ACI 318-25 Changes to Anchorage and Reinforcing Bar Provisions

ACI 318-25 anchoring provisions reduce conservatism, clarify usage, and account for the effects of reliability and redundancy, plus major updates to breakout calculation of reinforcing bar groups have been added.

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"Anchorage" in concrete is a broadly used term that can refer to concrete members, including pre-stressing anchorage devices, connections between concrete members via reinforcing bars, and connections between steel and concrete members via steel anchoring elements. While these various anchorage types possess common principles in force transfer, they have traditionally been treated as mutually exclusive in code provisions.

The American Concrete Institute's ACI 318-25, *Building Code Requirements for Structural Concrete*, introduces major changes to the anchorage of steel-to-concrete and reinforcing bar connections. In addition to updates to factors within existing equations, steps toward recognizing the commonalities between steel/concrete and concrete/concrete anchorage in "Chapter 17: Anchoring to Concrete and Chapter 25: Reinforcement Details" have been made.

This article focuses on major changes relating to anchorage in ACI 318-25 Chapter 17 and Chapter 25. Changes to Chapter 17 address inefficiencies and reliability concepts, while changes to Chapter 25 include new bridging provisions to Chapter 17 in the treatment of concrete breakout failure.

Changes to Chapter 17: Anchoring to Concrete in ACI 318-25

ACI 318 Chapter 17 provides design requirements for anchorage between steel and concrete members. The scope of Chapter 17 includes cast-in headed anchors, post-installed mechanical and adhesive anchors, and shear lugs. Failure modes incorporated into Chapter 17 for shear and tension design checks are summarized in Table 17.5.2. Section 17.8 addresses interaction between tension and shear failure modes.

This section examines five major changes to the design provisions:

Change 1: Updates to safety factors.

Change 2: Introduction of a beneficial overturning moment term.

Change 3: Beneficial separation of concrete and steel failure modes in interaction equations.

Change 4: Permissible use of new Chapter 25 factors for use of existing reinforcement.

Change 5: Clarifications on use of reinforcing bars as anchor reinforcement.

In addition to the five technical changes presented, clarifying editorial changes have been made throughout Chapter 17.

Chapter 17 Change 1: Updates to Safety Factors

In ACI 318-19, the strength reduction factors, ϕ, for anchorage are defined in Chapter 17 in contrast to other Chapters whose ϕ factors are housed in Chapter 21. The Chapter 17 factors were primarily separated to address product-specific sensitivity and reliability characteristics via an "Anchor Category" assignment from qualification.

In ACI 318-25, ϕ factors have been moved to Chapter 21 to be consistent with the remainder of the document. Anchor Category adjustments and the supplementary reinforcement condition have been decoupled from ϕ and separated into a new modification factor, ψ_a. All equations relating to concrete failure modes for post-installed mechanical or adhesive anchors have now been changed to incorporate this additional ψ_a factor. Finally, a new distinction between redundant and non-redundant fastenings has been made, providing a capacity benefit for fastenings that are considered redundant. Commentary on the redundancy of anchors is provided in a revised R17.5.3, which states that "Redundancy may be assumed where it can be shown that failure of a single anchor or anchorage point does not result in loss of position retention or progressive collapse." While every case will require engineering judgment to determine whether a fastening is redundant or not, an example of a redundant fastening might be a line of single-point fastenings of a pipe to a ceiling where failure of any individual anchor does not result in progressive failure of nearby anchors or failure of any other component in the load path. Another example in a group of anchors might be demonstrating that failure of any individual anchor will not cause failure of the anchor group, the base plate, or any components within the load path.

Table 1 provides the new anchor-related ϕ factors in Chapter 21 in ACI 318-25. Table 2 compares the outputs of the new $\phi \cdot \psi_a$ product for concrete tension failure modes in ACI 318-25 compared to the equivalent ϕ factor in ACI 318-19. It can be observed that the $\phi \cdot \psi_a$ product for redundant connections in ACI 318-25 is roughly equivalent to the ϕ factors in ACI 318-19, while the capacities of non-redundant connections are reduced by 10 to 15 percent. Table 3 compares the safety outputs between the two code editions for concrete shear failure modes.

