Constructability of Embedded Steel Plates in Cast-in-Place Concrete

Best practices for design, fabrication, coordination, and construction

by James Klinger, Frank Salzano, Tim Manherz, and Bruce A. Suprenant

Embedded steel plates with headed studs (embeds) serve as connections to structural steel framing, façade and curtain wall systems, elevator rails, steel or precast stairs, mechanical-electrical-plumbing components, and miscellaneous additional items. Proper anchorage and connection to concrete must be given a high priority by the entire design and construction team.

As members of the American Society of Concrete Contractors (ASCC), we met in May 2018 to share experiences on the topic of embeds. This article presents our recommendations for best practices for design, fabrication, coordination, and construction of embedded steel plates in cast-in-place concrete. All recommendations are directed at constructability (cost, jobsite safety, and schedule issues), not the structural capacity of the plate or anchors.

Design

Chapter 17, "Anchoring to Concrete," in ACI 318-14[1] provides design requirements for anchors in concrete used to transmit structural loads by tension, shear, or a combination thereof. The American Institute of Steel Construction (AISC) "Design Guide 23: Constructability of Structural Steel Buildings"[2] provides recommendations for the structural engineer of record (SER) to consider during the design phase, including:

- Design embeds for a minimum of 2 in. (50 mm) eccentricity in each direction, to allow for relocation of the plate due to reinforcing bar interferences;
- Detail the embed plate to be up to 6 in. (150 mm) wider and taller than designed, to allow for relocation due to bar interferences;
- Completely design embeds and include the necessary details within the contract documents, especially if the connections are governed by seismic design provisions;
- Require SER approval of repair, modification, or replacement of embeds, using the OSHA[3] procedure for SER approval of actions taken on anchor rods; and
- Develop action plans for dealing with misalignment, dislocation, or out-of-tolerance installations of embeds.

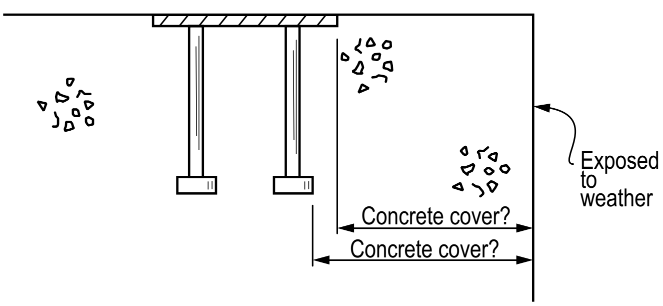

Fig. 1: The structural engineer of record must define the controlling concrete cover on an embed (based on Reference 4)

The SER must also define the controlling concrete cover along the vertical face exposed to weather on embeds, using a detail in the concrete documents (Fig. 1).[4] AISC's "Design Guide 22: Façade Attachments to Steel-Framed Buildings"[5] addresses the common façade attachment for a concrete slab-steel frame building. One of the most economical slab edge details incorporates a 10- to 20-gauge cold-formed metal pour stop (edge form) welded to the spandrel beam in the field, during erection of the metal deck (Fig. 2).

If the overhang carries any façade attachment loads, the load path must be directly into the slab and not through the pour stop itself, as light-gauge metal pour stops rarely have the strength required for façade attachments. Furthermore, if steel embedment plates are cast into the slab for façade attachment, only very heavy-gauge pour stops are stiff enough to secure the embedment plates for positioning in the slab. Reference 5 provides design guidelines for slab edge details when attaching façade elements to bent plates or other structural steel.

