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# Shear Transfer Resistance with Different Interface Conditions: Evaluation of Design Provisions and Proposed Equation

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**Abstract:** The design provisions in current codes for shear resistance of concrete-to-concrete interfaces exhibit significant differences. In this study, the accuracy of design provisions for interface shear resistance was evaluated and compared. From the literature search, a database of 458 push-off test results of interface shear resistance was created to evaluate the shear transfer provisions from the *ACI 318-19*, *PCI Design Handbook*, *AASHTO LRFD Bridge Design Specifications*, *CSA-S6*, *Eurocode 2*, and *Fib Model Code 2010*. In addition, an equation was derived based on push-off test results collected from the literature to calculate the interface shear resistance for the monolithic uncracked interface. According to many analyses and evaluations of parameters affecting the interface shear resistance, the compressive strength of concrete played an important role, especially for the monolithic uncracked interface. Therefore, the compressive strength of concrete was included in the proposed equation to calculate the interface shear resistance in this study. It is expected that this equation can be applied more accurately than the existing design provisions when high-strength concrete is used. Statistical analyses were carried out for comparison with the existing design provisions to verify the applicability of the proposed equation. The results show that the proposed equation reasonably predicted the interface shear resistance for the monolithic uncracked interface. Appropriate conclusions were also drawn for the design provisions.

**Keywords:** interface shear resistance; different interface conditions; design provisions; monolithic uncracked interface



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## 1. Introduction

In concrete mechanics, interface shear transfer in reinforced concrete is probably one of the most important properties to be studied. Shear forces are transferred across an interface in many practical situations. Some typical examples of shear transfer interfaces are a potential or existing crack in a corbel, a cold joint in the shear wall, and an interface between a precast girder and cast-in-place deck in bridges. Recently, innovative off-site constructions utilizing prefabricated bridge elements have been continuously developed. The full-depth deck panel system is a typical system. In recent studies [1–3], prefabricated composite girders with precast deck panels connected to the steel girders by injecting conventional grout into a continuous channel above the steel girders have been proposed. The performance of prefabricated composite girders with such injection channel connections is greatly influenced by the details and design of connections. The design of the injection channel connection is complicated with three different types of critical interfaces including the interface shear of monolithic grout (1) (consisting of (1A), (1B), and (1C)), interface shear between the precast deck and the field-cast haunch (2), and interface shear between the steel beam and the field-cast haunch (3), as indicated in Figure 1.

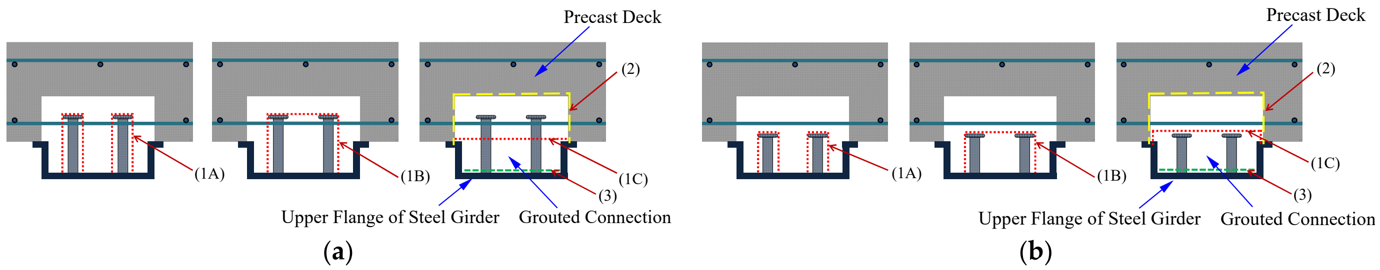



**Figure 1.** Interfaces of the injection channel connection: (**a**) conventional connection (shear connector and reinforcement intersect) and (**b**) novel connection (shear connector and reinforcement do not intersect).

There are two types of connection: conventional connection (shear connector and reinforcement intersect), as shown in Figure 1a, and novel connection (shear connector and reinforcement do not intersect), as shown in Figure 1b. These two cases are different in the interface shear of monolithic grout. For conventional connection, the shear strength of monolithic grout is reinforced by reinforcements (1A, 1B) or shear connectors (1C). For novel connection, the shear strength of monolithic grout includes only the shear strength of grout. The failure of the interface shear of monolithic grout is the minimum value corresponding to the interfaces (1A), (1B), and (1C). This study focuses on the interface types (1) and (2). Along with the development of prefabricated bridge elements, more different types of interfaces need to be considered. One of those categories that may be notable is the unreinforced monolithic uncracked interface, for which it is expected that the high compressive strength of concrete or grout can significantly improve the interface shear resistance. These interfaces should be designed carefully. Interface shear resistance is a research subject that has been extensively investigated in the past. For this purpose, the most typical types of specimens utilized are push-off specimens with uncracked, precracked, or cold-jointed interfaces. Most of the equations for the estimation of interface shear resistance are suggested based on the push-off test results. Many codes also suggest equations to compute the interface shear resistance for different interface types. This study evaluated the design provisions and proposed an equation that is expected to be more widely applicable to various cases for critical interfaces of prefabricated structures.

## 2. Background and Design Provisions of Interface Shear

Birkeland and Birkeland [4] were the first authors to propose a shear friction theory, as illustrated in Figure 2, to compute the ultimate shear resistance of concrete interfaces, which can be presented by the following equation:

$$v_u = \rho f_y \tan\varphi = \rho f_y \mu \tag{1}$$

where $v_u$ is the ultimate interface shear resistance, $\rho$ is the interface shear reinforcement ratio, $f_y$ is the reinforcement yield stress, $\varphi$ is the internal friction angle, $\mu$ is the friction factor, and $\rho f_y$ is known as the clamping stress.

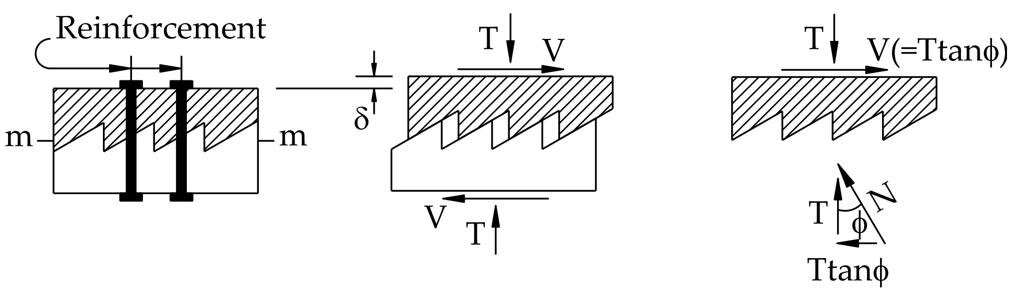



**Figure 2.** Shear friction theory model [4].

When first suggested by Birkeland and Birkeland, this equation included the following conditions:

$f_y \leq 60$ (ksi)

$\rho \leq 1.5\%$

$v_u \leq 800$ and $f_c{}' \geq 4000$ (psi)

The shear friction theory assumes that when shear and compression forces act on concrete-to-concrete interfaces, the main load transfer mechanism is friction. The shear resistance is generated by surface roughness and a relative slippage between two concrete surfaces. A normal displacement and tensile stresses in the reinforcement crossing the interface are generated which grow clamping stress and lead to slippage resistance. From Figure 2, the normal displacement grows with the increase in slippage, and this displacement causes the yield tension of the reinforcement, which corresponds to shear resistance. After the shear friction theory was proposed, many researchers introduced different terms to develop the shear friction theory. In 1972, an equation named "modified shear friction theory" was proposed by Mattock and Hawkins [5,6]. In this equation, besides the friction mechanism related to surface roughness and clamping stress, the cohesion mechanism was also considered for the first time. Mattock et al. carried out many studies on interface shear resistance [7–10]. Then, equations were attempted to be adopted by many researchers. In 1997, a remarkable development in the design equations for shear resistance of concrete interfaces was proposed by Randl [11]. Randl considered the interface shear resistance including three load transfer mechanisms: (1) cohesion related to adhesion and aggregate interlock, (2) friction caused by surface roughness and clamping stress and/or externally applied loads, and (3) dowel action due to the deformation of the shear reinforcement. Then, to simplify Randl's equation, other researchers suggested an equation neglecting the dowel action and considering the dowel action influence as a portion of the clamping stress [12]. In 2000, Zilch and Reinecke [13] analyzed the three different load transfer mechanisms in more detail by establishing the relationship between slippage and interface shear resistance, as indicated in Figure 3. First, cohesion activates after small interface slippage caused by the loss of adhesion; then, it declines quickly with the increase in slippage. Second, friction is related to external loads perpendicular to the interface and clamping influence due to tension force when using shear reinforcement. Lastly, dowel action occurs after cohesion is broken.

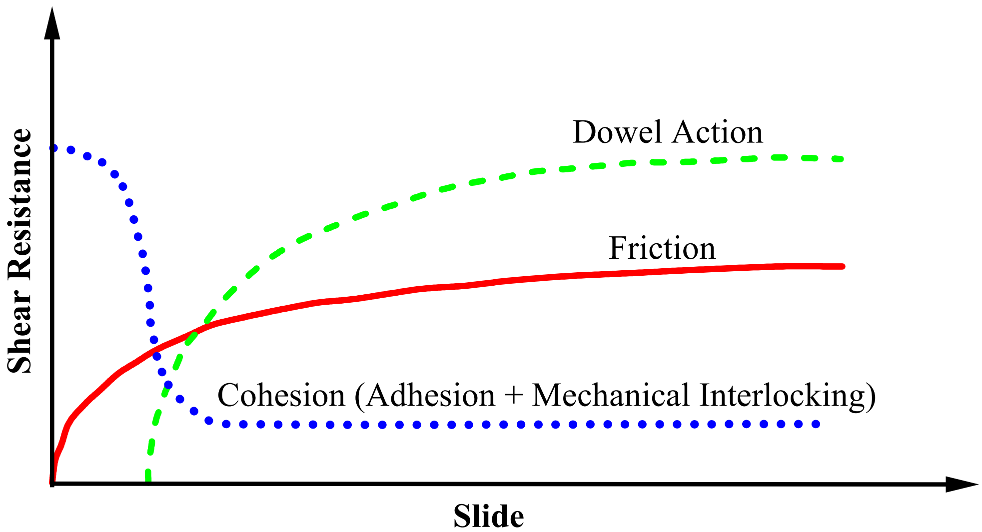



**Figure 3.** Three load transfer mechanisms are based on slippage [13].

In 2003, surface roughness was considered directly for the first time in the equation proposed by Gohnert [14]. To emphasize the importance of surface roughness, Santos and Júlio [15] suggested an equation for interfaces with different surface roughness preparations.

Based on a great amount of past research, the codes suggest equations for predicting the interface shear resistance of concrete-to-concrete interfaces. Provisions for interface shear resistance from *ACI 318-19* [16], *PCI Design Handbook* [17], *AASHTO LRFD* [18], *CSA-S6* [19], *Eurocode 2* [20], and *Fib Model Code 2010* [21] are presented below. In order to facilitate the comparison and presentation, the form of design equations is unified to be based on stress.

***ACI 318-19* [16]**

*ACI 318-19* [16] (Article 22.9.4) assumes a crack across the interface. Therefore, the cohesion mechanism (adhesion and aggregate interlock) is ignored. Friction due to clamping stress of reinforcement across the interface is the only load transfer mechanism considered. Moreover, the dowel action mechanism is also neglected. The friction factor based on four different interface conditions for normal weight concrete and lightweight concrete is presented. The strength reduction factor $\phi$ = 0.75. According to the *ACI 318-19*, when shear friction reinforcement is perpendicular to the interface, shear resistance across the assumed interface shall be calculated by:

$$\begin{gathered} v_n = \mu \rho f_y \\ v_n \leq v_{n,max} \end{gathered} \tag{2}$$

where $\mu$ is the friction factor (see Table 1), $\rho$ is the interface shear reinforcement ratio = $A_{vf}/A_{cv}$, $A_{vf}$ is the area of shear reinforcement crossing the interface, $A_{cv}$ is the area of the concrete section resisting shear transfer, $f_y$ is the reinforcement yield stress (limited in design to 413.7 MPa), $v_{n,max}$ is the maximum nominal interface shear resistance (see Table 1), and $v_n$ is the nominal interface shear resistance.

**Table 1.** Friction coefficients and upper limits.

| Contact Surface Condition | $\mu$ | $v_{n,max}$ (MPa) |
|---|---|---|
| Concrete placed monolithically | 1.4$\lambda$ | For normal-weight concrete (monolithic or roughened), least of $\left\{ \begin{array}{l} 0.2f'_c \\ 3.31 + 0.08f'_c \\ 11.03 \end{array} \right\}$ For all other cases, lesser of $\left\{ \begin{array}{l} 0.2f'_c \\ 5.52 \end{array} \right\}$ |
| Concrete placed against hardened concrete that is clean and intentionally roughened to a full amplitude of approximately 6 mm | 1.0$\lambda$ | |
| Concrete placed against hardened concrete that is clean and not intentionally roughened | 0.6$\lambda$ | |
| Concrete anchored to as-rolled structural steel by headed studs or by reinforcing bars where all steel in contact with concrete is clean and free of paint | 0.7$\lambda$ | |

$\lambda$ = modification factor for concrete weight ($\lambda$ = 1.0 for normal-weight concrete, $\lambda$ = 0.85 for sand lightweight concrete, $\lambda$ = 0.75 for all lightweight concrete). $f_c{}'$ = compressive strength of concrete.

***PCI Design Handbook*, seventh edition [17]**

The *PCI Design Handbook* [17] (Article 5.3.6) suggests two equations to calculate the interface shear resistance across an interface with reinforcement perpendicular to the interface:

$$v_n = \mu_e \rho f_y \tag{3a}$$

$$v_n = \mu \rho f_y \tag{3b}$$

$$\mu_e = \frac{\phi 1000 \lambda \mu}{v_u} (\text{psi}) = \frac{\phi 6.895 \lambda \mu}{v_u} (\text{MPa})$$

$$v_n \leq v_{n,max}$$

where $\mu_e$ is the effective coefficient of friction (limited by the values given in Table 2), $\phi$ is the strength reduction factor, $v_u$ is the factored shear stress demand, $\lambda$ is the concrete weight reduction factor (see Table 2), $\mu$ is the friction factor (see Table 2), $\rho$ is the interface shear reinforcement ratio = $A_{vf}/A_{cv}$, $A_{vf}$ is the area of the shear reinforcement crossing the interface, $A_{cv}$ is the area of the concrete section resisting shear transfer, $f_y$ is the reinforcement yield stress (limited in design to 413.7 MPa), $v_{n,max}$ is the maximum nominal interface shear resistance (see Table 2), and $v_n$ is the nominal interface shear resistance.

**Table 2.** Friction coefficients and upper limits.

| Contact Surface Condition | $\mu$ | $\mu_{e,max}$ | $v_{n,max}$ (Psi) |
|---|---|---|---|
| Concrete placed monolithically | $1.4\lambda$ | 3.4 | $0.3\lambda f_c' < 1000$ |
| Concrete to hardened concrete, with roughened surface | $1.0\lambda$ | 2.9 | $0.25\lambda f_c' < 1000$ |
| Concrete placed against hardened concrete not intentionally roughened | $0.6\lambda$ | n/a | $0.2\lambda f_c' < 800$ |
| Concrete to steel | $0.7\lambda$ | n/a | $0.2\lambda f_c' < 800$ |

$\lambda$ = modification factor for concrete weight ($\lambda$ = 1.0 for normal-weight concrete, $\lambda$ = 0.85 for sand lightweight concrete, $\lambda$ = 0.75 for all lightweight concrete). $f_c'$ = compressive strength of concrete.

Substituting $v_u/\phi$ by the nominal shear resistance $v_n$ and combining Equation (3a) and the equation for the calculation of $\mu_e$ gives Equation (4):

$$v_n = \sqrt{6.895\mu\lambda\rho f_y} \quad (4)$$

From the above equation, the shear resistance $v_n$ is proportional to the $\sqrt{\rho f_y}$ instead of $\rho f_y$. This increases the shear resistances at low values of clamping stress and thus has some similarities with the cohesion term addition. Monolithic interfaces and intentionally roughened cold joints are recommended using Equation (3a), while steel-to-concrete interfaces and non-roughened cold joints should utilize Equation (3b). The *PCI* uses the strength reduction factor $\phi$ = 0.75.

***AASHTO LRFD* (2020) [18]**

The *AASHTO LRFD Bridge Design Specifications* [18] (Article 5.7.4) suggests equations to compute the nominal shear resistance across any given plane. The *AASHTO LRFD* uses the modified shear friction model including the cohesion mechanism (adhesion and aggregate interlock). The strength reduction factor in the *AASHTO LRFD* is 0.9. The nominal interface shear resistance shall be taken as:

$$\begin{gathered} v_n = c + \mu(\rho f_y + N) \\ v_n \le K_1 f_c' \\ v_n \le K_2 \end{gathered} \quad (5)$$

where $c$ is the cohesive factor (see Table 3), $\mu$ is the friction factor (see Table 3), $\rho$ is the interface shear reinforcement ratio = $A_{vf}/A_{cv}$, $A_{vf}$ is the area of the shear reinforcement crossing the interface, $A_{cv}$ is the area of the concrete section resisting shear transfer, $N$ is the permanent net compressive stress = $P_c/A_{cv}$, $P_c$ is the permanent net compressive force, $f_y$ is the reinforcement yield stress (limited in design to 413.7 MPa), $K_1$ is the fraction of concrete strength available to resist interface shear (see Table 3), $K_2$ is the limiting interface shear resistance (see Table 3), $f_c'$ is the compressive strength of concrete, and $v_n$ is the nominal interface shear resistance.

**Table 3.** Coefficients for different interface types.

| Interface Type | $c$ (MPa) | $\mu$ | $K_1$ | $K_2$ (MPa) |
|---|---|---|---|---|
| Concrete placed monolithically | | | | |
| *For normal-weight concrete* | 2.8 | 1.4 | 0.25 | 10.3 |
| *For lightweight concrete* | 1.7 | 1 | 0.25 | 6.9 |
| Cast-in-place concrete slab on clean concrete girder surfaces, with surface roughened to an amplitude of 6 mm | | | | |
| *For normal-weight concrete* | 1.9 | 1 | 0.3 | 12.4 |
| *For lightweight concrete* | 1.9 | 1 | 0.3 | 9 |
| Concrete placed against a clean concrete surface, with surface intentionally roughened to an amplitude of 6 mm | | | | |
| *For normal-weight concrete* | 1.7 | 1 | 0.25 | 10.3 |
| *For lightweight concrete* | 1.7 | 1 | 0.25 | 6.9 |
| Concrete placed against a clean concrete surface, but not intentionally roughened | 0.52 | 0.6 | 0.2 | 5.5 |
| Concrete anchored to as-rolled structural steel by headed studs or by reinforcing bars where all steel in contact with concrete is clean and free of paint | 0.17 | 0.7 | 0.2 | 5.5 |

***CSA-S6-06* [19]**

The *Canadian Highway Bridge Design Code CSA-S6* [19] (Article 8.9.5.1) assumes that cracks occurring along with the interface and the shear resistance is constituted by two load transfer mechanisms: cohesion and friction. The strength reduction factor in the *CSA-S6* is 0.75. The interface shear resistance may be computed as:

$$\begin{gathered} v_n = \lambda\left[c + \mu(\rho f_y + N)\right] \\ v_n \le 0.25 f_c' \\ v_n \le 6.5\text{MPa} \end{gathered} \tag{6}$$

where $\lambda$ is the modification factor for concrete weight (equal to 1.0 for normal-weight concrete, 0.85 for sand lightweight concrete, and 0.75 for all lightweight concrete), $c$ is the cohesive factor (see Table 4), $\mu$ is the friction factor (see Table 4), $\rho$ is the interface shear reinforcement ratio = $A_{vf}/A_{cv}$, $A_{vf}$ is the area of the shear reinforcement crossing the interface, $A_{cv}$ is the area of the concrete section resisting shear transfer, $N$ is the permanent net compressive stress = $P_c/A_{cv}$, $P_c$ is the permanent net compressive force, $f_y$ is the reinforcement yield stress (limited in design to 500 MPa), $f_c{}'$ is the compressive strength of concrete, and $v_n$ is the nominal interface shear resistance.

**Table 4.** Coefficients for different interface types.

| Contact Surface Condition | $c$ (MPa) | $\mu$ |
|---|---|---|
| Concrete placed monolithically | 1 | 1.4 |
| Concrete placed against a clean concrete surface, with surface intentionally roughened to an amplitude of 5 mm | 0.5 | 1 |
| Concrete placed against a clean concrete surface, but not intentionally roughened | 0.25 | 0.6 |
| Concrete anchored to as-rolled structural steel by headed studs or by reinforcing bars | 0 | 0.6 |

***Eurocode 2* (EN 1992-1-1:2004) [20]**

*Eurocode 2* [20] (Article 6.2.5) suggests an equation for predicting interface shear resistance between concretes cast at different times. As indicated in Equation (7), *Eurocode*

2 considers the cohesion mechanism in relation to the lower design tensile strength of concrete and the friction mechanism related to clamping stress and externally applied stresses perpendicular to the interface. The dowel action effect is neglected. The factors of cohesion and friction are proposed for four different interface types.

$$\begin{gathered} v_{Rdi} = cf_{ctd} + \mu\sigma_n + \rho f_{yd}(\mu \sin\alpha + \cos\alpha) \leq 0.5vf_{cd} \\ v = 0.6\left(1 - \frac{f_{ck}}{250}\right) \end{gathered} \tag{7}$$

where $c$ and $\mu$ are the factors which depend on the surface roughness (see Table 5), $f_{ck}$ is the characteristic compressive cylinder strength of concrete, $f_{ctd}$ is the design tensile strength, $f_{yd}$ is the design yield strength of reinforcement, $f_{cd}$ is the design value of concrete compressive strength, $v$ is the strength reduction factor for concrete, $\rho$ is the interface shear reinforcement ratio = $A_{vf}/A_{cv}$, $A_{vf}$ is the area of the shear reinforcement crossing the interface, $A_{cv}$ is the area of the concrete section resisting shear transfer, $\sigma_n$ is the stress per unit area (positive for compression, such that $\sigma_n < 0.6f_{cd}$, and negative for tension; when $\sigma_n$ is tensile, $cf_{ctd}$ should be taken as 0), $\alpha$ is the angle of the interface shear reinforcement measured from the horizontal interface shear plane, and $v_{Rdi}$ is the design shear strength at the interface.

**Table 5.** Coefficients for different surface roughness.

| Surface Roughness | $c$ | $\mu$ |
|---|---|---|
| Very smooth | 0.025 to 0.1 | 0.5 |
| Smooth | 0.2 | 0.6 |
| Rough | 0.4 | 0.7 |
| Very rough | 0.5 | 0.9 |

***Fib model code 2010* [21]**

The *Fib model code 2010* (*Fib MC 2010*) [21] (Article 7.3.3.6) considers all three load transfer mechanisms, as indicated in Equation 8: The cohesion mechanism related to the lower characteristic compressive strength of concrete, the friction mechanism as a function of externally applied stresses and clamping stress, and the dowel action mechanism due to flexural deformation. It should be noted that this code is the first to consider the dowel action.

$$\begin{gathered} v_{Rdi} = c_r f_{ck}^{1/3} + \mu\sigma_n + k_1\rho f_{yd}(\mu \sin\alpha + \cos\alpha) + k_2\rho\sqrt{f_{yd}f_{cd}} \leq \beta_c v f_{cd} \\ v = 0.55\left(\frac{30}{f_{ck}}\right)^{1/3} < 0.55 \end{gathered} \tag{8}$$

where $c_r$ is the coefficient for aggregate interlock effects at rough interfaces (see Table 6), $f_{ck}$ is the characteristic compressive cylinder strength of concrete, $f_{yd}$ is the design yield strength of reinforcement, $f_{cd}$ is the design value of concrete compressive strength, $v$ is the strength reduction factor for concrete, $k_1$ is the interaction coefficient for tensile force activated in the reinforcement or the dowels (see Table 6), $k_2$ is the interaction coefficient for flexural resistance (see Table 6), $\mu$ is the friction factor (see Table 6), $\rho$ is the interface shear reinforcement ratio = $A_{vf}/A_{cv}$, $A_{vf}$ is the area of the shear reinforcement crossing the interface, $A_{cv}$ is the area of the concrete section resisting shear transfer, $\sigma_n$ is the compressive stress resulting from an eventual normal force acting on the interface, $\alpha$ is the inclination of the reinforcement crossing the interface, $\beta_c$ is the coefficient for the strength of the compression strut (see Table 6), and $v_{Rdi}$ is the design shear strength at the interface.

**Table 6.** Coefficients for different surface roughness.

| Surface Roughness | $c_r$ | $k_1$ | $k_2$ | $\beta_c$ | $\mu$ | |
|---|---|---|---|---|---|---|
| | | | | | $f_{ck} \geq 20$ | $f_{ck} \geq 35$ |
| Very rough $R_t \geq 3.0$ mm | 0.2 | 0.5 | 0.9 | 0.5 | 0.8 | 1.0 |
| Rough $R_t \geq 1.5$ mm | 0.1 | 0.5 | 0.9 | 0.5 | 0.7 | |
| Smooth | 0 | 0.5 | 1.1 | 0.4 | 0.6 | |
| Very smooth | 0 | 0 | 1.5 | 0.3 | 0.5 | |

$R_t$ = peak-to-meanline surface roughness.

## 3. Database

The literature search was conducted to collect published experimental data on the shear transfer of concrete interfaces. To concentrate on the basic shear transfer for the evaluation of design provisions, the database presented in this paper addresses only direct push-off, reinforcement perpendicular to the interface, and interfaces subject to monotonic pure shear loads. The test database included 458 push-off test specimens from nineteen studies. Details of the test programs that meet the data selection criteria in this study are summarized in Table 7. The database arrangement includes the source of test data, test year, interface type, concrete type, number of specimens, compressive strength of concrete $f_c{}'$, and clamping stress $\rho f_y$ ($\rho f_y$ is calculated using the upper limit of the yield strength of the reinforcement $f_y$ for each code). In each test program, the total number of test specimens conducted may be higher than that listed in the table (test specimens that do not satisfy the collection criteria are not included).

