Anchorage Design for Pre-Fabricated Shear Panels in Light-Framed Structures

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Design Issues

Most designers are aware that they must maintain a proper load path to transfer structural loads into the foundation in order for their structure to remain standing. While tracing the load path of vertical loads is well understood by many, establishing a load path for loads applied horizontally can be challenging. Horizontal loads, or lateral loads, are most frequently generated by a wind or seismic event. In light-framed structures, lateral loads are commonly resisted by prescriptive wall bracing or engineered shear walls. The lateral load generated at the top of a shear panel, or braced wall panel, results in vertical compression and tension forces at the bottom of the panel that must be resisted. As the length of the panel decreases, the horizontal moment arm decreases, and the tension and compression forces increase (*Figure 1*). When the architecture of a building does not allow for sufficient wall length to field construct wall bracing or site-built shear walls that meet code-specified aspect ratios, narrow prefabricated shear panels are solutions that provide lateral resistance to the structure. With narrow prefabricated shear panels, high tension and compression forces can be generated and proper anchorage design to the concrete foundation becomes critical.

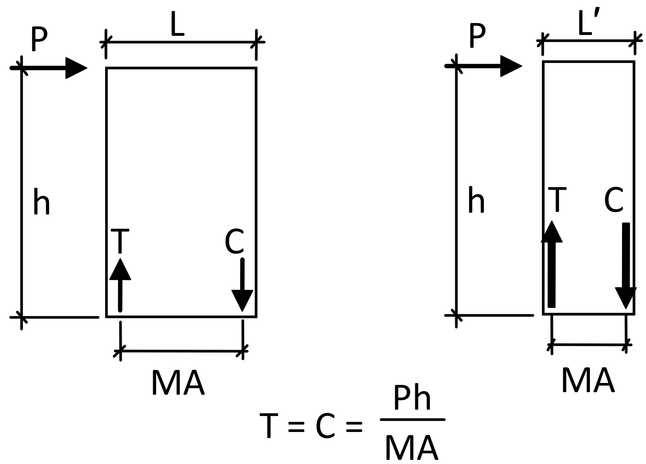

Figure 1: Free-body diagram of a shear wall.

The tension, or uplift, force is usually resisted with an embedded anchor bolt or threaded rod into the concrete foundation. For prescriptive designs, lateral loads per shear panel are relatively small. Most manufacturers of prefabricated shear panels have prescriptive anchorage charts showing the required footing size and embedment depth for the anchor bolt to resist the uplift force. For engineered designs, the lateral design loads to the panel can become very high resulting in tension and compression forces in the 20 kip range or higher. Uplift forces associated with allowable in-plane shear loads are often published by each manufacturer and are dependent on the panel geometry and the moment arm at the base of the panel. Although manufacturers publish embedment and footing width charts for these higher loads, it is the responsibility of the engineer-of-record to ensure the footing sizes, embedment depths, and concrete strength are correct for their specific application.

Code Requirements

Section 1912 of the 2006 *International Building Code* (IBC), *Anchorage to Concrete – Strength Design*, references *ACI 318* Appendix D for designing anchorage. For anchorage design in moderate to high seismic risk regions, defined as seismic design category C, D, E or F in ACI 318-08 Section D.3.3, the nominal concrete strength in tension must be reduced using a factor of 0.75. In addition, the anchorage design shall be controlled by the steel strength of the anchor bolt (ACI 318,

