Title No. 56-58

Final report of a project sponsored by Reinforced Concrete Research Council at the University of Illinois

Effect of Floor Concrete Strength on Column Strength

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Forty-five specimens representing portions of the corner, edge, and interior column and floor sections of a typical structure were tested under axial compressive loads and the results analyzed to determine the following: (1) how large a differential in column concrete strength and floor concrete strength could be tolerated without decreasing the load-carrying capacity of the column, and (2) the allowable load-carrying capacity of the column if this differential is exceeded. The following variables were included: type of specimen, column concrete strength, and floor concrete strength.

From the analysis of the test results, a procedure was developed for computing the ultimate load of a column in which the column concrete is intersected by floor concrete. These limited tests indicated that the column strength is a function of the ratio of column concrete strength to floor concrete strength and the number of restrained edges tributary to the column. No reduction in column strength occurred for ratios of column concrete strength to floor concrete strength up to 1.4 for all types of specimens and up to 1.5 for most types of specimens.

In present day reinforced concrete construction, substantial economies may be achieved by designing the floors, which may consist of slabs or slabs and beams, with medium strength concrete and the columns with high strength concrete. In the resulting structure, layers of floor concrete intersect the columns at each floor level. As these layers are usually made of lower strength concrete than the column itself, it is probable that under some circumstances such layers may decrease the load resisting capacity of the column.

The effect of the floor concrete on the strength of a column may be expected to depend on the lateral restraint offered to the lower strength floor concrete, on the relative strengths of the two concretes, on the relative thickness of the floor and the size of the column, on the percentage of column reinforcement, and on the eccentricity of the load.

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The restraint to the lower strength concrete may be offered by the surrounding floor, by the floor reinforcement, and by the column concrete located above and below the floor layer. The restraint may entirely prevent failure of the floor concrete, as may well be the case for interior columns in which the surrounding floor provides a very effective lateral restraint. In other cases, however, the restraint may just raise the strength of the layer of floor concrete above the value expected on the basis of known cylinder strength. The restraint offered by the floor is likely to be different for each of the three types of columns: corner, edge, and interior. The restraint offered by the floor reinforcement will probably vary with the amount and arrangement of this steel. And the restraint offered by the column concrete may be expected to be a function of the ratio of floor thickness to column size and of the ratio of concrete strengths.

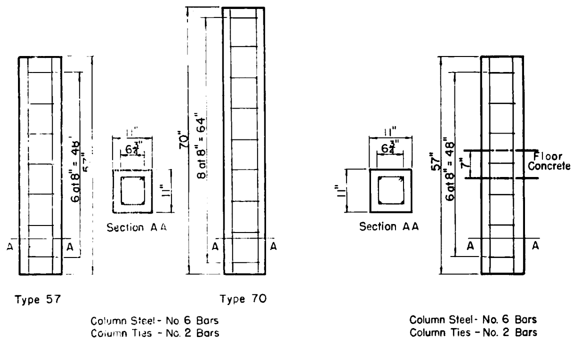
The effects of eccentricity of loads are related to the state of stress in the column-floor joints. Column-floor joints loaded eccentrically, in which the weaker floor concrete is only restrained laterally around a portion of its perimeter, may carry larger loads than concentrically loaded column-floor joints provided the eccentricity is in the right direction.

Object and scope

The object of this investigation was to determine how large a differential in column concrete strength and floor (slab or slab and beam) concrete strength could be tolerated without decreasing the load-carrying capacity of a column, and to determine the allowable load-carrying capacity of the column if this differential was exceeded.

The investigation included 54 axially loaded column specimens. Of the 54 specimens, 45 represented portions of the corner, edge, and interior column and floor sections of a typical structure and each specimen consisted of two tied columns with an intersecting floor between the two columns. The remaining nine specimens consisted of plain tied columns without any intersecting floor concrete. For the column and floor specimens, the ratio of column concrete strength to floor concrete

Fig. 1 (left) — Details of column specimens (column series). Fig. 2 (right)—Details of sandwich column specimens, Type S (slab series)



strength was varied systematically while the floor thickness, column cross section, and the percentage of column reinforcement were held constant.

