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Case study

Prediction of remaining design resistance and bending stiffness of the steel column base plate considering metal corrosion using GA-ANN model

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ABSTRACT

This study aims to predict the remaining design resistance and bending stiffness of steel column base plates considering metal corrosion, which helps construction managers make proper decisions about maintenance, reinforcement, or demolition. To achieve this, the paper introduces a method for predicting the design resistance and bending stiffness of the steel column base plate, considering metal corrosion using a hybrid Genetic Algorithm-Artificial Neural Network (GA-ANN) model. The GA-ANN model was trained using a dataset of 808 observations derived from calculating design resistance and bending stiffness of the steel column base plates. Fifteen input parameters of the GA-ANN model included geometric parameters and material properties of the concrete foundation block, base plate, steel column, and anchor bolts. Two output parameters were the design resistance and bending stiffness. The predicted results were then compared with those of the traditional Levenberg-Maquard-Artificial Neural Network (LM-ANN) model. Statistical indices including R^2, *RMSE*, and $a20-index$ demonstrated that the GA-ANN model was superior in predicting capability. By integrating the training results of GA-ANN with a metal corrosion model, this study proposed a procedure for forecasting the remaining design resistance and bending stiffness of corroded steel column base plates. Additionally, the study evaluated the remaining design resistance and bending stiffness of corroded steel column base plates after 100 years. A free-access graphical user interface was developed to aid in the practical prediction process.

1. Introduction

The steel column base plate is an indispensable component in civil and industrial steel structures such as steel bridges, transmission steel towers, light poles, and road signs. It distributes the internal forces from the columns onto the contact area and transfers them to the anchor bolts and concrete foundations. Over time, the base plates will deteriorate due to corrosion, leading to a reduction of load-bearing capacity and posing a danger to the structural integrity of the entire structure.

The design resistance and bending stiffness of steel column base plates are covered in design codes such as EN 1993–1–8 and AISC [1,2]. It is also a topic of interest to many scientists worldwide, particularly in research and testing to evaluate structural reliability and reduction. Grauvilardell et al. [3] conducted a synthesis of design, testing, and analysis research on steel column base plate connections

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in high-seismic zones. Moghimi and Driver [4] evaluated steel column base plate demands in shear with regular perforations using performance-based design methods. Idris and Umar [5] carried out the reliability analysis of steel column base plates designed according to BS5950 using the first-order reliability method. The influence of base-plate connection stiffness on the design of low-rise steel buildings was assessed in the study of Kavoura et al. [6].

The impact of corrosion on the mechanical performance of steel has been extensively studied through surface measurements and tensile tests on naturally corroded steel plates [7]. A corrosion prediction model was used to determine thickness reduction over time. The findings revealed that corrosion-induced volume loss significantly affects the ultimate strength of slender plates more than stiffened panels, with a reduction of up to 45 %. This indicated that choosing structural elements was crucial for accurately estimating the effects of corrosion damage [8]. Recently, experimental and numerical studies were carried out to quantify the effects of random corrosion on the tensile capacity of strands [9,10], shear capacity of corrugated steel plates [11], and load capacity of steel tubular columns [12]. Additional studies examined the degradation of mechanical properties in corroded steel plates based on surface topography [13], and both experimental and numerical investigations were conducted on corroded steel columns under in-plane compression and bending [14]. Few studies also focused on the seismic performance of corroded H-shaped steel columns [15] and the seismic behavior of corroded steel frame beams and columns in offshore atmospheric environments [16]. The effects of pitting corrosion on the ultimate strength of steel plates subjected to in-plane compression and bending were assessed [17], along with the ultimate strength of steel stiffened plate structures with grooving corrosion damage [18]. Moreover, experimental investigations were carried out on corroded cold-formed steel beam-columns under compression and major axis bending [19]. Previous studies focused on investigation of some specific cases; it is required to cover a wide range of structural dimensions and properties.

Metal corrosion is a complicated process often explained using mathematical equations. Komp [20] proposed a comprehensive corrosion model considering marine, urban, and rural environments. Afterwards, many authors applied this model in their research to evaluate the reduction of bearing capacity, longevity, and reliability of steel structures in fields such as construction, hydraulic works, civil engineering, marine vessels and ships [21–26]. Moreover, machine learning (ML) techniques have been widely applied in

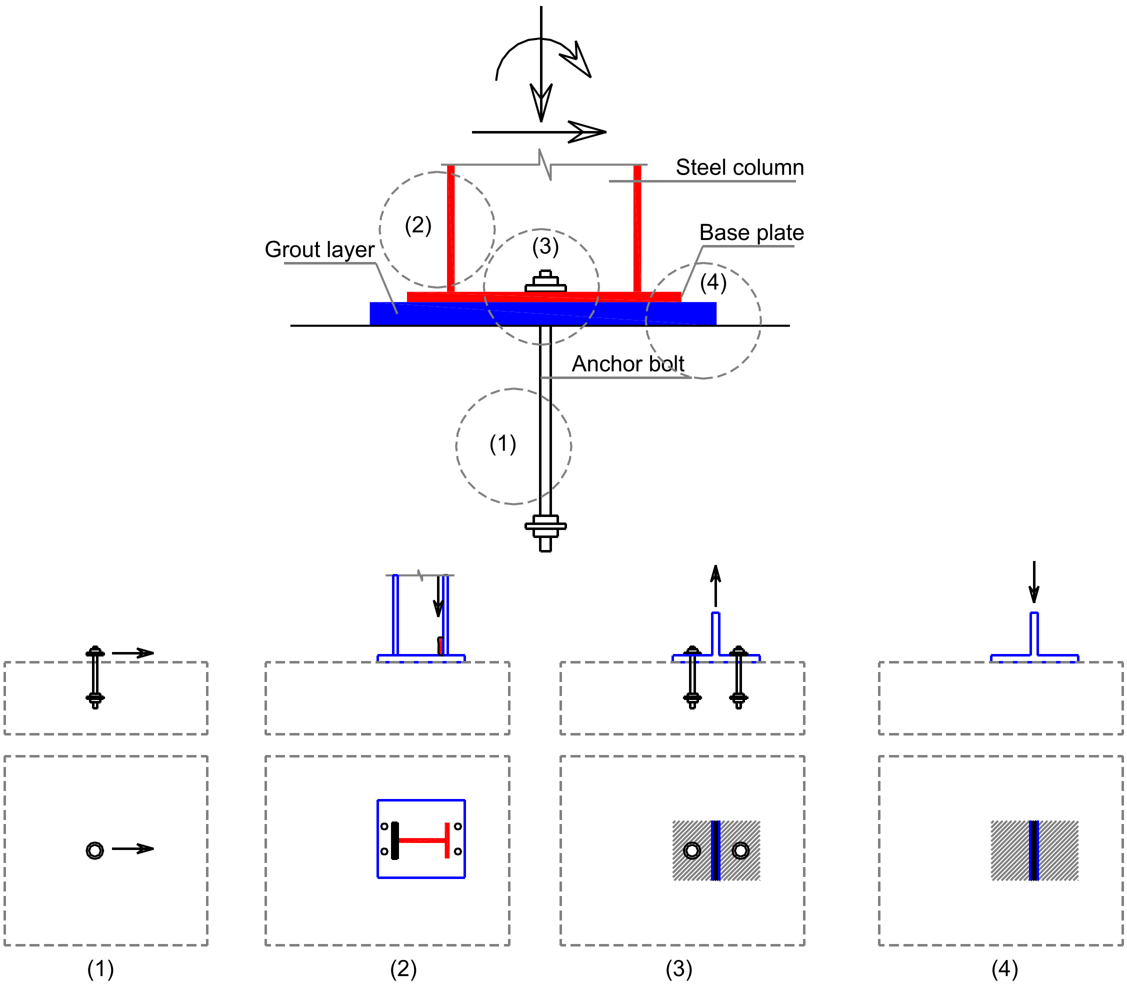

Fig. 1. Typical individual components of column base plates.

structural engineering, and artificial neural networks (ANNs) and genetic algorithms (GAs) are preferable options. The use of GA in optimizing parameters such as weights and biases in ANNs has been explored since the 1980s and early 1990s. In 1989, foundational principles for utilizing GA in various optimization problems, including those related to neural networks, were first introduced [27]. The application of GAs to optimize the topology and weights of neural networks was discussed in [28]. A comprehensive study, often considered one of the seminal works on applying genetic algorithms to neural network training, is detailed in [29]. The application of GA incorporating with ANN for engineering problems has been widely adopted, as evidenced by numerous studies [30–36]. However, a systematic study applying the hybrid GA-ANN model for predicting the structural capacity of corroded steel column base plates has not been conducted yet.

This study developed a prediction method for the design resistance and bending stiffness of steel column base plates considering metal corrosion. The predicted method was based on the hybrid GA-ANN technique integrated with a corrosion model outlined in a previous study [20]. A set of 808 data samples, generated through a detailed calculation process, was used to develop the ML model. The predictive model utilized fifteen input parameters including geometry, material properties, concrete foundation block, base plate, steel column, and anchor bolts. Two output parameters of the model were the design resistance and bending stiffness of the steel column base plate. The performance of the GA-ANN model was compared with that of the traditional LM-ANN model using various metrics such as R^2, *RMSE*, and the $a20-index$. By combining the training results of the GA-ANN model with a metal corrosion model, this study presented a procedure for predicting the remaining design resistance and bending stiffness of the steel column base plate, accounting for metal corrosion. Additionally, the remaining design resistance and bending stiffness of the steel column base plate after 100 years were evaluated. Furthermore, a user-friendly interface (GUI), which is freely accessible, was developed to aid in the practical prediction process.

2. Resistance and bending stiffness of the steel column base plate

2.1. Component method

The steel column base plate, which is either rigidly or semi-rigidly connected to a reinforced concrete foundation, comprises the following main components: (i) a steel column with a rigid or semi-rigid cross-section (HEA, HEB, IPE); (ii) a base plate welded to the column; (iii) a grout layer beneath the base plate; (iv) anchor bolts; and (v) a reinforced concrete foundation. According to Wald [37], the behaviors of these components are divided into load-bearing parts (as shown in Fig. 1), including:

(1) Component anchor bolt in shear.
(2) Column web and flange in compression.
(3) Anchor bolt in tension and base plate in bending.
(4) Concrete block in compression and base plate in bending.

The relationships between the components are used to obtain the overall structural properties, which include flexural resistance and strength. The design calculation sequence is implemented using the following steps.

Step 1. Identifying basic components.

Step 2. Describing mechanical properties of each part (i.e., strength and stiffness).

Step 3. Assembling individual component properties to obtain the overall properties of the connection.

Step 4. Classifying joints according to strength and stiffness.

2.2. Procedure for designing resistance and bending stiffness of the steel column base plate

In this study, we integrated methods proposed in previous research [1,2,37] to develop a comprehensive, accurate, and accessible design procedure for evaluating the resistance and stiffness properties of bolts under tension. According to EN 1993–1–8 [1], a model,

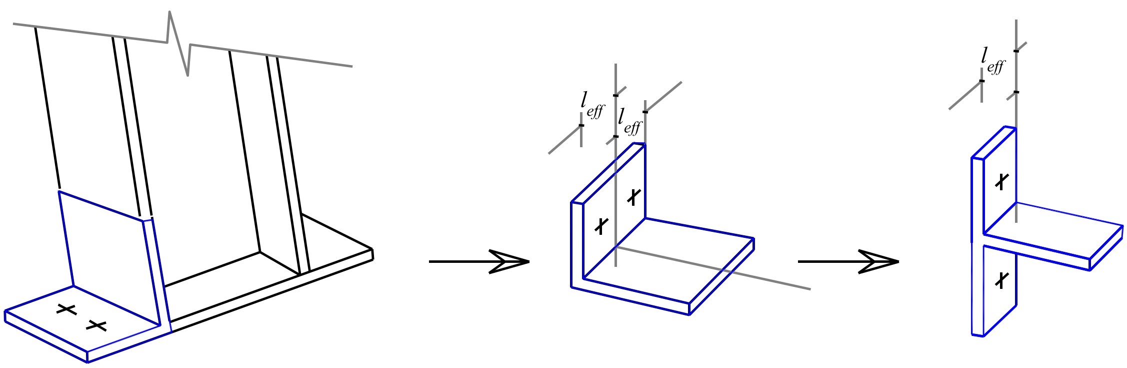

Fig. 2. T-stub nomenclature.

namely T-Stub, has been proposed for this design purpose. As shown in Fig. 2, the T-Stub model depends on the resistance F_{Rd} and the initial stiffness E_K, as shown in Fig. 3.

The design resistance and bending stiffness properties of bolts under tension depend on the T-stub's failure mode. According to Eurocode 3 [1], the T-stub has three typical failure modes:

Mode 1 - Plastic mechanism of the plate (see Figs. 3 - 4)

Mode 2 - Mixed failure of the bolts and the plate (see Figs. 3 - 4)

Mode 3 - Bolt fracture (see Figs. 3 - 4).

In addition, Eurocode 3 - Part 8 [1] also adds a case where the base plate is yielding, and no prying forces appear, namely Mode 1–2 (see Figs. 3 - 4).

Fig. 5 shows the flowchart for the design of resistance and bending stiffness of the steel column base plate. Appendix 1 provides the details of calculated expressions.

3. Database generation

3.1. Validation of computer program

The design procedure for the resistance and bending stiffness of the steel column base plate, as shown in Fig. 5, has been developed in the MATLAB platform. To ensure the reliability of the developed computer program, we verified its calculation results against those published by Wald [37]. The structural configurations and parameters of the validation study are shown in Fig. 6. Meanwhile, the material parameters, cross-section parameters, and calculation results from the computer program are provided in Table 1. It was observed that the error between the program in this study and the results published in Wald [37] was 2.90 %. This small error indicated that the proposed computer program is reliable for calculations in subsequent steps.

3.2. Database generation

The database plays a vital role in ensuring the accurate performance of predictive models. Generally, more data is required to get more accurate results. If the database is small, an overfitting problem can be happened during training ML models. Meanwhile, if the dataset is too large, the computation will be expensive. In this study, data sets were generated by considering different scenarios for steel column base plates. Various input parameters included steel column and base plate dimensions, material properties, anchor bolts, concrete foundation, and axial force. Input parameters cover a wide range of design cases. As a result, 808 sets were generated to develop the hybrid ML model. It should be noted that this number of database is not as large as the suggestion of Alwosheel et al. [38], however we employed GA to improve predictions for ANN in this study. The input parameters ensure that the structural requirements and destructive conditions of the steel column did not occur. The value of design resistance and bending stiffness was determined using the above computer program presented in the previous section. Table 2 provides statistical information on the used database. It should be noted that the first fifteen parameters are inputs, while the last two ones are outputs. Fig. 7 shows the frequency of all input and output parameters in the database.

Fig. 8 shows the Pearson's correlation coefficients between input and output variables. It was found that almost all coefficients are very small. Meanwhile, several pairs of input parameters have high coefficients such as b_f and h_c (0.91), b_1 and d_1 (0.90), t_{bp} and t_g (0.85). However, the variations of the ratios b_f/h_c, b_1/d_1, and t_{bp}/t_g were from 0.333 to 1.0, 0.615–1.0, and 0.20–1.0, respectively, implying a moderate variation interval. Moreover, the remaining bending moment and stiffness required detailed dimensions of the column, base plate, foundation, anchor bolts, and material properties in the calculated expressions. Therefore, fifteen input parameters were employed to preserve sufficient information for training ML models.

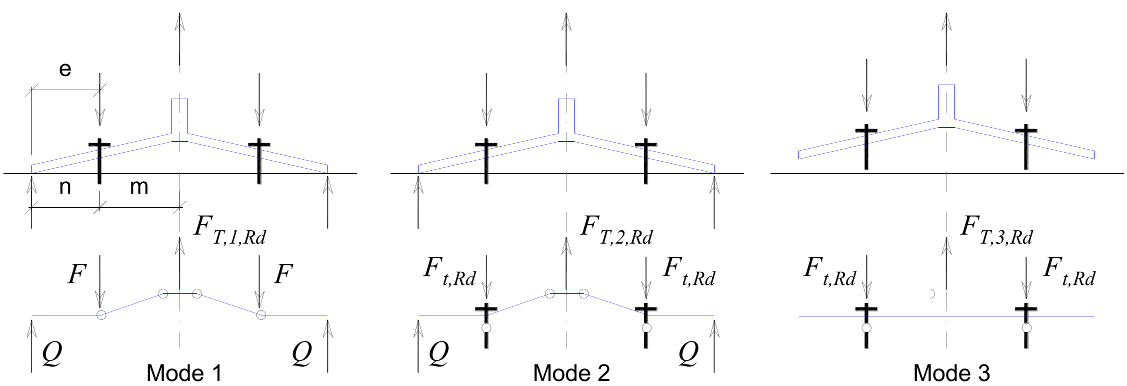

Fig. 3. Failure modes of T-Stub [37].

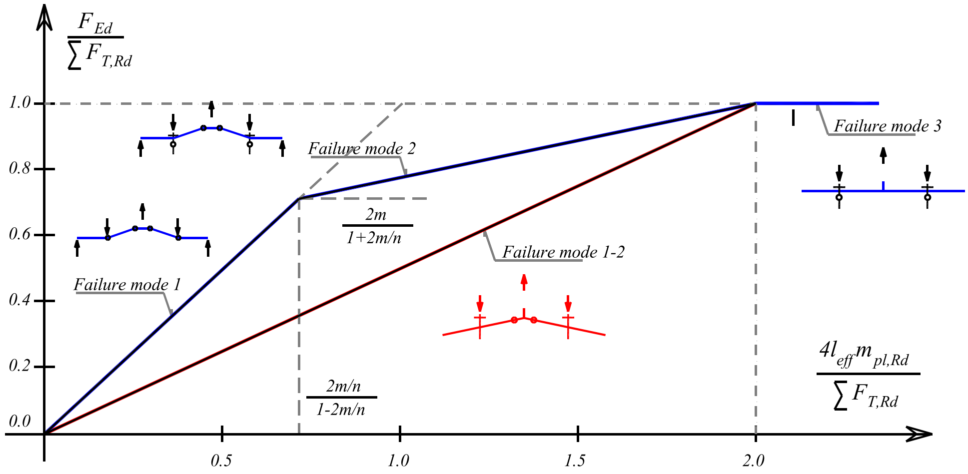

Fig. 4. The design resistance of the T-stub [37].

4. Development of GA-ANN model

4.1. Normalized training data

Data normalization is an essential step in data preprocessing, particularly for machine learning models. Its significance includes improving model performance, ensuring fairness, reducing the impact of outliers, and improving accuracy. In the GA-ANN model, normalized data was in the range $[-1, 1]$. According to [39], the normalized data was calculated as the following Eq. (1).

$$X_N = 2 \bullet \frac{(X - X_{\min})}{(X_{\max} - X_{\min})} - 1 \tag{1}$$

where X is the original sample; X_N is the normalized sample; $X_{\min}, X_{\max}$ are the minimum and maximum values of the sample under consideration, respectively.

4.2. GA-ANN model

The LM algorithm for training ANNs is an optimization technique that combines the concepts of the Gauss-Newton algorithm and gradient descent. It is particularly well-suited for training tiny to medium-sized neural networks and is known for its fast convergence. An LM-ANN structure consists of three layers: an input layer, a hidden layer, and an output layer. The connection between the three layers is adjusted by the weights and biases of neurons. The mathematical expressions are shown as follows.

$$f : X \in R^D \rightarrow Y \in R^1, \quad f(X) = f_0(b_2 + W_2(f_h(b_1 + W_1 X))) \tag{2}$$

where W_1, b_1 and f_h are weight matrix, biases vector and the activation function of the hidden layer, respectively; W_2, b_2 and f_0 are weight matrix, biases vector the activation function of the output layer, respectively.

According to Nikbin et al. [40], this study used a nonlinear activation function (namely *tansig*) for the hidden layer and a linear activation function (namely *purelin*) for the output layer, as shown in Fig. 9. Its mathematical equation has the form.

$$\text{tansig}(x) = \frac{2}{(1 + \text{epx}(-2x))} - 1 \tag{3}$$

$$\text{purelin}(x) = x \tag{4}$$

In this study, GA is incorporated with ANN to optimize the weights and biases, and then minimize mean squared error (MSE). The model involves the following steps.

- *Step 1. Define the neural network structure:* Start by specifying the neural network's architecture, including the number of input neurons, hidden layers, neurons per hidden layer, and output neurons.
- *Step 2. Initialize population:* Create an initial population of potential solutions. Each solution consists of a set of weights and biases for the neural network. Typically, this is done randomly.
- *Step 3. Encode solutions:* Encode the weights and biases into a chromosome format suitable for genetic algorithms. Each chromosome represents a complete set of weights and biases.

