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Predicting the Shear Strength of Corbels

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ABSTRACT: The point loads generating from precast concrete beams must often be supported by corbels in the vicinity of supporting columns. In practice, it is difficult to determine the behavior of such short and deep cantilevers. This study aims at proposing a new design equation for predicting the shear strength of corbels. Several parametric studies are carried out on an experimental database of corbels. The specimens that exhibited corbel end failure and flexural tension failure are disregarded in this study. It is apparent that the proposed design equation gives accurate predictions of the shear strength of corbels.

Keywords : Corbels, shear strength

ÖZET: Prefabrike betonarme kirişlerden gelen tekil yükler, kolonlara yakın bölgelerde kısa konsollar tarafından taşınmaktadır. Pratikte, kısa konsolların davranışını belirlemekte zorluklar vardır. Bu çalışmada, kısa konsolların kesme dayanımlarını belirlemek için yeni bir tasarım denklemi geliştirilmiştir. Kısa konsol kenar göçmesi ve kısa konsol eğilme göçmesi ile göçen konsollar bu çalışmanın dışında bırakılmıştır. Deney veri-tabanı üzerinde pek çok parametrik çalışma yapılmıştır. Parametrik çalışmalar sonucu bulunan tasarım denklemi deneysel veri-tabanı üzerinde uygulanmıştır. Her bir numune için önerilen tasarım denkleminin belirlediği kesme dayanımının gerçek kesme dayanımına oranı bulunmuş ve bunların ortalamaları alınmıştır. Tablo 1'den de görüldüğü üzere önerilen denklem kısa konsolların kesme dayanımlarını mühendislik açısından yeteri yakınsaklıkla belirlemektedir.

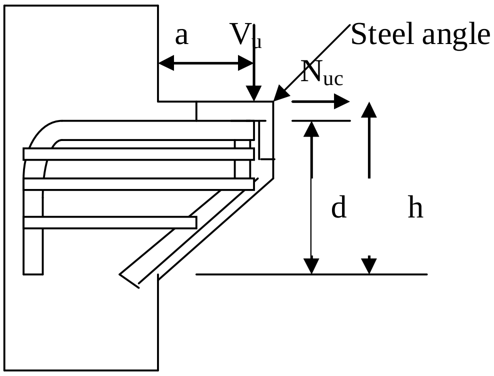
Introduction

Brackets such as shown in Figure 1 are commonly used in precast construction for supporting precast beams at the columns. When they extend from a wall, rather than from a column, they are called corbels, although the two terms are often used interchangeably. Kriz and Raths (1965) carried out an extensive test program on corbels. From their studies, seven failure mechanisms are identified .

1. Corbels exhibit flexural tension failure when excessive yielding of the flexural reinforcement causes the concrete to crush at the inclined end of the corbel. Extremely wide flexural cracks are generated.
2. Corbels exhibit shear compression failure when diagonal splitting develops along the diagonal compression strut after the formation of flexural cracks.
3. Corbels exhibit sliding shear failure when a series of short and steep diagonal cracks interconnect and the corbel separates itself from the column face.
4. When the load is applied too close to the free end of the cantilever, a splitting failure along poorly anchored flexural reinforcement can result.
5. Corbels can exhibit bearing failure when the bearing plates are too small or very flexible and the concrete underneath the loading is severely cracked.
6. Corbels can exhibit failures as a combination of several different types of failure modes when a horizontal force N_u is existent along with the gravity load V_u. This can occur in reality due to dynamic effects on crane girders, shrinkage, creep, or temperature shortening of restrained precast concrete beams attached to the corbel.

Corbels may exhibit anchorage failures. This type of failures are very detrimental because the strut mechanisms can only form if the horizontal component of the force in the strut mechanism can be transferred to the main reinforcement near the free end of the corbel. The cracking mechanisms of corbels are discussed in detail elsewhere. (Gündeş (Bakır) P., 1995).

