MODELLING ULTIMATE LOAD CAPACITY OF STEEL FIBRE REINFORCED CONCRETE CORBELS: PART 1.FORMULATION

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Abstract

In this study, ultimate load capacity of steel fibre reinforced concrete corbels have been formulated using nonlinear regression. For the formulation of the proposed empirical expression, an extensive literature survey has been conducted and experimental studies have been gathered to form an experimental database. Total of 84 tests from 6 seperate studies have been used for the formulation of ultimate load capacity of sfrc corbels. The correlation coefficient was found to be quite high (R2=0.95) which shows that the proposed formulation fits very well with experimental results.

Keywords: steel fibre reinforced concrete, corbels, ultimate load, nonlinear regression.

1. Introduction

Corbels are structural elements primarily used in reinforced concrete and precast structures. The main function of corbels is to transfer vertical and horizontal loads to the members to which they are connected (Figure 1) [1]. Corbels can be the overhanging portion of beam with a small span length. Their shear span to effective depth ratio (a/d) is less than unity [2].

Strength and ductility of corbels should be increased to improve their mechanical behavior. This improvement is possible either by increasing the percentage of transverse steel (generally achieved by horizontal stirrups) or by adding steel fibre to the reinforced concrete as secondary shear reinforcement replacing stirrups [3].

The aim of the current study is to propose an empirical formula for ultimate load capacity of steel fibre reinforced concrete (sfrc) corbels based on experimental studies and to determine significant parameters which are effective on the ultimate load capacity.

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2. Use of SFRC In Reinforced Concrete Corbels

Use of steel fibres increases the bond between steel and concrete and also tensile, compressive, flexural and fractural properties of the concrete. It was concluded from experimental studies of reinforced and pre-stressed beams that using steel fibres instead of horizontal stirrups or addition of steel fibres achieved efficient reinforcement effect to prevent shear failure.

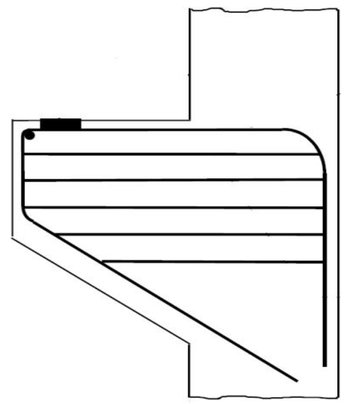

Fig. 1 Geometric Configuration and Typical Reinforcement Detailing for a Corbel

Previous studies related with corbels have concluded that reinforced concrete corbels which include only steel fibres as secondary reinforcement have almost same load carrying capacity with ones in which horizontal stirrups are used against shear failure. Therefore use of steel fibre facilitates the fabrication of corbels because of easier placement of it as compared to placement of horizontal stirrups [4]. Therefore use of steel fibre facilitates the fabrication of corbels because of easier placement of it as compared to placement of horizontal stirrups.

Steel fibres allow a corbel to experience large deflections after achieving ultimate load without a dramatic loss in load carrying capacity or demonstrating a sudden and brittle failure.

Another improvement achieved by steel fibres is the change of the failure mode of the corbel from being sudden and catastrophic to a slower and ductile mode. According to the results of former studies, sufficient amount of steel fibre provided an elastic – plastic behavior for corbels and the corbel failed in flexural mode in place of diagonal splitting mode [5]. Transformation of failure modes is an important feature in structural safety point of view, especially in earthquake zones.

3. Previous Studies about SFRC Corbels

Several experimental studies were carried out about analysis of steel fiber reinforced corbels. One of these studies was performed by Fattuhi [4]. In this sudy the aim was to determine the extent of improvement in the shear properties of concrete corbels reinforced with steel fibers being subjected to vertical loading only. The efficiency of the steel fibers was also examined when the corbel’s shear span to depth ratio and fiber content were changed. It was found from the investigation that the first crack and ultimate strength and toughness of concrete corbels were considerably improved by the addition of steel fibers and the efficiency of the steel fibers at ultimate loads increased with a decrease in the shear span to depth ratio.

