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The Comparison of Embedded Anchors Strength between ACI Code and EPRI Report for Seismic Fragility Analysis

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1. Introduction

Seismic margin and seismic fragility methodology recommend the use of the state of the art code provisions when using consensus National Codes and Standards as the basis for seismic capacities.

The seismic fragility analysis methods of EPRI TR-103959 [1] presented median equations for anchor bolt capacity before the Concrete Capacity Design(CCD) method was endorsed by NRC. Therefore, the median equation for the embedded anchors are not utilized in the EPRI technical report, the design code like ACI code is used conservatively for the seismic capacity of the embedded anchors.

The current version of ACI 349 and ACI 318 provide the CCD method to develop the capacity for the embedded anchors based on the past test results.

The CCD method cause to result in significantly reduced capacities when compared to earlier versions of these codes, particularly for larger embedment lengths. Consequently, these reduced seismic capacities would provide the conservative safety assessment results not realistic.

The EPRI report [2] presented median equations which is developed with embedded anchors test data to obtain realistic results. And the equation is applicable to a maximum concrete strength of 7,500 psi and not less than embedded length(h_{ef}) of 7.5 $in.$

So, the purpose of this paper is to compare the capacity between the recommended equation of the EPRI report [2] and the equation in ACI 349-13 [3].

2. Methods and Results

This paper covered the calculation capacity of the embedded anchors (i.e., cast-in-place bolts) for one of failure modes of equipment.

The EPRI report [2] provides the equation to determine the tensile strength of a single deeply embedded anchor without spacing and edge distance consideration. For these deep anchors, the only shear failure mode that could govern would be steel anchor failure. But the shear capacities of these steel anchor failures have not changed in recent code revision, and current criteria suffice to define both the high confidence of low probability of failure (HCLPF) and the best estimate capacities for seismic probabilistic risk assessments (SPRAs) and seismic margin applications (SMAs). So, the shear capacity is not considered in the EPRI report [2].

This paper provides the difference between methodology of ACI code (ACI 349-13 [3]) and methodology of the EPRI report [2] for tensile capacities (steel failure, concrete cone breakout and pullout failure) of single deeply embedded anchors without spacing and edge distance considerations.

To compare the tensile strength of the anchor, the installation assumptions of the embedded anchors are adopted as follows.

Anchor bolt type: 1 $in.$ hex headed stud bolt (ASTM F1554 Gr.105) with hardened washer (ASTM F436)

The effective area, $A_{se} = 0.606\ in.^2$

The bearing area, $A_{brg} = 4.12\ in.^2$

The 95% percentile steel material strength, $f_{u.95\%} = 125\ ksi$

The 95% percentile concrete compressive material strength, $f'_{c.95\%} = 3{,}000\ psi$

2.1 The strength calculation by EPRI Recommendations.

The detailed calculation process and results of the EPRI report [2] are described from Section 2.1.1. to 2.1.4

2.1.1 Steel strength

The steel reduction factor defined in Section 2-4 of the EPRI report [2], $\emptyset_s = 0.90$

The HCLPF steel capacity for embedded anchors bolts/studs is:

$$N_{s.HCLPF} = \emptyset_s A_{se} f_{u.95\%} \quad (1)$$
$$= 0.9 \times 0.606 \times 125 = 68.2\ kips$$

2.1.2 Concrete breakout strength($h_{ef} = 10\ in.$)

The concrete breakout strength reduction factor defined in Section 2-3 of the EPRI report [2], $\emptyset_c = 0.70$

The HCLPF concrete breakout capacity for embedded anchors in uncracked concrete is:

$$N_{c.HCLPF} = \emptyset_c 4.4 {f'_{c.95\%}}^{3/4} {h_{ef}}^{1.6} \quad (2)$$
$$= 0.7 \times 4.4 \times 3{,}000^{3/4} \times 10^{1.6}$$
$$= 49.8\ kips$$

2.1.3 Concrete breakout strength($h_{ef} = 20\ in.$)

The other conditions except an embedded length are as shown in Section 2.1.2

The HCLPF concrete breakout capacity for embedded anchors in uncracked concrete is:

$$N_{c.HCLPF} = \emptyset_c 4.4 {f'_{c.95\%}}^{3/4} {h_{ef}}^{1.6} \quad (3)$$
$$= 0.7 \times 4.4 \times 3{,}000^{3/4} \times 20^{1.6}$$
$$= 150.67\ kips$$

2.1.4 Pullout strength

The pullout strength reduction factor defined in Section D.4.5 of ACI 349-13 [3], $\emptyset_p = 0.75$ for anchor governed by pullout.

