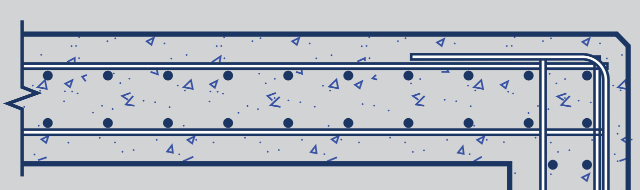
Reinforcing Bar Details for Mat Foundations

Mat foundations are commonly used to support heavy loads from multiple columns. Mats may bear on competent soil, on soil with a low bearing capacity, or be supported on piles or drilled shaft foundations (caissons). Depending on the total load applied to the mat and underlying foundation system, the thickness of mat foundations can vary from 1 ft (0.3 m) to more than 20 ft (7 m). The reinforcing system in the mat can be quite substantial, with heavy reinforcing bar mats in the bottom, top, or both locations within the mat depth. Improper detailing of the reinforcement can result in constructibility issues impacting other trades, the schedule, and costs. This Detailing Corner describes practices that can be used to simplify the design, detailing, and placement of mat reinforcement.



DETAILING CORNER

Joint ACI-CRSI Committee 315-B, Details of Concrete Reinforcement-Constructibility, has developed forums dealing with constructibility issues for reinforced concrete. To assist the Committee with disseminating this information, staff at the Concrete Reinforcing Steel Institute (CRSI) are presenting these topics in a regular series of articles. If you have a detailing question you would like to see covered in a future article, please send an e-mail to Neal Anderson, CRSI's Vice President of Engineering, at nanderson@crsi.org with the subject line "Detailing Corner."

Setting the Reinforcement

Minimum requirements

The mat depth is normally set by shear strength requirements. The amount of reinforcement A_s for the top and bottom reinforcing layers is set by meeting ACI 318 Code[1] requirements for flexural strength, minimum flexural reinforcement (Sections 10.5.1 through 10.5.4), and shrinkage and temperature reinforcement (Sections 7.12.2.1 through 7.12.2.3). Generally, A_s will be governed by flexural considerations, either through analysis or satisfying the minimum requirements. However, as the thickness of the mat increases, the minimum amount of shrinkage and temperature reinforcement will increase—it could control for very thick mats.

Once this reinforcement quantity is calculated, a suitable bar size and spacing can be selected. Depending on the layout configuration, the reinforcing bars can be placed in two layers (one mat) or four layers (two mats) at both the top and bottom. Per Code Section 7.12.2.2, the bar spacing is limited to five times the slab thickness or 18 in. (450 mm). Code Section 15.10.4 also sets the maximum spacing of mat reinforcement at 18 in.

Bars that are placed in the interior layers should follow the same spacing patterns as the main, outer reinforcement so that all bars in different layers are aligned (Fig. 1). This provides clear passage for concrete placement, which helps to reduce voids. It's considered good practice to select the size of the bars in the interior layers equal to or smaller than the outer layer reinforcing bars. Some designers prefer to specify bars in the interior layers with diameters different than the bars in the outer layer of reinforcement so they can be more easily identified and checked in the field. By a note or a section on the design drawing, the engineer should specify those bars that will be placed in the outer layer and the ones in the inner layer.

It's recommended that a clear spacing of at least 3 in. (75 mm) (more for deeper mats) be provided between the bars to facilitate concrete placement, as shown in Fig. 1. For deep foundation mats requiring worker access inside the cage, it's also good practice to provide openings in the top reinforcement. This can be accomplished by bundling the bars and providing additional steel around the resulting opening, as shown in Fig. 2.

As noted in ACI 336.2R,[2] Section 6.14: "It is essential that the engineer prepare thorough drawings documenting all phases of the reinforcement placement.... Specification of placement sequence is very important."

Additional bars

Additional flexural reinforcement may be required at heavily loaded or closely spaced columns or where substructure support conditions change. Any additional top and/or bottom reinforcement can be in the same layer as the outer, main reinforcement or within the interior layers.

