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Design of post-installed reinforcing bars as end anchorage or as bonded anchor

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ABSTRACT

Two different design methods for anchorages with post-installed reinforcing bars are available: Anchorages can be designed either as end anchorage equivalent to cast-in reinforcing bars or as bonded anchors. The two design methods are very different in their fundamental approach and range of application. This contribution presents both design methods including the technical background and addresses the qualification of systems for post-installed reinforcing bars. The interrelations between material strength parameters required for the design are systematically illustrated. The design of anchorages according to both design methods will be explained and their outcome compared.

1. Introduction

Connections between reinforced concrete elements, such as foundation-to-column connections (Fig. 1a), represent discontinuity regions and are designed using truss models [1]. Here, the starter bars of the element concreted in a second step are cast in the previously constructed concrete element, for which the anchorage length of the reinforcing bars is calculated in Europe or in the US according to the structural concrete design codes EN 1992-1 [2] (Eurocode 2 Part 1) or ACI 318 Section 12 [3], respectively. For the sake of simplicity, it is in general assumed that the anchorage length ℓ_b of the reinforcing bars loaded in tension begins at the concrete joint of the two elements (Fig. 1b).

Reinforced concrete elements may also be connected using post-installed reinforcing bars (Fig. 1c). The design of these connections according to EN 1992-1 or ACI 318 is possible if the post-installed reinforcing bar system has been qualified. Post-installed reinforcing bars are increasingly popular, e.g. for the retrofit of reinforced concrete structures or for the optimization of the construction processes.

Reinforcing bars are also used as steel elements for bonded anchors provided the anchoring system has been qualified. The design of post-installed anchors can be carried out according to CEN/TS 1992-4 [4], in future EN 1992-4 (Eurocode 2 Part 4), or ACI 318 Appendix D [3]. The following discussion only refers to the European regulations which, however, are to a great extend similar to the regulations in the US.

The approach to design end anchorages of post-installed reinforcing bars as bonded anchors was studied in the past and proven feasible for specific cases [e.g. 5,6]. However, the requirements valid for the anchor design method are not always met in case of anchorages with post-installed reinforcing bars, and the anchor design method then potentially results in unsafe design solutions. Furthermore, the coexistence of two different qualification regulations and design methods may lead to significantly different solutions which is not plausible.

While the components used for structural concrete are in general codified according to relevant standards, post-installed reinforcing bars and anchors are not. The therefore required qualification according to EOTA TR 023 [7] and ETAG 001 [8], respectively, results in European Technical Approvals or (since the Construction Product Directive (CPD) [9] has been replaced by the Construction Product Regulation (CPR) [10] in June 2013) European Technical Assessments, both of which abbreviated as ETAs. In this context, European Approval Guidelines ETAG 001 and EOTA TR 023 are also currently converted into the European Assessment Documents EADs. The substitute for EOTA TR 023 is currently drafted [11] and expected to be published soon. The

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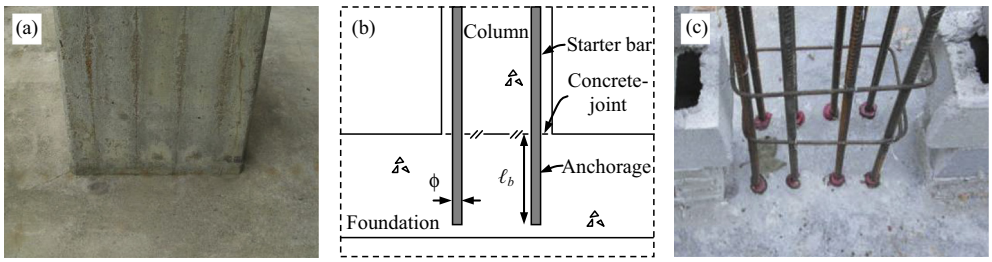

Fig. 1. Column-to-foundation connection: (a) with cast-in starter bars (after concreting); (b) scheme; (c) with post-installed starter bars (before concreting).

content basically remains identical with some smaller modifications, e.g. with regard to the required spacing and concrete cover. The most important amendment is the assessment of the resistance of the post-installation system to fire.

