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Shear strength model for reinforced concrete beam-column joints based on hybrid approach

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Abstract. Behavior of RC beam-column joint is very complex as the composite material behaves differently in elastic and inelastic range. The approaches generally used for predicting joint shear strength are either based on theoretical, strut-and-tie or empirical methods. These approaches are incapable of predicting the accurate response of the joint for entire range of loading. In the present study a new generalized RC beam-column joint shear strength model based on hybrid approach i.e. combined strut-and-tie and empirical approach has been proposed. The contribution of governing parameters affecting the joint shear strength under compression has been derived from compressive strut approach whereas; the governing parameters active under tension has been extracted from empirical approach. The proposed model is applicable for various conditions such as, joints reinforced either with or without shear reinforcement, joints with wide beam or wide column, joints with transverse beams and slab, joints reinforced with X-bars, different anchorage of beam bar, and column subjected to various axial loading conditions. The joint shear strength prediction of the proposed model has been compared with 435 experimental results and with eleven popular models from literature. In comparison to other eleven models the prediction of the proposed model is found closest to the experimental results. Moreover, from statistical analysis of the results, the proposed model has the least coefficient of variation. The proposed model is simple in application and can be effectively used by designers.

Keywords: reinforced concrete; beam-column joint; shear strength; parameters; experimental database

1. Introduction

Under seismic loading the reinforced concrete (RC) beam-column joints are subjected to large horizontal and vertical shear forces. This is attributed to the reversal of moment in beams and columns on either side of the joint, leading to subsequent reduction of bond strength between the concrete and reinforcement. As a result, the stiffness of joint decreases which increases the story drifts and corresponding damage in joint. To understand this complex behavior, many experimental and analytical researches have been carried in the last five decades. From past studies it has been observed that the seismic behavior and the shear strength of RC beam-column joint depends on various parameters like, concrete compressive strength, column axial load, geometry of beam and column, amount of beam and column longitudinal reinforcement and joint shear reinforcement. A detail review of various shear strength predicting models on RC exterior beam-column joints have been presented by Lima *et al*. (2012a). In their study, based on different joint shear strength predicting models various mechanical and geometrical parameters affecting the joint shear strength have been identified and a comparison amongst different models have been presented. The models considered by Lima *et al*. (2012) have been developed on different approaches.

In general for predicting the shear strength of RC beam-column joints, most of the researchers utilized one of the three approaches i.e. either strut-and-tie or theoretical or empirical approach. The strut-and-tie approach considers evaluation of shear force transfer mechanism through the joint panel via diagonal strut and ties. In this approach the strut mechanism is evaluated based on compressive strength of concrete and truss mechanism is evaluated based on interaction of longitudinal and transverse reinforcement inside the joint. Joint shear strength models based on strut-and-tie approach have been developed by various researchers (Paulay and Priestley 1992, Hwang, and Lee 2002, Pauletta *et al*. 2015, Kassem 2016). In order to model the complex behavior of joint using strut-and-tie approach researchers proposed to divide tie mechanism into three sub ties based on the presence of beam and column longitudinal reinforcement. Overall this procedure provides satisfactory result, however, it is cumbersome and time consuming due to number of iterations required.

Models developed using the theoretical approach utilizes the concept of principal stress and strain within joint panel (Tsonos 2007, Wang *et al*. 2012). This method primarily considers strength of concrete and column axial load to develop equilibrium and compatibility equations. In some theoretical models (Wang *et al*. 2011) the influence of shear reinforcement has been additionally considered. However, this approach does not consider joint yielding behavior and other complex interaction during various stages of loading. It has been observed that the simplified

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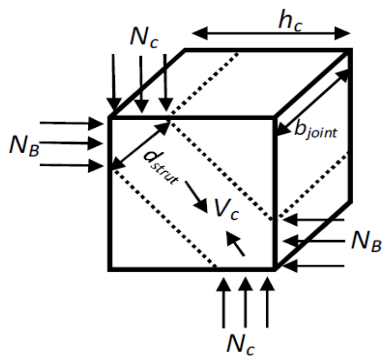
models based on theoretical approach do not yield precise results and considerably vary from the experimental results.

Empirical models are developed using parametric evaluation of experimental results (Vollum and Newman 1999, Bakir and Boduroğlu 2002, Hegger *et al*. 2003, Kim *et al*. 2009, Tran *et al*. 2014, Parate and Kumar 2019). It has been observed that most of these models are developed using limited set of experimental results and therefore, their predictions are not precise for wide range of parameters. This aspect has been clearly identified by Lima *et al.* (2012b) in which ten joint models have been put to test for a wide experimental database of 200 joint specimen. Most of these models were developed using a limited set of database and therefore they were unable to predict accurate results for the wide range considered. Further based on this assessment they proposed a recalibrated model. A similar approach has been considered in the present study to develop a new model.

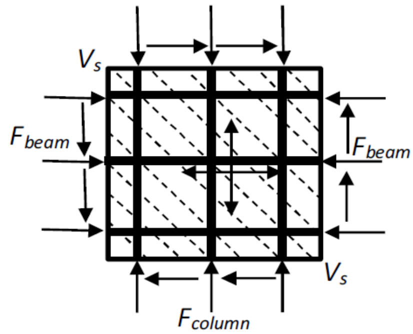
In present study a non-iterative joint shear strength model based on hybrid approach i.e., combination of strut-and-tie approach and empirical approach has been proposed. Under cyclic loading joint panel undergoes several actions of compression and tension. Shear strength model of joint under these actions have been developed using abovementioned two approaches i.e., under diagonal compression the strut action is derived using strut-and-tie approach and under tension the influence of transverse reinforcement obtained using empirical evaluation of experimental results. Proposed model is suitable for the wide range of variation in geometric and material properties. Experimental database consisting of a total 435 specimens (272 exterior and 163 interior) has been developed from the literature and used for validation purpose. Eleven joint shear strength models viz., Vollum and Newman (1999), Bakir and Boduroğlu (2002), Hwang and Lee (2002), Hegger *et al.* (2003), Kim *et al*. (2009), Wang *et al*. (2012), Tran *et al*. (2014), Pauletta *et al*. (2015), Kassem (2016), ACI 318-14 and EN 1998-1:2004 have been considered from literature. Efficacy of all the considered models along with proposed model has been verified on the basis of experimental results. Based on statistical evaluation of results it has been observed that prediction of proposed model is closer with actual experimental results as compared with the other models.

2. Shear resistance mechanism of beam-column joint

Beam-column joint is defined as a zone of intersection of beam and column member. The behavior of joint is different depending on the type of loading (i.e., static or dynamic) and on the performance of adjoining beam and column elements. Present study considers a typical geometry of interior and exterior RC beam-column joints as shown in Fig. 1. Paulay and Priestley in 1978 reported that the shear force developed inside the joint panel is generally resisted by two mechanisms i.e., strut and truss mechanism. In strut mechanism, the compressive forces from adjoining beam and column longitudinal reinforcement combines into a single diagonal compressive strut, as represented in Fig. 1.



(a) strut mechanism



(b) truss mechanism

Fig. 1 Shear force transfer mechanism of a typical interior beam-column joint

From past studies, it has been observed that strength of diagonal compressive strut depends on the compressive strength of concrete and geometry of the joint, however, the strength of truss mechanism depends on the bond strength between reinforcement and adjoining concrete, and the compression field formed in between the cracks. Forces from beam and column members result in shear forces in horizontal and vertical direction. These shear forces lead to the diagonal compressive and tensile stresses. Due to moment reversal, tensile cracks develop in the orthogonal direction of diagonal strut, which has been considered as the failure criteria of diagonal strut. Earlier research shows that in case of unreinforced joints only the strength of diagonal compressive strut governs the strength of joint, whereas, in reinforced joints, shear reinforcement confines the core concrete and generates the truss mechanism (Hakuto *et al*. 2000, Park and Mosalam 2012, Parate *et al*. 2014). In present study, the geometry considered for the interior and exterior beam-column joint and the formation of internal forces under cyclic loading have been presented in Fig. 2.

The total shear resistance (V_j) of beam-column joint considered as a combination of strength from both strut and truss mechanisms presented (shown in Fig. 1) as;

Total shear strength of joint is

$$V_j = V_c + V_s \tag{1}$$

Horizontal component for shear strength of joint is

$$V_{jh} = V_{ch} + V_{sh} \tag{2}$$

Vertical component for shear strength of joint is

$$V_{jv} = V_{cv} + V_{sv} \tag{3}$$

where, V_c and V_s represents the joint shear strength from strut mechanism and truss mechanism respectively; V_{ch} and V_{cv} are the horizontal and vertical component from diagonal strut action; V_{sh} and V_{sv} are the horizontal and vertical component from the truss action. In calculation of horizontal shear strength of joint, component of diagonal strut is computed by using theoretical strut approach and that of truss component by empirical approach as explained in following sections.

2.1 Diagonal strut approach for compression

Under the action of reversal in bending moment on either side of beam and column, the compression and tension forces generates in the longitudinal reinforcement. As shown in Fig. 1(a), at the junction of beam and column, compressive forces from the reinforcement combines to form a single diagonal compressive strut. Diagonal compressive strut forms in between opposite corners of joint. Angle of inclination of strut depends on the geometry of adjoining beam and column members. The strength and stability of diagonal strut depends on angle of inclination (θ). Based on ratio of beam depth and column depth, angle of diagonal strut (θ) can be defined as

$$\theta = \tan^{-1}\left(\frac{h_b}{h_c}\right) \tag{4}$$

where, h_b and h_c are the depths of beam and column members respectively. In general, diagonal compressive strut has non prismatic shape (i.e. bottle shape enlarged at the mid length as mentioned in the ACI 318-14 code) but for simplicity prismatic shape has been considered in this study as shown in Fig. 1(a).

$$V_{ch} = V_c \cos\theta \tag{5}$$

$$V_{cv} = V_c \sin\theta \tag{6}$$

To determine strength of diagonal strut, area of strut at horizontal cross-section has been considered. The area of the diagonal strut (A_{strut}) can be defined as a product of width of joint and effective depth of diagonal strut as (Hwang and Lee 2002)

$$A_{strut} = b_{ej} d_{strut} \tag{7}$$

where, b_{ej} is the effective width of joint considered as recommended in ACI 318-14 code as,

$$If,\ b_c > b_b,\ then, b_j = min\begin{cases} b_b + 2x \\ b_b + h_c \end{cases}\ and$$

$$If,\ b_c < b_b,\ then, b_j = b_c$$

As shown in Fig. 2, width of strut (d_{strut}) can be calculated from the combination of width of compressive strut from beam and column as

$$d_{strut} = \sqrt{a_c^2 + a_b^2} \tag{8}$$

where, width of compression zone in column (a_c) and beam (a_b) (as reported by Paulay and Priestley 1992, Hwang and Lee 2002) are presented as

$$a_c = \left(0.25 + \frac{0.85 N_c}{A_c f_{cc}}\right) h_c \tag{9}$$

where, N_c is column axial load in kN; A_c is column cross sectional area; f_{cc} is compressive strength of concrete in column; and h_c is the column depth.

$$a_b = \left(\frac{A_{sb} f_{yb}}{0.85 b_b f_{cb}}\right) \tag{10}$$

where, A_{sb} is the area of tensile reinforcement of beam; f_{yb} is the yield strength of beam longitudinal reinforcement; f_{cb} is compressive strength of concrete in beam; b_b is width of beam.

Most of the national codes (like, ACI 318-14, NZS 3101, EN 1998-1:2003 and IS 13920:2016) have also considered the concrete compressive strength as a main governing parameter for calculating the joint shear strength, however, their consideration differs significantly (Parate and Kumar 2019). In present study the influence of concrete compressive strength on joint shear strength is calculated based on experimental results. Fig. 3 shows the concrete

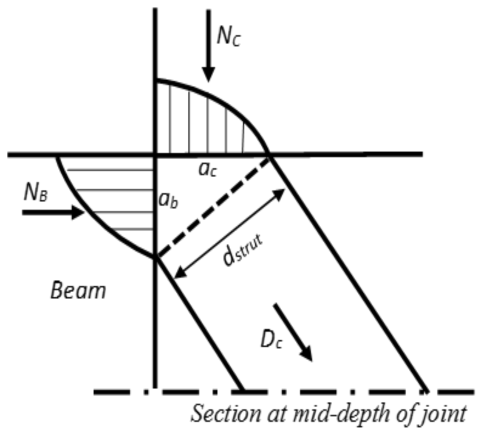


Fig. 2 Axial compressive forces from beam (NB) and column (NC) to form diagonal strut

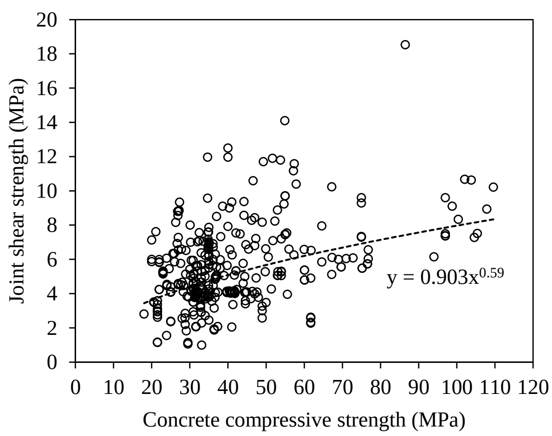


Fig. 3 Effect of concrete compressive strength (f_c) on the joint shear strength

compressive strength (MPa) on abscissa and the joint shear strength (MPa) on ordinate. Their correlation is presented by a trend-line, with equation $y=0.903x^{0.59}$, can be considered round off value as, $y=x^{0.59}\approx x^{0.6}$.

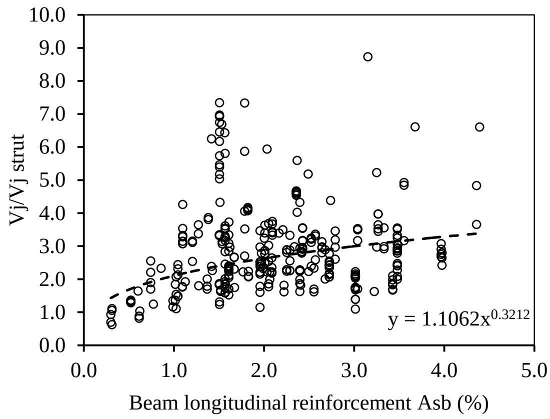
Eq. (11) represents the horizontal component of strut action from diagonal compressive strut (V_{ch}) as

$$V_{ch} = f_c^{0.6} A_{strut}\cos\theta \tag{11}$$

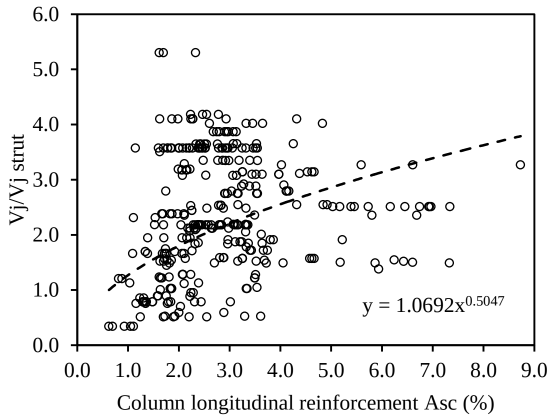
It has been observed from the Eq. (11) that the strength of diagonal strut is the function of only concrete compressive strength, angle of strut (i.e., beam to column depth ratio, h_b/h_c) and column axial load. However, for the development of diagonal strut action, beam and column longitudinal reinforcement plays a significant role. Reinforcement from both members forms a rigid frame and relatively increases the stiffness of joint (Anderson *et al.* 2008). Sufficient amount of longitudinal reinforcement enhances the efficiency of diagonal strut. Formation of plastic hinges in beams on either side of the joint governs the failure mode of beam-column joint. Two types of failure mechanism have been reported during experimental study as the failure either due to the flexural yielding of beam longitudinal reinforcements followed to shear failure of the joint (BFJS) or the beam failure before joint shear failure (BF). Experimental studies by Chun and Kim (2004), Wong (2005), Wong and Kuang (2008), showed that the specimens having low amount of beam reinforcement have been failed under the beam bar flexural yielding before joint shear failure (BFJS) mode, whereas, joint specimen with high amount of beam reinforcement have failed under joint shear (JS) failure mode. Analytically the contribution of beam longitudinal reinforcement has been considered by various researchers (viz., Paulay and Priestley 1992, Bakir and Boduroğlu 2002, Kim *et al.* 2007, Park and Mosalam 2012, Tran *et al.* 2014). The influence of anchorage type of beam longitudinal reinforcement (*L* and *U* bend) on joint shear strength have been introduced by Bakir and Boduroğlu (2002), Hegger *et al.* (2003) in their models.

In case of horizontal beam longitudinal reinforcement, the vertically distributed column reinforcement passing through the joint core can facilitate the partial replacement for the horizontal shear reinforcement (Paulay *et al.* 1978 and Wong 2005). Experimental evidences (viz. Tsonos 1992, Parker and Bullman 1997, Hwang *et al.* 2002) show that column longitudinal reinforcement passing through the joint core has a significant influence on joint shear strength. Study of Hegger *et al.* (2003) indicated that the column longitudinal reinforcement influences the joint stiffness and the width of compression zone in column. In case of strut-and-tie models proposed by Hwang and Lee (2002), Pauletta *et al.* (2015) presence of column intermediate bars leads to the formation of additional strut in between column intermediate reinforcement. Theoretically various researchers like, Sarsam and Phillips (1985), Parker and Bullman (1997), Hegger *et al.* (2003), have incorporated parameter of column longitudinal reinforcement in their joint shear strength predictive models for calculation of joint shear strength.

In present study from analysis of experimental results, two factors 'α' and 'β' are proposed to consider the effect of amount of beam and column longitudinal reinforcement on joint shear strength respectively. Fig. 4 presents the plot of normalized joint shear strength with respect to the beam and column longitudinal reinforcement. From Fig. 4, the equation representing the effect of beam and column longitudinal reinforcement in the nonlinear form.



(a) Beam longitudinal reinforcement



(b) Column longitudinal reinforcement

Fig. 4 Influence of longitudinal reinforcement on joint shear strength

Factor for beam longitudinal reinforcement

$$\alpha = \left(\frac{100\,A_{sb}}{A_b}\right)^{0.321}$$

Factor for column longitudinal reinforcement

$$\beta = \left(\frac{100\,A_{sc}}{A_c}\right)^{0.505}$$

Thus, shear strength component Eq. (10) have been modified and expressed as

$$V_{ch} = \alpha\beta\lambda\kappa\left(f_c^{0.6} A_{strut}\cos\theta\right) \tag{12}$$

where, term 'λ' indicate the influence of presence of transverse beam and slab taken equal to 1.20 for one transverse beam and 1.00 for no transverse beam. Term 'κ' is to consider the effect of wide beam/column on joint shear strength taken equal to the ratio of beam width to column width (b_b/b_c).

