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Computing Concrete Pullout Strength

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Design charts aid in calculating
concrete pullout strength for
multiple anchorage bolt configurations.

Computing Concrete Pullout Strength

by Faruq M. A. Siddiqui and Jan W. Beseler

This article will assist the designer in computing the concrete pullout strength for multiple anchor bolt configurations. Nondimensionalized area coefficients are plotted for four patterns: 4-bolt, 6-bolt and two 8-bolt patterns. The variables used are the center-to-center spacing of the bolts, the depth of embedment and the diameter of the mechanical anchor heads. It is assumed that in a particular pattern all the anchor bolts are of the same type and have the same embedment length.

Anchor bolts with a mechanical anchor (anchor head) at the bottom can fail when subjected to tension either by yielding of the shank or by the concrete failing. In the latter case, failure occurs suddenly and is generally due to insufficient embedment. This sudden brittle failure, often called a pullout cone failure, is undesirable and should be prevented. To insure ductile behavior in case of unanticipated overloads, the ACI Nuclear Safety Structures specification (ACI 349-85 Appendix B)[1] requires that sufficient embedment length be provided so that the concrete pullout strength exceeds

the minimum specified embedment tensile strength of the bolt.

Although the pullout strength of single anchor bolts is easy to determine, individual failure surfaces may intersect if bolts are closely spaced, and computing the concrete capacity of even simple bolt groups can be difficult. Charts that supplement existing design aids[2,3] have been developed and are presented here to assist the designer.

Definition of pullout strength

Although the theory for computing pullout strength is described in detail in the commentary to ACI 349-85,[1] a brief description of some definitions follows.

Single anchor bolt

The design pullout strength of concrete, P_d, in tension is defined for a single anchor as

$$P_d = 4\phi\sqrt{f_c'}\, A_{eff} \qquad (1)$$

where $A_{eff} = \pi\,[(L_d + 0.5d_H)^2 - (0.5d_H)^2]$, represents the projected area of the failure cone less the bearing area of the anchor head; L_d is the effective embedded length; d_H

is the diameter of the anchor head at the bottom; f_c' is the 28-day compressive strength of concrete; and ϕ is the capacity reduction factor. The definition of the failure cone is shown in Fig. 1.

Multiple anchor bolts

If the anchor bolts are spaced such that the projected circles of each stress cone do not overlap, then the pullout strength of the group is the sum of the individual pullout strengths (Fig. 2b).

