An Investigation of the Effective Concrete Slab Width for Composite Construction

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THIS PAPER describes an experimental investigation for determining the effective width of a concrete slab acting compositely with a series of three rolled steel beams. The program was conducted by the Department of Civil Engineering at Vanderbilt University under the sponsorship of the American Iron and Steel Institute.

The object of the program was to determine actual effective slab widths and compare them with allowable values as specified by the 1963 edition of the AISC Specification for the Design, Fabrication and Erection of Steel for Buildings. The Specification states that the effective slab width is to be computed by the smallest of the following criteria:

a. The total effective width shall be taken as not more than one-fourth the span of the beam.
b. The effective projection beyond the edge of the beam flange shall not be more than one-half the clear distance to the adjacent beam.
c. The effective projection beyond the edge of the beam flange shall not be more than eight times the slab thickness.

From a review of the literature, only one experimental and analytical investigation, conducted by Mackey and Wong of the University of Hong Kong,[1] could be found where a concrete slab was common to several beams and where the effective slab width was of primary interest. Although the test program conducted by Mackey and Wong was limited in scope, they concluded that the effective width is much larger than currently recommended for design. The test program at Vanderbilt reinforced those conclusions.

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TEST PROGRAM

The test program conducted at Vanderbilt consisted of three composite concrete slab and steel beam structures. Each test structure consisted of a 2-in. thick concrete slab resting on three 4I7.7 beams uniformly spaced and simply supported. The slab was anchored to the I-beams by ½-in. diam. stud shear connectors. Complete details are given in Table 1 and Figs. 1 through 5.

Approximately one-third size scale models were used as test structures and were designed to represent common conditions in building construction. All design parameters were held constant except the beam spacing which was thought to be most significant. The

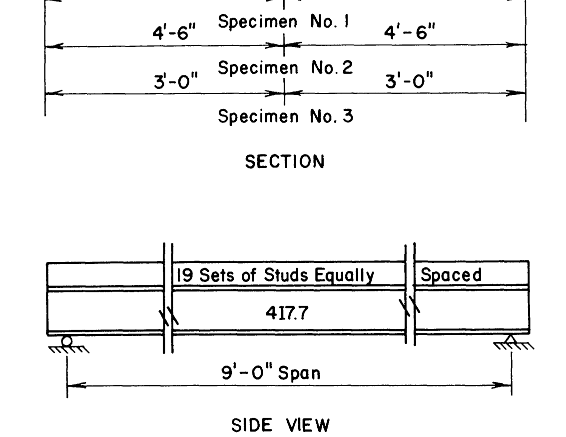

Fig. 1. Specimen assembly

Table 1. **Details of Test Specimens**

Description	Specimen No. 1	2	3
Steel I-beams	4I7.7—A36 Steel	4I7.7—A36 Steel	4I7.7—A36 Steel
Span length of I-beams (L)	9 ft	9 ft	9 ft
Spacing of I-beams (s)	6 ft-0 in.	4 ft-6 in.	3 ft-0 in.
Slab thickness (t)	2 in.	2 in.	2 in.
28 day slab strength	6000 psi	5500 psi	5000 psi
Concrete slump test	¾ in.	1½ in.	¾ in.
Concrete density test	144 lbs/cu ft	137 lbs/cu ft	138 lbs/cu ft
E_c of concrete slab[a]	3,950,000 psi	3,750,000 psi	3,460,000 psi
E_s of steel I-beams[b]	29,000,000 psi	29,000,000 psi	29,000,000 psi
Proportional limit—steel	—	42,000 psi	37,000 psi
Modular ratio, $n = E_s/E_c$	7.3	7.7	8.4
Shear connectors on the top flange of I-beams	Two ½-in. diameter by 1½-in. long headed studs at 6-in. spacings from end to end		

[a] *Secant modulus of elasticity.*
[b] *Standard steel modulus of elasticity.*

three values chosen covered what was considered the likely parameter range for buildings. The shear connectors were designed conservatively so that horizontal slippage between beam and slab would be negligible.