Additional bars should be spaced as a multiple or submultiple of the spacing for the main reinforcement. For example, if the mat foundation is 6 ft (2 m) thick and No. 9 (No. 29) bars have been provided at 15 in. (375 mm) on center for the main reinforcement in each direction for both top and bottom reinforcement, any additional bars required in any area can be provided at a spacing of 5, 7.5, 15, or 30 in. (125, 190, 375, or 750 mm).

Other Considerations

Some additional points to consider:

- When the column spacing is not laid out on a regular, symmetric grid, consider locating the bars on an orthogonal grid rather than skewing them with the actual column locations. Additional reinforcement can then be placed wherever it's required.
- It's common practice not to use shear reinforcement in a mat. This ensures that the depth and stiffness is maximized and flexural reinforcement is minimized (ACI 336.2R, Section 6.1.2, Item 2). However, when shear reinforcement is required, it's recommended that the selected vertical bars are larger than the main reinforcement and are placed at larger spacing—easing identification and inspection.
- It's preferable to extend column and wall dowels all the way down to the bottom mat of reinforcement. The dowels should incorporate a 90-degree hook at the bottom end, so the tail of the hook can be used for support and elevation control. This also allows the dowels to be tied to both the top and bottom mats of reinforcement for stability, as the two tie points will properly secure the dowel bars from displacing (Fig. 3).
- If lap splices in the foundation mat reinforcement are to be staggered, they need to be carefully detailed on the design drawings. Otherwise, the staggered splices for different layers of reinforcing bars may become quite confusing to place and subsequently inspect. If it's possible to avoid staggering splices, this should be the preferred placement for ease of constructibility.
- The common mill stock length of straight reinforcing bars is 60 ft (18.3 m). However, a local fabricator may have limitations (such as storage space, crane capacity, and bend table size), requiring stocked straight lengths less than 60 ft. It is thus advisable to verify with the