**Table 7.** Summary of database.

| Researchers | Year | Interface Type | Concrete Type | Number of Specimens | $f_c{}'$ (MPa) | $\rho f_y$ (MPa) |
|---|---|---|---|---|---|---|
| Hofbeck et al. [22] | 1969 | M-U | NW | 13 | 26.48 to 31.10 | 0.00 to 9.23 |
| | | M-P | NW | 19 | 16.44 to 29.92 | 1.54 to 9.23 |
| Mattock et al. [8] | 1975 | M-U | NW | 2 | 27.82 to 27.99 | 3.81 to 5.65 |
| | | M-P | NW | 2 | 26.58 to 29.10 | 3.74 to 5.43 |
| Mattock [9] | 1976 | M-P | NW | 8 | 40.13 to 42.23 | 1.57 to 13.29 |
| | | J-R | NW | 14 | 17.20 to 41.75 | 1.56 to 10.87 |
| | | J-S | NW | 18 | 40.16 to 42.61 | 1.45 to 10.33 |
| Mattock et al. [10] | 1976 | M-U | NW | 7 | 26.89 to 28.82 | 0.00 to 9.59 |
| | | M-U | SLW | 7 | 25.79 to 29.30 | 0.00 to 9.43 |
| | | M-U | ALW | 14 | 26.75 to 30.48 | 0.00 to 9.52 |
| | | M-P | NW | 6 | 26.89 to 28.82 | 1.54 to 9.10 |
| | | M-P | SLW | 18 | 13.79 to 41.34 | 1.50 to 9.43 |
| | | M-P | ALW | 14 | 26.75 to 30.48 | 1.51 to 9.68 |
| Hoff [23] | 1993 | M-P | SLW | 18 | 57.16 to 75.98 | 1.94 to 3.94 |
| Kahn and Mitchell [24] | 2002 | M-U | NW | 19 | 46.92 to 123.81 | 1.52 to 6.07 |
| | | M-P | NW | 19 | 46.92 to 113.60 | 1.52 to 6.07 |
| | | J-R | NW | 10 | 80.91 to 104.93 | 1.52 to 6.07 |
| | | J-S | NW | 2 | 83.11 to 98.78 | 1.52 to 3.03 |
| Mansur et al. [25] | 2008 | M-P | NW | 19 | 40.20 to 106.40 | 1.68 to 10.83 |
| Aziz [26] | 2010 | M-U | NW | 4 | 24 | 0.00 to 3.22 |
| Scott [27] | 2010 | J-R | NW | 3 | 42.40 | 2.00 |
| | | J-R | SLW | 6 | 39.51 | 2.00 |
| Harries et al. [28] | 2012 | J-R | NW | 8 | 33.99 | 1.65 to 2.90 |
| Shaw and Sneed [29] | 2014 | J-R | NW | 6 | 33.51 to 52.06 | 5.38 |
| | | J-R | SLW | 6 | 31.58 to 49.64 | 5.38 |
| | | J-R | ALW | 6 | 41.92 to 54.08 | 5.38 |
| | | J-S | NW | 6 | 33.51 to 52.06 | 5.38 |
| | | J-S | SLW | 6 | 31.58 to 49.64 | 5.38 |
| | | J-S | ALW | 6 | 41.92 to 54.08 | 5.38 |

**Table 7.** *Cont.*

| Researchers | Year | Interface Type | Concrete Type | Number of Specimens | $f_c{}'$ (MPa) | $\rho f_y$ (MPa) |
|---|---|---|---|---|---|---|
| Rahal and Al-Khaleefi [30] | 2015 | M-U | NW | 9 | 34.09 to 41.40 | 0.00 to 7.88 |
| Rahal et al. [31] | 2016 | M-U | NW | 15 | 34.96 to 81.20 | 0.93 to 7.88 |
| Sneed et al. [32] | 2016 | M-U | NW | 2 | 33.37 | 5.38 |
| | | M-U | SLW | 2 | 32.89 | 5.38 |
| | | M-U | ALW | 2 | 32.41 | 5.38 |
| | | M-P | NW | 2 | 33.37 | 5.38 |
| | | M-P | SLW | 2 | 32.89 | 5.38 |
| | | M-P | ALW | 2 | 32.41 | 5.38 |
| | | J-R | SLW | 12 | 31.99 to 38.41 | 3.72 to 9.10 |
| | | J-R | ALW | 4 | 30.20 to 30.75 | 5.38 |
| | | J-S | SLW | 14 | 31.37 to 38.41 | 3.72 to 9.10 |
| | | J-S | ALW | 4 | 30.20 to 30.75 | 5.38 |
| Waseem and Singh [33] | 2016 | M-U | NW | 48 | 30.24 to 73.60 | 0.00 to 5.28 |
| Xiao et al. [34] | 2016 | M-U | NW | 19 | 23.43 to 33.03 | 3.63 |
| Barbosa et al. [35] | 2017 | J-R | NW | 20 | 28.2 | 1.72 to 2.67 |
| Ahmad et al. [36] | 2018 | M-U | NW | 12 | 40 | 0.00 to 6.65 |
| Valikhani et al. [37] | 2021 | M-U | NW | 3 | 47 | 0.00 |
| Total | 1969 to 2021 | M-U, M-P, J-R, J-S | NW, SLW, ALW | 458 | 13.79 to 123.81 | 0 to 13.29 |

All test programs that constitute the database were carried out between 1969 and 2021. The test programs in the database consisted of specimens made of four interface conditions and three concrete types. The interface conditions were monolithic uncracked (M-U), monolithic precracked (M-P), and cold joints that were intentionally roughened (J-R) and not roughened (that is, smooth) (J-S), as shown in Figure 4. The concrete types were sand lightweight (SLW), all lightweight (ALW), and normal-weight (NW). Of the 458 test specimens given in the database, the number of normal-weight concrete specimens was 315, the number of sand lightweight concrete specimens was 91, and the number of all lightweight concrete specimens was 52 (69%, 20%, and 11% of the total, respectively). Most of the available tests (approximately 67% of the total) consisted of monolithic specimens, with the majority of tests carried out on uncracked specimens. Cold joint specimens accounted for about 33% of the total specimens collected, and most were intentionally roughened cold joints. The compressive strength of concrete varied over a wide range. The compressive strength of concrete of 13.79 through 55 MPa accounted for approximately 76% of the total. Around 24% of the total had a compressive strength of concrete of 55 through 123.81 MPa. For cold joint specimens, the lower compressive strength was only reported when the two sides of the interface had different compressive strengths of concrete. The clamping stresses ranged from 0 MPa to 13.29 MPa, with the majority of them varying in the 0 MPa to 10 MPa range.

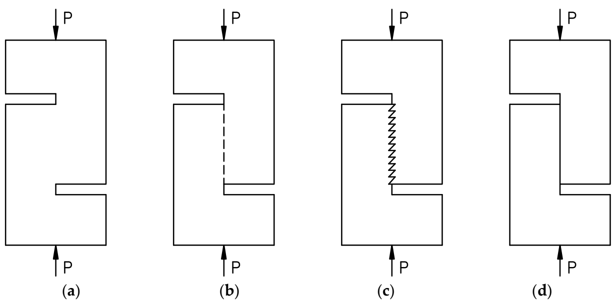



**Figure 4.** Direct push-off with interface conditions: (**a**) monolithic uncracked, (**b**) monolithic precracked, (**c**) intentionally roughened cold joint, and (**d**) cold joint that is not roughened.

## 4. Evaluation of Design Provisions

In this section, the interface shear resistance according to design codes is evaluated based on the test results in the database summarized in Section 3. The design provisions considered include six major international codes, namely, *ACI 318-19*; *PCI Design Handbook*; *AASHTO LRFD*; *CSA-S6*; *Eurocode 2*; and *Fib Model Code 2010*.

Details of test specimens and experimental and predicted results on interface shear resistance are presented in the Appendix A. Predicted interface shear resistance is compared with experimental results in original papers to evaluate the accuracy of design provisions. The columns of the Appendix A include the source of test data, specimen name, compressive strength of concrete $f_c{}'$, area of the concrete section resisting shear transfer $A_{cv}$, area of the shear reinforcement crossing the interface $A_{vf}$, reinforcement ratio $\rho$, yield strength of reinforcement $f_y$, clamping stress $\rho f_y$ ($\rho f_y$ is calculated using the upper limit of the yield strength of the reinforcement $f_y$ for each code), peak measured shear stress $v_{test}$, calculated interface shear resistance $v_{cal}$ ($v_{cal}$ is calculated utilizing $\rho f_y$), and ratio $v_{test}/v_{cal}$ for each test specimen and each of the design provisions. In addition, the mean, maximum, and minimum values, standard deviation (STD), and coefficient of variation (COV) of $v_{test}/v_{cal}$ are reported for each group of specimens. The peak measured shear stress $v_{test}$ is defined as $V_{test}/A_{cv}$, where $V_{test}$ is the peak measured shear force. Interface shear resistance $v_{cal}$ is calculated with the above-mentioned design provisions and proposed equation in this study (the proposed equation is presented in Section 6). The statistical results of $v_{test}/v_{cal}$ are not separated by concrete type, but for different concrete types (normal-weight, sand lightweight, or all lightweight concrete), appropriate equations are utilized.

From the calculation results listed in the Appendix A, ratios $v_{test}/v_{cal}$ are plotted against the compressive strength of concrete $f_c{}'$ and the clamping stress of shear reinforcement $\rho f_y$, as shown in Figures 5–8. The vertical axis of each graph ranges from 0 to 6.0 for each of the six design provisions evaluated. Ratios $v_{test}/v_{cal}$ greater than 6.0 are not indicated in the graphs, but they are listed in the Appendix A. These figures are plotted to compare the peak measured shear stress $v_{test}$ with the interface shear resistance $v_{cal}$ calculated utilizing equations from codes for specimens with different interface types (M-U, M-P, J-R, J-M) and different concrete types (NW, SLW, ALW).

From Figures 5–8, the evaluation and comparison of shear resistance for each interface had the following trends:

Monolithic uncracked: All four codes provided conservative predictions of the interface shear resistance (that is, $v_{test}/v_{cal}$ greater than 1.0) for the entire ranges of $f_c{}'$ and $\rho f_y$. The *AASHTO LRFD* tended to provide the most accurate overall predictions of the interface shear resistance. Larger conservative estimates were observed in all four design provisions at low values of clamping stress and high values of compressive strength of concrete.

Monolithic precracked: The *ACI 318-19* strength predictions were conservative at all clamping stresses and compressive strengths of concrete. The predictions of the *CSA-S6* and *PCI* provided some $v_{test}/v_{cal}$ values less than 1.0. Figure 6 illustrates that for these two codes, values less than 1.0 occur for specimens made with lightweight concrete and for low clamping stress. Although the *AASHTO LRFD* again tended to be more accurate than other codes, the *AASHTO LRFD* strength estimates were unconservative.

Intentionally roughened cold joint: All six design provisions provided conservative values of interface shear resistance (that is, $v_{test}/v_{cal}$ greater than 1.0) for the entire ranges of $f_c{}'$ and $\rho f_y$ and especially for high values of $f_c{}'$. The *AASHTO LRFD* and *Eurocode 2* tended to provide the most accurate estimates.

Cold joint that is not roughened: The effective friction approach is not applicable to this interface condition, so the *ACI 318-19* and *PCI* provided identical strength estimates. The *AASHTO LRFD*, *Eurocode 2*, and *Fib MC 2010* tended to be more accurate but provided some unconservative strength predictions that occur for normal-weight concrete (the mean value is still much greater than 1.0). The strength predictions of the *ACI 318-19*, *CSA-S6*, and *PCI* codes were conservative over the entire range of compressive strength of concrete and clamping stress, but the scatter was larger than the other codes.

The mean, maximum, and minimum values, standard deviation (STD), and coefficient of variation (COV) of $v_{test}/v_{cal}$ for each of the specimen groups with the same interface condition are summarized in Table 8. An alternative presentation of these results is shown in Figure 9. Not all design provisions are applicable to all interface conditions. Therefore, when the results are summarized, not applicable (n/a) is shown in these cases.

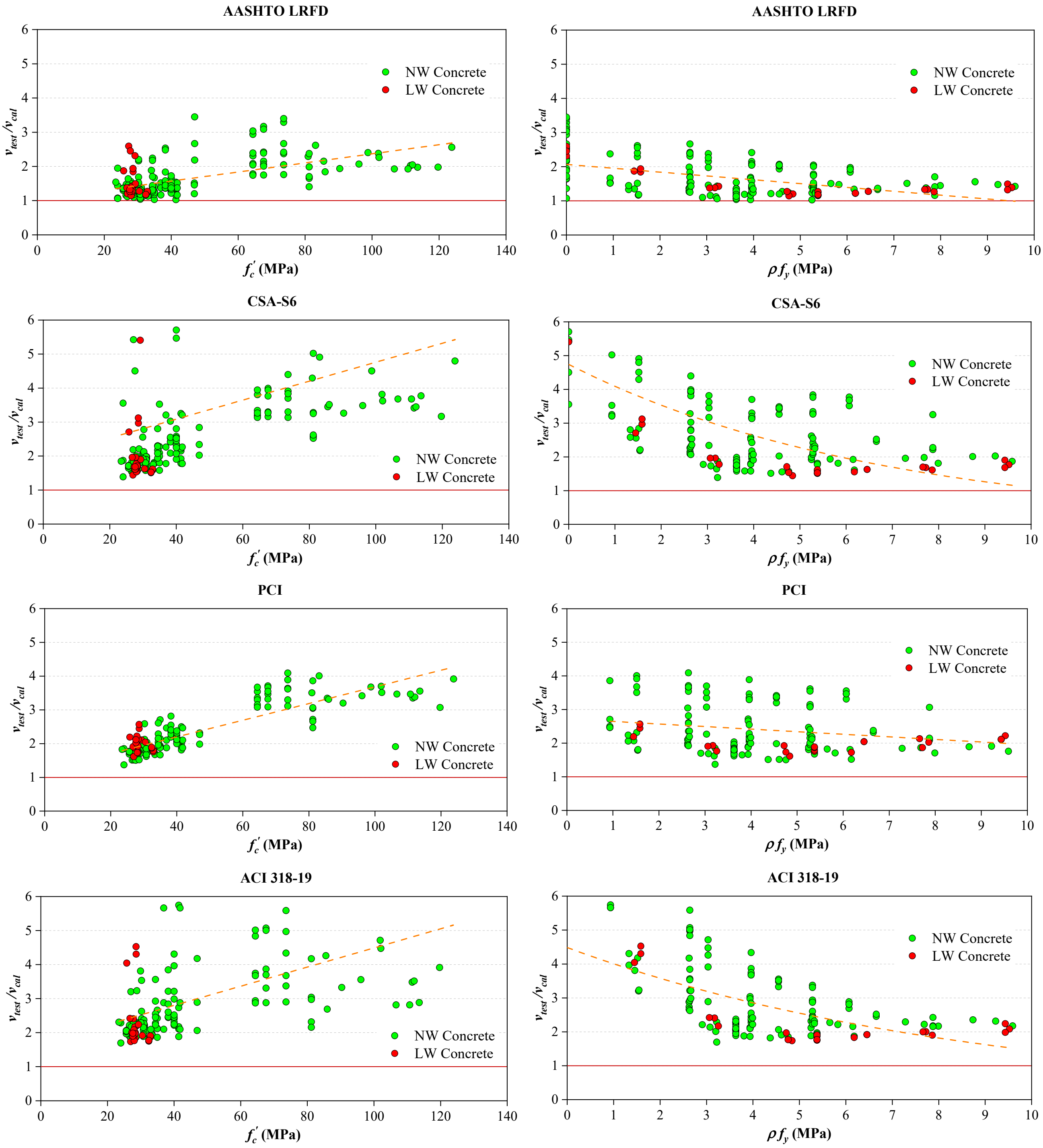



**Figure 5.** Compressive strength of concrete $f_c{}'$ and clamping stress $\rho f_y$ versus the ratio $v_{test}/v_{cal}$ (monolithic uncracked interface).

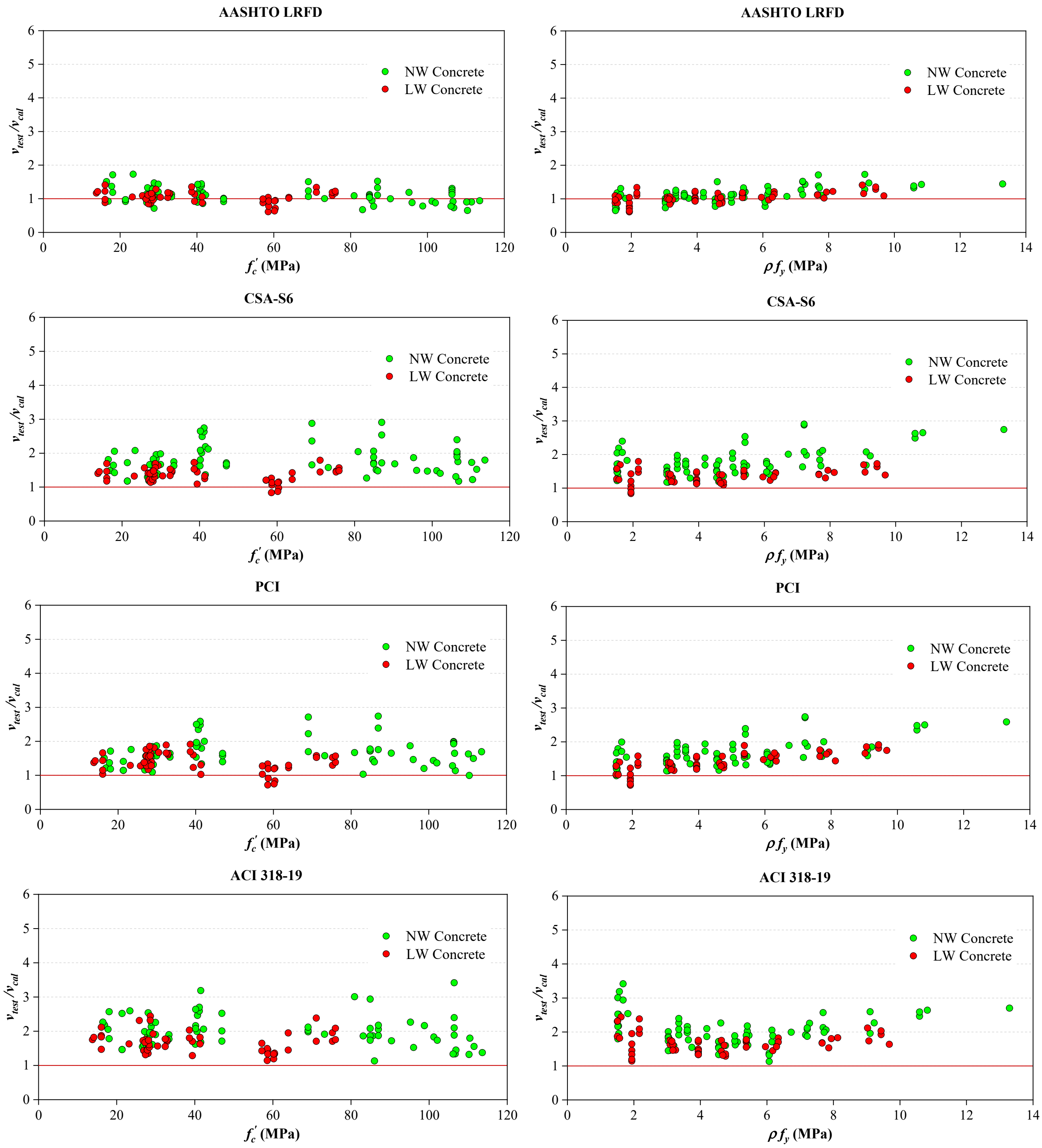



**Figure 6.** Compressive strength of concrete $f_c{}'$ and clamping stress $\rho f_y$ versus the ratio $v_{test}/v_{cal}$ (monolithic precracked interface).

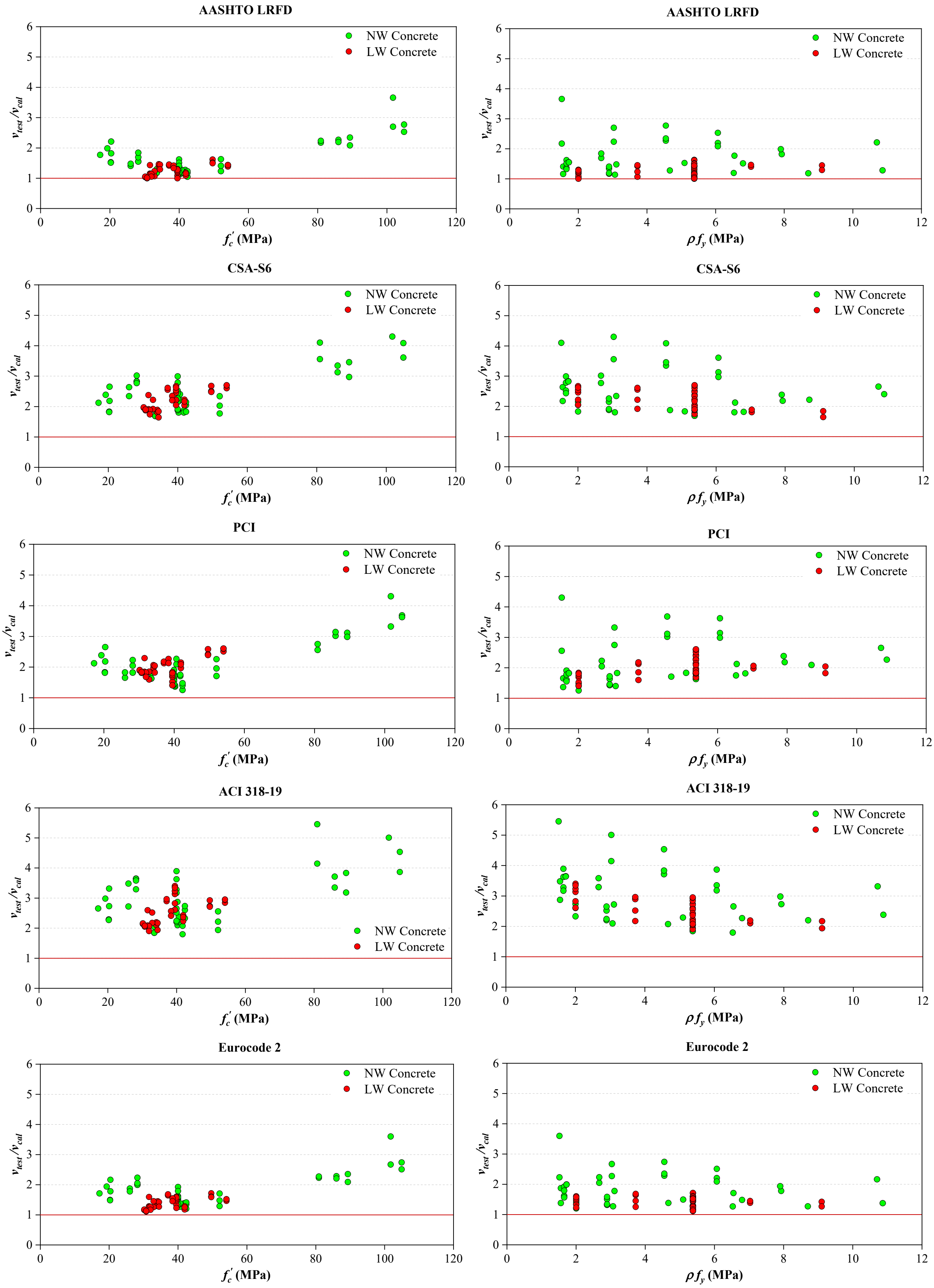



**Figure 7.** *Cont.*

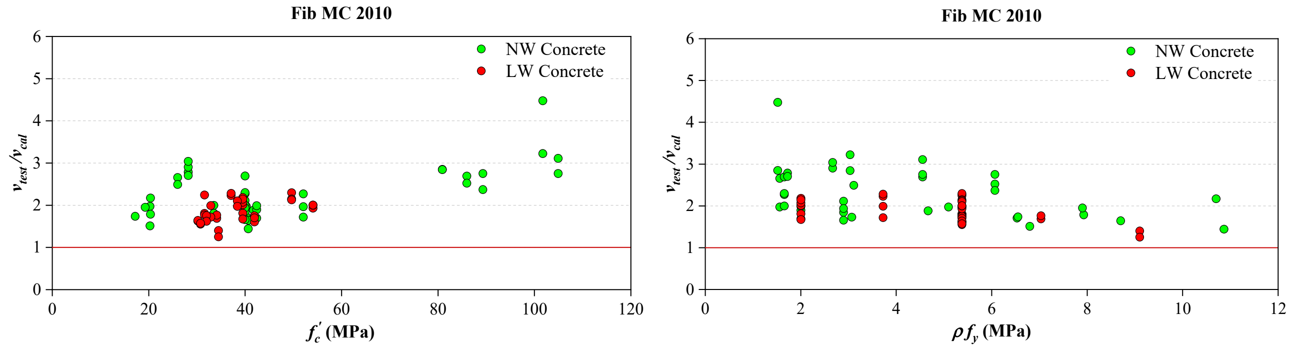



**Figure 7.** Compressive strength of concrete $f_c{}'$ and clamping stress $\rho f_y$ versus the ratio $v_{test}/v_{cal}$ (interface that is intentionally roughened).

