Document: CODE-440 Building Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars--Code and Commentary
Public Discussion Period: February 11, 2022 to April 6, 2022.

No.	Public Commenter Name	Pg #	Line #	Public Comment	Committee Response
1.	Brian Gerber	all		See attached draft for corrections to grammatical errors, such as punctuation and lack of determiners ("the").	ACI Code style does limit articles like "the." ACI Staff reviewed the suggestions.
2.	Brian Gerber			The viability of the document as a building code for adoption may be curtailed by the 440's restrictions from use in Seismic Design Categories D, E, and F.	Thank you for the comment. GFRP reinforcement structures are not intended for these applications.
3.	Brian Gerber	244-247	all	The publisher of the standards should be enumerated and italicized as done in Chapter 3. Another method to distinguish the publisher is possible, but right now it is not easy to pick the publisher.	ACI Staff will address formatting
4.	Peter Bischoff	190-191	26-30	This paragraph in the commentary needs to be revised to reflect using the 0.8Mcr when computing Ie.	24.2.3. 5and R 24.2.3.5 have been modified to harmonize with 318-19. The 0.8 factor has been taken out of the commentary and put in the code. **24.2.3.5** Unless obtained by a more comprehensive analysis, effective moment of inertia I_e~~, unless obtained by a more comprehensive analysis~~ shall be calculated in accordance with Table 24.2.3.5 using ~~and with γ calculated by Eq. 24.2.3.5a and M_{cr} calculated by Eq. 24.2.3.5b,~~ $\gamma = 1.72 - 0.72\left(\frac{0.8M_{cr}}{M_a}\right)$ (24.2.3.5a) and $M_{cr} = \frac{f_r I_g}{y_t}$ (24.2.3.5b), but I_e shall not be greater than I_g. **Table 24.2.3.5—Effective Moment of Inertia, I_e** **Service Moment** | **Effective Moment of Inertia, I_e (ir** M_a ~~£~~$\le 0.8M_{cr}$ | I_g $M_a > 0.8M_{cr}$ | $I_e = \frac{I_{cr}}{1-\gamma\left(\frac{0.8M_{cr}}{M_a}\right)^2\left(1-\frac{I_{cr}}{I_g}\right)}$ ***R24.2.3.5*** …

No.	Public Commenter Name	Pg #	Line #	Public Comment	Committee Response
					M_{cr} is multiplied by a reduction factor to account for restraint that can reduce the effective cracking moment as well as to account for reduced tensile strength of concrete during construction that can lead to cracking that later affects service deflections (Scanlon and Bischoff 2008). As the lower stiffness of GFRP reinforcement provides less restraint to shrinkage than occurs with steel reinforcement, the reduction factor for GFRP reinforcement ($0.8M_{cr}$) is larger than for steel reinforcement ($2/3M_{cr}$) (Bischoff and Gross 2011b). ~~When $M_a \geq M_{cr}$, the effects of cracking are taken into account using the equation for I_e given in Table 24.2.3.5. When calculations result in $M_a < M_{cr}$ but the difference between these two values is small, the member is theoretically uncracked but inherent variability in the tensile strength of concrete and the restraint of shrinkage due to the GFRP reinforcement may still cause the section to crack. In such cases, deflections will be significantly underestimated by the use of gross section properties; this effect tends to be more pronounced for GFRP-reinforced concrete than for steel-reinforced concrete due to the larger ratio of I_g to I_{cr}. The designer should exercise judgment and consider the project-specific impacts of underestimating deflections in determining whether I_g should be used when M_a approaches M_{cr}. Bischoff and Gross (2011b) recommend replacing M_{cr} with $0.8M_{cr}$ in Table 24.2.3.5 and Eq. (24.2.3.5a) to account for tensile stresses that develop in the concrete from restraint to shrinkage. Using the ratio of $0.8M_{cr}/M_a$ can result in a more realistic estimate of deflection if the member has cracked at a lower load than predicted by M_{cr}.~~
5.	Amy Trygestad, CRSI	4	13	Because 440 is a dependent code to 318, there is little direction on how the two codes interact. 440 simply states sections “do not apply” but there is no explicit provision that 318 governs the design for those sections, such as Ch. 12 diaphragms.	A Preface section has been added which explains the interaction and the meaning of terms such as “Does not apply.” Commentary has been added to Chapter 12 Diaphragms (and to other chapters that have not been included in this first version of the Code) to explain why

