نموذج جديد لمقاومة القص لعتب خرساني عميق بسيط الإسناد

د.حيدر كاظم عماش
جامعة القادسية/كلية الهندسة/قسم الهندسة المدنية

الخلاصة:

تهدف الدراسة إلى تقديم نموذج جديد لتحديد قوة القص للأعتاب الخرسانة المسلحة العميقة. تمت مقارنة النتائج لقوة القص من النموذج المقترح مع البيانات العملية التي تم جمعها من 49 عتب خرساني عميق بسيطة الإسناد، والمحملة بأحمال مركزة تقع على مسافة من وجه المسند. المقارنة تبين أن النموذج المقترح يمكنه التنبؤ بدقة لقوة القص للاعتاب العميقة ذات نسبة مسافة القص الى العمق (0.83-1.34). النموذج الحالي يأخذ بنظر الاعتبار بعض المؤثرات مثل نسبة الفضاء إلى العمق، قيم مختلفة من مقاومة الانضغاط للخرسانة، وكذلك المسافات الأفقية والعمودية لحديد الجذع وتأثير حديد التسليح الخاص بالانثناء. النتائج المستحصلة من النموذج الحالي تعطي توافق جيد مع النتائج العملية من الطرق ألأخرى.

الكلمات الدالة: أعتاب عميقة، خرسانة مسلحة، مقاومة القص

Introduction:

The classical definition of a deep beam is the member which has a depth much greater than the normal in relation to its span, while the thickness in the perpendicular direction is much smaller than either the span or the depth. Deep beam occur in engineering structures such as in bunkers and water tanks where the walls act as vertical beams spanning between column supports [Khalaf,(1986), Mahmoud,(1992)]. In some multistory buildings, it is often desirable to have the lower floors free of columns, therefore; these beams may be designed as beams spanning across the column free space (EL-Hashimy et al (1989)). ACI-2008 building code classified deep beams as those with span to depth ratio about (4) or less, or a shear span less than about twice the depth. Because of its proportions, the strength of deep beam is usually controlled by shear, rather than flexure, provided normal amounts of longitudinal reinforcement are used. On the other hand, shear strength of deep beams is significantly greater than that predicted using expression developed for shallow beams because the deep beams have behavior more complex and differ from it in many items:

1- In deep beams the transverse sections which are plane before bending does not remain plane after bending.
2-The neutral axis does not usually lie at mid-depth and moves away from the loaded face of the member as the span to depth ratio decreases.
3- Flexural stresses and strains are not linearly distributed across the beam depth (Winter and Nilson (1978)).

The shear strength of reinforced concrete deep beams had been predicted by Tang and Tan (2004); Russo et al. (2005); and Hwang et al. (2000). The model proposed by Hwang et al. (2000), termed as the softened strut-and-tie (SST) model, is developed from the strut-and-tie concept and is derived to satisfy equilibrium, compatibility, and constitutive law of cracked reinforced concrete. The strength analysis of the extent of softening involves five unknowns. Zhang et al. (2009) were investigated the effects of unsymmetrical loadings on the strength and behavior of simply supported deep beams. An experimental program consisting of 14 specimens has been carried out. Test results including crack patterns, load deflection responses, steel and concrete strains, and failure loads are presented and discussed with the effects of load inequality and load asymmetry. Brown and Bayrak (2007) were used experimental program to examine the effects of load distribution and shear reinforcement on the strength of deep beams. Additionally, the strength of these specimens was calculated with a simple strut-and-tie model based on the provisions of two U.S. codes. Tan et al. (2001) This study deal with the analysis of prestressed concrete deep beams by strut-tie model. The model can be used for both pre and post-tensioned deep beams. Ashour (2000) carried out a mechanism analysis of shear failure of simply supported reinforced concrete deep beams. Concrete and steel reinforcement were modeled as rigid perfectly plastic materials. The failure modes were idealized as an assemblage of rigid blocks separated by yield line. Comparison of the predicted shear capacity of numerous deep beams showed good agreement with the results obtained from experiments. A parametric study of main variables affecting shear strength of deep beams was conducted. Siao (1995) used the strut-tie approach for the analysis of shear strength of simply supported and continuous reinforced concrete deep beams. In this analysis he illustrated that there was no difference in shear behavior of single and double span deep beams. Mahmoud (1992) Presented nonlinear analysis of reinforced concrete deep beams under static load by using the finite element method. Concrete was represented by 8-noded plane stress isoparametric elemenl for two dimensional analysis and 20-noded brick element for three dimensional analysis. Bar elements were used to represent the reinforcement in this analysis. Perfect bond between the concrete and reinforcement was assumed. An elastic-perfectly plastic model was used for plane stress analysis, and a strain hardening model was used in the three dimensional finite element analysis. AL-Taan and Ali (1998) presented a nonlinear finite element analysis of fibrous concrete deep beams with conventional reinforcement under static load. The constitutive models of nonlinear materials behavior were presented to take into account the nonlinear stress-strain relationship of concrete, cracking, pullout of the steel fibres, yielding of the reinforcement, and post-cracking shear transferred by aggregate interlock. EL-Hashimy et al. (1989) investigated the cracking load of reinforced concrete deep beams with openings by two dimensional finite element method. The study includes beams subjected to uinform and concentreted loads. Concrete and main steel reinforcement were simulated by rectangular plane stress elements which behave as elastic materials. Cervera et al (1987) used a three dimensional analysis to study plates, shells and deep beams. His study adopted the 20-noded isoparametric element and the effect of shear and normal stresses were included in this analysis. In concrete, the nonlinear behavior and crushing were considerded in compression. In tension, cracking and tension stiffening were considered.

This paper proposes a new model to determine the shear strength of reinforced concrete deep beams. The shear strength predictions of the proposed model are compared with the experimental data collected from 49 simply supported reinforced concrete deep beams, loaded with concentrated loads located at a distance a from face of support.

Methods of R.C. deep beam:

Method 1

According to Section 11.8 of the ACI 318-2008 Code, the sectional shear strength for deep flexural members is calculated by adding the contributions from the concrete and the distributed vertical and horizontal reinforcement. The concrete contribution can be computed by using:

$$V_c = \left\{3.5 - 2.5\left(\frac{Mu}{V_u.d}\right)\right\}\left\{0.16\sqrt{fc'} + 17\rho_w\left(\frac{V_u.d}{M_u}\right)\right\}b_w.d \qquad (1)$$

where $\left\{3.5 - 2.5\left(\frac{Mu}{V_u.d}\right)\right\}$ is to be kept less than or equal to 2.5, V_u = Shear force at the critical section, M_u = Moment at the critical section, ρ_w = Ratio of flexural tensile reinforcement, *Ln* = Clear span of beam., *d* =Effective depth of tension region., b_w= Width of beam, *a* = Shear span from face of support to point load, f'_c =Compressive strength of concrete.

This Equation should not be greater than the upper bound $\mathbf{0.49}\sqrt{f_{c'}}\,b_w d$, Furthermore the shear strength V_u for the deep beam should not be greater than $\mathbf{0.66}\sqrt{f_{c'}}\,b_w d$ when L_n/d **< 2.0** but when L_n/d is between **2.0** and **4.0**, then $\left[0.055\left(10 + L_n/d\right)\sqrt{f_{c'}}\,b_w d\right]$ is to be used.