Each test structure was fabricated in the load frame and centered with the hydraulic jack. The I-beams were supported on bearing plates and rollers. The falsework for the slab consisted of a simple arrangement of ¾-in. plywood and 2 × 4's. Between I-beams the falsework was sufficiently supported to minimize falsework deflections during each concrete pour. One mat of 6 × 6—10/10 welded wire fabric was properly placed within the slab, and at each end of Specimens 2 and 3, two No. 3 deformed reinforcing bars were placed in the transverse direction to prevent longitudinal tension cracks from forming in the slab. After pouring, the concrete slab was wet-cured for 14 days and then allowed to cure naturally 14 more days.

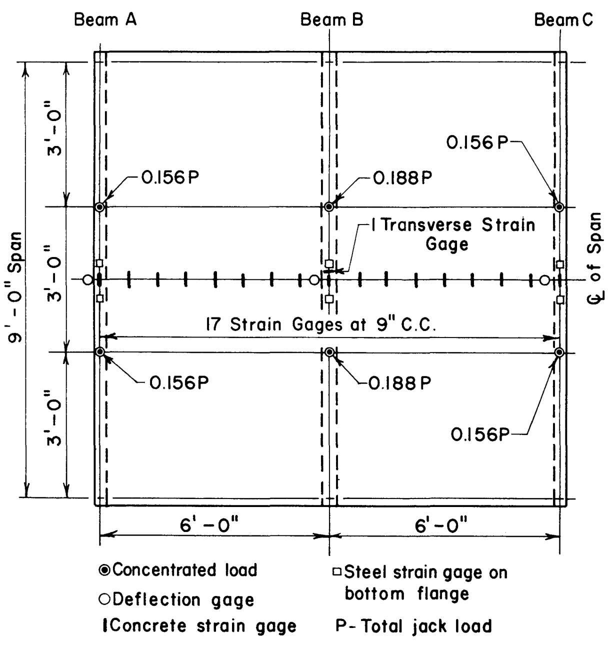

Fig. 2. Load and instrumentation arrangement, Specimen No. 1

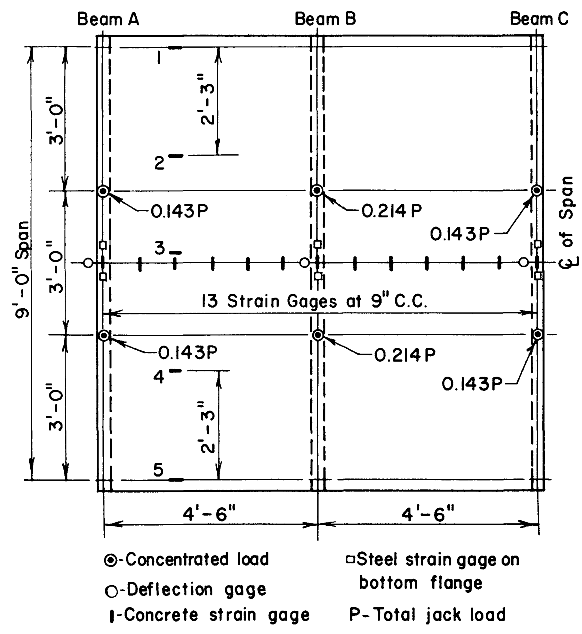

Fig. 3. Load and instrumentation arrangement, Specimen No. 2

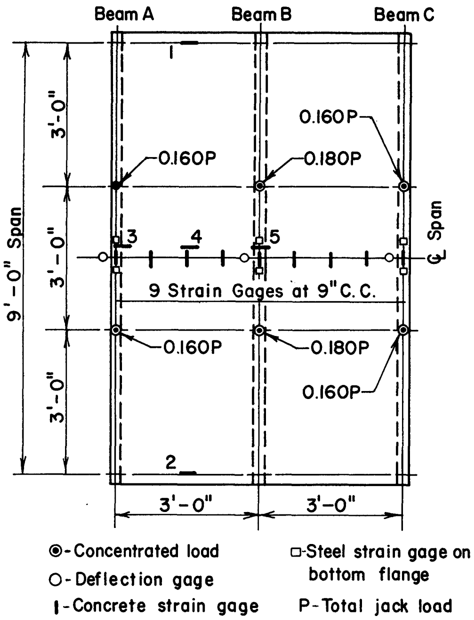

Fig. 4. Load and instrumentation arrangement, Specimen No. 3

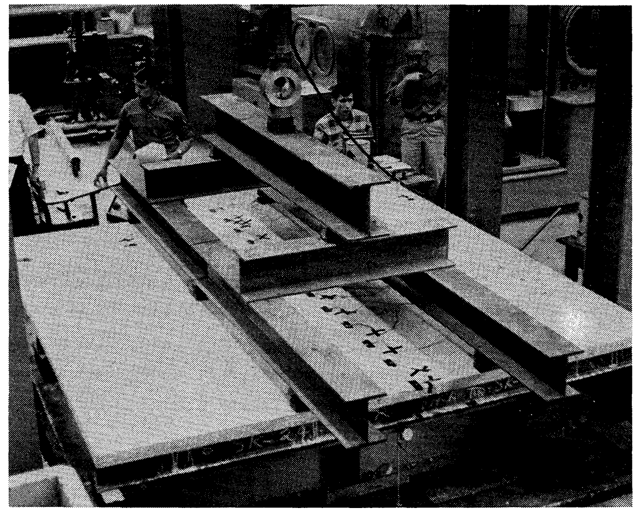

Fig. 5. Test assembly, Specimen No. 2

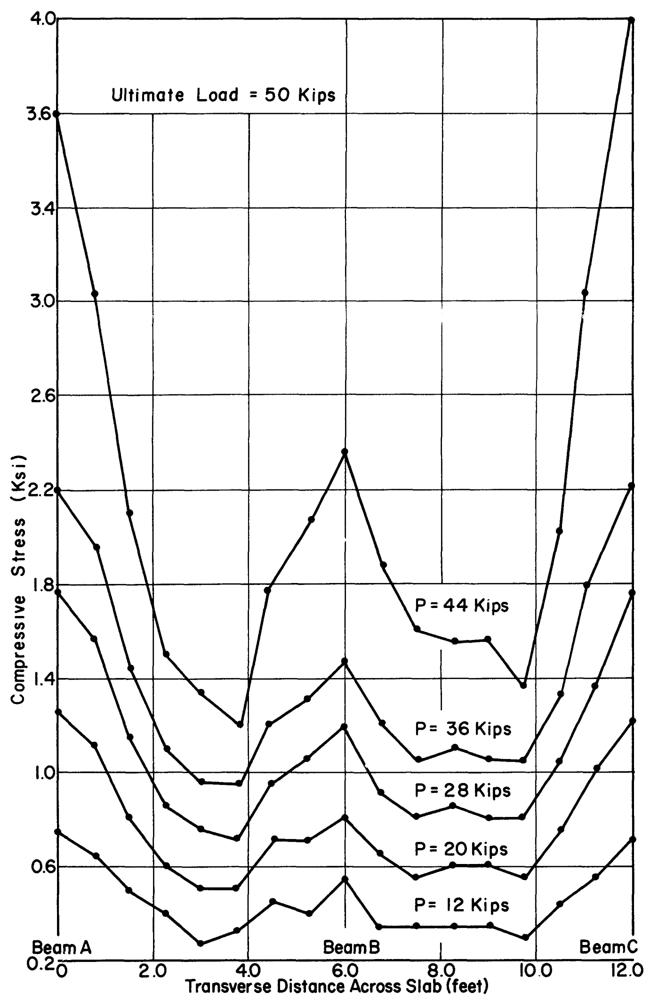

Fig. 6. Transverse distribution of longitudinal stresses at mid-span at top of slab, Specimen No. 1

