

Dimensions of Sloped Walls and a Clarification to Mechanical Splice Staggering (RFI 11-10)

In this month's Detailing Corner, we examine dimensions of sloped walls and how they can affect the reinforcing bar details. In addition, we provide a clarification to the August 2011 *Concrete International* article, "Detailing Concrete Columns," in response to an RFI from members of Joint ACI-ASCE Committee 408, Development and Splicing of Deformed Bars. We thank those who contacted us and encourage all readers to participate in this forum.

Sloped Wall Dimensions

Know your height

Dimensioning wall heights on a slope can be confusing, depending on the height desired for the wall. Figure 1 shows a 10 ft 0 in. (3.05 m) high wall that follows the existing grade with an approximately constant slope. It's customary to dimension the height of a wall along a vertical (plumb) line. This gives a wall a uniform height along its entire length, provided the wall slope is uniform. In Fig. 1, the A dimension will be less than the 10 ft dimensioned height along a plumb line, but this dimension nevertheless remains uniform along the wall's entire length.

Figure 2 illustrates a somewhat exaggerated condition where the grade starts at a gradual slope on the left and becomes steeper on the right. In this case, the slope of the wall is not uniform along the entire length. Dimensioning the height of the wall as 10 ft 0 in. (3.05 m) along the vertical gives a wall of uniform height along its entire length, but the dimension of the wall along a line perpendicular to the

bottom of the wall is increasingly shorter from the left to the right. From this point of view, this wall is not uniform in height along its entire length. This may or may not be a concern, depending on the wall's intended purpose and/or aesthetic requirements.



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

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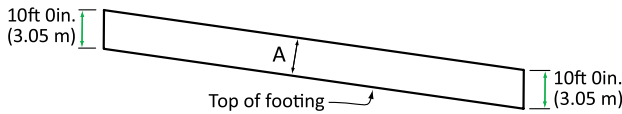


Fig. 1: Wall with a uniform slope

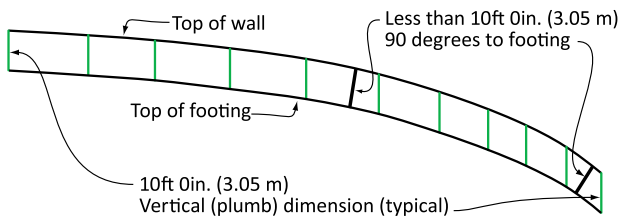


Fig. 2: Wall with a nonuniform slope. Dimension of wall perpendicular to the bottom becomes increasingly smaller as the slope of the grade increases

As to where this may be an issue, consider this wall as one of the sides of a lined, three-sided water channel or a covered water flume. The cross-sectional area of the channel or flume must be constant to provide the necessary drainage capacity, so dimensioning the actual height vertically along a plumb line would be incorrect. The dimension perpendicular to the bottom of the wall is the critical height dimension to maintain the waterway opening, and thus would have to be constant. In such an instance, the vertical plumb dimension would vary, increasing as the slope becomes steeper.

Assuming that the wall can be detailed with a varying vertical (plumb) dimension as shown in Fig. 2, the spacing between “horizontal” wall bars will have to decrease for all of the bars to fit in the wall, moving left to right. Note that the term “horizontal” is used rather loosely here, as it actually refers to the reinforcing bars parallel to the bottom of the wall on the slope. In other words, the bar spacing will narrow so all the bars can fit as the wall gets shorter at the right end, so congestion of the bars may become an issue and minimum bar spacing may need to be verified.

Alternately, as the wall gets shorter at the right end, some of the horizontal runs of bars may be discontinued to maintain a more uniform or consistent spacing of the bars in the wall.

Stairs

The issue illustrated in Fig. 2 arises frequently in dimensioning parapets along stairways with landings. For instance, in Fig. 3, the parapet will usually carry a single dimension; in this case, the 4 ft 0 in. (1.22 m) along the vertical is normally dimensioned on the left only. It's obvious that this dimension

holds for the portions of the wall at the upper and lower landings. But at the sloped section at the stairway, what is the intended height of the parapet? More appropriately, what is the architect or the designer (you) expecting?

One possible solution could be as shown in Fig. 3(a). From an architectural point of view, this condition is not visually appealing, and a shorter wall height within the stair run may result in a wall height that doesn't meet the code requirements for railing height—something to watch.