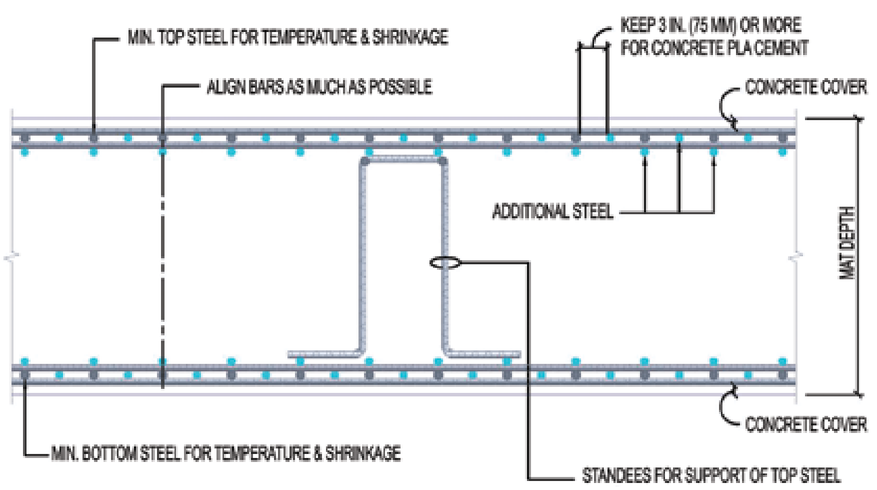


Fig. 1: Typical configuration of reinforcement in a deep mat foundation

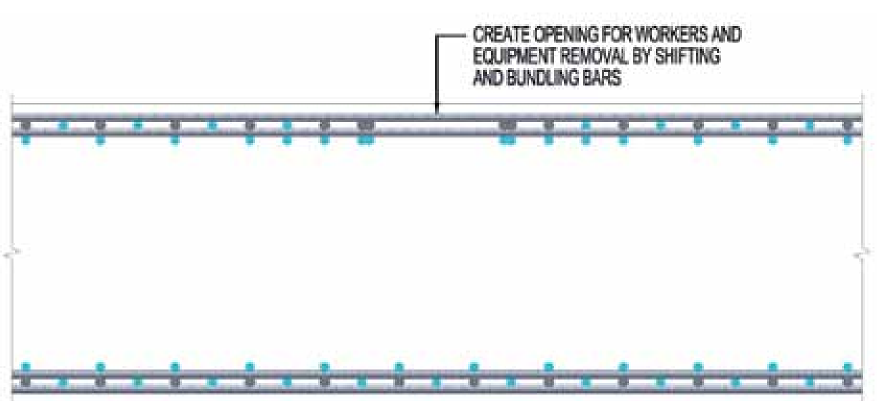


Fig. 2: Openings in the top mat of reinforcement allow access to lower levels

local fabricator the maximum available stock length. Because a mat foundation requires long runs of straight bars, it's recommended that the maximum straight bar length be used as much as possible. This minimizes the quantity of potential lap splices. If an actual bar length shorter than the typical stock length is needed to complete the reinforcing bar run, this "short bar" should be located at either end of the mat foundation. Alternately, stock length bars could be provided throughout the mat, with the lap lengths increased along the run. Although the lap lengths will be greater than Code minimums, material waste and fabrication costs could be reduced because a long bar will not have to be sheared to a shorter length. It will also aid in constructibility, as a separate bar length bundle will not have to be inventoried at the construction site.

- Standees for supporting the top layers of reinforcement should be sturdy and stable enough to support the weight of the top steel, workers, and equipment. For further guidance of using standees for supporting heavy reinforcement, see the Detailing Corner article "Using Standees."[3] In addition, diagonal bracing bars may be required to ensure stability of the entire reinforcing bar assembly.
- Mat foundations will typically incorporate elevator or sump pits. If the mat depth can accommodate the pit, an additional mat of reinforcing steel can be added to serve as the top steel in the mat section below the pit (Fig. 4). The top reinforcement in the mat foundation (full-depth) will be interrupted, however; so the engineer will have to analyze the opening region to determine if hooks are required on the terminated bars or additional "framing" bars are required adjacent to the opening.

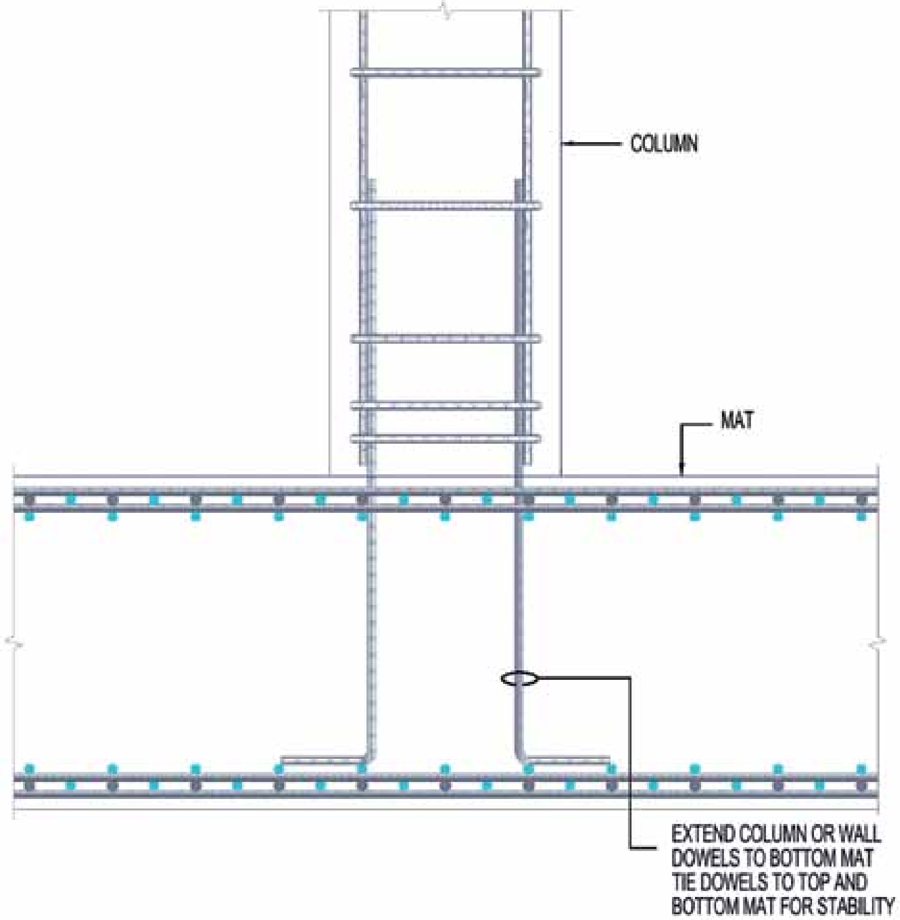


Fig. 3: Column dowels should be hooked and extended to the bottom mat of reinforcement to provide support