Electrical SR-4, A-7 strain gages were installed on the bottom of the I-beams at the center of the span; electrical SR-4, A-9-4 strain gages were installed on the top of the slab, at the center of the span, spaced 9 in. on centers in the transverse direction as shown in Figs. 2, 3 and 4. Mechanical dial gages were placed under each I-beam at the center of each span to measure deflection.

Each test structure was loaded with concentrated loads at the third points of each I-beam. The single 60-kip hydraulic jack load was carried to each beam by a distributing beam as shown in Fig. 5.

Each test was conducted at the 28-day concrete strength. Initial strain gage and deflection dial readings were recorded before the load distributing beams were placed. The distributing beams were placed so that the concentrated loads would produce equal deflections under each beam. The initial position of the distributing beams was determined analytically; however, some repositioning was necessary. The load was applied in increments up to ultimate load. All strain and dial gages were recorded after each loading. Careful attention was given to formation of crack patterns during each test.

TEST RESULTS

Table 2 gives a bird's-eye comparison of the test results for the three test structures compared with analysis by the 1963 AISC Specification. Figures 6, 7 and 8 are plots of measured top-fiber slab stresses versus load, and Figs. 9 and 10 show a typical failure condition.

The effective flange width can be found for the three test structures by three methods. Two of these methods utilize, in part, data given in Figs. 6, 7 and 8. The first

Table 2. **Test Results Comparison Study**

Description of Results	Computed Results Using AISC Specification (Specimen No. 2)	Test Results		
		Specimen No. 1	Specimen No. 2	Specimen No. 3
Jack load producing the working stress (24 ksi) at bottom of I-beams	17 kips	28 kips	26 kips	22 kips
Jack load producing the nominal yield stress (36 ksi) at bottom of I-beams	26 kips	38 kips	34 kips	33 kips
Jack load producing the ultimate load	46 kips	50 kips	56 kips	52 kips
Average deflection at mid-span of I-beams at 17 kip jack load	0.25 in.	0.18 in.	0.18 in.	0.21 in.
Average deflection at mid-span of I-beams at 26 kip jack load	0.38 in.	0.37 in.	0.35 in.	0.40 in.
Modular ratio	7	7.3	7.7	8.4

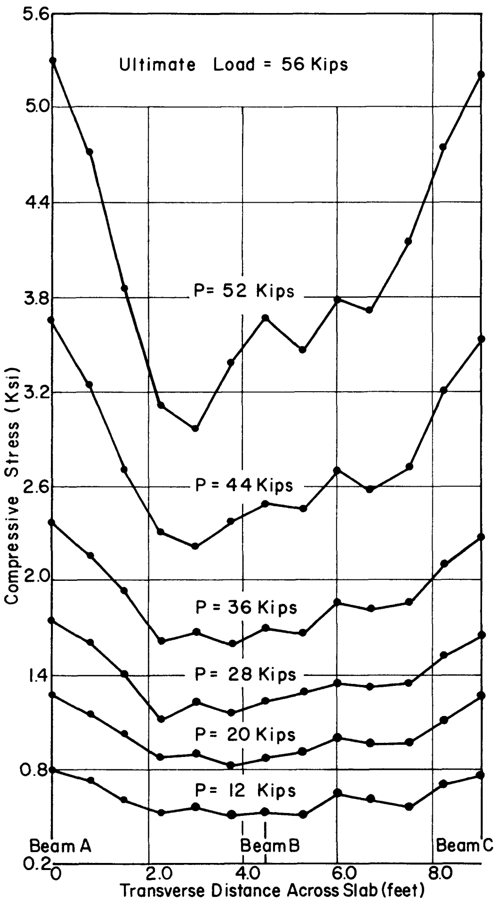

Fig. 7. Transverse distribution of longitudinal stresses at mid-span at top of slab, Specimen No. 2