The HCLPF pullout capacity is:

$$N_{p.HCLPF} = \emptyset_p 11.2 f'_{c.95\%} A_{brg} \quad (4)$$
$$= 0.75 \times 11.2 \times 3{,}000 \times 4.12$$
$$= 103.82\ kips$$

2.2 The strength calculation by ACI 349-13 [3]

The detailed calculation process and results of ACI 349-13 [3] are described from Section 2.2.1. to 2.2.4

2.2.1 Steel strength

The steel reduction factor defined in Section D.4.5 of ACI 349-13 [3], $\emptyset_s = 0.80$ for anchor governed by strength of a ductile steel element.

The nominal steel strength is:

$$N_{sa} = nA_{se}f_u \quad (5)$$

Where, $n = 1$ for single anchor

The design steel capacity for embedded anchors bolts/studs is:

$$\emptyset_s N_{sa} = 0.8 \times 1 \times 0.606 \times 125 = 60.6\ kips$$

2.2.2 Concrete breakout strength($h_{ef} = 10\ in.$)

The concrete reduction factor defined in Section D.4.5 of ACI 349-13 [3], $\emptyset_c = 0.75$ for anchor governed by concrete breakout without supplementary reinforcement.

The nominal concrete breakout strength is:

$$N_{cb} = \frac{A_{Nc}}{A_{Nco}} \varphi_{ed,N} \varphi_{c,N} \varphi_{cp,N} N_b \quad (6)$$

Where $\frac{A_{Nc}}{A_{Nco}} = 1$ for single anchor without spacing and edge distance considerations; and $\varphi_{ed,N} = 1$ for no edge distance consideration; and $\varphi_{c,N} = 1.25$ for cast-in anchors; and $\varphi_{cp,N} = 1$ for cast-in anchors

The basic concrete breakout strength is:

$$N_b = k_c \sqrt{f'_c} h_{ef}^{1.5} \quad (7)$$

Where $k_c = 24$ for cast-in headed stud

The design concrete breakout strength is:

$$\emptyset_c N_{cb} = 0.75 \times 1.25 \times 24 \times \sqrt{3{,}000} \times 10^{1.5}$$
$$= 38.97\ kips$$

2.2.3 Concrete breakout strength($h_{ef} = 20\ in.$)

The other conditions except an embedded length and equations are as shown in Section 2.2.2

The basic concrete breakout strength for cast-in anchors with $11\ in. \leq h_{ef} \leq 25\ in.$ is:

$$N_b = 16 \sqrt{f'_c} h_{ef}^{5/3} \quad (8)$$

The design concrete breakout strength is:

$$\emptyset_c N_{cb} = 0.75 \times 1.25 \times 16 \times \sqrt{3{,}000} \times 20^{5/3}$$
$$= 121.07\ kips$$

2.2.4 Pullout strength

The pullout strength reduction factor defined in Section D.4.5 of ACI 349-13 [3], $\emptyset_c = 0.75$

The nominal pullout strength is:

$$N_{pn} = \varphi_{c,P} N_p \quad (9)$$

Where $\varphi_{c,P} = 1.4$ for no cracking

The pullout strength,

$$N_p = 8A_{brg} f'_c \quad (10)$$

The design pullout strength is:

$$\emptyset_c N_{pn} = 0.75 \times 1.4 \times 8 \times 4.12 \times 3{,}000$$
$$= 103.82\ kips$$

2.3 Summary of the results

The results according to the calculations in Section 2.1 and 2.2 are summarized in the following Table I.

Table I. The results of calculation

Failure mode	EPRI report (kips)	ACI 349-13 (kips)	Differences (%)
Steel	68.20	60.60	12.54
Concrete breakout ($h_{ef} = 10\ in.$)	49.80	38.97	27.79
Concrete breakout ($h_{ef} = 20\ in.$)	150.67	121.07	24.45
Pullout	103.82	103.82	0.00

In the comparison of steel strength, the result using EPRI recommended equation is 12.54 percent greater than that of ACI method. And, similarly to steel strength, the concrete breakout strength of the EPRI report [2] increased by 27.79 percent and 24.45 percent respectively compared to results of ACI method. But, in the comparison of pullout strength, there is no difference in the result.

3. Conclusions

The tensile capacities using the recommended equation of the EPRI report [2] are 12.54 percent to 27.79 percent greater than that using ACI 349-13 [3] method in steel and concrete breakout strength. The past anchorage capacity by using ACI 349 code might have provided the conservative capacity but it is not fit the PRA philosophy.

As a results, using the recommended equations of the EPRI report [2] when steel or concrete breakout tensile failure is governed, the more realistic capacities of embedded anchors would be obtained for the seismic fragility analysis.

REFERENCES

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