S. K. Ghosh Associates LLC
Seismic and Building Code Consulting

QUICK ANCHOR

Version 3.9.4

User Manual

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DISCLAIMER

Every attempt has been made to ensure correctness in implementing code provisions as well as the accuracy of the calculations in Quick Anchor. In using the program, however, the user accepts and understands that no warranty is expressed or implied by SKGA as to the accuracy or the reliability of the program. The user must carefully read the "Computational Background" section of this manual and thoroughly understand the assumptions of the program and must independently verify the results. In addition, in no event shall SKGA, or its employees or affiliates be liable for any indirect, incidental, consequential, or punitive damages whatsoever relating to the use of Quick Anchor.

REVISION HISTORY

Version 3.9.4

1. An error was corrected where a custom anchor material specified as “Ductile” was being considered as “Brittle”.

Version 3.9.3

1. Provisions were made so that the program can correctly open an old input file where edge reinforcement was not specified separately from supplementary reinforcement for shear.
2. Some minor typographical errors were corrected in the detailed output report.

Version 3.9.2

1. Input for edge reinforcement has been added separately from shear supplementary reinforcement.
2. An error has been corrected where a ductile anchor material could be marked as nonductile while saving an input file under certain situations.

Version 3.9.1

1. An error has been corrected in the calculation of modification factor for post-installed anchors designed for uncracked concrete without supplementary reinforcement and with small edge distance.

Version 3.9.0

1. An error has been corrected in the way the special seismic requirements for preventing brittle failure is checked when anchor reinforcement for tension is provided.

Version 3.8.1

1. A revision has been made in the way the program calculates the average seismic ratios for tension and shear loading.
2. An error has been corrected in the way an additional phi-factor for seismic shear is applied when ACI 318-11 or ACI 318-14 is selected as the governing code.
3. Some issues in the Detailed Output Report has been addressed.

Version 3.8.0

1. An error has been corrected where application of a tension load without any eccentricity was creating incorrect bending moments in an anchor system for certain base plate configurations.
2. An error in the output has been rectified where the table displaying anchor forces was not being written when there was no applied tension.

Version 3.7.1

1. An error has been corrected where governing load combination was not being read correctly from an input file.

Version 3.7.0

1. Support for the 2015 IBC and ACI 318-14 has been included.
2. Outputs are now generated in PDF format for easy navigation and file handling.
3. A feature is added for easy upgrade of USB license keys.

Version 3.6.1

1. An error in printing output has been fixed.

Version 3.6.0

1. An error in determining ϕ-factor for pryout failure in post-installed anchors has been corrected.
2. An option has been provided for users to specify λ_a for light-weight concrete from test reports for post-installed anchors.
3. An issue with saving and reading “default input” has been rectified.

Version 3.5.0

1. An issue has been resolved where the program was not able to converge in determining anchor forces for certain anchor formations.

Version 3.4.1

1. An error has been rectified where the program was printing the left and right edge distances of the base plate incorrectly on the detailed output.

Version 3.4.0

1. A new approach is employed to produce the output in order to mitigate conflicts with MS Office applications.

Version 3.3.1

1. A display issue has been resolved where one of the objects on the “Check for Splitting” window was not shown completely for post-installed anchors.
2. An error has been rectified where the program was not using the absolute eccentricity values in determining the concrete pryout strength of adhesive anchors in shear.

Version 3.3.0

1. An error has been rectified where the program was mistakenly applying the 0.75 seismic design factor to the concrete pryout strength of anchors in shear when using ACI 318-11.

Version 3.2.2

1. An error has been rectified where the program was not determining the concrete breakout strength of headed studs in shear correctly.

Version 3.2.1

1. An error has been rectified where the program was skipping the shear strength calculations where there was no shear force applied.

Version 3.2.0

1. An error has been rectified where the program was not initializing the N_{sb}/N_{sbg} value in consecutive runs.

Version 3.1.0

1. An error has been rectified where the program was not determining the concrete pryout strength of adhesive anchors in shear correctly.
2. A new web-based temporary license feature has been added which enables the users to start using the full features of the program right after the purchase/upgrade for 14 days while they are waiting to receive/upgrade their USB license key.

Version 3.0.1

1. A display issue has been fixed where the program was not scaling properly when viewed on a high DPI monitor.

Version 3.0.0

1. Added a new option for a “Perimeter” arrangement of anchors.
2. Added input options for applied moments and torsion. The program will determine the anchors that are to be included in tension and shear analyses based on all applied loads.
3. Re-designed and improved program interface.
4. Improved detailed output report.

INPUT INTERFACE

The input fields in the Quick Anchor interface are mostly self-explanatory. However, a short description of each input field is provided below for better clarity. Different input fields are marked by item numbers, as shown below in Figure 1. Units used in this program are as follows:

Quantities related to length (spacing, edge distance, diameter, etc.): inches
Material strength: psi
Applied load: Kips or Kip-ft

ANCHOR ARRANGEMENT

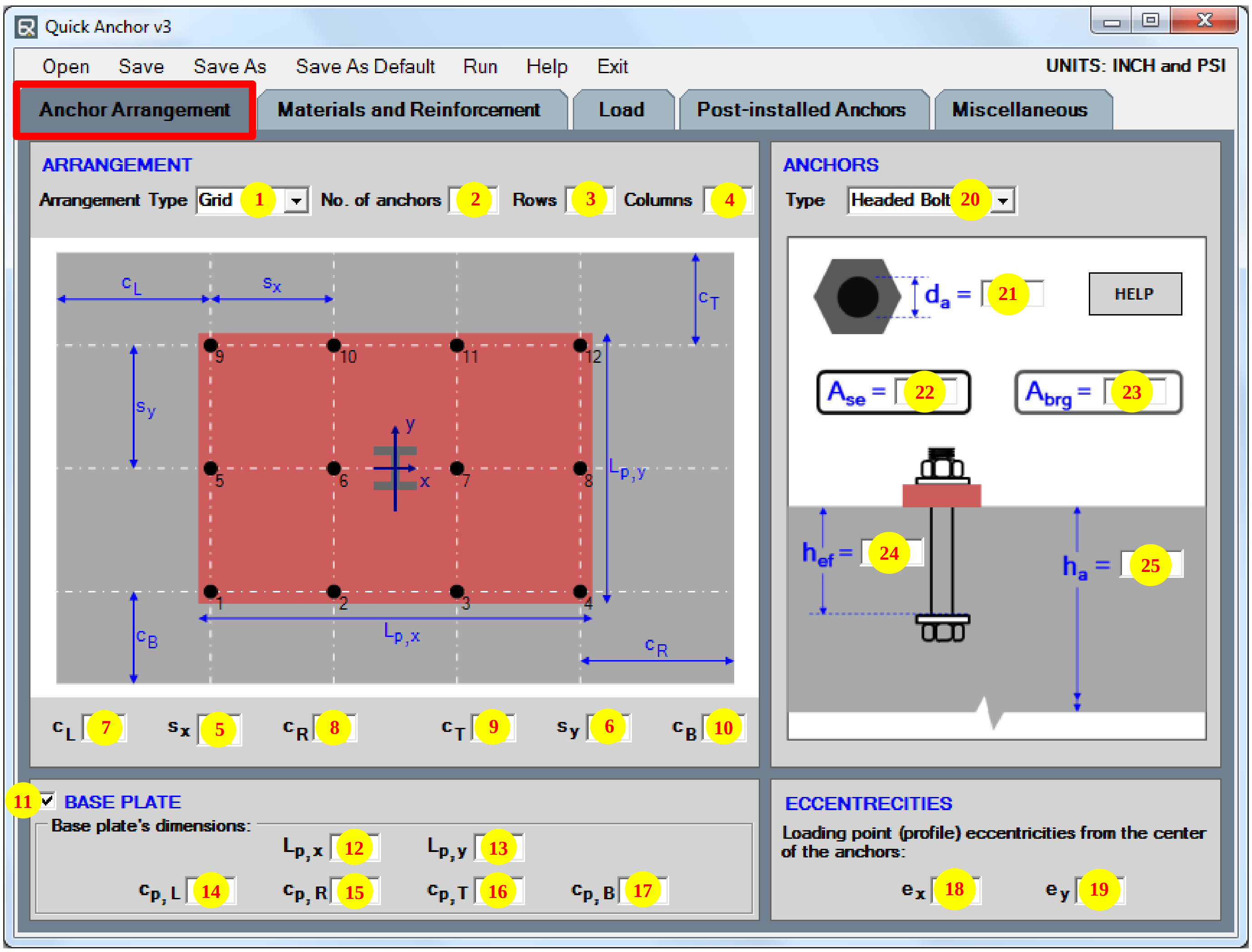


Figure 1. ANCHORARRANGEMENT input page of Quick Anchor

Item 1: Select the type of arrangement – grid (rectangular w/ middle anchors) or perimeter (rectangular w/o middle anchors).

Item 2: Total number of anchors, n, must be greater than or equal to one.

Item 3: Number of rows in which the anchors are arranged.

Item 4: Number of columns in which the anchors are arranged.

Item 5: Spacing of anchor columns, s_x.
This is automatically set as 0 when there is only one column of anchors.

Item 6: Spacing of anchor rows, s_y.
This is automatically set as 0 when there is only one column of anchors.

> **Note:** For a *perimeter* arrangement, these values show the spacing of gridlines.

Items 7 through 10: Edge distances, in inches, on all four sides of the anchor or the anchor group.

Item 11: Select if there is a base plate. Specifying base plate parameters is required only when there are applied moments (including eccentrically applied tension) on a group of anchors, so that the program can determine the distribution of tension forces on the anchors. The baseplate itself is not designed by the program.

Items 12 and 13: Lengths of the base plate in x- and y-direction, respectively.

Items 14 through 17: Edge distances on all four sides of the base plate. Base plate must extend at least half an inch beyond the center of the edge anchors.

Items 18 and 19: Eccentricities of the applied load in x- and y-direction with respect to the center of a group of anchors.

> **Note:** Quick Anchor v3 assumes all loads, tension and shear, are applied at a single point. In other words: *eccentricities of applied tension = eccentricities of applied shear force(s)*

Item 20: Select anchor type – headed bolts, headed studs, hooked (J- or L-) bolts, adhesive, undercut or expansion.