The use of shear reinforcement is required whenever the factored shear force at the critical section exceeds the shear strength $(V_c\ /2)$. The contribution from the shear reinforcement is computed with:

$$V_s = \left[\frac{A_v}{s}\left(\frac{(1+\frac{L_n}{d})}{12}\right) + \frac{A_{vh}}{s_2}\left(\frac{(11-\frac{L_n}{d})}{12}\right)\right] f_y d \qquad \textbf{(2)}$$

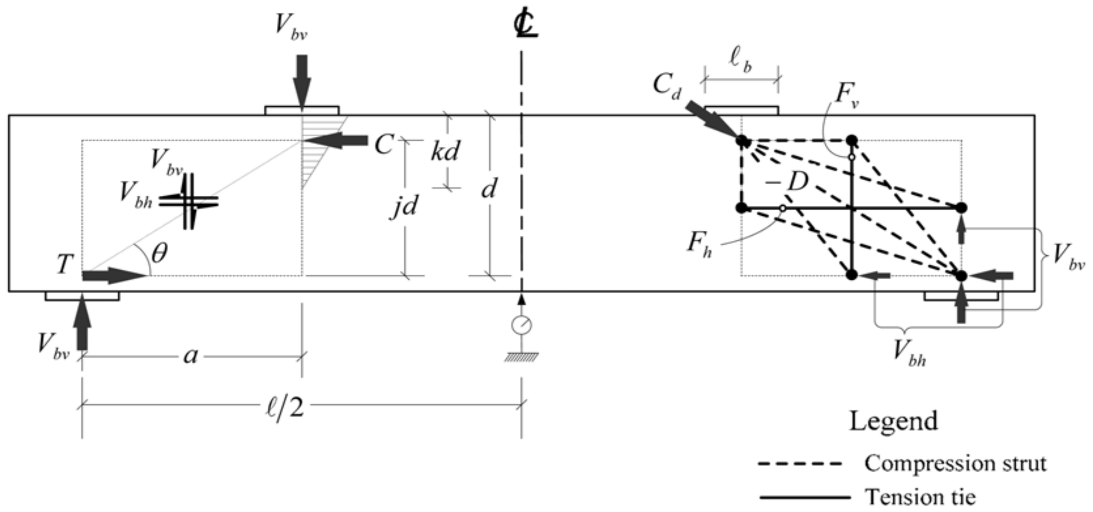
Where

A_h = Area of the horizontal stirrups, A_v =Area of the vertical stirrups, s_2 = Horizontal spacing of stirrups, s = Vertical spacing of stirrups.

$$V_{ACI} = 0.75\left(V_s + V_c\right) \qquad \textbf{(3)}$$

Method 2

On the basis of the softened strut-and-tie model, Hwang and Lee(2002) were proposed new model for calculating the shear strength of reinforced concrete deep beams. **Figure (1)** shows the loads acting on a deep beam and the force transferring mechanisms. By considering the distances between force couples, it will be sufficiently accurate to express the following relationship between vertical and horizontal shears.



Figure(1): Softened strut-and-tie model for internal force[8]

$$\frac{V_{bv}}{V_{bh}} \approx \frac{jd}{a} \qquad (4)$$

where V_{bv} is the vertical shear force, V_{bh} is the horizontal shear force, jd is the length of the lever arm from the resultant compressive force to the centroid of the flexural reinforcement, and a is the shear span measured center-to-center from load to support. According to the linear bending theory, the lever arm jd can be estimated as:

$$jd = d - (kd/3) \qquad (5)$$

where coefficient k can be derived as:

$$k = \sqrt{[n\rho + (n-1)\rho']^2 + 2[n\rho + (n-1)\rho' d'/d]} - [n\rho + (n-1)\rho'] \qquad (6)$$

Where kd is the depth of compression zone at the section, n the modular ratio of elasticity, ρ is the ratio of tension reinforcement, ρ' is the ratio of compression reinforcement, and d' is the effective depth of compression region.

The diagonal mechanism is a diagonal compression strut whose angle of inclination θ is taken as:

$$\theta = tan^{-1}\left(\frac{jd}{a}\right) \qquad (7)$$

The effective area of the diagonal strut (A_{str}) can be estimated as:

$$A_{str} = t_s \times b_s \qquad (8)$$

where t_s is the thickness of the diagonal strut and b_s is the width of the diagonal strut which can be taken as the width of the beam web. The thickness of the diagonal strut t_s depends on its end condition, which is provided by the compression zone at the section and the bearing plate (Hwang et al. 2000). It is intuitively assumed that:

$$t_s = \sqrt{(kd)^2 + l_b^2} \qquad (9)$$

where l_b is the width of the bearing plate, measured parallel to the axis of the beams.

The horizontal mechanism consists of one horizontal tie and two flat struts (Hwang et al. 2000, Hwang and Lee 2002). The horizontal tie is made up of horizontal hoops. When computing the area of the horizontal tie **(A_{th})**, it is roughly assumed that the horizontal hoops within the center half of the height are fully effective, and the rest at 50% effectiveness (Hwang et al. 2000, Hwang and Lee 2002). If the horizontal hoops are uniformly distributed within the length of the lever arm, then $A_{th} = 0.75 A_h$, where A_h is the area of horizontal hoops. The vertical mechanism consists of one vertical tie and two steep struts. The vertical tie is made up of vertical hoops. The area of the vertical tie **(A_{tv})** is computed in the same way as that of the horizontal tie. If the vertical hoops are uniformly distributed within the shear span, then $A_{tv} = 0.75\, A_v$; in which, A_v is the area of the vertical hoops. According to Hwang et al (2010), the shear strength of deep beams can be estimated as follows:

$$V_{bv}(Hwang) = (K_h + K_v - 1)\zeta f_c' A_{str} \sin\theta \qquad (10)$$

Where V_{bv} is the predicted shear strength, K_h is the horizontal tie, K_v is the vertical tie index and ζ is the softening coefficient of concrete. The horizontal tie index can be estimated as follows:

$$K_h = 1 + (\overline{K}_h - 1)\frac{A_{th} f_{yh}}{\overline{F}_h} \le \overline{K}_h \qquad (11)$$

where

$$\overline{K}_h \approx \frac{1}{1 - 0.2(\gamma_h + \gamma_h^2)} \qquad (12)$$

$$\gamma_h = \frac{2\tan\theta - 1}{3}, \text{ but } 0 \le \gamma_h \le 1 \qquad (13)$$

$$\overline{F}_h = \gamma_h \times (\overline{K}_h \zeta f_c' A_{str}) \times \cos\theta \qquad (14)$$

$$\zeta = \frac{3.35}{\sqrt{f_c'}} \le 0.52 \quad \text{(MPa)} \qquad (15)$$

Here $\overline{K}_h$ is the horizontal tie index with sufficient horizontal hoops, f_{yh} is the yield stress of horizontal hoops, γ_h is the fraction of horizontal shear transferred by the horizontal tie in the absence of the vertical tie and $\overline{F}_h$ is the balance amount of horizontal tie force. The vertical tie index can be estimated as follows:

$$K_v = 1 + (\overline{K}_v - 1)\frac{A_{tv} f_{yv}}{\overline{F}_v} \le \overline{K}_v \qquad (16)$$