No.	Public Commenter Name	Pg #	Line #	Public Comment	Committee Response
					they have not been included and, where possible, to provide information as to where pertinent information may be found.
6.	Amy Trygestad, CRSI	5	23	R1.4.2 “may be used for nonbuilding structures, where applicable” is too vague.	This is language exactly out of 318-19, so no change was made to the Code provision. Language was added to the commentary to indicate that approval is by the authority having jurisdiction and give examples of cases that it might pertain to. ***1.4.3*** *~~1.4.2~~ Applicable provisions of this Code shall be permitted to be used for structures not governed by the general building code.* **R1.4.3** **~~R1.4.2~~** ~~The design principles and material properties of this Code may be used for nonbuilding structures, where applicable.~~ Structures such as underground utility structures and sea walls involve design and construction requirements that are not specifically addressed by this Code. Many Code provisions, however, may be applicable for these structures if approved by the authority having jurisdiction.
7.	Amy Trygestad, CRSI	5	33	This provision allows the use of 440 to design for SOG transfer of lateral loads, however, Chapter 12 diaphragm provisions do not apply in 440.	Revise 1.4.8 as follows: **1.4.8** This Code does not apply to design and construction of slabs-on-ground, unless the slab transmits vertical loads ~~or lateral forces~~ from other portions of the structure to the soil.
8.	Amy Trygestad, CRSI	6	3	R1.4.7 contradicts the code exclusion of slabs on grade design except for transfer of vertical and lateral loadings.	Non-persuasive. R1.4.8 (note change in section numbering to update to 318-19) commentary does not contradict SOG code exclusion. This provision and commentary are consistent with the language in 318. The R1.4.8 commentary provides the designer with alternate sources other than the Code which may be useful for designing SOG that are not covered by the 440 Code. 440.1R is a previously published guideline, NOT the 440 Code document.

No.	Public Commenter Name	Pg #	Line #	Public Comment	Committee Response
9.	Amy Trygestad, CRSI	7	16	1.5.8 There is concern that the dependent 440 will be able to take precedence over 318 (Ch. 3 reference) for sections not truly governed by the design of GFRP members, such as loads and concrete mix designs. Recommend 440 direct to use 318 in these provisions and not re-state.	Non-persuasive. The 440 Code is dependent to 318-19, which means that the 440 Code does not take precedence over 318 and adheres to 318 language unless the use of GFRP reinforcement necessitates changes to the 318 Code language.
10.	Amy Trygestad, CRSI	9	11	Change “the code” to “this Code”.	Strike the first line in **2.2 Notation** as follows, to be consistent with 318-19: ~~The terms in this list are used in the code and as needed in the commentary.~~ The following language has been added: **2.1** - Scope **2.1.1** This chapter defines notation and terminology used in this Code.
11.	Amy Trygestad, CRSI	13	45	Change “the code” to “this Code”	Strike the first line in **2.3 Terminology** as follows, to be consistent with 318-19: ~~The following terms are defined for general use in this code.~~
12.	Amy Trygestad, CRSI	32	17	Section 4.11.1: GFRP members must satisfy the fire protection requirements of the general building code; however, the IBC does not have fire rating provisions for GFRP – reinforced concrete. The general building code provisions are based on ASTM E119 fire testing of steel-reinforced or plain concrete members.	The fire provisions for the document have been substantially rewritten to reflect that the Code has been limited to structures for which fire-resistance ratings are not required. 4.11.1 has been changed to read: ***4.11.1*** *~~Structural concrete members shall satisfy the fire protection requirements of the general building code.~~* <u>*Structural concrete reinforced with GFRP bars shall not be permitted where fire-resistance ratings are required except where the structural fire resistance has been shown to be adequate by calculations or tests and approved by the building official.*</u> In addition, the fire sections in the member chapters have been removed, the commentary that was in the fire sections in the member chapters has been revised and

