論文 Parameters affecting steel anchorages under shear

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ABSTRACT: Steel anchorages find various applications in concrete structures, including rehabilitation of deteriorated structures. Experiments were carried out to study the effect of various parameters on the load carrying capacity of steel anchors in shear, and the results compared with other published data and empirical formulae. It was found that there could be a large variation in the load capacities and the failure modes, depending on embedment length and the presence of reinforcement near the anchors. It was also found that the actual failure loads were sometimes considerably lower than the estimates given by available empirical relations.

KEYWORDS: anchorages; structural anchors; fastening anchors; concrete; shear strength; capacity; design; repair; retrofitting

1. INTRODUCTION

Steel anchorages find various applications in concrete structures, including repair and retrofitting, where the embedment length and relative placing of anchors is largely governed by the reinforcement present in the existing structure. It is largely understood that the load carrying capacity of such anchors depends on factors such as the strength of concrete, diameter and embedment depth of anchor, distance of the anchor from the edge, presence of other anchors in vicinity, and, the presence of reinforcing bars in the neighborhood. However, a definite and reliable relationship to estimate the actual load carrying capacity is not yet established, and therefore it is important that experiments are carried out to check the applicability of existing relations and establish new empirical relationships, if required.

This study was carried out to study the effect of some of the parameters on the load carrying capacity of steel anchors in shear, and to compare the results with other published data and empirical formulae. The number and layout of the anchors, presence of additional reinforcing bars in the vicinity and embedment length were the other variables used in the study. Tests were carried out in two stages and data from previous studies carried out have also been closely studied and the results obtained have been discussed within a larger framework.

2. EXPERIMENTAL

The outline of the experimental programme followed in the study is given in **Table 1**. Experiments were carried out to study the behavior of cast in-situ anchors under the action of direct shear in terms of load-displacement curves, load carrying capacity, and mode of failure

Table 1 Experiments conducted

Series	Objective	Details
I	Establish the test set-up, and obtain preliminary data concerning factors affecting the load-carrying capacity	Four specimens tested with varying number of anchors and embedment length.
II	Study the effect of embedment length, and presence of additional reinforcement on the load carrying capacity and failure mode.	Ten specimens tested at five combinations of the variables (using two specimens at each combination)

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2.1 SPECIMENS USED

Concrete with water-cement ratio 0.5 and unit water content 190 liters was mixed in the laboratory to cast the test specimens, and 15cm side cubes for determining the compressive strength of concrete. The specimens and cubes cured under water for 14 days, before testing. Bolts with a diameter of 21 mm, with their heads embedded inside the concrete were used as anchors. **Fig. 1** shows the details of the geometry of the specimens and placement of anchors. Except in one, case, all specimens carried the reinforcing bars shown in the figure. Anchors in a row were placed at a separation of 50 mm c/c and a separation of 125 mm c/c was used between the rows.

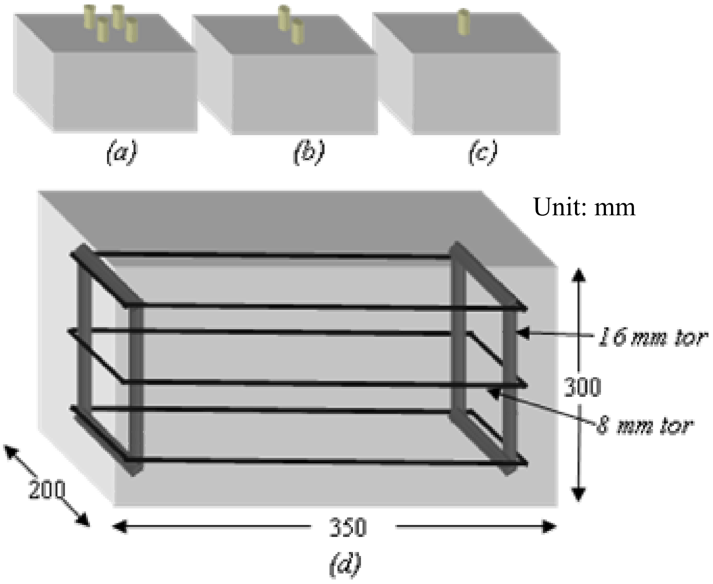

Fig.1 Specimens used: (a)-(c) location of anchors in specimens; (d) dimensions of specimen and reinforcement

2.2 APPLICATION OF LOADS

Fig.2 shows the set up used for applying the load to specimens along with the reaction frame used to hold the specimen. It can be seen that pure shear was applied using a hydraulic actuator with displacement control, and a 10 mm thick steel plate. The anchors were snug tightened to the loading apparatus with nuts using a hand wrench. Displacement at both ends of the setup was measured using LVDTs, and corrections applied (δ_2) for any rigid body motion observed.

