ISSN: 0128-7680
Pertanika J. Sci. & Technol. 7(1): 1 - 11 (1999)

The Effect of Web Reinforcement on the Shear Capacity of Brick Aggregate Concrete Beams

Md. Monjur Hossain, M. Shamim Z. Bosunia[1], Md. Hazrat Ali*

Dept. of Civil Engineering
BIT
Khulna, Bangladesh

[1]*Dept. of Civil Engineering*
BUET
Dhaka, Bangladesh

**Dept. of Civil Engineering*
BIT
Chittagong, Bangladesh

Received 16 March 1999

ABSTRAK

Kapasiti pancang tiang konkrit campuran batu bata yang diperkukuh tanpa sebarang lapisan dan dengan nisbah pengukuhan lapisan yang berza-beza dikaji dalam penyelidikan ini. Pembiasan pancaran dan retak semasa mengisi muatan direkodkan. Tiang konkrit campuran batu bata dengan pengukuhan lapisan serta dua lapisan kukuh yang diregang didapati menambahkan keretakan yang agak besar. Persamaan keretakan dan tekanan tiang dasar dicadangkan dalam skop kajian ini. Nilai-nilai percubaan kekuatan tiang dasar dibandingkan dengan nilai yang diperoleh melalui persamaan yang dicadangkan oleh ACI dan penyelidikan lain. Persamaan yang dicadangkan di sini mendapati keputusan ujian ini lebih baik daripada yang dibuat oleh para penyelidik lain manakala mengekalkan yang konservatif. Diharap persamaan ini yang dikembangkan di dalam penyelidikan ini akan menyediakan perkara-perkara yang rasional dan asas memulakan konsep yang lazim terdapat dan akan membantu ke arah rumusan kod yang sesuai untuk menyediakan pengukuhan lapisan bagi tiang konkrit campuran batu bata.

ABSTRACT

Shear capacity of reinforced brick aggregate concrete beams without any web reinforcement and with varying ratio of web reinforcement was studied in this investigation. Deflections of beams and cracks during the progress of loading were recorded. Brick aggregate concrete beams with web reinforcement and two layers of tensile reinforcement were found to have increased cracking shear stress by a considerable amount. Equations for cracking and ultimate shear stresses were suggested within the scope of this study. The experimental values of ultimate shear strength of beams were compared with the values obtained by equations proposed by ACI and other researchers. The equations proposed herein were found to represent the test results better than those of other researchers while remaining on the conservative side. It is hoped that the equations developed herein will provide a rational and basic point of departure from the prevailing concept and will help towards the formulation of a suitable code to provide web reinforcement for brick aggregate concrete beams.

*Corresponding author's address: Ph.D. Student, Faculty of Engineering, University Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia

Keywords: shear capacity, cracking shear stress, brick aggregate, web reinforcement, shear reinforcement parameter

INTRODUCTION

Brick aggregate plays a key role in the construction field, particularly in countries where sources of natural stone and gravel are limited. For reasons of availability, economy and low weight, this artificial aggregate, of crushed burnt brick, is increasingly becoming popular in the concrete trade. In Bangladesh alone, nearly 90% of concrete construction uses brick aggregate. Crushed brick is also used as aggregate in large quantities in India and Pakistan.

Although a thorough study of structural behaviour of concrete made of brick aggregate has been felt to be necessary for a long time, so far only a few studies (Habibullah 1967; Akhtaruzzaman 1968; Rashid 1968; Alee 1976; Akhtaruzzaman 1983; Hossain 1986; Hossain 1984; Shamim-uz-Zaman 1986) have been carried out. But no test has yet been reported for investigating the effect of web reinforcement on the shear capacity of brick aggregate concrete beams.

The code provisions followed in Bangladesh are prepared on the basis of studies on conventional stone aggregate concrete in general. These need to be verified for the design of brick aggregate concrete structures. Keeping the above objective in view, the present research was undertaken to investigate the shear problem in particular. Shear failure of rectangular brick aggregate concrete beams with web reinforcement was studied. Concrete strength and web reinforcement are taken as principal variables.

