_f/d_f$ | $V_u$, $\tau_u$ | Steel fiber | 785,730 sets training, 55 sets testing | MAE, RMSE, R | [84]–[88] | Yes |
| [89] | ANN | $d, b_w, ad, \rho_t, v_f, l_f/d_f$ | V | Fiber reinforced polymer FRP | 87, 80% training, 20% testing | Mean, standard deviation, COV, MAE | [31], [90]–[108] | Yes |
| [72] | ANN | $b_w, d, f_c, w_f/s_f, \beta, E_f$, $\epsilon_f, t_f, a/d$ | V | FRP | 84, 51 sets training, 33 sets testing | $R^2$, RMSE | [109]–[125] | Yes |
| [126] | ANN | $b_w$, $d$, $V_f$, $l_f/d_f$, $a/d$, $f_c, A_{st}, L/D$ | V | Steel fiber | 118, 80% training, 10% testing, 10% validation | $R^2$, sensitivity analysis | [27], [79], [127]–[129] | No |
| [130] | ANN | $b_w, d, f_c, w_f/s_f, \beta, E_f$, $\epsilon_f, t_f, a/d$ | V | Carbon fiber reinforced polymer | 79, 59 sets training, 20 sets testing | COV, AVG | [111], [116], [118], [122], [125], [131]–[140] | Yes |
| [141] | ANN | $b_w, d\ a/d, f_c, \rho, E_f$, | V | FRP | 177, 60% training, 20% validation, 20% testing | MSE, $R^2$, MAE, COV | [31], [91]–[94], [96]–[100], [103], [105], [107], [108], [142]–[147] | Yes |
| [73] | ANN | $b_w$, $d$ $a/d$, $f_y$, $d_a$, $f_c c, c\gamma, f_{tenf}, \rho, E_f$ | V | Steel fiber | 430 | R, Min. error, Max error, SD, COV | 27], [29], [74]–[79], [83], [127], [148]–[195] | No |
| [196] | ANN, PMLR | $h, d_l, b_c, f_c, \rho, V_f$ | $V_p$ | Steel fiber | 140, 80% training, 10% testing, 10% validation | MAPE, MAE, $R^2$, RMSE | [197]–[209] | Yes |
| [210] | ANN | $b_l$, $h$, $d_l$, $_{span}$, $\rho_x$, $\rho_y$, $b_r$, $l_{load}$, $M_E/V_E$, $d_t$, $a_v/d_t$ | $V_R$ | - | 287, 50% training, 25% validation, 25% testing | Max error, R | [211]–[247] | No |

### 2.2 Support Vector Machine Models

SVM is developed as a ML-based classification algorithm and has found application in different tasks, such as pattern recognition, classification, and prediction. SVM maps instances by creating a hyperplane in an N-dimensional plane that guarantees the maximum distance between instances of a class [248]. In the N-dimensional plane, data points that are close to the hyperplane are known as support vectors; they are responsible for the position and orientation of the hyperplane. A higher dimensional nonlinear hyperplane is used to separate classes that cannot be separated by a linear hyperplane. Such cases are addressed using some accessible kernel functions, such as polynomial, sigmoid, and radial basis function (RBF) kernels. SVM is expensive computationally and requires a prolonged training time. It can regularize and can work with both linear and nonlinear data forms. The process of using SVM to construct hyperplane between two data groups for classification tasks is presented in Figure 6a.

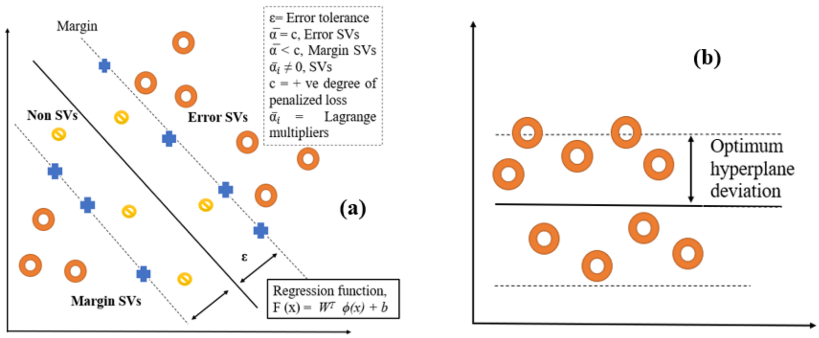


**Figure 6:** *(a) Non-linear SVR vapnik's ϵ-insensitivity loss function, (b) the mechanism of the SVR model.*

The mode of operation of SVR algorithm differs significantly from that of other regression algorithms [249]. For instance, most regression frameworks strive towards sum of squared error minimization while SVR considers the error when it is within a given range [250]. The operation mode of this regression method resembles that of SVM, but rather than providing a class as output, SVR generates a real number. In the presence of an error, SVR offers flexibility towards minimization of the coefficients (ϵ-value) while optimizing them for better performance [251]. To ensure that both low and high miss are penalized equally, SVR is trained with symmetrical loss function. Its computation complexity is independent of the dimension of the input shape. SVR implements nonlinear operations using polynomial kernel as represented as follows: $f(x_i, x_j = (x_i \times x_j \times r)^d)$, where $x_i$ and $x_j$ represent two varying observations in the considered dataset, $r$ represent the polynomial coefficient, while d is the degree of the Gaussian RBF and polynomial kernel that presented as follow $f(x_i, x_j = e^{-\gamma \|x_i - x_j\|^2})$, where $x_i$ and $x_j$ represent are two varying observations in the considered dataset, while $\gamma$ is the kernel spread. It can generalize excellently and can achieve high prediction accuracy. Figure 6b is a depiction of this process. Table 2 presents the adopted literature on the implementation of hybrid AI models for share strength prediction of beam concrete.

Several parameters are affected on the shear strength capacity of the RC beams with/without steel stirrups including the parameters of web-width, span-depth, and steel reinforcement ratios, as shown in Figure 7. Thus, an empirical model was developed using the machine learning approaches for predicting the shear strength capacity of these RC beams [252]. The dataset of 194 and 1849 tested samples of RC beams with and without stirrups, respectively, were used for this purpose. High accuracy was achieved by the proposed model for predicting the shear strength of RC beams with/without stirrups those tested by others.

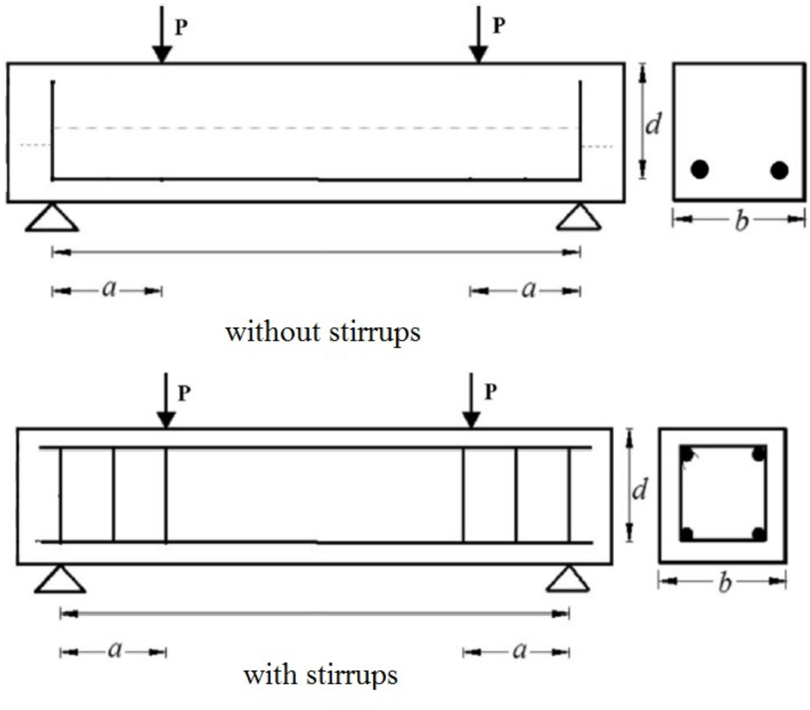


**Figure 7:** *Geometry of RC beam with and without steel stirrups [252].*

The machine learning framework was adopted to develop an artificial algorithm model to predict the failure mode and shear strength capacity of Ultra-High Performance Concrete (UHPC) beams [253]. The database of 360 tested samples of UHPC beams that have varied geometric, loading scenario, materials properties, and fiber properties had been used to develop the proposed model. The database analyzed using different algorithms, which are the support vector machine (SVM), k-nearest neighbor (k-NN), ANN, and genetic programing (GP). Figure 8 presents the schematic procedure of the proposed machine learning methodology. The reliability of the proposed model was confirmed by a valid compassion with the values obtained using the existing design methods in codes, and with those established from the experimental tests of UHPC beams with varied configurations and reinforcement details.

