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Welded Reinforcing Bar Anchors in Concrete

Barres en acier soudé ancrées dans le béton

Gechweißte Betonstahl-Bolzen

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SUMMARY

Forces are frequently transferred across the joints between precast reinforced concrete members through anchorages composed of embedded steel plates and concrete anchors. The purpose of this paper is to present the results of an investigation into problems affecting the design of such joints which utilize deformed reinforcing bars for anchors. The investigation considered also the influence of high temperatures due to welding on the joint.

RÉSUMÉ

Les forces exercées entre les joints d'éléments préfabriqués en béton armé sont souvent transmises à l'aide de plaques d'ancrage composées de plaques et de barres d'acier soudé noyées dans le béton. L'objectif de cet exposé est de présenter les résultats obtenus à partir d'essais effectués sur des barres d'ancrage en acier à haute adhérence conçues pour de tels joints, en tenant compte de l'influence des températures élevées dues à la soudure sur les joints.

ZUSAMMENFASSUNG

Die Kraftübertragung zwischen Betonfertigteilen kann mittels einbetonierter Ankerplatten mit daran angeschweissten Verankerungsstählen erfolgen. Im Folgenden werden Untersuchungsergebnisse für Verankerungsstähle aus Betonstahl, auch unter Berücksichtigung von schweissbedingten Temperatureinwirkungen vorgestellt.

1. INTRODUCTION

Welded connections in precast concrete construction (Fig. 1) are utilized in order to achieve:

- Immediate capability to transmit force.
- Structural continuity across the joints.

The stress analysis of the steel components of such anchorages is generally not difficult, but the analysis of the concrete to which the anchorage forces are transmitted is likely to be more challenging. Such an analysis would consist of the following activities:

- Calculation of the strength (load capacity) of embedded anchors under shear or tension.
- Analysis of the capability of the anchors to carry combined tension and shear and to transfer such forces into the concrete.
- Determination of the effect that a welding process has upon the strength of the concrete in the vicinity of the anchorage. Weld temperatures may reach 1400 °C, and much of the heat generated will be conducted from the steel being welded into the concrete. It must be assumed, therefore, that concrete will experience a brief but significant rise in temperature, a source of concern since temperatures as low as 500 °C may damage the texture of the concrete and impair bond.

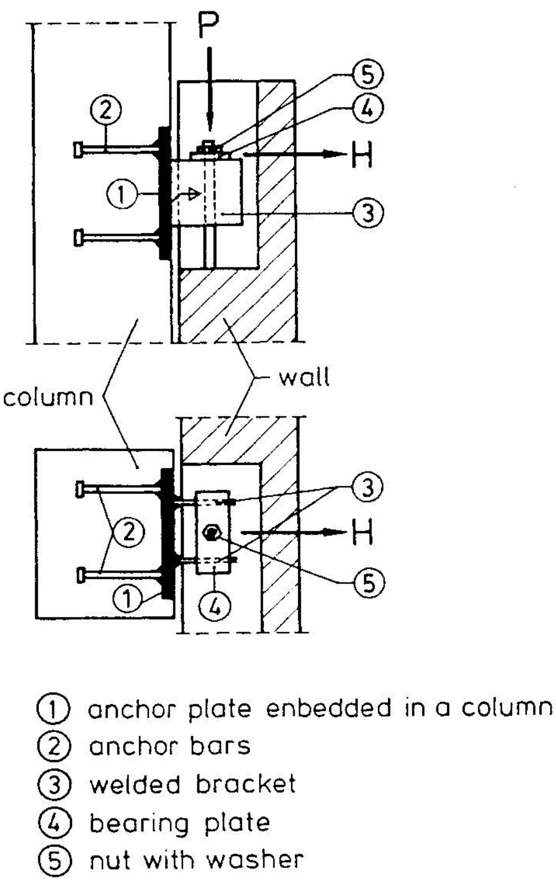


Fig.1 Anchorage of a suspended facade panel

Round reinforcing bars are considerably more economical than headed studs and can frequently be utilized with little or no sacrifice of capacity, especially where shear loads are large. The following discussion, therefore, considers only anchors fabricated of deformed reinforcing bars.