Where

$$\overline{K}_v \approx \frac{1}{1 - 0.2(\gamma_v + \gamma_v^2)} \qquad (17)$$

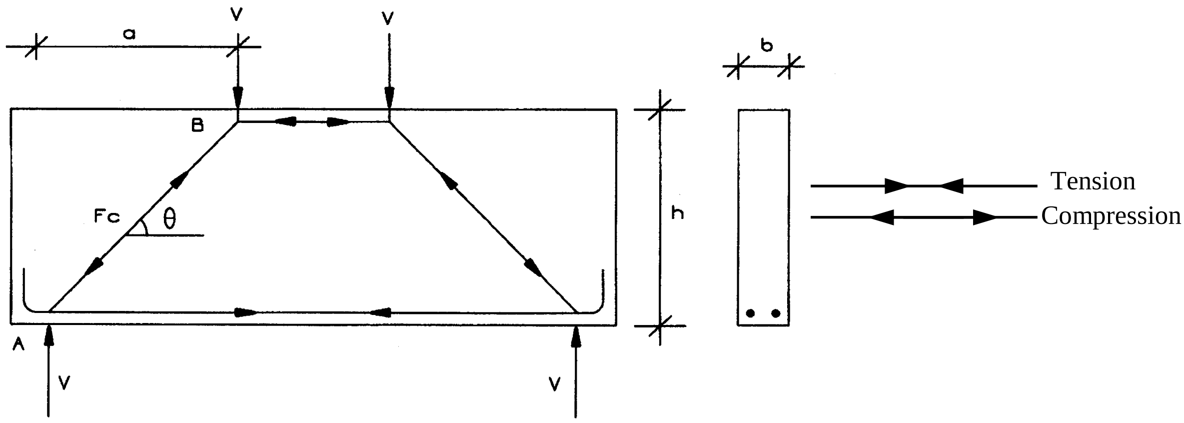
$$\gamma_v = \frac{2\cot\theta - 1}{3} \quad \text{,but } 0 \le \gamma_v \le 1 \qquad (18)$$

$$\overline{F}_v = \gamma_v \times (\overline{K}_v \zeta f_c' A_{str}) \times \sin\theta \qquad (19)$$

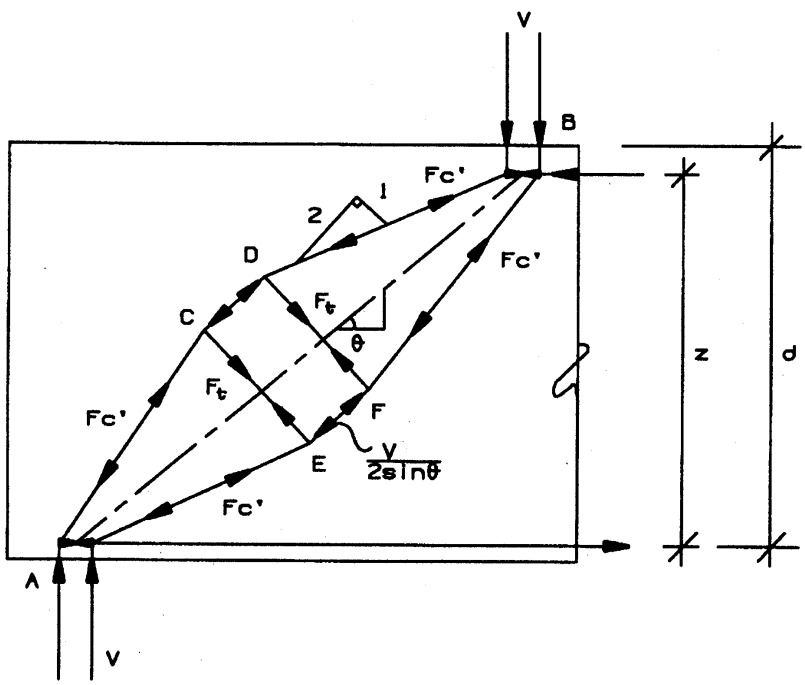
where $\overline{K}_v$ is the vertical tie index with sufficient vertical hoops, f_{yv} is the yield stress of vertical hoops, γ_v is the fraction of vertical shear transferred by the vertical tie in the absence of the horizontal tie and $\overline{F}_h$ is the balance amount of vertical tie force.

Method 3

Siao (1995) used the strut-tie approach for the analysis of shear strength of simply supported deep beams. **Figure(2)** shows the conventional load path in deep beam. In Figure **(3)**, the compression strut AB has been replay by a refined strut-and-tie system.



Figure(2): Forces in Concrete deep beams



Figure(3): Refined model of compression strut in deep beams[13]

Thus;

$$F_t = \frac{F_c'}{2} = \frac{1}{2} \times \frac{V}{2\sin\theta} = \frac{V}{4\sin\theta} \qquad \textbf{(20)}$$

Hence, tensile stress at right angles to AB

$$f_t = \frac{2F_t}{bz/\sin\theta} = \frac{2F_t \sin\theta}{0.9bd} = \frac{V}{1.8bd} \qquad \text{(assume z = 0.9d)} \qquad \textbf{(21)}$$

Hence,

$$Vu = 1.8 f_{sp} bd \qquad \textbf{(22)}$$

where

$$f_{sp} = 0.52\sqrt{f_{cu}}\, N/mm^2 \qquad \textbf{(23)}$$

Equation (23) is arrived at assuming that $f_c' = 0.8 f_{cu}$, but where steel reinforcement is present in the web:

$$f_{sp} = 6.96\sqrt{f_c'}\left[1 + n\left(\rho_h \sin^2\theta + \rho_v \cos^2\theta\right)\right] \qquad \textbf{(24)}$$

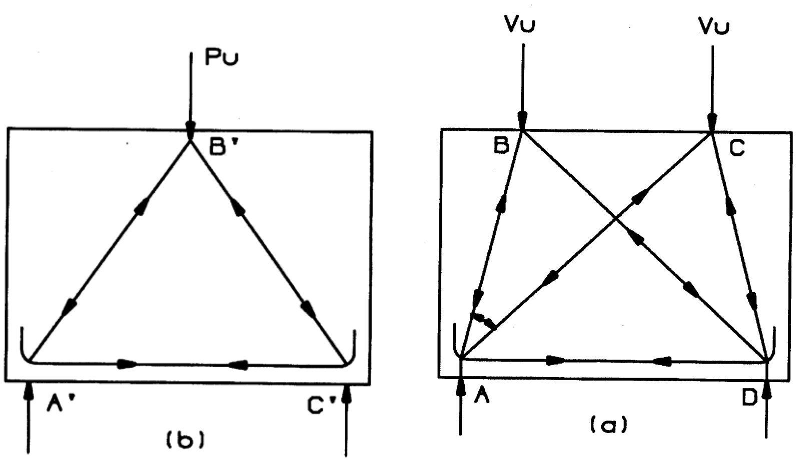
$$V_u = 1.05\sqrt{f_c'}\,bd\left[1 + n\left(\rho_h \sin^2\theta + \rho_v \cos^2\theta\right)\right] \qquad \textbf{(25)}$$

where

f_{sp} **:** Concrete tensile stress, f_{cu} **:** Cubic strength of concrete, ρ_h **:** Horizontal steel ratio, ρ_v **:** Vertical steel ratio.

