Safety Assessment of Shear Strength Current Formulations for Composite Concrete Beams without Web Reinforcement

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Abstract

Construction with precast concrete elements without web reinforcement and cast-in-place concrete on them to enhance the overall structure's integrity is a widespread practice in building construction. However as these composite elements' vertical shear strength has not been studied in-depth, a clear criterion about cast-in-place concrete's contribution to shear resistance is still a pending matter. The present study intends to reach practical conclusions about the shear strength assessment of composite concrete elements without web reinforcement. To do so, the shear strengths of 36 specimens, provided by existing shear formulations, were compared: 19 specimens tested by the authors, in which the existence of an interface between concretes, the cross-sectional shape and the concrete compressive strengths of the beam and slab were studied; and 17 specimens taken from a previous study about composite elements by Kim et al. (2016). The applied shear formulations were those of EC2-04, Draft 7 of EC2-20, *fib* MC-10, ACI 318-19 and the model proposed by Kim et al. (2016). Firstly, specimens' shear strength was calculated by considering that only the beam resisted shear. Secondly according to ACI 318-19 indications about assessing composite elements' shear strength, the entire composite element's effective depth was used considering the lower of the compressive strengths of the beam's and slab's concretes and the weighted average of the compressive strengths. Additionally, the entire effective depth and the beam's concrete compressive strength were used. Codes formulations were more precise when estimating the monolithic specimens' shear strengths than those of composites. Therefore, the development of an adapted methodology to assess these elements' shear strengths is needed. EC2-20 obtained the most accurate results and gave quite good estimations for composite elements when the entire effective depth and weighted average of the concretes compressive strengths were considered.

Keywords: *reinforced concrete, composite beam, precast construction, vertical shear strength, codes' shear formulations.*

1. Introduction

Ever since the first prestressed joists began to be manufactured halfway through the last century, the use of precast elements without transverse reinforcement on which a layer of cast-in-place concrete is poured has spread worldwide in the construction world. Given the widespread use of composite elements, the study of their structural behaviour is most important.

In the composite elements field, studies about the horizontal shear strength of the interface between concretes are common (e.g., Loov and Patnaik 1994 or Kovach and Naito 2008) because reaching the potential bending and shear strength of a composite beam is not possible if the interface strength has been exceeded (Halicka 2011). However, as the behaviour of these elements subjected to vertical shear forces has not been studied in-depth, a clear criterion about the contribution of the cast-in-place concrete to shear resistance is still a pending matter. This contribution in design is often omitted to, thus, stay on the safety side because shear is a phenomenon with many unknowns. Nonetheless, this contribution exists (Rueda-García et al. 2021) and its consideration could be favourable for assessing the shear strength of existing structures.

Some current design codes like *fib* Model Code (2010) do not refer to the shear strength treatment of composite elements. Other codes, such as EN 1992 Eurocode 2 (2004) in Section 10.9.3(8) and Draft 7 of the prEN 1992 Eurocode 2 (2020) in Section 13.6.1(5), allow the design of concrete elements with a topping at least 40 mm thick as composite elements if the shear at the interface is verified. ACI 318 (2019) in Section 22.5.4, apart for requiring the horizontal shear strength of the interface to be verified, it also indicates how the shear strength of these composite elements can be calculated: using the properties of the individual elements or the properties of the element that result in the most critical value.

Of all existing experimental studies on composite beams subjected to shear, that carried out by Kim et al. (2016) should be mentioned. It is an experimental study that was performed with 22 monolithic and composite rectangular concrete beams without web reinforcement, with a cross-section of 0.26x0.40 m, shear span-depth ratios *a/d* of 2.5 and 4.0, and different longitudinal reinforcement ratios (ρ_l = 1.31%, 1.75% and 2.87%). In both monolithic and composite beams, the authors used different concrete classes, e.g. normal-strength concrete (NSC) and high-strength concrete (HSC), with a nominal compressive strength of 24 MPa and 60 MPa, respectively. In composite beams, they studied different area ratios of HSC to NSC. Their study analysed the existence of different concrete classes, but not distinct concrete ages (in composite specimens, the upper layer concrete casting was carried out 24 h after the lower layer concrete casting). For the assessment of composite beams' shear strengths with existing formulations, they used the weighted average of the beam and slab's concrete compressive strengths $f_{c,wa}$, according to the ACI 318 proposal about employing properties of individual elements. These authors observed how design codes formulations underestimated shear strength, except for the beams with $f_{c,wa} \geq 50$ MPa and $\rho_l \leq 1.75\%$, in which strength was overestimated. Consequently, they proposed a shear strength calculation method for composite beams, which is also applicable to monolithic beams, and is based on using the compressive strengths of each element, which well fitted the shear strength of the beams in their experimental programme.

