FAST™ SYSTEM

Fero Angle Support Technology

TECHNICAL REPORT

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Executive Summary

In this report, the new angle support system developed by Fero Corp. for veneer walls and known as FAST™, Fero Angle Support System, is discussed and analyzed. The new system consists of a FAST™ bracket, an anchor bolt, optional shim plates and wedge shim, and a retaining pin. Unlike conventional angle support methods, FAST™ system eliminates the need for field weld and offsets the shelf angle away from the structural packing allowing the continuity of the cavity insulation and vapour barrier; hence, minimize thermal bridging. The new system is more economical than other systems and lead to reduction of about 50% in the cost of material and labour.

The report includes a description of the FAST™ system and a discussion of its advantages over conventional shelf angle support systems. The methods of installation of the FAST™ system are explained with the aid of illustrative figures. The test program that was carried out in house in Fero’s laboratory to determine the allowable capacities of the system is briefly described. A step-by-step design approach for all system components is presented and further explained through a numeric example.
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1. Introduction

Veneers are external non-loadbearing walls that can be constructed from masonry, thin granite sheets, concrete pre-cast panels or natural stone. To minimize the possibility of thermal bridging and rain penetration, especially in the Canadian climate, veneer walls are typically supported on shelf angles that are welded to an anchoring system embedded or secured into a structural slab.

While welding provides a secure attachment, it is expensive and time consuming which delays the construction of the veneer. Another disadvantage of welding the shelf angle to the structural members is that the size of the shelf angle has to be large to accommodate the width of the cavity needed for the application of the thermal insulation and air/vapour barrier [1].

To overcome these disadvantages, FERO Corporation has introduced a new technology to support veneer walls known as FAST™ (FERO Angle Support Technology) which utilizes anchored brackets (and not welding) to support the shelf angle. This technology has proven to be a fast and cost-effective veneer support system.

The main advantage of FAST™ is that it offsets the shelf angle away from the structural backing which permits the continuity of the cavity insulation and air/vapour barrier, and thus reduces thermal bridging and air leakage. Because the size of the cavity is accounted for by the FAST™ bracket, the size of the shelf angle used with the system is relatively small (100×100×6 mm) and readily available from local suppliers. Compared to conventional veneer support systems, FAST™ could save up to 50% of the material and labour cost.

2. Description of FAST™

FAST™ system, shown in Figure 1, consists of a bracket, an anchor bolt, optional shim plates and wedge shim, and a retaining pin (see Figure 1). The FAST™ brackets, shims and retaining pins are provided by FERO Corporation. Anchor bolts and shelf angles are available from local suppliers. Mild steel of 4.76 mm thickness is used to manufacture FAST™ brackets, shim plates and bolt washers [3]. All components supplied by FERO are hot galvanized after fabrication in accordance with ASTM A123-12 [2].

![Figure 1: FAST™ components: a) Side view of bracket, b) Elevation view of bracket, c) Side view of shelf angle, d) Elevation view of shelf angle, and e) anchor bolt](image-url)
The bracket is available in various dimensions in 12.7 mm intervals. To accommodate different widths, the dimension "D" shown in Figure 1 is equal to the width of the cavity (air space and insulation), and ranges from 25 mm to 165 mm [3]. The slot at the back of the bracket is designed to receive one bolt of 15.9 mm diameter and allows vertical adjustment up to 45 mm. The slot is inclined at an angle of +/- 22.5 degree from the vertical to prevent bracket slippage under load. When two or more brackets are used, the orientation of the slot should be alternated to prevent bracket slippage. Figure 2 shows a typical detail for FAST™ used to support a clay brick veneer of a masonry cavity wall.

![Figure 2: Typical detail for FAST™ used to support a brick veneer wall](image)

An oversized, 5 mm thick, rectangular washer supplied by FERO is required for use with the anchor bolt. Circular washers cannot be used. The optional shim plate is sized and shaped to fit the back surface of the FAST™ bracket and provide full bearing. The FAST™ bracket is designed to receive shelf angle with dimensions 100×100×6 mm.

### 3. Installation of FAST™

The installation of FAST™ is simple compared to other conventional shelf angle support methods. A chalk line is snapped to identify the location of the brackets in elevation; anchor holes are predrilled at the required spacing. FAST™ brackets are installed using one of two methods:
**Method 1:** Accurately position the shelf angle temporarily by installing a bracket at each end. Hook the intermediate brackets onto the angle and spread them horizontally to their bolt locations. Securely fasten the brackets against the structural slab.

**Method 2:** Accurately position the bracket at each anchor location, both in the elevation and perpendicular to the wall. Securely fasten the brackets against the structural slab. Rotate the angle into the claws of the brackets and set it firmly on top of the bracket legs.

FAST™ shim plates are placed between the structural slab and the backside of the bracket to accommodate the tolerance in the position of the structural slab that cannot be overcome by using different sizes of brackets. Shim plates must bear directly against the structural backing and be of, exactly, the same height as the bracket. If the number of shim plates per bracket exceeds two, the next size bracket should be used in lieu of shimming. The bracket is installed so that the shelf angle rests firmly on the lower supporting legs of the bracket. After adjusting the position of the bracket, the anchor bolts are seated by applying the adequate torque specified by the bolt manufacturer but not exceeding the values given in Appendix B. The lower end of the angle's vertical leg must rest against the back of the bracket slot, while the upper end should be in direct contact with the bracket claw.

If required, a wedge shim is inserted between the shelf angle and bracket to ensure that the vertical leg of the shelf angle bears properly against the bracket. The shelf angle must be installed in full contact with the bracket and not allowed to rotate or drop under the weight of the veneer. FERO provides a 9.5 mm diameter pin that is driven between the backside of the vertical leg of the shelf angle and the bracket claw to brace the shelf angle so that it will not move from the FAST™ bracket during construction and before installation of the veneer. After all the adjustments have been made, the veneer can be placed on the shelf angle in a manner that satisfies the requirements of all applicable standards and industry practice for veneer construction. Figure 3 illustrates the steps of installing the FAST™ system.