Outline of tests

The investigation included seven different types of specimens and was divided into three series: column series, slab series, and beam series. An outline of the tests given in Table 1 indicates that the major variables were: type of specimen, column concrete strength, and floor concrete strength. The types of specimens investigated are shown in Fig. 1 through 7. In all specimens an axial compressive load was applied to the columns.

Notations

The following notations are used:

A_c = net area of concrete in column section

A_g = gross area of column section

A_s = area of column reinforcement

C = ratio of the concrete stress on an axially loaded column without floor (slab or slab and beam) concrete to the compressive strength of a 6 x 12-in. concrete cylinder

f_c' = 28-day standard cylinder compressive strength

f'_{cc} = 27-day, 28-day, or 29-day compressive strength of 6 x 12-in. *column* concrete control cylinders

f'_{cf} = 28-day compressive strength of 6 x 12-in. floor (slab or slab and beam) concrete control cylinders

f'_{cp} = apparent strength of floor concrete

f_s = 0.40 f_y, nominal allowable stress in the column reinforcement

f_y = yield point stress of column reinforcement

G = geometry of specimen

P = ultimate strength of a concentrically loaded column

P_a = total allowable axial load on the column

P_{calc} = $A_s f_y + C A_c f'_{cp}$. Calculated load on the specimen where $C = 0.85$

P_{test} = maximum test load on specimen

p_c = percentage of column reinforcement

p_g = ratio of the cross-sectional area of column reinforcement to the gross area A_g

p_f = percentage of floor reinforcement

R_c = restraint afforded the floor portion of the column section by higher strength column concrete

R_l = lateral restraint afforded the floor portion of the column section by overhanging floor concrete

SPECIMENS, MATERIALS, AND TEST PROCEDURE

Description of specimens

The details and dimensions of the specimens used in this investigation are shown in Fig. 1 through 7. All columns used in this investigation were tied columns 11 in. square and reinforced with four #6 bars. Column ties consisted of #2 bars.

The details of the specimens used in the column series are shown in Fig. 1. The specimens in this series had no intersecting floor concrete; they were either 57 in. long or 70 in. long and were used to evaluate the adequacy of the present ACI Building Code (318-56) ultimate load column formula.

The details of the four different types of specimens tested in the slab series are shown in Fig. 2 through 5. The specimens in this series consisted of two square tied columns and a slab 7 in. thick placed between the columns. The slab portions were reinforced on top and bottom with #4 bars as shown in Fig. 3 through 5. In the sandwich column specimens, Type S, the slab was cut off along the column periphery. For the corner column specimens, Type C, the slab was square and the column was in one corner. In the edge column specimens, Type E, the slab was rectangular and the column was in the middle of one side. For the interior column specimens, Type I, the slab was square and placed concentrically with respect to the column.

Details of the two different types of specimens tested in the beam series are shown in Fig. 6 and 7. The specimens in this series consisted of two square tied column sections and a 7 in. thick slab and 8 x 20-in. beams placed between the columns. The slabs were reinforced on top and bottom with #4 bars, and the beams reinforced with #8 bars. In the beam sections #3 bars were used for the stirrups. In this series, Type E and Type I specimens were similar to the Type E and Type I specimens of the slab series. In the edge column specimens,

TABLE 1—OUTLINE OF TESTS

Column series		Slab series				Beam series			
f'_{cc}, psi	Specimen No.*	f'_{cc} psi	f'_{cf} psi	f'_{cc}/f'_{cf}	Specimen No.†	f'_{cc}, psi	f'_{cf}, psi	f'_{cc}/f'_{cf}	Specimen No.†
Series 57		Type S				Type E			
7500	C7557	7500	2500	3.0	S75S3.0	9000	3000	3.0	B90E3.0
6000	C6057	6000	2500	2.4	S60S2.4	7500	2500	3.0	B75E3.0
5000	C5057	5000	2500	2.0	S50S2.0	6000	2000	3.0	B60E3.0
4500	C4557	3750	2500	1.5	S37S1.5				
3750	C3757	Type C,E,I				Type E,I			
3000	C3057	9000	3000	3.0	S90C,E, or I3.0	6000	3000	2.0	B60E or I2.0
Series 70		7500	2500	3.0	S75C,E, or I3.0	5000	2500	2.0	B50E or I2.0
7500	C7570	6000	2000	3.0	S60C,E, or I3.0	4000	2000	2.0	B40E or I2.0
5000	C5070	Type C,E,I				Type E			
3000	C3070	6000	3000	2.0	S60C,E, or I2.0	4500	3000	1.5	B45E1.5
		5000	2500	2.0	S60C,E, or I2.0	3750	2500	1.5	B37E1.5
		4000	2000	2.0	S40C,E, or I2.0	3000	2000	1.5	B30E1.5
		Type C,E,I							
		4500	3000	1.5	S45C,E, or I1.5				
		3750	2500	1.5	S37C,E, or I1.5				
		3000	2000	1.5	S30C,E, or I1.5				