Figure (4) postulate the load transmission paths for each load case. It would appear that the two-point load case is less troublesome where diagonal splitting is concerned, as splitting stresses due to each point loads are applied, Eq.(25) ought to be modified :

$$V_u \text{ (single point load)} = 0.83 \times V_u \text{ (double-point load)} = 0.87\sqrt{f_c'}\,bd\left[1 + n\left(\rho_h \sin^2\theta + \rho_v \cos^2\theta\right)\right] \qquad \textbf{(26)}$$



Figure(4): Load transmission paths for deep beams with double and single point loads[13]

Proposed model

The proposed model for the shear strength of reinforced concrete deep beam takes into account several effects such as (span/depth) ratio, (shear span/depth) ratio, reinforcement ratio, vertical and horizontal reinforcement ratio, vertical and horizontal spacing of stirrups, and compressive strength of concrete]. The proposed model takes the following form:

$$V_{calc} = \left(0.85 - 0.08\frac{Ln}{d}\right)\sqrt{f_c'}\,b_w d\left[\lambda + \alpha + n\left(\rho_h \sin^2\theta + \rho_v \cos^2\theta\right)\right] \qquad \textbf{(27)}$$

where:

$$\lambda = \left(\frac{Ln}{2a}\right)^{\left(\frac{d}{Ln}+\frac{bw}{a}\right)} \qquad \textbf{(28)}$$

$$\xi = \frac{kd}{2}\left(\rho_h + \rho_v\right) + \psi \qquad \textbf{(29)}$$

$$\psi = \frac{1}{2}\times\frac{s_v}{s_h}\times\frac{\rho_v}{\rho_h}, \quad \text{but } \psi = 0 \text{ when } (\rho_h \text{ or } s_h = 0) \qquad \textbf{(30)}$$

$$\alpha = \left(\frac{d}{Ln}\right)^{(H)} \qquad \textbf{(31)}$$

$$H = \frac{d}{b_w} - 2n\rho - \xi \qquad \textbf{(32)}$$

Where

a = Shear span from face of support to point load,

s_h = Horizontal spacing of stirrups,

s_v = Vertical spacing of stirrups.

The computer program (SSRCDB)(Shear Strength of Reinforced Concrete Deep Beams) is designed to deal with reinforced concrete deep beam with different dimensions and parameters . The computer program is coded in FORTRAN90 language. The properties and abilities of this program may be summarized as follows:

1- Different section of members,2-Various parameters,3- Using three different types of methods.

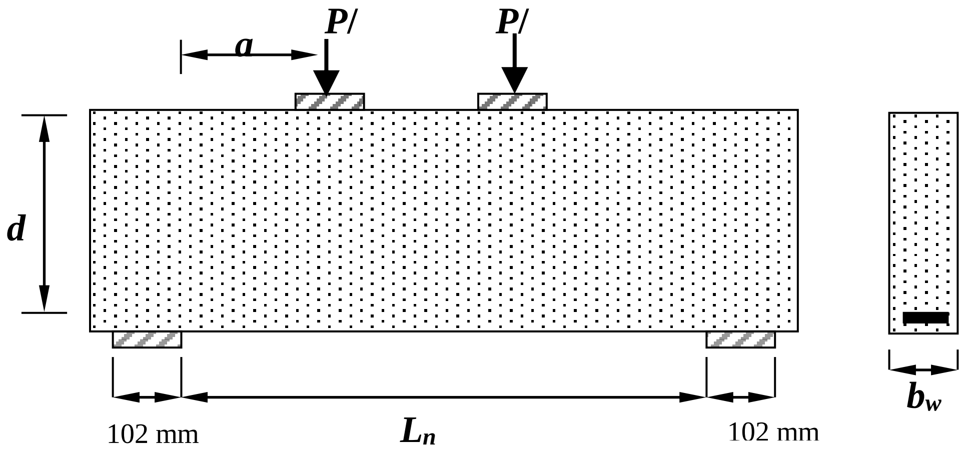
Numerical Examples:

A total of 49 test specimens of simply supported deep beams and their results were employed to verify the reliability of the proposed model; properties of all beams are listed in **Table (1)**. All beams had rectangular cross section and loaded directly on the top compressive face with two equal concentrated loads as shown in **Figure(5)**.

In selecting these data, the test specimens satisfying the following variables were considered as follows:

1. Span-to-depth ratio **(L_n/d = 2.3, 2.75, and 3.3)**
2. Shear span-to-depth ratio **(a/d = 0.83, 1.0, 1.34)**
3. Compressive strength of concrete.
4. Different value of vertical and horizontal shear reinforcement ratio.
5. Different value of vertical and horizontal stirrups.

The test results presented by Smith and Vantsiotis (1982) that are listed in **Table (2)** and compared with proposed model, ACI-metod, Siao 1995 model, and Hwang and Lee model.