When paying attention to the geometric characteristics of the composite elements typically employed in building constructions (for example, beam-and-block floors, one-way ribbed slabs or two-way ribbed slabs), the behaviour of these elements could resemble that of a T-shaped composite beam more than that of a rectangular composite beam. As T-shaped monolithic beams behave differently to rectangular beams due to the section width change, the study of T-shaped composite beams is considered to be of interest. Therefore, the authors of the present communication recently developed an experimental programme in 21 monolithic and composite beams with rectangular and T-shaped cross-sections without web reinforcement, and with *a/d* = 4.0, ρ_l = 4.08% using concretes of different compressive strengths (NSC and HSC of 30 and 60 MPa nominal strength, respectively), where the concretes in the composite beams were cast with a 24-hour difference, except for two specimens in which the influence on the shear strength of a large age difference between concretes was studied (Rueda-García et al. 2021). The main characteristics and results of this study are explained in the next section.

The present study aims to analyse the accuracy of existing shear formulations in composite concrete elements without web reinforcement to reach practical conclusions about their shear strength assessment. For this purpose, the shear strength of a selection of monolithic and composite beams from the studies of Rueda-García et al. (2021) and Kim et al. (2016) was calculated with formulations of EC2-04, EC2-20 D7, MC-10, ACI 318-19 and Kim et al. (2016) using different criteria to assess shear strength in composite beams. In particular, those specimens with *a/d* = 4.0 and with a 24-hour age difference between concretes in composite beams were herein included. There were, thus, 36 specimens with different: longitudinal reinforcement ratios (ρ_l = 1.31%, 1.75%, 2.87% and 4.08%); concrete classes (NSCs of 24 or 30 MPa nominal compressive strength and HSCs of 60 MPa nominal compressive strength); cross-sectional geometries (rectangular or T-shaped); slab to beam area ratios.

2. The authors' test programme

In this communication, the experimental results of 19 of the 21 specimens tested by the authors in Rueda-García et al. (2021) were compared to the shear strengths predicted by different formulations. The main characteristics of these tests, as well as the obtained results and relevant observations, are explained below.

2.1. Test specimens

Nineteen monolithic and composite simply-supported beams without web reinforcement were fabricated and tested under two point loads. The variables analysed to study their influence on shear strength were: cross-sectional shape, the existence of an interface between concretes and the concrete compressive strengths of both the beam and slab.

The fixed parameters in all the specimens were: shear span-effective depth ratio (*a/d* = 4.0) of the principal span (the non-reinforced span in shear in which failure was expected); longitudinal reinforcement ratio (ρ_l = 4.08%); relative concrete cover (*c/h* = 0.16); roughness of the interface in composite beams (very rough interface according to design codes EC2-04, EC2-20, MC-10 and ACI 318-19). Figure 1 shows the geometry and reinforcement of the test specimens.

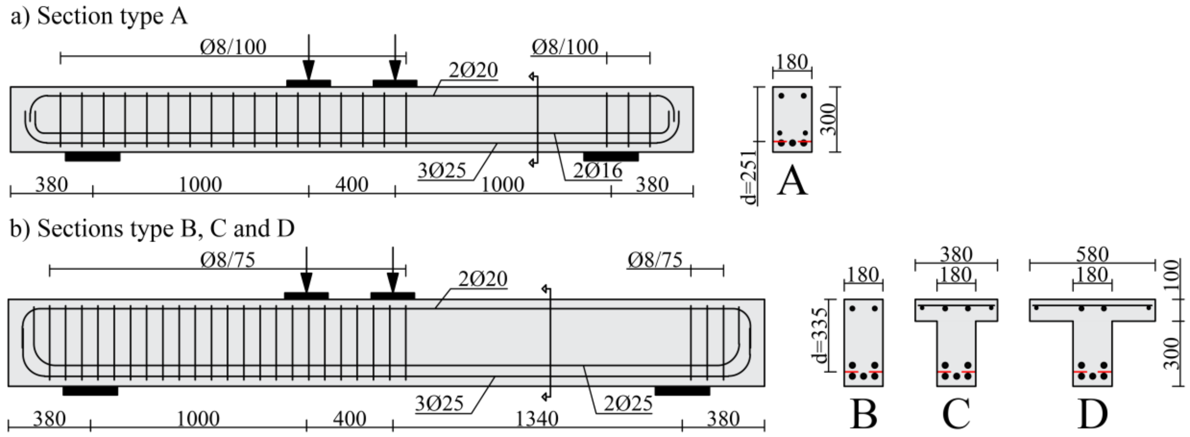

Figure 1. Geometry and reinforcement of the test specimens: a) specimens with section type A; b) specimens with sections type B, C and D (units: mm).