Item 21: Specify anchor diameter, d_a (d_o in ACI 318-05), in inches. User can also click on the "Help" button to choose a standard diameter from a drop-down menu (See Items 22 and 23 for more detail).

Items 22 and 23: Specify the effective cross-sectional area of a single anchor, A_{se}, and bearing area of the head of a headed anchor, A_{brg}, in square inches. When hooked (J- or L-) bolts are used, the bearing length of the hook (e_h) is specified, in inches, in **Item 23**, instead of A_{brg}.

Effective cross-sectional area of threaded rods is calculated from the following formula:

$$A_{se} = \pi \, (d_o - 0.9743/n_t)^2 \, / \, 4$$

where n_t is the number of threads per inch of the anchor.

When headed studs or bolts are used, the bearing area of the anchor head, A_{brg}, is calculated by simply subtracting the gross shank area of the anchor (not A_{se}) from the area of the head.

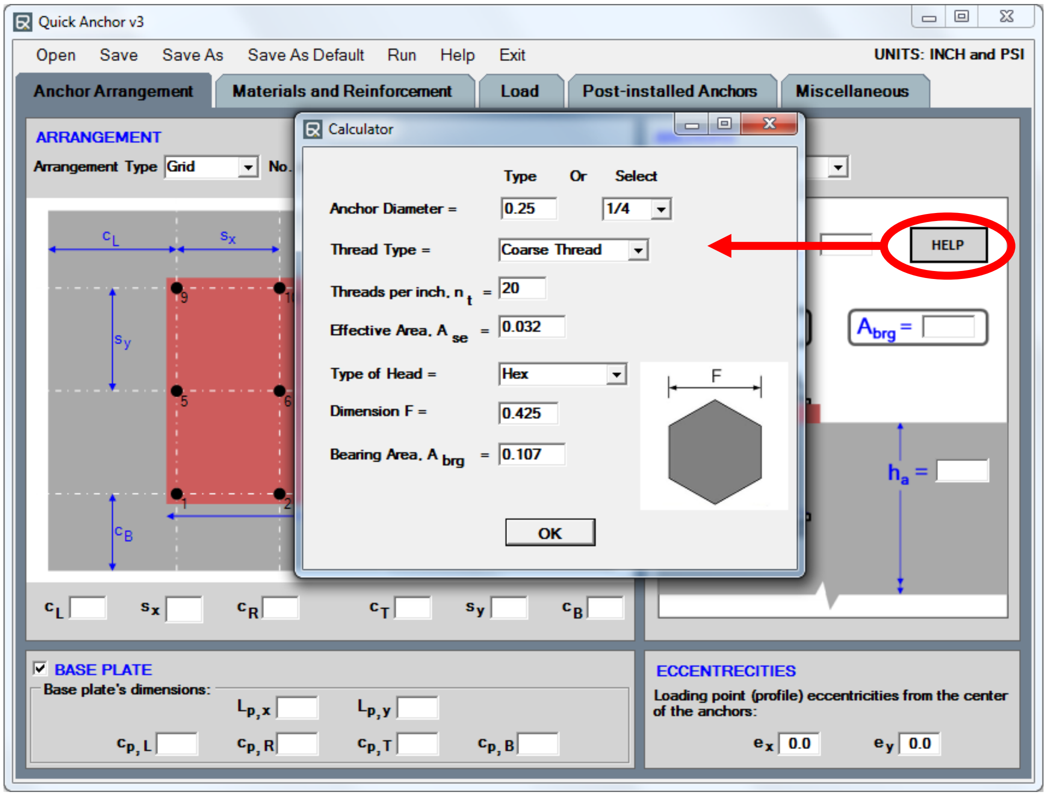


Figure 2. Calculator for determining A_{se} and A_{brg}

<u>anchor area calculator:</u> A calculator has been provided to facilitate the computation of A_{se}. Click on the “Help” button to open the calculator, which appears in a separate window (Figure 2). In the calculator, user can type in a diameter (in inches) in the box provided or simply choose from a list of standard diameters from a drop-down menu. When a standard diameter is selected, the value of n_t is obtained automatically based on the selected thread type (“Coarse Thread” or “Fine Thread”). However, when the user chooses to enter a custom diameter, the value of n_t also needs to be specified.

To calculate A_{brg} of one of the listed anchor diameters, the user simply needs to choose the anchor head type (“Hex”, “Heavy Hex” or “Square”). When using a custom diameter, the user also needs to specify the dimension F of the head.

Once A_{se} and A_{brg} have been calculated, click “OK” to import the values into the corresponding boxes (22 and 23, respectively) in the main window of the program.

The calculator provides anchor diameters up to $1^1/_2$ inches for Fine Thread and/or Square Head anchors. For other types of anchor, the calculator can help the user with anchor diameters up to 4 inches.

Item 24: Specify the effective embedment depth of the anchor(s) in inches.

Item 25: Specify concrete depth, h_a, in inches.

MATERIALS AND REINFORCEMENT

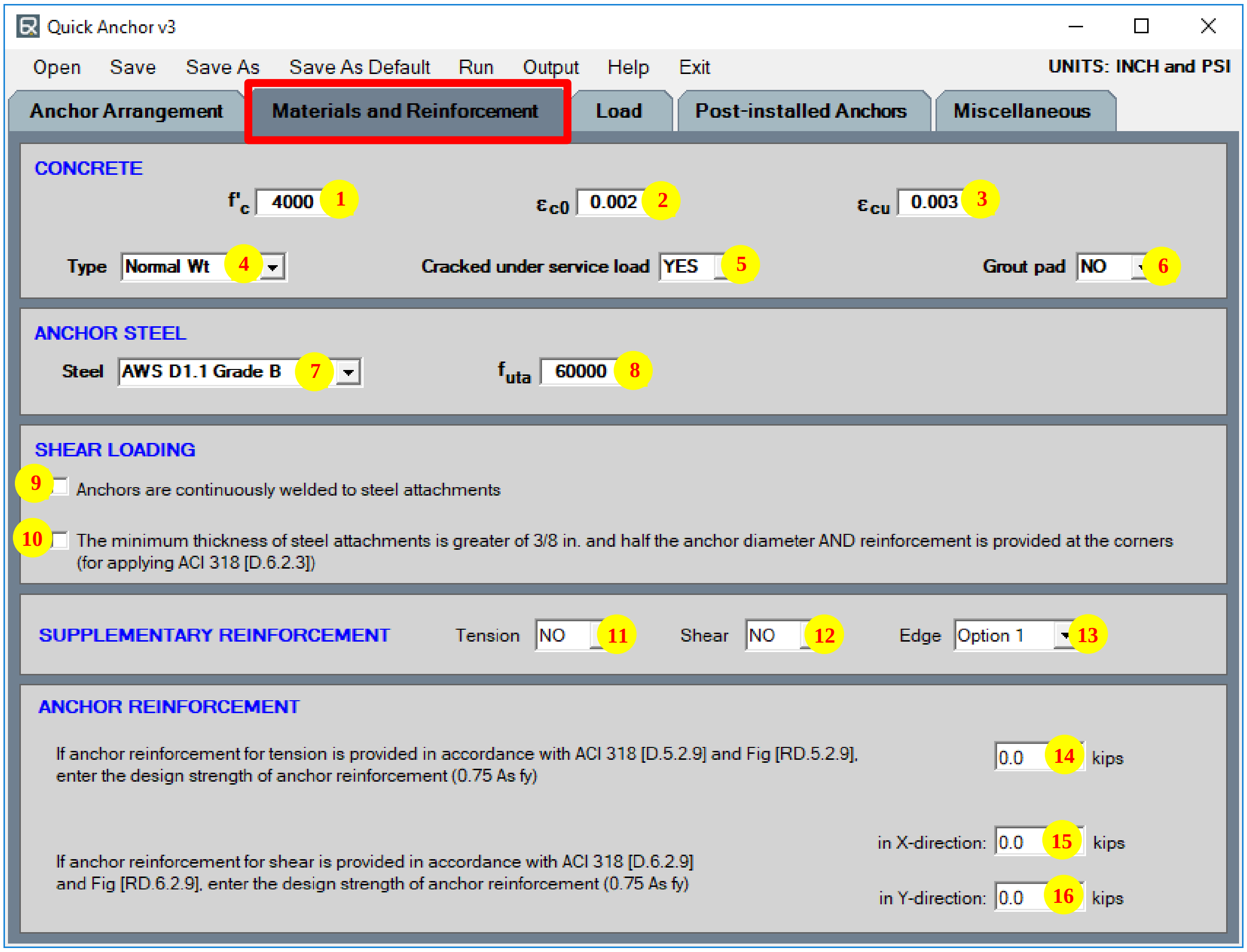


Figure 3. MATERIALS AND REINFORCEMENT input page of Quick Anchor

Item 1: Nominal strength of concrete, f'_c, in psi (see Figure 4).

Item 2: Concrete strain at maximum strength (see Figure 4).

Item 3: Concrete strain at crushing strength (see Figure 4).

Item 4: Select the type of concrete – normalweight, sand-lightweight or all-lightweight. By default, the program assumes the type to be normalweight.