Based on discussions at the recent ASCC meeting, we assembled additional recommendations for the SER:

- Detail reinforcing bars at any embed with a plate thickness exceeding the concrete cover minus the clearance required per Section 2.3.1 of ACI 117[6] (Fig. 3 and 4). The SER will be in the best position to evaluate the effects such a detail will have on structural behavior, while also considering the effects it will have on cost and schedule. Options might include:
  - Increasing the cover for the entire reinforcing bar curtain;
  - Providing offset bends in the affected bars (note that this may necessitate additional ties);
  - Treating the plate as an opening (terminating affected bars and adding splice bars to maintain continuity across the plate dimension); and
  - Using a thinner plate, with stiffeners oriented parallel to the outer bars.
- Adjust stud spacing when plates are used at the edges of walls, columns, or slabs. Embed details often indicate that studs are about 2 in. from the edge of a plate; however, if the plate is to be located at an edge, then the first row of studs will probably conflict with a reinforcing bar (Fig. 5). It may also be necessary to consider the effect of a chamfer at a wall or column corner;

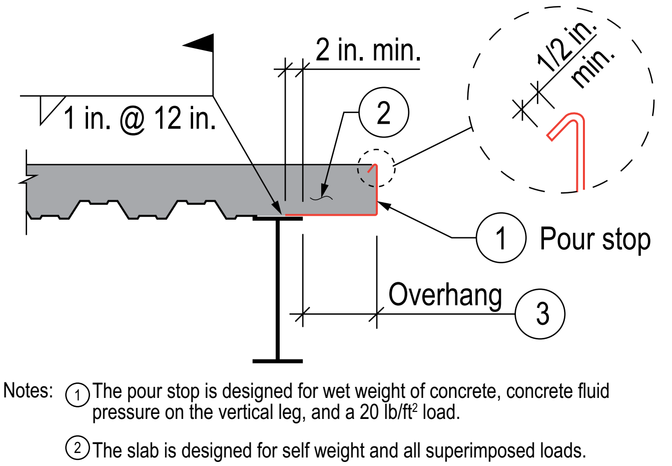

Fig. 2: A typical pour stop detail for a slab on metal deck (based on Reference 5) (Note: 1 in. = 25 mm; 1 lb/ft² = 0.96 kN/m²)

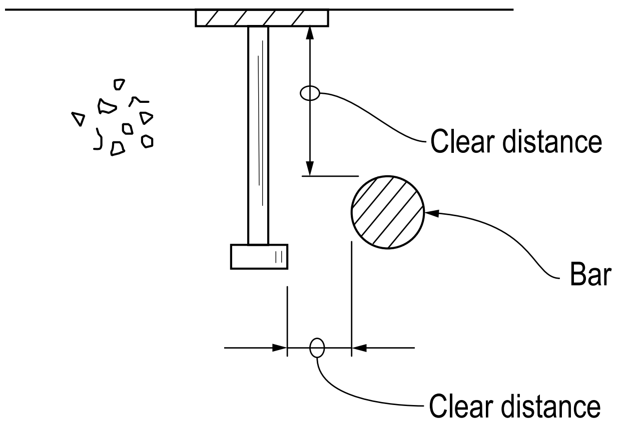

Fig. 4: An illustration of the requirements in Section 2.3.1 of ACI 117, which specifies that the clearance between embedded items and the nearest reinforcing bar shall be the greater of the bar diameter, largest aggregate size, or 1 in. (25 mm). The figure in the associated commentary indicates that the clear distance is a tolerance

Fig. 3: Reinforcing bars must clear embed plates and studs by the clearance provided in Section 2.3.1 of ACI 117, and the SER must provide details showing how the clearance is to be maintained. This is particularly critical when the embeds have very thick plates

Fig. 5: A reinforced concrete wall with embeds and penetrations, shown prior to closure of the formwork. The embeds adjacent to the wall penetrations interfere with the vertical bars in the wall