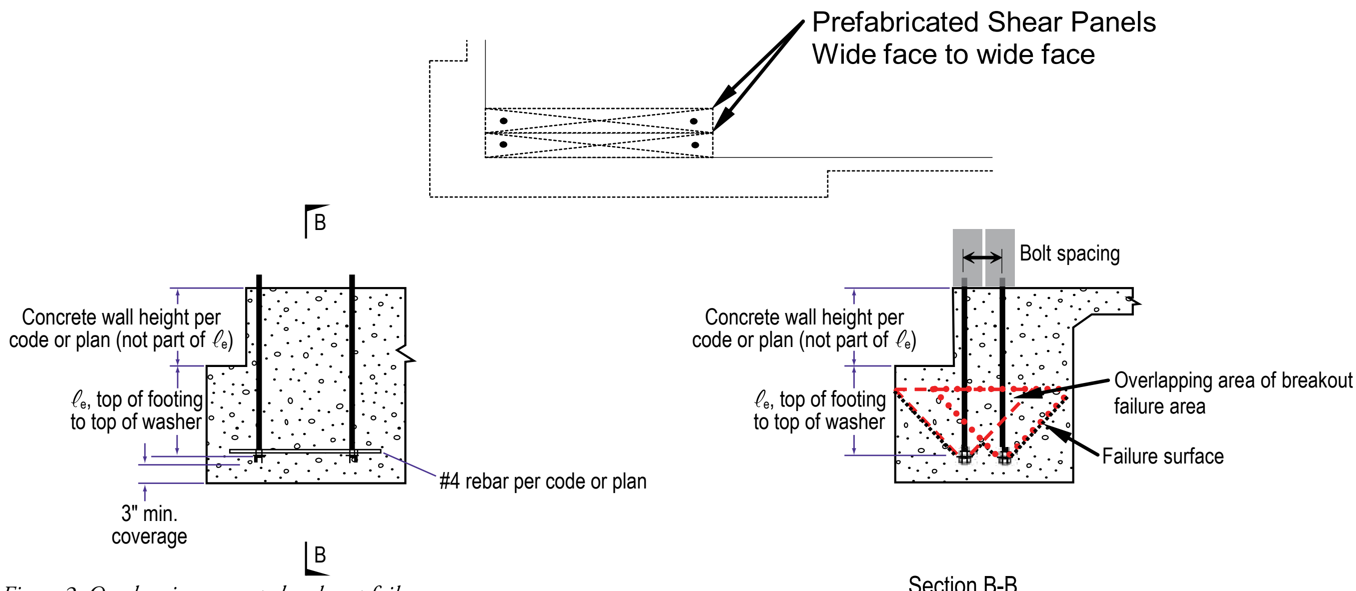

Figure 2: Overlapping concrete break-out failure areas.

D.3.3.4) or the hold-down attachment must undergo ductile yielding at a force level less than the nominal strength of the anchorage associated with concrete failure modes (ACI 318, D3.3.5). As an alternative, the 2008 ACI 318 allows the design strength of the anchors to be taken as 0.40 times the calculated nominal concrete design strength (ACI 318-08, D.3.3.6). This alternate provision is also part of the 2007 *California Building Code* (CBC) (1908.1.16) which states, "….the minimum design strength of the anchors shall be at least 2.5 times the factored forces transmitted by the attachment." In other words, a ductile steel anchor bolt or hold-down attachment must govern the design to avoid brittle failures. If this cannot be accomplished, the concrete design strength should be reduced by 60% or the concrete should be designed for a higher load – 2.5 times the factored design load – to allow the steel anchor or the hold-down attachment to yield.

In some instances the engineer-of-record will place prefabricated shear panels wide-face-to-wide-face due to large, local, lateral loads that the wall line needs to resist. Due to overlapping concrete breakout failure areas, as shown in *Figure 2*, the manufacturer's details that are developed for a single panel will not achieve double the panel's published allowable loads. In fact, depending upon the bolt embedment depth, end and edge distances, and the bolt spacing usually equal to the thickness of the prefabricated shear panel, the concrete capacity may increase only 25% although the demand on the concrete may have doubled. The engineer-of-record must reduce the demand on the panels or modify the anchorage to accommodate the design loads.

In addition to designing anchorage for the tension force, the designer must also consider the compression force on the concrete. As stated previously, the lateral load at the top of the panel will induce compression on the concrete below. If the panel is supporting a vertical load from above, the vertical load must be added to the compression developed from the lateral load. The bearing strength of the concrete assembly must be greater than the cumulative compression force. This is especially critical when bearing near the edge of the concrete or in a corner, which is often the case with prefabricated shear panels. Section 10.14 of ACI 318-08 provides a procedure for calculating bearing strength. If there is sufficient bearing surface around all sides of the loaded area, A_1, the loaded area can be increased by multiplying the bearing strength by the square root of (A_2/A_1), in which the square root of (A_2/A_1) shall not exceed 2. A_2 can be determined as shown in *Figure 3*. However, many prefabricated shear panels are installed in applications with one face flush with the edge of concrete. Thus, this increase is not applicable and the bearing strength is calculated as $\Phi(0.85f'_c A_1)$, where A_1 is the load area in compression below the footprint of the prefabricated shear panel.

When designing stacked prefabricated shear panels, the anchorage must consider the cumulative overturning forces.

$$OM_{base} = (V_1H_1 + V_2H_2)/MA$$

The overturning moment at the base of the lower shear panel (OM_{base}) is equal to the sum of the shear at the first story (V_1) times the height of the first story (H_1) plus the shear at the second story (V_2) times the height from the base to the top of the second story (H_2). This value is then divided by the moment arm (MA) at the base of the prefabricated shear panel to calculate the tension and compression forces that the anchorage must resist.

In addition to designing the anchorage to resist compression and tension forces, the anchorage must be designed to resist horizontal shear forces. As with tension, the shear design strength associated with concrete failure modes must be taken as 0.75 times the nominal

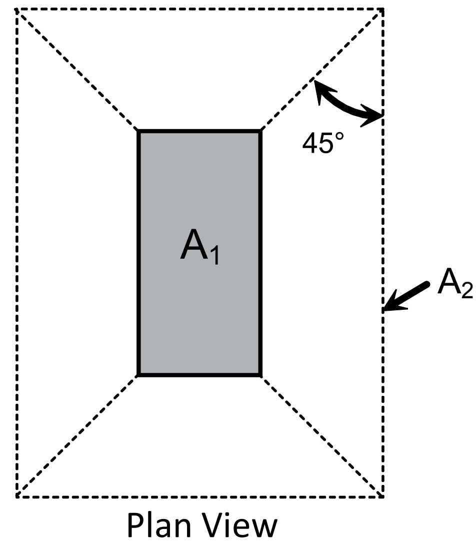

Figure 3: Diagram illustrating frustum to find A_2.