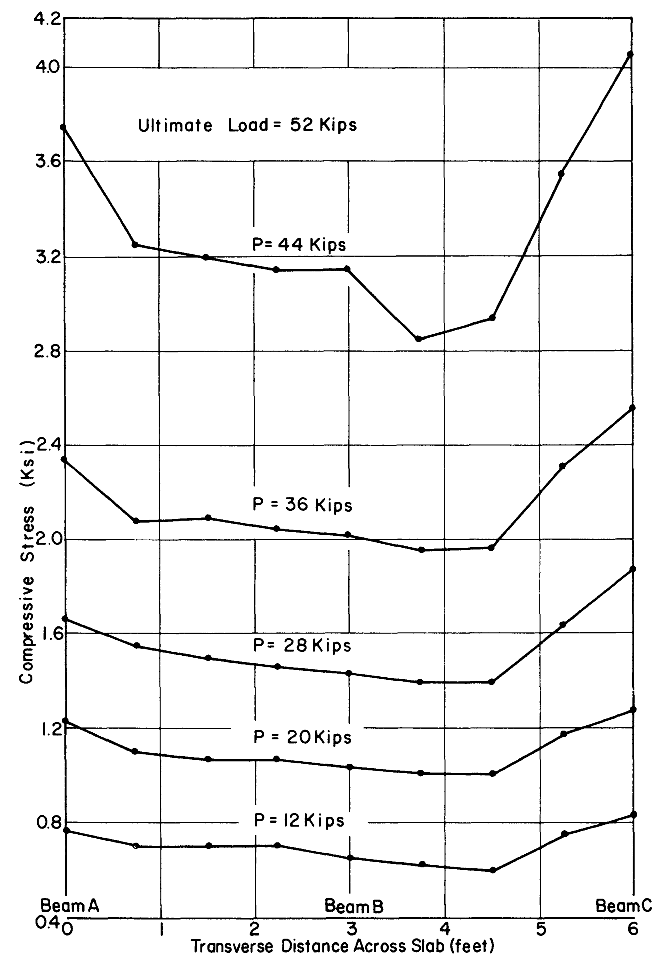

Fig. 8. Transverse distribution of longitudinal stresses at mid-span at top of slab, Specimen No. 3

of these (Method I) determines the effective slab width by summing the area under the curve for the transverse distribution of longitudinal top-fiber strains, equating this area to an equivalent rectangular area represented by the product of the effective width and the maximum strain ordinate in that area as shown in Fig. 11. The second experimental method (Method II) is used by taking the strain at the top of the slab and the bottom of the beam in a vertical plane, plotting these values to scale and connecting the points to determine the neutral

