CHAPTER 8

EVALUATION OF COMPOSITE BEAM TESTS AT VT AND ELSEWHERE

8.1 General

A new stud strength prediction method that was developed using push-out tests was presented in Chapter 6. As discussed in Section 1.1, push-out tests are used to explore the effects of many different parameters on stud strength in a relatively easy fashion. Push-out tests require significantly less time and material than full-scale beam tests and are much more sensitive than beam tests are to the strength of the studs. Because a composite beam's bending strength is based on parameters other than stud strength, such as the geometric and strength properties of the steel beam and concrete, it is difficult to assess or "back-calculate" the shear stud behavior from a full-scale beam test.

As an example, Fig. 8.1 shows how the bending strength of a beam varies with the strength of the studs. The intersection of the curve with the left vertical axis represents the plastic flexural strength when no shear studs are used. The intersection of the curve with the right vertical axis represents the strength of the beam with full composite action, where the sum of the strengths of the studs equals the yield strength of the bare steel beam. Notice that the bending strength and percent composite action are nonlinearly related. For low degrees of shear connection, the increase in stud strength causes a greater increase in bending strength than for high degrees of shear connection. For example, at 50% composite action, the bending strength is about 80% of the fully-composite bending strength. To make the beam fully composite, i.e. increasing the

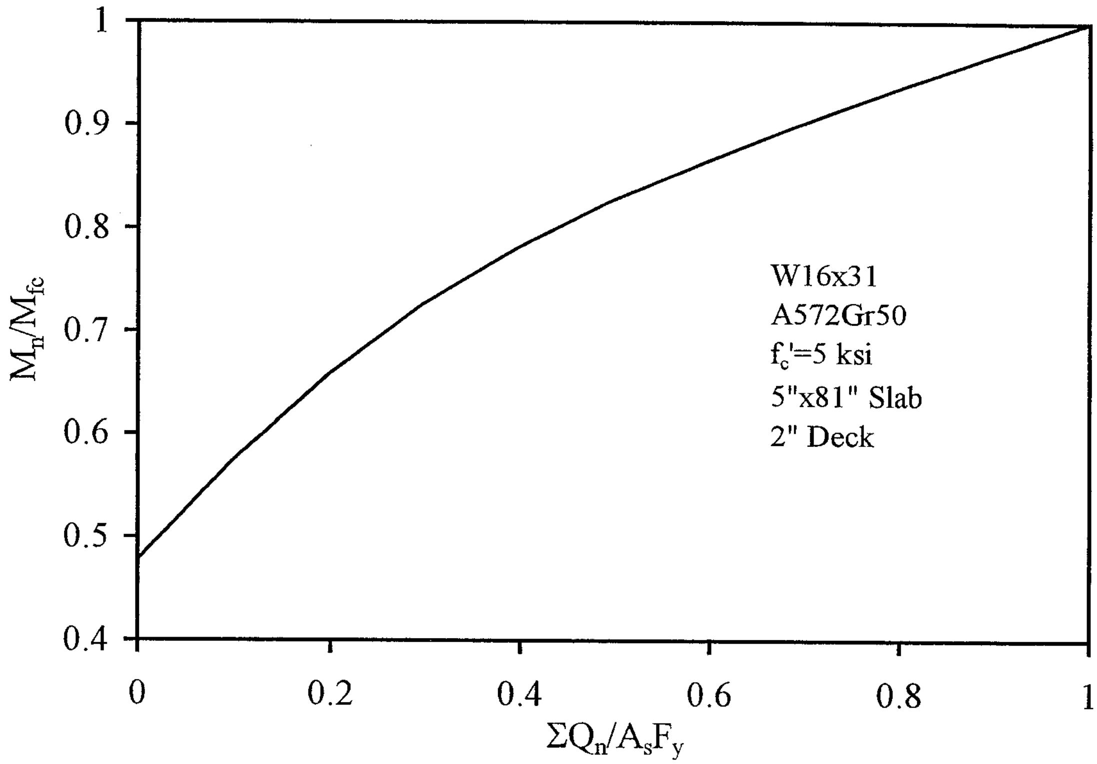

Fig. 8.1 Flexural Strength vs. Shear Connection Strength

bending strength an additional 20%, the number of studs would have to be doubled. This illustrates the sensitivity, or actually the lack of it, and thus indicates why it is reasonable to use push-out tests to formulate a stud strength model and to use beam tests to validate the model.

This chapter will verify the new stud strength prediction method that was presented in Chapter 6 by using the results of experimental beam tests. The stud and beam strengths from these tests will be compared to the AISC predicted strengths and also to the predicted strengths found from the new method. The tests that will be studied are those that were summarized by Grant et al (1977), along with more recent beam tests by Robinson (1988), Jayas and Hosain (1989), and Gibbings et al (1993), as well as the beam tests reported in Chapter 7. All of these tests will be used again in Chapter 9 to determine a reliability factor for composite beams that are designed using this new stud strength prediction method.

8.2 Composite Beam Test Parameters

Tables 8.1 and 8.2 report the parameters of the composite beam tests used in this study. In cases where the stud tensile strength was unknown, a value of 65 ksi was assumed.

8.3 Composite Beam Ultimate Strength Comparison

8.3.1 General

The maximum experimental moment, M_e, will be compared to strengths calculated using the AISC procedures (*Load* 1993), M_{AISC}, and also to calculated strengths using the new stud model, M_c. The experimental stud strengths, Q_{bc}, that were found by back-calculating the stud strengths necessary to achieve the maximum experimental moments, will be compared to the AISC stud strength predictions, Q_{AISC}, and also to the new stud strength predictions, Q_c.