factored shear stress in areas of moderate or high seismic risk. The connection must be controlled by the strength of the steel bolt or a ductile attachment when calculating the design shear strength as well. Often the concrete break-out strength of the anchor in shear governs the design strength, due to close end and edge distances of the anchor bolt to the surfaces of the concrete. For conditions with the prefabricated shear panel located in a corner, the concrete breakout strength shall be taken as the minimum of the value calculated based on the concrete breakout failure area using the bolt end distance, or twice the value calculated based on the concrete failure area using the bolt distance perpendicular to the edge. See section D.6.2.1 of ACI 318 for more information. For prefabricated shear panels located with minimal edge and end distances, concrete shear reinforcement is usually required in the form of hairpin or stirrup reinforcement or other proprietary reinforcement to enhance the concrete breakout strength. Placement of hairpin or stirrup reinforcement should be such that it is in contact with the anchor bolt and is as close to the top surface of the concrete, as allowed per the concrete coverage provisions of ACI 318.

For some prefabricated shear panels, the allowable in-plane shear load varies based on the grade of bolt. The engineer-of-record must indicate the grade of bolt required for the anchorage. For prescriptive loading, an ASTM A307 grade threaded rod or bolt is usually sufficient for single-story applications. For engineered projects, projects located in moderate to high seismic risk areas, and stacked applications, a high strength threaded rod or bolt, such as an ASTM A449 or equivalent grade, is required. Keep in mind that for anchorage in regions of moderate to high seismic risk, anchor design shall be controlled by a ductile steel element, the hold-down attachment shall be designed to undergo ductile yielding, or the concrete design strength must be reduced.

Many prefabricated shear panels now use only two bolts to anchor their panels to the concrete. The engineer-of-record needs to understand how the manufacturer has analyzed their anchor bolts for the combination of shear and tension. Section D.7 of the ACI 318-08 provides an equation for analyzing anchors subject to both shear and tension loads simultaneously.

Adhesive Anchors

When considering post-installed, adhesive anchors for prefabricated shear panels, designers need to make sure they are using current information. Adhesive anchors in concrete now fall under International Code Council Evaluation Service (ICC-ES) acceptance criteria, AC308, *Post-Installed Adhesive Anchors in Concrete Elements*. AC308 was developed for use in combination with ACI 318 Appendix D and strength design. For minimum edge distances, typical for prefabricated shear panel installation, tension strength based on AC308 is reduced from previously published values. Adhesive solutions are possible for most prefabricated shear panel applications installed per prescriptive wall bracing rules in low seismic areas, but are often inadequate for increased seismic risk areas and engineered applications where the design loads are higher. Cast-in-place anchors are the preferred anchorage and care should be taken to ensure proper field placement to avoid costly repairs for misplaced bolts.

Non-concrete Foundations

Installing prefabricated shear panels on concrete masonry units present some design challenges. Compression strength of the grout filled concrete masonry unit (CMU) usually will govern the design. High strength grout is required to develop capacities needed for prescriptive wall bracing in the lower seismic design categories A and B. For other applications with higher loads, prefabricated shear panels should bear directly on concrete. If the prefabricated shear panel is located in a corner, near the end of the CMU wall, calculated allowable shear strength will be small. A bond beam may be required to facilitate installing needed horizontal reinforcement. Anchorage will need to extend to a concrete footing to resist tension forces and likely requires an engineer-of-record to design.

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For applications in which the prefabricated shear panel will bear on a flexible member such as a wood or steel beam, design of the anchorage connection is left to the engineer-of-record. In addition, the drift at the top of the prefabricated shear panel must be calculated to include the effects of the beam deflection, compression perpendicular to grain of a wood beam or wood plate on a steel beam, and wood shrinkage.

Detailing

Although manufacturers of prefabricated shear panels provide anchorage information to assist the design professional with detailing, the design professional is still responsible to ensure the information and details are in conformance with current codes and meet the project needs. Detail sheets offered by the prefabricated shear panel manufacturers usually show general footing requirements, and then refer the contractor to charts for specific embedment and footing dimensions depending upon the panel or bolt size. It is recommended that the design professional modify the manufacturer's details for the specific project, showing specific dimensions and embedments rather than relying on the contractor to interpret charts.

Conclusion

Prefabricated shear panels provide solutions to resist lateral loads where site-built shear walls or code prescribed bracing cannot. Their high height-to-width ratios result in significant forces on the concrete that must be properly anchored. Anchorage can be designed using resources such as ACI-318 and current ICC-ES code evaluation reports. Contact the specific prefabricated shear panel manufacturer to gain understanding of their embedment and footing width recommendations so job specific requirements are communicated on drawings.▪

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