Regarding the cross-section shape, specimens with rectangular cross-sections were fabricated (sections A and B in Figure 1) and with T-shape sections (sections C and D in Figure 1) to study the influence of flange width on the shear strength of composite beams without web reinforcement.

In order to study how the existence of an interface between concretes influences shear strength, specimens of one concrete or monolithic (A1, B1 and C1 in Table 1) and of two concretes or composite (B2, C2 and D2 in Table 1) were fabricated. In the composite specimens, the lower 3/4 area of the cross-section (0.30 m) corresponded to the concrete of the precast beam and the upper 1/4 area (0.10 m) corresponded to the concrete of the cast-in-place slab on top of the beam.

The analysis of the influence of the compressive strengths of the beam's and slab's concretes was carried out by manufacturing a series of specimens in which both the beam and slab were fabricated with a normal-strength concrete NSC of 30 MPa nominal compressive strength (series NO in Table 1), and by producing series of specimens in which the beam had a high-strength concrete HSC of 60 MPa and the slab had an NSC of 30 MPa (series HO in Table 1).

The specimens' fabrication was divided into four fabrication batches (P1 to P4 in Table 1). In them all, firstly the concrete of the monolithic specimens and the beam's concrete of the composite specimens were poured. Before concrete hardened, composite beams' surface was raked to obtain a very rough interface. After 24 h, the slab's concrete of the composite elements was poured.

Table 1. Summary of specimens and test results.

Series	Fabrication batch	Specimen	Section type	f_c beam (MPa)	f_c slab (MPa)	V_{exp} (kN)
NO	P1	NOP1B2	B2	32	31	91
	P2	NOP2A1	A1	39	-	75
		NOP2B1	B1	40	-	88
		NOP2C1	C1	40	-	72
		NOP2C2	C2	39	34	94
		NOP2D2	D2	39	34	84
	P3	NOP3A1	A1	33	-	62
		NOP3B1	B1	30	-	81
		NOP3B2a	B2	31	38	70
		NOP3B2b	B2	31	38	86
		NOP3C1	C1	30	-	79
		NOP3C2	C2	29	38	86
		NOP3D2	D2	29	38	85
HO	P4	HOP4A1	A1	61	-	86
		HOP4B1	B1	63	-	93
		HOP4B2	B2	63	31	101
		HOP4C1	C1	63	-	90
		HOP4C2	C2	63	31	86
		HOP4D2	D2	63	31	99

Specimens were tested approximately 30 days after being fabricated. The compressive strengths of concretes on the day specimens were tested are shown in Table 1 (f_c). The maximum aggregate size d_g of concretes was 10 mm. For the steel properties of the longitudinal reinforcement, a yield strength f_y of 557 MPa and a modulus of elasticity E_s of 199 GPa were measured.

2.2. Test results

All the specimens showed diagonal cracking failure. In most of the T-shaped monolithic specimens and the rectangular and T-shaped composite specimens, the diagonal critical shear crack deviated horizontally along the interface between concretes or on the plane in which the section width changed. No specimen underwent pure horizontal shear failure. Crack patterns representative examples of rectangular and T-shaped monolithic and composite specimens are shown in Figure 2. Specimens' experimental shear strength is shown in Table 1 as V_{exp}.

