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CODE

anchor design tensile strength shall be determined in accordance with 17.10.5.4.

17.10.5.3 Anchors and their attachments shall satisfy (a), (b), (c), or (d).

(a) For single anchors, the concrete-governed strength shall be greater than the steel strength of the anchor. For anchor groups, the ratio of the tensile load on the most highly stressed anchor to the steel strength of that anchor shall be equal to or greater than the ratio of the tensile load on anchors loaded in tension to the concrete-governed strength of those anchors. In each case:

(i) The steel strength shall be taken as 1.2 times the nominal steel strength of the anchor.

(ii) The concrete-governed strength shall be taken as the nominal strength considering pullout, side-face blowout, concrete breakout, and bond strength as applicable. For consideration of pullout in groups, the ratio shall be calculated for the most highly stressed anchor.

In addition, the following shall be satisfied:

(iii) Anchors shall transmit tensile loads via a ductile steel element with a stretch length of at least $8d_a$ unless otherwise determined by analysis.

(iv) Anchors that resist load reversals shall be protected against buckling.

(v) If connections are threaded and the ductile steel elements are not threaded over their entire length, the ratio of f_{uta}/f_{ya} shall be at least 1.3 unless the threaded portions are upset. The upset portions shall not be included in the stretch length.

(vi) Deformed reinforcing bars used as ductile steel elements to resist earthquake-induced forces shall be in accordance with the anchor reinforcement requirements of 20.2.2.

(b) Anchor or anchor groups shall be designed for the maximum tension that can be transmitted to the anchor or group of anchors based on the development of a ductile yield mechanism in the attachment in tension, flexure, shear, or bearing, or a combination of those conditions, considering both material overstrength and strain-hardening effects for the attachment. The anchor design tensile strength shall be calculated in accordance with 17.10.5.4.

(c) Anchor or anchor groups shall be designed for the maximum tension that can be transmitted to the anchors by a non-yielding attachment. The anchor design tensile strength shall be calculated in accordance with 17.10.5.4.

(d) Anchor or anchor groups shall be designed for the maximum tension obtained from factored load combinations that include E, with E_h increased by Ω_o. The anchor

COMMENTARY

Section R17.6.1.2 provides additional information on the steel properties of anchors. Use of upset threaded ends, whereby the threaded end of the anchor is enlarged to compensate for the area reduction associated with threading, can ensure that yielding occurs over the stretch length regardless of the tensile to yield strength ratio.

R17.10.5.3 Four options are provided for determining the required anchor or attachment strength to protect against nonductile tensile failure:

In option (a), anchor ductility requirements are imposed, and the required anchor strength is that determined using strength-level earthquake-induced forces acting on the structure. Research (Hoehler and Eligehausen 2008; Vintzileou and Eligehausen 1992) has shown that if the steel of the anchor yields before the concrete anchorage fails, no reduction in the anchor tensile strength is needed for earthquake–induced forces. Ductile steel anchors should satisfy the definition for **steel element, ductile** in Chapter 2. To facilitate comparison between steel strength, which is based on the most highly-stressed anchor, and concrete strength based on group behavior, the design is performed on the basis of the ratio of applied load to strength for the steel and concrete, respectively.

For some structures, anchors provide the best locations for energy dissipation in the nonlinear range of response. The stretch length of the anchor, shown in Fig. R17.10.5.3, affects the lateral displacement capacity of the structure; therefore, that length needs to be sufficient such that the displacement associated with the design-basis earthquake can be achieved (FEMA P750). Observations from earthquakes indicate that the provision of a stretch length of $8d_a$ results in good structural performance. If the required stretch length is calculated, the relative stiffness of the connected elements needs to be considered. When an anchor is subject to load reversals, and its yielding length outside the concrete exceeds $6d_a$, buckling of the anchor in compression is likely. Buckling can be restrained by placing the anchor in a tube. However, care must be taken that the tube does not share in resisting the tensile load assumed to act on the anchor. For anchor bolts that are not threaded over their length, it is important to ensure that yielding occurs over the unthreaded portion of the bolt within the stretch length before failure in the threads. This is accomplished by maintaining sufficient margin between the specified yield and tensile strengths of the bolt. It should be noted that the available stretch length may be adversely influenced by construction techniques (for example, the addition of leveling nuts to the examples illustrated in Fig. R17.10.5.3).

In option (b), the anchor is designed for the tensile force associated with the expected strength of the attachment. Care must be taken in design to consider the consequences of potential differences between the specified yield strength and the expected strength of the attachment. An example is the design of connections of intermediate precast walls

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