2.2 Empirical approach for tension

Even though the strength of diagonal compressive strut do not rely primarily on the presence of shear reinforcement but adequate confinement is recommended to provide ductility to the joint core concrete and to prevent the outward buckling of longitudinal reinforcement. The main assumption for formation of truss mechanism is based on equilibrium of bond forces among beam and column longitudinal reinforcement (Paulay *et al.* 1978). This bond force introduces shear stress which results in diagonal tension in joint core concrete. Due to limited tension capacity of concrete the diagonal tension cracks developed in orthogonal direction, however, to prevent excessive distress of joint panel; reinforcement both in vertical and horizontal directions are recommended (Hwang and Lee 2002, Pauletta *et al.* 2015). As shown in Fig. 1(b), truss mechanism can be developed from the combined action from joint shear reinforcement, beam and column longitudinal reinforcement and diagonal concrete compression field between the tension cracks (Pauletta *et al.* 2015). The influence of beam and column longitudinal reinforcement have been already evaluated in earlier section of strut mechanism, however, in present section influence of shear reinforcement on shear strength of joint is derived from the analysis of experimental database i.e., by using empirical approach. Generalized equation representing truss mechanism is

$$V_{sh} = \phi A_{sj} f_{yj} \tag{13}$$

where, A_{sj} is area of shear reinforcement inside the joint panel and f_{yj} is yield strength of joint shear reinforcement. Multiplication factor 'ϕ' represents different amount of shear reinforcement inside the joint.

The role of shear reinforcement inside joint is to confine joint core concrete. Shear reinforcement either in horizontal or vertical direction improves shear force transfer mechanism. Various national code recommends nominal use of shear reinforcement inside the joint, however, restricts the spacing between stirrups (ACI 318M-14). Many researchers viz., Hwang *et al.* (2005), Hamil (2000), Murty *et al.* (2003), Tsonos *et al.* (1992), have studied the influence of shear reinforcement on shear strength of joint and observed that shear reinforcement enhances shear strength of joint significantly. From experimental database influence of joint shear reinforcement on joint shear strength can be represented by Eq. (14) as

$$V_{sh} = \phi\left(A_{sjh} f_{ysjh} + A_{sjv} f_{ysjv} + A_{sji} f_{ysji}\right) \tag{14}$$

where, A_{sjh}, A_{sjv}, and A_{sji} are areas of horizontal, vertical shear reinforcement and inclined cross bars inside the joint. Multiplication factor 'ϕ' is to consider the influence of various amount of shear reinforcement i.e., equal to 0.20 for shear reinforcement less than 0.50%; equal to 0.25 for shear reinforcement varies from 0.51% to 1.00%; equal to 0.30 for shear reinforcement varies from 1.00% to 2.00%; and equal to 0.35 for shear reinforcement greater than 2.00%.

2.3 Proposed joint shear strength model

Based on concept of diagonal strut and truss approach an Eq. (1) can be modified by adding the derived terms. Effect of compression under cyclic loading has been derived based on strut method only (Eqs. (4)-(12)), however, contribution of truss mechanism is derived from evaluation of experimental database (Eqs. (13)-(14)). The final proposed equation is given as

$$V_{jh} = \left(\alpha\beta\lambda\kappa f_c^{0.6} A_{strut}\cos\theta\right) + \phi A_{sj} f_{yj} \tag{15}$$

where, the factors 'α' and 'β' represents influence of amount of beam and column longitudinal reinforcement respectively; factor 'λ' indicate the influence of presence of transverse beam and slab taken equal to 1.20 for one transverse beam and 1.00 for no transverse beam; factor 'κ' is to consider the effect of wide beam/column, taken equal to the ratio of beam width to column width (b_b/b_c). Above equation is applicable for prediction of shear strength for both interior and exterior beam-column joint. The sample calculation procedure using the proposed model is presented in the Appendix A.

3. Assessment of existing shear strength models

From literature, nine existing shear strength models based on the three aforementioned approaches have been considered in this study. Out of the considered nine models, the models proposed by Hwang and Lee (2002), Pauletta *et al.* (2015), Kassem (2016) have been grouped under strut-and-tie approach, whereas, the models of Vollum and Newman (1999), Bakir and Boduroğlu (2002), Hegger *et al.* (2003), Kim *et al.* (2009), Tran *et al.* (2014), have been grouped under empirical approach. The model of Wang *et al.* (2012) has been considered under theoretical approach. Additionally recommendations from the two national codes viz., ACI 318-14; and EN 1998-1:2004 have also been considered for comparison. Description of the aforementioned models are already mentioned by Parate and Kumar (2016) as,

1. Vollum and Newman (1999) proposed a semi empirical model based on parametric study for exterior beam column joint subjected to monotonic loading. Several parameters like concrete strength (f_c), depth of beam (h_b) and column (h_c), width of beam (b_b) and column (b_c), joint shear reinforcement (A_{sj}) and yield strength of shear reinforcement (f_{ysj}) have been considered for modeling. The model also considers anchorage type of beam longitudinal reinforcement. However, it neglects the effect of column axial load and longitudinal reinforcement in beam and column.

$$V_{jh} = V_{ch} + \left(A_{sj} f_{ysj} - \alpha b_j h_c \sqrt{f_c}\right)$$

where, the coefficient α is taken to consider effect of column load, concrete strength, stirrup index, and joint aspect ratio conservatively taken equal to 0.2. The joint shear strength without shear reinforcement (V_{ch}) can be determined by

$$V_{ch} = 0.642\zeta\left[1 + 0.555\left(2 - \frac{h_b}{h_c}\right)\right] b_j h_c \sqrt{f_c}$$

where, the factor, ξ represents the detailing of reinforcement, ξ=1.00 for L bend and ξ =0.90 for U bend bars bent into the joint. Finally the equation for V_{jh} becomes

$$V_{jh} = \left[0.642\xi\left[1+0.552\left(2-{h_b}/{h_c}\right)\right]b_j h_c\sqrt{f_c}\right] + \left[A_{sj} f_{sj}\right] \tag{16}$$

2. Bakir and Boduroğlu (2002) proposed an empirical design equation based on regression analysis of 58 experimental test results. This model considers mainly the parameters like, concrete strength (f_c), width of beam (b_b) and column (b_c), depth of beam (h_b) and column (h_c), beam longitudinal reinforcement (A_{sb}), joint shear reinforcement (A_{sjh}) and yield strength of joint shear reinforcement (f_{ysj}). Similar to the previously proposed model by Vollum and Newman (1999), the effect of anchorage of beam bar inside the joint has also been considered. The effect of column axial load and column reinforcement has not been considered.

$$V_{jh} = \left[\frac{0.71\beta\gamma\left(100A_{sb}/b_b h_b\right)^{0.4289}\left(\frac{b_b+b_c}{2}\right)h_c\sqrt{f_c}}{\left({h_b}/{h_c}\right)^{0.61}}\right] + \left[\alpha A_{sj} f_{ysj}\right] \tag{17}$$

where, β=0.85 for the joints detailed by U type bars and β=1.00 for L type bars. γ=1.37 for inclined bars inside joint and γ=1.00 for other cases. α=0.664 for joints with low amount of stirrups; α=0.60 for joints with medium amount of stirrups; and α=0.37 for joints with low amount of stirrups. In this the joints are consider to have low amount of stirrups when the stirrups ratio is below 0.003, for medium amount of stirrups when ratio ranges between 0.003 to 0.0055 and for high amount of stirrups for ratio exceeds 0.0055.

3. Hwang and Lee (2002) proposed a model based on strut and tie approach. The model is based on contributions from three types of struts in the joint i.e., diagonal, horizontal, and vertical. The model considers the effect of parameters like concrete grade (f_c), width of beam (b_b) and column (b_c), depth of beam (h_b) and column (h_c) and the column axial stress (N_c/A_c). The horizontal shear strength is provided by the component in horizontal axis as

$$V_j = C_d \cos\theta \tag{18}$$

where, the diagonal compressive strength is expressed as $C_d = K\xi f_c A_{str}$. The coefficient of stiffness ξ depend on concrete compressive strength as, $\xi = \left(3.35/\sqrt{f_c}\right) \le 0.52$. The area of diagonal strut, $A_{str}=a_s b_j$, in which $a_s$represents the strut depth and b_j is the effective width of joint.

$$a_s = \left(0.25 + 0.85 N_c / A_c f_c\right) h_c$$

The factor K represents the effect of tie force on joint shear strength and it is the sum of horizontal (K_h) and vertical (K_v) tie forces.

$$K = K_h + K_v$$

$$K_h = 1 + \left(\overline{K_h} - 1\right)\frac{F_{yh}}{\overline{F_h}} \le \overline{K_h}$$

$$K_v = 1 + \left(\overline{K_v} - 1\right)\frac{F_{yh}}{\overline{F_h}} \le \overline{K_v}$$

The contribution of horizontal ($\overline{K_h}$) and vertical ($\overline{K_v}$) tie force to the diagonal compressive strength are represented by following expressions,

$$\overline{K_h} = \frac{1}{1-0.2\left(\gamma_h - \gamma_h^2\right)} \quad \text{and} \quad \overline{K_v} = \frac{1}{1-0.2\left(\gamma_v - \gamma_v^2\right)}$$

$$\overline{F_h} = \gamma_h\left(\overline{K_h}\xi f_c A_{str}\right)\cos\theta \quad \text{and} \quad \overline{F_v} = \gamma_v\left(\overline{K_v}\xi f_c A_{str}\right)\sin\theta$$

The strain parameters γ_h and γ_v of above equations can be evaluated as,

$$\gamma_h = \frac{2\tan\theta - 1}{3} \quad 0 \le \gamma_h \le 1.00$$

and $$\gamma_v = \frac{2\cot\theta - 1}{3} \quad 0 \le \gamma_v \le 1.00$$

The tensile forces in horizontal and vertical stirrups are as follows,

$$F_{yh} = A_{sjh} f_{yj} \text{ and } F_{yv} = A_{sjv} f_{yj}$$

4. Hegger *et al.* (2003) proposed a complete empirical model based on regression analysis of experimental database. The model considers the parameters i.e., concrete strength (f_c), width of beam (b_b) and column (b_c), depth of beam (h_b) and column (h_c), column reinforcement ratio (ρ_c), joint shear reinforcement (A_{sjh}) and yield strength of joint shear reinforcement (f_{ysj}). From the regression analysis the following expressions are proposed.

$$V_{jh} = \left[2\xi\left(1.2 - 0.3\,{h_b}/{h_c}\right)\left(1 + \frac{\rho_c - 0.5}{7.5}\right)b_j h_c \sqrt[3]{f_c}\right] + \left[\alpha A_{sj} f_{ysj}\right] \tag{19}$$

where, ξ represents the effect of beam bar anchorage detail; ξ=0.95 and 0.85, for L and U bars respectively. Author proposed different values for the coefficient α based on the anchorage type. For 90° and 180° bent bars the value of α is 0.7 and 0.6 for hairpins and 0.6 and 0.5 for closed stirrups respectively. The upper limit of joint shear strength ($V_{\max}$) according to experimental results is found as,

$$V_{max} = \gamma_1\gamma_2\gamma_3 0.25 f_c b_j h_c \le 2V_{ch}$$

in which the coefficients γ_1 is 1.00 for bent bars and 1.20 for headed bars. The other two coefficients γ_2 and γ_3 are based on the column axial stress (N_c/A_c), concrete strength (f_c) and aspect ratio (h_b/h_c) as stated below,

$$\gamma_2 = 1.5 - 1.2\frac{\left(N_c/A_c\right)}{f_c} \le 1.0 \quad \gamma_3 = 1.9 - 0.6\frac{h_b}{h_c} \le 1.0$$

The limiting parameters are joint aspect ratio and concrete grade such as; $0.75 \le h_b/h_c \le 2$ and $20 \le f_c \le 100$ MPa respectively.

5. Kim *et al.* (2009) developed a complete empirical model based on the Bayesian parameter estimation method for exterior beam column joint. Earlier the model proposed by Kim *et al.* (2007) was found inadequate for evaluating the shear strength in unreinforced beam-to-column joints. Now this model is considered suitable for both interior and exterior joints, both for unreinforced and reinforced types of joints. Author considers the parameters like concrete strength (f_c), width of beam (b_b) and column (b_c), depth of beam (h_b) and column (h_c), beam reinforcement (A_{sb}), eccentricity of beam (e_b) and joint shear reinforcement (A_{sjh}).

$$V_{jh} = 1.3\alpha_t \beta_t \eta_t \left(JI^{0.15}\right)\left(BI^{0.3}\right)\left(f_C^{0.75}\right)A_{ej} \tag{20}$$

where, α_t and β_t are parameters for describing the in-plane and out-of-plane geometry, respectively; η_t is a parameter to account for the influence of beam eccentricity; JI is the joint transverse reinforcement index depending mostly on the volumetric joint shear reinforcement ratio; BI is the beam reinforcement index.

$$\eta_t = \left(1 - \frac{e_b}{b_c}\right)^{0.67} \qquad BI = \frac{\rho_b f_{yb}}{f_c} \qquad JI = \frac{\rho_j f_{yj}}{f_c} > 0.139$$

Beam reinforcement ratio (ρ_b) and joint transverse reinforcement ratio (ρ_j) needed for evaluating the beam and transverse reinforcement index, respectively, can be evaluated as follows;

$$\rho_b = \frac{A_{sbtop} + A_{sbbot}}{b_b h_b} \qquad \rho_j = \frac{A_{sj} h_c}{b_c h_c \left(h_b - 2h_b^{'}\right)}$$

6. Wang *et al.* (2011) proposed a theoretical model based on the assumption that the material is under plane stress state and the effect of tensile straining in the transverse direction on the compressive strength of the idealized material is accounted by using the Kupfer-Gerstle biaxial tension-compression failure envelope. The model considers the effect of tensile reinforcement in the joint but neglects effect parameters like the beam and column reinforcement and column axial load ratio.

$$V_{jhmax} = \beta \frac{1.0 - \left(sin^2 \dfrac{\alpha}{f_{tn}} - 0.8 cos^2 \alpha / f_c\right)\sigma_y}{\left(1/f_{tn} + 0.8/f_c\right) sin 2\alpha} b_j h_c \tag{21}$$

The nominal tensile strength of concrete (f_{tn}) is,

$$f_{tn} = f_{ct} + \frac{A_{sh} f_{yh}\, cos\alpha}{b_j h_c / sin\alpha} + \frac{A_{sv} f_{yv}\, sin\alpha}{b_j h_c / sin\alpha}$$

The contribution of concrete tensile strength (f_{ct}) is, $f_{ct} = 0.556\sqrt{f_c}$. A_{sh} and A_{sv} is the total area of the horizontal and vertical shear reinforcement of the joint. The angle of inclination α is equal to the ratio of column to beam depth (h_c/h_b) and the reduction factor β according to the confinement action of beams into the joint is taken as 0.8 for exterior joint.

7. Tran *et al.* (2014) considers the contribution of bond strength in the formulation of empirical model. The model is based on the regression analysis based on collected past experimental database. The four parameters are considered such as concrete strength (f_c), width of beam (b_b) and column (b_c), depth of beam (h_b) and column (h_c), column axial stress (N_c/A_c), beam reinforcement (A_{sb}) and joint horizontal and vertical shear reinforcement ($A_{sjh}$and A_{sjv})

$$V_{jh} = \left(\gamma_1 + \frac{N_c}{b_c h_c f_c} + 1.2\chi_b\right) A_{jh} f_c^{0.5} + \gamma_2\left(A_{sjh} f_{yjh} + A_{sjv} f_{yjv}\right) \tag{22}$$

where, the coefficients γ_1 =0.34 and γ_2=0.22 for exterior joints. And the additional new parameter of bond strength (χ_b) is defined as

$$\chi_b = \frac{n_b d_b h_c}{b_b h_b} \le 0.4$$

In this equation the effect of parameter of column reinforcement is not considered. The beam reinforcement is considered in terms of bond strength (χ_b); n_b is the number of longitudinal beam reinforcement inside the joint core.

8. Pauletta *et al.* (2015) proposed a strut and tie model to determine nominal design shear strength (V_{jh}) of exterior RC beam column joint. The contribution from the horizontal hoops and intermediate column reinforcing bars within the joint region are also considered. The model considers the effect of parameters like concrete grade (f_c), width of beam (b_b) and column (b_c), depths of beam (h_b) and column (h_c), column axial stress (N_c/A_c), horizontal (A_{jh}) and vertical (A_{jv}) joint shear reinforcement as

$$V_{jh} = 0.45\left[\frac{\delta f_c b_j c \cos\theta}{\alpha} + 0.79 A_{sh} f_{ysh} + 0.52 \frac{A_{sv} f_{ysv}}{\tan\theta}\right] \tag{23}$$

where, A_{sh} , A_{sv} and f_{ysh}, f_{ysv} are areas and yield strengths of horizontal and vertical joint shear reinforcement respectively; θ is the angle of inclination of the strut, $\theta = tan^{-1}\left(h_b^{''}/h_c^{''}\right)$, $h_b^{''}$ is distance between top and bottom beam longitudinal bars and $h_c^{''}$ is the distance measured from the centroid of bar extension at the free end of the 90° hooked bar to the centroid of longitudinal column reinforcement in the opposite side; c is the depth of the compression zone in the column. In this δ is the nondimentional interpolating parameter given by the expression,

$$\delta = \left[0.74\left(\frac{f_c}{105}\right)^3 - 1.28\left(\frac{f_c}{105}\right)^2 + 0.22\left(\frac{f_c}{105}\right) + 0.87\right]$$

9. Kassem (2016) suggested a closed form equation based on strut-and-tie mechanism suitable for interior and exterior beam-column joints as

$$V_{jh} = \left(\frac{\gamma_c\left[\psi a_c \cos(\phi)\right] + \gamma_h\left[\omega_h + 3.47\omega_b\left(\dfrac{b_b}{b_j}\right)\right]}{\tan(\phi) + \gamma_v\left[\omega_v\left(\dfrac{b_c}{b_j}\right)\cot(\phi)\right]}\right) f_c \tag{24}$$

where, γ_c, γ_h and γ_v are the multiplying constants for diagonal concrete strut, horizontal truss and vertical truss mechanism; ψ represents the non-dimensional function of concrete compressive strength proposed by European code; ω_h , ω_b and ω_v are the reinforcement index of horizontal shear reinforcement, beam reinforcement and vertical reinforcement respectively.