*The designation of each specimen in the column series consists of one letter and four numbers. The first letter C designates the column series; the next two numbers represent the nominal column concrete strength (75 for 7500 psi, 50 for 5000 psi, etc.); and the last two numbers represent the height of the column (57 for 57 in., 70 for 70 in.).

†The designation of each specimen in the slab and beam series consists of two letters and four numbers. The first letter designates the phase of the investigation (S—slab series, column to slab; B—beam series, column to slab and beam); the next two numbers represent the nominal column concrete strength (75 for 7500 psi, 50 for 5000 psi, etc.); the second letter stands for the type of specimen (S—sandwich column, C—corner column, E—edge column, I—interior column); and the last two numbers represent the ratio of the nominal column concrete strength to the nominal floor concrete strength.

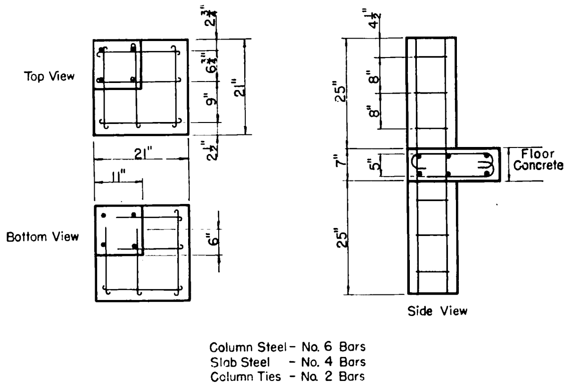


Fig. 3 — Details of corner column specimens, Type C (slab series)

Type E, the slab was rectangular and the column was in the middle of one side. Also, two beams were placed underneath, parallel and flush to the outside edge of the slab and connected into the column. For the interior column specimens, Type I, the slab was square and placed concentrically with respect to the column. Also, beams extended in four directions underneath the slab from the column faces.

Materials

Cement — A standard brand of Type I portland cement was used throughout the investigation.

Aggregates — Both the well graded fine and coarse aggregates used in the concrete mixtures were from the Wabash River near Covington, Ind. The sand had a fineness modulus of 3.12 and the gravel had a fineness modulus of 6.75. The bulk specific gravities, based on saturated surface dry, were approximately 2.65 and 2.70 for the sand and gravel, respectively. The absorption of both fine and coarse aggregate was about 1 percent, by weight, of the surface dry aggregate.

Concrete mixtures — The investigation involved ten different concrete strengths ranging from 2000 to 9000 psi. Mixes were designed for 28-day nominal compressive strengths.

The average column and floor compressive strengths, f'_{cc} and f'_{cf}, determined from a minimum of five 6 x 12-in. control cylinders, are listed in Tables 2 and 3 for the specimens in the column series and the slab and beam series, respectively.

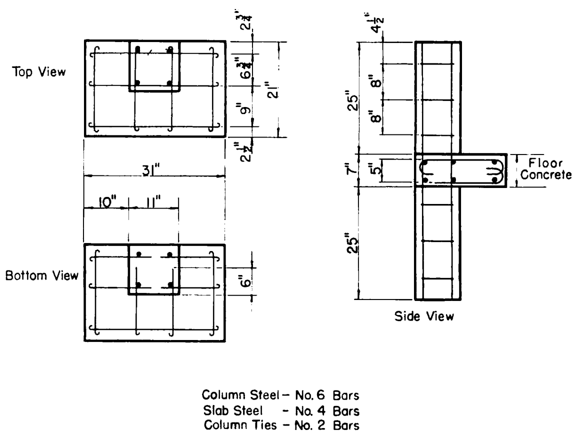


Fig. 4—Details of edge column specimens, Type E (slab series)