Item 5: Select if concrete is cracked or uncracked under service load. By default, the program assumes concrete to be cracked under service load. ACI 318-05 and ACI 318-08 require that, for Seismic Design Category (SDC) C or higher, the concrete be assumed cracked at service load unless it can be demonstrated that it remains uncracked. When using ACI 318-11, the same is required for SDC C or higher when the seismic component of the applied loads on the anchors is more than 20% of the total load on the anchors. ACI 318-11 Commentary Section RD.3.3.4.4 says the following:

"…..*Because seismic design generally assumes that all or portions of the structure are loaded beyond yield, it is likely that the concrete is cracked throughout for the purpose of determining the anchor strength. In locations where it can be demonstrated that the concrete does not crack, uncracked concrete may be assumed for determining the anchor strength as governed by concrete failure modes.*"

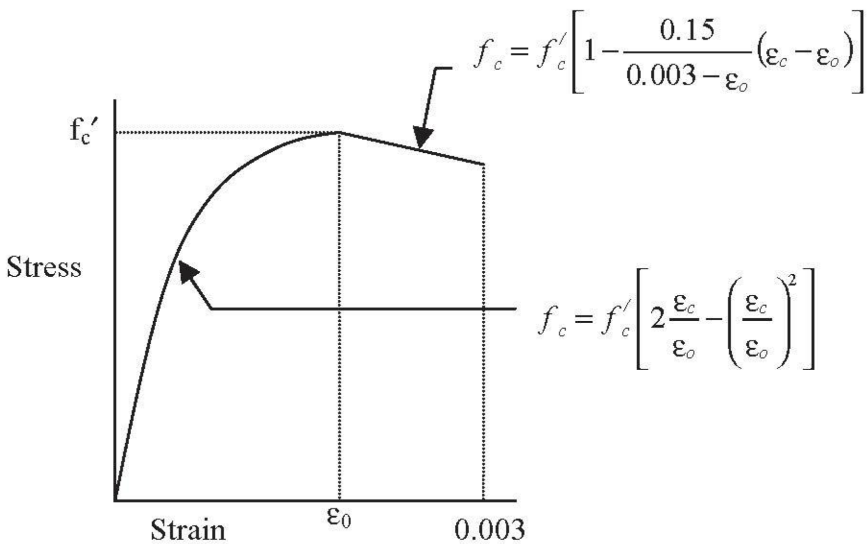


Figure 4. Theoretical stress-strain curve of concrete

Item 6: Specify whether grout pads are provided between the anchors and the concrete base or not. This affects the calculation of steel strength of anchor in shear.

Item 7: Select the grade of anchor steel from the built-in options or select "Other" to use a different material. When one of the built-in options is selected, the steel tensile strength, f_{uta}, is automatically selected by the program, which appears in **Item 8**. All these options are also considered to be ductile as per the definition of "ductile steel element" given in ACI 318 D.1. When "Other" option is selected, user needs to specify f_{uta} in **Item 8**. Additionally, when "Other" is selected, user is presented with two more input parameters (Figure 5) that need to be specified – one to specify the yield strength of the anchor steel (**Item 8a**), and the other to select if the user-defined anchor steel is ductile as per ACI 318 D.1 (**Item 8b**).

Not all grades of steel are available for all types of anchors. For example, ASTM A 307 Grade C is for hooked bolts only, and not for headed bolts or studs. User should be careful when selecting anchor material for a certain type of anchors.

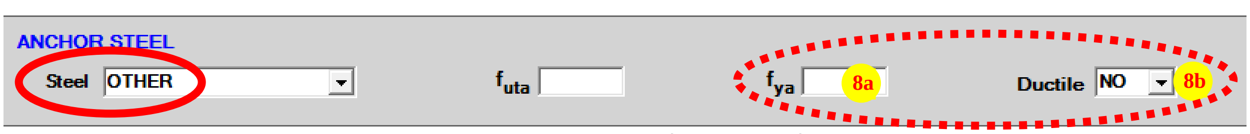
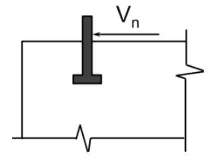


Figure 5. Additional input parameters for user-defined anchor material

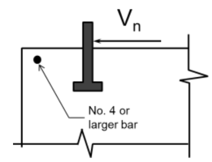
Items 9 and 10: These apply for cast-in headed studs, headed bolts, or hooked bolts, for the purpose of ACI 318 Section D.6.2.3. By default, both boxes are unchecked.

Items 11, 12 and 13: User can input if supplementary reinforcement is provided for tension, shear and for splitting. When supplemental reinforcement is provided for tension loading, it increases the values of the strength reduction factors associated with two tension failure modes - concrete breakout and concrete side-face blowout. When supplemental reinforcement is provided for shear loading, it increases the value of the strength reduction factor associated with concrete breakout in shear. Presence of edge reinforcement helps prevent splitting failure under tension loading, and can have a beneficial effect on the tension strength of post-installed anchors under certain situations. It could also have a beneficial effect on the strength in concrete breakout in shear when concrete is selected as cracked in Item 5. Three options are available for edge reinforcement :

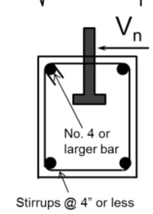
I) OPTION 1 – This option is selected when there is no edge reinforcement present between the anchors and the edge of concrete, or when the edge reinforcement comprises of bars smaller than No. 4. (ACI 318 D.6.2.7 Paragraph 3)



II) OPTION 2 – This option is selected when No. 4 or larger bars are present between the anchors and the concrete edge. (ACI 318 D.6.2.7 Paragraph 4)



III) OPTION 3 – This option is selected when No. 4 or larger bars are present between the anchors and the concrete edge AND the bars are enclosed within stirrups spaced not more than 4 in. (ACI 318 D.6.2.7 Paragraph 5)



Item 14: When using ACI 318-08, -11 or -14, it is permitted to use design strength of anchor reinforcement for tension instead of concrete breakout strength, ϕN_{cb} or ϕN_{cbg}. If anchor reinforcement for tension is provided in accordance with ACI 318 Section D.5.2.9 and Fig. RD.5.2.9, specify its design strength using a strength reduction factor of 0.75. If no anchor reinforcement is provided, leave the value as zero.

Items 15 and 16: When using ACI 318-08, -11 or -14, it is permitted to use design strength of anchor reinforcement for shear instead of concrete breakout strength, ϕV_{cb} or ϕV_{cbg}. If anchor reinforcement for shear in X-direction (Item 15) and/or in Y-direction (Item 16) is provided in accordance with ACI 318 Section D.6.2.9 and Fig. RD.6.2.9, specify its design strength using a strength reduction factor of 0.75. If no anchor reinforcement is provided, leave the values as zero.

LOAD

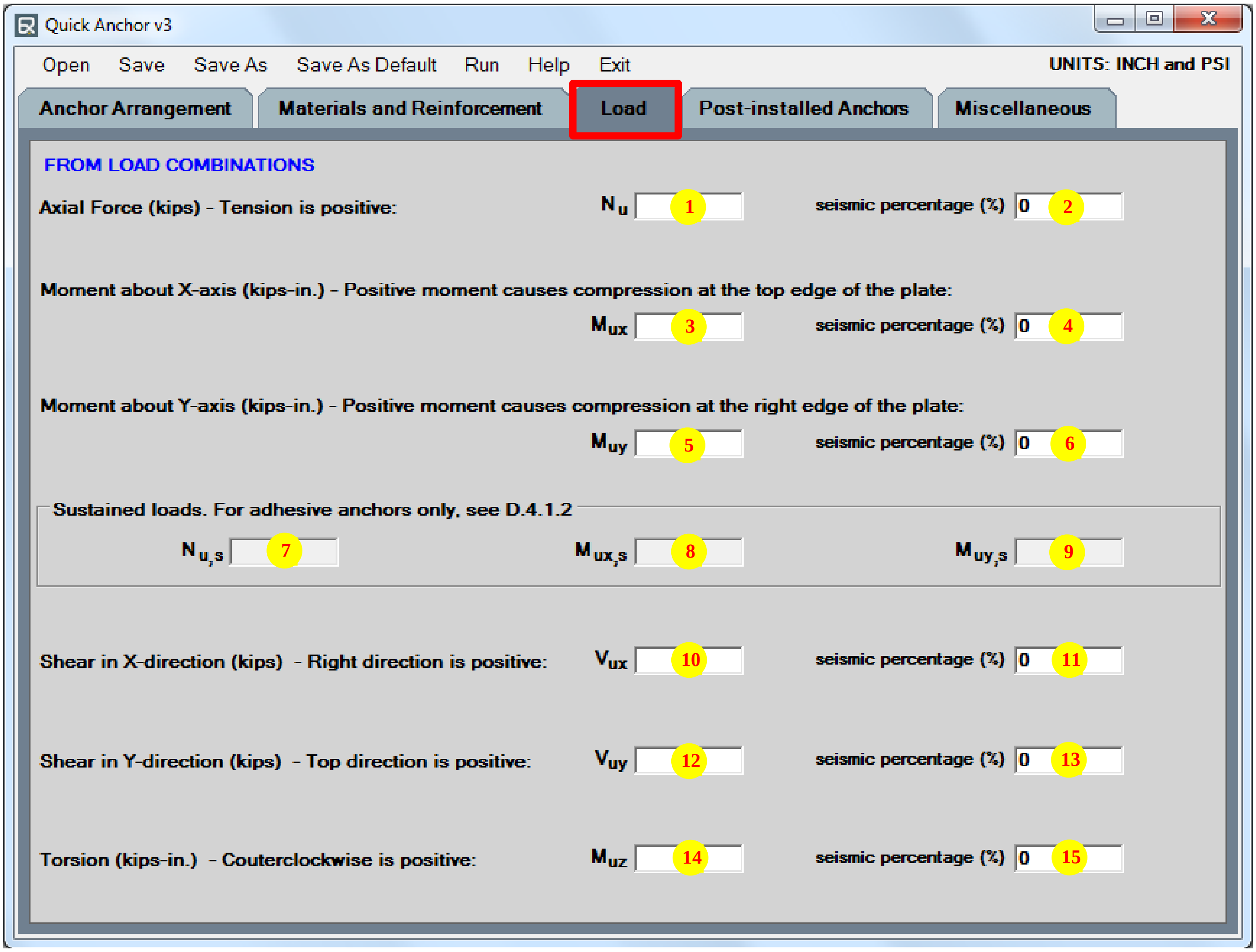


Figure 6. LOAD input page of Quick Anchor

Items 1, 3, 5, 10, 12, and 14: Specify the factored loads acting on the anchors as determined from the 2012 IBC strength design load combinations. Please note the correct sign for the desired direction of load application.

Items 2, 4, 6, 11, 13, and 15: When using ACI 318-11, specify the percentages of the each applied load that is caused by seismic effects on the structure. For example, if the applied tension, Nu, was determined from the load combination 1.2D + 0.5L + E, then the seismic percentage should be calculated as:

$$\frac{E}{1.2D + 0.5L + E} \times 100$$

The specified seismic percentages are used to determine if the special seismic requirements of ACI 318-11 are applicable or not.

