Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.VII)

12-4-18

BEHAVIOUR OF METALLIC ANCHORS UNDER GENERALIZED EXCITATIONS

Rolf ELIGEHAUSEN[1] and Elizabeth VINTZĒLEOU[2]

[1]University of Stuttgart, West Germany
[2]National Technical University of Athens, Greece

SUMMARY

In this paper are briefly presented the results of an experimental program which was carried out with the aim to investigate the behaviour of several types of metallic anchors (undercut, expansion and chemical anchors) under both monotonic and cyclic shear actions.

Several parameters were investigated within the program, namely: the presence of cracks crossing the anchor, the distance of the anchor from the free edges of the concrete section, the presence of transverse reinforcement, the loading history, etc. The influence of these parameters on the mechanical characteristics of anchors is illustrated in this paper, while empirical formulae for the calculation of the maximum shear force which may be transferred by metallic anchors are given.

INTRODUCTION

The increasing demand for flexibility in planning and construction of reinforced concrete structures has led in recent years to a rather extensive use of metallic anchors to attach either structural or non-structural elements to R.C. members after their hardening.

Such fastening techniques are used also in earthquake prone areas. Besides, in seismic regions, the use of metallic anchors in repair and strengthening is a very promising technique. However, the experimental results concerning the behaviour of anchors, especially under cyclic actions, are rather scarce.

Therefore, the scope of the experimental program, which is briefly presented hereafter, is to contribute to the enrichment of the knowledge about the behaviour of metallic anchors, thus making possible their safe and economic design and use.

TEST PROCEDURE

Both monotonic and cyclic tests were carried out on specimens similar to those shown in Fig.1. The dimensions of the concrete block, as well as the number of reinforcing bars passing through the specimen, were depending on the diameter, the embedment length and the desired concrete cover of the anchor tested each time.

All the results presented in this paper were obtained from tests on anchors which were inserted into cracked concrete (the direction of the crack was parallel to the direction of loading). There was no transverse reinforcement in the concrete cover of the anchors.

The test procedure was the following: The specimen was placed in the testing frame and it was subject to axial tension. As soon as hair cracks were appearing (in places where metal sheets were inserted before concreting so as to serve as crack initiators), the tension load was removed and anchors were inserted in the cracks. After the installation of anchors, the cracks were opened up to a predetermined width value (varying between 0.10mm and 0.80mm and held constant during the test) and the anchor was subjected to shear.

TEST RESULTS-MONOTONIC TESTS

Failure modes Two main failure modes were observed, depending on the edge distance of anchors (s. Fig.2):

For small edge distances and for shear load applied at right angles to the free edge of the section, the anchors failed due to break-out of the concrete (Fig.2a). The inclination of the break-out body in relation to the face of the concrete member was about 30°, while its depth was equal to $1.30 \div 1.50$ times the edge distance of the anchor.

For large concrete covers, steel failure was observed, while a "shell-shaped" local spalling of concrete was apparent (Fig.2b).

Obviously, the same failure modes were observed also in case of cyclic tests.

Shear force vs. shear displacement curve For both failure modes and for all three types of anchors which were tested, the shear force vs. shear displacement curves were similar to those shown in Fig.3.

In case of concrete failure, the maximum shear response, V_u, depends on the diameter of the drilled hole, d_b, on the cube strength of concrete, f_c, as well as on the edge distance of the anchor, c. On the basis of 31 series of tests on various types of anchors, the following empirical expression was found for the calculation of V_u (Ref. 1):

$$V_u = 1.30\sqrt{d_b}\sqrt{f_c} \cdot c^{1.5} \tag{1}$$

In Fig.4 experimental V_u-values obtained from tests on undercut and expansion anchors are compared with ultimare response values predicted by Equ.1.
It should be noted that Equ.1 holds for anchors with anchorage length equal to $4 \div 6d_b$, for hole diameters ≤28mm, for concrete compressive strength f_c varying between 15MPa and 60MPa, and for thickness of member ≥1.40c.

In case of steel failure, the maximum shear response may be predicted using the following expression deduced from a systematic evaluation of about 230 series of tests on various anchors (Ref.2):

$$V_u = \alpha A_s f_s \tag{2}$$

where A_s denotes the cross sectional area of the anchor, f_s is the tensile strength of the steel and α is equal to 0.60. The validity of Equ.2 was checked for nominal screw thread diameters ≤20mm and for f_s ≤800MPa.

The role of the crack width In cases where the failure of the fastening was due to the break-out of the concrete cover, it was observed that the maximum shear response was decreasing with increasing crack width (Fig.5).