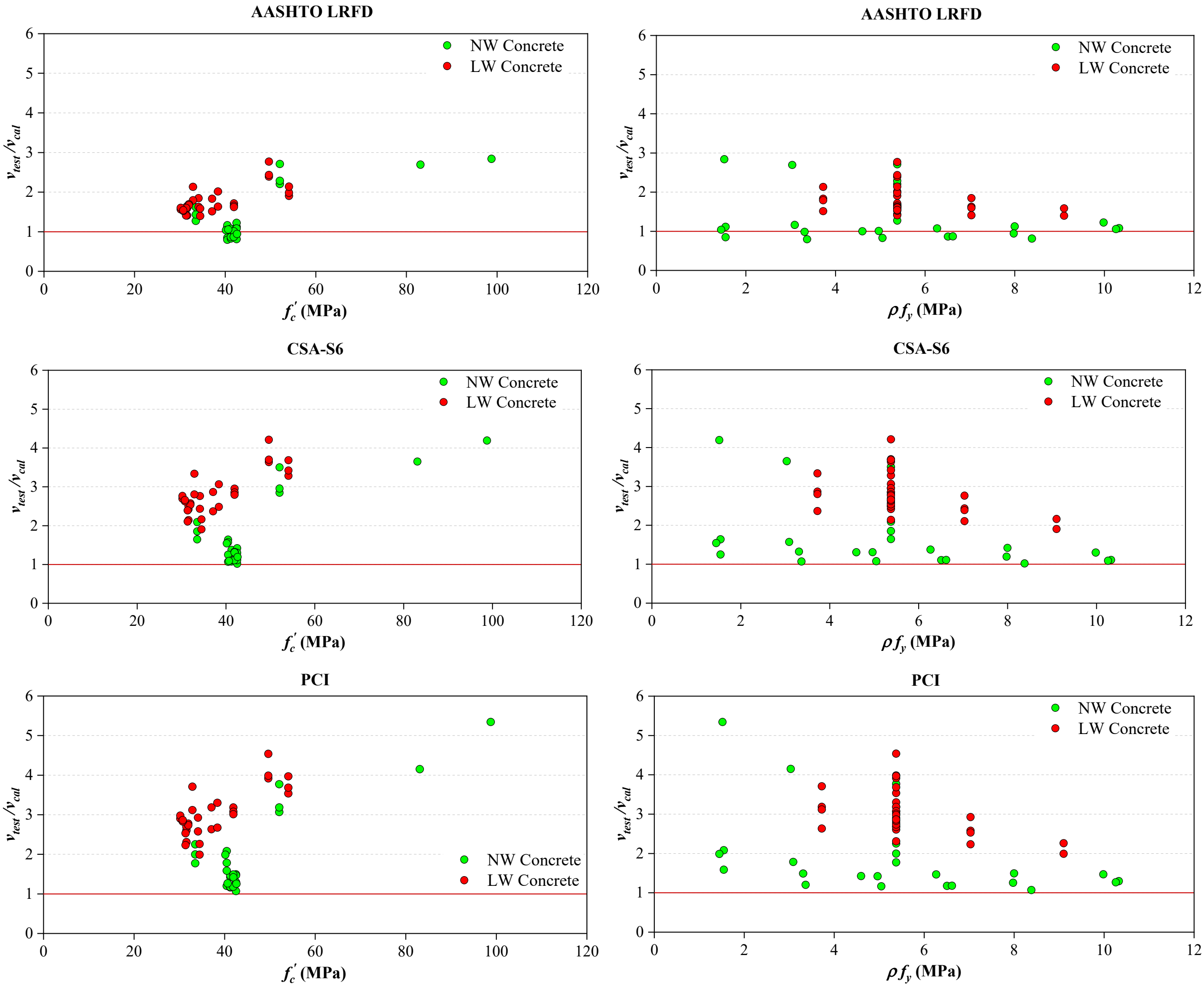



**Figure 8.** *Cont.*

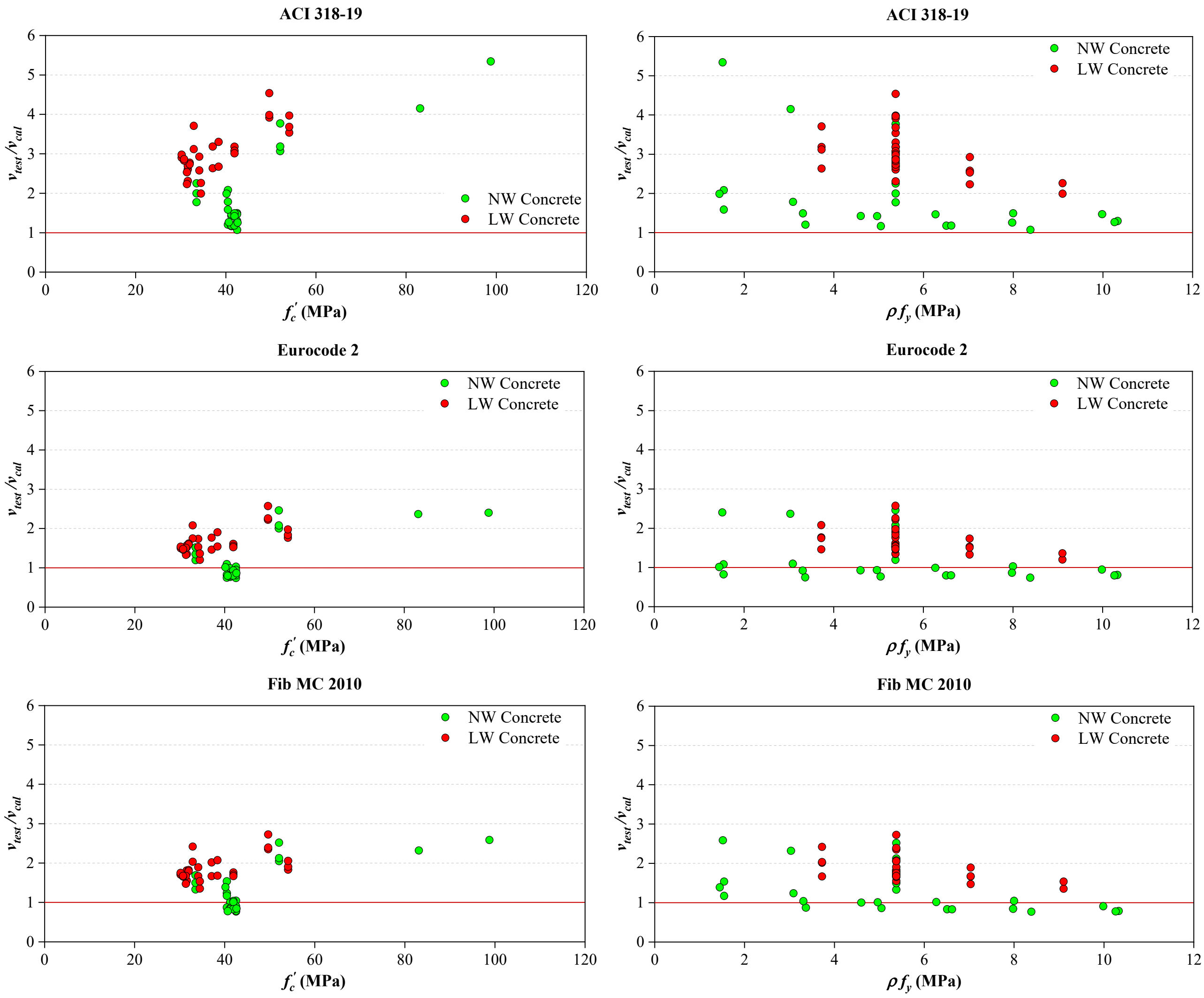



**Figure 8.** Compressive strength of concrete $f_c{}'$ and clamping stress $\rho f_y$ versus the ratio $v_{test}/v_{cal}$ (interface that is not roughened).

**Table 8.** Statistical analysis of design provisions depending on the interface conditions.

| Codes | Statistics | Monolithic Uncracked | Monolithic Precracked | Roughened | Smooth |
|---|---|---|---|---|---|
| *AASHTO LRFD* | Average | 1.65 | 1.08 | 1.49 | 1.57 |
| | Maximum | 3.45 | 1.73 | 3.66 | 2.84 |
| | Minimum | 1.03 | 0.61 | 1.00 | 0.80 |
| | STD | 0.53 | 0.21 | 0.47 | 0.54 |
| | COV (%) | 31.87 | 19.29 | 31.75 | 34.10 |
| *CSA-S6* | Average | 3.18 | 1.59 | 2.44 | 2.32 |
| | Maximum | 11.41 | 2.91 | 6.91 | 4.21 |
| | Minimum | 1.39 | 0.84 | 1.64 | 1.02 |
| | STD | 2.14 | 0.40 | 0.77 | 0.89 |
| | COV (%) | 67.31 | 24.85 | 31.60 | 38.64 |
| *PCI* | Average | 2.35 | 1.54 | 2.08 | 2.54 |
| | Maximum | 4.09 | 2.74 | 4.31 | 5.34 |
| | Minimum | 1.37 | 0.72 | 1.26 | 1.07 |
| | STD | 0.70 | 0.37 | 0.57 | 0.99 |
| | COV (%) | 29.60 | 23.74 | 27.60 | 39.13 |

**Table 8.** *Cont.*

| Codes | Statistics | Monolithic Uncracked | Monolithic Precracked | Roughened | Smooth |
|---|---|---|---|---|---|
| *ACI 318-19* | Average | 2.94 | 1.86 | 2.86 | 2.54 |
| | Maximum | 8.86 | 3.42 | 9.18 | 5.34 |
| | Minimum | 1.70 | 1.13 | 1.80 | 1.07 |
| | STD | 1.28 | 0.42 | 1.03 | 0.99 |
| | COV (%) | 43.39 | 22.49 | 35.99 | 39.13 |
| *Eurocode 2* | Average | n/a | n/a | 1.62 | 1.46 |
| | Maximum | | | 3.60 | 2.57 |
| | Minimum | | | 1.11 | 0.74 |
| | STD | | | 0.44 | 0.50 |
| | COV (%) | | | 27.08 | 33.99 |
| *Fib MC 2010* | Average | n/a | n/a | 2.09 | 1.60 |
| | Maximum | | | 4.48 | 2.73 |
| | Minimum | | | 1.25 | 0.77 |
| | STD | | | 0.51 | 0.52 |
| | COV (%) | | | 24.49 | 32.45 |

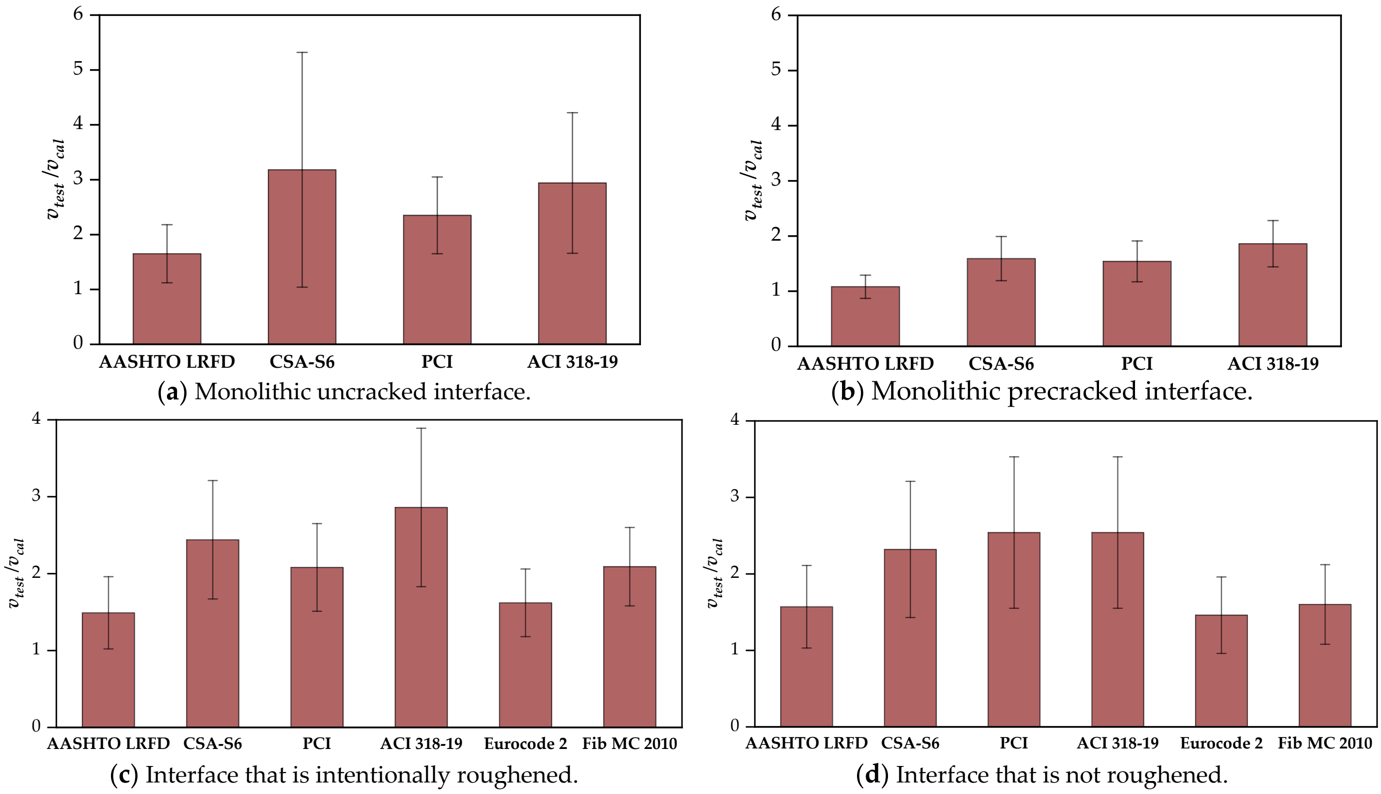



**Figure 9.** Bar charts for statistical analysis of design provisions depending on the interface conditions.

Monolithic uncracked: mean values of $v_{test}/v_{cal}$ summarized in Table 8 indicate that the *AASHTO LRFD* was the most accurate because the mean value is closest to 1.0, while the *CSA-S6*, *PCI*, and *ACI 318-19* provided more conservative estimates for interface shear resistance (mean $v_{test}/v_{cal}$ of 3.18, 2.35, and 2.94, respectively). The *AASHTO LRFD* and *PCI* codes provided the most stable estimates (the lowest COV values for $v_{test}/v_{cal}$ were 31.87% and 29.60%, respectively). In contrast, the *CSA-S6* and *ACI 318-19* provided the most scattered estimates (their COV values for $v_{test}/v_{cal}$ were 67.31% and 43.39%, respectively).

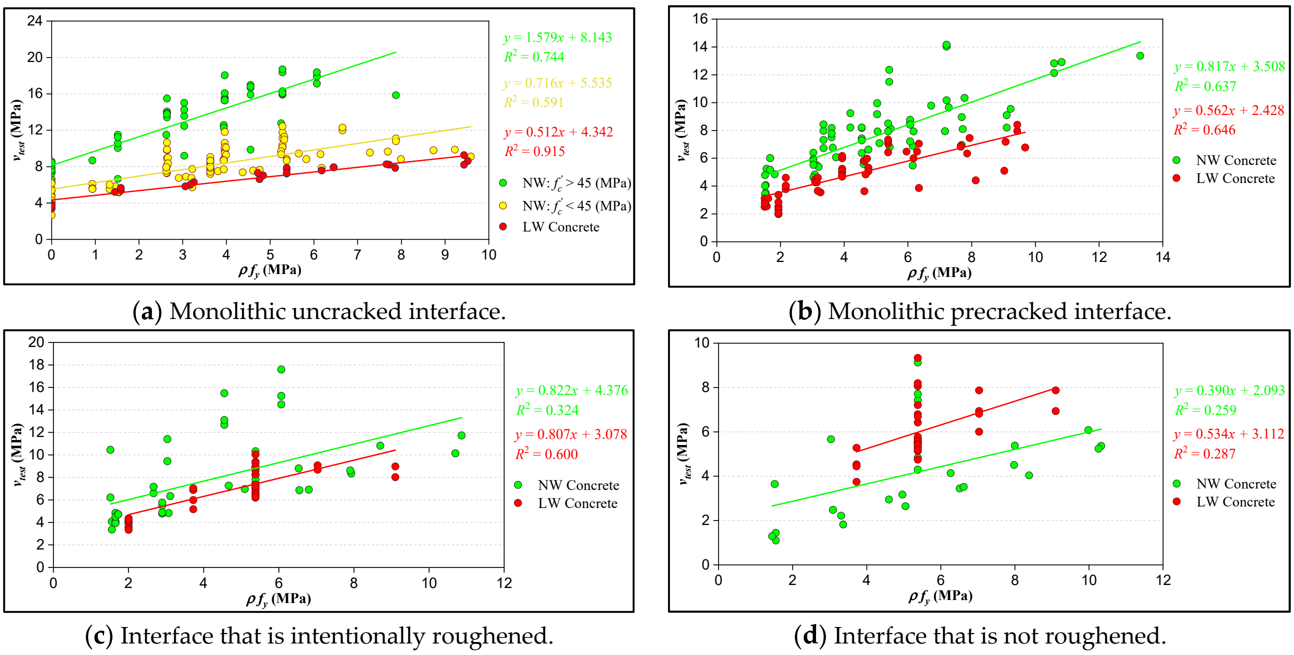
Monolithic precracked: The *AASHTO LRFD* was the most accurate and consistent due to the lowest mean and COV values for $v_{test}/v_{cal}$ (1.08 and 19.29%, respectively), but there were many unconservative cases. The *ACI 318-19* is secure to calculate for monolithic precracked specimens because all ratios $v_{test}/v_{cal}$ are greater than 1.0.

Intentionally roughened cold joint: Values of $v_{test}/v_{cal}$ summarized in Table 8 indicate that the *AASHTO LRFD* and *Eurocode 2* were the most accurate because the mean value is closest to 1.0 and it is stable due to low COV values, while the *CSA-S6*, *PCI*, and *Fib MC 2010* provided more conservative predictions for interface shear resistance (mean $v_{test}/v_{cal}$ of 2.44, 2.08, and 2.09, respectively). The *ACI 318-19* provided the most conservative and scattered estimates as their mean and COV for $v_{test}/v_{cal}$ were 2.86 and 35.99%, respectively.

Cold joint that is not roughened: The *AASHTO LRFD*, *Eurocode 2*, and *Fib MC 2010* were the most accurate and consistent due to the lowest mean and COV values for $v_{test}/v_{cal}$, but there were many unconservative cases. The *CSA-S6*, *PCI*, and *ACI 318-19* are secure to calculate for cold joint specimens that are not roughened because all ratios $v_{test}/v_{cal}$ are greater than 1.0.

## 5. Effect of Key Parameters

Figure 10 indicates the peak measured shear stress as a function of the clamping stress for all four interface conditions. In each interface type, the peak measured shear stress is grouped by concrete type. Moreover, for the monolithic uncracked interface, the peak measured shear stress is further grouped by the compressive strength of concrete. Trends were detected from Figure 10: The peak measured shear stress $v_{test}$ generally increased with growth in clamping stress $\rho f_y$ for all four interface types. This trend indicated a positive friction factor in the context of shear friction. The specimens with lightweight concrete tended to fail at lower shear stresses than specimens using normal-weight concrete, except for the interface that was not roughened. The interface shear stress was not zero when $\rho f_y = 0$ for monolithic uncracked specimens, suggesting that there was an existence of some cohesive component of shear resistance. Although no monolithic precracked specimens with $\rho f_y = 0$ were available, it is expected that, for monolithic precracked specimens, no cohesion could exist. This is consistent with the idea that the cohesion component would not appear across an open crack. Also, no cold joint specimens with $\rho f_y = 0$ were available and reported in this study.

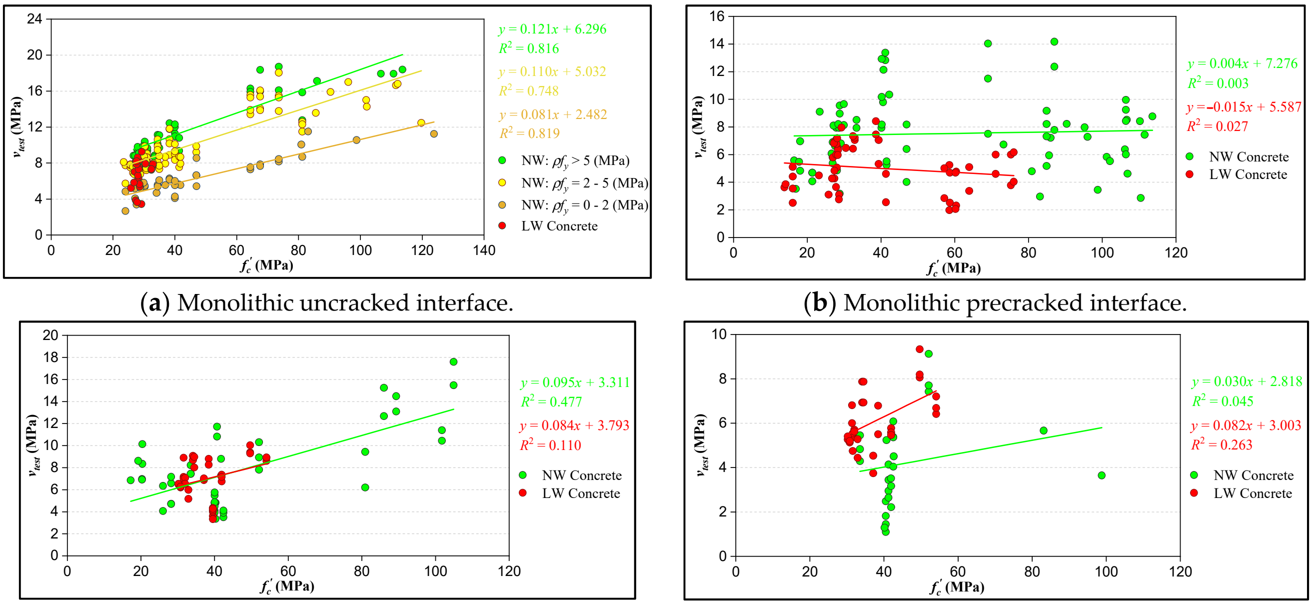



(**a**) Monolithic uncracked interface. (**b**) Monolithic precracked interface.

(**c**) Interface that is intentionally roughened. (**d**) Interface that is not roughened.

**Figure 10.** Effect of clamping stress $\rho f_y$ on ultimate interface shear stress $v_{test}$.

Figure 11 illustrates the peak measured shear stress as a function of the compressive strength of concrete $f_c{}'$ for all four interface types. In each interface type, the peak measured shear stress is grouped by concrete type. Moreover, for the monolithic uncracked interface, the peak measured shear stress is further grouped by the clamping stress. Although the clamping stress is the core factor influencing the interface shear resistance, the compressive strength of concrete played a crucial role as well. This section presents the effect of this parameter on the shear resistance for different interface conditions. The interface shear resistance generally increased with the growth in compressive strength of concrete $f_c{}'$ for monolithic uncracked specimens. For monolithic precracked specimens, the compressive strength of concrete $f_c{}'$ did not appear to influence the interface shear resistance. The interface shear resistance tended to rise with growing compressive strength of concrete $f_c{}'$ for cold joints that were intentionally roughened. The higher shear resistance was recorded for specimens that utilized high-strength concrete. For the interface shear resistance of cold joints that were not roughened, no appropriate trends were seen with respect to the effect of the compressive strength of concrete $f_c{}'$.




(**a**) Monolithic uncracked interface. (**b**) Monolithic precracked interface.

(**c**) Interface that is intentionally roughened. (**d**) Interface that is not roughened.

**Figure 11.** Effect of compressive strength of concrete $f_c{}'$ on ultimate interface shear stress $v_{test}$.

## 6. Proposal of the Design Equation

As analyzed in the previous section, the compressive strength of concrete played a crucial role as well, especially for the monolithic uncracked interface. However, codes that can apply to the monolithic uncracked interface such as the *ACI 318-19*, *PCI*, *AASHTO LRFD*, and *CSA-S6* do not include the compressive strength of concrete in the equations. The *Eurocode 2* and *Fib MC 2010* consider the compressive strength of concrete in the equations but do not apply to the monolithic uncracked interface. Therefore, the equation to determine the interface shear resistance for the monolithic uncracked interface is proposed in this section with consideration of the compressive strength of concrete directly in the equation.

In the case of the monolithic uncracked interface, the applied shear is subjected partly by cohesion provided by the concrete and partly by the friction offered by the reinforcement crossing the interface. The dowel action is neglected. Therefore, the general equation is proposed as follows (this is also a general form that often appears in the literature):

$$v_u = c + \mu \rho f_y \tag{9}$$

where $v_u$ is the ultimate interface shear resistance, $c$ is the cohesion, $\rho f_y$ is the clamping stress, and $\mu$ is the friction factor. To propose the equation, cohesion $c$ and friction factor $\mu$ should be determined based on push-off test results collected from the literature.

First, the experimental results with $\rho f_y$ = 0 are chosen to determine cohesion $c$ (these results are highlighted in the gray background in the Appendix A). Now, the shear resistance includes only cohesion $c$ so the shear resistance $v_u$ = $c$. Cohesion $c$ is governed by the concrete, in particular the compressive strength of concrete. Therefore, the relationship between cohesion $c$ and compressive strength of concrete $f_c{}'$ is plotted to determine the correlation coefficients between $c$ and $f_c{}'$, as shown in Figure 12. From Figure 12, the trend line indicates a good correlation between cohesion $c$ and compressive strength of concrete $f_c{}'$, with its Pearson correlation coefficient being 0.68. To be safer for design purposes, the equation for calculating cohesion c is suggested as follows (it is also illustrated in Figure 12):

$$c = 0.14\left(f_c'\right)^{0.85} \tag{10}$$

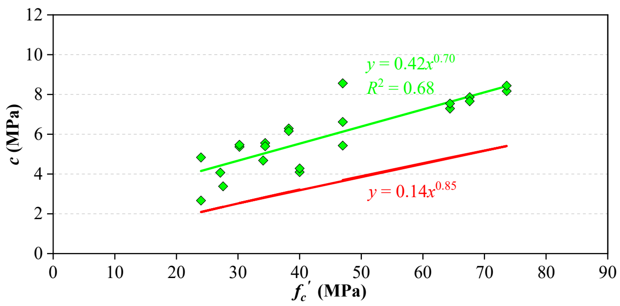



**Figure 12.** Relationship between cohesion and compressive strength of concrete.

To determine friction factor $\mu$, the remaining experimental results with non-zero $\rho f_y$ are selected. Friction factors are obtained from these test results by utilizing the following equation:

$$\mu = \frac{v_{test} - c}{\rho f_y} \tag{11}$$

Friction factors obtained experimentally are plotted as a function of clamping stress $\rho f_y$, as shown in Figure 13. Therefore, the following equation is proposed to express the friction factor as a function of clamping stress. This equation is conservative and can be used for design purposes.

$$\mu = 2.0\left(\rho f_y\right)^{-0.5} \tag{12}$$

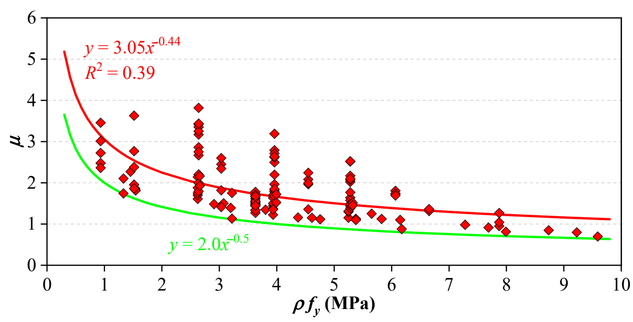



**Figure 13.** Relationship between friction factor and clamping stress.

Substituting Equations (10) and (12) into Equation (9), the equation for predicting interface shear resistance is as follows:

$$v_u = 0.14\left(f_c'\right)^{0.85} + 2.0\sqrt{\rho f_y} \leq 0.3 f_c' \tag{13}$$

Ultimate interface shear resistance is limited to a value of $0.3f_c{}'$ in the above equation because interface shear resistance does not increase considerably in over-reinforced specimens. The compressive strength of concrete governs the failure in such specimens, as indicated in studies [22,24,38].