Table 8.1 Beam Test Parameters

Test Program	Test Designation	Steel Section	Span (ft)	Slab Depth (in.)	Slab Width (in.)	f'c (ksi)	w (pcf)	Deck Ht. (in.)	Ave. Rib Width (in.)	Deck Gage
Grant et al (1977)	1A1R	W16x40	24	4	72	3.47	114.6	1.5	2.25	20
Grant et al (1977)	1A2	W16x40	24	4.5	72	3.71	117.9	2	3	20
Grant et al (1977)	1A3R	W16x40	32	5.5	96	3.25	115	3	4.5	20
Grant et al (1977)	1A5R	W16x45	20	4	60	3.71	117.9	1.5	3	20
Grant et al (1977)	1A6R	W16x45	24	4.5	72	4.93	126	2	4	20
Grant et al (1977)	1A7	W16x40	32	5.5	96	4.20	119.4	3	6	20
Grant et al (1977)	1B1	W16x58	32	5.5	96	3.75	122.8	3	4.5	20
Grant et al (1977)	1B2	W16x58	24	4	72	4.83	115.1	1.5	3	20
Grant et al (1977)	1C1	W16x40	24	4	72	4.35	116.6	1.5	2.25	20
Grant et al (1977)	1C2A	W16x40	32	5.5	96	4.13	113.3	3	4.5	20
Grant et al (1977)	1C2B	W16x40	32	5.5	96	3.99	113.3	3	4.5	20
Grant et al (1977)	1C3	W16x40	24	4.5	72	4.84	117.8	2	4	20
Grant et al (1977)	1C4	W16x45	32	5.5	96	3.25	118.7	3	6	20
Grant et al (1977)	1D1	W16x40	24	4	72	3.47	114.8	1.5	2.25	20
Grant et al (1977)	1D2	W16x40	24	4	72	4.61	115.1	1.5	2.25	20
Grant et al (1977)	1D3	W16x45	32	5.5	96	3.96	122.4	3	6	20
Grant et al (1977)	1D4	W16x40	32	5.5	96	4.85	124.8	3	6	20

Table 8.1 Beam Test Parameters

Test Program	Test Designation	Steel Section	Span (ft)	Slab Depth (in.)	Slab Width (in.)	f'c (ksi)	w (pcf)	Deck Ht. (in.)	Ave. Rib Width (in.)	Deck Gage
Robinson and Wallace (1971)	71-17(A1)	W12x19	21	4	63	4.29	145	1.5	2.25	18
Robinson and Wallace (1971)	71-17(A2)	W12x19	21	4	63	5.67	145	1.5	2.25	18
Robinson and Wallace (1971)	71-17(A3)	W12x19	21	4	63	5.67	145	1.5	2.25	18
Robinson and Wallace (1971)	71-17(A4)	W12x19	21	4	63	3.89	145	1.5	2.25	18
Robinson and Wallace (1971)	71-17(A5)	W12x19	21	5	63	3.89	145	1.5	2.25	18
Robinson and Wallace (1971)	71-17(B1)*	W12x19	21	4	63	4.65	145	1.5	2.25	18
Robinson and Wallace (1971)	71-17(B2)	W12x19	21	4	63	3.46	145	1.5	2.25	18
Robinson and Wallace (1971)	71-17(B3)	W12x19	21	4	63	3.41	145	1.5	2.25	18
Robinson and Wallace (1971)	71-17(B4)	W12x19	21	4	63	3.53	145	1.5	2.25	18
Fisher et al (1967)	67-11(B1)	W12x27	15	5.5	45	4.40	116	3	4.06	Not Avail.
Fisher et al (1967)	67-11(B2)	W12x27	15	5.5	45	4.90	116	3	4.06	Not Avail.
Seek et al (1970)	70-31(A)	W14x30	19	4	48	3.30	116	1.5	2.25	Not Avail.
Seek et al (1970)	70-31(D)	W14x30	19	4	48	3.30	116	1.5	2.25	Not Avail.
Seek et al (1970)	70-31(C)	W18x60	35.5	6	72	3.30	116	3	5.63	Not Avail.
Errera (1967)	67-36(CU3)	W12x27	24	3.5	62.5	3.20	145	1.5	2.25	Not Avail.
Errera (1967)	67-36(CU2)	W12x27	24	3.5	62.5	4.20	145	1.5	3.63	Not Avail.
Errera (1967)	67-36(CU1)	W12x27	21	3.5	62.5	4.30	145	1.5	5	Not Avail.
Furlong and Henderson (1975)	TEX-1	W16x50	32	6.3	96	3.00	109	3	6	18
Furlong and Henderson (1975)	TEX-2	W16x50	32	6.3	96	3.80	108	3	6	18
Furlong and Henderson (1975)	TEX-3	W16x50	32	6.3	96	3.80	106	3	6	18
Furlong and Henderson (1975)	TEX-4	W16x50	32	6.3	96	3.50	102.4	3	6	18
Furlong and Henderson (1975)	TEX-5	W16x50	32	6.3	96	3.50	102.4	3	6	18
Furlong and Henderson (1975)	TEX-6	W16x50	32	6.3	96	3.60	102.1	3	6	18
Furlong and Henderson (1975)	TEX-7	W16x50	32	6.3	96	3.90	106.6	3	6	18
Furlong and Henderson (1975)	TEX-8	W16x50	32	6.3	96	4.05	105	3	6	18
Allan et al (1976)	HHR-1-76	W16x45	32	5.5	95	4.26	144	3	6	18
Allan et al (1976)	IR-1-76	W16x45	32	5.5	95	4.18	144	3	7.25	18
Allan et al (1976)	HHR-2-76	W16x45	32	5.5	95	4.59	145	3	6	18

Table 8.1 Beam Test Parameters

Test Program	Test Designation	Steel Section	Span (ft)	Slab Depth (in.)	Slab Width (in.)	f'c (ksi)	w (pcf)	Deck Ht. (in.)	Ave. Rib Width (in.)	Deck Gage
Allan et al (1976)	IR-2-76	W16x45	32	5.5	95	4.73	144	3	7.25	18
Allan et al (1976)	RF-1-76	W16x45	32	5.5	95	4.40	145	3	6	18
Allan et al (1976)	RF-2-76	W16x45	32	5.5	95	4.31	143	3	6	18
Jones (1975)	75-16	W16x40	30	5	87	3.29	145	3	6	18
Lacap (1975)	175-75	W24x55	34.9	6.3	103	4.04	116	3	7.25	16
Lacap (1975)	174-75	W24x61	34.9	9	103	4.25	144	3	7.25	16

Table 8.1 Beam Test Parameters

Test Program	Test Designation	Steel Section	Span (ft)	Slab Depth (in.)	Slab Width (in.)	f'c (ksi)	w (pcf)	Deck Ht. (in.)	Ave. Rib Width (in.)	Deck Gage
Robinson (1988)	1	W16x36	30	5.6	90	3.09	145	3	7.17	Not Avail.
Robinson (1988)	2	W16x36	30	5.6	90	3.18	145	3	6.02	Not Avail.
Jayas and Hosain (1989)	JB-1	W12x35	13.5	6	40.5	3.90	146.1	3	8.86	Not Avail.
Jayas and Hosain (1989)	JB-2	W12x35	6.7	6	20.1	4.41	149.8	3	5.67	Not Avail.
Jayas and Hosain (1989)	JB-3	W12x35	13.5	6	40.5	3.54	144.8	3	6.02	Not Avail.
Jayas and Hosain (1989)	JB-4	W12x35	13.5	6	40.5	3.54	144.8	3	6.02	Not Avail.
Gibbings et al (1993)	1	W16x31	30	6	81	4.81	145	3	6	20
Gibbings et al (1993)	2	W16x31	30	6	81	3.20	145	3	6	20
Gibbings et al (1993)	3	W16x31	30	6	81	2.28	145	3	6	20
Gibbings et al (1993)	4	W16x31	30	6	81	4.99	145	3	6	20
Rambo-Roddenberry	1	W16x31	30	5	81	5.00	141.3	2	6	20
Rambo-Roddenberry	2	W16x31	30	5	81	4.84	141.1	2	6	20
Rambo-Roddenberry	3	W16x31	30	5	81	5.61	143.4	2	6	20