No.	Public Commenter Name	Pg #	Line #	Public Comment	Committee Response
					moved to R4.11.1, and the Preface and 20.5.1.1 and R20.5.1.3.1 have been revised accordingly.
13.	Vicki L. Brown	33	13-17	How is 4.12.1.4 to be interpreted given that diaphragms are not addressed?	No change to document There are other mechanisms for transferring in-plane loads besides diaphragms.
14.	Brian Gerber	38	22	Section 5.3.11 should include the words "The most unfavorable effects from wind or seismic loads shall be investigated, where appropriate." This statement is taken from ASCE 7. Equations 5.3.1.f and 5.3.1.g are intended to address net uplift due to wind or earthquake and would counteract the dead loads. As such the values of W or E would be subtracted to establish a net uplift. Wind & earthquake may be bi-directional so this added statement helps to guide the critical effects be considered.	Non-persuasive. From the context of the comment, the comment appears to refer to section 5.3.1 rather than 5.3.11. No change is made, as the R5.3.1 commentary language is directly from 318-19. Section 5.3.11 in 318 refers to internal load effects due to reactions induced from prestressing. Prestressing is not covered by this Code.
15.	Amy Trygestad, CRSI	39	10	6.2.3 gives methods of analysis permitted by this chapter shall be (a) through (c) and (e), but there is no (e) in the list.	Adjust lettering as follows: **6.2.3** Methods of analysis permitted by this chapter shall be (a) through~~ (c) and~~ (e). Redistribution of moments calculated in accordance with (a) through (~~d~~e) is not permitted. (a) The simplified method for analysis of continuous beams and one-way slabs for gravity loads in 6.5 (b) Linear elastic first-order analysis in 6.6 (c) Linear elastic second-order analysis in 6.7 (d) Intentionally left blank (e~~d~~) Finite element analysis in 6.9
16.	Brian Gerber	56	3	Section 7.2.4 should include the words "Structural concrete members shall satisfy the fire protection requirements of the general building code." This is taken from ACI 318.	Section 7.2.4 has been removed from the document. See response to Comment 12.
17.	Amy Trygestad, CRSI	57	3	Section 7.2.4: Fire resistance for one-way slabs; many prescriptive requirements must be satisfied for	Section 7.2.4 has been removed from the document.

No.	Public Commenter Name	Pg #	Line #	Public Comment	Committee Response
				maximum bar stress and cover, based on a prescribed level of insulation.	
18.	Amy Trygestad, CRSI	68	7	6.2.3 does not allow moment redistribution; however, R8.3.6.1 states reinforcement ratios are given to ensure sufficient moment redistribution. The direct design and equivalent frame analysis methods are based upon moment redistribution and may not be applicable.	Non-persuasive. R8.2.1 includes commentary and provides references that discuss moment redistribution that is possible with GFRP-reinforced concrete. While moment redistribution in one-way members is not currently permitted in this Code, research has demonstrated that two-way slabs which meet the reinforcement limits of 8.3.6.1 achieve sufficient moment redistribution upon which the direct design and equivalent frame analysis methods are based.
19.	Amy Trygestad, CRSI	69	19	Section 8.4.2.3.2: Fraction of slab moment resisted by the column transferred by flexure is the same as that for steel reinforced two-way slabs, but no justification is given on why this is applicable to GFRP slabs.	Non-persuasive. 318 moment fractions were derived using elastic analysis without considering reinforcement and thus are equally applicable to GFRP as to steel reinforcement.
20.	Vicki L. Brown	73	23-24	Please provide explanation as to why $A_{f\,min}$ for two-way slabs in 8.6.1.1 is different from $A_{f\,min}$ for one-way slabs in 7.6.1.1.	Revise 8.6.1.1 and R8.6.1.1 to be consistent with 7.6.1.1 and R7.6.1.1 as follows: **8.6.1.1** A minimum area of flexural reinforcement, <u>equal to the greater of the requirement for shrinkage and temperature reinforcement in 24.4.3.2 and $\frac{300}{f_{fu}}A_g$,</u> shall be provided near the tension face in the direction of the span under consideration ~~in accordance with 24.4.3.2~~. ***R8.6.1.1*** <u>*See R7.6.1.1.*</u> ~~*The required area of reinforcement used as minimum flexural reinforcement is the same as that required for shrinkage and temperature in 24.4.3.2. However, whereas shrinkage and temperature reinforcement is permitted to be distributed between the two faces of the slab as deemed appropriate for specific conditions, minimum flexural reinforcement should be placed as close as practicable to the face of the concrete in tension due to applied loads.*~~