Table 1. New Anchor-related Factors in ACI 318-25 Chapter 21

Description	ϕ
Anchorage of reinforcing bars	0.75
Anchor reinforcement in accordance with Sect. 17.5.2.1	0.90
Concrete failure of anchors in tension, non-redundant	0.65
Concrete failure of anchors in tension, redundant	0.75
Concrete failure of anchors in shear	0.75
Anchor steel, tension, ductile	0.75
Anchor steel, tension, nonductile	0.65
Anchor steel, shear, ductile	0.65
Anchor steel, shear, nonductile	0.60

Table 2. Comparison Between 2019 and 2025 Safety Factors for Concrete Tension Failure Modes in Chapter 17

Variables			**ACI-318-19**	**ACI 318-25**				
				ψ_a	Redundant		Non-redundant	
Condition	Type	Cat.	ϕ		ϕ	$\phi \times \psi_a$	ϕ	$\phi \times \psi_a$
Supplementary reinforcement not present	*Cast-in*	*n/a*	*0.70*	*0.95*	*0.75*	*0.71*	*0.65*	*0.62*
	Post-installed	*1*	*0.65*	*0.85*		*0.64*		*0.55*
		2	*0.55*	*0.75*		*0.56*		*0.49*
		3	*0.45*	*0.60*		*0.45*		*0.39*
Supplementary reinforcement present*	*Cast-in*	*n/a*	*0.75*	*1.0*		*0.75*		*0.65*
	Post-installed	*1*	*0.75*	*1.0*		*0.75*		*0.65*
		2	*0.65*	*0.85*		*0.64*		*0.55*
		3	*0.55*	*0.75*		*0.56*		*0.49*

Table 3. Comparison Between 2019 and 2025 Safety Factors for Concrete Shear Failure Modes in Chapter 17

Condition	**318-19**		**318-25**	
	ϕ	ψ_a	ϕ	$\phi \times \psi_a$
Supplementary reinforcement not present	*0.70*	*0.95*	*0.75*	*0.71*
Supplementary reinforcement present*	*0.75*	*1.0*		*0.75*

**Supplementary reinforcement factors do not apply to pullout strength in ACI 318-19, but do apply to pullout strength in ACI 318-25.*

Chapter 17 Change 2: Introduction of a Beneficial Term to Account for Compression Due to Connection Overturning Moment

ACI 318-25 introduces a new strength-increasing factor, $\psi_{cm,N}$, in Section 17.6.2.7 for concrete breakout in tension to account for the positive influence of the compressive toe of an overturning connection moment. While the behavior described by this factor is related in principle to a concrete strut, it does not function the same because the anchorage condition includes an unconfined concrete surface that does not produce the same triaxial stress state as a strut within a concrete mass. The new Equation (17.6.2.7.1) is provided below.

$$\Psi_{cm,N} = 2 - \frac{z}{1.5h_{ef}} \geq 1.0 \qquad \text{CI 318-25 Eq. (17.6.2.7.1)}$$

Figure 1 (left) illustrates the variables included in the calculation of $\psi_{cm,N}$ and Figure 1 (right) shows the influence of the ratio of the internal lever arm to the embedment depth of the anchor group.

Chapter 17 Change 3: Beneficial Separation of Failure Modes in Interaction Equations

ACI 318-19 conservatively simplifies the interaction between tensile and shear failure modes by determining the governing tensile failure mode and the governing shear failure mode and combining them into a single interaction equation. By reducing all failure modes to a single interaction equation, ACI 318-19 allows for the possibility that a governing concrete failure mode interacts with a governing steel failure mode. A flowchart of the interaction between tension and shear in ACI 318-19 is shown in Figure 2.

However, it is well understood that concrete failure modes only interact with other concrete failure modes and steel failure modes only interact with other steel failure modes. Recognizing that concrete and steel failure modes behave separately and also recognizing that a simplified interaction calculation is not necessary to simplify the design process, ACI 318-25 separates interaction into three equations, one for concrete failure of individual anchors, one for concrete failure of anchor groups, and one for steel failure. By separating steel and concrete interaction, unnecessary conservatism is removed, producing more efficient designs in many cases. A flowchart of the interaction between tension and shear in ACI 318-25 is shown in Figure 3.