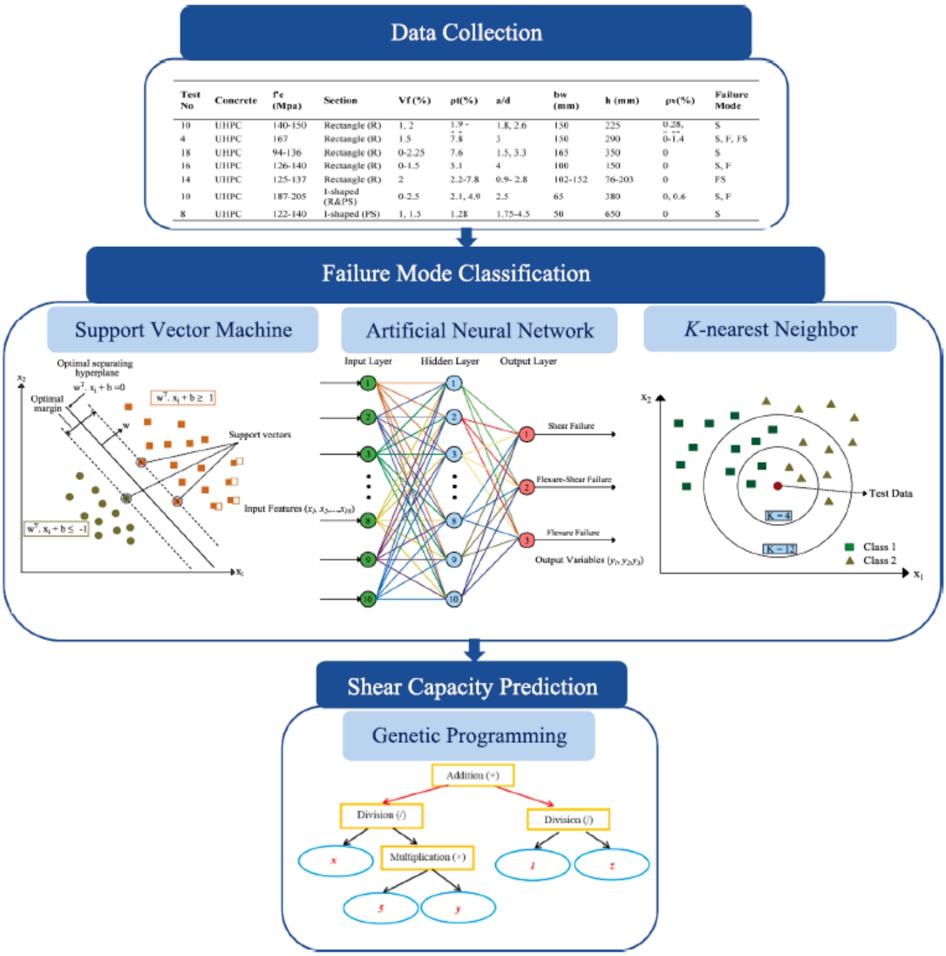


**Figure 8:** *Schematic of the proposed machine learning framework [253].*

**Table 2:** *The established literature review research on the beam shear strength prediction using kernel models.*

| Research | Applied models | Input parameters | Output parameter | Type of additive | Number of modeled datasets | Performance metrics | Source of the dataset | Research provide their dataset |
|---|---|---|---|---|---|---|---|---|
| [252] | MBAS-RF, LR, MLR, BPNN | $M_1$ : $b, b_w, h_b, d, a/d$, $bear$, ρ, $M_2$ : $a, b_w, d, f_c$, ρ, $f_{ry}, f_{sy}$, $\rho_y$ | V | - | Datasets 1: 1894 Datasets 2: 194 k- fold cross-validation (CV) k = 10 | RMSE, R, SD | [254], [255] | No |
| [256] | RF, CART, RT, FS-RF, FS-CART, FS-RT | $h, d_l, b_c, f_c$, ρ, $V_f$ | $V_p$ | Steel fiber | 140, 70% training, 30% testing | MAPE, MAE, $R^2$, RMSE | [198]–[209], [257]–[260] | No |
| [261] | GP, RF | $a/d, d, b_w, \rho_l, f_c, d_a, F$ | $V, \tau_u$ | Steel fiber | 326 , k- fold cross-validation (CV) k = 10 | MAE, $R^2$, RMSE | [262] | No |
| [253] | SVM, ANN, KNN, GP | $M1$ : beam configurat $M_2$ : $f_c, F, F_{sf}, a$, ρ, $\rho_v, f_{ys}$, σ | $M_1$: shear failure, flexural failure, flexural-shear failure $M_2$: V | Steel fiber | 360, 70% training, 30% testing | Confusion matrix, ROC curve, $R^2$ | [169], [194], [263]–[301] | Yes |

### 2.3 Evolutionary Computing Models

A group of global optimization techniques that take into account organic development is known as evolutionary computation [302]. This approach begins with the creation of a group of individuals who work together to solve problems [303]. An algorithm may be used to create the initial population at random. A health test is used to assess individuals, and the results indicate how effectively they handle the issue based on how well the feature performs. Following that, various operators, including convergence, mutations, selecting, and reproduction are also applied to individuals who are affected by natural evolution [304]. Depending on the fitness magnitudes of recently evolved individuals, a new population is generated. Some entities are eliminated so that the population number may remain constant with the surrounding environment. This approach is maintained until the terminating requirements are satisfied. EC seems to be a branch of artificial intelligence and soft computing. The following are the main difficulties faced by ECs.

- Inability to repeat experiments: EC suffers from a lack of acknowledged benchmark issues, the difficulty of evaluating performance, and the absence of standardized implementations and algorithms.
- Poor performance: EC method performance was inefficient when comparing to other CI approaches because of the lengthy defining lengths of the algorithms and schemes.
- Unsuitable for real-time situations: Simple problems with accessible derivative information are not suited for EC approaches. Repeated calculations of the fitness magnitude might be computationally costly for particular issues. The solution's quality or optimal are not guaranteed since it is stochastic.

Genetic Programming, Genetic Algorithms, Evolutionary Programming, and Evolution Strategies are four traditional EA versions that vary in their evolution and method of representation (see Figure 9). Rechenberg and Schwefel developed evolutionary strategies. Instead of utilizing recombination, real numbers have been used in evolutionary strategies to describe the solutions, and selection and self-adaptive mutations have been used as searching operators. The most desirable person is chosen to reproduce in the next generation (elitism) [305]. To produce new people for the following generations, self-adaptive mutation is used [306].

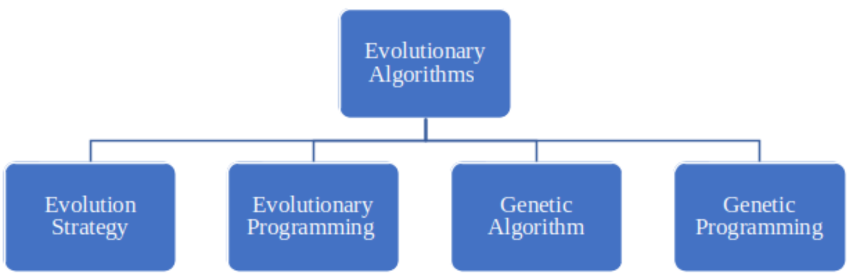


**Figure 9:** *Evolutionary algorithms classification.*

Fogel created evolutionary programming to tackle engineering issues with populations of finite state machines. The approach is depending on a description of the issue in string form and does not have a specific kind of representation for such people. Recombination is not used in this optimization strategy, unlike evolutionary strategies [307].

The genetic algorithm, created by Holland, is the most well-known kind of EA [308]. The people are represented by this stochastic method in a linear and binary-coded representation. Typically, a population of randomly created individuals serves as the starting point for the evolutionary process. Rearrangements and mutations operators are used by a genetic algorithm to address optimization issues [309]. Inverting the genetic information's parameters is a common way to create mutations. The fitness, a magnitude of an optimization problem in the optimization process, rates each person's quality [310].

Informatics [311], [312], mechanical engineering [313], [314], and Electrical engineering [315] are a few technical areas where EAs have recently been used. Additionally, research has focused on the application of machine learning for structural damage tracking [316], [317] and evolutionary algorithms (EAs) as cutting-edge optimization tools to update finite element (FE) models for damage detection [318]–[320]. EAs are strong mathematical tools that may be used to tackle challenging optimization issues with high nonlinearity, multimodal interactions, etc. Single-objective EAs have been employed alone [321] or in combination with the weighted sum technique [322]–[325] to address FE model update issues. The distribution of solutions along the Pareto optimal front, which is crucial to determining the caliber of the achieved solution, might not even be properly guaranteed even though a single-objective evolutionary algorithm requires sufficient knowledge of the problem. Additionally, choosing the optimal weight combination is a challenging process. The typical method of trial and error is ineffective for this job when dealing with sophisticated FE model update issues. Due to these factors, a few studies have used multi-objective EAs to update FE models for detection of defects. Their research has successfully shown that multi-objective functions are superior to single-objective functions when employing the weighted sum approach. On the other hand, the use of EAs for structural detection of defects depending on FE model update is still not well understood. The established literature review research on the beam shear strength prediction using the feasibility of evolutionary computing models was demonstrated in Table 3.

Gene expression programming (GEP) and genetic programming (GP), two EC techniques that were deemed suitable for simulating different civil engineering applications, are among the several kinds of AI models [326]. When the idea of GP was initially proposed, Koza [327] was the one who first created these models. When attempting to find a mathematical function that fits a collection of data, they were theoretically designed based on the genetic algorithm (GA), an algorithm used for the implementation of symbolic regression [328]. Regarding the viability of employing EC to resolve issues like circuit design, multiagent systems, and time-series prediction, various efforts were undertaken [329]. Similar to this, during the last 20 years, a number of scholars have investigated whether EC may be used to address issues with hydrology, climatology, the environment, and ecology [330].