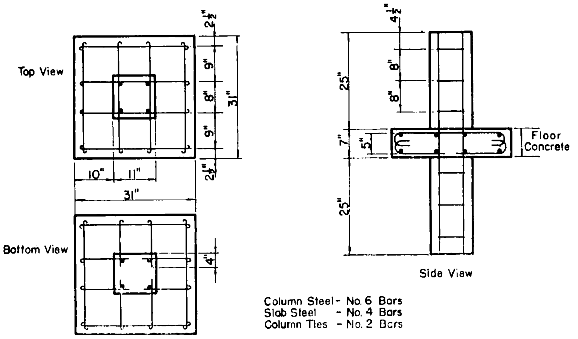


Fig. 5 — Details of interior column specimens, Type I (slab series)

The compressive strength values listed in Table 2, for the bottom column and top column of each specimen in the column series are 28-day strengths. In addition, the average of these two strengths is given. In Table 3, the compressive strength values listed for the bottom column, top column, and intersecting floor of each specimen in the slab series and beam series are 29-day, 27-day, and 28-day strengths, respectively.

Reinforcement — Intermediate grade deformed bars, satisfying the requirements of ASTM A 305-53T and A 15-54T, were used as reinforcement. The column reinforcement consisted of four #6 bars with #2 bars as ties. The slabs were reinforced, both on top and bottom, with #4 bars and the beam reinforcement consisted of four #8 bars. Beam stirrups were #3 bars.

In Tables 2 and 3, the yield point and ultimate strength values of the column reinforcement are listed for each specimen tested. The column reinforcement for any one specimen was cut from one bar 30 ft long. One coupon 2 ft long was then cut from each bar and tested. A typical tensile stress-strain curve for the column reinforcement is shown in Fig. 8.

Fabrication and curing

All specimens were cast in waterproof plywood forms in an upright position. The column reinforcement was placed in position with the use of steel chairs. The bottom reinforcement for the slab or beam was supported on small wood blocks resting on the bottom of the forms.

All concrete was mixed from 3 to 5 min in a nontilting, horizontal, 6.5-cu ft drum mixer. Slump was determined immediately after mixing. After the concrete was placed in the forms and control cylinder molds, it was vibrated for approximately 15 sec with an internal high frequency rod vibrator.

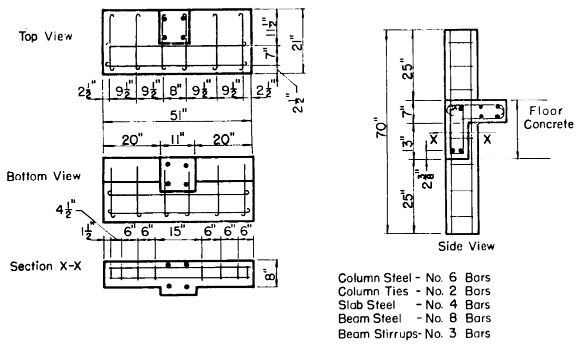
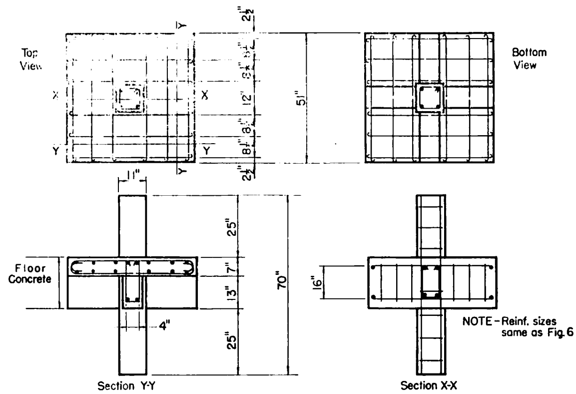


Fig. 6—Details of edge column specimens, Type E (beam series)

Fig. 7 — Details of interior column specimens, Type I (beam series)



Each specimen in the column series was cast in 1 day. Each specimen required two batches of concrete, and for each batch, six 6 x 12-in. concrete control cylinders were made. The forms were removed the day after casting, and the specimen placed in a fog room at 75 F for 6 days. It was then stored in the air of the laboratory until tested at an age of 28 days.