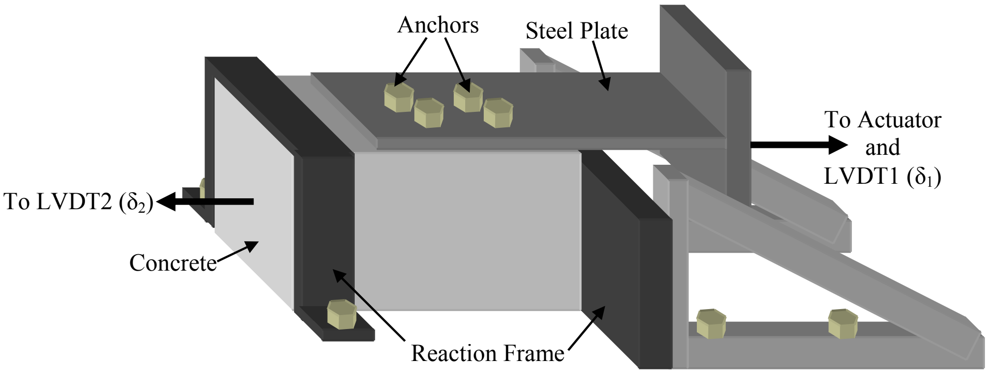

Fig. 2 Experimental setup

3. RESULTS AND DISCUSSION

A summary of the results obtained in the study is given in **Table 2**.

Table 2 Summary of results obtained

Sp. No.	Str. (MPa)	No. of bolts	Embed-ment (mm)	Max. Load (P_{max} kN)	Displ. at P_{max} (mm)	Failure Mode
1(i)	48.6	2	150	195.0	18.06	Shear of bolt and crushing of concrete
2(i)	42.0	2	100	151.0	14.02	Crushing of concrete
3(i)	48.6	4	150	228.7	12.01	Did not fail
4(i)	42.0	4	100	191.4	12.04	Crushing of concrete and pull out
1	39.25	1	50	46.2(46.25)	1.99(1.13)	Pull out of bolt
2			100	89.7(91.39)	4.75(4.68)	Shear failure of bolt
3			150	85.2(83.2)	5.3(6.49)	Shear failure of bolt
4			100	72.3(77.0)	4.66(3.61)	Cracking in concrete (W/o R/f)
5		2	100	130.2(109)	12.82(4.71)	Cracking in concrete

3.1 OBSERVATIONS

In **Table 2**, specimens from Series I have been numbered 1(i) through 4(i) and those from Series II have been numbered 1 through 5. The values in brackets for Series II are for the second set of specimens tested under identical conditions. It should be noted that the values for both specimens are in fact quite close. **Fig. 3** shows the load-displacement curves obtained for the two specimens (No. 3), and similar agreement was observed for others.