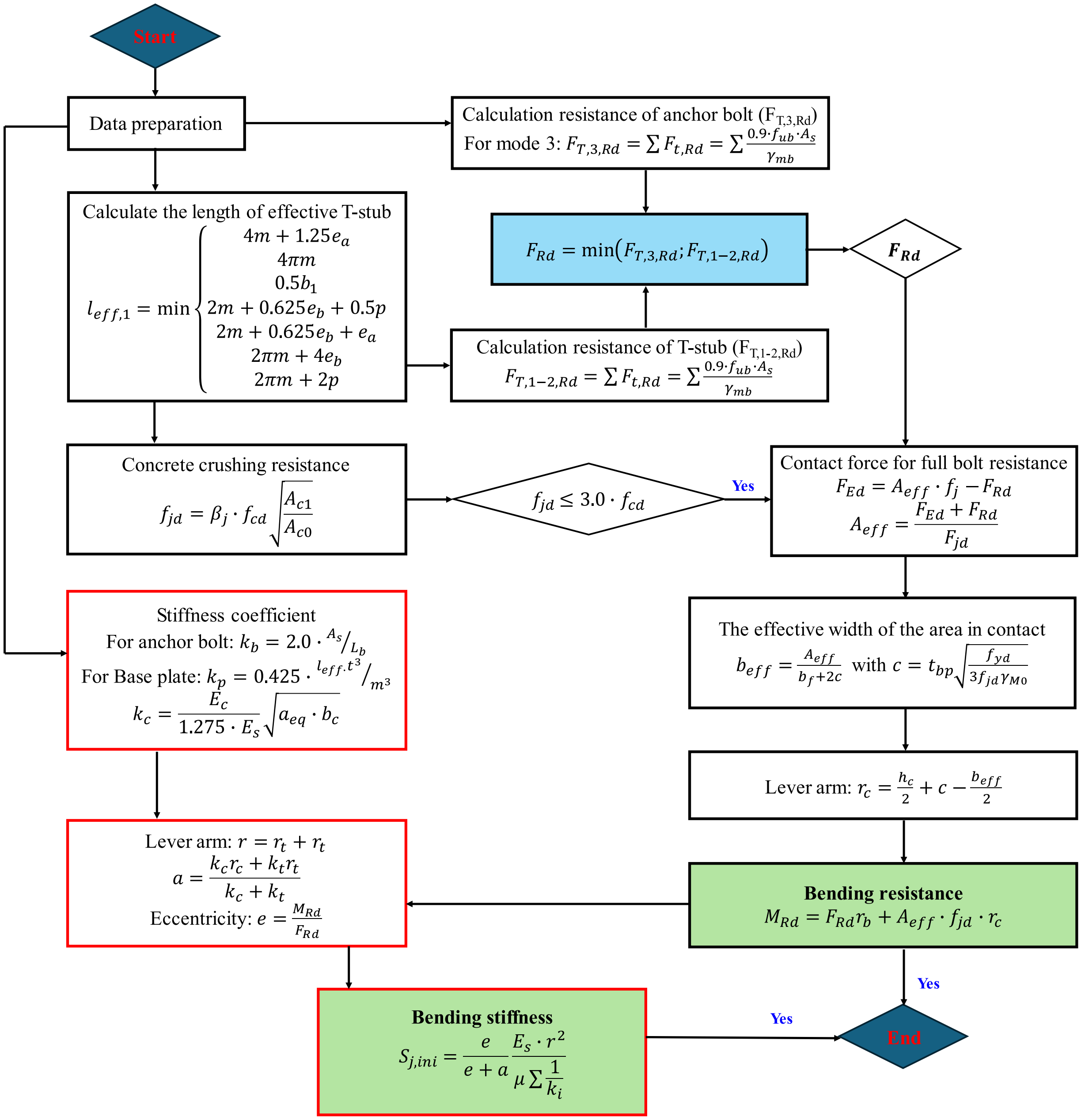

Fig. 5. Flowchart for design process of resistance and bending stiffness of the steel column base plate.

- *Step 4. Fitness function:* Define a fitness function to evaluate how well a particular set of weights and biases performs. The fitness function should calculate the MSE on the training data:

$$MSE = \frac{1}{n} \sum_{i=1}^{n} (t_i - o_i)^2 \tag{5}$$

where t_i is the actual output and o_i is the predicted output of the ANN

- *Step 5. Selection:* Use a selection method to choose the best-performing chromosomes to be parents for the next generation. Common methods include tournament selection, roulette wheel selection, or rank-based selection.
- *Step 6. Crossover:* Perform crossover (recombination) to produce offspring from the selected parents. Crossover combines parts of two (or more) parent solutions to create new offspring solutions.

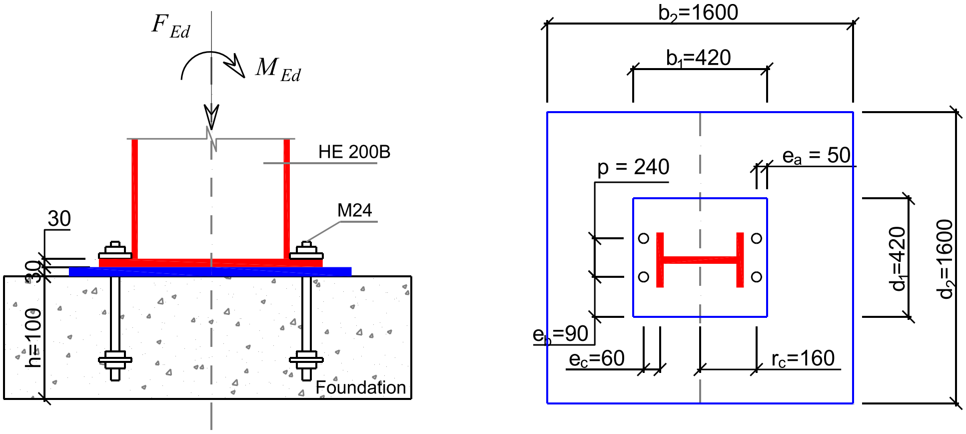

Fig. 6. The structural dimensions and geometric parameters of the validated case.

Table 1
The validation result of propsed procedure in this study.

Properties		Bending resistance (kN.m)		Error
		Wald [33]	This study	
Column	HE 200B	100.90	103.92	2.90 %
Force	500 (kN)			
Concrete block	C16/20			
Steel	S235			
Thickness	30 (mm)			

Table 2
Statistical indicators of input and output values of database.

	Symbol	Unit	Minimum	Mean	Maximum	Std	CoV
Bolt diameter	d	*mm*	16.00	22.47	30.00	5.17	0.23
Height of concrete foundation block	h	*mm*	800.00	899.93	1000.00	66.25	0.07
Width of concrete foundation block	b_2	*mm*	1000.00	1500.12	2000.00	289.95	0.19
Length of concrete foundation block	d_2	*mm*	1000.00	1500.12	2000.00	289.96	0.19
Width of base plate	b_1	*mm*	320.00	418.65	520.00	60.20	0.14
Length of base plate	d_1	*mm*	320.00	418.65	520.00	60.20	0.14
Concrete strength	f_{ck}	*MPa*	12.00	18.22	25.00	4.82	0.26
Grout thickness	t_g	*mm*	10.00	30.25	50.00	12.33	0.40
Base plate thickness	t_{bp}	*mm*	10.00	30.25	50.00	12.33	0.40
Steel strength	f_y	*MPa*	235.00	288.27	355.00	49.89	0.17
Column-section height (HBE)	h_c	*mm*	100.00	198.65	300.00	60.20	0.30
Column-section flange thickness (HBE)	t_f	*mm*	8.00	14.29	20.00	3.51	0.24
Column-section flange width (HBE)	b_f	*mm*	100.00	198.65	300.00	60.20	0.30
Column-section web thickness (HBE)	t_w	*mm*	6.00	10.98	16.00	3.22	0.29
Axial force	F_{Ed}	*kN*	50.00	519.58	1000.00	280.58	0.54
Design resistance	M_{Rd}	*kN.m*	10.12	100.49	283.11	52.09	0.51
Bending stiffness	$S_{j,ini}$	*kN.m/rad*	3113.40	22968.04	64405.55	13331.31	0.58

- *Step 7. Mutation:* Mutation can be applied to introduce small changes in the offspring chromosomes, which helps maintain genetic diversity in the population and prevents premature convergence.
- *Step 8. Evaluation:* Evaluate the new population by decoding the chromosomes back into weights and biases, setting them in the neural network, and calculating the *MSE* on the training data.
- *Step 9. Replacement:* Replace the old population with the new one, often keeping the best individuals from both generations.
- *Step 10. Termination:* Repeat steps 5–9 until a stopping criterion is met. Common criteria include a fixed number of generations, a satisfactory error level, or no significant improvement over many generations. The sequence of steps is shown in Fig. 10.

4.3. Performance metric

To evaluate the accuracy of prediction results using the GA-ANN model, this study used three statistical indices: (R^2), root mean

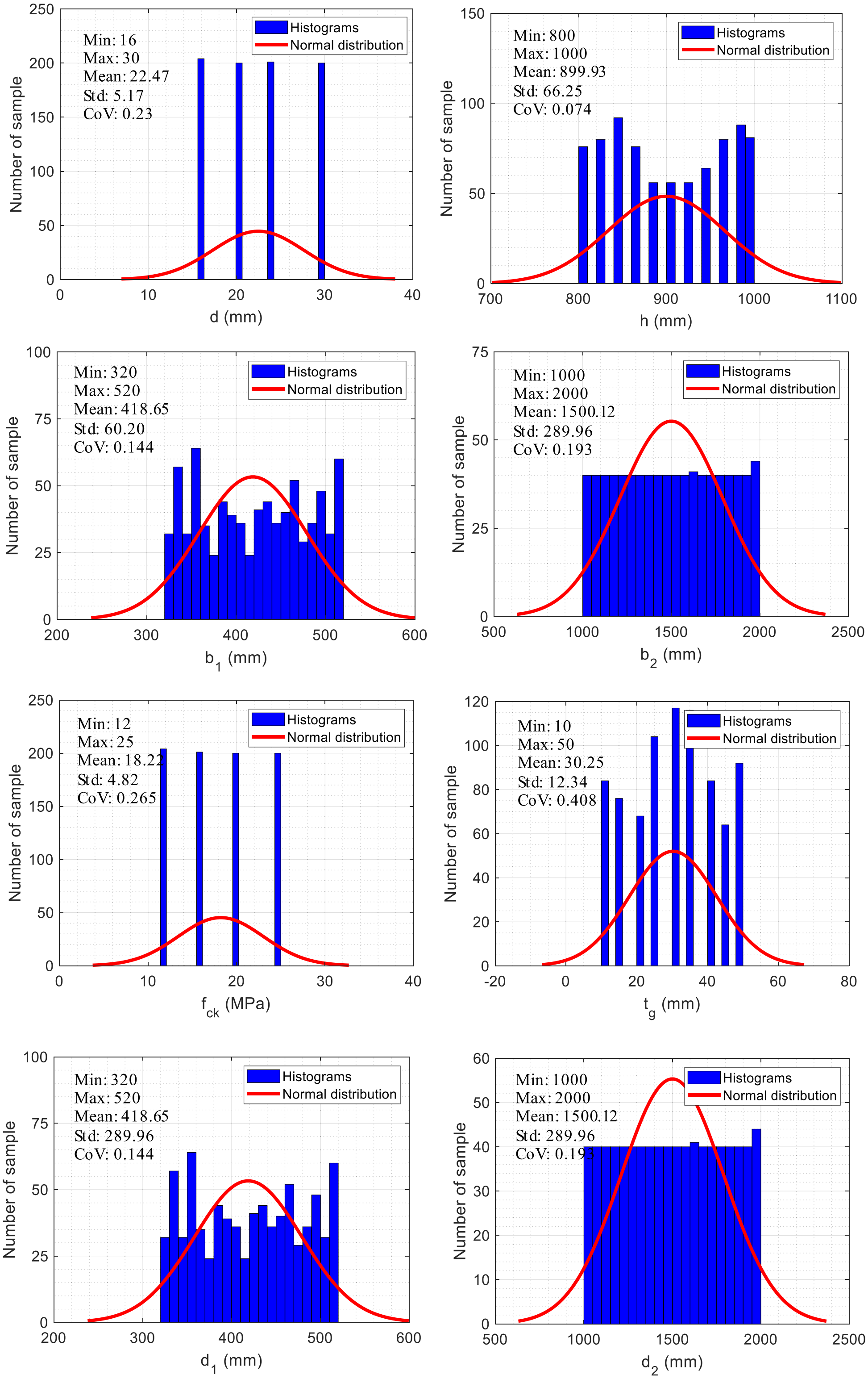

Fig. 7. Histogram of input and output parameters.

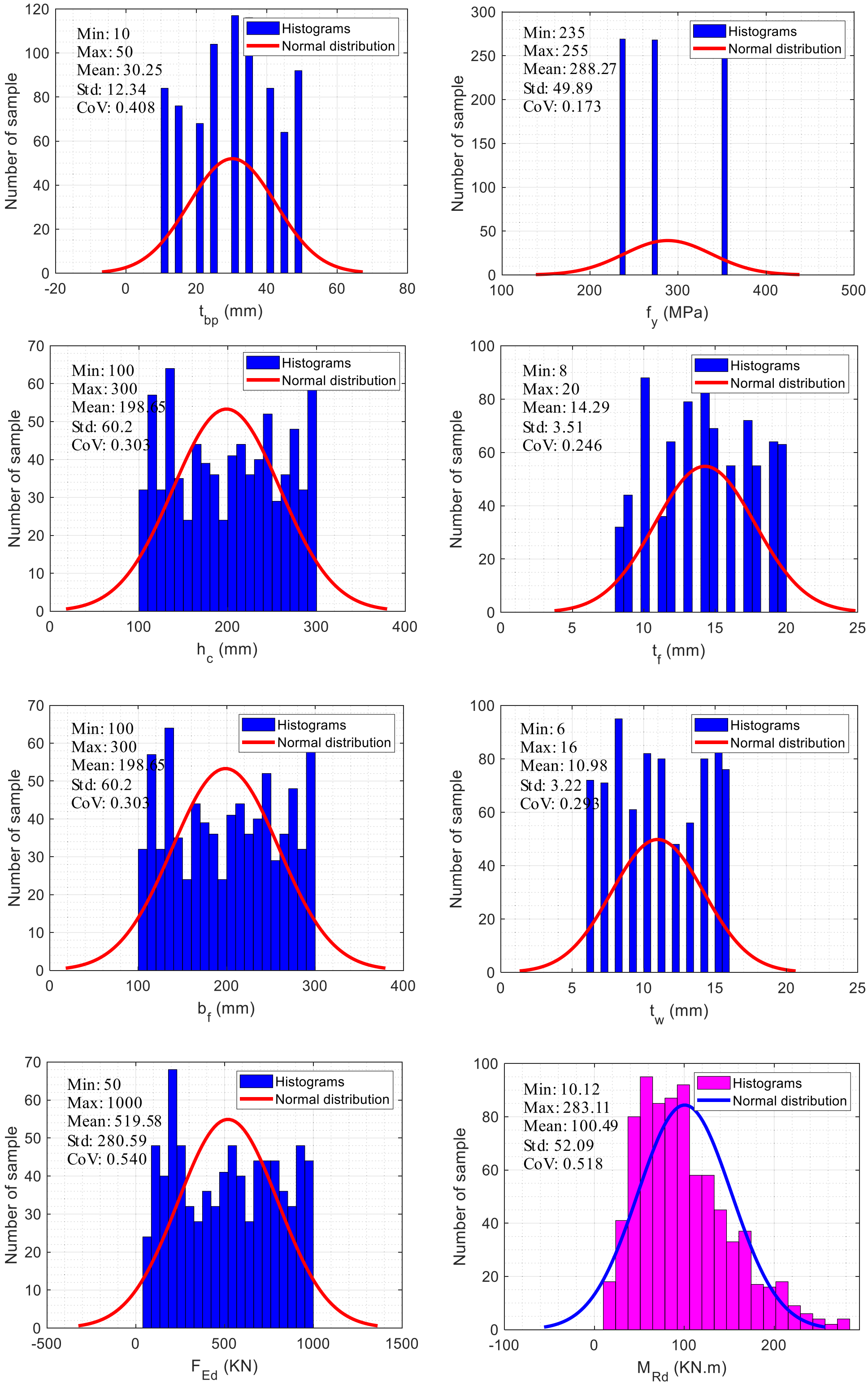

Fig. 7. (*continued*).

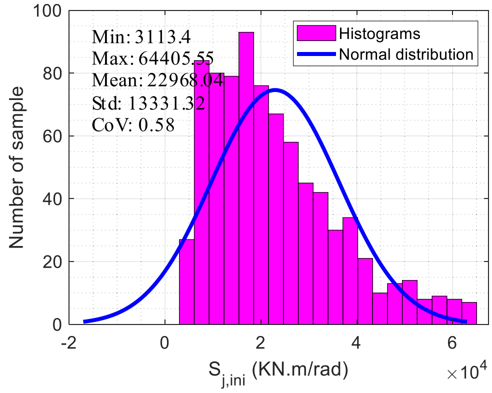

Fig. 7. (*continued*).

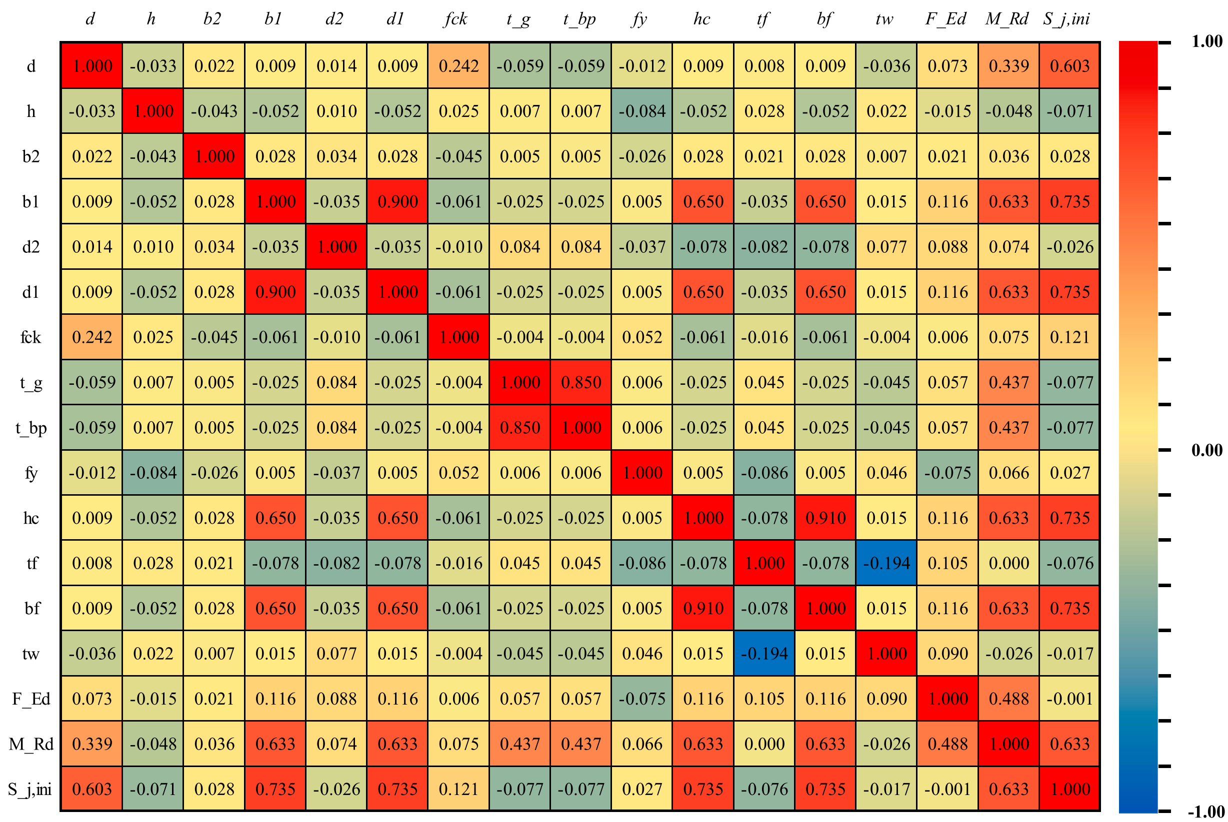

Fig. 8. Pearson correlation coefficients of input and output parameters.

squared error (*RMSE*), and $a20 - index$, as recommended by Zorlu et al. [41]. The best-performing GA-ANN model was identified by the highest R^2 and $a20 - index$, and the smallest *RMSE*. Its mathematical expressions are as follows.

$$R^2 = 1 - \left(\frac{\sum_{i=1}^{N} (t_i - o_i)^2}{\sum_{i=1}^{N} (t_i - \overline{o})^2} \right) \tag{6}$$

$$RMSE = \sqrt{\left(\frac{1}{n}\right) \sum_{i=1}^{n} (t_i - o_i)^2}; \tag{7}$$

$$a20 - index = \frac{n20}{n} \tag{8}$$

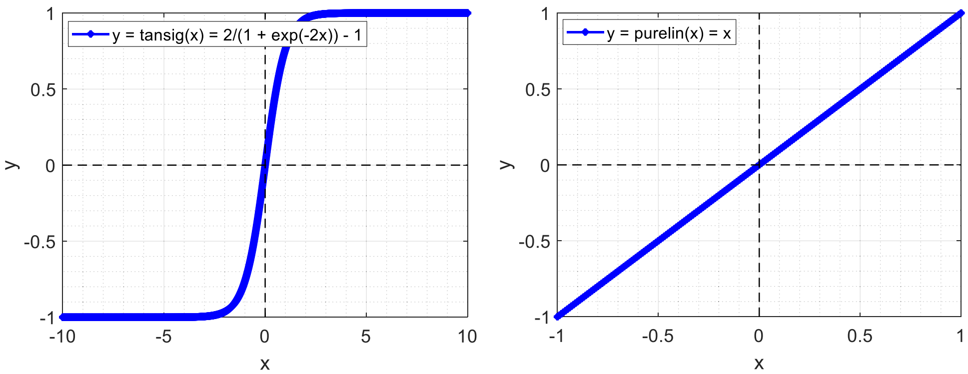

Fig. 9. Activation functions for LM-ANN: *tansig(x)* (left) và *purelin(x)* (right).

where t_i and o_i represent the target and output of i^{th} data point, respectively; $\overline{o}$ is the mean of output data samples; n is the number of samples; $n20$ is the number of samples with the ratio of the experimental value to the predicted value between 0.8 and 1.0.

4.4. Performance of GA-ANN model

To identify the best ANN model, we tested 120 different ANN structures using various training data ratios: 0.6, 0.65, 0.7, 0.75, 0.8, and 0.85. Half of the remaining data was allocated for testing and validation data. Additionally, we varied the number of neurons in the hidden layer from 1 to 20. The models were assessed using three statistical indicators: R^2, RMSE, and a20-index, as shown in Fig. 11. We chose the optimal model based on the highest R^2 and a20-index values and the lowest *RMSE*. The selected ANN model had training, testing, and validation data ratios of 0.7, 0.15, and 0.15, respectively, and included eight neurons in the hidden layer. It is important to note that this optimal ANN structure will be used to develop the hybrid GA-ANN model.