Over the last ten years, the areas of automotive, structural, aerospace, etc. engineering have shown increased interest in the study area of structural damage diagnosis uses the finite element (FE) model update. There have been several research on updating FE models for structural damage diagnosis using direct, sensitivity-based, probabilistic, statistical, and iterative techniques. In contrast, a sort of contemporary technique for FE model update is called evolutionary algorithms (EAs). Although a thorough assessment is missing, structural damage diagnosis via FE model update by evolutionary algorithms is an ongoing research area. Alkayem et al. [331] reviewed important elements of FE model update using evolutionary algorithms to identify structural deterioration. The topic of structural damage identification and the different FE model update strategies are first presented in a theoretical context. Second, a summary of the different residuals between the dynamic properties of the FE model and the corresponding physical model is provided. These residuals were utilized to build the objective function for tracking damage. Third, issues with the parameter selection for FE model update are looked into. The fourth step examines the use of evolutionary methods to update FE models for damage detection. Finally, a case study comparing the applications of two single-objective EAs and one multi-objective EA for damage detection based on updated FE models is shown. The use of evolutionary algorithms-based FE model update to resolve damage detection issues is suggested as a last line of inquiry. This research should aid in identifying key areas for future theories, approaches, and technological advancements in evolutionary algorithm-based FE model update for structural damage identification.

A genetic algorithms (Gas) approach was developed to predict the shear strength capacity of the RC beams externally bonded with FRP [332]. The schematic view of the RC beam externally bonded with FRP is shown in Figure 10. The adequacy of the results predicted using the proposed approach was compared to those obtained using the existing methods such as the Eurocode (EC2), ACI 440, Colotti model, Matthys Model and ISIS Canada. Compared to the effects of the ultimate strain in FRP sheets, and the ultimate stress in transverse steel bars, the study showed that the shear span-to-depth ratio showed the most significant effect on the shear capacity of RC beams bonded with FRP.

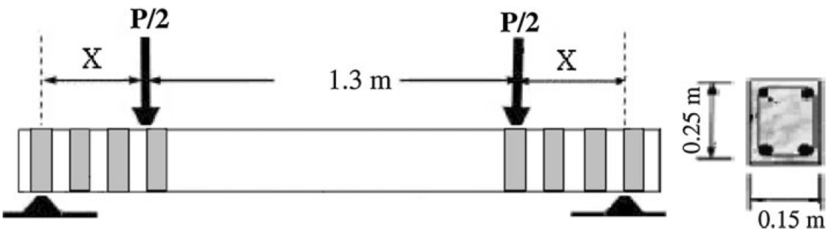


**Figure 10:** *Schematic of RC beam externally bonded with FRP [332].*

A new model called Gene Expression Programming (GEP) was developed to predict the shear strength capacity of RC deep beams [333]. A database collected from 214 test results was adopted for developing and verifying the proposed GEP model. The schematic parameters of the RC deep beam is presented in Figure 11. Compared to the existing models of the Canadian Standard Association (CSA) and the American Concrete Institute (ACI), the proposed GEP model in this study achieved better prediction strength capacity values, and well agreed with those obtained using the ANN model.

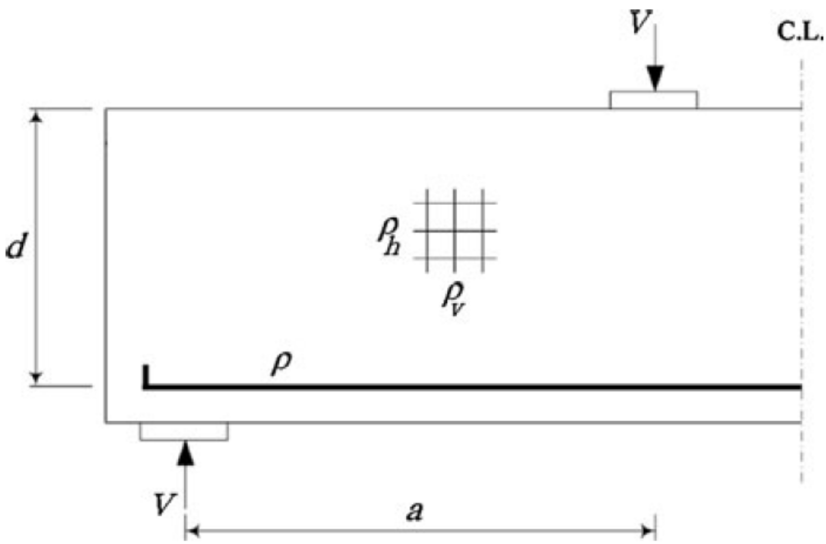


**Figure 11:** *Schematic details of RC deep beams [333].*

A new AI model named biogeography-based programming (BBP) has been developed to predicting the shear capacity of the concrete beams reinforced with Fiber Reinforced Polymer (FRP) bars

[334]. The geometry of FRP bars reinforced concrete (FRP-RC) beams without stirrups presented in Figure 12. The validity of the proposed BBP model for predicting had been examined with the results obtained using the existing AI models and experimental results done by others, where the proposed model achieved the most accurate shear capacity results of FRP-RC beams.

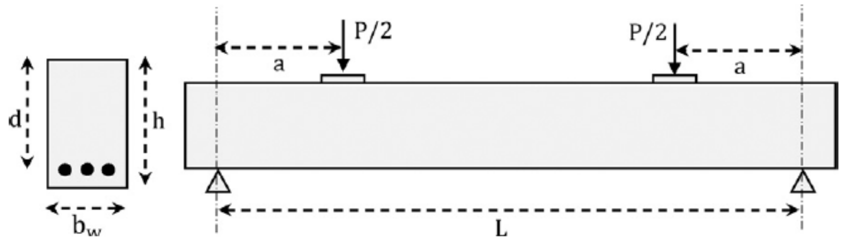


**Figure 12:** *Geometry of FRP-RC beam without stirrups [334].*

**Table 3:** *The established literature review research on the beam shear strength prediction using the feasibility of evolutionary computing models.*

| Research | Applied models | Input parameters | Output parameter | Type of additive | Number of modeled datasets | Performance metrics | Source of the dataset | Research provide their dataset |
|---|---|---|---|---|---|---|---|---|
| [335] | GA | $b_w, d, a/d, f_c, \rho_x, E_f/E_s$ | V | FRP | 168 | SD, COV, MAE | [90], [102], [103], [107], [336] | No |
| [337] | LGP | $A, d, f_c, \rho, L_f/d_f, V_f, d_f$ | V | Steel fiber | 213, 107 training, 42 testing, 64 validation | R, MAE, sensitivity analysis | [2], [3], [60], [99], [101], [108], [110], [111], [114], [244]–[246], [4], [247] [5]–[10], [13] | No |
| [332] | GA | $b_w, d, a/d, f_c, \epsilon_{fv}$ | $V, \tau_u$ | FRP | 212 | SD, COV, MAE | [112], [114], [116], [118], [119], [122], [136], [342]–[363] | No |
| [364] | GEP | $b_w, d, a/d, f_c, \rho_x, E_f$ | V | FRP | 104, 56 training, 28 testing, 20 validation | Mean, SD, MAE | [31], [91]–[94], [96], [101]–[104], [106]–[108], [365] | Yes |
| [366] | GEP | $b_w, d, a/d, f_c, \rho, \rho_x, \rho_y$ | V | - | 214, 150 training, 42 testing, 22 validation | RMSE, MAE, R | [31], [91]–[94], [96], [101]–[104], [106]–[108], [365] | No |
| [366] | BBP | $b_w, d, a/d, f_c, \rho_x, E_f$ | V | FRP | 87, 70 training, 17 testing | RMSE, MAE, R, MAPE | [31], [90]–[98], [101]–[104], [106]–[108], [365] | Yes |
| [376] | GEP, NMR | $d, a/d, V_f, l_f/d_f, f_c$ | V | Steel fiber | 239, 191 training, 48 testing | MAE, MSE, R | [27], [29], [74]–[77], [79], [80], [83], [127], [157], [159], [171], [174], [177], [181], [187], [341], [377]–[382] | No |
| [24] | GA | $b, h, d, a/d, f_c, \rho_x, f_y, l_f/l$ | V | Steel fiber | 358, 50% training , 50% testing | SD, COV, MAE, $R^2$ | [27], [29], [74]–[76], [78], [80], [83], [94], [127], [149], [154], [157], [162], [165], [167], [171], [174], [177], [182], [187], [188], [256], [338], [339], [341], [377]–[379], [383]–[387] | Yes |

### 2.4 Fuzzy Logic (FL) Models

The human decision -making process differs significantly from that of machines; for instance, humans have other choices in-between "yes" and "no" which is lacking in machines. This is a fuzzy-logic system of making decisions. In a fuzzy logic system, there are modules with which the system makes decisions. During module fuzzification, a membership function (MF) is used to generate a membership degree (which can range from large positive to large negative) from crisp inputs. Then comes the knowledge base with some IF-THEN rules that are conceptualized from human behaviours. The inference engine provides reasoning for the input by comparing the input with the established rules. Then, this reasoning is converted to crisp output by the fuzzification module. The popularity of Fuzzy logic is driven by its flexibility and ease of use. The basic structure of Fuzzy logic system is depicted in Figure 13a. A neuro-fuzzy system (NFS) refers to a network of Fuzzy systems represented as ANN in a manner that they can be optimized using either genetic algorithm (GA) or backpropagation. This system can be implemented using the Mamdani approach as presented by [388]. This approach requires that the system input and output must be a fuzzy quantity. It is a good model for human inference systems because of its reliance on the min-max operations structure; it can be easily understood by humans even though its complexity increases as the number of input rules increase. The five layers used in this model for prediction tasks are as follows: (i) Fuzzification layer: the input vector that consists various features enters this layer for the calculation of its membership value. The membership value is generally calculated using the Gaussian function [388]. (ii) Fuzzy inference layer: the fuzzy rules of this layer are based on the input vector via the multiplication of the calculated membership values. (iii) Implication layer: the calculation of the resulting membership functions is done in this layer based on their strength. (iv) Aggregation layer: here, the multiplication of _ring strength & resulting parameters are aggregated. (v) Defuzzification layer: This layer produces the final crisp output via a defuzzification process; this process follows the Center of the Area method.