Figure 1: Typical reinforced concrete bracket; loads and reinforcement



In this study, the specimens that exhibited corbel end failure are disregarded, and those which failed by yielding of the reinforcement are not analyzed here. The test data for the corbel specimens are given in Table 1.

Development of the design equation

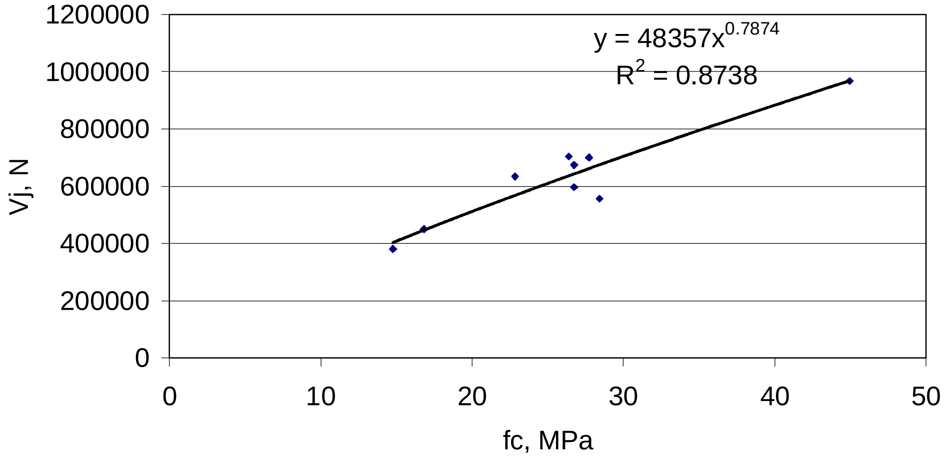
In order to determine the factors influencing the shear strength of corbels, several parametric studies are carried out on an experimental database. The details of these parametric studies are explained below:

Concrete cylinder strength

The parametric study carried out on the experimental database in Figure 2, shows that there is a close relationship between the concrete cylinder strength and the shear strength of corbels as shown in Eq. (1).

$$V \approx 48357 f_c^{0.787} \tag{1}$$

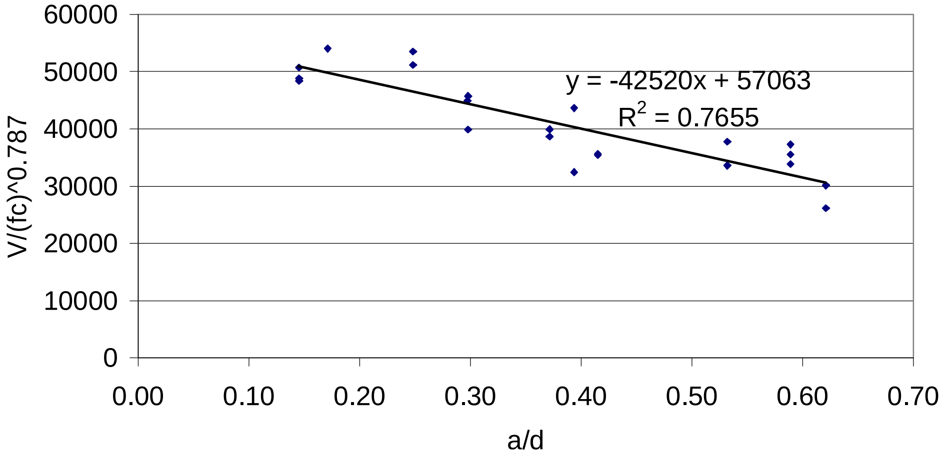
Figure 2: The influence of the concrete cylinder strength on the shear strength of corbels