10. ACI 318-14 recommended equation for the calculation of shear strength of joint is expressed as

$$V_j = \lambda\phi\sqrt{f_c}A_{ej} \tag{25}$$

where, ϕ is 0.75 for lightweight concrete and 1.0 for normal weight concrete; λ is the factor for confinement of beam in column equal to 1.7 for beam confinement on all four sides of column, 1.2 for beam confinement on three sides or on two opposite side of column, and 1.0 for all other cases; and A_{ej} is the effective area of joint taken equal to the column depth times effective joint width.

11. EN 1998-1:2004 recommended equation for calculation of joint shear strength based on the compressive strength of diagonal concrete strut considering the reduction in strength due to tensile strain in transverse direction. Additionally the provision for horizontal shear reinforcement and vertical column reinforcement has been made for the proper functionality of the joint.

$$V_j = \eta f_{cd} \sqrt{1 - \frac{v_d}{\eta}} A_{ej} \tag{26}$$

where, f_{cd} is the design value of tensile strength of concrete taken as,

$$f_{cd} = 0.30 \left(f_c\right)^{2/3}$$

η is the reduction factor on concrete compressive strength due to tensile strain in transverse direction equal to,

$$\eta = \kappa \left(1 - \frac{f_c}{250}\right)$$

where, the factor κ is 0.60 for interior joint and 0.48 for exterior joint, v_d represents the normalized axial load on the column above the joint.

The ACI 318-M14 code considers the contribution of concrete compressive strength in terms of flexural strength of concrete, whereas, EN1998-1:2004 considers the softening effect of concrete with a different coefficient for interior and exterior type of joint. Out of the considered nine models, the models of Vollum and Newman (1999), Bakir and Boduroğlu (2002), Hegger *et al*. (2003), Kim *et al*. (2009), Tran *et al*. (2014), have considered the compressive strength of concrete. The proposed models of Hwang and Lee (2002), Pauletta *et al*. (2015) have considered the softening effect on the compressive strength.

The model of Kassem (2016) follows the similar provision given in EN 1998-1:2004 for the concrete strength. The influence of column axial load has been considered in the formulation of width of compression zone (a_c). The joint shear strength models like, Hegger *et al.* (2003). Hwang and Lee (2002), Tran *et al.* (2014), Kassem (2016), have considered the positive influence of column axial load on joint shear strength, whereas, the models of Vollum and Newman (1999), Bakir and Boduroğlu (2002), Kim *et al.* (2009), Pauletta *et al.* (2015), do not consider the effect of column axial load. The EN 1998-1:2004 code consider the influence of column axial load on joint shear strength. From the considered models, it has been observed that for calculation of joint shear strength, the basic parameters have been identified like, beam width, beam depth, beam longitudinal reinforcement, column width, column depth, column longitudinal reinforcement, joint shear reinforcement, yield strength of reinforcement, concrete compressive strength and axial load from column. With the use of these basic parameters, these models have been developed. It has been observed that none of the model considers all above mentioned parameters, however, proposed model considers all thirteen governing parameters reported in Table 1.

Table 1 List of significant parameters considered by various strength models

Sr. No.	Analytical models	Parameters												
		Beam				Column				Joint			f_c	N_c
		b_b	h_b	A_{sb}	f_{yb}	b_c	h_c	A_{sc}	f_{yc}	A_{sjh}	A_{sjv}	f_{yj}		
1	Vollum and Newman (1999)	√	√	-	-	√	√	-	-	√	-	√	√	-
2	Hwang and Lee (2002)	√	√	-	-	√	√	-	-	√	√	√	√	√
3	Bakir and Boduroğlu (2002)	√	√	√	-	√	√	-	-	√	-	√	√	-
4	Hegger et al. (2003)	√	√	-	-	√	√	√	√	√	-	√	√	-
5	Kim *et al.* (2009)	√	√	√	√	√	√	-	-	√	-	√	√	-
6	Wang *et al.* (2012)	√	√	-	-	√	√	-	-	√	√	-	√	√
7	Tran *et al.* (2014)	√	√	√	√	√	√	-	-	√	-	√	√	√
8	Pauletta *et al.* (2015)	√	√	-	-	√	√	√	√	√	-	√	√	√
9	Kassem (2016)	√	√	√	√	√	√	√	√	√	-	√	√	√
10	ACI 318-14	√	√	-	-	√	√	-	-	-	-	-	√	-
11	EN1998-1:2004	√	√	-	-	√	√	-	-	-	-	-	√	√
12	Proposed model	√	√	√	√	√	√	√	√	√	√	√	√	√

4. Experimental database

A database of 435 experimental results (272 exterior and 163 interior) of RC beam-column joint have been compiled from the literature as presented in Appendix-B. For exterior beam-column joints the test conducted by various researchers viz., Hanson and Conner 1967 (2); Megget 1971 (4); Hanson 1971 (4); Taylor 1974 (6); Ohwada 1976 (3); Ogura 1977 (4); Uzumeri 1977 (8); Ehsani and Wight 1985 (9); Durrani and Zerbe 1987 (3); Ehsani *et al*. 1987 (5); Kurose 1987 (3); Kaku and Asakusa 1991 (15); Ehsani and Alameddine 1991 (12); Tsonos *et al*. 1992 (4); Ortiz 1993 (6); Scott 1996 (14); Parker and Bullman 1997 (11); Wallace *et al*. 1998 (2); Tsonos 1999 (1); Clyde *et al*. 2000 (4); Hamil 2000 (16); Hakuto *et al*. 2000 (2); Calvi *et al*. 2001 (1); Pantelides *et al*. 2002 (6); Gencoglu and Eren 2002 (1); Hegger *et al*. 2003 (8); Chutarat and Aboutaha 2003 (3); Chun and Kim 2004 (2); Hwang *et al*. 2004 (4); Alva *et al*. 2004 (1); Hwang *et al*. 2005 (8); Kuang and Wong 2006 (4); Liu 2006 (2); Climent 2007 (1); Chun *et al*. 2007 (5); Tsonos 2007 (3); Idayani 2007 (3); Alva *et al*. 2007 (4); Lee and Ko 2007 (5); Karayannis *et al*. 2007 (4); Karayannis *et al*. 2008 (5); Bindu and Jaya 2008 (4); Chalioris *et al*. 2008 (12); Karayannis and Sirkelis 2008 (2); Wong and Kuang 2008 (5); Kusuhara and Shiohara 2008 (2); Masi *et al*. 2009 (9); Kaung and Wong 2011 (6); Kotsovou and Mouzakis 2012 (5); Elsouri and Harajli 2013 (4); Hwang *et al*. 2014 (3); Chun and Shin 2014 (8); Fadwa

Table 2 Minimum and maximum range of various parameters in the database

Sr. No.	Parameters	Interior joints		Exterior joints	
		Min.	Max.	Min.	Max.
1.	Width ratio (b_b/b_c)	0.33	1.78	0.65	2.00
2.	Depth ratio (h_b/h_c)	0.50	2.00	0.67	2.50
3.	Concrete compressive strength (f_c)	18	118	18	110
4.	Column longitudinal reinforcement (% ρ_c)	0.32	7.56	0.26	4.18
5.	Beam longitudinal reinforcement (% ρ_b)	0.60	6.90	0.30	4.18
6.	Joint shear reinforcement (% ρ_j)	0.00	5.11	0.00	3.43
7.	Yield strength of reinforcement (f_y)	288	858	276	630
8.	Column axial load ratio (N_c/A_cf_c)	0.00	1.83	0.00	1.46

Table 3 Average (AVG) and coefficient of variation (CV) values for different analytical models

Sr. No.	Researcher	Interior joint		Exterior joint	
		AVG	CV	AVG	CV
1.	Vollum and Newman (1999)	1.18	0.39	1.05	0.40
2.	Hwang and Lee (2002)	0.74	0.44	0.72	0.49
3.	Bakir and Boduroğlu(2002)	1.26	0.37	1.37	0.44
4.	Hegger *et al*. (2003)	1.06	0.44	1.03	0.52
5.	Kim *et al*. (2009)	1.09	0.62	1.03	0.57
6.	Wang *et al*. (2012)	1.47	0.48	1.28	0.44
7.	Tran *et al.* (2014)	0.73	0.38	0.97	0.52
8.	Pauletta *et al.* (2015)	1.06	0.36	1.16	0.63
9.	Kassem (2016)	1.03	0.50	1.31	0.51
10.	ACI 318-M14	0.91	0.79	0.58	0.44
11.	EN 1998-1:2004	0.74	0.75	0.54	0.52
12.	Proposed model	1.25	0.26	1.24	0.24

et al. 2014 (1); Rissi *et al*. 2016 (2); Mirzabagheri *et al*. 2016 (1); Behnam *et al*. 2017 (4), have been collected (numbers in the close parenthesis indicates the specimen numbers).

Similarly, for interior beam-column joints test results conducted by various researchers viz., Higashi and Ohwada 1969 (7); Meinheit and Jirsa 1977 (6); Birss *et al*. 1978 (2) Soleimani *et al*. 1979 (2); Beckingsale 1980 (2); Park and Milburn 1983 (2); Durrani and Wight 1982 (9); Otani *et al*. 1984 (5); Kitayama *et al*. 1987 (4); Park and Ruitong 1988 (4); Leon 1990 (1); Endoh *et al*. 1991 (4); Joh *et al*. 1991 (9); Fujii and Morita 1991 (1); Kitayama *et al*. 1991 (1); Noguchi and Kashiwazaki 1992 (5); Oka and Shiohara 1992 (9); Teraoka *et al*. 1994 (6); Hayashi *et al*. 1994 (11), Teraoka *et al*. 1997 (14), Walker 2001, Alire 2002 (3); Shiohara *et al*. 2000 (1); Li *et al*. 2002 (4); Hegger *et al*. 2003 (7); Teng and Zhou 2003 (5); Kusuhara *et al*. 2004 (2); Shin and LaFave 2004 (2); Shannag and Alhassan 2005 (4); Au *et al*. 2005 (3) Supuviriyakit and Pimanmas 2007 (2); Shiohara and Kusuhara 2008 (5); Benevant *et al*. 2008 (2); Wang and Hsu 2009 (1); Li *et al*. 2009 (8); Lee *et al*. 2009 (5); Li and Leong 2014 (3); Fadwa *et al*. 2014 (2), have been collected.

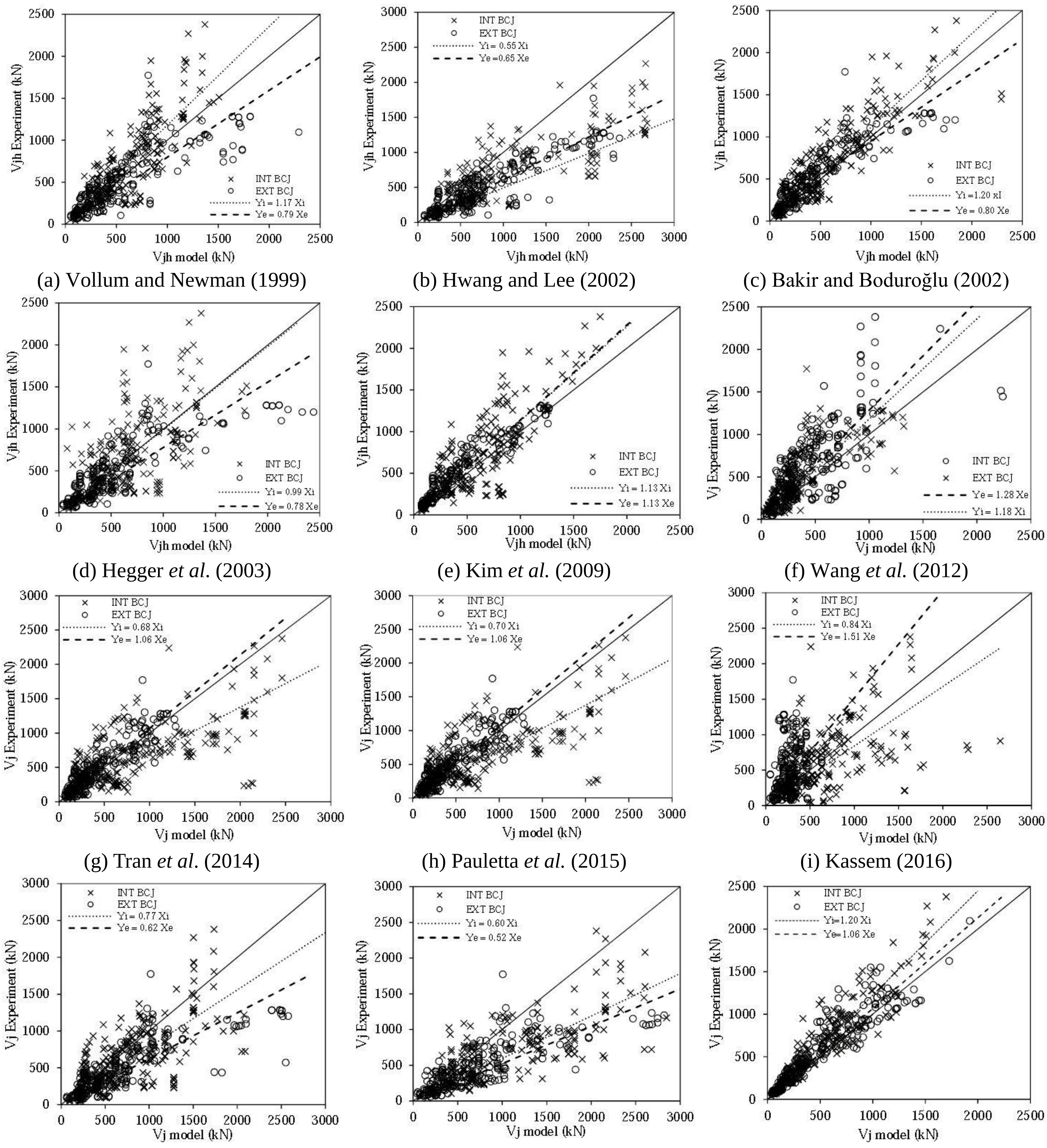
Database includes various specimen detailed with or without shear reinforcement and the specimens tested with or without column axial load. Specimens having transverse beam and slab are also included. Specimens reinforced with different pattern like, conventional type shear reinforcement, cross inclined bars through column and headed type reinforcement are also included. Specimens with high strength concrete and steel reinforcement are also included. Database covers a broad range of different parameters. The minimum and maximum range of various parameters is presented in Table 2.

Based on experimental results (Table B1 of Appendix-B), it has been observed that under cyclic or monotonic loading, beam-column joint specimens failed in different modes. Database considers the specimens with different failure modes. Observed failure modes are, (a) joint shear failure occurs before plastic hinges develop in the adjacent beam or column termed as 'joint shear failure' (JS); (b) joint failure occurs after plastic hinges develop at the adjoining beams termed as 'beam flexure yielding-joint shear failure' (BFJS); (c) joint failure occurs after plastic hinges develop in column termed as 'column flexure yielding-joint shear failure' (CFJS); and (d) failure occurs due to only 'beam flexure yielding' (BF). It has been observed that these failure mode of beam-column joint depends on interaction of aforementioned governing parameters presented in Table 2.

5. Shear strength prediction of proposed model

Shear strength prediction of aforementioned models along with the proposed model has been carried out on basis of collected experimental database. Shear strength of proposed model (V_{jmodel}) is compared with the results obtained from the experiments (V_{jexpt}). Prediction of proposed model for interior and exterior joint has been evaluated and presented in Fig. 6. In this figure, a diagonal line indicates that shear strength prediction of model is equal to the experimental results. In addition to diagonal line, two dotted lines having zero intercept with origin have been plotted representing the trend line of results for interior and exterior beam-column joints.

Equations presented in figures showed the slope of trend line (in terms of $y=mx$). The slope of trend line is used to determine the deviation of model prediction with experimental results. The eleven considered models either overestimate or underestimate the joint shear strength with respect to the experimental results. For exterior beam-column joint database, six models viz., Vollum and Newman (1999), Hwang and Lee (2002), Bakir and Boduroğlu (2002), Hegger *et al*. (2003), ACI 318-M14; and, EN 1998-1 (2004), predict higher joint shear strength than experimental results (means slope of trend line is significantly lower than one). However, in case of other five models viz., Kim *et al*. (2009), Wang *et al*. (2012), Tran *et al*. (2014), Pauletta *et al*. (2015), Kassem (2016), slope of trend line is higher than one indicating that model prediction is well below the experimental results. In case of interior joint, six models viz., Hwang and Lee (2002), Tran *et al*. (2014), Pauletta *et al*. (2015), Kassem (2016), ACI



(a) Vollum and Newman (1999) (b) Hwang and Lee (2002) (c) Bakir and Boduroğlu (2002)

(d) Hegger *et al.* (2003) (e) Kim *et al.* (2009) (f) Wang *et al.* (2012)

(g) Tran *et al.* (2014) (h) Pauletta *et al.* (2015) (i) Kassem (2016)

(j) ACI 318-M14 (k) EN 1998-1:2004 (l) Proposed Model

Fig. 6 Comparison of joint shear strength prediction with experimental results of various models

318-M14; and EN 1998-1 (2004), predicts higher joint shear strength than experimental results (slope of trend line is well below than one). However, some model viz., Vollum and Newman (1999), Bakir and Boduroğlu (2002), Kim *et al*. (2009), Wang *et al*. (2012), predicts lower joint shear strength than experimental results. In case of Hegger *et al.* (2003) model trend line for interior joint coincides with the diagonal line with a large deviation in results, which indicates that model prediction for 50 percent of database is higher and for the rest database, model prediction is lower than experimental results.

Table 3 shows results of statistical analysis for the ratio of V_{jexpt}/V_{jmodel} in terms of average (AVG) and coefficient of variation (CV) with respect to entire database. In most of the models, even though the slope of trend line is near to unity, value of standard deviation is very high indicating large scatter. For better fit of any model the average values should be near to unity and coefficient of variation should be minimum as possible. Larger value of coefficient of variation indicates that deviation is large in between the prediction of model and experimental results. Proposed model holds good agreement with experimental results with an average (AVG) of 1.25 and 1.24 and coefficient of variation (CV) of 0.26 and 0.24 for interior and exterior joints respectively.

6. Conclusions

Most of the available models and various national codes in literature for predicting joint shear strength are based on either of the three approaches i.e. theoretical, strut-and-tie or empirical methods. It has been observed that the shear strength predicted by these models vary considerably with experimental results and are inadequate for predicting the same with sufficient accuracy for wide range of parameters. In present study a simplified joint shear strength model based on hybrid approach has been proposed which overcomes the limitations of existing models.

