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Optimization by RSM of Reinforced Concrete Beam Process Parameters

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Abstract Reinforced concrete beams must have an adequate safety margin against bending and shear forces. Therefore, it will perform effectively during its service life. The aim of this work is to optimize the parameters of strength reinforced concrete beam, such as strength concrete, of stirrup spacing, and stirrup inclined presenting the techniques of characterization. An optimization of the reinforced concrete beam parameters was developed using the Response Surface Methodology (RSM). A flexural test was performed on reinforced concrete beam, and an empirical relationship was developed and used to predict the optimized strength reinforced concrete beam parameters.

Keywords: *reinforced concrete beam, stirrups spacing, shear, flexural, response surface methodology (RSM), mechanical properties*

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1. Introduction

Reinforced concrete beams are important structural elements; it will perform effectively during its service life only when there is sufficient safety margin against bending and shear forces. At the ultimate limit state, the combined effects of bending and shear may exceed the resistance capacity of the beam causing tensile cracks. The shear failure is usually sudden, without sufficient advanced warning [1]. Normally, the inclined shear cracks start at the middle height of the beam near support at approximately 45°and extend toward the compression zone. Any form of effectively anchored reinforcement that intersects these diagonal cracks will be able to resist the shear forces to a certain extent. In practice, shear reinforcement is provided in three forms; stirrups, inclined bent-up bars and combination system of stirrups and bent-up bars [2]. Noor et al. [3] presented several results of experimental investigation on six reinforced concrete beams in which their structural behavior in shear was studied. The research conducted about the use of additional horizontal and independent bent- up bars to increase the beam resistance against shear forces. The main objectives was to study the effectiveness of adding horizontal bars on shear strength in rectangular beams, the effectiveness of shear reinforcement, and determining the optimum amount of both types of shear reinforcement to achieve a shear capacity similar to that of a normal links system. From experimental investigation of the system, it was found that the use of independent horizontal and bent-up bars as shear reinforcement were stronger than conventional shear reinforcement system. Ahmed et al. [4] studied the effect of the size of specimen on the flexural tensile strength of concrete. They concluded that the concrete member size has a significant effect. They proposed an equation incorporating the effect of size of concrete for predicting the flexural tensile strength of concrete. Altun et al. [5] studied the mechanical properties of concrete with different dosage of steel fibers. Experimental tests indicated that beams with SF dosage of 30 kg/m^3 exhibited a remarkable increase in strength when compared to RC beams without steel fibers. The same study also showed that increasing the fiber dosage to 60 kg/m^3 adds only a small improvement to the beam toughness.

In present work, the aim is to optimize the parameters of strength reinforced concrete beam, such as strength concrete, of stirrup spacing, and stirrup inclined presenting the techniques of characterization. A flexural test was performed on reinforced concrete beam. An empirical relationship (RSM) was developed and used to predict the optimized strength reinforced concrete beam parameters.

