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INFLUENCE OF IN-FILLED CONCRETE STRENGTH AND STEEL TUBE THICKNESS ON THE STRENGTH CAPACITY CFST COLUMN-RSM MODELLING APPROACH

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ABSTRACT. In CFST composite column, the increase in the independent variables includes grade of concrete, steel tube thickness and confinement factor causes improvement in the strength capacity of the column according to their impact and interaction. However, to design the column to serve the desired function, the interaction and the influence of those parameters combinations on the strength capacity of CFST column need to be established. The present paper presents the RSM modeling approach to study the influence of concrete strength and steel tube thickness in the strength capacity of the CFST column. Two factors central composite design (CCD) was used to design the experiments and the response was the strength capacity of the CFST column. Based on the design of experiments (DOE), the CFST columns were tested, significance of each parameter was assessed by means of analysis of variance (ANOVA), response surface plot, Pareto chart and contour plot. Because the value of the predicted R^2 of the proposed response was near to 9.90%, the response model was very realistic to determine the strength capacity of the CFST column. The ANOVA results were revealed that the effect of steel tube thickness on the strength capacity of CFST column was significant (P-value < 0.05) and the effect of concrete strength was insignificant (P-value > 0.05). The results of Pareto chart analysis also exhibited the thickness of the steel tube is the key parameter in determining the strength CFST column and the standardized effect of the parameter was higher.

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1. INTRODUCTION

In the new era, the in-filled steel tubular columns or concrete filled steel tubular (CFST) columns have been extensively utilized in the modern construction projects because of their high ductility and large energy absorption capacity [1-3]. Since the steel tube positioned in the outer exerted aignificant confinement pressure to the in-filled concrete, enhanced the concrete compressive strength, consequently, the dynamic properties of the CFST column improved. Hitherto, several researches have been carried out on CFST member exposed to full compression and the key parameters were material properties and applied load. It has been recognized that the hoop tension provided by the steel tube keeps the concrete in the tri - axial state and enhanced the deformation capacity of the section [4].

Through experimental investigation, Nardin and El Debs [5] found that the increase in the concrete strength boosted the ductile performance of the column. You-Fu Yang and Lin-Hai Han [6] established that the curvature and the slenderness value of the slender column are the key parameters in influencing the column stiffness and strength. Mursi and Uy [7] stated that the column strength can be altered by changing the cross-sectional shape of the CFST section [6, 7]. Very recently Yansheng Du et al. [8] made an attempt to understand the influence of the cross-sectional slenderness ratio on the performance of CFST and the test results was revealed that the confining pressure developed by the columnists become feeble as the D/t ratio of the column increased. The test results of Shiming Zhou [9] demonstrated that the CFST column with lower thickness could not able to develop its upper yield strength because of the local buckling. From the detailed literature survey, it can be understood that the concrete strength and the steel tube thickness are the chief parameters determining the structural behavior of the CFST column subjected axial compression. Although, there have been researches related to influence of concrete strength, and steel tube thickness have been carried out on an axial compression column, the key parameters which is significantly influence the strength capacity of the column need to be established. Among the various statistical analysis, Design of Experiment (DOE) is a distinctive technique to correlate the experimental results with respect to the independent variables. DOE technique optimizes the experiments, establish the relationships between experimental parameters variables, develop an mathematical equation, and finally provide the optimum response. Response Surface Methodology (RSM) is the statistical technique of DOE, provide an idea us understand the effects if process variables on the responses [10]. From the vast literature study, it has been found that the application of RSM in the area of structural engineering, particularly in the field of CFST column is not yet carried out. In order to fill this research gap, RSM modelling based investigation was carried out to study the influence of concrete strength and steel tube thickness on the strength capacity of CFST column.

