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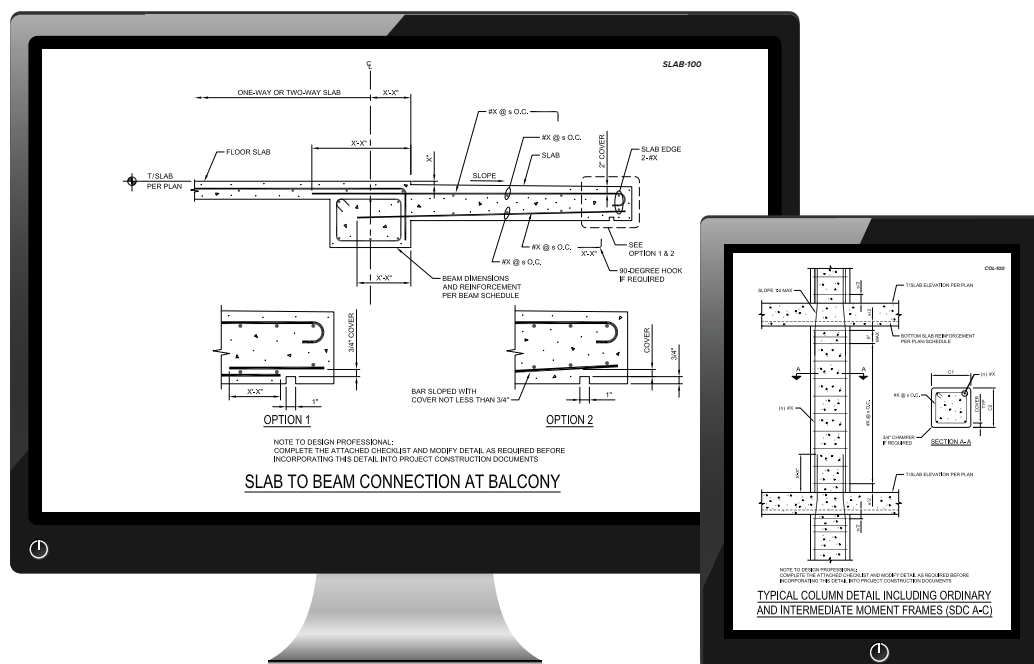
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ACI DETAILING MANUAL—MNL-66(20)

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ABOUT THIS BOOK

The 2020 edition of the *ACI Detailing Manual*, MNL-66, provides answers to many detailing questions asked by design engineers, architects, contractors, detailers, and engineering students. The Manual is divided in three sections: Section 1 includes a copy of ACI 315R-18, *Guide to Presenting Reinforcing Steel Design Details*; Section 2 includes individual details with corresponding checklists; and Section 3 includes a compilation of *Concrete International* articles chosen for their relevance to detailing reinforced concrete. Appendix A has tables to help the engineer in the detailing effort.

Section 1 guides designers of concrete structures in determining information and design details that are required to prepare reinforcing steel fabrication and placing drawings. The guide stresses the importance of this information to ensure that the reinforcing steel detailer effectively and accurately captures the intent of the designer, presenting it in a manner that is clear and unambiguous to the reinforcing steel fabricator and placer.

Section 2 illustrates methods for presenting necessary design information through over 100 individual details that provide examples of ways to communicate design information effectively and completely to the contractor. The details conform to “Building Code Requirements for Structural Concrete (ACI 318-19)” and were prepared with the assistance of a task group consisting of detailers, contractors, and practicing engineers. Each detail is placed on one page with dimensions and bar sizes left to be completed by the user. Alongside each detail, notes to the user are listed as a reminder of the main code requirements that need to be satisfied for that particular detail. This section is planned to be interactive with the engineering community. It is anticipated that engineers, architects, contractors, and detailers will not only submit comments to improve the details shown in this edition of the manual, but also submit other relevant details to be added to future editions at teching@concrete.org.

Section 3 includes a collection of 37 articles published in *Concrete International* related to concrete detailing that were authored by detailers and practicing engineers. The articles identify constructability issues specific to reinforcing steel. Common problems found on engineering drawings are discussed along with solutions drawn from the experiences of knowledgeable practitioners in the industry. The article topics vary from describing the tolerance cloud to addressing constraints in reinforcing bar modeling to avoiding ambiguous callouts, among other topics. These solutions are not offered as official ACI-recommended practice.

Supporting reference data in Section 4 includes specific chapters on reinforcing bars, wires, bar supports, spirals, mathematical formulas and tables, and common symbols and abbreviations.

This guide is intended to provide examples and guidance for how licensed design professionals may satisfy the prescribed provisions of ACI 318-19, *Building Code Requirements for Structural Concrete*. It does not, however, purport to represent the only suitable way to satisfy the requirements for every project. Engineering judgment must be applied to the unique requirements of individual projects and the details should be modified accordingly before applying to a project.

ACKNOWLEDGMENTS

The development of MNL-66(20), “ACI Detailing Manual,” is a must-have resource that provides answers to many detailing questions asked by design engineers, architects, contractors, detailers, and engineering students. The structural drawings conform to the “Building Code Requirements for Structural Concrete (ACI 318-19).”

ACI would like to thank the review group for this manual consisting of Chair Richard Birley, James Cornell, Jason Draper, John Hausfeld, Christopher Perry, and Tom Schaeffer. Their careful review and dedication to the project on top of all their other volunteer time made it possible to develop and revise this guide in a timely manner while maintaining the quality expected by the industry.

ACI would also like to thank Burns & McDonnell for providing examples of typical details that were used to develop the drawing in this detailing manual.

Khaled Nahlawi
Managing Editor



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SECTION 1

ACI 315R-18

ACI 315R-18**Guide to Presenting Reinforcing Steel Design Details**

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*The Committee acknowledges P. Brien, D. Fontenot, and C. Yokoyama for their contributions to this guide.

This document guides designers of concrete structures how to determine information and design details that are required to prepare reinforcing steel fabrication details and placing drawings. The guide stresses the importance of this information to ensure that the reinforcing steel detailer effectively and accurately captures the intent of the designer, presenting it in a manner that is clear and unambiguous to the reinforcing steel fabricator and placer. Recommendations are also provided concerning the review of placing drawings.

Keywords: concrete structures; design details; detailing; engineering drawings; fabrication details; placing drawings; reinforcement; reinforcing steel; tolerances.

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Reference to this document shall not be made in contract documents. If items found in this document are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

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ACI 315R-18 supersedes ACI 315-99 and was adopted and published January 2018. Copyright © 2018, American Concrete Institute.

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CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

The purpose of this document is to guide the licensed design professional (LDP) in determining the information a reinforcing steel detailer requires to properly prepare reinforcing steel fabrication details and placing drawings. Guidance to the LDP is provided on how to present that information on their structural drawings so that the design intent is effectively and accurately conveyed.

The intent of this guide is to encourage clarity and consistency in reinforcing steel design details to help improve the quality and uniformity of steel reinforcement detailing, fabrication, and installation. It is intended to facilitate clear communication between LDPs, reinforcing steel detailers, fabricators, and placers by encouraging clear presentation of design details and information. Information presented is consistent with the requirements and recommendations of several ACI documents, including [ACI 318](#), [ACI 301](#), [ACI 117](#), [ACI 131.1R](#), and [ACI 132R](#).

1.2—Scope

This guide provides general and specific information, as well as illustrative design details that are required for steel-reinforced concrete members such as slabs, beams, and columns. The importance of this information is emphasized to ensure that the reinforcing steel detailer effectively and accurately captures the intent of the LDP, and presents it in a manner that is clear and unambiguous to the reinforcing steel fabricator and placer. Recommendations are also provided concerning the review of placing drawings by the LDP.

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

- A_g = gross area of concrete section, in.² (mm²) where for a hollow section, A_g is the area of the concrete only and does not include the area of the void(s)
- A_{st} = total area of nonprestressed longitudinal reinforcement, including bars or steel shapes and excluding prestressing reinforcement, in.² (mm²)
- b = width of member, in. (mm)
- d = distance from extreme compression fiber to centroid of tension reinforcement, in. (mm)

- d_{agg} = nominal maximum size of coarse aggregate, in. (mm)
- d_b = nominal diameter of bar or wire, in. (mm)
- f'_c = specified compressive strength of concrete, psi (MPa)
- f_y = specified yield strength for nonprestressed reinforcement, psi (MPa)
- h = overall thickness, height, or depth of member, in. (mm)
- ℓ_d = development length in tension of deformed bar, deformed wire, or plain and deformed welded wire reinforcement, in. (mm)
- ℓ_{dh} = development length in tension of deformed bar or deformed wire with a standard hook, measured from outside end of hook, point of tangency, toward critical section, in. (mm)
- ℓ_{ext} = straight extension at the end of a standard hook, in. (mm)
- V_u = factored shear force

2.2—Definitions

ACI provides a comprehensive list of definitions through an online resource, ACI Concrete Terminology. The definitions provided herein complement that resource.

design details—drawings or other information presented by the licensed design professional (LDP) defining steel reinforcement sizes, locations, clearances, splices, geometry, points of termination, relationships, and tolerances.

detailer—person, firm, or corporation producing the reinforcing steel fabrication details and placing drawings based on the design drawings and design details for the structure.

detailing—the process of determining fabrication details based on design details.

fabrication details—dimensions and geometry of steel reinforcement determined for fabrication.

fabricator—person, firm, or corporation producing the reinforcing steel cut and bent to needed dimensions and geometry.

federated model—a building information model (BIM) that electronically links, but does not merge, single-discipline models together for analysis or presentation; the model databases remain distinct and are not combined into a single database.

placing drawings—detailed drawings that give the quantity, size, dimensions, spacing, locations, and other information required for reinforcement fabrication and installation.

CHAPTER 3—GENERAL CONSIDERATIONS

3.1—Building information modeling (BIM)

3.1.1 Introduction to BIM—Building information modeling is a three-dimensional process used to generate and manage digital models of buildings and other structures. This process is used by those who plan, design, and build structures, as well as those who manage these facilities. The process involves creating and maintaining intelligent models with attributes that represent characteristics of a facility and contain parametric data about the elements within the model. Many software packages exist that fall within the definition

of BIM; each of these have distinct advantages to varying elements of the life cycle of a facility, from its design to construction through operation.

Although the focus of most BIM discussions center on the three-dimensional virtual model, the parametric data is of equal importance. The following is from the National BIM Standard-United States™ (NBIMS-US™ 2015):

Building Information Model: Is the DIGITAL REPRESENTATION of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onwards.

In general, what makes BIM different than simple three-dimensional modeling is more information; not only is it a virtual mockup of a structure, but also a relational database of information.

A building information model is applied to the details of concrete reinforcement in the design and construction phases of a structure. In the design phase, BIM is often used by the design team to define the physical characteristics of the concrete to be reinforced by defining concrete edges in physical space, and reinforcement information using either data within the concrete elements or physical representations of the reinforcement. During the construction phase, concrete geometry is often further developed to the level required for construction, and reinforcement is defined to a level from which it can be fabricated and installed. The definition of the level of modeling, which is known as the Level of Development (LOD), is a key concept described as follows.

3.1.2 Level of Development—The content and reliability of a BIM is defined by an industry standard referred to as the Level of Development (LOD). The American Institute of Architects (AIA) and BIMForum have developed an **LOD specification (2016)** to standardize these definitions. The specification enables BIM stakeholders to specify and discuss with precision the content and reliability of models at different stages of the design and construction process. The LOD specification incorporates the AIA definition from the **AIA G202™-2013** form and is organized in The Construction Specifications Institute (CSI) **UniFormat™ (2010)**, which defines the important properties of model elements at various levels of development. This establishes a framework that allows model creators and users to establish reliable uses for the model. The intent of the specification is strictly to facilitate communication; it does not establish or prescribe what LOD is to be attained at any specific point in the project.

For example, in the construction phase, the concrete geometry is defined to a construction level of at least LOD 300 or 350, and the reinforcement is defined to LOD 350 to 400 to assure proper fabrication and placement (CSI UniFormat™ 2010). Many structural design models produced are not able to provide this level of detail for reinforcing steel.

3.1.3 Benefits and challenges of BIM—The technology of building construction and the preparation of documents for construction is rapidly evolving. All stakeholders should be

aware of the potential benefits and wary of potential challenges in using new or evolving technology.

Licensed design professionals who are using BIM will, in most cases, be focused on developing models for the primary purpose of design rather than construction. Consequently, downstream users of design models should be wary that the information found in them might not be developed to the level required for their purposes.

The benefits of BIM accrue at all stages of a project to all stakeholders, including the owner, owner's representative, construction manager, contractors, subcontractors, material and equipment suppliers, and designers. The manner of BIM implementation can be tailored to the nature of the project, nature of the owner, delivery method, and delivery time available. Potential benefits include:

3.1.3.1 Design and detailing—

- a) Better visualization, especially when dealing with complex structures
- b) Improved coordination between trades through information sharing, which is one goal of a BIM process
- c) Ability to rapidly compare alternatives
- d) Improved communications and efficiency and reduced errors through:
 - 1) Detecting and addressing issues earlier in the design process, thereby reducing the number of requests for information (RFIs) and issues in the field
 - 2) Clearer communication of structural geometry and design intent from the LDP to the reinforcement detailer than what would be possible using traditional two-dimensional documents
 - 3) Reinforcing details presented in three dimensions at a construction LOD
 - 4) Better communication of reinforcement fabrication and placement information with downstream entities

3.1.3.2 Construction—Enhanced project visualization made possible by having full building models and related information readily available

- a) More accurate material takeoffs, leading to less waste and reduced overall project costs
- b) Improved project coordination, clash detection, and resolution achieved by combining three-dimensional models from various subcontractors into a single federated model
- c) Validate the work sequence or progress with four-dimensional models created by the intelligent linking of individual three-dimensional components or assemblies with time- or schedule-related information
- d) Increased change management so stakeholders better understand the impacts associated with them

3.1.3.3 Operation

- a) Better 'as-built' documentation than conventional two-dimensional drawings, leading to easier remodels, rebuilds, and additions
- b) Improved management of a building's life cycle achieved by using the three-dimensional model as a central database of all the building's systems and components
- c) Enhanced tracking of building performance and maintenance needs

3.1.4 IFC files and BIM file transfers—Numerous BIM software packages exist that can define concrete geometry and data, detailing reinforcement, or both. Most BIM software is compatible with an open file format specification known as the Industry Foundation Classes (IFC) data models (ISO 16739:2013). This is an object-based file format that allows ease of interoperability between software platforms. Industry Foundation Classes files can be exported from, and imported into, most BIM software platforms, allowing model content and data created in different software to be viewed and used in other software.

In addition to IFC data file transfers, which can be brought directly into a building information model, there are many other electronic deliverable formats available for conveying model content to other stakeholders. Many programs share information-rich models securely, accurately, and in a relevant context that can be viewed on a variety of platforms—from desktop computers to hand-held tablets and smartphones. There are also various types of two- and three-dimensional PDF documents that can be used.

3.1.5 State of the technology—Building information modeling began in the late 1990s. One characteristic that makes BIM superior to past technologies is the ability to change and evolve with newly developing technologies that are providing an ever-increasing level of detail and volume of information. Building information modeling use varies with companies, industry segments, and regions, and is continually expanding. The introduction and development of technology for mobile access to data and the documentation of field conditions is shaping the development of BIM methods and capabilities for the future. A major focus for the evolution of BIM is improving the ability of different users applying different tools to readily use the database information. Although most BIM software packages are compatible with opening IFC format databases, each interprets the data differently, which leads to differences and errors when applying this method. The goal of improved access is not only intended for designer-to-designer transfer; there has also been much effort in developing processes for transferring data for downstream fabrication uses. Structural steel, pipe and duct, and reinforcing steel fabricators benefit from the ability to seamlessly use information from the building information model directly on the fabrication line of these elements.

Reinforcement placement in the field is being enhanced through technology in similar ways to others in the reinforcing market. Using devices such as tablets and smartphones makes access to BIM, fabrication information, placing drawings, three-dimensional PDFs, and a host of other electronic data available on the job site at the point of reinforcement placement. This easy access to information, which in many cases is bidirectional, is providing a real-time exchange of information that ensures the most up-to-date details are installed correctly, a better visual understanding, and more efficient tracking of work. From hand-held scanners to smart devices, field placement crews can also record important information in real-time by scanning a variety of data from fabrication tags and other identification markers to track receipt, installation, location, heat and mill cert information and production rates,

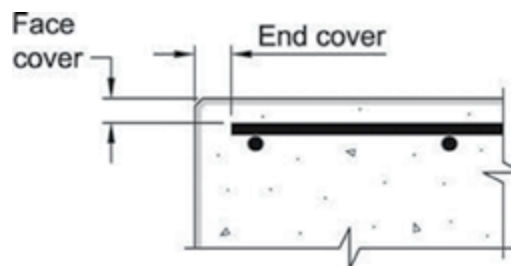


Fig. 3.2.2—Face cover and end cover for reinforcement.

as well as actual installation as-built conditions that can then be used for documentation, change management, coordination, and constructability reviews.

3.2—Tolerance considerations

3.2.1 Introduction and ACI 117—ACI 301 requires that construction tolerances comply with ACI 117. ACI 117 provides tolerances for concrete construction, including tolerances for concrete forming, reinforcing bar fabrication, and placement. These tolerances, which can have an effect on cover, strength, constructability, and serviceability, are required to make concrete construction physically possible and economically practical. If more restrictive tolerances are required than those shown in ACI 117, they should be clearly indicated in the construction documents.

Note that while welded wire reinforcement (WWR) is not explicitly referenced in ACI 117, the fabrication tolerance information therein is normally applicable to WWR produced for concrete construction, and is enforced at the plant level accordingly. Fabrication of WWR styles is carried out in accordance with ASTM A1064/A1064M with due consideration for tolerances set forth in ACI 117. Refer to the Wire Reinforcement Institute manuals WWR-500-R-16 and WWR-600 for additional specifics.

In areas of potential reinforcement congestion, the LDP should consider combinations of tolerances—namely, reinforcing bar fabrication; reinforcing bar placement; clearance and congestion resulting from items such as couplers, headed bars, and other reinforcing bar accessories; and formwork. Combinations of tolerances can result in placement conflicts that are not readily resolved in the field. As an example, bars fabricated to the maximum positive (+) tolerance could create a conflict with required cover in some circumstances, or with an embedded element. The design/construction team should be aware of tolerances and work to identify and remove conflicts prior to construction.

3.2.2 Concrete cover for reinforcement—ACI 301 and ACI 318 define concrete cover requirements for reinforcement. Concrete cover as protection of reinforcement against weather and other effects is measured from the concrete surface to the outermost surface of the steel to which the cover requirement applies. ACI 117 defines tolerances for concrete cover (measured perpendicular to the concrete surface). There are two measurements for concrete cover, as shown in Fig. 3.2.2:

- (1) Face cover – measured from the face or surface of a bar to the concrete surface

(2) End cover – measured from the end of a bar (straight or hooked) to the concrete surface

Cover values defined by **ACI 301** and **ACI 318** vary based on exposure conditions and the concrete element containing the reinforcement.

Where concrete cover is prescribed for a class of structural members, it is measured to the:

- a) Outer edge of stirrups, ties, or spirals if transverse reinforcement encloses main reinforcement
- b) Outermost layer of reinforcement if more than one layer is used without stirrups or ties
- c) Metal end fitting or duct on post-tensioned prestressing steel
- d) Outer edge of mechanical splices
- e) Outermost part of the head on headed bars

The condition, “concrete surfaces exposed to earth or weather,” in addition to temperature changes, refers to direct exposure to moisture changes. Slab or thin shell soffits are not usually considered directly exposed unless subject to alternate wetting and drying, including that due to condensation conditions or direct leakage from exposed top surface, run off, or similar effects.

3.2.3 Spacing of reinforcement—The spacing of reinforcement should comply with project drawings with some exceptions including one or more of the following:

- (a) Field conditions
- (b) Accumulating tolerances
- (c) Coordination of concrete reinforcement
- (d) Other embedded items

ACI 117 defines tolerances for the spacing of reinforcement.

The reinforcement spacing tolerance consists of an envelope with an absolute limitation on one side of the envelope determined by the limit on the reduction in distance between reinforcement. In addition, the allowable tolerance on spacing should not cause a reduction in the specified area of reinforcement used.

Designers are cautioned that selecting member sizes that exactly meet their design requirements might not allow for reinforcement placement tolerance. This can occur when laps or intersecting reinforcement elements take up extra space and, therefore, cannot accommodate the placement tolerance. Where reinforcement quantities and available space conflict with spacing requirements, the contractor and designer might consider bundling a portion of the reinforcement. Bundling of bars requires approval of the designer.

In the case of WWR, where reinforcement styles are prefabricated with electrical resistance welding, wire spacing and style squareness are also subject to tolerances prescribed in **ASTM A1064/A1064M**.

3.2.4 Reinforcement placement

3.2.4.1 General information—Just as there are tolerances in the fabrication of a bar or WWR style, there are also tolerances in the placement of reinforcement in a concrete member, creating potential placement tolerance clouds. Because LDPs and reinforcement detailers could overlook the impact of placement tolerances on constructability, a few examples are given herein.

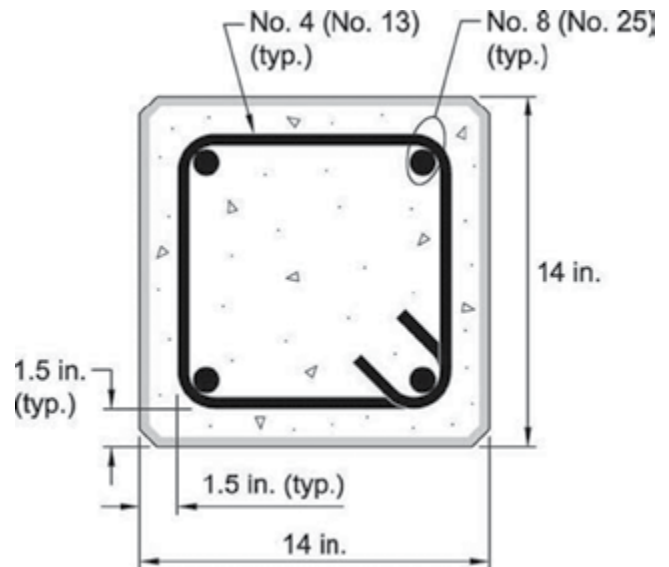


Fig. 3.2.4.2a—Column the designer defined. (Note: 1 in. = 25.4 mm.)