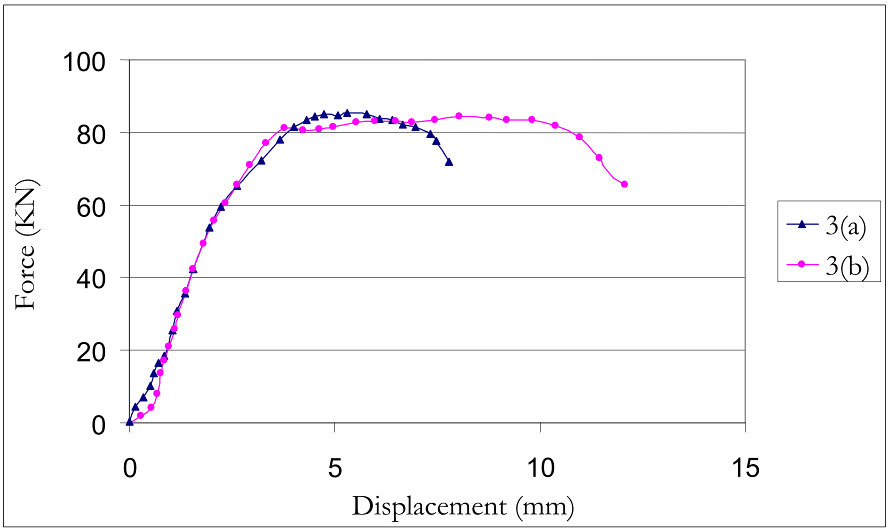

Fig. 3 Load displacement curve of specimens 3(a) and (b)

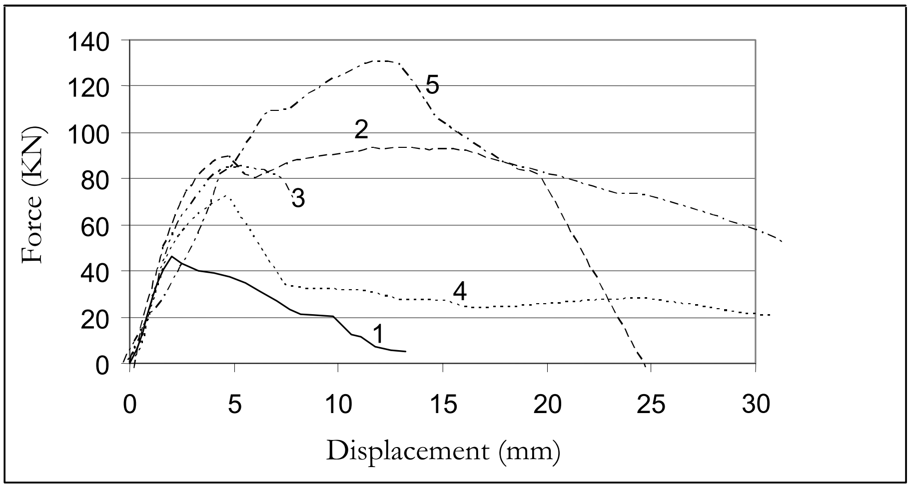

Fig. 4 Load displacement curves obtained in Series II

3.2 DISCUSSION

The load displacement curves for the specimens tested in Series II are shown in **Fig. 4**. The figure shows that the absence of reinforcement (Specimen 4) does not adversely affect the stiffness of the system, though the failure does become ‘brittle’. A similar conclusion can be made for the behavior observed for Specimen 1, when the embedment depth is small and the failure occurs by pull-out.

As given in **Table 2**, results obtained in the experiments show that failure was predominantly due to crack propagation in concrete. Cracks were found to propagate at around 45° angle to the direction of loading. It was also found that closely placed bolts in the same and different rows do not affect the capacity of the system linearly (specimens 2 and 5). The cracks formed in concrete are arrested by steel reinforcement present in the specimens and the load carrying capacity is thus increased (specimens 2 and 4). The highest capacities were found when the material of the anchor itself failed in shear and the lowest when the anchor failed in pull out, though increase in embedment length also leads to an increase in the capacity (specimens 1(i) and 2(i)).

3.3 COMPARISON WITH OTHER PUBLISHED RESULTS AND EMPIRICAL ESTIMATES AS PER ACI COMMITTEE 355 PROVISIONS

ACI Committee 355 lays down guidelines and recommendations for design of steel anchors embedded in concrete, on the basis of relations derived by various researchers. According to Eligehausen and Fuchs (1988) the shear capacity of a steel anchor (F_u), if the failure of the steel itself does not occur, is given by the following relation:

$$F_u = 1.4\sqrt{D}\sqrt{f_c'}m^{1.5}\chi_n \text{ N} \tag{1}$$

where:

D = Shank diameter of the anchor in mm

m = Edge distance of the bolt in mm

f_c' = Compressive strength of concrete in MPa

$\chi_n = \dfrac{n}{1.4m}$

n = member thickness in mm

For an anchor away from the edge, the capacity is given by the relation

$$F_u = 0.5A_b\sqrt{f_c'E_c} \text{ lb} \tag{2}$$

where A_b is cross section area of shank in in^2, f_c' and E_c are the compressive strength and the elastic modulus of concrete in psi.