2. STRENGTH OF ANCHORAGE STEELS UNDER SHEAR LOADING

2.1 Analysis for Shear Load

The allowable shear load can be calculated to (Ref.1):

$$P_{all} = \frac{f_c'}{3} \cdot \left(\frac{d^{2,1}}{333 + a \cdot 12{,}2}\right) \qquad (1)$$

where:

P_{all} = allowable shear load
d = diameter of the bar
a = projecting length of the anchor bar
f_c' = ultimate compressive strength of the concrete

The comparison between experimental data and the ultimate shear load ($P_u = 3 \cdot P_{all}$) is shown in Fig. 2.

In the above expressions the anchor length is assumed to be equal to or greater than five bar diameters.

In this analysis the assumption is made that the anchor is sufficiently embedded to assure that the only failure will be of the concrete adjacent to the anchor where the shear load is resisted by bearing on the concrete. However, if the anchor is located relatively close to a free edge failure will occur as the result of the tensile stress in the concrete exceeding tolerable values. In general, the distance from the center of the anchor to any free edge should not be less than six bar diameters unless the following expression can be satisfied:

$$P_{all} = \frac{f_c' \cdot \alpha \cdot \beta}{3} \cdot \frac{d^{2,1}}{333 + 12{,}2 \cdot a} \qquad (2)$$

where:

$$\alpha = \frac{m}{6 \cdot d} \leq 1$$

$$\beta = \frac{n}{6 \cdot d} \leq 1$$

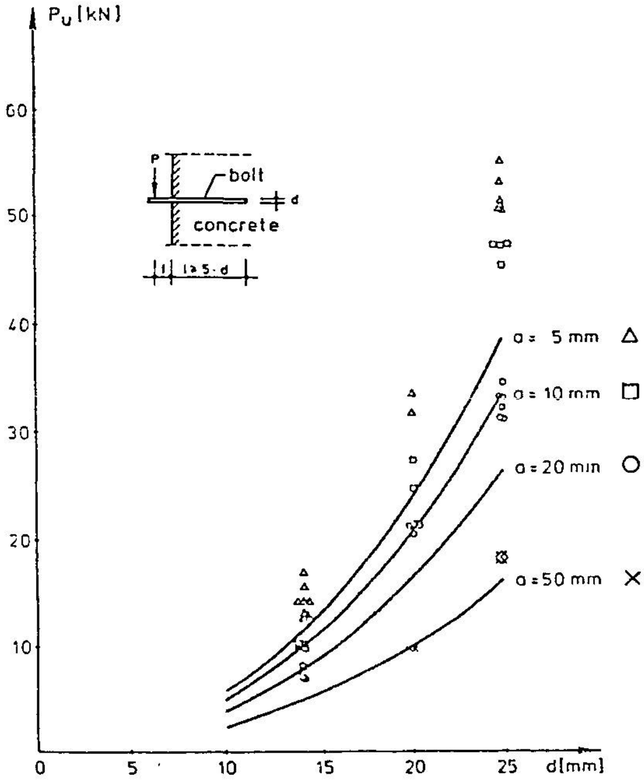
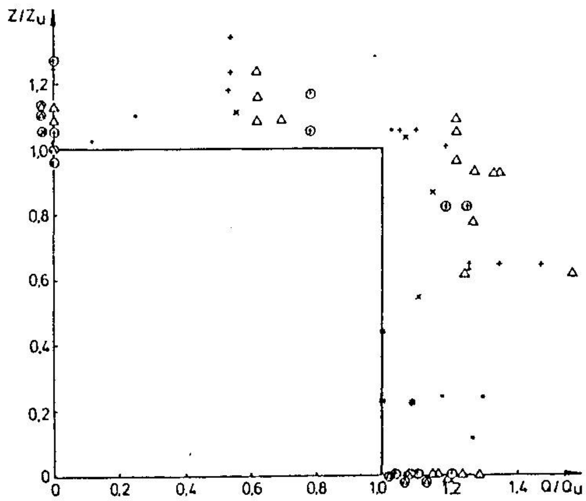


Fig.2 Comparison between actual and calculated ultimate shear load

In no case should the depth of cover be less than three bar diameters.