The aim of this contribution is to explain the design of connections with post-installed reinforcing bars according to the conventional structural concrete design rules for end anchorages, and according to the design rules for bonded anchors. For this reason, the design method for end anchorages and bonded anchors according to EN 1992-1 and CEN/TS 1992-4, respectively, are discussed and compared. The various concepts and key terms are laid out in Fig. 2. Note that for clarity, in this contribution strengths are indicated with the unit MPa and stresses with the unit N/mm^2, and ultimate strengths in the sense of forces given in kN are denominated as capacities.

2. Explanation of both design methods

2.1. Design of end anchorages according to EN 1992-1 [2] (Eurocode 2 Part 1)

In reinforced concrete structures, reinforcing bars carry the tensile forces developing in the elements. At the end of the reinforcing bar, the tension load is transferred via bond into the concrete. At overlap splices, the bond forces are in equilibrium with local struts developing from an adjoining reinforcing bar (Fig. 3a). At end anchorages, starter bars represent ties which form a framework together with global struts (Fig. 3b). For the design of reinforced concrete structures, it is assumed that reinforcing bars do not transfer shear loads for which shear reinforcement is required. In this contribution, the verification of the struts is not addressed. Furthermore, it is assumed that the concrete surface at a joint between two reinforced concrete elements is roughened to ensure a reliable transmission of shear forces.

When designing end anchorages according to EN 1992-1 (Eurocode 2 Part 1), sufficient safety margin is required against steel failure due to exceedance of the steel yield strength (yielding, Fig. 3c), bond failure due to exceedance of the bond strength (pull-out, Fig. 3d), and splitting due to exceedance of the concrete tensile strength (cracking of concrete cover, Fig. 3e). The verification is not carried out for each failure mode separately because the provisions require an anchorage length which ensures adequate safety margin against all failure modes. In the following, the rules for the determination of the anchorage length of tensioned reinforcement bars according to EN 1992-1 [2] are explained. The coefficients which are irrelevant for the comparison with bonded anchors in Section 3 are omitted. The design value of bond strength is:

$$f_{bd} = 2.25 \cdot \eta_1 \cdot \eta_2 \cdot f_{ctd} \tag{1}$$

where f_{ctd} is the design concrete tensile strength, the factor η_1 takes into account the position of the reinforcement during concreting ($\eta_1 = 1.0$ or $\eta_1 = 0.7$ for good or poor bond conditions,

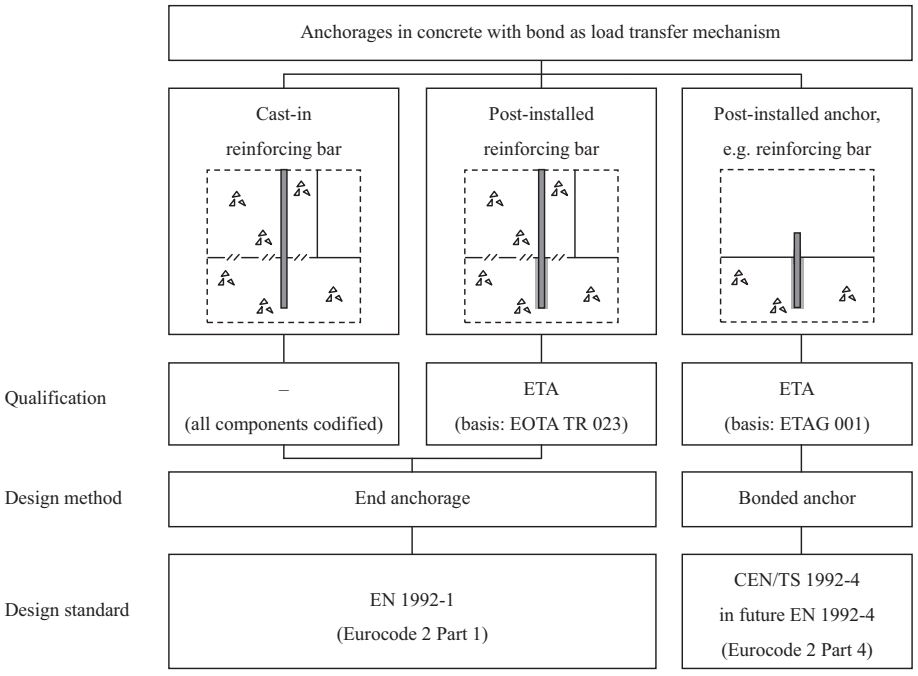

Fig. 2. Methods und standards for the design of anchorages in concrete.