### 4. Advantages of FAST™

FAST™ has many advantages over traditional systems. It eliminates the need for welded connections and therefore requires less time and costs less to install compared to conventional systems. All parts of the FAST™ system are hot galvanized prior to installation, thus ensuring integral corrosion protection. FAST™ is engineered to offset the shelf angle from the structural backing, and allow cavity insulation and the air/vapour barrier to be continuous behind the shelf angle. This dramatically reduces thermal bridging; reduces the number of penetrations through the insulation; minimizes joints/junctions in the air/vapour barriers; lessens the cross-section and cost for shelf angles; and reduces insulation and air/vapour barrier installation time. Compared to alternative offset shelf angle supports such as gusset plates, FAST™ system requires a fraction of the time to install and has been proven to be more economical and performances better.
a. Snap a chalk line, mark the location of the anchor bolt and drill the anchor holes

b. Install FAST™ brackets and tighten the anchor bolt’s nut by hand

c. Insert the shelf angle, adjust the brackets and tighten the anchor bolt securely to the structural slab

d. Install shim plates and wedge shim as required to ensure that the angle vertical leg is in full contact with the bracket claw. Alternate between right slot and left slot brackets to prevent slippage

Figure 3: Steps for the installation of FAST™
5. Experimental Testing

The performance of the FAST™ bracket was examined experimentally at FERO Corporation laboratory to verify the maximum design loads that could be applied. Tests were conducted on 25 mm and 89 mm wide FAST™ brackets using 90×90×6 mm shelf angles. The brackets were connected to a rigid steel plate and to a concrete fixture. Selected photographs of the experimental testing are shown in Appendix A. Bolts having a diameter of 12.7 were used to secure the FAST™ bracket. Some of the shelf angles were stiffened to study the failure modes of the bracket. The veneer weight was represented by a point load acting at a 20 mm distance from the end (toe) of the shelf angle. Failure was observed to be buckling in the bracket’s claws supporting the shelf angle and in the back of the bracket around the anchor bolt. No slippage of the anchor bolt was observed.

The allowable service (unfactored) loads which were established for FAST™ bracket from the experimental test results and theoretical analysis are given in Table B.1 in Appendix B. These loads meet or exceed the safety levels and serviceability requirements of the North American design codes and standards. Table B.1 also gives the maximum values for veneer height that correspond to the vertical allowable loads. Maximum veneer heights were computed as: the maximum allowable vertical load per bracket divided by the weight of veneer per unit area multiplied by the bracket spacing. Veneer weights are based on 90 mm thick veneer and were taken as 170 kg/m² for clay brick, 125 kg/m² for lightweight concrete blocks, 190 kg/m² for normal weight concrete blocks, 220 kg/m² for natural stone. The masonry veneer should not exceed 11.0 m in height, and the bracket spacing should be limited to 900 mm. If the previous limits are exceeded, the design methodology below could be used to determine the adequate sizes of the FAST™ system components.

6. Design Methodology

The design methodology discussed in this section is based on the principles of the ultimate limit state method for all system components. The design loads and material strength reduction factors are those specified in the National Building Code of Canada [4] and CSA S16-01 Standard: Limit State Design of Steel Structures [5]. The design of anchor bolts conforms to CSA A23.3-04 Standard: Design of concrete structures [6]. The bracket and shelf angle used in FAST™ are made of mild steel (Fy = 245 MPa). This design approach is not limited to a specific anchor bolt grade. The following are general guidelines for the design of FAST™ system components.

6.1 Design of the FAST™ Bracket and Shelf Angle

The typical shelf angle used with the FAST™ system has dimensions of 100×100×6 mm. The veneer is assumed to be 90 mm in thickness. Figure 4 shows free body diagrams for (a) the shelf angle and (b) the FAST™ bracket. Forces R1 and R2 shown in Figure 4 are those developed due to the bearing of the angle against the bracket legs and claws; respectively. Since the load will cause the angle to tend to rotate, triangular stress distributions are assumed at the legs and claws of the FAST™ bracket supporting the angle. The value and location of the forces acting on the bracket are the same as those acting on the angle but in opposite direction.
Figure 4: Critical sections for (a) Steel shelf angle and (b) Steel Bracket and (c) Dimensions of FAST™ bracket

1. Compute the unfactored load of the veneer ($w_\text{u}$) acting on the shelf angle.
2. Determine the ultimate load by multiplying $w_\text{u}$ by the 1.4 load factor, since all applied loads are dead loads.
3. Determine the straining actions acting on the bracket and shelf angle. Values of the reaction forces are computed as follows:

$$\Sigma F_y=0 \quad \text{yields} \quad R_1 = w_\text{u} \quad \text{Eq. (1)}$$

Taking the moment about Point O (refer to Fig. 4):

$$\Sigma M_o=0 \quad \text{yields} \quad R_2 = \left( w_\text{u} \cdot \frac{x}{3} \cdot \frac{2}{3} \cdot y \cdot R_1 \right) / (100 \cdot h) \quad \text{Eq. (2)}$$

where, $x$: the distance from the angle outer fibers to the point of action of the masonry veneer load,
$y$: the length of the bracket leg supporting the angle,
h: the contact length of the bracket claw and the angle

4. Check that stresses developed at the critical sections shown in Figure 4 do not exceed normal, $\sigma_r$, and shear, $\tau_r$, resistances as defined in CSA S16-01 [5] and given below:

$$\sigma_r=\Phi F_y \quad \text{Eq. (3)}$$

$$\tau_r=0.66 \Phi F_y \quad \text{Eq. (4)}$$
6.2 Design of the Anchor Bolt

The design approach illustrated in this section is suitable for all grades of anchor bolts. Figure 5 shows a typical connection of the FAST™ bracket to a concrete slab. The veneer weight causes the bracket to compress against the concrete floor slab at its lower end and to pull on the anchor bolt at its upper end causing the development of a compression force in the concrete and a tension force in the anchor bolt. The value of the veneer load per bracket spacing is referred to as $P_u = w_u \times S$, where $S$ is the bracket spacing. The ultimate resistance of the anchor bolts are determined in accordance with CSA A23.3-04 [6]. The following steps summarize the design procedure for anchor bolts.