No.	Public Commenter Name	Pg #	Line #	Public Comment	Committee Response
21.	Brian Gerber	84	14	Change sentence to declarative like the rest of the document: ~~Also refer to~~ Additional related commentary is available in R8.10.5.	No change needed, Section 8.10 has been removed.
22.	Carol Shield	91	20	Why does the commentary for R9.1 say that Composite structural steel-concrete beams are not covered by this code. Why would anyone every think that they were covered by this code. This part of the commentary should be deleted.	Persuasive. Revise R9.1.1 as follows: **R9.1.1** Composite ~~structural steel-concrete beams and composite~~ GFRP-structural profile concrete beams are not covered in this chapter.
23.	Carol Shield	101	5-6	Does this sentence – "Equation 9.6.4.3(a) is based on a 2:1 ratio of torsion stress to shear stress and results in a GFRP torsional reinforcement volumetric ratio of approximately 0.5 percent (Hsu 1968)." Still apply to GFRP reinforced concrete? The reference certainly predates GFRP	Revise R9.6.4.3 as follows: **R9.6.4.3** Under combined torsion and shear, the torsional cracking moment decreases with applied shear, which leads to a reduction in torsional reinforcement required to prevent brittle failure immediately after cracking. When subjected to pure torsion, steel-reinforced concrete beam specimens with less than 1 percent torsional reinforcement by volume have failed at first torsional cracking (MacGregor and Ghoneim 1995). ~~Equation 9.6.4.3(a) is based on a 2:1 ratio of torsion stress to shear stress and results in a torsional reinforcement volumetric ratio of approximately 0.5 percent (Hsu 1968).~~
24.	Vicki L. Brown	125	11-14	R11.6.1 states that the 0.0036 value for the minimum reinforcement ratios in GFRP-reinforced concrete walls is the same as the value provided for shrinkage and temperature reinforcement in 24.4.3.2. However, 24.4.3.2 specifies a value other than 0.0036.	Revise as suggested but with the reinforcement ratio updated from 0.0055 to 37,500/E_f and in the same format as 11.6.1. See also response to Comment 65. **11.6.2** If in-plane V_u ~~≥~~ ≥ $\underline{\phi 2.5 k_{cr}\sqrt{f'_c} b_w d}$ $\cancel{0.5\phi V_c}$, minimum $\rho_{f\ell}$ and minimum ρ_{ft} shall be in accordance with (a) and (b) ~~shall be satisfied~~: (a) 37,500/E_f. (b) 0.0025. ~~(a) $\rho_{f\ell}$ shall be at least 0.0055 but need not exceed ρ_{ft} required for strength by 11.5.4.8.~~ ~~(b) ρ_{ft} shall be at least 0.0055~~

Document: CODE-440 Building Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars--Code and Commentary
Public Discussion Period: February 11, 2022 to April 6, 2022.

No.	Public Commenter Name	Pg #	Line #	Public Comment	Committee Response
25.	Brian Gerber	151	12	ASTM D7957 does not provide for resistance to an acid environment, only alkaline. A statement such as follows should be added: *The Code does not include provisions for especially severe exposures, such as acids or high temperatures.* This was taken from Section R19.3, last line.	Revise R20.5 commentary as follows (note that additional changes to R20.5 may result from response to Comment #28): **R20.5 – Provisions for Durability of GFRP reinforcement** Durability requirements for structures utilizing GFRP bars are inherently different from those of steel-reinforced concrete due to the corrosion-resistant nature of GFRP. A major benefit of GFRP bars is that corrosion of the internal reinforcement is eliminated enabling a longer service life. Design criteria intended to mitigate corrosion of the internal reinforcement such as increased concrete cover, the use of corrosion inhibiting admixtures, use of epoxy coatings, and limitations on crack widths to delay the initiation of corrosion are not necessary in GFRP-reinforced concrete structures. However, <u>the Code does not include provisions for especially severe exposures such as acids although low pH environments are less severe for GFRP reinforcement than are high pH environments (Al-Zahrani et al. 2002, Bazli et al. 2017). In addition</u>, the effects of creep rupture (static fatigue) and/or time dependent properties of the GFRP bars must be taken into account to ensure long-term safe use. The durability provisions of this section pertain to fire protection and the long-term bond properties of GFRP bars. Effects of creep rupture (static fatigue) are addressed in 24.6. Add to References section: <u>Al-Zahrani, M.M., Al-Dulaijan, S.U., Sharif, A. and Maslehuddin, M. (2002). Durability performance of glass fiber reinforced plastic reinforcement in harsh environments. 6th Saudi Engineering Conference, vol. 3 pp 307-319. KFUPM, Dhahran.</u>