The structure of the layers of the Mamdani FNN is depicted in Figure 13b. The Takagi Sugeno neuro-fuzzy system is the other approach; it is also known as ANFIS as it is a combination of the NN and fuzzy inference system (FIS) [389]. Owing to the fixed membership function of the FIS, it does not usually have learning ability. These problems are solved using the five layered ANFIS approach; it generates the IF-THEN rules from expert knowledge; the system is computationally more efficient because it avoids the extensive initialization stage.

The grade membership functions are generated in the first layer; these functions include Gaussian functions, trapezoid functions, and triangular functions; they are used for the _ring strength generation. In the second layer, the grade of the MF is used to estimate the _ring strength. A comparison of the output of each model is made and the product or minimum of the outputs is selected. Normalization is done in the 3rd layer by dividing the _ring strength of a rule by the overall _ring strength. The next layer is defuzzification which involves the calculation of the output using the weighted parameters. Then, the sum of the defuzzified nodes is aggregated to get the overall ANFIS output in the last layer. The structure of ANFIS model is depicted in Figure 13c. The square layers can be adjusted with some optimization frameworks, such as BP or GA. The established literature review research on the beam shear strength prediction using the feasibility of fuzzy logic models as demonstrated in Table 4.

Because to the intricacy of the shear transfer mechanism, accurate prediction of the shear behaviour of Reinforced Concrete (RC) beams—as opposed to its flexural behavior—is a difficult task. Compared to beams made of regular strength concrete, this problem may be more serious for high-strength concrete (HSC) beams. The current work uses the M5' method to potentially establish a novel formulation for forecasting the shear strength of HSC narrow RC beams without stirrup, which is an effective rule-based data mining technique [390]. The prediction of the shear strength involves a large database with a number of useful characteristics that take into account the

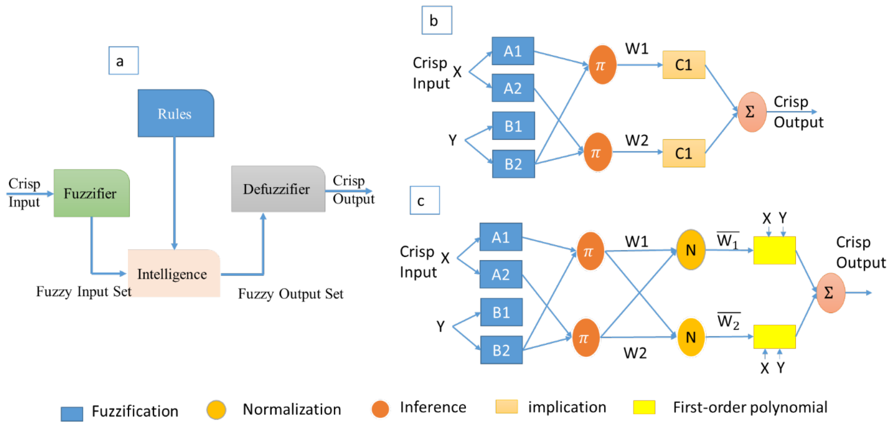


**Figure 13:** *(a) The basic structure of fuzzy logic system model, (b) the structure of the layers of the Mamdani FNN, (c) The structure of ANFIS model.*

geometrical and mechanical qualities of the concrete, aggregate, and reinforcement. The proposed model outperforms the most popular design codes in terms of correctness, as shown by a comparison between the two. Furthermore, the dependability of the suggested formulation is further supported by the safety study based on the Demerit Points Classification scale.

The shear strength of the high strength concrete (HSC) RC beams without steel stirrups had been predicted using the adaptive nerou-based inference system (ANFIS) [391]. Figure 14 presents the shear resistance components of the RC beams without having a steel stirrups. The fuzzy model was developed based on enormous data collected from of about 122 experimental database that included varied parameters, such as, concrete shear span to depth ratio, compressive strength, and tensile reinforcement ratio. The validity of the ANFIS model was examined with experimental results which achieved mean value and coefficient of variation equal to 0.995 and 11.97%, respectively.

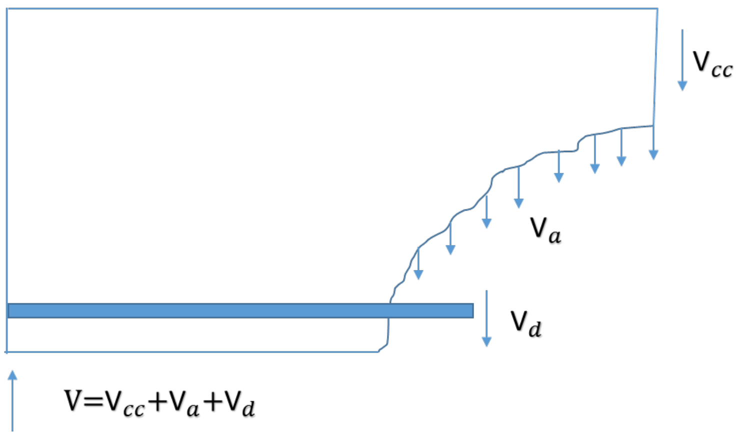


**Figure 14:** *Shear resistance components of RC beams without steel stirrups [391].*

There are several related research have been adopted using fuzzy logical model for modeling shear strength. Among several, one study [392], the authors developed two types of models including group method of data handling (GMDH) and adaptive neuro fuzzy inference system (ANFIS), were developed to predict the shear failure of concrete beam-column joint. The sample of the test presented in the research was displayed in Figure 15. In Figure 15 the structural joint frame is presented where a panel between the beam and columns. The researchers approved their proposed models for determining the shear failure.

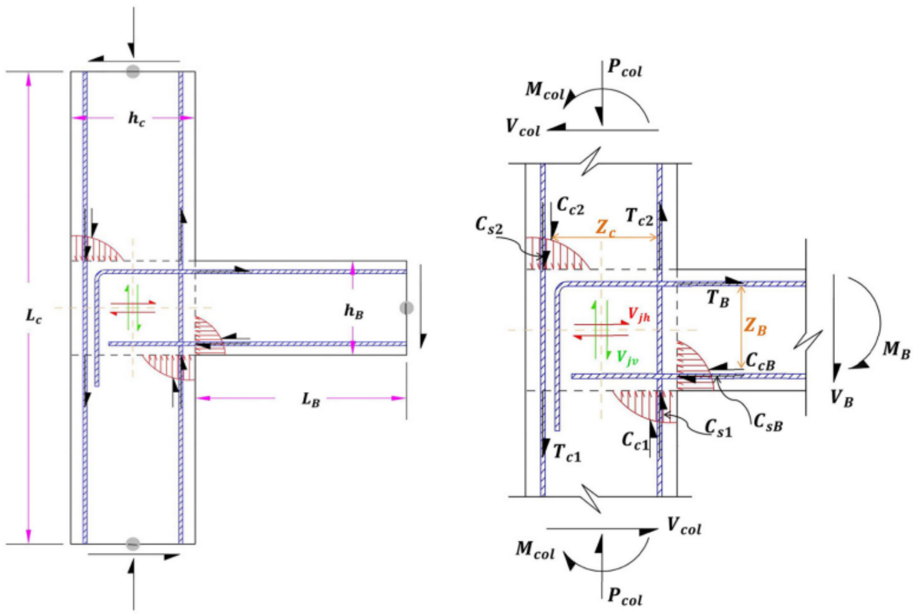


**Figure 15:** *Structural beam-column joint frame [392].*

The shear capacity of the exterior RC beam-column joint has been estimated using a combination of three soft computing techniques which are ANN, GMDH, and ANFIS [393]. The effects of seven (7) parameters were considered, including the steel yield stress and the reinforcement ratio of the joint stirrups, compressive strength of concrete, width of the joint panel, column's cross-section, beam tensile and compressive longitudinal reinforcement ratios, and column longitudinal reinforcement ratio. The typical forces distribution on the exterior RC beam-column joint are shown in Figure 16. The efficiency of developed model was verified with the existing experimental results, where the effects of beam reinforcement was showed the most important factor in the estimated shear capacity of exterior RC beam–column joint.