The GA-ANN model converged at epoch 35 with an MSE of 0.000809 approaching zero, as depicted in Fig. 12. Furthermore, performance results for the GA-ANN model relating to design resistance can be observed in Fig. 13 and Table 3. The R^2 values for training, testing, validation, and overall data were 0.9954, 0.9949, 0.9924, and 0.9948, respectively. The performance results for the GA-ANN model on bending stiffness are presented in Fig. 14 and Table 4. The R^2 values for training, testing, validation, and overall data were 0.9973, 0.9975, 0.9977, and 0.9974, respectively. Additionally, the a20-index values were almost up to 1.0. These metrics demonstrated a significant improvement in predicting the steel column base plate's design resistance and bending stiffness through the hybrid GA-ANN model.

A comparison of the performance between GA-ANN and traditional LM-ANN models is presented in Tables 3–4. The GA-ANN model showed superior performance to the LM-ANN model in terms of R^2, RMSE, and a20-index indicators. The standard deviation (SD) and coefficient of variation (CoV) of the actual/predicted ratio for the GA-ANN model were significantly lower than those of the LM-ANN model. These results highlighted the high effectiveness of the GA-ANN model in predicting the design resistance and bending stiffness of the steel column base plate.

4.5. Predictive formula for design resistance and bending stiffness of the steel column base plate

It is challenging to directly apply GA-ANN to calculate the design resistance and bending stiffness of the steel column base plate. Therefore, a simple and practical formula is needed to use GA-ANN. This study proposed formulas to determine the design resistance and bending stiffness of the steel column base plate based on GA-ANN training results. The expression to calculate the design resistance is shown in Eq. (9), and the expression to determine the bending stiffness is shown in Eq. (11).

$$M_{Rd} = 136.50\left(M_{Rd}^{N} + 1\right) + 10.12 \tag{9}$$

where the coefficient 136.50 is half the difference between the maximum and minimum values of M_{Rd}, and 10.12 is the minimum value of M_{Rd}. M_{Rd}^{N} is the normalized value of M_{Rd} and is determined according to Eq. (10).

$$M_{Rd}^{N} = h_{01} + \sum_{i=1}^{8} h_i H_i \tag{10}$$

where $H_i = \tanh\left(c_{i,01} + c_{i1}X_1 + c_{i2}X_2 + \ldots + c_{i15}X_{15}\right)$

$$S_{j,ini} = 30646.08\left(S_{j,ini}^{N} + 1\right) + 3113.40 \tag{11}$$

where the coefficient 30646.08 is half the difference between the maximum and minimum values of $S_{j,ini}$; and 3113.40 is the minimum

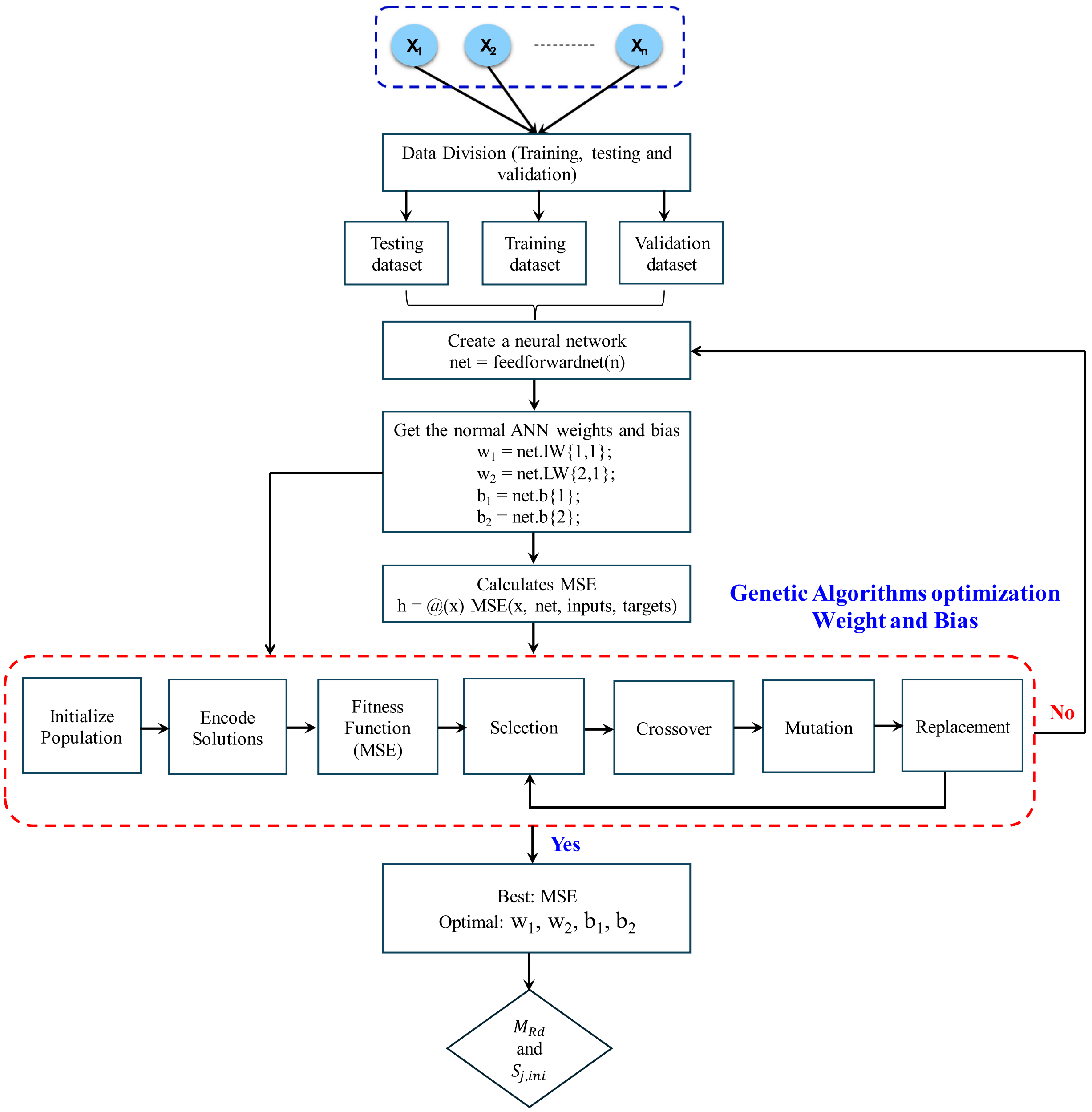

Fig. 10. Flowchart for predicting design resistance and bending stiffness using GA-ANN.

value of $S_{j,ini}$. $S^N_{j,ini}$ is the normalized value of $S_{j,ini}$ and is determined according to Eq. (12).

$$S^N_{j,ini} = h_{02} + \sum_{i=1}^{8} h_i H_i \tag{12}$$

where $H_i = \tanh(c_{i,02} + c_{i1}X_1 + c_{i2}X_2 + \ldots + c_{i15}X_{15})$

The coefficients h_i, h_{01}, h_{02} and $c_i, c_{i,01}, c_{i,02}$ are determined from the weights and biases obtained from the GA-ANN training process, as shown in Table 6.

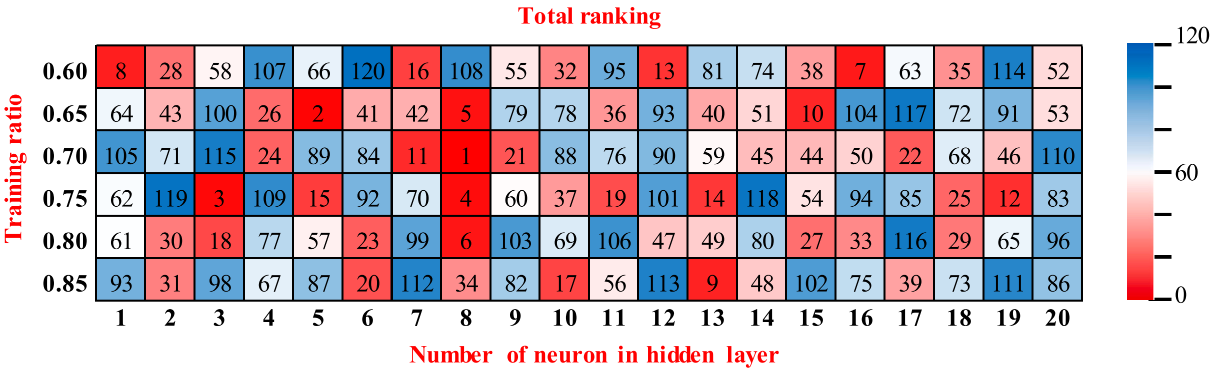

Fig. 11. Ranking matrix of 120 proposed ANN structures.

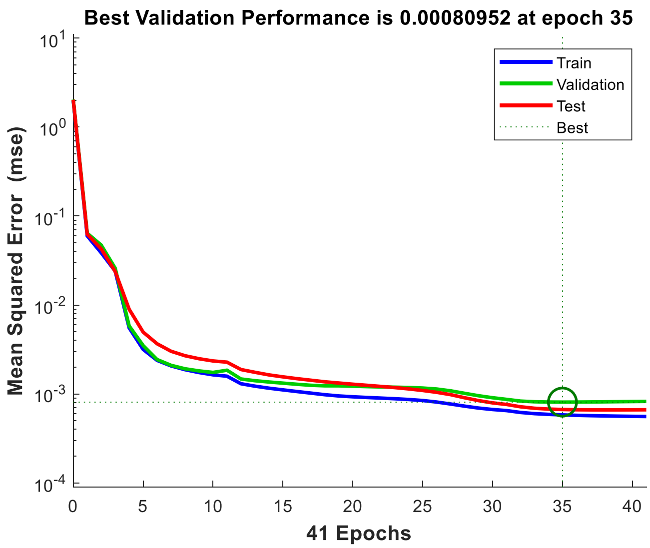

Fig. 12. Best validation performance of GA-ANN.

5. Proposing a prediction model based on the GA-ANN model and metal corrosion model

5.1. Atmospheric corrosion rate of carbon steel

In this study, we examined the corrosion of steel column base plates under three different environmental conditions: marine, urban, and rural areas. These areas correspond to high, medium, and low corrosion rates, respectively, as shown in Table 5. The atmospheric corrosion rate of carbon steel is described by the exponential law proposed by Komp [20], as shown in Eq. (13).

$$r(t) = \alpha_A \bullet t^{\alpha_B} \quad (\mu m) \tag{13}$$

where $r(t)$ represents the average corrosion rate, t is the corrosion time in years. α_A and α_B are coefficients determined based on local experimental data. The protective coating is expected to be effective for up to 20 years with zero corrosion. Fig. 15 shows the corrosion rate curves for three different environmental conditions.

5.2. Proposing a prediction model

In this section, we proposed a predictive model for estimating the remaining resistance and bending stiffness of the steel column base plate, considering atmospheric corrosion. The process was based on the GA-ANN training results and the previously discussed atmospheric corrosion model. The flowchart of the proposed model is presented in Fig. 16. It should be noted that the training results of GA-ANN were obtained in terms of the matrix of weights and biases. When combining the corrosion model and GA-ANN, we used the corrosion model to calculate the loss of the base plate and the anchor bolt diameter, then updated the input parameters after considering corrosion. Finally, the predicted outputs were achieved using the general analytical expression, which contained the

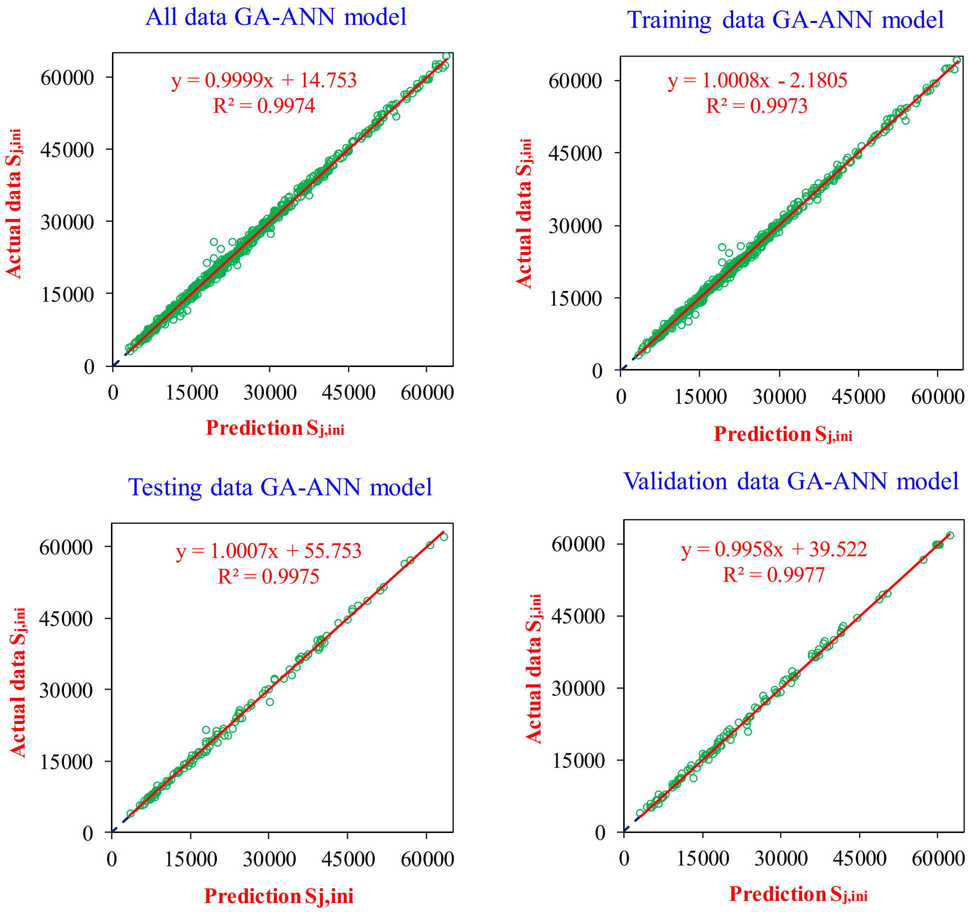

Fig. 13. Regression performance of $S_{j,ini}$ using GA-ANN model.

Table 3
Statistical properties of $S_{j,ini}$ using GA-ANN model.

GA-ANN model								
	R^2	a−20 index	RMSE	Actual /predict				
				Min	Max	Mean	SD	CoV
Training	0.9973	0.9929	682.3945	0.7534	1.2606	1.0004	0.0388	0.0387
Testing	0.9975	1.0000	709.9279	0.8388	1.1024	0.9971	0.0389	0.0391
Validation	0.9977	0.9917	675.6994	0.8463	1.2161	1.0031	0.0459	0.0457
All data	0.9974	0.9938	685.6076	0.7534	1.2606	1.0003	0.0400	0.0400
LM-ANN model								
Training	0.9023	0.7300	720.0	0.900	1.300	0.980	0.050	0.051
Testing	0.9215	0.7850	730.0	0.950	1.250	0.985	0.045	0.046
Validation	0.9158	0.7780	710.0	0.980	1.220	0.975	0.048	0.049
All data	0.9883	0.7820	715.0	0.920	1.280	0.980	0.047	0.048

optimal weights and biases.

5.3. Graphical user interface

For practical applications, a user-friendly graphical interface program (GUI) was developed using MATLAB, as illustrated in Fig. 17. This tool is simple to predict the remaining design resistance and bending stiffness of the steel column base plate. Users need to provide 15 input parameters (Table 2), including geometric parameters, base plate properties, column cross-section, anchor bolts, concrete foundation, different corrosion environments, and corrosion time to obtain the results. The tool is freely accessible and easy to use. After providing all the input variables, users click the "Start Predict" button to get the result. It should be noted that the values in square brackets are the lower and up limits, respectively. The GUI tool is developed based on the proposed GA-ANN model, ensuring the

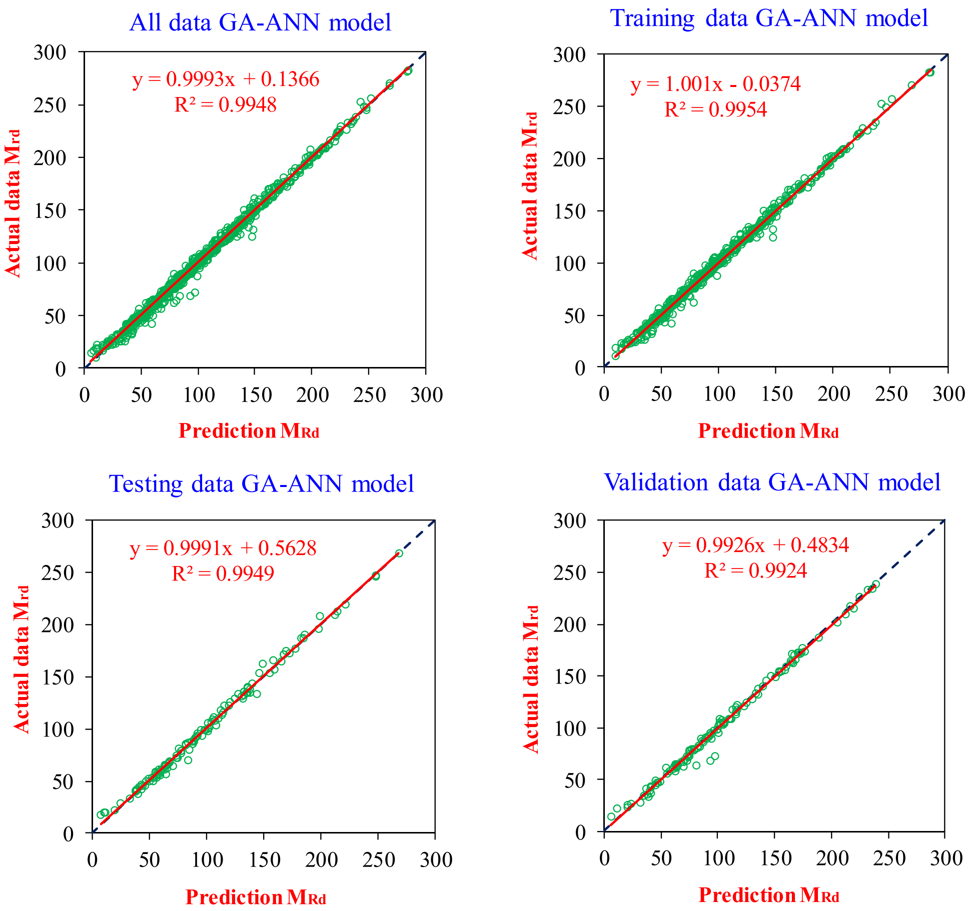

Fig. 14. Regression performance of M_{Rd} using GA-ANN model.

Table 4
Statistical properties of M_{Rd} using GA-ANN model.

GA-ANN model								
	R^2	a−20 index	RMSE	Actual /predict				
				Min	Max	Mean	SD	CoV
Training	0.9954	0.9769	3.5248	0.6104	1.4041	1.0015	0.0601	0.0601
Testing	0.9949	0.9669	3.8616	0.4469	1.2237	0.9872	0.0868	0.0879
Validation	0.9924	0.9587	4.5942	0.4099	1.3603	0.9969	0.0966	0.0969
All data	0.9948	0.9727	3.7554	0.4099	1.4041	0.9987	0.0714	0.0715
LM-ANN model								
Training	0.9438	0.8600	4.0000	1.550	2.500	0.990	0.070	0.070
Testing	0.9398	0.8500	4.2000	1.500	2.450	0.980	0.075	0.076
Validation	0.9507	0.8450	4.5000	1.480	2.470	0.985	0.080	0.081
All data	0.9486	0.8550	4.1000	1.520	2.480	0.988	0.072	0.073

Table 5
α_A and α_B coefficients for different environmental conditions.

Environment					
Rural		Urban		Marine	
α_A = 34.0	α_B = 0.64	α_A = 80.2	α_B = 0.59	α_A = 70.6	α_B = 0.79

Table 6
The coefficients of predictive formulas based on GA-ANN.

	h_i	$c_{i,01}$	$c_{i,02}$	c_{i1}	c_{i2}	c_{i3}	c_{i4}	c_{i5}	c_{i6}	c_{i7}	c_{i8}	c_{i9}	c_{i10}	c_{i11}	c_{i12}	c_{i13}	c_{i14}	c_{i15}
01	0.716																	
02	3.211																	
1	−1.588	−1.443	−0.926	0.159	−0.005	−0.103	−0.292	−0.124	−0.047	−0.258	0.115	−0.508	0.017	0.594	0.012	−0.246	0.008	0.587
2	−0.788	−8.879	−0.257	0.065	0.001	−0.010	0.099	−0.012	0.398	−0.024	−0.264	0.423	0.052	0.023	−0.007	−0.047	−0.007	−0.114
3	−1.166	1.367	2.620	0.246	−0.001	0.004	−0.239	0.012	0.595	0.026	−0.334	0.294	−0.006	−0.397	−0.007	0.442	−0.005	−0.239
4	4.192	−0.097	0.523	0.396	−0.002	−0.055	−0.675	−0.041	0.646	−0.045	1.445	1.689	0.034	−0.614	0.010	0.109	−0.007	0.160
5	−1.163	0.094	3.460	0.315	−0.005	−0.018	−0.216	−0.036	0.491	−0.063	−0.327	0.168	0.008	−0.032	0.007	−0.163	0.007	0.212
6	−0.770	11.171	0.530	0.066	0.001	−0.011	0.521	−0.014	0.616	−0.028	0.131	0.020	0.048	−0.579	−0.005	−0.159	−0.005	−0.010
7	−0.801	−0.003	−0.438	0.980	−0.018	−0.027	−0.298	−0.067	0.622	−0.076	−0.483	0.129	0.004	−0.597	0.030	−0.067	0.021	0.198
8	7.028	0.365	−0.054	−0.430	−0.006	−0.039	−0.626	−0.102	0.333	−0.135	3.268	2.523	0.171	−0.519	0.038	0.324	0.032	0.369

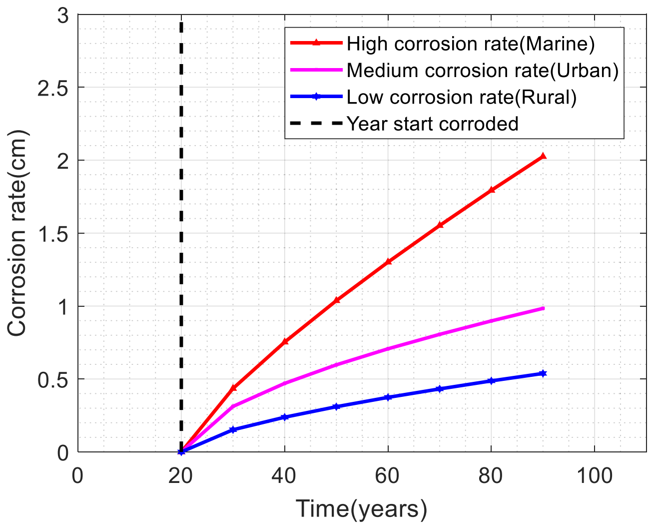

Fig. 15. The corrosion rate in different environment.