If the failure surface of the stress cones intersect, as in Fig. 2a, the effective stress area must be reduced to take into account the overlapping of the projected circles. The total area then has to be determined. The concrete pullout capacity is also given by Eq. (1), where the effective area of the bolt group is used for A_{eff}.
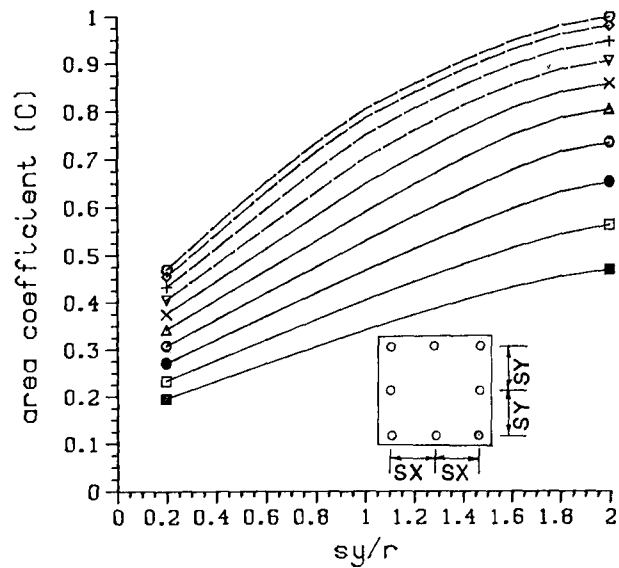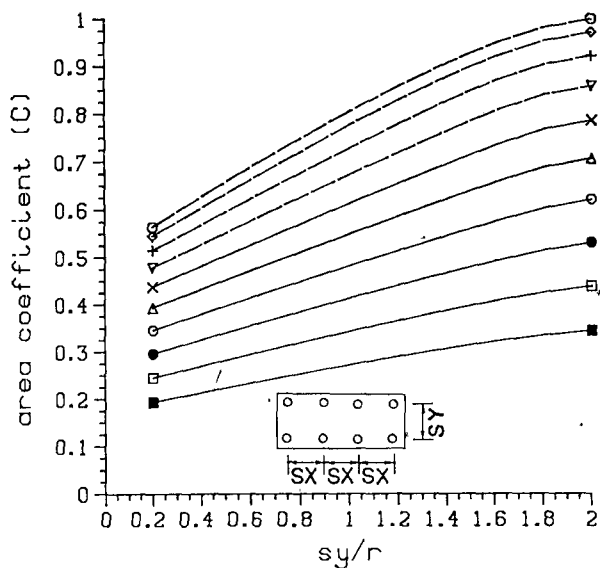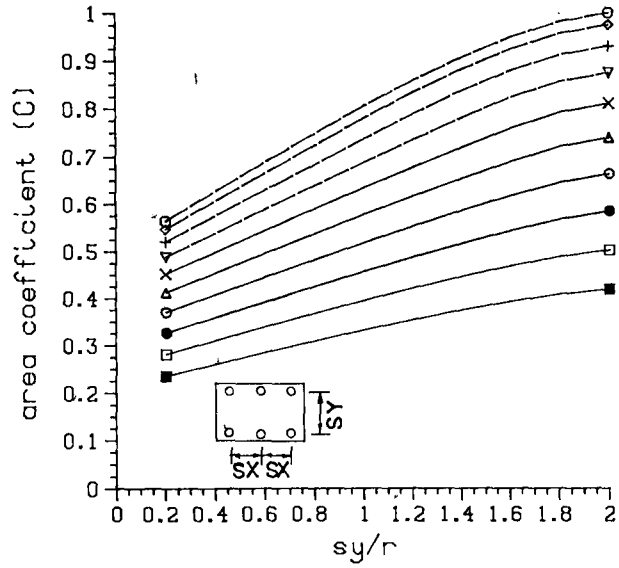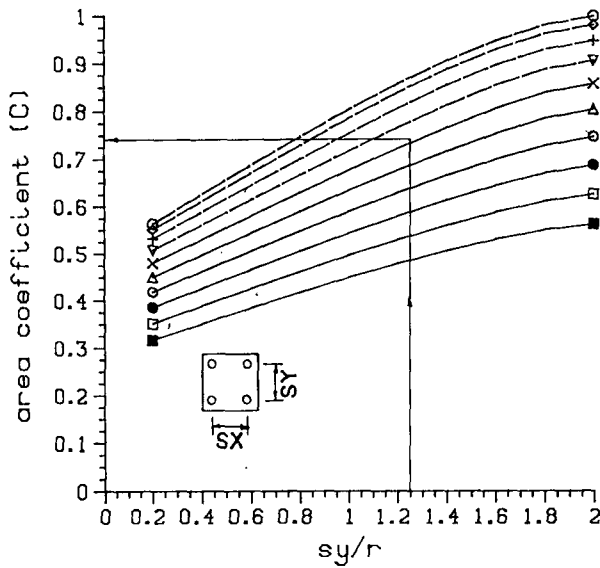
Design aid charts

Determining the effective area when the projected circles overlap can be time consuming if several design iterations have to be made. Thus, charts for standard bolt configurations can be used to alleviate this problem.

The variables used in the charts

Legend: ■ sx/r - 0.2   ● sx/r - 0.6   △ sx/r - 1.0   ▽ sx/r - 1.4   ◇ sx/r - 1.8
         □ sx/r - 0.4   ○ sx/r - 0.8   × sx/r - 1.2   + sx/r - 1.6   ○ sx/r - 2.0

Charts for computing concrete pullout strength for various anchor bolt configurations.

are the spacings of the bolts in two directions sx and sy, and the radius of the overlapping circles, r, which is equal to the sum of the embedment length (L_d) and the radius of the anchor head $(0.5d_H)$. The values in the charts have been non-dimen-sionalized by using the ratio of the spacing to the radius of the projected circle and by normalizing the computed projected area by the sum of the areas of the individual circles. For example, in case of the four-bolt pattern, the effective area was divided by the term $4\pi r^2$ to give the corresponding area coefficient, C. The area coefficients can thus have a maximum value of 1. This approach gives an idea of the efficiency of the bolt configuration used, since the value of the coeffi-