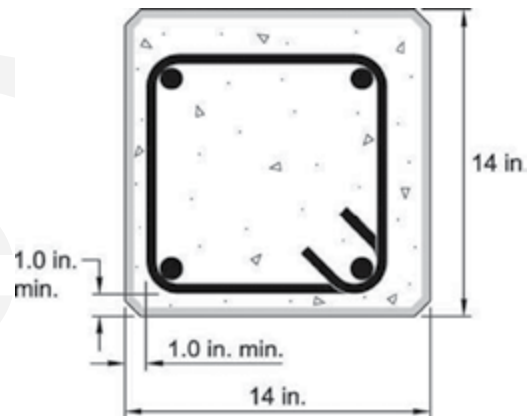


Fig. 3.2.4.2b—Column that could be placed within the specified tolerances. (Note: 1 in. = 25.4 mm.)

3.2.4.2 Tolerance cloud—The tolerances for reinforcement location are found in **ACI 117**. Cover tolerances vary from 1/4 in. (6 mm) for member sizes of 4 in. (100 mm) or less to 1 in. (25 mm) when member size is over 2 ft (0.6 m). The maximum reduction in cover is limited to one-third of the specified cover. In slabs and walls, the spacing tolerance is 3 in. (76 mm) for reinforcement other than stirrups and ties. For example, consider the simple 14 x 14 in. (355 x 355 mm) concrete column shown in Fig. 3.2.4.2a.

The column is reinforced with four No. 8 (No. 25) bars enclosed within No. 4 (No. 13) ties. Normally, concrete cover to the ties of this column would be 1-1/2 in. (38 mm). The cover tolerance is $\pm 1/2$ in. (13 mm). If the reinforcement was placed to the minimum tolerance in two directions, the column could appear as in Fig. 3.2.4.2b.

However, the reinforcement could be placed to minimum tolerance in any of the four directions. Thus, the placement tolerance clouds would appear as in Fig. 3.2.4.2c. This could be a significantly different image than the precise image envisioned at the outset.

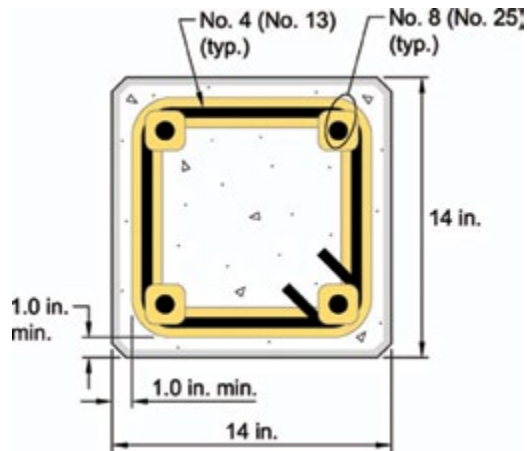


Fig. 3.2.4.2c—Column with placement tolerance clouds (1 in. = 25.4 mm).

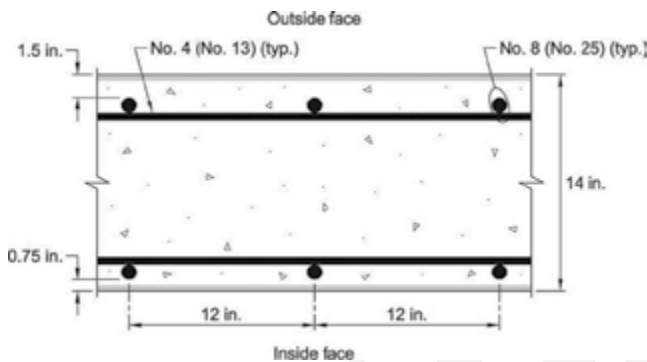


Fig. 3.2.4.2d—Wall the designer defined. (Note: 1 in. = 25.4 mm).

For a second example, consider the case of a simple 14 in. (355 mm)-thick wall reinforced with No. 8 (No. 25) vertical bars at 12 in. (300 mm) on center each face, and No. 4 (No. 13) horizontal bars at 12 in. (300 mm) on center each face (Fig. 3.2.4.2d).

The outside face cover is 1-1/2 in. (38 mm) and inside face cover is 3/4 in. (19 mm). The cover tolerance for the bars on the outside face is $\pm 1/2$ in. (13 mm). For the inside face cover, the maximum cover reduction is limited to one-third of the specified cover, resulting in a cover tolerance of $+1/2$ or $-1/4$ in. (+13 or -6.5 mm). Thus, the outside face cover could be as little as 1 in. (25 mm) and the inside face cover as little as 1/2 in. (13 mm) (Fig. 3.2.4.2e).

Consider that any one of the vertical and horizontal bars can be located as far as 3 in. (76 mm) either way from its designated location; the tolerance cloud would appear as in Fig. 3.2.4.2f.

3.2.4.3 Design considerations—Like the fabrication tolerance cloud of a single bar, the placement cloud of a group of placed bars presents a different image than the one probably envisioned by the designer or reinforcement detailer. If placement tolerances are factored into the design, they would realize the available space expected, which is to pass beam bars through a column or to place a vertical embed in a wall, might not be what is actually available, especially if the beam reinforcement and embed considered also have fabri-

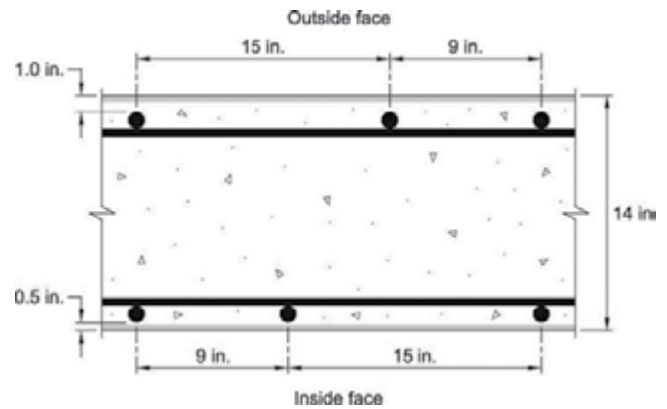


Fig. 3.2.4.2e—Wall that could be placed within the specified tolerances. (Note: 1 in. = 25.4 mm.)

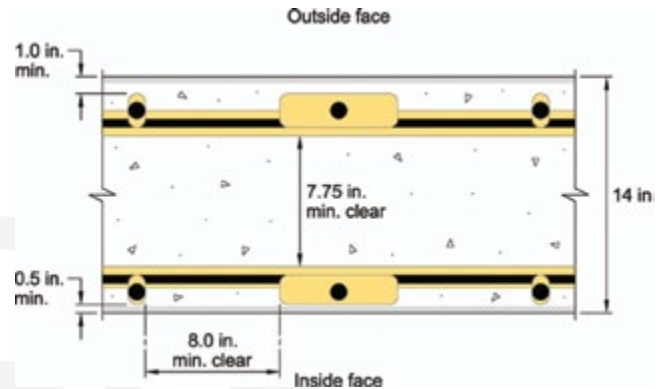


Fig. 3.2.4.2f—Wall with placement tolerance clouds. (Note: 1 in. = 25.4 mm.)

cation and placement tolerances of their own. Awareness of placement tolerance clouds can lead to design options that avoid tolerance issues.

3.2.5 Reinforcing bar fabrication

3.2.5.1 General information—The Concrete Reinforcing Steel Institute (CRSI) *Manual of Standard Practice* (2017) list properties of reinforcing bars. Practical limitations of equipment and production efficiency have led to the establishment of certain fabrication tolerances that can be met with standard shop equipment. These standard tolerances are shown in ACI 117 and the CRSI *Manual of Standard Practice* (2017) for both straight and bent bars. Where more restrictive tolerances are required than those shown in the referenced figures, they should be clearly indicated in the contract documents.

3.2.5.2 Restrictive tolerances—Tolerances more restrictive than those in ACI 117 should be used sparingly. If more restrictive tolerances are required, this is generally characterized as special bending by the reinforcing bar fabricator and requires special arrangements in the production shops. These special arrangements include, but are not limited to: additional equipment, modifications to existing equipment, additional staff, and inspection devices. Special bending is generally more time-consuming than normal bending, can be subject to additional costs, and could create delays in material deliveries to the job site.

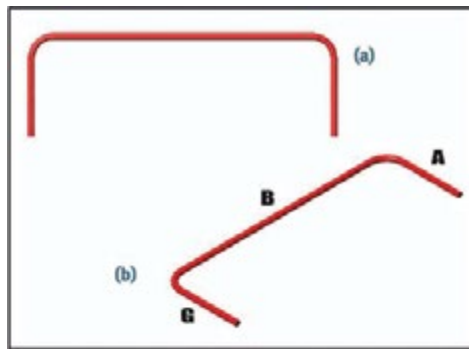


Fig. 3.2.5.3a: Standard (theoretical) hooked bar with Sides A, B, and G: (a) plan view, and (b) isometric view

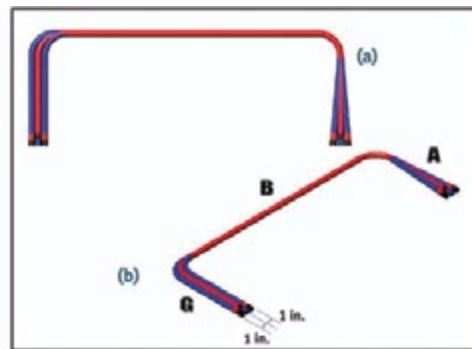


Fig. 3.2.5.3d: Hooked bar with ± 1 in. tolerance envelope on Sides A and G, ± 2.5 degrees in-plane angular tolerance envelope at Side A, and ± 1 in. tolerance envelope on Side B

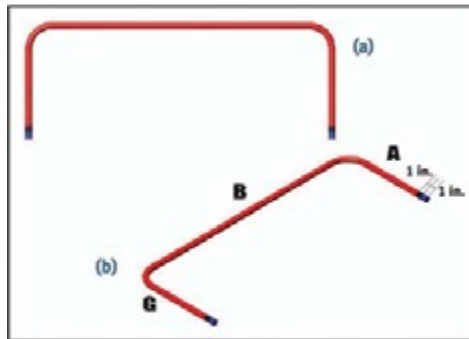


Fig. 3.2.5.3b: Hooked bar with ± 1 in. tolerance envelope on Sides A and G

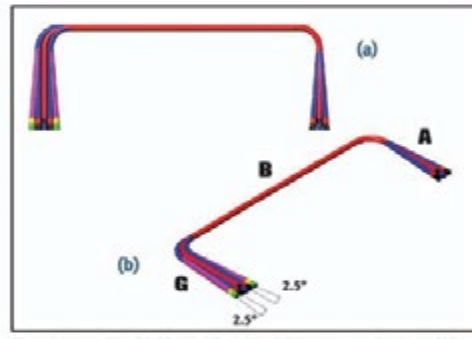


Fig. 3.2.5.3e: Hooked bar with ± 1 in. tolerance envelope on Sides A, B, and G and ± 2.5 degrees in-plane angular tolerance envelope at Sides A and G

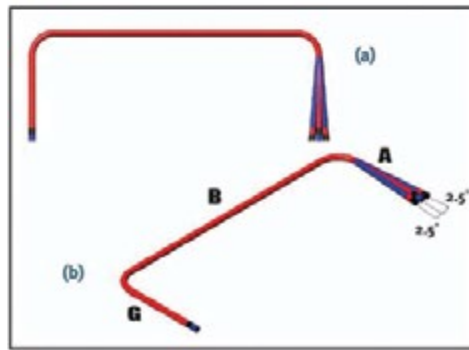


Fig. 3.2.5.3c: Hooked bar with ± 1 in. tolerance envelope on Sides A and G and ± 2.5 degrees in-plane angular tolerance envelope at Side A

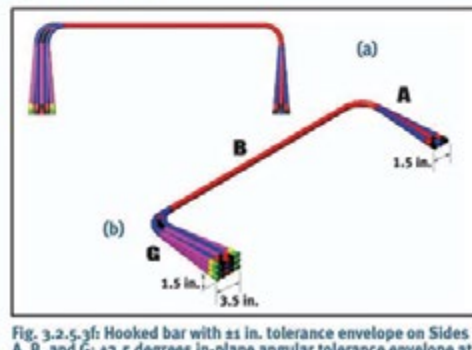


Fig. 3.2.5.3f: Hooked bar with ± 1 in. tolerance envelope on Sides A, B, and G; ± 2.5 degrees in-plane angular tolerance envelope at Sides A and G; and ± 2.5 degrees out-of-plane angular tolerance envelope at Side G

Fig. 3.2.5.3—Hooked reinforcing bar tolerances (Birley 2005). (Note: 1 in. = 25.4 mm.)

3.2.5.3 Fabrication tolerance clouds—Licensed design professionals should be aware of the tolerance cloud that exists for fabricated reinforcing bar. As a simple example, consider the fabrication tolerances for a simple reinforcing bar with 90-degree bends at each end as given by Birley (2005) (Fig. 3.2.5.3(a)). For the purposes of this example, assume the bar is a No. 8 (No. 25) and Side A is anchored in the (idealized) plane ABG. For this bar size, the standard hook is 16 in. (400 mm) long, and the linear and angular tolerances are ± 1 in. (± 25 mm) and ± 2.5 degrees, respectively.

Next, examine the potential effects of these tolerances (Fig. 3.2.5.3). First, note that Sides A and G can be as short as 15 in. (380 mm) (red to black zone interface), or as long as 17 in. (430 mm) (end of blue zone), and still be within allowable tolerances (Fig. 3.2.5.3(b)).

Because it is assumed Side A is anchored in ABG, there is no need to consider out-of-plane angular deviation for Side A. However, in-plane angular deviation will need to be considered. When this angular deviation of ± 2.5 degrees is added to Side A, the tolerance envelope (cloud) will appear as shown in Fig. 3.2.5.3(c). Note that to simplify the illustrations, the effects of angular tolerances are shown as one-bar-diameter deviations in the position of the ends of the 16 in. (400 mm) hooks. Actual deviations will be about 70 percent of a bar diameter.

Next, add the dimensional tolerance of ± 1 in. (± 25 mm) for Side B as given in (Fig. 3.2.5.3(d)) and the in-plane angular deviation of ± 2.5 degrees to Side G in (Fig. 3.2.5.3(e)). Finally, add the out-of-plane angular deviation of ± 2.5 degrees to Side G. The resulting tolerance cloud is as shown in Fig. 3.2.5.3(f).

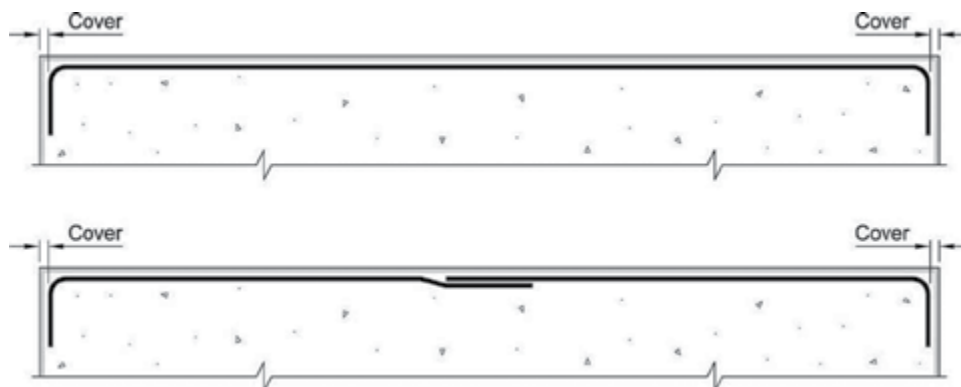


Fig. 3.2.5.4a—Reducing tolerance problems by replacing single bar with two lapped bars. Note that the lap splice shown offset is for clarity only.

3.2.5.4 Design considerations—The fabricated bar arriving at the construction site can be different from the bar the LDP or reinforcing bar detailer expected. Keeping this in mind during design could significantly reduce constructability problems. For instance, if our example bar was replaced with two hooked bars lapped in the middle (Fig. 3.2.5.4a), the only tolerance that might introduce problems would be in-plane angular deviation.

Because both hooks could be rotated, there would be no out-of-plane deviations. Further, because the lap length could be adjusted slightly in the field, there would be little chance of problems with the length of Side B.

Consideration of tolerances becomes even more of an issue when two or more bars are being assembled together in a structure. In this case, work with the accumulation of tolerances.

ACI 318-14 Section 25.3 restricts the minimum inside bend diameter of standard hook geometry for deformed bars in tension and the minimum inside bend diameters and standard hook geometry of stirrups, ties, and hoops. Primary factors affecting the minimum bend diameter are feasibility of bending without breakage and avoidance of crushing the concrete inside the bend. **ACI 117** tolerance on these minimum inside bend diameters is -0 in. (-0 mm). Thus, bars cannot be requested, or expected, to be bent to a tighter diameter to solve a fit-up or congestion problem. Furthermore, there is not a $+$ tolerance for minimum bend diameter, and the bend diameter can be larger than the minimum due spring-back and other factors. Design drawings sometimes illustrate hooks wrapping tightly around another bar with assumed bar positions based on the sum of the required cover, diameter of one bar, and half diameter of the other bar. A comparison of that incorrect assumption to the reality with a $6d_b$ minimum bend diameter is shown in Fig. 3.2.5.4b, and for larger bars, the minimum bend diameter could be $8d_b$ or $10d_b$.

3.2.6 Forming tolerances

3.2.6.1 General information—The last two sections discussed tolerance clouds associated with fabrication and placement of reinforcing bars. While every builder strives to cast concrete to the precise dimensions indicated by the designer, reasonable constraints of time, technology, and

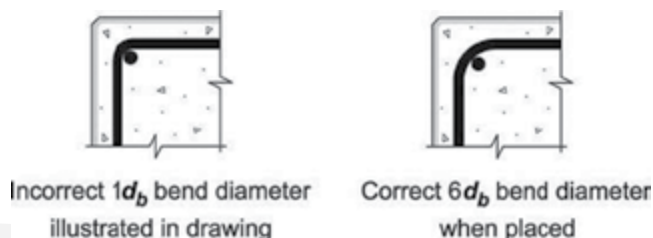


Fig. 3.2.5.4b—Comparison of minimum bend diameter position effect for a No. 7 (No. 22) bar.

economy make this impractical. Therefore, it is important for designers to understand the forming tolerances associated with concrete construction.

3.2.6.2 Forming tolerance clouds—Tolerances for forming concrete are found in ACI 117. The tolerances for cross-sectional dimensions of cast-in-place members vary with the overall dimension. Using the example from Section 3.2.4.2 of a 14 x 14 in. (355 x 355 mm) column, the tolerance is $+1/2$ in. or $-3/8$ in. ($+13$ mm or -10 mm). Ignoring vertical alignment, this produces the forming tolerance cloud shown in Fig. 3.2.6.2a, with a column having acceptable dimensions as large as 14-1/2 x 14-1/2 in. (368 x 368 mm) or as small as 13-5/8 x 13-5/8 in. (346 x 346 mm).

While it is highly unlikely that these small variations would create any constructability or design concerns with everything else being perfect, a different scenario arises when they are considered in conjunction with other possible tolerances.

With 1-1/2 in. (38 mm) cover, the design width for the column ties is 11 in. (280 mm), and the tolerance is $\pm 1/2$ in. (19 mm). Combining the maximum acceptable tie dimensions with the minimum acceptable column dimensions produces the configuration shown in Fig. 3.2.6.2b. With the reinforcing cage centered, the cover is reduced from the design value of 1-1/2 in. to 1-1/16 in. (38 mm to 27 mm) on all four sides. Recalling that the placement tolerances allow the cover to decrease to 1 in. (25 mm) minimum, the cage should be placed within $\pm 1/16$ in. (1.6 mm) of the center of the column in both directions if it is to meet tolerance requirements. Considering the straightness of the bars and forms, this could be difficult for the contractor.

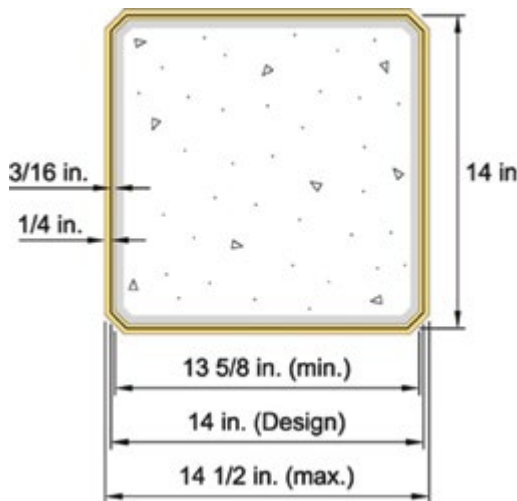


Fig. 3.2.6.2a—Forming tolerance cloud for the column.
(Note: 1 in. = 25.4 mm.)

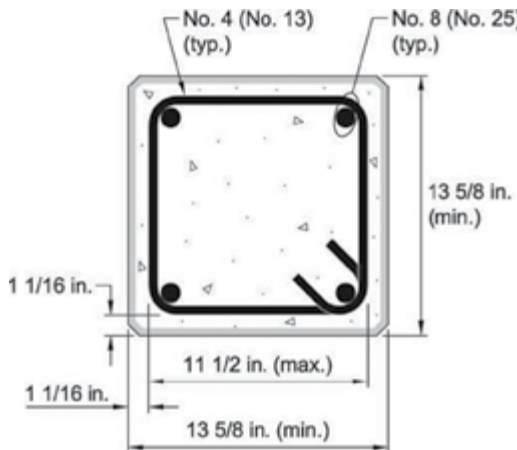


Fig. 3.2.6.2b—Combining the maximum acceptable tie dimensions with the minimum acceptable column dimensions effectively limits placing tolerances to $\pm 1/16$ in. (± 2 mm). (Note: 1 in. = 25.4 mm.)

For the example of a 14 in. (355 mm)-thick wall that was discussed in previous sections, the situation is somewhat different because there are no tie tolerances to contend with. However, as seen in the following example, other issues arise that should be dealt with. The forming tolerance for the wall thickness allows the wall to be between 14-1/2 and 13-5/8 in. (368 and 346 mm) thick, as shown in Fig. 3.2.6.2c.

Reinforcement placement tolerances allow the 1-1/2 in. (38 mm) design cover on the outside face to be between 1 and 2 in. (25 and 50 mm) and the 3/4 in. (19 mm) design cover on the inside face to be between 1/2 and 1-1/4 in. (13 and 32 mm). The minimum wall thickness combined with the maximum cover on the outside face reinforcing is shown in Fig. 3.2.6.2d.