No.	Public Commenter Name	Pg #	Line #	Public Comment	Committee Response
					Bazli, M., Ashrafi, H. and Oskouei, A.V. (2017). Experiments and probabilistic models of bond strength between GFRP bars and different types of concrete under aggressive environments. Construction and Building Materials, 148, pp 429-443.
26.	Amy Trygestad, CRSI	151	3	Modify the commentary of to reflect the surface treatment must be able to transit *adequate* force between the bar and the concrete …. *as defined by ASTM D7957*.	Non-persuasive, as the point of this commentary is to provide a physical description of surface enhancements for bond. Code provision 20.2.1.4 requires that bars conform to ASTM D7957 so suggested language is redundant.
27.	Amy Trygestad, CRSI	152	23	There is not a definition for "service temperature" for the environment in which the structure will operate. This is not a criterion that designers will be familiar with and a definition is critical. A reference should also be included.	Persuasive. Add definition for service temperature in 2.3 as follows: **service temperature—**highest ambient temperature expected to be experienced by a structure or structural member under intended occupancy and use Add following reference to R4.11.3 (the commentary the comment refers to was moved from R20.2.2.3 to R4.11.3) as follows: **R4.11.3** GFRP bars can lose bond with concrete if used in conditions that have service temperatures approaching the glass transition temperature of the bar, due to softening of the resin (Xian and Karbhari 2007). Add to References section: Xian, G. and Karbhari, V.M., (2007). Segmental relaxation of water-aged ambient cured epoxy. Journal of Polymer Degradation and Stability, 92(9), pp. 1650-1659.
28.	Amy Trygestad, CRSI	153	21	R20.6: Durability; Section R20.6 states: "A major benefit of GFRP bars is that corrosion…" Totally misleading and unsubstantiated statement and needs to be eliminated from a building code.	It is well understood and documented that GFRP reinforcing bars do not corrode as do steel reinforcing bars. While the statement is neither misleading nor unsubstantiated, it is not required as part of the explanation on the provisions for durability of GFRP

No.	Public Commenter Name	Pg #	Line #	Public Comment	Committee Response
					reinforcement and can be eliminated from the commentary. Revise R20.5 as follows (note that additional changes to R20.5 may result from response to Comment #25): **R20.5 – Provisions for Durability of GFRP reinforcement** Durability requirements for structures utilizing GFRP bars are inherently different from those of steel-reinforced concrete due to the corrosion-resistant nature of GFRP. ~~A major benefit of GFRP bars is that corrosion of the internal reinforcement is eliminated enabling a longer service life.~~ Design criteria intended to mitigate corrosion of the internal reinforcement such as increased concrete cover, the use of corrosion inhibiting admixtures, use of epoxy coatings, and limitations on crack widths to delay the initiation of corrosion are not necessary in GFRP-reinforced concrete structures. However, the effects of creep rupture (static fatigue) and/or time dependent properties of the GFRP bars must be taken into account to ensure long-term safe use. The durability provisions of this section pertain to fire protection and the long-term bond properties of GFRP bars. Effects of creep rupture (static fatigue) are addressed in 24.6.
29.	Amy Trygestad, CRSI	153	24	R20.6 states crack width limitations can be removed based on corrosion; however, crack limitations are also in place for structural design. Serviceability is often the controlling factor for GFRP-reinforced concrete. Crack limit must still be in place to maintain appropriate section properties for structural analysis.	Non-persuasive The indicated commentary is provided to explain the provisions for **durability** of GFRP reinforcement. It is well understood that crack width limitations to delay the initiation of corrosion are not required for GFRP reinforcement. This Code has required limits to control cracking at service load levels that can be found in section 24.3 of the chapter on Serviceability Requirements.

Document: CODE-440 Building Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars--Code and Commentary
Public Discussion Period: February 11, 2022 to April 6, 2022.

No.	Public Commenter Name	Pg #	Line #	Public Comment	Committee Response
					Comment is unclear as to what is intended by "crack limitations are also in place for structural design." The Code specifies a 0.7mm crack width limit at service load levels which is sufficient for maintaining appropriate section properties for structural analysis at the service load level where I_e accounts for cracking. Steel reinforced concrete also has no crack width limits at ultimate for structural analysis.
30.	Amy Trygestad, CRSI	154	3	Section 20.6.1.1: Minimum specified concrete cover must be in accordance with Sections 20.6.1.2 through 20.6.1.3 unless the general building code requires a greater concrete cover for fire protection. Table R20.6.1.3.1 gives fire resistance ratings provided by the minimum specified cover in Table 20.6.1.3 for nonbond-critical GFRP bars; the maximum rating is 1.5 hours. There is no background information (including reports from ASTM E119 testing) given that would permit LDPs to assume these concrete covers and associated fire ratings are adequate. Fire ratings are a part of the general building code and not in 440.	The Code has been limited to structures for which fire-resistance ratings are not required per 4.11.1; thus, the comment is no longer applicable. As part of the response to Public Comment 12, 20.5.1.1 (renumbered from 20.6.1.1 after conversion to ACI 318-19) has been changed to read: **20.5.1.1** ~~Unless the general building code requires a greater concrete cover for fire protection, the~~ *The minimum specified concrete cover shall be in accordance with 20.5.1.2 through 20.5.1.3.*
31.	Amy Trygestad, CRSI	155	10	Define "adequately anchored" as this language is vague. Various sections state high temperatures will cause lack of bond for GRFP and the sentence should be removed.	The R4.11.1 commentary has been revised in response to comments and provides guidance on detailing for adequately anchoring GFRP reinforcement to prevent anchorage failure during a fire event. See response to Comment 12.
32.	Amy Trygestad, CRSI	155	19	Recommending an increase in concrete cover "may" increase the fire resistance is speculative when there is not fire testing to support prescribed increase. Fire resistance is a life safety requirement and must have adequate technical data to support.	It is well understood that additional concrete cover decreases the increase in GFRP bar temperature under fire condition. The references in this section provide experimental evidence and correlated GFRP bar temperature modeling under fire that provides the technical data to support this statement. *The sentence* "An increase in concrete cover from 1-1/2 to 2 inches for beams and columns and from ¾ to 1-1/2 inches for slabs and walls may increase the fire resistance to 1 hour." *has been deleted.*