- Provide special studrail details when the concrete slopes or reduces in thickness, such as at a balcony. For instance, an 8 in. (200 mm) thick slab may have a 3/4 in. (19 mm) step-down to accommodate a balcony door, and the balcony may slope for drainage. The final slab thickness will then be about 7 in. (175 mm). If stud rails are used to reinforce the balcony, the stud height must be reduced to accommodate the depth change as well as maintain adequate cover for the exterior environment;
- Avoid embeds with attachments welded on both sides of the plate, as formwork will need expensive modifications to accommodate the outer attachment and thus may not be reusable. Such embeds are typically more difficult to set within tolerances. The cost-effective option is to weld or anchor attachments to embed plates after concrete has been placed;
- Design embeds at tops of walls and curbs, slabs, and other locations so that they do not interfere with concrete placement. Consider options such as discontinuous embeds. Also, consider allowing wet-setting embeds in accordance with ACI provisions for precast and tilt-up construction[7];
- Provide direction to the concrete contractor if the perimeter embeds must be positioned to offset slab shortening due to post-tensioning;
- Indicate whether reinforcing bar clearance next to the plate is important. ACI 117 requires at least 1 in. (25 mm) clearance between embed plates and reinforcing bars, to allow concrete to flow between the bar and plate (Fig. 4);
- Perform a constructability review that includes checks for interference between embeds and bars or tendons. Be particularly careful to avoid locating slab embed plates directly above post-tensioning anchors. Also note that the details may have to be revisited after bidding, for coordination with the architect and specialty engineers responsible for post-tensioning and cladding;
- Specify nail and air holes in fabricated items to facilitate constructability (see “Fabrication”);
- Specify whether the position of the embed, reinforcing bars, or post-tensioning tendons controls when interference occurs;
- Design fewer standardized embed types;
- Provide an embed schedule for clarity; and
- Require an embed coordination meeting between the design and construction teams, separate from the concrete preconstruction meeting (see “Coordination”).

Fabrication

ACI Committee E703, Concrete Construction Practices, recommends in “Cast-in-Place Walls (CCS-02[00])” that “weld plates, angles or channels, frames for openings, loading dock equipment, edge protection and trench drains should be predrilled for nailing to the forms.”[8] Concrete contractors may include the predrilling requirement for embeds in the scope of work, which is submitted to the general contractor or

Fig. 6: Embed plates require small diameter holes for installation on wall form

construction manager (the controlling contractor). Concrete contractors may condition their bids upon the timely delivery of embeds with plates predrilled for nailing to forms. Often, however, the requirement is neglected, and embeds are shipped to the site without predrilling. This causes delays, as embeds must be shipped back to the fabricator’s shop for drilling. The SER should address the issue in the project specifications by requiring predrilling of the plates. This will reduce confusion and minimize delays.

At a minimum, embeds that will be installed on formwork will need erection holes at all four corners of the embed plate (Fig. 6). Plates exceeding about 24 in. (600 mm) in width require additional holes spaced no more than 18 in. (450 mm) apart to ensure the plate remains in contact with the formwork sheathing during concrete placement. Holes should be 3/16 in. (4.75 mm) in diameter, to accommodate a 16d nail or a No. 8 (4 mm) drywall screw. Holes this size must be drilled—they are too small to be punched.

One or more larger holes will be necessary for embeds that will be set in tops of slabs. In addition to pre-drilled corner holes, embeds larger than 24 in. in both directions placed on the top of slabs need an air relief hole or “sight hole” to verify that the concrete flows under the plate (Fig. 7). The air relief hole can be 3/4 in. in diameter and can therefore be punched.

Coordination

To maximize embed constructability, the design and construction team should make coordination their highest priority. This is especially critical when there are separate work packages and thus different subcontractors placing the reinforcement, the forms, and the concrete. The SER should require an embed coordination meeting, as formwork, embed, and reinforcing bar placing drawings need to be carefully reviewed along with structural steel and cladding erection drawings. The SER should send an agenda and minutes to relevant members of the design and construction teams at least a week before and after the meeting date, respectively.

The coordination paragraphs in two sections of the AIA MasterSpec guide specifications “Section 051200: Structural Steel Framing”[9] and “Section 055000: Metal Fabrications”[10] require that embeds and embed drawings be furnished to other trades without delaying the work. The concrete contractor provides a schedule of work that the controlling contractor uses to set deadlines for approval of embed drawings and shipping of embeds. The concrete contractor needs to review the drawings at least 2 weeks before fabrication starts, and the concrete contractor needs embeds at least 2 weeks prior to installation. The first deadline allows sufficient time to check the drawings for possible placement difficulties (including conflicts with reinforcing bars). The second deadline allows sufficient time to verify the accuracy of materials received and physically check for placement difficulties. The controlling contractor must take into account any extra lead time that may be required to procure nonstandard conditions such as galvanized or stainless steel embeds.