2. Methods and Materials

2.1. Experimental Details

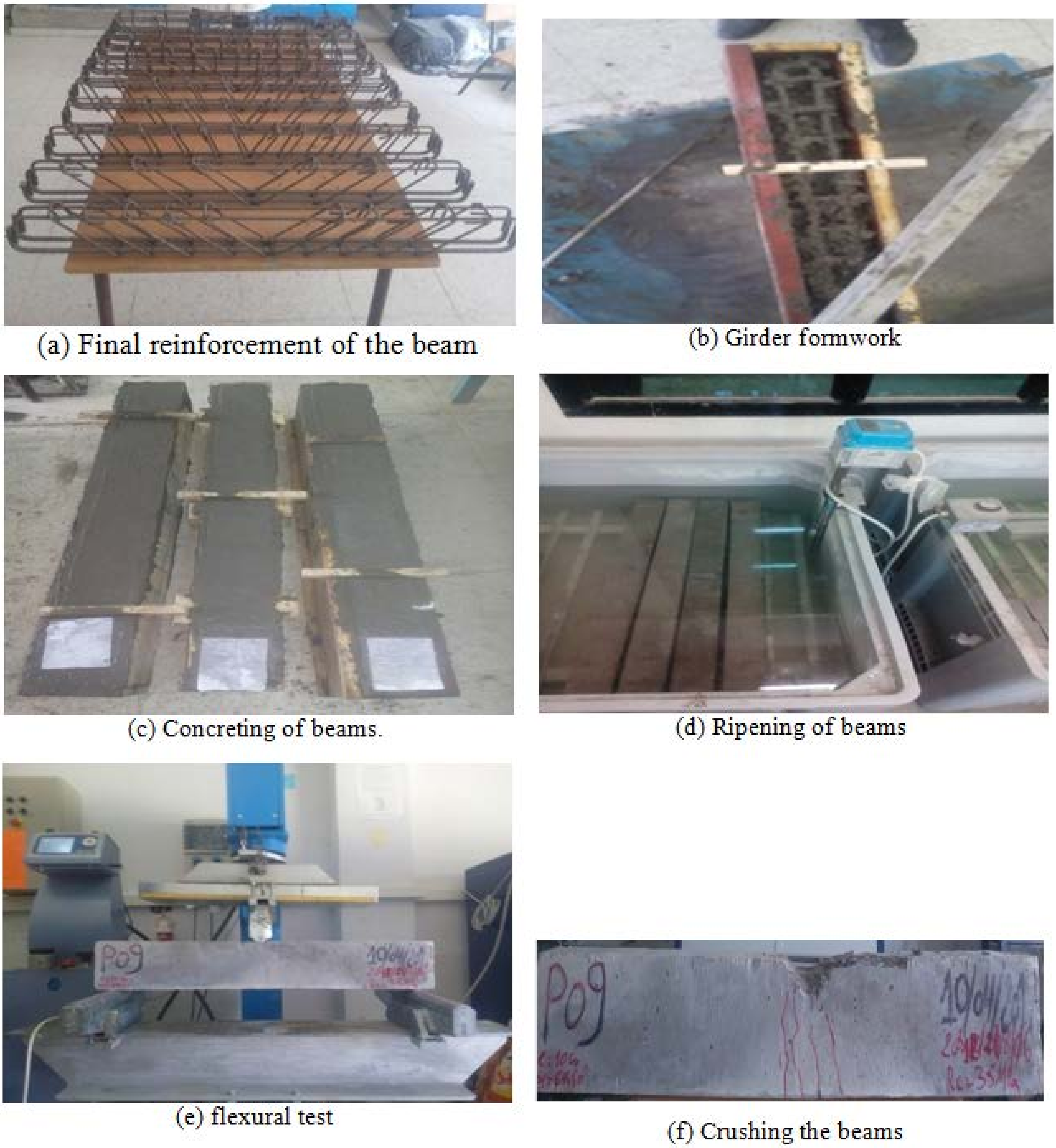
The details of the fabricated beams are shown in Figure 1. All beams were 200 mm of height, 150 mm of width, and overall 960 mm of long. Fifteen beams had 12 mm diameter as main longitudinal reinforcement lower, and had two 8 mm diameters longitudinal reinforcement upper. The variables in these beams are the concrete compressive strength, the spacing vertical stirrups and inclined of vertical stirrups. The details of theses parameters and their levels are resume, in the Table 1.

2.2. Materials Properties

The cement used in this work was Ordinary Portland Cement (OPC) for all test specimens. For this study, three mixes are produced according to concrete strength. The used quantities of materials are listed in Table 1. Concrete compressive strength after 28 days was 25 MPa, 27.5 MPa and 30 MPa. Figure 2 illustrates strength compressive after the compressive test. The cube specimen is of size 150 × 150 × 150 mm. The compressive strength of concrete is done by using compressive testing machine.

Table 1. Reinforced concrete beam parameters and their levels

Parameters	Notation	Unit	–1	0	+1
Strength of concrete (*SC*)	A	MPa	25	27.5	30
Stirrup Spacing (*SS*)	B	cm	7	10	13
Stirrup Inclined (*SI*)	C	degree	45	67.5	90



(a) Final reinforcement of the beam

(b) Girder formwork

(c) Concreting of beams.

(d) Ripening of beams

(e) flexural test

(f) Crushing the beams

Figure 1. Experimental details

3. Response Surface Methodology (RSM)

The influences of parameters on the strength of reinforced concrete beam, can be studied using the Response Surface Methodology (RSM), which is a collection of statistical and mathematical techniques useful for analyzing and developing the effect of several independent variables (known as the factors) on dependent variable (response), in the goal to optimize this response [6,7].

The present work emphasizes on the optimization of various parameters that influence the strength reinforced concrete beam. Through investigation using the RSM with selecting the three-factor and three-level factorial design matrix. The levels of reinforced concrete beam parameters and the experimental design matrix are shown in Table 1 and Table 2 respectively. Flexural measurements, was recorded using the flexural test at the middle of beams.

For this study, three mixes are produced according to concrete strength. Concrete compressive strength after 28 days was 25 MPa, 27.5 MPa and 30 MPa. Figure 2 illustrates strength compressive after compressive test.