In this case, the original effective depth of 12 in. (250 mm) for the vertical No. 8 (No. 25) bars on the outside face has decreased to only 11-1/8 in. (282 mm). Assuming 4000 psi (25.6 MPa) concrete and Grade 60 reinforcement, this reduction in effective depth would result in a decrease in

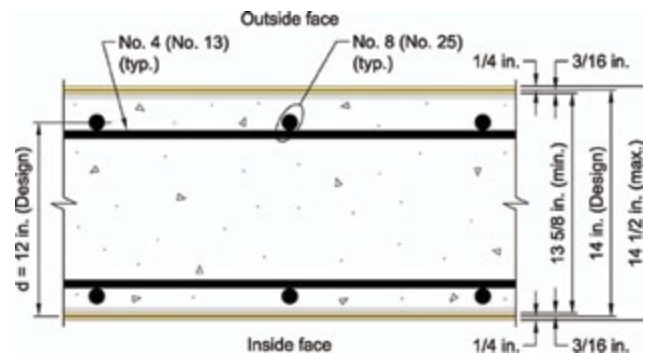


Fig. 3.2.6.2c—Forming tolerance cloud for the wall. (Note: 1 in. = 25.4 mm.)

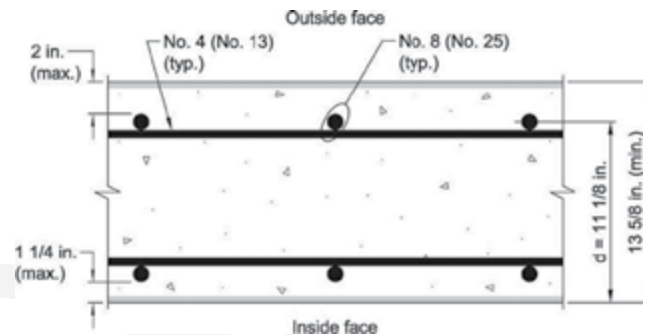


Fig. 3.2.6.2d—Minimum acceptable wall thickness and maximum acceptable cover combine to produce an effective depth for outside face vertical bars violating ACI 318 tolerances (1 in. = 25.4 mm).

nominal moment capacity from the original 45.1 kip·ft/ft (200 kNm/m) to 41.6 kip·ft/ft (185 kNm/m)—a 7.7 percent reduction due to forming and placement tolerances alone. The effect on moment strength would be even more drastic for thinner walls. To guard against this, Section 26.6.2.1(a) of ACI 318-14 places a tolerance on effective depth d of $\pm 3/8$ in. (10 mm) for $d \leq 8$ in. (200 mm) and $\pm 1/2$ in. (± 13 mm) for $d > 8$ in. (200 mm). These tolerances would produce a 4.4 percent reduction in nominal moment strength for the example wall considered herein; however, designers should realize that effective depth is not checked in the field. Reinforcement is placed and tolerances checked relative to the formwork surfaces.

3.2.7 Confined reinforcing bars—Confined reinforcing bars add one more level of complexity to the tolerance issues described in previous sections. In the context of detailing and placing reinforcing steel, a confined bar is one that is restricted by face cover requirements at both ends. The best example of a confined reinforcing bar is a bar with hooks at each end, as would be seen in an elevated beam as shown in Fig. 3.2.7a.

On the surface, this does not seem to be significant, other than the tolerance issues previously discussed. However, when considering that in most cases there is adjacent reinforcement for a beam, column, or wall, and that this double-hooked bar needs to fit within, the situation becomes much more complicated as shown in Fig. 3.2.7b.



Fig. 3.2.7a—Single bar with hook at both ends.

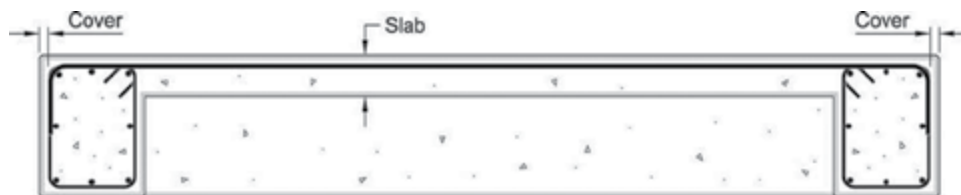


Fig. 3.2.7b—Single bar with hook at both ends and intersecting reinforcement.

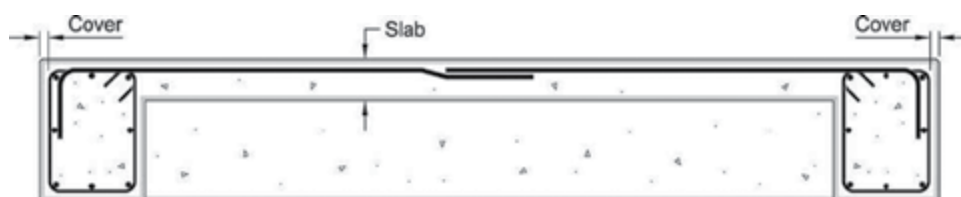


Fig. 3.2.7c—Substitution of two hooked bars with lap splice (lap splice shown offset for clarity only).



Fig. 3.2.7d—Single bar with hook at both ends placed within beam cages.

The designer needs to consider that a bar with hooks at each end creates a situation where the bar is extremely restricted and should be exactly right; otherwise, the bar placer may not be able to place it. The reality is worse if the reinforcing bar detailer details the double hooked bars as shown in the design drawings with the correct concrete cover; it will almost never fit during field installation.

Because there is no flexibility with this bar, if it does not fit, it will most likely need to be replaced, causing delays on the job site. There are two options for addressing this situation. The first and most preferred is to allow the use of a lap splice, as shown in Fig. 3.2.7c. This gives the bar placer the flexibility to place the bars within the beam while avoiding conflicts with the adjacent steel.

If a lap splice is not permissible, a second option is for the designer to increase the end covers of the bar and place the hooks within the adjacent steel similar to Fig. 3.2.7c, as shown in Fig. 3.2.7d.

This situation needs to be addressed by the reinforcing bar detailer and shown in one of these two ways on the placing drawings. Notating this practice on the design drawings will provide clear direction to the detailer and bar placer, and avoid confusion during the detailing process and installation in the field.

These scenarios are commonly seen as shown in the following examples. In Fig. 3.2.7e, the left illustration shows the end of a confined bar where no adjacent steel is present; the right illustration shows the end of a confined bar with adjacent steel that should be accounted for in the design, detailing, and installation processes.

Figure 3.2.7f shows situations where the end position of a confined bar (in the last lift of a column or wall) with adjacent slab steel should be accounted for in the design, detailing, and installation processes.

3.2.8 Accumulated (combined) tolerances—The effects of tolerances on cover, strength, constructability, and serviceability of the structure should be considered by

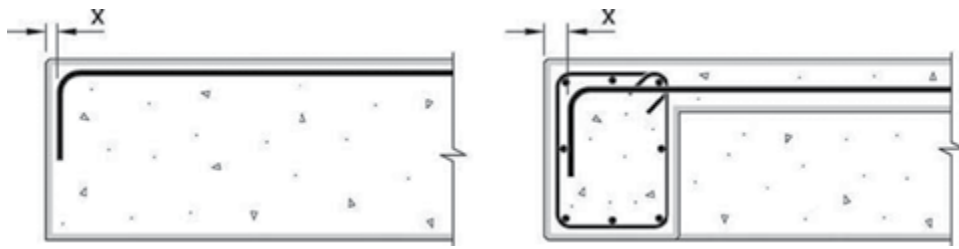


Fig. 3.2.7e—Confined hooked bars in slabs and beams.

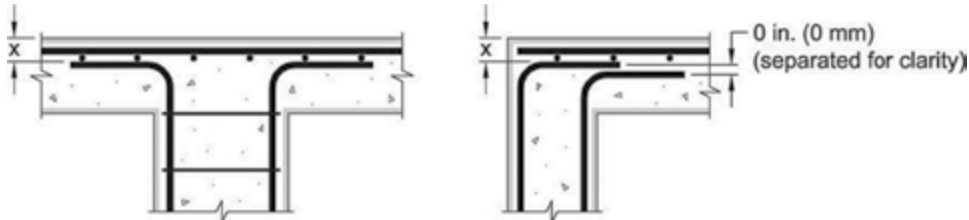


Fig. 3.2.7f—Confined hooked bars in columns and walls.

the LDP. Casting of concrete always involves the fabrication, placement, and formation of tolerance clouds. While these instances are not encountered every day, they occur frequently enough to create constructability problems. Any combination of tolerances as discussed in this section that are working against each other has the potential to create a constructability concern that often is difficult to reconcile, especially if it involves two different trades, each within their own acceptable tolerances. The designer should always assess the risk of this kind of problem arising in critical areas of the structure and consider options that mitigate or eliminate the possible constructability problem.

3.3—General cautions

3.3.1 Revisions of drawings—All revisions to drawings should be clouded. Be as specific as possible when putting a cloud on a drawing. Place a cloud around each revision, rather than a large cloud around several revisions. Remove all previous clouds from a drawing before initiating a new revision. Clearly annotate the revision on the revision list at the side of the drawing. It is good practice to identify revisions on pre-IFC drawings with letters, for example “Rev A, B, C,” and on post-IFC drawings with numbers, for example, “Rev 1, 2, 3.”

3.3.2 Dimensioning—Dimensioning of splice lengths should be clear and unambiguous so that the detailer and reviewer arrive at the same interpretation of the intent. Showing the anchorage and splice lengths on the drawing and sketches is the most certain way to convey intent. However, a well-prepared table of anchorage and splice lengths can work well. The table should include only the strengths of concrete and grades of reinforcement being used on the project and show development and splice lengths for bars in compression and bars in tension. For bars in tension, it should show development and splice lengths for top bars and other bars. The tables should be complete enough that the detailer and reviewer do not have to make calculations

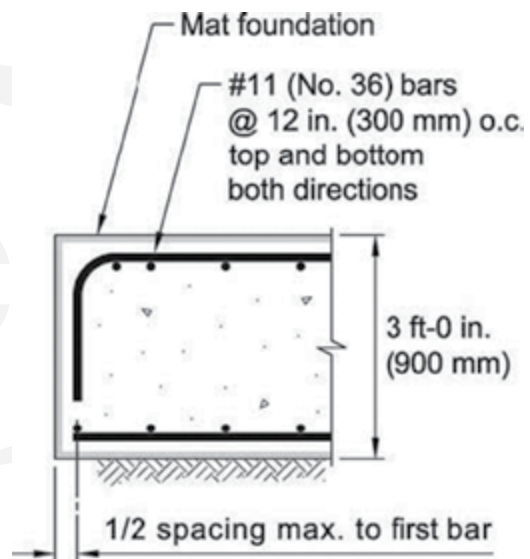


Fig. 3.3.2—Effect of hooked bar confinement on first and last bars.

to arrive at the proper dimension. A brief sentence defining what constitutes a top bar is also good additional information.

Normally, the location of first and last reinforcing elements follows the general convention of one-half space from the face of a support for slab reinforcement or beam ties and one-half space from the top of a footing or slab for column ties or wall horizontals. Dimensioning the location of first and last reinforcing elements is not necessary in these situations unless there is a special situation that requires a nonconventional location. In such cases, dimensioning of the location should be clearly indicated.

First and last bars confined by transverse reinforcing elements with hooks at each end present a unique situation—for example, hooked top bars in a spread footing (Fig. 3.3.2). To maintain proper vertical elevation, the first and last bar in the upper layer of the mat should start at the beginning of

the radius of the bend, not at the specified clearance from the concrete face. In such a case, one could question if the LDP intends that spacing be from the center lines of the first and last bars or from clearance-to-clearance. In this situation, it would be better for the LDP to give a quantity of reinforcing elements or area of steel required rather than spacing of the bars.

3.3.3 Field cutting of bars—Methods for field cutting any reinforcing steel, other than saw cutting, should be approved by the LDP. If the location is confined, the only practical alternative is to flame-cut the reinforcement. Bar placers are trained in the use of a cutting torch and can make the cut without any deleterious effect on the steel material. **ACI 301** prohibits flame cutting of epoxy-coated bars. If the LDP has some compelling reason against flame-cutting uncoated reinforcement, this should be stated clearly in the general notes. In the absence of such an instruction, the bar placer will assume that flame-cutting uncoated reinforcement is permitted.

3.3.4 Field bending of bars—Field bending of embedded reinforcement may occasionally be required due to incorrect fabrication or placing, or due to a design change that requires the reinforcement to be reconfigured. ACI 301 specifies requirements for field bending. Small bars can usually be bent cold, especially if it is their first bend; that is, a straight wall vertical bar being bent into a slab. Large bars require preheating. Straightening and rebending of previously bent reinforcement should be approached cautiously. With caution, and if the bend radius is sufficiently large, the bars should not be affected. Other more extreme situations may require that the LDP set parameters for the process and ensure that the operation is supervised and executed by qualified personnel, subject to on-site inspector review.

3.3.5 Mechanical connectors—Mechanical connectors require similar considerations to those for splices. The LDP should indicate on the drawing where they are to be used. Specific limitations should be listed such as spacing, stagger, and clearance. The type of connector should be listed along with the manufacturer if this is critical.

3.3.6 Mixing grades of steel on a project—Frequently a project will require more than one grade of steel or more than one kind of coating. The LDP should be specific about where the various grades or coatings are to be used. This information can be given in the general notes and on the drawings to avoid any ambiguity about intent. Mixing grades or coatings in a single member should be avoided if possible. For example, do not call for coated top reinforcement in a beam while the remainder of the reinforcement is uncoated bar.

3.4—Drawing types and purposes

Design drawings for concrete structures are developed by LDPs. Those documents render the design and establish the design predicates for the construction. They include, at a minimum, building code required information for review by the pertinent code authority.

Design drawings are also contract documents. These form the contractual basis between the general contractor and owner. They should graphically show the scope, extent, and character of the construction work.

Placing drawings for reinforcement (and shop drawings for other trades) include graphics and schedules, and are specifically prepared by the contractor to illustrate specific portions of the construction work. These drawings, whether approved or not, do not become contract documents or design plans.

The normal process is for the designer to render the design and for the contractor (and subcontractors) to prepare trade-specific drawings extracted from the design plans that define the particular work. Usually the trade-specific drawings are submitted to the designer of record for review to confirm that contractor's interpretation of the design intent is correct.

Field construction is then conducted from the approved trade-specific drawings in conformance with the contract documents.

CHAPTER 4—STRUCTURAL DRAWINGS

4.1—Scope

This chapter describes information typically necessary to the structural design drawings, so the scope of the construction based on the design plans can be established. Normally, engineering offices develop an office standard suitable to their practice area for the presentation of design information. This guide, as an example, presents the project sheet order found in the United States National CAD Standard® (**NCS-V6**), as outlined in 4.3.

4.2—General

Structural drawings are prepared by a licensed design professional (LDP). The drawings, along with the project specifications, form the bulk of the contract documents. Structural drawings should contain an adequate set of notes, instructions, and information necessary to permit the reinforcing steel detailer to produce reinforcing steel placing drawings. Each sheet should have a title block, production data, and a drawing area as shown in Fig. 4.2.

The drawing area, which is the largest portion of the sheet, is where technical information is presented. Examples of technical information are the overall framing plan, sections, and details needed to illustrate information at specific areas, and additional notes as required.

The production data area is located in the left margin of the sheet and includes information such as the computer-aided design (CAD) filename and path to the file, default settings, printer/plotter commands, date and time of plot, overlay drafting control data, and reference files.

The title block area, which is located to the right side of the sheet, usually includes the designer's name, address, and logo; basic information about the project, including location of the work site, owner, and project name; an information block regarding issue type of this sheet, such as addendum, design development, bidding, and bulletin; a sheet responsibility block that indicates the project manager, engineer, draftsman, and reviewer of the information on the drawing; a sheet title block; and a sheet numbering block. The title block also contains space for a disclaimer, if it is a prelimi-

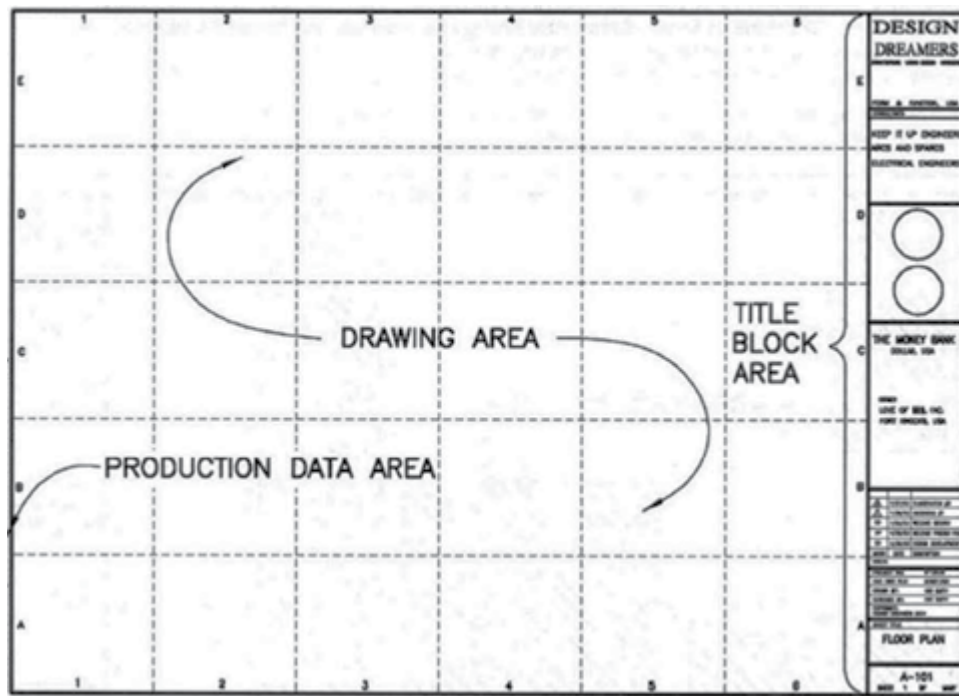


Fig. 4.2—United States National CAD Standard® (NCS-V6) overall sheet layout.

nary set of drawings, or a PE seal for the construction or permit set.

4.3—Order of sheets

The order of drawings shown in the United States National CAD Standard® (NCS-V6) is as listed in Table 4.3.

If more than one sheet is required within the listed order, then decimal sheet numbers are used, such as 5.0, 5.1, 5.2, 5.3. Often, the structural drawing order will be coordinated with the sheet order used by the other technical disciplines.

4.4—General notes sheets

A general notes sheet presents project design loads, the codes and standards that are the basis of design, material and product requirements, and construction directions. General notes can be the entire project structural specifications, act as an extension of the project structural specifications, or simply duplicate important aspects of the project structural specifications.

4.4.1 Codes and standards—The general building code, referenced standards, and authority having jurisdiction, or all these, require specific information be included on the construction documents and that the general notes sheet(s) present this information. ACI 318-14 also requires that all applicable information from Chapter 26 related to construction be provided in the construction documents. This includes design criteria, member information, concrete materials and mixture requirements, concrete production and construction, anchoring to concrete, embedments, precast and prestressed concrete requirements, formwork, concrete evaluation and acceptance, and inspection.

4.4.2 Design loads—Section 1603.1 of the International Building Code (IBC) (2015) requires the following design

Table 4.3—NCS-V6 drawing sheet numbering

Sheet number	Sheet title	Information included
0	General notes	Symbols legend, general notes
1	Plans	Horizontal views of the project
2	Elevations	Vertical views
3	Sections	Sectional views, wall sections
4	Large-scale views	Plans, elevations, stair sections, or sections that are not details
5	Details	
6	Schedules and diagrams	
7	User defined	For types that do not fall in other categories, including typical detail sheets
8	User defined	For types that do not fall in other categories
9	Three-dimensional representations	Isometrics, perspectives, photographs

loads and other information pertinent to structural design be indicated on the construction documents.

- (a) Floor live load
- (b) Roof live load
- (c) Roof snow load data
- (d) Wind design data
- (e) Earthquake design data
- (f) Geotechnical information
- (g) Flood design data
- (h) Special loads

(i) Systems and components requiring special inspections for seismic resistance



Design loads are presented on the general notes sheet. Floor live loads, roof live loads, snow loads, and other simple gravity loads are commonly shown in a table. Basic wind load criteria assumptions and, when necessary, wind-loading diagrams are included. Earthquake design data are usually presented as a list of the different criteria used to develop the design earthquake loads. It is preferred to indicate if and where live load reductions were applied.

Geotechnical design information shown is usually supplied to the structural designer in a geotechnical report. This can be presented as a note when the soil and water table on-site is relatively consistent, or in a table format when there is significant soil or water table variability.

Flood design data and criteria used to determine the flood design loads are typically shown using notes.

Special loads not included in the code-required live loads are also noted in the table that includes live loads. Examples of such loads are architectural features, partition live loads, ceiling and hanging loads, and superimposed dead loads. A diagram might be needed for heavy pieces of equipment, such as forklifts, with their assumed wheel spacing and axle loads.

Showing the self-weight of the structure is not a requirement of the code. However, an indication of where lightweight, normalweight, and heavyweight concrete is used should be provided on the drawings so that the self-weight of the structure can be reasonably determined by the formwork engineer.

4.4.3 Specifications—The first concrete general note is commonly a reference to require construction be in accordance with **ACI 301**. The LDP ensures that the construction documents meet code provisions; therefore, requiring the contractor to conform to **ACI 318** is not appropriate, as it provides code requirements to the LDP and not the contractor or materials supplier. By incorporating ACI 301 by reference into the construction documents and using the ACI 301 mandatory and optional checklists, the concrete materials and construction requirements will satisfy ACI 318. In addition, ACI 301 also specifies that fabrication and construction tolerances should comply with **ACI 117**.

ACI 301 contains the following three checklists: mandatory requirements, optional requirements, and submittals. The LDP is often also the specifier on a project and should go through these checklists and make necessary exceptions to ACI 301 in the construction documents. The general notes sheet is a convenient way to communicate any necessary exceptions to ACI 301.

4.4.4 Concrete notes—The Mandatory Requirements Checklist items in ACI 301 that are related to concrete can be specified in the general concrete notes and indicate that the construction documents include:

- (a) Exposure class and specified compressive strength, f'_c , for different concrete elements
- (b) Handling, placing, and constructing requirements
- (c) Designations and requirements for architectural concrete, lightweight concrete, mass concrete, post-tensioned concrete, shrinkage-compensating concrete, industrial floor slabs, tilt-up construction, and precast concrete

Concrete general notes can show this information in a table with each structural element type, along with its corresponding exposure class, specified compressive strength, and other requirements.