Chapter 17 Change 4: Permissible Use of New Chapter 25 Factors for Use of Existing Reinforcement

The use of the new Chapter 25 Eq. (25.4.11.2) is permitted to be used for calculation of tensile breakout capacity of anchors in the new Section 17.1.9 of ACI 318-25. See the "Change 1" section of Chapter 25. When

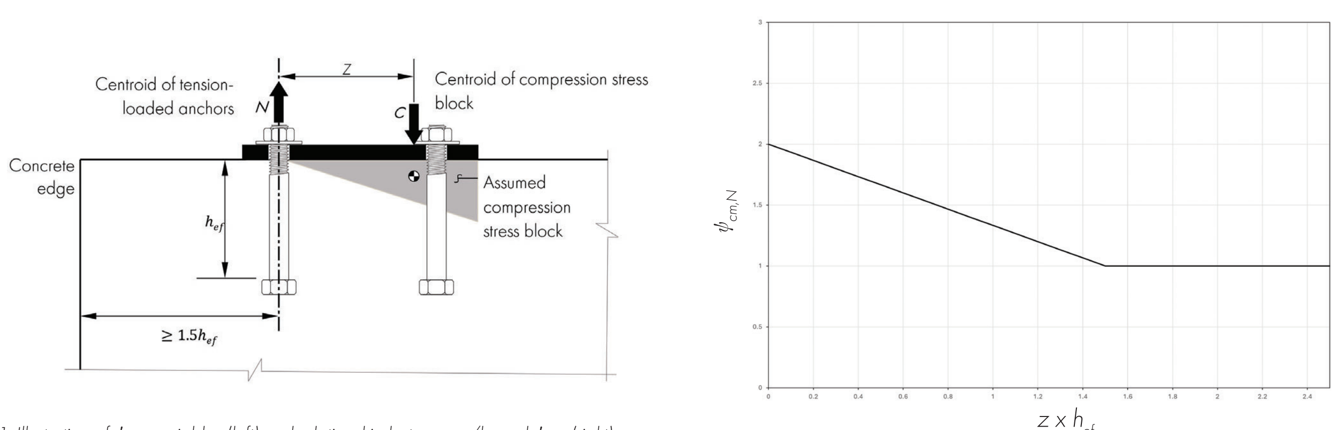

Fig. 1. Illustration of $\psi_{cm,N}$ variables (left) and relationship between z/h_{ef} and $\psi_{cm,N}$ (right).

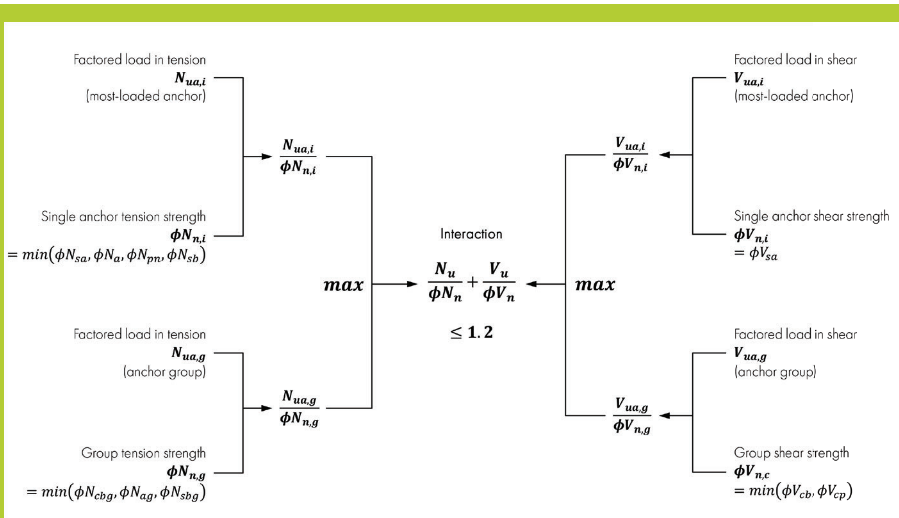

Fig. 2. Flowchart for the interaction equation in ACI 318-19 Chapter 17.