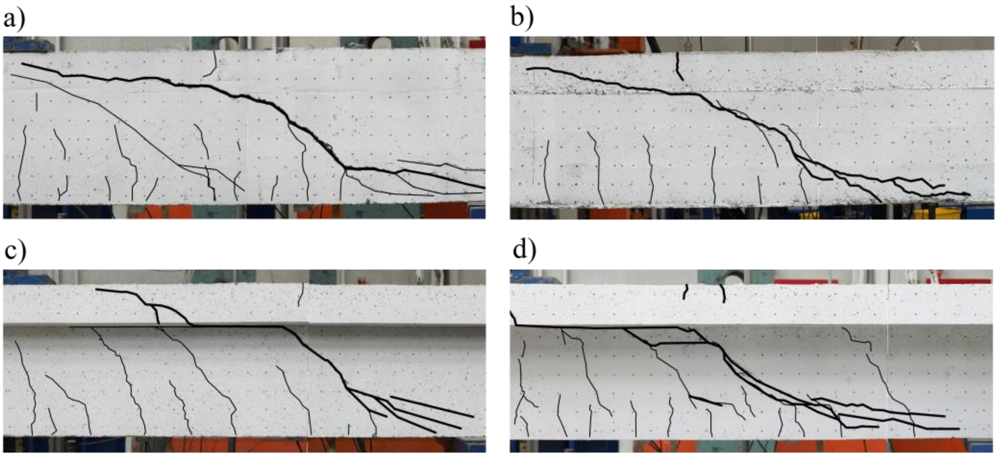

Figure 2. Examples of the test specimens crack patterns: a) rectangular monolithic beam HOP4B1; b) rectangular composite beam NOP1B2; T-shaped monolithic beam NOP3C1; d) T-shaped composite beam HOP4D2.

By comparing beams A1 with beams B2, it was concluded that the cast-in-place slab contributed to resist shear in the specimens of this experimental programme. It was observed that the V_{exp} in the rectangular and T-shaped specimens was similar, thus it was concluded that shear strength was governed by the shear transfer actions that occurred on the beams' web. On average, the HO series specimens showed slightly higher shear strength than those of the NO series, which once again proves the importance of the beam's web concrete in the shear strength of beams without web reinforcement. In most cases, it was also noted that the composite specimens displayed slightly higher shear strength than their homologous monolithic specimens, which was possibly due to the critical shear crack propagating along the interface, which could increase compression chord depth and, thus, its shear strength.

3. Vertical shear strength predictions

In order to carry out this comparative study between shear formulations to assess their precision in calculating the shear strength of composite elements without web reinforcement, the results of the 19 specimens described in Section 3 and the results of 17 of the specimens tested by Kim et al. (2016) were used.

In the study by Kim et al. (2016), four beam series were fabricated, of which only the three series with a/d = 4.0 were taken for this study in order to avoid possible overstrengths by the arching action of the series with a/d = 2.5. Each series had a different longitudinal reinforcement ratio (ρ_l = 1.31%, 1.75% and 2.87%). In this communication, only the influence of using different concrete classes in the beam and slab (NSC and HSC), the location of these concretes in the beam or slab, and the relation between the depth of both the beam and slab, were analysed. In each series, five cross-section types were studied, all of which were rectangular (0.26x0.40 m): sections A and B, both monolithic, were fabricated with NSC and HSC, respectively; composite sections C and D, in which NSC was used in the upper 3/8 and 5/8 areas of the cross-section, respectively, and HSC in the lower area; composite section E, where HSC was employed in the upper 3/8 and NSC in the lower area.

For calculations, the shear formulations for elements without web reinforcement of the following current design codes were used: EC2-04, MC-10 at its two approximation levels and ACI 318-19. Additionally, the new formulation of the future EC2-20 presented in Draft 7, based on the Critical Shear Crack Theory (CSCT), was applied, as was the method proposed by Kim et al. (2016) for monolithic and composite beams, in which the effective depths of the tension and compression zones, and their respective concrete compressive strengths, are used.

When predicting the shear strength of composite beams with the codes' formulations, four different perspectives were employed. On the one hand, it was considered that only the beam resisted shear. Thus the beam's effective depth d_b and the compressive strength of the beam's concrete $f_{c,b}$ were used. On the other hand, the entire composite beam's effective depth d_c was employed. In this case, the minimum of the beam's and slab's compressive strengths ($f_{c,min}$), the weighted average of the beams' and slab's compressive strengths ($f_{c,wa}$), obtained from the area ratio of both concretes, or the beam's concrete compressive strength ($f_{c,b}$), were used. Although only ACI 318-19 proposes utilising d_c and $f_{c,min}$ or $f_{c,wa}$, the four perspectives were calculated with all the considered codes' formulations for comparison purposes.

Firstly, the precision of formulations was analysed in the 16 monolithic beams selected from the studies of Rueda-García et al. (2021) (9 tests) and Kim et al. (2016) (7 tests). Table 2 provides the mean value and coefficient of variation (CV) of the relation between the experimental shear strength V_{exp} and the shear strength predicted by the different formulations V_{pred} for the nine monolithic beams fabricated with NSC and the seven monolithic beams produced with HSC.