Figure(5): Simply Supported reinforced concrete deep beams geometry details

Table (1): Geometrical and material properties of experimental concrete beams

Specimen	L_n/d	*b* (mm)	*d* (mm)	*a/d*	$f_{c'}$ (MPa)	*ρ* %	*ρ´* %	*d´* (mm)	f_{yh} (Mpa)	f_{yv} (Mpa)	ρ_h %	ρ_v %	s_h (mm)	s_v (mm)
Series A beams														
0A0-44	2.33	101.6	304.8	0.83	20.5	1.94	0.1	25.4	0.0	0.0	0	0	0	0
0A0-48	2.33	101.6	304.8	0.83	20.9	1.94	0.1	25.4	0.0	0.0	0	0	0	0
1A1-10	2.33	101.6	304.8	0.83	18.7	1.94	0.1	25.4	460.9	460.7	0.23	0.28	139.7	228
1A3-11	2.33	101.6	304.8	0.83	18.0	1.94	0.1	25.4	460.0	460.7	0.45	0.28	69.85	228
1A4-12	2.33	101.6	304.8	0.83	16.1	1.94	0.1	25.4	460.3	460.7	0.68	0.28	93.98	228
1A4-51	2.33	101.6	304.8	0.83	20.6	1.94	0.1	25.4	460.3	460.7	0.68	0.28	93.98	228
1A6-37	2.33	101.6	304.8	0.83	21.1	1.94	0.1	25.4	460.4	460.7	0.91	0.28	69.85	228
2A1-38	2.33	101.6	304.8	0.83	21.7	1.94	0.1	25.4	460.9	460.3	0.23	0.63	139.7	101.6
2A3-39	2.33	101.6	304.8	0.83	19.8	1.94	0.1	25.4	460.0	460.3	0.45	0.63	69.58	101.6
2A4-40	2.33	101.6	304.8	0.83	20.3	1.94	0.1	25.4	460.3	460.3	0.68	0.63	93.98	101.6
2A6-41	2.33	101.6	304.8	0.83	19.1	1.94	0.1	25.4	460.4	460.3	0.91	0.63	69.85	101.6
3A1-42	2.33	101.6	304.8	0.83	18.4	1.94	0.1	25.4	460.9	456.0	0.23	1.25	139.7	50.8
3A3-43	2.33	101.6	304.8	0.83	19.2	1.94	0.1	25.4	460.0	456.0	0.45	1.25	69.85	50.8
3A4-45	2.33	101.6	304.8	0.83	20.8	1.94	0.1	25.4	460.3	456.0	0.68	1.25	93.98	50.8
3A6-46	2.33	101.6	304.8	0.83	19.9	1.94	0.1	25.4	460.4	456.0	0.91	1.25	69.85	50.8
Series B beams														
0B0-49	2.75	101.6	304.8	1	21.7	1.94	0.1	25.4	0.0	0.0	0	0	0	0
1B1-01	2.75	101.6	304.8	1	22.1	1.94	0.1	25.4	460.9	458.3	0.23	0.24	139.7	266.7
1B3-29	2.75	101.6	304.8	1	20.1	1.94	0.1	25.4	460.0	458.3	0.45	0.24	69.85	266.7
1B4-30	2.75	101.6	304.8	1	20.8	1.94	0.1	25.4	460.3	458.3	0.68	0.24	93.98	266.7
1B6-31	2.75	101.6	304.8	1	19.5	1.94	0.1	25.4	460.4	458.3	0.91	0.24	69.85	266.7
2B1-05	2.75	101.6	304.8	1	1.2	1.94	0.1	25.4	460.9	459.5	0.23	0.42	139.7	152.4
2B3-06	2.75	101.6	304.8	1	19	1.94	0.1	25.4	460.0	459.5	0.45	0.42	69.85	152.4
2B4-07	2.75	101.6	304.8	1	17.5	1.94	0.1	25.4	460.3	459.5	0.68	0.42	93.98	152.4
2B4-52	2.75	101.6	304.8	1	21.8	1.94	0.1	25.4	460.3	459.5	0.68	0.42	93.98	152.4
2B6-32	2.75	101.6	304.8	1	19.8	1.94	0.1	25.4	460.4	459.5	0.91	0.42	69.85	152.4
3B1-08	2.75	101.6	304.8	1	16.2	1.94	0.1	25.4	460.9	460.3	0.23	0.63	139.7	101.6
Series C beams														
0C0-50	3.33	101.6	304.8	1.33	20.7	1.94	0.1	25.4	0.0	0.0	0	0	0	0
1C1-14	3.33	101.6	304.8	1.33	19.2	1.94	0.1	25.4	460.9	461.1	0.23	0.18	139.7	355.6
1C3-02	3.33	101.6	304.8	1.33	21.9	1.94	0.1	25.4	460.0	461.1	0.45	0.18	69.85	355.6
1C4-15	3.33	101.6	304.8	1.33	22.7	1.94	0.1	25.4	460.3	461.1	0.68	0.18	93.98	355.6
1C6-16	3.33	101.6	304.8	1.33	21.8	1.94	0.1	25.4	460.4	461.1	0.91	0.18	69.85	355.6
2C1-17	3.33	101.6	304.8	1.33	19.9	1.94	0.1	25.4	460.9	461.3	0.23	0.31	139.7	203.2
2C3-03	3.33	101.6	304.8	1.33	19.2	1.94	0.1	25.4	460.0	461.3	0.45	0.31	69.85	203.2
2C3-27	3.33	101.6	304.8	1.33	19.3	1.94	0.1	25.4	460.0	461.3	0.45	0.31	69.85	203.2
2C4-18	3.33	101.6	304.8	1.33	20.4	1.94	0.1	25.4	460.3	461.3	0.68	0.31	93.98	203.2
2C6-19	3.33	101.6	304.8	1.33	20.8	1.94	0.1	25.4	460.4	461.3	0.91	0.31	69.85	203.2
3C1-20	3.33	101.6	304.8	1.33	21	1.94	0.1	25.4	460.9	460.7	0.23	0.56	139.7	114.3
3C3-21	3.33	101.6	304.8	1.33	16.6	1.94	0.1	25.4	460.0	460.7	0.45	0.56	69.85	114.3
3C4-22	3.33	101.6	304.8	1.33	18.3	1.94	0.1	25.4	460.3	460.7	0.68	0.56	93.98	114.3
3C6-23	3.33	101.6	304.8	1.33	19	1.94	0.1	25.4	460.4	460.7	0.91	0.56	69.85	114.3
4C1-24	3.33	101.6	304.8	1.33	19.6	1.94	0.1	25.4	460.9	459.7	0.23	0.77	139.7	82.55

Table (1): Continued

Specimen	L_n/d	b (mm)	d (mm)	a/d	$f_{c'}$ (Mpa)	ρ %	ρ' %	d' (mm)	f_{yh} (Mpa)	f_{yv} (Mpa)	ρ_h %	ρ_v %	s_h (mm)	s_v (mm)
Series C beams														
4C3-04	3.33	101.6	304.8	1.33	18.6	1.94	0.1	25.4	460.0	460.3	0.45	0.63	69.85	101.6
4C3-28	3.33	101.6	304.8	1.33	19.2	1.94	0.1	25.4	460.0	459.7	0.45	0.77	69.85	82.55
4C4-25	3.33	101.6	304.8	1.33	18.5	1.94	0.1	25.4	460.3	459.7	0.68	0.77	93.98	82.55
4C6-26	3.33	101.6	304.8	1.33	21.2	1.94	0.1	25.4	460.4	459.7	0.91	0.77	93.98	82.55

Table (2): Shear strength comparison of the present study with other methods for concrete deep beam

Specimen	V_{exp}	V_{pres}	V_{siao}	V_{ACI}	V_{hwang}
0A0-44	139.5	132.9	116.4	86.6	119.2
0A0-48	136.1	134.1	117.5	87.0	121.5
1A1-10	161.2	145.2	114.0	111.4	121.0
1A3-11	148.3	146.9	113.0	127.0	119.5
1A4-12	141.2	133.5	108.1	142.7	109.5
1A4-51	170.9	149.2	121.7	147.4	134.6
1A6-37	184.1	155.2	124.2	165.7	138.4
2A1-38	174.5	154.8	125.1	131.1	136.3
2A3-39	170.6	158.7	120.4	139.2	138.6
2A4-40	171.9	153.0	122.9	157.5	142.0
2A6-41	161.9	154.3	120.6	174.0	135.0
3A1-42	161.0	155.0	118.7	139.2	126.7
3A3-43	172.7	166.4	122.3	157.1	134.9
3A4-45	178.5	164.2	128.1	176.4	145.1
3A6-46	168.1	169.0	126.7	85.9	140.0
0B0-49	149.0	116.1	119.7	70.4	111.1
1B1-01	147.5	132.5	123.4	95.6	125.0
1B3-29	143.6	130.6	118.7	110.0	116.7
1B4-30	140.3	126.4	121.6	127.5	119.9
1B6-31	153.3	126.3	118.7	143.2	113.5
2B1-05	129.0	126.1	116.4	99.0	119.2
2B3-06	131.2	129.9	116.8	115.0	120.0
2B4-07	126.1	119.2	113.1	130.5	113.6
2B4-52	149.9	131.4	125.6	134.5	133.8
2B6-32	145.2	129.1	120.0	132.6	124.1
3B1-08	130.8	119.1	108.7	103.1	106.3
3B1-36	159.0	133.4	122.3	111.8	126.1
3B 3-33	158.4	135.0	119.2	126.7	120.0