![Figure 5: Straining actions acting on the anchor bolt for FAST™ connection](image)

1. Determine the straining actions acting on the anchor bolts; tension force $(N_f)$ and shear force $(V_f)$ created by the moment due to the veneer weight. Taking the moment around $Q$,

$$N_f = (P_u z)/(d - \frac{\beta_1 c}{2})$$  \hspace{1cm} Eq. (5)

$$V_f = P_u$$  \hspace{1cm} Eq. (6)

Where, $P_u$ is the weight of the veneer per bracket spacing, $N_f$ is the tension developed in the anchor, $V_f$ is the shear force acting on the anchor bolt, $z$ is the distance between the back of the bracket and the veneer load representing its weight, $d$ is the distance from the bottom of the bracket to the centreline of the anchor bolt, and $\beta_1 c$ is the depth of the equivalent compression zone assuming a rectangular stress distribution.

2. Determine the allowable tensile strength, $N_r$, for the anchor bolt based on CSA A23.3-04.

$$N_r = \text{smaller of } (N_{sr}, N_{cbr}, N_{cpr}, N_{shb})$$  \hspace{1cm} Eq. (7)
Where, $N_{sr}$ is the factored resistance of a single anchor bolt in tension as governed by the steel resistance, $N_{cbr}$ is the factored concrete breakout resistance in tension for a single anchor bolt, $N_{cpr}$ is factored pullout resistance in tension for a single anchor bolt, and $N_{sbr}$ is the factored side-face blowout resistance of a single anchor bolt.

$$N_{sr} = A_{se} \phi_s f_{ut} R \quad \text{Eq. (8)}$$
$$A_{se} = 0.70 \ A_g \quad \text{Eq. (9)}$$
$$f_{ut} = \text{smaller of (1.9} \ f_y, \ 860 \text{ MPa)} \quad \text{Eq. (10)}$$

Where $A_{se}$ and $A_g$ are the effective cross-section and gross cross-section areas of the anchor bolt, $f_{ut}$ is the specified tensile strength of the anchor bolt, $f_y$ is the anchor bolt yield strength, and $R$ is a resistance modification factor taken equal to 0.8 for tension and 0.7 for shear for ductile steel element.

$$N_{cbr} = \frac{\psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_{br}}{A_{No}} \quad \text{Eq. (11)}$$

$$N_{br} = k \ \phi_c \ \sqrt{f'_c h_{ef}^{1.5} R} \quad \text{Eq. (12)}$$

Where, $N_{br}$ is the factored concrete breakout resistance in tension of a single anchor bolt in cracked concrete, $A_N$ is the concrete projected failure area of an anchor bolt for calculation of resistance in tension, $A_{No}$ is the concrete projected failure area for one anchor bolt, for calculation of resistance in tension, $h_{ef}$ is the effective anchorage embedded length, $\psi_{ed,N}$ is the modification factor for resistance in tension to account for edge distance smaller than $1.5h_{ef}$, $\psi_{c,N}$ is the modification factor for resistance in tension to account for cracking, $\psi_{cp,N}$ modification factor for concrete breakout resistance to account for premature splitting failure, $N_{br}$ is the factored concrete breakout resistance in tension of a single anchor bolt in cracked concrete, $k$ is coefficient for concrete breakout resistance, $f'_c$ is the concrete characteristic compressive strength, $\phi_c$ is concrete material resistance factor.

$$\psi_{ed,N} = \begin{cases} 
1 & \text{if } c_{min} \geq 1.5 \ h_{ef} \\
0.7+0.3 \frac{c_{min}}{1.5 \ h_{ef}} & \text{if } c_{min} < 1.5h_{ef}
\end{cases} \quad \text{Eq. (13)}$$

$$\psi_{c,N} = \begin{cases} 
1.25 & \text{for cast-in headed studs, headed bolts,} \\
1.4 & \text{and hooked bolts} \\
& \text{for post-installed anchors}
\end{cases} \quad \text{Eq. (14)}$$

$$\psi_{cp,N} = \begin{cases} 
1 & \text{if } c_{a, min} \geq c_{ac} \\
\frac{c_{a, min}}{c_{ac}} \geq \frac{1.5 h_{ef}}{c_{ac}} & \text{if } c_{a, min} < c_{ac}
\end{cases} \quad \text{Eq. (15)}$$
\[ k = \begin{cases} 
10 & \text{for cast-in headed studs, headed bolts,} \\
7 & \text{and hooked bolts} \\
\text{for post-installed anchors} 
\end{cases} \quad \text{Eq. (16)} \]

Where \( c_{\text{min}} \) is the smallest edge distance, \( c_{a,\text{min}} \) is the minimum edge distance to preclude premature splitting failure of post-installed anchors, and \( c_{ac} \) is the critical edge distance.

\[ N_{\text{cpr}} = \psi_{c, p} N_{pr} \quad \text{Eq. (17)} \]

\[ N_{pr} = \begin{cases} 
8 A_{bh} \phi_c f_c^i R & \text{for single headed stud or headed bolt} \\
0.9 \phi_c f_c^i e_h d_o R & \text{for single J-bolt and L-bolt} 
\end{cases} \quad \text{Eq. (18)} \]