Fig. 2 — Multiple bolt anchorages.
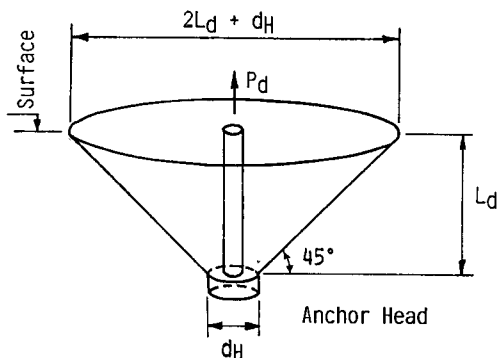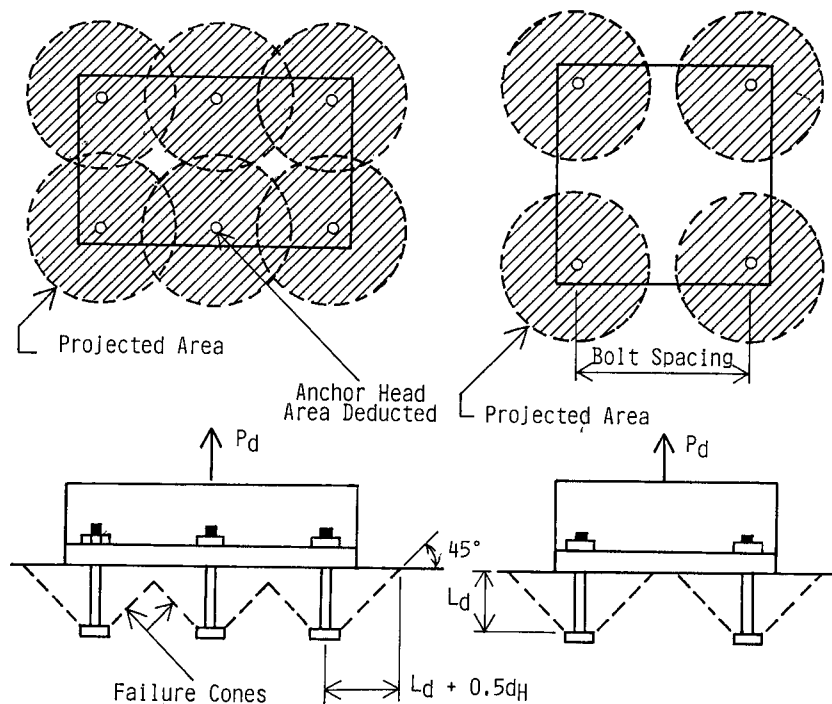
(a) Intersecting Cones   (b) Nonintersecting Cones

Fig. 1 — Definition of pullout failure cone.

cient shows the pullout capacity of the group as a fraction of the sum of the individual capacities.

Usage procedure for charts

The procedure for using the charts is as follows:

1. Choose the chart corresponding to the bolt configuration.
2. Compute r = length of embedment (L_d) + radius of anchor head $(0.5d_H)$.
3. Compute the following ratios: sx/r and sy/r.
4. Obtain the plotted value of the area coefficient, C from the selected chart for the computed values of sx/r and sy/r. Use interpolation if necessary.
5. Compute the effective area as follows:

$$A_{eff} = N \pi [C r^2 - (0.5d_H)^2]$$

where N = number of bolts and C = area coefficient from the plots.

6. Compute pullout capacity using equation for P_d.

Due to the smooth behavior of the function for the area coeffi-

cient, test cases have shown that interpolation will result in errors of less than 5 percent. A conservative approach would be to use the next lowest values for the spacing/radius ratios.

The use of these charts is limited only to the determination of the concrete pullout strength. The designer should check the requirements for the minimum side cover distance and for concrete slab depth. If the depth of the slab is insufficient, the effective stress area has to be reduced.[1] The procedure in that case is exactly as outlined previously except that the computed area A_{eff} has to be further reduced.

References

1. ACI Committee 349, "Code Requirements for Nuclear Safety Related Concrete Structures (ACI 349-85) and Commentary (ACI 349R-85)," American Concrete Institute, Detroit, 1985, 129 pp.

2. Marsh, M. Lee, and Burdette, Edwin G., "Multiple Bolt Anchorages: Method for Determining the Effective Projected Area of Overlapping Stress Cones," *Engineering Journal*, AISC, V. 22, No. 1, 1985, pp. 29-32.

3. "Maxi-Bolt Anchoring System," Drillco Devices Ltd., New York, 1983.

Acknowledgements

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