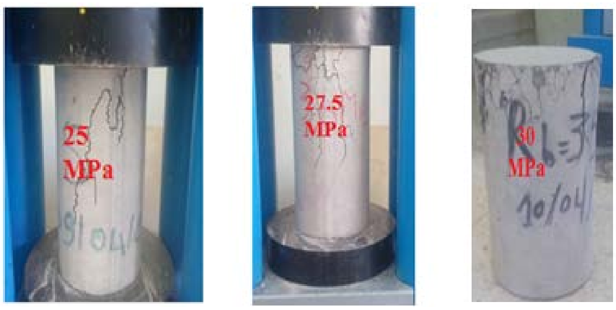


Figure 2. Strength compressive after compressive test

Table 2. Designed matrix and experimental results

Expt. N°	Strength of concrete (MPa)	Transversal reinforcement (Ø 6)		Longitudinal reinforcement	Responses	
		Stirrups inclined (°)	Stirrups spacing (cm) [cm]		Ultimate load (KN)	Failure mode
1	25	67.5	10	2 HA 8 sup 2 HA 12 inf	71.66	Flexural
2	30	45	13	2 HA 8 sup 2 HA 12 inf	74.21	Flexural
3	27.5	67.5	13	2 HA 8 sup 2 HA 12 inf	69.99	Shear
4	25	45	07	2 HA 8 sup 2 HA 12 inf	31.29	Shear
5	27.5	67.5	10	2 HA 8 sup 2 HA 12 inf	75.26	Flexural
6	27.5	45	10	2 HA 8 sup 2 HA 12 inf	74.20	Flexural
7	27.5	67.5	07	2 HA 8 sup 2 HA 12 inf	73.90	Flexural
8	27.5	90	10	2 HA 8 sup 2 HA 12 inf	67.97	Shear
9	30	67.5	10	2 HA 8 sup 2 HA 12 inf	70.06	Flexural
10	30	90	07	2 HA 8 sup 2 HA12 inf	75.11	flexural
11	25	90	13	2 HA 8 sup 2 HA 12 inf	44.83	Shear

3.1. Developing of Empirical Relationship

Based in RSM, an empirical relationship (equation or model) between the process parameters and output response can be developed, and used for reaching an optimum response value.

For our study kind, a second order polynomial (regression) equation is tried in the form [8]:

$$y = b_0 + \sum_{i=1}^{n} b_i X_i + \sum_{i=1}^{n} b_{ii} X_i^2 + \sum_{i<j}\sum b_{ij} X_i X_j + \varepsilon \quad (1)$$

Where ε represents the noise (residual) or error observed in the response y and n are the factor's number.

So for our case, three factors A, B and C, the selected polynomial could be expressed as:

$$\begin{aligned} y = {} & b_0 + b_1 A + b_2 B + b_3 C \\ & + b_{12} AB + b_{13} AC + b_{23} BC \\ & + b_{11} A^2 + b_{22} B^2 + b_{33} C^2 \end{aligned} \quad (2)$$

Where b_0 is the average value (intercept) of the response and b_1, b_2, b_3, …., b_{33} are the regression coefficients [8,9].

In order to find the regression coefficients, small central composite design technique (small CCD) was used in this work. With statistical software Design Expert 7.0, we are obtained all of them.

4. Results and Discussion

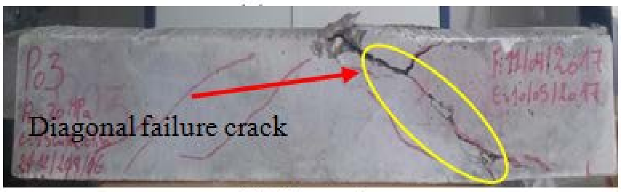
The crack patterns and failure modes of beams for the 11 beams are presented in Figure 3. As expected, the initial stiffness and the overall response of the specimens differ according to the strength of concrete, spacing of stirrup, and incline of the stirrup. The modes of failure for all specimens are listed in Table 2, while typical failure modes are shown in Figure 3. Two different modes of failure were observed:

Diagonal splitting failure occurred when the diagonal cracks propagated initially towards the load and then towards the support (show beam 4 and 11). This type of failure was less brittle compared to the shear failure modes of other specimens.

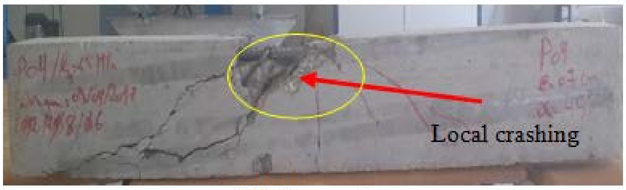
1. Shear failure occurred after diagonal cracks propagated in the shear span causing high stresses to be developed in the compression zone above the tip of the cracks, which lead to an explosive failure (show beam 3 and 8) .
2. Flexural cracks, these cracks form at the bottom near the midspan and propagate upwards (show beam 1, 6 and 9).
3. The curves obtained for all beams are in agreement with the theoretical curves available in the literature, where the overall behavior is divided into three main phases. The first elastic phase corresponds to the behavior of non-cracked elements. The second corresponds to the behavior of cracked sections, while the third relates to the plasticization of tensile steels (Figure 4).