2. Response Surface Method

In the mid of 19^{th} century, RSM was evolved 1, still, it is an excellent tool used to design the experiments [10]. It is well documented that the linear regression analysis and RSM are having a strong relationship. It is a combination of statistical and mathematical techniques to establish the relation between the independent process variables and one or more response [10]. If the output of the any response influenced by several parameters, RSM can be effectively in that place to establish the interaction of process variables on the output. In RSM, the Central Composite Design (CCD) is a technique used to establish the experiments and the number of experiments to be performed can be discovered by Eq. 2.1:

$$N = 2^k + 2k + c. \tag{2.1}$$

Here, k is the number of input parameters or independent variables [10]. For a nonlinear system, the second-order polynomial equation (Eq. 2.2) will be used to establish the responses and to define the relationship between the process variables as well. The advantage of the second-order polynomial equation is having more flexibility

$$Y = B_0 + \sum_i^k B_i X_i + \sum_i^k B_{ii} X_i^2 + \sum_{ij}^k B_{ij} X_i X_j + E, \tag{2.2}$$

where, Y is predicted response (strength of CFST column), B_0 is intercept, B_i is linear (first order) co-efficient, B_{ii} is quadratic (second order) co-efficient, B_{ij} is the co-efficient of interaction effect, X_i and X_j is the process variables, and E is the random error associated. Generally the difference of the predicted R2 and adjustable-R^2 are used to ascertain the precise and accuracy of the response.

2.1. **Factors, levels and specimen details.** The factors which are influencing the experiment output and these levels are needed to describe to establish the experiments. Generally the levels of the process variables may be more than two. From the response, the effects of concrete strength and the thickness of steel tube on the strength of CFST column evaluated. The factors of the presents study response is 2 and their levels are 3 with eight points at axis and the five points at mid, as shown in Fig. 1. For response, thirteen runs (p unique tests) were considered and the details of the thirteen columns are presented in Table 1.

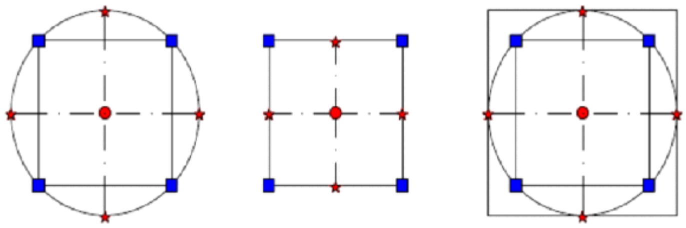


FIGURE 1. Central composite design – two factors model

TABLE 1. Factors and their levels

Parameters	Coding	Factors level		
		-1	0	+1
Response 1				
Concrete strength	X_1	$40N/mm^2$	$50N/mm^2$	$60N/mm^2$
Steel tube thickness	X_2	3.6mm	4.5mm	5.4mm

3. MATERIALS, FABRICATION AND TEST METHOD

3.1. **Materials.** Circular hollow tube confirming to 1161-1998 was used in this study to cast the CFST member. The peripheral diameter of the tube was $114.6mm$ and the height of the column maintained as $300mm$ for all the tests. For Response, the steel tube having three different thicknesses ($3.6mm$, $4.5mm$ and $5.4mm$) was used and the other material properties were same. Coupons test was carried out to determine the real yield strength of the hollow section. At the age of 28 days, the concrete having cube strength of $35N/mm^2$, $40N/mm^2$,

$50N/mm^2$ and $60N/mm^2$ and $64N/mm^2$ was used as an in-filled concrete. According to the methodology suggested in IS 10262 concrete mix designs were prepared and the water to binder ratio of the design mixture was 0.35 to 0.43.

3.2. **Specimen fabrication and experimental setup.** The steel tube having a height of 300mm machined and the steel tubes was faced in the lathe to obtain even cross sectional surface and to avoid the load eccentricity. The dusts, rubbles and other volatile material present inside of the steel tube was thoroughly cleaned and steel brush was used to achieve the cleaning. Once the inside of the tube cleaned, the concrete was filled in the steel tube and the filled concrete layers were rigorously vibrated to avoid the honey comb and segregation. The in-filled steel tubes were subjected to curing in room temperature for 28 days. Compression testing machine was utilizing to tests all the columns and the tests were instrumented with LVDTs and dial gauges to measure the deformation in all direction of the columns.