Items 7, 8, and 9: For adhesive anchors, specify the sustained loads, if present. See ACI 318-11 Sections D.3.5 and D.4.1.2 for more information. Note ACI 318-11 needs to be set as the governing code (see Figure 8) in order to use adhesive anchors in Quick Anchor v3.

POST-INSTALLED ANCHORS

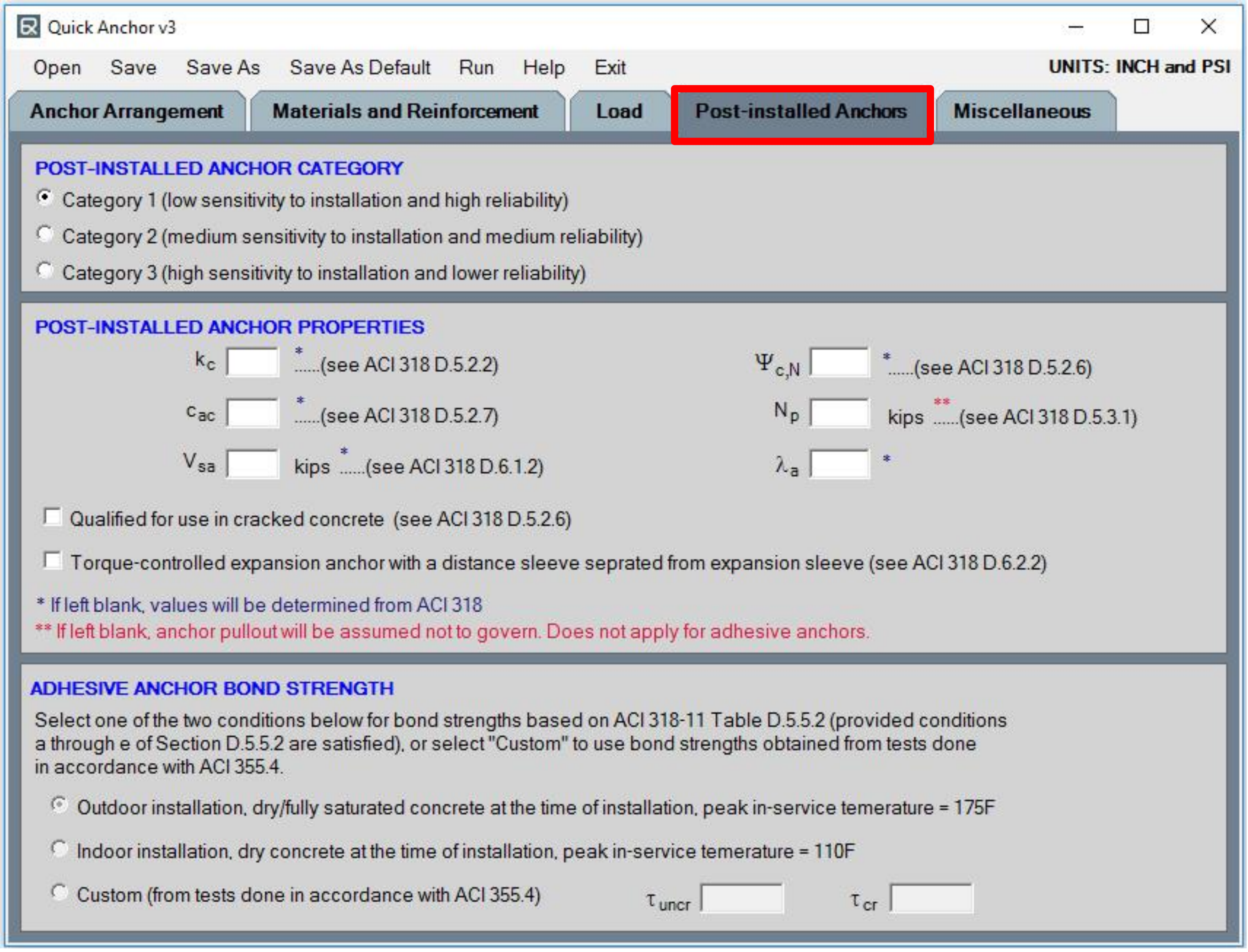


Figure 7. POST-INSTALLED ANCHORS input page of Quick Anchor

The post-installed anchor properties window shown in Figure 7 can be used to enter post-installed anchor category and other design parameters. The area for entering adhesive anchor bond strengths in uncracked and cracked concrete appears only when adhesive anchor is selected on the main form. These anchor properties are determined based on the tests done in accordance with ACI 355.2 or ACI 355.4, and are obtained from anchor manufacturers.

MISCELLANEOUS

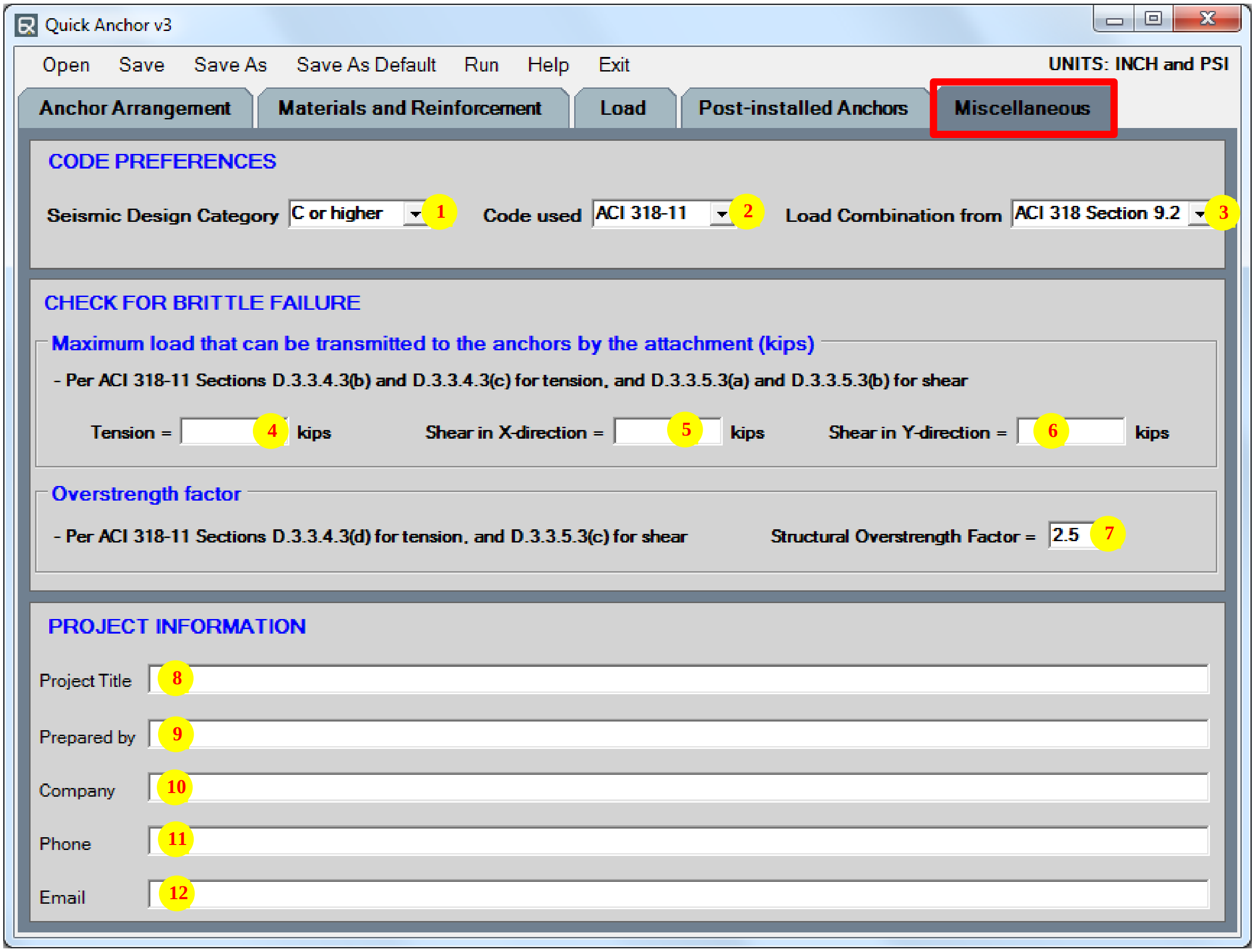


Figure 8. MISCELLANEOUS input page of Quick Anchor

Item 1: Select if the structure that is assigned to SDC *B* or *C or higher*.

Item 2: Select if the strength calculation should be done in accordance with ACI 318-05, ACI 318-08 or ACI 318-11.

Item 3: Select which load combination equations were used to calculate the tension and shear demands on the anchor or anchor group. Strength reduction factors (ϕ-factors) are calculated based on this selection.

Items 4, 5, and 6: Specify the maximum loads that can be transmitted to the anchors by the attachment. Anchors can be designed for these loads to avoid meeting the ductile failure requirement of anchors when designed for seismic loading.

Item 7: Specify the structural overstrength factor, Ω_0. Anchors can be designed for factored loads amplified by Ω_0 to avoid meeting the ductile failure requirement of anchors when designed for seismic loading.

Items 8 through 12: *Project Info* fields can be used to enter the details of the anchor design project. These details show up on the header of the output reports.