Document: CODE-440 Building Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars--Code and Commentary
Public Discussion Period: February 11, 2022 to April 6, 2022.

No.	Public Commenter Name	Pg #	Line #	Public Comment	Committee Response
33.	Amy Trygestad, CRSI	156	26	What is the basis for using a minimum reinforcement ratio around an embedment twice the requirement for steel reinforcement? This is arbitrary and not based on research.	The committee revisited this provision and made changes to the code provision and commentary as shown to make it consistent with the philosophy used to determine the amount of shrinkage and temperature steel required in section in 24.4.3.2. **20.6.4** ~~**20.7.4**~~ ~~GFRP~~ Reinforcement with an area at least ~~0.004~~ **$20,000/E_f$** times the area of the concrete section shall be provided perpendicular to pipe embedments. **R20.6.4** ~~**R20.7.4** The value of 0.004 is twice the amount required by ACI 318-14 for steel reinforcement.~~ The value of $20,000/E_f$ is the same as the requirement for shrinkage and temperature reinforcement.
34.	Fabio Matta	170	11	The references Bažant and Kim (1984) and Bažant et al. (2007) seem to be missing from the list of Commentary References. The reviewer believes these references are the following: Bažant ZP, Kim J-K (1984), Size Effect in Shear Failure of Longitudinally Reinforced Beams, ACI Journal, 456-468 (Title 81-38). Bažant ZP et al. (2007), Justification of ACI 446 Proposal for Updating ACI Code Provisions for Shear Design of Reinforced Concrete Beams, ACI Structural Journal, 104(5), 601-610. If so, these seminal references are appropriate to convey the contents in Lines #11-14, together with the other ones listed in Lines #11-12.	Persuasive. Add the two Bazant references to the References section as follows: Bazant, ZP and Kim, JK (1984). Size effect in shear failure of longitudinally reinforced beams. ACI Journal, 81(5), 456-468. Bazant, ZP; Yu, Q; Gerstle, W; Hanson, J and Ju, JW (2007). Justification of ACI 446 proposal for updating ACI Code provisions for shear design of reinforced concrete beams. ACI Structural Journal, 104(5), 601-610.
35.	Fabio Matta	170	11-12	The references between parentheses should be listed in chronological order.	Revise R22.5.5.1.3 as follows (additional changes to the references at the end of the paragraph are in response to Comment #38: ~~**R22.5.5.1.1**~~ **R22.5.5.1.3** Test results (Frosch 2017) for steel and GFRP-reinforced nonprestressed concrete

No.	Public Commenter Name	Pg #	Line #	Public Comment	Committee Response
					members without shear reinforcement indicate that the measured shear strength attributed to concrete does not increase in direct proportion with member depth. This phenomemon is often referred to as the "size effect"… …….Research (<u>Anderson 1978</u>; Bazant and Kim 1984; <u>Becker and Buettner 1985</u>; Angelakos et al. 2001; Lubell et al. 2004; Brown et al. 2006; ~~Becker and Buettner 1985; Anderson 1978;~~ Bazant et al. 2007) has shown that shear stress at failure is lower for beams with increased depth and a reduced area of longitudinal reinforcement. The parameters within the size effect modification factor, $\boldsymbol{\lambda}_s$, are consistent with fracture mechanics theory for reinforced concrete and are appropriate for sections reinforced with either steel <u>(Bazant et al. 2007 and Frosch et al. 2017)</u> or GFRP <u>(Frosch et al. 2017</u>) reinforcement ~~(Bazant et al. 2007 and Frosch et al. 2017)~~.
36.	Fabio Matta	170	11-14	To the best of the reviewer's knowledge, to date, two archival papers report on large-scale tests providing evidence "that shear stress at failure is lower for beams with increased depth and a reduced area of longitudinal reinforcement" (Lines #13-14) for the specific case of FRP reinforced concrete (RC) beams without transverse reinforcement: Bentz EC, Massam L, Collins MP (2010), Shear Strength of Large Concrete Members with FRP Reinforcement, Journal of Composites for Construction, 14(6), 637-646. Matta F, El-Sayed AK, Nanni A, Benmokrane B (2013), Size Effect on Concrete Shear Strength in Beams Reinforced with Fiber-Reinforced Polymer Bars, ACI Structural Journal, 110(4), 617-628.	Take up as new business.