Table 8.2 Shear Stud Details for Beam Tests

Test Program	Test Designation	Stud Dia. (in.)	Stud Ht. (in.)	No. Studs	Stud Position	e (in.)	No. Studs	Stud Position	e (in.)	No. Studs	Stud Position	e (in.)	F_u (ksi)
Grant et al (1977)	1A1R	0.75	3	20	2M	1.13	4	M	1.13				65
Grant et al (1977)	1A2	0.75	3.5	20	2M	1.5	4	M	1.5				65
Grant et al (1977)	1A3R	0.75	4.5	26	2M	2.25							65
Grant et al (1977)	1A5R	0.75	3	16	2M	1.5	2	M	1.5				65
Grant et al (1977)	1A6R	0.75	3.5	20	2M	2							65
Grant et al (1977)	1A7	0.75	4.5	14	2M	3	4	M	3				65
Grant et al (1977)	1B1	0.75	4.5	24	2M	2.25	1	M	2.25				65
Grant et al (1977)	1B2	0.75	3	18	2M	1.5	1	M	1.5				65
Grant et al (1977)	1C1	0.75	3				11	M	1.13				65
Grant et al (1977)	1C2A	0.75	4.5	4	2M	2.25	5	M	2.25				65
Grant et al (1977)	1C2B	0.75	4.5	10	2M	2.25	2	M	2.25				65
Grant et al (1977)	1C3	0.75	3.5				8	M	2				65
Grant et al (1977)	1C4	0.75	4.5	14	2M	3							65
Grant et al (1977)	1D1	0.75	3	20	2M	1.13							65
Grant et al (1977)	1D2	0.75	3	20	2M	1.13	4	M	1.13				65
Grant et al (1977)	1D3	0.75	4.5	14	2M	3	4	M	3				65
Grant et al (1977)	1D4	0.75	4.5	14	2M	3	4	M	3				65

Table 8.2 Shear Stud Details for Beam Tests

Test Program	Test Designation	Stud Dia. (in.)	Stud Ht. (in.)	No. Studs	Stud Position	e (in.)	No. Studs	Stud Position	e (in.)	No. Studs	Stud Position	e (in.)	F_u (ksi)
Robinson and Wallace (1971)	71-17(A1)	0.75	3				6	M	1.13				65
Robinson and Wallace (1971)	71-17(A2)	0.75	3	12	2M	1.13							65
Robinson and Wallace (1971)	71-17(A3)	0.75	3				9	M	1.13				65
Robinson and Wallace (1971)	71-17(A4)	0.75	3	12	2M	1.13							65
Robinson and Wallace (1971)	71-17(A5)	0.75	4	12	2M	1.13							65
Robinson and Wallace (1971)	71-17(B1)*	0.75	3				21	M	1.13				65
Robinson and Wallace (1971)	71-17(B2)	0.75	3				11	M	1.13				65
Robinson and Wallace (1971)	71-17(B3)	0.75	3				16	M	1.13				65
Robinson and Wallace (1971)	71-17(B4)	0.75	3				21	M	1.13				65
Fisher et al (1967)	67-11(B1)	0.75	5	8	2M	2.03							75.6
Fisher et al (1967)	67-11(B2)	0.75	5	8	2M	2.03							75.6
Seek et al (1970)	70-31(A)	0.75	3	10	2M	1.13	8	M	1.13				75.5
Seek et al (1970)	70-31(D)	0.5	3	18	2M	1.13	5	M	1.13				75.5
Seek et al (1970)	70-31(C)	0.75	5	2	2M	2.82	16	M	2.82				75.5
Errera (1967)	67-36(CU3)	0.625	2.5	6	2M	1.13	12	M	1.13				65
Errera (1967)	67-36(CU2)	0.625	2.5				18	M	1.82				65
Errera (1967)	67-36(CU1)	0.625	2.5	8	2M	2.5	10	M	2.5				65
Furlong and Henderson (1975)	TEX-1	0.75	4.5	26	Stag	3							65
Furlong and Henderson (1975)	TEX-2	0.75	5.5	26	Stag	3							65
Furlong and Henderson (1975)	TEX-3	0.75	6	26	Stag	3							65
Furlong and Henderson (1975)	TEX-4	0.75	5	26	Stag	3							65
Furlong and Henderson (1975)	TEX-5	0.75	5	26	Stag	3							65
Furlong and Henderson (1975)	TEX-6	0.75	4.5	26	Stag	3							65
Furlong and Henderson (1975)	TEX-7	0.75	5	26	Stag	3							65
Furlong and Henderson (1975)	TEX-8	0.75	5.5	26	Stag	3							65
Allan et al (1976)	HHR-1-76	0.75	5	8	Stag	3	2	2S	4.5	2	2W	1.5	65
Allan et al (1976)	IR-1-76	0.75	5	8	Stag	3.63	4	2S	5.44				65
Allan et al (1976)	HHR-2-76	0.75	5	8	Stag	3	2	2S	4.5	2	2W	1.5	65

Table 8.2 Shear Stud Details for Beam Tests

Test Program	Test Designation	Stud Dia. (in.)	Stud Ht. (in.)	No. Studs	Stud Position	e (in.)	No. Studs	Stud Position	e (in.)	No. Studs	Stud Position	e (in.)	F_u (ksi)
Allan et al (1976)	IR-2-76	0.75	5	8	Stag	3.63	4	2S	5.44				65
Allan et al (1976)	RF-1-76	0.75	5	8	Stag	3	4	2S	4.5				65
Allan et al (1976)	RF-2-76	0.75	5	8	Stag	3	4	2S	4.5				65
Jones (1975)	75-16	0.75	4.5				12	M	3				65
Lacap (1975)	175-75	0.75	5	14	2S	5.44	4	S	5.44				65
Lacap (1975)	174-75	0.75	7	10	2S	5.44	18	3	3.63				65