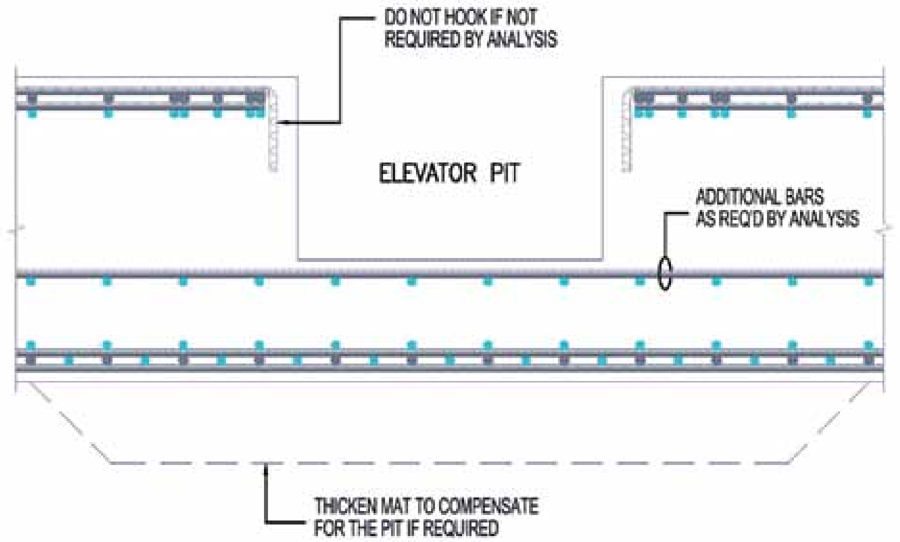
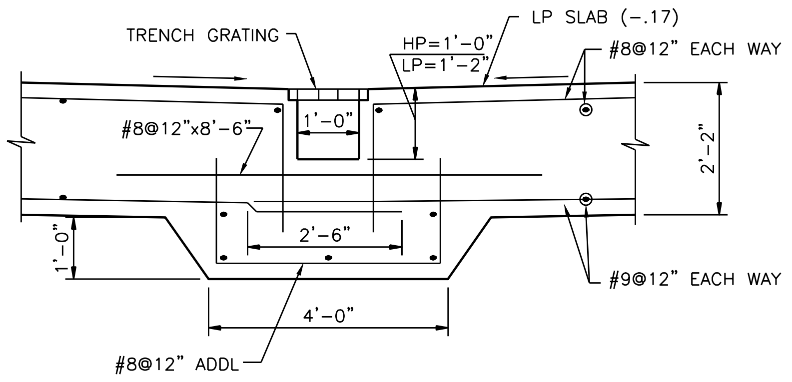
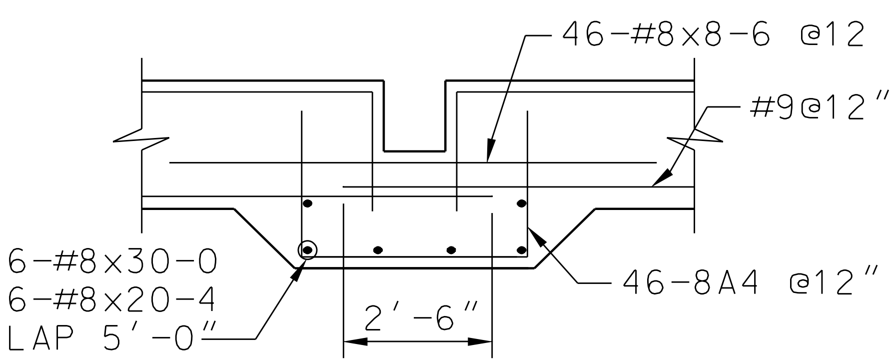