Where, \( N_{pr} \) is the factored pullout resistance in tension for a single anchor bolt, \( \psi_{c, p} \) is a modification factor for the pullout resistance taken equal to 1.4 in case of no cracking or 1 otherwise, \( A_{bh} \) is the bearing area of the head of the anchor bolt or stud, \( e_h \) is the distance from the inner surface of the shaft of a J-bolt or L-bolt to its outer tip, \( d_o \) is the outside diameter of anchor or shaft diameter of headed stud, headed anchor bolt or hooked anchor bolt.

\[ N_{\text{sbr}} = 13.3 c \sqrt{A_{bh} \phi_c \sqrt{f_c^i} R} \quad \text{Eq. (19)} \]

Where, \( c \) is the distance from the center of the anchor shaft to the concrete edge.

3. Determine the allowable shear strength, \( V_r \), of the anchors according to CSA A23.3-04 [6].

\[ V_r = \text{smaller of } (V_{sr}, V_{cbr}, V_{cpr}) \quad \text{Eq. (20)} \]

Where, \( V_{sr} \) is the factored resistance in shear of a single anchor bolt as governed by the steel resistance, \( V_{cbr} \) is the factored concrete breakout resistance in shear of a single anchor bolt, and \( V_{cpr} \) is the factored concrete pryout resistance of a single anchor bolt.

\[ V_{sr} = \begin{cases} 
A_{sc} \phi_s f_{ut} R & \text{for cast-in headed anchors} \\
A_{sc} \phi_s 0.6 f_{ut} R & \text{for cast-in headed bolts, hooked} \\
\text{bolt anchors and post-installed} \\
\text{anchors with and without sleeves} \\
\text{extending through the shear plane} 
\end{cases} \quad \text{Eq. (21)} \]

Where, \( A_{sc} \) is the effective cross-section area of the anchor bolt. The value of \( V_{sr} \) should be reduced by 20% when anchors are used with built-up grout pads.

\[ V_{cbr} = \frac{A_{sc}}{A_{vo}} \psi_{ed, v} \psi_{c, v} V_{br} \quad \text{Eq. (22)} \]

\[ \psi_{ed, v} = \begin{cases} 
1 & \text{if } c_2 \geq 1.5 c_1 \\
0.7 + 0.3 \frac{c_2}{1.5 c_1} & \text{if } c_2 < 1.5 c_1 
\end{cases} \quad \text{Eq. (23)} \]
ψ_{c, v} = \begin{cases} 
1.0 & \text{for anchor in cracked concrete with no edge reinforcement or edge reinforcement smaller than 15M bars} \\
1.2 & \text{for anchor in concrete with edge reinforcement of 15M bar or greater between anchor and the edge} \\
1.4 & \text{for anchor in cracked concrete with edge reinforcement of 15M bars or greater between the anchor and the edge with edge reinforcement enclosed within stirrups not less than 100 mm apart} \\
1.4 & \text{for anchors where temperature and shrinkage were considered in the analysis and no tension is developed at service loads}
\end{cases} \quad \text{Eq. (24)}

Where, \( A_v \) is the concrete projected failure area of an anchor bolt, for calculation of resistance in shear, \( A_{vo} \) is the concrete projected failure area of one anchor bolt, for calculation of resistance in shear, when not limited by corner influences, spacing, or member thickness, \( c_1 \) is the distance from the center of an anchor shaft to the edge of concrete in the same direction as the applied shear, \( \psi_{ed, v} \) is the modification factor for resistance in shear to account for edge distance smaller than 1.5 \( c_1 \), \( \psi_{c, v} \) is the modification factor for resistance in shear to account for cracking, and \( c_2 \) is the distance from the center of an anchor shaft to the edge of concrete in the direction orthogonal to \( c_1 \).

\[ V_{br} = 0.58 \left( \frac{1}{d_o} \right)^{0.2} \sqrt{d_o} \phi_c \sqrt{f_{c1}^{1.5}} R \quad \text{Eq. (25)} \]

Where, \( d_o \) outer diameter of anchor bolt or shaft diameter of headed stud, headed anchor bolt, or hooked anchor bolts; \( l \) is load bearing length of anchor for shear, not to exceed \( 8d_o \); it is also equal to \( 2d_o \) for torque controlled expansion anchors with a distance sleeve separated from the expansion sleeve.

\[ V_{cpr} = k_{cpr} N_{cbr} \quad \text{Eq. (26)} \]

\[ k_{cpr} = \begin{cases} 
1.0 & \text{for } h_{ef} < 65 \text{ mm} \\
2.0 & \text{for } h_{ef} \geq 65 \text{ mm}
\end{cases} \quad \text{Eq. (27)} \]

Where, \( k_{cpr} \) is the coefficient for pry-out resistance.

4. A tension force equal to 10% of the capacity of the bolt material \((0.1 \times N_{sr})\) should be added to \( N_f \) to account for the force generated by tightening the nut.

5. Check that the developed force in the anchor bolt did not exceed its capacity.

\[ \frac{N_f}{N_c} \leq 1.0 \quad \text{and} \quad \frac{V_f}{V_t} \leq 1.0 \quad \text{Eq. (28)} \]

\[ \frac{N_f}{N_r} + \frac{V_f}{V_r} \leq 1.2 \quad \text{Eq. (29)} \]
Table B.1 shows the dimensions of FAST™ plate as well as the maximum allowable vertical load applied on the connection. The design allowable load was based on experimental testing of FAST™ bracket connection. The listed loads are service load. Table B.1 also gives an estimate for the anchors that can be used with the connection. A sample computation for the forces and stresses developed in FAST™ connection is presented in Appendix C.