MATERIALS AND METHODS

Eighteen single span simply supported beams were tested under two-point loading. The load was applied by a 200-ton universal testing machine. A fixed value of shear span ratio equal to 2.5 was maintained for each test.

Manually crushed first class brick chips 3/4 inch down grade, and locally available coarse sand, known as Sylhet sand were used as coarse and fine aggregate respectively. Physical properties of the aggregates are given in Table 1a.

TABLE 1(a)
Physical properties of aggregates

Property	Brick aggregate	Fine aggregate
Fineness modulus	6.88	2.65
Unit weight (1b/cft) (Dry, loose)	60.00	91.25
Unit weight (1b/cft) (dry, compacted)	64.00	101.87
Absorption (% dry weight)	14.75	1.46
Bulk specific gravity (SSD)	2.00	2.70

Details of mix proportioning is given in Table 1(b). Type 1 normal Portland cement was used. Three grades of concrete with 28 day's nominal strengths of 13.8 Mpa (2,000) psi, 20.7 Mpa (3,000 psi) and 27.6 Mpa (4,000 psi) were selected for this investigation. Average concrete strengths for each beam with details of main reinforcement and shear reinforcement are given in Table 2.

TABLE 1(a)
Details of concrete mix proportioning ratio

Nominal strength in psi	Ratio of mix proportion by weight, aggregates in SSD condition	Water cement ratio by wt	Per cubic yard of concrete		
			cement (lb)	Loose dry state	
				Sand (lb)	Aggregate (lb)
2000	1:2.35:4.46	0.75	406	911	1822
3000	1:1.90:3.80	0.65	472	896	1792
4000	1:1.67:3.33	0.58	530	884	1763

lbs/cu yd = 0.593 kg/m^3, 1 cubic yard =0.765 m^3

TABLE 2
Physical properties of beams

Beam designation	Cylinder strength (psi)	Average	Bottom reinforcement, f_y & steel ratio	Top reinforcement, f_y & steel ratio	Web reinforce-ment & (inches)	$rf_y = \frac{A_u f_y}{sb}$
$25C_1$	2218				NIL	0.00
$27C_2$	2297		4≠8	2≠7	#2 @ 13.5	44.43
$29C_3$	2772	2566	f_y = 52473 psi	f_y = 46916 psi	#2 @ 3.0	200.00
$32C_4$	2851		A_s = 2.956 in^2	A'_s = 1.108 in^2	#3 @ 4.0	371.20
$33C_5$	2693		ρ = 0.0547	ρ' = 0.02	#3 @ 3.0	495.00
$36C_0$	2059				Nil	0.00
$1A_1$	3433				Nil	0.00
$3A_2$	3644		4#8	2#7	#2 @ 13.5	45.00
$6A_3$	3406		f_y = 52473 psi	f_y = 46916 psi	#2 @ 3.0	201.00
$7A_4$	3248	3569	A_s = 2.956 in^2	A'_s = 1.108 in^2	#3 @ 4.0	305.00
$10A_5$	3644		ρ = 0.0547	ρ' = 0.02	#3 @ 3.0	407.00
$12A_6$	4040				#4 @ 3.5	740.00
$13A_0$	3287				Nil	0.00
$14B_1$	4515				Nil	0.00
$15B_2$	4357		4#8	2#7	#2 @ 13.5	44.43
$16B_3$	4040	4436	f_y = 34632 psi	fy = 39362 psi	#2 @ 4.5	133.30
$19B_4$	4832		A_s = 2.54 in2	A'_s = 1.087 in^2	#3 @ 4.5	412.50
$20B_5$	4436		ρ = 0.0525	ρ' = 0.02	#3 @ 4.0	464.00

TEST RESULTS AND DISCUSSION

The general behaviour of the test beams under load was in good agreement with other investigators (Clark 1951; Bresler and Scordelis 1963; Habibullah 1967; Akhtaruzzaman 1968; Haddadin *et al.* 1971; Hossain 1984;). Typical flexural cracks appeared first in the pure bending zone, followed by flexural and/or diagonal tension cracks in the shear span at increased loading. Diagonal tension cracks generally occur in the middle third of the overall depth, extending upward and downward.