Fig. 4: A schematic of an elevator pit. In a deep mat, a thickened slab may not be required



(a)



(b)

Fig. 5: Details for a thickened mat below a trench drain: (a) design detail; and (b) reinforcing bar placing detail

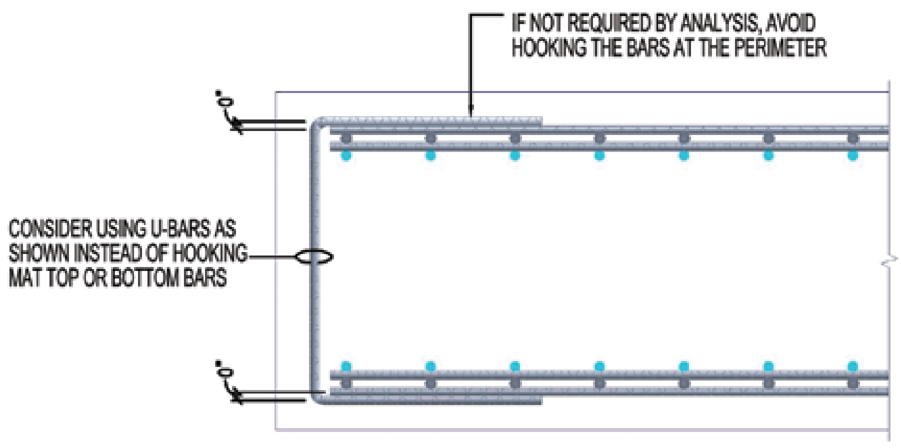


Fig. 6: Designers should consider using U-bars (hairpins) in place of hooked bars for each bar layer at the edge of a mat foundation

- If the mat depth cannot accommodate the elevator or sump pit, the mat will have to be locally thickened to provide the necessary flexural capacity. A typical reinforcing scheme for this condition is shown in Fig. 5.
- If the horizontal bars must be anchored at the mat edges, it may be necessary to tilt hooks so that hook extensions fit within the geometric depth of the footing (this may require additional horizontal bars in the depth of the footing to hold the hooks at the proper angle). As an alternative, U-bent bars could be lapped with straight bars in the top and bottom layers (a hairpin detail—refer to Fig. 6). Depending on the specific reinforcement layout and spacing, hairpins may be more constructible than individual hooks.
- It's common practice to place sheets of welded wire reinforcement (WWR) between the two layers of reinforcing steel within the top mat. The WWR will allow laborers to walk on the mat before and during concrete placement (when the top bars will be buried in the concrete), preventing them from falling through the mat. The WWR is sacrificial and is not usually considered in the structural design computations. Examples are shown in Fig. 7 on foundations for recently constructed buildings in Chicago.

Summary

Experience has shown that simple measures can have a big impact on the efficiency and cost of constructing mat foundations. Varying bar sizes according to the mat region or the direction of the bars, providing details for openings in the top reinforcement needed for access to the layers below, using a consistent bar spacing, and planning for anchorage at edges of pits and the mat itself can reduce requests for information and/or errors.

References

1. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-11) and Commentary," American Concrete Institute, Farmington Hills, MI, 2011, 503 pp.

2. ACI Committee 336, "Suggested Analysis and Design Procedures for Combined Footings and Mats (ACI 336.2R-88) (Reapproved 2002)," American Concrete Institute, Farmington Hills, MI, 2002, 27 pp.

3. CRSI, "Detailing Corner: Using Standees," *Concrete International*, V. 32, No. 8, Aug. 2010, pp. 52-54.

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Selected for reader interest by the editors.

Fig. 7: WWR placed between the top reinforcing bar layers allows the workers to safely walk on the mat before and during concrete placement: (a) Trump Tower, Chicago, IL; and (b) Roosevelt University, Chicago, IL *(photos courtesy of Jack Gibbons, CRSI)*