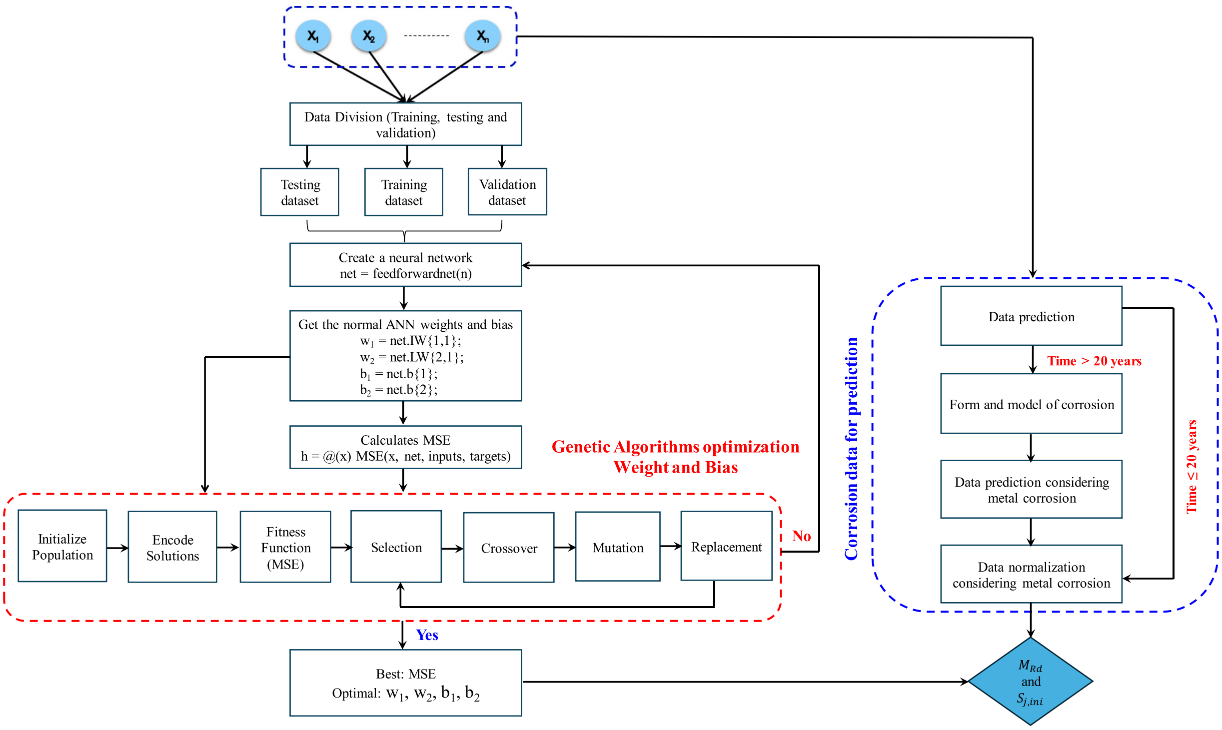

Fig. 16. Flowchart for design resistance and bending stiffness of corroded column base plate using GA-ANN.

accuracy of the predictions as demonstrated in the previous section. It can be freely downloaded at the link: https://github.com/duankxd/GUI_CorrodedBasePlate.

5.4. Evaluation of structural capacity after 100 years

The steel column base plate, shown in Fig. 6, is considered in the evaluation. Geometric parameters, base plate structure properties, column cross-section, anchor bolts, and concrete foundation are detailed in Table 1. The research aimed to assess the remaining design resistance and bending stiffness of the steel column base plate due to metal corrosion after 100 years. It is assumed that corrosion begins in the 20th year when the protective layer becomes ineffective. The results obtained after 100 years regarding the design resistance and bending stiffness of the steel column base plate in three different environmental conditions (marine, urban, and rural

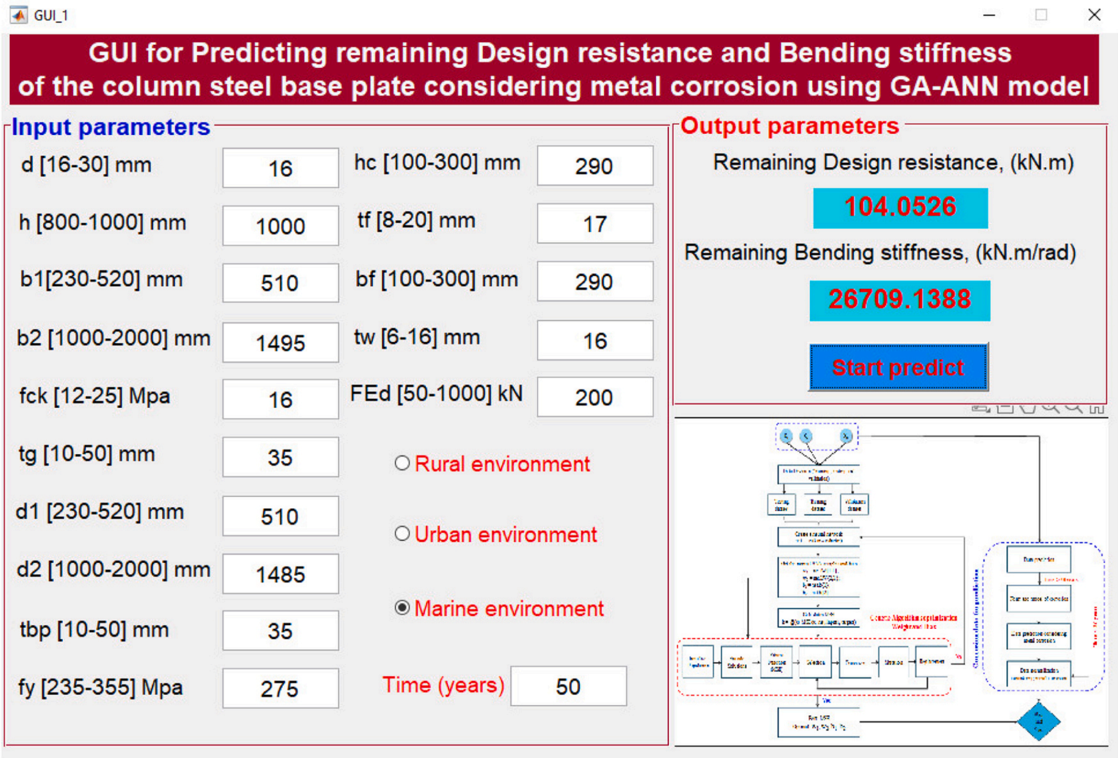

Fig. 17. Graphical interface program.

areas) are presented in Fig. 18.

It was observed that the remaining capacity of the design resistance and bending stiffness of the steel column base plate decreased slightly in rural and urban environments, particularly after 100 years; the remaining values of M_{Rd} and $S_{j,ini}$ were 86.98% and 94.59% compared to the pristine. Meanwhile, after 100 years, the M_{Rd} and $S_{j,ini}$ were reduce to 64.77% and 58.93%, respectively, for the structure in the marine environment. These findings emphasized that when designing steel structures in marine environments, special attention must be given to the issue of corrosion in the atmospheric environment.

Once again, the results of this study confirm that the GA-ANN model is a powerful and effective tool for predicting the remaining design resistance and bending stiffness of steel column base plates considering metal corrosion. The model not only enhances the accuracy of technical forecasts but also provides practical support tools for the maintenance and design of steel structures, especially in corrosive environments, therefore improving structural durability and safety.

6. Conclusions

This study developed a hybrid Genetic Algorithm (GA) and Artificial Neural Network (ANN) model to predict the remaining design resistance and bending stiffness of corroded steel column base plates. A set of 808 data observations were generated using a code-based procedure for training machine learning models. The performance results of the GA-ANN model were compared with those of the traditional LM-ANN model. The following conclusions are achieved:

- A calculation program implemented in MATLAB is proposed to determine the remaining design resistance and bending stiffness of corroded steel column base plates, ensuring high feasibility and accuracy.
- A hybrid procedure using the hybrid GA-ANN model incorporating with a corrosion model is proposed to predict the remaining design resistance and bending stiffness of corroded steel column base plates.
- The GA-ANN model is superior to LM-ANN in predicting the structural capacity of corroded steel column base plates in terms of statistical indicators, including the coefficient of determination (R^2), root mean square error (RMSE), and a20-index.
- An analytical formula based on GA-ANN is developed to calculate the remaining design resistance and bending stiffness of steel column base plates.
- A user-friendly graphical user interface (GUI) is established to assist engineers in freely applying the machine learning model for practical design projects.

It should be noted that random corrosion is not considered in this study. A future study should be conducted to investigate the

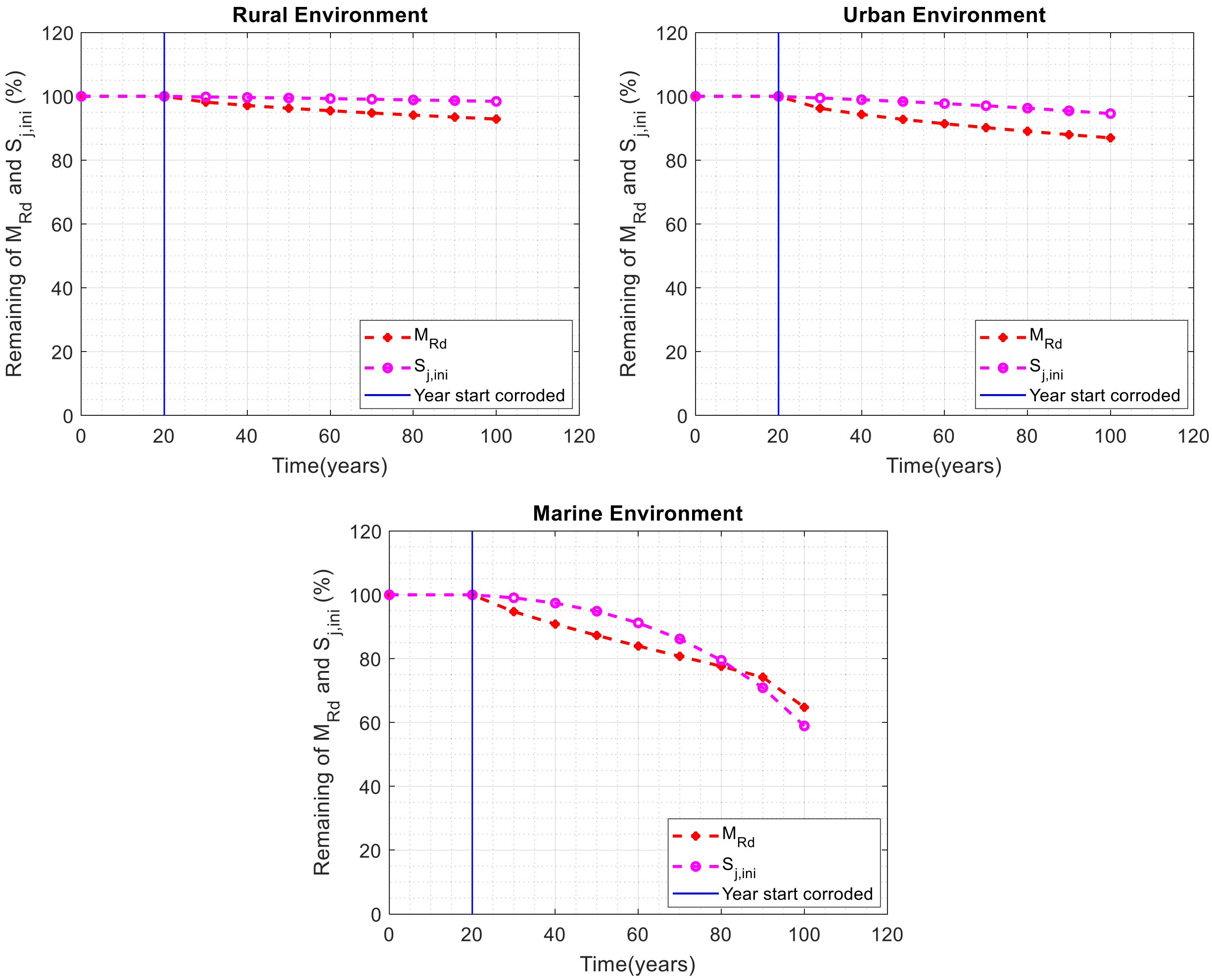

Fig. 18. Remaining design resistance and bending stiffness of the steel column base plate in different environment after 100 years.

natural corrosion phenomenon of steel structures.

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CRediT authorship contribution statement

Duy-Duan Nguyen: Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis. **Ngoc-Giang Tran:** Visualization, Validation. **Viet-Chuong Ho:** Visualization, Validation. **Trong-Ha Nguyen:** Writing – review & editing, Writing – original draft, Software, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix 1. Procedure for design resistance and bending stiffness

Length of effective T stub:

$$l_{eff,1} = \min\begin{cases} 4m + 1.25e_a \\ 4\pi m \\ 0.5b_1 \\ 2m + 0.625e_b + 0.5p \\ 2m + 0.625e_b + e_a \\ 2\pi m + 4e_b \\ 2\pi m + 2p \end{cases} \tag{14}$$

where $m = e_c - 0.8a_w\sqrt{2}$

Design strength $F_{T,i,Rd}$ according to modes 3, modes 1–2 according to the following expressions:

$$\text{For mode3}: \quad F_{T,3,Rd} = \sum F_{t,Rd} = \sum \frac{0.9 \bullet f_{ub} \bullet A_s}{\gamma_{mb}} \tag{15}$$

$$\text{For mode1} - 2: \quad F_{T,1-2,Rd} = \sum F_{t,Rd} = \sum \frac{0.9 \bullet f_{ub} \bullet A_s}{\gamma_{mb}} \tag{16}$$

$$F_{Rd} = \min\left(F_{T,3,Rd}; F_{T,1-2,Rd}\right) \tag{17}$$

Concrete crushing resistance f_{jd}:

$$f_{jd} = \beta_j \bullet f_{cd}\sqrt{\frac{A_{c1}}{A_{c0}}} = \beta_j \bullet \frac{f_{ck}}{\gamma_c}\sqrt{\frac{b_2 d_2}{b_1 d_1}} \leq 3.0 \bullet f_{cd} \tag{18}$$

Force equilibrium F_{Ed}:

$$F_{Ed} = A_{eff} \bullet f_{jd} - \min\left(F_{T,1-2,Rd}; F_{T,3,Rd}\right) \tag{19}$$

where $A_{eff} = \frac{F_{Ed} + \min\left(F_{T,1-2,Rd}; F_{T,3,Rd}\right)}{F_{jd}}$

Effective width of base plate c:

$$c = t_{bp}\sqrt{\frac{f_{yd}}{3f_{jd}\gamma_{M0}}} \tag{20}$$

The effective width of the area in contact:

$$b_{eff} = \frac{A_{eff}}{b_f + 2c} \tag{21}$$

Lever arm r_c:

$$r_c = \frac{h_c}{2} + c - \frac{b_{eff}}{2} \tag{22}$$

Bending resistance for normal force:

$$M_{Rd} = \min\left(F_{T,1-2,Rd}; F_{T,3,Rd}\right) \bullet r_b + A_{eff} \bullet f_{jd} \bullet r_c \tag{23}$$

Stiffness coefficient:

$$\text{For anchor bolt}: \quad k_b = 2.0 \bullet A_s / L_b \tag{24}$$

$$\text{For base plate}: \quad k_p = 0.425 \bullet l_{eff \bullet} t^3 / m^3 \tag{25}$$

The concrete block stiffness can be evaluated based on T-stub in compression:

$$a_{eq} = t_f + 2.5 \bullet t_p \tag{26}$$

$$\text{Stiffness coefficient}: \quad k_c = \frac{E_c}{1.275 \bullet E_s}\sqrt{a_{eq} \bullet b_c} \tag{27}$$

Lever arm in tension z_t and in compression z_c to column neutral axis:

$$r_t = \frac{h_c}{2} + e_c \tag{28}$$

$$r_c = \frac{h_c}{2} - \frac{t_f}{2} \tag{29}$$

The stiffness of tension part, bolts and T stub, can be calculated:

$$k_t = \frac{1}{\frac{1}{k_b} + \frac{1}{k_p}} \tag{30}$$

For the calculation of the initial stiffness of column base is evaluated the lever arm *r*:

Lever arm : $r = r_t + r_t$

$$a = \frac{k_c r_c + k_t r_t}{k_c + k_t} \tag{31}$$

The bending stiffness is calculated for particular constant eccentricity:

$$e = \frac{M_{Rd}}{F_{Rd}} \tag{32}$$

Bending stiffness:

$$S_{j,ini} = \frac{e}{e + a} \frac{E_s \bullet r^2}{\mu \sum \frac{1}{k_i}} \tag{33}$$

Appendix 2. Detailed information of the database

d	h	b_2	b_1	d_2	d_1	f_{ck}	t_g	t_{bp}	f_y	h	t_f	b_f	t_w	F_{Ed}	M_{Rd}	$S_{j,ini}$
(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(MPa)	(mm)	(mm)	(MPa)	(mm)	(mm)	(mm)	(mm)	(kN)	(kN.m)	(kN.m/rad)
24	1000	1600	420	1600	420	16	30	30	235	200	15	200	9	500	103.91	20844.91
16	800	1510	355	1720	355	12	40	40	235	135	15	135	7	680	73.63	6964.68
20	1000	1395	510	1485	510	16	35	35	275	290	17	290	16	290	107.84	35281.93
24	880	1315	465	1820	465	20	25	25	355	245	14	245	15	260	100.20	36953.45
30	800	1610	480	1560	480	25	20	20	235	260	15	260	6	690	170.25	50510.48
16	980	1635	435	1055	435	12	50	50	275	215	11	215	9	290	88.42	14826.39
20	860	1690	335	1755	335	16	20	20	355	115	11	115	15	160	35.73	10009.24
24	960	1625	410	1515	410	20	15	15	235	190	14	190	16	770	83.91	21442.43
30	860	1925	485	1195	485	25	25	25	275	265	14	265	6	740	190.26	50917.60
16	800	1940	435	1230	435	12	40	40	355	215	13	215	16	730	140.10	14247.56
20	860	1685	420	1390	420	16	30	30	235	200	13	200	13	460	87.79	18904.66
24	960	1935	390	1860	390	20	30	30	275	170	16	170	12	460	90.70	19223.95
30	900	1575	490	1280	490	25	30	30	355	270	19	270	11	100	125.79	60428.80
16	820	1700	420	1745	420	12	45	45	235	200	15	200	11	520	102.05	12488.91
20	800	1065	335	1395	335	16	50	50	275	115	20	115	11	980	104.66	7288.02
24	820	1390	405	1995	405	20	50	50	355	185	13	185	6	50	68.39	23492.15
30	840	1620	425	1565	425	25	35	35	235	205	11	205	13	110	101.18	37895.19
16	920	1475	380	1475	380	12	40	40	275	160	18	160	6	150	45.44	10492.57
20	920	1340	515	1025	515	16	45	45	355	295	13	295	14	800	226.57	31691.45
24	940	1880	325	1170	325	20	35	35	235	105	20	105	12	970	56.19	8662.47
30	1000	1165	440	1255	440	25	15	15	275	220	17	220	10	440	116.67	40860.36
16	860	1145	410	1655	410	12	10	10	355	190	19	190	6	480	43.93	7323.00
20	840	1605	330	1865	330	16	30	30	235	110	13	110	10	680	49.74	7722.53
24	900	1030	335	1905	335	20	15	15	275	115	14	115	10	240	40.94	12250.01
30	900	1275	460	1095	460	25	25	25	355	240	13	240	14	800	177.79	43101.79
16	940	1040	320	1915	320	12	10	10	235	100	14	100	10	160	14.24	3725.98
20	860	1035	350	1350	350	16	25	25	275	130	20	130	12	200	43.33	11148.53
24	840	1705	405	1610	405	20	40	40	355	185	10	185	10	180	82.17	23192.65
30	960	1665	485	1315	485	25	10	10	235	265	19	265	6	820	124.59	50516.33
16	880	1795	350	1555	350	12	40	40	275	130	15	130	11	240	48.26	7613.11
20	880	1290	400	1615	400	16	30	30	355	180	13	180	14	620	99.20	15860.89
24	800	1505	515	1460	515	20	20	20	235	295	9	295	12	210	101.42	52258.96
30	820	1670	375	1065	375	25	30	30	275	155	12	155	8	870	113.79	21578.47
16	980	1150	370	1430	370	12	30	30	355	150	8	150	16	850	73.79	8046.15
20	960	1010	390	1845	390	16	35	35	235	170	17	170	16	540	86.15	14099.56
24	840	1770	520	1680	520	20	40	40	275	300	13	300	14	950	238.93	41248.48
30	920	1895	495	1825	495	25	40	40	355	275	10	275	9	320	171.65	56633.99
16	980	1025	385	1540	385	12	25	25	235	165	17	165	11	380	51.57	10405.78
20	1000	1090	455	1980	455	16	15	15	275	235	17	235	8	530	87.56	23230.49
24	920	1910	435	1635	435	20	25	25	355	215	13	215	8	710	130.92	26872.22
30	800	1420	370	1525	370	25	10	10	235	150	9	150	14	180	41.99	23804.71