Figure 3(b) presents a more visually appealing solution because the concrete band appears to be a constant dimension. However, it does present a slight issue. The height from the slab and stair to the top of the parapet must be constant, yet the vertical dimension at the stair is greater than at the upper or lower slab levels. Architects typically solve this dilemma by locating the parapet soffit below the slab and stair soffits to compensate for the discrepancy in dimensions. By constructing the wall in this manner, the rail height above the stair and landings can be consistent and the wall will appear to have a constant height.

Design considerations

The designer must be aware that the method of dimensioning has critical ramifications, especially when considering sloped concrete elements exposed to view. The designer must determine which dimension is critical in each particular instance and be sure it is presented clearly and unambiguously.

RFI 11-10: In the August 2011 *Concrete International* Detailing Corner article, “Detailing Concrete Columns,” the following statement is made:

“ACI 318-08 requires mechanical splices be staggered, which results in both short and long vertical bars in the column run.”

Unfortunately, this maintains the old mythology of staggering being required at all times, which is not necessarily the case. Because staggering is difficult to detail and a costly option to produce, this issue needs clarification.

ACI 318-08¹ requires staggering only when the mechanical splice strength is less than Type 1 (namely, less than 125% of the specified yield strength, f_y , of the reinforcement), or when full mechanical splices are used in tension tie members. In today's domestic (U.S.) market, there are no mechanical splices promoted with design strengths less than Type 1. Thus, the general case is that staggering is not required. In fact, Commentary Section R12.15.5 of ACI 318-08 states, in part: “A full mechanical or welded splice conforming to 12.14.3.2 or 12.14.3.4 can be used without the stagger requirement instead of the lower strength mechanical splice.”

Response: You are correct in that the ACI 318-08¹ (and now ACI 318-11²) building code requires staggering of

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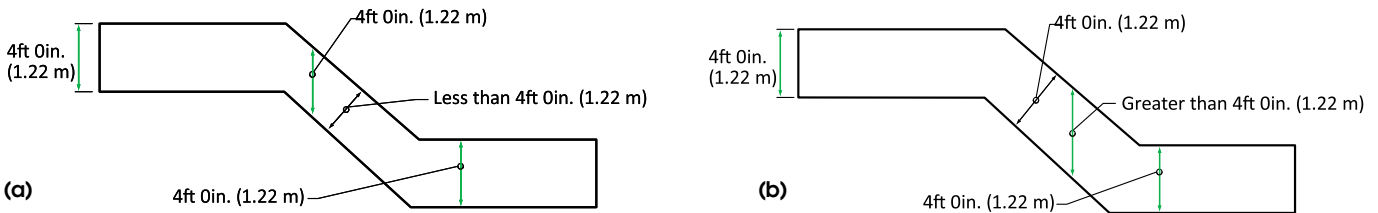


Fig. 3: Concrete parapet wall along a stair and landings: (a) if the vertical height of the parapet remains constant, the proportions are not correct, and the rail height may violate code requirements; and (b) if the vertical height is maintained from the landings to the sloped portion at the stair, the proportions are more balanced

mechanical splices only when they do not meet Type 1 requirements or when used in tension tie members. However, there are several other points to consider regarding the issue of staggering, whether it concerns mechanical splices, lap splices, or hooked reinforcement. Some of these issues are code-related, whereas others are constructibility-focused:

The Commentary to ACI 318-11² acknowledges the benefits of staggering, such as the staggering of bar cutoffs in bundles (Section R7.6.6), staggering hooks within a bundle (Section R7.6.6), staggering tie hooks (Section R7.10.5), and staggering the heads of headed bars (Section R12.6). Section R12.15.4 reads, in part: “..when located in regions of high tensile stress in the reinforcement. Such splices need not be staggered, **although such staggering is encouraged where the area of reinforcement provided is less than twice that required by the analysis**” [emphasis added].

In the AASHTO *LRFD Bridge Design Specifications*,³ there are no stagger requirements when a mechanical splice conforms to the Type 1 ACI equivalent requirements. However, there are some requirements regarding staggering for other cases. Clause 5.11.5.3.2 notes that “mechanical connections or welded splices, used where the area of reinforcement provided is at least twice that required by analysis and where the splices are staggered at least 24.0 in. (600 mm), may be designed to develop not less than either twice the tensile force

effect in the bar at the section or half the minimum specified yield strength of the reinforcement.” In addition, Clause 5.11.5.4 requires “splices of reinforcement in tension tie members shall be made only with either full-welded splices or full-mechanical connections. Splices in adjacent bars shall be staggered not less than 30.0 in. (750 mm) apart.”