OTHER INPUT WINDOWS - CHECK FOR SPLITTING FAILURE

A tool to check for a possible splitting failure in tension can be accessed as shown in Figure 9. The tool checks if the anchor spacings and the edge distances specified in the input conform to the requirements of ACI 318 Section D.8

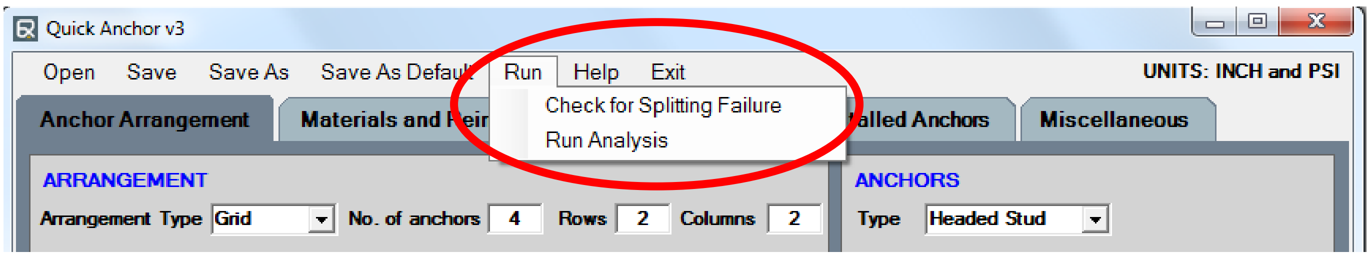


Figure 9. Splitting Failure Checking Tool

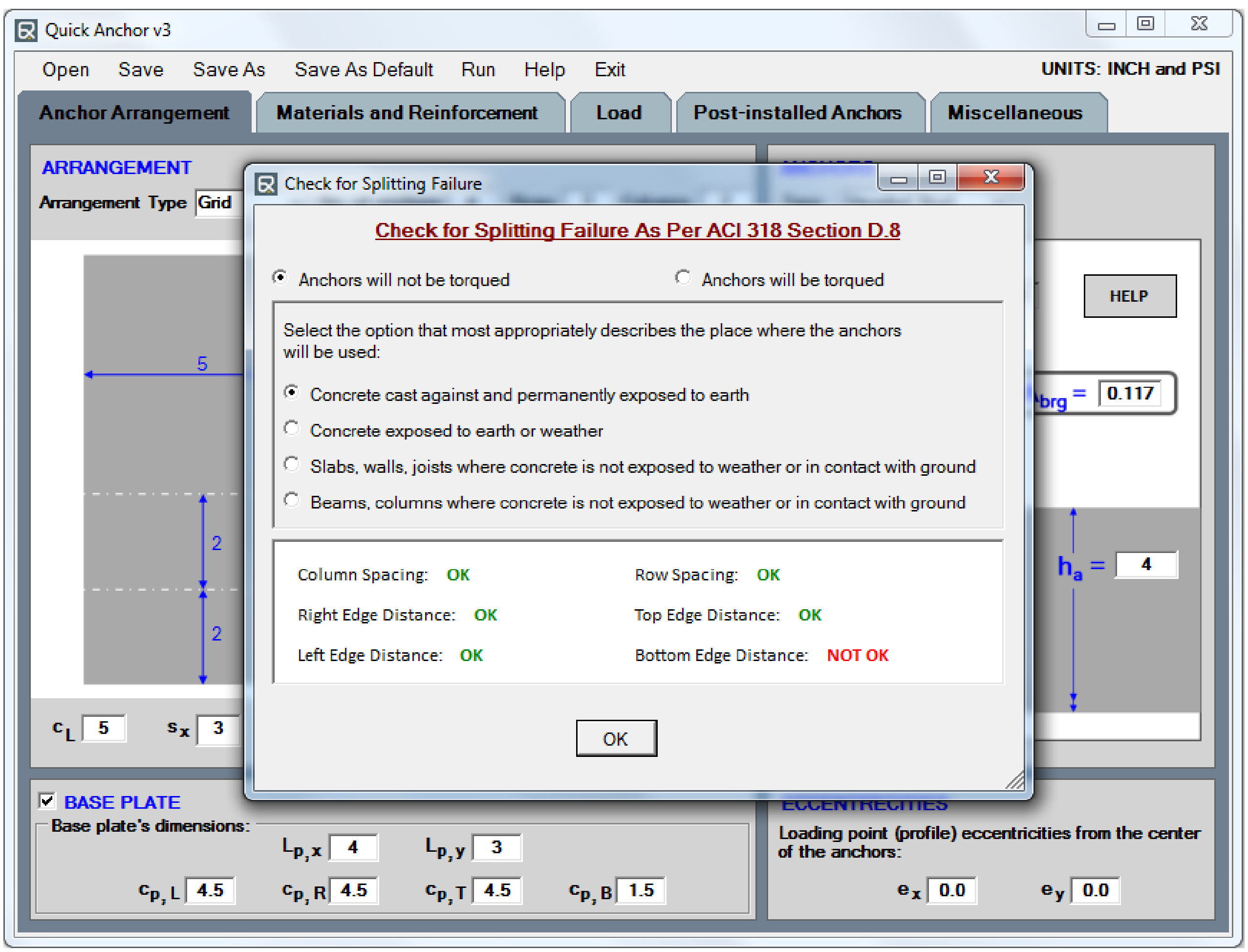


Figure 10. Checking Tool for Splitting Failure

This check is optional in Quick Anchor and does not need to be done for the purpose of strength calculation. However, it is strongly recommended that the user do this check in order to make sure that the requirements of ACI 318 Section D.8 are satisfied. The user needs to first specify the anchor diameter as well as all four edge distances and the anchor spacings (for a group of anchors) for the checking tool to run properly.

The checking tool opens in a separate window (Figure 10). When "Anchors will be torqued" option is selected, the checking tool simply displays if the anchor spacings in X- and Y-directions (for a group of anchors) as well as all the edge distances meet the minimum values specified in Section D.8 for the anchor diameter being used. The user has the option of either selecting a smaller diameter anchor or increase the distance (spacing and/or edge distance) that failed the check.

When the option "Anchors will not be torqued" is selected, the user also needs to select the type of place where the anchors will be used. If any of the anchor spacing or edge distance fails the check, depending on the place where the anchors will be used, the user may get an option of using a smaller diameter just for the purpose of calculation (ACI 318 Section D.8.4). When this option is available, it is shown at the bottom of the window and the smaller diameter that can be used in accordance with Section D.8.4 is also mentioned. The user can choose to use this smaller diameter for the purpose of the strength calculations by clicking on "Revise Diameter" button, or simply click on "OK" to close the checking tool without changing anything. If the user chooses to revise the diameter, the suggested smaller diameter will be displayed in the corresponding box in the main program window. The program also revises the value of Ase based on this revised diameter. The revised Ase¬ is the gross cross-sectional area calculated from the revised diameter. However, if this value is greater than the original Ase, then the original value is retained. The value of Abrg is not changed.

OUTPUT INTERFACE

Each time Quick Anchor is run, a separate output window (Figure 11) will be displayed. User will be able to select to *Simple Output or Detailed Output* on this window.

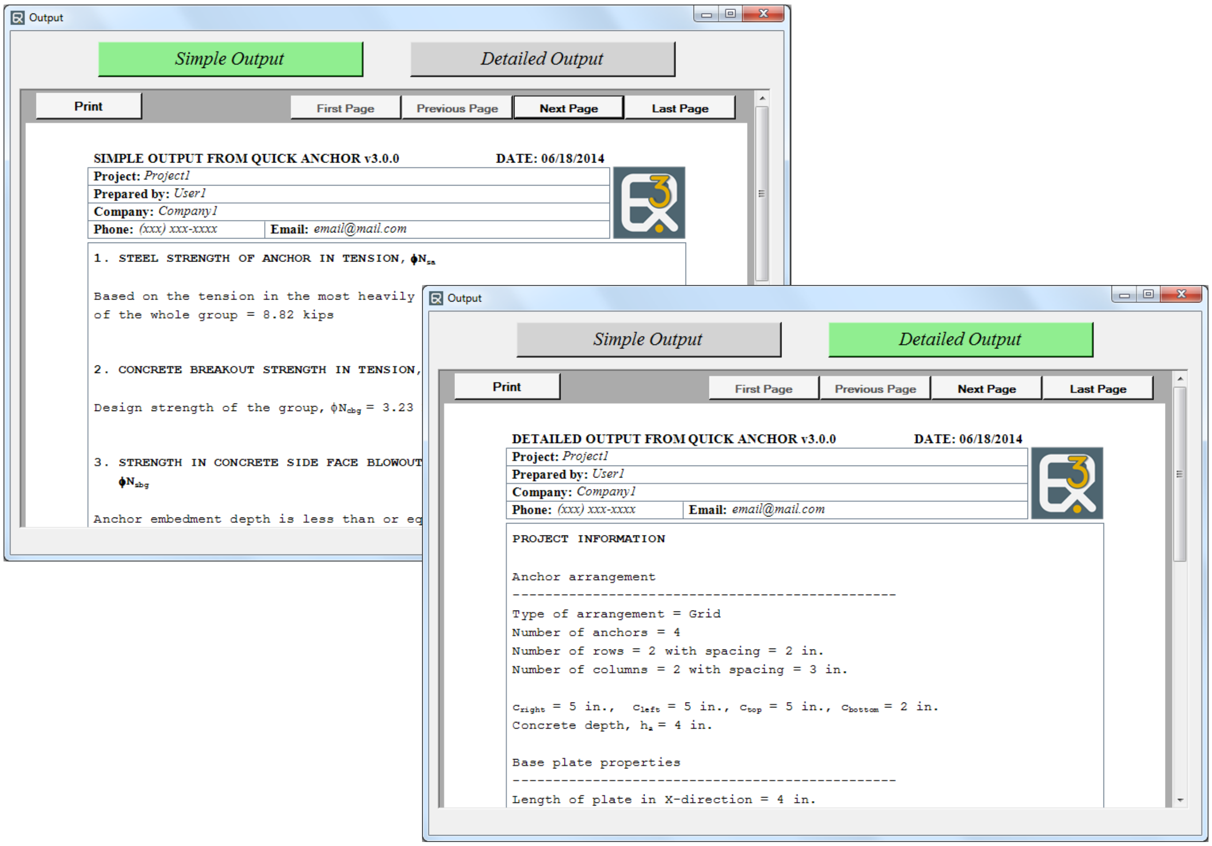


Figure 11. Simple and Detailed Output Window

User can easily look through the output reports using navigation buttons. A Print button is also provided.

COMPUTATIONAL BACKGROUND

Important Note:

This program skips strength calculation unless there is a corresponding applied load. In other words, tensile failure modes will be investigated only if the anchor formation is subjected to a tensile force (either from direct applied tensile axial load or from applied moments). Similarly, shear failure modes in X- or Y-direction will be investigated when the anchor formation is subjected to a shear force (either from direct applied shear load or from applied torsion) in the corresponding direction.