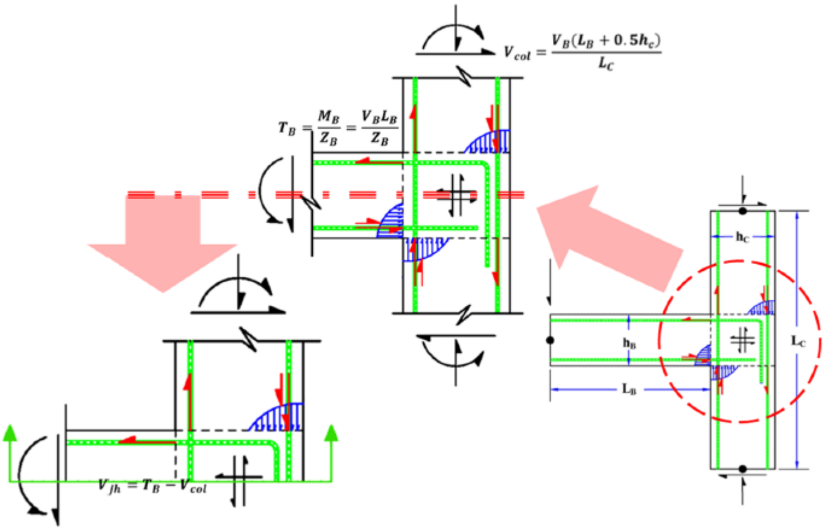


**Figure 16:** *Structural beam-column joint frame [393].*

**Table 4:** *The established literature review research on the beam shear strength prediction using the feasibility of fuzzy logic models.*

| Research | Applied models | Input parameters | Output parameter | Type of additive | Number of modeled datasets | Performance metrics | Source of the dataset | Research provide their dataset |
|---|---|---|---|---|---|---|---|---|
| [394] | FIS | $f_c, d, b, a/d, \rho_f, E_f, \rho_w,$ | V | FRP | 128, 60% training, 40% testing | Mean, COV, MAPE | [31], [90]–[99], [101]–[104], [106]–[108], [395] | No |
| [391] | ANFIS | $f_c, a/d, \rho$ | V | - | 122, 80%, 20% | MSE, $R^2$ | [396]–[398] | No |
| [399] | ANFIS | $h, t, f_c, L_c$ | L | - | - | r,$R^2$, RMSE | - | No |
| [400] | ANFIS | $t_w, h, t, f_c, L_c$, slope of inclination | L | - | - | r,$R^2$, RMSE | - | No |
| [392] | ANFIS, GMDH | $f_c$, JE, JP, TB, JI, BI | V | - | 306, 216 sets training, 45 sets testing | RMSE, $R^2$,MAE | [401]–[442] | No |
| [1] | ANFIS | $B, d, a/d, f_c, \rho_y, t_f, E_f, u$ | V | FRP | 119, 80% training, 20% testing | MAPE, RMSE, $R^2$ | [110], [112], [113], [115], [119], [120], [122], [124], [134], [136], [345], [349], [362], [443]–[454] | Yes |
| [393] | ANN, ANFIS, GMDH | $f_c, \rho_s, f_y, b_j, h_c, \rho_x, \rho_y,$ | $V_J$ | - | 60% training, 20% testing, 20% validation | MSE, RMSE, SD | [419], [422], [438], [440], [442], [455]–[475] | No |

## 2.5 Ensemble Models

The past few years have witnessed a remarkable implication of the newly explored ensemble ML including for example random forest (Figure 17a) and decision tree (Figure 17b) models for solving the Vs problems of structural engineering. For instance, the study by [261] reported the use of “Gaussian Process regression (GPR) and random forest (RF) models” for the prediction of ultimate shear resistance for SFRC slender beams without stirrups. The development of the models relied on 326 experiments on SFRC slender beams called from literature; 75% of the dataset was used for the model training while 25% was used to test the model. The proposed models were compared statistically to the experimental results for performance, as well as against the existing fib Model Code 2010, German guideline, and Bernat et al. model. The performance of the proposed RF model showed close agreement with the experimental Vs. Furthermore, both GPR and RF showed the lowest bias & variability with no obvious trend with the input variables. However, the observed inconsistencies in the predictions using the existing shear design equations upon the variation of the shear span to effective depth ratio remains a major problem; hence, there is a need for reliability analysis.

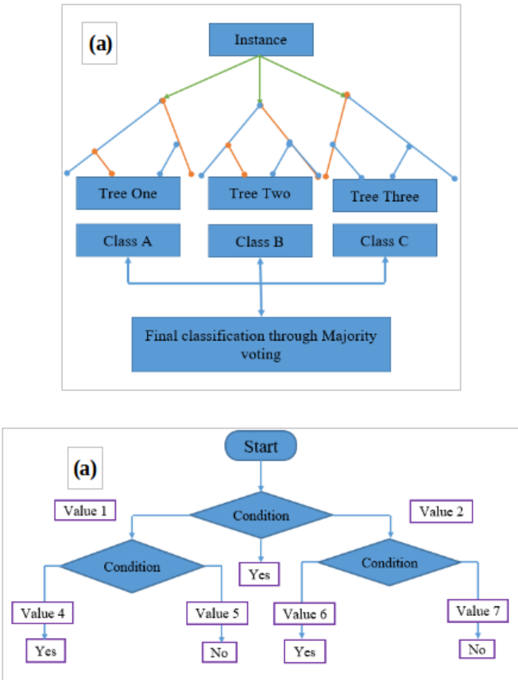


**Figure 17:** *(a) The structure of random forest model, (b) the structure of the decision tree model.*

The study by [476] aimed at solving the issue of overfitting and coming up with a more reliable method for ultimate Vs prediction using a decision-tree-based ensemble ML algorithm that uses a gradient boost framework. The whole training samples were used without the validation set during the development to improve the robustness of the results; K-fold cross-validation was used to reduce the randomness in test samples selection. The results show better performance of the extreme gradient boosting framework (XGBoost) on the dataset that contains 205 samples. XGBoost also achieved the highest precision and generalization compared to the benchmarking techniques.

The use of ML models to predict the Vs of recycled aggregate concrete (RAC) was reported by [477]. The study assessed the established shear design equations for conventional concrete beams on RAC beams and found that the equations achieved inaccurate estimations when applied to the shear test database for RAC beams. As such, the study proposed the use of ML models as alternative predictors. The procedure involves the use of Grey Relational Analysis (GRA) to first rank the significance of the parameters in consideration of their impact on the Vs of the RAC beams. This is followed by using Vs simulation using ANN & RF models. The analysis showed that the two models performed better predictions than the existing equations. A parametric study was further conducted to determine the trends of the influencing role of the parameters on the shear resistance of RAC beams and from the result, the replacement ratio of RA was significant but less influential than the structural parameters.

A hybrid model of RF and beetle antennae search algorithm was suggested by [252] for Vs prediction in RC beams. Two datasets were used to train the model (a set of RC beams with stirrup containing 194 samples and a set of RC beams without stirrup containing 1849 samples). The model achieved a good level of prediction accuracy on the adopted datasets, recording correlation coefficients of 0.9367 on a dataset with stirrups and 0.9424 on the dataset without stirrups. The robustness of the proposed method in the prediction of the shear design of RC beams with/out stirrups was validated, thereby paving the way to intelligent designs.

The Vs of RC beams improves by incorporating steel fibers in the concrete mix; hence, it is important to understand this mechanism to be able to accurately make estimates of engineering designs. XGBoost model was introduced by [478] a new ML model for the prediction of Vs of SFRC beams; the model was based on 507 experimental data and the considered predictors were "the ratio of shear span to effective depth, concrete CS, longitudinal reinforcement ratio, volume fraction, aspect ratio, and type of fiber." The performance of the proposed XGBoost was better than that of numerous ML models in terms of achieving accurate predictions. The parametric study showed that the most influential parameters were the shear span to effective depth ratio, concrete strength, longitudinal reinforcement ratio, & volume fraction of fiber.

A practical approach to the use of ensemble models to predict the Vs for RC deep beams with/out web reinforcements was presented by [479]. The predictive model was developed using 4 ensemble ML models (RF, gradient boosting regression tree, adaptive boosting, and XGBoost). The performance of the model was validated using the 10-fold cross-validation method while the hyperparameters were identified using the grid search method; the outputs of the model were interpreted based on partial dependence analysis and feature importance. The model developed relied on a total of 271 test data on RC deep beams. The evaluations showed good performance of the model in terms of predicting the SS; the model also performed better than the other conventional ML models. Sensitivity analysis was also performed to determine the important factors of the ensemble models. The outcome suggested better performance of the ensemble models compared to the mechanics-driven models in terms of discrepancy and predictive accuracy.

The ensemble approaches are used in a practical but thorough manner to forecast the shear strength of deep reinforced concrete beams with or without web reinforcements [33]. In this work, four common ensemble machine learning models—Random Forest, Adaptive Boosting, Gradient Boosting Regression Tree, and Extreme Gradient Boosting—are used to create a predictive model after first introducing the principles of the backdrop of ensemble machine learning techniques. The process for applying these strategies to train a predictive model is then described in detail. A total of 271 test data sets were gathered to train the models in order to forecast the shear strength of reinforced concrete deep beams using ensemble techniques. All of the models successfully forecast the shear strength and outperform more conventional machine learning techniques.

As a contrast, the traditional mechanics-driven shear models are also used. The relevance of the input variables is determined by analysing the sensitivity of the important ensemble model components. It is demonstrated that the ensemble machine learning models outperform mechanics-driven models in terms of both disagreement and accuracy of prediction. The shear strength of reinforced-concrete (RC) deep beams can be predicted using a novel AI method called "optimized supporting vector machines with adaptive ensemble weighting" (OSVM-AEW), which is based on two support vector machine (SVM) models and the symbiotic organisms search (SOS) algorithm [480]. The SOS optimization method serves as the optimizer in an ensemble learning-based system, which integrates the least-squares supporting vector machine (LS-SVM) and supporting vector machine (SVM) supervised learning models. In OSVM-AEW, SOS was incorporated to concurrently choose the best SVM and LS-SVM parameters as well as manage the coordination of learning outputs. According to experimental findings, OSVM-AEW meets the highest standards for assessment in terms of root-mean-squared error (0.5265 MPa), mean absolute percentage error (7.68 percent), mean absolute absolute error (0.3854 MPa), coefficients of determination (0.9254), and coefficients of correlation (0.9620). This work illustrates the effective use of OSVM-AEW as a tool to aid structural engineers in the design of RC deep beams.