For anchors placed close to the edge, ACI 349, Appendix B gives the following relation:

$$V_u = 1.7\sqrt{f_c'}\pi m^2 \text{ lb} \tag{3}$$

It should be noted that these relations are applicable provided $L_d > 4D$, L_d being the embedment depth of the anchor, implying that the capacity of anchors remains largely unchanged by varying the embedment beyond 4D. However, as is seen from the results of the experiments mentioned in this work, embedment has a large role to play in the shear capacity of anchors and also the failure mode. Results from both series of experiments in the present also highlight the increase in the capacity of anchors with increase of embedment beyond 4D.

Table 3 shows a comparison of the results from Series II with the values derived using the empirical relations (1) through (3) cited above. The diameter used in case of multiple bolts in the comparison, is equivalent diameter for the total cross-section area of the anchors, and concrete strength reduced by 15% to obtain an estimate of the cylinder strength.

Table 3 Comparison of experimental and predicted values(Series II)

Sp. no.	**L_d** (mm)	**D** (mm)	**f_c** (MPa)	**m** (mm)	**n** (mm)	χ_n	**P_{ult}** (kN)	**P_{ult} as % of Eq.** (1)	(2)	(3)	**Md**
1	50	21	33.4	100	350	2.50	46.2	42	23	153	C
2	100						89.7	82	44	298	B
3	150						85.23	78	42	283	B
4	100						72.31	66	36	240	R
5	100	29.7					130.3	100	32	432	R

L_d: Embedment length (mm)
D: Diameter of bolt (mm)
f_c: Compressive strength of concrete (MPa)
m: Edge distance (mm)
n: Thickness of specimen (mm)
P_{ult}: Ultimate load carried (KN)

Md: Mode of failure (as below)
B: Shear failure of bolt
C: Pull out of bolt from specimen
F: Flexural failure of specimen
R: Failure of concrete by crack propagation

As can be seen from the **Table 3**, whereas the observed values are far in excess of the estimate from Eq. (3), the actual value ranges between only 23% and 44% for Eq (2), which may in fact be considered to be basically applicable considering the conditions of the tests carried out. Thus, it is clear that the relations do not provide a necessarily conservative estimate for the shear carrying capacities of anchor systems. In order to confirm the findings obtained here, experimental results obtained by Hawkins [2] and Ueda, et al. [3] were also compared with these relations, and the results summarized in **Table 4**.

*Table 4 Comparison of experimental and predicted values for References 2 and 3**

No.	**L_d** (mm)	**D** (mm)	**f_c** (MPa)	**m** (mm)	**n** (mm)	χ_n	**P_{ult}** (kN)	**P_{ult} as % of Eq.** (1)	(2)	(3)	**Md**
Reference 2:											
1	76	25	21.2	228.5	457	1.43	105.5	66	63	99	C
2	127		20.8				111.9	71	68	106	R
3	76		20				98.2	64	62	95	C
4	178		20.8				123.3	78	75	117	R
5	127		20				100.4	65	63	97	R
6	76		21.4				86.7	54	52	81	R
7	76		34				121.2	60	51	90	C
8	127		34				130.2	65	55	96	R
9	127	19	21.2				96.3	69	100	90	R
10	178		21.2				105.5	76	110	99	R
11	76		21				102.7	74	108	97	C
12	127		21				93.6	68	98	88	R
13	76		21.2				89.9	65	94	84	R
14	76		34.8				125.7	71	90	92	C
15	127		34.8				115.6	65	83	85	R
Reference 3:											
1	200	16	18.4	50	300	4.29	10.7	29	18	225	R
2				100		2.14	36.2	70	59	191	R
3				150		1.43	85.8	136	140	201	F
4				200		1.07	78.4	108	128	103	F
5				50		4.29	6.7	18	11	141	R
6				100		2.14	39.7	77	65	209	R
7				150		1.43	56.8	90	93	133	F
8				200		1.07	73	100	119	96	B
9			25.7	150		1.43	59.8	80	76	118	R
10				150		1.43	44.1	59	56	87	F
11			21	50		4.29	10.5	27	16	207	R
12				100		2.14	9.3	17	14	46	R
13				150		1.43	38.2	57	57	84	R
14				200		1.07	92.1	118	136	113	F
15			21.7	50		4.29	10.8	27	16	209	R
16				100		2.14	34.3	61	50	166	R
17				150		1.43	72.5	106	105	156	R
18				50		4.29	13.7	35	20	266	R
19				100		2.14	38.2	68	55	185	R
20				150		1.43	68.6	100	99	148	F,B
**** Please refer to Table 3 for the details of the symbols used in this table***											