Various test data, including the initial flexural cracking load P_f, initial diagonal tension cracking load P_c, failure load P_u and the observed mid-span deflection y_c are shown in Table 3. This table also includes the mode of failure and ratio of P_f/P_u, P_c/P_u and P_f/P_c for each beam. Table 3 reveals that flexural cracks started on an average at 44, 26 and 24% of the ultimate load for 2000, 3000 and 4000 psi series, respectively. Akhtaruzzaman (1968) recorded this value as 24% while Bresler and Scordelis (1963) and Clark (1951) obtained this value as 15 and 20%, respectively. Studies carried out by Clark (1951) and Bresler and Scordelis (1963) were with conventional concrete. The higher

TABLE 3
Observed values from beam tests

Series	Beam designation	Glexural cracking load, Pf (kip)	Diagonal tension cracking load, Pc (kip)	Ultimate load, Pu (kip)	Ratio Pf/Pu	Ratio Pc/Pu	Ratio Pf/pc	Recorded midspan deflection P_c y_c	P_u y_u	Mode of failure
2000 psi	$25C_1$	17.5	20.0	40.0	0.44	0.50	0.87	0.09	0.25	DT
	$27C_2$	27.0	27.0	45.0	0.60	0.60	1.00	0.14	0.33	DT
	$39C_3$	20.0	28.5	55.5	0.36	0.51	0.70	0.13	0.35	DT
	$32C_4$	30.0	30.0	60.0	0.50	0.50	1.00	0.08	0.40	DT
	$33C_5$	20.0	30.0	60.0	0.33	0.50	0.67	0.15	0.34	DT
	$36C_0$	16.0	16.0	41.0	0.39	0.39	1.00	0.08	–	ST
3000 psi	$1A_1$	15.0	24.0	35.0	0.43	0.68	0.63	0.17	0.27	DT
	$3A_2$	15.0	30.0	56.0	0.27	0.53	0.50	0.12	0.38	DT
	$6A_3$	17.0	25.0	70.0	0.24	0.36	0.68	0.10	0.41	DT
	$7A_4$	14.0	25.0	80.0	0.18	0.31	0.56	0.10	–	SC
	$10A_5$	15.0	30.0	86.0	0.17	0.35	0.50	0.15	0.15	SC
	$12A_6$	15.0	30.0	100.0	0.15	0.30	0.50	0.16	0.55	SC
	$13A_0$	15.0	28.0	43.0	0.35	0.65	0.54	0.13	–	ST
4000 psi	$14B_1$	13.0	30.0	44.4	0.29	0.67	0.43	0.18	0.35	DT
	$15B_2$	13.8	34.0	64.5	0.21	0.53	0.41	0.20	–	DT
	$16B_3$	15.6	35.0	70.0	0.22	0.50	0.44	0.16	–	SC
	$19B_4$	20.0	30.0	83.0	0.24	0.36	0.67	0.15	0.65	F
	$20B_5$	20.0	36.0	80.0	0.25	0.45	0.55	0.27	0.65	F

P_f/P_u value recorded in this investigation was due to higher tensile capacity of brick aggregate concrete. Previous authors (Akhtaruzzaman 1983; Hossain, 1984; Shamim-uz-Zaman 1986) also observed higher tensile capacity of brick aggregate concrete. Table 3 also reveals that the critical diagonal tension crack in general appeared at about 42% of the ultimate load, indicating significant reserve strength for brick aggregate concrete beam.