3. LOAD CAPACITY OF ANCHORS UNDER SIMULTANEOUS TENSILE AND SHEAR LOADING.

Tests were performed to determine the load-bearing behavior of embedded anchors (straight reinforcing bars) subjected to the simultaneous application of tensile and shear forces. From the results of those tests (see Figure 3), it was concluded that, for round bars under combined tension and shear, the permissible values for shear and tension can be determined independently disregarding simultaneous application of load. The reduction in loading, as dictated by an elliptical interaction curve for headed studs under combined loads, is not necessary for deformed reinforcing bars for which the interaction curve appears to be square (see Figure 3).



Symbol	Φ [mm]	l [mm]	Anchor present	Q_u [kN]	Z_u [kN]
*	10	92	yes	22,0	29,5
▲	10	50	no	8,2	22,0
•	16	92	yes	62,9	45,2
x	20	92	yes	71,0	46,5
+	28	140	no	95,0	86,4
o	Rupture after 20 load oscillations between 10% and 50% of the ultimate load				

Fig.3 Test results with combined tensile and shear loading. Interaction curve is square.

4. EFFECT OF WELDING TEMPERATURES ON THE STRENGTH OF EMBEDDED ANCHOR PLATES

4.1 Review of the Problem

When steel connector elements (brackets) are subsequently welded to a steel plate anchored in the concrete, high temperatures (around 1500 °C at the weld) briefly occur in the steel and also in the concrete. The distribution of temperatures can affect permissible shear and axial forces and are of central importance to the design process.

4.2 Temperature Distribution in the Concrete and at the Anchors During Welding

To determine the distribution of temperatures, test specimens were made and subjected to heat from electric arc welding. Figure 4 illustrates the temperatures recorded at various measurement locations during the duration of the test. At measuring point 1, directly beneath the anchor plate, the abrupt change in temperature that occurs on detachment of the slag from the weld seam formed in two runs is clearly evident. The maximum temperatures in the specimens occur in the anchor bar and at the anchor plate, as shown in Figure 5.

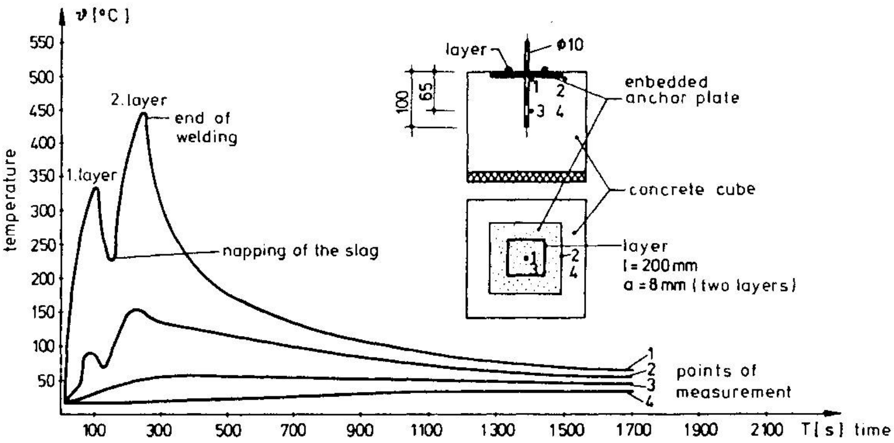


Fig.4 Concrete temperature during and after the welding process

Evaluation of the test results showed that the maximum temperature decreases as longer cooling intervals are allowed between the applications of the weld beads. Thus the welding can be performed such that the maximum temperatures developed are independent of the quantity of weld metal deposited. Moreover, the tests showed that the maximum temperatures are virtually independent of the boundary conditions of the concrete surrounding the anchor bar.