Equation (13) is established from experimental results for normal-weight concrete. Referring to the modification factor for concrete weight according to the *ACI 318-19*, *PCI*, and *CSA-S6*, the final equation to predict the interface shear resistance is taken as follows:

$$v_u = \lambda\left(0.14\left(f_c'\right)^{0.85} + 2.0\sqrt{\rho f_y}\right) \leq 0.3\lambda f_c' \quad (14)$$

$\lambda$ is the modification factor for concrete weight. $\lambda$ = 1 for normal-weight concrete, 0.85 for sand lightweight concrete, and 0.75 for all lightweight concrete.

It should be noted that reinforcement yield strength is also limited in design to 413.7 MPa like the *AASHTO LRFD*, *PCI*, and *ACI 318-19*.

## 7. Evaluation of the Proposed Equation

Statistical analysis of design provisions and a proposal for the monolithic uncracked interface are presented in Table 9. It can be seen that the proposed equation in this study provided more accurate and stable estimates than the mentioned design provisions (the lowest mean and COV values for $v_{test}/v_{cal}$, 1.42 and 18.87%, respectively). These design provisions gave over-conservative and scattered predictions of the interface shear resistance for the monolithic uncracked interface. The ratios $v_{test}/v_{cal}$ are plotted against the compressive strength of concrete and clamping stress, as shown in Figure 14. The limit of the vertical axes in Figure 14 is kept the same as that in Figure 5 to make comparisons easily. It may be noticed that the design provisions gave over-conservative predictions of the interface shear resistance for high values of compressive strength of concrete and low clamping stress values (referring to Section 4 and Figure 5). Moreover, all the design provisions indicated the nearly linear trend of increasing ratios $v_{test}/v_{cal}$ with rising compressive strength of concrete and decreasing ratios $v_{test}/v_{cal}$ with rising clamping stress. Figure 14 shows that conservative and uniform predictions over the entire range of compressive strength of concrete and clamping stress are produced for the proposed equation in this study.

**Table 9.** Statistical analysis of design provisions and proposal for monolithic uncracked interface.

| Codes | *AASHTO LRFD* | *CSA-S6* | *PCI* | *ACI 318-19* | PROPOSAL |
|---|---|---|---|---|---|
| Average | 1.65 | 3.18 | 2.35 | 2.94 | 1.42 |
| Maximum | 3.45 | 11.41 | 4.09 | 8.86 | 2.32 |
| Minimum | 1.03 | 1.39 | 1.37 | 1.70 | 1.00 |
| STD | 0.53 | 2.14 | 0.70 | 1.28 | 0.27 |
| COV (%) | 31.87 | 67.31 | 29.60 | 43.39 | 18.87 |

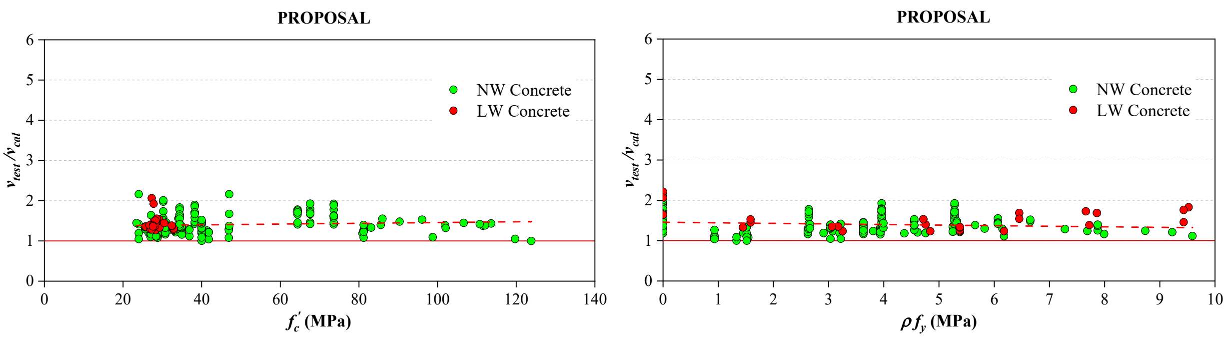



**Figure 14.** Compressive strength of concrete $f_c'$ and clamping stress $\rho f_y$ versus the ratio $v_{test}/v_{cal}$ (proposal).

## 8. Conclusions

The major conclusions of the study can be summarized as follows:

(1) For the monolithic uncracked or roughened interfaces, all mentioned codes provided conservative predictions of the interface shear resistance. The *AASHTO LRFD* tended to provide the most accurate predictions of the interface shear resistance for the monolithic uncracked interface. The most precise shear resistance was found for the roughened interface when calculated using the *AASHTO LRFD* or *Eurocode 2*. It should be noted that *Eurocode 2* is not applicable to the monolithic uncracked interface.

(2) For the monolithic precracked interface, only the *ACI 318-19* gave conservative estimates, while the other codes gave more or less unconservative cases. It proves that the pure friction approach is more suitable when calculating shear resistance for this interface type.

(3) For the smooth interface, the *ACI 318-19*, *PCI*, and *CSA-S6* were conservative for all collected experimental data. But it should be noted that this interface condition has fewer data and high scatter in the tests.

(4) The proposed equation for predicting the shear resistance for the monolithic uncracked interface is more accurate than the equations that are provided from the mentioned codes. Also, the proposed equation produced conservative and uniform predictions over the entire range of compressive strength of concrete and clamping stress. It is expected that this equation can be applied more accurately than the existing design provisions when high-strength concrete or grout is used for prefabricated structures.

**Author Contributions:** Conceptualization, B.H.C.; methodology, B.H.C. and H.T.D.; software, H.T.D.; validation, B.H.C.; formal analysis, H.T.D. and B.H.C.; investigation, H.T.D. and B.H.C.; resources, B.H.C.; data curation, B.H.C.; writing—original draft preparation, H.T.D.; writing—review and editing, B.H.C.; visualization, H.T.D.; supervision, B.H.C.; project administration, B.H.C.; funding acquisition, B.H.C. All authors have read and agreed to the published version of the manuscript.

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**Data Availability Statement:** The data presented in this study are available in the article.

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**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A

**Table 1.** Monolithic uncracked.

| Researcher(s) | Specimen | $f_c{}'$ (MPa) | $A_{cv}$ (mm$^2$) | $A_{vf}$ (mm$^2$) | $\rho$ | $f_y$ (MPa) | $\rho f_y$ (MPa) | $v_{test}$ (MPa) | AASHTO LRFD | | CSA-S6 | | PCI | | ACI 318-19 | | Proposal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ |
| **Normalweight concrete** | | | | | | | | | | | | | | | | | | |
| Hofbeck et al. (1969) | 1 | 27.58 | 32258.0 | 0.00 | 0.000 | 0.0 | 0.00 | 3.38 | 2.48 | 1.36 | 0.75 | 4.50 | | | | | 2.35 | 1.44 |
| | 1.1A | 27.03 | 32258.0 | 141.94 | 0.004 | 349.6 | 1.54 | 5.17 | 4.42 | 1.17 | 2.36 | 2.19 | 2.89 | 1.79 | 1.61 | 3.20 | 4.79 | 1.08 |
| | 1.1B | 29.92 | 32258.0 | 141.94 | 0.004 | 331.0 | 1.45 | 5.82 | 4.32 | 1.35 | 2.28 | 2.56 | 2.81 | 2.07 | 1.53 | 3.81 | 4.93 | 1.18 |
| | 1.2A | 26.48 | 32258.0 | 283.87 | 0.009 | 349.6 | 3.08 | 6.90 | 5.96 | 1.16 | 3.98 | 1.73 | 4.09 | 1.69 | 3.23 | 2.14 | 5.77 | 1.19 |
| | 1.2B | 28.82 | 32258.0 | 283.87 | 0.009 | 331.0 | 2.91 | 6.76 | 6.15 | 1.10 | 3.81 | 1.78 | 3.97 | 1.70 | 3.06 | 2.21 | 5.85 | 1.16 |
| | 1.3A | 26.48 | 32258.0 | 425.81 | 0.013 | 349.6 | 4.61 | 7.58 | 5.96 | 1.27 | 4.88 | 1.56 | 5.00 | 1.52 | 3.97 | 1.91 | 6.56 | 1.16 |
| | 1.3B | 27.03 | 32258.0 | 425.81 | 0.013 | 331.0 | 4.37 | 7.38 | 6.08 | 1.21 | 4.88 | 1.51 | 4.87 | 1.51 | 4.05 | 1.82 | 6.49 | 1.14 |
| | 1.4A | 31.10 | 32258.0 | 567.74 | 0.018 | 349.6 | 6.15 | 9.38 | 7.00 | 1.34 | 4.88 | 1.92 | 5.17 | 1.81 | 4.35 | 2.16 | 7.56 | 1.24 |
| | 1.4B | 26.58 | 32258.0 | 567.74 | 0.018 | 331.0 | 5.83 | 8.83 | 5.98 | 1.48 | 4.88 | 1.81 | 5.17 | 1.71 | 3.99 | 2.21 | 7.10 | 1.24 |
| | 1.5A | 31.10 | 32258.0 | 709.68 | 0.022 | 349.6 | 7.69 | 9.65 | 7.00 | 1.38 | 4.88 | 1.98 | 5.17 | 1.87 | 4.35 | 2.22 | 8.15 | 1.19 |
| | 1.5B | 28.03 | 32258.0 | 709.68 | 0.022 | 331.0 | 7.28 | 9.54 | 6.31 | 1.51 | 4.88 | 1.96 | 5.17 | 1.85 | 4.16 | 2.29 | 7.78 | 1.23 |
| | 1.6A | 29.72 | 32258.0 | 851.61 | 0.026 | 349.6 | 9.23 | 9.87 | 6.69 | 1.48 | 4.88 | 2.03 | 5.17 | 1.91 | 4.27 | 2.31 | 8.58 | 1.15 |
| | 1.6B | 27.92 | 32258.0 | 851.61 | 0.026 | 331.0 | 8.74 | 9.79 | 6.28 | 1.56 | 4.88 | 2.01 | 5.17 | 1.89 | 4.16 | 2.35 | 8.28 | 1.18 |
| Mattock et al. (1975) | E1U | 27.99 | 54193.4 | 567.74 | 0.010 | 363.4 | 3.81 | 7.51 | 6.30 | 1.19 | 4.75 | 1.58 | 4.55 | 1.65 | 4.00 | 1.88 | 6.28 | 1.20 |
| | F1U | 27.82 | 54193.4 | 851.61 | 0.016 | 359.9 | 5.65 | 9.44 | 6.26 | 1.51 | 4.88 | 1.94 | 5.17 | 1.83 | 4.15 | 2.27 | 7.12 | 1.33 |
| Mattlock et al. (1976) | M0 | 27.13 | 32258.0 | 0.00 | 0.000 | 0.0 | 0.00 | 4.07 | 2.48 | 1.64 | 0.75 | 5.42 | | | | | 2.32 | 1.76 |
| | M1 | 28.82 | 32258.0 | 141.94 | 0.004 | 351.0 | 1.54 | 5.24 | 4.43 | 1.18 | 2.37 | 2.21 | 2.90 | 1.81 | 1.62 | 3.23 | 4.92 | 1.06 |
| | M2 | 26.89 | 32258.0 | 283.87 | 0.009 | 363.4 | 3.20 | 6.76 | 6.05 | 1.12 | 4.11 | 1.64 | 4.17 | 1.62 | 3.36 | 2.01 | 5.87 | 1.15 |
| | M3 | 27.55 | 32258.0 | 425.81 | 0.013 | 360.6 | 4.76 | 7.65 | 6.20 | 1.23 | 4.88 | 1.57 | 5.08 | 1.51 | 4.13 | 1.85 | 6.71 | 1.14 |
| | M4 | 28.61 | 32258.0 | 567.74 | 0.018 | 351.0 | 6.18 | 7.86 | 6.44 | 1.22 | 4.88 | 1.61 | 5.17 | 1.52 | 4.20 | 1.87 | 7.39 | 1.06 |
| | M5 | 27.13 | 32258.0 | 709.68 | 0.022 | 363.4 | 7.99 | 8.83 | 6.10 | 1.45 | 4.88 | 1.81 | 5.17 | 1.71 | 4.07 | 2.17 | 7.97 | 1.11 |
| | M6 | 28.41 | 32258.0 | 851.61 | 0.026 | 363.4 | 9.59 | 9.10 | 6.39 | 1.42 | 4.88 | 1.87 | 5.17 | 1.76 | 4.19 | 2.17 | 8.52 | 1.07 |
| Kahn and Mitchell (2002) | SF-4-1-U | 46.92 | 38709.6 | 141.94 | 0.004 | 479.2 | 1.52 | 6.65 | 4.39 | 1.51 | 2.34 | 2.84 | 2.87 | 2.32 | 1.59 | 4.18 | 6.15 | 1.08 |
| | SF4-2-U | 46.92 | 38709.6 | 283.87 | 0.007 | 479.2 | 3.03 | 9.20 | 6.30 | 1.46 | 3.94 | 2.34 | 4.06 | 2.27 | 3.19 | 2.89 | 7.17 | 1.28 |
| | SF-4-3-U | 46.92 | 38709.6 | 425.81 | 0.011 | 479.2 | 4.55 | 9.87 | 8.22 | 1.20 | 4.88 | 2.02 | 4.97 | 1.98 | 4.78 | 2.06 | 7.95 | 1.24 |
| | SF-7-1-U | 80.91 | 38709.6 | 141.94 | 0.004 | 572.3 | 1.52 | 10.06 | 4.39 | 2.29 | 2.34 | 4.29 | 2.87 | 3.51 | 1.59 | 6.32 | 8.32 | 1.21 |
| | SF-7-2-U | 85.57 | 38709.6 | 283.87 | 0.007 | 572.3 | 3.03 | 13.58 | 6.30 | 2.15 | 3.94 | 3.45 | 4.06 | 3.34 | 3.19 | 4.26 | 9.63 | 1.41 |
| | SF-7-3-U | 90.35 | 38709.6 | 425.81 | 0.011 | 572.3 | 4.55 | 15.91 | 8.22 | 1.94 | 4.88 | 3.26 | 4.97 | 3.20 | 4.78 | 3.33 | 10.70 | 1.49 |
| | SF-7-4-U | 85.99 | 38709.6 | 567.74 | 0.015 | 572.3 | 6.07 | 17.13 | 9.31 | 1.84 | 4.88 | 3.51 | 5.17 | 3.31 | 6.37 | 2.69 | 11.10 | 1.54 |
| | SF-10-1-U-a | 83.11 | 38709.6 | 141.94 | 0.004 | 572.3 | 1.52 | 11.50 | 4.39 | 2.62 | 2.34 | 4.91 | 2.87 | 4.01 | 1.59 | 7.22 | 8.46 | 1.36 |
| | SF-10-1-U-b | 98.78 | 38709.6 | 141.94 | 0.004 | 572.3 | 1.52 | 10.56 | 4.39 | 2.40 | 2.34 | 4.51 | 2.87 | 3.68 | 1.59 | 6.63 | 9.41 | 1.12 |
| | SF-10-2-U-a | 101.88 | 38709.6 | 283.87 | 0.007 | 572.3 | 3.03 | 15.02 | 6.30 | 2.38 | 3.94 | 3.82 | 4.06 | 3.70 | 3.19 | 4.71 | 10.61 | 1.42 |
| | SF-10-2-U-b | 102.07 | 38709.6 | 283.87 | 0.007 | 572.3 | 3.03 | 14.26 | 6.30 | 2.26 | 3.94 | 3.62 | 4.06 | 3.51 | 3.19 | 4.48 | 10.62 | 1.34 |
| | SF-10-3-U-a | 111.49 | 38709.6 | 425.81 | 0.011 | 572.3 | 4.55 | 16.64 | 8.22 | 2.03 | 4.88 | 3.41 | 4.97 | 3.35 | 4.78 | 3.48 | 11.96 | 1.39 |
| | SF-10-3-U-b | 96.07 | 38709.6 | 425.81 | 0.011 | 572.3 | 4.55 | 17.00 | 8.22 | 2.07 | 4.88 | 3.49 | 4.97 | 3.42 | 4.78 | 3.56 | 11.05 | 1.54 |
| | SF-10-4-U-a | 106.65 | 38709.6 | 567.74 | 0.015 | 572.3 | 6.07 | 17.93 | 9.31 | 1.93 | 4.88 | 3.68 | 5.17 | 3.47 | 6.37 | 2.81 | 12.34 | 1.45 |
| | SF-10-4-U-b | 113.60 | 38709.6 | 567.74 | 0.015 | 572.3 | 6.07 | 18.39 | 9.31 | 1.98 | 4.88 | 3.77 | 5.17 | 3.56 | 6.37 | 2.89 | 12.75 | 1.44 |
| | SF-14-1-U | 123.81 | 38709.6 | 141.94 | 0.004 | 572.3 | 1.52 | 11.24 | 4.39 | 2.56 | 2.34 | 4.80 | 2.87 | 3.92 | 1.59 | 7.06 | 10.88 | 1.03 |
| | SF-14-2-U | 119.71 | 38709.6 | 283.87 | 0.007 | 572.3 | 3.03 | 12.47 | 6.30 | 1.98 | 3.94 | 3.17 | 4.06 | 3.07 | 3.19 | 3.91 | 11.66 | 1.07 |
| | SF-14-3-U | 112.08 | 38709.6 | 425.81 | 0.011 | 572.3 | 4.55 | 16.80 | 8.22 | 2.05 | 4.88 | 3.45 | 4.97 | 3.38 | 4.78 | 3.52 | 12.00 | 1.40 |
| | SF-14-4-U | 110.73 | 38709.6 | 567.74 | 0.015 | 572.3 | 6.07 | 17.93 | 9.31 | 1.93 | 4.88 | 3.68 | 5.17 | 3.47 | 6.37 | 2.81 | 12.58 | 1.43 |
| Aziz (2010) | S1 | 24.00 | 60000.0 | 0.00 | 0.000 | 0.0 | 0.00 | 4.83 | 2.48 | 1.95 | 0.75 | 6.44 | | | | | 2.09 | 2.32 |

**Table 1.** *Cont.*

| Researcher(s) | Specimen | $f_c{}'$ (MPa) | $A_{cv}$ (mm$^2$) | $A_{vf}$ (mm$^2$) | $\rho$ | $f_y$ (MPa) | $\rho f_y$ (MPa) | $v_{test}$ (MPa) | AASHTO LRFD | | CSA-S6 | | PCI | | ACI 318-19 | | Proposal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ |
| Aziz (2010) | S2 | 24.00 | 60000.0 | 0.00 | 0.000 | 0.0 | 0.00 | 2.67 | 2.48 | 1.07 | 0.75 | 3.56 | | | | | 2.09 | 1.28 |
| | S3 | 24.00 | 60000.0 | 471.24 | 0.008 | 410.0 | 3.22 | 7.73 | 5.40 | 1.43 | 4.13 | 1.87 | 4.18 | 1.85 | 3.38 | 2.29 | 5.67 | 1.36 |
| | S4 | 24.00 | 60000.0 | 471.24 | 0.008 | 410.0 | 3.22 | 5.73 | 5.40 | 1.06 | 4.13 | 1.39 | 4.18 | 1.37 | 3.38 | 1.70 | 5.67 | 1.01 |
| Rahal and Al-Khaleefi (2015) | 35-2T6-0 | 36.89 | 31250.0 | 113.10 | 0.004 | 258.0 | 0.93 | 5.55 | 3.66 | 1.52 | 1.73 | 3.21 | 2.25 | 2.46 | 0.98 | 5.66 | 4.94 | 1.12 |
| | 35-2T8-0 | 36.89 | 31250.0 | 201.06 | 0.006 | 408.0 | 2.63 | 7.94 | 5.79 | 1.37 | 3.51 | 2.26 | 3.78 | 2.10 | 2.76 | 2.88 | 6.25 | 1.27 |
| | 35-3T8-0 | 36.89 | 31250.0 | 301.59 | 0.010 | 408.0 | 3.94 | 8.68 | 7.44 | 1.17 | 4.88 | 1.78 | 4.62 | 1.88 | 4.13 | 2.10 | 6.97 | 1.24 |
| | 35-0T-100 | 34.09 | 31250.0 | 0.00 | 0.000 | 0.0 | 0.00 | 4.68 | 2.48 | 1.89 | 0.75 | 6.24 | | | | | 2.81 | 1.67 |
| | 35-2T6-100 | 41.40 | 31250.0 | 113.10 | 0.004 | 258.0 | 0.93 | 5.63 | 3.66 | 1.54 | 1.73 | 3.25 | 2.25 | 2.50 | 0.98 | 5.74 | 5.25 | 1.07 |
| | 35-2T8-100 | 41.40 | 31250.0 | 201.06 | 0.006 | 408.0 | 2.63 | 7.54 | 5.79 | 1.30 | 3.51 | 2.15 | 3.78 | 2.00 | 2.76 | 2.74 | 6.56 | 1.15 |
| | 35-3T8-100 | 41.40 | 31250.0 | 301.59 | 0.010 | 408.0 | 3.94 | 8.71 | 7.44 | 1.17 | 4.88 | 1.79 | 4.62 | 1.88 | 4.13 | 2.11 | 7.28 | 1.20 |
| | 35-4T8-100 | 41.40 | 31250.0 | 402.12 | 0.013 | 408.0 | 5.25 | 9.36 | 9.10 | 1.03 | 4.88 | 1.92 | 5.17 | 1.81 | 4.97 | 1.88 | 7.90 | 1.19 |
| | 35-6T8-100 | 41.40 | 31250.0 | 603.19 | 0.019 | 408.0 | 7.88 | 10.80 | 9.31 | 1.16 | 4.88 | 2.22 | 5.17 | 2.09 | 4.97 | 2.17 | 8.93 | 1.21 |
| Sneed et al. (2016) | N-MO-U-1 | 33.37 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 8.83 | 7.51 | 1.18 | 4.88 | 1.81 | 5.17 | 1.71 | 4.48 | 1.97 | 7.40 | 1.19 |
| | N-MO-U-2 | 33.37 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 8.67 | 7.51 | 1.15 | 4.88 | 1.78 | 5.17 | 1.68 | 4.48 | 1.93 | 7.40 | 1.17 |
| Rahal et al. (2016) | 35-2T6-SCC | 34.96 | 31250.0 | 113.10 | 0.004 | 258.0 | 0.93 | 6.10 | 3.66 | 1.67 | 1.73 | 3.53 | 2.25 | 2.71 | 0.98 | 6.22 | 4.80 | 1.27 |
| | 35-2T8-SCC | 34.96 | 31250.0 | 201.06 | 0.006 | 408.0 | 2.63 | 7.33 | 5.79 | 1.27 | 3.51 | 2.09 | 3.78 | 1.94 | 2.76 | 2.66 | 6.11 | 1.20 |
| | 35-3T8-SCC | 34.96 | 31250.0 | 301.59 | 0.010 | 408.0 | 3.94 | 7.70 | 7.44 | 1.03 | 4.88 | 1.58 | 4.62 | 1.67 | 4.13 | 1.86 | 6.84 | 1.13 |
| | 35-3T8-SCCrb | 34.96 | 31250.0 | 301.59 | 0.010 | 408.0 | 3.94 | 8.79 | 7.44 | 1.18 | 4.88 | 1.80 | 4.62 | 1.90 | 4.13 | 2.13 | 6.84 | 1.28 |
| | 35-4T8-SCC | 34.96 | 31250.0 | 402.12 | 0.013 | 408.0 | 5.25 | 9.70 | 7.87 | 1.23 | 4.88 | 1.99 | 5.17 | 1.88 | 4.58 | 2.12 | 7.45 | 1.30 |
| | 35-6T8-SCC | 34.96 | 31250.0 | 603.19 | 0.019 | 408.0 | 7.88 | 11.10 | 7.87 | 1.41 | 4.88 | 2.28 | 5.17 | 2.15 | 4.58 | 2.42 | 8.48 | 1.31 |
| | 70-2T6-SCC | 81.20 | 31250.0 | 113.10 | 0.004 | 258.0 | 0.93 | 8.69 | 3.66 | 2.38 | 1.73 | 5.02 | 2.25 | 3.86 | 0.98 | 8.86 | 7.81 | 1.11 |
| | 70-2T8-SCC | 81.20 | 31250.0 | 201.06 | 0.006 | 408.0 | 2.63 | 11.50 | 5.79 | 1.99 | 3.51 | 3.28 | 3.78 | 3.05 | 2.76 | 4.17 | 9.12 | 1.26 |
| | 70-3T8-SCC | 81.20 | 31250.0 | 301.59 | 0.010 | 408.0 | 3.94 | 12.57 | 7.44 | 1.69 | 4.88 | 2.58 | 4.62 | 2.72 | 4.13 | 3.04 | 9.85 | 1.28 |
| | 70-3T8-SCCrb | 81.20 | 31250.0 | 301.59 | 0.010 | 408.0 | 3.94 | 12.30 | 7.44 | 1.65 | 4.88 | 2.52 | 4.62 | 2.66 | 4.13 | 2.97 | 9.85 | 1.25 |
| | 70-4T8-SCC | 81.20 | 31250.0 | 402.12 | 0.013 | 408.0 | 5.25 | 12.77 | 9.10 | 1.40 | 4.88 | 2.62 | 5.17 | 2.47 | 5.51 | 2.32 | 10.46 | 1.22 |
| | 70-6T8-SCC | 81.20 | 31250.0 | 603.19 | 0.019 | 408.0 | 7.88 | 15.85 | 9.31 | 1.70 | 4.88 | 3.25 | 5.17 | 3.07 | 7.35 | 2.16 | 11.49 | 1.38 |
| | 35-2T6-0 | 41.80 | 31250.0 | 113.10 | 0.004 | 258.0 | 0.93 | 5.55 | 3.66 | 1.52 | 1.73 | 3.21 | 2.25 | 2.46 | 0.98 | 5.66 | 5.28 | 1.05 |
| | 35-2T8-0 | 41.80 | 31250.0 | 201.06 | 0.006 | 408.0 | 2.63 | 7.94 | 5.79 | 1.37 | 3.51 | 2.26 | 3.78 | 2.10 | 2.76 | 2.88 | 6.58 | 1.21 |
| | 35-3T8-0 | 41.80 | 31250.0 | 301.59 | 0.010 | 408.0 | 3.94 | 8.68 | 7.44 | 1.17 | 4.88 | 1.78 | 4.62 | 1.88 | 4.13 | 2.10 | 7.31 | 1.19 |
| Waseem and Singh (2016) | N-00-0-A | 38.24 | 31500.0 | 0.00 | 0.000 | 0.0 | 0.00 | 6.29 | 2.48 | 2.53 | 0.75 | 8.39 | | | | | 3.10 | 2.03 |
| | N-00-0-B | 38.24 | 31500.0 | 0.00 | 0.000 | 0.0 | 0.00 | 6.16 | 2.48 | 2.48 | 0.75 | 8.21 | | | | | 3.10 | 1.99 |
| | N-00-2-A | 38.24 | 31500.0 | 201.06 | 0.006 | 525.0 | 2.64 | 8.92 | 5.81 | 1.54 | 3.52 | 2.53 | 3.79 | 2.36 | 2.77 | 3.22 | 6.35 | 1.40 |
| | N-00-2-B | 38.24 | 31500.0 | 201.06 | 0.006 | 525.0 | 2.64 | 10.66 | 5.81 | 1.84 | 3.52 | 3.03 | 3.79 | 2.82 | 2.77 | 3.84 | 6.35 | 1.68 |
| | N-00-3-A | 38.24 | 31500.0 | 301.59 | 0.010 | 525.0 | 3.96 | 11.81 | 7.47 | 1.58 | 4.88 | 2.42 | 4.64 | 2.55 | 4.16 | 2.84 | 7.08 | 1.67 |
| | N-00-3-B | 38.24 | 31500.0 | 301.59 | 0.010 | 525.0 | 3.96 | 10.17 | 7.47 | 1.36 | 4.88 | 2.09 | 4.64 | 2.19 | 4.16 | 2.45 | 7.08 | 1.44 |
| | N-00-4-A | 38.24 | 31500.0 | 402.12 | 0.013 | 525.0 | 5.28 | 11.77 | 8.60 | 1.37 | 4.88 | 2.41 | 5.17 | 2.28 | 4.78 | 2.46 | 7.70 | 1.53 |
| | N-00-4-B | 38.24 | 31500.0 | 402.12 | 0.013 | 525.0 | 5.28 | 12.44 | 8.60 | 1.45 | 4.88 | 2.55 | 5.17 | 2.41 | 4.78 | 2.60 | 7.70 | 1.62 |
| | N-50-0-A | 34.40 | 31500.0 | 0.00 | 0.000 | 525.0 | 0.00 | 5.56 | 2.48 | 2.24 | 0.75 | 7.41 | | | | | 2.83 | 1.96 |
| | N-50-0-B | 34.40 | 31500.0 | 0.00 | 0.000 | 525.0 | 0.00 | 5.40 | 2.48 | 2.18 | 0.75 | 7.20 | | | | | 2.83 | 1.91 |
| | N-50-2-A | 34.40 | 31500.0 | 201.06 | 0.006 | 525.0 | 2.64 | 9.88 | 5.81 | 1.70 | 3.52 | 2.80 | 3.79 | 2.61 | 2.77 | 3.56 | 6.08 | 1.62 |
| | N-50-2-B | 34.40 | 31500.0 | 201.06 | 0.006 | 525.0 | 2.64 | 8.11 | 5.81 | 1.40 | 3.52 | 2.30 | 3.79 | 2.14 | 2.77 | 2.93 | 6.08 | 1.33 |
| | N-50-3-A | 34.40 | 31500.0 | 301.59 | 0.010 | 525.0 | 3.96 | 9.46 | 7.47 | 1.27 | 4.88 | 1.94 | 4.64 | 2.04 | 4.16 | 2.27 | 6.81 | 1.39 |
| | N-50-3-B | 34.40 | 31500.0 | 301.59 | 0.010 | 525.0 | 3.96 | 10.61 | 7.47 | 1.42 | 4.88 | 2.18 | 4.64 | 2.29 | 4.16 | 2.55 | 6.81 | 1.56 |
| | N-50-4-A | 34.40 | 31500.0 | 402.12 | 0.013 | 525.0 | 5.28 | 11.14 | 7.74 | 1.44 | 4.88 | 2.29 | 5.17 | 2.15 | 4.55 | 2.45 | 7.43 | 1.50 |
| | N-50-4-B | 34.40 | 31500.0 | 402.12 | 0.013 | 525.0 | 5.28 | 10.14 | 7.74 | 1.31 | 4.88 | 2.08 | 5.17 | 1.96 | 4.55 | 2.23 | 7.43 | 1.36 |
| | N-100-0-A | 30.24 | 31500.0 | 0.00 | 0.000 | 525.0 | 0.00 | 5.37 | 2.48 | 2.16 | 0.75 | 7.16 | | | | | 2.54 | 2.12 |
| | N-100-0-B | 30.24 | 31500.0 | 0.00 | 0.000 | 525.0 | 0.00 | 5.47 | 2.48 | 2.20 | 0.75 | 7.29 | | | | | 2.54 | 2.15 |