7. Closure

The new shelf angle support technology, FAST™, developed by FERO for veneer walls was discussed in this report. The system consists of a FAST™ bracket, an anchor bolt, shim plates and wedge shim (optional), and a retaining pin (optional). This system proved to perform better than conventional angle support methods. It offsets the shelf angle from the structural backing allowing cavity insulation and air/vapour barrier to be continuous behind the shelf angle; hence, minimize thermal bridging. The new system is more economical than other systems and lead to a reduction of about 50% in the material and installation cost. Description of the methods of installation of the system was covered. The report also included a methodology that can be used to design the system when the limits of Table B.1 are exceeded.

8. References


### 9. Notations

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A&lt;sub&gt;b&lt;/sub&gt;</td>
<td>Bearing area of the head of the stud or anchor bolt</td>
</tr>
<tr>
<td>A&lt;sub&gt;g&lt;/sub&gt;</td>
<td>Gross cross-section areas of the anchor bolt</td>
</tr>
<tr>
<td>A&lt;sub&gt;N&lt;/sub&gt;</td>
<td>Concrete projected failure area of an anchor bolt for calculation of resistance in tension</td>
</tr>
<tr>
<td>A&lt;sub&gt;No&lt;/sub&gt;</td>
<td>Concrete projected failure area for one anchor bolt, for calculation of resistance in tension</td>
</tr>
<tr>
<td>A&lt;sub&gt;v&lt;/sub&gt;</td>
<td>Concrete projected failure area of an anchor bolt, for calculation of resistance in shear</td>
</tr>
<tr>
<td>A&lt;sub&gt;vo&lt;/sub&gt;</td>
<td>Concrete projected failure area of one anchor bolt, for calculation of resistance in shear, when not limited by corner influences, spacing, or member thickness</td>
</tr>
<tr>
<td>A&lt;sub&gt;se&lt;/sub&gt;</td>
<td>Effective cross-section of the anchor bolt</td>
</tr>
<tr>
<td>c&lt;sub&gt;1&lt;/sub&gt;</td>
<td>Distance from the center of an anchor shaft to the edge of concrete in one direction (same direction as the applied shear)</td>
</tr>
<tr>
<td>c&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Distance from the center of an anchor shaft to the edge of concrete in the direction orthogonal to c&lt;sub&gt;1&lt;/sub&gt;</td>
</tr>
<tr>
<td>c&lt;sub&gt;ac&lt;/sub&gt;</td>
<td>Critical edge distance</td>
</tr>
<tr>
<td>c&lt;sub&gt;a,min&lt;/sub&gt;</td>
<td>The minimum edge distance to preclude premature splitting failure of post-installed anchors</td>
</tr>
<tr>
<td>c&lt;sub&gt;min&lt;/sub&gt;</td>
<td>The smallest edge distance</td>
</tr>
<tr>
<td>d&lt;sub&gt;0&lt;/sub&gt;</td>
<td>The outside diameter of anchor or shaft diameter of headed stud, headed anchor bolt or hooked anchor bolt.</td>
</tr>
<tr>
<td>d</td>
<td>Distance from the bottom of the bracket till the centerline of the anchor shaft (refer to Fig. 5)</td>
</tr>
<tr>
<td>e&lt;sub&gt;h&lt;/sub&gt;</td>
<td>The distance from the inner surface of the shaft of a J-bolt or L-bolt to its outer tip</td>
</tr>
<tr>
<td>f&lt;sub&gt;c&lt;/sub&gt;</td>
<td>Concrete characteristic compressive strength</td>
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<tr>
<td>f&lt;sub&gt;y&lt;/sub&gt;</td>
<td>Anchor bolt yield strength</td>
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<tr>
<td>F&lt;sub&gt;y&lt;/sub&gt;</td>
<td>Yield strength of the bracket and shelf angle steel material</td>
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<tr>
<td>f&lt;sub&gt;ut&lt;/sub&gt;</td>
<td>Specified tensile strength of the anchor bolt</td>
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<td>h</td>
<td>Contact length between the bracket claw and the shelf angle</td>
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<td>h&lt;sub&gt;ef&lt;/sub&gt;</td>
<td>Effective anchorage embedded length</td>
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<tr>
<td>k&lt;sub&gt;cp&lt;/sub&gt;</td>
<td>Coefficient for pryout resistance</td>
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<tr>
<td>k</td>
<td>Coefficient for concrete breakout resistance</td>
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<tr>
<td>l</td>
<td>Load bearing length of anchor for shear, not to exceed 8d&lt;sub&gt;0&lt;/sub&gt;; also equal to 2d&lt;sub&gt;0&lt;/sub&gt; for torque controlled expansion anchors with a distance sleeve separated from the expansion sleeve</td>
</tr>
<tr>
<td>N&lt;sub&gt;br&lt;/sub&gt;</td>
<td>Factored concrete breakout resistance in tension of a single anchor bolt in cracked concrete</td>
</tr>
<tr>
<td>N&lt;sub&gt;cb&lt;/sub&gt;</td>
<td>Factored concrete breakout resistance in tension for a single anchor bolt</td>
</tr>
<tr>
<td>N&lt;sub&gt;cp&lt;/sub&gt;</td>
<td>Factored pullout resistance in tension for a single anchor bolt</td>
</tr>
<tr>
<td>N&lt;sub&gt;f&lt;/sub&gt;</td>
<td>Ultimate tension force developed in the anchor bolt</td>
</tr>
<tr>
<td>N&lt;sub&gt;pr&lt;/sub&gt;</td>
<td>Factored pullout resistance in tension for a single anchor bolt</td>
</tr>
<tr>
<td>N&lt;sub&gt;r&lt;/sub&gt;</td>
<td>Allowable tensile force developed in the anchor bolt</td>
</tr>
<tr>
<td>N&lt;sub&gt;sbr&lt;/sub&gt;</td>
<td>Factored side-face blowout resistance of a single anchor bolt</td>
</tr>
<tr>
<td>N&lt;sub&gt;sr&lt;/sub&gt;</td>
<td>Factored resistance of a single anchor bolt in tension as govern by the steel resistance</td>
</tr>
<tr>
<td>P&lt;sub&gt;u&lt;/sub&gt;</td>
<td>Ultimate load of masonry veneer (per bracket spacing)</td>
</tr>
<tr>
<td>R&lt;sub&gt;1&lt;/sub&gt;</td>
<td>Reaction at brackets leg</td>
</tr>
</tbody>
</table>
\( R_2 \): Reaction at bracket claw
\( R \): Resistance modification factor taken equal to 0.80 for tension load and 0.70 for shear load for ductile steel element as per CSA A23.3-04
\( V_{cbr} \): Factored concrete breakout resistance in shear of a single anchor bolt
\( V_{cpr} \): Factored concrete pryout resistance of a single anchor bolt
\( V_f \): Ultimate shear force developed in the anchor bolt
\( V_r \): Allowable shear strength of the anchor bolt
\( V_{ar} \): Factored resistance in shear of a single anchor bolt as governed by the steel resistance
\( w_s \): Dead load of masonry veneer (per meter)
\( w_u \): Ultimate load of masonry veneer (per meter)
\( x \): Contact length between the bracket leg and the shelf angle
\( y \): Distance to the line of action of the veneer wall
\( z \): Distance from the concrete slab to line of action of the masonry veneer load
\( \psi_{c,N} \): Modification factor for resistance in tension to account for cracking
\( \psi_{c,P} \): Modified pullout resistance taken equal to 1.4 in case of no cracking or 1 otherwise
\( \psi_{c,V} \): Modification factor for resistance in shear to account for cracking
\( \psi_{cp,N} \): Modification factor for concrete breakout resistance to account for premature splitting failure
\( \psi_{ed,N} \): Modification factor for resistance in tension to account for edge distance smaller than 1.5 \( h_{ef} \)
\( \psi_{ed,V} \): Modification factor for resistance in shear to account for edge distance smaller than 1.5 \( c_1 \)
\( \varnothing \): Strength reduction factor for steel as per S16-01
\( \varnothing_c \): Concrete material resistance factor as per CSA A23.3-04
\( \varnothing_s \): Steel material resistance factor as per CSA A23.3-04
\( \sigma_r \): Allowable bending stress for steel
\( \tau_r \): Allowable bending stress for steel
\( \beta_{1,c} \): Concrete compression block length
Appendix A
Test Set-up Photographs