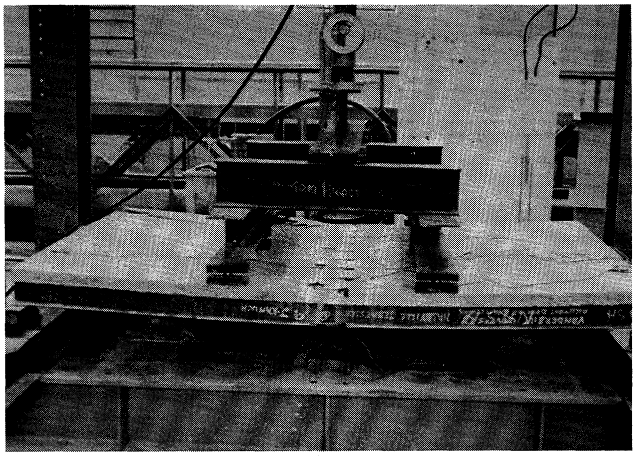

Fig. 9. Specimen No. 3, slab after failure

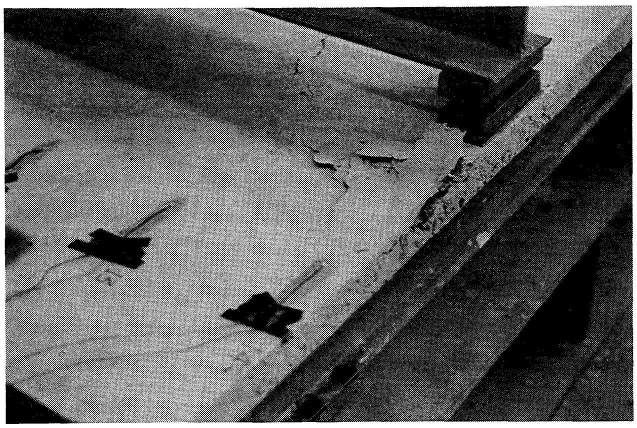

Fig. 10. Specimen No. 3, slab failure over exterior I-beam "C"

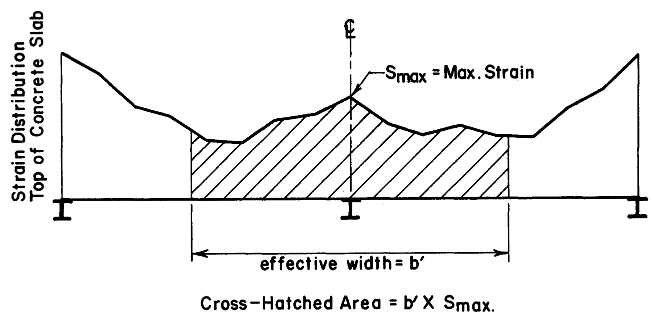

Fig. 11. Effective width—Method I

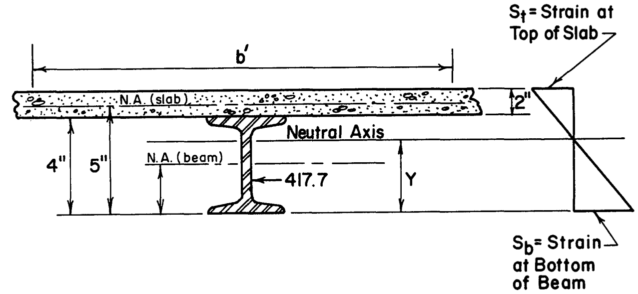

Fig. 12. Effective width—Method II

axis of the cross-section. The effective slab width is then computed using stress triangles as shown in Fig. 12.

Mackey and Wong presented an analytical method which is based on plane stress theory which assumes:

a. Thickness of slab is small compared with depth of beam.
b. Transverse bending of slab is neglected.
c. During bending of the structure, forces are transmitted to the flange at its middle plane.

This analytical method is presented very well in Mackey and Wong's paper and will not be repeated here; however, the results of several calculations from their equations are included in Tables 3 and 4.

Table 3 shows the comparsion between the various methods for calculating the effective width for the interior beams of the three test structures and the Mackey and Wong test structures. Values given by the analytical method were obtained with a value of Poisson's Ratio equal to zero for the slab. Values shown for Methods I and II are average values in that slightly different values are obtained depending upon which load level is used for the calculations. Note that AISC values are also given, keeping in mind that the designer must use the smallest of the three possibilities. Table 4 shows similar comparisons for the exterior beams. No results were available from the Mackey and Wong study for exterior beams.

Figures 13 and 14 sum up the study. Figure 13 is a plot of the beam spacing to beam span ratio versus the effective width to beam span ratio for interior beams. Mackey and Wong's results agree very well with those obtained by the authors, even though slightly different testing techniques were used. One will note that as beam spacing to beam span ratio increases beyond approximately 0.4, the AISC criteria for effective width become increasingly conservative. The degree of conservatism depends, however, upon which method one wishes to consider as being the most representative. Figure 14, on the other hand, indicates that the AISC criteria for exterior beams are reasonable.