On the contrary, when steel failure occurred, the maximum shear response seemed to be independent of the crack width (Fig.6).

TEST RESULTS-CYCLIC TESTS

Loading history Undercut, expansion and chemical anchors were subject to full displacement reversals (displacement controlled tests). It was initially planned to impose to the anchors cyclic post-yield shear displacements. However, since after the attainment of the maximum shear response, V_u, either the concrete cover was splitting away or the anchor itself failed, the application of large post-yield displacements was not possible. Hence, full displacement reversals between values $+\Delta_u, -\Delta_u$ or $+0.50\Delta_u, -0.50\Delta_u$ were performed.

The role of the crack width For both failure modes, no apparent influence of the crack width on the cyclic behaviour of anchors was observed.

Characteristics of hysteresis loops In Figs 7 to 9 typical hysteresis loops are presented as obtained from tests on undercut, expansion and chemical anchors respectively.

Independently of the type of anchor tested each time, as well as independently of the failure mode of the anchors, the following typical characteristics of the hysteresis loops were observed:

There was a more or less pronounced asymmetry of the hysteresis loops in the two loading directions (smaller force-response in the second loading direction than in the first one for the same shear displacement value). The asymmetry was very pronounced in case of chemical anchors and less important for the other types of anchors.

A very pronounced pinching effect was observed in all cases in both loading directions. Therefore, even during the second reversal, a large shear displacement (approximately equal to half the maximum one) was needed for the mobilisation of the shear response. Besides, due to pinching effect, the area of the hysteresis loops was small; hence, the hysteretic damping was also small.

Considerable force-response degradation due to cycling was observed for all three types of anchors. The larger part of this response degradation occurred during the second reversal; in the subsequent cycles, a tendency to response stabilisation was recorded (Fig.10). After five full reversals, the force response of anchors was varying between 60% and 80% that of the first reversal (depending on the type of anchor).

In case of undercut and expansion anchors, the cycling at displacement values smaller than the one corresponding to the maximum shear response, V_u, did not seem to influence the behaviour of anchors when they were subsequently loaded up to failure. In fact, as shown in Figs 7 and 8, when after cycling anchors were subjected to larger Δ-values, the V-Δ curve seemed to meet the "virgin" one corresponding to monotonically increasing shear displacements. On the contrary, in case of chemical anchors, even cycling at low displacement values led to a considerable deterioration influencing the behaviour of anchors at higher Δ-values (comp. Fig.9).

It should be mentioned that considerable improvement of the cyclic behaviour of anchors may be expected, in case transverse reinforcement is added to the concrete cover. As tests on monotonic actions have already proved (Ref. 3), considerable increase of both the maximum force-response and the shear displacement corresponding to V_u occurred when transverse reinforcement was present, while a considerably smoother falling branch was obtained. It should be noted, however, that such an improved behaviour may not be expected in case of steel failure of the fastening.

REFERENCES

1. Fuchs, W., Eligehausen, R., "Tragverhalten und Bemessung von auf Querzug beanspruchten Dübelbefestigungen mit Randeinfluss im ungerissenen Beton", Report No 10/9-86/13, University of Stuttgart, (1986)
2. Fuchs, W., "Tragverhalten von Befestigungsmitteln bei Querzugbeanspruchung. Werkstoffe und Konstruktion", Institut fuer Werkstoffe im Bauwesen der Universitaet Stuttgart und Forschungs- und Material-pruefungsanstalt Baden-Wuerttemberg, (1984)
3. Eligehausen,R., Mallée, R., Ick, U., "Bemessung von Kopfbolzenverankerungen", (in preparation)