The Canadian Standards Association’s (CSA) “Design of Concrete Structures,” CSA A23.3-04,⁴ has similar language to the preceding Item 2 (Clause 12.15.4). Finally, the ACI 343R⁵ report “Analysis and Design of Reinforced Concrete Bridge Structures” also has similar language for mechanical splices (Section 13.2.15.a).

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The CSA Canadian Highway Bridge Design Code CAN/CSA-S6-06⁶ (Clause 8.15.9.3) requires that all mechanical splices in components subjected to axial tension shall be staggered at least 32 in. (800 mm).

And a sampling of state Department of Transportation (DOT) Bridge Design Specifications reveals that several states, including California, Illinois, New York, Pennsylvania, and Wisconsin, require all splices be staggered a specific distance, whereas some DOTs require splices be staggered “as far as possible.”

The ACI Committee 439⁷ report, “Types of Mechanical Splices for Reinforcing Bars,” has some good information regarding splice staggering. In Section 1.3.1, “Spacing and Cover Requirements,” the following is presented:

“Clearance limits for mechanical splices may be a factor in the selection and positioning of the appropriate mechanical splice. The outside diameter of the mechanical splice should be known. Up-to-date dimensional data should be obtained from the splice manufacturer. By knowing the diameter of the mechanical splice, the engineer/specifier can decide whether the mechanical splices need to be staggered on the basis of the clearance required. For constructibility reasons, mechanical splices are usually best located in the same plane or elevation. There is little justification for staggering mechanical splices solely to prevent undesirable failure modes that are associated with lap splices because, unlike lap splices, the ability of mechanical splices to carry and transfer load from bar-to-bar is not affected by concrete cover or the compressive strength of concrete. Nevertheless, it has been the practice of some

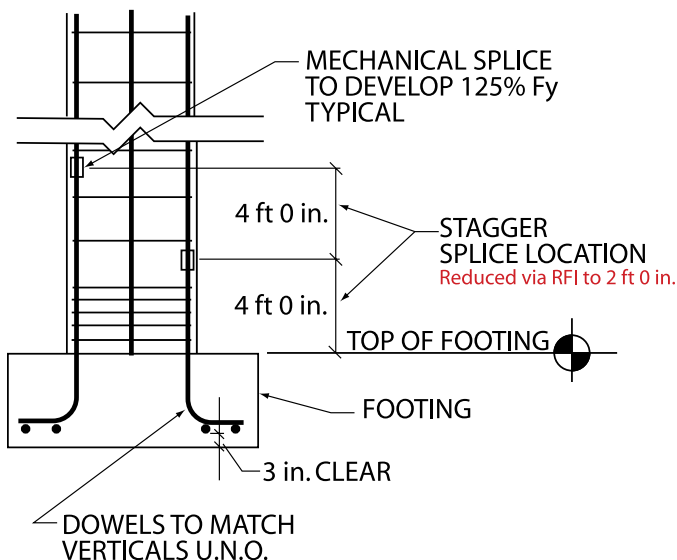


Fig. 4: An example of a project detail showing staggered mechanical splices in a column (1 in. = 25.4 mm; 1 ft = 0.3048 m)

designers in the past to stagger mechanical splices as if they were lap splices. Pending any future code revisions, however, the minimum stagger length should be checked and specified by the engineer only when required to be consistent with an applicable code section, such as the provisions in Chapter 12 of ACI 318 related to splices that do not meet Type 1 or 2 requirements.”

Section 1.3.5 of this document has further discussion regarding field erection. It states:

“In many applications, mechanical splices may be staggered for clearance, access, and code requirements. If staggered mechanical splices are used in columns, for example, free-standing erection and assembly of the reinforcement may be required rather than preassembled cages, thus necessitating use of external bracing or formwork to hold bars while completing splices.

“There is a considerable difference in the time and equipment required to install different mechanical splices. Therefore, the field erection procedure and schedule should be coordinated with the selection and installation procedure of the mechanical splices. If special equipment is required, particular information regarding its size, weight, operation, and availability should be obtained from the supplier or splice manufacturer.”