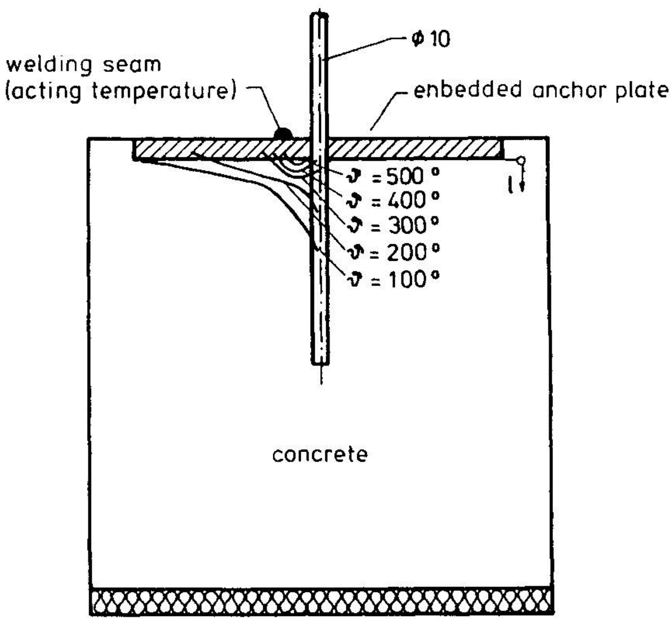


Fig.5 Distribution of temperatures by welding

Next, an unheaded anchor embedded in concrete and subjected to elevated temperatures was analyzed using finite element method. Evaluation of these results showed that in the first inch of the anchorage length there occur stresses that far exceed the allowable bond strength between steel and concrete. Hence, it is not possible to evaluate anchor capacity by means of an analysis based on elastic theory. On the other hand, it can be inferred from this analysis that a bond disruption at the loaded end does indeed occur as a result of the application of the welding temperature. This disruption is due to the differential longitudinal expansion of steel and concrete (thermal expansion coefficient of steel is about 1.2 times that of concrete) and to difference in thermal conductivity of the two materials (conductivity coefficient of steel is about 30 times that of concrete) causing splitting forces in the concrete.

To summarize, it can be stated that:

- The temperatures in the concrete and in the anchor bars are governed by the quantity of heat supplied (mass of weld deposit), by the distance of the weld to the anchor and by the duration of cooling intervals between the successive welding runs.
- A disruption of bond between steel and concrete can occur just beneath the anchor plate when sufficient heat is applied to the anchor.

4.3 Effect of Welding on the Shear Strength of Anchors

Tests have shown that the brief period of high temperatures due to welding has no appreciable effect on the shear load capacity of the anchors. Also, a bond disruption has practically no effect on the capacity of anchors loaded in pure shear. The bond behavior between steel and concrete does not affect the strength of such anchors because the shear stresses occurring in the longitudinal direction (bond stresses) are small. If the high temperatures are sustained for a fairly long time, however, a strength loss due to the deterioration of concrete when exposed to temperatures over 500 °C (900 °F) could occur. For this reason it is recommended, in cases where substantial amounts of welding have to be accomplished, to allow suitable cooling intervals between the individual runs.

4.4 Effect of Welding on the Strength of Anchor Bars Under Tensile Loading

Losses of strength of up to 25 percent occur when straight re-bars are subjected to the effects of high temperatures. The actual strength loss is a function of the size of the weld deposit, the distance of the weld to the anchor, and the depth of embedment. In further tests it was found that when the anchorage zone was shifted a distance of one inch in the direction of the anchor, there was no effect on the tensile load capacity. On the basis of these tests it is considered to be acceptable to neglect the effects of elevated temperature on the tensile load capacity of straight reinforcing bars when welding is carried out in the immediate vicinity of the embedded anchors, provided the embedment length is at least 12 bar diameters. If the embedment length is less than 12 bar diameters, the actual embedment length 1 in should be further reduced by 2 cm for design purposes.

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