A series of studies on SFRC corbels was carried out by Fattuhi and Hughes [5, 6, and 7]. They investigated the change of the failure mode from being sudden and catastrophic to a more gradual and ductile mode. Since the earlier results had showed that when an adequate volume of steel fibers was added to concrete, an almost elastic-plastic behavior was recorded, and the mode of failure changed from being diagonal splitting to flexure. Therefore, the purpose of the study is to provide further information on the safety aspect and to investigate the strength and ductility of corbels reinforced with different volumes of main bars and tested at different shear span to depth ratios. As result of the investigation, it was confirmed that the maximum strength and ductility of reinforced concrete corbels are improved considerably by the addition of steel fibers and showed that the improvement in ductility depends on the volume of main bars and the shear span to depth ratio.

Column load effect on SFRC corbels was investigated by Fattuhi [8]. The results of their studies showed that ultimate load carried by the corbel is not affected significantly from the loading of column or symmetric side corbel. However existence of column load can retard the formation of initial cracks.

For determining the most important parameters which influences the strength of SFRC corbels and finding a more general equation for the ultimate load of the corbels, an experiment was implemented by Fattuhi [9]. His study provided additional data useful in the development of more general design criteria for determining the strength of fiber reinforced concrete corbels subjected to vertical loading only.

In the other experiment of Fattuhi [10], flexural strength of SFRC corbels was investigated and flexural and truss models were used in an attempt to predict the load carrying capacities of corbels failing in flexure. It was concluded from the experiment that failure mode of corbels can be changed from being sudden and brittle to a ductile mode. Effective parameters on the transformation of failure modes are shear span to depth ratio, amount of steel fibres and main bars. Amount of steel fibres also have positive effect on the crack width and it tends to reduce the size of crack width.

Ultimate load investigations of SFRC corbels for the geometrical configuration different from his previous studies (trapezoidal corbel configuration) were investigated by Fattuhi [11]. Experimental studies showed that besides the addition of steel fibers improve the strength and ductility of corbels, no apparent effect of fiber length to corbel depth ratio on fiber efficiency, and consequently on strength of corbels.

Campione, Mendola and Mangiavillano [1] studied the flexural behavior of fibrous reinforced corbels and suggested simple analytical expressions for bearing capacity considering the shear contribution due to steel reinforcements and fibers.

4. Previous Proposed Formulations for Ultimate Load Capacity of SFRC Corbels

Fattuhi et al. [9] proposed a practical empirical formulation based on experimental results which finds ultimate load of both RC and SFRC by considering some parameters which influence the mechanical behavior of corbels. The expression of the formula is;

$$V_u = k_1 bh(f_{ct})^{k_2}(\frac{a}{h})^{k_3}(\frac{f_y}{f_{cu}})^{k_4}(\frac{d}{h})^{k_5}(r)^{k_6} \quad (1)$$

where, k_1 = 57.292, k_2 = 0.315, k_3 = -0.812, k_4 = -0.049, k_5 = 0.678 and k_6 = 0.626

Fattuhi also developed two models et al. [10], namely flexural and truss model, for predicting ultimate load of SFRC corbels whose failure mode is dominated by flexural behaviour.

5. Nonlinear Regression Technique

Nonlinear Regression (NR) is a form of regression analysis in which one estimates the coefficients of a nonlinear model that is intrinsically nonlinear, that is, cannot be linearized by suitable transformation. The use of NR begins with the choice of a nonlinear model. The user of NR regression software must specify the particular nonlinear equation to be estimated. The coefficients in NR must be found by trial and error, in an iterative solution which requires the initial estimates of the coefficients termed as start values [12].

The primary idea of nonlinear regression is the same with one of linear regression. Both of them relate a response Y to a vector of input variables $x = (x_1, ..., x_k)^T$. The characteristic feature of nonlinear regression is that the prediction equation changes nonlinearly with respect to one or more unknown inputs. Linear regression can be used to construct only emprical model. However nonlinear regression comes up when it is predicted that the predictors and the response are related with each other by a specific functional form. A nonlinear regression model has the form

$$Y_i = f(x_i, q) + e_i \quad , \quad i = 1, ..., n \quad (2)$$

where the Y_i are responses, f is is a known function of the covariate vector, $x_i = (x_{i1}, ..., x_{ik})^T$ and the parameter vector $q = (q_1, ..., q_p)^T$ and e_i are random errors. The e_i is usually assumed to be uncorrelated with mean zero and constant variance [13].