In addition, when computing the tensile strength of a group of anchors, this program excludes anchors not carrying tensile forces (check Anchor Forces table on the detailed output report). In computing the shear strength, the program starts the calculations considering active anchors carrying shear forces in desirable direction only. In other words, some of anchors may carry compression forces in certain loading situations such as large applied moments. These anchors will be excluded from the tensile strength calculation. Similarly, some anchors may take shear in opposite direction to the direction of applied shear load, mostly due to large eccentricity values or large applied pure torsion, and will be excluded from the shear strength computations (see Figure 12).

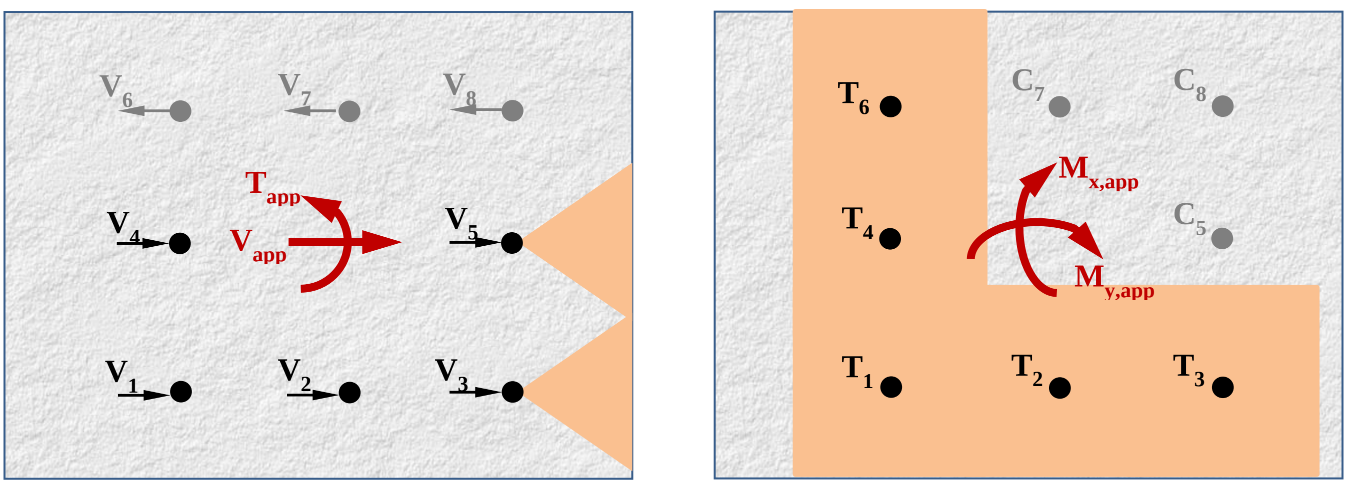


Figure 12. Anchors Excluded from Strength Computations

1. Steel strength of anchor in tension:

Design tensile strength of a single anchor is calculated as

$$\phi N_{sa} = \phi_{st} A_{se} f_{uta}$$

For structures assigned to SDC C or higher, a factor of 0.75 is applied to the above value when design is performed in accordance with ACI 318-05. With ACI 318-08 or -11, this factor is not required in this mode of failure.

In a group of anchors, the strength computed above needs to be compared against the maximum tension demand that occurs on a single anchor in the group. Conversely, this strength of a single anchor can also be converted to the strength of the whole group by dividing it by the fraction of the total tension demand that the most heavily loaded anchor resists. For example, if the maximum tension demand on a single anchor is 40% of the total tension demand N_u, then the above design strength can be divided by 0.4 to compute the maximum tension that the group can resist. This approach makes it easy to compare the strengths obtained from different failure modes, so that a governing strength can be determined.

2. Concrete breakout strength of anchor in tension:

Design concrete breakout strength is calculated as:

$$\phi N_{cb} = \phi_{ct} \frac{A_{nc}}{A_{nco}} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$$, for a single anchor, and

$$\phi N_{cbg} = \phi_{ct} \frac{A_{nc}}{A_{nco}} \psi_{ec,N} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$$, for a group of anchors.

Additionally, a factor of 0.75 is also applied when special seismic provisions are required by the code. In ACI 318-05 and -08, this applies to structures assigned to SDC C or higher. In ACI 318-11, this applies to structures assigned to SDC C or higher provided the seismic component of the resulting tension is more than 20% of the total applied tension obtained from the load combinations.

For the purpose of concrete breakout in tension, anchors are considered to be in a *group* when the anchor spacing is not more than $3h_{ef}$. When the spacing between the anchor columns or the rows or both exceed $3h_{ef}$, one of the three cases described below can arise.

Case 1. $\boldsymbol{s_x > 3h_{ef}}$ **and** $\boldsymbol{s_y \leq 3h_{ef}}$**:** In this case, each anchor column acts in a group, but the columns act independent of one another (Figure 13).

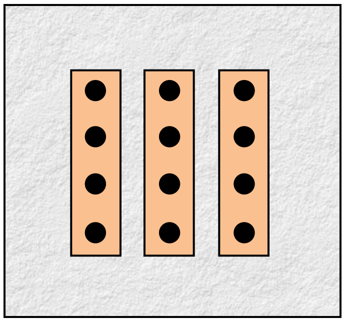


Figure 13. Column spacing more than $3h_{ef}$

In this case, concrete breakout strengths of each column are calculated separately. Because only one column is considered at a time, eccentricity in X-direction, e'_{Nx}, is not considered in computing the eccentricity factor, and only e'_{Ny} is used. The effect of e'_{Nx} is accounted for while calculating the tension demand on each anchor column.

The strengths of each column of anchors is compared against the tension load carried by that column, and extrapolated to compute the strength of the whole anchor formation. It should be noted that the anchor column with the lowest strength may not produce the governing strength for the whole anchor formation if the demand on that column is also low.

Case 2. $s_y > 3h_{ef}$ and $s_x \leq 3h_{ef}$: Same approach as in Case 1. Strengths of each row are calculated separately, and the strength of the whole anchor formation is determined based on them.

Case 3. $s_x > 3h_{ef}$ and $s_y > 3h_{ef}$: In this case, all anchors act on their own without any group action in either direction. Thus, strengths of each anchor are calculated separately, and the strength of the whole anchor formation is determined based on them.

Please note, when using ACI 318-08 or ACI 318-11, user has the option to indicate if anchor reinforcement for tension is provided in accordance with ACI 318 Section D.5.2.9 and Fig. RD.5.2.9 by entering the design strength of anchor reinforcement calculated with a strength reduction factor of 0.75 (see Item 13 under "MATRIALS AND REINFORCEMENT" input tab). If anchor reinforcement design strength is provided by the user, Quick Anchor will not investigate the concrete breakout failure of anchors in tension and will simply use the design strength of anchor reinforcement for tension instead of concrete breakout strength, ϕN_{cb} or ϕN_{cbg}.

<u>3. Concrete side-face blowout strength of a headed anchor in tension:</u>

Concrete side-face blowout applies only for headed bolts or studs when anchor embedment depth, h_{ef}, is greater than 2.5 times the minimum edge distance, c_{a1}. Strength of a single anchor is calculated as

$$\phi N_{sb} = \phi_{ct}(160c_{a1}\sqrt{A_{brg}})\ \lambda_a \sqrt{f_c'}$$

Also, if $c_{a2} < 3c_{a1}$, then an edge distance correction factor $(1+c_{a2}/c_{a1})/4$ is applied to the above strength, where c_{a2} is the minimum edge distance orthogonal to c_{a1}.

Additionally, a factor of 0.75 is also applied when special seismic provisions are required by the code. In ACI 318-05 and -08, this applies to structures assigned to SDC C or higher. In ACI 318-11, this applies to structures assigned to SDC C or higher provided the seismic component of the resulting tension is more than 20% of the total applied tension obtained from the load combinations.

For a group of anchors, possible side-face blowout failure is investigated in both X- and Y-directions. In the X-direction, two anchor columns closest the left and the right edge of concrete are investigated for potential side-face blowout failure. Similarly, for the Y-direction, two anchor rows closest the top and the bottom edge of concrete are investigated for potential side-face blowout failure.

While computing strength in any direction, two scenarios are considered as described below. Even though the description below illustrates failure in the X-direction only, the same is applicable to a failure in the Y-direction as well.

Case 1. $s_y \leq 6c_{a1}$: The whole edge column acts as a group (Figure 14). Strength of this column is calculated as

$$\phi N_{sbg} = \phi_{ct}(160c_{a1}\sqrt{A_{brg}})\ \lambda_a \sqrt{f_c'} \times (1+s/6c_{a1})$$

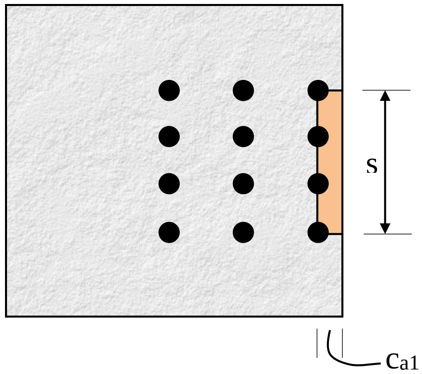


Figure 14. Side-face blowout as a group

The design strength calculated above relates to the anchor column nearest to an edge (the right edge in Figure 13). This needs to be compared against the tension demand on that column only. Conversely, the above design strength can be scaled up by dividing it by the fraction of the total tension demand that this column resists to calculate the strength of the whole anchor group. For example, if the tension demand on the column shown is 40% of the total

tension demand N_u, then the above design strength can be divided by 0.4 to compute the maximum tension demand that the group can support.

Case 1. s_y > $6c_{a1}$: The whole column does not act as a group (Figure 15). Rather, individual anchors can undergo side-face blowout failure.