4. RSM Modelling for Strength Capacity of CFST Column

To understand the properties of concrete strength and steel tube thickness on the strength capacity of CFST column and to predict the strength capacity of the column with different parameters, central composite design (CCD) process was considered in the present study. The obtained response through CCD was expressed in second-order polynomial equation (Eq. 4.1) and the obtained results using second-order polynomial equation are presented in Table 2.

$$\begin{aligned} Y_{fck-t} &= 103 - 0.8X_1 + 286X_2 + 0.0031X_1^2 - 28.6X_2^2 + 2.08X_1X_2 \\ &\qquad (or) \\ Y_{fck-t} &= 103 - 0.8f_{ck} + 286t_s + 0.0031f_{ck}^2 - 28.6t^2 + 2.08f_{ck}t \end{aligned} \tag{4.1}$$

Here, Y_{fck-t} is the strength capacity of the column considering concrete strength-steel tube thickness.

The probability plots of the residual fit and histogram of the response is presented in Fig. 2. From Fig. 2, it is worthy to note that the residuals are populated very near to the centre line and shows the results were uniformly distributed. Moreover, the Fig. 1 also shows the correctness of the least-squares fit. Analysis of variance (ANOVA) of the RSM models is very similar to regression analysis;

TABLE 2. Comparison of experimental and predicted strength capacity using RSM

Test No.	Specimen designation	Concrete strength (N/mm^2) (X1)	Steel tube thickness (mm) (X2)	Actual strength capacity (kN)	Predicted capacity (kN)	Actual / Predicted
1	C-50-5.4	50	5.4	1348	1342.8	1.004
2	C-50-4.5	50	4.5	1256	1246.6	1.008
3	C-60-3.6	60	3.6	1135	1174.4	0.966
4	C-40-5.4	40	5.4	1275	1235.7	1.032
5	C-50-3.6	50	3.6	1046	1104.1	0.947
6	C-35-4.5	35	4.5	1108	1114.2	0.994
7	C-40-3.6	40	3.6	1028	1034.4	0.994
8	C-60-5.4	60	5.4	1452	1450.5	1.001
9	C-64-4.5	64	4.5	1381	1371.4	1.007

represent the interface between the output and the process variables. In addition, ANOVA can be used to examine the association between the output and the process variables. From ANOVA, it can be understood that the P-value for the Y_{fck-t} are less than 0.0001, revealing that the response model is highly precise. The adequacy and the appropriateness of the response can be confirmed through predicted R^2 and the variance between the adj.-R^2 and pre.R^2 should be less than 20% [10]. The proportions of variance (R^2) of the regression model are summarized in Table 3. Since the variance between the adj.-R^2 and pre.R^2 of response was near to 9.99% (See Table 3), the response model was very realistic to calculate the CFST column strength.

TABLE 3. Proportion of variance (R^2)

Responses	R^2 (%)	Adjustable R^2 (%)	Predictable R^2 (%)	Adj.R^2-Pred.R^2 (%)	P-Value
Strength Capacity Y_{fck-t}-X_1X_2	97.6	95.86	85.94	9.92	<0.0001