The concrete contractor does not have control over other subcontractors. Thus, it is imperative that the controlling contractor enforces the coordination requirements set forth in the project specification, including predrilling of plates. This includes providing the embed layout drawings early so that changes, if necessary, can be made to the reinforcement bar placing drawings. If the embeds are not received 2 weeks before placement, delays or repairs may result; and the concrete contractor will be justified in demanding reimbursement for additional costs.

The concrete contractor should have one person on site responsible for managing embeds to ensure coordination between different subcontractors supplying embeds, that drawings are received and reviewed promptly for accuracy, to verify that the drawings satisfy the architectural and structural specifications, and to identify potential conflicts with reinforcing bars and post-tensioning.

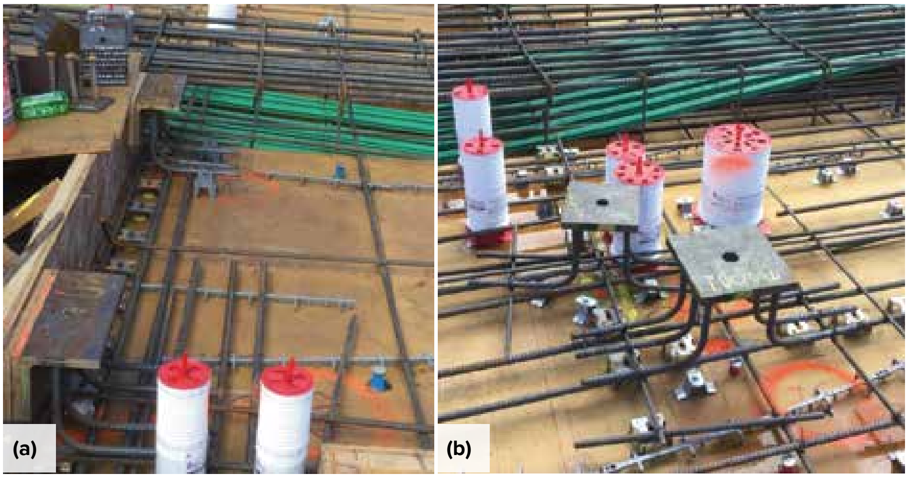

Fig. 7: Air holes are used to ensure that concrete flows under plates

This person should track:

- Invoices and shipping tickets that accompany embed deliveries;
- Embed inventories, including types, quantities, delivery dates, and back orders; and
- Problems, including discrepancies, errors, shipping issues, or conflicts.

This person should produce an embed list for each placement or each floor, and this person must ensure that the correct

Fig. 8: Embeds must be stored in a designated area and supported on cribbing or pallets. In this example, several of the embed plates are curved, warped. or twisted. Slight imperfections can be corrected during installation once embeds are nailed in place. Note, however, that these plates lack nail holes. If adequate corrections cannot be made, deformed embeds should not be used

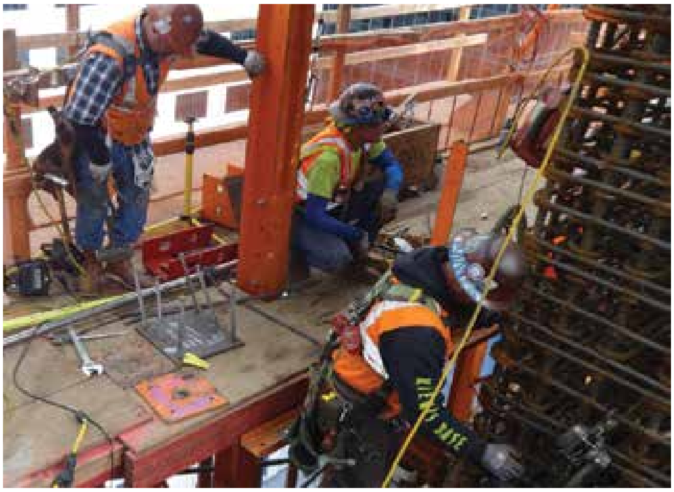

Fig. 9: Embeds with studs that have been bent in the field

embeds are delivered to each placement location at the appropriate time prior to concrete placement. A designated area on site will be needed for the storage of all embeds (Fig. 8). Embeds should be clearly marked and stored in separate crates or on pallets, out of the soil and mud, and protected from snow and ice during winter.