Figure A.1: View showing the details of FAST™ connection

Figure A.2: Load used to test the FAST™ bracket
Figure A.3: Setup for testing FAST™ bracket

Figure A.4: View of test setup showing FAST™ bracket and shelf angle
Figure A.5: Test setup for the FAST™ bracket mounted on rigid steel plate

Figure A.6: Failure in the FAST™ bracket claw and back
## Appendix B

Table B.1: Design information for FAST™ bracket

<table>
<thead>
<tr>
<th>FAST Bracket Size</th>
<th>Max Vert. Load per Bracket (kN)</th>
<th>Bracket Spacing (mm)</th>
<th>Maximum Allowable Veneer height</th>
<th>Minimum Anchor size **</th>
<th>( \gamma_c = 40 \text{ MPa} )</th>
<th>( \gamma_c = 60 \text{ MPa} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>D (mm)</td>
<td>W (mm)</td>
<td>H (mm)</td>
<td>Clay Brick (m)</td>
<td>Lightweight Concrete Units (m)</td>
<td>Normal Concrete Units (m)</td>
<td>Natural Stone (m)</td>
</tr>
<tr>
<td>25</td>
<td>95</td>
<td>188</td>
<td>6.7</td>
<td>600</td>
<td>6.0</td>
<td>8.4</td>
</tr>
<tr>
<td>38</td>
<td>95</td>
<td>160</td>
<td>6.2</td>
<td>600</td>
<td>6.0</td>
<td>8.4</td>
</tr>
<tr>
<td>51</td>
<td>95</td>
<td>160</td>
<td>9.3</td>
<td>600</td>
<td>9.2</td>
<td>12.5*</td>
</tr>
<tr>
<td>64</td>
<td>95</td>
<td>160</td>
<td>9.3</td>
<td>600</td>
<td>9.2</td>
<td>12.5*</td>
</tr>
<tr>
<td>76</td>
<td>95</td>
<td>160</td>
<td>9.3</td>
<td>600</td>
<td>9.2</td>
<td>12.5*</td>
</tr>
<tr>
<td>89</td>
<td>95</td>
<td>160</td>
<td>9.3</td>
<td>600</td>
<td>9.2</td>
<td>12.5*</td>
</tr>
<tr>
<td>102</td>
<td>95</td>
<td>160</td>
<td>8.6</td>
<td>600</td>
<td>8.4</td>
<td>11.5*</td>
</tr>
<tr>
<td>114</td>
<td>95</td>
<td>160</td>
<td>7.8</td>
<td>600</td>
<td>7.6</td>
<td>10.4</td>
</tr>
<tr>
<td>127</td>
<td>95</td>
<td>160</td>
<td>7</td>
<td>600</td>
<td>6.9</td>
<td>9.4</td>
</tr>
<tr>
<td>140</td>
<td>95</td>
<td>160</td>
<td>6.2</td>
<td>600</td>
<td>6.0</td>
<td>8.3</td>
</tr>
<tr>
<td>152</td>
<td>95</td>
<td>160</td>
<td>5.6</td>
<td>600</td>
<td>5.4</td>
<td>7.4</td>
</tr>
<tr>
<td>165</td>
<td>95</td>
<td>160</td>
<td>4.9</td>
<td>600</td>
<td>4.8</td>
<td>6.5</td>
</tr>
</tbody>
</table>