(continued on next page)

(*continued*)

d	h	b_2	b_1	d_2	d_1	f_{ck}	t_g	t_{bp}	f_y	h	t_f	b_f	t_w	F_{Ed}	M_{Rd}	$S_{j,ini}$
16	940	1980	515	1470	515	12	40	40	275	295	18	295	9	740	172.87	22720.67
20	980	1370	435	1585	435	16	45	45	355	215	11	215	9	130	71.23	22829.66
24	820	1055	330	1570	330	20	35	35	235	110	16	110	7	780	62.53	9630.78
30	1000	1310	400	1260	400	25	20	20	275	180	10	180	8	310	96.24	30570.66
16	940	1565	430	1080	430	12	30	30	355	210	11	210	15	130	49.09	17401.46
20	880	1500	330	1410	330	16	20	20	235	110	14	110	14	190	32.81	9199.56
24	960	1745	455	1155	455	20	35	35	275	235	9	235	15	760	159.03	29347.62
30	900	1945	380	1605	380	25	10	10	355	160	12	160	9	930	73.29	25926.56
16	980	1180	500	1245	500	12	20	20	235	280	17	280	11	100	47.24	28222.11
20	840	1400	330	1490	330	16	50	50	275	110	13	110	7	320	66.15	7885.80
24	900	1785	465	1990	465	20	25	25	355	245	9	245	16	980	172.63	31729.89
30	800	1955	365	1705	365	25	35	35	235	145	18	145	11	880	118.00	19064.16
16	920	1445	500	1020	500	12	25	25	275	280	10	280	8	740	122.84	21405.41
20	840	1000	390	1030	390	16	30	30	355	170	10	170	14	480	85.12	15220.39
24	940	1725	440	1185	440	20	45	45	235	220	13	220	9	570	143.08	26057.99
30	840	1140	485	1045	485	25	25	25	275	265	13	265	11	230	134.89	57159.85
16	840	1215	360	1700	360	12	40	40	355	140	15	140	10	990	104.58	7191.14
20	800	1455	450	1375	450	16	10	10	235	230	12	230	15	230	47.70	20093.41
24	860	1930	390	1815	390	20	10	10	275	170	16	170	9	50	32.22	20764.30
30	980	1200	455	2000	455	25	50	50	355	235	8	235	16	770	233.96	39238.46
16	900	1810	520	1840	520	12	35	35	235	300	13	300	16	410	111.43	25610.65
20	820	1715	365	1985	365	16	35	35	275	145	20	145	10	610	82.03	11121.47
24	980	1410	500	1900	500	20	20	20	355	280	14	280	6	700	158.68	41480.39
30	840	1210	505	1310	505	25	10	10	235	285	12	285	13	870	133.36	56516.49
16	940	1220	490	1500	490	12	45	45	275	270	16	270	8	850	186.62	19035.20
20	840	1675	515	1250	515	16	10	10	355	295	17	295	9	720	118.51	25821.77
24	860	1535	425	1930	425	20	15	15	235	205	8	205	6	580	92.39	25869.65
30	840	1115	330	1710	330	25	25	25	275	110	13	110	7	600	66.35	14684.06
16	820	1135	450	1645	450	12	20	20	355	230	10	230	13	350	70.18	17927.90
20	1000	1585	385	1675	385	16	35	35	235	165	14	165	7	270	63.85	14773.15
24	1000	1865	475	1880	475	20	25	25	275	255	9	255	11	860	163.25	34125.02
30	840	1255	475	1810	475	25	20	20	355	255	13	255	11	670	172.36	49614.01
16	980	1860	495	1040	495	12	15	15	235	275	14	275	14	730	91.53	17811.33
20	900	1540	325	1295	325	16	30	30	275	105	17	105	8	210	40.57	8297.90
24	940	1580	510	1180	510	20	25	25	355	290	20	290	16	980	200.20	40675.77
30	980	1125	520	1400	520	25	10	10	235	300	13	300	8	600	124.75	64306.70
16	820	1485	495	1890	495	12	40	40	275	275	10	275	15	200	75.31	23803.17
20	860	1495	395	1835	395	16	30	30	355	175	16	175	11	480	87.15	15638.63
24	840	1320	515	1590	515	20	20	20	235	295	19	295	12	660	153.31	44550.13
30	1000	1650	335	1650	335	25	30	30	275	115	20	115	16	980	80.00	14356.01
16	820	1855	495	1920	495	12	50	50	355	275	9	275	8	110	63.73	23954.07
20	800	1820	355	1945	355	16	35	35	235	135	15	135	6	210	49.56	11325.45
24	860	1095	455	1190	455	20	30	30	275	235	14	235	7	130	82.14	35855.16
30	820	1380	345	1465	345	25	25	25	355	125	16	125	7	680	85.21	16965.53
16	920	1775	420	1365	420	12	50	50	235	200	20	200	8	660	126.12	11771.97
20	1000	1825	360	1440	360	16	35	35	275	140	12	140	16	640	80.08	10731.03
24	820	1175	405	1085	405	20	50	50	355	185	10	185	16	730	170.43	19861.10
30	940	1595	515	1070	515	25	50	50	235	295	19	295	6	910	282.16	53525.02
16	800	1480	345	1910	345	12	30	30	275	125	15	125	14	930	47.37	5543.24
20	920	1270	480	1805	480	16	15	15	355	260	15	260	15	90	56.63	34358.59
24	800	1985	385	1780	385	20	25	25	235	165	17	165	16	790	92.05	17304.32
30	920	1885	350	1625	350	25	35	35	275	130	10	130	7	110	73.85	18788.74
16	1000	1415	490	1275	490	12	30	30	355	270	14	270	11	260	82.05	23870.42
20	960	1520	520	1220	520	16	50	50	235	300	19	300	8	500	164.12	32259.19
24	820	1545	400	1050	400	20	30	30	275	180	19	180	13	410	91.26	20999.31
30	880	1695	325	1665	325	25	45	45	355	105	18	105	15	720	113.09	12396.40
16	940	1845	340	1205	340	12	30	30	235	120	14	120	16	540	45.25	6301.26
20	960	1405	430	1300	430	16	40	40	275	210	15	210	15	370	98.55	20136.59
24	960	1780	330	1965	330	20	35	35	355	110	13	110	15	60	44.75	11476.52
30	900	1260	330	1335	330	25	10	10	235	110	18	110	7	400	29.33	17373.18
16	900	1850	440	1345	440	12	25	25	275	220	10	220	12	380	72.95	16542.02
20	1000	1530	385	1215	385	16	50	50	355	165	15	165	6	270	85.68	13932.01
24	960	1345	350	1075	350	20	35	35	235	130	15	130	12	140	54.92	13995.47
30	960	1300	440	1685	440	25	25	25	275	220	8	220	6	920	164.29	37031.83
16	940	1790	465	1105	465	12	35	35	355	245	18	245	9	910	160.18	16926.16
20	1000	1630	470	1285	470	16	30	30	235	250	14	250	10	500	112.75	26431.52
24	900	1045	320	1145	320	20	10	10	275	100	14	100	6	200	22.07	9695.53
30	920	1730	410	1385	410	25	30	30	355	190	19	190	9	160	102.29	32832.71
16	840	1590	440	1660	440	12	10	10	235	220	19	220	14	960	41.53	5719.51
20	800	1740	340	1140	340	16	45	45	275	120	12	120	12	560	82.26	8626.25

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d	h	b_2	b_1	d_2	d_1	f_{ck}	t_g	t_{bp}	f_y	h	t_f	b_f	t_w	F_{Ed}	M_{Rd}	$S_{j,ini}$
24	860	1560	420	1290	420	20	15	15	355	200	9	200	9	50	56.03	29885.31
30	880	1915	390	1015	390	25	50	50	235	170	16	170	6	950	172.33	22554.25
16	980	1430	365	1875	365	12	50	50	275	145	18	145	7	970	122.11	7156.94
20	820	1130	460	1855	460	16	15	15	355	240	19	240	7	210	66.71	27518.85
24	860	1905	355	1210	355	20	40	40	235	135	20	135	11	580	88.00	12762.74
30	880	1070	350	1785	350	25	30	30	275	130	15	130	8	480	88.64	17790.03
16	860	1350	430	1125	430	12	20	20	355	210	9	210	8	260	56.41	16267.21
20	880	1280	330	1355	330	16	25	25	235	110	18	110	10	620	35.80	7614.04
24	820	1680	415	1200	415	20	40	40	275	195	12	195	7	140	77.61	25398.97
30	960	1170	465	1405	465	25	30	30	355	245	8	245	15	150	124.33	51343.78
16	800	1815	465	1225	465	12	25	25	235	245	15	245	8	740	103.39	16905.71
20	1000	1110	455	1695	455	16	35	35	275	235	14	235	8	540	121.87	23459.34
24	980	1335	485	1370	485	20	45	45	355	265	10	265	15	460	165.58	36756.89
30	880	1265	430	1480	430	25	10	10	235	210	8	210	15	340	68.80	38659.74
16	860	1375	350	1600	350	12	45	45	275	130	17	130	7	280	57.13	7284.42
20	980	1425	435	1545	435	16	10	10	355	215	18	215	14	360	64.53	17562.35
24	840	1515	320	1505	320	20	50	50	235	100	18	100	8	200	58.06	8893.42
30	1000	1360	395	1520	395	25	30	30	275	175	20	175	10	300	105.01	27773.08
16	960	1230	345	1120	345	12	10	10	355	125	15	125	6	210	22.33	4944.93
20	880	1995	465	1870	465	16	35	35	235	245	10	245	6	780	147.19	23737.78
24	980	1075	415	1445	415	20	35	35	275	195	10	195	13	240	87.18	25049.11
30	880	1245	365	1000	365	25	15	15	355	145	17	145	7	230	71.01	22189.69
16	940	1890	500	1330	500	12	40	40	235	280	13	280	16	550	132.96	21585.85
20	820	1660	350	1270	350	16	15	15	275	130	11	130	15	770	23.33	7499.69
24	860	1250	450	1740	450	20	40	40	355	230	17	230	15	950	197.34	27115.78
30	1000	1205	465	1425	465	25	35	35	235	245	14	245	11	270	138.70	47722.87
16	820	1080	445	1510	445	12	50	50	275	225	20	225	7	680	152.55	14339.65
20	800	1460	500	1115	500	16	45	45	355	280	20	280	8	720	202.54	29058.44
24	920	1555	475	1940	475	20	35	35	235	255	16	255	11	240	103.66	37600.32
30	860	1050	435	1005	435	25	25	25	275	215	14	215	14	540	134.21	37507.67
16	940	1465	390	1320	390	12	50	50	355	170	12	170	13	100	47.78	11449.06
20	980	1020	510	1135	510	16	50	50	235	290	9	290	12	960	231.90	28664.09
24	880	1750	505	1950	505	20	10	10	275	285	19	285	16	810	130.18	36731.12
30	800	1615	440	1175	440	25	25	25	355	220	14	220	8	310	126.62	41155.14
16	980	1440	475	1235	475	12	20	20	235	255	10	255	10	540	85.70	18997.81
20	840	1235	390	1160	390	16	30	30	275	170	18	170	8	1000	84.18	12201.51
24	960	1385	405	1925	405	20	50	50	355	185	12	185	11	500	135.39	20306.26
30	860	1600	460	1415	460	25	50	50	235	240	14	240	7	850	226.70	38909.20
16	1000	1645	325	1550	325	12	25	25	275	105	9	105	14	480	34.59	5618.95
20	940	1060	350	1850	350	16	30	30	355	130	10	130	7	570	69.99	10271.73
24	980	1355	355	1240	355	20	25	25	235	135	12	135	10	100	47.62	15726.35
30	980	1490	425	1575	425	25	25	25	275	205	8	205	15	940	152.58	33138.00
16	900	1735	320	1595	320	12	10	10	355	100	19	100	10	90	17.31	4066.51
20	960	1760	395	1535	395	16	20	20	235	175	20	175	13	240	53.31	16907.16
24	800	1830	420	1620	420	20	50	50	275	200	16	200	12	810	169.60	21203.11
30	880	1720	450	1895	450	25	20	20	355	230	18	230	6	890	172.18	40484.63
16	920	1325	465	1640	465	12	45	45	235	245	11	245	10	590	131.75	16986.16
20	820	1640	420	1455	420	16	15	15	275	200	13	200	13	850	74.22	15818.68
24	800	1875	510	1955	510	20	40	40	355	290	16	290	9	720	208.74	40675.76
30	840	1550	465	1360	465	25	45	45	235	245	15	245	13	560	187.39	42824.54
16	900	1870	485	1765	485	12	15	15	275	265	16	265	8	570	90.65	18641.66
20	800	1470	400	1935	400	16	50	50	355	180	14	180	14	410	108.02	15253.59
24	980	1365	370	1630	370	20	35	35	235	150	18	150	10	230	67.66	16500.90
30	960	1990	360	1495	360	25	45	45	275	140	20	140	10	870	138.57	17542.05
16	860	1225	380	1975	380	12	10	10	355	160	10	160	16	500	33.96	5557.68
20	860	1015	465	1265	465	16	25	25	235	245	18	245	7	70	54.60	32035.90
24	960	1965	365	1690	365	20	35	35	275	145	12	145	9	370	78.13	15474.23
30	800	1085	505	1885	505	25	35	35	355	285	12	285	14	540	207.61	58062.95
16	840	1285	490	1970	490	12	50	50	235	270	10	270	15	900	195.11	18369.99
20	920	1950	335	1035	335	16	45	45	275	115	16	115	14	790	88.32	7725.74
24	820	1710	445	1090	445	20	10	10	355	225	19	225	16	440	81.16	27750.33
30	840	1525	405	1580	405	25	25	25	235	185	19	185	15	650	122.17	28947.38
16	980	1305	355	1420	355	12	35	35	275	135	16	135	11	850	67.37	6620.22
20	840	2000	495	1100	495	16	40	40	355	275	16	275	8	450	141.96	30436.97
24	960	1330	470	1450	470	20	45	45	235	250	19	250	9	850	193.15	29930.29
30	840	1570	355	1010	355	25	15	15	275	135	17	135	14	500	64.66	19905.16
16	900	1190	415	1305	415	12	35	35	355	195	9	195	14	610	107.27	12920.72
20	960	1435	495	1380	495	16	40	40	235	275	11	275	8	860	182.80	27523.35
24	920	1295	330	1750	330	20	30	30	275	110	8	110	16	520	60.98	10793.20
30	960	1900	350	1760	350	25	35	35	355	130	12	130	10	680	112.67	17357.79

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d	h	b_2	b_1	d_2	d_1	f_{ck}	t_g	t_{bp}	f_y	h	t_f	b_f	t_w	F_{Ed}	M_{Rd}	$S_{j,ini}$
16	820	1835	335	1435	335	12	15	15	235	115	11	115	13	380	23.51	5642.90
20	940	1105	485	1725	485	16	30	30	275	265	17	265	8	230	86.53	32023.01
24	980	1765	375	1800	375	20	15	15	355	155	19	155	10	220	57.14	18410.91
30	1000	1005	345	1830	345	25	45	45	235	125	10	125	10	380	97.00	16440.67
16	840	1805	350	1730	350	12	30	30	275	130	17	130	14	780	56.60	6485.38
20	920	1755	365	1770	365	16	20	20	355	145	20	145	9	950	57.86	10152.77
24	1000	1655	450	1325	450	20	40	40	235	230	20	230	11	420	123.62	29098.42
30	880	1155	515	1165	515	25	35	35	275	295	17	295	12	620	217.07	59620.44
16	820	1840	435	1530	435	12	30	30	355	215	14	215	6	700	112.51	14635.51
20	960	1195	470	1150	470	16	35	35	235	250	15	250	13	140	71.45	29985.67
24	820	1450	385	1960	385	20	25	25	275	165	13	165	12	940	94.79	16868.05
30	980	1160	380	1340	380	25	50	50	355	160	15	160	13	260	122.17	23282.78
16	940	1970	490	1790	490	12	40	40	235	270	12	270	13	360	98.85	21364.44
20	1000	1975	495	1670	495	16	20	20	275	275	12	275	11	440	106.70	32519.34
24	900	1920	345	1795	345	20	15	15	355	125	17	125	11	700	51.10	12662.60
30	1000	1800	440	1060	440	25	15	15	235	220	12	220	14	60	89.26	44908.38
16	860	1185	480	1735	480	12	15	15	275	260	10	260	10	370	71.12	19569.09
20	940	1100	320	1775	320	16	20	20	355	100	17	100	15	470	34.90	7587.35
24	1000	1120	380	1715	380	20	10	10	235	160	10	160	15	980	23.10	11011.67
30	840	1960	380	1110	380	25	30	30	275	160	10	160	15	940	122.04	22498.21
16	980	1240	340	1130	340	12	40	40	355	120	10	120	8	220	50.69	7173.27
16	840	1285	355	1130	355	12	35	35	235	135	15	135	7	680	60.15	6868.13
20	820	1830	510	1110	510	16	10	10	275	290	17	290	16	290	72.34	28680.91
24	920	1435	465	1715	465	20	30	30	355	245	14	245	15	260	105.08	36223.35
30	980	1680	480	1775	480	20	30	30	235	260	15	260	6	690	186.31	48545.73
16	840	1575	435	1735	435	25	30	30	275	215	11	215	9	290	64.59	16141.94
20	880	1470	335	1060	335	25	35	35	355	115	11	115	15	160	44.15	9513.94
24	860	1210	410	1795	410	12	30	30	235	190	14	190	16	770	100.60	20359.10
30	840	1975	485	1670	485	12	35	35	275	265	14	265	6	740	205.75	48914.98
16	820	1700	435	1790	435	12	25	25	355	215	13	215	16	730	102.30	14512.86
20	820	1110	420	1340	420	25	20	20	235	200	13	200	13	460	76.96	19380.85
24	860	1240	390	1960	390	12	30	30	275	170	16	170	12	460	88.25	19137.44
30	880	1740	490	1150	490	20	35	35	355	270	19	270	11	100	131.76	59465.32
16	880	1550	420	1530	420	12	10	10	235	200	15	200	11	520	44.05	7534.27
20	800	1270	335	1165	335	12	50	50	275	115	20	115	11	980	103.86	7276.52
24	980	1950	405	1325	405	20	45	45	355	185	13	185	6	50	66.46	24046.20
30	880	1875	425	1770	425	16	15	15	235	205	11	205	13	110	87.57	39372.07
16	840	1315	380	1730	380	16	15	15	275	160	18	160	6	150	31.73	10435.64
20	880	1830	515	1830	515	16	35	35	355	295	13	295	14	800	195.22	32671.44
24	840	1175	370	1800	370	20	10	10	235	150	20	150	12	970	18.77	9538.87
30	960	1015	440	1725	440	16	50	50	275	220	17	220	10	440	176.24	36476.41
16	820	1925	410	1435	410	20	45	45	355	190	19	190	6	480	99.34	11743.82
20	1000	1400	330	1760	330	25	35	35	235	110	13	110	10	680	61.82	7732.92
24	800	1345	335	1750	335	25	50	50	275	115	14	115	10	240	67.16	10790.62
30	860	1635	460	1380	460	25	40	40	355	240	13	240	14	800	219.40	41296.37
16	940	1560	320	1305	320	12	30	30	235	100	14	100	10	160	28.30	5920.02
20	800	1990	350	1010	350	25	30	30	275	130	20	130	12	200	45.62	10897.49
24	960	1035	405	1450	405	20	35	35	355	185	10	185	10	180	80.75	23772.08
30	940	1580	485	1100	485	12	40	40	235	265	19	265	6	820	212.08	46453.71
16	900	1625	350	1420	350	12	40	40	275	130	15	130	11	240	48.93	7630.02
20	840	1295	400	1580	400	20	35	35	355	180	13	180	14	620	108.87	15627.17
24	840	1820	515	1090	515	20	15	15	235	295	9	295	12	210	97.41	52159.56
30	820	1425	375	1035	375	25	50	50	275	155	12	155	8	870	163.07	20358.10
16	820	1060	370	1970	370	20	15	15	355	150	8	150	16	850	45.80	6768.96
20	980	1205	390	1885	390	25	40	40	235	170	17	170	16	540	92.52	13805.63
24	860	1995	520	1690	520	12	35	35	275	300	13	300	14	950	220.87	41703.09
30	840	1240	495	1265	495	16	35	35	355	275	10	275	9	320	173.44	57986.51
16	960	1885	385	1975	385	12	35	35	235	165	17	165	11	380	63.33	10178.50
20	1000	1620	455	1495	455	20	40	40	275	235	17	235	8	530	126.39	22798.47
24	980	1915	435	1630	435	25	35	35	355	215	13	215	8	710	150.35	25942.70
30	860	1985	370	1935	370	25	50	50	235	150	9	150	14	180	94.63	21825.50
16	920	1745	515	1765	515	12	40	40	275	295	18	295	9	740	172.73	22714.42
20	900	1620	435	1360	435	12	25	25	355	215	11	215	9	130	59.99	25213.39
24	900	1710	330	1955	330	25	40	40	235	110	16	110	7	780	79.85	9629.76
30	960	1975	400	1455	400	25	10	10	275	180	10	180	8	310	64.20	30916.52
16	860	1410	430	1640	430	25	50	50	355	210	11	210	15	130	52.48	15131.49
20	1000	1520	330	1895	330	20	45	45	235	110	14	110	14	190	45.89	8247.72
24	940	1745	455	1620	455	25	30	30	275	235	9	235	15	760	152.20	30026.26
30	800	1150	380	1535	380	25	30	30	355	160	12	160	9	930	129.84	22652.33
16	920	1635	500	1595	500	12	35	35	235	280	17	280	11	100	52.99	26770.84