Table 8.2 Shear Stud Details for Beam Tests

Test Program	Test Designation	Stud Dia. (in.)	Stud Ht. (in.)	No. Studs	Stud Position	e (in.)	No. Studs	Stud Position	e (in.)	No. Studs	Stud Position	e (in.)	F_u (ksi)
Robinson (1988)	1	0.75	4.57	3.5	S	5.67	3.5	W	1.5				65
Robinson (1988)	2	0.75	4.57	8	M	3							65
Jayas and Hosain (1989)	JB-1	0.75	5	10	2S	>2.2							65
Jayas and Hosain (1989)	JB-2	0.75	5	10	2M	2.83							65
Jayas and Hosain (1989)	JB-3	0.75	5	12	2S	>2.2							65
Jayas and Hosain (1989)	JB-4	0.75	5	6	S	>2.2							65
Gibbings et al (1993)	1	0.75	5	6	S	4.5							64.8
Gibbings et al (1993)	2	0.75	5				6	W	1.5				64.8
Gibbings et al (1993)	3	0.75	5	3	S	4.5	2	W	1.5				64.8
Gibbings et al (1993)	4	0.75	5	3	S	4.5	2	W	1.5				64.8
Rambo-Roddenberry	1	0.75	3.5	12	S	4.5							66.81
Rambo-Roddenberry	2	0.75	3.5				12	W	1.5				66.81
Rambo-Roddenberry	3	0.75	3.5	12	2S	4.5							66.81

8.3.2 AISC Flexural Theory

The flexural theory for composite beams, used by AISC, will now be reviewed. The predicted flexural strength of a composite beam is found from the following procedure:

1. Sum the strengths of the studs, Q_c or Q_{AISC}, located between zero and maximum moment. At ultimate load, it is assumed that all studs in a "shear span" share equally the shear force at the concrete/steel beam interface. If concentrated loads are applied to the beam, the flexural strength must be checked between zero moment and each location of a concentrated load. In this case, only the studs located between zero moment and the concentrated load are to be used in the calculation of the flexural strength.
2. Calculate the effective width, b_e, of the concrete slab. The effective width on each side of the beam centerline is the minimum of
   - one-eighth of the beam span, center-to-center of supports
   - one-half the distance to the centerline of the adjacent beams
   - the distance to the edge of the slab
3. Calculate the force, C, in the concrete slab at ultimate load. This value is taken as the minimum of C_1, C_2, and C_3, where

$$C_1 = A_s F_y \tag{8.1}$$

$$C_2 = 0.85 f_c^{'} A_c = 0.85 f_c^{'} b_e \left(t_{slab} - h_r \right) \tag{8.2}$$

$$C_3 = \sum Q_c \qquad (or\ C_3 = \sum Q_{AISC} \text{ if calculating } M_{AISC}) \tag{8.3}$$

$$C = \min(C_1, C_2, C_3) \tag{8.4}$$

4. Calculate the depth, a, of the equivalent rectangular stress block in the slab. This depth must be equal to or less than the thickness of the slab above the deck ribs.

$$a = \frac{C}{0.85 f_c^{'} b_e} \tag{8.5}$$

5. Determine the location of the plastic neutral axis (p.n.a.). This assumes that the steel section has reached its yield stress at all locations. If the beam is partially composite, the p.n.a. may be located in the web or flange of the steel beam. If the beam is fully composite $\left(\sum Q_c \geq A_s F_y\right)$, the p.n.a. is located in the slab.

6. Calculate the flexural strength of the beam. Add the couples caused by the compression force in the concrete and the compression and tension forces in the beam, with respect to a force, such as the tension force in the bottom flange, in the beam. To do this, two different models may be used to account for the fillets in the steel section. The model used herein assumes that the two flange areas each equal the product of the flange thickness and flange width. The web area is assumed to equal the total beam area minus the two flange areas. The web thickness is the web area divided by the web height, which is equal to the total beam depth minus the two flange thicknesses. The expression for the flexural strength, given by AISC, is as follows:

$$M_n = C(d_1 + d_2) + P_y(d_3 - d_2) \tag{8.6}$$

where P_y = tensile strength of the steel section = $A_s F_y$

d_1 = distance from the centroid of the compression force C in concrete to the top of the steel section

d_2 = distance from the centroid of the compression force in the steel section to the top of the steel section

d_3 = distance from P_y to the top of the steel section = 1/2 (beam depth)

An example, using the parameters of beam test 1, is given in Appendix A.

8.3.3 AISC

8.3.3.1 Flexural Strength

The experimental flexural strength, M_e, and AISC calculated flexural strength, M_{AISC}, are given in Table 8.3, and are shown graphically in Fig. 8.2. The average ratio of experimental-to-AISC calculated flexural strength for the tests performed before Grant et al (1977) is 0.980; for the tests performed by Grant et al (1977) is 0.946; and for the tests performed since Grant et al (1977) is 0.945. These and other statistical parameters are given in Table 8.5. These ratios demonstrate that the AISC specification is unconservative for predicting flexural strength.

8.3.3.2 Shear Stud Strength

The experimental shear stud strength, Q_{bc}, and AISC predicted shear stud strength, Q_{AISC}, are given in Table 8.4, and are shown graphically in Fig. 8.3. The average ratio of experimental-to-AISC predicted stud strength for the tests performed before Grant et al (1977) is 0.866; for the tests performed by Grant et al (1977) is 0.743;

Table 8.3 Beam Test Results (Flexural Strengths)