Table 2. Statistical indicators of the V_{exp}/V_{pred} ratio for the 16 monolithic beams without web reinforcement.

Concrete type	EC2-04		EC2-20 D7		MC-10 LI		MC-10 LII		ACI 318-19		Kim et al. 2016	
	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)
NSC	0.89	14.50	1.06	9.20	1.99	11.62	1.16	10.87	1.21	17.77	0.92	12.36
HSC	0.85	12.00	0.99	9.46	1.61	18.07	1.07	10.72	1.03	13.01	0.91	11.48

The results in Table 2 show that EC2-04 gave a very unsafe V_{pred} for the monolithic specimens in this study. On the contrary, the formulation proposed in the new EC2-20 D7 gave the highest precision values of all the employed formulations, plus a low CV. Although the MC-10 Level I has a simple formulation, it was very much on the safety side. Level II showed more accurate results and little dispersion. Unlike the other applied formulations, it was observed that both ACI 318-19 and MC-10 LI gave a very different result between the specimens with NSC and those with HSC. The method proposed by Kim et al. (2016) led to unsafe results in monolithic beams.

Table 3 shows the mean value and CV of the V_{exp}/V_{pred} ratio for the seven composite specimens fabricated with NSC in the beam and slab, which all come from Rueda-García et al. (2021), and the 13 composite beams fabricated with HSC and NSC (3 from Rueda-García et al. (2021) and 10 from Kim et al. (2016)) for the four described calculation perspectives. Regarding the different studied cross-section types, those whose result did not differ significantly from the rest were included in the analysis. For this reason, the three specimens from Kim et al. (2016) with section type D (NSC in the upper 5/8 area of the cross-section and HSC in the lower area), were separated from the population in the d_b, $f_{c,b}$ method for the HSC-NSC beams, because, as the beam's depth was much lower than the slab's depth, the V_{pred} was very much on the safety side. Therefore, if these specimens were analysed with the other specimens, they would increase the safety of the method's mean value. Similarly in the d_c, $f_{c,b}$ method for the HSC-NSC beams, the three specimens of Kim et al. (2016) with section type E (HSC in the upper 3/8 and NSC in the lower area) were separated from the rest because, as the HSC was in the slab and not in the beam, the V_{pred} was very much on the safety side, which would also increase the safety of the method's mean value.

Table 3. Statistical indicators of the V_{exp}/V_{pred} ratio for the 20 composite beams without web reinforcement.

Concrete types	Method	EC2-04		EC2-20 D7		MC-10 LI		MC-10 LII		ACI 318-19		Kim et al. (2016)	
		Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)
NSC-NSC	d_b, $f_{c,b}$	1.01	7.68	1.23	7.68	2.75	8.22	1.53	7.73	1.37	8.22	0.89	7.63
	d_c, $f_{c,min}$	0.88	7.82	1.11	7.82	2.15	7.84	1.18	7.82	1.19	7.84		
	d_c, $f_{c,wa}$	0.86	7.87	1.08	7.87	2.08	8.12	1.15	7.90	1.15	8.12		
	d_c, $f_{c,b}$	0.87	7.68	1.09	7.68	2.10	8.22	1.16	7.74	1.16	8.22		
HSC-NSC	d_b, $f_{c,b}$ (1)	1.35	24.27	1.45	18.42	2.67	22.51	2.13	26.04	1.84	31.07	0.99	14.78
	d_b, $f_{c,b}$ (2)	2.18	1.17	2.16	1.17	4.24	11.31	5.51	3.29	3.51	1.06		
	d_c, $f_{c,min}$	1.09	12.99	1.23	11.69	2.26	16.40	1.36	11.83	1.52	14.62		
	d_c, $f_{c,wa}$	0.93	11.03	1.05	8.79	1.77	13.75	1.16	9.48	1.20	12.38		
	d_c, $f_{c,b}$ (3)	0.85	11.66	0.97	10.49	1.56	15.32	1.06	10.54	1.04	12.00		
	d_c, $f_{c,b}$ (4)	1.08	3.55	1.18	3.55	2.14	12.91	1.32	3.41	1.52	4.12		

(1) The three specimens with section type D of Kim et al. (2016) are not included.
(2) Only the three specimens with section type D of Kim et al. (2016).
(3) The three specimens with section type E of Kim et al. (2016) are not included.
(4) Only the three specimens with section type E of Kim et al. (2016).