This approach considers the compressive strut contribution based on strut-and-tie method and the parameters active under tension using empirical method. In compressive strut contribution the concrete compressive strength, column axial load and geometry of the joint panel zone have been considered. The parameters active under tension such as percentage of longitudinal reinforcement of beams and columns and shear reinforcement have been evaluated using empirical approach. Overall proposed model considers the influence of thirteen governing parameters. The prediction of proposed model has been compared with the eleven existing models from literature including model proposed by ACI 318 - 14 and Eurocode-8, using a total of 435 experimental results of interior and exterior beam-column joints. For same experimental database all eleven models predicts different joint shear strength for both interior and exterior joints. Moreover, the level of accuracy of the prediction of each model also varies with experimental results. To quantify the level of accuracy of shear strength predictions of proposed and existing models, statistical assessment of the results have been performed and the corresponding average (AVG) and coefficient of variation (CV) have been compared. Based on statistical analysis it is concluded that considered eleven models either overestimate or underestimate the joint shear strength. Whereas, proposed model predicts shear strength with reasonable accuracy as the average value is near to unity and coefficient of variation is 0.26 (interior) and 0.24 (exterior) which is least among all the considered models. Proposed model is non-iterative and simple in application for wide range of parameters.

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CC

Appendix A. Sample calculation by proposed model for experimental specimen 'BS-L-H1' of Wong and Kuang (2008)

Specimen details: (See Appendix B :- Table B1 :- Sr. No. 211)

(a) Column:
Width of column (b_c)=300 mm
Depth of column (h_c)=300 mm
Longitudinal reinforcement (%)=4-25 mm dia. =1962 mm^2 (2.18%)
Yield strength of reinforcement (f_{yc})=520 MPa
Axial load (N_c)=561.6 kN
Axial load ratio (N_c/A_cf_c)=0.19

(b) Beam:
Width of beam (b_b)=260 mm
Depth of beam (h_b)=450 mm
Longitudinal reinforcement (%)
Top=3-20 mm dia. 942 mm^2
Bottom=3-20 mm dia. 942 mm^2 (Total 1.61%)
Yield strength of reinforcement (f_{yc})=520 MPa

(c) Joint:
Shear reinforcement=1-10 mm dia. Stirrup=78.50 mm^2 (0.09%)
Yield strength of reinforcement (f_{yc})=500 MPa
Concrete compressive strength (f_c)=33.3 MPa
Total shear strength of joint=389.3 kN
Joint failed in 'Joint shear failure (JS)' mode.

Calculation as per the proposed model:
Total joint shear strength, $V_{jh} = V_{ch} + V_{sh}$

1. Strut mechanism,

$$V_{ch} = \alpha \beta f_c^{0.6} A_{strut} \cos\theta$$

Factor for beam longitudinal reinforcement;

$$\alpha = \left(\frac{100 A_{sb}}{A_b}\right)^{0.321}$$

Factor for column longitudinal reinforcement;

$$\beta = \left(\frac{100 A_{sc}}{A_c}\right)^{0.505}$$

$\alpha = 1.61$^$^{0.321} = 1.17$ and $\beta = 2.18$^$^{0.505} = 1.48$

$f_c^{0.6} = (33.3)^{0.6} = 8.19$ MPa

$A_{strut} = b_{ej} d_{strut}$

$b_{ej} = 300$ mm

$$a_c = \left(0.25 + \frac{0.85 N_c}{A_c f_{cc}}\right) h_c = 122.78 \text{ mm}$$

$$a_b = \left(\frac{A_{sb} f_{yb}}{0.85 b_b f_{cb}}\right) = 66.56 \text{ mm}$$

$$d_{strut} = \sqrt{a_c^2 + a_b^2} = 139.66 \text{ mm}$$

$A_{strut} = 41899.36$ mm^2

$\theta = 56.31$ degrees

Therefore, V_{ch}=329 kN

2. Truss mechanism, $V_{sh} = \phi A_{sj} f_{yj}$

ϕ=0.20

V_{sh}=0.20* 78.50* 500=7.85 kN

Therefore total joint shear strength;

V_{jh}=329+7.85=336.85 kN

It is seen that the proposed model prediction is lower than experimental result and hence it can be considered for the design purpose. The ratio of joint shear strength by proposed model with the experimental result is 1.15

Appendix B

Table B1 Experimental database for Exterior RC beam-column joints

Sr. No.	Researchers Group	Specimen Details	Column Properties					Beam Properties					ASB TOTAL	%ASB	Asjh	Asjv	Asj cross	fyj	fc (MPa)	Axial load (KN)	Axial Load Ratio (N/Ag.fc)	Vjh expt (KN)	Vjh expt (Mpa)	Failure mode
			bc	hc	Asc	%ASC	fyc	bb	hb	Asb bot	Asb top	fyb												
			(mm)	(mm)	(mm^2)		(MPa)	(mm)	(mm)	(mm^2)	(mm^2)	(MPa)			(mm^2)	(mm^2)	(mm^2)	(MPa)						
1	Hanson & Connor (1967)	I	381	381	7696	5.30	462	305	508	1320	2640	356	3960	2.56	1267	0	0	321	*35*	2865	0.57	972	6.70	BFJS
2	Hanson & Connor (1967)	I-A	381	381	7696	5.30	481	305	508	1320	2640	330	3960	2.56	713	0	0	364	*37*	2878	0.54	915	6.30	BFJS
3	Hanson (1971)	3	380	380	6040	4.18	415	305	508	1020	2038	440	3058	1.97	197	0	0	510	35	640	0.127	823	5.70	BFJS
4	Hanson (1971)	4	380	380	6040	4.18	415	305	508	1020	2038	440	3058	1.97	127	0	0	510	37	640	0.120	801	5.55	BFJS
5	Hanson (1971)	5	380	380	6040	4.18	415	305	508	1020	2038	440	3058	1.97	220	0	0	510	36	320	0.062	815	5.64	BFJS
6	Hanson (1971)	7	380	380	6040	4.18	415	305	508	1290	2580	352	3870	2.50	0	0	0	510	39	640	0.114	730	5.06	BFJS
7	Megget (1971)	M1	330	380	1548	1.23	303	254	457	1290	1290	290	2580	2.22	145	0	0	317	28	0	0.000	320	2.55	BFJS
8	Megget (1971)	M3	330	380	1548	1.23	303	254	457	1290	1290	290	2580	2.22	193	0	0	248	35	0	0.000	308	2.46	BFJS
9	Megget (1971)	Unit A	330	380	3060	2.44	365	254	457	1020	1638	372	2658	2.29	212	0	0	320	22	200	0.072	531	4.23	BFJS
10	Megget (1971)	Unit B	330	380	3060	2.44	365	254	457	1020	1638	372	2658	2.29	212	0	0	320	22	200	0.072	531	4.23	BFJS
11	Taylor (1974)	P1/41/24	140	140	804	4.10	365	100	200	240	240	372	480	2.40	73	0.00	0	460	33	240	0.37	125	6.38	JS
12	Taylor (1974)	P2/41/24	140	140	804	4.10	365	100	200	240	240	372	480	2.40	69	0.00	0	460	29	240	0.42	128	6.52	JS
13	Taylor (1974)	P3/41/24A	140	140	804	4.10	365	100	200	240	240	372	480	2.40	76	0.00	0	460	47	240	0.26	165	8.43	JS
14	Taylor (1974)	A3/41/24A	140	140	804	4.10	365	100	200	240	240	372	480	2.40	66	0.00	0	460	27	240	0.45	128	6.55	JS
15	Taylor (1974)	B3/41/24	140	140	804	4.10	365	100	200	240	240	372	480	2.40	150	0.00	0	460	22	240	0.56	114	5.82	JS
16	Taylor (1974)	C3/41/24BY	140	140	804	4.10	365	100	200	240	240	372	480	2.40	75	0.00	0	460	32	240	0.38	104	5.32	JS
17	Ohwada (1976)	JO-0	100	150	502	3.35	407	100	150	250	250	407	500	3.33	0	0	0	460	20	0	0.000	90	6.00	JS
18	Ohwada (1976)	JE-0	100	150	502	3.35	407	100	150	250	250	407	500	3.33	0	0	0	460	20	0	0.000	88	5.87	JS
19	Ohwada (1976)	JI-0	100	150	502	3.35	407	100	150	250	250	407	500	3.33	0	0	0	460	20	0	0.000	107	7.13	JS
20	Uzumeri (1977)	sp1	380	380	3060	2.12	330	304	508	1290	1935	350	3225	2.09	0	0	0	552	31	520	0.116	623	4.31	BFJS
21	Uzumeri (1977)	sp2	380	380	3060	2.12	330	304	508	1290	1935	350	3225	2.09	0	0	0	552	31	520	0.116	612	4.24	BFJS
22	Uzumeri (1977)	sp3	380	380	3060	2.12	330	304	508	1290	1935	350	3225	2.09	139	0	0	430	27	520	0.133	652	4.52	BFJS
23	Uzumeri (1977)	sp4	380	380	3060	2.12	330	304	508	1290	1935	350	3225	2.09	254	0	0	380	31	520	0.116	742	5.14	BFJS
24	Uzumeri (1977)	sp5	380	380	3060	2.12	330	380	508	1290	1935	350	3225	1.67	0	0	0	380	31	520	0.116	612	4.24	BFJS
25	Uzumeri (1977)	sp6	380	380	3060	2.12	330	380	508	1290	1935	350	3225	1.67	549	0	0	375	37	520	0.097	733	5.08	BFJS
26	Uzumeri (1977)	sp7	380	380	3060	2.12	330	380	508	1290	1935	350	3225	1.67	318	0	0	375	31	520	0.116	706	4.89	BFJS
27	Uzumeri (1977)	sp8	380	380	3060	2.12	393	380	508	1935	2580	350	4515	2.34	549	0	0	375	26	520	0.139	846	5.86	BFJS
28	Ogura (1977)	SS28	250	250	800	1.28	365	180	280	161	761	380	922	1.83	32	0	0	552	25	98	0.063	256	4.10	BFJS
29	Ogura (1977)	SS68	250	250	800	1.28	365	180	280	161	761	380	922	1.83	77	0	0	270	25	98	0.063	255	4.08	BFJS
30	Ogura (1977)	SST28	250	250	800	1.28	365	180	280	161	761	380	922	1.83	32	0	0	552	25	98	0.063	256	4.10	BFJS
31	Ogura (1977)	SS56	250	250	800	1.28	365	180	280	161	761	380	922	1.83	63	0	0	552	25	98	0.063	275	4.40	BFJS
32	Ehsani and Wight (1985 a)	1S (TR. B/SLAB)	300	300	1720	1.91	NA	259	480	860	860	NA	1720	1.38	507	573	0	437	51	222	0.05	384	4.27	BFJS
33	Ehsani and Wight (1985 a)	2S (TR. B/SLAB)	300	300	1720	1.91	NA	259	480	860	860	NA	1720	1.38	760	573	0	437	48	222	0.05	368	4.09	BFJS
34	Ehsani and Wight (1985 a)	3S (TR. B/SLAB)	300	300	2292	2.55	NA	259	439	860	860	NA	1720	1.51	507	573	0	437	35	222	0.07	402	4.47	BFJS
35	Ehsani and Wight (1985 a)	6S (TR. B/SLAB)	340	340	1720	1.49	NA	300	480	1161	1161	NA	2322	1.61	507	573	0	437	42	303.31	0.06	490	4.24	BFJS
36	Ehsani and Wight (1985 b)	1B	300	300	1720	1.91	NA	259	480	2021	2021	458	4042	3.25	507	573	0	437	41	178	0.05	591	6.57	BFJS
37	Ehsani and Wight (1985 b)	2B	300	300	2292	2.55	NA	259	439	2021	2021	458	4042	3.55	507	573	0	437	42	221	0.06	679	7.54	BFJS
38	Ehsani and Wight (1985 b)	3B	300	300	1720	1.91	NA	259	480	2021	2021	458	4042	3.25	760	573	0	437	49	221	0.05	1053	11.70	BFJS
39	Ehsani and Wight (1985 b)	4B	300	300	2292	2.55	NA	259	439	2021	2021	458	4042	3.55	760	573	0	437	54	221	0.05	1062	11.80	BFJS
40	Ehsani and Wight (1985 b)	6B	340	340	1720	1.49	NA	300	480	1734	1734	458	3468	2.41	507	NA	0	437	48	303	0.05	437	3.78	BFJS
41	Ehsani et al. (1987)	1	340	340	2122	1.84	428	300	480	1169	1169	428	2338	1.62	760	NA	0	428	65	133	0.02	676	5.85	BFJS
42	Ehsani et al. (1987)	2	340	340	2122	1.84	428	300	480	1433	1433	428	2866	1.99	760	NA	0	428	67	338	0.04	592	5.12	BFJS
43	Ehsani et al. (1987)	3	300	300	2122	2.36	428	259	439	1257	1257	428	2514	2.21	760	NA	0	428	65	383	0.07	716	7.96	BFJS
44	Ehsani et al. (1987)	4	300	300	2800	3.11	428	259	439	1558	1558	428	3116	2.74	760	NA	0	428	67	325	0.05	921	10.23	JS
45	Ehsani et al. (1987)	5	300	300	2292	2.55	428	259	439	2021	2021	276	4042	3.55	760	NA	0	428	44	222	0.06	844	9.38	BFJS
46	Durrani and Zerbe (1987)	J2 (TR BEAM)	305	305	3040	3.27	NA	254	381	1146	1146	NA	2292	2.37	1267	1013	0	531	47	175	0.04	633	6.80	BFJS
47	Durrani and Zerbe (1987)	J5 (TR. B/SLAB)	305	305	3040	3.27	NA	254	381	1146	1906	NA	3052	3.15	1267	1013	0	531	47	175	0.04	985	10.59	BFJS
48	Durrani and Zerbe (1987)	J7 (TR. B/SLAB)	305	305	3040	3.27	NA	254	381	1146	2413	NA	3559	3.68	1267	1013	0	531	49	175	0.04	760	8.17	BFJS

Table B1 Continued

Sr. No.	Researchers Group	Specimen Details	Column Properties					Beam Properties																
			bc	hc	Asc	%ASC	fyc	bb	hb	Asb bot	Asb top	fyb	ASB TOTAL	%ASB	Asjh	Asjv	Asj cross	fyj	fc (MPa)	Axial load (KN)	Axial Load Ratio (N/Ag.fc)	Vjh expt (KN)	Vjh expt (Mpa)	Failure mode
			(mm)	(mm)	(mm^2)		(MPa)	(mm)	(mm)	(mm^2)	(mm^2)	(MPa)			(mm^2)	(mm^2)	(mm^2)	(MPa)						
49	Kurose (1987)	S41	300	300	2280	2.53	387	260	360	1133	1133	387	2266	2.42	382	0	0	294	24	0	0.00	408	4.53	JS
50	Kurose (1987)	S42	300	300	2280	2.53	387	260	360	1133	1133	387	2266	2.42	763	0	0	294	24	0	0.00	402	4.47	JS
51	Kurose (1987)	U41L	300	300	2280	2.53	387	260	360	1133	1133	387	2266	2.42	382	0	0	294	27	0	0.00	413	4.59	JS
52	Ehsani and Alameddine (1991)	LL8	356	356	3482	2.75	458	318	508	1962	1962	458	3924	2.43	1520	774	0	427	55	278	0.04	942	7.43	BFJS
53	Ehsani and Alameddine (1991)	LH8	356	356	3482	2.75	458	318	508	1962	1962	458	3924	2.43	2280	774	0	427	55	278	0.04	946	7.46	BFJS
54	Ehsani and Alameddine (1991)	HL8	356	356	3925	3.10	458	318	508	2640	2640	458	5280	3.27	1520	1013	0	427	55	487	0.07	1231	9.71	JS
55	Ehsani and Alameddine (1991)	HH8	356	356	3925	3.10	458	318	508	2640	2640	458	5280	3.27	2280	1013	0	427	55	487	0.07	1230	9.71	BFJS
56	Ehsani and Alameddine (1991)	LL11	356	356	3482	2.75	458	318	508	1962	1962	458	3924	2.43	1520	774	0	427	75	285	0.03	929	7.33	BFJS
57	Ehsani and Alameddine (1991)	LH11	356	356	3482	2.75	458	318	508	1962	1962	458	3924	2.43	1520	774	0	427	75	285	0.03	925	7.30	BFJS
58	Ehsani and Alameddine (1991)	HL11	356	356	3925	3.10	458	318	508	2640	2640	458	5280	3.27	1520	1013	0	427	75	570	0.06	1177	9.29	JS
59	Ehsani and Alameddine (1991)	HH11	356	356	3925	3.10	458	318	508	2640	2640	458	5280	3.27	2280	1013	0	427	75	570	0.06	1217	9.60	BFJS
60	Ehsani and Alameddine (1991)	LL14	356	356	3482	2.75	458	318	508	1962	1962	458	3924	2.43	1520	774	0	427	97	246	0.02	936	7.39	BFJS
61	Ehsani and Alameddine (1991)	HL14	356	356	3482	2.75	458	318	508	1962	1962	458	3924	2.43	2280	1013	0	427	97	246	0.02	950	7.50	BFJS
62	Ehsani and Alameddine (1991)	LH14	356	356	3482	2.75	458	318	508	1962	1962	458	3924	2.43	1520	774	0	427	97	246	0.02	933	7.36	BFJS
63	Ehsani and Alameddine (1991)	HH14	356	356	3925	3.10	458	318	508	2640	2640	458	5280	3.27	2280	1013	0	427	97	492	0.04	1217	9.60	BFJS
64	Kaku and Asakusa (1991)	2	220	220	804	1.66	360	160	220	531	531	391	1061	3.02	113	0	0	250	42	199	0.10	201.34	4.16	BF
65	Kaku and Asakusa (1991)	3	220	220	804	1.66	360	160	220	531	531	391	1061	3.02	113	0	0	250	42	0	0	198.92	4.11	BFJS
66	Kaku and Asakusa (1991)	4	220	220	804	1.66	360	160	220	531	531	391	1061	3.02	28	0	0	281	45	360	0.17	196.50	4.06	BFJS
67	Kaku and Asakusa (1991)	5	220	220	804	1.66	360	160	220	531	531	391	1061	3.02	28	0	0	281	37	160	0.09	196.50	4.06	BFJS
68	Kaku and Asakusa (1991)	6	220	220	804	1.66	360	160	220	531	531	391	1061	3.02	28	0	0	281	40	0	0	200.86	4.15	BFJS
69	Kaku and Asakusa (1991)	7	220	220	804	1.66	360	160	220	531	531	392	1061	3.02	113	0	0	250	32	194	0.12	198.92	4.11	BF
70	Kaku and Asakusa (1991)	8	220	220	804	1.66	360	160	220	531	531	393	1061	3.02	113	0	0	250	41	160	0.08	197.47	4.08	BF
71	Kaku and Asakusa (1991)	9	220	220	942	1.95	395	160	220	531	531	391	1061	3.02	113	0	0	250	41	0	0	197.47	4.08	BFJS
72	Kaku and Asakusa (1991)	11	220	220	942	1.95	395	160	220	531	531	391	1061	3.02	28	0	0	281	42	160	0.08	196.99	4.07	BFJS
73	Kaku and Asakusa (1991)	12	220	220	942	1.95	395	160	220	531	531	391	1061	3.02	28	0	0	281	35	0	0	198.92	4.11	BFJS
74	Kaku and Asakusa (1991)	13	220	220	942	1.95	395	160	220	531	531	391	1061	3.02	113	0	0	250	46	-100	-0.04	199.89	4.13	BFJS
75	Kaku and Asakusa (1991)	14	220	220	757	1.56	395	160	220	531	531	391	1061	3.02	28	0	0	281	41	160	0.08	196.99	4.07	BFJS
76	Kaku and Asakusa (1991)	15	220	220	845	1.75	395	160	220	531	531	391	1061	3.02	28	0	0	281	40	160	0.08	196.50	4.06	BFJS
77	Kaku and Asakusa (1991)	17	220	220	540	1.12	395	160	220	531	531	391	1061	3.02	113	0	0	250	40	0	0	200.38	4.14	CFJS
78	Kaku and Asakusa (1991)	18	220	220	339	0.70	285	160	220	531	531	391	1061	3.02	113	0	0	250	41	0	0	194.57	4.02	CF
79	Tsonos et al. (1992)	X2	200	200	314	0.79	465	200	300	305	305	496	610	1.02	302	0	616	495	31	580	0.46	150.68	3.77	BF
80	Tsonos et al. (1992)	X6	200	200	616	1.54	485	200	300	616	616	485	1232	2.05	0	0	616	495	33	520	0.40	302.5	7.56	JS
81	Tsonos et al. (1992)	S'6	200	200	1232	3.08	485	200	300	616	616	485	1232	2.05	0	0	0	495	35	558	0.40	303.77	7.59	JS
82	Tsonos et al. (1992)	F2	200	200	616	1.54	485	200	300	616	616	485	1232	2.05	0	0	0	495	29	462.2	0.40	205.55	5.14	JS
83	Ortiz (1993)	BCJ2	200	300	1314	2.19	485	200	400	440	440	720	880	1.10	99	0.00	0	600	38	0	0.05	359	5.98	JS
84	Ortiz (1993)	BCJ3	200	300	1752	2.92	485	200	400	440	440	720	880	1.10	0	0.00	0	600	33	0	0.06	341	5.69	JS
85	Ortiz (1993)	BCJ4	200	300	2190	3.65	485	200	400	440	440	720	880	1.10	192	0.00	0	600	34	0	0.06	374	6.24	JS
86	Ortiz (1993)	BCJ5	200	300	2190	3.65	485	200	400	440	440	720	880	1.10	0	0.00	0	600	38	300	0.05	329	5.49	JS
87	Ortiz (1993)	BCJ6	200	300	2190	3.65	485	200	400	440	440	720	880	1.10	0	0.00	0	600	35	300	0.05	330	5.50	JS
88	Ortiz (1993)	BCJ7	200	300	2190	3.65	485	200	400	440	440	720	880	1.10	438	0.00	0	600	35	300	0.08	472	7.87	JS
89	Scott (1996)	C1	150	150	804	3.57	525	110	210	226	226	575	452	1.96	57	0	0	414	50	275	0.24	148.80	6.61	BF
90	Scott (1996)	C1A	150	150	804	3.57	525	110	210	226	226	575	452	1.96	57	0	0	414	60	275	0.20	148.00	6.58	BF
91	Scott (1996)	CIAL	150	150	804	3.57	525	110	210	226	226	575	452	1.96	57	0	0	414	42	50	0.05	114	5.08	JS
92	Scott (1996)	C2	150	150	804	3.57	525	110	210	226	226	575	452	1.96	57	0	0	414	62	275	0.20	110.36	4.90	JS
93	Scott (1996)	C3	150	150	804	3.57	525	110	210	226	226	575	452	1.96	57	0	0	414	45	275	0.27	148.48	6.60	BF
94	Scott (1996)	C3L	150	150	804	3.57	525	110	210	226	226	575	452	1.96	57	0	0	414	44	50	0.05	112	4.99	JS
95	Scott (1996)	C4	150	150	804	3.57	525	110	210	226	226	525	452	1.96	57	0	0	414	52	275	0.24	159.61	7.09	JS