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d	h	b_2	b_1	d_2	d_1	f_{ck}	t_g	t_{bp}	f_y	h	t_f	b_f	t_w	F_{Ed}	M_{Rd}	$S_{j,ini}$
20	920	1450	330	1575	330	12	25	25	275	110	13	110	7	320	41.07	8798.00
24	960	1485	465	1240	465	12	50	50	355	245	9	245	16	980	252.76	29688.26
30	980	1195	365	1850	365	20	20	20	235	145	18	145	11	880	64.99	19903.65
16	840	1150	500	1550	500	25	25	25	275	280	10	280	8	740	136.46	22248.24
20	1000	1030	390	1415	390	20	30	30	355	170	10	170	14	480	85.04	15217.34
24	880	1405	440	1925	440	12	10	10	235	220	13	220	9	570	60.78	23981.60
30	860	1255	485	1160	485	20	15	15	275	265	13	265	11	230	122.09	58510.33
16	980	1570	360	1235	360	25	10	10	355	140	15	140	10	990	26.25	3113.40
20	920	1190	450	1175	450	12	20	20	235	230	12	230	15	230	66.15	26279.25
24	840	1805	390	1950	390	12	30	30	275	170	16	170	9	50	55.82	22206.35
30	840	1370	455	1135	455	12	10	10	355	235	8	235	16	770	68.97	40409.34
16	960	1210	520	1320	520	12	50	50	235	300	13	300	16	410	134.13	23890.27
20	940	1395	365	1005	365	12	35	35	275	145	20	145	10	610	78.36	11013.19
24	800	1180	500	1940	500	20	50	50	355	280	14	280	6	700	223.23	37310.14
30	800	1115	505	1115	505	25	25	25	235	285	12	285	13	870	202.80	55499.17
16	860	1125	490	1510	490	12	50	50	275	270	16	270	8	850	201.66	18724.21
20	860	1595	515	1425	515	25	45	45	355	295	17	295	9	720	200.36	31328.03
24	820	1495	425	1740	425	16	30	30	235	205	8	205	6	580	111.83	24914.08
30	980	1885	330	1270	330	12	30	30	275	110	13	110	7	600	63.05	14160.89
16	960	1170	450	1330	450	16	35	35	355	230	10	230	13	350	89.09	17607.48
20	960	1165	385	1000	385	25	35	35	235	165	14	165	7	270	63.72	14768.31
24	880	1145	475	1445	475	20	10	10	275	255	9	255	11	860	98.36	29357.38
30	1000	1605	475	1870	475	12	25	25	355	255	13	255	11	670	173.56	48320.58
16	900	1590	495	1120	495	20	20	20	235	275	14	275	14	730	117.43	20846.31
20	960	1580	325	1520	325	12	10	10	275	105	17	105	8	210	19.69	6708.78
24	800	1900	510	1505	510	16	15	15	355	290	20	290	16	980	164.93	40352.97
30	820	1355	520	1545	520	25	45	45	235	300	13	300	8	600	229.55	59483.63
16	800	1945	495	1600	495	20	25	25	275	275	10	275	15	200	63.26	25455.60
20	960	1805	395	1480	395	12	35	35	355	175	16	175	11	480	96.28	15403.24
24	940	1295	515	1370	515	16	15	15	235	295	19	295	12	660	134.28	43667.66
30	940	1825	335	1695	335	25	25	25	275	115	20	115	16	980	69.16	14923.16
16	960	1440	495	1225	495	20	15	15	355	275	9	275	8	110	46.54	25682.24
20	1000	1655	355	1405	355	25	15	15	235	135	15	135	6	210	38.56	11652.01
24	840	1640	455	1200	455	25	40	40	275	235	14	235	7	130	85.83	34161.65
30	920	1100	420	1355	420	12	15	15	355	200	20	200	10	680	76.39	31751.07
16	880	1930	420	1125	420	12	35	35	235	200	20	200	8	660	97.46	12378.31
20	840	1455	360	1785	360	25	10	10	275	140	12	140	16	640	41.28	8390.99
24	860	1195	405	1210	405	20	10	10	355	185	10	185	16	730	58.67	18531.31
30	900	1215	515	1855	515	16	50	50	235	295	19	295	6	910	283.11	53566.60
16	940	1540	345	1875	345	20	45	45	275	125	15	125	14	930	93.27	6018.70
20	800	1025	480	1015	480	16	10	10	355	260	15	260	15	90	52.12	28464.30
24	920	1695	385	1290	385	16	30	30	235	165	17	165	16	790	90.78	16597.67
30	900	1320	350	1140	350	16	15	15	275	130	10	130	7	110	56.75	19219.73
16	1000	1625	490	1660	490	16	50	50	355	270	14	270	11	260	95.03	21101.12
20	920	1340	520	1385	520	12	15	15	235	300	19	300	8	500	105.08	34286.67
24	860	1290	400	1145	400	16	35	35	275	180	19	180	13	410	98.47	20606.73
30	880	1240	325	1285	325	12	25	25	355	105	18	105	15	720	36.33	13806.23
16	840	1480	340	1105	340	12	30	30	235	120	14	120	16	540	43.55	6236.00
20	940	1205	430	1685	430	25	30	30	275	210	15	210	15	370	85.66	20973.43
24	880	1710	330	1075	330	25	50	50	355	110	13	110	15	60	51.58	10795.14
30	1000	1660	330	1215	330	25	10	10	235	110	18	110	7	400	30.98	17168.03
16	820	1085	440	1345	440	12	50	50	275	220	10	220	12	380	106.85	15058.52
20	820	1200	385	1335	385	20	40	40	355	165	15	165	6	270	74.54	14588.59
24	860	1660	350	1965	350	20	40	40	235	130	15	130	12	140	55.90	13667.43
30	880	1305	440	1300	440	16	40	40	275	220	8	220	6	920	193.70	35052.93
16	960	1050	465	1205	465	25	30	30	355	245	18	245	9	910	149.41	17222.74
20	820	1485	470	1665	470	16	20	20	235	250	14	250	10	500	99.01	27001.58
24	900	1605	320	1050	320	20	30	30	275	100	14	100	6	200	47.20	9926.95
30	1000	1130	410	1220	410	25	15	15	355	190	19	190	9	160	88.06	33988.13
16	860	1175	440	1275	440	16	10	10	235	220	19	220	14	960	41.91	5752.38
20	820	1875	340	1625	340	12	50	50	275	120	12	120	12	560	90.87	8472.50
24	900	1985	420	1780	420	20	25	25	355	200	9	200	9	50	60.24	29893.99
30	820	1360	390	1805	390	25	15	15	235	170	16	170	6	950	90.07	25834.88
16	840	1210	365	1910	365	20	50	50	275	145	18	145	7	970	120.35	7128.50
20	1000	1380	460	1070	460	25	40	40	355	240	19	240	7	210	85.54	26111.04
24	980	1080	420	1085	420	12	10	10	235	200	20	200	11	580	32.42	17264.46
30	960	1765	350	1440	350	20	30	30	275	130	15	130	8	480	87.94	17780.88
16	1000	1120	430	1365	430	25	30	30	355	210	9	210	8	260	63.38	16059.37
20	1000	1225	330	1465	330	12	50	50	235	110	18	110	10	620	83.81	7293.47
24	1000	1450	415	1190	415	25	15	15	275	195	12	195	7	140	62.04	27259.92

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d	h	b_2	b_1	d_2	d_1	f_{ck}	t_g	t_{bp}	f_y	h	t_f	b_f	t_w	F_{Ed}	M_{Rd}	$S_{j,ini}$
30	820	1125	465	1945	465	25	35	35	355	245	8	245	15	150	127.94	50549.89
16	800	1690	465	1920	465	16	25	25	235	245	15	245	8	740	112.92	17460.40
20	940	1190	455	1650	455	16	30	30	275	235	14	235	8	540	113.46	23880.48
24	920	1985	485	1590	485	20	10	10	355	265	10	265	15	460	103.18	36694.70
30	1000	1870	430	1835	430	16	25	25	235	210	8	210	15	340	117.04	38175.45
16	820	1050	350	1890	350	12	10	10	275	130	17	130	7	280	22.68	4774.74
20	800	1785	435	1400	435	20	35	35	355	215	18	215	14	360	95.73	21391.60
24	960	1100	320	1180	320	25	30	30	235	100	18	100	8	200	45.39	9740.94
30	860	1075	395	1295	395	25	35	35	275	175	20	175	10	300	110.91	27310.42
16	800	1315	345	1040	345	25	45	45	355	125	15	125	6	210	47.46	7101.00
20	920	1815	465	1810	465	20	15	15	235	245	10	245	6	780	113.82	23882.54
24	840	1080	415	1880	415	16	35	35	275	195	10	195	13	240	87.67	25067.21
30	980	1915	365	1675	365	16	45	45	355	145	17	145	7	230	106.95	20421.24
16	940	1765	500	1645	500	16	45	45	235	280	13	280	16	550	137.14	20905.18
20	960	1155	350	1710	350	20	30	30	275	130	11	130	15	770	67.47	9508.07
24	860	1250	450	1930	450	16	35	35	355	230	17	230	15	950	181.24	27447.56
30	940	1775	465	1250	465	16	30	30	235	245	14	245	11	270	133.60	48558.21
16	980	1385	445	1500	445	12	50	50	275	225	20	225	7	680	150.54	14287.83
20	860	1605	500	1310	500	16	10	10	355	280	20	280	8	720	110.15	23445.47
24	980	1865	475	1900	475	25	50	50	235	255	16	255	11	240	111.22	34829.71
30	860	1790	435	1985	435	12	15	15	275	215	14	215	14	540	108.49	38498.74
16	800	1895	390	1840	390	12	20	20	355	170	12	170	13	100	32.51	13044.74
20	840	2000	510	2000	510	12	10	10	235	290	9	290	12	960	108.90	22114.38
24	800	1945	505	1815	505	12	40	40	275	285	19	285	16	810	209.56	38348.33
30	820	1970	440	1375	440	16	40	40	355	220	14	220	8	310	148.76	39268.13
16	1000	1280	475	1700	475	16	30	30	235	255	10	255	10	540	105.84	19475.58
20	800	1455	390	1045	390	12	45	45	275	170	18	170	8	1000	133.31	12451.80
24	800	1105	405	1185	405	12	20	20	355	185	12	185	11	500	77.26	22024.56
30	880	1065	460	1030	460	16	30	30	235	240	14	240	7	850	156.48	40105.10
16	920	1655	370	1020	370	12	10	10	275	150	9	150	14	480	21.71	4387.97
20	900	1520	350	1705	350	12	35	35	355	130	10	130	7	570	79.86	10147.10
24	1000	1225	355	1990	355	16	45	45	235	135	12	135	10	100	57.97	14540.70
30	980	1470	425	1490	425	16	25	25	275	205	8	205	15	940	131.06	32136.15
16	800	1585	320	1245	320	25	45	45	355	100	19	100	10	90	28.28	5471.65
20	1000	1335	395	1605	395	20	40	40	235	175	20	175	13	240	66.63	15587.10
24	800	1810	420	1155	420	16	25	25	275	200	16	200	12	810	108.75	22568.19
30	980	1805	450	1410	450	20	45	45	355	230	18	230	6	890	234.95	37218.65
16	940	1570	465	1080	465	16	25	25	235	245	11	245	10	590	97.50	18066.11
20	900	1670	420	1260	420	25	35	35	275	200	13	200	13	850	130.52	17201.61
24	840	1790	510	1570	510	12	15	15	355	290	16	290	9	720	140.43	42360.87
30	920	1245	465	1585	465	16	30	30	235	245	15	245	13	560	159.18	44957.51
16	840	1330	485	1470	485	20	40	40	275	265	16	265	8	570	131.37	19659.34
20	940	1720	400	1525	400	20	40	40	355	180	14	180	14	410	94.01	15918.23
24	960	1615	370	1635	370	12	30	30	235	150	18	150	10	230	64.32	16874.67
30	860	1475	360	1980	360	12	25	25	275	140	20	140	10	870	61.11	17999.48
16	980	1170	380	1540	380	25	20	20	355	160	10	160	16	500	59.33	9968.99
20	900	1730	465	1825	465	16	20	20	235	245	18	245	7	70	51.72	32319.74
24	900	1140	365	1680	365	20	20	20	275	145	12	145	9	370	61.07	16337.13
30	940	2000	505	1845	505	20	15	15	355	285	12	285	14	540	170.67	62087.75
16	1000	1335	490	1430	490	20	35	35	235	270	10	270	15	900	160.29	19458.11
20	980	1280	335	1065	335	20	30	30	275	115	16	115	14	790	52.78	7829.33
24	980	1415	445	1460	445	16	25	25	355	225	19	225	16	440	112.04	30183.10
30	960	1600	405	1615	405	12	20	20	235	185	19	185	15	650	87.76	28520.66
16	980	1325	355	1555	355	20	25	25	275	135	16	135	11	850	54.26	6714.31
20	820	1950	495	1315	495	25	15	15	355	275	16	275	8	450	106.07	31552.93
24	900	1840	470	1610	470	25	25	25	235	250	19	250	9	850	157.75	32503.55
30	820	1845	355	1350	355	20	10	10	275	135	17	135	14	500	43.08	21132.74
16	960	1500	415	1915	415	25	40	40	355	195	9	195	14	610	108.64	12437.03
20	840	1620	495	1095	495	16	30	30	235	275	11	275	8	860	156.49	28233.47
24	980	1040	330	1905	330	16	30	30	275	110	8	110	16	520	58.36	10737.41
30	980	1705	350	1865	350	16	50	50	355	130	12	130	10	680	145.32	16532.29
16	980	1355	335	1655	335	25	20	20	235	115	11	115	13	380	34.71	6556.76
20	800	1845	485	1255	485	16	25	25	275	265	17	265	8	230	82.05	32661.77
24	840	1545	375	1170	375	12	45	45	355	155	19	155	10	220	90.30	16818.60
30	900	1930	345	1025	345	12	10	10	235	125	10	125	10	380	21.79	21438.67
16	1000	1815	350	1475	350	20	20	20	275	130	17	130	14	780	44.62	6381.33
20	960	1860	365	1565	365	20	50	50	355	145	20	145	9	950	141.30	10160.78
24	1000	1960	450	1995	450	16	50	50	235	230	20	230	11	420	134.12	27805.71
30	840	1760	515	1395	515	16	20	20	275	295	17	295	12	620	181.38	62504.57
16	920	1565	435	1745	435	25	35	35	355	215	14	215	6	700	121.65	14397.73

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d	h	b_2	b_1	d_2	d_1	f_{ck}	t_g	t_{bp}	f_y	h	t_f	b_f	t_w	F_{Ed}	M_{Rd}	$S_{j,ini}$
20	980	1570	470	1280	470	20	40	40	235	250	15	250	13	140	71.69	29028.99
24	820	1510	385	1860	385	12	45	45	275	165	13	165	12	940	140.15	15985.31
30	960	1640	380	1390	380	20	20	20	355	160	15	160	13	260	86.53	25511.19
16	880	1415	490	1230	490	25	40	40	235	270	12	270	13	360	95.88	21183.02
20	820	1795	495	1195	495	16	35	35	275	275	12	275	11	440	126.33	31055.95
24	920	1725	345	1515	345	16	25	25	355	125	17	125	11	700	65.84	12197.55
30	940	1750	440	1755	440	25	40	40	235	220	12	220	14	60	102.44	42691.22
16	940	1115	480	1055	480	16	40	40	275	260	10	260	10	370	103.21	20448.96
20	860	1030	320	1560	320	20	30	30	355	100	17	100	15	470	52.55	7441.92
24	980	1250	380	1820	380	25	35	35	235	160	10	160	15	980	112.37	15635.80
30	840	1335	380	1485	380	20	45	45	275	160	10	160	15	940	157.43	21472.47
16	880	1040	340	1720	340	16	25	25	355	120	10	120	8	220	36.06	7573.33
16	980	1790	355	1130	355	25	20	20	235	135	15	135	7	680	47.35	7066.47
20	900	1050	510	1110	510	16	20	20	275	290	17	290	16	290	92.22	37120.97
24	920	1070	465	1715	465	12	30	30	355	245	14	245	15	260	108.96	36416.34
30	920	1550	480	1775	480	20	25	25	235	260	15	260	6	690	175.84	49376.30
16	820	1755	435	1735	435	20	35	35	275	215	11	215	9	290	68.49	15761.12
20	820	1850	335	1060	335	25	30	30	355	115	11	115	15	160	40.96	9733.90
24	1000	1940	410	1795	410	12	20	20	235	190	14	190	16	770	81.70	20781.64
30	900	1940	485	1670	485	20	10	10	275	265	14	265	6	740	127.09	52148.00
16	940	1960	435	1790	435	16	45	45	355	215	13	215	16	730	145.21	13808.05
20	800	1715	420	1340	420	12	10	10	235	200	13	200	13	460	46.36	13788.75
24	960	1330	390	1960	390	12	40	40	275	170	16	170	12	460	105.48	18509.02
30	820	1525	490	1150	490	12	35	35	355	270	19	270	11	100	137.40	59592.06
16	820	1715	420	1530	420	20	25	25	235	200	15	200	11	520	76.75	13473.54
20	820	1575	335	1165	335	25	40	40	275	115	20	115	11	980	82.34	7492.23
24	940	1835	405	1325	405	12	25	25	355	185	13	185	6	50	59.11	26116.28
30	960	1060	425	1770	425	12	40	40	235	205	11	205	13	110	110.13	37396.65
16	860	1835	380	1730	380	12	40	40	275	160	18	160	6	150	44.21	10450.23
20	800	1505	515	1830	515	12	15	15	355	295	13	295	14	800	132.68	31323.65
24	980	1245	370	1800	370	12	25	25	235	150	20	150	12	970	40.50	11608.34
30	800	1055	440	1725	440	12	30	30	275	220	17	220	10	440	136.63	38762.28
16	960	1165	410	1435	410	16	40	40	355	190	19	190	6	480	98.73	12217.51
20	960	1375	330	1760	330	25	25	25	235	110	13	110	10	680	47.34	7992.69
24	1000	1410	335	1750	335	20	10	10	275	115	14	115	10	240	29.15	11380.83
30	820	1215	460	1380	460	16	35	35	355	240	13	240	14	800	203.62	41809.21
16	1000	1480	320	1305	320	12	25	25	235	100	14	100	10	160	25.57	6020.13
20	920	1410	350	1010	350	12	40	40	275	130	20	130	12	200	57.00	10459.62
24	1000	1590	405	1450	405	25	15	15	355	185	10	185	10	180	63.95	24853.64
30	900	1130	485	1100	485	25	20	20	235	265	19	265	6	820	169.98	49876.94
16	920	1345	350	1420	350	25	50	50	275	130	15	130	11	240	50.00	7079.78
20	1000	1325	400	1580	400	25	10	10	355	180	13	180	14	620	65.94	12462.37
24	800	1205	515	1090	515	12	50	50	235	295	9	295	12	210	134.63	46406.34
30	860	1375	375	1035	375	25	15	15	275	155	12	155	8	870	64.24	23047.59
16	840	1895	370	1970	370	20	20	20	355	150	8	150	16	850	66.89	8243.30
20	940	1900	390	1885	390	25	50	50	235	170	17	170	16	540	101.11	13102.95
24	860	1440	520	1690	520	20	25	25	275	300	13	300	14	950	199.60	43372.99
30	800	1685	495	1265	495	12	25	25	355	275	10	275	9	320	154.53	59679.11
16	840	1365	385	1975	385	16	20	20	235	165	17	165	11	380	49.19	10409.45
20	960	1020	455	1495	455	25	20	20	275	235	17	235	8	530	99.17	24379.77
24	840	1175	435	1630	435	16	25	25	355	215	13	215	8	710	124.19	26546.91
30	1000	1425	370	1935	370	16	25	25	235	150	9	150	14	180	77.80	23511.19
16	940	1220	515	1765	515	16	15	15	275	295	18	295	9	740	117.85	21266.47
20	820	1795	435	1360	435	16	10	10	355	215	11	215	9	130	48.27	20301.04
24	900	1405	330	1955	330	16	50	50	235	110	16	110	7	780	95.02	9235.26
30	920	1290	400	1455	400	16	10	10	275	180	10	180	8	310	56.87	30805.63
16	800	1435	430	1640	430	12	30	30	355	210	11	210	15	130	48.17	17348.69
20	840	1475	330	1895	330	25	35	35	235	110	14	110	14	190	40.49	8690.17
24	980	1390	455	1620	455	12	50	50	275	235	9	235	15	760	196.36	28059.35
30	840	1315	380	1535	380	16	45	45	355	160	12	160	9	930	174.17	21755.92
16	920	1650	500	1595	500	16	30	30	235	280	17	280	11	100	49.87	27475.80
20	1000	1715	330	1575	330	16	25	25	275	110	13	110	7	320	42.36	8830.14
24	860	1660	465	1240	465	25	25	25	355	245	9	245	16	980	171.50	31672.58
30	940	1120	365	1850	365	20	50	50	235	145	18	145	11	880	144.53	18028.87
16	900	1760	500	1550	500	12	40	40	275	280	10	280	8	740	164.81	21127.21
20	980	1675	390	1415	390	16	25	25	355	170	10	170	14	480	77.10	15403.83
24	840	1650	440	1925	440	16	35	35	235	220	13	220	9	570	128.06	27112.32
30	880	1510	485	1160	485	16	30	30	275	265	13	265	11	230	141.28	56303.77
16	880	1200	360	1235	360	16	30	30	355	140	15	140	10	990	69.48	6897.14
20	1000	1855	450	1175	450	16	50	50	235	230	12	230	15	230	89.38	23135.36