Table (2): Continued

Specimen	V_{exp}	V_{pres}	V_{siao}	V_{ACI}	V_{hwang}
3B4-34	155.0	128.9	120.7	143.7	121.0
4B1-09	153.5	129.1	115.8	124.8	110.4
0C0-50	115.4	99.4	116.9	52.1	91.1
1C1-14	119.0	113.8	114.7	73.6	96.7
1C3-02	123.4	113.3	123.1	90.6	108.2
1C4-15	131.0	119.9	125.9	106.9	111.0
1C6-16	122.3	120.5	124.1	121.9	107.2
2C1-17	124.1	116.6	117.8	79.1	110.8
2C3-03	103.6	108.1	116.4	93.6	107.9
2C3-27	115.3	108.4	116.7	93.7	107.7
2C4-18	124.5	116.0	120.6	110.2	112.1
2C6-19	124.1	119.8	122.3	126.2	113.8
3C1-20	140.8	122.1	122.9	89.6	114.4
3C3-21	125.0	115.1	110.5	101.1	96.9
3C4-22	127.7	118.0	116.4	118.2	103.8
3C6-23	137.2	129.3	119.2	134.5	106.4
4C1-24	146.6	120.8	120.6	96.6	120.1
4C3-04	128.6	121.3	117.2	105.4	115.8
4C3-28	152.3	124.6	120.1	111.4	118.0
4C4-25	152.6	127.1	118.7	126.5	115.6
4C6-26	159.5	133.1	126.5	128.6	126.5

From this table, can be noticed that the present method gives agreement values and nearest to experimental study from other methods. This is because of the present study take into account the effect of horizontal and vertical reinforcement with their spacing and so the flexural reinforcement was taken.

Table (3) present the ratio of the present study and other studies to the experimental studies. This table gives the range of accuracy of the present study to the experimental study compared with the other studies.

Table (3): Shear strength ratios of the experimental study to the present study and other studies

Specimen	$V_{test/calc}$	$V_{test/Siao}$	$V_{test/ACI}$	$V_{test/Hwang}$
0A0-44	1.05	1.20	1.61	1.17
0A0-48	1.01	1.16	1.56	1.12
1A1-10	1.11	1.41	1.45	1.33
1A3-11	1.01	1.31	1.17	1.24
1A4-12	1.06	1.31	0.99	1.29
1A4-51	1.15	1.40	1.16	1.27
1A6-37	1.19	1.48	1.11	1.33
2A1-38	1.13	1.40	1.33	1.28
2A3-39	1.07	1.42	1.22	1.23
2A4-40	1.12	1.40	1.09	1.21
2A6-41	1.05	1.34	0.93	1.20
3A1-42	1.04	1.36	1.16	1.27
3A3-43	1.04	1.41	1.10	1.28
3A4-45	1.09	1.39	1.01	1.23
3A6-46	0.99	1.33	1.96	1.20
0B0-49	1.28	1.24	2.12	1.34
1B1-01	1.11	1.20	1.54	1.18
1B3-29	1.10	1.21	1.30	1.23
1B4-30	1.11	1.15	1.10	1.17
1B6-31	1.21	1.29	1.07	1.35
2B1-05	1.02	1.11	1.30	1.08
2B3-06	1.01	1.12	1.14	1.09
2B4-07	1.06	1.11	0.96	1.11
2B4-52	1.14	1.19	1.11	1.12
2B6-32	1.12	1.21	1.10	1.17
3B1-08	1.10	1.20	1.27	1.23
3B1-36	1.19	1.30	1.42	1.26
3B 3-33	1.17	1.33	1.25	1.32
3B4-34	1.20	1.28	1.08	1.28
4B1-09	1.19	1.33	1.24	1.39
0C0-50	1.20	0.99	2.22	1.27
1C1-14	1.05	1.04	1.62	1.23
1C3-02	1.09	1.00	1.36	1.14
1C4-15	1.09	1.04	1.22	1.18
1C6-16	1.01	0.99	1.01	1.14
2C1-17	1.06	1.05	1.56	1.12
2C3-03	0.96	0.89	1.11	0.96
2C3-27	1.06	0.99	1.24	1.07
2C4-18	1.07	1.03	1.13	1.11
2C6-19	1.03	1.01	0.99	1.09
3C1-20	1.15	1.15	1.58	1.23
3C3-21	1.08	1.13	1.24	1.29
3C4-22	1.08	1.10	1.08	1.23
3C6-23	1.06	1.15	1.02	1.29

Table (3): Continued

Specimen	$V_{test/calc}$	$V_{test/Siao}$	$V_{test/ACI}$	$V_{test/Hwang}$
4C1-24	1.20	1.22	1.52	1.22
4C3-04	1.06	1.10	1.22	1.11
4C3-28	1.22	1.27	1.37	1.29
4C4-25	1.20	1.29	1.20	1.32
4C6-26	1.19	1.26	1.24	1.26

Parametric Study:

a- Effect of span-to-depth ratios on shear strength predictions.

A simply supported deep beam **(1B1-01)** subjected to two concentrated load was analyzed with a range of span to depth ratio **(L_n/d) (2.3-3.3)**. The following properties of the beam **(1B1-01)** are (L_n=838.2 mm, d=304.8 mm, a=304.8 mm, b=101.6 mm, fc'= 22.1 MPa, ρ_v = 0.24 %, ρ_h = 0.23 %).

Figure (6) shows the relation of shear strength and span-to-depth ratios (L_n/d) with range of span shear to depth ratio **(a/d)** ranging from 0.83 to 1.34.

From this figure can be noticed that the shear strength is decreasing with increasing the span to depth ratio. The decreasing percentage about (9%) for span shear to depth ratio (1.34) while the decreasing percentage about (6%) for span shear to depth ratio (0.83).