Table B1 Continued

Sr. No.	Researchers Group	Specimen Details	Column Properties bc (mm)	hc (mm)	Asc (mm^2)	%ASC	fyc (MPa)	Beam Properties bb (mm)	hb (mm)	Asb bot (mm^2)	Asb top (mm^2)	fyb (MPa)	ASB TOTAL	%ASB	Asjh (mm^2)	Asjv (mm^2)	Asj cross (mm^2)	fyj (MPa)	fc (MPa)	Axial load (KN)	Axial Load Ratio (N/Ag.fc)	Vjh expt (KN)	Vjh expt (Mpa)	Failure mode
96	Scott (1996)	C4A	150	150	804	3.57	525	110	210	226	226	525	452	1.96	57	0	0	414	55	275	0.22	169.61	7.54	JS
97	Scott (1996)	C4AL	150	150	804	3.57	525	110	210	226	226	525	452	1.96	57	0	0	414	45	50	0.05	154	6.86	JS
98	Scott (1996)	C6	150	150	804	3.57	525	110	210	226	226	525	452	1.96	57	0	0	414	50	275	0.25	118.66	5.27	JS
99	Scott (1996)	C6L	150	150	804	3.57	525	110	210	226	226	525	452	1.96	57	0	0	414	57	50	0.04	141	6.26	JS
100	Scott (1996)	C7	150	150	804	3.57	525	110	300	226	226	575	452	1.37	57	0	0	414	44	275	0.28	103.48	4.60	JS
101	Scott (1996)	C8	150	150	804	3.57	525	110	300	226	226	576	452	1.37	57	0	0	414	56	275	0.22	89.04	3.96	JS
102	Scott (1996)	C9	150	150	804	3.57	525	110	300	226	226	577	452	1.37	57	0	0	414	45	275	0.27	92.21	4.10	JS
103	Parker & Bullman (1997)	4a	300	300	804	0.89	550	250	500	981	981	560	1963	1.57	0	0	0	560	49	0	0.00	231.27	2.57	JS
104	Parker & Bullman (1997)	4b	300	300	804	0.89	550	250	500	981	981	560	1963	1.57	0	0	0	560	49	300	0.07	270.47	3.01	JS
105	Parker & Bullman (1997)	5a	300	300	1963	2.18	485	250	500	981	981	485	1963	1.57	679	0	0	480	53	0	0.00	455.89	5.07	JS
106	Parker & Bullman (1997)	5e	300	300	1963	2.18	485	250	500	1608	1608	515	3215	2.57	679	0	0	480	56	300	0.00	593.93	6.60	JS
107	Parker & Bullman (1997)	5f	300	300	1963	2.18	485	250	500	1608	1608	515	3215	2.57	679	0	0	480	54	600	0.06	647.67	7.20	JS
108	Wallace et al. (1998)	BCEJ1	457	457	3854	1.85	455	457	610	1520	2027	483	3547	1.27	1520	1285	0	462	36	0	0.00	741.86	3.55	BF
109	Wallace et al. (1998)	BCEJ2	457	457	3854	1.85	455	457	610	1520	2027	483	3547	1.27	760	1285	0	462	34	0	0.00	790.53	3.79	CFJS
110	Tsonos (1999)	M1	200	200	314	0.79	465.1	200	300	383	383	465.1	766	1.28	402	0	0	494.6	34	300	0.22	153.66	3.84	CFJS
111	Clyde et al. (2000)	#2	305	457	3040	2.18	469.5	305	406	2462	2462	454.4	4924	3.98	0	0	0	427	46	689	0.11	1154	8.28	JS
112	Clyde et al. (2000)	#4	305	457	3040	2.18	469.5	305	406	2462	2462	454.4	4924	3.98	0	0	0	427	41	1380	0.24	1302.5	9.34	JS
113	Clyde et al. (2000)	#5	305	457	3040	2.18	469.5	305	406	2462	2462	454.4	4924	3.98	0	0	0	427	37	1357	0.26	1184.8	8.50	JS
114	Clyde et al. (2000)	#6	305	457	3040	2.18	469.5	305	406	2462	2462	454.4	4924	3.98	0	0	0	427	40	587	0.11	1104.5	7.92	JS
115	Hamil (2000)	C6LN0	150	150	804	3.57	525	110	210	402	402	525	804	3.48	0	0	0	414	53	50	0.04	114	5.06	JS
116	Hamil (2000)	C6LN1	150	150	804	3.57	525	110	210	402	402	525	804	3.48	57	0	0	414	53	50	0.04	119	5.27	JS
117	Hamil (2000)	C6LN3	150	150	804	3.57	525	110	210	402	402	525	804	3.48	170	0	0	414	51	50	0.04	138	6.13	JS
118	Hamil (2000)	C6LN5	150	150	804	3.57	525	110	210	402	402	525	804	3.48	283	0	0	414	38	50	0.06	165	7.33	JS
119	Hamil (2000)	C6LH0	150	150	804	3.57	525	110	210	402	402	525	804	3.48	0	0	0	414	105	100	0.04	164	7.28	JS
120	Hamil (2000)	C6LH1	150	150	804	3.57	525	110	210	402	402	525	804	3.48	57	0	0	414	105	100	0.04	169	7.51	JS
121	Hamil (2000)	C6LH3	150	150	804	3.57	525	110	210	402	402	525	804	3.48	170	0	0	414	100	100	0.04	188	8.34	JS
122	Hamil (2000)	C6LH5	150	150	804	3.57	525	110	210	402	402	525	804	3.48	283	0	0	414	104	100	0.04	239	10.63	BF
123	Hamil (2000)	C4ALN0	150	150	804	3.57	525	110	210	402	402	525	804	3.48	0	0	0	414	44	50	0.05	130	5.76	JS
124	Hamil (2000)	C4ALN1	150	150	804	3.57	525	110	210	402	402	525	804	3.48	57	0	0	414	47	50	0.05	162	7.21	JS
125	Hamil (2000)	C4ALN3	150	150	804	3.57	525	110	210	402	402	525	804	3.48	170	0	0	414	43	50	0.05	168	7.48	JS
126	Hamil (2000)	C4ALN5	150	150	804	3.57	525	110	210	402	402	525	804	3.48	283	0	0	414	52	50	0.04	185	8.23	JS
127	Hamil (2000)	C4ALH0	150	150	804	3.57	525	110	210	402	402	525	804	3.48	0	0	0	414	108	100	0.04	201	8.93	JS
128	Hamil (2000)	C4ALH1	150	150	804	3.57	525	110	210	402	402	525	804	3.48	57	0	0	414	99	100	0.04	205	9.11	BF
129	Hamil (2000)	C4ALH3	150	150	804	3.57	525	110	210	402	402	525	804	3.48	170	0	0	414	110	100	0.04	230	10.21	BF
130	Hamil (2000)	C4ALH5	150	150	804	3.57	525	110	210	402	402	525	804	3.48	283	0	0	414	102	100	0.04	240	10.67	BF
131	Hakuto et al (2000)	O6	460	460	1810	0.86	308	300	500	905	1357	308	2262	1.51	57	0	0	398	41	0	0.00	434	2.05	BFJS
132	Hakuto et al (2000)	O7	460	460	1810	0.86	308	300	500	905	1357	308	2262	1.51	57	0	0	398	37	0	0.00	440	2.08	BFJS
133	Calvi et al (2001)	T1	200	200	302	0.76	386	200	330	327	327	366	654	0.99	0	0	0	366	24	120	0.13	62.29	1.56	BFJS
134	Pampanin et al. (2002)	T2	200	200	302	0.76	386	200	330	327	327	366	654	0.99	0	0	0	366	29	100	0.09	72.9	1.82	JS
135	Pantelides et al (2002)	1	406	406	3925	2.38	469.9	406	406	2826	2826	458.9	5652	3.43	0	0	0	458.9	33	546.7	0.10	872	5.29	JS
136	Pantelides et al (2002)	2	406	406	3925	2.38	469.9	406	406	2826	2826	458.9	5652	3.43	0	0	0	458.9	30	1247	0.25	833	5.05	JS
137	Pantelides et al (2002)	3	406	406	3925	2.38	469.9	406	406	2826	2826	458.9	5652	3.43	0	0	0	458.9	34	561.5	0.10	826	5.01	JS
138	Pantelides et al (2002)	4	406	406	3925	2.38	469.9	406	406	2826	2826	458.9	5652	3.43	0	0	0	458.9	32	1304.8	0.25	927	5.62	CFJS
139	Pantelides et al (2002)	5	406	406	3925	2.38	469.9	406	406	2826	2826	458.9	5652	3.43	0	0	0	458.9	32	523.6	0.10	770	4.67	BFJS
140	Pantelides et al (2002)	6	406	406	3925	2.38	469.9	406	406	2826	2826	458.9	5652	3.43	0	0	0	458.9	31	1280	0.25	851	5.16	CFJS
141	Gencoglu & Eren (2002)	#2	250	400	1206	1.21	500	250	600	462	462	500	924	0.62	0	0	0	500	30	150	0.05	114	1.14	JS
142	Hegger et al. (2003)	RK1	150	240	804	2.23	530	150	300	628	628	530	1256	2.79	628	402	0	530	58	500	0.24	374	10.39	BF
143	Hegger et al. (2003)	RK2	150	240	1005	2.79	530	150	300	628	942	530	1570	3.49	402	353	0	530	57	500	0.24	417	11.58	BF
144	Hegger et al. (2003)	RK3	150	240	1206	3.35	530	150	300	628	628	530	1256	2.79	628	402	0	530	57	500	0.24	402	11.17	BF
145	Hegger et al. (2003)	RK4	150	200	1206	4.02	530	150	300	628	628	530	1256	2.79	628	402	0	530	52	500	0.32	357	11.90	JS