In the slab series and the beam series, 3 days were required to cast each specimen. The bottom column was cast the first day, the floor portion the second day, and the top column the third day. Each portion of the specimen required one or two batches of concrete, and for each portion of the specimen, six 6 x 12-in. concrete control cylinders were made. On the third day after casting the bottom column, the forms were removed, and the specimen was placed in a fog room at 75 F for 5 days. This, in effect, resulted in 7 days moist curing on the floor portion of the specimen. It was then stored in the air of the laboratory and tested when the floor concrete was 28 days old.

Test procedure

All specimens were tested in compression in a 3,000,000-lb capacity hydraulic machine. A typical test set-up is shown in Fig. 9. Each specimen was placed centrally under the loading head of the testing machine, and a high strength gypsum cement placed between the bottom column stub and the flat steel bed of the testing machine to insure a smooth bearing surface. The top column stub was capped with a high strength gypsum cement and an 11 x 11 x 1½-in. steel plate. The capping compound was allowed to dry for approximately 1 hr before any load was applied to the specimen.

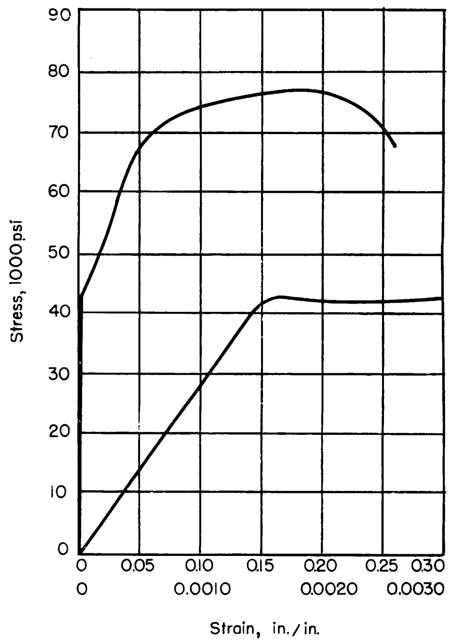


Fig. 8—Typical stress-strain curve for column reinforcement

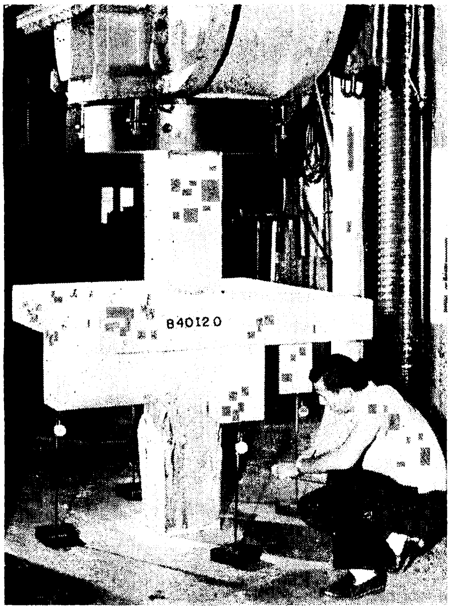


Fig. 9—Test set-up

To insure that the specimens were being loaded axially, three or four dial gages, graduated directly to 0.001 in., were placed around the perimeter of the specimens. The dial gages were mounted on posts which were set on bed of testing machine as shown in Fig. 9.

A preload of 20,000 lb was applied to the specimen before the spherical seat, attached to the head of the testing machine, was wedged in a fixed position to prevent any rotation. The column portions were thus loaded as *flat-ended columns.* The load was then increased to 50,000 lb and in increments of 50,000 lb thereafter until failure occured. At each loading increment, deflection measurements were taken. In addition, the specimen was examined for cracks, and in most cases, a pictorial record was made of changes in the crack pattern. Testing of each specimen took approximately 1½ to 2 hr.

TEST RESULTS

Test data

The test data, for specimens in the column series and for specimens in the slab series and beam series, are summarized in Tables 2 and 3, respectively.