Construction documents should also indicate any exceptions to the default requirements of ACI 301. ACI 301 lists possible exceptions in the Optional Requirements Checklist. Concrete general notes often contain the following optional requirements checklist exceptions to ACI 301 default requirements:

- (a) Air entrainment in percentage (%), along with the respective tolerance
 - (b) Slump in inches (in.), along with the respective tolerance
 - (c) When high-range water-reducing admixtures are allowed or required
 - (d) Additional testing and inspection services
- 4.4.5 Reinforcement notes**—ACI 301 Mandatory Requirements Checklist items related to reinforcing steel can be specified in the general reinforcement notes and indicate that the construction documents include:
- (a) Type and grade of reinforcing steel
 - (b) Bar development and splice lengths and locations
 - (c) Types of reinforcement supports and locations used within the structure
 - (d) Cover for headed shear stud reinforcement and headed reinforcing bars

Construction documents should indicate any exceptions to the default requirements of ACI 301. ACI 301 lists possible exceptions to the default requirements in the Optional Requirements Checklist. Some exceptions to ACI 301 default requirements can include the following:

- (a) Weldability of bars
- (b) Concrete cover to reinforcement
- (c) Specialty item type and grade
- (d) Coatings such as epoxy or zinc where applicable
- (e) Permitting field cutting of reinforcement and cutting methods

Reinforcement requires concrete cover to protect the steel from corrosion. ACI 301 Table 3.3.2.3 shows concrete cover requirements for specific members. The concrete cover requirements for a project are typically shown in a table or list showing the type of member, concrete exposure, type of reinforcement, and concrete cover requirements for each. If there are questionable locations on a specific project, the contract documents should indicate the specific concrete cover requirement controls at each location; an example is fire-rated elements.

When proprietary reinforcement products are required on a project, they can be specified in the general notes.

4.4.5.1 ACI 318 reinforcement requirements—Reinforcing bars, spirals, wires, and welded wire styles in conformance with ASTM International specifications are accepted for construction in the United States and are required by ACI 318. Type and grade of reinforcement are typically shown in a note. When there is more than one type, grade, or both of reinforcement used on a project, it is recommended to show

this information in a table indicating the type and grade used in specific parts of the structure (Fig. 4.4.5.1).

4.4.5.2 Development and splices—ACI 318 requires that the development length/embedment of reinforcement, length of lap splices, and where critical to design, location of lap splices, be shown on the construction documents. Bar development and lap splice lengths and locations can be shown using tables, but the preferred method for showing development and lap splice length and location is graphically in plan, elevation, section, or detail with dimensions provided. This allows the fabrication detailer to more accurately read this information from the drawings. Where lap splice location and length have structural safety implications, the lap splice lengths should be shown graphically.

Reinforcing steel shall be domestic deformed billet steel conforming to the following types, grades, size and locations.

Type of steel and ASTM specification	Grade	Bar size	Location
A615	40	#3 – #4	Paving and sidewalks
	60	#3 – #11	Piers, grade beams, slabs on grade, elevated floors and all ties
	75	#8 – #11	Column verticals
A706	60	#3 – #11	Embedded plates

Fig. 4.4.5.1—Example table of reinforcing bar locations and grades.

When engineering judgment indicates that embedment and lap splice locations and length are less critical, a table can be used (Fig. 4.4.5.2a and 4.4.5.2b). Calculations should not be required of the fabrication detailer to determine the lap splice length or development lengths. Lap and development lengths calculated by the LDP should be shown on the design drawings. The LDP should verify that all possible bar development and lap splice length arrangements that are required on the project can be found on the drawings.

If mechanical splices are permitted or required on a project, make a note of it on the general notes sheet or project specifications to permit them as well as the required type of splice. The LDP should also include a typical detail or specific details on where mechanical splices are required or permitted.

If headed bars are permitted or required on a project, make a note of it on the general notes sheet or project specifications to permit them. Make a note of the required bearing area, cover, and embedment lengths as well. The LDP should also include typical or specific details on where headed bars are required or permitted.

4.4.5.3 Supports for reinforcing steel—Before and during concrete placement, reinforcing steel should be supported and held firmly in place at the proper distance from the forms. The LDP specifies acceptable materials and corrosion protection for reinforcement supports, side form spacers, and supports or spacers for other embedded structural items or specific areas. **ACI 301** specifies bar supports meeting

EMBEDMENT OF DOWELS

WHERE EMBEDMENT IS DIMENSIONED ON THE DRAWINGS, SUCH DIMENSION SHALL APPLY

WHERE THE DRAWINGS INDICATE COMPRESSION EMBEDMENT OR WHERE NO EMBEDMENT TYPE IS CALLED FOR, IT SHALL BE NOTED BELOW FOR COMPRESSION EMBEDMENT

WHERE THE DRAWINGS INDICATE TENSION EMBEDMENT, IT SHALL BE NOTED BELOW FOR TENSION EMBEDMENT

LENGTH: INCHES

DESIG-NATIO N	REINF. GRADE (PSI)	COMPRESSION EMBEDMENT			REGULAR TENSION EMBEDMENT (SEE NOTE)								
		CONCRETE STRENGTH			CONCRETE STRENGTH								
		2000 PSI	2500 PSI	3000 PSI AND OVER	2500 PSI OR LESS	3000 PSI	3500 PSI	4000 PSI	4500 PSI	5000 PSI	5500 PSI	6000 PSI	6500 PSI
#3	40000	8"	7"	6"	12"	12"	12"	12"	12"	12"	12"	12"	12"
#4	40000	10"	9"	8"	13"	12"	12"	12"	12"	12"	12"	12"	12"
#5	40000	14"	12"	11"	18"	17"	15"	14"	14"	13"	12"	12"	12"
#6	40000	17"	15"	14"	22"	20"	19"	17"	16"	16"	15"	14"	14"
#7	40000	19"	17"	15"	29"	27"	25"	23"	22"	21"	20"	19"	18"
#8	40000	21"	19"	17"	36"	33"	30"	28"	27"	25"	24"	23"	22"
#9	40000	25"	22"	21"	42"	39"	36"	34"	32"	30"	29"	27"	26"
#10	40000	28"	25"	23"	48"	43"	41"	27"	35"	33"	32"	30"	29"
#11	40000	30"	27"	25"	51"	46"	43"	40"	38"	36"	34"	33"	31"
#14	40000	36"	33"	31"	54"	49"	46"	43"	41"	39"	37"	36"	34"
#18	40000	44"	41"	39"	66"	61"	58"	55"	53"	51"	49"	48"	46"

FOR HORIZONTAL SPLICES AND EMBEDDED BARS SO PLACED THAT MORE THAN 12" OF CONCRETE IS CAST IN THE MEMBER BELOW THE REINFORCEMENT, INCREASE THE SPLICE AND EMBEDMENT LENGTHS LISTED ABOVE BY A FACTOR OF 1.3. FOR EPOXY COATED BARS INCREASE THE EMBEDMENT LENGTHS LISTED ABOVE BY A FACTOR OF 1.2

Fig. 4.4.5.2a—Example reinforcement embedment schedule for a specific project



Documents

Document Sharing Hub



SPLICE LENGTHS

WHERE SPLICE LENGTHS ARE DIMENSIONED ON THE DRAWINGS, SUCH DIMENSION SHALL APPLY

WHERE THE DRAWINGS INDICATE COMPRESSION SPLICES OR WHERE NO SPLICE TYPE IS CALLED FOR, THEY SHALL BE NOTED BELOW FOR COMPRESSION SPLICES

WHERE THE DRAWINGS INDICATE TENSION SPLICES THEY SHALL BE NOTED BELOW FOR TENSION SPLICES.

LENGTH: INCHES

BAR DESIGN- ATION	REINF. GRADE (PSI)	COMP- RESSIO N	TENSION SPLICE								
			CONCRETE STRENGTH								
			2500 PSI OR LESS	3000 PSI	3500 PSI	4000 PSI	4500 PSI	5000 PSI	5500 PSI	6000 PSI	6500 PSI
#3	40000	17"	20	18	17	16	15	14	14	13	12
#4	40000	18"	27	25	23	21	20	19	18	18	17
#5	40000	19"	34	31	28	26	25	24	23	22	21
#6	40000	23"	41	43	39	37	35	33	32	31	29
#7	40000	26"	47	43	39	37	35	33	32	31	29
#8	40000	29"	54	49	45	42	40	38	36	35	33
#9	40000	35"	61	55	51	47	45	43	41	39	37
#10	40000	39"	68	61	56	53	50	48	45	44	41
#11	40000	42"	74	67	62	58	55	52	50	48	45
#14	40000	53"	95	86	79	74	70	67	63	61	58
#18	40000	67"	122	110	101	95	90	86	81	79	74

FOR HORIZONTAL SPLICES AND EMBEDDED BARS SO PLACED THAT MORE THAN 12" OF CONCRETE IS CAST IN THE MEMBER BELOW THE REINFORCEMENT, INCREASE THE SPLICE AND EMBEDMENT LENGTHS LISTED ABOVE BY A FACTOR OF 1.3. FOR EPOXY COATED BARS INCREASE THE EMBEDMENT LENGTHS LISTED ABOVE BY A FACTOR OF 1.2

Fig. 4.4.5.2b—Example reinforcement lap schedule for a specific project.

the requirements of the Concrete Reinforcing Steel Institute (CRSI) RB4.1.

If the construction documents only state that reinforcement needs to be accurately placed, adequately supported, and secured against displacement within permitted tolerances, the contractor selects the type, class, and spacing of wire supports, precast blocks, composite (plastic), or other materials to use for each area.

CRSI RB4.1 describes the various types of wire, composite, and precast bar supports. There are three common material types of bar supports: wire bar supports shown in Fig. 4.4.5.3a, precast concrete block bar supports shown in Fig. 4.4.5.3b, and composite (plastic) bar supports shown in Fig. 4.4.5.3c.

Certain reinforcement support types can cause aesthetic issues. For example, if precast blocks are used and the surface has a sand-blasted finish, the different texture and color between the precast blocks and the cast-in-place concrete might be objectionable. Also, Class 3 wire bar supports could leave rust stains on the exposed concrete surfaces due to corrosion. A common sub-type of wire bar supports is plastic-tipped wire bar supports that are often used when surface corrosion spots would be of concern. The LDP should clearly define areas on the drawings where

specific types of supports are needed to avoid aesthetic problems and future repairs that can be costly.

Beam bolsters support bottom beam reinforcement and are placed in the beam form, usually perpendicular to the axis of the beam under the stirrups. Beams can also be supported with individual chairs or blocks placed under the beam stirrups.

Bar supports are furnished for bottom bars in grade beams or slabs-on-ground only if required in the construction documents. For a structural element, the LDP should specify bar supports for the bottom bars in grade beams or slabs-on-ground. Aesthetics are not a concern in the bottom of a slab-on-ground or grade beam, which allows the use of precast blocks for bar supports.

Side form spacers (Fig. 4.4.5.3d) can be specified for use, but are usually selected by the contractor.

4.4.5.4 Weldability of bars—The weldability of steel is established by its chemical composition. The American Welding Society (AWS) D1.4 sets the minimum preheat and interpass temperatures and provides the applicable welding procedures. Carbon steel bars conforming to ASTM A615/A615M are weldable with appropriate preheating. Only reinforcing bars conforming to ASTM A706/A706M are preapproved for welding without preheating. Welding of rail and

SYMBOL	BAR SUPPORT ILLUSTRATION*	BAR SUPPORT ILLUSTRATION PLASTIC TIPPED	TYPE OF SUPPORT	TYPICAL SIZES
BB			Beam Bolster	1, 1 1/2, 2 to 5 in. heights in increments of 1/4 in. in lengths of 5 ft
BBU**			Beam Bolster Upper	Same as BB
BC			Individual Bar Chair	3/4, 1, 1 1/2, 1 3/4, and 2 in. heights
CHC			Continuous High Chair	Same as HC in 5 ft and 10 ft
CHCM**			Continuous High Chair for Metal Deck	Up to 5 in. heights in increments of 1/4 in.
CHCU**			Continuous High Chair Upper	Same as CHC
CS			Continuous Support	1 1/2 to 12 in. in increments of 1/4 in. in lengths of 8' - 8'
HC			Individual High Chair	2 to 15 in. heights in increments of 1/4 in.
HCM**			High Chair for Metal Deck	2 to 15 in. heights in increments of 1/4 in.
JC			Joist Chair	4, 5, and 6 in. widths and 3/4, 1 and 1 1/2 in. heights
JCU***			Joist Chair Upper	14 in. span; heights -1 in. thru +3 1/2 in. vary in 1/2 in. increments
SB			Slab Bolter	3/4, 1, 1 1/2, 2, and 3 in. heights in 5 ft and 10 ft lengths
SBC			Single Bar Centralizer (Friction)	6 in. to 24 in. diameter
SBU**			Slab Bolster Upper	Same as SB

*Illustrations are intended for informational purposes only.

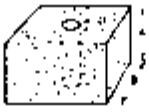
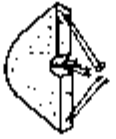
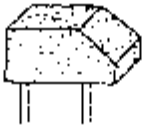
**Usually available in Class 3 only, except on special order.

***Usually available with Class 3 only, with upturned or end-bearing legs.

1 in. = 25.4 mm

1 ft = 304.8 mm

Fig. 4.4.5.3a—Example wire bar supports (courtesy CRSI (CRSI RB4.1)).

z	BAR SUPPORT ILLUSTRATION	TYPE OF SUPPORT	TYPICAL SIZES, IN.	DESCRIPTION
CB		Combination Block	A – 1 ½ to 4 B – 2 to 4 C – 2 to 4 D – fits #3 to #5 [#10 to #16] bar	Commonly used on horizontal work.
DB		Dowel Block	A – 3 B – 3 to 5 C – 3 to 5 D – hole to accommodate a #4 [13] bar	Used to support top mat from dowel placed in hole. Block can also be used to support bottom mat.
DSBB		Bottom Bolster – Wired	Concrete cover, 3 to 6	Used to keep the reinforcing bar cage off the floor of the drilled shaft. * Support for 6 in. concrete cover is actually 8 in. in height with a 2 in. shaft cast in the top of the bolster to hold the vertical bar.
DSSS		Side-Form Spacer – Wired	Concrete cover, 2 to 6	Used to align the reinforcing bar cage in a drilled shaft. * Commonly 16-gauge tie wires are cast in the spacer. Supports for 5 in. to 6 in. cover have 9-gauge tie wires at top and bottom of the spacer.
DSWS		Side-form spacer for drilled shaft applications	Concrete cover, 3 to 6	Generally used to align reinforcing bar in a drilled shaft. * Commonly manufactured with two sets of 12-gauge annealed wires, assuring proper clearance from the shaft wall surface.
PB		Plain Block	A – ¾ to 6 B – 2 to 6 C – 2 to 48	Used when placing bars off grade and form work. When "C" dimension exceeds 16 in. the block should be cast with a piece of reinforcing bar inside the block.
WB		Wired Block	A – ¾ to 4 B – 2 to 3 C – 2 to 3	Generally, block is cast with embedded 16-gauge tie wire, commonly used against vertical forms or in positions necessary to secure the block by tying to the reinforcing bars.

* Also known as a pier, caisson or cast-in drilled hole

1 in. = 25.4 mm

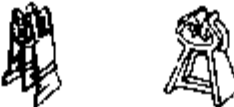
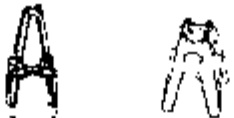
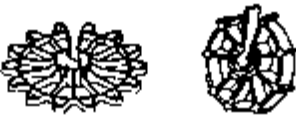
Fig. 4.4.5.3b—Example concrete supports (courtesy CRSI (CRSI RB4.1)).

axle-steel bars is not recommended. Welding of stainless-steel reinforcing bars is discouraged, but if necessary, done in accordance with **AWS D1.6**. Low-carbon chromium reinforcing bars should not be welded.

4.4.5.5 Hooks and bends—Standard practice is to show all bar dimensions as out-to-out and consider the bar lengths as the sum of all detailed primary dimensions, including Hooks A and G. Note the difference between “minimum” bend diameter and “finished” bend diameter. “Finished” bend diameters include a “spring-back” effect when bars straighten out slightly after being bent and are slightly larger than “minimum” bend diameters.

Standard bend shapes will have not more than six bend points in one plane, bent to normal tolerances. Shapes with more than six bends, or bent to special tolerances, or in more than one plane, involve greater difficulty and are subject to added costs.

Although bar hooks and bends are occasionally not shown on the drawings, a note should be placed stating that certain bars are required to end in a standard hook. Specifications that require a nonstandard hook should be used with caution because nonstandard hooks could be difficult to achieve. If the LDP shows a hook but does not dimension the hook, the reinforcing steel detailer will use an algorithm similar to the Block Flow diagram in Fig. 4.4.5.5 to determine the proper

SYMBOL	BAR SUPPORT ILLUSTRATION	TYPE OF SUPPORT	TYPICAL SIZES, IN.	DESCRIPTION
BS		Bottom Support	Heights, ¾ to 6	Generally for horizontal work. Not recommended for ground or exposed aggregate finish.
BS-CL		Bottom Support	Heights, ¾ to 12	Generally for horizontal work, provides bar clamping action. Not recommended for ground or exposed aggregate finish.
DSBB		Bottom Bolster (Gripping)	Concrete cover, 3 Height, 6	Used to keep the reinforcing bar cage off of the bottom of a drilled shaft.** Fits #6 through #14 [#19 through #43] reinforcing bars.
DSWS		Side-Form Spacer for drilled shaft applications	Concrete cover, 2 ¾ to 6	Generally used to align reinforcing bars in a drilled shaft.** Two-piece wheel that closes and locks on to the tie or spiral assuring proper clearance from the shaft wall surface.
HC		High Chair	Heights, ¾ to 6	For use in slabs or panels
HC-V		High Chair, Variable	Heights, 2 ¾ to 7 ¾	For horizontal and vertical work. Provides for different heights.
HDHC		Heavy Duty High Chair	Heights, 2 ¾ to 26	For use in slabs, or on grade with plate.
OGC		On Grade Chair	Heights, 1 ¾ to 6 ¾	Used primarily on grade.
SB		Slab Bolster	Heights ¾ to 4 Lengths up to 60***	Commonly used in horizontal and vertical applications. When used as a side-form spacer in vertical work, slab bolster must be tied to the reinforcement.
SBU		Slab Bolster Upper	Heights, 1 to 5 Lengths up to 30	Commonly used in supporting the upper mat in a double mat application.
VLWS		Locking Wheel Side-Form Spacer for all vertical applications	Concrete cover, ¾ to 6	Generally used in both drilled shaft** and vertical applications where heavy loading occurs. Surface spines provide minimal contact while maintaining required tolerance.
WS		Wheel Side-Form Spacer	Concrete cover, ¾ to 3	Generally for vertical work. Bar clamping action and minimum contact with forms. Applicable for column reinforcing bars

*Illustrations are intended for informational purposes only.

**Also known as a pier, caisson, or cast-in drilled hole.

***Pieces can be locked together to form longer lengths.

1 in. = 25.4 mm

Fig. 4.4.5.3c—Example plastic supports (courtesy CRSI (CRSI RB4.1)).



Fig. 4.4.5.3d—Side form spacers to maintain reinforcement cover in a wall form.

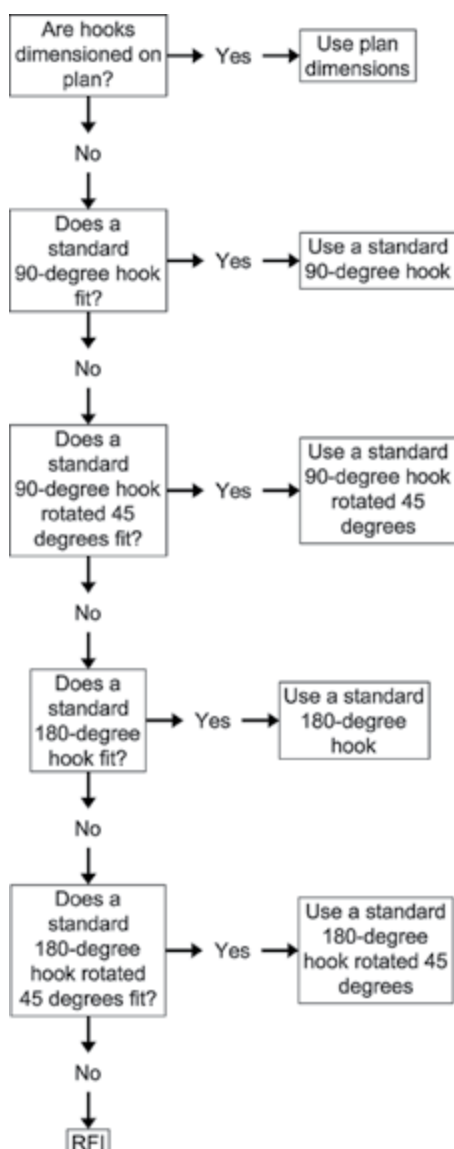


Fig. 4.4.5.5—Block flow diagram to determine hook type and size.

SPECIAL INSPECTION

1. SPECIAL INSPECTION BY A REGISTERED DEPUTY BUILDING INSPECTOR, APPROVED BY THE ARCHITECT AND THE BUILDING DEPARTMENT, SHALL BE REQUIRED FOR THE FOLLOWING TYPES OF WORK. SEE PROJECT SPECIFICATIONS FOR SPECIFIC REQUIREMENTS.
 - A. ALL CONCRETE WORK, INCLUDING REINFORCEMENT IN PLACE PRIOR TO PLACEMENT OF CONCRETE, AS WELL AS CONCRETE PLACEMENT ITSELF.
 - B. ALL FIELD WELDING (EXCEPT METAL STUDS, FURRING CHANNELS, ETC.)
 - C. MASONRY WORK WHERE NOTED ON THE DRAWINGS, AND DURING ALL HIGH LIFT GROUTING OPERATIONS.
 - D. HIGH STRENGTH BOLTING
 - E. STEEL FLOOR AND ROOF DECK WELDING.

Fig. 4.4.7—Example of special inspection notes.

hook to use. If the standard hook possibilities will not fit, a delaying request for information (RFI) becomes necessary. A standard hook only defines dimensions of the bend shape and is not an indicator of required development length.

4.4.5.6 Wire and welded wire reinforcement (WWR)—Welded wire reinforcement is produced by electrical resistance welding. In North America, it typically consists of a series of cold-drawn steel wires typically arranged at right angles to each other, although in other parts of the world it is produced at various angles besides right angles. Welded wire reinforcement can be used in slabs-on-ground, joist and waffle slab construction, walls, pavements, box culverts, and canal linings. The Wire Reinforcement Institute manuals **WWR-500-R-16** and **WWR-600** provide guidance on specification and development of design details.

General notes or the specifications will specify the WWR required. Welded wire reinforcement is produced in flat sheets called “styles” or in rolls. The wire may be plain or deformed.

Welded wire reinforcement in conformance with **ASTM A1064/A1064M** is most typically specified unless stainless or zinc-coated types are needed. Welded wire reinforcement can be fabricated in many configurations, ranging from 2 x 2-W1.4 x W1.4 to 16 x 16-D31 x D31, with many different combinations between. An example of one type of style is 3 x 12-D31 x W12.4. WWR-500-R-16 lists properties of common styles of WWR.

4.4.6 Construction notes—Construction notes are general notes that discuss many of the miscellaneous aspects of construction not covered by the other types of notes. These notes might include information pertinent to detailing, fabrication, and reinforcement placement.