When designing structural elements, the reinforced concrete (RC) beams shear strength is crucial. For the benefit of civil engineers, an efficient mathematical technique for precisely predicting the RC beams' shear strength should be developed. In this study, a hybrid AI model is presented for accurately forecasting the shear strength of different RC beam types. The least squares support vector regression (LSSVR) and the smart firefly algorithm (SFA) were combined to create the hybrid AI model. The SFA was then utilised to improve the prediction accuracy of the LSSVR by optimising its hyperparameters. The hybrid AI model for forecasting the shear strength of RC beams was trained and tested using three sizable datasets. Comprehensive comparisons between the hybrid AI model's predicted accuracy and that of individual AI models, ensembles of AI models, and empirical techniques were conducted [481]. The comparative findings demonstrate that in forecasting the shear strength of a variety of RC beam types, the hybrid AI model performed better than the others. In instance, the hybrid AI model produced a mean absolute percentage error (MAPE) of 21.703% for the test data of RC beams without stirrups. The hybrid AI model produced a MAPE of 12.941% for estimating the shear strength of RC beams with stirrups. The hybrid AI model's MAPE for RC beams with FRP reinforcement was 18.951%. In order to assist civil engineers in developing RC beams, this hybrid AI model may be a better solution.

The metaheuristics-optimized ensemble system (MOES), a unique AI-based method, was created by Chou et al., [482] to greatly aid civil engineers in obtaining precise estimates of the mechanical strength of reinforced concrete (RC) materials. By fusing a metaheuristic optimization method with effective AI models, MOES blends the benefits of hybrid and ensemble models. The best optimized-weight-ensemble model is produced by the metaheuristic algorithm, which concurrently determines the ideal hyperparameters for each unique AI approach and modifies its weights. In particular, the produced MOES was created by combining the least squares support vector regression, radial basis function neural network, and forensic-based investigation optimization method. In order to assess the performance of MOES and compare it to that of other single AI models, traditional ensemble models, hybrid models, and empirical approaches, four case studies of forecasting the structural mechanics of RC beams were conducted. The cross-validation analysis findings show that MOES was the most trustworthy method, attaining the best values across all performance assessment indices. The MOES's reliability, effectiveness, and stability were disclosed by the automated predictive analytics. As a result, the suggested method is a very effective tool for forecasting the structural mechanics of RC beams. The main addition of this study to the pertinent body of knowledge is how MOES' performance in predicting the mechanical strength of RC beams has redefined how an ensemble AI model is optimised.

### 2.6 Hybridized Artificial Intelligence (HAI) Models

A software system is often referred to as a hybrid intelligent system once it simultaneously uses a variety of AI sub-fields' techniques and methods, including: neuro-symbolic, neuro-fuzzy, hybrid connectionist-symbolic models, fuzzy expert, connection expert, genetic fuzzy, evolutionary neural network, fuzzy rough hybridizations, reinforcement learning with fuzzy, neural, or evolutionary techniques, and also symbolic reasoning [483]–[486].

Every natural intelligence system was hybrid from the standpoint of cognitive science because it executes mental processes at both the sub-symbolic and symbolic levels. The significance of AI Systems Integration has been a topic of growing debate over the last several years. based on the idea that software that uses some of the models stated above or techniques for computer vision, voice synthesis, etc. were already developed, and that comprehensive AI systems may now be produced by integrating these systems [487].

In the digital era, the bulk of labor would be done by hybrid intelligence, a combination of AI and human, employing complimentary traits that, when combined, strengthen one another. Human intelligence excels at quite different tasks than artificial intelligence. The capabilities of AI models are (still) constrained, whereas those of humans are not. It excels in carrying out specified, well-defined activities that are based on a particular kind of data in a controlled environment. Artificial general intelligence will need a lot of training data in compared to humans, who could only learn from a small number of examples and cannot work with specific data types, including soft data. It is crucial to keep in mind that humans have an unmatched competitive advantage in this area [488].

The brain thrives in ways that the AI entirely fails since they employ very different methods. In large data sets, machine learning algorithms do better than humans in finding intricate and subtle patterns. Nevertheless, even in the presence of noise and ambiguity in the input, as well as when circumstances abruptly shift, the brain is still capable of processing information efficiently. For this reason, AI and humans should work together to form a hybrid intellect.

AI has lately been used to forecast the mechanical characteristics of concrete materials because of its great efficiency and accuracy in modeling the nonlinear relationship between input factors and outputs. To anticipate the compressive strength of lightweight foamed concrete, for instance, Yaseen et al. [489] used an extreme learning machine technique while taking into account the impacts of cement quantity, dry density, the proportion of water to binder, and foamed volume. Pham et al. [490] developed a model using the Firefly algorithm (FA) in the least squares support vector regression to describe the functional connection between compressive strength and the components of high-performance concrete. By combining the ANN model with the improved FA, Bui et al. [491] were able to estimate the compressive and tensile strengths of high-performance concretes. Many research have reported on the use of AI to estimate the mechanical strength of fiber-reinforced concrete. To predict the compressive, split tensile, and flexure strengths of SFRC, for example, Mashhadban et al. [492] proposed ANN and particle swarm optimization approach.

The nonparametric random forest algorithm seem to be a collection of random decision trees used to handle nonlinear regression issues [493]. Numerous civil engineering problems [493], [494] have shown their superiority in numerical prediction. However, it has not yet been determined if RF may be used to estimate DIF of SFRC. The amount of relevance of every factor that influence for the DIF of SFRC may also be assessed thanks to RF's ability to quantify the relative importance rating of every input parameter. Tuning RF hyper-parameters seems to be a consideration while developing RF algorithm so as to get accurate forecasting (for example, the trees and leaves/tree numbers). AI-based optimisation methods are used to finish the tuning process. FA is regarded as one of the most effective optimization tools available, with perfect convergence speeding and success rates, as shown by [491], [495].

In order to help the RF model forecast the DIF magnitudes of the SFRC, Yang et al. [496] used FA, where the DIF magnitudes of SFRC are predicted using an AI method, and where the combined effects of six factors involved, such as strain rate, matrix strength, fiber dosage, fiber shape, fiber tensile strength, and fiber aspect proportion are examined. Additionally, these impacting factors' relative weights are measured and presented. By using the experimental CDIF and TDIF datasets obtained for training and testing, the suggested hybrid RFFA model's effectiveness and validity were proven. The anticipated outcomes show that the created model is a reliable and effective way to forecast the DIF magnitudes for SFRC. The relative significance of every input variable is also looked at Table 5. It is discovered that the SFRC DIF magnitudes are most responsive to matrix strength.

A new model for predicting the shear strength of concrete beams reinforced by steel fibers using the Support Vector Regression algorithm combined with the Particle Swarm Optimization (SVR-PSO) was developed in [497]. The materials and dimensional properties are the main variables that used to construct the suggested model. The loading scenario of steel fiber-reinforced concrete (SFRC) beam described in Figure 18. Acceptable accuracy had been achieved by the developed SVR-PSO methodology in this study compared to the existing ANN-PSO model with attending a lesser number of input data.

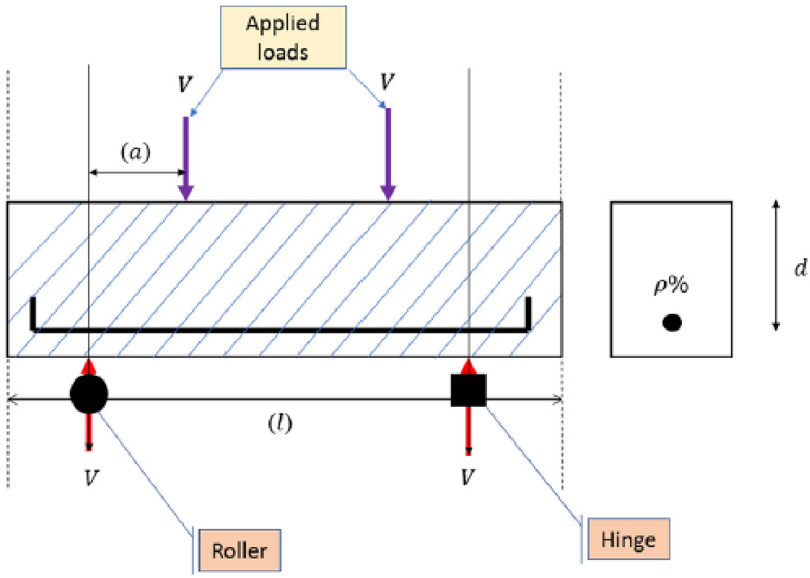


**Figure 18:** *Description of SFRC beam loading scenario [497].*

A nonlinear hybrid model of Response Surface Method and Support Vector Regression (RSM-SVR) was developed to theoretically predicting the shear strength capacity of SFRC beams [498]. The schematic structure of the new hybrid RSM-SVR model is presented in Figure 19. The data collected from 139 experimentally tested results of AFRC beams without stirrups were adopted for build and verify the developed hybrid RSM-SVR model in this study. The influence of varied steel fiber volume, longitudinal steel ratio, and the normal and high strength concrete strength are considered. The prediction achieved by the hybrid RSM-SVR model was adequate over the comparable models.

A new AI model called (SVR-FFA) that hybridized from support vector regression (SVR) with firefly optimization algorithm (FFA) was developed to predict the shear capacity of SFRC beam without stirrups [499]. The related beam properties including the concrete materials and dimensions are utilized to construct the proposed SVR-FFA model. Figure 20 presents the stress components of a single steel fiber. The validity of this SVR-FFA model was confirmed against the classical model of SVR.