**Table 1.** *Cont.*

| Researcher(s) | Specimen | $f_c{}'$ (MPa) | $A_{cv}$ (mm$^2$) | $A_{vf}$ (mm$^2$) | $\rho$ | $f_y$ (MPa) | $\rho f_y$ (MPa) | $v_{test}$ (MPa) | AASHTO LRFD | | CSA-S6 | | PCI | | ACI 318-19 | | Proposal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ |
| Waseem and Singh (2016) | N-100-2-A | 30.24 | 31500.0 | 201.06 | 0.006 | 525.0 | 2.64 | 9.80 | 5.81 | 1.69 | 3.52 | 2.78 | 3.79 | 2.59 | 2.77 | 3.53 | 5.79 | 1.69 |
| | N-100-2-B | 30.24 | 31500.0 | 201.06 | 0.006 | 525.0 | 2.64 | 7.28 | 5.81 | 1.25 | 3.52 | 2.07 | 3.79 | 1.92 | 2.77 | 2.63 | 5.79 | 1.26 |
| | N-100-3-A | 30.24 | 31500.0 | 301.59 | 0.010 | 525.0 | 3.96 | 9.75 | 6.80 | 1.43 | 4.88 | 2.00 | 4.64 | 2.10 | 4.16 | 2.34 | 6.52 | 1.50 |
| | N-100-3-B | 30.24 | 31500.0 | 301.59 | 0.010 | 525.0 | 3.96 | 9.86 | 6.80 | 1.45 | 4.88 | 2.02 | 4.64 | 2.13 | 4.16 | 2.37 | 6.52 | 1.51 |
| | N-100-4-A | 30.24 | 31500.0 | 402.12 | 0.013 | 525.0 | 5.28 | 10.13 | 6.80 | 1.49 | 4.88 | 2.08 | 5.17 | 1.96 | 4.30 | 2.36 | 7.13 | 1.42 |
| | N-100-4-B | 30.24 | 31500.0 | 402.12 | 0.013 | 525.0 | 5.28 | 10.38 | 6.80 | 1.53 | 4.88 | 2.13 | 5.17 | 2.01 | 4.30 | 2.42 | 7.13 | 1.45 |
| | H-00-0-A | 73.60 | 31500.0 | 0.00 | 0.000 | 525.0 | 0.00 | 8.17 | 2.48 | 3.29 | 0.75 | 10.89 | | | | | 5.41 | 1.51 |
| | H-00-0-B | 73.60 | 31500.0 | 0.00 | 0.000 | 525.0 | 0.00 | 8.44 | 2.48 | 3.40 | 0.75 | 11.25 | | | | | 5.41 | 1.56 |
| | H-00-2-A | 73.60 | 31500.0 | 201.06 | 0.006 | 525.0 | 2.64 | 13.78 | 5.81 | 2.37 | 3.52 | 3.91 | 3.79 | 3.64 | 2.77 | 4.97 | 8.66 | 1.59 |
| | H-00-2-B | 73.60 | 31500.0 | 201.06 | 0.006 | 525.0 | 2.64 | 15.49 | 5.81 | 2.67 | 3.52 | 4.40 | 3.79 | 4.09 | 2.77 | 5.59 | 8.66 | 1.79 |
| | H-00-3-A | 73.60 | 31500.0 | 301.59 | 0.010 | 525.0 | 3.96 | 15.29 | 7.47 | 2.05 | 4.88 | 3.14 | 4.64 | 3.30 | 4.16 | 3.68 | 9.39 | 1.63 |
| | H-00-3-B | 73.60 | 31500.0 | 301.59 | 0.010 | 525.0 | 3.96 | 18.04 | 7.47 | 2.41 | 4.88 | 3.70 | 4.64 | 3.89 | 4.16 | 4.34 | 9.39 | 1.92 |
| | H-00-4-A | 73.60 | 31500.0 | 402.12 | 0.013 | 525.0 | 5.28 | 18.70 | 9.14 | 2.05 | 4.88 | 3.84 | 5.17 | 3.62 | 5.55 | 3.37 | 10.00 | 1.87 |
| | H-00-4-B | 73.60 | 31500.0 | 402.12 | 0.013 | 525.0 | 5.28 | 16.09 | 9.14 | 1.76 | 4.88 | 3.30 | 5.17 | 3.11 | 5.55 | 2.90 | 10.00 | 1.61 |
| | H-50-0-A | 67.60 | 31500.0 | 0.00 | 0.000 | 525.0 | 0.00 | 7.86 | 2.48 | 3.17 | 0.75 | 10.48 | | | | | 5.03 | 1.56 |
| | H-50-0-B | 67.60 | 31500.0 | 0.00 | 0.000 | 525.0 | 0.00 | 7.66 | 2.48 | 3.09 | 0.75 | 10.21 | | | | | 5.03 | 1.52 |
| | H-50-2-A | 67.60 | 31500.0 | 201.06 | 0.006 | 525.0 | 2.64 | 14.06 | 5.81 | 2.42 | 3.52 | 3.99 | 3.79 | 3.71 | 2.77 | 5.07 | 8.28 | 1.70 |
| | H-50-2-B | 67.60 | 31500.0 | 201.06 | 0.006 | 525.0 | 2.64 | 13.88 | 5.81 | 2.39 | 3.52 | 3.94 | 3.79 | 3.67 | 2.77 | 5.01 | 8.28 | 1.68 |
| | H-50-3-A | 67.60 | 31500.0 | 301.59 | 0.010 | 525.0 | 3.96 | 16.08 | 7.47 | 2.15 | 4.88 | 3.30 | 4.64 | 3.47 | 4.16 | 3.87 | 9.01 | 1.78 |
| | H-50-3-B | 67.60 | 31500.0 | 301.59 | 0.010 | 525.0 | 3.96 | 15.39 | 7.47 | 2.06 | 4.88 | 3.16 | 4.64 | 3.32 | 4.16 | 3.70 | 9.01 | 1.71 |
| | H-50-4-A | 67.60 | 31500.0 | 402.12 | 0.013 | 525.0 | 5.28 | 18.35 | 9.14 | 2.01 | 4.88 | 3.76 | 5.17 | 3.55 | 5.55 | 3.31 | 9.63 | 1.91 |
| | H-50-4-B | 67.60 | 31500.0 | 402.12 | 0.013 | 525.0 | 5.28 | 15.97 | 9.14 | 1.75 | 4.88 | 3.28 | 5.17 | 3.09 | 5.55 | 2.88 | 9.63 | 1.66 |
| | H-100-0-A | 64.40 | 31500.0 | 0.00 | 0.000 | 525.0 | 0.00 | 7.29 | 2.48 | 2.94 | 0.75 | 9.72 | | | | | 4.83 | 1.51 |
| | H-100-0-B | 64.40 | 31500.0 | 0.00 | 0.000 | 525.0 | 0.00 | 7.54 | 2.48 | 3.04 | 0.75 | 10.05 | | | | | 4.83 | 1.56 |
| | H-100-2-A | 64.40 | 31500.0 | 201.06 | 0.006 | 525.0 | 2.64 | 13.41 | 5.81 | 2.31 | 3.52 | 3.81 | 3.79 | 3.54 | 2.77 | 4.84 | 8.08 | 1.66 |
| | H-100-2-B | 64.40 | 31500.0 | 201.06 | 0.006 | 525.0 | 2.64 | 13.90 | 5.81 | 2.39 | 3.52 | 3.95 | 3.79 | 3.67 | 2.77 | 5.01 | 8.08 | 1.72 |
| | H-100-3-A | 64.40 | 31500.0 | 301.59 | 0.010 | 525.0 | 3.96 | 15.57 | 7.47 | 2.08 | 4.88 | 3.19 | 4.64 | 3.36 | 4.16 | 3.74 | 8.81 | 1.77 |
| | H-100-3-B | 64.40 | 31500.0 | 301.59 | 0.010 | 525.0 | 3.96 | 15.28 | 7.47 | 2.04 | 4.88 | 3.13 | 4.64 | 3.29 | 4.16 | 3.67 | 8.81 | 1.73 |
| | H-100-4-A | 64.40 | 31500.0 | 402.12 | 0.013 | 525.0 | 5.28 | 16.29 | 9.14 | 1.78 | 4.88 | 3.34 | 5.17 | 3.15 | 5.55 | 2.94 | 9.42 | 1.73 |
| | H-100-4-B | 64.40 | 31500.0 | 402.12 | 0.013 | 525.0 | 5.28 | 15.92 | 9.14 | 1.74 | 4.88 | 3.27 | 5.17 | 3.08 | 5.55 | 2.87 | 9.42 | 1.69 |
| Xiao et al. (2016) | NC-1-U-A | 30.94 | 36000.0 | 402.12 | 0.011 | 325.0 | 3.63 | 8.45 | 6.96 | 1.21 | 4.56 | 1.85 | 4.44 | 1.90 | 3.81 | 2.22 | 6.40 | 1.32 |
| | NC-1-U-B | 30.94 | 36000.0 | 402.12 | 0.011 | 325.0 | 3.63 | 9.05 | 6.96 | 1.30 | 4.56 | 1.98 | 4.44 | 2.04 | 3.81 | 2.37 | 6.40 | 1.41 |
| | NC-1-U-C | 30.94 | 36000.0 | 402.12 | 0.011 | 325.0 | 3.63 | 8.65 | 6.96 | 1.24 | 4.56 | 1.90 | 4.44 | 1.95 | 3.81 | 2.27 | 6.40 | 1.35 |
| | NC-1-U-D | 30.94 | 36000.0 | 402.12 | 0.011 | 325.0 | 3.63 | 8.01 | 6.96 | 1.15 | 4.56 | 1.76 | 4.44 | 1.80 | 3.81 | 2.10 | 6.40 | 1.25 |
| | NC-1-U-E | 30.94 | 36000.0 | 402.12 | 0.011 | 325.0 | 3.63 | 8.65 | 6.96 | 1.24 | 4.56 | 1.90 | 4.44 | 1.95 | 3.81 | 2.27 | 6.40 | 1.35 |
| | RC-2-U | 31.41 | 36000.0 | 402.12 | 0.011 | 325.0 | 3.63 | 7.84 | 7.06 | 1.11 | 4.56 | 1.72 | 4.44 | 1.77 | 3.81 | 2.06 | 6.43 | 1.22 |
| | RC-3-U-A | 25.64 | 36000.0 | 402.12 | 0.011 | 325.0 | 3.63 | 7.86 | 5.77 | 1.36 | 4.56 | 1.72 | 4.44 | 1.77 | 3.81 | 2.06 | 6.02 | 1.31 |
| | RC-3-U-B | 25.64 | 36000.0 | 402.12 | 0.011 | 325.0 | 3.63 | 7.86 | 5.77 | 1.36 | 4.56 | 1.72 | 4.44 | 1.77 | 3.81 | 2.06 | 6.02 | 1.31 |
| | RC-3-U-C | 25.64 | 36000.0 | 402.12 | 0.011 | 325.0 | 3.63 | 7.50 | 5.77 | 1.30 | 4.56 | 1.64 | 4.44 | 1.69 | 3.81 | 1.97 | 6.02 | 1.25 |
| | RC-3-U-D | 25.64 | 36000.0 | 402.12 | 0.011 | 325.0 | 3.63 | 7.75 | 5.77 | 1.34 | 4.56 | 1.70 | 4.44 | 1.75 | 3.81 | 2.03 | 6.02 | 1.29 |
| | RC-3-U-E | 25.64 | 36000.0 | 402.12 | 0.011 | 325.0 | 3.63 | 7.82 | 5.77 | 1.36 | 4.56 | 1.71 | 4.44 | 1.76 | 3.81 | 2.05 | 6.02 | 1.30 |
| | RC-4-U | 30.06 | 36000.0 | 402.12 | 0.011 | 325.0 | 3.63 | 8.73 | 6.76 | 1.29 | 4.56 | 1.91 | 4.44 | 1.97 | 3.81 | 2.29 | 6.34 | 1.38 |
| | RC-5-U-A | 30.76 | 36000.0 | 402.12 | 0.011 | 325.0 | 3.63 | 7.43 | 6.92 | 1.07 | 4.56 | 1.63 | 4.44 | 1.67 | 3.81 | 1.95 | 6.39 | 1.16 |
| | RC-5-U-B | 30.76 | 36000.0 | 402.12 | 0.011 | 325.0 | 3.63 | 7.92 | 6.92 | 1.14 | 4.56 | 1.74 | 4.44 | 1.78 | 3.81 | 2.08 | 6.39 | 1.24 |
| | RC-5-U-C | 30.76 | 36000.0 | 402.12 | 0.011 | 325.0 | 3.63 | 7.20 | 6.92 | 1.04 | 4.56 | 1.58 | 4.44 | 1.62 | 3.81 | 1.89 | 6.39 | 1.13 |
| | RC-5-U-D | 30.76 | 36000.0 | 402.12 | 0.011 | 325.0 | 3.63 | 7.43 | 6.92 | 1.07 | 4.56 | 1.63 | 4.44 | 1.67 | 3.81 | 1.95 | 6.39 | 1.16 |
| | RC-5-U-E | 30.76 | 36000.0 | 402.12 | 0.011 | 325.0 | 3.63 | 8.21 | 6.92 | 1.19 | 4.56 | 1.80 | 4.44 | 1.85 | 3.81 | 2.15 | 6.39 | 1.29 |
| | RC-6-U | 23.43 | 36000.0 | 402.12 | 0.011 | 325.0 | 3.63 | 8.12 | 5.27 | 1.54 | 4.39 | 1.85 | 4.44 | 1.83 | 3.51 | 2.31 | 5.85 | 1.39 |

**Table 1.** *Cont.*

| Researcher(s) | Specimen | $f_c{}'$ (MPa) | $A_{cv}$ (mm$^2$) | $A_{vf}$ (mm$^2$) | $\rho$ | $f_y$ (MPa) | $\rho f_y$ (MPa) | $v_{test}$ (MPa) | AASHTO LRFD | | CSA-S6 | | PCI | | ACI 318-19 | | Proposal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ |
| Xiao et al. (2016) | RC-7-U | 33.03 | 36000.0 | 402.12 | 0.011 | 325.0 | 3.63 | 7.99 | 7.06 | 1.13 | 4.56 | 1.75 | 4.44 | 1.80 | 3.81 | 2.10 | 6.55 | 1.22 |
| Ahmad et al. (2018) | N-0a | 40.00 | 31250.0 | 0.00 | 0.000 | 0.0 | 0.00 | 4.10 | 2.48 | 1.65 | 0.75 | 5.47 | | | | | 3.22 | 1.27 |
| | N-0b | 40.00 | 31250.0 | 0.00 | 0.000 | 0.0 | 0.00 | 4.28 | 2.48 | 1.72 | 0.75 | 5.71 | | | | | 3.22 | 1.33 |
| | N-1a | 40.00 | 31250.0 | 100.53 | 0.003 | 567.2 | 1.33 | 5.54 | 4.16 | 1.33 | 2.15 | 2.58 | 2.69 | 2.06 | 1.40 | 3.96 | 5.53 | 1.00 |
| | N-1b | 40.00 | 31250.0 | 100.53 | 0.003 | 567.2 | 1.33 | 6.02 | 4.16 | 1.45 | 2.15 | 2.80 | 2.69 | 2.24 | 1.40 | 4.31 | 5.53 | 1.09 |
| | N-2a | 40.00 | 31250.0 | 201.06 | 0.006 | 567.2 | 2.66 | 8.98 | 5.84 | 1.54 | 3.54 | 2.53 | 3.80 | 2.36 | 2.79 | 3.21 | 6.48 | 1.39 |
| | N-2b | 40.00 | 31250.0 | 201.06 | 0.006 | 567.2 | 2.66 | 8.35 | 5.84 | 1.43 | 3.54 | 2.36 | 3.80 | 2.20 | 2.79 | 2.99 | 6.48 | 1.29 |
| | N-3a | 40.00 | 31250.0 | 301.59 | 0.010 | 567.2 | 3.99 | 9.30 | 7.51 | 1.24 | 4.88 | 1.91 | 4.66 | 2.00 | 4.19 | 2.22 | 7.22 | 1.29 |
| | N-3b | 40.00 | 31250.0 | 301.59 | 0.010 | 567.2 | 3.99 | 10.10 | 7.51 | 1.34 | 4.88 | 2.07 | 4.66 | 2.17 | 4.19 | 2.41 | 7.22 | 1.40 |
| | N-4a | 40.00 | 31250.0 | 402.12 | 0.013 | 567.2 | 5.32 | 11.30 | 9.00 | 1.26 | 4.88 | 2.32 | 5.17 | 2.19 | 4.88 | 2.31 | 7.83 | 1.44 |
| | N-4b | 40.00 | 31250.0 | 402.12 | 0.013 | 567.2 | 5.32 | 10.97 | 9.00 | 1.22 | 4.88 | 2.25 | 5.17 | 2.12 | 4.88 | 2.25 | 7.83 | 1.40 |
| | N-5a | 40.00 | 31250.0 | 502.65 | 0.016 | 567.2 | 6.65 | 11.98 | 9.00 | 1.33 | 4.88 | 2.46 | 5.17 | 2.32 | 4.88 | 2.45 | 8.38 | 1.43 |
| | N-5b | 40.00 | 31250.0 | 502.65 | 0.016 | 567.2 | 6.65 | 12.30 | 9.00 | 1.37 | 4.88 | 2.52 | 5.17 | 2.38 | 4.88 | 2.52 | 8.38 | 1.47 |
| Valikhani et al. (2021) | Ref.1 | 47.00 | 93330.0 | 0.00 | 0.000 | 0.0 | 0.00 | 8.56 | 2.48 | 3.45 | 0.75 | 11.41 | | | | | 3.69 | 2.32 |
| | Ref.2 | 47.00 | 93330.0 | 0.00 | 0.000 | 0.0 | 0.00 | 6.62 | 2.48 | 2.67 | 0.75 | 8.83 | | | | | 3.69 | 1.79 |
| | Ref.3 | 47.00 | 93330.0 | 0.00 | 0.000 | 0.0 | 0.00 | 5.43 | 2.48 | 2.19 | 0.75 | 7.24 | | | | | 3.69 | 1.47 |
| **Sand-lightweight concrete** | | | | | | | | | | | | | | | | | | |
| Mattock et al. (1976) | A0 | 29.17 | 32258.0 | 0.00 | 0.000 | 0.0 | 0.00 | 3.45 | 1.49 | 2.31 | 0.64 | 5.41 | | | | | 2.09 | 1.65 |
| | A1 | 25.79 | 32258.0 | 141.94 | 0.004 | 328.9 | 1.45 | 5.23 | 2.79 | 1.87 | 1.93 | 2.71 | 2.38 | 2.19 | 1.29 | 4.04 | 3.93 | 1.33 |
| | A2 | 28.24 | 32258.0 | 283.87 | 0.009 | 369.6 | 3.25 | 6.30 | 4.42 | 1.43 | 3.54 | 1.78 | 3.57 | 1.76 | 2.90 | 2.17 | 5.10 | 1.24 |
| | A3 | 26.96 | 32258.0 | 425.81 | 0.013 | 366.8 | 4.84 | 7.03 | 5.85 | 1.20 | 4.88 | 1.44 | 4.36 | 1.61 | 4.04 | 1.74 | 5.70 | 1.23 |
| | A4 | 28.27 | 32258.0 | 567.74 | 0.018 | 351.0 | 6.18 | 7.58 | 6.21 | 1.22 | 4.88 | 1.56 | 4.40 | 1.73 | 4.14 | 1.83 | 6.13 | 1.24 |
| | A5 | 27.30 | 32258.0 | 709.68 | 0.022 | 351.0 | 7.72 | 8.21 | 6.14 | 1.34 | 4.88 | 1.68 | 4.40 | 1.87 | 4.10 | 2.00 | 5.92 | 1.39 |
| | A6 | 29.30 | 32258.0 | 851.61 | 0.026 | 357.2 | 9.43 | 9.27 | 6.21 | 1.49 | 4.88 | 1.90 | 4.40 | 2.11 | 4.14 | 2.24 | 6.35 | 1.46 |
| Sneed et al. (2016) | S-SH-MO-U-1 | 32.89 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 7.72 | 6.21 | 1.24 | 4.88 | 1.58 | 4.40 | 1.76 | 4.14 | 1.87 | 6.26 | 1.23 |
| | S-SH-MO-U-2 | 32.89 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 7.88 | 6.21 | 1.27 | 4.88 | 1.62 | 4.40 | 1.79 | 4.14 | 1.91 | 6.26 | 1.26 |
| **All-lightweight concrete** | | | | | | | | | | | | | | | | | | |
| Mattock et al. (1976) | E0 | 27.30 | 32258.0 | 0.00 | 0.000 | 0.0 | 0.00 | 3.86 | 1.49 | 2.59 | 0.56 | 6.86 | | | | | 1.75 | 2.21 |
| | E1 | 28.61 | 32258.0 | 141.94 | 0.004 | 360.6 | 1.59 | 5.38 | 2.92 | 1.84 | 1.81 | 2.97 | 2.20 | 2.44 | 1.25 | 4.31 | 3.71 | 1.45 |
| | E2 | 27.79 | 32258.0 | 283.87 | 0.009 | 360.6 | 3.17 | 6.01 | 4.34 | 1.38 | 3.06 | 1.96 | 3.11 | 1.93 | 2.50 | 2.41 | 4.44 | 1.35 |
| | E3 | 28.03 | 32258.0 | 425.81 | 0.013 | 360.6 | 4.76 | 6.62 | 5.77 | 1.15 | 4.31 | 1.54 | 3.81 | 1.74 | 3.75 | 1.77 | 4.73 | 1.40 |
| | E4 | 27.86 | 32258.0 | 567.74 | 0.018 | 366.8 | 6.45 | 7.93 | 6.21 | 1.28 | 4.88 | 1.63 | 3.88 | 2.04 | 4.14 | 1.92 | 4.70 | 1.69 |
| | E5 | 28.37 | 32258.0 | 709.68 | 0.022 | 348.2 | 7.66 | 8.27 | 6.21 | 1.33 | 4.88 | 1.70 | 3.88 | 2.13 | 4.14 | 2.00 | 4.79 | 1.73 |
| | E6 | 27.92 | 32258.0 | 851.61 | 0.026 | 360.6 | 9.52 | 8.62 | 6.21 | 1.39 | 4.88 | 1.77 | 3.88 | 2.22 | 4.14 | 2.08 | 4.71 | 1.83 |
| | G0 | 27.79 | 32258.0 | 0.00 | 0.000 | 0.0 | 0.00 | 3.65 | 1.49 | 2.45 | 0.56 | 6.50 | | | | | 1.77 | 2.06 |
| | G1 | 28.58 | 32258.0 | 141.94 | 0.004 | 360.6 | 1.59 | 5.65 | 2.92 | 1.94 | 1.81 | 3.12 | 2.20 | 2.57 | 1.25 | 4.53 | 3.70 | 1.53 |
| | G2 | 26.75 | 32258.0 | 283.87 | 0.009 | 348.2 | 3.06 | 5.83 | 4.24 | 1.37 | 2.97 | 1.96 | 3.06 | 1.91 | 2.41 | 2.42 | 4.34 | 1.34 |
| | G3 | 28.27 | 32258.0 | 425.81 | 0.013 | 357.2 | 4.72 | 7.31 | 5.73 | 1.27 | 4.28 | 1.71 | 3.80 | 1.93 | 3.71 | 1.97 | 4.77 | 1.53 |
| | G4 | 30.48 | 32258.0 | 567.74 | 0.018 | 366.8 | 6.45 | 7.93 | 6.21 | 1.28 | 4.88 | 1.63 | 3.88 | 2.04 | 4.14 | 1.92 | 5.14 | 1.54 |
| | G5 | 27.61 | 32258.0 | 709.68 | 0.022 | 357.2 | 7.86 | 7.86 | 6.21 | 1.27 | 4.88 | 1.61 | 3.88 | 2.03 | 4.14 | 1.90 | 4.66 | 1.69 |
| | G6 | 27.61 | 32258.0 | 851.61 | 0.026 | 357.2 | 9.43 | 8.21 | 6.21 | 1.32 | 4.88 | 1.68 | 3.88 | 2.12 | 4.14 | 1.98 | 4.66 | 1.76 |
| Sneed et al. (2016) | A-SH-MO-U-1 | 32.41 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 7.25 | 6.21 | 1.17 | 4.80 | 1.51 | 3.88 | 1.87 | 4.14 | 1.75 | 5.47 | 1.33 |
| | A-SH-MO-U-2 | 32.41 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 7.32 | 6.21 | 1.18 | 4.80 | 1.53 | 3.88 | 1.89 | 4.14 | 1.77 | 5.47 | 1.34 |
| | | | | | | | | | Average | 1.65 | | 3.18 | | 2.35 | | 2.94 | | 1.42 |
| | | | | | | | | | Maximum | 3.45 | | 11.41 | | 4.09 | | 8.86 | | 2.32 |
| | | | | | | | | | Minimum | 1.03 | | 1.39 | | 1.37 | | 1.70 | | 1.00 |
| | | | | | | | | | STD | 0.53 | | 2.14 | | 0.70 | | 1.28 | | 0.27 |
| | | | | | | | | | COV | 31.87 | | 67.31 | | 29.60 | | 43.39 | | 18.87 |