4.4.7 Inspection notes—The general notes sheet should indicate the level of inspection required for the project. If the structure includes members that require special inspection, such as a special seismic-force-resisting system, they should be identified (Fig. 4.4.7).

4.5—Plan sheets

IBC (2015) Section 1603.1 requires construction documents to show the size, section, and relative locations of

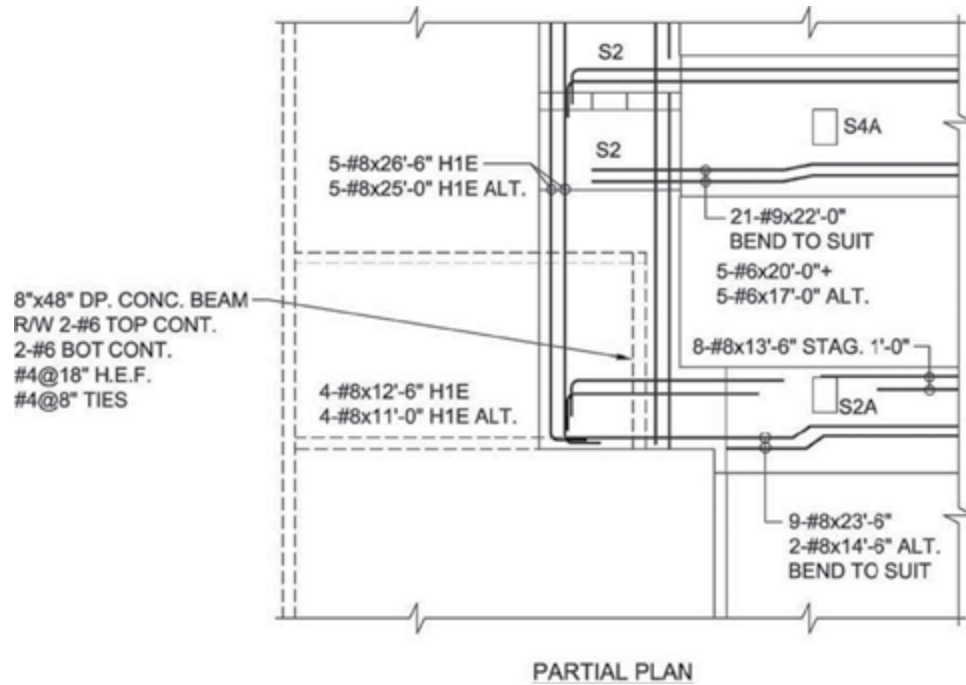


Fig. 4.5a—Beam shown on plan.

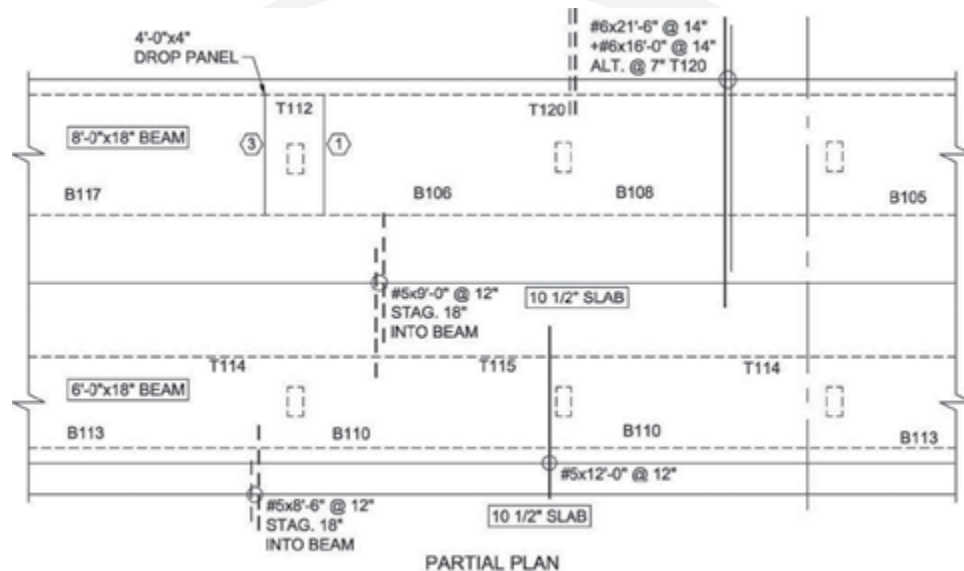


Fig. 4.5b—Beam numbered on plan.

structural members with floor levels, column centers, and offsets dimensioned. A plan drawing provides information about an identified building floor, including overall geometry and dimensions, and concrete member width and thicknesses, either directly or by a designation keyed to a schedule, as well as reinforcement information for concrete members either directly, or by a designation keyed to a schedule. A plan drawing can include a general reference to other sheets, such as an elevation or detail sheet. A floor plan also includes orientation information, such as column line numbers, a north arrow, top of concrete relative to a datum, and general notes specific to the floor plan.

Member reinforcement such as beams, can be directly shown on the plan (Fig. 4.5a) or indirectly provided through use of schedule marks, such as beam numbers (Fig. 4.5b), which are listed on a corresponding beam schedule (Fig. 4.5c).

Plan drawings are usually drawn to 1/16 or 1/8 in. (1 mm = 100 to 200 mm) scale. For small floor plans larger scales can be used. The primary consideration for scale to be used is the complexity of the plan. Clarity should be maintained by using a larger scale if a large amount of information requires conveyance in a small area of the plan. If the designer needs to separate the plan into several parts for a floor, the designer should consider portions of the structure, assumed placement sequences, or some other easily readable way of

BEAM REBAR LEGEND			
BEAM TOP REINFORCEMENT CENTER OVER SUPPORT U.N.O.		BEAM BOTTOM REINFORCEMENT STAG. 3" PAST CENTER OF SUPPORT U.N.O.	
TYPE	REINFORCING 4-#6 CONT. BARS LAP 24" AT MID SPAN + FOLLOWING	TYPE	REINFORCING
T101	#6 6'-0" @ 6" H.1.E.	B101	8-#9 23'-3" 18-#9 20'-0" ALT. 6" INTO LINTEL
T102	8-#9 17'-0" 8-#9 14'-0" ALT.	B102	12-#8 18'-6" STAG.
T103	7-#9 17'-0" 6-#9 12'-0" ALT.	B103	13-#8 18'-6" STAG.
T104	8-#11 19'-6" 8-#11 14'-0" ALT.	B104	5-#8 11'-0" STAG. 5-#8 9'-0" 6" INTO WALL
T105	8-#8 17'-0" 7-#8 10'-6" ALT.	B105	14-#8 19'-6" STAG.
T106	7-#8 13'-0" 6-#8 10'-0" ALT.	B106	13-#8 18'-6" STAG.
T107	7-#8 13'-0" 6-#8 10'-0" ALT.	B107	12-#8 18'-6" STAG.
T108	8-#8 13'-0" 8-#8 10'-0" ALT.	B108	7-#8 15'-0" 7-#8 12'-6" ALT. 6" INTO WALL
T109	7-#9 14'-0" 6-#9 12'-0" ALT.	B109	10-#8 22'-6" STAG.
T110	5-#8 17'-6" 5-#8 11'-0" ALT.	B110	8-#8 18'-6" STAG.
T111	5-#8 19'-0" 5-#8 12'-0" ALT.	B111	8-#8 18'-6" STAG.
T112	7-#8 19'-0" 7-#8 12'-0" ALT.	B112	4-#8 11'-0" 4-#8 9'-6" ALT. 6" INTO WALL
T113	#6 12'-0" @ 6" center over wall	B113	9-#8 15'-0" 4-#8 12'-6" ALT. 6" INTO WALL
T114	5-#8 15'-0" 4-#8 10'-0" ALT.	B114U	14-#8 22'-6" STAG.
T115	3-#8 13'-0" 3-#8 10'-0" ALT.	B115	15-#8 18'-0" STAG.
T116	7-#9 17'-0" 7-#9 12'-0" ALT.	B116	5-#8 11'-0" STAG. 4-#8 9'-0" 6" ALT. INTO WALL
T117	6-#9 19'-6" 6-#9 12'-0" ALT.	B117	6-#8 20'-6" 6-#8 17'-6" ALT. 6" INTO WALL
T118	6-#11 19'-6" 6-#11 14'-0" ALT.	B118	7-#8 23'-3" 7-#8 19'-0" ALT. 6" INTO WALL
T119	8-#8 15'-0" 7-#8 10'-0" ALT.	B119	6-#8 19'-3" 6-#8 16'-6" ALT. 6" INTO WALL
T120	7-#8 13'-0" 7-#8 10'-0" ALT.	B120	12-#9 28'-0" STAG.
T121	7-#9 16'-0" 7-#9 12'-0" ALT.	B121	16-#8 28'-0" STAG.
T122	9-#11 19'-6" 9-#11 14'-0" ALT.	B122	14-#8 25'-6" STAG.
T123	7-#11 19'-6" 7-#11 14'-0" ALT.	B123	6-#8 19'-3" 5-#8 16'-6" ALT. 6" INTO WALL
T124	9-#11 18'-0" 8-#11 12'-6" ALT.	B124	9-#9 27'-0" 5-#9 23'-6" ALT. 6" INTO WALL
T125	6-#9 22'-0" 5-#9 18'-0" ALT. Over 2 walls	B125	5-#8 18'-6" 5-#8 16'-6" ALT. 6" INTO WALL

NOTE THE REBAR LENGTH SHOWN ABOVE ARE HORIZ. PROJECTED LENGTH
ADD EXTRA FOR HOOK ONE END, BENT TO SUIT, ETC.

Fig 4.5c—Corresponding beam schedule for Fig. 4.5b.

breaking the plan into smaller parts. Match lines, indicating the adjacency of the separated parts, are typically used.

Because plans only provide information in the horizontal direction, use section cuts and elevations to clarify geometric and reinforcement information in the vertical direction. A section cut is indicated by a directional mark or cut drawn on the floor plan (Fig. 4.5d and 4.5e).

4.5.1 Plan graphics and member geometry—The assumed view point for a plan drawing is above the slab on each floor level of a structure (Fig. 4.5.1). Therefore, slab edges are shown as solid lines on the plan drawings. Concrete beams' and girders' locations are usually shown as hidden on the plan drawings because they are typically below the surface

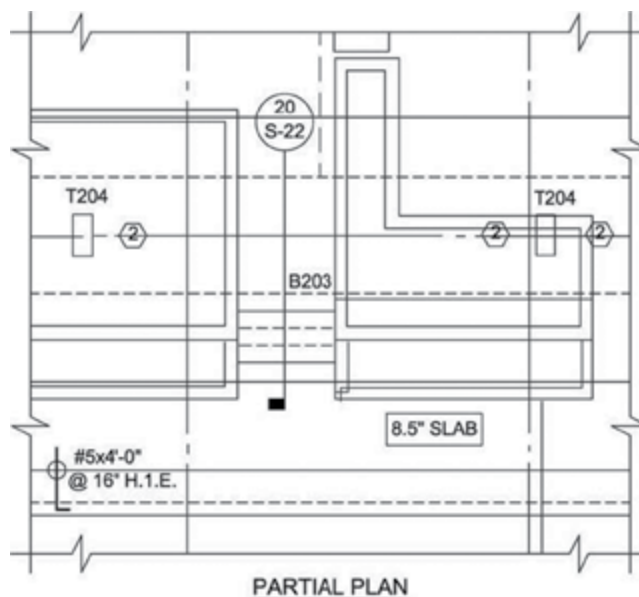


Fig 4.5d—Section cut through slab.

of the slab. Columns and walls above the slab are shown with solid lines.

Columns and walls that are shown solid extend above the slab on the plan. These vertical members of the structure will be shown on all the plans from their lowest elevation in the structure, usually the foundation but occasionally a transfer girder or slab, to their highest elevation in the structure, usually the top tier where they will be drawn as hidden.

Foundations are drawn as hidden when they are below the slab-on-ground and solid when not covered by structural members or slab-on-ground concrete. Soil is not considered a structural member for this purpose.

4.5.2 Reinforcement on plan views—Reinforcement that is atypical, such as slab reinforcement required where a varied column layout or a large slab opening occurs, is often shown on the plan drawings instead of using slab marks (Fig. 4.5.2).

When the amount of slab reinforcement being shown on a plan drawing becomes so large that the plan is difficult to read, it is acceptable to make additional plans. These additional plan sheets can be used so that one shows the bottom reinforcement, the other the top reinforcement, and another that shows additional steel, such as that required around openings. Each plan should be properly labeled. Additional beam and girder reinforcement is not typically shown on plan drawings because it can cause confusion. If additional reinforcement is required for beams and girders, it is typically shown in a note or remark in the beam schedule, and a corresponding detail or section cut will be provided to show the additional reinforcement.

4.6—Elevation sheets

An elevation sheet contains drawing information about identified concrete members from an elevation view (Fig. 4.6a). Elevation drawings do not require a set scale, so an appropriate scale is chosen based on the height of the elevation being drawn and the level of detail needed. Similar to

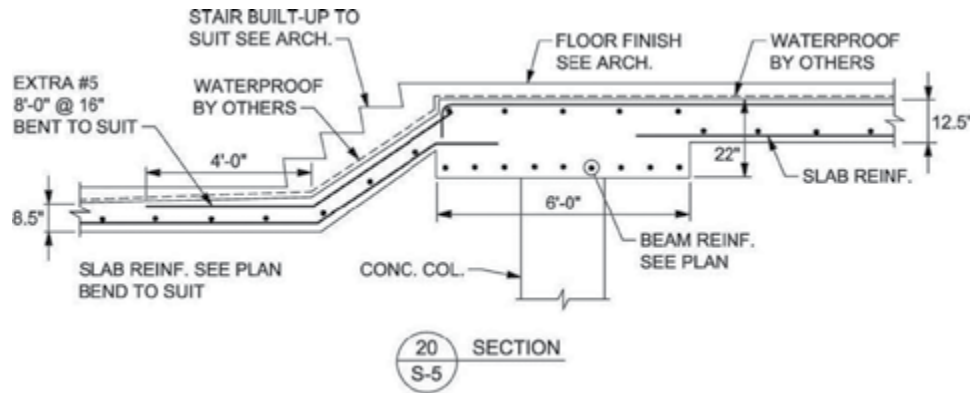


Fig. 4.5e—Corresponding detail for Fig. 4.5d.

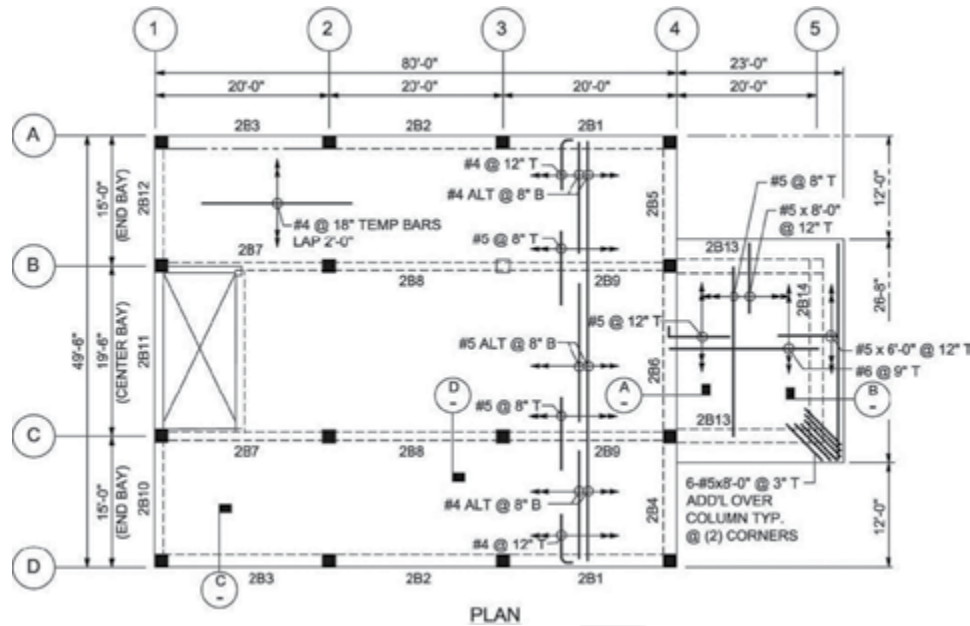


Fig. 4.5.1—Floor plan with beams with hidden lines and columns and walls with solid lines.

plan drawings, the scale is often based on the complexity of the structure. The elevation can be split into several drawings as required to show enough detail with match lines, as shown in Fig. 4.6a.

The elevation drawing provides orientation information, such as column lines or floor levels, and is connected to the plan drawings by noted concrete elevations relative to a datum, section references, and orientation information.

An elevation drawing that provides member dimensions can also provide member reinforcement. This information can be provided directly or by a designation referenced to a schedule.

When beams, columns, walls, or all are part of a seismic lateral-load-resisting system, elevations are often used to show all the reinforcement in the members that are part of that system (Fig. 4.6b). Ordinary moment frames, intermediate moment frames, and special moment frames and shear walls all have seismic detail requirements in ACI 318.

4.7—Section sheets

A section sheet is used for most projects. Sometimes, a single sheet combines sections, details, and schedules. Most sections are drawn at 3/4 in. = 1 ft (20 mm = 300 mm) scale, however, larger scales can be used if more detail is necessary for clarity. Sections are usually drawn from a point of view perpendicular to that of the drawing that calls out for the section, and is oriented by pointers on the section callout (Fig. 4.7). A section cut will show the geometry and reinforcement details at the cut plane, and may be drawn on a plan sheet, a sections sheet, or on a details sheet. The cut identifies the section number and the sheet number where the section is drawn.

4.8—Large-scale view sheets

Large-scale views are used if a dramatically increased scale of a section or detail is necessary to show additional clarity in an area of a structure. They are used to clarify reinforcement detailing in an unusual element, such as a curved staircase, complex elevator core, or heavily reinforced link

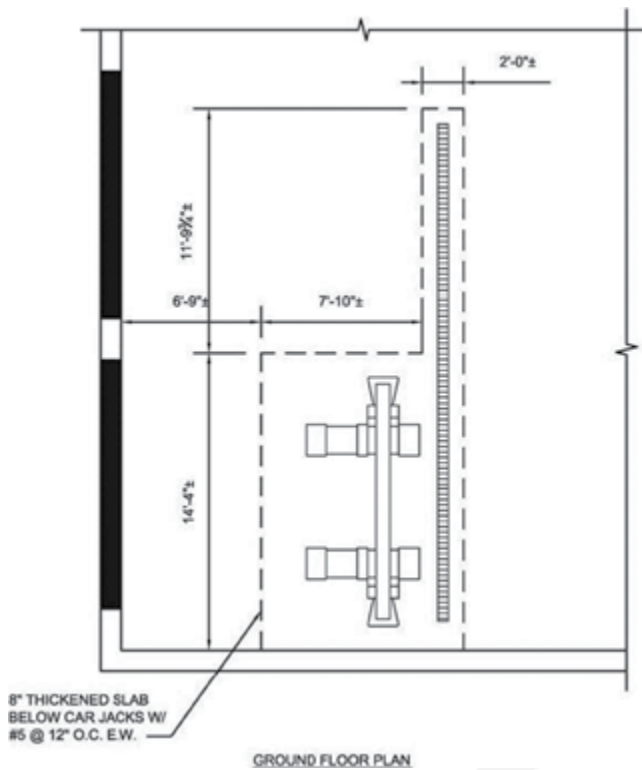


Fig. 4.5.2—Supplementary reinforcement shown on floor plan.

beam. These sheets are rarely titled “large-scale views,” but instead, usually titled by what is being shown on the sheet. For example, “Stairs – Plans and Sections” could be an example title for a large-scale view sheet for a stair tower.

4.9—Detail sheets

Details are usually drawn from the same point of view as the drawing that calls out the detail (Fig. 4.9a).

A separate detail sheet is usually used on a project. However, small projects may have a single sheet that combines sections, details, and schedules. Many details are drawn at 3/8 to 1 in. = 1 ft (1 mm = 10 to 50 mm) scales, but larger scales are used if needed for clarity. In heavily congested areas, using full-scale drawings is suggested to help with checking constructability.

Details that are applicable to commonly encountered conditions are usually placed on “typical details” sheets. Often, the typical details are schematic only and are not exactly drawn. When the typical details are schematic only, the information regarding the detail is shown in a separate table or given in the notes. If not, it is typically shown simply as an example of what needs to be done, giving the contractor some freedom to choose the best means and methods for building the detailed item as shown.

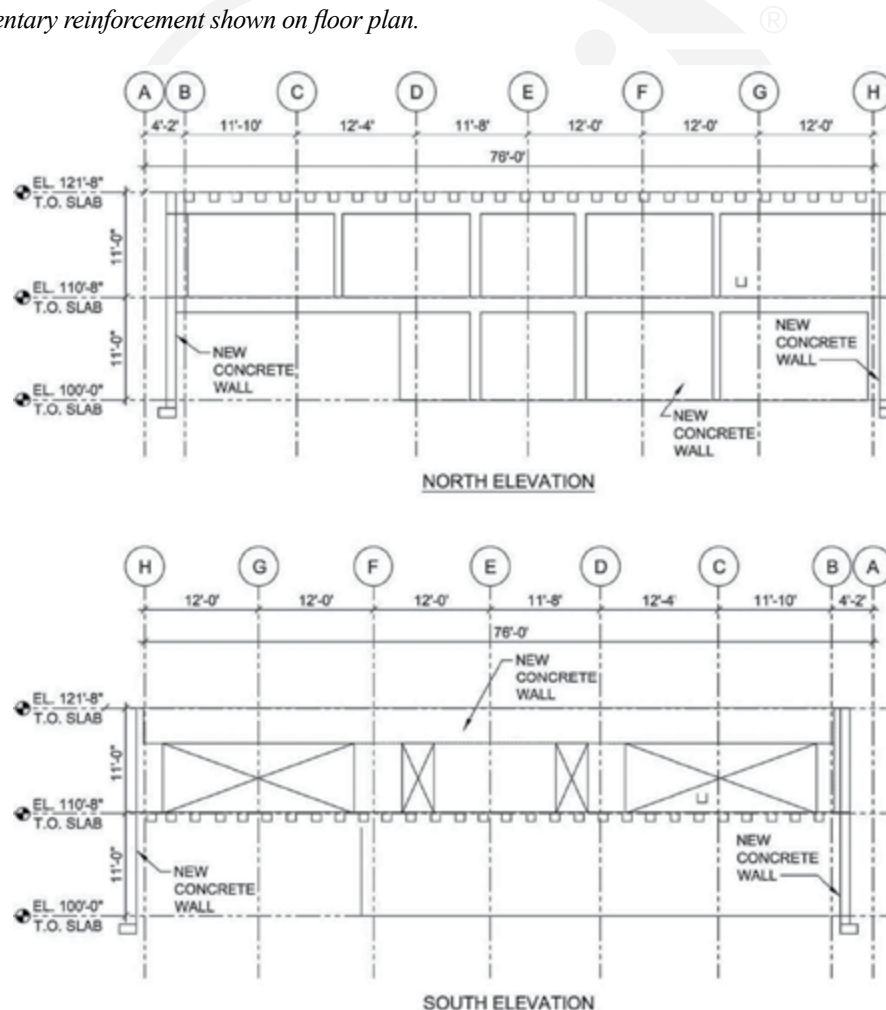


Fig. 4.6a—Building elevation with detail callouts.