Test Program	Test Designation	M_c (k-ft)	M_{AISC} (k-ft)	M_e (k-ft)	M_e/M_c	M_e/M_{AISC}
Grant et al (1977)	1A1R	621.6	663.1	609.5	0.98	0.92
Grant et al (1977)	1A2	547.3	575.1	519.9	0.95	0.90
Grant et al (1977)	1A3R	687.4	594.8	581.3	0.85	0.98
Grant et al (1977)	1A5R	620.1	683.7	756.7	1.22	1.11
Grant et al (1977)	1A6R	688.0	744.4	697.2	1.01	0.94
Grant et al (1977)	1A7	623.9	611.7	515.3	0.83	0.84
Grant et al (1977)	1B1	548.5	483.1	479.5	0.87	0.99
Grant et al (1977)	1B2	487.3	563.7	503.3	1.03	0.89
Grant et al (1977)	1C1	478.7	533.0	508.9	1.06	0.95
Grant et al (1977)	1C2A	554.6	513.6	524.2	0.95	1.02
Grant et al (1977)	1C2B	588.2	530.1	537.2	0.91	1.01
Grant et al (1977)	1C3	563.4	599.1	577.2	1.02	0.96
Grant et al (1977)	1C4	655.0	607.0	620.7	0.95	1.02
Grant et al (1977)	1D1	597.0	643.7	599.7	1.00	0.93
Grant et al (1977)	1D2	528.5	590.2	515.0	0.97	0.87
Grant et al (1977)	1D3	701.0	682.2	623.9	0.89	0.91
Grant et al (1977)	1D4	638.6	648.5	529.2	0.83	0.82
Robinson and Wallace (1971)	71-17(A1)	145.5	174.9	144.3	0.99	0.83
Robinson and Wallace (1971)	71-17(A2)	169.6	198.2	165.2	0.97	0.83
Robinson and Wallace (1971)	71-17(A3)	162.2	195.4	168.5	1.04	0.86
Robinson and Wallace (1971)	71-17(A4)	166.4	191.7	167.5	1.01	0.87
Robinson and Wallace (1971)	71-17(A5)	178.8	211.9	191.5	1.07	0.90
Robinson and Wallace (1971)	71-17(B1)*	194.9	194.9	195.8	1.00	1.00
Robinson and Wallace (1971)	71-17(B2)	170.0	191.5	156.0	0.92	0.81
Robinson and Wallace (1971)	71-17(B3)	188.5	191.3	181.8	0.96	0.95
Robinson and Wallace (1971)	71-17(B4)	191.7	191.7	199.3	1.04	1.04
Fisher et al (1967)	67-11(B1)	194.5	192.7	186.1	0.96	0.97
Fisher et al (1967)	67-11(B2)	194.8	198.0	181.9	0.93	0.92
Seek et al (1970)	70-31(A)	252.4	261.7	263.8	1.05	1.01
Seek et al (1970)	70-31(D)	225.3	235.6	252.8	1.12	1.07
Seek et al (1970)	70-31(C)	624.6	601.7	625.4	1.00	1.04
Errera (1967)	67-36(CU3)	184.0	195.4	199.1	1.08	1.02
Errera (1967)	67-36(CU2)	203.4	235.0	233.9	1.15	1.00
Errera (1967)	67-36(CU1)	199.7	211.7	250.7	1.26	1.18
Furlong and Henderson (1975)	TEX-1	549.4	497.6	499.5	0.91	1.00
Furlong and Henderson (1975)	TEX-2	571.7	632.8	663.2	1.16	1.05
Furlong and Henderson (1975)	TEX-3	540.3	597.4	634.2	1.17	1.06
Furlong and Henderson (1975)	TEX-4	541.0	540.6	554.8	1.03	1.03
Furlong and Henderson (1975)	TEX-5	556.4	556.0	582.8	1.05	1.05
Furlong and Henderson (1975)	TEX-6	554.7	512.6	534.7	0.96	1.04
Furlong and Henderson (1975)	TEX-7	572.4	592.0	604.6	1.06	1.02
Furlong and Henderson (1975)	TEX-8	573.7	641.3	639.9	1.12	1.00
Allan et al (1976)	HHR-1-76	413.4	458.8	437.1	1.06	0.95
Allan et al (1976)	IR-1-76	410.1	470.8	475.9	1.16	1.01
Allan et al (1976)	HHR-2-76	409.7	462.1	435.4	1.06	0.94

Table 8.3 Beam Test Results (Flexural Strengths)

Test Program	Test Designation	M_c (k-ft)	M_{AISC} (k-ft)	M_e (k-ft)	M_e/M_c	M_e/M_{AISC}
Allan et al (1976)	IR-2-76	413.1	485.6	471.0	1.14	0.97
Allan et al (1976)	RF-1-76	416.9	461.0	447.2	1.07	0.97
Allan et al (1976)	RF-2-76	413.6	453.9	450.6	1.09	0.99
Jones (1975)	75-16	432.9	433.1	404.0	0.93	0.93
Lacap (1975)	175-75	749.7	797.0	790.6	1.05	0.99
Lacap (1975)	174-75	967.0	1087.5	1084.0	1.12	1.00
Robinson (1988)	1	380.8	407.9	397.2	1.04	0.97
Robinson (1988)	2	410.1	412.9	396.5	0.97	0.96
Jayas and Hosain (1989)	JB-1	331.7	371.5	339.8	1.02	0.91
Jayas and Hosain (1989)	JB-2	325.0	344.0	319.3	0.98	0.93
Jayas and Hosain (1989)	JB-3	315.4	329.1	296.6	0.94	0.90
Jayas and Hosain (1989)	JB-4	280.7	295.9	300.0	1.07	1.01
Gibbings et al (1993)	1	290.7	324.6	305.7	1.05	0.94
Gibbings et al (1993)	2	262.3	298.9	272.9	1.04	0.91
Gibbings et al (1993)	3	281.4	282.7	282.5	1.00	1.00
Gibbings et al (1993)	4	289.2	333.9	303.2	1.05	0.91
Rambo-Roddenberry	1	424.3	469.2	412.1	0.97	0.88
Rambo-Roddenberry	2	389.2	468.7	379.0	0.97	0.81
Rambo-Roddenberry	3	408.8	470.8	376.1	0.92	0.80