Figure 3 depicts the results obtained for the seven composite specimens of Rueda-García et al. (2021) fabricated with NSC with the formulations showing the highest precision according to the observations in Table 3 (EC2-20 D7, MC-10 LII and ACI 318-19, and the calculation methods of d_c with $f_{c,min}$, $f_{c,wa}$ and $f_{c,b}$). Figure 4 shows the results of these same formulations for the 13 composite specimens of Rueda-García et al. (2021) and Kim et al. (2016) fabricated with HSC and NSC, but excluding the three type E specimens of Kim et al. (2016) in the method with d_c and $f_{c,b}$.

Table 3 and Figures 3 and 4 show that, generally, considering that only the beam resisted shear gave results very much on the safety side with all the formulations in both specimens NSC-NSC (mean value of 1.58 on average for all the formulations) and HSC-NSC (1.89). As expected, for the NSC-NSC specimens the three methods that used d_c gave a similar mean value for each formulation and with similar dispersion (around 8%) because the compressive strengths of the beam's and slab's concretes were similar. If the results of each formulation for the composite beams are compared with those of the same formulation for the monolithic beams (Table 2), it is observed that the precision of formulations was higher for the monolithic beams, which proves that incorporating an adapted methodology into existing formulations to assess composite beams' shear strength would be needed. It was also found that if concrete's compressive strength was similar at both the beam and slab (NSC-NSC), the existence of an interface did not significantly change the dispersion of the calculation method (8% on average for all formulations and methods), while for different class concretes at the beam and the slab (HSC-NSC), the dispersion of the results increased (15%).

Regarding the precision shown by the different formulations, EC2-04 gave unsafe results for the NSC-NSC specimens and for the HSC-NSC specimens when d_c and $f_{c,wa}$ or $f_{c,b}$ were used. EC2-20 D7 was generally the most accurate formulation with the least dispersion in the specimens made with NSC, especially when d_c and $f_{c,wa}$ or $f_{c,b}$ were used. In the HSC-NSC beams, while the use of d_c and $f_{c,min}$ gave a very safe result, that of d_c and $f_{c,wa}$ showed the highest precision and lowest dispersion (Fig. 3). However, the use of d_c and $f_{c,b}$ (excluding type E beams) gave a slightly unsafe result. MC-10 LI obtained a very safe results compared to the other codes, and had the highest dispersion in the HSC-NSC beams. MC-10 LII and ACI 318-19 showed better precision, with similar results and on the safety side, but ACI 318-19 gave higher dispersion. The model of Kim et al. (2016) was greatly adjusted to the results of beams with different strength concretes, which was characteristic of their experimental programme, but was unsafe for the NSC-NSC beams.