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d	h	b_2	b_1	d_2	d_1	f_{ck}	t_g	t_{bp}	f_y	h	t_f	b_f	t_w	F_{Ed}	M_{Rd}	$S_{j,ini}$
24	840	1475	390	1950	390	20	50	50	275	170	16	170	9	50	62.11	20313.21
30	800	1555	455	1135	455	25	30	30	355	235	8	235	16	770	187.44	41748.25
16	920	1000	520	1320	520	25	50	50	235	300	13	300	16	410	124.41	23392.76
20	880	1515	365	1005	365	25	50	50	275	145	20	145	10	610	103.82	10446.68
24	820	1330	500	1940	500	25	35	35	355	280	14	280	6	700	189.68	39455.44
30	1000	1630	505	1115	505	16	10	10	235	285	12	285	13	870	111.82	54306.05
16	980	1775	490	1510	490	16	40	40	275	270	16	270	8	850	172.05	19327.34
20	980	1935	515	1425	515	25	30	30	355	295	17	295	9	720	172.69	33519.65
24	880	1255	425	1740	425	16	40	40	235	205	8	205	6	580	128.38	24054.66
30	900	1480	330	1270	330	20	15	15	275	110	13	110	7	600	35.17	16866.93
16	860	1105	450	1330	450	16	35	35	355	230	10	230	13	350	89.35	17620.53
20	860	1075	385	1000	385	25	30	30	235	165	14	165	7	270	60.07	15122.90
24	1000	1075	475	1445	475	20	20	20	275	255	9	255	11	860	138.89	33687.92
30	820	1545	475	1870	475	12	50	50	355	255	13	255	11	670	248.67	45310.34
16	860	1560	495	1120	495	25	15	15	235	275	14	275	14	730	113.15	19394.32
20	920	1085	325	1520	325	25	45	45	275	105	17	105	8	210	48.39	7655.35
24	1000	1735	510	1505	510	25	10	10	355	290	20	290	16	980	160.47	37722.82
30	980	1220	520	1545	520	12	15	15	235	300	13	300	8	600	150.21	64405.55
16	940	1935	495	1600	495	12	25	25	275	275	10	275	15	200	64.81	25601.65
20	980	1010	395	1480	395	12	50	50	355	175	16	175	11	480	127.90	14634.23
24	840	1320	515	1370	515	25	50	50	235	295	19	295	12	660	204.91	39593.40
30	880	1120	355	1695	355	25	10	10	275	135	20	135	16	980	22.79	25638.67
16	800	1655	495	1225	495	20	15	15	355	275	9	275	8	110	46.46	25674.03
20	940	1615	355	1405	355	20	25	25	235	135	15	135	6	210	43.81	11852.55
24	820	1280	455	1200	455	16	25	25	275	235	14	235	7	130	78.92	36570.27
30	960	1940	345	1355	345	16	45	45	355	125	16	125	7	680	130.60	15718.44
16	980	1400	420	1125	420	25	20	20	235	200	20	200	8	660	78.27	12621.02
20	1000	1160	360	1785	360	20	15	15	275	140	12	140	16	640	44.69	10352.85
24	860	1975	405	1210	405	25	15	15	355	185	10	185	16	730	93.44	21696.78
30	820	1130	515	1855	515	20	50	50	235	295	19	295	6	910	282.65	53546.44
16	960	1775	345	1875	345	16	25	25	275	125	15	125	14	930	45.68	5725.13
20	940	1905	480	1015	480	16	35	35	355	260	15	260	15	90	67.87	33426.96
24	920	1445	385	1290	385	20	25	25	235	165	17	165	16	790	83.11	16906.53
30	840	1450	350	1140	350	20	20	20	275	130	10	130	7	110	63.35	19259.18
16	900	1700	490	1660	490	25	20	20	355	270	14	270	11	260	69.50	23851.52
20	1000	1125	520	1385	520	20	10	10	235	300	19	300	8	500	91.94	27339.92
24	800	1525	400	1145	400	16	35	35	275	180	19	180	13	410	98.30	20601.26
30	1000	1395	325	1285	325	20	50	50	355	105	18	105	15	720	127.65	12191.68
16	940	1010	340	1105	340	20	45	45	235	120	14	120	16	540	68.40	6121.07
20	980	1180	430	1685	430	20	30	30	275	210	15	210	15	370	86.19	21001.29
24	820	1135	330	1075	330	20	30	30	355	110	13	110	15	60	44.63	11690.22
30	900	1825	330	1215	330	16	25	25	235	110	18	110	7	400	58.89	14503.26
16	840	1090	440	1345	440	25	25	25	275	220	10	220	12	380	73.21	16558.25
20	840	1585	385	1335	385	16	35	35	355	165	15	165	6	270	70.61	14965.18
24	900	1425	350	1965	350	12	30	30	235	130	15	130	12	140	52.15	14287.31
30	860	1670	440	1300	440	20	30	30	275	220	8	220	6	920	170.67	36168.46
16	960	1870	465	1205	465	25	35	35	355	245	18	245	9	910	162.51	17007.81
20	860	1390	470	1665	470	25	25	25	235	250	14	250	10	500	108.13	27022.67
24	880	1735	320	1050	320	12	30	30	275	100	14	100	6	200	47.73	9931.30
30	840	1505	410	1220	410	20	25	25	355	190	19	190	9	160	98.61	33318.16
16	1000	1490	440	1275	440	25	40	40	235	220	19	220	14	960	145.06	13442.75
20	820	1350	340	1625	340	20	50	50	275	120	12	120	12	560	87.06	8410.63
24	860	1155	420	1780	420	20	30	30	355	200	9	200	9	50	63.57	29424.24
30	800	1745	390	1805	390	25	30	30	235	170	16	170	6	950	131.75	24169.52
16	960	1870	365	1910	365	20	25	25	275	145	18	145	7	970	68.39	7405.01
20	980	1265	460	1070	460	20	25	25	355	240	19	240	7	210	75.51	28147.50
24	860	1320	355	1085	355	16	45	45	235	135	20	135	11	580	96.11	12527.98
30	820	1725	350	1440	350	12	40	40	275	130	15	130	8	480	103.49	17154.93
16	800	1430	430	1365	430	20	15	15	355	210	9	210	8	260	52.19	15029.93
20	860	1990	330	1465	330	16	10	10	235	110	18	110	10	620	10.12	4489.82
24	940	1955	415	1190	415	16	10	10	275	195	12	195	7	140	43.12	24622.55
30	1000	1060	465	1945	465	25	15	15	355	245	8	245	15	150	109.94	52746.55
16	940	1065	465	1920	465	12	20	20	235	245	15	245	8	740	89.50	16218.03
20	800	1385	455	1650	455	20	50	50	275	235	14	235	8	540	141.35	21855.91
24	800	1875	485	1590	485	25	25	25	355	265	10	265	15	460	133.36	39735.39
30	960	1800	430	1835	430	25	35	35	235	210	8	210	15	340	128.63	36980.05
16	880	1625	350	1890	350	25	25	25	275	130	17	130	7	280	39.22	7921.93
20	840	1930	435	1400	435	16	20	20	355	215	18	215	14	360	79.30	22438.99
24	960	1890	320	1180	320	12	10	10	235	100	18	100	8	200	18.06	9622.47
30	900	1690	395	1295	395	16	20	20	275	175	20	175	10	300	90.22	28610.96

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d	h	b_2	b_1	d_2	d_1	f_{ck}	t_g	t_{bp}	f_y	h	t_f	b_f	t_w	F_{Ed}	M_{Rd}	$S_{j,ini}$
16	840	1580	345	1040	345	25	35	35	355	125	15	125	6	210	41.23	7517.48
20	960	1045	465	1810	465	12	35	35	235	245	10	245	6	780	140.00	23370.08
24	840	1965	415	1880	415	16	40	40	275	195	10	195	13	240	90.02	24459.24
30	860	1865	365	1675	365	20	25	25	355	145	17	145	7	230	84.06	21705.03
16	860	1145	500	1645	500	12	35	35	235	280	13	280	16	550	124.98	22070.74
20	900	1530	350	1710	350	12	35	35	275	130	11	130	15	770	73.13	9298.21
24	900	1230	450	1930	450	20	50	50	355	230	17	230	15	950	224.65	26248.42
30	880	1795	465	1250	465	16	10	10	235	245	14	245	11	270	72.33	49328.21
16	980	1565	445	1500	445	25	35	35	275	225	20	225	7	680	118.22	15079.29
20	980	2000	500	1310	500	20	40	40	355	280	20	280	8	720	184.50	29384.39
24	880	1515	475	1900	475	25	10	10	235	255	16	255	11	240	62.01	35394.09
30	880	1160	435	1985	435	25	30	30	275	215	14	215	14	540	147.38	37054.46
16	800	1595	390	1840	390	16	45	45	355	170	12	170	13	100	41.58	11687.75
20	880	1760	510	2000	510	16	35	35	235	290	9	290	12	960	194.56	30274.47
24	980	1690	505	1815	505	12	40	40	275	285	19	285	16	810	209.42	38341.95
30	820	1000	440	1375	440	20	30	30	355	220	14	220	8	310	134.30	40555.96
16	980	1515	475	1700	475	12	40	40	235	255	10	255	10	540	120.91	18712.22
20	1000	1065	390	1045	390	20	35	35	275	170	18	170	8	1000	105.11	12574.25
24	920	1135	405	1185	405	12	30	30	355	185	12	185	11	500	104.73	21934.22
30	1000	1910	460	1030	460	20	45	45	235	240	14	240	7	850	215.43	39512.91
16	800	1500	325	1020	325	12	25	25	275	105	9	105	14	480	31.71	5497.21
20	880	1270	350	1705	350	16	50	50	355	130	10	130	7	570	105.82	9590.77
24	980	1910	355	1990	355	25	50	50	235	135	12	135	10	100	55.82	14159.11
30	920	1730	425	1490	425	20	35	35	275	205	8	205	15	940	174.25	31975.44
16	960	1095	320	1245	320	16	30	30	355	100	19	100	10	90	26.02	6036.30
20	1000	1305	395	1605	395	20	25	25	235	175	20	175	13	240	56.89	16758.18
24	820	1960	420	1155	420	20	20	20	275	200	16	200	12	810	104.47	23130.40
30	960	1110	450	1410	450	16	50	50	355	230	18	230	6	890	256.84	36890.99
16	960	1495	465	1080	465	20	15	15	235	245	11	245	10	590	84.14	16401.63
20	960	1350	420	1260	420	16	15	15	275	200	13	200	13	850	65.11	15064.23
24	860	1500	510	1570	510	20	25	25	355	290	16	290	9	720	177.36	43074.03
30	960	1190	465	1585	465	12	30	30	235	245	15	245	13	560	153.56	44679.60
16	980	1640	485	1470	485	25	30	30	275	265	16	265	8	570	116.84	20568.69
20	980	1725	400	1525	400	25	50	50	355	180	14	180	14	410	101.54	15076.32
24	820	1675	370	1635	370	16	30	30	235	150	18	150	10	230	64.14	16870.21
30	840	1915	360	1980	360	16	40	40	275	140	20	140	10	870	124.27	17782.69
16	820	1530	380	1540	380	25	35	35	355	160	10	160	16	500	77.19	9792.99
20	920	1675	465	1825	465	16	50	50	235	245	18	245	7	70	62.43	27905.59
24	940	1355	365	1680	365	25	25	25	275	145	12	145	9	370	68.43	16138.56
30	800	1015	505	1845	505	20	15	15	355	285	12	285	14	540	164.14	61734.80
16	940	1820	490	1430	490	20	40	40	235	270	10	270	15	900	171.54	19105.29
20	840	1400	370	1065	370	12	20	20	275	150	16	150	14	790	28.77	8597.82
24	980	1595	445	1460	445	25	35	35	355	225	19	225	16	440	125.46	28983.57
30	980	1920	405	1615	405	12	35	35	235	185	19	185	15	650	131.05	27637.85
16	800	1105	355	1555	355	25	50	50	275	135	16	135	11	850	105.69	6618.77
20	840	1295	495	1315	495	20	50	50	355	275	16	275	8	450	155.04	28960.86
24	840	1370	470	1610	470	12	40	40	235	250	19	250	9	850	177.13	30229.98
30	900	1540	355	1350	355	25	25	25	275	135	17	135	14	500	85.04	18949.45
16	960	1040	415	1915	415	12	35	35	355	195	9	195	14	610	106.79	12904.23
20	840	1530	495	1095	495	12	25	25	235	275	11	275	8	860	130.52	27465.20
24	840	1575	330	1905	330	16	30	30	275	110	8	110	16	520	60.31	10779.37
30	840	1880	350	1865	350	20	45	45	355	130	12	130	10	680	131.93	16762.46
16	900	1275	335	1655	335	25	25	25	235	115	11	115	13	380	38.44	6601.93
20	860	1300	485	1255	485	16	35	35	275	265	17	265	8	230	91.29	31284.10
24	860	1030	375	1170	375	12	30	30	355	155	19	155	10	220	73.43	17895.93
30	920	1020	345	1025	345	20	45	45	235	125	10	125	10	380	99.12	16466.96
16	840	1230	350	1475	350	12	35	35	275	130	17	130	14	780	64.84	6463.70
20	820	1365	365	1565	365	25	30	30	355	145	20	145	9	950	93.93	10779.50
24	960	1445	450	1995	450	20	15	15	235	230	20	230	11	420	95.54	31614.56
30	980	1710	515	1395	515	12	15	15	275	295	17	295	12	620	156.70	62622.75
16	880	1600	435	1745	435	20	30	30	355	215	14	215	6	700	113.90	14692.26
20	800	1265	470	1280	470	25	30	30	235	250	15	250	13	140	66.38	30623.52
24	1000	1045	385	1860	385	25	40	40	275	165	13	165	12	940	131.68	16301.25
30	800	1235	380	1390	380	12	40	40	355	160	15	160	13	260	117.94	24172.33
16	880	1285	490	1230	490	25	45	45	235	270	12	270	13	360	100.23	20584.88
20	940	1905	495	1195	495	16	40	40	275	275	12	275	11	440	132.82	30334.36
24	980	1980	345	1515	345	16	45	45	355	125	17	125	11	700	112.14	11460.70
30	920	1245	440	1755	440	20	30	30	235	220	12	220	14	60	98.58	44002.44
16	940	1110	480	1055	480	16	10	10	275	260	10	260	10	370	62.75	13498.73
20	820	1055	320	1560	320	20	30	30	355	100	17	100	15	470	52.57	7442.19

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d	h	b_2	b_1	d_2	d_1	f_{ck}	t_g	t_{bp}	f_y	h	t_f	b_f	t_w	F_{Ed}	M_{Rd}	$S_{j,ini}$
24	860	1545	380	1820	380	12	40	40	235	160	10	160	15	980	109.61	14958.43
30	960	1275	380	1485	380	12	25	25	275	160	10	160	15	940	60.38	20399.91
16	940	1310	340	1720	340	25	10	10	355	120	10	120	8	220	26.40	4923.58
16	980	1860	355	1130	355	25	50	50	235	135	15	135	7	680	87.81	6700.97
20	1000	1185	510	1110	510	20	30	30	275	290	17	290	16	290	102.90	36144.10
24	1000	1705	465	1715	465	20	25	25	355	245	14	245	15	260	99.91	36937.69
30	820	1460	480	1775	480	25	15	15	235	260	15	260	6	690	161.56	51544.86
16	800	1290	435	1735	435	20	50	50	275	215	11	215	9	290	79.90	14495.59
20	1000	1925	335	1060	335	20	10	10	355	115	11	115	15	160	28.63	8032.42
24	940	1005	410	1795	410	25	45	45	235	190	14	190	16	770	143.07	20011.02
30	980	1535	485	1670	485	16	50	50	275	265	14	265	6	740	245.49	46869.65
16	900	1970	435	1790	435	16	20	20	355	215	13	215	16	730	96.19	14409.88
20	800	1090	420	1340	420	12	35	35	235	200	13	200	13	460	94.09	18535.58
24	980	1920	390	1960	390	16	45	45	275	170	16	170	12	460	109.21	18056.45
30	820	1900	490	1150	490	16	10	10	355	270	19	270	11	100	87.02	62310.84
16	900	1200	420	1530	420	16	35	35	235	200	15	200	11	520	88.12	13030.25
20	980	1415	335	1165	335	25	45	45	275	115	20	115	11	980	93.42	7394.80
24	1000	1855	405	1325	405	12	20	20	355	185	13	185	6	50	55.93	26364.00
30	840	1590	425	1770	425	12	25	25	235	205	11	205	13	110	95.01	38926.10
16	980	1430	380	1730	380	12	30	30	275	160	18	160	6	150	39.75	11078.54
20	860	1015	515	1830	515	16	45	45	355	295	13	295	14	800	223.84	31583.27
24	1000	1365	340	1800	340	12	30	30	235	120	20	120	12	970	33.84	8880.95
30	860	1800	440	1725	440	25	50	50	275	220	17	220	10	440	165.77	36174.77
16	840	1435	410	1435	410	25	25	25	355	190	19	190	6	480	75.81	12796.08
20	940	1470	330	1760	330	20	35	35	235	110	13	110	10	680	60.15	7690.64
24	1000	1380	335	1750	335	25	35	35	275	115	14	115	10	240	57.24	11550.42
30	800	1505	460	1380	460	20	15	15	355	240	13	240	14	800	146.20	44333.14
16	1000	1910	320	1305	320	12	40	40	235	100	14	100	10	160	33.03	5599.74
20	940	1345	350	1010	350	25	50	50	275	130	20	130	12	200	57.84	9822.07
24	840	1695	405	1450	405	12	35	35	355	185	10	185	10	180	82.85	23832.05
30	860	1730	485	1100	485	12	30	30	235	265	19	265	6	820	177.56	47273.52
16	860	1610	350	1420	350	12	30	30	275	130	15	130	11	240	41.32	8012.19
20	920	1265	400	1580	400	20	35	35	355	180	13	180	14	620	108.91	15628.47
24	860	1750	515	1090	515	20	20	20	235	295	9	295	12	210	101.37	52255.22
30	820	1465	375	1035	375	25	15	15	275	155	12	155	8	870	66.38	23115.03
16	940	1360	370	1970	370	25	25	25	355	150	8	150	16	850	78.20	8526.04
20	920	1925	390	1885	390	20	20	20	235	170	17	170	16	540	70.13	14818.07
24	800	1840	520	1690	520	12	50	50	275	300	13	300	14	950	268.33	39948.21
30	820	1945	495	1265	495	25	35	35	355	275	10	275	9	320	167.48	57734.53
16	1000	1460	385	1975	385	12	40	40	235	165	17	165	11	380	68.79	9958.98
20	980	1360	455	1495	455	25	15	15	275	235	17	235	8	530	93.88	23670.84
24	940	1305	435	1630	435	20	30	30	355	215	13	215	8	710	140.04	26394.59
30	940	1020	370	1935	370	25	30	30	235	150	9	150	14	180	82.48	23244.36
16	840	1235	515	1765	515	20	35	35	275	295	18	295	9	740	161.62	23171.85
20	900	1275	435	1360	435	16	50	50	355	215	11	215	9	130	75.62	22270.22
24	860	1390	330	1955	330	25	40	40	235	110	16	110	7	780	79.03	9614.67
30	1000	1880	400	1455	400	12	25	25	275	180	10	180	8	310	99.29	30095.85
16	840	1990	430	1640	430	20	35	35	355	210	11	210	15	130	47.01	16670.80
20	840	1780	330	1895	330	16	25	25	235	110	14	110	14	190	36.15	9119.95
24	880	1525	455	1620	455	20	15	15	275	235	9	235	15	760	117.24	30548.59
30	820	1720	380	1535	380	16	10	10	355	160	12	160	9	930	36.61	25758.35
16	820	1935	500	1595	500	16	20	20	235	280	17	280	11	100	46.22	28116.52
20	980	1140	330	1575	330	20	15	15	275	110	13	110	7	320	32.34	8645.86
24	880	1905	465	1240	465	20	20	20	355	245	9	245	16	980	151.78	31635.42
30	880	1185	365	1850	365	20	10	10	235	145	18	145	11	880	25.28	24339.73
16	820	1395	500	1550	500	12	45	45	275	280	10	280	8	740	177.40	20751.65
20	960	1770	390	1415	390	20	20	20	355	170	10	170	14	480	70.93	15484.98
24	860	1225	440	1925	440	16	35	35	235	220	13	220	9	570	127.59	27090.26
30	1000	1645	485	1160	485	25	40	40	275	265	13	265	11	230	149.77	54308.46
16	800	1820	420	1235	420	12	10	10	355	200	15	200	10	990	26.22	3852.35
20	880	1980	450	1175	450	20	40	40	235	230	12	230	15	230	80.42	24285.38
24	820	1535	390	1950	390	16	40	40	275	170	16	170	9	50	59.42	21283.33
30	840	1755	455	1135	455	25	40	40	355	235	8	235	16	770	212.29	40521.50
16	960	1535	520	1320	520	16	25	25	235	300	13	300	16	410	99.95	26619.25
20	840	1840	365	1005	365	16	15	15	275	145	20	145	10	610	39.77	10329.10
24	820	1540	500	1940	500	12	35	35	355	280	14	280	6	700	192.28	39588.29
30	960	1090	505	1115	505	12	20	20	235	285	12	285	13	870	135.67	51861.13
16	960	1370	490	1510	490	12	15	15	275	270	16	270	8	850	94.54	16499.92
20	840	1455	515	1425	515	16	45	45	355	295	17	295	9	720	209.21	31706.15
24	960	1980	425	1740	425	25	30	30	235	205	8	205	6	580	115.70	25099.87