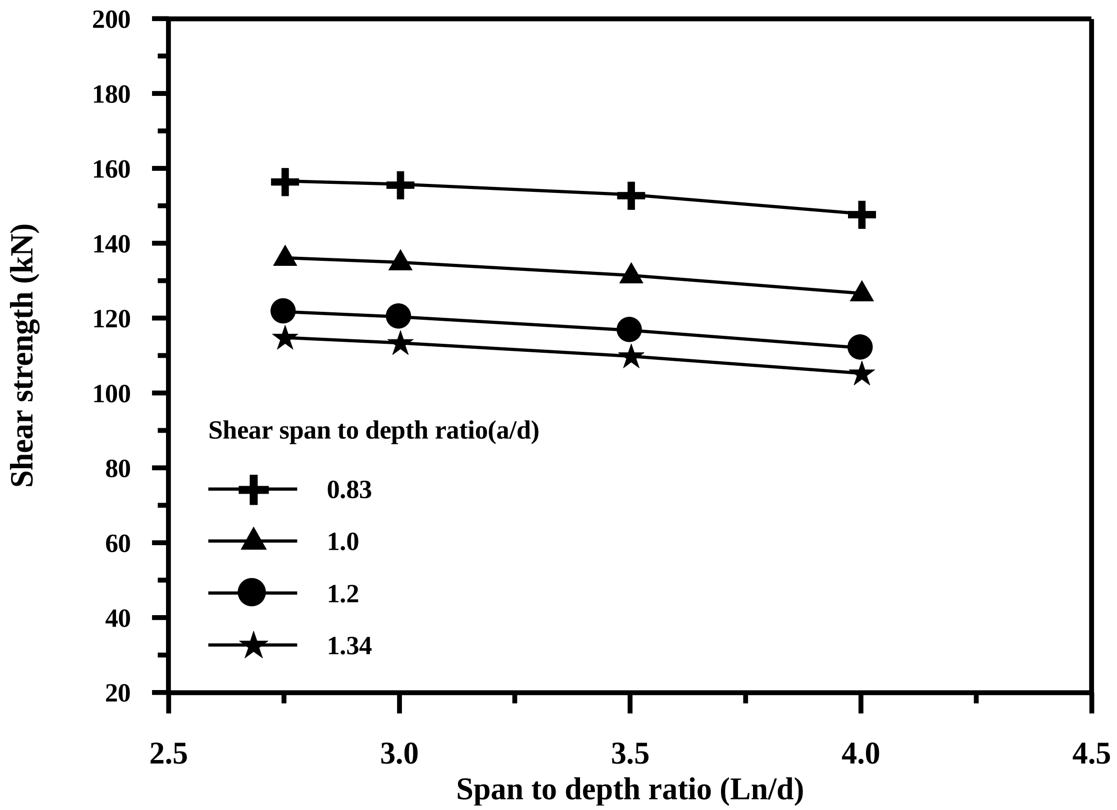


Figure (6): Shear strength-span to depth ratio curve of reinforced concrete deep beam with a range of shear span to depth ratios

b- Effect of compressive strength on shear strength predictions.

A simply supported deep beam **(1A1-10)** subjected to two concentrated load was analyzed with a range of **($f_{c'}$)** from **(18.7-40)** MPa. The following properties of the beam **(1A1-10)** are (L_n=710.8 mm, d=304.8 mm, a=254 mm, b=101.6mm, $f_{c'}$= 18.7 MPa, ρ_v = 0.28 %, ρ_h = 0.23 %).

Figure (7) present the shear strength and compressive strength of concrete curve of a simply supported reinforced concrete deep beam under two concentrated loads with range of shear span to depth ratio ***(a/d)*** ratios ranging from (0.83) to (1.34). From this figure, it can be noticed that the shear strength increase with increasing compressive strength of concrete where the shear strength increase about (42%) for the range of compressive strength of concrete from (18.7 MPa to 40.0 MPa) and for shear span to depth ratio (0.83).

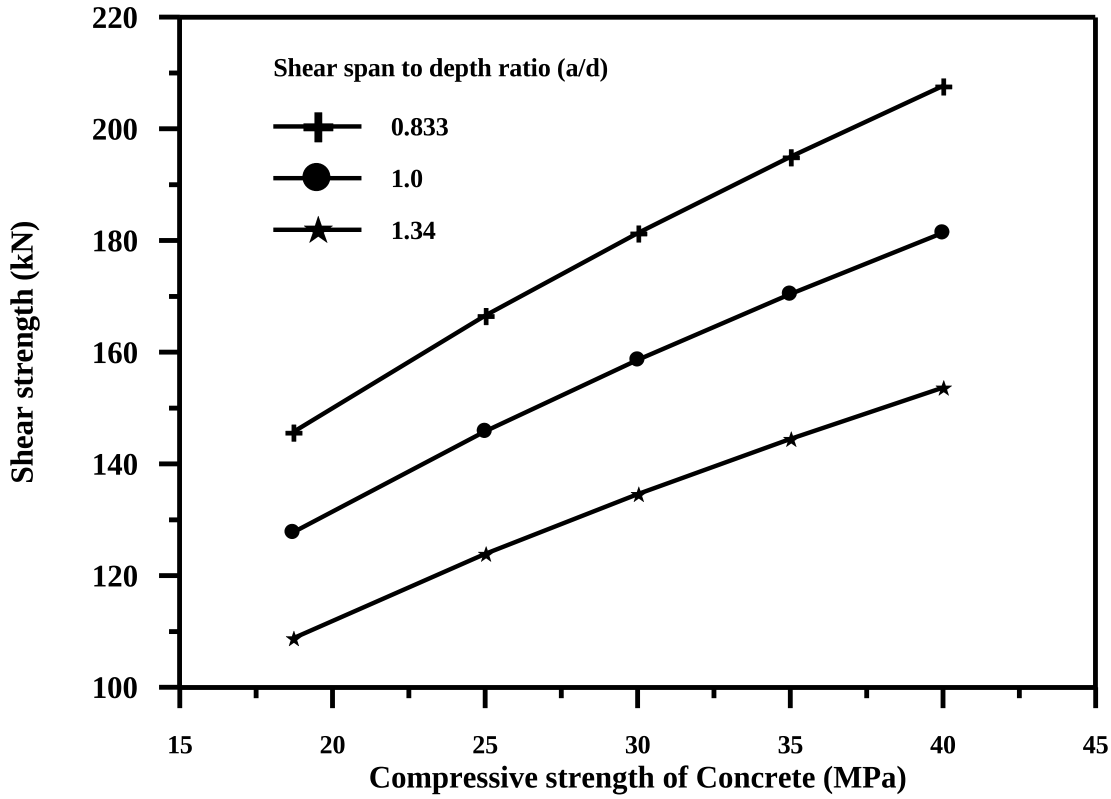


Figure (7): Shear strength-compressive strength curve of reinforced concrete deep beam with a range of shear span to depth ratio

c- Effect of Shear span-to-depth ratio on shear strength predictions.

A simply supported reinforced concrete deep beam **(1C1-14)** subjected to two concentrated load was analyzed with a range of vertical reinforcement **(ρ_v')** from **(0.18%-0.63%)**. The following properties of the beam **(1C1-14)** are (L_n=1016 mm, d=304.8 mm, **a**=406.4 mm, b=101.6mm, , $f_{c'}$= 19.2 MPa, ρ_v = 0.18 %, ρ_h = 0.23 %).

Figure (8) shows the shear strength and shear span curve of a simply supported reinforced concrete deep beam with a range of vertical reinforcement. From this figure can be noticed that the increasing shear span **(*a*/*d*)** ratios will decrease the shear strength of beam, where the decreasing percentage about (28%) for vertical reinforcement ratio(0.18) and so the decreasing percentage about (9%) for vertical reinforcement ratio(0.63).