When curved, warped, or twisted embeds (Fig. 8) are received, the fabricator should be notified, using identification numbers and photographs. Many imperfections can be corrected as deformed embeds are being nailed in place. If imperfections cannot be corrected, the deformed embeds must be replaced. By notifying the supplier in advance, delays will be minimized.

The concrete contractor must advise the SER if embeds cannot be placed due to interferences with reinforcing bars, post-tensioning tendons, or other items. The contractor must receive approval from the SER on any modifications prior to concrete placement. This process, including the timing of submittal and approval, should be discussed at the coordination meeting. If a modification such as bending of headed studs is allowed (Fig. 9), for example, the SER should set the maximum bend (a bend angle of 15 degrees would be consistent with AWS[11] testing protocols) and appropriate field test for the modification.

Construction

To ensure success, the concrete contractor must consider forming, layout, installation, concrete placement, and post-placement activities. The following sections describe many of the associated issues.

Forming

Embed plate sizes or locations may force altering of formwork tie locations. Check formwork drawings against embed locations and alter formwork as needed prior to submitting formwork shop drawings for review. Planning is also necessary to minimize damage to formwork panels caused by installation of embeds—particularly on formwork comprising steel frames or aluminum panels.

Layout

The field engineer should double check that dimensions are measured from top of slab and not "elevations." Layout should be done by trained and experienced personnel. The layout crew must:

- Locate the centerline of embeds and spot check embed edges and sizes on initial placements and when exact location and placement are critical;
- Ensure that the layout crew has reviewed the latest approved shop drawings;
- Make sure there are sufficient control lines to provide accurate and consistent layout;
- Check control lines back to primary control on ground, at least every other floor;
- Double check dimensions prior to performing field layout. When using dimension strings for embeds, use the layout from column grid lines, as this is more accurate than measuring each individual dimension; and
- While the concrete contractor usually provides the layout and sets embeds provided by others, that is not always the case. Some follow-on trades, such as curtainwall and wood framing subcontractors, may request that they locate and set their own embeds. This should not be an issue if it does not delay the concrete placements. Regardless of who provides the layout and sets embeds, rework and associated back charges can be significant and thus need to be discussed at the coordination meeting.

Installation

The layout crew should begin by marking adjacent reinforcing bars with a white paint stick to fix the general location and elevation of embeds. The crew can then loosely attach embeds to the reinforcing bars, using tie wire routed through the previously discussed holes in the embed plates.

Many concrete contractors then set the forms and tighten the form ties near embeds to maintain contact between the forms and embed and minimize paste between embeds and form. It may be necessary to place a bent reinforcing bar or a slab bolster behind embeds to position the plate slightly outboard of its final position. When the form is closed and the form ties are tightened, the reinforcing bar or slab bolster will deform, thereby clamping the form snug against embeds. Other contractors set the form and run tie wire from embeds through the form. This often requires drilling multiple holes in the form to locate the tie wires. Once the tie wire is located, it is pulled through the form to snug the form against embeds.

At wall and column corners, the chamfer is generally removed as required to allow the edge of the embed plate to be flush with the face of the concrete element.

Concrete placement

All embeds should be set prior to concrete placement. Placement watch personnel should keep finishers and other personnel from stepping on embeds or moving them during placement and ensure proper consolidation at embeds. When placing concrete around a slab embed, it is important to direct concrete flow in one direction, with the vibrator operator close by to watch the concrete come out the other side. The "sight hole" in a slab embed assists the vibrator operator in making sure that concrete is under the plate and there is minimal trapped air.

Post concrete placement

As soon as possible after stripping the forms, the concrete contractor should use scrapers or chisels to clean grout leakage that could affect attachments to embed faces. The concrete contractor's quality assurance crew should survey critical embed locations to be sure they have been correctly placed, document the as-built conditions, and advise the SER immediately of anything out of tolerance. If issues are discovered, the quality assurance crew should confirm the cause and provide corrective action for future embed placements.