Furthermore, in order to estimating the shear strength capacity of the RC beams, three ANNs models have been proposed in [501]. The structures of these models are a feed-forward neural network

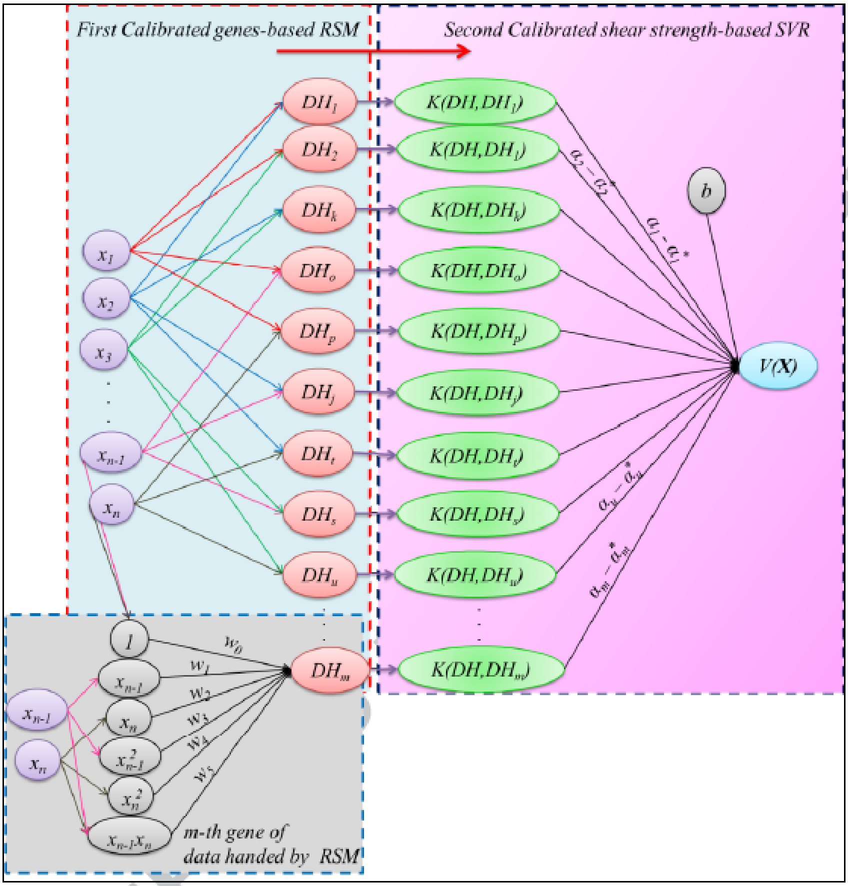


**Figure 19:** *The schematic structure of the hybrid RSM-SVR model [498].*

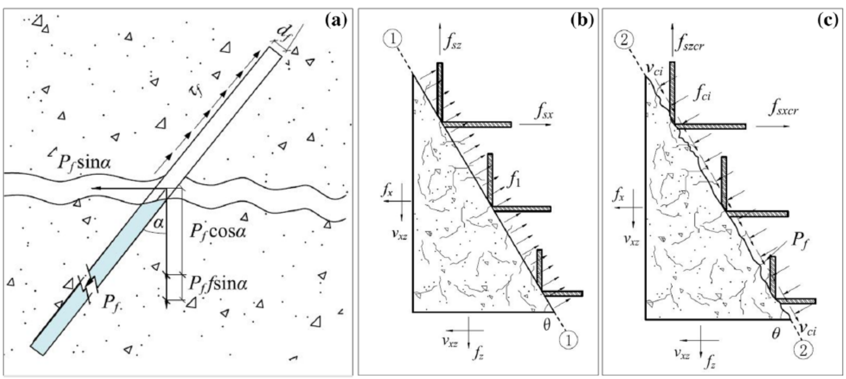

**Figure 20:** *The stress component of single-fiber transferred perpendicular and parallel cracks (a), computed mean stress (b), and local stress at crack (c) [499], [500].*

with the Levenberg–Marquardt algorithm, and one middle layer. The typical shear resistance components in the RC beam are shown in Figure 21. The data of 194 experimental test results are used for developing and verifying the proposed model. The study concluded that the new proposed model reasonably predicted the shear capacity of RC beams compared with the results obtained by the ACI-318 code's formula.

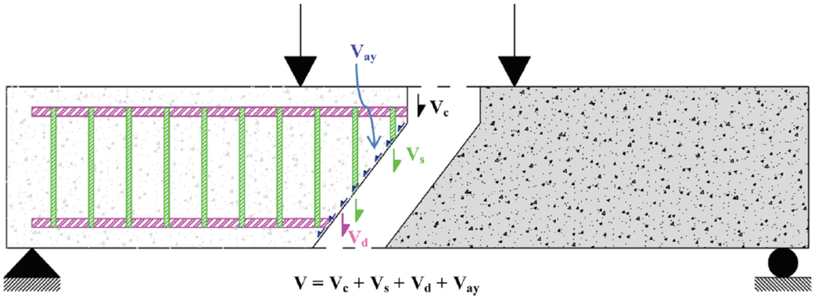


**Figure 21:** *Typical shear resistance components in RC beam [501].*

**Table 5:** *The established literature review research on the beam shear strength prediction using the feasibility of hybrid AI models.*

| Research | Applied models | Input parameters | Output parameter | Type of additive | Number of modeled datasets | Performance metrics | Source of the dataset | Research provide their dataset |
|---|---|---|---|---|---|---|---|---|
| [497] | SVR-PSO, ANN | $V_f, l_f/d_f, F, \rho, d, a/d, f_c$ | V | Steel fiber | - | SI, MAPE, RMSE, MAE, RMSE, MRE, $R^2$ | [27], [60], [74], [75], [77]–[80], [83], [502] | No |
| [503] | ANN-PSO | $\rho, f_c, F, V_f, l_f/d_f, d, a/d$ | V | Steel fiber | 85, 80% training, 20% testing | SI, MAPE, RMSE, MAE, $R^2$ | [27], [60], [74], [75], [77]–[80], [83], [504]–[507] | No |
| [498] | RSM, SVR, ANN, RSM-SVR | $f_c, f_y, a/d, b, d, d_a, V_f, d_f$ | V | Steel fiber | 139,104 sets training, 35 sets testing | RMSE, MAE, d, NSE | [21], [27], [29], [77], [127], [500], [508], [509] | No |
| [510] | ANN, ICA | $f_c, \rho_f, E_w, a/d, d, t_w$ | V | FRP | 198, 70% training, 15% testing, 15% evaluation | R, MSE, ME, MAE, RMSE | [31], [90]–[94], [96]–[108], [143], [144], [146], [395], [511]–[519] | No |
| [520] | SVR-GA, ANN, SVR, GBDTs | $b_w, d, \rho, \rho_x, \rho_y, a/d$ | $V/b_d d$ | - | 217, 152 sets training, 65 sets testing | MAE, RMSE, $R^2$, RE, WI, NSE | [126], [368]–[371], [373]–[375] | No |
| [481] | Multilayer perceptron, SMOreg, REPtree, Linear regression , Votting, bagging, stacking,SFA-LSSVR | Dataset$_1$ : $a/d, d, b_w, \rho$<br>Dataset$_2$ : $a, b, d, f_c, \rho,$<br>Dataset$_3$ : $b, d, a/d, f_c,$ | V | FRP | Dataset 1: 1849<br>Dataset 2: 194<br>Dataset 3: 209 Five fold cross validation | R, RMSE, MAPE, MAE | [254], [255], [521] | No |
| [522] | ANFIS-PSO, ANFIS-ACO, ANFIS-DE, ANFIS-GA | $d, a, f_c, \rho, a/d, d_a$ | V | - | 250, 70% training, 30% testing | R, RMSE, SRMSE, MAE, WI, RRMSE | [61], [126], [396], [523]–[552] | No |
| [499] | SVR-FFA | $f_c, f_y, a/d, d, b, d_a, \rho_x, v_f$ | V | Steel fiber | 139, 70% training, 30% testing | SI, RMSE, MAPE, MAE, MRE, RMSE, BIAS, $R^2$ | [500] | No |
| [501] | ANN | $f_c, b, d, f_{sy}, \rho rt, \rho_y, f_y$ | V | - | 194, 85% training, 15% testing | RMSE, MAE, $R^2$ | [369], [370], [525], [528], [529], [553]–[564] | No |
| [565] | ANN-RCGA, ANN-FFA | $b_w, H, d, l_{span}, a, a_w, \rho, f$ | V | Steel fiber | 463, 70% training, 30% testing | R, RMSE, MAE | [77], [80], [127], [149], [157], [159], [161], [162], [164], [170]–[172], [174], [176], [178], [179], [181], [183]–[185], [187]–[189], [191], [194], [341], [565]–[568] | Yes |
| [569] | SVM | $a/d, \rho, f_y, f_c, f_{ry}, v_f$ | V | Steel fiber | 126, 75% training, 25% testing | RMSE, $R^2$, COV | [84], [87], [570]–[574] | Yes |

## 3. Literature Review Assessment

This section is presented an assessment for the presented literature on the development of AI models for simulating the beam concrete shear strength. Those assessments are essential for the conducted review where more informative understating for the underlying concept for the established modeling procedures, types of fibers, data span, limitation of the empirical formulations, the significant of the parametric analysis and the pros and cons of the developed AI models.