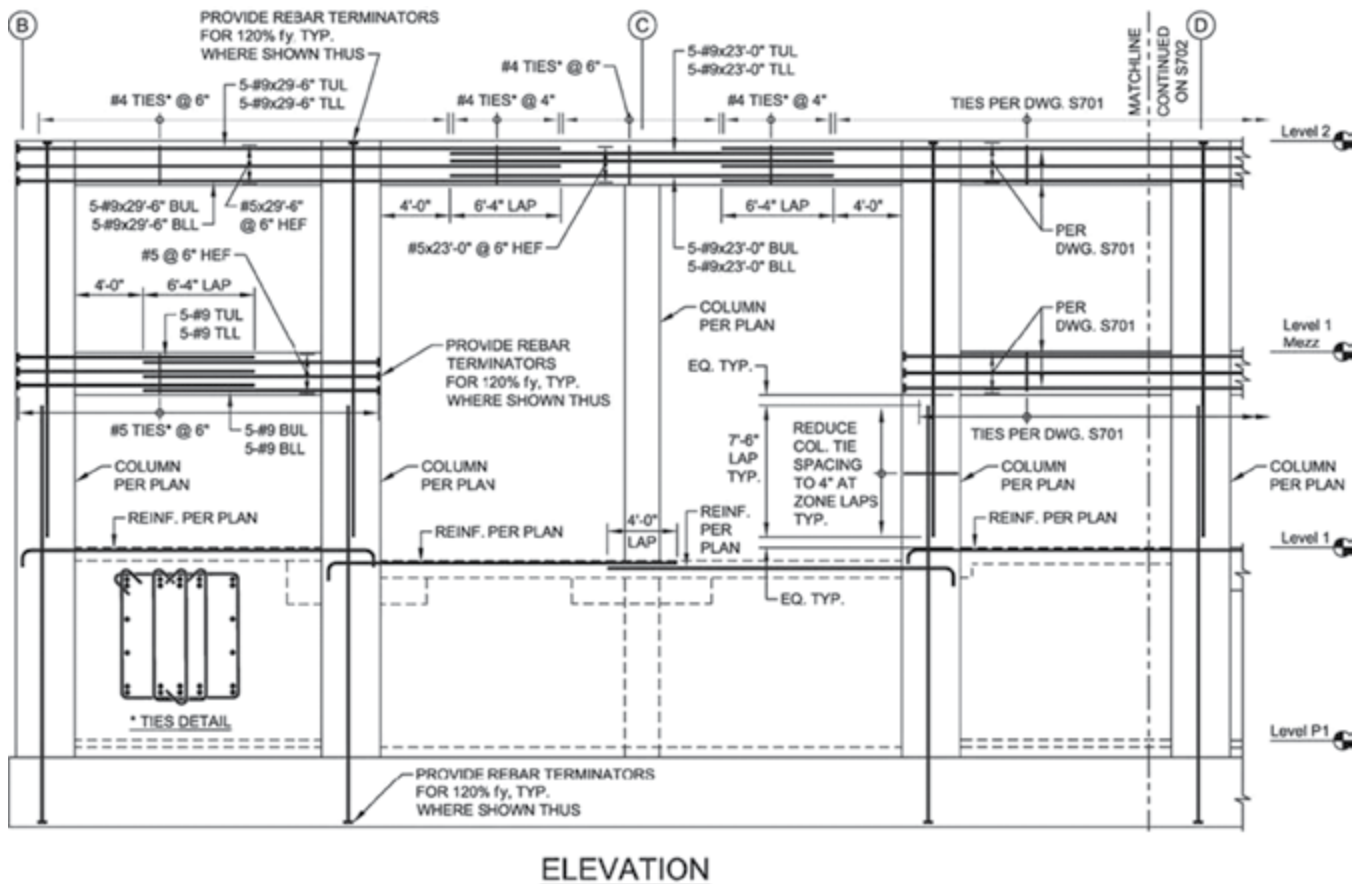


Fig. 4.6b—Building elevation with detail call-outs for lateral load-resisting system.

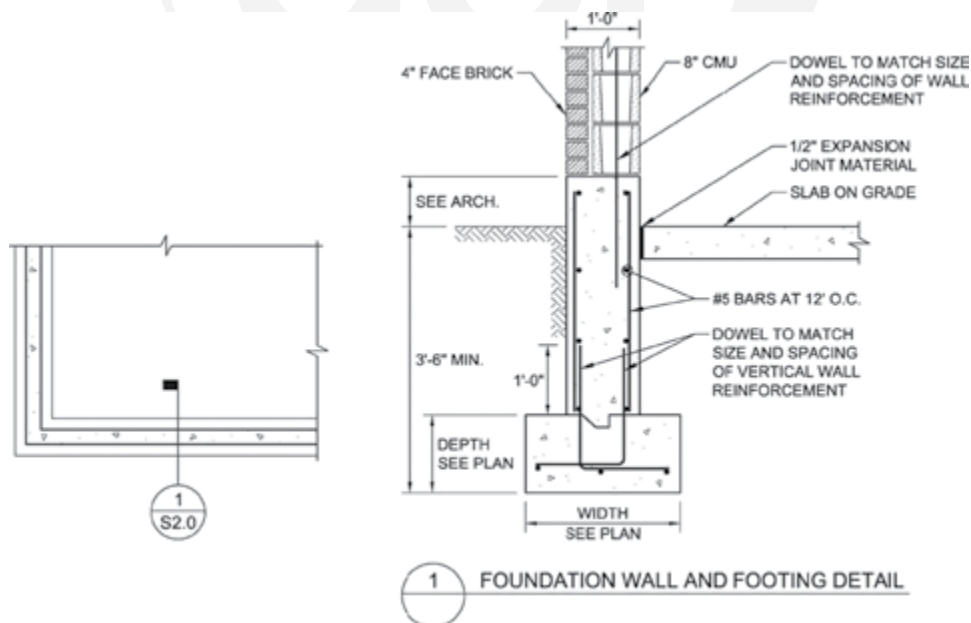


Fig. 4.7—Example plan sheet section cut call-out and section sheet section cut detail.

For example, trim reinforcement around a slab or wall opening is often standard for a certain range of opening sizes, and this arrangement shown in a typical detail. This allows the fabrication detailer to trim any opening within the stated range without asking the engineer for a specific solu-

tion. Other typical details include reinforcement around an in-slab conduit, a mechanical chase through a concrete slab, openings through a beam, reinforcement termination details at edges of concrete, contraction joints in slab-on-ground, and construction joints.

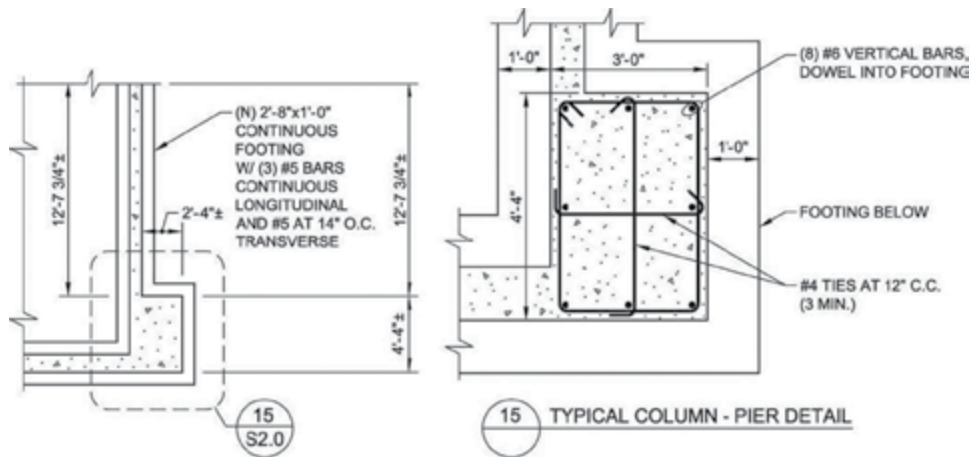


Fig. 4.9a—Example plan detail callout and detail on detail sheet.

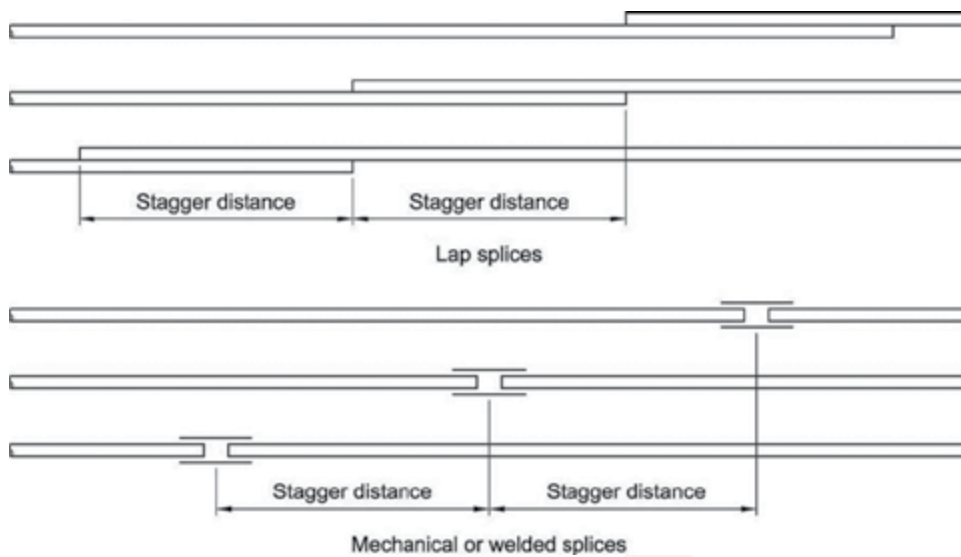


Fig. 4.9b—Staggered layout of splices in bundled bars.

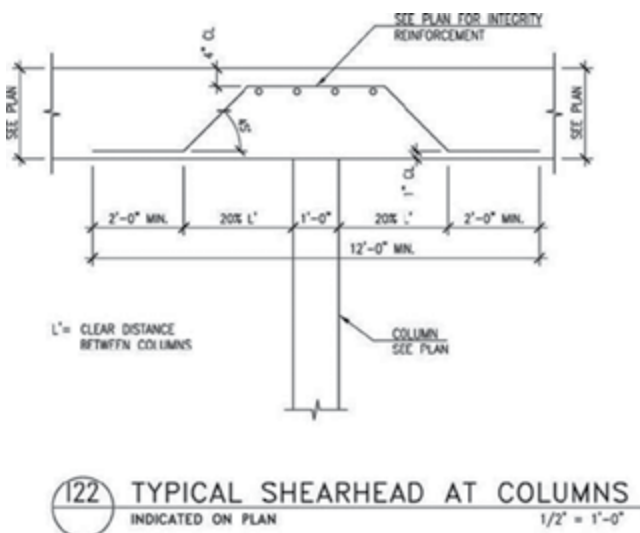


Fig. 4.9c—Example detail of a shear head.

Special member-specific information, such as bundled bar splices, or atypical splice lengths for beams, slabs, walls, and columns is best shown in typical details (Fig. 4.9b) or schedules on the respective member schedule sheets.

Shear reinforcement in a one-way slab is rarely used, but if it is, the shear reinforcement area is typically shaded or hatched on the plan drawing. A detail should be included, sometimes on the slab schedule sheet to indicate bar size, spacing of shear reinforcement, and shape of bent bar (Fig. 4.9c). Headed shear studs can also be a viable option, and a detail drawn if chosen.

4.10—Schedule and diagram sheets

Schedule sheets provide reinforcement information for various members, such as slabs, beams, columns walls, and foundations. A diagram to explain the schedule information is usually provided (Fig. 4.10).

Member schedules usually contain the following:

- Member mark that should have a standard naming convention and be identified on plans and elevations
- Member dimensions

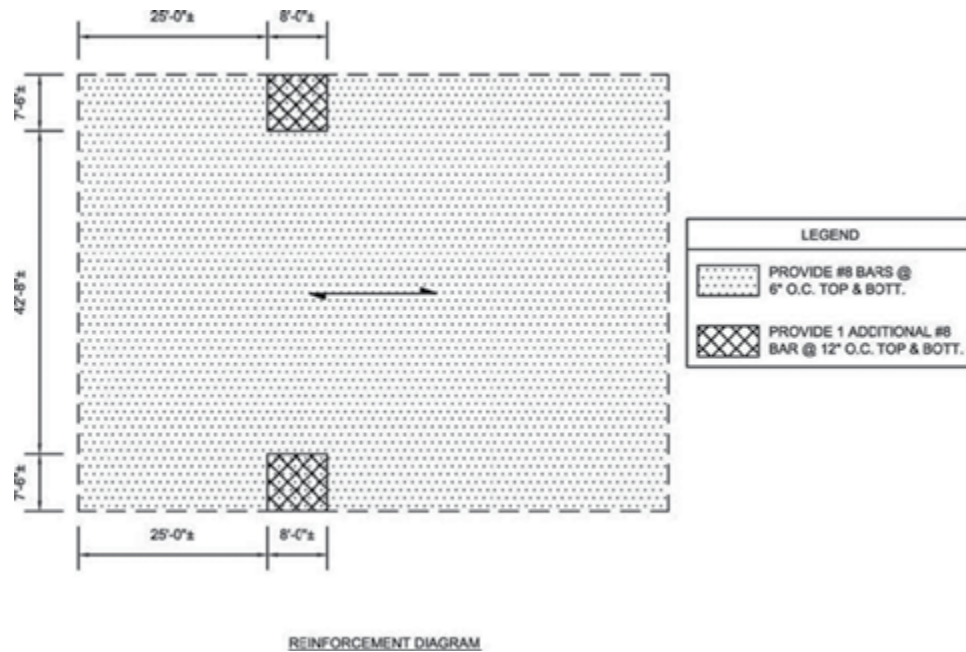


Fig. 4.10—Diagram provided to explain schedule information.

- (c) Member reinforcement
- (d) Remarks or notes describing to include atypical reinforcement patterns, elevation, and concrete strength

4.10.1 Slab schedules

Slab schedules usually contain the slab mark, thickness of slab, bottom and top reinforcement, and any notes or remarks necessary for that slab.

If the LDP chooses to terminate some of the reinforcement short of the support in one-way slabs, it should be indicated in a detail similar to Fig. 4.10.1a.

Two-way slabs supported by edge walls or by edge-beams require reinforcement in the top and bottom of the slab at the intersection of the two-way slab and edge members. This reinforcement is shown using typical details if it occurs throughout the structure, or the information is shown right on the plan drawings if it is not a prevalent detail. Refer to Fig. 4.10.1b for an example.

Two-way slab structural integrity reinforcement requirements can be shown in different ways. The splicing requirements for structural integrity reinforcement can be shown on the slab schedule diagram. The requirement of two column strip bottom bars or wires that are required to go through the columns can also be shown on the plan or in a typical detail. The typical detail option is probably used most often because other information can be shown on the same detail if the designer wishes. Refer to Fig. 4.10.1c for an example.

Two-way shear reinforcement in slabs could be headed shear studs, typical stirrups, or structural steel members. Headed shear studs are used most often; a detail should be drawn to show the layout of the headed shear studs, especially at a column. When several different layouts of headed shear studs are needed in a structure, it may be clearer to use a series of headed shear stud diagrams, possibly in a table, to show their layouts as they vary throughout the structure

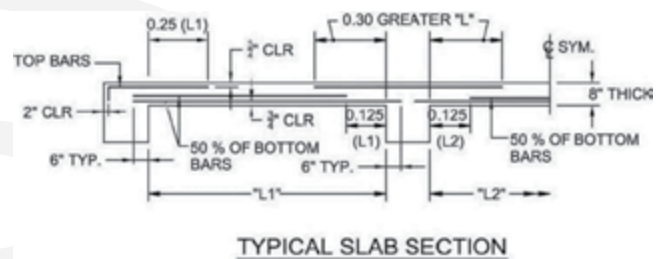


Fig. 4.10.1a—Example reinforcement terminations for a one-way slab.

(Fig. 4.10.1d). The plan drawings should be marked at each column to indicate which headed shear stud diagram should be used at that location.

While stirrups are not used as regularly as headed shear studs for two-way shear reinforcement, they are permitted by the ACI 318 Code. When stirrups are used for two-way shear reinforcement, they can be shown on a schedule similar to the schedule for headed shear studs (Fig. 4.10.1e). Structural steel members are rarely used; however, if they are used their locations should be identified and special details provided.

4.10.2 Beam and girder schedules—Beams and girders are often shown in the same schedule and the information presented is similar. For simplicity of wording, the terms “beam” and “beam schedule” will be used here to include both. Beam schedules contain the beam mark, beam width and depth, top and bottom reinforcement and extent, post-tensioning reinforcement when applicable, and stirrup size, and spacing (Fig. 4.10.2).

Along with the beam schedule, there should be a diagram to show the basic layout of the reinforcing steel in a beam. For clarity, this often requires two diagrams with one showing the longitudinal reinforcing steel and the other showing the shear reinforcing steel. The diagrams are often

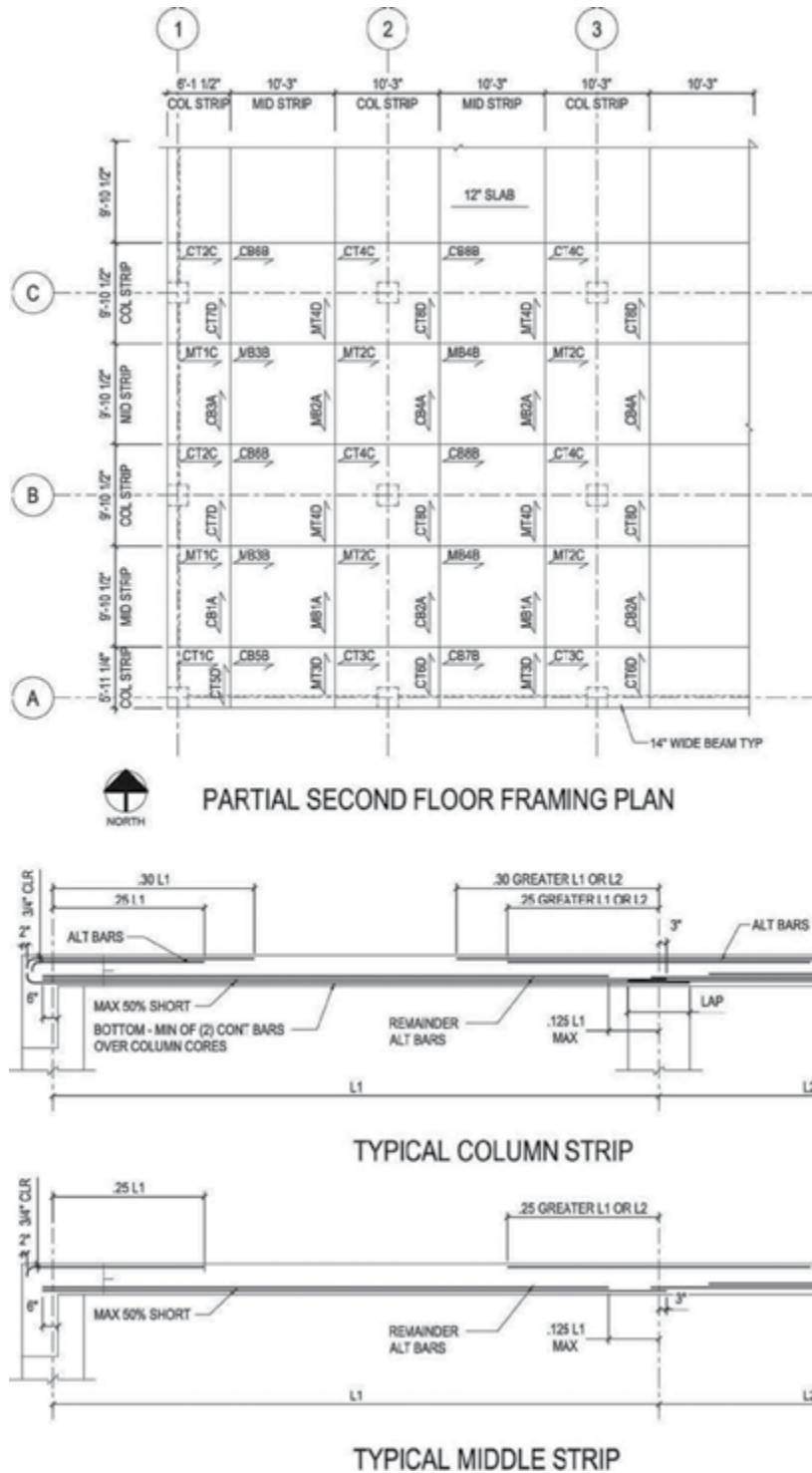


Fig. 4.10.1b—Termination rules for a two-way slab.

split into the following different types of beams: single span, multiple spans, and cantilever.

When applicable, the post-tensioning is typically specified using the assumed effective force that is expected to be applied to the beam, or using the number of tendons from the design. Typical shear reinforcing stirrup sizes and spacing are shown in the schedule by specifying each group of stirrups. For example, a beam might need six No. 4 (No. 13) stirrups at 2 in. (50 mm) o.c., and then six No. 4 (No. 13) stirrups at 6 in.

(150 mm) o.c. at each beam end, and the remainder along the length of the beam at 12 in. (300 mm) o.c.

Often, this type of shear reinforcing spacing at the ends of the beams or at other special shear reinforcing locations is shown in a typical diagram on the beam schedule sheet. The design drawings should provide a detail of stirrups showing the stirrup shape.