Although staggering of mechanical splices may be construed as legacy thinking in design, there may be good reasons for this. Clearly, from the preceding discussion, the mechanical splices could all be located at the same elevation without compromising strength. With higher percentages of vertical column reinforcement, this may give rise to congestion at the splice elevation, depending on the mechanical splice type used—this may or may not be a consideration. Furthermore, some types of construction rely on having splices at the same elevation; as an example, precast columns oftentimes use a grouted-sleeve mechanical splice to establish continuity.

An informal poll of CRSI detailer/fabricator members showed that mechanical splices are staggered for the majority of cases, as indicated on the designer’s structural drawings. A portion of a detail from a project is shown in Fig. 4. (As a side note to the detail shown in Fig. 4, a project RFI asked to lower the elevation of the second splice line. This would allow the ironworkers to stand on the footing and reach the upper coupler, without needing to use a ladder.)

Two benefits of staggering were cited: (1) staggering helps provide adequate room for installation of the mechanical splices, especially if tools are needed to facilitate completion of the splice; and (2) staggering reduces congestion around the splices, which facilitates meeting the spacing requirements of Section 7.6.3 of the ACI 318-11² code. This section requires the clear spacing between longitudinal bars be at least 1.5 in. and $1.5d_b$ (d_b is the bar diameter). In the case of bars that are

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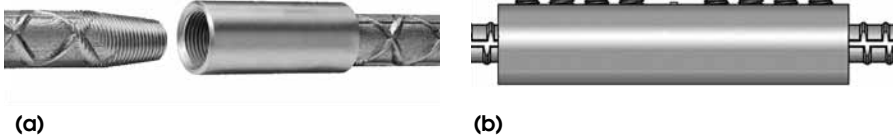


Fig. 5: Mechanical splices: (a) taper-threaded and (b) shear screw sleeve⁷

mechanically spliced, the clear spacing requirement is traditionally applied to the spacing between neighboring splices, although this section does not specifically address clearance limits for mechanical splices. A closer spacing may prohibit the concrete from fully encapsulating the splicing device, similar to the bars being lap spliced. The inquiry stated that the staggering of mechanical splices is “difficult to detail and a costly option to produce.” From Fig. 4 and items addressed previously, it would seem that staggering has a minimal impact on cost and could actually enhance constructibility.

With these points in mind, we’d like to offer the following revision to the statement in the August *CI* article:

“Although ACI 318-08 does not require the staggering of mechanical splices for the general case, other codes may require this in certain instances. Staggering of mechanical splices may actually be preferred from the standpoint of constructibility. If the splices are staggered, this will result in both short and long vertical bars in the column run.”

When accommodating mechanical splices in design and construction, it would be helpful to have some idea of the overall dimensions for a typical splice. Although these dimensions vary due to the numerous types of splices available, two general types from various manufacturers were studied—the taper-threaded coupler and the shear screw coupling sleeve (Fig. 5). A conservative length and diameter was determined from these representative mechanical splices, expressed as a multiple of the spliced bar diameter. The rough working dimensions are $3d_b$ to $4d_b$ for length and $1.5d_b$ for

diameter of taper-threaded splices, and $13d_b$ to $14d_b$ for length and $3d_b$ for diameter of shear screw couplers; d_b is the spliced bar diameter, as stated previously. These approximate dimensions can be used when checking clear spacing or the layout of staggered splices if required for adequate clear spacing.

References

1. ACI Committee 318, “Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary,” American Concrete Institute, Farmington Hills, MI, 2008, 473 pp.
2. ACI Committee 318, “Building Code Requirements for Structural Concrete (ACI 318-11) and Commentary,” American Concrete Institute, Farmington Hills, MI, 2011, 503 pp.
3. *LRFD Bridge Design Specifications (Customary U.S. Units)*, fourth edition, American Association of State Highway and Transportation Officials, Washington, DC, 2007, 1822 pp.
4. CAN/CSA-A23.3-04, “Design of Concrete Structures,” Canadian Standards Association, Mississauga, ON, Canada, 2004, 258 pp.
5. Joint ACI-ASCE Committee 343, “Analysis and Design of Reinforced Concrete Bridge Structures (ACI 343R-95) (Reapproved 2004),” American Concrete Institute, Farmington Hills, MI, 2004, 158 pp.
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7. ACI Committee 439, “Types of Mechanical Splices for Reinforcing Bars (ACI 439.3R-07),” American Concrete Institute, Farmington Hills, MI, 2007, 20 pp.

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