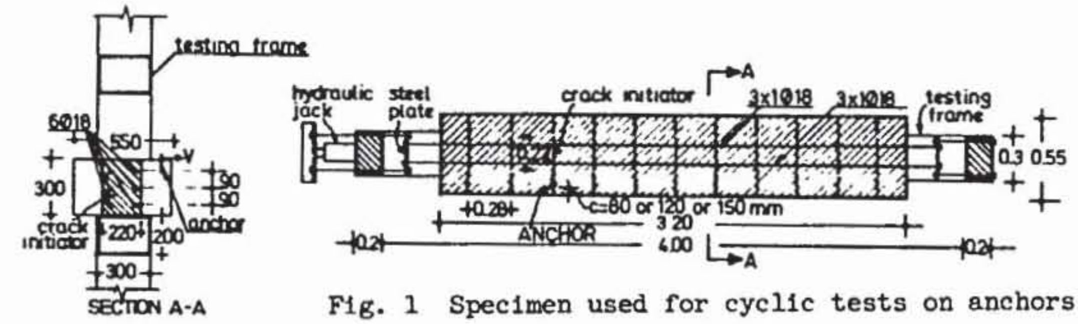

Fig. 1 Specimen used for cyclic tests on anchors

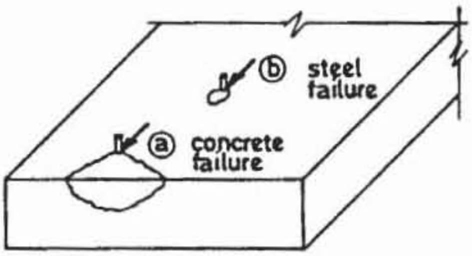

Fig. 2 Modes of failure

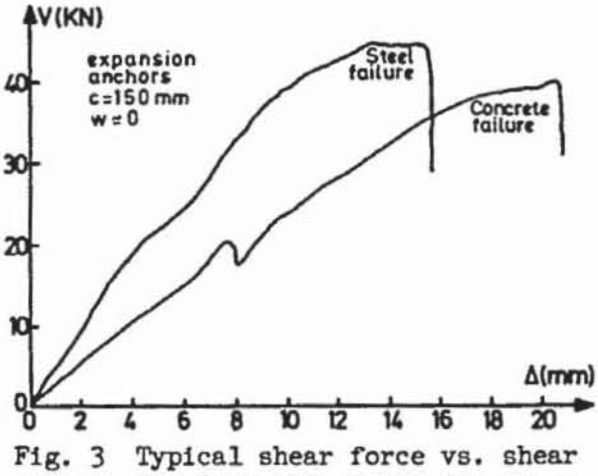

Fig. 3 Typical shear force vs. shear displacement curves for monotonic actions (f_c=25MPa)

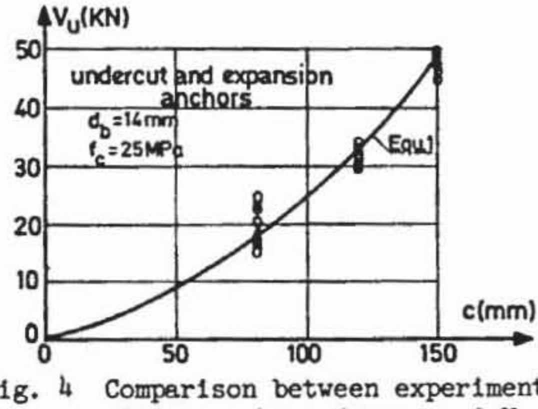

Fig. 4 Comparison between experimental ultimate shear forces and V_u-values predicted by Equ.1.

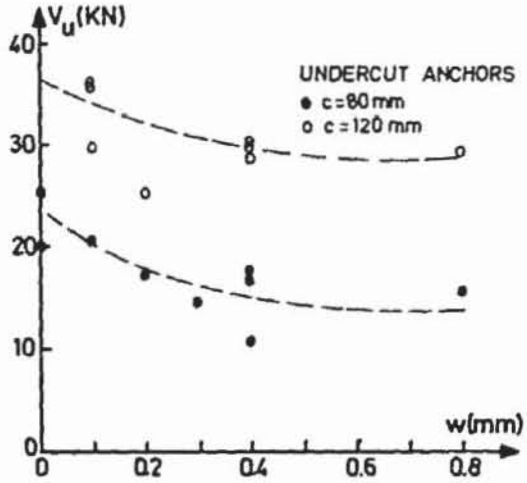

Fig. 5 Influence of the crack width on the maximum shear response of anchors (concrete failure)

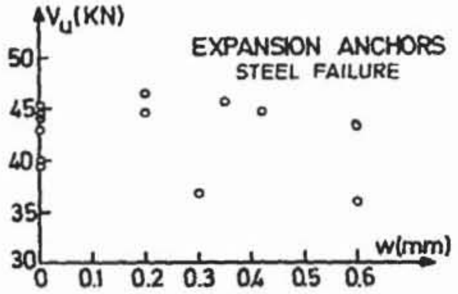

Fig. 6 Influence of the crack width on the maximum shear response of anchors (steel failure)