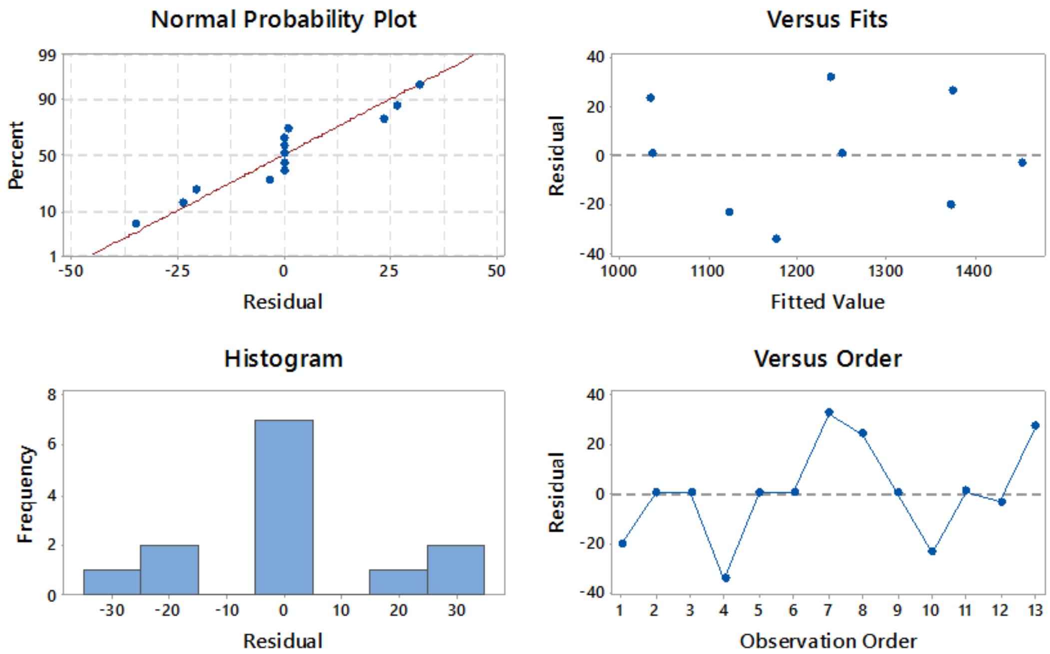


FIGURE 2. Normal probability residual plot for Y_{fck-t}

4.1. **Surface plot and contour analysis.** To understand the influence of each pair of independent variables on the response, three dimensional response surface plots were prepared to describe the regression response surface model. The surface plots obtained through plotting the response (z direction) against the two independent variables (x and y direction). Fig. 3 present the surface plot of Y_{fck-t}. From Fig. 3, it is worthy to note that the column strength increased as the concrete strength and the thickness of steel tube increased. Therefore, the maximum strength can be obtained with higher concrete strength and thickness and the minimum strength can be attained with lower concrete strength and thickness.

4.2. **Pareto analysis.** Even though, the increase in the strength of concrete and thickness improved the strength capacity of the CFST column, the most significant factor among the two factors needs to be determined. Pareto Chart is a type of bar graph represents the significance of factors/independent variables influencing the responses. The Pareto chart of responses Y_{fck-t} is presented in Fig. 4. From Fig. 4 it can be understood that the chief parameters determining the strength capacity of CFST column is both strength of concrete and thickness

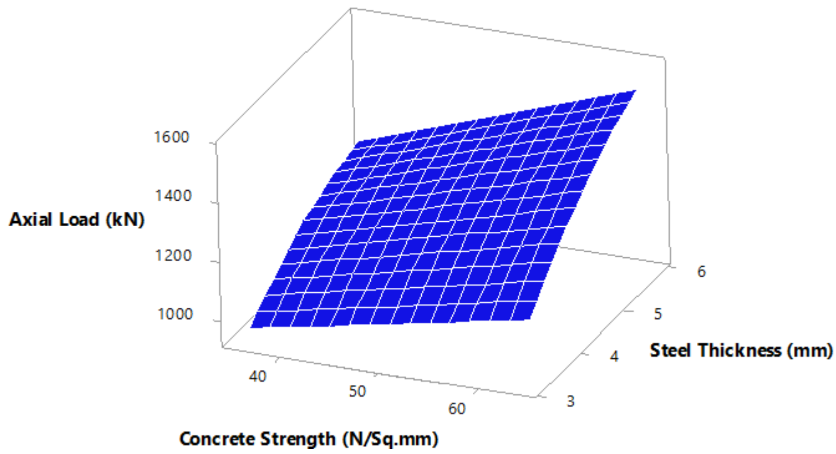


FIGURE 3. Response surface plot of Y_{fck-t}

of steel tube. However, while prioritizing both strength of concrete and thickness of steel tube, the effects of the thickness of steel tube was significant when compared to the concrete strength. From the response, it can be concluded that the effect of the steel tube thickness is the key parameters to progress the column strength and the increase in the in-filled concrete strength may exhibit little improvement in the CFST column strength.