Table B1 Continued

Sr. No.	Researchers Group	Specimen Details	Column Properties					Beam Properties												fc (MPa)	Axial load (KN)	Axial Load Ratio (N/Ag.fc)	Vjh expt (KN)	Vjh expt (Mpa)	Failure mode
			bc (mm)	hc (mm)	Asc (mm^2)	%ASC	fyc (MPa)	bb (mm)	hb (mm)	Asb bot (mm^2)	Asb top (mm^2)	fyb (MPa)	ASB TOTAL	%ASB	Asjh (mm^2)	Asjv (mm^2)	Asj cross (mm^2)	fyj (MPa)							
146	Hegger et al. (2003)	RK5	150	200	1206	4.02	530	150	300	981	981	530	1963	4.36	628	402	0	530	55	500	0.30	423	14.10	JS
147	Hegger et al. (2003)	RK6	150	200	1206	4.02	530	150	300	981	981	530	1963	4.36	628	402	0	530	87	500	0.19	556	18.53	JS
148	Hegger et al. (2003)	RK7	150	200	1206	4.02	530	150	400	628	628	530	1256	2.09	628	402	0	530	55	500	0.30	277	9.23	JS
149	Hegger et al. (2003)	RK8	150	200	1206	4.02	530	150	300	628	628	530	1256	2.79	628	402	0	530	39	500	0.43	273	9.10	JS
150	Chutarat & Aboutaha (2003)	B-Group-2 (H)	508	406	2322	1.13		356	457	2055	2055		4110	2.53	2027	774	0	365	33	0	0	471	2.28	BF
151	Chutarat & Aboutaha (2003)	I-Group 1	508	406	3096	1.50		356	457	2027	2027		4054	2.49	2027	1548	0	365	28	0	0	932	4.52	JS
152	Chutarat & Aboutaha (2003)	II-Group 1 (H)	508	406	3096	1.50		356	457	3575	3575		7150	4.39	2027	1548	0	365	28	0	0	1188	5.76	JS
153	Chun & Kim (2004)	JC2	500	500	3802	1.52	402.9	350	500	2281	3041	402.9	5322	3.04	471	2281	0	383.9	60	490	0.03	1343	5.37	JS
154	Chun & Kim (2004)	JM2	500	500	3802	1.52		350	500	2281	3041		5322	3.04	471	2281	0	383.9	60	490	0.03	1342	5.37	JS
155	Alva (2004)	LVP1	200	300	1206	2.01	630	200	400	804	804	630	1608	2.01	402		0	610	40	360	0.15	540	9.00	JS
156	Hwang et al (2004)	28-3T4	550	550	9646	3.19	458	380	500	1963	1963	491	3925	2.07	760	0	0	436	35	196	0.02	1290	4.26	BF
157	Hwang et al (2004)	28-0T0	550	550	9646	3.19	458	380	500	1963	1963	491	3925	2.07	0	0	0	0	33	196	0.02	1138	3.76	BFJS
158	Hwang et al (2004)	70-2T5	450	450	6431	3.18	458	320	450	1963	1963	491	3925	2.73	792	0	0	469	77	196	0.01	1162	5.74	BF
159	Hwang et al (2004)	70-1T55	450	450	6431	3.18	458	320	450	1963	1963	491	3925	2.73	792	0	0	469	70	196	0.01	1126	5.56	BF
160	Hwang et al. (2005)	2T5	450	450	6431	3.18	458	320	450	1963	1963	491	3925	2.73	792	0	0	469	77	196	0.01	1162	5.74	BF
161	Hwang et al. (2005)	1T55	450	450	6431	3.18	458	320	450	1963	1963	491	3925	2.73	792	0	0	469	70	196	0.01	1126	5.56	BF
162	Hwang et al. (2005)	0T0	420	420	6431	3.65	421	320	450	1963	1963	430	3925	2.73	0	0	0	430	67	196	0.02	1078	6.11	BFJS
163	Hwang et al. (2005)	3T44	420	420	6431	3.65	421	320	450	1963	1963	430	3925	2.73	1140	0	0	498	77	196	0.01	1157	6.56	BF
164	Hwang et al. (2005)	1B8	420	420	6431	3.65	430	320	450	1963	1963	435	3925	2.73	0	0	0	435	62	196	0.02	1151	6.52	BFJS
165	Hwang et al. (2005)	3T3	420	420	6431	3.65	421	320	450	1963	1963	430	3925	2.73	638	0	0	471	69	196	0.02	1058	6.00	BFJS
166	Hwang et al. (2005)	2T4	420	420	6431	3.65	421	320	450	1963	1963	430	3925	2.73	507	0	0	498	71	196	0.02	1066	6.04	BFJS
167	Hwang et al. (2005)	1T44	420	420	6431	3.65	421	320	450	1963	1963	430	3925	2.73	507	0	0	498	73	196	0.02	1072	6.08	BFJS
168	Kuang & Wong (2006)	BS-OL	300	300	1964	2.18	520	260	450	942	942	520	1884	1.61	0	0	0	520	31	402.98	0.14	264	2.94	JS
169	Kuang & Wong (2006)	BS-LL	300	300	1964	2.18	520	260	450	942	942	520	1884	1.61	0	0	0	520	31	402.98	0.14	535	5.94	JS
170	Kuang & Wong (2006)	BS-U	300	300	1964	2.18	520	260	450	942	942	520	1884	1.61	0	0	0	520	31	402.98	0.14	411	4.57	JS
171	Kuang & Wong (2006)	BS-L-LS	300	300	1964	2.18	520	260	450	942	942	520	1884	1.61	0	0	0	520	31	402.98	0.14	416	4.62	JS
172	Liu (2006)	RC-6	250	250	472	0.76	306.7	250	330	452	452	306.7	904	1.10	57	226	0	383.7	25	100	0.06	149	2.38	BFJS
173	Liu (2006)	NZ-7	250	250	904	1.45	306.7	250	330	452	452	306.7	904	1.10	283	226	0	383.7	25	100	0.06	147	2.36	BFJS
174	Chun et.al (2007)	JM1	500	500	3042	1.22	NA	350	500	3041	2281	NA	5322	3.04	1013	3041	0	500	60	0	0	1199	4.80	JS
175	Chun et.al (2007)	JM2 (H)	500	500	3042	1.22	NA	350	500	3041	2281	NA	5322	3.04	1013	3041	0	500	60	0	0	1197	4.79	JS
176	Chun et.al (2007)	JC-NO 11-1	650	520	6334	1.87	NA	450	505	2870	2870	NA	5740	2.53	1520	1583	0	500	33	0	0	1125	3.33	JS
177	Chun et.al (2007)	JM-NO 11-1a (H)	650	520	6334	1.87	NA	450	505	2870	2870	NA	5740	2.53	1520	1583	0	500	33	0	0	1113	3.29	BFJS
178	Chun et.al (2007)	JM-NO 11-1b (H)	650	520	6334	1.87	NA	450	505	2870	2870	NA	5740	2.53	1520	1583	0	500	33	0	0	1080	3.20	BFJS
179	Lee and Ko (2007)	S0	400	600	2280	0.95	NA	300	450	1521	1521	NA	3042	2.25	1571	0	0	471	33	942	0.12	883	3.68	BF
180	Lee and Ko (2007)	S50	400	600	2280	0.95	NA	300	450	1521	1521	NA	3042	2.25	1571	0	0	471	34	988	0.12	886	3.69	BF
181	Lee and Ko (2007)	W0	600	400	3802	1.58	NA	300	450	1521	1521	NA	3042	2.25	942	0	0	471	35	835	0.10	907	3.78	BFJS
182	Lee and Ko (2007)	W75	600	400	3802	1.58	NA	300	450	1521	1521	NA	3042	2.25	628	0	0	471	37	878	0.10	907	3.78	BFJS
183	Lee and Ko (2007)	W150	600	400	3802	1.58	NA	300	450	1521	1521	NA	3042	2.25	942	0	0	471	35	842	0.10	914	3.81	BFJS
184	Alva et al. (2007)	LVP2	200	300	2010	3.35	594	200	400	804	804	594	1608	2.01	100	0	0	602	44	397	0.15	514	8.57	JS
185	Alva et al. (2007)	LVP3	200	300	2010	3.35	594	200	400	804	804	594	1608	2.01	201	0	0	602	24	215	0.15	364	6.07	JS
186	Alva et al. (2007)	LVP4	200	300	2010	3.35	594	200	400	804	804	594	1608	2.01	100	0	0	602	25	221	0.15	327	5.45	JS
187	Alva et al. (2007)	LVP5	200	300	2010	3.35	594	200	400	804	804	594	1608	2.01	201	0	0	602	26	233	0.15	380	6.33	JS
188	Tsonos (2007)	A1	200	200	628	1.57	500	200	300	314	314	500	628	1.05	424	157	0	540	35	200	0.14	157.28	3.93	BFJS
189	Tsonos (2007)	E1	200	200	1231	3.08	500	200	300	462	462	495	923	1.54	424	308	0	540	22	200	0.23	233.96	5.85	JS
190	Tsonos (2007)	G1	200	200	1231	3.08	500	200	300	462	462	495	923	1.54	452	308	0	500	22	200	0.23	239.32	5.98	JS
191	Climent (2007)	IWB	230	230	804	1.52	500	700	165	678	1130	500	1808.64	1.57	0	0	0	0	21	0	0	403	7.62	JS
192	Idayani (2007)	S1	180	180	804	2.48	460	150	300	402	628	460	1030	2.29	0	0	0	250	36	90	0.08	194	5.99	JS
193	Idayani (2007)	S2	180	180	804	2.48	460	150	300	402	628	460	1030	2.29	0	0	0	250	94	90	0.03	199	6.14	JS
194	Idayani (2007)	S3	180	180	804	2.48	460	150	300	402	628	460	1030	2.29	170	0	0	250	36	90	0.08	224	6.91	JS
195	Karayannis et al. (2007)	A0	200	200	314	0.79	580	200	300	157	157	580	314	0.52	0	0	0	580	32	152.29	0.12	82.56	2.06	JS

Table B1 Continued

Sr. No.	Researchers Group	Specimen Details	Column Properties					Beam Properties											fc (MPa)	Axial load (KN)	Axial Load Ratio (N/Ag.fc)	Vjh expt (KN)	Vjh expt (Mpa)	Failure mode
			bc	hc	Asc	%ASC	fyc	bb	hb	Asb bot	Asb top	fyb	ASB TOTAL	%ASB	Asjh	Asjv	Asj cross	fyj						
			(mm)	(mm)	(mm^2)		(MPa)	(mm)	(mm)	(mm^2)	(mm^2)	(MPa)			(mm^2)	(mm^2)	(mm^2)	(MPa)						
196	Karayannis et al. (2007)	A1	200	200	314	0.79	580	200	300	157	157	580	314	0.52	101	0	0	580	32	126.4	0.10	82.93	2.07	BFJS
197	Karayannis et al. (2007)	A2	200	200	314	0.79	580	200	300	157	157	580	314	0.52	201	0	0	580	32	152.29	0.12	82.93	2.07	BFJS
198	Karayannis et al. (2007)	A3	200	200	314	0.79	580	200	300	157	157	580	314	0.52	302	0	0	580	32	152.29	0.12	82.2	2.06	BFJS
199	Karayannis & sirkelis (2008)	A1	200	200	314	0.79	574	200	300	157	157	574	314	0.52	0	0	0	574	36	70	0.05	74.95	1.87	JS
200	Karayannis & sirkelis (2008)	A2	200	200	314	0.79	574	200	300	157	157	574	314	0.52	0	0	0	574	36	70	0.05	76.06	1.90	JS
201	Karayannis et al. (2008)	B1	200	300	314	0.52	580	200	300	471	471	580	942	1.57	101	0	0	580	32	228.43	0.12	253.29	4.22	JS
202	Karayannis et al. (2008)	C0	200	300	616	1.03	580	200	300	452	452	580	904	1.51	0	157	0	580	32	228.43	0.12	239.7	4.00	JS
203	Karayannis et al. (2008)	C2	200	300	616	1.03	580	200	300	452	452	580	904	1.51	201	157	0	580	32	228.43	0.12	242.76	4.05	BFJS
204	Karayannis et al. (2008)	C3	200	300	616	1.03	580	200	300	452	452	580	904	1.51	302	157	0	580	32	228.43	0.12	239.7	4.00	BFJS
205	Karayannis et al. (2008)	C5	200	300	616	1.03	580	200	300	452	452	580	904	1.51	503	157	0	580	32	228.43	0.12	243.53	4.06	BFJS
206	Kusuhara and Shiohara (2008)	E2	300	300	530	0.59	NA	300	300	1206	1206	387	2412	2.68	170	265	0	471	30	216	0.08	371	4.12	JS
207	Kusuhara and Shiohara (2008)	B2	300	300	796	0.88	NA	300	300	796	796	387	1592	1.77	170	265	0	471	28	216	0.08	370	4.11	JS
208	Wong & Kuang (2008)	BS-L-450	300	300	1963	2.18	520	260	450	942	942	520	1884	1.61	0	0	0	500	31	521.1	0.19	315.5	3.51	JS
209	Wong & Kuang (2008)	BS-L-V2	300	300	2120	2.36	520	260	450	942	942	520	1884	1.61	0	0	0	500	33	549.45	0.19	398.8	4.43	JS
210	Wong & Kuang (2008)	BS-L-V4	300	300	2277	2.53	520	260	450	942	942	520	1884	1.61	0	0	0	500	28	477.9	0.19	402.9	4.48	JS
211	Wong & Kuang (2008)	BS-L-H1	300	300	1963	2.18	520	260	450	942	942	520	1884	1.61	79	0	0	500	33	561.6	0.19	389.3	4.33	JS
212	Wong & Kuang (2008)	BS-L-H2	300	300	1963	2.18	520	260	450	942	942	520	1884	1.61	157	0	0	500	42	710.1	0.19	479.3	5.33	JS
213	Bindu & Jaya (2008)	A1	100	150	258	1.72	432	100	150	157	157	432	314	2.09	339	57	0	432	37	15.92	0.03	74.71	4.98	BFJS
214	Bindu & Jaya (2008)	A2	100	150	258	1.72	432	100	150	157	157	432	314	2.09	339	57	0	432	37	15.92	0.03	73.18	4.88	BF
215	Bindu & Jaya (2008)	B1 (X)	100	150	258	1.72	NA	100	150	157	157	NA	314	2.09	85	57	101	432	37	53.06	0.10	72.56	4.84	BF
216	Bindu & Jaya (2008)	B2 (X)	100	150	258	1.72	NA	100	150	157	157	NA	314	2.09	85	57	101	432	37	53.06	0.10	73.17	4.88	BF
217	Chalioris, Favvata, Karayannis (2008	JA-s5	200	300	616	1.03	NA	200	300	452	452	NA	904	1.51	503	157	0	580	34	102	0.05	242	4.03	BFJS
218	Chalioris, Favvata, Karayannis (2008	JA-X12 (X)	200	300	1068	1.78	NA	200	300	452	452	NA	904	1.51	0	157	226	580	34	102	0.05	241	4.02	BFJS
219	Chalioris, Favvata, Karayannis (2008	JA-X14 (X)	200	300	1232	2.05	NA	200	300	452	452	NA	904	1.51	0	157	308	580	34	102	0.05	240	4.00	BFJS
220	Chalioris, Favvata, Karayannis (2008	JCa-X10 (X)	100	200	628	3.14	NA	100	200	157	157	NA	314	1.57	0	0	157	470	21	41.2	0.1	70	3.50	BFJS
221	Chalioris, Favvata, Karayannis (2008	JCa-s1	100	200	314	1.57	NA	100	200	157	157	NA	314	1.57	101	0	0	470	21	41.2	0.1	70	3.50	BFJS
222	Chalioris, Favvata, Karayannis (2008	JCa-s1-X10 (X)	100	200	628	3.14	NA	100	200	157	157	NA	314	1.57	101	0	157	470	21	41.2	0.1	70	3.50	BFJS
223	Chalioris, Favvata, Karayannis (2008	JCa-s2	100	200	314	1.57	NA	100	200	157	157	NA	314	1.57	201	0	0	470	21	41.2	0.1	70	3.50	BFJS
224	Chalioris, Favvata, Karayannis (2008	JCb-X10 (X)	100	200	628	3.14	NA	100	200	236	236	NA	472	2.36	0	0	157	470	23	46	0.1	103	5.15	BFJS
225	Chalioris, Favvata, Karayannis (2008	JCb-s1	100	200	314	1.57	NA	100	200	236	236	NA	472	2.36	101	0	0	470	23	46	0.1	104	5.20	JS
226	Chalioris, Favvata, Karayannis (2008	JCb-s1-X10 (X)	100	200	628	3.14	NA	100	200	236	236	NA	472	2.36	101	0	157	470	23	46	0.1	105	5.25	BFJS
227	Chalioris, Favvata, Karayannis (2008	JCb-s2	100	200	314	1.57	NA	100	200	236	236	NA	472	2.36	201	0	0	470	23	46	0.1	106	5.30	JS
228	Chalioris, Favvata, Karayannis (2008	JCb-s2-X10 (X)	100	200	628	3.14	NA	100	200	236	236	NA	472	2.36	201	0	157	470	23	46	0.1	106	5.30	BFJS
229	Masi et al. (2009)	T2	300	300	462	0.51	478	300	500	512	603	478	1115	0.74	603	0	0	478	22	580.5	0.30	264.8	2.94	BFJS
230	Masi et al. (2009)	T3	300	300	462	0.51	478	600	240	512	603	478	1115	0.77	603	0	0	478	22	580.5	0.30	282	3.13	BFJS
231	Masi et al. (2009)	T4	300	300	308	0.34	478	600	240	226	226	478	452	0.31	603	0	0	478	22	580.5	0.30	235.6	2.62	BFJS
232	Masi et al. (2009)	T5	300	300	462	0.51	478	300	500	512	603	478	1115	0.74	603	0	0	478	22	290.25	0.15	267.9	2.98	BFJS
233	Masi et al. (2009)	T6	300	300	308	0.34	478	300	500	226	226	478	452	0.30	0	0	0	478	22	580.5	0.30	103.3	1.15	BFJS
234	Masi et al. (2009)	T7	300	300	308	0.34	478	600	240	226	226	478	452	0.31	0	0	0	478	22	290.25	0.15	104.6	1.16	BFJS
235	Masi et al. (2009)	T8	300	300	308	0.34	478	600	240	226	226	478	452	0.31	603	0	0	478	22	580.5	0.30	248.5	2.76	BFJS
236	Masi et al. (2009)	T9	300	300	462	0.51	580	300	500	512	603	580	1115	0.74	603	0	0	580	22	580.5	0.30	303.2	3.37	BFJS
237	Masi et al. (2009)	T10	300	300	462	0.51	580	300	500	512	603	580	1115	0.74	603	0	0	580	22	290.25	0.15	322.5	3.58	BFJS
238	Kaung and Wong (2011)	BS-450	300	300	1963	2.18	520	260	450	942	942	520	1884	1.61	0	0	0	580	31	0	0.00	315	3.50	JS
239	Kaung and Wong (2011)	BS-450-H1T10	300	300	1963	2.18	520	260	450	942	942	520	1884	1.61	79	0	0	500	33	0	0.00	389	4.32	JS
240	Kaung and Wong (2011)	BS-450-H2T10	300	300	1963	2.18	520	260	450	942	942	520	1884	1.61	157	0	0	500	42	0	0.00	480	5.33	JS
241	Kaung and Wong (2011)	BS-600	300	300	1963	2.18	520	260	600	942	942	520	1884	1.21	0	0	0	500	36	0	0.00	284	3.16	JS
242	Kaung and Wong (2011)	BS-600-H2T8	300	300	1963	2.18	520	260	600	942	942	520	1884	1.21	80	0	0	500	42	0	0.00	360	4.00	JS
243	Kaung and Wong (2011)	BS-600-H4T8	300	300	1963	2.18	520	260	600	942	942	520	1884	1.21	160	0	0	500	30	0	0.00	342	3.80	JS
244	Kotsovou and Mouzakis (2012)	S1	300	300	2512	2.79	560	300	450	1230	1230	563	2460	1.82	1545	785	0	500	35	0	0	632	7.02	JS
245	Kotsovou and Mouzakis (2012)	S2	300	300	2512	2.79	560	300	450	1230	1230	563	2460	1.82	1158	785	0	500	35	0	0	624	6.93	JS

Table B1 Continued

Sr. No.	Researchers Group	Specimen Details	Column Properties					Beam Properties					ASB TOTAL	%ASB					fc (MPa)	Axial load (KN)	Axial Load Ratio (N/Ag.fc)	Vjh expt (KN)	Vjh expt (Mpa)	Failure mode
			bc (mm)	hc (mm)	Asc (mm^2)	%ASC	fyc (MPa)	bb (mm)	hb (mm)	Asb bot (mm^2)	Asb top (mm^2)	fyb (MPa)			Asjh (mm^2)	Asjv (mm^2)	Asj cross (mm^2)	fyj (MPa)						
246	Kotsovou and Mouzakis (2012)	S3	300	300	2512	2.79	560	300	450	1230	1230	563	2460	1.82	452	785	0	500	35	0	0	624	6.93	JS
247	Kotsovou and Mouzakis (2012)	S4	300	300	2512	2.79	560	300	450	1230	1230	563	2460	1.82	452	785	0	500	35	0	0	626	6.96	JS
248	Kotsovou and Mouzakis (2012)	S5	300	300	2612	2.90	571	300	450	1230	1230	563	2460	1.82	452	785	0	500	35	0	0	617	6.86	JS
249	Elsouri and Harajli (2013)	UIJ-F1	250	700	2412	1.38	590	800	250	2462	1608	566	4069.44	2.03	1790	0	0	596	40	700	0.1	2094	11.97	
250	Elsouri and Harajli (2013)	UIJ-F2	200	650	2010	1.55	590	800	250	1231	1608	584	2838.56	1.42	1790	0	0	623	40	520	0.1	1625	12.50	
251	Elsouri and Harajli (2013)	UEJ-F1	700	250	3617	2.07	527	800	250	2462	1608	566	4069	2.03	1790	0	0	596	37	647.5	0.1	873	4.99	BFJS
252	Elsouri and Harajli (2013)	UEJ-F2	650	200	2412	1.86	527	800	250	1231	1608	584	2839	1.42	1790	0	0	623	37	481	0.1	648	4.98	BFJS
253	Hwang et al. (2014)	T1-400	500	550	7922	2.88	510	350	500	2370	1140	710	3510	2.01	531	0	0	446	32	0	0.00	1549	5.63	BFJS
254	Hwang et al. (2014)	T2-600	500	550	7922	2.88	510	350	500	2370	760	710	3130	1.79	531	0	0	446	32	0	0.00	1549	5.63	BFJS
255	Hwang et al. (2014)	T3-600	500	550	7922	2.88	510	350	500	2813	981	635	3794	2.17	531	0	0	446	30	0	0.00	1490	5.42	BFJS
256	Chun & Shin (2014)	H0.7S	300	300	3482	3.87	461	250	200	850	1134	488	1984	3.97	1375	0	0	460	35	0	0.00	646	7.18	BF
257	Chun & Shin (2014)	H0.7U	300	300	3482	3.87	461	250	200	850	1134	488	1984	3.97	942	0	0	460	35	0	0.00	611	6.79	BF
258	Chun & Shin (2014)	M0.7S	300	300	3482	3.87	461	250	200	850	1134	488	1984	3.97	1375	0	0	460	35	0	0.00	596	6.62	BF
259	Chun & Shin (2014)	M0.7U	300	300	3482	3.87	461	250	200	850	1134	488	1984	3.97	942	0	0	460	35	0	0.00	683	7.59	BF
260	Chun & Shin (2014)	H1.0S	300	300	3482	3.87	461	250	300	850	1134	488	1984	2.64	345	0	0	460	35	0	0.00	563	6.26	BF
261	Chun & Shin (2014)	H1.0U	300	300	3482	3.87	461	250	300	850	1134	488	1984	2.64	235	0	0	460	35	0	0.00	529	5.88	BF
262	Chun & Shin (2014)	M1.0S	300	300	3482	3.87	461	250	300	850	1134	488	1984	2.64	345	0	0	460	35	0	0.00	557	6.19	BF
263	Chun & Shin (2014)	M1.0U	300	300	3482	3.87	461	250	300	850	1134	488	1984	2.64	235	0	0	460	35	0	0.00	592	6.58	BF
264	Fadwa et al. (2014)	ECBCC	400	450	3768	2.09	494	300	550	615	804	500	1419.28	0.86	251	628	0	346	34	350	0.06	489	2.72	
265	Rissi et al. (2016)	Test #1	300	300	2512	2.79	450	300	500	1256	1256	450	2512	1.67	0	0	0	0	29	260	0.10	256	2.84	JS
266	Rissi et al. (2016)	Test #2	300	300	904	1.00	450	300	500	452	452	450	904	0.60	0	0	0	0	29	260	0.10	198	2.20	BFJS
267	Mirzabagheri, et al. (2016)	RIWBC-roof	200	200	942	2.36	502	400	150	471	471	457	942	1.57	0	0	0	0	33	0	0	284	7.10	BF
268	Mirzabagheri, et al. (2016)	RICBC-roof	200	200	942	2.36	502	200	250	383	383	457	766.16	1.53	0	0	0	0	32	0	0	281	7.03	BF
269	Behnam et al. (2017)	S1-BC1	360	300	1608	1.49	520	300	300	804	804	520	1607.68	1.79	231	804	0	485	36	500	0.13	483	4.47	BF
270	Behnam et al. (2017)	S2-BC1.5	360	300	1608	1.49	520	450	300	1206	1206	520	2411.52	1.79	312	804	0	485	36	500	0.13	725	6.71	BF
271	Behnam et al. (2017)	S3-BC2	360	300	1608	1.49	520	600	300	1608	1608	520	3215.36	1.79	312	804	0	485	35	480	0.13	1034	9.57	BFJS
272	Behnam et al. (2017)	S4-BC2.5	360	300	1608	1.49	520	750	300	2010	2010	520	4019.2	1.79	312	804	0	485	35	480	0.13	1292	11.96	BFJS