6. Proposed Model and Comparison of the Model with Existing Experimental Results

For nonlinear regression modeling process, an experimental database was used, taken from experimental studies carried out by Fattuhi and Hughes [5-10]. 84 sfrc corbel test results were considered to propose the formula. Several input parameters which can influence the mechanical behavior of sfrc corbels were considered. As a consequence of the nonlinear regression studies, the following formulation was proposed:

$$V_u = 0.04226 bh(\frac{d}{a})^{0.8323}(f_{ct})^{0.3344}(0.01(\frac{A_s}{bh}))^{0.5903} \quad (3)$$

where b and h are width and height of the corbel in mm respectively, f_{ct} is the splitting tensile strength of fibrous concrete in MPa, $\frac{d}{a}$ the reciprocal of the shear span to depth ratio and A_s is sectional area of main reinforcement. The resulted ultimate load carrying capacity of sfrc corbel is in kN.

When compared to the formulation which is stated in section 4 of this paper, the formulation proposed in this study simpler and more practical. Necessity to less input parameters as compared to other proposed formulations is another advantage of the new formulation.

The results of the formulation are compared with the experimental results which were used for modeling process and a very good fit was observed given in Figure 3.

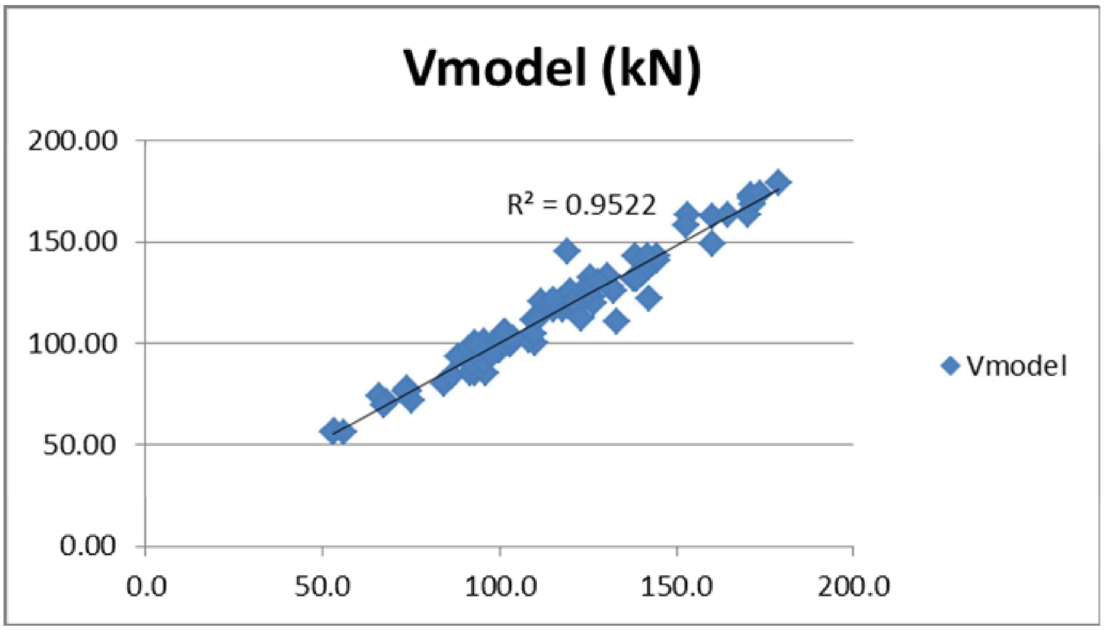

Fig. 2 Goodness of Fit of the Proposed Model

Correlation coefficient (R^2) of the new formulation is 0.952, mean and coefficient of variation of V_{exp}/V_{cal} is 1.00 and 0.057 respectively. On the other hand, Correlation coefficient (R^2) of the Fattuhis's formulation given in Eq (1) is 0.949, mean and coefficient of variation of V_{exp}/V_{cal} is 1.00 and 0.058 respectively. The statistical values of both formula are nearly same. However the formulation proposed in this study is more simple and needs less input parameters.