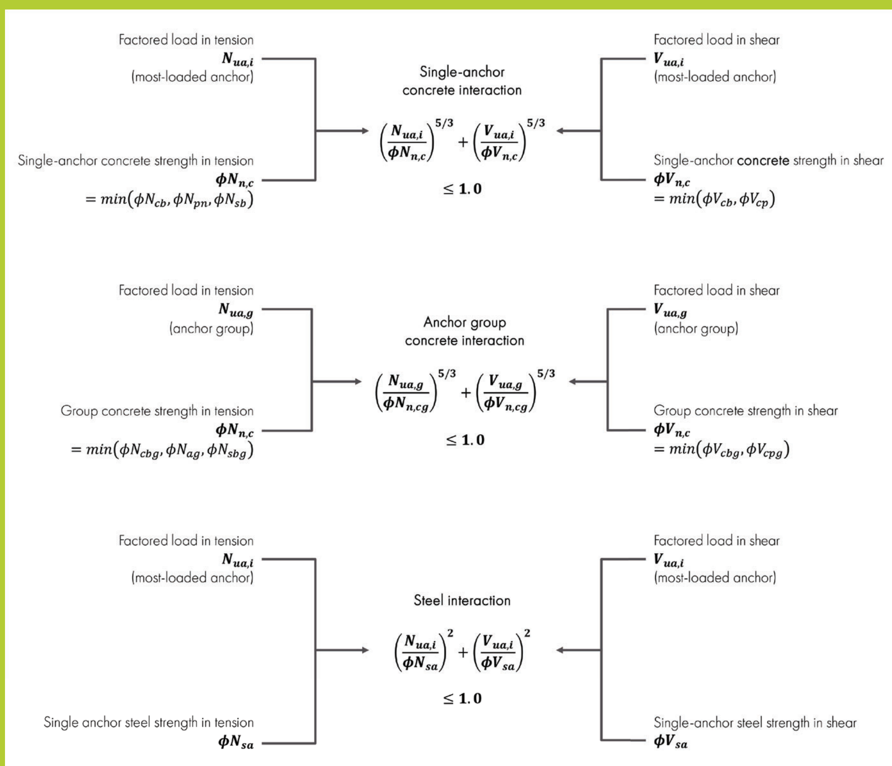

Fig. 3. Flowchart for the interaction equation in ACI 318-25 Chapter 17.

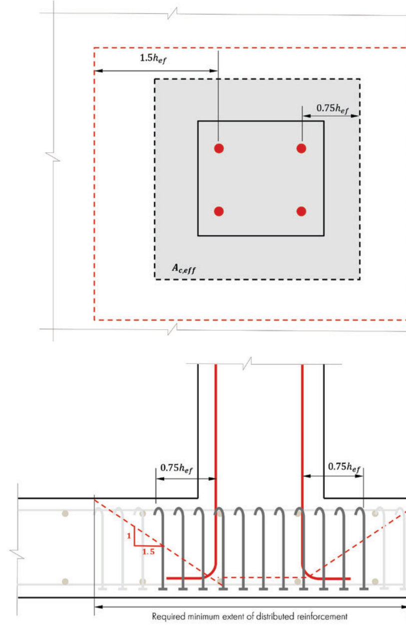

Fig. 4. Schematic of distributed reinforcement variables.

using Eq. (25.4.11.2) in a Chapter 17 design, the following notable requirements and restrictions apply:

- The k_c factors used for the determination of N_{cpg} are the same as are used for Chapter 17 design in contrast to the higher permitted k_c factors used in the Eq. (25.4.11.2) design.
- The factor relating to concrete cracking, $\psi_{c,N}$, is permitted to be greater than 1.0 in accordance with Chapter 17.
- Factor ψ_a is determined in accordance with Chapter 17.

The "distributed reinforcement" term N_{srg} cannot be used in combination with the "anchor reinforcement" provisions of Chapter 17.

Chapter 17 Change 5: Clarifications on Use of Reinforcing Bars as Anchor Reinforcement

The anchor reinforcement provisions in ACI 318 Chapter 17 permit concrete breakout calculations to be omitted and replaced with steel calculations of special reinforcing bars when those bars comply with the geometric requirements of Section 17.5.2.1. Two clarifying technical changes are made in the use of reinforcing bars as anchor reinforcement.

Section 17.5.2.1 is now split into two subsections 17.5.2.1.1 and 17.5.2.1.2 for anchor reinforcement meant to intercept tension and shear breakout, respectively. In both subsections, a clarifying component (b) states that anchor reinforcement legs must be parallel to the direction of the applied load. New Section 17.5.2.1.3 further clarifies that where anchor reinforcement meeting the requirements of 17.5.2.1 are not oriented parallel to the load, only the parallel component of the reinforcing bars is permitted to contribute to the strength calculation of the anchor reinforcement.