(a) Beam 1

(b) Beam 2

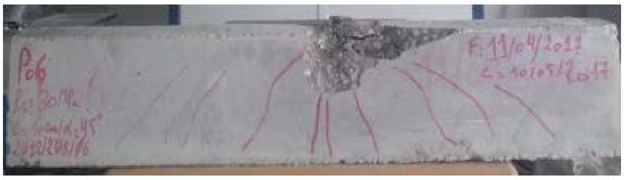


(c) Beam 3

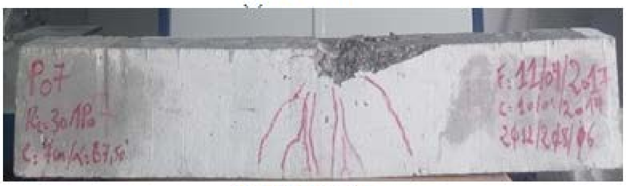


(d) Beam 4

(e) Beam 5



(f) Beam 6



(g) Beam 7

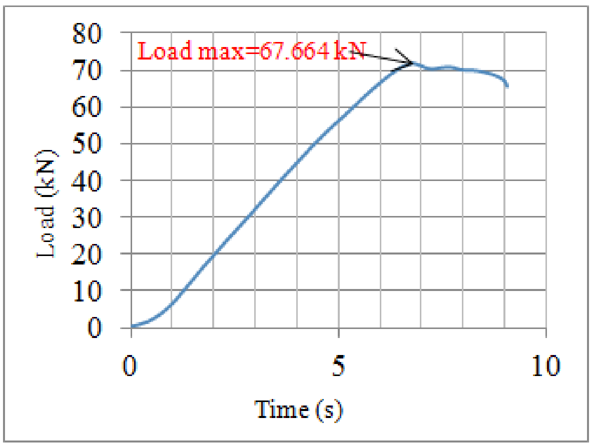
(h) Beam 8

(i) Beam 9

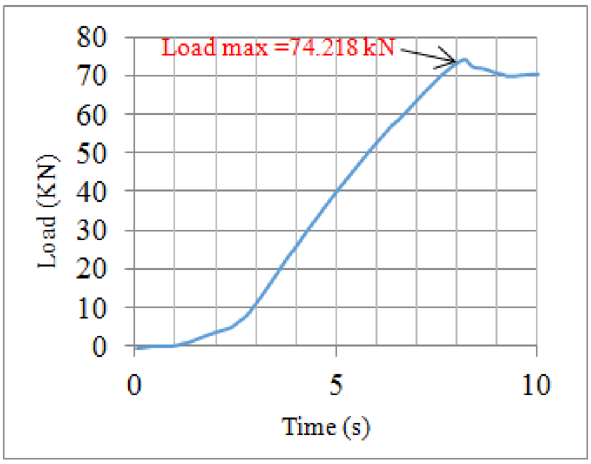
(j) Beam 10

(k) Beam 11

Figure 3. Crack patterns and failure modes of beams

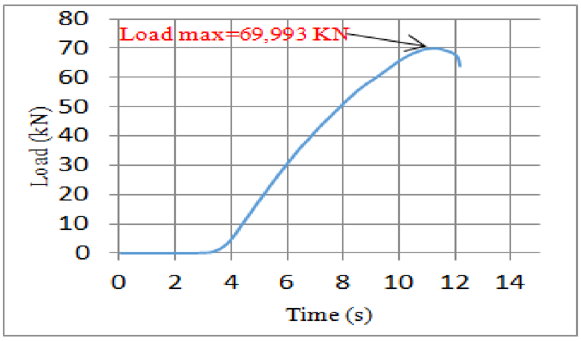


(a) Beam 1

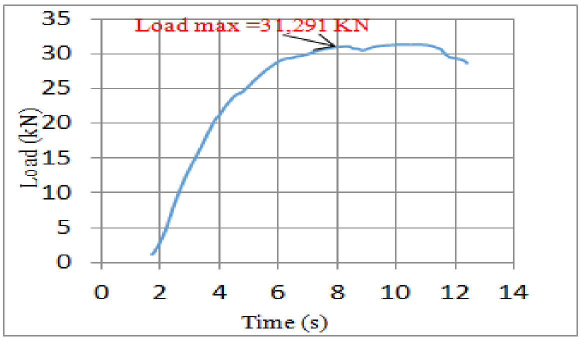


(b) Beam 2

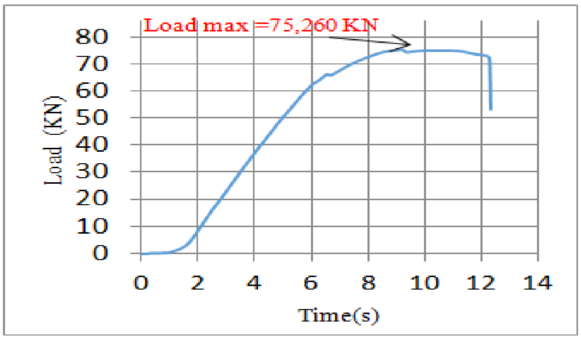
Figure 4. a-b.