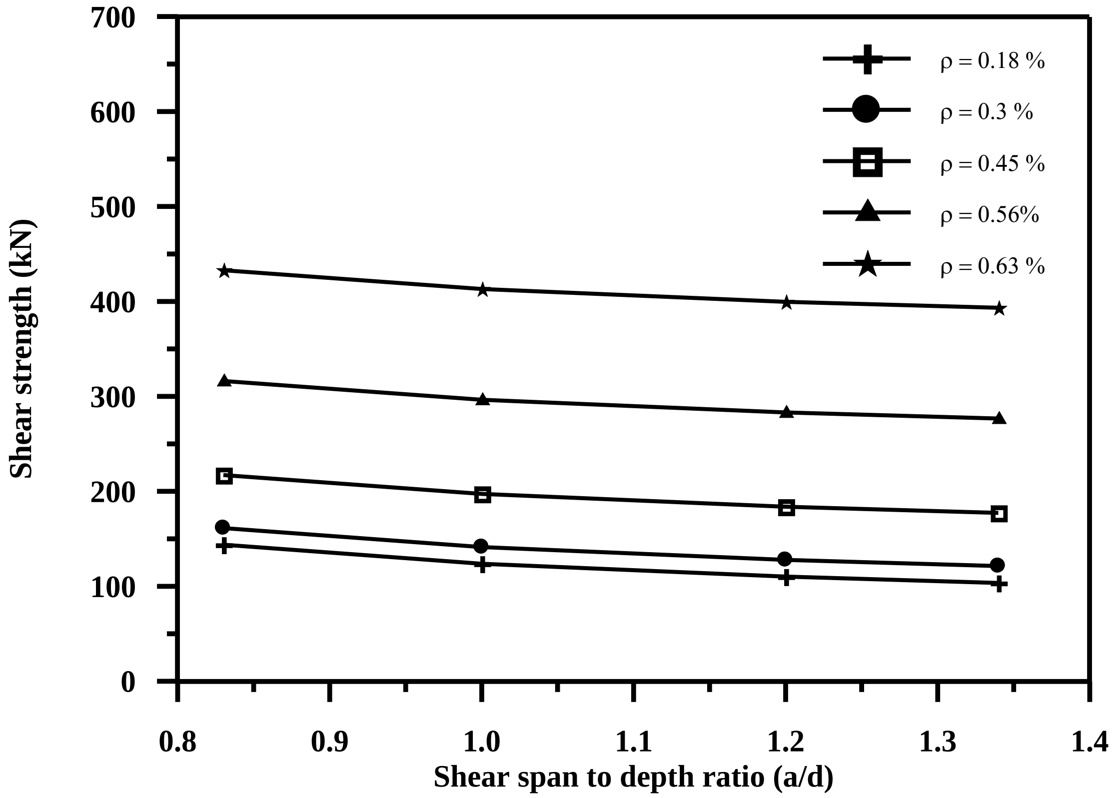


Figure (8): Shear strength-shear span to depth ratio curve of reinforced concrete deep beam with a range of vertical reinforcement ratio

Conclusions:

1. A simplified model for determining the shear strength of deep beams state was proposed in this study. Comparisons with the available test results and other method in the literature reveal that the proposed model can accurately predict the shear strength of simply supported deep beams at ultimate state for a range of shear span-to-depth ratios (0.83-1.34), compressive strengths of concrete, as well as horizontal and vertical hoops.
2. The shear span-depth ratio ***a/d*** has a significant influence on the ultimate shear strength, as ***a/d*** increasing the shear strength is decrease.

3. The effective span-depth ratio ***ln/d*** has a qualitative influence on the shear strength, as L_n/d increase the shear strength is decrease.
4. The shear span to depth ratio has more influence on the shear capacity than the span to depth ratio and as the former increases, the shear strength decreases.

References:

1. American Concrete Institute, "**Building Code Requirements for Reinforced Concrete**", Detroit, ACI-381-08, (2008).

2. AL-Taan, S.A., and Ali, T.Q., " **Nonlinear Finite Element Analysis of Fibrous Concrete Deep Beams**", Engineering and Technology, Vol. 17, No. 9, 862-876, (1998).

3. Ashour, A.F.," **Shear Capacity of Reinforced Concrete Deep Beams**", Journal of Struct. Eng., ASCE, V.126, No. 9, September, 1045-1052, (2000).

4. Brown, M.D, and Bayrak, O.," **Investigation of Deep Beams with Various Load Configurations**", ACI Structural Journal, V. 104, No. 5, September-October, 611-620, (2007).

5. Cervera, M., Hinton, E., and Hassan, O., "**Nonlinear Analysis of Reinforced Concrete Plate and Shell Structures Using 20-Noded Isoparametric Brick Element**", Computers and Structures, Vol. 25, No. 6, pp. 845-869, (1987).

6. El-Hashimy. H., Naser. M., and Farahat. A., **"Cracking Load of Reinforced Concrete Deep Beams with Openings",** Convention paper, (1990).

7. Hwang, S.J., Lu, W.Y. and Lee, H.J., **"Shear strength prediction for deep beams"**, ACI Struct. J., 97(3), 367-376, (2000).

8. Hwang, S.J. and Lee, H.J., **"Strength prediction for discontinuity regions failing in diagonal compressions by softened strut-and-tie model",** J. Struct. Eng., ASCE, 128(12), 1519-1526, (2002).

9. Hwang , S.J., Lu, W.Y. and Lin , L.J. ,"**Deflection prediction for reinforced concrete deep beams**", Computers and Concrete, Vol.7, No. 1, 1-16, (2010).

10. Khalaf, I.M., "**Nonlinear Finite Elements Analysis of Reinforced Concrete Deep Beam",** M.Sc. Thesis, University of Mosul, (1986).

11. Mahmoud, M.N., "**Nonlinear Finite Elements Analysis of Reinforced Concrete Deep Beam",** M.Sc. Thesis, University of Mosul, (1992).

12. Russo, G., Venir, R. and Pauletta , M., "**Reinforced concrete deep beams-shear strength model and design formula**", ACI Struct. J., 102(3), 429-437, (2005).

13. Siao,W.B.,"Deep Beam Revisited", ACI Structural Journal, Vol. 92, No. 1, January-February, pp. 95-102,(1995).

14. Smith, K.N. and Vantsiotis, A.S., **"Shear strength of deep beams",** ACI J., 79(3), 201-213,(1982).

15. Tan, K.H., Tong, K., and Tang, C.Y. ,"**Direct Strut-and-Tie Model for Prestressed deep Bea***ms*", Journal of Struct. Eng., ASCE, V.127, No. 9, September, 1076-1084, (2001).

16. Tang, C.Y. and Tan, K.H., "**Interactive mechanical model for shear strength of deep beams**", J. Struct. Eng., ASCE, 130(10), 1534-1544, (2004).

17. Winter, G., and Nilson, A.H., "**Design of Concrete Structures**", 9th Edition, (1978).

18. Zhang, N., Tan, K.H., and Leong, C.L. " **Single-Span Deep Beams Subjected to Unsymmetrical Loads**", Journal of Struct. Eng., ASCE, March, 239-252, (2009).