Special Topics

Expansion joints

The concrete contractor must ensure that embeds that form expansion joints:

- Are not warped or twisted (inspect embeds before installation);
- Are set plumb and level (embeds must be securely tied to the reinforcing bars);
- Remain in the correct position during concrete placement (workers must avoid walking on embeds); and
- Checked after forms are stripped (embeds must be aligned and plumb to ensure proper installation and function of expansion joint material [Fig. 10]).

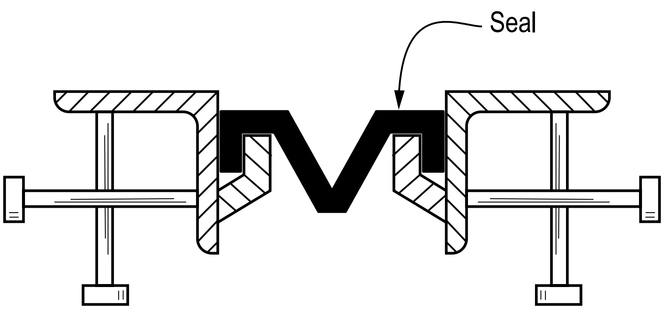

Fig. 10: Embeds for expansion joints must be installed to accommodate joint seals

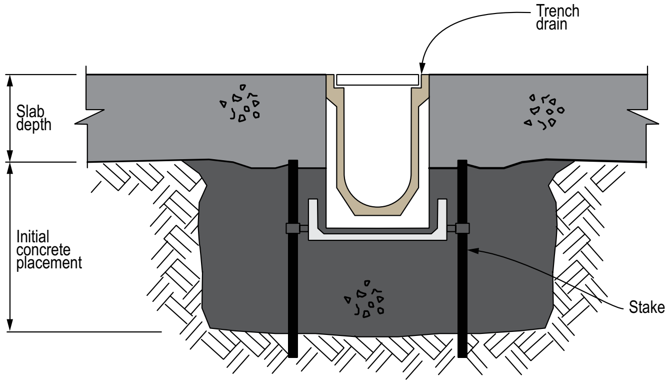

Fig. 11: Embeds such as trench drains may be set in concrete before placement of the slab

Long embeds could comprise shorter embeds that have been tack welded together after setting to ensure alignment before, during, and after concrete placement. This solution must be discussed and agreed at the embed coordination meeting.

Slab embeds

In slab-on-ground construction, it may be possible to set trench drains, plates, bollards, and other embeds in concrete the day before slab placement, with the reinforcing bars in place, to ensure no movement during the main placement (Fig. 11). This approach should also be discussed at the embed coordination meeting.

Tolerances

Concrete contractors set embeds to meet tolerances in Section 2.3 of ACI 117.[6] The horizontal or vertical centerlines of the assembly can vary from the specified location by ±1 in. The surface of the assembly can vary from the surface of the concrete by ±1/2 in. (13 mm) if the assembly is larger than 12 in. (300 mm). For 12 in. or smaller assemblies, the variance is ±1/2 in. per 12 in. but not less than ±1/4 in. (40 mm/m but not less than 6 mm).

The trades furnishing embeds to the concrete contractors may want or need tighter tolerances. For instance, Section 7.5.3. of the AISC Code of Standard Practice[12] requires that embeds to receive structural steel be set to a tolerance consistent with those specified in Section 7.13 for the erection of structural steel. The façade or curtain wall, elevator, stairs, operable partitions, and other trades may request different tolerances. It is the responsibility of the design team to coordinate these tolerance requirements and indicate which controls. This issue must also be discussed at the embed coordination meeting. Since this is discussed after bidding and contract signing, the concrete contactor will submit a bid for embeds consistent with ACI 117 tolerances. Tolerances that differ from ACI 117 may result in a change order. Alternatively, Mohr and Harris[13] present options for embed design and construction in a design-build environment.

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Selected for reader interest by the editors.

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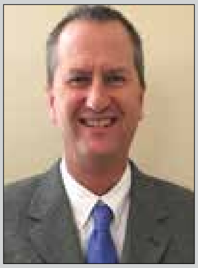

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