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(*continued*)

d	h	b_2	b_1	d_2	d_1	f_{ck}	t_g	t_{bp}	f_y	h	t_f	b_f	t_w	F_{Ed}	M_{Rd}	$S_{j,ini}$
30	880	1665	420	1270	420	12	15	15	275	200	20	200	7	600	84.86	32925.61
16	800	1045	450	1330	450	25	10	10	355	230	10	230	13	350	60.73	11661.95
20	800	1825	385	1000	385	20	15	15	235	165	14	165	7	270	48.40	15064.52
24	940	1440	475	1445	475	16	10	10	275	255	9	255	11	860	92.23	28746.27
30	800	1005	475	1870	475	12	30	30	355	255	13	255	11	670	185.79	47606.19
16	820	1235	495	1120	495	16	10	10	235	275	14	275	14	730	80.32	11996.20
20	800	1815	325	1520	325	20	35	35	275	105	17	105	8	210	42.62	8075.31
24	840	1965	510	1505	510	25	40	40	355	290	20	290	16	980	247.06	38952.96
30	820	1785	520	1545	520	12	45	45	235	300	13	300	8	600	233.41	59677.45
16	860	1800	495	1600	495	20	25	25	275	275	10	275	15	200	63.37	25466.50
20	960	1150	395	1480	395	16	30	30	355	175	16	175	11	480	87.39	15647.78
24	900	1780	515	1370	515	16	50	50	235	295	19	295	12	660	208.72	39775.01
30	960	1070	335	1695	335	20	30	30	275	115	20	115	16	980	61.26	14059.40
16	800	1250	495	1225	495	16	30	30	355	275	9	275	8	110	54.81	27167.63
20	840	1115	355	1405	355	20	40	40	235	135	15	135	6	210	53.32	11057.52
24	840	1220	455	1200	455	20	20	20	275	235	14	235	7	130	74.98	37050.51
30	820	1215	345	1355	345	16	50	50	355	125	16	125	7	680	146.03	15506.16
16	860	1750	420	1125	420	12	35	35	235	200	20	200	8	660	97.09	12363.51
20	840	1810	360	1785	360	12	30	30	275	140	12	140	16	640	68.94	10784.78
24	920	1680	405	1210	405	25	35	35	355	185	10	185	16	730	133.20	20761.09
30	880	1380	515	1855	515	25	45	45	235	295	19	295	6	910	270.36	54418.07
16	960	1695	345	1875	345	20	45	45	275	125	15	125	14	930	93.32	6019.57
20	920	1510	480	1015	480	16	35	35	355	260	15	260	15	90	68.70	33469.36
24	880	1135	385	1290	385	16	10	10	235	165	17	165	16	790	16.85	10202.76
30	920	1155	350	1140	350	20	45	45	275	130	10	130	7	110	84.88	18302.63
16	940	1700	490	1660	490	12	45	45	355	270	14	270	11	260	94.65	21932.53
20	940	1845	520	1385	520	12	45	45	235	300	19	300	8	500	158.26	33106.72
24	840	1555	400	1145	400	16	35	35	275	180	19	180	13	410	98.28	20600.59
30	960	1340	325	1285	325	12	35	35	355	105	18	105	15	720	80.56	12858.73
16	820	1860	340	1105	340	16	40	40	235	120	14	120	16	540	61.40	6232.21
20	840	1490	430	1685	430	16	10	10	275	210	15	210	15	370	56.50	16460.85
24	860	1055	330	1075	330	25	45	45	355	110	13	110	15	60	51.26	11037.07
30	920	1195	330	1215	330	12	50	50	235	110	18	110	7	400	101.26	13193.88
16	980	1005	440	1345	440	25	30	30	275	220	10	220	12	380	77.93	16310.44
20	940	1810	385	1335	385	16	50	50	355	165	15	165	6	270	83.69	13885.29
24	960	1880	350	1965	350	12	35	35	235	130	15	130	12	140	55.07	13997.77
30	880	1555	440	1300	440	12	40	40	275	220	8	220	6	920	189.18	34874.23
16	900	1260	465	1205	465	16	50	50	355	245	18	245	9	910	207.89	16203.68
20	900	1260	470	1665	470	12	45	45	235	250	14	250	10	500	136.68	24909.69
24	920	1650	320	1050	320	12	10	10	275	100	14	100	6	200	19.03	9736.51
30	960	1995	410	1220	410	16	10	10	355	190	19	190	9	160	67.28	33889.35
16	1000	1565	440	1275	440	12	35	35	235	220	19	220	14	960	120.69	13141.79
20	1000	1025	340	1625	340	25	15	15	275	120	12	120	12	560	37.58	8902.50
24	900	1000	420	1780	420	20	30	30	355	200	9	200	9	50	63.91	29430.41
30	960	1890	390	1805	390	25	25	25	235	170	16	170	6	950	122.16	24708.44
16	980	1010	365	1910	365	20	40	40	275	145	18	145	7	970	97.19	7301.23
20	820	1035	460	1070	460	25	15	15	355	240	19	240	7	210	66.88	27530.32
24	880	1420	355	1085	355	25	35	35	235	135	20	135	11	580	80.79	13024.55
30	800	1375	350	1440	350	20	50	50	275	130	15	130	8	480	119.53	16591.49
16	940	1310	430	1365	430	16	20	20	355	210	9	210	8	260	56.36	16263.94
20	860	1780	330	1465	330	16	30	30	235	110	18	110	10	620	49.23	7765.64
24	960	1835	415	1190	415	12	35	35	275	195	12	195	7	140	77.28	26059.01
30	960	1865	465	1945	465	25	35	35	355	245	8	245	15	150	125.99	50495.54
16	980	1920	465	1920	465	12	15	15	235	245	15	245	8	740	87.92	15202.97
20	860	1645	455	1650	455	25	25	25	275	235	14	235	8	540	108.28	24391.98
24	840	1950	485	1590	485	16	10	10	355	265	10	265	15	460	100.02	36457.86
30	900	1405	430	1835	430	12	40	40	235	210	8	210	15	340	137.17	36451.40
16	820	1995	350	1890	350	25	40	40	275	130	17	130	7	280	46.64	7319.77
20	960	1300	435	1400	435	12	10	10	355	215	18	215	14	360	59.09	17182.20
24	900	1895	320	1180	320	20	30	30	235	100	18	100	8	200	45.38	9740.79
30	920	1420	395	1295	395	25	30	30	275	175	20	175	10	300	105.00	27772.77
16	1000	1550	345	1040	345	20	10	10	355	125	15	125	6	210	25.76	5099.45
20	820	1785	465	1810	465	16	40	40	235	245	10	245	6	780	156.16	23266.38
24	820	1445	415	1880	415	16	10	10	275	195	10	195	13	240	50.15	23653.62
30	960	1160	365	1675	365	20	35	35	355	145	17	145	7	230	95.84	21088.74
16	920	1385	500	1645	500	20	25	25	235	280	13	280	16	550	111.31	22869.59
20	840	1830	350	1710	350	16	35	35	275	130	11	130	15	770	78.03	9447.25
24	980	1680	450	1930	450	20	45	45	355	230	17	230	15	950	209.53	26636.59
30	880	1255	465	1250	465	12	30	30	235	245	14	245	11	270	132.64	48521.20
16	940	1600	445	1500	445	16	30	30	275	225	20	225	7	680	109.26	15319.34

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d	h	b_2	b_1	d_2	d_1	f_{ck}	t_g	t_{bp}	f_y	h	t_f	b_f	t_w	F_{Ed}	M_{Rd}	$S_{j,ini}$
20	840	1460	500	1310	500	25	20	20	355	280	20	280	8	720	144.66	31241.74
24	880	1340	475	1900	475	20	15	15	235	255	16	255	11	240	88.65	39989.56
30	800	1670	435	1985	435	16	35	35	275	215	14	215	14	540	154.74	36395.33
16	900	1755	390	1840	390	20	35	35	355	170	12	170	13	100	36.62	12391.66
20	840	1630	510	2000	510	16	40	40	235	290	9	290	12	960	205.92	29695.63
24	980	1705	505	1815	505	12	35	35	275	285	19	285	16	810	195.51	38922.84
30	820	1665	440	1375	440	16	50	50	355	220	14	220	8	310	164.84	38002.79
16	1000	1740	475	1700	475	20	25	25	235	255	10	255	10	540	100.71	19816.10
20	960	1585	470	1045	470	12	10	10	275	250	20	250	10	1000	45.09	11534.02
24	860	1170	405	1185	405	16	15	15	355	185	12	185	11	500	71.66	22074.24
30	960	1095	460	1030	460	16	15	15	235	240	14	240	7	850	96.89	40162.25
16	900	1180	325	1020	325	16	35	35	275	105	9	105	14	480	49.88	5631.64
20	980	1720	350	1705	350	20	25	25	355	130	10	130	7	570	63.64	10453.43
24	920	1685	355	1990	355	20	10	10	235	135	12	135	10	100	26.33	14406.62
30	940	1615	425	1490	425	16	10	10	275	205	8	205	15	940	64.72	33490.26
16	980	1025	320	1245	320	20	20	20	355	100	19	100	10	90	21.54	6125.99
20	920	1955	395	1605	395	25	45	45	235	175	20	175	13	240	66.86	15073.09
24	940	1165	420	1155	420	12	15	15	275	200	16	200	12	810	43.95	17997.83
30	940	1285	450	1410	450	12	30	30	355	230	18	230	6	890	172.09	38018.65
16	920	1885	465	1080	465	25	45	45	235	245	11	245	10	590	125.56	16739.39
20	1000	1490	420	1260	420	25	45	45	275	200	13	200	13	850	149.56	16567.58
24	1000	1185	510	1570	510	20	10	10	355	290	16	290	9	720	129.39	38999.84
30	840	1465	465	1585	465	12	50	50	235	245	15	245	13	560	202.02	42325.87
16	800	1080	485	1470	485	25	50	50	275	265	16	265	8	570	143.43	18587.18
20	800	1095	400	1525	400	20	20	20	355	180	14	180	14	410	69.96	16982.82
24	860	1635	370	1635	370	20	10	10	235	150	18	150	10	230	35.30	15833.43
30	800	1230	360	1980	360	25	25	25	275	140	20	140	10	870	92.16	18936.71
16	820	1420	380	1540	380	20	20	20	355	160	10	160	16	500	58.53	9931.87
20	860	1100	465	1825	465	25	20	20	235	245	18	245	7	70	51.43	32303.96
24	940	1645	365	1680	365	12	15	15	275	145	12	145	9	370	49.49	16162.77
30	980	1300	505	1845	505	25	45	45	355	285	12	285	14	540	224.58	56022.04
16	980	1770	490	1430	490	16	45	45	235	270	10	270	15	900	181.84	18691.09
20	960	1610	335	1065	335	12	25	25	275	115	16	115	14	790	23.98	6487.58
24	920	1560	445	1460	445	12	40	40	355	225	19	225	16	440	140.42	28677.61
30	880	1520	405	1615	405	25	35	35	235	185	19	185	15	650	138.99	27885.48
16	860	1350	355	1555	355	12	25	25	275	135	16	135	11	850	37.17	5780.23
20	860	1070	495	1315	495	16	20	20	355	275	16	275	8	450	109.15	32316.43
24	860	1430	470	1610	470	20	25	25	235	250	19	250	9	850	149.75	32046.21
30	880	1765	355	1350	355	12	10	10	275	135	17	135	14	500	24.98	22333.46
16	980	1140	415	1915	415	12	40	40	355	195	9	195	14	610	117.38	12706.38
20	800	1955	495	1095	495	12	20	20	235	275	11	275	8	860	119.95	27357.55
24	840	1495	330	1905	330	16	35	35	275	110	8	110	16	520	68.05	10567.59
30	820	1965	350	1865	350	25	50	50	355	130	12	130	10	680	138.42	16448.76
16	800	1855	335	1655	335	25	30	30	235	115	11	115	13	380	42.24	6502.97
20	900	1890	485	1255	485	12	15	15	275	265	17	265	8	230	72.97	31920.90
24	800	1310	375	1170	375	20	25	25	355	155	19	155	10	220	65.79	18172.15
30	980	1850	345	1025	345	20	10	10	235	125	10	125	10	380	33.55	19864.00
16	920	1850	350	1475	350	25	50	50	275	130	17	130	14	780	96.13	6316.60
20	980	1465	365	1565	365	25	25	25	355	145	20	145	9	950	82.16	10842.46
24	900	1325	450	1995	450	16	35	35	235	230	20	230	11	420	118.13	29764.44
30	840	1685	515	1395	515	20	10	10	275	295	17	295	12	620	131.80	62673.48
16	960	1770	435	1745	435	12	40	40	355	215	14	215	6	700	135.68	14259.77
20	840	1610	470	1280	470	16	30	30	235	250	15	250	13	140	67.58	30702.52
24	1000	1260	385	1860	385	25	50	50	275	165	13	165	12	940	153.42	15796.38
30	1000	1085	380	1390	380	20	25	25	355	160	15	160	13	260	92.53	25186.92
16	900	1270	490	1230	490	12	20	20	235	270	12	270	13	360	77.08	22486.15
20	1000	1145	495	1195	495	16	20	20	275	275	12	275	11	440	103.57	32267.97
24	880	1630	345	1515	345	12	25	25	355	125	17	125	11	700	58.14	11963.72
30	980	1485	440	1755	440	20	30	30	235	220	12	220	14	60	98.31	43999.02
16	980	1035	480	1055	480	16	50	50	275	260	10	260	10	370	115.99	19441.38
20	1000	1665	320	1560	320	20	20	20	355	100	17	100	15	470	39.11	7681.13
24	800	1740	380	1820	380	20	15	15	235	160	10	160	15	980	61.82	15797.26
30	860	1970	380	1485	380	12	50	50	275	160	10	160	15	940	170.66	21201.37
16	980	1735	340	1720	340	16	50	50	355	120	10	120	8	220	50.95	6650.74

Data Availability

Data will be made available on request.

References

[1] E. CEN, 1-8 eurocode 3: design of steel structures–part 1–8: design of joints, Eur. Comm. Stand., Bruss. (2005).
[2] J.M. Fisher, L.A. Kloiber, Base plate and anchor rod design, American Institute of Steel Construction, 2006.
[3] J.E. Grauvilardell, D. Lee, J.F. Hajjar, R.J. Dexter, Synth. Des., Test. Anal. Res. Steel Column base plate Connect. High. -Seism. zones, *Struct. Eng. Rep. no. ST-04-02. Minneap. (MN): Dep. Civ. Eng., Univ. Minn.* (2005).
[4] H. Moghimi, R.G. Driver, Column demands in steel plate shear walls with regular perforations using performance-based design methods, J. Constr. Steel Res. 103 (2014) 13–22.
[5] A. Idris, A.I. Umar, Reliability analysis of steel column base plates, J. Appl. Sci. Res. 3 (3) (2007) 189–194.
[6] F. Kavoura, B. Gencturk, M. Dawood, M. Gurbuz, Influence of base-plate connection stiffness on the design of low-rise metal buildings, J. Constr. Steel Res. 115 (2015) 169–178.
[7] Y. Wang, S. Xu, H. Wang, A. Li, Predicting the residual strength and deformability of corroded steel plate based on the corrosion morphology, Constr. Build. Mater. 152 (2017) 777–793.
[8] S. Sultana, Y. Wang, A. Sobey, J. Wharton, R. Shenoi, Influence of corrosion on the ultimate compressive strength of steel plates and stiffened panels, Thin-Walled Struct. 96 (2015) 95–104.
[9] Z. Zhao, W. Wang, R. Yan, B. Zhao, Tensile capacity degradation of randomly corroded strands based on a refined numerical model, Reliab. Eng. Syst. Saf. (2024) 110512.
[10] Z. Zhao, W. Wang, R. Yan, B. Zhao, Experimental and numerical investigations on tensile capacity of corroded strands, J. Constr. Steel Res. 213 (2024) 108402.
[11] Z. Zhao, J. Liu, B. Zhao, Z. Jin, X. Jian, N. Zhang, Shear capacity of corrugated steel plates with a random corrosion damage, Thin-Walled Struct. 193 (2023) 111264.
[12] Q. Yang, B. Zhao, B. Liu, Z. Zhao, S. Mo, Influence of corrosion on loading capacity of circular concrete-filled steel tubular column, J. Constr. Steel Res. 215 (2024) 108564.
[13] J. Silva, Y. Garbatov, C.G. Soares, Ultimate strength assessment of rectangular steel plates subjected to a random localised corrosion degradation, Eng. Struct. 52 (2013) 295–305.
[14] Z. Zhang, S. Xu, B. Nie, R. Li, Z. Xing, Experimental and numerical investigation of corroded steel columns subjected to in-plane compression and bending, Thin-Walled Struct. 151 (2020) 106735.
[15] S. Xu, Z. Zhang, G. Qin, Study on the seismic performance of corroded H-shaped steel columns, Eng. Struct. 191 (2019) 39–61.
[16] X. Zhang, S. Zheng, X. Zhao, Experimental and numerical investigations into seismic behavior of corroded steel frame beams and columns in offshore atmospheric environment, J. Constr. Steel Res. 201 (2023) 107757.
[17] T. Nakai, H. Matsushita, N. Yamamoto, Effect of pitting corrosion on the ultimate strength of steel plates subjected to in-plane compression and bending, J. Mar. Sci. Technol. 11 (2006) 52–64.
[18] Y. Wang, J.A. Wharton, R.A. Shenoi, Ultimate strength assessment of steel stiffened plate structures with grooving corrosion damage, Eng. Struct. 94 (2015) 29–42.
[19] B. Nie, S. Xu, Z. Zhang, R. Gu, Experimental investigation on corroded cold-formed steel beam-columns under compression and major axis bending, J. Constr. Steel Res. 169 (2020) 106026.
[20] M. Komp, Atmospheric corrosion ratings of weethering steels–calculation and significance, Mater. Perform. 26 (7) (1987) 42–44.
[21] D.-D. NGUYEN, T.-H. NGUYEN, Reliability evaluation of 2D semi-rigid steel frames accounting for corrosion effects, J. Mater. Eng. Struct. «JMES» 9 (3) (2022) 339–353.
[22] S.-M. Nguyen, V.-L. Phan, N.-L. Tran, X.-H. Nguyen, T.-H. Nguyen, Time-dependent reliability assessment of a continuous i-shaped steel beam considering corrosion effects, Eng., Technol. Appl. Sci. Res. 12 (6) (2022) 9523–9526.
[23] T.-H. Nguyen, D.-D. Nguyen, Reliability assessment of steel-concrete composite beams considering metal corrosion effects, Adv. Civ. Eng. 2020 (2020) 1–15.
[24] T.-H. Nguyen, N.-L. Tran, V.-T. Phan, D.-D. Nguyen, Prediction of shear capacity of RC beams strengthened with FRCM composite using hybrid ANN-PSO model, Case Stud. Constr. Mater. 18 (2023) e02183.
[25] N.-L. Tran, T.-H. Nguyen, The effect of metal corrosion on the structural reliability of the pre-engineered steel frame, J. Mater. Eng. Struct. «JMES» 7 (2) (2020) 155–165.
[26] N.-L. Tran, T.-H. Nguyen, V.-T. Phan, D.-D. Nguyen, A machine learning-based model for predicting atmospheric corrosion rate of carbon steel, Adv. Mater. Sci. Eng. 2021 (2021) 1–25.
[27] D. Goldberg, Genetic Algorithms in Search, Optimization and Machine Learning, Addison-Wesley Longman Publishing Co., Inc, 1989.
[28] D. Whitley, T. Starkweather, C. Bogart, Genetic algorithms and neural networks: optimizing connections and connectivity, Parallel Comput. 14 (3) (1990) 347–361.
[29] D.J. Montana, L. Davis, Training feedforward neural networks using genetic algorithms, *IJCAI* 89 (1989) (1989) 762–767.
[30] T.-H. Nguyen, N.-L. Tran, V.-T. Phan, D.-D. Nguyen, Improving axial load-carrying capacity prediction of concrete columns reinforced with longitudinal FRP bars using hybrid GA-ANN model, Asian J. Civ. Eng. (2023) 1–11.
[31] W. Liu, Q. Liu, F. Ruan, Z. Liang, H. Qiu, Springback prediction for sheet metal forming based on GA-ANN technology, J. Mater. Process. Technol. 187 (2007) 227–231.
[32] Y. Zhang, G. Pan, B. Chen, J. Han, Y. Zhao, C. Zhang, Short-term wind speed prediction model based on GA-ANN improved by VMD, Renew. Energy 156 (2020) 1373–1388.
[33] S. Deshwal, A. Kumar, D. Chhabra, Exercising hybrid statistical tools GA-RSM, GA-ANN and GA-ANFIS to optimize FDM process parameters for tensile strength improvement, CIRP J. Manuf. Sci. Technol. 31 (2020) 189–199.
[34] M. Khandelwal, D.J. Armaghani, Prediction of drillability of rocks with strength properties using a hybrid GA-ANN technique, Geotech. Geol. Eng. 34 (2) (2016) 605–620.
[35] E. Amoosoltani, A. Ameli, F. Jabari, S. Asadi, Employing a hybrid GA-ANN method for simulating fracture toughness of RCC mixture containing waste materials, Constr. Build. Mater. 272 (2021) 121928.

[36] Q.-V. Vu, S. Tangaramvong, T.H. Van, G. Papazafeiropoulos, Hybrid GA-ANN and PSO-ANN methods for accurate prediction of uniaxial compression capacity of CFDST columns, Steel Compos. Struct. 47 (6) (2023) 759–779.
[37] F. Wald, Resistance and stiffness model of column bases by component method, *Konferencja. Węzły podatne w konstrukcjach metalowych i zespolonych. Warszawa,* vol. 24, p. 25.
[38] A. Alwosheel, S. van Cranenburgh, C.G. Chorus, Is your dataset big enough? Sample size requirements when using artificial neural networks for discrete choice analysis, J. Choice Model. 28 (2018) 167–182.
[39] E.M. Golafshani, A. Ashour, A feasibility study of BBP for predicting shear capacity of FRP reinforced concrete beams without stirrups, Adv. Eng. Softw. 97 (2016) 29–39.
[40] I. M. Nikbin, S. Rahimi, H. Allahyari, A new empirical formula for prediction of fracture energy of concrete based on the artificial neural network, Eng. Fract. Mech. 186 (2017) 466–482.
[41] K. Zorlu, C. Gokceoglu, F. Ocakoglu, H. Nefeslioglu, S. Acikalin, Prediction of uniaxial compressive strength of sandstones using petrography-based models, Eng. Geol. 96 (3-4) (2008) 141–158.