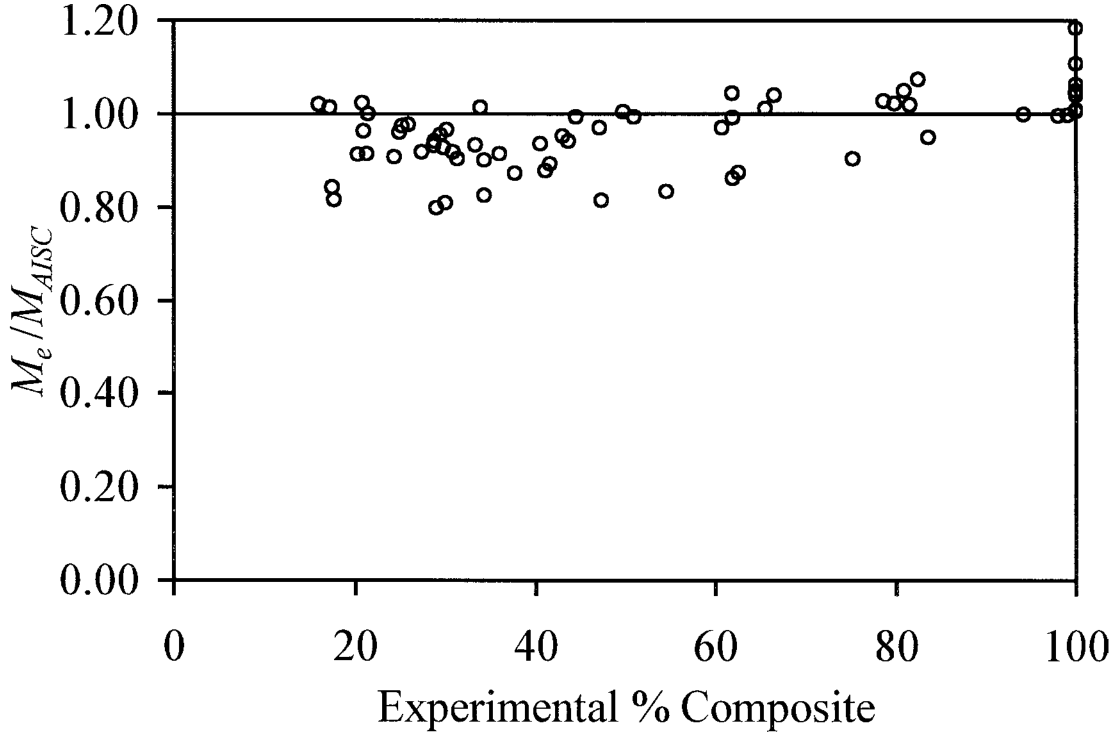

Fig. 8.2 Experimental-to-AISC Predicted Moment Capacity vs. Experimental % Composite

Table 8.4 Beam Test Results (Shear Stud Strengths)

Test Program	Test Designation	Predicted % Comp.	AISC Pred. % Comp.	Experim. % Comp.	Q_c (k)	Q_{AISC} (k)	Q_{bc} (k)	Q_{bc}/Q_c	Q_{bc}/Q_{AISC}
Grant et al (1977)	1A1R	34.4	52.7	30.8	289.5	442.7	258.7	0.89	0.58
Grant et al (1977)	1A2	41.5	53.6	31.3	289.5	374.4	218.7	0.76	0.58
Grant et al (1977)	1A3R	54.9	28.6	25.9	431.6	224.8	203.4	0.47	0.90
Grant et al (1977)	1A5R	24.1	43.6	100.0	215.1	388.5	f.c.		
Grant et al (1977)	1A6R	37.4	57.0	40.5	332.0	506.3	359.8	1.08	0.71
Grant et al (1977)	1A7	40.9	37.2	17.5	310.5	282.5	132.8	0.43	0.47
Grant et al (1977)	1B1	74.8	46.0	44.5	417.9	257.0	248.9	0.60	0.97
Grant et al (1977)	1B2	35.3	77.1	41.6	224.8	490.9	265.0	1.18	0.54
Grant et al (1977)	1C1	21.6	37.7	29.4	151.8	265.3	206.4	1.36	0.78
Grant et al (1977)	1C2A	20.9	14.4	16.0	164.1	113.3	125.8	0.77	1.11
Grant et al (1977)	1C2B	25.8	16.1	17.2	205.1	127.9	136.5	0.67	1.07
Grant et al (1977)	1C3	18.5	25.0	20.9	156.2	210.6	176.1	1.13	0.84
Grant et al (1977)	1C4	26.4	18.8	20.8	232.4	165.3	183.2	0.79	1.11
Grant et al (1977)	1D1	28.0	43.3	28.7	234.4	362.8	240.2	1.02	0.66
Grant et al (1977)	1D2	42.7	81.0	37.7	289.5	549.6	255.7	0.88	0.47
Grant et al (1977)	1D3	35.3	31.3	21.3	310.5	275.4	187.0	0.60	0.68
Grant et al (1977)	1D4	39.8	41.7	17.7	310.5	325.3	137.6	0.44	0.42
Robinson and Wallace (1971)	71-17(A1)	35.3	68.6	34.3	86.8	168.6	84.4	0.97	0.50
Robinson and Wallace (1971)	71-17(A2)	60.1	100.0	54.5	147.7	344.6	134.0	0.91	0.39
Robinson and Wallace (1971)	71-17(A3)	53.8	100.0	61.9	130.2	258.4	149.9	1.15	0.58
Robinson and Wallace (1971)	71-17(A4)	61.0	100.0	62.5	147.7	282.6	151.3	1.02	0.54
Robinson and Wallace (1971)	71-17(A5)	61.0	100.0	75.2	147.7	313.4	182.1	1.23	0.58
Robinson and Wallace (1971)	71-17(B1)*	100.0	100.0	100.0	303.9	603.0	f.c.	f.c.	f.c.
Robinson and Wallace (1971)	71-17(B2)	65.3	100.0	47.3	159.2	263.0	115.5	0.73	0.44
Robinson and Wallace (1971)	71-17(B3)	94.9	100.0	83.5	231.5	378.6	203.7	0.88	0.54
Robinson and Wallace (1971)	71-17(B4)	100.0	100.0	100.0	303.9	509.9	f.c.	f.c.	f.c.
Fisher et al (1967)	67-11(B1)	35.8	34.5	30.1	109.0	105.1	91.6	*0.84*	*0.87*
Fisher et al (1967)	67-11(B2)	35.8	37.4	27.4	109.0	114.0	83.5	*0.77*	*0.73*
Seek et al (1970)	70-31(A)	81.8	100.0	100.0	264.2	332.3	f.c.	f.c.	f.c.
Seek et al (1970)	70-31(D)	44.7	57.0	82.4	144.5	184.2	266.2	1.84	1.45
Seek et al (1970)	70-31(C)	66.1	56.4	66.5	401.0	341.8	403.1	1.01	1.18
Errera (1967)	67-36(CU3)	56.6	74.7	81.5	163.7	216.3	235.8	1.44	1.09
Errera (1967)	67-36(CU2)	53.5	100.0	98.0	172.3	345.8	315.6	1.83	0.91
Errera (1967)	67-36(CU1)	79.4	100.0	100.0	227.8	351.9	f.c.	f.c.	f.c.
Furlong and Henderson (1975)	TEX-1	70.1	49.0	49.7	388.2	271.2	275.2	0.71	1.01
Furlong and Henderson (1975)	TEX-2	66.9	92.3	100.0	388.2	535.0	f.c.	f.c.	f.c.
Furlong and Henderson (1975)	TEX-3	73.0	99.3	100.0	388.2	527.5	f.c.	f.c.	f.c.
Furlong and Henderson (1975)	TEX-4	72.5	72.4	78.6	388.2	387.3	420.8	1.08	1.09
Furlong and Henderson (1975)	TEX-5	69.5	69.3	80.8	388.2	387.3	451.2	1.16	1.16
Furlong and Henderson (1975)	TEX-6	69.9	53.3	61.8	388.2	296.0	343.3	0.88	1.16
Furlong and Henderson (1975)	TEX-7	67.0	74.7	79.8	388.2	432.9	462.7	1.19	1.07
Furlong and Henderson (1975)	TEX-8	66.9	94.7	94.1	388.2	549.4	545.9	1.41	0.99
Allan et al (1976)	HHR-1-76	34.0	51.4	43.0	177.3	267.5	223.8	1.26	0.84
Allan et al (1976)	IR-1-76	36.7	63.0	65.5	185.8	318.6	331.2	1.78	1.04
Allan et al (1976)	HHR-2-76	34.5	55.4	43.6	177.3	284.3	224.0	1.26	0.79