* Bearing diameter is 2 mm bigger than anchor diameter

** Anchor bolts in this table are of grade 4.6 (fy = 248 MPa, Fu = 413 MPa). For different steel grades, refer to the design approach discussed earlier
Appendix C: Design Example

Design a FAST\textsuperscript{TM} system to support a clay brick veneer wall of double height (6.0 m). The bracket and the shelf angle have yield strength of 245 MPa. Also, design the anchor bolt required to secure the brackets. The bracket is mounted on a concrete beam of thickness 600 mm and compressive strength of 45 MPa.

Solution:

The brackets are spaced every 900 mm and the size of the bracket had a depth, width and height of 89 mm, 95 mm and 160 mm, respectively. The thickness of the bracket is 4.76 mm. The shelf angle used has the dimensions 100×100×6 mm.

a. Check on shelf angle adequacy

Loads applied on the shelf angle

\[ w_s = \gamma_b \cdot h \cdot g \]

Where,

- \( w_s \): is the weight applied on the shelf angle per m
- \( \gamma_b \): is the density of brick veneer wall per surface area (170 kg/m\(^2\))
- \( g \): is the acceleration due to gravity

\[ w_s = 0.17 \times 1.0 \times 6.0 \times 9.81 = 10.0 \text{ kN/m} \]

\[ w_u = 1.4 \times w_s = 1.4 \times 10.00 = 14.0 \text{ kN/m} \]

Compute the ultimate stress

Compute the value of normal stress, \( \sigma_r \), and shear stress, \( \tau_r \).

\[ \sigma_r = \phi \cdot F_y = 0.9 \times 245 = 220.5 \text{ MPa} \]

\[ \tau_r = 0.66 \cdot \phi \cdot F_y = 0.66 \times 0.9 \times 245 = 145.5 \text{ MPa} \]

Check the adequacy of Sec. A-A

\[ M_{A-A} = w_u \cdot e = 14 \times 1000 \times (75-20) = 770 \text{ N.m} \]

\[ \sigma_u = \frac{M}{S_x} = \frac{770 \times 10^3}{(1000 \times 6^2)/6} = 128 \text{ MPa} \ll \sigma_r \]

\[ \therefore \text{OK} \]
\[ \tau_u = \frac{w_u}{b \times t} = \frac{14000}{1000 \times 6} = 2.33 \text{ MPa} \ll \tau_r \quad \therefore \text{OK} \]

b. Design of the bracket

\[ \sigma_r = 220.5 \text{ MPa} \text{ and } \tau_r = 145.5 \text{ MPa}; \text{ as shown before.} \]

\[ \begin{align*}
\tau_u &= \frac{w_u}{b \times t} = \frac{14000}{1000 \times 6} = 2.33 \text{ MPa} \ll \tau_r \quad \therefore \text{OK} \\
\end{align*} \]

**Figure C.2: Reaction forces on the bracket from the shelf angle**

Compute the loads acting on the bracket

From Figure C.2a

\[ P_{\text{bracket}} = \gamma_b \cdot S \cdot h = 170 \times 0.9 \times 6.0 \times 9.81 = 9.0 \text{ kN} \]

\[ P_u = 1.4 \times 9.0 = 12.6 \text{ kN} = 6.3 \text{ kN/bracket leg} \]

\[ \Sigma F_y = 0 \quad \text{yields} \quad R_1 = P_u = 6.3 \text{ kN/bracket leg} \]

\[ \Sigma M_o = 0 \quad \text{yields} \quad R_2 = \left( P_u \times \frac{2}{3} y R_1 \right) / (95 - \frac{h}{3}) = \left( 6.3 \times 80 - \frac{2}{3} \times 25 \times 6.3 \right) / (95 - \frac{15}{3}) \]

\[ R_2 = 4.4 \text{ kN/bracket claw} \]

Check Sec. D-D

\[ \tau_u = \frac{R_1}{A} = \frac{6300}{25 \times 4.76} = 55.3 \text{ MPa} \ll \tau_r \quad \therefore \text{OK} \]
\[ M_{u,D-D} = 6300 \times \frac{2}{3} \times 25 = 105 \text{ N.m} \]

\[ \sigma_u = \frac{M}{S} = \frac{105000}{(4.76 \times 25^2)/6} = 212 < \sigma_r \quad \therefore \text{OK} \]

**Check Sec. B-B**

\[ \tau_u = \frac{R_2}{A} = \frac{4400}{15 \times 4.76} = 62 \text{ MPa} < \tau_r \quad \therefore \text{OK} \]

\[ M_{u,B-B} = 4400 \times (\frac{1}{3} \times 15 + 2) = 31 \text{ N.m} \]

\[ \sigma_u = \frac{M}{S} = \frac{31000}{(4.76 \times 17^2)/6} = 135 \text{ MPa} < \sigma_r \quad \therefore \text{OK} \]

**Check Sec. C-C**

\[ M_{u,C-C} = 4400 \times (17.5 + \frac{1}{3} \times 15) = 99 \text{ N.m} \]

\[ \sigma_u = \frac{N}{A} \times \frac{M}{S} = \frac{4400}{4.76 \times 30} + \frac{99000}{(4.76 \times 30^2)/6} = 195 \text{ MPa} < \sigma_r \quad \therefore \text{OK} \]

c. **Design of the anchor bolt**

**Straining actions acting on the anchor**

Try anchor bolt is constructed from grade 8.8 (\(F_y = 640 \text{ MPa}\)) with embedded length of 120 mm and a diameter of 16 mm. Referring to Fig. C.3.