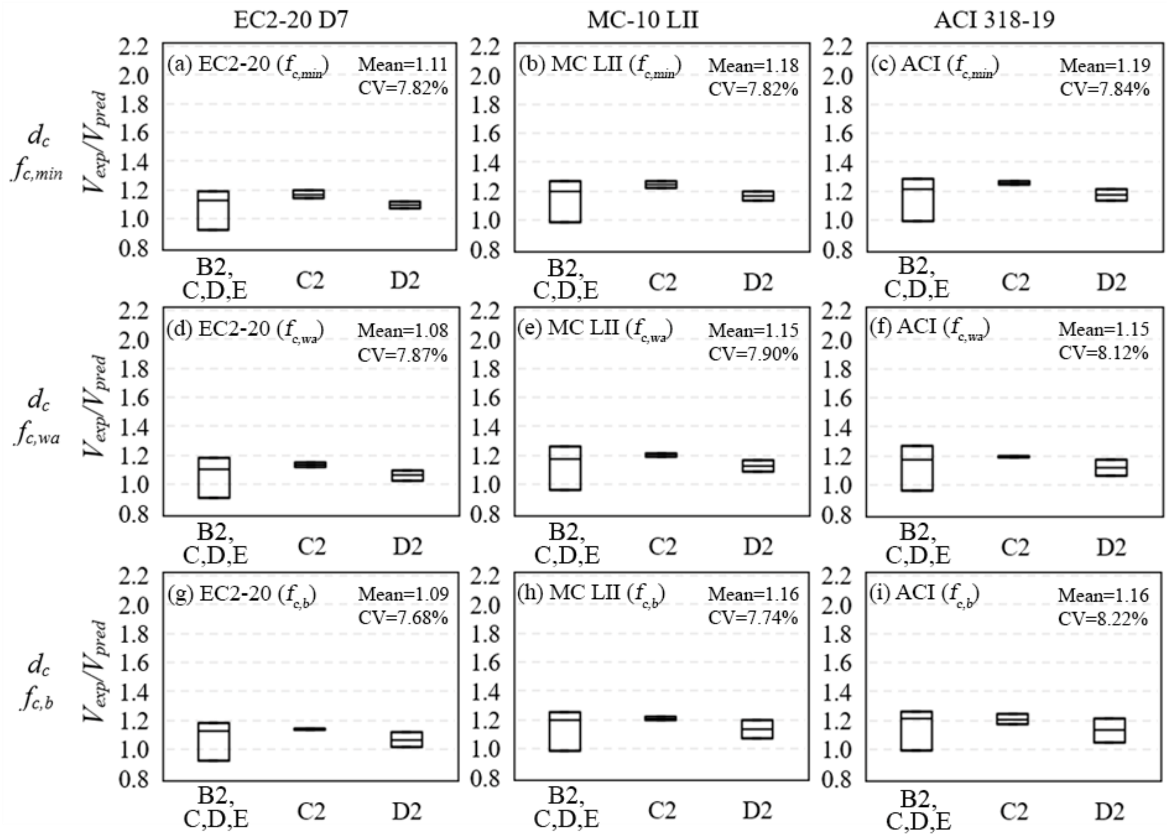

Figure 3. Shear strengths predicted by the codes for the 7 composite beams without web reinforcement made of NSC.

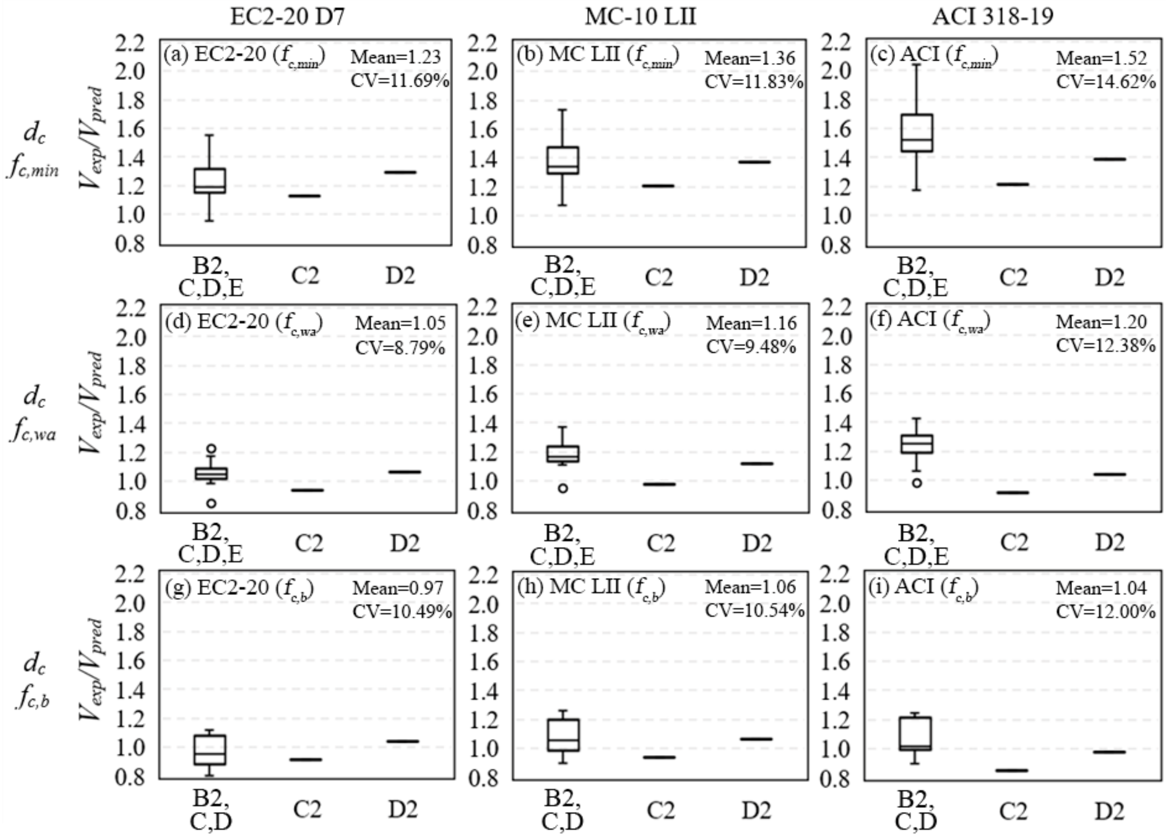

Figure 4. Shear strengths predicted by the codes for the 13 composite beams without web reinforcement made of HSC and NSC (10 specimens in method d_c, $f_{c,b}$).