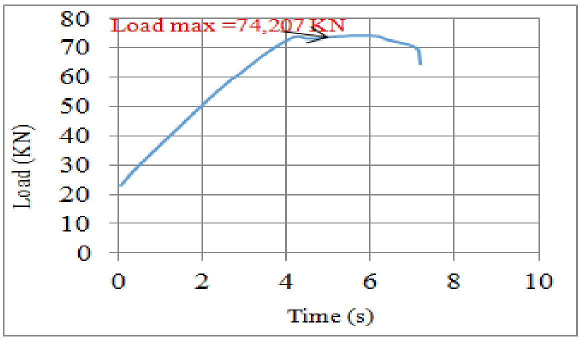
(c) Beam 3



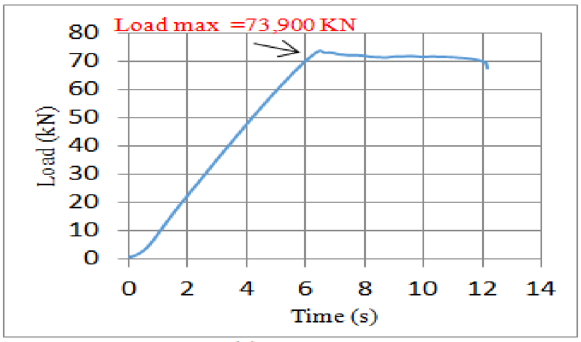
(d) Beam 4



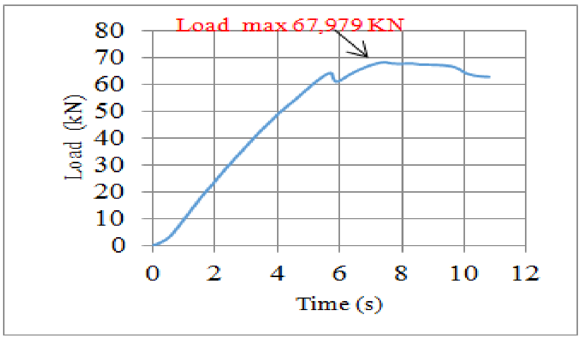
(e) Beam 5



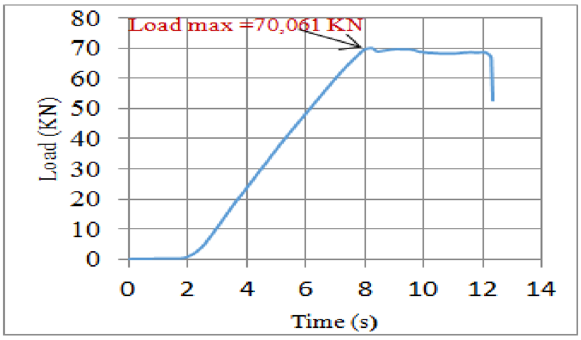
(f) Beam 6



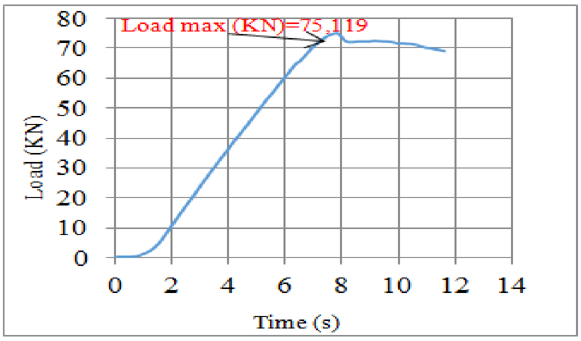
(g) Beam 7



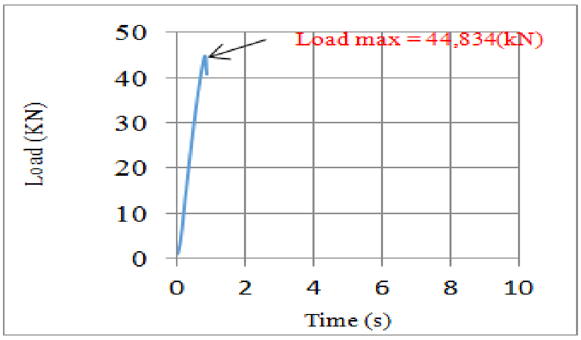
(h) Beam 8



(i) Beam 9



(j) Beam 10



(k) Beam 11

Figure 4. Load deflection response for specimens

4.1. RSM Result

4.1.1. Test for Significance of Regression (ANOVA)

To check the adequacy of the developed empirical relationship, an analysis of variance (ANOVA) is carried out, and the probability of significance of each coefficient was determined by “Prob>F”. For our study, the confidence level is set at 95 %. In these condition, “Prob>F” less than 0.05 indicates that the model terms are significant. Table 3 reports the ANOVA results for the flexural test (*FT*). Figure 5 shows the correlation between experimental values and predicted values for each response. It is clearly observed that each experimental value well adapted to its predicted value. These results confirm that the above model is adequate. According to this model, the final empirical relationships to estimate the flexural test, were developed, and given as:

$$Y_{Fs} = 75.07 - 0.8A - 1.95B - 3.11C + 1.51AB + 3.12AC - 10.87BC - 3.97A^2 - 2.88B^2 - 3.74C^2. \quad (3)$$

4.1.2. Flexural Test: (Coded Value)

The observed response (Flexural strength) of reinforced concrete beam compared with the predicted responses calculated from the model and their respective correlation graphs are presented in figure 5. The value of ‘R^2’ for the above developed relationships is found to be in the range of 95–99%, which indicates a high correlation between the experimental values and the predicted values.