It is a common practice to provide stirrup in beams. The ACI provision also advocates providing minimum stirrup. In the presence of stirrup the dowel shear in the main reinforcement becomes more significant. Again, the compactness of the concrete due to shear reinforcement couples with the dowel shear to increase the cracking shear stress. The ratio of cracking shear stress obtained from test to the cracking shear stress calculated by ACI provision (v_c^T/v_c ACI) is recorded as high as 1.52 by Haddadin *et al.* (1971) and 1.44 by Bresler and Scordelis (1963), also pointed out that the shear rigidity of the multilayered tensile reinforcement contributes a significant portion of the calculated reserve shear strength due to so-called dowel action. Due to the facts mentioned above and since the brick aggregate concrete possesses higher tensile strength, the analysis of cracking shear stress is justified.

In *Fig. 1* the ratio of $v_c/\sqrt{f_c'}$ is drawn in ordinate against $\left(rf_y/\sqrt{f_c'}\right)\left(\frac{Vd}{M}\right)$ in abscissa, where v_c is the cracking shear stress; V is the maximum shear; M is the maximum moment and rf_y is the shear reinforcement parameter in which 'r' is ratio of web reinforcement $(=A_u/bs)$. The results of the beams tested by Haddadin *et al.* (1971) are higher than corresponding values proposed by ACI. The results of the beams tested in the present study are also well above the corresponding ACI values and can be distinguished by the lower ceiling line shown in the figure. This line is represented by Eq. (1). Since all the points are above this reference line, Eq. (1) may be taken as a safe basis to predict v_c for brick aggregate concrete beams with web reinforcement and multilayered

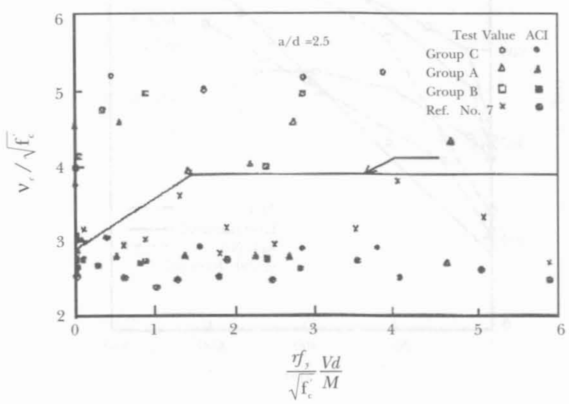

Fig 1. Comparison of proposed equation for vc with ACI code and test values

tensile reinforcement. Although these scant data are not adequate for a statistical evaluation, a very tentative equation is suggested as follows:

$$v_c = \left(2.9\sqrt{f_c'} + 2500\,\rho\frac{Vd}{M} + 0.7 f_y \frac{Vd}{M}\right) \leq 3.9\sqrt{f_c'}\ \text{psi} \qquad (1)$$

The term $2500\,\rho\frac{Vd}{M}$ is taken directly from Code.

The effect of variation of concrete strength on relation between v_u and rf_y is shown in *Fig. 2.* From this figure it is clear that the ACI Code provides a very conservative value of shear strength for beams with small rf_y. The trend of the curves shows an appreciable rise in capacity up to a certain limit of rf_y (varies with the concrete strength) and then flattens, indicating that further increase in shear reinforcement will not materially increase this capacity. This upper limit of ultimate shear stress as proposed by ACI $\left(10\sqrt{f_c'}\right)$ is also conservative, particularly for the higher strength concrete. In the present research a ceiling value higher than that of the ACI provision is suggested. The initial steeper slope of the curves indicates that the small amount of stirrups have a large effect on the ultimate shear capacity of the beams. These facts were also observed by other researchers (Clark, 1951; Bresler and Scordelis 1963; Haddadin *et al.* 1971) who worked with conventional stone aggregate concrete.