Table B2 Experimental database for Interior RC beam-column joints

Sr. No.	Researchers Group	Specimen Details	Column Properties					Beam Properties					ASB TOTAL	%ASB					fc (MPa)	Axial load (KN)	Axial Load Ratio (N/Ag.fc)	Vjh expt (KN)	Vjh expt (Mpa)	Failure mode
			bc (mm)	hc (mm)	Asc (mm^2)	%ASC	fyc (MPa)	bb (mm)	hb (mm)	Asb bot (mm^2)	Asb top (mm^2)	fyb (MPa)			Asjh (mm^2)	Asjv (mm^2)	Asj cross (mm^2)	fyj (MPa)						
1	Higashi & Ohwada (1969)	SD35Aa-4	300	200	628	1.05	419	200	150	236	236	419	471	1.57	63	0	0	350	30	78	0.06	104	2.61	JF
2	Higashi & Ohwada (1969)	SD35Aa-7	300	200	628	1.05	400	200	150	236	236	400	471	1.57	63	0	0	350	38	78	0.05	101	2.52	JF
3	Higashi & Ohwada (1969)	SD35Aa-8	300	200	628	1.05	400	200	150	236	236	400	471	1.57	63	0	0	350	38	157	0.1	104	2.61	JF
4	Higashi & Ohwada (1969)	LSD35Aa-1	300	200	628	1.05	400	200	150	236	236	400	471	1.57	63	0	0	350	41	78	0.05	102	2.54	JF
5	Higashi & Ohwada (1969)	LSD35Aa-2	300	200	628	1.05	400	200	150	236	236	400	471	1.57	63	0	0	350	41	157	0.1	97	2.43	JF
6	Higashi & Ohwada (1969)	LSD35Ab-1	300	200	628	1.05	400	200	150	236	236	400	471	1.57	63	0	0	350	41	78	0.05	100	2.51	JF
7	Higashi & Ohwada (1969)	LSD35Ab-2	300	200	628	1.05	400	200	150	236	236	400	471	1.57	63	0	0	350	41	157	0.1	94	2.34	JF
8	Meinheit & Jirsa (1977)	U1	458	331	3040	2.00	457	458	280	1472	2412	406	3883	3.03	265	0	0	409	26	1589	0.4	678	4.47	JF
9	Meinheit & Jirsa (1977)	U2	458	331	6431	4.24	449	458	280	1472	2412	406	3883	3.03	265	0	0	409	42	1602	0.25	990	6.53	JF
10	Meinheit & Jirsa (1977)	U5	458	331	6431	4.24	449	458	280	1472	2412	406	3883	3.03	265	0	0	409	36	214	0.04	952	6.28	JF
11	Meinheit & Jirsa (1977)	U6	458	331	6431	4.24	449	458	280	1472	2412	406	3883	3.03	265	0	0	409	37	2683	0.48	1025	6.76	JF
12	Meinheit & Jirsa (1977)	U12	458	331	6431	4.24	449	458	280	1472	2412	406	3883	3.03	1206	0	0	423	35	1615	0.3	1205	7.95	BFJF
13	Meinheit & Jirsa (1977)	U13	458	331	6431	4.24	449	458	280	1472	2412	406	3883	3.03	796	0	0	409	41	1571	0.25	964	6.36	JF
14	Birss, Park & Paulay (1978)	B1	610	457	5426	1.95	427	457	356	2512	2512	288	5024	3.09	531	0	0	346	28	311	0.05	998	4.78	BF
15	Birss, Park & Paulay (1978)	B2	610	457	5426	1.95	427	457	356	2512	2512	288	5024	3.09	154	0	0	398	32	2890	0.44	1000	4.79	BF

Table B2 Continued

Sr. No.	Researchers Group	Specimen Details	Column Properties					Beam Properties											fc (MPa)	Axial load (KN)	Axial Load Ratio (N/Ag.fc)	Vjh expt (KN)	Vjh expt (Mpa)	Failure mode
			bc (mm)	hc (mm)	Asc (mm^2)	%ASC	fyc (MPa)	bb (mm)	hb (mm)	Asb bot (mm^2)	Asb top (mm^2)	fyb (MPa)	ASB TOTAL	%ASB	Asjh (mm^2)	Asjv (mm^2)	Asj cross (mm^2)	fyj (MPa)						
16	Soleimani et al. (1979)	BC2	432	432	1140	0.61	465	229	406	593	1140	465	1733	1.86	633		0	445.1	27	2002	1.07	702	7.10	BFJFF
17	Soleimani et al. (1979)	BC3	432	432	1140	0.61	490	229	406	593	1140	490	1733	1.86	633		0	445.1	30	2002	1.07	856	8.65	BFJFF
18	Beckingsale (1980)	U11	610	457	4559	1.64	423	457	356	1134	2267	298	3401	2.09	1061	0	0	336	36	311	0.04	723	3.46	BF
19	Beckingsale (1980)	U12	610	457	4559	1.64	422	457	356	1700	1700	298	3401	2.09	1061	0	0	336	35	311	0.04	721	3.45	BF
20	Durrani & Wight (1982)	X1	420	362	3925	2.58	414	362	280	1134	1520	345	2653	2.62	265	0	0	352	34	245	0.05	684	5.22	BFJF
21	Durrani & Wight (1982)	X2	420	362	3925	2.58	414	362	280	1134	1520	345	2653	2.62	398	0	0	352	34	245	0.06	717	5.47	BF
22	Durrani & Wight (1982)	X3	420	362	3040	2.00	331	362	280	850	1140	345	1990	1.96	265	0	0	352	31	214	0.05	573	4.37	BF
23	Durrani & Wight (1982)	X3	362	362	1061	0.81	330	279	419	855	1163	330	2018	1.73	428	570	0	503	31	214	0.16	949	9.40	JF
24	Durrani & Wight (1982)	S3	362	362	1164	0.89	344	279	419	855	1282	344	2137	1.83	428	776	0	503	28	240	0.18	962	9.52	JF
25	Durrani & Wight (1982)	X1	362	362	1502	1.15	330	279	419	1140	1551	330	2691	2.30	428	1013	0	503	34	244	0.19	1117	11.06	JF
26	Durrani & Wight (1982)	S1	362	362	1520	1.16	346	279	419	1140	1535	346	2675	2.29	428	1013	0	503	42	311	0.24	1204	11.92	JF
27	Durrani & Wight (1982)	X2	362	362	1502	1.15	330	279	419	1140	1551	330	2691	2.30	641	1013	0	503	34	244	0.19	1167	11.56	JF
28	Durrani & Wight (1982)	S2	362	362	1520	1.16	346	279	419	1140	1535	346	2675	2.29	641	1013	0	503	31	311	0.24	1200	11.88	BFJFF
29	Park & Milburn (1983)	U1	457	305	2713	1.95	473	406	229	1608	1608	315	3215	3.46	1608	0	0	320	41	511	0.1	713	5.76	BF
30	Park & Milburn (1983)	U2	457	305	2713	1.95	473	406	229	1256	1256	307	2512	2.70	1206	0	0	320	47	581	0.1	776	6.27	BFJF
31	Otani, Kobayashi & Aoyama (1984)	J1	300	300	2123	2.36	401	300	200	531	1061	401	1592	2.65	85	0	0	368	26	176	0.08	314	3.49	BF
32	Otani, Kobayashi & Aoyama (1984)	J2	300	300	2123	2.36	401	300	200	531	1061	401	1592	2.65	85	0	0	368	24	176	0.08	325	3.61	BF
33	Otani, Kobayashi & Aoyama (1984)	J3	300	300	2123	2.36	401	300	200	531	1061	401	1592	2.65	198	0	0	368	24	176	0.08	361	4.01	BF
34	Otani, Kobayashi & Aoyama (1984)	J5	300	300	1327	1.47	401	300	200	531	1061	401	1592	2.65	85	0	0	368	29	176	0.07	365	4.06	BFJF
35	Otani, Kobayashi & Aoyama (1984)	J6	300	300	942	1.05	362	300	200	398	531	346	929	1.55	141	0	0	368	29	529	0.2	268	2.98	BFJF
36	Kitayama, Otani & Aoyama (1987)	J1	300	300	2123	2.36	401	300	200	531	1061	401	1592	2.65	85	0	0	368	26	177	0.08	385	4.28	BF
37	Kitayama, Otani & Aoyama (1987)	J6	300	300	942	1.05	320	300	200	398	531	346	929	1.55	141	0	0	324	26	177	0.08	275	3.06	BFJF
38	Kitayama, Otani & Aoyama (1987)	C1	300	300	2123	2.36	422	300	200	471	942	320	1413	2.36	85	0	0	324	26	177	0.08	336	3.73	BF
39	Kitayama, Otani & Aoyama (1987)	C3	300	300	2123	2.36	422	300	200	471	942	320	1413	2.36	393	0	0	324	26	177	0.08	329	3.66	BF
40	Park & Ruitong (1988)	U1	457	305	1608	1.15	498	406	229	402	1005	294	1407	1.51	565	0	0	283	46	110	0.02	312	2.52	BF
41	Park & Ruitong (1988)	U2	457	305	2512	1.80	476	406	229	628	1231	300	1859	2.00	565	0	0	283	36	134	0.03	435	3.51	BF
42	Park & Ruitong (1988)	U3	457	305	1608	1.15	498	406	229	402	1005	294	1407	1.51	141	0	0	282	36	110	0.02	310	2.5	BF
43	Park & Ruitong (1988)	U4	457	305	2512	1.80	476	406	229	628	1231	300	1859	2.00	393	0	0	320	40	134	0.03	415	3.35	BFJF
44	Leon (1990)	BCJ2	254	254	1267	1.96	498	203	305	285	506	498	791	1.28	253	506	0	498.1	28	0	0.00	360	6.98	JF
45	Endoh, Kamura Otani & Aoyama (1991)	HC	300	300	2412	2.68	369	300	200	942	942	374	1884	3.14	57	0	0	282	41	177	0.05	425	4.72	BF
46	Endoh, Kamura Otani & Aoyama (1991)	HLC	300	300	2412	2.68	360	300	200	942	942	368	1884	3.14	57	0	0	290	41	177	0.05	425	4.72	BFJF
47	Endoh, Kamura Otani & Aoyama (1991)	LA1	300	300	3215	3.57	550	300	200	531	1061	801	1592	2.65	85	0	0	286	35	177	0.06	536	5.96	JF
48	Endoh, Kamura Otani & Aoyama (1991)	A1	300	300	3215	3.57	539	300	200	531	1061	780	1592	2.65	85	0	0	320	31	177	0.06	503	5.59	JF
49	Fujii & Morita (1991)	A2	250	220	2123	3.86	388	220	160	628	628	409	1256	3.57	85	0	0	291	40	147	0.08	194	4	JF
50	Joh, Goto & Shibata (1991)	B1	350	300	1061	1.01	371	300	150	398	398	371	796	1.77	85	0	0	307	21	309	0.16	210	2.33	BFJF
51	Joh, Goto & Shibata (1991)	B2	350	300	1061	1.01	371	300	280	398	398	371	796	0.95	170	0	0	307	23	309	0.15	227	2.52	BFJF
52	Joh, Goto & Shibata (1991)	B8HH	350	300	1857	1.77	404	300	200	398	398	404	796	1.33	118	0	0	1320	26	353	0.15	230	2.56	BFJF
53	Joh, Goto & Shibata (1991)	B8HL	350	300	1857	1.77	404	300	200	398	398	404	796	1.33	118	0	0	1320	27	353	0.14	241	2.68	BFJF
54	Joh, Goto & Shibata (1991)	B8LH	350	300	1857	1.77	404	300	200	398	398	404	796	1.33	85	0	0	377	27	353	0.15	241	2.68	BFJF
55	Joh, Goto & Shibata (1991)	B8MH	350	300	1857	1.77	404	300	200	398	398	404	796	1.33	141	0	0	377	28	353	0.14	230	2.56	BFJF
56	Joh, Goto & Shibata (1991)	B9	350	300	1857	1.77	404	300	200	398	398	404	796	1.33	118	0	0	1320	26	353	0.15	268	2.98	BF
57	Joh, Goto & Shibata (1991)	B10	350	300	1857	1.77	404	300	200	398	398	404	796	1.33	118	0	0	1320	25	353	0.16	298	3.31	BF
58	Joh, Goto & Shibata (1991)	B11	350	300	1857	1.77	404	300	200	398	398	404	796	1.33	118	0	0	1320	26	353	0.15	304	3.38	BF
59	Kitayama et al. (1991)	J1	300	300	664	0.74	375	200	300	398	1061	375	1459	2.43	170	796	0	375	26	180	0.20	445	7.42	JF
60	Noguchi & Kashiwazaki (1992)	J1	300	300	2653	2.95	718	300	200	929	1194	718	2123	3.54	85	0	0	955	70	756	0.12	794	8.82	BFJF
61	Noguchi & Kashiwazaki (1992)	J3	300	300	2919	3.24	718	300	200	1327	1327	718	2653	4.42	85	0	0	955	107	1156	0.12	1007	11.19	JF
62	Noguchi & Kashiwazaki (1992)	J4	300	300	2653	2.95	718	300	200	929	1194	718	2123	3.54	85	0	0	955	70	756	0.12	838	9.31	BFJF
63	Noguchi & Kashiwazaki (1992)	J5	300	300	3184	3.54	718	300	200	1327	1327	718	2653	4.42	85	0	0	955	70	756	0.12	824	9.16	JF
64	Noguchi & Kashiwazaki (1992)	J6	300	300	2653	2.95	718	300	200	929	1061	718	1990	3.32	85	0	0	955	54	578	0.12	731	8.12	JF
65	Oka & Shiohara (1992)	J1	300	300	3184	3.54	638	300	240	929	1194	638	2123	2.95	141	0	0	1374	81	834	0.11	847	9.41	BFJF