No.	Public Commenter Name	Pg #	Line #	Public Comment	Committee Response
				These two references may be included in the list in Lines #11-12 to support the statement in Lines #11-14 for the case of FRP reinforced concrete (RC) beams; thus, specific to the type of reinforcement that is covered in this very document.	
37.	Fabio Matta	170	14-16	The reference Frosch et al. (2007) is not included in the Commentary References. The reviewer is not familiar with any such reference that may support the statement in Lines #14-16.	Reference is to Frosch (2017) [not 2007] Add the Frosch 2017 reference to the commentary reference section. Robert J. Frosch, Qiang Yu, Gianluca Cusatis, and Zdeněk P. Bažant (2017). A unified approach to shear design. **Concrete International**, 39(9), pp. 47-52
38.	Fabio Matta	170	14-16	If the reference Bažant et al. (2007), which is missing from the list of Commentary References, is Bažant ZP et al. (2007), Justification of ACI 446 Proposal for Updating ACI Code Provisions for Shear Design of Reinforced Concrete Beams, ACI Structural Journal, 104(5), 601-610, then said reference does not support the statement in Lines #14-16 for "either steel or GFRP reinforcement". In fact, it does so for steel reinforcement only. To the best of the reviewer's knowledge, to date, three archival papers support the statement in Lines #14-16 for the specific case of FRP reinforcement: Matta F, Mazzoleni P, Zappa E, Sutton MA, ElBatanouny MK, Larosche AK, Ziehl P (2012), Shear Strength of FRP Reinforced Concrete Beams without Stirrups: Verification of Fracture Mechanics Formulation, ACI SP-286 – A Fracture Approach for FRP-Concrete Structures, M. Lopez and C. Carloni (eds.), #SP-286–6. Matta F, El-Sayed AK, Nanni A, Benmokrane B (2013), Size Effect on Concrete Shear Strength in Beams	Persuasive, Bazant 2007 deals with steel, Frosch 2017 deals with both steel and GFRP. Revised as shown in Comment #35. Take up remaining references as new business for next version of Code.

No.	Public Commenter Name	Pg #	Line #	Public Comment	Committee Response
				Reinforced with Fiber-Reinforced Polymer Bars, ACI Structural Journal, 110(4), 617-628. Khodaie S, Matta F, Alnaggar M (2019), Discrete Meso-Scale Modeling and Simulation of Shear Response of Scaled Glass FRP Reinforced Concrete Beams without Stirrups, Engineering Fracture Mechanics, 216, 106486. These references may be cited to support the statement in Lines #14-16 for FRP reinforced concrete (RC) beams, specific to the type of reinforcement that is covered in this document. In light of the considerations above, the text in Lines #14-16 may be revised as "The parameters within the size effect modification factor, λ_s, are consistent with fracture mechanics theory for reinforced concrete and are appropriate for sections reinforced with either steel (Bažant et al. 2007) or GFRP (Matta et al. 2012, 2013, Khodaie et al. 2019) reinforcement."	
39.	Peter Bischoff	189	28	In 2nd row of Table 24.2.3.5 change Ma £ Mcr to Ma <= Mcr	Implemented in Table 24.2.3.5
40.	Peter Bischoff	189	28	In the 3rd row of Table 24.2.3.5 change Mcr to 0.8Mcr to make consistent with ACI 318-19 which uses a reduced cracking moment to account for tensile stresses that develop in the concrete from restraint to shrinkage. While ACI 318-19 uses 2/3 Mcr, a value of 0.8 Mcr is more realistic for GFRP since there is less restraint to shrinkage from lower modulus FRP bars. Tensile stresses that develop from restraint to shrinkage by the internal reinforcement are not as great for GFRP.	24.2.3. 5and R 24.2.3.5 have been modified to harmonize with 318-19. The 0.8 factor has been taken out of the commentary and put in the code. **24.2.3.5** Unless obtained by a more comprehensive analysis, effective moment of inertia $\boldsymbol{I_e}$~~, unless obtained by a more comprehensive analysis~~ shall be calculated in accordance with Table 24.2.3.5 using ~~and with $\boldsymbol{\gamma}$ calculated by Eq. 24.2.3.5a and $\boldsymbol{M_{cr}}$ calculated by Eq. 24.2.3.5b,~~ $\gamma = 1.72 - 0.72\left(\frac{0.8M_{cr}}{M_a}\right)$ (24.2.3.5a) and