Table 8.4 Beam Test Results (Shear Stud Strengths)

Test Program	Test Designation	Predicted % Comp.	AISC Pred. % Comp.	Experim. % Comp.	Q_c (k)	Q_{AISC} (k)	Q_{bc} (k)	Q_{bc}/Q_c	Q_{bc}/Q_{AISC}
Allan et al (1976)	IR-2-76	36.4	67.6	60.7	185.8	344.6	309.6	1.67	0.90
Allan et al (1976)	RF-1-76	35.9	53.1	47.1	185.8	275.5	244.1	1.31	0.89
Allan et al (1976)	RF-2-76	36.3	52.4	50.9	185.8	268.4	260.9	1.40	0.97
Jones (1975)	75-16	44.6	44.7	33.3	234.4	234.9	174.8	0.75	0.74
Lacap (1975)	175-75	49.9	64.1	61.9	310.5	399.0	385.3	1.24	0.97
Lacap (1975)	174-75	71.2	100.0	99.1	464.8	776.9	647.3	1.39	0.83
Robinson (1988)	1	21.2	28.0	25.2	116.6	153.8	138.5	1.19	0.90
Robinson (1988)	2	28.4	29.2	24.9	156.2	160.3	136.6	0.87	0.85
Jayas and Hosain (1989)	JB-1	32.6	51.7	36.0	166.0	263.1	183.5	1.11	0.70
Jayas and Hosain (1989)	JB-2	32.6	43.7	29.8	166.0	222.7	151.6	0.91	0.68
Jayas and Hosain (1989)	JB-3	44.3	52.2	34.3	199.2	234.6	154.2	0.77	0.66
Jayas and Hosain (1989)	JB-4	25.7	31.9	33.9	117.2	145.9	154.8	1.32	1.06
Gibbings et al (1993)	1	24.1	35.4	28.8	97.5	143.1	116.5	1.19	0.81
Gibbings et al (1993)	2	17.3	28.4	20.3	68.5	112.8	80.6	1.18	0.71
Gibbings et al (1993)	3	21.1	21.5	21.4	85.9	87.5	86.9	1.01	0.99
Gibbings et al (1993)	4	20.4	34.0	24.3	85.9	143.1	102.1	1.19	0.71
Rambo-Roddenberry	1	47.1	69.2	41.1	240.8	354.2	211.8	0.88	0.60
Rambo-Roddenberry	2	33.2	69.2	30.0	170.0	354.2	153.4	0.90	0.43
Rambo-Roddenberry	3	40.0	69.2	29.0	204.7	354.2	148.3	0.72	0.42

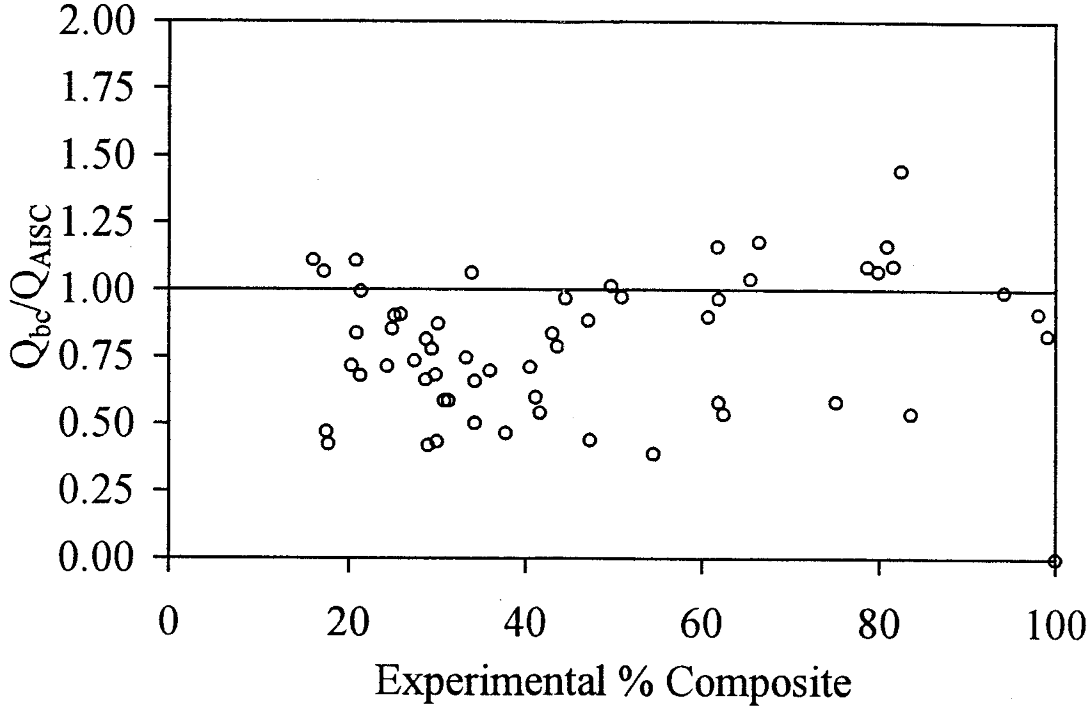

Fig. 8.3 Experimental-to-AISC Predicted Shear Stud Strength vs. Experimental % Composite

and for the tests performed since Grant et al (1977) is 0.808. These and other statistical parameters are given in Table 8.5. These ratios demonstrate that the AISC stud strength model is unconservative for predicting the strength of studs in deck transverse to the beam.

8.3.4 New Strength Prediction Method

8.3.4.1 Flexural Strength

The experimental flexural strength, M_e, and new calculated flexural strength, M_c, are given in Table 8.3, and are shown graphically in Fig. 8.4. The average ratio of experimental-to-new calculated flexural strength for the tests performed before Grant et al (1977) is 1.050; for the tests performed by Grant et al (1977) is 0.961; and for the tests performed since Grant et al (1977) is 1.017. These and other statistical parameters are given in Table 8.5. These ratios show that the new stud strength model yields flexural strengths closer to those obtained by tests than the AISC stud strength model.