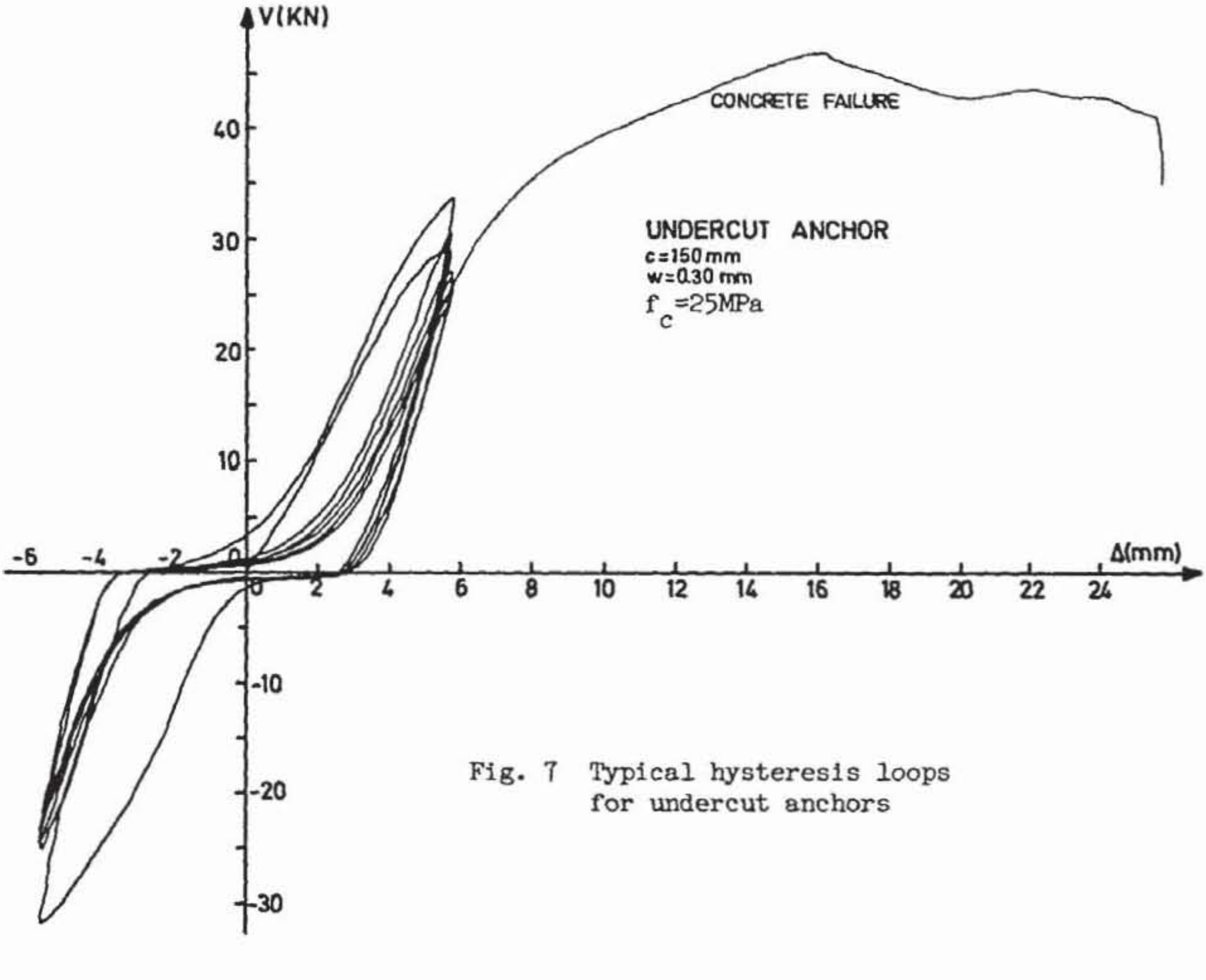

Fig. 7 Typical hysteresis loops for undercut anchors

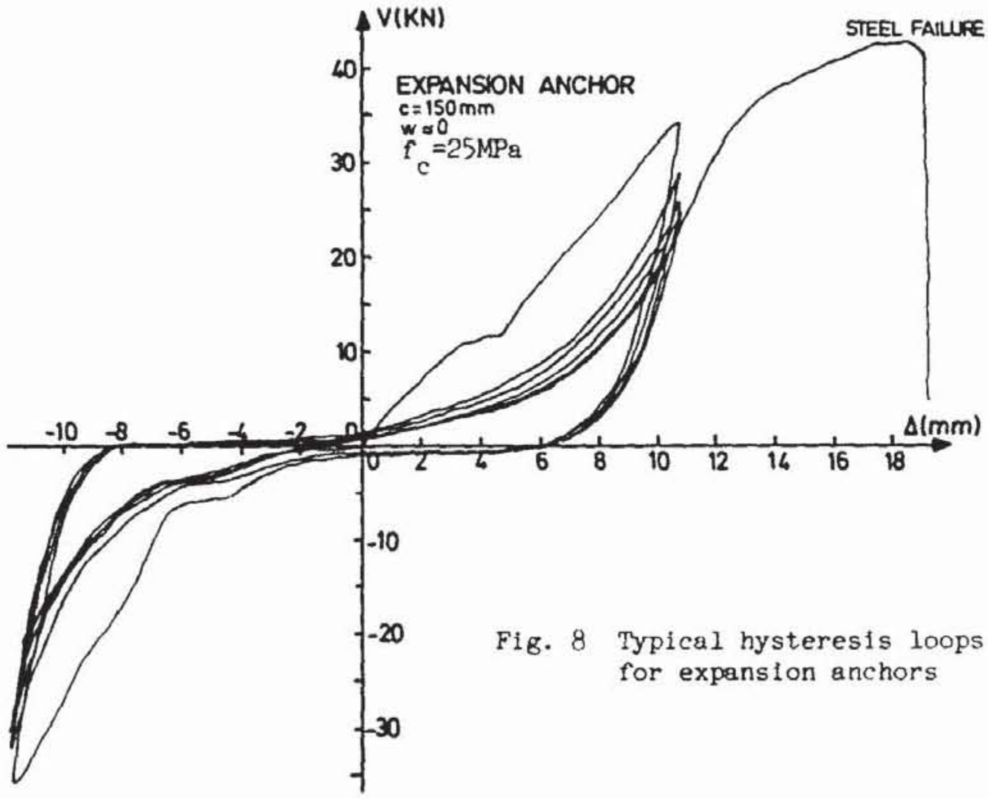

Fig. 8 Typical hysteresis loops for expansion anchors