**Table 2.** Monolithic precracked.

| Researcher(s) | Specimen | $f_c'$ (MPa) | $A_{cv}$ (mm$^2$) | $A_{vf}$ (mm$^2$) | $\rho$ | $f_y$ (MPa) | $\rho f_y$ (MPa) | $v_{test}$ (MPa) | AASHTO LRFD | | CSA-S6 | | PCI | | ACI 318-19 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ |
| **Normalweight concrete** | | | | | | | | | | | | | | | | |
| Hofbeck et al. (1969) | 2.1 | 21.37 | 32258.0 | 141.94 | 0.004 | 349.6 | 1.54 | 4.07 | 4.42 | 0.92 | 2.36 | 1.72 | 2.89 | 1.41 | 1.61 | 2.52 |
| | 2.2 | 21.37 | 32258.0 | 283.87 | 0.009 | 349.6 | 3.08 | 4.69 | 4.81 | 0.97 | 3.98 | 1.18 | 4.09 | 1.15 | 3.21 | 1.46 |
| | 2.3 | 26.89 | 32258.0 | 425.81 | 0.013 | 349.6 | 4.61 | 5.79 | 6.05 | 0.96 | 4.88 | 1.19 | 5.00 | 1.16 | 4.03 | 1.44 |
| | 2.4 | 26.89 | 32258.0 | 567.74 | 0.018 | 349.6 | 6.15 | 6.90 | 6.05 | 1.14 | 4.88 | 1.41 | 5.17 | 1.33 | 4.03 | 1.71 |
| | 2.5 | 28.82 | 32258.0 | 709.68 | 0.022 | 349.6 | 7.69 | 8.96 | 6.48 | 1.38 | 4.88 | 1.84 | 5.17 | 1.73 | 4.21 | 2.13 |
| | 2.6 | 28.82 | 32258.0 | 851.61 | 0.026 | 349.6 | 9.23 | 9.55 | 6.48 | 1.47 | 4.88 | 1.96 | 5.17 | 1.85 | 4.21 | 2.27 |
| | 3.3 | 21.37 | 32258.0 | 283.77 | 0.009 | 349.6 | 3.08 | 4.69 | 4.81 | 0.97 | 3.98 | 1.18 | 4.09 | 1.15 | 3.21 | 1.46 |
| | 3.4 | 27.86 | 32258.0 | 506.42 | 0.016 | 325.4 | 5.11 | 7.09 | 6.27 | 1.13 | 4.88 | 1.45 | 5.17 | 1.37 | 4.15 | 1.71 |
| | 3.5 | 27.86 | 32258.0 | 790.47 | 0.025 | 292.3 | 7.16 | 7.94 | 6.27 | 1.27 | 4.88 | 1.63 | 5.17 | 1.54 | 4.15 | 1.91 |
| | 4.1 | 28.06 | 32258.0 | 141.94 | 0.004 | 455.8 | 1.82 | 4.85 | 4.78 | 1.02 | 2.66 | 1.82 | 3.14 | 1.54 | 1.91 | 2.54 |
| | 4.2 | 28.06 | 32258.0 | 283.87 | 0.009 | 455.8 | 3.64 | 6.76 | 6.31 | 1.07 | 4.57 | 1.48 | 4.45 | 1.52 | 3.82 | 1.77 |
| | 4.3 | 29.92 | 32258.0 | 425.81 | 0.013 | 455.8 | 5.46 | 8.14 | 6.73 | 1.21 | 4.88 | 1.67 | 5.17 | 1.57 | 4.28 | 1.90 |
| | 4.4 | 29.92 | 32258.0 | 567.74 | 0.018 | 455.8 | 7.28 | 9.65 | 6.73 | 1.43 | 4.88 | 1.98 | 5.17 | 1.87 | 4.28 | 2.26 |
| | 4.5 | 23.37 | 32258.0 | 709.68 | 0.022 | 455.8 | 9.10 | 9.10 | 5.26 | 1.73 | 4.38 | 2.08 | 5.17 | 1.76 | 3.51 | 2.60 |
| | 5.1 | 16.89 | 32258.0 | 141.94 | 0.004 | 349.6 | 1.54 | 3.52 | 3.80 | 0.93 | 2.36 | 1.49 | 2.89 | 1.22 | 1.61 | 2.18 |
| | 5.2 | 18.06 | 32258.0 | 283.87 | 0.009 | 349.6 | 3.08 | 4.83 | 4.06 | 1.19 | 3.39 | 1.42 | 4.06 | 1.19 | 2.71 | 1.78 |
| | 5.3 | 16.44 | 32258.0 | 425.81 | 0.013 | 349.6 | 4.61 | 5.58 | 3.70 | 1.51 | 3.08 | 1.81 | 3.70 | 1.51 | 2.47 | 2.26 |
| | 5.4 | 17.79 | 32258.0 | 567.74 | 0.018 | 349.6 | 6.15 | 5.48 | 4.00 | 1.37 | 3.34 | 1.64 | 4.00 | 1.37 | 2.67 | 2.05 |
| | 5.5 | 18.06 | 32258.0 | 709.68 | 0.022 | 349.6 | 7.69 | 6.96 | 4.06 | 1.71 | 3.39 | 2.06 | 4.06 | 1.71 | 2.71 | 2.57 |
| Mattock et al. (1975) | E1C | 26.58 | 54193.4 | 567.74 | 0.010 | 357.2 | 3.74 | 6.07 | 5.98 | 1.02 | 4.68 | 1.30 | 4.51 | 1.35 | 3.93 | 1.55 |
| | F1C | 29.10 | 54193.4 | 851.61 | 0.016 | 345.4 | 5.43 | 6.81 | 6.55 | 1.04 | 4.88 | 1.40 | 5.17 | 1.32 | 4.23 | 1.61 |
| Mattock (1976) | A1 | 41.51 | 32258.0 | 141.94 | 0.004 | 356.1 | 1.57 | 5.24 | 4.45 | 1.18 | 2.39 | 2.19 | 2.92 | 1.80 | 1.64 | 3.19 |
| | A2 | 41.51 | 32258.0 | 283.87 | 0.009 | 356.1 | 3.13 | 5.52 | 6.43 | 0.86 | 4.04 | 1.37 | 4.12 | 1.34 | 3.29 | 1.68 |
| | A3 | 40.13 | 32258.0 | 425.81 | 0.013 | 382.3 | 5.05 | 7.93 | 8.84 | 0.90 | 4.88 | 1.63 | 5.17 | 1.53 | 4.89 | 1.62 |
| | A4 | 40.54 | 32258.0 | 567.74 | 0.018 | 382.3 | 6.73 | 9.79 | 9.12 | 1.07 | 4.88 | 2.01 | 5.17 | 1.89 | 4.91 | 1.99 |
| | A5 | 42.23 | 32258.0 | 709.68 | 0.022 | 353.5 | 7.78 | 10.34 | 9.31 | 1.11 | 4.88 | 2.12 | 5.17 | 2.00 | 5.02 | 2.06 |
| | A6 | 40.68 | 32258.0 | 1032.26 | 0.032 | 331.0 | 10.59 | 12.14 | 9.15 | 1.33 | 4.88 | 2.49 | 5.17 | 2.35 | 4.92 | 2.46 |
| | A6A | 41.16 | 32258.0 | 1032.26 | 0.032 | 331.0 | 10.59 | 12.82 | 9.26 | 1.38 | 4.88 | 2.63 | 5.17 | 2.48 | 4.95 | 2.59 |
| | A7 | 41.16 | 32258.0 | 1290.32 | 0.040 | 332.3 | 13.29 | 13.38 | 9.26 | 1.44 | 4.88 | 2.74 | 5.17 | 2.59 | 4.95 | 2.70 |
| Mattock et al. (1976) | N1 | 28.82 | 32258.0 | 141.94 | 0.004 | 351.0 | 1.54 | 3.17 | 4.43 | 0.72 | 2.37 | 1.34 | 2.90 | 1.10 | 1.62 | 1.96 |
| | N2 | 26.89 | 32258.0 | 283.87 | 0.009 | 363.4 | 3.20 | 5.38 | 6.05 | 0.89 | 4.11 | 1.31 | 4.17 | 1.29 | 3.36 | 1.60 |
| | N3 | 27.55 | 32258.0 | 425.81 | 0.013 | 360.6 | 4.76 | 6.62 | 6.20 | 1.07 | 4.88 | 1.36 | 5.08 | 1.30 | 4.13 | 1.60 |
| | N4 | 28.61 | 32258.0 | 567.74 | 0.018 | 351.0 | 6.18 | 7.93 | 6.44 | 1.23 | 4.88 | 1.63 | 5.17 | 1.53 | 4.20 | 1.89 |
| | N5 | 27.13 | 32258.0 | 709.68 | 0.022 | 351.0 | 7.72 | 8.10 | 6.10 | 1.33 | 4.88 | 1.66 | 5.17 | 1.57 | 4.07 | 1.99 |

**Table 2.** *Cont.*

| Researcher(s) | Specimen | $f_c'$ (MPa) | $A_{cv}$ (mm$^2$) | $A_{vf}$ (mm$^2$) | $\rho$ | $f_y$ (MPa) | $\rho f_y$ (MPa) | $v_{test}$ (MPa) | AASHTO LRFD | | CSA-S6 | | PCI | | ACI 318-19 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ |
| Mattock et al. (1976) | N6 | 28.41 | 32258.0 | 851.61 | 0.026 | 344.8 | 9.10 | 8.21 | 6.39 | 1.28 | 4.88 | 1.68 | 5.17 | 1.59 | 4.19 | 1.96 |
| Kahn and Mitchell (2002) | SF-4-1-C | 46.92 | 38709.6 | 141.94 | 0.004 | 479.2 | 1.52 | 4.02 | 4.39 | 0.91 | 2.34 | 1.72 | 2.87 | 1.40 | 1.59 | 2.52 |
| | SF-4-2-C | 46.92 | 38709.6 | 283.87 | 0.007 | 479.2 | 3.03 | 6.40 | 6.30 | 1.01 | 3.94 | 1.63 | 4.06 | 1.58 | 3.19 | 2.01 |
| | SF-4-3-C | 46.92 | 38709.6 | 425.81 | 0.011 | 479.2 | 4.55 | 8.18 | 8.22 | 1.00 | 4.88 | 1.68 | 4.97 | 1.65 | 4.78 | 1.71 |
| | SF-7-1-C | 80.91 | 38709.6 | 141.94 | 0.004 | 572.3 | 1.52 | 4.79 | 4.39 | 1.09 | 2.34 | 2.05 | 2.87 | 1.67 | 1.59 | 3.01 |
| | SF-7-2-C | 85.57 | 38709.6 | 283.87 | 0.007 | 572.3 | 3.03 | 5.94 | 6.30 | 0.94 | 3.94 | 1.51 | 4.06 | 1.46 | 3.19 | 1.87 |
| | SF-7-3-C | 90.35 | 38709.6 | 425.81 | 0.011 | 572.3 | 4.55 | 8.22 | 8.22 | 1.00 | 4.88 | 1.69 | 4.97 | 1.65 | 4.78 | 1.72 |
| | SF-7-4-C | 85.99 | 38709.6 | 567.74 | 0.015 | 572.3 | 6.07 | 7.21 | 9.31 | 0.77 | 4.88 | 1.48 | 5.17 | 1.39 | 6.37 | 1.13 |
| | SF-10-1-C-a | 83.11 | 38709.6 | 141.94 | 0.004 | 572.3 | 1.52 | 2.96 | 4.39 | 0.67 | 2.34 | 1.27 | 2.87 | 1.03 | 1.59 | 1.86 |
| | SF-10-1-C-b | 98.78 | 38709.6 | 141.94 | 0.004 | 572.3 | 1.52 | 3.45 | 4.39 | 0.78 | 2.34 | 1.47 | 2.87 | 1.20 | 1.59 | 2.16 |
| | SF-10-2-C-a | 101.19 | 38709.6 | 283.87 | 0.007 | 572.3 | 3.03 | 5.83 | 6.30 | 0.93 | 3.94 | 1.48 | 4.06 | 1.44 | 3.19 | 1.83 |
| | SF-10-2-C-b | 102.07 | 38709.6 | 283.87 | 0.007 | 572.3 | 3.03 | 5.53 | 6.30 | 0.88 | 3.94 | 1.41 | 4.06 | 1.36 | 3.19 | 1.74 |
| | SF-10-3-C-a | 111.49 | 38709.6 | 425.81 | 0.011 | 572.3 | 4.55 | 7.43 | 8.22 | 0.90 | 4.88 | 1.52 | 4.97 | 1.50 | 4.78 | 1.56 |
| | SF-10-3-C-b | 96.01 | 38709.6 | 425.81 | 0.011 | 572.3 | 4.55 | 7.28 | 8.22 | 0.89 | 4.88 | 1.49 | 4.97 | 1.46 | 4.78 | 1.52 |
| | SF-10-4-C-a | 106.65 | 38709.6 | 567.74 | 0.015 | 572.3 | 6.07 | 8.52 | 9.31 | 0.92 | 4.88 | 1.75 | 5.17 | 1.65 | 6.37 | 1.34 |
| | SF-10-4-C-b | 113.60 | 38709.6 | 567.74 | 0.015 | 572.3 | 6.07 | 8.76 | 9.31 | 0.94 | 4.88 | 1.80 | 5.17 | 1.69 | 6.37 | 1.38 |
| | SF-14-1-C | 110.42 | 38709.6 | 141.94 | 0.004 | 572.3 | 1.52 | 2.86 | 4.39 | 0.65 | 2.34 | 1.22 | 2.87 | 1.00 | 1.59 | 1.80 |
| | SF-14-2-C | 106.84 | 38709.6 | 283.87 | 0.007 | 572.3 | 3.03 | 4.62 | 6.30 | 0.73 | 3.94 | 1.17 | 4.06 | 1.14 | 3.19 | 1.45 |
| | SF-14-3-C | 106.13 | 38709.6 | 425.81 | 0.011 | 572.3 | 4.55 | 6.38 | 8.22 | 0.78 | 4.88 | 1.31 | 4.97 | 1.28 | 4.78 | 1.33 |
| | SF-14-4-C | 110.20 | 38709.6 | 567.74 | 0.015 | 572.3 | 6.07 | 8.42 | 9.31 | 0.90 | 4.88 | 1.73 | 5.17 | 1.63 | 6.37 | 1.32 |
| Mansur et al. (2008) | AN-2 | 40.20 | 35999.9 | 314.16 | 0.009 | 530.0 | 3.61 | 8.18 | 7.03 | 1.16 | 4.54 | 1.80 | 4.43 | 1.85 | 3.79 | 2.16 |
| | AN-4 | 40.20 | 35999.9 | 628.32 | 0.017 | 530.0 | 7.21 | 10.17 | 9.05 | 1.12 | 4.88 | 2.09 | 5.17 | 1.97 | 4.89 | 2.08 |
| | AN-6 | 40.20 | 35999.9 | 942.48 | 0.026 | 530.0 | 10.83 | 12.92 | 9.05 | 1.43 | 4.88 | 2.65 | 5.17 | 2.50 | 4.89 | 2.64 |
| | AM-2 | 69.01 | 35999.9 | 314.16 | 0.009 | 530.0 | 3.61 | 7.50 | 7.03 | 1.07 | 4.54 | 1.65 | 4.43 | 1.70 | 3.79 | 1.98 |
| | AM-3 | 69.01 | 35999.9 | 471.24 | 0.013 | 530.0 | 5.41 | 11.50 | 9.30 | 1.24 | 4.88 | 2.36 | 5.17 | 2.22 | 5.68 | 2.02 |
| | AM-4 | 69.01 | 35999.9 | 628.32 | 0.017 | 530.0 | 7.21 | 14.03 | 9.31 | 1.51 | 4.88 | 2.88 | 5.17 | 2.71 | 6.62 | 2.12 |
| | AH-2 | 87.00 | 35999.9 | 314.16 | 0.009 | 530.0 | 3.61 | 7.78 | 7.03 | 1.11 | 4.54 | 1.71 | 4.43 | 1.76 | 3.79 | 2.05 |
| | AH-3 | 87.00 | 35999.9 | 471.24 | 0.013 | 530.0 | 5.41 | 12.36 | 9.30 | 1.33 | 4.88 | 2.54 | 5.17 | 2.39 | 5.68 | 2.18 |
| | AH-4 | 87.00 | 35999.9 | 628.32 | 0.017 | 530.0 | 7.21 | 14.17 | 9.31 | 1.52 | 4.88 | 2.91 | 5.17 | 2.74 | 7.57 | 1.87 |
| | B1-4 | 73.21 | 35999.9 | 402.12 | 0.011 | 300.0 | 3.35 | 6.73 | 6.70 | 1.00 | 4.27 | 1.58 | 4.27 | 1.58 | 3.52 | 1.91 |
| | B2-2 | 84.91 | 35999.9 | 201.06 | 0.006 | 300.0 | 1.68 | 5.17 | 4.59 | 1.13 | 2.51 | 2.06 | 3.02 | 1.71 | 1.76 | 2.94 |
| | B2-4 | 84.91 | 35999.9 | 402.12 | 0.011 | 300.0 | 3.35 | 7.32 | 6.70 | 1.09 | 4.27 | 1.72 | 4.27 | 1.72 | 3.52 | 2.08 |
| | B2-5 | 84.91 | 35999.9 | 502.65 | 0.014 | 300.0 | 4.19 | 8.21 | 7.76 | 1.06 | 4.88 | 1.68 | 4.77 | 1.72 | 4.40 | 1.87 |
| | B2-6 | 84.91 | 35999.9 | 603.19 | 0.017 | 300.0 | 5.03 | 9.17 | 8.82 | 1.04 | 4.88 | 1.88 | 5.17 | 1.77 | 5.29 | 1.74 |

**Table 2.** *Cont.*

| Researcher(s) | Specimen | $f_c{}'$ (MPa) | $A_{cv}$ (mm$^2$) | $A_{vf}$ (mm$^2$) | $\rho$ | $f_y$ (MPa) | $\rho f_y$ (MPa) | $v_{test}$ (MPa) | AASHTO LRFD | | CSA-S6 | | PCI | | ACI 318-19 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ |
| Mansur et al. (2008) | B3-4 | 95.21 | 35999.9 | 402.12 | 0.011 | 300.0 | 3.35 | 7.97 | 6.70 | 1.19 | 4.27 | 1.87 | 4.27 | 1.87 | 3.52 | 2.27 |
| | B4-2 | 106.40 | 35999.9 | 201.06 | 0.006 | 300.0 | 1.68 | 6.01 | 4.59 | 1.31 | 2.51 | 2.40 | 3.02 | 1.99 | 1.76 | 3.42 |
| | B4-4 | 106.40 | 35999.9 | 402.12 | 0.011 | 300.0 | 3.35 | 8.43 | 6.70 | 1.26 | 4.27 | 1.98 | 4.27 | 1.98 | 3.52 | 2.40 |
| | B4-5 | 106.40 | 35999.9 | 502.65 | 0.014 | 300.0 | 4.19 | 9.24 | 7.76 | 1.19 | 4.88 | 1.90 | 4.77 | 1.94 | 4.40 | 2.10 |
| | B4-6 | 106.40 | 35999.9 | 603.19 | 0.017 | 300.0 | 5.03 | 9.96 | 8.82 | 1.13 | 4.88 | 2.04 | 5.17 | 1.93 | 5.29 | 1.89 |
| Sneed et al. (2016) | N-MO-P-1 | 33.37 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 8.51 | 7.51 | 1.13 | 4.88 | 1.75 | 5.17 | 1.65 | 4.48 | 1.90 |
| | N-MO-P-2 | 33.37 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 7.94 | 7.51 | 1.06 | 4.88 | 1.63 | 5.17 | 1.53 | 4.48 | 1.77 |
| **Sand-lightweight concrete** | | | | | | | | | | | | | | | | |
| Mattock et al. (1976) | B1 | 25.79 | 32258.0 | 141.94 | 0.004 | 342.0 | 1.50 | 3.10 | 2.84 | 1.09 | 1.98 | 1.57 | 2.43 | 1.28 | 1.34 | 2.31 |
| | B2 | 23.17 | 32258.0 | 283.87 | 0.009 | 351.0 | 3.09 | 4.50 | 4.27 | 1.05 | 3.39 | 1.32 | 3.48 | 1.29 | 2.76 | 1.63 |
| | B3 | 26.96 | 32258.0 | 425.81 | 0.013 | 351.0 | 4.63 | 5.79 | 5.66 | 1.02 | 4.77 | 1.21 | 4.26 | 1.36 | 4.04 | 1.43 |
| | B4 | 28.27 | 32258.0 | 567.74 | 0.018 | 338.5 | 5.96 | 6.48 | 6.21 | 1.04 | 4.88 | 1.33 | 4.40 | 1.47 | 4.14 | 1.57 |
| | B5 | 27.30 | 32258.0 | 709.68 | 0.022 | 348.2 | 7.66 | 6.90 | 6.14 | 1.12 | 4.88 | 1.41 | 4.40 | 1.57 | 4.10 | 1.68 |
| | B6 | 29.30 | 32258.0 | 851.61 | 0.026 | 357.2 | 9.43 | 7.96 | 6.21 | 1.28 | 4.88 | 1.63 | 4.40 | 1.81 | 4.14 | 1.92 |
| | C1 | 16.07 | 32258.0 | 141.94 | 0.004 | 342.0 | 1.50 | 2.51 | 2.84 | 0.88 | 1.98 | 1.27 | 2.43 | 1.03 | 1.34 | 1.87 |
| | C2 | 16.07 | 32258.0 | 283.87 | 0.009 | 369.6 | 3.25 | 3.54 | 3.61 | 0.98 | 3.01 | 1.18 | 3.07 | 1.15 | 2.41 | 1.47 |
| | C3 | 13.79 | 32258.0 | 425.81 | 0.013 | 351.0 | 4.63 | 3.63 | 3.10 | 1.17 | 2.59 | 1.40 | 2.64 | 1.38 | 2.07 | 1.75 |
| | C4 | 14.13 | 32258.0 | 567.74 | 0.018 | 360.6 | 6.34 | 3.86 | 3.18 | 1.21 | 2.65 | 1.46 | 2.70 | 1.43 | 2.12 | 1.82 |
| | C5 | 16.07 | 32258.0 | 709.68 | 0.022 | 369.6 | 8.13 | 4.41 | 3.61 | 1.22 | 3.01 | 1.46 | 3.07 | 1.44 | 2.41 | 1.83 |
| | C6 | 16.07 | 32258.0 | 851.61 | 0.026 | 342.0 | 9.03 | 5.10 | 3.61 | 1.41 | 3.01 | 1.69 | 3.07 | 1.66 | 2.41 | 2.12 |
| | D1 | 41.34 | 32258.0 | 141.94 | 0.004 | 357.2 | 1.57 | 2.55 | 2.90 | 0.88 | 2.04 | 1.25 | 2.48 | 1.03 | 1.40 | 1.82 |
| | D2 | 41.34 | 32258.0 | 283.87 | 0.009 | 360.6 | 3.17 | 4.61 | 4.34 | 1.06 | 3.47 | 1.33 | 3.53 | 1.31 | 2.83 | 1.63 |
| | D3 | 39.37 | 32258.0 | 425.81 | 0.013 | 360.6 | 4.76 | 5.32 | 5.77 | 0.92 | 4.88 | 1.09 | 4.32 | 1.23 | 4.14 | 1.29 |
| | D4 | 39.37 | 32258.0 | 567.74 | 0.018 | 360.6 | 6.34 | 7.05 | 6.21 | 1.14 | 4.88 | 1.45 | 4.40 | 1.60 | 4.14 | 1.70 |
| | D5 | 38.61 | 32258.0 | 709.68 | 0.022 | 360.6 | 7.94 | 7.46 | 6.21 | 1.20 | 4.88 | 1.53 | 4.40 | 1.70 | 4.14 | 1.80 |
| | D6 | 38.61 | 32258.0 | 851.61 | 0.026 | 357.2 | 9.43 | 8.41 | 6.21 | 1.36 | 4.88 | 1.73 | 4.40 | 1.91 | 4.14 | 2.03 |
| Hoff (1993) | 1 LWC1 | 58.54 | 54193.4 | 283.87 | 0.005 | 369.6 | 1.94 | 1.98 | 3.23 | 0.61 | 2.37 | 0.84 | 2.76 | 0.72 | 1.73 | 1.14 |
| | 2 LWC1 | 58.68 | 54193.4 | 283.87 | 0.005 | 369.6 | 1.94 | 2.52 | 3.23 | 0.78 | 2.37 | 1.06 | 2.76 | 0.91 | 1.73 | 1.46 |
| | 3 LWC1 | 57.16 | 54193.4 | 283.87 | 0.005 | 369.6 | 1.94 | 2.85 | 3.23 | 0.88 | 2.37 | 1.20 | 2.76 | 1.03 | 1.73 | 1.65 |
| | 4 LWC1 | 58.54 | 54193.4 | 567.74 | 0.01 | 468.9 | 3.94 | 5.25 | 5.03 | 1.04 | 4.15 | 1.26 | 3.93 | 1.34 | 3.51 | 1.49 |
| | 5 LWC1 | 58.68 | 54193.4 | 567.74 | 0.01 | 475.8 | 3.94 | 4.69 | 5.03 | 0.93 | 4.15 | 1.13 | 3.93 | 1.19 | 3.51 | 1.33 |
| | 6 LWC1 | 57.16 | 54193.4 | 567.74 | 0.01 | 468.9 | 3.94 | 5.01 | 5.03 | 1.00 | 4.15 | 1.21 | 3.93 | 1.28 | 3.51 | 1.43 |
| | 1 LWC2 | 63.92 | 54193.4 | 283.87 | 0.005 | 369.6 | 1.94 | 3.37 | 3.23 | 1.04 | 2.37 | 1.42 | 2.76 | 1.22 | 1.73 | 1.95 |
| | 2 LWC2 | 60.40 | 54193.4 | 283.87 | 0.005 | 369.6 | 1.94 | 2.31 | 3.23 | 0.71 | 2.37 | 0.98 | 2.76 | 0.84 | 1.73 | 1.34 |