Table 3. Design-expert ANOVA

Source	Sum of Squares	*df*	Mean Square	F – Value	P – Value Prob > F	
Model	878.06	9	97.56	842.98	< 0.0001	significant
A-Strength of concrete	1.28	1	1.28	11.10	0.0207	
B- stirrup spacing	7.63	1	7.63	65.95	0.0005	
C- stirrup inclined	19.39	1	19.39	167.57	< 0.0001	
AB	3.03	1	3.03	26.21	0.0037	
AC	12.97	1	12.97	112.09	0.0001	
BC	157.64	1	157.64	1362.05	< 0.0001	
A^2	41.20	1	41.20	355.94	< 0.0001	
B^2	21.76	1	21.76	188.06	< 0.0001	
C^2	36.55	1	36.55	315.80	< 0.0001	
Residual	0.58	5	0.12			
Lack of Fit	0.58	1	0.58			
Pure Error	0.000	4	0.000			
Cor Total	878.64	14				
Std. Deviation	0.34		R^2		0.9993	
Mean	70.83		Adj. R^2		0.9982	
CV (%)	0.48		Pred. R^2		0.8519	
PRESS	130.10		Adeq. precision		109.294	

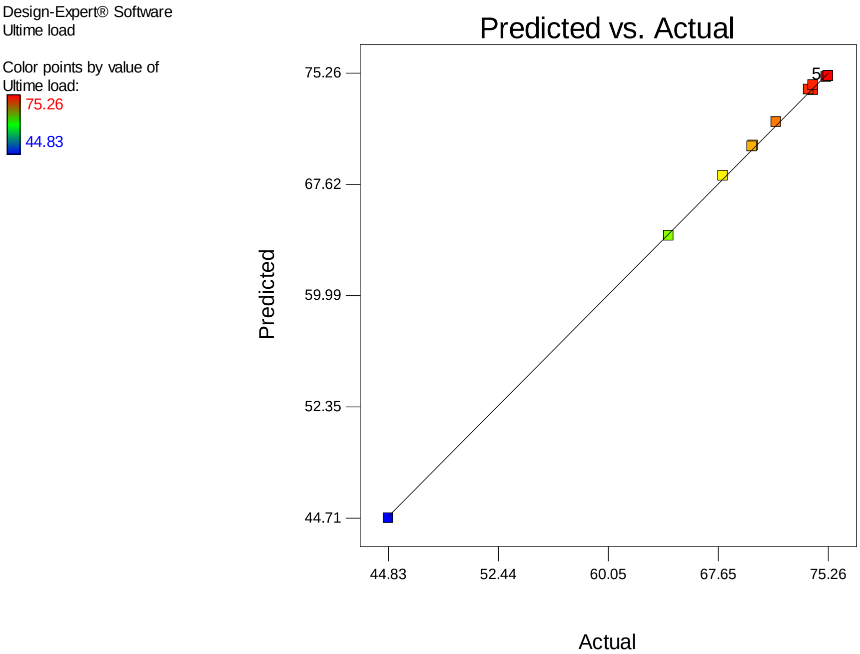
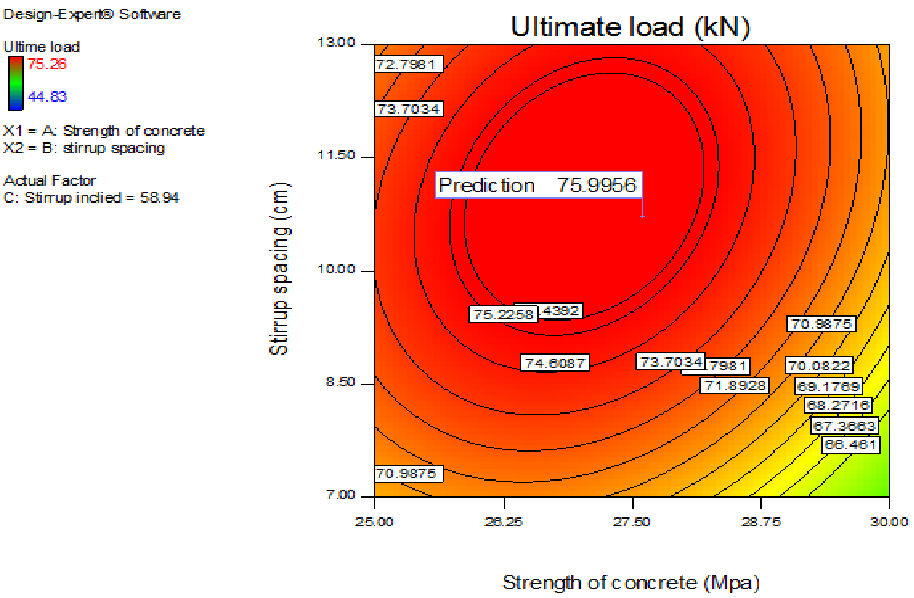
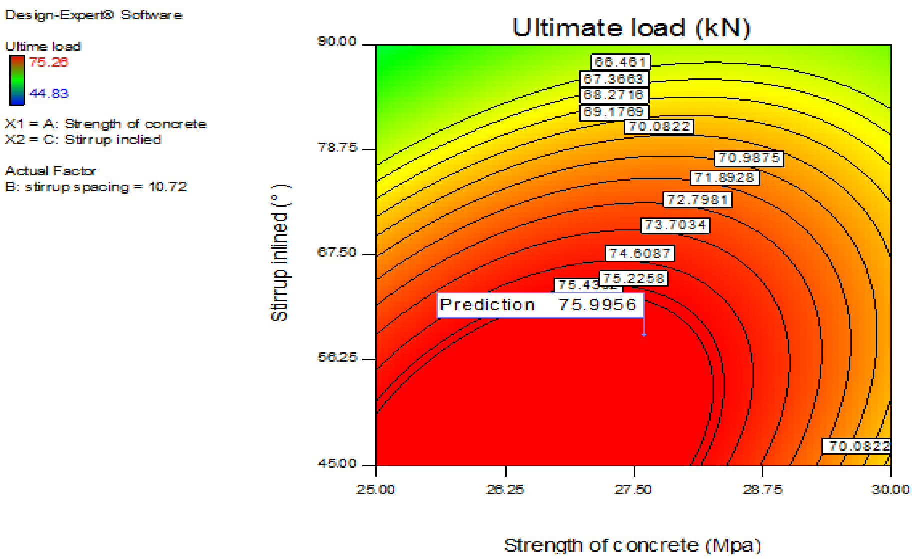