4.10.3 Column schedules—Column schedules usually contain the column mark, vertical reinforcement, and the

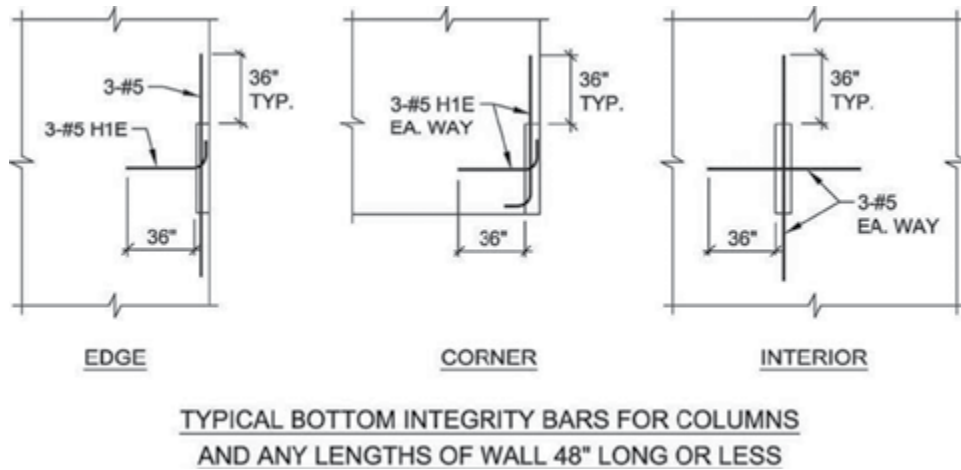


Fig. 4.10.1c—Typical column strip bottom integrity bars.

HEADED SHEAR STUD SCHEDULE - LEVEL 2							
MARK	NUMBER OF STUD RAILS	# OF STUDS PER RAIL	STUD DIAMETER	STUD HEIGHT 'H'	STUD SPACING 'S'	BOTTOM PLATE	PLAN VIEW
SR1	8	9	1/2"	6" (ADJUST FOR SLAB DEPTH SEE BELOW)	6"	1/4" x 1"	
SR2	5	6	1/2"	6" (ADJUST FOR SLAB DEPTH SEE BELOW)	6"	1/4" x 1"	
SR3	7	6	5/8"	6" (ADJUST FOR SLAB DEPTH SEE BELOW)	6"	1/4" x 1"	
TYPICAL CONDITION (NOTE: STUD HEIGHT 'H' INCLUDES BOTTOM PLATE THICKNESS)				STEPPED SLAB CONDITION (NOTE: STUD HEIGHT 'H' INCLUDES BOTTOM PLATE THICKNESS)			

Fig. 4.10.1d—Headed shear stud schedule.

size and spacing of shear reinforcement (Fig. 4.10.3). Along with the column schedule, typical layout information for the column reinforcement from the bottom of one level to the bottom of the next or the top of the column, is often shown in section cuts or diagrams. These diagrams should show splice locations, including locations of staggered splices and

reinforcement termination requirements. Often, spacing of the shear reinforcement at the tops and bottoms of columns varies and shown in a typical diagram on the column schedule sheet. If applicable, the following diagrams also should be included with the column schedule: basic transi-

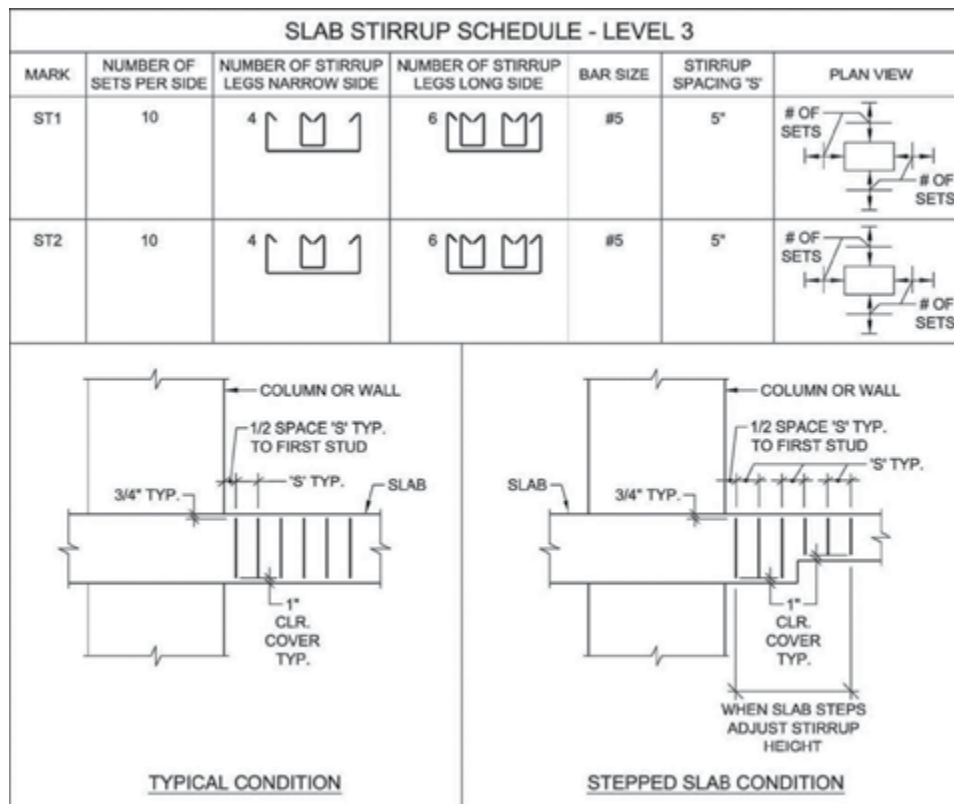


Fig. 4.10.1e—Shear stirrup schedule.

Grade beam schedule						
Mark	Size (in.) $b \times h$ 	Reinforcing			Stirrups each end	Remarks
		Top bars	Bott. bars	Mid bars	Size & spacing	
GB1	30 x 42	(8) #10	(6) #7	(2) #5 E.F.	#4 @ 18 in. o/c	
GB2	48 x 36	(10) #8	(8) #8	(1) #5 E.F.	#4 @ 16 in. o/c	
GB3	24 x 36	(6) #9	(6) #9	(1) #5 E.F.	#4 @ 16 in. o/c	
GB4	24 x 36	(4) #9	(4) #9	(1) #5 E.F.	#4 @ 16 in. o/c	
GB5	24 x 30	(3) #6	(4) #8	(1) #5 E.F.	#4 @ 12 in. o/c	
GB6	30 x 36	(4) #8	(7) #8	(1) #5 E.F.	#4 @ 16 in. o/c	
GB7	24 x 28	(5) #8	(4) #5	(1) #5 E.F.	#4 @ 12 in. o/c	
GB8	34 x 28	(2) #6	(4) #6	(1) #5 E.F.	#4 @ 12 in. o/c	
GB9	24 x 16	(4) #6	(4) #9	-	#4 @ 12 in. o/c	

Fig. 4.10.2—Example grade beam schedule.

tion from floor-to-floor, offset transitions, sloped transitions, and top of column terminations.

4.10.4 Wall schedules—Wall schedules usually contain the wall mark and amount of vertical and horizontal reinforcement for each curtain of reinforcement required.

Along with the wall schedule, typically there will be a diagram of the wall from the bottom of the wall to the top of the wall, sometimes with section cuts showing the layout information for the wall reinforcement. These diagrams should show splice locations, including locations of staggered splices if necessary. Placing location of the rein-

COLUMN SCHEDULE			
LOCATION		B-2	C-2
NO. REQD		1	1
ROOF (EL. 144'-8")	COLUMN SIZE	16" x 16"	16" Ø
	VERTICALS	4 #8 8C5	8 #8 8C5
	TIES	14 #3 3C2 @12" 	12 #3 3C16 @16" 
	LAPABOVE	2'-6"	2'-6"
4th FLOOR (EL. 132'-8")	COLUMN SIZE	16" x 16"	18" x 18"
	VERTICALS	4 #8 8C4	8 #7 7C12 8 #8 x 5-2 DWLS
	TIES	14 #3 3C2 @12" 	12 #3 3C16 @12" 2x12 #3 3C11 @12" 
	LAPABOVE	2'-6"	2'-3"
3rd FLOOR (EL. 123'-0")	COLUMN SIZE	16" x 16"	18" x 18"
	VERTICALS	4 #8 8C3	8 #8 8C9
	TIES	13 #3 3C2 @12" 	13 #3 3C10 @12" 2x13 #3 3C11 @12" 
	LAPABOVE	2'-6"	2'-6"
2nd FLOOR (EL. 112'-8")	COLUMN SIZE	16" x 16"	30" x 30"
	VERTICALS	4 #8 8C1	12 #9 9C6 8 #8 x 5-2 DWLS
	TIES	17 #3 3C2 @12" 	26 #3 3C7 @8" 4x26 #3 3C8 @8" 
	LAPABOVE	2'-6"	2'-6"
TOP/FOOTING		(EL. 98'-0")	(EL. 96'-6")

Fig. 4.10.3—Example column schedule.

forcement should be clearly shown, such as VEF (Vertical Each Face), HIF (Horizontal Inside Face), HOF (Horizontal Outside Face), HFF (Horizontal Far Face), and HNF (Horizontal Near Face). Where not clear, inside and outside faces of walls should be identified on the drawings.

4.11—Foundation sheets and schedules

Foundations are sometimes treated separately from the remainder of the structural systems because of their unique

characteristics and the fact that foundation systems are used for many superstructure types. Foundation drawings can be issued separately from the superstructure drawings, or could be the only reinforced concrete drawings on a project. Foundation sheets are commonly used for shallow foundations (Fig. 4.11) such as strip footings, isolated footings, combined footings, mat foundations, and grade beams. Foundation sheets are also used for deep foundation systems, including pile caps, piles, drilled piers, and caissons.

design intent. These considerations will help the process of producing good detailing for construction.

Design information can be represented with typical details, sections, or schedules containing the specific information for bar diameters, spacing, clearances and dimensions, construction and expansion joint locations, lap locations, and schedules. As reinforcement placement is essential to the strength of the structural members, a generic statement for reinforcement clearance might not be applicable in all cases. Therefore, critical clearances should also be shown on details when applicable so the LDP's intent is conveyed and followed. The LDP should minimize the use of multiple bar sizes when possible for ease of fabrication and placing. As this is not always achievable, the LDP should avoid specifying bar sizes less than 1/4 in. apart in diameter in a single element. Hook lengths and sizes that are different than standard hooks as defined by **ACI 318-14** Section 25.3 should be specifically noted on the construction documents. Hook lengths not specified will be assumed to be standard hooks.

Clarity in identifying the different concrete and masonry elements and their corresponding reinforcement is important for the fabrication detailer to correctly detail the reinforcement in the placing drawings.

5.1—Defining requirements for concrete cover, clearance, development, and splices

During the process of preparing the detail drawings for a project, the reinforcing steel detailer performs many calculations. These calculations fall into two general categories. The first category includes calculations made for reinforcing steel quantities, lengths, and bending dimensions based on design requirements presented in the design drawings through typical specific sections, details, or both. These types of calculations generally fall under the responsibility of the reinforcing steel detailer. The second category includes calculations made from design data for dimensions such as concrete cover, development lengths, lap splice lengths, and hook lengths. These dimensions are particularly critical because they directly affect the integrity of the structure. These types of calculations are the responsibility of the LDP, should be completed and clearly presented in the design drawings, and should not be passed on as a responsibility of the reinforcing steel detailer.

5.1.1 Calculations for reinforcement made by the reinforcing steel detailer—Reinforcing steel detailers should review and understand all design requirements that are presented in the design documents so the reinforcing bars can be detailed correctly in terms of bar size, length, bending dimensions, quantity, and placement/location within each concrete element. If conflicting or missing information is identified, reinforcing steel detailers should ask questions or request clarifications via the request for information (RFI) process, or ask questions on the placing drawings that are submitted for approval.

The LDP may consider reviewing the quantities and bar spacings presented on the placing drawings for reasonableness and general conformance with the structural design.

5.1.2 Calculations for reinforcement made by the LDP—The LDP can reduce the amount of complex or critical calculations reinforcing bar detailers are required to make. For especially complex calculations or calculations requiring design data, the LDP can also consider presenting the calculated data on their design documents. For instance, a reinforcing bar detailer should not be expected to determine if a lap splice qualifies as Class A or Class B based on analyzing the ratio of the area of bars provided versus the area of bars required. In this case, the basis for calculation is only known by the LDP. Calculations such as this should be handled while completing the design, and presented clearly on the design documents in an effort to reduce the number of RFIs, speed up both the detailing and review process, and reduce the risk of error.

5.1.3 Concrete cover—The building code considers concrete cover to be a critical element of the structure. The design drawings should clearly enumerate the design required cover. Parametric cover requirements or delegating the assessment of particular environmental judgments to the nonprofessional should be avoided.

5.1.4 Construction and expansion joints—When construction and expansion joints are not specifically shown on the contract documents, the LDP should give guidance for construction and expansion joint locations and spacing, and should review joint locations provided by contractor for compliance.

5.2—Defining bar placing configuration

5.2.1 Staggered laps—General notes should never just state, “Stagger all laps.” Staggering laps can add extra costs to a project in terms of detailing, greater number of different bar lengths, and placing. The LDP should note possible exceptions, such as for temperature steel and horizontal steel in walls.

The design documents should clearly indicate the type of stagger, such as if the stagger is a single or double lap length, or a specified dimension between the laps. A detail such as shown in Fig. 5.2.1 is a good way to show intent. Lap locations should be clearly indicated, as should those areas where laps are not allowed. Staggering of mechanical splices should be equally defined and indicated.

5.2.2 Lap splice and development length tables—Tables of lap splice and development length requirements are usually sufficient for most situations. Take care to clearly indicate special embedment locations development and appropriate instructions given to ensure they are correctly placed. The LDP should provide an appropriate table on the drawings. Examples are shown in Fig. 5.2.2.

5.2.3 Bar dimensioning—The most common bar dimensioning issue involves hooks. When the LDP indicates a dimension of a hooked bar on the drawing it should clearly indicate in the general notes or on the drawing if the dimension includes the hook length.

Reinforcing bar detailers will assume that all hooks are standard hooks unless indicated otherwise. Often, drawing sections of raft footings show the bottom and top bars hooked and lapping. If standard hooks are detailed there will

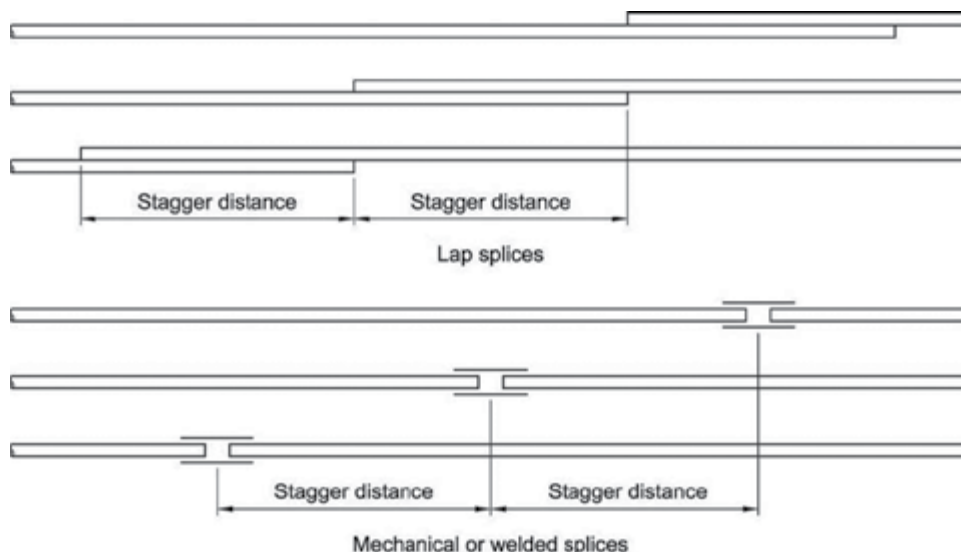


Fig. 5.2.1—Staggered lap splices and staggered mechanical splices.

be no lap. The design drawings should clearly indicate if a lap is intended and if so, dimension the lap (Fig. 5.2.3).

Where standard hooks would be too long to fit within the concrete member, the desired hook should be clearly dimensioned on the drawing.

5.2.4 Skewed bars—In plan views of trapezoidal-shaped slabs, the LDP should clearly indicate if the main bars are perpendicular to the parallel sides or parallel to the sloped sides (Fig. 5.2.4). Also indicate if the spacing of the bars is measured at right angles to the main bars or along the skew. These points should also be made clear for triangular or other irregular-shaped slabs.

Top steel over beams in skewed slabs can conflict with top bars from adjacent regular-shaped slabs and could cause layering and clearance problems. These conditions should be considered and addressed by the LDP.

5.2.5 Termination of vertical bars—The design drawings should always indicate how vertical bars are to be terminated. If the bars are to be hooked, there are several considerations as follows:

- (a) If the hook is not a standard hook, the length should be indicated
- (b) If the hook is located in either of the top layers or beneath both layers
- (c) If the member into which the hook is to be embedded is sufficiently deep enough to accommodate the curvature of the bend
- (d) If the direction of the hook is critical, it should be clearly indicated.

If nothing is indicated, hook direction will not be noted on the shop drawings and will likely be placed based on other field constraints. Member intersections can require additional consideration of bar interferences.

5.2.6 Beam stirrups—On a beam schedule, it should be clear whether a stirrup callout—for example, 3 @ 6 in.; 5 @ 9 in.; rem @ 12 in. (3 @ 150 mm; 5 @ 225 mm; rem @ 300 mm)—is referring to the number of stirrups or the number of spaces. If spacing of the first stirrup from a support is

critical, it should be indicated, otherwise it will be located one-half space from the face of support.

In multiple tie sets, indicate if these are to be a series of nested stirrups or a series of interlocking stirrups. If open stirrups are indicated, if possible, try to provide a continuous top bar in each stirrup hook. Consider a greater quantity of smaller longitudinal bars rather than fewer larger bars.

In very narrow beams, determine if the stirrup hooks will allow the top bars to fit within the tie. If critical, indicate if longitudinal bars are to be lapped in a vertical or horizontal plane. At intersecting beams, indicate if the stirrups run through one beam or the other, or through both beams.

5.3—Foundations

This section applies to nonprestressed steel reinforcement of shallow and deep structural foundations as defined by [ACI 318-14](#) Chapter 13 and includes piles, drilled piers, and caissons as further discussed in [ACI 336.3R](#) and [ACI 543R](#). Refer to Section 5.5 of [ACI 543R-12](#) for the supplemental details of deep foundations in structures assigned to Seismic Design Categories D, E, and F as prescribed by [ACI 318-14](#) Section 18.13.4.

5.3.1 Types—Generally, foundation systems are categorized as either shallow foundations or deep foundations. Shallow foundations include such types as strip footings; isolated, spread, or pad footings; mat foundations; and grade beams. Caps are typically shallow elements transferring load to deep foundations.

5.3.2 Bar arrangements—Bar arrangements vary widely based on both the foundation type and the lateral, gravity, and torsional loadings imposed on the foundations. The example reinforcing details described in this section are common arrangements. The LDP should specify appropriate bar arrangements for the various conditions.

Shallow foundations such as strip, isolated, and mat foundations often have a bar arrangement similar to that of a slab with a bottom mat, a top mat, or both bottom and top mat of reinforcement with bars in each direction. In some instances,

LAP SPLICE AND DEVELOPMENT LENGTH SCHEDULE (INCHES)						
BAR SIZE	F _c = 3,500 PSI					
	COMP		TENSION			
	LCE	LCS	LDH	LTE OTR	LTS TOP	LTS OTR LTE TOP
#3	8	12	6	15	26	20
#4	10	15	7	20	34	26
#5	13	19	9	25	43	33
#6	16	23	11	30	51	40
#7	18	27	12	44	75	58
#8	21	30	14	51	86	66
#9	23	34	16	57	97	74
#10	26	38	18	64	109	84
#11	29	43	20	72	121	93

'LCE' = COMPRESSION EMBEDMENT LENGTH
 'LCS' = COMPRESSION LAP SPLICE LENGTH
 'LDH' = HOOK DEVELOPMENT LENGTH
 'LTE' = TENSION EMBEDMENT LENGTH
 'LTS' = TENSION LAP SPLICE LENGTH

LAP SPLICE AND DEVELOPMENT LENGTH SCHEDULE (INCHES)						
BAR SIZE	F _c = 4,000 PSI					
	COMP		TENSION			
	LCE	LCS	LDH	LTE OTR	LTS TOP	LTS OTR LTE TOP
#3	8	12	6	14	24	18
#4	10	15	7	19	32	25
#5	12	19	8	24	40	31
#6	15	23	10	28	48	37
#7	17	27	12	42	70	54
#8	19	30	13	47	80	62
#9	22	34	15	54	91	70
#10	24	38	17	60	102	78
#11	27	43	19	67	113	87

'LCE' = COMPRESSION EMBEDMENT LENGTH
 'LCS' = COMPRESSION LAP SPLICE LENGTH
 'LDH' = HOOK DEVELOPMENT LENGTH
 'LTE' = TENSION EMBEDMENT LENGTH
 'LTS' = TENSION LAP SPLICE LENGTH

LAP SPLICE AND DEVELOPMENT LENGTH SCHEDULE (INCHES)						
BAR SIZE	F _c = 4,500 PSI					
	COMP		TENSION			
	LCE	LCS	LDH	LTE OTR	LTS TOP	LTS OTR LTE TOP
#3	8	12	6	14	23	18
#4	10	15	6	18	30	23
#5	12	19	8	22	38	29
#6	15	23	9	27	45	35
#7	17	27	11	39	66	51
#8	19	30	13	45	76	58
#9	22	34	14	51	85	66
#10	24	38	16	57	96	74
#11	27	43	18	63	107	82

'LCE' = COMPRESSION EMBEDMENT LENGTH
 'LCS' = COMPRESSION LAP SPLICE LENGTH
 'LDH' = HOOK DEVELOPMENT LENGTH
 'LTE' = TENSION EMBEDMENT LENGTH
 'LTS' = TENSION LAP SPLICE LENGTH

LAP SPLICE AND DEVELOPMENT LENGTH SCHEDULE (INCHES)						
BAR SIZE	F _c = 5,000 PSI					
	COMP		TENSION			
	LCE	LCS	LDH	LTE OTR	LTS TOP	LTS OTR LTE TOP
#3	8	12	6	13	22	17
#4	9	15	6	17	29	22
#5	12	19	7	21	36	28
#6	14	23	9	25	43	33
#7	16	27	10	37	63	48
#8	18	30	12	42	72	55
#9	21	34	13	48	81	62
#10	23	38	15	54	91	70
#11	26	43	17	60	101	78

'LCE' = COMPRESSION EMBEDMENT LENGTH
 'LCS' = COMPRESSION LAP SPLICE LENGTH
 'LDH' = HOOK DEVELOPMENT LENGTH
 'LTE' = TENSION EMBEDMENT LENGTH
 'LTS' = TENSION LAP SPLICE LENGTH

Fig 5.2.2—Development and lap splice table.