**Table 2.** *Cont.*

| Researcher(s) | Specimen | $f_c{}'$ (MPa) | $A_{cv}$ (mm$^2$) | $A_{vf}$ (mm$^2$) | $\rho$ | $f_y$ (MPa) | $\rho f_y$ (MPa) | $v_{test}$ (MPa) | AASHTO LRFD | | CSA-S6 | | PCI | | ACI 318-19 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ |
| Hoff (1993) | 3 LWC2 | 60.19 | 54193.4 | 283.87 | 0.005 | 369.6 | 1.94 | 2.06 | 3.23 | 0.64 | 2.37 | 0.87 | 2.76 | 0.75 | 1.73 | 1.19 |
| | 4 LWC2 | 63.92 | 54193.4 | 567.74 | 0.01 | 468.9 | 3.94 | 5.10 | 5.03 | 1.01 | 4.15 | 1.23 | 3.93 | 1.30 | 3.51 | 1.45 |
| | 5 LWC2 | 60.40 | 54193.4 | 567.74 | 0.01 | 472.3 | 3.94 | 4.77 | 5.03 | 0.95 | 4.15 | 1.15 | 3.93 | 1.21 | 3.51 | 1.36 |
| | 6 LWC2 | 60.19 | 54193.4 | 567.74 | 0.01 | 472.3 | 3.94 | 4.69 | 5.03 | 0.93 | 4.15 | 1.13 | 3.93 | 1.19 | 3.51 | 1.33 |
| | 1 HSLWC | 71.09 | 54193.4 | 283.87 | 0.005 | 497.1 | 2.17 | 4.61 | 3.44 | 1.34 | 2.57 | 1.79 | 2.91 | 1.58 | 1.93 | 2.38 |
| | 2 HSLWC | 75.22 | 54193.4 | 283.87 | 0.005 | 497.1 | 2.17 | 3.78 | 3.44 | 1.10 | 2.57 | 1.47 | 2.91 | 1.30 | 1.93 | 1.96 |
| | 3 HSLWC | 75.98 | 54193.4 | 283.87 | 0.005 | 497.1 | 2.17 | 4.03 | 3.44 | 1.17 | 2.57 | 1.57 | 2.91 | 1.38 | 1.93 | 2.09 |
| | 4 HSLWC | 71.09 | 54193.4 | 567.74 | 0.01 | 460.6 | 3.94 | 6.00 | 5.03 | 1.19 | 4.15 | 1.45 | 3.93 | 1.53 | 3.51 | 1.71 |
| | 5 HSLWC | 75.22 | 54193.4 | 567.74 | 0.01 | 460.6 | 3.94 | 6.00 | 5.03 | 1.19 | 4.15 | 1.45 | 3.93 | 1.53 | 3.51 | 1.71 |
| | 6 HSLWC | 75.98 | 54193.4 | 567.74 | 0.01 | 460.6 | 3.94 | 6.16 | 5.03 | 1.22 | 4.15 | 1.48 | 3.93 | 1.57 | 3.51 | 1.75 |
| Sneed et al. (2016) | S-SH-MO-P-1 | 32.89 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 7.05 | 6.21 | 1.14 | 4.88 | 1.45 | 4.40 | 1.60 | 4.14 | 1.70 |
| | S-SH-MO-P-2 | 32.89 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 7.23 | 6.21 | 1.16 | 4.88 | 1.48 | 4.40 | 1.64 | 4.14 | 1.75 |
| **All-lightweight concrete** | | | | | | | | | | | | | | | | |
| Mattock et al. (1976) | F1 | 28.61 | 32258.0 | 141.94 | 0.004 | 366.8 | 1.61 | 3.10 | 2.94 | 1.05 | 1.83 | 1.69 | 2.22 | 1.40 | 1.27 | 2.44 |
| | F2 | 27.79 | 32258.0 | 283.87 | 0.009 | 360.6 | 3.17 | 3.65 | 4.34 | 0.84 | 3.06 | 1.19 | 3.11 | 1.17 | 2.50 | 1.46 |
| | F2A | 27.37 | 32258.0 | 283.87 | 0.009 | 351.0 | 3.09 | 4.27 | 4.27 | 1.00 | 3.00 | 1.43 | 3.07 | 1.39 | 2.43 | 1.76 |
| | F3 | 28.03 | 32258.0 | 425.81 | 0.013 | 360.6 | 4.76 | 5.06 | 5.77 | 0.88 | 4.31 | 1.17 | 3.81 | 1.33 | 3.75 | 1.35 |
| | F3A | 27.37 | 32258.0 | 425.81 | 0.013 | 354.4 | 4.67 | 4.84 | 5.70 | 0.85 | 4.24 | 1.14 | 3.78 | 1.28 | 3.68 | 1.31 |
| | F4 | 27.86 | 32258.0 | 567.74 | 0.018 | 351.0 | 6.18 | 6.00 | 6.21 | 0.97 | 4.88 | 1.23 | 3.88 | 1.55 | 4.14 | 1.45 |
| | F5 | 28.37 | 32258.0 | 709.68 | 0.022 | 357.2 | 7.86 | 6.34 | 6.21 | 1.02 | 4.88 | 1.30 | 3.88 | 1.64 | 4.14 | 1.53 |
| | F6 | 27.92 | 32258.0 | 851.61 | 0.026 | 366.8 | 9.68 | 6.77 | 6.21 | 1.09 | 4.88 | 1.39 | 3.88 | 1.75 | 4.14 | 1.64 |
| | H1 | 28.58 | 32258.0 | 141.94 | 0.004 | 343.4 | 1.51 | 2.76 | 2.85 | 0.97 | 1.75 | 1.57 | 2.15 | 1.28 | 1.19 | 2.32 |
| | H2 | 26.75 | 32258.0 | 283.87 | 0.009 | 357.2 | 3.14 | 4.27 | 4.32 | 0.99 | 3.04 | 1.41 | 3.10 | 1.38 | 2.48 | 1.73 |
| | H3 | 28.27 | 32258.0 | 425.81 | 0.013 | 357.2 | 4.72 | 5.97 | 5.73 | 1.04 | 4.28 | 1.40 | 3.80 | 1.57 | 3.71 | 1.61 |
| | H4 | 30.48 | 32258.0 | 567.74 | 0.018 | 357.2 | 6.29 | 6.48 | 6.21 | 1.04 | 4.88 | 1.33 | 3.88 | 1.67 | 4.14 | 1.57 |
| | H5 | 27.24 | 32258.0 | 709.68 | 0.022 | 348.2 | 7.66 | 6.83 | 6.13 | 1.11 | 4.88 | 1.40 | 3.88 | 1.76 | 4.09 | 1.67 |
| | H6 | 28.13 | 32258.0 | 851.61 | 0.026 | 343.4 | 9.07 | 7.18 | 6.21 | 1.16 | 4.88 | 1.47 | 3.88 | 1.85 | 4.14 | 1.74 |
| Sneed et al. (2016) | A-SH-MO-P-1 | 32.41 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 6.43 | 6.21 | 1.04 | 4.80 | 1.34 | 3.88 | 1.66 | 4.14 | 1.55 |
| | A-SH-MO-P-2 | 32.41 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 7.34 | 6.21 | 1.18 | 4.80 | 1.53 | 3.88 | 1.89 | 4.14 | 1.77 |
| | | | | | | | | | Average | 1.08 | | 1.59 | | 1.54 | | 1.86 |
| | | | | | | | | | Maximum | 1.73 | | 2.91 | | 2.74 | | 3.42 |
| | | | | | | | | | Minimum | 0.61 | | 0.84 | | 0.72 | | 1.13 |
| | | | | | | | | | STD | 0.21 | | 0.40 | | 0.37 | | 0.42 |
| | | | | | | | | | COV | 19.29 | | 24.85 | | 23.74 | | 22.49 |

**Table 3.** Intentionally roughened cold joint.

| Researcher(s) | Specimen | $f_c'$ (MPa) | $A_{cv}$ (mm$^2$) | $A_{vf}$ (mm$^2$) | $\rho$ | $f_y$ (MPa) | $\rho f_y$ (MPa) | $v_{test}$ (MPa) | AASHTO LRFD | | CSA-S6 | | PCI | | ACI 318-19 | | EuroCode 2 | | CEB-FIP 2010 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ |
| **Normalweight concrete** | | | | | | | | | | | | | | | | | | | | |
| Mattock (1976) | B1 | 40.27 | 32258.0 | 141.94 | 0.004 | 353.5 | 1.56 | 3.36 | 2.89 | 1.16 | 1.54 | 2.18 | 2.46 | 1.37 | 1.17 | 2.87 | 2.43 | 1.38 | 1.70 | 1.97 |
| | B2 | 40.27 | 32258.0 | 283.87 | 0.009 | 348.5 | 3.07 | 4.83 | 4.25 | 1.14 | 2.68 | 1.80 | 3.45 | 1.40 | 2.30 | 2.10 | 3.79 | 1.27 | 2.79 | 1.73 |
| | B3 | 41.75 | 32258.0 | 425.81 | 0.013 | 353.5 | 4.67 | 7.27 | 5.69 | 1.28 | 3.88 | 1.87 | 4.25 | 1.71 | 3.50 | 2.08 | 5.25 | 1.38 | 3.86 | 1.88 |
| | B4 | 41.75 | 32258.0 | 567.74 | 0.018 | 371.1 | 6.53 | 8.80 | 7.37 | 1.19 | 4.88 | 1.80 | 5.03 | 1.75 | 4.90 | 1.80 | 6.93 | 1.27 | 5.15 | 1.71 |
| | B5 | 40.65 | 32258.0 | 800.00 | 0.025 | 339.6 | 8.70 | 10.83 | 9.15 | 1.18 | 4.88 | 2.22 | 5.17 | 2.09 | 4.92 | 2.20 | 8.51 | 1.27 | 6.58 | 1.64 |
| | B6 | 40.65 | 32258.0 | 1032.26 | 0.032 | 339.6 | 10.87 | 11.72 | 9.15 | 1.28 | 4.88 | 2.40 | 5.17 | 2.27 | 4.92 | 2.38 | 8.51 | 1.38 | 8.12 | 1.44 |
| | D1 | 25.99 | 32258.0 | 141.94 | 0.004 | 353.5 | 1.56 | 4.07 | 2.89 | 1.41 | 1.54 | 2.64 | 2.46 | 1.65 | 1.17 | 3.48 | 2.17 | 1.87 | 1.53 | 2.66 |
| | D2 | 25.99 | 32258.0 | 283.87 | 0.009 | 353.5 | 3.11 | 6.34 | 4.29 | 1.48 | 2.71 | 2.34 | 3.47 | 1.83 | 2.33 | 2.72 | 3.57 | 1.78 | 2.55 | 2.49 |
| | D3 | 20.27 | 32258.0 | 425.81 | 0.013 | 386.1 | 5.10 | 6.96 | 4.56 | 1.53 | 3.80 | 1.83 | 3.80 | 1.83 | 3.04 | 2.29 | 4.66 | 1.50 | 3.53 | 1.97 |
| | D4 | 20.27 | 32258.0 | 567.74 | 0.018 | 386.1 | 6.80 | 6.91 | 4.56 | 1.51 | 3.80 | 1.82 | 3.80 | 1.82 | 3.04 | 2.27 | 4.66 | 1.48 | 4.57 | 1.51 |
| | D4A | 17.20 | 32258.0 | 567.74 | 0.018 | 372.3 | 6.55 | 6.85 | 3.87 | 1.77 | 3.23 | 2.12 | 3.23 | 2.12 | 2.58 | 2.66 | 4.00 | 1.71 | 3.94 | 1.74 |
| | D5 | 20.37 | 32258.0 | 800.00 | 0.025 | 319.7 | 7.93 | 8.34 | 4.58 | 1.82 | 3.82 | 2.18 | 3.82 | 2.18 | 3.06 | 2.73 | 4.68 | 1.78 | 4.67 | 1.79 |
| | D5A | 19.27 | 32258.0 | 800.00 | 0.025 | 318.5 | 7.90 | 8.62 | 4.34 | 1.99 | 3.61 | 2.39 | 3.61 | 2.39 | 2.89 | 2.98 | 4.45 | 1.94 | 4.42 | 1.95 |
| | D6 | 20.37 | 32258.0 | 1032.26 | 0.032 | 334.4 | 10.70 | 10.14 | 4.58 | 2.21 | 3.82 | 2.65 | 3.82 | 2.65 | 3.06 | 3.32 | 4.68 | 2.17 | 4.67 | 2.17 |
| Kahn and Mitchell (2002) | SF-7-1-CJ | 80.91 | 38709.6 | 141.94 | 0.004 | 572.3 | 1.52 | 6.21 | 2.85 | 2.17 | 1.51 | 4.10 | 2.43 | 2.56 | 1.14 | 5.45 | 2.78 | 2.23 | 2.18 | 2.85 |
| | SF-7-2-CJ | 80.91 | 38709.6 | 283.87 | 0.007 | 572.3 | 3.03 | 9.43 | 4.22 | 2.24 | 2.65 | 3.56 | 3.43 | 2.75 | 2.28 | 4.15 | 4.15 | 2.27 | 3.32 | 2.84 |
| | SF-7-3-CJ | 85.99 | 38709.6 | 425.81 | 0.011 | 572.3 | 4.55 | 12.67 | 5.59 | 2.27 | 3.79 | 3.35 | 4.20 | 3.02 | 3.41 | 3.71 | 5.54 | 2.29 | 4.71 | 2.69 |
| | SF-7-4-CJ | 85.99 | 38709.6 | 567.74 | 0.015 | 572.3 | 6.07 | 15.24 | 6.95 | 2.19 | 4.88 | 3.13 | 4.85 | 3.14 | 4.55 | 3.35 | 6.91 | 2.21 | 6.04 | 2.52 |
| | SF-10-3-CJ | 89.31 | 38709.6 | 425.81 | 0.011 | 572.3 | 4.55 | 13.09 | 5.59 | 2.34 | 3.79 | 3.46 | 4.20 | 3.12 | 3.41 | 3.84 | 5.56 | 2.35 | 4.76 | 2.75 |
| | SF-10-4-CJ | 89.31 | 38709.6 | 567.74 | 0.015 | 572.3 | 6.07 | 14.49 | 6.95 | 2.08 | 4.88 | 2.97 | 4.85 | 2.99 | 4.55 | 3.18 | 6.93 | 2.09 | 6.11 | 2.37 |
| | SF-14-1-CJ | 101.74 | 38709.6 | 141.94 | 0.004 | 572.3 | 1.52 | 10.45 | 2.85 | 3.66 | 1.51 | 6.91 | 2.43 | 4.31 | 1.14 | 9.18 | 2.90 | 3.60 | 2.33 | 4.48 |
| | SF-14-2-CJ | 101.74 | 38709.6 | 283.87 | 0.007 | 572.3 | 3.03 | 11.40 | 4.22 | 2.70 | 2.65 | 4.30 | 3.43 | 3.32 | 2.28 | 5.01 | 4.27 | 2.67 | 3.53 | 3.22 |
| | SF-14-3-CJ | 104.93 | 38709.6 | 425.81 | 0.011 | 572.3 | 4.55 | 15.48 | 5.59 | 2.77 | 3.79 | 4.09 | 4.20 | 3.68 | 3.41 | 4.54 | 5.65 | 2.74 | 4.98 | 3.11 |
| | SF-14-4-CJ | 104.93 | 38709.6 | 567.74 | 0.015 | 572.3 | 6.07 | 17.60 | 6.95 | 2.53 | 4.88 | 3.61 | 4.85 | 3.63 | 4.55 | 3.87 | 7.01 | 2.51 | 6.39 | 2.75 |
| Scott (2010) | NN-3-A | 42.40 | 247741.4 | 1200.00 | 0.005 | 413.7 | 2.00 | 3.50 | 3.33 | 1.05 | 1.92 | 1.83 | 2.79 | 1.26 | 1.50 | 2.33 | 2.91 | 1.20 | 2.07 | 1.69 |
| | NN-3-B | 42.40 | 247741.4 | 1200.00 | 0.005 | 413.7 | 2.00 | 3.91 | 3.33 | 1.17 | 1.92 | 2.04 | 2.79 | 1.40 | 1.50 | 2.60 | 2.91 | 1.34 | 2.07 | 1.89 |
| | NN-3-C | 42.40 | 247741.4 | 1200.00 | 0.005 | 413.7 | 2.00 | 4.11 | 3.33 | 1.23 | 1.92 | 2.15 | 2.79 | 1.47 | 1.50 | 2.74 | 2.91 | 1.41 | 2.07 | 1.99 |
| Harries et al. (2012) | 615-3A | 39.99 | 103225.6 | 425.81 | 0.004 | 464.0 | 1.65 | 4.83 | 2.98 | 1.62 | 1.62 | 2.99 | 2.53 | 1.91 | 1.24 | 3.89 | 2.51 | 1.92 | 1.79 | 2.69 |
| | 615-3B | 39.99 | 103225.6 | 425.81 | 0.004 | 464.0 | 1.65 | 4.07 | 2.98 | 1.37 | 1.62 | 2.52 | 2.53 | 1.61 | 1.24 | 3.28 | 2.51 | 1.62 | 1.79 | 2.27 |
| | 615-4A | 39.99 | 103225.6 | 722.58 | 0.007 | 424.0 | 2.90 | 4.79 | 4.10 | 1.17 | 2.55 | 1.88 | 3.35 | 1.43 | 2.17 | 2.20 | 3.63 | 1.32 | 2.59 | 1.85 |
| | 615-4B | 39.99 | 103225.6 | 722.58 | 0.007 | 424.0 | 2.90 | 5.47 | 4.10 | 1.34 | 2.55 | 2.15 | 3.35 | 1.63 | 2.17 | 2.52 | 3.63 | 1.51 | 2.59 | 2.11 |
| | 1035-3A | 39.99 | 103225.6 | 425.81 | 0.004 | 896.4 | 1.65 | 3.94 | 2.98 | 1.32 | 1.62 | 2.44 | 2.53 | 1.55 | 1.24 | 3.17 | 2.51 | 1.57 | 1.97 | 2.00 |
| | 1035-3B | 39.99 | 103225.6 | 425.81 | 0.004 | 868.8 | 1.65 | 4.50 | 2.98 | 1.51 | 1.62 | 2.79 | 2.53 | 1.78 | 1.24 | 3.63 | 2.51 | 1.79 | 1.96 | 2.30 |
| | 1035-4A | 39.99 | 103225.6 | 722.58 | 0.007 | 965.3 | 2.90 | 5.76 | 4.10 | 1.41 | 2.55 | 2.26 | 3.35 | 1.72 | 2.17 | 2.65 | 3.63 | 1.59 | 2.97 | 1.94 |
| | 1035-4B | 39.99 | 103225.6 | 722.58 | 0.007 | 905.3 | 2.90 | 4.87 | 4.10 | 1.19 | 2.55 | 1.91 | 3.35 | 1.45 | 2.17 | 2.24 | 3.63 | 1.34 | 2.94 | 1.66 |
| Shaw and Sneed (2014) | N-5-R-4 | 33.51 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 8.23 | 6.33 | 1.30 | 4.41 | 1.87 | 4.57 | 1.80 | 4.03 | 2.04 | 5.75 | 1.43 | 4.12 | 2.00 |
| | N-5-R-5 | 33.51 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 7.44 | 6.33 | 1.18 | 4.41 | 1.69 | 4.57 | 1.63 | 4.03 | 1.84 | 5.75 | 1.29 | 4.12 | 1.81 |
| | N-5-R-6 | 33.51 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 7.45 | 6.33 | 1.18 | 4.41 | 1.69 | 4.57 | 1.63 | 4.03 | 1.85 | 5.75 | 1.30 | 4.12 | 1.81 |
| | N-8-R-1 | 52.06 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 10.31 | 6.33 | 1.63 | 4.41 | 2.34 | 4.57 | 2.26 | 4.03 | 2.56 | 6.04 | 1.71 | 4.54 | 2.27 |
| | N-8-R-2 | 52.06 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 7.81 | 6.33 | 1.23 | 4.41 | 1.77 | 4.57 | 1.71 | 4.03 | 1.94 | 6.04 | 1.29 | 4.54 | 1.72 |
| | N-8-R-3 | 52.06 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 8.94 | 6.33 | 1.41 | 4.41 | 2.03 | 4.57 | 1.96 | 4.03 | 2.22 | 6.04 | 1.48 | 4.54 | 1.97 |
| Barbosa et al. (2017) | 4G60 | 28.2 | 247660 | 1032.00 | 0.0042 | 473 | 1.72 | 4.72 | 3.04 | 1.55 | 1.67 | 2.83 | 2.59 | 1.82 | 1.29 | 3.65 | 2.36 | 2.00 | 1.69 | 2.79 |
| | 4G80 | 28.2 | 247660 | 1032.00 | 0.0042 | 591 | 1.72 | 4.71 | 3.04 | 1.55 | 1.67 | 2.82 | 2.59 | 1.82 | 1.29 | 3.64 | 2.36 | 1.99 | 1.74 | 2.71 |
| | 5G60 | 28.2 | 186050 | 1200.00 | 0.0064 | 443 | 2.67 | 6.59 | 3.89 | 1.69 | 2.38 | 2.77 | 3.22 | 2.05 | 2.00 | 3.29 | 3.21 | 2.05 | 2.27 | 2.90 |
| | 5G80 | 28.2 | 186050 | 1200.00 | 0.0064 | 589 | 2.67 | 7.17 | 3.89 | 1.84 | 2.38 | 3.02 | 3.22 | 2.23 | 2.00 | 3.58 | 3.21 | 2.23 | 2.36 | 3.04 |