The bolt is assumed to be located at the mid-height of the slot.

\[ \therefore d = 100 \text{ mm} \]

\[ \Sigma F_y = 0 \quad \text{yields} \quad V_i = P_u = 1.4 \times 9.0 = 12.6 \text{ kN} \]

\[ \Sigma M_Q = 0 \quad \text{yields} \quad N_i = \frac{(P_uz)}{(d-\frac{\beta_1 c}{2})} \]

Assume \((d-\frac{\beta_1 c}{2}) = 0.95 \text{ d}\)

\[ \therefore N_i = \frac{(P_uz)}{(d-\frac{\beta_1 c}{2})} = (12.6 \times (89+55)) / (0.95 \times 100) = 19.1 \text{ kN} \]
Figure C.3: Straining actions acting on the anchor at FASTTM connection

Determine the allowable tensile capacity of the bolt using Eqs 7 through 19 in this report.

\[ N_r = \text{smaller of} \ (N_{sr}, N_{chr}, N_{cpp}, N_{shr}) \]

\[ f_{ut} = \text{smaller of} \ (1.9 \ f_y, \ 860 \text{ MPa}) = \text{smaller} \ (1.9 \times 640, 860) = 860 \text{ MPa} \]

\[ N_{sr} = A_{se} \ \phi_s \ f_{ut} \ \text{R} = 0.7 \times \frac{\pi}{4} \times 16^2 \times 0.85 \times 860 \times 0.8 = 82 \text{ kN} \]

\[ h_{ef} = 120 \text{ mm} \]

Figure C.4: Projected areas of \( A_{No} \) and \( A_N \)
\[A_N = (2 \times 1.5 \times 120) \times (1.5 \times 120 + 50.8) = 83088 \text{ mm}^2\]

\[A_{No} = 9 \times h_{ef}^2 = 9 \times 120^2 = 129600 \text{ mm}^2\]

\[\psi_{ed, N} = 0.8 + 0.3 \times (50.5/120) = 0.827 \quad \text{c}_{\text{min}} < 1.5 \ h_{ef}\]

\[\psi_{c, N} = 1.4 \quad \text{for post-installed anchors}\]

\[\psi_{cp, N} = 1 \quad c_{a, \text{min}} \geq c_{ac}\]

\[k = 7 \quad \text{post-installed anchor}\]

\[N_{br} = k \varnothing_c \sqrt{f_c h_{ef}^{1.5}} = 7 \times 0.65 \times \sqrt{45 \times 120^{1.5}} \times 0.8 = 32 \text{ kN}\]

\[N_{cbr} = \frac{A_N}{A_{No}} \psi_{ed, N} \psi_{c, N} \psi_{cp, N} N_{br} = (83088/129600) \times 0.827 \times 1.4 \times 1 \times 32 = 24 \text{ kN}\]

\[N_{pr} = 8 A_{bh} \varnothing_c f_c^{1.5} R \quad \text{for single headed bolt or headed bolt}\]

\[N_{pr} = 8 \times \frac{\pi}{4} \times 18^2 \times 0.65 \times 45 \times 0.8 = 48 \text{ kN}\]

Assume cracked concrete \[\therefore \psi_{c, p} = 1.0\]

\[\therefore N_{cpr} = \psi_{c, p} N_{pr} = 48 \text{ kN}\]

\[N_{sbr} = 13.3 c \sqrt{A_{bh}} \varnothing_c \sqrt{f_c^{1.5} R} = 13.3 \times 50.8 \times \sqrt{\frac{\pi}{4} \times 18^2 \times 0.65 \times \sqrt{25} \times 0.8} = 38 \text{ kN}\]

\[\therefore N_f = 24 \text{ kN} > N_f \quad \therefore \text{OK}\]

Determine the allowable shear capacity of the bolt using Eqs 20 through 27 in this report.

\[V_r = \text{smaller of } (V_{sr}, V_{cbr}, V_{cpr})\]

\[V_{sr} = A_{sc} \varnothing_s 0.6 f_{ut} R \quad \text{for post-installed anchors}\]

\[\therefore V_{sr} = 0.7 \times \frac{\pi}{4} \times 16^2 \times 0.85 \times 0.6 \times 860 \times 0.75 = 46 \text{ kN}\]

\[V_{cbr} = \frac{A_v}{A_{vo}} \psi_{ed, v} \psi_{c, v} V_{br}\]

\[\psi_{ed, v} = 1 \quad c_2 \geq 1.5 c_1\]

\[\psi_{c, v} = 1.4\]
Figure C.5: Projected area for the computation of $A_v$ and $A_v$

$$V_{br} = 0.58 \left( \frac{1}{d_0} \right)^{0.2} \sqrt{d_0} \phi_c f'c_1^{1.5}R = 0.58 \times \left( \frac{120}{16} \right)^{0.2} \times \sqrt{16} \times 0.65 \times \sqrt{45 \times 549.2^{1.5} \times 0.75}$$

$V_{br} = 146$ kN

$$V_{cbr} = \frac{A_v}{A_{vo}} \psi_{ed, v} \psi_{c, v} V_{br} = 1 \times 1 \times 1.4 \times 146 = 205$ kN

$$V_{cpr} = k_{cp} N_{cpr} = 2.0 \times 24 = 48$ kN

$$V_r = 48$ kN > $V_f \quad \therefore$ OK

Check on interaction between Normal and Shear on the bolt

$$\frac{N_f}{N_r} = \frac{19.1}{24} + \frac{12.6}{48} = 1.06 \leq 1.2 \quad \therefore$ OK