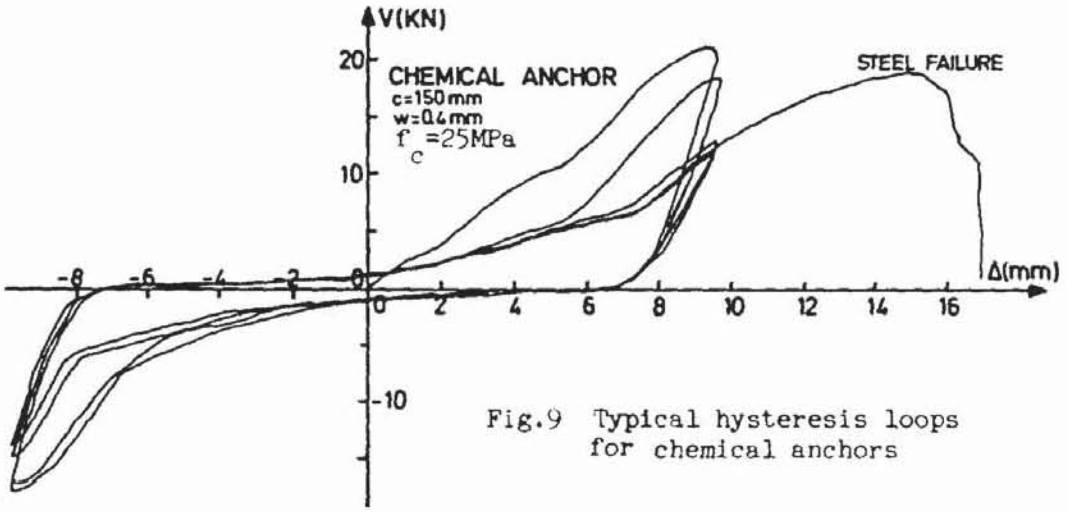

Fig.9 Typical hysteresis loops for chemical anchors

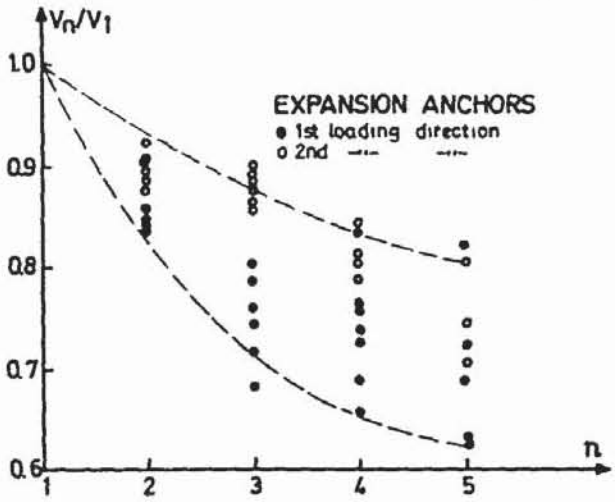

Fig. 10 Force-response degradation due to cycling