8.3.4.2 Shear Stud Strength

The experimental shear stud strengths, Q_{bc}, and new predicted shear stud strengths, Q_c, are given in Table 8.4, and are shown graphically in Fig. 8.5. The average ratio of experimental-to-new predicted stud strength for the tests performed before Grant et al (1977) is 1.183; for the tests performed by Grant et al (1977) is 0.817; and for the tests performed since Grant et al (1977) is 1.075. These and other statistical parameters are given in Table 8.5. These ratios show that the new stud strength model yields stud strengths closer to those obtained by tests than the AISC stud strength model.

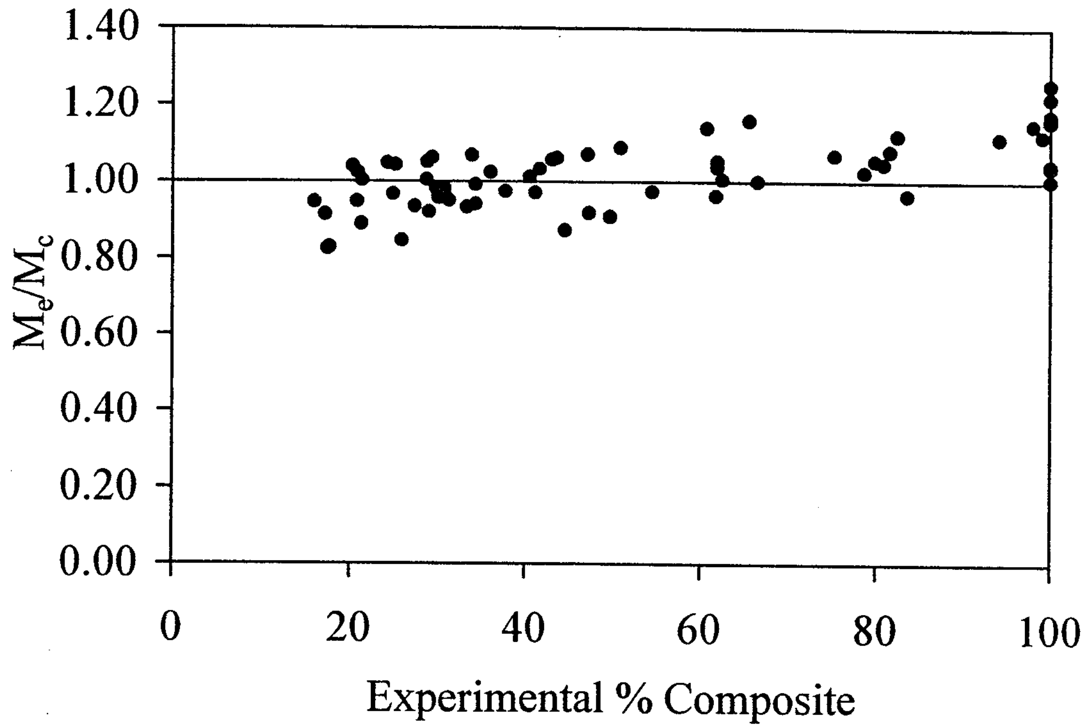

Fig. 8.4 Experimental-to-New Predicted Moment Capacity vs. Experimental % Composite

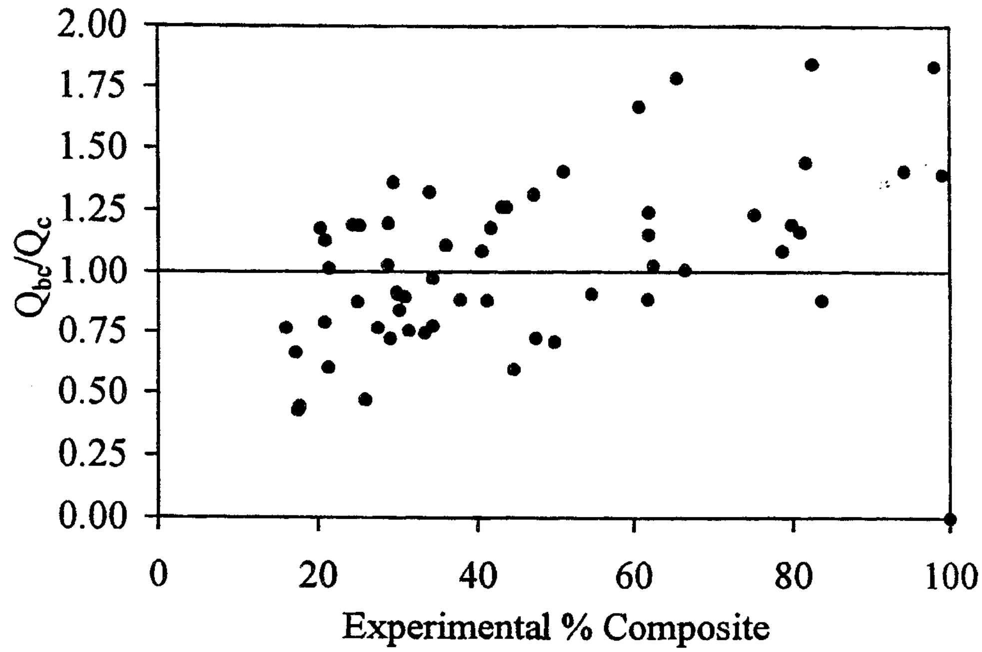

Fig. 8.5 Experimental-to-New Predicted Shear Stud Strength vs. Experimental % Composite

Table 8.5 Statistics of Stud and Moment Strengths from Beam Tests

Tests	Statistical Parameter	Q_{bc}/ Q_c	Q_{bc}/ Q_{AISC}	M_e/ M_c	M_e/ M_{AISC}
Tests Prior to 1977	σ	0.332	0.259	0.082	0.078
	average	**1.183**	**0.866**	**1.050**	**0.980**
	c.o.v.	0.281	0.299	0.078	0.079
Tests from Grant et al (1977)	σ	0.281	0.234	0.099	0.073
	average	**0.817**	**0.743**	**0.961**	**0.946**
	c.o.v.	0.344	0.314	1.029	0.077
Tests Since 1977	σ	0.188	0.192	0.047	0.064
	average	**1.020**	**0.733**	**1.003**	**0.918**
	c.o.v.	0.184	0.262	0.047	0.070
All Tests	σ	0.326	0.243	0.089	0.077
	average	**1.043**	**0.801**	**1.017**	**0.958**
	c.o.v.	0.313	0.303	0.088	0.080