Figure 4 shows the differences in the three methods that used d_c in beams with different concretes at both the beam and slab. This case is especially important because the use of different concretes is more widespread in composite construction. On the one hand, the use of $f_{c,min}$ was much safer than that of $f_{c,wa}$ and $f_{c,b}$ because of the large difference in the compressive strengths of both the beam and slab concretes in this series. The use of $f_{c,min}$ in beams with different concretes gave a mean value of 1.49 on average for all the formulations, while the beams with equal strength concretes gave, on average, 1.30. The smallest dispersions in the results were obtained when $f_{c,wa}$ was used (10% on average for all the formulations, with a mean value of 1.24) as the method's precision is independent of where HSC and NSC are in the composite beam and the relation between their effective depths. Although the use of d_c and $f_{c,b}$ is commonplace for calculating shear strength (Runzell et al. 2007 or Avendaño and Bayrak 2008, among others), and may be on the safety side if the beam's depth is much higher than that of the slab, this method proved slightly unsafe for the beams in this analysis when they were assessed with EC2-20 D7. The result came quite close to the actual one when MC-10 LII and ACI 318-19 were used, albeit with considerable dispersion because, in this case, the method's precision depends on the relation between the effective depths of both the beam and slab. A mean value of 1.17 was obtained by this method for all the composite specimens and formulations (1.28 for equal strength concretes and 1.10 for different strength concretes).

By way of conclusion, it can be deduced that the calculation of the shear strength of the composite beams without web reinforcement, fabricated with two concretes of equal or different compressive strengths using the entire depth of composite beam d_c and the weighted average of the beam's and slab's concrete compressive strengths estimated from the area ratio ($f_{c,wa}$), gave a precise value that was on the safety side with little dispersion when the EC2-20 D7 formulation was applied.

4. Conclusions

The objective of this communication was to reach practical conclusions for the assessment of the shear strength of composite concrete beams without web reinforcement by means of a safety analysis of the existing shear formulations. The major findings of the study were:

1. Existing formulations were more accurate when assessing the shear strength of the monolithic specimens than the composite specimens. Therefore, the need to incorporate a calculation methodology into design codes that adapts to composite concrete elements without web reinforcement was found.
2. Formulations showed greater dispersion for the composite specimens made of different compressive strength concretes (coefficient of variation of 15%, on average for all the formulations) than for those made with equal compressive strength concretes (8%).
3. Of all the calculation methods herein used, the assessment of the composite beams' shear strength when considering that only the beam resisted shear gave a very safe result (1.58 and 1.89 for the beams with equal and different compressive strength concretes, respectively, on average for all the formulations). Employing the entire depth of composite element d_c and the minimum compressive strength of the beam's and slab's concretes increased safety in the beams with different compressive strengths at the beam and the slab (1.30 for equal compressive strengths vs. 1.49 for different compressive strengths). The use of d_c and the weighted average of the compressive strengths of the beam's and slab's concretes generally gave the best results (1.24 on average for all the formulations). Employing d_c and the compressive strength of the beam's concrete provided good results (1.17), but they were unsafe in some cases.
4. The formulation of Draft 7 of EC2-20, using the entire depth of the composite element and the weighted average of the compressive strengths of the beam's and slab's concretes, gave the most accurate results, which remained on the safety side (mean value of 1.08 for the composite beams with equal strength concretes and 1.05 for different strength concretes).

However, the number of experimental specimens is still limited and, thus, further studies are required to verify the shear strength of composite concrete elements without web reinforcement. In the future, a detailed study of the existing formulations, paying attention to their theoretical basis in order to specify how the beam's and slab's concretes contribute to shear strength, would be of great interest.

Acknowledgements

This study forms part of the research conducted at the Concrete Science and Technology University Institute (ICITECH) of the Universitat Politècnica de València (UPV, Spain) with concrete supplied by Caplansa. The project has been supported by the Spanish Ministry of Science and Innovation through Projects BIA2015-64672-C4-4-R and RTI2018-099091-B-C21-AR; the Regional Government of Valencia through Project AICO/2018/250, and the European Union with FEDER funds. The authors thank the Spanish Ministry of Economy and Business for Grant BES-2016-078010.

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