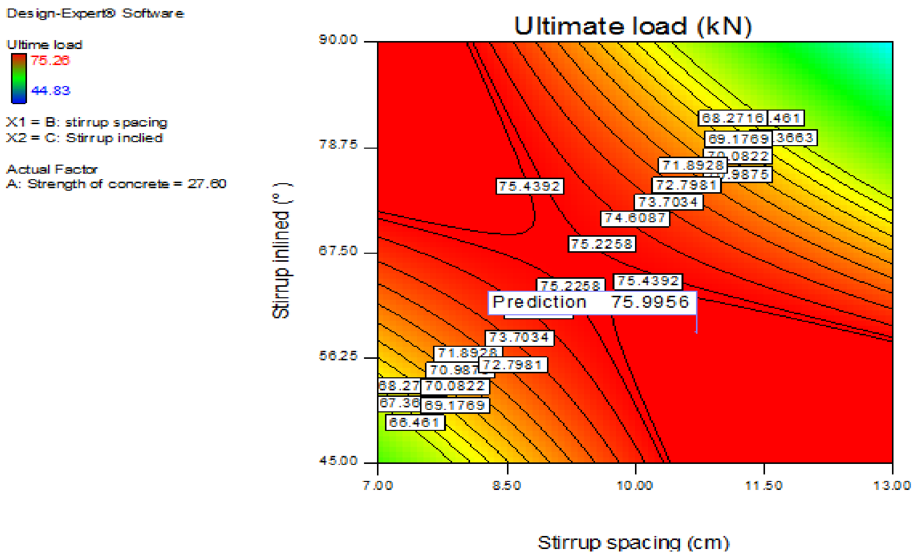
Figure 5. Normal probability plot of experimental versus predicted ultimate load