7. Conclusion

As a consequence of the study, a general formulation was produced for ultimate load capacity of steel fibre reinforced concrete corbels. The model is simpler and more practical as compared to other formulations used in the literature and its statistical outputs allow to be used for obtaining the ultimate load safely.

When the formulation was analyzed in detail, it is observed that splitting tensile strength of concrete is efficient on the ultimate load. This situation can be expected due to improvement of tensile properties of the concrete by addition of steel fibres.

Corbels are usually characterized by their shear span to depth ratios. Since they are short and deep structural members. The proposed formulation also includes the reciprocal of this important ratio for the corbel.

To sum up, the empirical formulation proposed in this study can be effectively used to calculate ultimate load capacity of steel fiber reinforced corbels.

Notations

a : shear span of corbel

A_s : area of main tension steel

b : width of corbel

d : effective depth of main bars

f_{ct} : splitting tensile strength of the concrete

f_{cu} : cubic compressive strength of the concrete

f_y : yield strength of main bars

h : depth of corbel section

V_u : ultimate load carrying capacity of corbel

r : ratio of sectional area of reinforcement to corbel cross section

References

[1] Campione, G., Mendola, L. L., Mangiavillano, M. L. Steel Fiber-Reinforced Concrete Corbels: Experimental Behavior and Shear Strength Prediction. American Concrete Institute, Structural Journal, 2007. p. 570-579. Volume 104. No.5

[2] Ersoy, U., Özcebe, G., Tankut, T.; *Reinforced Concrete*. Middle East Technical University Press, 2006. ISBN 9786054362172

[3] Campione, G. Performance of Steel Fibrous Reinforced Concrete Corbels Subjected to Vertical and Horizonal Loads. Journal of Structural Engineeing, ASCE, 2009. p. 519-529. ISSN 0733-9445/2009/5

[4] Fattuhi, N. Sfrc Corbel Tests. Structural Journal, American Concrete Institute, 1987. p. 119-123.

[5] Fattuhi, N., Hughes, B. Reinforced steel fiber concrete corbel with various shear span-to-depth ratios. ACI Materials Journal, 1989. p. 590–596. Volume 86. No.6.

[6] Fattuhi, N., Hughes, B. Reinforced steel and polypropylene fiber concrete corbel tests. The Structural Engineer, London, 1989. p. 68-72. Volume 67. No.4.

[7] Fattuhi, N., Hughes, B. Ductility of reinforced concrete corbels containing either steel fibers or stirrups. ACI Structural Journal, 1989. p. 644-651. Volume 86. No. 6.

[8] Fattuhi, N. Column-load effect on reinforced concrete corbels. Journal of Structural Engineeing, ASCE, 1990. p. 188-197. ISSN 0733-9445/90/0001-0188.

[9] Fattuhi, N. Strength of SFRC corbels subjected to vertical load. Journal of Structural Engineeing, ASCE, 1990. p. 701-718. ISSN 0733-9445/90/0003-0701.

[10] Fattuhi, N. Strength of FRC Corbels in Flexure. Journal of Structural Engineeing, ASCE, 1994. p. 360-377. ISSN 0733-9445/94/0002-0360.

[11] Fattuhi, N. Reinforced Corbels with Plain and Fibrous Concretes. ACI Structural Journal, 1994. p. 530-536. Volume 91. No. 5.

[12] Christensen, R. *Analysis of variance design and regression.* CRC Press,1996. ISBN 9780412062919

[13] Gordon, K.,S. Nonlinear regression, Encyclopedia of Environmetrics. John Wiley & Sons, Ltd, Chichester, 2002. p.1405–1411. Volume 3.