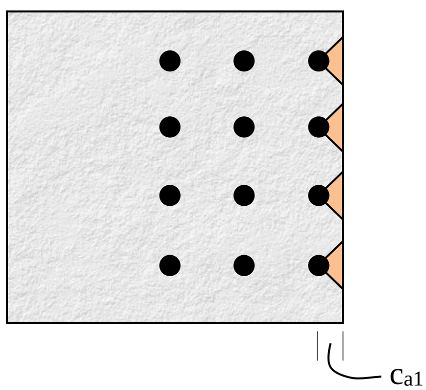


Figure 15. Side-face blowout of individual anchors

In this case, the strengths of each anchor are calculated, and extrapolated to compute the group strength.

4. Pullout strength of anchor in tension:

Design tensile strength of a single anchor is calculated as

1. For headed studs and bolts, $\phi N_{pn} = \phi \Psi_{c,P}\, N_p = \phi_{\text{cpt}}\, \Psi_{c,P}\, (8A_{brg} f_c')$

2. For J- or L-hooks, $\phi N_{pn} = \phi \Psi_{c,P}\, N_p = \phi_{\text{cpt}}\, \Psi_{c,P}\, (0.9 f_c' e_h d_a)$

Additionally, a factor of 0.75 is also applied when special seismic provisions are required by the code. In ACI 318-05 and -08, this applies to structures assigned to SDC C or higher. In ACI 318-11, this applies to structures assigned to SDC C or higher provided the seismic component of the resulting tension is more than 20% of the total applied tension obtained from the load combinations.

For hooked (J- or L-) bolts, if bearing length, e_h, is less than $3d_a$, pullout strength is not calculated due to insufficient bearing length. If e_h is more than $4.5d_a$, then the pullout strength is calculated assuming $e_h = 4.5d_a$, neglecting the excess bearing length.

For post-installed expansion and undercut anchors, the values of N_p is to be determined based on the 5 percent fractile of results of tests performed and evaluated according to ACI 355.2. This value needs to be obtained from the anchor manufacturer and entered in the appropriate place on the *Post-installed Anchor Properties* window as described before. If no value of N_p is supplied, the program will assume the anchor pullout failure not to govern.

For adhesive anchors, pullout failure does not apply.

In a group of anchors, the strength computed above needs to be compared against the maximum tension demand that occurs on a single anchor in the group. Conversely, this strength of a single anchor can also be converted to the strength of the whole group by dividing it by the fraction of the total tension demand that the most heavily loaded anchor resists. For example, if the maximum tension demand on a single anchor is 40% of the total tension demand N_u, then the above design strength can be divided by 0.4 to compute the maximum tension that the group can resist. This approach makes it easy to compare the strengths obtained from different failure modes, so that a governing strength can be determined.

5. Bond strength of adhesive anchor in tension:

This failure mode is new to ACI 318-11. Design concrete breakout strength is calculated as:

$$\phi N_a = \phi_{ctp} \frac{A_{Na}}{A_{Nao}} \psi_{ed,Na} \psi_{cp,Na} N_{ba}$$, for a single anchor, and

$$\phi N_{ag} = \phi_{ctp} \frac{A_{Na}}{A_{Nao}} \psi_{ec,Na} \psi_{ed,Na} \psi_{cp,Na} N_{ba}$$, for a group of anchors.

Additionally, a factor of 0.75 is also applied to structures assigned to SDC C or higher provided the seismic component of the resulting tension is more than 20% of the total applied tension obtained from the load combinations.

For the purpose of bond failure of adhesive anchors, anchors are considered to be in a *group* when the anchor spacing is not more than $2c_{Na}$, where c_{Na} is a parameter computed based on anchor diameter and characteristics bond stress of adhesive anchor in uncracked concrete, τ_{uncr}.

The characteristic bond stress in cracked concrete, τ_{cr}, as well as in uncracked concrete, τ_{uncr}, are to be determined based on the 5 percent fractile of results of tests performed and evaluated according to ACI 355.4. These values can be obtained from the anchor manufacturer and entered in the appropriate places on the “POST-INSTALLED ANCHORS” input tab as described before. The program also permits the use of the τ_{uncr} and τ_{cr} values given in ACI 318-11 Table D.5.5.2, provided the conditions listed in Section D.5.5.2(a) through (e) are satisfied.

When the spacing between the anchor columns or the rows or both exceed $2c_{Na}$, one of the three cases described below can arise.

Case 1. $s_x > 2c_{Na}$ **and** $s_y \leq 2c_{Na}$**:** In this case, each anchor column acts in a group, but the columns act independent of one another (Figure 16).

In this case, strengths of each column are calculated separately. Because only one column is considered at a time, eccentricity in X-direction, e'_{Nx}, is not considered in computing the eccentricity factor, and only e'_{Ny} is used. The effect of e'_{Nx} is accounted for while calculating the tension demand on each anchor column.

The strengths of those two columns are compared against the tension load carried by them, and extrapolated to compute the strength of the whole anchor formation. It should be noted that the anchor column with the lowest strength may not produce the governing strength for the whole anchor formation if the demand on that column is also low.

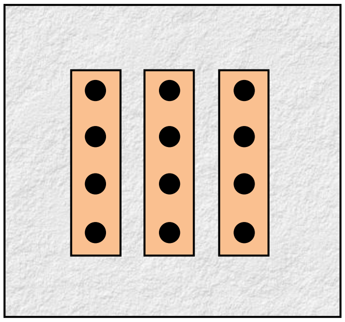


Figure 16. Column spacing more than $2c_{Na}$

Case 2. $s_y > 2c_{Na}$ **and** $s_x \leq 2c_{Na}$**:** Same approach as in Case 1. Strengths of each row are calculated separately, and the strength of the whole anchor formation is determined based on them.

Case 3. $s_x > 2c_{Na}$ **and** $s_y > 2c_{Na}$**:** In this case, all anchors act on their own without any group action in either direction. Thus, strengths of each anchor are calculated separately, and the strength of the whole anchor formation is determined based on them.

6. Steel strength of anchor in shear:

When using ACI 318-11, Section D.6.1.1 requires the steel shear strength to be consistent with the assumed concrete breakout surface in shear. This means only those anchors involved in the governing failure mode of the concrete breakout in shear (please see the next section for more information) must be considered in determining the steel strength of anchor in shear. This provision does not apply when anchor reinforcement for shear is provided.

Design shear strength of a single cast-in-place headed stud is calculated as

$$\phi N_{sa} = \phi_{sv} A_{se} f_{uta}$$

Design shear strength of a single cast-in headed bolt, hooked bolt, or post-installed anchors is calculated as

$\phi N_{sa} = \phi_{sv} 0.6 A_{se} f_{uta}$

For structures assigned to SDC C or higher, a factor of 0.75 is applied to the above value when design is performed in accordance with ACI 318-05. With ACI 318-08 or -11, this factor is not required in this mode of failure.

In a group of anchors, where the applied shear has an eccentricity with respect to the centerline of the anchor layout, the strength computer above needs to be compared against the maximum shear demand that occurs on a single anchor in the group. Conversely, this strength of a single anchor can also be converted to the strength of the whole group by dividing it by the fraction of the total shear demand that the most heavily loaded anchor resists. For example, if the maximum shear demand on a single anchor is 40% of the total shear demand V_u, then the above design strength can be divided by 0.4 to compute the maximum shear that the group can resist. This approach makes it easy to compare the strengths obtained from different failure modes, so that a governing strength can be determined.

If there is no eccentricity in the applied load, it can be assumed that all anchors share the load equally, and the above strength can simply be multiplied by the total number of anchors in the group, *n*, to obtain the strength of the whole group.

7. Concrete breakout strength of anchor in shear:

Design shear strength of a single anchor or a group of anchors is calculated as

$$\phi V_{cb} = \phi_{cv} \frac{A_{vc}}{A_{vco}} \psi_{ed,V} \psi_{c,V} V_b$$, for a single anchor, and

$$\phi V_{cbg} = \phi_{cv} \frac{A_{vc}}{A_{vco}} \psi_{ec,V} \psi_{ed,V} \psi_{c,V} V_b$$, for a group of anchors.

For structures assigned to SDC C or higher, a factor of 0.75 is applied to the above value when design is performed in accordance with ACI 318-05 or -08. With ACI 318-11, this factor is not required in this mode of failure.

ACI 318-11 Figure RD.6.2.1(b) suggests a number of load cases to be considered while evaluating concrete breakout in shear. Below is a complete description of how the program implements them. The description below is based on shear in X-direction. However, the same approach is adopted for shear in Y-direction as well. An anchor arrangement of 2 rows and 3 columns is considered. It is assumed that shear is not distributed evenly over the two rows.

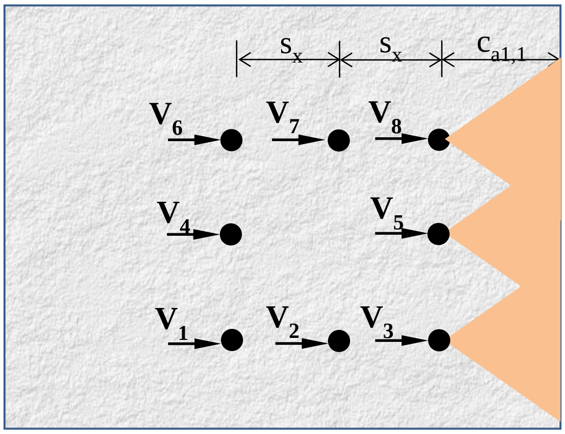
Please note, when using ACI 318-08 or ACI 318-11, user has the option to indicate if anchor reinforcement for X- and/or Y-direction is provided in accordance with ACI 318 Section D.6.2.9 and Fig. RD.6.2.9 by entering the design strength of anchor reinforcement calculated with a strength reduction factor of 0.75 (see Items 14 and 15 under “MATERIALS AND REINFORCEMENT” input tab). If anchor reinforcement design strength is provided by the user, Quick Anchor will not investigate the concrete breakout failure of anchors in shear and will simply use the design strength of anchor reinforcement instead of concrete breakout strength, ϕV_{cb} or ϕV_{cbg}.