i. Despite the high accuracy of the existing ML models in shear strength prediction, their implementation still faces certain problems. For instance, sensitivity analysis has shown that the fiber factor has little effect on the predicted shear value, but this is not consistent with some previous studies possibly due to the influence of different fiber types contained in the database on the shear strength of the resulting concrete; hence, these models cannot capture the exact effect of each fiber in some cases as it rather reveals the average effect on the entire dataset. Therefore, future studies should focus on the investigation of such a limitation.
ii. Even though this is achievable by considering the fiber characteristics as model input parameters, effort should be made towards the development of a strong and comprehensive dataset that can reflect the complex influence of such features during the training and testing phases of the model. The proposed models have also been noted to have limited applicability as they can only be applied to a specific range of variables, prompting the need to verify the generalization capability of the models to large-scale beams that exhibit complex behaviours. The extension of the model to large-scale beams can be achieved only when the comprehensive dataset on such beams is available and this demands further investigation.
iii. Various studies have been focused on concrete shear strength capacity prediction; yet, the clear path to the prediction of the shear failure mechanisms of concrete elements remains unclear as most of the available expressions on shear design differed in forms and have failed to the needed safety factor against shear failure. Therefore, many researchers have devoted time and effort to the study of the behavior of concrete beams over the past few years, resulting in the development of various theoretical models that investigate the relationship between several forces, such as torsion, axial, bending, and shear strengths.
iv. The limited validity range of empirical models is their major challenge as their development is mainly based on few data instances, making their validity and accuracy over new instances a doubt. Hence, machine learning (ML) models were developed recently as potential alternatives to the empirical models for the prediction of the mechanical strength of concrete materials [575]. The development of these ML models involved numerous databases that contain several features and a wide range of values; this is the reason for the strong generalization capability of the ML models; it also accounts for their higher accuracy in determining the strength of concrete materials produced from different components. The use of SVM and ANN in the prediction of the mechanical strength of SFRC has been reported [498]; these models are used either alone or in combination with other algorithms as a hybrid model. Being that these models cannot generate a mathematical equation that can describe the nature of the relationship between the predictors and the predictands, they are often referred to as "black box" models.
v. The literature review research indicated that empirical equations and standard codes that were designed for the beam shear strength determination are not efficient and effective and this was observed for all reinforcement types. Also, the development of the empirical equations and standard codes exhibited a noticeable limitation against the generalization of the implementation for all types of structural beam. Hence, the proposal of the soft computing models technologies come up with reliable solution for modelling shear strength behaviour.
vi. There were four main categories of ML models were applied over the literature for simulating the shear strength of RC beam including classical neural network models, fuzzy logic models, evolutionary computing models and the most recently discovered the hybrid ML models.

vii. The ML models were developed for shear strength prediction using several geometric, fiber properties "if existed", loading and material characteristics. Evaluation and assessment for those parameters is very essential for the modeling development. Hence, identification of the significant of each parameter can contribute to the best knowledge of beam design.
viii. The classical ML models including (e.g., ANFIS, ANN, SVM) have major drawbacks which is the hyper parameters tuning for the internal network. Hence, the proposition of the hybrid ML version was an excellent developed technology for solving this problem. However, proper selection for optimizer comes as a critical issue for solving this modeling procedure.
ix. Based on the tabulated literature, a varied number of experimental dataset were used for the models development. This is clearly initiate a kind of redundant aspect of the modeling procedure. It is advisable to set a minimum standard number of experimental laboratory dataset as a guideline for future development of soft computing models.
x. Among all the applied soft computing models, the evolutionary computing models such as genetic programming model could have the merit and provided the feasibility to generate a formulation for the simulate dataset. However, several limitations have been reported for those models.

## 4. Possible Future Research

i. As per the reported survey, several researches have presented the simulated data of beam shear strength and their related parameters such as geometric, concrete properties and the additive material of reinforcement. It is suggested to initiate a standard database that is accommodating all the reported data over the literature in which accessible for interested researchers of this domain. In addition, to avoid repetitive introduced soft computing models.
ii. Exploration of more reliable nature inspired optimization algorithms can be further explored to tune the classical AI models. In which better learning process can be attained where more accurate predictive models can be established.
iii. Uncertainties of data and related input parameters toward the beam shear strength considered as essential concern to be investigated in parallel with the predictive model's prediction accuracy.
iv. Parametric investigation is highly important for such a case of theoretical modeling where the significant of each predictor can be physically explained especially for concrete mixture that contain additive materials.
v. Expert system is always the eager for structural engineers/designers to be ultimately accomplished for the purpose of using predictive models based AI can be practically implemented for real engineering practice.

## Abbreviations

Artificial neural network (ANN), slab width ($b_l$), slab height (h), slab effective depth ($d_l$), span length ($l_{span}$), average concrete cylinder compressive strength ($f_{cm}$), longitudinal reinforcement ratio ($\rho_x$), transverse reinforcement ratio ($\rho_y$), distance from the slab edge to the center of the load ($b_r$), dimension of the loading plate ($l_{load}$), ratio of sectional moment to product of sectional shear and effective depth ($M_E/V_E d_t$), ratio of clear shear span to effective depth of slab ($a_v/d_t$), slab shear capacity ($V_R$), length of or radius of the loading pad or column ($b_c$), punching shear strength of slab ($V_p$), Pearson correlation coefficient (R) , effective depth (d), web width ($b_w$), flange width (b), overall beam depth ($h_b$), shear span to depth ratio (a/d),concrete compressive strength $f_c$), reinforcement ratio ($rho$), modulus of elasticity of fiber reinforced polymer ($E_f$), modulus of elasticity of steel ($E_s$), yield strength of steel ($f_y$), maximum aggregate size ($d_a$), average concrete compressive strength ($f_{c,cyl}$), bearing plate length in longitudinal direction on flexural tension side (bear), shear span (a), fiber factor (F), tensile strength for fiber ($f_{tenf}$), length of fiber ($l_f$), diameter of fiber ($d_f$), percentage longitudinal steel ratio ($\rho_t$), percentage fiber volume fraction ($v_f$), shear reinforcement ratio ($\rho_v$), fiber length ($L_f$), fiber diameter ($d_f$), presstressing level ($\sigma_p$), ultimate shear force ($V_u$), ultimate shear stress ($\tau_u$), hear capacity (V), amount of longitudinal reinforcement ($\rho_l$), concrete design strength ($f_{ck}$), longitudinal reinforcement area ($A_{st}$), clear span to depth ratio of deep beam (L/D), type of wrapping scheme ($w_f/s_f$), width of FRP ($w_f$), center to center spacing steps ($s_f$), axial tensile strength of concrete ($f_{ry}$), yielding strength of transverse reinforcement ($f_{sy}$), angle between principal fiber orientation and the longitudinal axis of the member (β), design rupture strain of fiber reinforced polymer reinforcement ($\epsilon_{fu}$), total fabric design thickness ($t_f$), yield stress ($f_{ys}$), reinforcement factor (ω), arch action factor (e), $v_b = 0.14\tau F$, splitting tensile strength ($f_t$), computed value of split- cylinder strength of fiber concrete ($f_{spfc}$), reinforcement ratio of joints stirrups ($\rho_s$), effective width of joint panel ($b_j$), cross section column width ($h_c$), column longitudinal tensile ratio ($\rho_{col}$), Shear strength of reinforced concrete joint ($V_J$), web thickness ($t_w$), flange thickness (t), connector length ($L_c$), shear strength capacity of composite beam (L), joint eccentricity (JE), ratio of the number of not-free in-plane surfaces around a joint panel to the total number of in-plane surfaces of the joint panel (JP), joint conferment factor (TB), beam reinforcement index (BI), joint transverse reinforcement index (JI), Joint shear ($V_j$), FRP longitudinal reinforcement ratio ($\rho_f$), FRP transverse reinforcement ratio ($\rho_w$), elastic modules of FRP transverse reinforcement ($E_w$), cross sectional area of the reinforcement as a proportion of the cross sectional area of the beam ($\rho_{rt}$), Height of cross section (H), clear shear span ($a_v$), coefficient of variation (COV), mean absolute error (MAE), mean square error (MSE), Squared correlation between outputs and targets in the network ($R^2$), tandard deviation (SD), root mean square error (RMSE), mean absolute percentage error (MAPE), modified agreement index (d), modified Nash and Sutcliffe efficiency (NSE), Standardized root mean squared error (SRMSE), relative root mean squared error (RRMSE), Legate and McCabe's index (LMI), mean relative error (MRE), Piecewise multiple linear regression (PMLR), average value of the ratio between experimental and analytical results (AVG), mean bias error (MBE), modified beetle antennae search (MBAS), random forest (RF), logistic regression ( LR), multiple linear regression (MLR), back propagation neural network (BPNN), random tree (RT), feature selection (FS), Gaussian process (GP), Genetic programming (GP), Support vector machine (SVM), k-nearest neighbor (KNN), Gene expression programming (GEP), linear genetic programming (LGP), nonlinear multiple regression (NMR), biogeography – based programming (BBP), genetic algorithm (GA), adaptive neuro fuzzy system (ANFIS), group method of data handling (GMDH), fuzzy inference system (FIS), smart firefly algorithm (SFA), least squares support vector regression (LSSVR), sequential minimal optimization – based support vector regression (SMOreg), Particle swarm optimization (PSO), support vector regression (SVR), response surface method (RSM), firefly algorithm (FFA), gradient boosted decision trees (GBDTs), relative error (RE), Willmott Index (WI), mean error (ME), imperialist competitive algorithm (ICA), Real-Coded Genetic Algorithm (RCGA).

**Conflicts of Interest:** **The authors have no conflict of interest to any part.**

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