A new Section 17.5.2.1.4 states that the shear friction calculations of Section 22.9 cannot be used in the design of anchor reinforcement. This translates to the prohibition of the use of shear friction calculations to replace concrete breakout calculations in tension and shear.

Changes to Chapter 25: Reinforcement Details in ACI 318-25

Anchorage of reinforcing bars typically applies to the connection between two concrete structural members, e.g., between columns and foundations.

This section examines two major changes to the design provisions:

Change 1: Design requirements for breakout of reinforcing bar groups

Change 2: Updates to hooked-bar and headed-bar development length equations

Other changes to Chapter 25 not expanded upon within this article include updates to coupler qualification and classification requirements and editorial changes throughout the chapter.

Chapter 25 Change 1: Design Requirements for Breakout of Reinforcing Bar Groups

ACI 318-19 Section 17.1.6 states that consideration of breakout of reinforcing bar groups is required. However, it does not provide solutions for determining the breakout capacity that incorporate the proper safety levels for the problem of reinforcing bar groups, leaving all such consideration to engineering judgment.

ACI 318-25 introduces a major expansion to the provisions for breakout of reinforcing bar groups by providing explicit equations in new Section 25.4.11 at a safety level corresponding to existing Chapter 25 development length equations. Equation (25.4.11.2) provides the basic expression for the breakout capacity of reinforcing bar groups, incorporating a concrete contribution term, N_{cpg}, and a steel contribution term, N_{srg}.

$$N_{rg} = N_{cpg} + N_{srg} \qquad \text{ACI 318-25 Eq. (25.4.11.2)}$$

N_{cpg} is calculated using the breakout equation in Section 17.6.2 with the following modifications:

A ϕ factor of 0.90 is assigned to the breakout capacity, in contrast with lower ϕ factors for Chapter 17 design. The author infers ψ_a=1.0 in this calculation (see Chapter 17 Change 1).

The concrete effectiveness factor, k_c, is permitted to be taken as 35 for straight reinforcing bars and 40 for hooked and headed reinforcing bars OR Eq. 17.6.2.2.3 is permitted to be used with an additional increase factor of 5/3.

The cracked concrete factor $\psi_{c,N}$ is always taken as 1.0, as the k_c factors above already incorporate the uncracked concrete condition. The uncracked concrete condition is accepted in these provisions because reinforcing bar anchorage includes longer embedments than shallow anchors that are much more affected by bisecting cracks.

N_{srg} is defined by ACI 318-25 Eq. (25.4.11.5) and applies to "distributed reinforcement" with the following properties illustrated by Figure 4:

Distributed reinforcement does not have a larger diameter than the anchored bars, is headed or hooked at the embedded end, and is oriented parallel to the anchored bars within the area $A_{c,eff}$.

Spacing of distributed reinforcement is no greater than $0.25h_{ef}$ for $N_{rg} > 2.5N_{cbg}$ and no greater than $0.5h_{ef}$ for $N_{rg} \leq 2.5N_{cbg}$.

Distributed reinforcement extends over 90% of the embedment of the bar group and terminates beyond the embedded end of the bar group.

In ACI 318-25 Equation (25..4.11.5), ρ_t is the average reinforcing ratio within the potential breakout surface; $A_{c,eff}$ is the area defined by dimensions in both directions not exceeding $0.75h_{ef}$ from outside anchors and the distance from those anchors to the edge of the concrete, whichever is less, as illustrated in Figure 4; and f_y is the nominal yield strength of the distributed reinforcement.

$$N_{srg} = \rho_t A_{c,eff} f_y \qquad \text{ACI 318-25 Eq. (25.4.11.5)}$$

Chapter 25 Change 2: Updates to Hooked-bar and Headed-bar Development Length Equations

Hooked and headed reinforcing groups are subject to the breakout calculation requirements described in the Change 1 section above. In addition to the newly required breakout calculation checks, both of the basic equations for development length have changed as described in this section.