The influence of a/d ratio

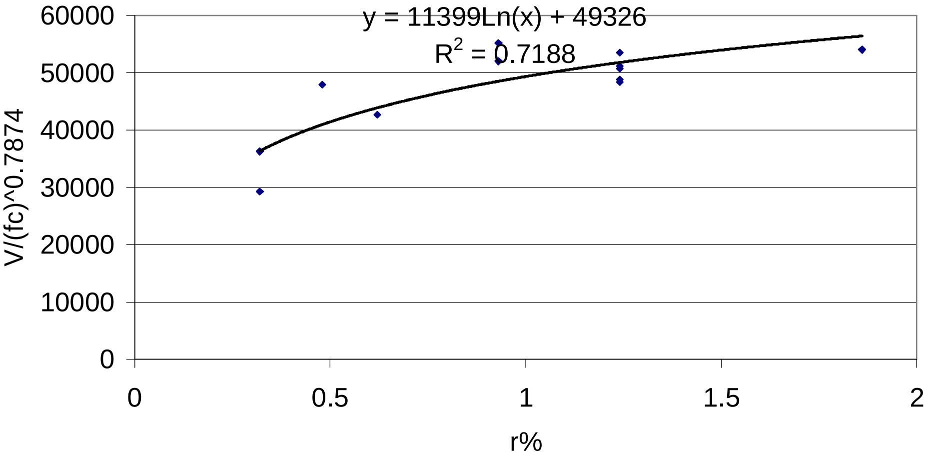
The influence of a/d ratio on the shear strength of corbels is shown in Figure 3 and Eq. (2).

Figure 3: The influence of the a/d ratio on the shear strength of corbels



$$\frac{V}{(f_c)^{0.787}} \approx -42520\frac{a}{d} + 57063 \qquad (2)$$

Figure 4: The influence of the longitudinal reinforcement ratio on the shear strength of corbels



The influence of the longitudinal reinforcement ratio

The influence of the longitudinal reinforcement ratio on the shear strength of corbels is shown in Figure 4 and Eq. (3).

$$\frac{V}{f_c^{0.7874}} \approx 11399\ln(r) + 49326 \qquad (3)$$

The final design equation of authors is shown in Equation 4. The authors applied their equation on the experimental database. The average of the ratio of the predicted shear strength to the actual shear strength of corbels is 0.99.

$$V = \frac{1.85}{100000} f_c^{0.7874}(-42520 * \frac{a}{d} + 57063)(11399 * \ln(r) + 49326) \qquad (4)$$

Alternatively, the corbels are designed by strut and tie modeling approach. The strut and tie model of authors is given in Figure 5

Table 1: The corbel specimens test data

Corbel	fc	a/d	ρ%	$V_{jpredequation}/V_{jtest}$	$V_{jpredstruttie}/V_{jtest}$
7	22.82	0.17	1.86	0.96	0.69
17	27.93	0.37	0.48	1.12	1.20
20	24.85	0.30	0.38	1.02	1.12
22	26.18	0.25	0.32	0.86	0.97
23	27.65	0.25	0.32	1.07	1.21
24	29.75	0.37	0.93	1.33	1.25
29	26.11	0.25	0.62	0.88	0.86
33	26.81	0.37	1.86	1.11	0.89
34	28.49	0.37	1.86	1.08	0.87
35	26.74	0.30	1.49	0.99	0.80
36	27.72	0.25	1.24	0.87	0.72
37	26.39	0.25	1.24	0.83	0.69
38	32.9	0.59	0.93	1.16	1.47
39	31.43	0.59	0.93	1.11	1.39
42	33.95	0.39	0.62	0.78	1.01
45	29.96	0.59	1.86	0.90	0.97
46	26.88	0.59	1.86	0.94	1.01
47	28.42	0.59	1.86	0.99	1.06
49	29.26	0.39	1.24	0.88	0.96
50	30.73	0.39	1.24	1.38	1.51
51	31.43	0.39	1.24	1.19	1.30
60	26.74	0.62	0.93	1.01	1.04
61	28.77	0.62	0.93	1.14	1.18
65	25.62	0.42	0.62	0.91	0.95
66	28.28	0.42	0.62	1.06	1.11
67	28.42	0.42	0.62	1.12	1.18
69	25.76	0.62	1.86	1.06	0.94
70	28.07	0.62	1.86	1.22	1.09
73	28.35	0.42	1.24	1.06	0.94
74	30.52	0.42	1.24	1.07	0.96
75	28.77	0.30	0.95	0.58	0.79
76	28.63	0.30	0.95	0.50	0.67
77	15.47	0.14	0.48	0.81	0.89
78	15.4	0.15	0.93	0.83	0.80
79	16.8	0.15	1.24	1.00	0.91
82	14.77	0.30	1.23	0.93	0.93
84	16.03	0.53	0.93	0.87	0.99
85	15.19	0.53	1.23	0.98	1.08
87	27.16	0.15	0.93	0.88	0.91
88	26.74	0.15	1.24	0.96	0.93
91	28.42	0.30	1.23	1.06	1.15
94	27.48	0.53	1.23	0.87	1.03
97	44.94	0.15	1.24	1.01	1.00
			average	0.99	1.01