The ACI Code assumes a constant increase in stirrup contribution, $v_s = rf_y$ at all stages. The stirrup contribution in any beam of a series in the present research is assumed by $v_s = v_u - v_{u1}$ where v_u is the shear capacity of a beam with

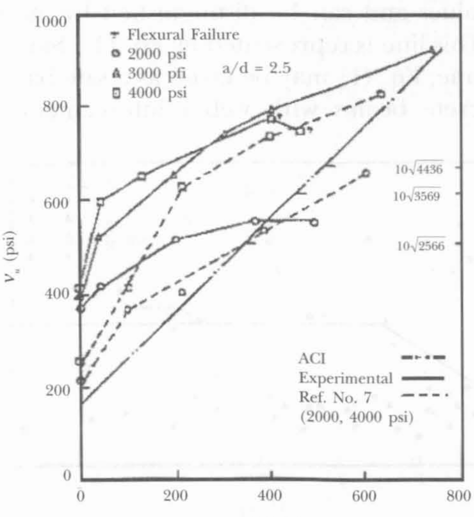

Fig 2. Effect of variation of concrete strength on relation between v_u and rf_y

stirrup at failure load and v_{u1} is that of a beam from the same strength series without any stirrup. Since the beams have identical physical properties, the additional strength of web reinforced beam thus obtained is totally due to web reinforcement. Bresler and Scordelis (1963) also expressed a similar concept. The shear contribution of stirrup, v_s depending on rf_y and concrete strength can be given by a generalized form of $y = ax^n$, where $y = v_s$, and $x = rf_y$ and 'a' and 'n' are constants depending on concrete cylinder strength. The values obtained were as follows:

Nominal f'_c (psi)	a	n
2000	5	0.604
3000	15.4	0.536
4000	23	0.527

The value of 'n' was taken on an average equal to 0.55. A generalized form for value of 'a' in terms of f'_c is given by, $a = 0.64e^{\frac{8.34 f'_c}{10^4}}$. Thus the vertical stirrup contribution is given by

$$v_s = 0.64(rf_y)^{0.55} e^{\frac{8.34 f'_c}{10^4}} \text{ psi} \tag{2}$$

A ceiling value for v_s is, however, employed and is given by $32.26e^{\frac{7.3 f'_c}{10^4}}$. The details of deduction v_s and its limiting value can be found elsewhere (Hossain 1986). By adding Eq. 1 to Eq. 2 ultimate shear capacity of brick aggregate concrete beams with stirrup and multilayered tensile reinforcement arrangement may be obtained. Thus,

$$v_u = v_c + v_s \tag{3}$$

where, $v_c = \left(2.9\sqrt{f'_c} + 2500\,\rho\frac{Vd}{M} + 0.7 f_y \frac{Vd}{M}\right) \leq 3.9\sqrt{f'_c}$ psi,

and $v_s = \left[0.64(rf_y)^{0.55} e^{\frac{8.34 f'_c}{10^4}}\right] \leq 32.26e^{\frac{7.3 f'_c}{10^4}}$ psi

The equations are based on the data from the results of brick aggregate concrete beams tested in this research where concrete strength varied from 2566 psi to 4436 psi and rf_y varied from 0-740 psi.

A comparison chart for the calculated shear at failure v_u and the actual ultimate shear v_u for the beams tested is shown in *Fig. 3*. In this chart, points which fall below the 45° line are conservative and those above are overestimated i.e. unconservative. Agreement between tests and the equation proposed by the author is seen to be more satisfactory than the agreement between test and the equation proposed by ACI and other investigators (Clark 1951; Haddadin *et al.*

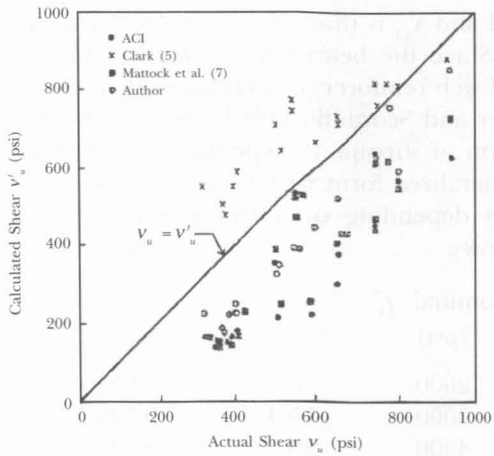

Fig 3. Comparison of proposed equation for v_u with ACI and other authors (Beams tested in the present study)