(a) Stirrup spacing = 10.71 cm, strngth concrete =27.60 MPa



(b) Stirrup inclined=58.94°, strngth concrete =27.60 MPa



(c) Stirrup spacing = 10.71 cm, stirrup inclined=58.94°

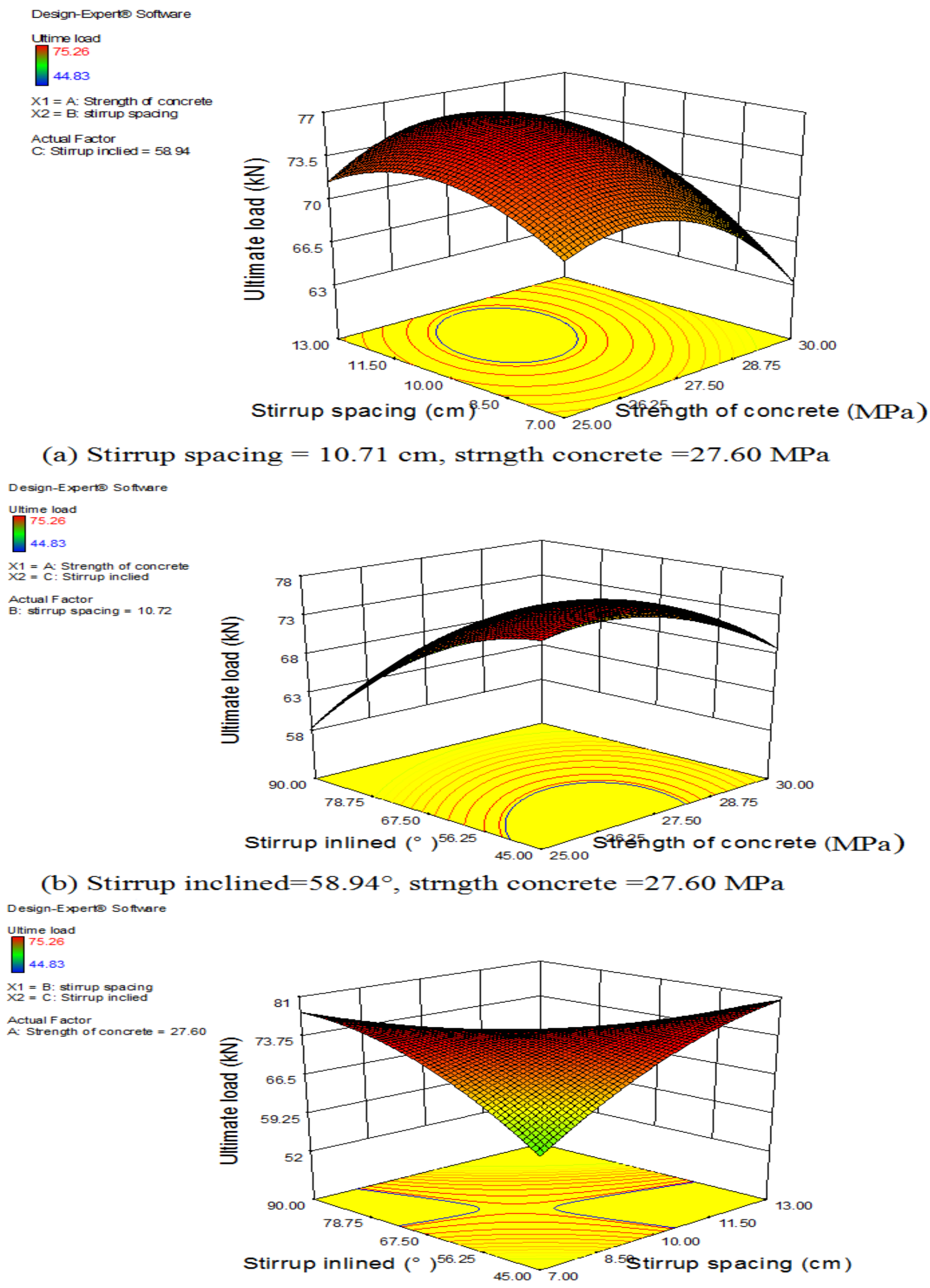
Figure 6. Contour graphs for reinforced concrete beam

4.1.3. Parameters Effect on the Response

In the present investigation, the process parameters corresponding to the maximum flexural strength are considered as optimum after analyzing the contour graphs by using Design Expert 7.1. Contour plots show a distinctive circular shape indicative of possible independence of factors with response. A contour plot is produced to display the region of optimal factor settings. For second order response surfaces, such a plot can be more complex than the simple series of parallel lines that can occur with first order models. Once the stationary point is found, it is usually necessary to characterize the response surface in the immediate vicinity of the point. Characterization means, identifying whether the found stationary point is a maximum response or minimum response or a saddle point. Figure 6.a exhibits almost a circular contour, which suggests independence of factor. It is relatively easy by examining the contour plots of Figure 6.c.

This change in the flexural strength is more sensitive to change in spacing between stirrups than to change in incline of stirrups and strength of concrete. The response surfaces are clearly revealing the optimal response point. From the contour plots and response surfaces, it can be inferred that, the flexural strength increases with the increase in spacing between stirrups, strength of concrete and incline between stirrups to a limiting level. However, when the limiting level crosses, the flexural strength decreases.

The maximum flexural strength is obtained from the response surface and contour plots by using stirrups spacing of 10.71 cm, with strength of concrete of 27.60 MPa, and stirrups inclined of 58.94°.



(a) Stirrup spacing = 10.71 cm, strngth concrete =27.60 MPa

(b) Stirrup inclined=58.94°, strngth concrete =27.60 MPa

(c) Stirrup spacing = 10.71 cm, stirrup inclined=58.94°

Figure 7. Response graphs for reinforced concrete beam

5. Conclusion

In this study, flexural tests on short beam sections with different parameters were carried out to investigate the flexural behavior considering the stirrup spacing, the strength of concrete, and stirrup inclined. Findings obtained through the experiments are as follows:

1. During the tests up to the ultimate strength, it was possible to clearly distinguish the three phases of the overall behavior of a reinforced concrete beam (elastic, service cracked and plastic).

2. The incline of the stirrup is contributing more on strength of flexural, and it is followed by spacing between stirrup, and strength of concrete.

3. The maximum flexural strength is obtained in the case of the spacing between stirrups equal to 10.71cm, with strength of concrete of 27.60 MPa, and incline between stirrups of 58.94°.

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