ACI 318-19 conservatively increased the development length of hooked bars in comparison to ACI 318-14 and prior editions. ACI 318-25 has refined the hooked-bar development equation to return to the same basic development length equation as ACI 318-14, but incorporating adjusted modification factors, including a new modification factor for size effect.

Table 4. Progression of Hooked-bar Development Length Equations From 2014 Through 2025

ACI-318 Edition	Basic hooked-bar equation	Modification factors
2014	$\ell_{dh} = \min\left(\frac{f_y\psi_e\psi_c\psi_r}{55\lambda\sqrt{f'_c}}, 8d_b, 6in.\right)$	ψ_e Epoxy (1.0 to 1.2)
		ψ_c Cover (0.7 to 1.0)
		ψ_r Confining reinforcement (0.8 to 1.0)
		λ Lightweight concrete (0.75 to 1.0)
2019	$\ell_{dh} = \min\left(\frac{f_y\psi_e\psi r\psi_o\psi_c}{50\lambda\sqrt{f'_c}}, 8d_b, 6in.\right)$	ψ_e Epoxy (1.0 to 1.2)
		ψ_r Confining reinforcement (1.0 to 1.6)
		ψ_o Location (1.0 to 1.25)
		ψ_c Concrete strength (~0.7 to 1.0)
		λ Lightweight concrete (0.75 to 1.0)
2025	$\ell_{dh} = \min\left(\frac{f_y\psi_e\psi_s\psi_{cc}\psi_r}{55\lambda\sqrt{f'_c}}, 8d_b, 6in.\right)$	ψ_e Epoxy (1.0 to 1.2)
		ψ_s Size (1.0 to 1.5)
		ψ_{cc} Cover (0.7 to 1.0)
		ψ_r Confining reinforcement (0.8 to 1.0)
		λ Lightweight concrete (0.75 to 1.0)

Red text indicates a change from the preceding version. Blue text indicates a reversion to 2014 usage.

Table 5. Progression of Headed-bar Development Length Equations From 2014 Through 2025

ACI-318 Edition	Basic hooked-bar equation	Modification factors
2014	$\ell_{dt} = \min\left(\frac{f_y\psi_e}{62.5\sqrt{f'_c}}, d_b, 8d_b, 6in.\right)$	ψ_e Epoxy (1.0 to 1.2)
		ψ_c Cover (0.7 to 1.0)
		ψ_r Confining reinforcement (0.8 to 1.0)
		λ Lightweight concrete (0.75 to 1.0)
2019	$\ell dt = \min\left(\frac{f_y\psi_e\psi_p\psi_o\psi_c}{75\lambda\sqrt{f'_c}}d_b^{1.5}, 8d_b, 6in.\right)$	ψ_e Epoxy (1.0 to 1.2)
		ψ_p Parallel tie reinforcement (1.0 to 1.6)
		ψ_o Location (1.0 to 1.25)
		ψ_c Concrete strength (~0.7 to 1.0)
		λ Lightweight concrete (0.75 to 1.0)
2025	$\ell_{dt} = \min\left(\frac{f_y\psi_e\psi_p\psi_o\psi_c}{90\lambda\sqrt{f'_c}}d_b^{1.5}, 8d_b, 6in.\right)$	ψ_e Epoxy (1.0 to 1.2)
		ψ_p Parallel tie reinforcement (1.0 to 1.6)
		ψ_o Location (1.0 to 1.25)
		ψ_c Concrete strength (~0.7 to 1.0)
		λ Lightweight concrete (0.75 to 1.0)

Red text indicates a change from the preceding version.

Table 4 shows the progression of the hooked-bar development length equation from 2014 through the 2025 edition.

The headed-bar development length has retained its structure from the 2019 edition but has been shortened by approximately 17% by increasing the constant term in the equation's denominator. Table 5 shows the progression of the headed-bar development length equation from 2014 through the 2025 edition.

Summary

Anchorage provisions in ACI 318 Chapters 17 and 25 have been significantly updated in the 2025 edition. In Chapter 17, several changes have been made to reduce conservatism, clarify usage, and provide direct accounting of the effects of reliability and redundancy. In Chapter 25, a major new requirement has been added to account for the potential breakout of reinforcing bar groups while also updating the basic development length equations for hooked and headed bars. While the subject of anchorage still remains disjointed between Chapter 17 and Chapter 25, some common elements have been bridged in this newly published document. ▪

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