1971). It is also clear from the same figure that the results of the equation proposed herein are mostly on the conservative side. In spite of the limited number of test results a statistical evaluation of the tests has been made in Table 4. The evaluation shows that the values given by the proposed equation herein can be regarded as indicative of satisfactory agreement. A similar comparison chart is shown in *Fig. 4* for the beams tested by Bresler and Scordelis (1963) and Haddadin *et al.* (1971). In this chart also, the scatter of the values calculated by the equation suggested herein is in reasonable agreement with the scatter of results of other investigators.

Table 4 shows the statistical comparison of the ultimate shear strength obtained v_s. the ultimate shear strength proposed by different authors. It also

TABLE 4

Statistical comparison of the test values of v_u obtained by different authors with their proposed equations

Values of v_u from Eg. given by	Ratio of v_u test/v_u equation of beams tested by									
	Authors		Akhtaruzzaman(2)		Mattock(7)		Scordelis(4)		Clark(5)	
	Avg. of v_u^T/v_u	Std. deviaction	Avg. of v_u^T/v_u	Std. deviation	Avg. of v_u^T/v_u	Std. deviation	Avg. of v_u^T/v_u	Std. deviation	Av. of v_u^T/v_u	Std. deviaction
Scordelis	2.34	1.02	2.50	0.96	1.50	0.44	1.51	0.05	1.35	0.08
ACI	1.86	0.56	2.17	0.65	1.48	0.18	1.42	0.05	1.25	0.07
Mattock	1.72	0.47	2.17	0.65	1.16	0.22	1.22	1.13	1.11	0.06
Authors	1.50	0.31	1.53	0.52	1.26	0.35	0.92	0.06	0.96	0.15
Clark	0.81	0.11	0.89	0.21	0.89	0.19	0.76	0.02	0.83	0.03

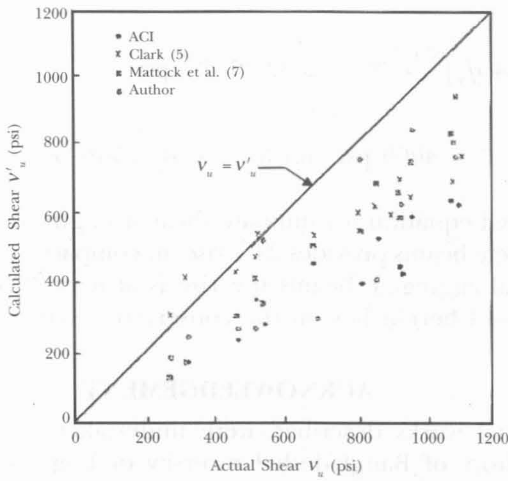

Fig 4. Comparison of proposed equation for v_u with ACI and other authors (Beams tested by Mattock et al. 1971)

shows that the equation proposed herein to calculate ultimate shear strength capacity is more reliable for brick aggregate concrete beam than others while remaining on the conservative side. The proposed equation can also be used for economic design of stone aggregate concrete beams. The details of the statistical evaluation can be obtained elsewhere (Hossain 1986).