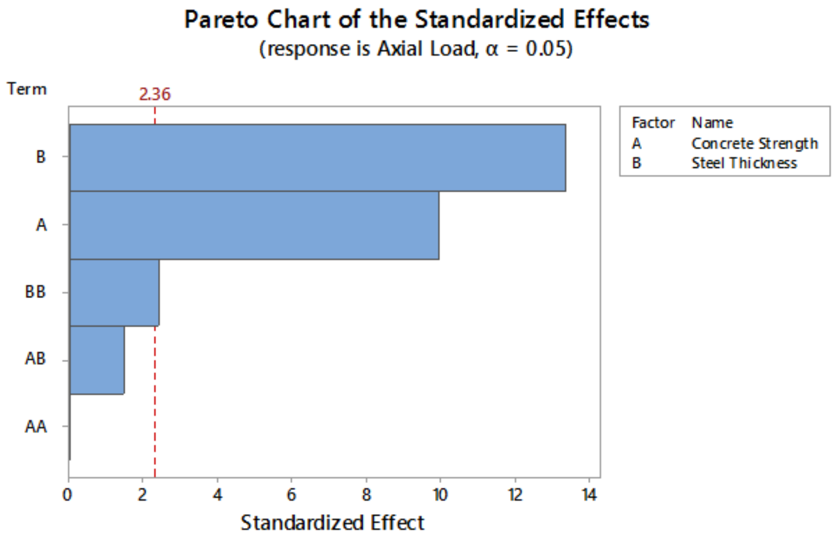
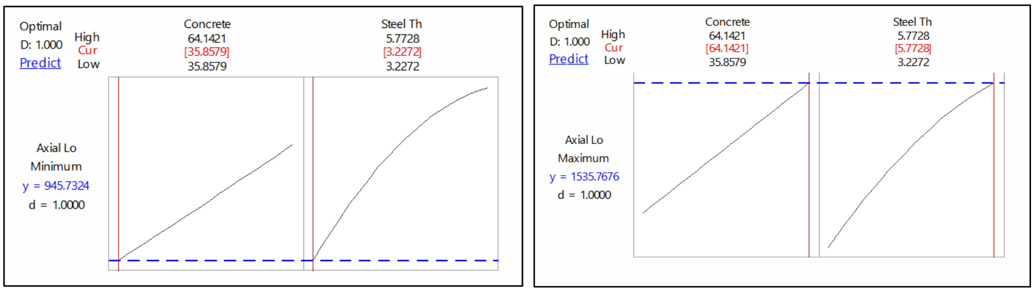


FIGURE 4. Pareto chart for Response–I Y_{fck-t}

4.3. **Optimization of response.** The optimized strength capacity (response) is presented in Fig. 5. In Fig. 5, the y represent the highest column strength 'd' represent the desirable combination of process variables extending from 0 to 1, where zero indicate the undesirable grouping and one indicate the desirable combination or ideal mode. As shown in Fig. 5, the optimal amount of concrete strength and steel tube thickness to achieve a minimum strength (945KN) is 35.85N/$mm2$ and 3.55mm, respectively. To achieve a maximum strength of 1536kN, the optimal value of concrete strength and steel tube thickness is 64.14N/mm^2 and 5.77mm, respectively. From Fig. 5, it is seen that the parameters strength of concrete and steel tube thickness influenced the column strength; however, the impact of concrete strength has less influence on column strength. In addition, for the small amount of increase in thickness of steel tube, the strength y of the column increased significantly.



(A) Minimum strength (B) Maximum strength

FIGURE 5. Response optimization plots

5. CONCLUSION

In the present study, the effects of concrete strength and the thickness of tube on the strength capacity of the CFST column was investigated using RSM modeling approach. To establish the relation between the independent variable, column strength was considered as a response. Based on the design of experiments obtained through CCD, columns were tested. Concerning the RSM modeling, the obtained response through CCD design of experiments was expressed in second-order polynomial equation. Because the variation between the pre.R^2 and the adj.R^2 of the proposed response was near to 9.90%, the response model was very realistic to calculate the column strength. Furthermore, the predicted strength capacity using RSM were shown good correlation between the actual strength. The results of ANOVA exhibited that the influence of steel thickness on the column strength was significant (P-value < 0.05) and the effect of concrete strength was insignificant (P-value > 0.05). Pareto chart analysis also exhibited that the steel thickness is the key parameters in determining column.

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