The strut and tie modeling approach

The strut and tie modeling approach will be explained here only briefly.

Figure 5: The proposed strut and tie model

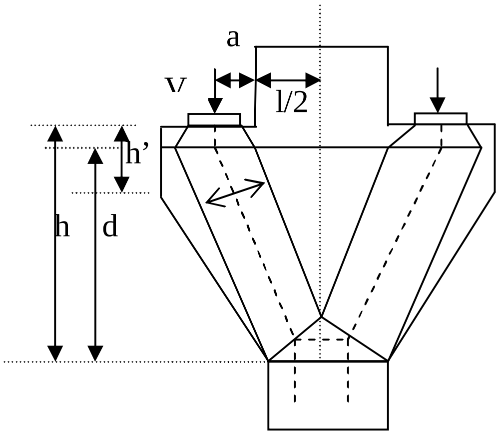
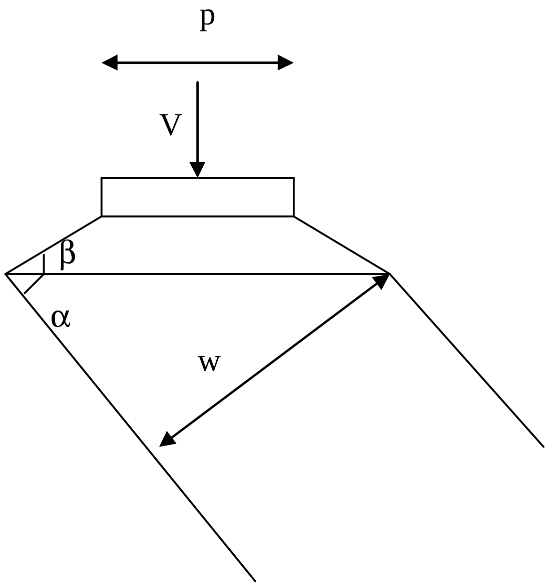


Figure 6 : The top node



As apparent from Figure 5, the strut mechanism resists the vertical shear in the corbel. The angle β is determined empirically as 33^0. The total shear resistance of the direct strut mechanism will be given as:

$$V_j = 0.6 f_c (1 - \frac{f_c}{250}) * b * (p + \frac{2(h-d)}{\tan b})(\sin a)^2 \qquad (5)$$

where f_c is the concrete cylinder strength in MPa

b is the width of the corbels
α is the angle of inclination of the strut mechanism
w is the width of the strut mechanism
p is the width of the loading plate

The proposed strut and tie model is applied on the experimental database. It is apparent that the model gives accurate predictions of the shear strength of corbels.

Conclusions

Alternative design methods are proposed for predicting the shear strength of corbels. In the first part of this study, an empirical design equation is suggested for the design of corbels. In the second part of this study, a strut and tie model is proposed. It is apparent from Table 1 that both of the methods give accurate predictions of the shear strength of corbels. The standard deviation however, is much smaller in the proposed equation and the proposed equation is an improvement on the strut and tie modeling approach.

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