CONCLUSION

1. Flexural cracks in beams form at a higher percentage of its ultimate load for lower strength concrete; whereas for the higher strength they form at a much lower percentage of its ultimate load.
2. The web shear crack is the dominant type to initiate as the diagonal tension crack in the beams with rf_y less than 500 psi. With higher rf_y the existing flexural cracks were inclined to initiate the diagonal tension cracks and fail at higher loads. Small amounts of stirrup have large effects on beams, which fail in diagonal tension.
3. The minimum reserve strength recorded is about 50% of the initial diagonal tension cracking load in beams without web reinforcement. For the web reinforced beams it is as high as 233%.
4. Shear capacity of brick aggregate concrete beams with stirrup and multilayered tensile reinforcement arrangement may be given by the equation

$$v_u = v_c + v_s$$

where, $v_c = \left(2.9\sqrt{f'_c} + 2500\,\rho\frac{Vd}{M} + 0.7f_y\frac{Vd}{M}\right) \leq 3.9\sqrt{f'_c}$ psi, and $$v_s = \left[0.64 (rf_y)^{0.55} e^{\frac{8.34 f_c'}{10^4}} \right] \leq 32.26 e^{\frac{7.3 f_c'}{10^4}} \text{ psi}$$

for 2000 psi < f'_c < 4000 psi and for 0 < rf_y < 740 psi.

5. The proposed equation for ultimate shear strength of web reinforced brick aggregate concrete beams provides 24% rise, in comparison to the ACI equation. For conventional aggregate beams the rise is at least 17%. In both cases the equation proposed herein lies on the conservative side.

ACKNOWLEDGEMENT

The experimental works described were undertaken and performed in the concrete laboratory of Bangladesh University of Engineering & Technology, Dhaka.

NOTATION

A_u = Cross-sectional area of shear reinforcement
b = Width of rectangular beam
f'_c = Cylinder strength of concrete
f_y = Yield strength of reinforcing steel
M = Maximum moment
P_f = Initial flexural cracking load
P_u = Failure load
r = Ratio of web reinforcement (= A_u/bs)
rf_y = Shear reinforcement parameter
ρ = Longitudinal steel ratio
s = Spacing of web reinforcement
V = Maximum shear
V_c = Cracking shear stress
V_s = Total shear supplied by stirrup
V_u = Unit shear stress at ultimate load

REFERENCES

AKHTARUZZAMAN, A. A. 1968. Influence of concrete strength on the shear capacity of Brick Aggregate Concrete Beams without web-reinforcement. Masters Thesis, East Pakistan University of Engineering and Technology, Dhaka.

AKHTARUZZAMAN, A. A. and ABUL HASANAT. 1983. Properties of concrete using crushed brick as aggregate. *Concrete International* February: 58-63.

ALEE, M. M. 1976. Effect of torsion bending and shear on rectangular reinforced concrete beams of brick aggregate. Masters Thesis, University of Engineering and Technology, Dhaka.

BRESLER, B., and SCORDELIS, A. C. 1963. Shear strength of reinforced concrete beams. *ACI Journal* **60**:51-72.

CLARK, A. P. 1951. Diagonal tension in reinforced concrete beams. *ACI Journal* **23(2)**: 145-156.

HABIBULLAH, G. M. 1967. Shear strength of brick aggregate concrete beams without web reinforcement. Masters Thesis, East Pakistan University of Engineering and Technology, Dhaka.

HADDADIN, M. J., SHEU-TIEN HONG and MATTOCK, A. H. 1971. Stirrup effectiveness in Reinforced Concrete Beams with Axial Force. *ASCE* 97(ST9) (Sept).

HOSSAIN, M. 1984. Investigation of shear capacity of brick aggregate beams without web reinforcement. Masters Thesis, Bangladesh University of Engineering and Technology, Dhaka.

HOSSAIN, M. 1986. Shear capacity of brick aggregate concrete beams with web-reinforcement. Masters Thesis, Bangladesh University of Engineering & Technology, Dhaka.

RASHID, S. M. 1968. Shear strength of pre-stressed beams of brick aggregate concrete without web reinforcement. Masters Thesis, East Pakistan University of Engineering and Technology, Dhaka.

SHAMIM-UZ-ZAMAN, M. 1986. Use of crushed brick aggregates in concrete construction. In *Proceedings of the Conference on the Asia- Pacific Concrete Technology* '86, p. 6.1-6.13. Oct 13–15, Jakarta, Indonesia.