No.	Public Commenter Name	Pg #	Line #	Public Comment	Committee Response
					$$M_{cr} = \frac{f_r I_g}{y_t} \quad (24.2.3.5b),$$ but I_e shall not be greater than I_g. **Table 24.2.3.5—Effective Moment of Inertia, I_e** Service Moment: M_a £≤ <u>0.8</u>M_{cr} — Effective Moment of Inertia, I (in⁴): I_g Service Moment: $M_a >$ <u>0.8</u>M_{cr} — Effective Moment of Inertia: $I_e = \dfrac{I_{cr}}{1-\gamma\left(\frac{0.8M_{cr}}{M_a}\right)^2\left(1-\frac{I_{cr}}{I_g}\right)}$ ***R24.2.3.5*** *…* <u>*M_{cr} is multiplied by a reduction factor to account for restraint that can reduce the effective cracking moment as well as to account for reduced tensile strength of concrete during construction that can lead to cracking that later affects service deflections (Scanlon and Bischoff 2008). As the lower stiffness of GFRP reinforcement provides less restraint to shrinkage than occurs with steel reinforcement, the reduction factor for GFRP reinforcement (0.8M_{cr}) is larger than for steel reinforcement (2/3M_{cr}) (Bischoff and Gross 2011b).*</u> ~~When $M_a \geq M_{cr}$, the effects of cracking are taken into account using the equation for I_e given in Table 24.2.3.5. When calculations result in $M_a < M_{cr}$ but the difference between these two values is small, the member is theoretically uncracked but inherent variability in the tensile strength of concrete and the restraint of shrinkage due to the GFRP reinforcement may still cause the section to crack. In such cases, deflections will be significantly underestimated by the use of gross section properties; this effect tends to be more pronounced for GFRP-reinforced concrete than for steel-reinforced concrete due to the larger ratio of I_g to I_{cr}. The designer should exercise judgment and consider the project-specific impacts of underestimating deflections in determining whether I_g should be used~~

Document: CODE-440 Building Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars--Code and Commentary
Public Discussion Period: February 11, 2022 to April 6, 2022.

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					~~when $\mathbf{M_a}$ approaches $\mathbf{M_{cr}}$. Bischoff and Gross (2011b) recommend replacing $\mathbf{M_{cr}}$ with $\mathbf{0.8M_{cr}}$ in Table 24.2.3.5 and Eq. (24.2.3.5a) to account for tensile stresses that develop in the concrete from restraint to shrinkage. Using the ratio of $\mathbf{0.8M_{cr}/M_a}$ can result in a more realistic estimate of deflection if the member has cracked at a lower load than predicted by $\mathbf{M_{cr}}$.~~
41.	Peter Bischoff	190	1	In Equation 24.2.3.5a for gamma γ , change Mcr to 0.8Mcr for the same reason above.	Incorporated. See Comment 40.
42.	Vicki L. Brown	195	17	Please review value for k_b in 24.3.2.3 based on recent work at the University of Sherbrooke.	Based on a recent experimental program at University of Sherbrooke, data has been obtained that justifies use of k_b = 1.2 for all bar types. Revise 24.3.2.3 and associated commentary as follows: **24.3.2.3** The bond factor for GFRP reinforcing bars $\mathbf{k_b}$ shall be taken as ~~1.35~~ <u>1.2</u>. **R24.3.2.3** The bond factor $\boldsymbol{k_b}$ is a coefficient that accounts for the degree of bond between the GFRP bar and the surrounding concrete. Shield et al. (2019) found $\boldsymbol{k_b}$ values varied between 0.69 and 1.61 based on an examination of available crack width data in the literature. A $\boldsymbol{k_b}$ value of ~~1.35~~ <u>1.2</u> was selected so that the crack widths would be no larger than 0.028 in. approximately 70% of the time for all GFRP bar surface types.