When anchor spacing in the direction of shear is greater or equal to the governing edge distance ($s_x \geq c_{a1,1}$), the following cases are considered:

Case 1: Breakout takes place from the 1st column

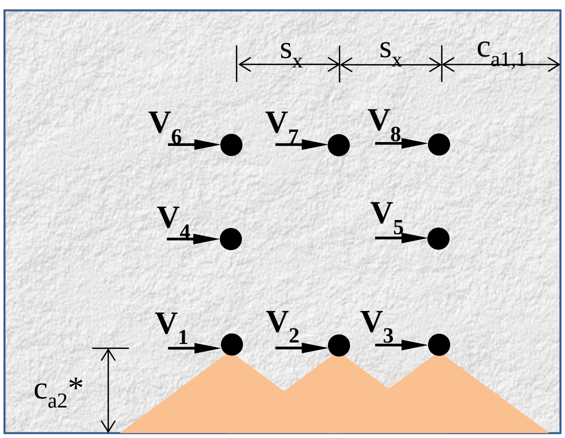
The whole anchor formation is analyzed under applied shear force in X-direction and/or applied tension. Anchors carrying shear forces in the desired direction (positive X here) will be included in strength calculations only.

(a) Shear perpendicular to edge



1. Strength is calculated based on $c_{a1} = c_{a1,1}$
2. Strength is checked against $V_3 + V_5 + V_8$.

(b) Shear parallel to edge



1. Strength is calculated based on $c_{a1} = c_{a2}$
2. Strength calculated as $2\phi V_{cbg}$ with $\Psi_{ed,V} = 1.0$ [see ACI 318 Section D.6.2.1(c)]
3. Strength is checked against $V_1 + V_2 + V_3$

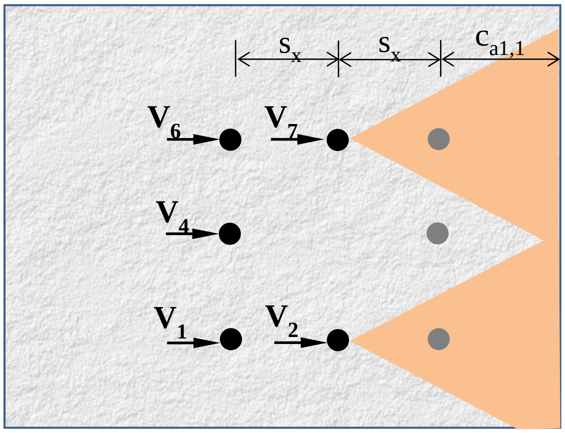
* c_{a2} = the distance to the top edge when calculating the shear strength of the top row of active anchor (strength would be checked against $V_6 + V_7 + V_8$)

When anchor spacing in the direction of shear is greater or equal to the governing edge distance ($s_x \geq c_{a1,1}$), the following cases are considered:

Case 2: Breakout takes place from the 2nd column

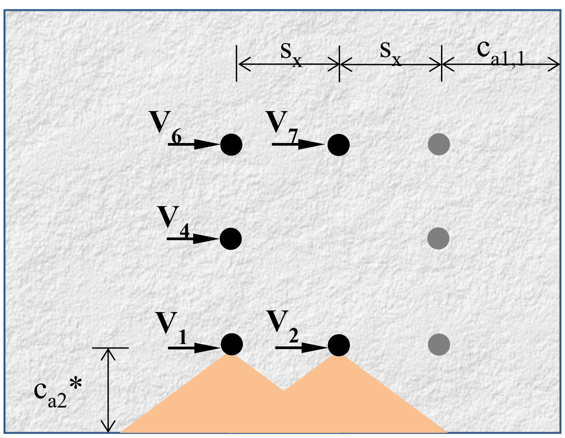
Excluding the 1st column, the rest of anchor formation (the 2nd and the 3rd columns) is analyzed under applied shear force in X-direction and/or applied tension. Among them, anchors carrying shear forces in the desired direction (positive X here) will be included in strength calculations only.

(a) Shear perpendicular to edge



1. Strength is calculated based on $c_{a1} = c_{a1,1} + s_x$
2. Strength is checked against $V_2 + V_7$

(b) Shear parallel to edge



1. Strength is calculated based on $c_{a1} = c_{a2}$
2. Strength calculated as $2\phi V_{cbg}$ with $\Psi_{ed,V} = 1.0$ [see ACI 318 Section D.6.2.1(c)]
3. Strength is checked against $V_1 + V_2$

* c_{a2} = the distance to the top edge when calculating the shear strength of the top row of active anchor (strength would be checked against $V_6 + V_7$)

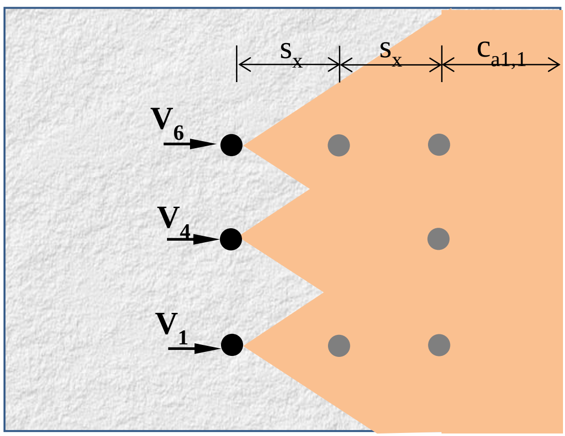
When anchor spacing in the direction of shear is greater or equal to the governing edge distance ($s_x \geq c_{a1,1}$), the following cases are considered:

Case 3: Breakout takes place from the 3rd column

Excluding the 1st and the 2nd columns, the rest of anchor formation (the 3rd column) is analyzed under applied shear force in X-direction and/or applied tension. Among them, anchors carrying shear forces in the desired direction (positive X here) will be included in strength calculations only.

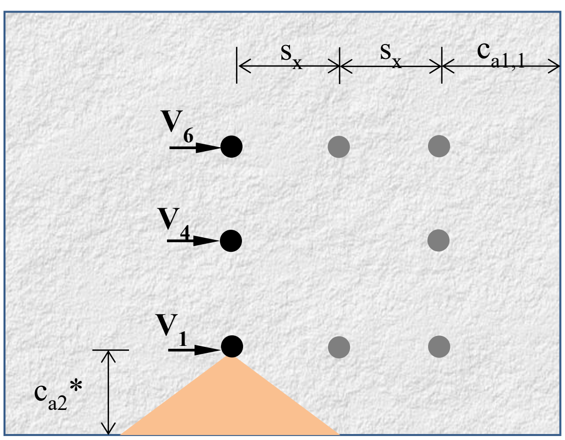
*****Note: only this assumption needs to be considered when anchors are welded to a common plate independent of *s*.**

(a) Shear perpendicular to edge



1. Strength is calculated based on $c_{a1} = c_{a1,1} + 2s_x$

(b) Shear parallel to edge



1. Strength is calculated based on $c_{a1} = c_{a2}$
2. Strength calculated as $2\phi V_{cbg}$ with $\Psi_{ed,V} = 1.0$ [see ACI 318 Section D.6.2.1(c)]
3. Strength is checked against V_1

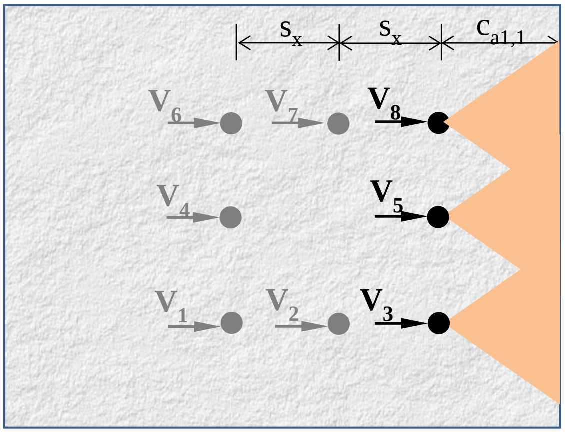
* c_{a2} = the distance to the top edge when calculating the shear strength of the top row of active anchor (strength would be checked against V_6)

When anchor spacing in the direction of shear is less than the governing edge distance ($s_x < c_{a1,1}$), the following cases are considered:

Case 1: Breakout takes place from the 1st column

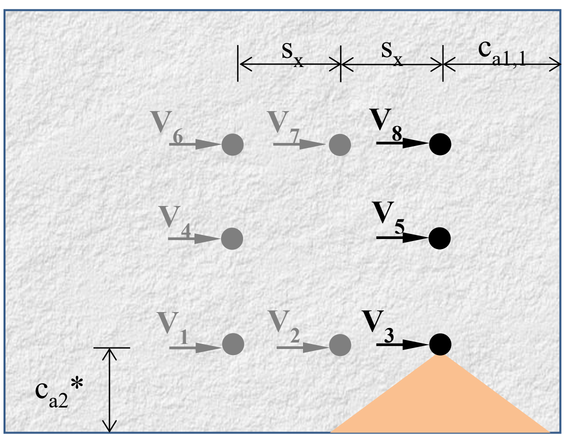
The whole anchor formation is analyzed under applied shear force in X-direction and/or applied tension. Anchors carrying shear forces in the desired direction (positive X here) will be included in strength calculations only.

(a) Shear perpendicular to edge



1. Strength is calculated based on $c_{a1} = c_{a1,1}$

(b) Shear parallel to edge



1. Strength is calculated based on $c_{a1} = c_{a2}$
2. Strength calculated as $2\phi V_{cbg}$ with $\Psi_{ed,V} = 1.0$ [see ACI 318 Section D.6.2.1(c)]

* c_{a2} = the distance to the top edge when calculating the shear strength of the top active anchor.

8. Concrete pryout strength of anchor in shear:

Design pryout strength of one anchor is calculated as

$$\phi V_{cp} = \phi_{cpv} k_{cp} N_{cp}$$

Design pryout strength of a group of anchors is calculated as

$$\phi V_{cpg} = \phi_{cpv} k_{cp} N_{cpg}$$

For adhesive anchors, N_{cp} (or N_{cpg}) is the smaller of the nominal strengths in concrete breakout in tension and the adhesive bond failure in tension calculated for active anchors carrying shear forces in the direction of applied shear. For all other anchor types, N_{cp} (or N_{cpg}) is the nominal strength in concrete breakout in tension calculated for active anchors.

$k_{cp} = 1$ for $h_{ef} < 2.5$ in. and
$k_{cp} = 2$ for $h_{ef} \geq 2.5$ in.