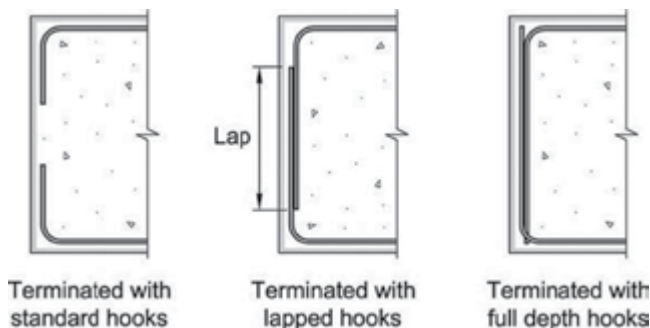


Fig. 5.2.3—Possible hook configurations at edge of raft footing.

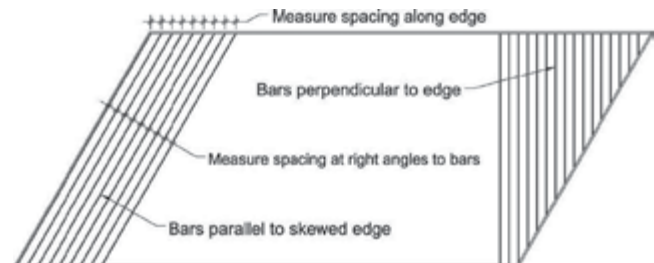


Fig. 5.2.4—Skewed slab.

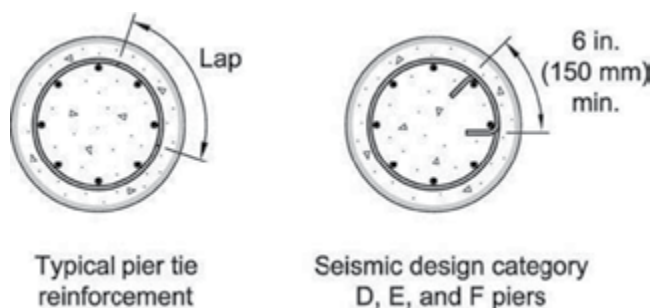


Fig. 5.3.2—Pier tie arrangements.

the bars can be required to be hooked at ends for development as prescribed by the LDP.

Grade beams and tie beams sometime span between foundation elements such as pile caps. Grade beams usually project above grade to support walls; tie beams are usually below grade and spread lateral loads to multiple deep foundations. Grade beams and tie beams have two primary reinforcement arrangements. The first is similar to a beam with reinforcing ties or stirrups, top and bottom longitudinal steel, and in some cases side longitudinal steel. The second arrangement is still similar to a beam; however, it might only have top and bottom reinforcement. Ties in the second arrangement may only be required for constructability as a method to support the top reinforcement.

Deep foundations are often round and have a bar arrangement similar to that of a round column with circular ties or a spiral around the perimeter and longitudinal steel spaced around the perimeter inside the tie. Smaller drilled piers might only have longitudinal steel that is centered in the drilled pier. In these cases, reinforcement can be added for constructability to keep the reinforcement centered in the shaft. Although reinforcement in piers is similar to that of columns, it is not fully prescribed by ACI 318 and, therefore, is often excluded from the ACI 318-14 Section 25.7.2.4.1 requirement for standard hooks at the ends of ties, except for the case of piers in Seismic Design Categories D, E, and F. Refer to Fig. 5.3.2 of this guide.

5.3.3 Bar supports—Special consideration should be given to mat foundations. Top steel support systems are commonly designed by the contractor, bar fabricator, or bar placer. Support systems for concrete foundations 4 ft (1.2 m) or more in depth should be approved by a licensed professional engineer. The supports should carry the weight of the steel and the forces created by movement of the concrete crew and others walking on the top mat. Contractors can request the use of WWR for worker safety on slabs and mat foundations, if a foot could slip between bars and fall 2 ft or more. At times, workers may have to work between the bottom and top mats. Bottom reinforcement of elements cast against the earth is usually supported on concrete or concrete blocks known as “dobies.”

Support systems can vary from simple standees to elaborate structural frames. Design of the support system should consider that the support/top mat structure is not free-standing, but requires lateral support by the formwork. The

formwork for a thick mat foundation has been designed to withstand the lateral forces of a significant head of fresh concrete. While the vertical load of the top mat is significant, the lateral forces generated within the formwork are relatively small. Plastic or concrete spacers can secure the top mat against the formwork. The need for the formwork to restrain lateral movement of the support/top mat structure should be coordinated with the formwork engineer.

5.3.4 Layering—The direction of reinforcing steel layers in foundations primarily only applies to shallow foundations because grade beams are typically reinforced, similar to beams and deep foundations are typically reinforced similar to columns as noted in 5.3.2. For strip footings, the layering might be with transverse bars bottom-most for flexural strength, but for construction efficiency in placing reinforcement, it is better to locate the longitudinal bars bottom-most. Isolated pad footing layering most often depends on the geometry of the pad footing. For square pad footings, layering can go either way. For rectangular pad footings, reinforcement along the larger dimension usually runs in the bottom and top outer layers, and the reinforcement along the shorter dimension runs inside of the outer layers. For thick mat foundations not supported by deep foundations, the layering will be similar to that of rectangular pad footings. The cases discussed previously are typical layering conditions for foundations; however, each is also dependent on the design of the foundation. Always refer to the contract documents for specific requirements. Contract documents should specifically note the layering arrangement when it is critical to the design.

All reinforcement layering should be properly supported to keep the reinforcement at the correct location in the element.

5.4—Walls

ACI 318-14 Section 2.3 defines a wall as “A vertical element designed to resist axial load, lateral load, or both, with a horizontal length-to-thickness ratio greater than 3, used to enclose or separate spaces.” Concrete walls are structural elements that are generally used as vertical- and lateral-force-resisting members. Walls may be used in underground or aboveground tanks to contain liquids, as retaining walls, or for providing one-sided lateral confinement for soil or other materials, and for providing continuous support for floor or roof systems, in which case they should absorb and resist all reactions from these systems.

This section applies to steel reinforcement of nonprestressed ordinary structural walls, including: cast-in-place, precast in-plant and precast on-site, and tilt-up construction as defined in ACI 318-14 Chapter 11.

5.4.1 General—Steel reinforcement should be provided in walls to resist all in-plane and out-of-plane forces acting on ordinary structural walls, as shown in Fig. 5.4.1 of this guide (ACI 318-14 Chapter 11). Walls subjected to these forces will require longitudinal and transverse reinforcement, as well as additional reinforcement around openings. Design requirements are contained in ACI 318-14 Sections 11.3, 11.4 and 11.5.

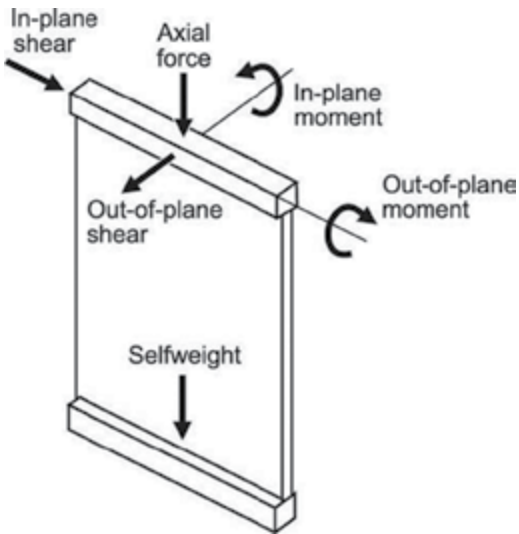


Fig. 5.4.1—In-plane and out-of-plane forces (ACI 318-14).

Cantilever retaining walls should be designed in accordance with ACI 318-14 Sections 22.2 through 22.4 with minimum horizontal reinforcement in accordance with Section 11.6.

5.4.2 Reinforcement design considerations (ACI 318-14)—Reinforcement limits for vertical and horizontal bars are indicated in Sections 11.6.1 and 11.6.2 for relative values of V_u (factored shear force). General bar design details should conform to Section 11.7. Concrete cover for reinforcement should conform to Table 20.6.1.3.1. Development lengths and splice lengths of reinforcement should be in accordance with Sections 25.4 and 25.5, respectively. Distribution and spacing of transverse and longitudinal reinforcement should conform to Sections 11.7.2 and 11.7.3. In ordinary structural walls, if longitudinal reinforcement is required for axial strength, or if A_{sr} exceeds $0.01A_g$, longitudinal reinforcement should be laterally supported by transverse ties. In all walls, reinforcement is required around wall openings (ACI 318-14 Section 11.7.5).

5.4.3 Best practices—For constructability purposes as shown in Fig. 5.4.3, reinforcement on both faces of a wall should be equally spaced; or that spacing of bars on one face be a multiple of the bars on the other face; or that spacing of bars at each face be multiple of a common value, for example: 2, 3, or 4 in., (50, 75, or 100 mm). These practices facilitate formwork tie locations and installation.

For constructability, transverse or horizontal reinforcing bars are often placed closest to wall face and conform to cover limits mentioned in ACI 318-14 Table 20.6.1.3.1. Trim reinforcement is required in both directions around openings as well as diagonally at the corners of openings. As a rule of thumb, trim bars should be at least equal in area to the bars interrupted by the openings, and consist of at least two No. 5 (No. 16) bars, anchored to develop f_y in tension.

5.4.3.1 Footing to wall connections—In cantilever retaining walls, vertical projecting reinforcement should extend through the depth of the wall footing and be anchored on top of the footing bottom reinforcement. The footing

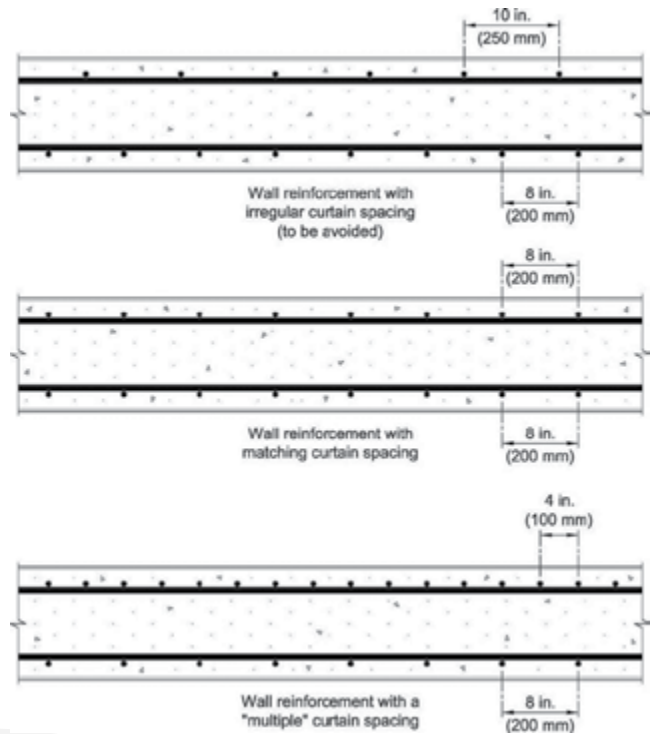


Fig. 5.4.3—Various spacing arrangements.

thickness should be such as to permit the vertical reinforcing bar standard hooks to be correctly anchored a distance ℓ_{dh} .

5.4.3.2 Corners and intersections—As shown in Fig. 5.4.3.2a, horizontal wall reinforcement should be anchored in vertical wall corners and intersections. To achieve proper anchorage, the bar should be extended across the intersection so that the end hook will be placed at the opposite (outer) face of the intersecting wall at corners and T-intersections.

Occasionally, additional diagonally placed horizontal reinforcement (Fig. 5.4.3.2b) is necessary to resist shear forces and help avoid opening of cracks at the corner or intersection. The additional bar is usually accommodated in a corner fillet and should extend to the opposite face of each intersecting wall, terminating with a bar bend at least equal to the bar development length (ℓ_d).

A typical design detail of the correct bar arrangement at wall corners and midlength intersections will clarify the design intent. This information will help the detailer provide correct dimensioning and placing of reinforcing bars and avoid errors that could compromise the structural integrity of the walls.

5.4.3.3 Steps and sectional transitions—Steps and sectional transitions at base of walls should have design details showing the transitional reinforcement. Steel reinforcement across wall steps or sectional transitions should comply with ACI 318-14 Chapter 25. Attention should be given to providing continuous and correctly anchored reinforcement across any section change.

5.4.3.4 Multiple curtains and layers—Generally, walls are reinforced with a single curtain with two layers of steel at right angles to each other, or with two curtains of steel, one on each face, with each curtain consisting of two layers of

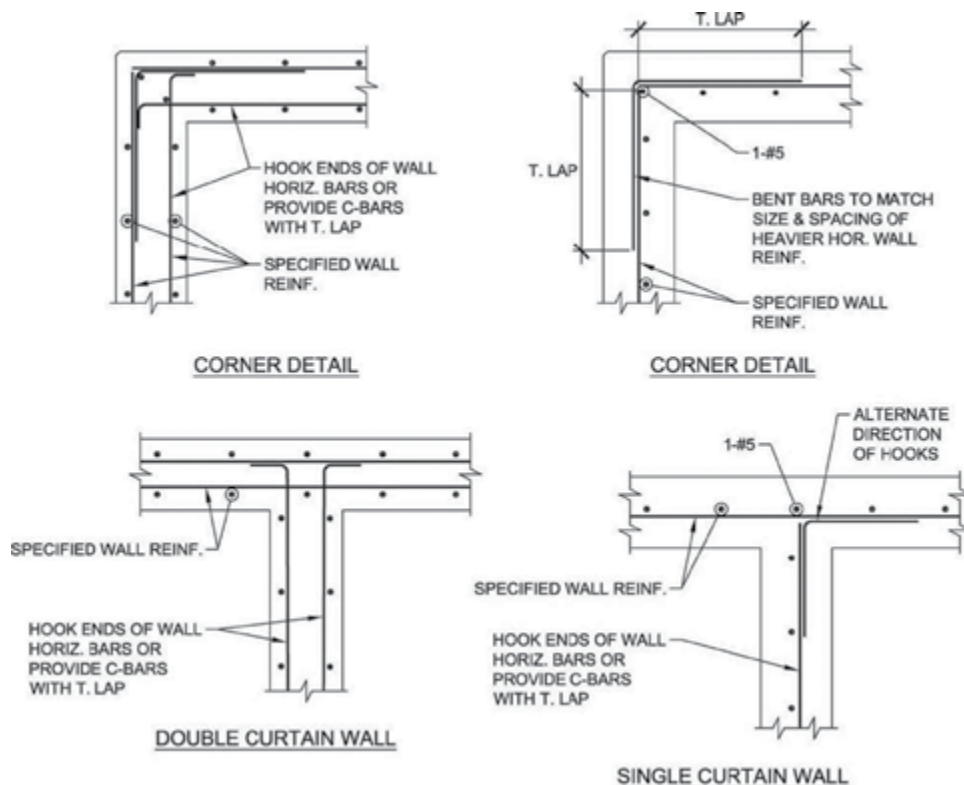


Fig 5.4.3.2a—Wall corner and intersection details.

steel at right angles to each other. Sometimes a curtain is made up of more than the usual two layers. In Fig. 5.4.3.4, Curtain A has the usual two layers of steel—one vertical, and one horizontal. Curtain B has three layers—two vertical and one horizontal. Curtain C has four layers of steel—two vertical and two horizontal.

When designing multiple layers of steel, such as in Curtains B and C, there are three considerations that will help to avoid concrete consolidation problems around and between the bars and the form:

- (a) Place the larger bars in the outer layers of the member
- (b) Space bars at the same dimension or multiples of that dimension in all layers
- (c) Use only one bar size in a given layer

Frequently, designing curtains with more than the usual two layers of steel will cause spatial problems that affect clearances and constructability. Attention should be given to potential problems that can occur at wall corners and when staggering laps. The designer should consider using larger bar sizes, higher-strength steel, closer spacing, bundled bars, or a combination of these to avoid the need for multiple layers of reinforcing bars. Space between parallel bars should be adequate for the maximum size aggregate used and a vibrator to be inserted between the bars for consolidating the concrete.

5.4.3.5 Design details at joints and waterstops—The design details for reinforcement continuity or termination at wall joints with or without waterstops should be provided.

Construction joints are vertical or horizontal joints that are intentionally created between two successive placements of

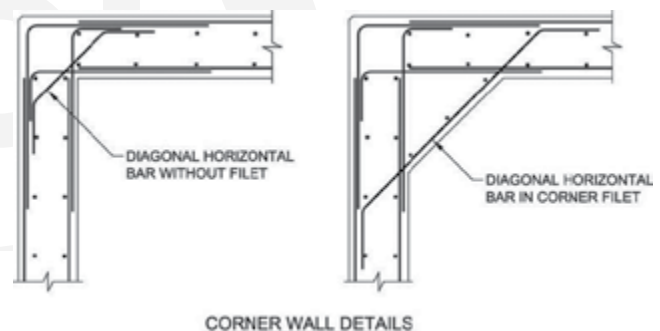


Fig 5.4.3.2b—Wall corner details.

concrete. Shear keys can be used to increase the shear resistance at the joint. If keys are not used, the surface of the first pour should be cleaned and roughened as required per the construction documents before the next concrete pour. Keys are commonly formed in the wall base to give the stem more sliding resistance. Wall reinforcement is placed continuously across the joint (Fig. 5.4.3.5a).

Contraction joints are joints formed, sawed, or tool-grooved in a concrete structure to create a weakened plane to regulate the location of cracking resulting from the dimensional change of different parts of the structure. In walls, vertical contraction joints are usually about 1/4 in. (5 to 6 mm) wide and approximately 1/2 to 3/4 in. (12 to 20 mm) deep, and are provided at various intervals, depending on wall height, thickness, and amount of reinforcement, but usually not exceeding approximately 30 ft (9 to 10 m). Wall reinforcement is placed continuously across the joint (Fig. 5.4.3.5b).

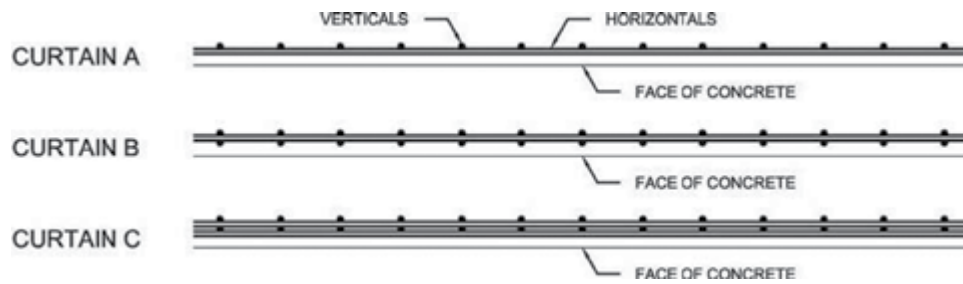


Fig. 5.4.3.4—Wall reinforcement curtain arrangements.

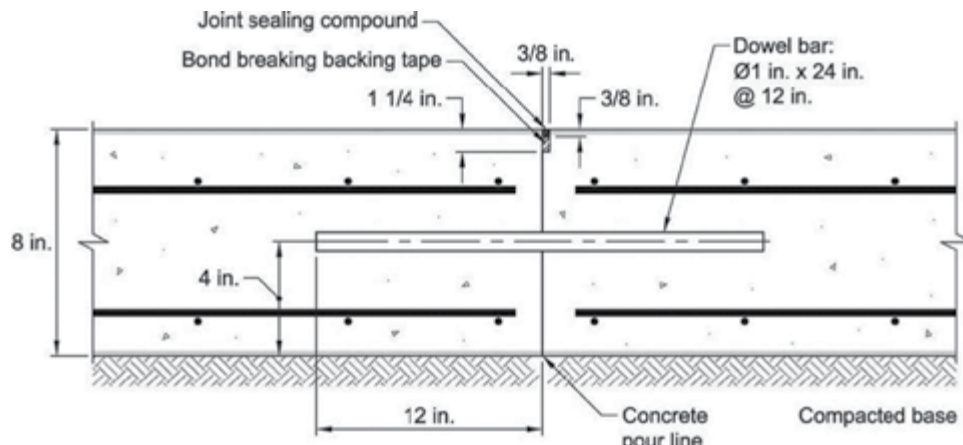


Fig. 5.4.3.5a—Detail of a wall construction joint.

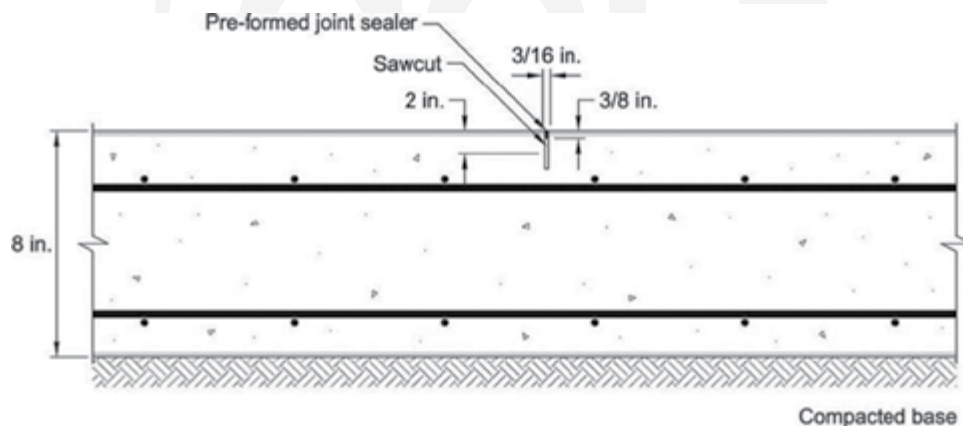


Fig. 5.4.3.5b—Detail of a wall contraction joint.

Expansion joints are a separation provided between adjacent sections of a concrete structure to allow movement due to dimensional increases and reductions of the adjacent sections, and through which some or all the bonded reinforcement is interrupted. In walls, horizontal greased dowels are usually placed across vertical joints to tie adjacent sections together. Expansion joints are located at various intervals, depending on wall dimensions, but should not be spaced more than 75 to 90 ft (25 to 30 m) apart. Wall reinforcement is discontinuous across the joint, not placed across the joint but rather terminated at each joint face (Fig. 5.4.3.5c).

Waterstops are thin sheets of metal, rubber, plastic, or other material inserted across a joint to obstruct the seepage of water

through the joint. They should be embedded equally in each side of the joint. There are various sections that can be used for the different types of joints named previously. In addition to molded waterstops that are embedded in concrete across the joint, there are adhesive-type waterstops that do not interfere with the reinforcement. These are strips of rubber and mastic that adhere to the surface of set concrete. The next placement of concrete compresses the rubber strip to form a watertight seal between the two placements of concrete. Steel reinforcement design details should be developed with consideration of the waterstop to be used in the joint. An example design detail for a waterstop and the effect of depressing the slab top reinforcement is shown in Fig. 5.4.3.5d.