Table B2 Continued

Sr. No.	Researchers Group	Specimen Details	Column Properties					Beam Properties																
			bc (mm)	hc (mm)	Asc (mm^2)	%ASC	fyc (MPa)	bb (mm)	hb (mm)	Asb bot (mm^2)	Asb top (mm^2)	fyb (MPa)	ASB TOTAL	%ASB	Asjh (mm^2)	Asjv (mm^2)	Asj cross (mm^2)	fyj (MPa)	fc (MPa)	Axial load (KN)	Axial Load Ratio (N/Ag.fc)	Vjh expt (KN)	Vjh expt (Mpa)	Failure mode
66	Oka & Shiohara (1992)	J2	300	300	3184	3.54	1456	300	240	1061	1061	1456	2123	2.95	141	0	0	1374	81	834	0.11	910	10.11	JF
67	Oka & Shiohara (1992)	J4	300	300	3184	3.54	515	300	240	1327	1327	515	2653	3.69	141	0	0	1374	73	834	0.13	874	9.71	BF
68	Oka & Shiohara (1992)	J5	300	300	3184	3.54	839	300	240	929	1194	839	2123	2.95	141	0	0	1374	73	834	0.13	979	10.88	BFJF
69	Oka & Shiohara (1992)	J6	300	300	3184	3.54	676	300	240	929	1194	676	2123	2.95	85	0	0	775	79	834	0.12	904	10.04	BFJF
70	Oka & Shiohara (1992)	J7	300	300	3184	3.54	676	300	240	663	929	676	1592	2.21	141	0	0	857	79	834	0.12	722	8.02	BF
71	Oka & Shiohara (1992)	J8	300	300	6801	7.56	370	300	240	1984	2550	370	4534	6.30	141	0	0	775	79	834	0.12	1025	11.39	BFJF
72	Oka & Shiohara (1992)	J10	300	300	3184	3.54	700	300	240	929	1194	700	2123	2.95	141	0	0	598	39	417	0.12	646	7.18	JF
73	Oka & Shiohara (1992)	J11	300	300	6801	7.56	372	300	240	1984	2550	372	4534	6.30	141	0	0	401	39	417	0.12	765	8.5	JF
74	Teraoka, Kanoh, Tanaka & Hayashi (1994	HNO1	400	400	4559	2.85	610	400	300	1608	1608	611	3215	2.68	402	0	0	681	89	2354	0.17	1280	8	JF
75	Teraoka, Kanoh, Tanaka & Hayashi (1994	HNO2	400	400	4559	2.85	610	400	300	1608	1608	611	3215	2.68	402	0	0	681	89	2354	0.17	1842	11.51	BF
76	Teraoka, Kanoh, Tanaka & Hayashi (1994	HNO3	400	400	4559	2.85	442	400	300	3040	3040	442	6079	5.07	402	0	0	681	89	2354	0.17	1682	10.51	JF
77	Teraoka, Kanoh, Tanaka & Hayashi (1994	HNO4	400	400	4559	2.85	610	400	300	3040	3040	605	6079	5.07	402	0	0	681	89	2354	0.17	1922	12.01	JF
78	Teraoka, Kanoh, Tanaka & Hayashi (1994	HNO5	400	400	4559	2.85	610	400	300	2035	2035	623	4069	3.39	402	0	0	681	117	2354	0.13	1602	10.01	JF
79	Teraoka, Kanoh, Tanaka & Hayashi (1994	HNO6	400	400	4559	2.85	610	400	300	3040	3040	605	6079	5.07	402	0	0	681	117	2354	0.13	2082	13.01	JF
80	Hayashi, Teraoka, Mollick & Kanoh (1994	NO43	400	400	3401	2.13	383	400	300	1134	1134	383	2267	1.89	628	0	0	347	54	1600	0.18	658	4.11	BF
81	Hayashi, Teraoka, Mollick & Kanoh (1994	NO44	400	400	3401	2.13	383	400	300	804	804	624	1608	1.34	628	0	0	347	54	1600	0.18	733	4.58	NA
82	Hayashi, Teraoka, Mollick & Kanoh (1994	NO45	400	400	3401	2.13	383	400	300	1520	1520	599	3040	2.53	628	0	0	347	54	1600	0.18	872	5.45	JF
83	Hayashi, Teraoka, Mollick & Kanoh (1994	NO46	400	400	3401	2.13	383	400	300	567	567	858	1134	0.94	628	0	0	347	54	1600	0.18	658	4.11	BF
84	Hayashi, Teraoka, Mollick & Kanoh (1994	NO47	400	400	3401	2.13	645	400	300	1700	1700	382	3401	2.83	628	0	0	347	54	1600	0.18	843	5.27	BFJF
85	Hayashi, Teraoka, Mollick & Kanoh (1994	NO48	400	400	3401	2.13	645	400	300	1134	1134	645	2267	1.89	628	0	0	347	54	1600	0.18	986	6.16	NA
86	Hayashi, Teraoka, Mollick & Kanoh (1994	NO49	400	400	3401	2.13	645	400	300	1900	1900	599	3799	3.17	628	0	0	347	54	1600	0.18	1245	7.78	BFJF
87	Hayashi, Teraoka, Mollick & Kanoh (1994	NO50	400	400	3401	2.13	645	400	300	850	850	858	1700	1.42	628	0	0	347	54	1600	0.18	954	5.96	NA
88	Hayashi, Teraoka, Mollick & Kanoh (1994	HNO8	400	400	3401	2.13	645	400	300	2280	2280	422	4559	3.80	402	0	0	797	88	2824	0.2	1250	7.81	NA
89	Hayashi, Teraoka, Mollick & Kanoh (1994	HNO9	400	400	3401	2.13	645	400	300	1520	1520	599	3040	2.53	402	0	0	797	88	2824	0.2	1317	8.23	NA
90	Hayashi, Teraoka, Mollick & Kanoh (1994	HNO10	400	400	3401	2.13	645	400	300	1134	1134	858	2267	1.89	402	0	0	797	88	2824	0.2	1275	7.97	NA
91	Teraoka, Kanoh, Hayashi & Sasaki (1997)	HJ1	400	400	3401	2.13	383	400	300	1134	1134	382	2267	1.89	628	0	0	347	54	1726	0.2	658	4.11	BF
92	Teraoka, Kanoh, Hayashi & Sasaki (1997)	HJ2	400	400	3401	2.13	383	400	300	804	804	624	1608	1.34	628	0	0	347	54	1726	0.2	733	4.58	BF
93	Teraoka, Kanoh, Hayashi & Sasaki (1997)	HJ3	400	400	3401	2.13	383	400	300	567	567	858	1134	0.94	628	0	0	347	54	1726	0.2	658	4.11	BF
94	Teraoka, Kanoh, Hayashi & Sasaki (1997)	HJ4	400	400	3401	2.13	646	400	300	1700	1700	382	3401	2.83	628	0	0	347	54	1726	0.2	843	5.27	BFJF
95	Teraoka, Kanoh, Hayashi & Sasaki (1997)	HJ5	400	400	3401	2.13	646	400	300	1134	1134	645	2267	1.89	628	0	0	347	54	1726	0.2	987	6.17	BF
96	Teraoka, Kanoh, Hayashi & Sasaki (1997)	HJ6	400	400	3401	2.13	646	400	300	850	850	858	1700	1.42	628	0	0	347	54	1726	0.2	955	5.97	BFJF
97	Teraoka, Kanoh, Hayashi & Sasaki (1997)	HJ7	400	400	3401	2.13	646	400	300	2280	2280	422	4559	3.80	402	0	0	681	88	2824	0.2	1251	7.82	BF
98	Teraoka, Kanoh, Hayashi & Sasaki (1997)	HJ8	400	400	3401	2.13	646	400	300	1520	1520	599	3040	2.53	402	0	0	681	88	2824	0.2	1317	8.23	BF
99	Teraoka, Kanoh, Hayashi & Sasaki (1997)	HJ9	400	400	3401	2.13	646	400	300	1134	1134	858	2267	1.89	402	0	0	681	88	2824	0.2	1275	7.97	BFJF
100	Teraoka, Kanoh, Hayashi & Sasaki (1997)	HJ10	400	400	4154	2.60	614	400	300	1608	1608	611	3215	2.68	402	0	0	681	88	2824	0.2	1482	9.26	BF
101	Teraoka, Kanoh, Hayashi & Sasaki (1997)	HJ11	400	400	4154	2.60	442	400	300	3040	3040	441	6079	5.07	402	0	0	681	88	2824	0.2	1934	12.09	BFJF
102	Teraoka, Kanoh, Hayashi & Sasaki (1997)	HJ12	400	400	4154	2.60	614	400	300	3040	3040	604	6079	5.07	402	0	0	681	88	2824	0.2	2269	14.18	BFJF
103	Teraoka, Kanoh, Hayashi & Sasaki (1997)	HJ13	400	400	4154	2.60	614	400	300	2035	2035	623	4069	3.39	402	0	0	681	118	3766	0.2	1805	11.28	BF
104	Teraoka, Kanoh, Hayashi & Sasaki (1997)	HJ14	400	400	4154	2.60	614	400	300	3040	3040	604	6079	5.07	402	0	0	681	118	3766	0.2	2379	14.87	BFJF
105	Shiohara et al. (2000)	S3	300	300	1134	1.26	470	200	300	1005	1005	470	2010	3.35	452	1134	0	390	23	100	0.11	774	12.90	JF
106	Hegger et al. (2003)	RA1	150	240	1257	3.49	530	150	300	929	929	530	1858	4.13	0	0	0	530	53	497	1.38	573	15.92	JF
107	Hegger et al. (2003)	RA2	150	240	1257	3.49	530	150	300	615	615	530	1230	2.73	226	0	0	530	66	458	1.27	703	19.53	JF
108	Hegger et al. (2003)	RA5	150	240	1257	3.49	530	150	300	565	565	530	1130	2.51	283	0	0	530	56	499	1.39	598	16.61	JF
109	Hegger et al. (2003)	RA6	150	240	1257	3.49	530	150	300	615	615	530	1230	2.73	283	0	0	530	56	641	1.78	683	18.97	JF
110	Hegger et al. (2003)	RA3	150	240	1257	3.49	530	150	300	728	728	530	1456	3.24	503	0	0	530	44	502	1.39	538	14.94	JF
111	Hegger et al. (2003)	RA4	150	240	1232	3.42	530	150	300	1030	1030	530	2060	4.58	503	0	0	530	66	336	0.93	789	21.92	JF
112	Hegger et al. (2003)	RA7	150	240	1257	3.49	530	150	300	917	917	530	1834	4.08	785	0	0	530	80	457	1.27	850	23.61	JF
113	Walker, (2001) & Alire (2002)	PEER14	509	407	3040	1.47	423	458	407	804	1520	503	2324	1.25	0	0	0	0	32	590	0.1	747	4.01	BFJF
114	Walker, (2001) & Alire (2002)	PEER22	509	407	5281	2.55	538	458	407	1520	2280	528	3799	2.04	0	0	0	0	38	714	0.1	1005	5.39	BFJF
115	Walker, (2001) & Alire (2002)	PEER4150	509	407	6602	3.19	545	458	407	3961	3961	545	7922	4.25	0	0	0	0	33	613	0.1	1568	8.41	JF
116	Li et al. (2002)	A2	300	900	982	0.36	477	300	600	1472	1874	477	3346	1.86	0	4906	0	499	33	0	0.00	1444	5.35	BFJFF
117	Li et al. (2002)	M2	300	900	982	0.36	477	300	600	1472	1874	477	3346	1.86	302	4906	0	499	30	0	0.00	1513	5.60	BFJFF

Table B2 Continued

Sr. No.	Researchers Group	Specimen Details	Column Properties					Beam Properties											fc (MPa)	Axial load (KN)	Axial Load Ratio (N/Ag.fc)	Vjh expt (KN)	Vjh expt (Mpa)	Failure mode
			bc	hc	Asc	%ASC	fyc	bb	hb	Asb bot	Asb top	fyb	ASB TOTAL	%ASB	Asjh	Asjv	Asj cross	fyj						
			(mm)	(mm)	(mm^2)		(MPa)	(mm)	(mm)	(mm^2)	(mm^2)	(MPa)			(mm^2)	(mm^2)	(mm^2)	(MPa)						
118	Li et al. (2002)	A2	300	900	1964	0.73	477	300	600	1472	1874	477	3346	1.86	0	4906	0	499	32.5	0	0.00	1445	5.35	BFJS
119	Li et al. (2002)	M2	300	900	1964	0.73	477	300	600	1472	1874	477	3346	1.86	302	4906	0	499	30.3	0	0.00	1514	5.61	BFJS
120	Teng & Zhou (2003)	S1 (Series 1)	300	300	1571	1.75	510	200	400	603	1005	510	1608	2.01	1178	628	0	440	33	441	0.49	746	12.43	JF
121	Teng & Zhou (2003)	S2 (Series 1)	400	300	1571	1.31	510	200	400	603	1005	510	1608	2.01	1178	628	0	440	34	441	0.37	743	12.38	JF
122	Teng & Zhou (2003)	S3 (Series 1)	400	300	1571	1.31	510	200	400	603	1005	510	1608	2.01	1178	628	0	440	35	441	0.37	729	12.15	JF
123	Teng & Zhou (2003)	S5 (Series 2)	400	200	1571	1.96	425	200	400	398	663	425	1061	1.33	1414	628	0	440	39	343	0.43	413	10.33	JF
124	Teng & Zhou (2003)	S6 (Series 2)	400	200	1571	1.96	425	200	400	398	663	425	1061	1.33	1414	628	0	440	38	343	0.43	408	10.20	JF
125	Kusuhara et al. (2004)	JE-55 (ECE)	320	280	1592	1.78	387	180	300	785	785	387	1570	2.91	170	531	0	364	24	0	0.00	581.48	6.49	JS
126	Kusuhara et al. (2004)	JE-55S (ECE)	320	280	1592	1.78	387	180	300	785	785	387	1570	2.91	254	531	0	364	24	0	0.00	662.56	7.39	JS
127	Shin & LaFave (2004)	1 (ECE/SLAB)	457	330	1710	1.13	500	279	406	396	791	500	1187	1.05	641	570	0	450	29.9	0	0.00	558.75	3.70	JS
128	Shin & LaFave (2004)	2 (ECE/SLAB)	457	330	1710	1.13	500	178	406	396	791	500	1187	1.64	641	570	0	450	36.2	0	0.00	586.07	3.89	JS
129	Au et al. (2005)	E-0.3	300	300	3215	3.57	558	250	300	803	803	558	1606	2.14	0	0	0	0	46	1035	0.3	814	10.85	JF
130	Au et al. (2005)	H-0.3	300	300	3215	3.57	518	250	300	803	803	518	1606	2.14	1050	0	0	460	45	1012	0.3	744	9.92	JF
131	Au et al. (2005)	AD-0.3	300	300	3215	3.57	538	250	300	803	803	538	1606	2.14	1020	0	0	460	39	877	0.3	1049	13.99	JF
132	Shannag & Alhassan (2005)	S2	125	150	308	1.64	310	125	200	308	308	310	616	2.46	0	0	0	310	27	75	0.40	61	3.25	JF
133	Shannag & Alhassan (2005)	S5	125	150	308	1.64	310	125	200	308	308	310	616	2.46	0	0	0	310	27	120	0.64	67	3.57	JF
134	Shannag & Alhassan (2005)	S8	125	150	308	1.64	310	125	200	308	308	310	616	2.46	0	0	0	310	27	0	0.00	41	2.19	JF
135	Shannag & Alhassan (2005)	S1	125	150	308	1.64	310	125	200	308	308	310	616	2.46	101	100	0	310	27	75	0.40	97	5.17	CFJF
136	Supuviriyakit & Pimanmas (2007)	Control	200	350	565	0.81	488	175	300	452	679	488	1131	2.15	0	905	0	312	20	300	0.43	426	6.96	JF
137	Supuviriyakit & Pimanmas (2007)	Debond	200	350	565	0.81	488	175	300	452	679	488	1131	2.15	0	905	0	312	22	300	0.43	349	5.70	BFJFF
138	Shiohara & Kusuhara (2008)	D05	240	340	398	0.49	378	170	240	929	929	378	1858	4.55	226	0	0	399	27	0	0.00	289	5.00	JF
139	Shiohara & Kusuhara (2008)	D06	240	340	531	0.65	378	170	240	929	929	378	1858	4.55	226	0	0	399	27	0	0.00	318	5.50	JF
140	Shiohara & Kusuhara (2008)	D07	240	340	796	0.98	378	170	240	929	929	378	1858	4.55	226	0	0	399	27	0	0.00	356	6.16	JF
141	Kusuhara & Shiohara (2008)	A2	300	300	664	0.74	456	300	300	1062	1062	456	2124	2.36	170	796	0	326	28	216	0.24	462	5.13	BFJFF
142	Kusuhara & Shiohara (2008)	A3	300	300	664	0.74	456	300	300	1062	1062	456	2124	2.36	170	796	0	326	28	216	0.24	437	4.86	JF
143	Benevant et al. (2008)	IL	270	270	1608	2.21	404	480	180	1017	1583	404	2600	3.01	0	402	0	404	24.9	296	0.16	932	12.79	JS
144	Benevant et al. (2008)	IU	270	210	1030	1.82	404	360	180	452	1130	404	1582	2.44	0	804	0	404	24.9	74	0.05	434	7.65	JS
145	Lee et al. (2009)	BJ2	350	350	2642	2.16	509	300	400	1005	1005	509	2010	1.68	628	2641	0	510.4	40	0	0.00	1027	9.78	BFJF
146	Lee et al. (2009)	BJ3	350	350	2642	2.16	509	300	400	804	804	509	1608	1.34	628	2641	0	510.4	40	0	0.00	809	7.70	BFJF
147	Lee et al. (2009)	B1	350	350	2642	2.16	509	300	400	603	603	509	1206	1.01	628	2641	0	510.4	40	0	0.00	597	5.69	BFJF
148	Lee et al. (2009)	J1	350	350	2642	2.16	509	300	400	2010	2010	509	4020	3.35	942	2641	0	510.4	40	0	0.00	1372	13.07	JF
149	Lee et al. (2009)	BJ1	350	350	2642	2.16	509	300	400	1206	1206	509	2412	2.01	942	2641	0	510.4	40	0	0.00	1243	11.84	BFJF
150	Wang & Hsu (2009)	Ko-JI1	300	300	1473	1.64	533	300	500	1963	1963	533	3926	2.62	0	0	0	533	32	403	0.45	639	7.10	CFJF
151	Li, Pan & Tran (2009)	C1A	820	280	3482	1.52	510	230	300	422.33	422.33	510	844.66	1.22	0	0	0	0	20	0	0	187	1.31	NA
152	Li, Pan & Tran (2009)	C1B	820	280	3482	1.52	510	230	300	422.33	422.33	510	844.66	1.22	0	0	0	0	20	459.2	0.1	194	1.36	NA
153	Li, Pan & Tran (2009)	E1A ECE 67	820	280	3482	1.52	510	230	300	422.33	422.33	510	844.66	1.22	0	0	0	0	20	0	0	230	1.61	NA
154	Li, Pan & Tran (2009)	E1B ECE 67	820	280	3482	1.52	510	230	300	422.33	422.33	510	844.66	1.22	0	0	0	0	20	459.2	0.1	240	1.68	NA
155	Li, Pan & Tran (2009)	E1C ECE 67	820	280	3482	1.52	510	230	300	422.33	422.33	510	844.66	1.22	0	0	0	0	20	1607.2	0.35	245	1.71	NA
156	Li, Pan & Tran (2009)	C2B	1600	300	14771	3.08	504	230	600	422.33	422.33	510	844.66	0.61	0	0	0	0	20	960	0.1	198	1.25	BFJS
157	Li, Pan & Tran (2009)	AL2	400	200	2512	3.14	473	200	400	628	828.96	473	1456.96	1.82	0	0	0	0	32.1	0	0	391	4.89	NA
158	Li, Pan & Tran (2009)	AS2 SLAB/TB	400	200	2512	3.14	473	200	400	628	828.96	473	1456.96	1.82	0	0	0	0	31.9	0	0	335	4.19	NA
159	Fadwa et al. (2014)	IWBCC	400	450	3768	2.09	494	900	300	1265.42	1780.38	500	3045.8	1.13	100.48	628	0	346	28.5	230	0.04	464	2.58	JS
160	Fadwa et al. (2014)	ICBCC	400	450	3768	2.09	494	300	550	615.44	803.84	500	1419.28	0.86	251.2	628	0	346	39.43	350	0.05	501	2.78	JS
161	Bing Li & Leong (2014)	NS1	450	300	1890	1.40	510	250	500	912.5	912.5	510	1825	1.46	785	0	0	357	60	0	0.00	338	4.51	JF
162	Bing Li & Leong (2014)	NS3	450	300	2160	1.60	510	250	500	887.5	887.5	510	1775	1.42	785	0	0	357	60	0	0.00	333	4.44	JF
163	Bing Li & Leong (2014)	NS4	450	300	1741.5	1.29	510	250	500	700	450	510	1150	0.92	628	0	0	357	60	0	0.00	368	4.9	JF