**Table 3.** *Cont.*

| Researcher(s) | Specimen | $f_c'$ (MPa) | $A_{cv}$ (mm$^2$) | $A_{vf}$ (mm$^2$) | $\rho$ | $f_y$ (MPa) | $\rho f_y$ (MPa) | $v_{test}$ (MPa) | AASHTO LRFD | | CSA-S6 | | PCI | | ACI 318-19 | | EuroCode 2 | | CEB-FIP 2010 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ |
| **Sand-lightweight concrete** | | | | | | | | | | | | | | | | | | | | |
| Scott (2010) | LL-3-A | 39.51 | 247741.4 | 1200.00 | 0.005 | 413.7 | 2.00 | 3.61 | 3.33 | 1.08 | 1.63 | 2.22 | 2.37 | 1.52 | 1.28 | 2.83 | 2.71 | 1.33 | 1.99 | 1.81 |
| | LL-3-B | 39.51 | 247741.4 | 1200.00 | 0.005 | 413.7 | 2.00 | 4.00 | 3.33 | 1.20 | 1.63 | 2.46 | 2.37 | 1.69 | 1.28 | 3.13 | 2.71 | 1.48 | 1.99 | 2.01 |
| | LL-3-C | 39.51 | 247741.4 | 1200.00 | 0.005 | 413.7 | 2.00 | 4.13 | 3.33 | 1.24 | 1.63 | 2.54 | 2.37 | 1.74 | 1.28 | 3.23 | 2.71 | 1.52 | 1.99 | 2.07 |
| | NL-3-A | 39.51 | 247741.4 | 1200.00 | 0.005 | 413.7 | 2.00 | 4.35 | 3.33 | 1.30 | 1.63 | 2.67 | 2.37 | 1.83 | 1.28 | 3.40 | 2.71 | 1.60 | 1.99 | 2.18 |
| | NL-3-B | 39.51 | 247741.4 | 1200.00 | 0.005 | 413.7 | 2.00 | 4.27 | 3.33 | 1.28 | 1.63 | 2.62 | 2.37 | 1.80 | 1.28 | 3.35 | 2.71 | 1.58 | 1.99 | 2.15 |
| | NL-3-C | 39.51 | 247741.4 | 1200.00 | 0.005 | 413.7 | 2.00 | 3.34 | 3.33 | 1.00 | 1.63 | 2.05 | 2.37 | 1.41 | 1.28 | 2.61 | 2.71 | 1.23 | 1.99 | 1.67 |
| Shaw and Sneed (2014) | S-5-R-1 | 31.58 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 7.16 | 6.21 | 1.15 | 3.75 | 1.91 | 3.88 | 1.85 | 3.43 | 2.09 | 5.58 | 1.28 | 3.97 | 1.81 |
| | S-5-R-2 | 31.58 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 7.02 | 6.21 | 1.13 | 3.75 | 1.87 | 3.88 | 1.81 | 3.43 | 2.05 | 5.58 | 1.26 | 3.97 | 1.77 |
| | S-5-R-3 | 31.58 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 8.90 | 6.21 | 1.43 | 3.75 | 2.38 | 3.88 | 2.29 | 3.43 | 2.60 | 5.58 | 1.59 | 3.97 | 2.24 |
| | S-8-R-1 | 49.64 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 10.03 | 6.21 | 1.62 | 3.75 | 2.68 | 3.88 | 2.58 | 3.43 | 2.93 | 5.84 | 1.72 | 4.37 | 2.30 |
| | S-8-R-2 | 49.64 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 9.38 | 6.21 | 1.51 | 3.75 | 2.50 | 3.88 | 2.42 | 3.43 | 2.74 | 5.84 | 1.61 | 4.37 | 2.15 |
| | S-8-R-3 | 49.64 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 9.29 | 6.21 | 1.50 | 3.75 | 2.48 | 3.88 | 2.39 | 3.43 | 2.71 | 5.84 | 1.59 | 4.37 | 2.13 |
| Sneed et al. (2016) | S-SL-CJ-09-R-1 | 37.10 | 31935.4 | 283.87 | 0.009 | 497.8 | 3.72 | 6.87 | 4.84 | 1.42 | 2.69 | 2.55 | 3.23 | 2.13 | 2.37 | 2.90 | 4.18 | 1.65 | 3.08 | 2.23 |
| | S-SL-CJ-09-R-2 | 37.10 | 31935.4 | 283.87 | 0.009 | 497.8 | 3.72 | 7.03 | 4.84 | 1.45 | 2.69 | 2.61 | 3.23 | 2.18 | 2.37 | 2.96 | 4.18 | 1.68 | 3.08 | 2.28 |
| | S-SL-CJ-13-R-1 | 38.41 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 8.80 | 6.21 | 1.42 | 3.75 | 2.35 | 3.88 | 2.27 | 3.43 | 2.57 | 5.69 | 1.55 | 4.19 | 2.10 |
| | S-SL-CJ-13-R-2 | 38.41 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 8.27 | 6.21 | 1.33 | 3.75 | 2.21 | 3.88 | 2.13 | 3.43 | 2.41 | 5.69 | 1.45 | 4.19 | 1.97 |
| | S-SL-CJ-17-R-1 | 34.13 | 31935.4 | 567.74 | 0.017 | 497.8 | 7.03 | 8.69 | 6.21 | 1.40 | 4.80 | 1.81 | 4.40 | 1.98 | 4.14 | 2.10 | 6.26 | 1.39 | 5.14 | 1.69 |
| | S-SL-CJ-17-R-2 | 34.13 | 31935.4 | 567.74 | 0.017 | 497.8 | 7.03 | 9.07 | 6.21 | 1.46 | 4.80 | 1.89 | 4.40 | 2.06 | 4.14 | 2.19 | 6.26 | 1.45 | 5.14 | 1.77 |
| | S-SL-CJ-22-R-1 | 34.48 | 31935.4 | 709.68 | 0.022 | 497.8 | 9.10 | 8.98 | 6.21 | 1.45 | 4.88 | 1.84 | 4.40 | 2.04 | 4.14 | 2.17 | 6.32 | 1.42 | 6.41 | 1.40 |
| | S-SL-CJ-22-R-2 | 34.48 | 31935.4 | 709.68 | 0.022 | 497.8 | 9.10 | 8.02 | 6.21 | 1.29 | 4.88 | 1.64 | 4.40 | 1.82 | 4.14 | 1.94 | 6.32 | 1.27 | 6.41 | 1.25 |
| | S-CL-CJ-9-R-1 | 32.89 | 31935.4 | 283.87 | 0.009 | 497.8 | 3.72 | 5.16 | 4.84 | 1.07 | 2.69 | 1.92 | 3.23 | 1.60 | 2.37 | 2.18 | 4.11 | 1.26 | 3.00 | 1.72 |
| | S-CL-CJ-9-R-2 | 32.89 | 31935.4 | 283.87 | 0.009 | 497.8 | 3.72 | 5.98 | 4.84 | 1.23 | 2.69 | 2.22 | 3.23 | 1.85 | 2.37 | 2.52 | 4.11 | 1.45 | 3.00 | 1.99 |
| | S-CL-CJ-13-R-1 | 31.99 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 7.07 | 6.21 | 1.14 | 3.75 | 1.89 | 3.88 | 1.82 | 3.43 | 2.06 | 5.59 | 1.27 | 4.03 | 1.76 |
| | S-CL-CJ-13-R-2 | 31.99 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 6.53 | 6.21 | 1.05 | 3.75 | 1.74 | 3.88 | 1.68 | 3.43 | 1.90 | 5.59 | 1.17 | 4.03 | 1.62 |
| **All-lightweight concrete** | | | | | | | | | | | | | | | | | | | | |
| Shaw and Sneed (2014) | A-5-R-1 | 41.92 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 6.75 | 6.21 | 1.09 | 3.31 | 2.04 | 3.43 | 1.97 | 3.03 | 2.23 | 5.74 | 1.18 | 4.21 | 1.60 |
| | A-5-R-2 | 41.92 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 7.36 | 6.21 | 1.19 | 3.31 | 2.23 | 3.43 | 2.15 | 3.03 | 2.43 | 5.74 | 1.28 | 4.21 | 1.75 |
| | A-5-R-3 | 41.92 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 7.16 | 6.21 | 1.15 | 3.31 | 2.17 | 3.43 | 2.09 | 3.03 | 2.37 | 5.74 | 1.25 | 4.21 | 1.70 |
| | A-8-R-1 | 54.08 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 8.60 | 6.21 | 1.39 | 3.31 | 2.60 | 3.43 | 2.51 | 3.03 | 2.84 | 5.88 | 1.46 | 4.45 | 1.93 |
| | A-8-R-2 | 54.08 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 8.91 | 6.21 | 1.44 | 3.31 | 2.69 | 3.43 | 2.60 | 3.03 | 2.94 | 5.88 | 1.52 | 4.45 | 2.00 |
| | A-8-R-3 | 54.08 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 8.93 | 6.21 | 1.44 | 3.31 | 2.70 | 3.43 | 2.61 | 3.03 | 2.95 | 5.88 | 1.52 | 4.45 | 2.00 |
| Sneed et al. (2016) | A-SL-CJ-13-R-1 | 30.20 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 6.47 | 6.21 | 1.04 | 3.31 | 1.96 | 3.43 | 1.89 | 3.03 | 2.14 | 5.56 | 1.16 | 3.98 | 1.63 |
| | A-SL-CJ-13-R-2 | 30.20 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 6.53 | 6.21 | 1.05 | 3.31 | 1.97 | 3.43 | 1.91 | 3.03 | 2.16 | 5.56 | 1.17 | 3.98 | 1.64 |
| | A-CL-CJ-13-R-1 | 30.75 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 6.20 | 6.21 | 1.00 | 3.31 | 1.88 | 3.43 | 1.81 | 3.03 | 2.05 | 5.57 | 1.11 | 4.00 | 1.55 |
| | A-CL-CJ-13-R-2 | 30.75 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 6.28 | 6.21 | 1.01 | 3.31 | 1.90 | 3.43 | 1.83 | 3.03 | 2.08 | 5.57 | 1.13 | 4.00 | 1.57 |
| | | | | | | | | | Average | 1.49 | | 2.44 | | 2.08 | | 2.86 | | 1.62 | | 2.09 |
| | | | | | | | | | Maximum | 3.66 | | 6.91 | | 4.31 | | 9.18 | | 3.60 | | 4.48 |
| | | | | | | | | | Minimum | 1.00 | | 1.64 | | 1.26 | | 1.80 | | 1.11 | | 1.25 |
| | | | | | | | | | STD | 0.47 | | 0.77 | | 0.57 | | 1.03 | | 0.44 | | 0.51 |
| | | | | | | | | | COV | 31.75 | | 31.60 | | 27.60 | | 35.99 | | 27.08 | | 24.49 |

**Table 4.** Cold joint that is not roughened.

| Researcher(s) | Specimen | $f_c{}'$ (MPa) | $A_{cv}$ (mm$^2$) | $A_{vf}$ (mm$^2$) | $\rho$ | $f_y$ (MPa) | $\rho f_y$ (MPa) | $v_{test}$ (MPa) | AASHTO LRFD | | CSA-S6 | | PCI | | ACI 318-19 | | EuroCode 2 | | CEB-FIP 2010 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ |
| **Normalweight concrete** | | | | | | | | | | | | | | | | | | | | |
| Mattock (1976) | C1 | 40.47 | 32258.0 | 141.94 | 0.004 | 351.0 | 1.54 | 1.45 | 1.30 | 1.11 | 0.88 | 1.64 | 0.70 | 2.08 | 0.70 | 2.08 | 1.34 | 1.08 | 0.94 | 1.54 |
| | C2 | 40.47 | 32258.0 | 283.87 | 0.009 | 351.0 | 3.09 | 2.48 | 2.13 | 1.16 | 1.58 | 1.57 | 1.39 | 1.79 | 1.39 | 1.79 | 2.27 | 1.10 | 2.00 | 1.24 |
| | C3 | 41.23 | 32258.0 | 425.81 | 0.013 | 348.5 | 4.60 | 2.95 | 2.95 | 1.00 | 2.26 | 1.31 | 2.07 | 1.43 | 2.07 | 1.43 | 3.18 | 0.93 | 2.94 | 1.00 |
| | C4 | 41.23 | 32258.0 | 567.74 | 0.018 | 356.1 | 6.27 | 4.14 | 3.85 | 1.07 | 3.01 | 1.38 | 2.82 | 1.47 | 2.82 | 1.47 | 4.18 | 0.99 | 4.07 | 1.02 |
| | C5 | 42.51 | 32258.0 | 709.68 | 0.022 | 363.6 | 8.00 | 5.38 | 4.78 | 1.12 | 3.79 | 1.42 | 3.60 | 1.49 | 3.60 | 1.49 | 5.23 | 1.03 | 5.15 | 1.05 |
| | C6 | 42.51 | 32258.0 | 1032.26 | 0.032 | 312.0 | 9.98 | 6.08 | 4.96 | 1.23 | 4.68 | 1.30 | 4.14 | 1.47 | 4.14 | 1.47 | 6.42 | 0.95 | 6.70 | 0.91 |
| | G1 | 40.47 | 32258.0 | 141.94 | 0.004 | 351.0 | 1.54 | 1.10 | 1.30 | 0.85 | 0.88 | 1.25 | 0.70 | 1.59 | 0.70 | 1.59 | 1.34 | 0.82 | 0.94 | 1.17 |
| | G2 | 40.47 | 32258.0 | 283.87 | 0.009 | 351.0 | 3.36 | 1.82 | 2.28 | 0.80 | 1.70 | 1.07 | 1.51 | 1.20 | 1.51 | 1.20 | 2.43 | 0.75 | 2.09 | 0.87 |
| | G3 | 41.23 | 32258.0 | 425.81 | 0.013 | 348.5 | 5.05 | 2.65 | 3.19 | 0.83 | 2.46 | 1.08 | 2.27 | 1.17 | 2.27 | 1.17 | 3.45 | 0.77 | 3.08 | 0.86 |
| | G4 | 41.23 | 32258.0 | 567.74 | 0.018 | 356.1 | 6.51 | 3.45 | 3.98 | 0.87 | 3.12 | 1.11 | 2.93 | 1.18 | 2.93 | 1.18 | 4.32 | 0.80 | 4.14 | 0.83 |
| | G5 | 42.51 | 32258.0 | 800.00 | 0.022 | 363.6 | 8.38 | 4.04 | 4.96 | 0.81 | 3.96 | 1.02 | 3.77 | 1.07 | 3.77 | 1.07 | 5.46 | 0.74 | 5.26 | 0.77 |
| | G6 | 42.51 | 32258.0 | 1032.26 | 0.032 | 312.0 | 10.33 | 5.36 | 4.96 | 1.08 | 4.84 | 1.11 | 4.14 | 1.30 | 4.14 | 1.30 | 6.62 | 0.81 | 6.80 | 0.79 |
| | H1 | 40.16 | 32258.0 | 141.94 | 0.004 | 382.3 | 1.45 | 1.30 | 1.25 | 1.04 | 0.84 | 1.54 | 0.65 | 1.99 | 0.65 | 1.99 | 1.28 | 1.01 | 0.93 | 1.39 |
| | H2 | 41.92 | 32258.0 | 283.87 | 0.009 | 382.3 | 3.31 | 2.22 | 2.25 | 0.99 | 1.68 | 1.32 | 1.49 | 1.49 | 1.49 | 1.49 | 2.41 | 0.92 | 2.14 | 1.04 |
| | H3 | 41.92 | 32258.0 | 425.81 | 0.013 | 382.3 | 4.96 | 3.17 | 3.15 | 1.01 | 2.42 | 1.31 | 2.23 | 1.42 | 2.23 | 1.42 | 3.40 | 0.93 | 3.14 | 1.01 |
| | H4 | 41.89 | 32258.0 | 567.74 | 0.018 | 369.8 | 6.62 | 3.52 | 4.04 | 0.87 | 3.17 | 1.11 | 2.98 | 1.18 | 2.98 | 1.18 | 4.39 | 0.80 | 4.24 | 0.83 |
| | H5 | 42.61 | 32258.0 | 800.00 | 0.025 | 322.7 | 7.98 | 4.51 | 4.77 | 0.94 | 3.78 | 1.19 | 3.59 | 1.26 | 3.59 | 1.26 | 5.21 | 0.86 | 5.34 | 0.84 |
| | H6 | 40.68 | 32258.0 | 1032.26 | 0.032 | 322.7 | 10.26 | 5.24 | 4.96 | 1.06 | 4.80 | 1.09 | 4.14 | 1.27 | 4.14 | 1.27 | 6.57 | 0.80 | 6.74 | 0.78 |
| Kahn and Mitchell (2002) | SF-10-1-CJ† | 98.78 | 38709.6 | 141.94 | 0.004 | 572.3 | 1.52 | 3.65 | 1.28 | 2.84 | 0.87 | 4.19 | 0.68 | 5.34 | 0.68 | 5.34 | 1.52 | 2.40 | 1.41 | 2.59 |
| | SF-10-2-CJ† | 83.11 | 38709.6 | 283.87 | 0.007 | 572.3 | 3.03 | 5.67 | 2.10 | 2.69 | 1.55 | 3.65 | 1.37 | 4.15 | 1.37 | 4.15 | 2.39 | 2.37 | 2.44 | 2.32 |
| Shaw and Sneed (2014) | N-5-S-4 | 33.51 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 4.30 | 3.37 | 1.27 | 2.61 | 1.65 | 2.42 | 1.77 | 2.42 | 1.77 | 3.59 | 1.20 | 3.23 | 1.33 |
| | N-5-S-5 | 33.51 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 4.83 | 3.37 | 1.43 | 2.61 | 1.85 | 2.42 | 2.00 | 2.42 | 2.00 | 3.59 | 1.35 | 3.23 | 1.50 |
| | N-5-S-6 | 33.51 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 5.45 | 3.37 | 1.62 | 2.61 | 2.09 | 2.42 | 2.25 | 2.42 | 2.25 | 3.59 | 1.52 | 3.23 | 1.69 |
| | N-8-S-1 | 52.06 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 9.13 | 3.37 | 2.71 | 2.61 | 3.50 | 2.42 | 3.77 | 2.42 | 3.77 | 3.71 | 2.46 | 3.63 | 2.52 |
| | N-8-S-2 | 52.06 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 7.43 | 3.37 | 2.20 | 2.61 | 2.85 | 2.42 | 3.07 | 2.42 | 3.07 | 3.71 | 2.00 | 3.63 | 2.05 |
| | N-8-S-3 | 52.06 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 7.71 | 3.37 | 2.29 | 2.61 | 2.96 | 2.42 | 3.19 | 2.42 | 3.19 | 3.71 | 2.08 | 3.63 | 2.13 |
| **Sand-lightweight concrete** | | | | | | | | | | | | | | | | | | | | |
| Shaw and Sneed (2014) | S-5-S-1 | 31.58 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 5.36 | 3.37 | 1.59 | 2.22 | 2.42 | 2.06 | 2.61 | 2.06 | 2.61 | 3.52 | 1.52 | 3.06 | 1.75 |
| | S-5-S-2 | 31.58 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 4.75 | 3.37 | 1.41 | 2.22 | 2.14 | 2.06 | 2.31 | 2.06 | 2.31 | 3.52 | 1.35 | 3.06 | 1.55 |
| | S-5-S-3 | 31.58 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 5.54 | 3.37 | 1.65 | 2.22 | 2.50 | 2.06 | 2.69 | 2.06 | 2.69 | 3.52 | 1.57 | 3.06 | 1.81 |
| | S-8-S-1 | 49.64 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 9.34 | 3.37 | 2.77 | 2.22 | 4.21 | 2.06 | 4.54 | 2.06 | 4.54 | 3.63 | 2.57 | 3.43 | 2.73 |
| | S-8-S-2 | 49.64 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 8.06 | 3.37 | 2.39 | 2.22 | 3.64 | 2.06 | 3.92 | 2.06 | 3.92 | 3.63 | 2.22 | 3.43 | 2.35 |
| | S-8-S-3 | 49.64 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 8.20 | 3.37 | 2.43 | 2.22 | 3.70 | 2.06 | 3.99 | 2.06 | 3.99 | 3.63 | 2.26 | 3.43 | 2.39 |
| Sneed et al. (2016) | S-SL-CJ-09-S-1 | 37.10 | 31935.4 | 283.87 | 0.009 | 497.8 | 3.72 | 3.75 | 2.48 | 1.51 | 1.58 | 2.37 | 1.42 | 2.63 | 1.42 | 2.63 | 2.56 | 1.46 | 2.25 | 1.67 |
| | S-SL-CJ-09-S-2 | 37.10 | 31935.4 | 283.87 | 0.009 | 497.8 | 3.72 | 4.54 | 2.48 | 1.83 | 1.58 | 2.87 | 1.42 | 3.19 | 1.42 | 3.19 | 2.56 | 1.77 | 2.25 | 2.02 |
| | S-SL-CJ-13-S-1 | 38.41 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 5.50 | 3.37 | 1.63 | 2.22 | 2.48 | 2.06 | 2.67 | 2.06 | 2.67 | 3.57 | 1.54 | 3.28 | 1.68 |
| | S-SL-CJ-13-S-2 | 38.41 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 6.79 | 3.37 | 2.02 | 2.22 | 3.06 | 2.06 | 3.30 | 2.06 | 3.30 | 3.57 | 1.90 | 3.28 | 2.07 |
| | S-SL-CJ-17-S-1 | 34.13 | 31935.4 | 567.74 | 0.017 | 497.8 | 7.03 | 6.94 | 4.26 | 1.63 | 2.85 | 2.43 | 2.69 | 2.58 | 2.69 | 2.58 | 4.53 | 1.53 | 4.16 | 1.67 |
| | S-SL-CJ-17-S-2 | 34.13 | 31935.4 | 567.74 | 0.017 | 497.8 | 7.03 | 7.87 | 4.26 | 1.85 | 2.85 | 2.76 | 2.69 | 2.93 | 2.69 | 2.93 | 4.53 | 1.74 | 4.16 | 1.89 |
| | S-SL-CJ-22-S-1 | 34.48 | 31935.4 | 709.68 | 0.022 | 497.8 | 9.10 | 6.94 | 4.96 | 1.40 | 3.64 | 1.91 | 3.48 | 1.99 | 3.48 | 1.99 | 5.78 | 1.20 | 5.13 | 1.35 |
| | S-SL-CJ-22-S-2 | 34.48 | 31935.4 | 709.68 | 0.022 | 497.8 | 9.10 | 7.87 | 4.96 | 1.59 | 3.64 | 2.16 | 3.48 | 2.26 | 3.48 | 2.26 | 5.78 | 1.36 | 5.13 | 1.54 |
| | S-CL-CJ-9-S-1 | 32.89 | 31935.4 | 283.87 | 0.009 | 497.8 | 3.72 | 4.44 | 2.48 | 1.79 | 1.58 | 2.80 | 1.42 | 3.12 | 1.42 | 3.12 | 2.54 | 1.75 | 2.18 | 2.03 |
| | S-CL-CJ-9-S-2 | 32.89 | 31935.4 | 283.87 | 0.009 | 497.8 | 3.72 | 5.28 | 2.48 | 2.13 | 1.58 | 3.34 | 1.42 | 3.71 | 1.42 | 3.71 | 2.54 | 2.08 | 2.18 | 2.42 |
| | S-CL-CJ-13-S-1 | 31.99 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 5.71 | 3.37 | 1.69 | 2.22 | 2.58 | 2.06 | 2.78 | 2.06 | 2.78 | 3.53 | 1.62 | 3.13 | 1.82 |
| | S-CL-CJ-13-S-2 | 31.99 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 5.63 | 3.37 | 1.67 | 2.22 | 2.54 | 2.06 | 2.74 | 2.06 | 2.74 | 3.53 | 1.60 | 3.13 | 1.80 |
| | S-CL-CJ-17-S-1 | 31.37 | 31935.4 | 567.74 | 0.017 | 497.8 | 7.03 | 6.01 | 4.26 | 1.41 | 2.85 | 2.11 | 2.69 | 2.23 | 2.69 | 2.23 | 4.52 | 1.33 | 4.08 | 1.47 |
| | S-CL-CJ-17-S-2 | 31.37 | 31935.4 | 567.74 | 0.017 | 497.8 | 7.03 | 6.81 | 4.26 | 1.60 | 2.85 | 2.39 | 2.69 | 2.53 | 2.69 | 2.53 | 4.52 | 1.51 | 4.08 | 1.67 |

**Table 4.** *Cont.*

| Researcher(s) | Specimen | $f_c{}'$ (MPa) | $A_{cv}$ (mm$^2$) | $A_{vf}$ (mm$^2$) | $\rho$ | $f_y$ (MPa) | $\rho f_y$ (MPa) | $v_{test}$ (MPa) | AASHTO LRFD | | CSA-S6 | | PCI | | ACI 318-19 | | EuroCode 2 | | CEB-FIP 2010 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ | $v_{cal}$ (MPa) | $v_{test}/v_{cal}$ |
| **All-lightweight concrete** | | | | | | | | | | | | | | | | | | | | |
| Shaw and Sneed (2014) | A-5-S-1 | 41.92 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 5.78 | 3.37 | 1.71 | 1.96 | 2.95 | 1.82 | 3.18 | 1.82 | 3.18 | 3.59 | 1.61 | 3.28 | 1.76 |
| | A-5-S-2 | 41.92 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 5.58 | 3.37 | 1.66 | 1.96 | 2.86 | 1.82 | 3.08 | 1.82 | 3.08 | 3.59 | 1.56 | 3.28 | 1.70 |
| | A-5-S-3 | 41.92 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 5.47 | 3.37 | 1.62 | 1.96 | 2.80 | 1.82 | 3.01 | 1.82 | 3.01 | 3.59 | 1.52 | 3.28 | 1.67 |
| | A-8-S-1 | 54.08 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 6.42 | 3.37 | 1.91 | 1.96 | 3.28 | 1.82 | 3.54 | 1.82 | 3.54 | 3.64 | 1.76 | 3.50 | 1.83 |
| | A-8-S-2 | 54.08 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 6.69 | 3.37 | 1.98 | 1.96 | 3.42 | 1.82 | 3.68 | 1.82 | 3.68 | 3.64 | 1.84 | 3.50 | 1.91 |
| | A-8-S-3 | 54.08 | 31935.4 | 425.81 | 0.013 | 456.4 | 5.38 | 7.21 | 3.37 | 2.14 | 1.96 | 3.68 | 1.82 | 3.97 | 1.82 | 3.97 | 3.64 | 1.98 | 3.50 | 2.06 |
| Sneed et al. (2016) | A-SL-CJ-13-S-1 | 30.20 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 5.27 | 3.37 | 1.56 | 1.96 | 2.69 | 1.82 | 2.90 | 1.82 | 2.90 | 3.52 | 1.50 | 3.09 | 1.71 |
| | A-SL-CJ-13-S-2 | 30.20 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 5.41 | 3.37 | 1.60 | 1.96 | 2.76 | 1.82 | 2.98 | 1.82 | 2.98 | 3.52 | 1.54 | 3.09 | 1.75 |
| | A-CL-CJ-13-S-1 | 30.75 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 5.14 | 3.37 | 1.52 | 1.96 | 2.63 | 1.82 | 2.83 | 1.82 | 2.83 | 3.52 | 1.46 | 3.10 | 1.66 |
| | A-CL-CJ-13-S-2 | 30.75 | 31935.4 | 425.81 | 0.013 | 497.8 | 5.38 | 5.20 | 3.37 | 1.54 | 1.96 | 2.66 | 1.82 | 2.86 | 1.82 | 2.86 | 3.52 | 1.48 | 3.10 | 1.68 |
| | | | | | | | | | Average | 1.57 | | 2.32 | | 2.54 | | 2.54 | | 1.46 | | 1.60 |
| | | | | | | | | | Maximum | 2.84 | | 4.21 | | 5.34 | | 5.34 | | 2.57 | | 2.73 |
| | | | | | | | | | Minimum | 0.80 | | 1.02 | | 1.07 | | 1.07 | | 0.74 | | 0.77 |
| | | | | | | | | | STD | 0.54 | | 0.89 | | 0.99 | | 0.99 | | 0.50 | | 0.52 |
| | | | | | | | | | COV | 34.10 | | 38.64 | | 39.13 | | 39.13 | | 33.99 | | 32.45 |

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