CONCLUSION

One can conclude from this study, at least within the range of parameters tested by both the authors and by Mackey and Wong, present effective slab width requirements for composite construction are conservative for interior beams. On the other hand, the results indicate that present specification requirements are reasonable for exterior beams.

REFERENCE

1. *Mackey and Wong* The Effective Width of a Composite Tee-Beam Flange, *The Structural Engineer, Sept. 1961, pp. 277–285.*

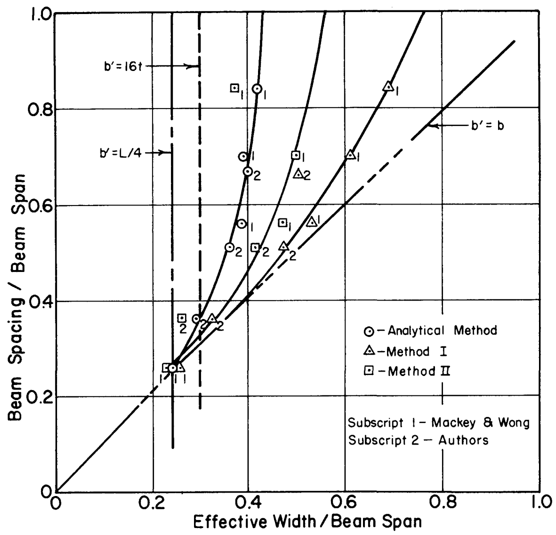

Fig. 13. (*Beam spacing/beam span*) *vs.* (*effective width/beam span*) *for interior beams*

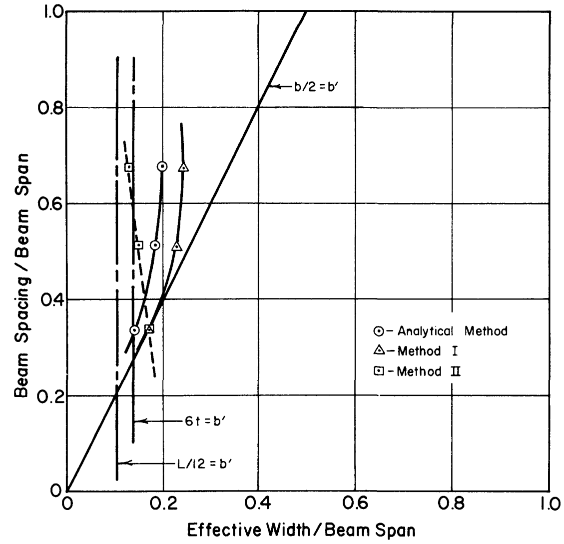

Fig. 14. (*Beam spacing/beam span*) *vs.* (*effective width/beam span*) *for exterior beams*

Table 3. Comparison of Analytical and Experimental Values of Slab Effective Width

Specimen No.	Effective Width, Interior Beam (in.)					
	Analytical Method	Experimental		AISC Specification		
		Method I	Method II	$L/4$	$16t + b_f$	s
1—M & W[a]	27	29	26	28.5	35	30
3	30	34	27	27	35	36
2	38	49	44	27	35	54
2—M & W	43	60	54	28.5	35	64
1	43	54	36	27	35	72
3—M & W	45	70	57	28.5	35	80
4—M & W	48	79	42	28.5	35	96

[a] *M & W refers to Mackey and Wong.*

Table 4. Comparison of Analytical and Experimental Values of Effective Width

Specimen No.	Effective Width, Exterior Beam (in.)					
	Analytical Method	Experimental		AISC Specification		
		Method I	Method II	$L/12$	$6t + b_f$	$s/2$
1	22	26	14	12	15	37
2	19	24	16	12	15	28
3	15	18	17.5	12	15	19