To facilitate further discussion the results from **Tables 3 and 4** have been plotted in **Fig. 5**.

It can be seen that only in the case of results by Hawkins [2], the estimates are at least consistent. Eq (3) provides the best estimates (84% to 117%), and the values from Eq (2) and (1) range between 51 and 110, and 54 and 78, respectively. However, it should be pointed out that Eq.3 is valid only for specimens having a low edge distance for the bolts, which is not strictly true for [2], where the edge distance was kept constant at 228.5 mm for all the specimens is greater than the embedment depth.

From the variations observed for the data from Ueda [3], it can be seen that the actual value ranges from 84% to 266% of the estimates from Eq (3), though one of the values is actually only 46%. As far as estimates based on Eq (1) and (2) are concerned, it can be seen that they too tend to grossly overestimate the failure load, and in some cases the failure load is less than one-third of the estimated value. It should be noted that in the experiments by Ueda, et al., the edge distance of the anchors has been varied.

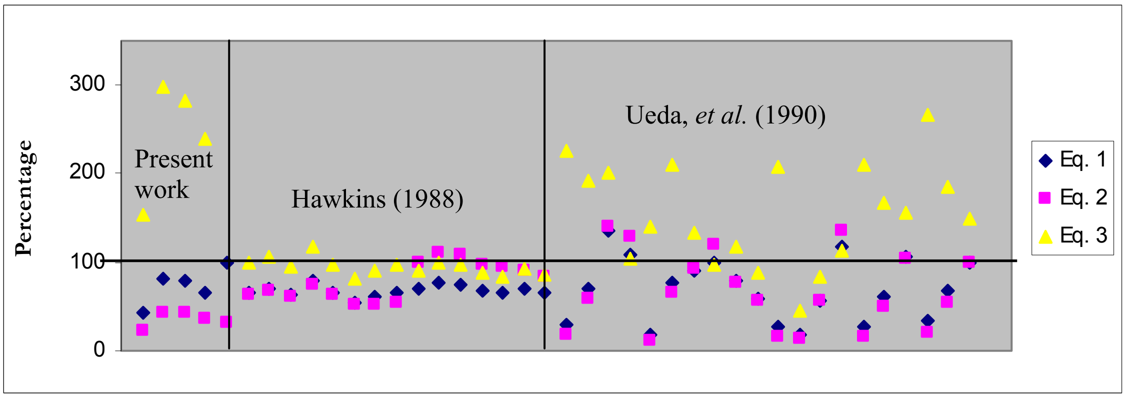

Fig. 5 Plot of capacities as percentages of values predicted by equations

The observations made on the basis of comparison with the results of Ueda are similar to that mentioned above on the basis of experimental results of the present study, where the actual values were much higher compared to estimates based on Eq (3), but lower when compared to estimates based on Eq (1) and (2).

4. CONCLUSIONS

Though it may be difficult to draw conclusive results on the basis of the limited experiments carried out in the study, it became clear that the failure is sudden in the case of pull-out kind of a failure, and in cases when additional reinforcing bars are not provided. Further, the load carrying capacity was found to increase as the embedment length increases, and the reach a maximum when the anchors failed in shear.

Comparison with some of the other similar studies and available empirical relations to estimate the shear capacity, showed that available data is far from enough to be able to reliably estimate the failure capacities. In fact, the extent of overestimation in some of the equations is very large.

Given that the results could have far reaching implications in terms of application of steel anchors and plates in rehabilitation of structures, and also design of composite structures, an urgent need is thus identified to develop a better understanding of some of the parameters that affect the load carrying capacity and failure mechanism of anchorages in shear.

REFERENCES

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