Table 2 includes the concrete strengths of the bottom and top portions of the column, the yield point and ultimate strength of the column

TABLE 2—MEASURED AND COMPUTED QUANTITIES—COLUMN SERIES

Specimen No.	Concrete strength*, f'_{cc}, psi			Tensile strength of column steel, psi		P_{test}, lb	P_{test}/P_{calc}†
	Bottom of column	Top of column	Avg.	Yield strength	Ultimate strength		
Column series — Type 57							
C7557	7100	7240	7170	49,410	76,770	748,000	0.92
C6057	5650	5000	5330	44,150	75,190	640,000	1.04
C5057	4690	5180	4940	44,840	77,030	586,000	1.01
C4557	4630	4690	4660	44,980	77,050	560,000	1.02
C3757	2960	3300	3130	48,360	80,380	408,000	1.01
C3057	2800	2710	2760	46,830	76,820	345,000	0.95
Column series — Type 70							
C7570	6450	6820	6640	45,180	76,960	709,000	0.94
C5070	4050	4860	4460	44,750	76,355	548,000	1.03
C3070	2490	2430	2460	45,870	79,300	357,000	1.08
				Average			1.00
				Standard deviation			0.049

*28-day compressive strengths.

†$P_{calc} = A_s f_y + A_c C f'_{cc}$ — Calculated load on the specimen using the 1956 ACI Code ultimate load column formula.

reinforcement, and the ultimate load, P_{test}. The average column concrete strength listed was determined by averaging the bottom column and top column concrete strengths.

Table 3 includes the bottom column and top column concrete strength, floor concrete strength, the ratio of the column concrete strength to the floor concrete strength, the yield point and ultimate strength of the column reinforcement, the location of the failure, and the ultimate load, P_{test}. In computing the ratio of the column concrete strength to the floor concrete strength the compressive strength of either the bottom or top column, which ever was lower, was used.

Behavior of specimens under load

For each type of specimen tested various stages of cracking were observed prior to failure. These are shown in Fig. 10 through 14. In all cases failure occurred by crushing of concrete and yielding of the column reinforcement. The typical behaviors, before and at failure, of the specimens tested were as follows:

Column series — Vertical cracks first appeared in the column faces at loads approaching failure. Final failure occurred by yielding of the column reinforcement and crushing of the concrete.

Slab series — For the sandwich column specimens, Type S, vertical cracks first appeared in the slab concrete between the two columns. Failure occurred in the slab concrete sandwiched between the two column sections.

For the corner column and edge column specimens, Types C and E, three stages of cracking were observed: vertical cracks appearing on the exterior face, or faces, of the slab concrete which were flush with the top and bottom columns; cracking of the slab around the perimeters of the top and bottom columns; and cracks extending from the crack around the perimeter of the column towards the slab edges directly over the slab reinforcement.

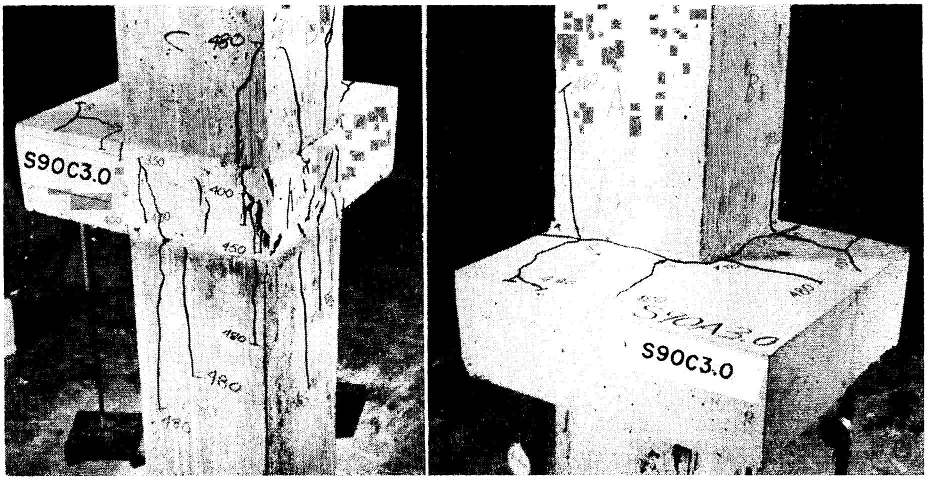


Fig. 10—Typical cracking for corner column specimens, Type C (slab series)

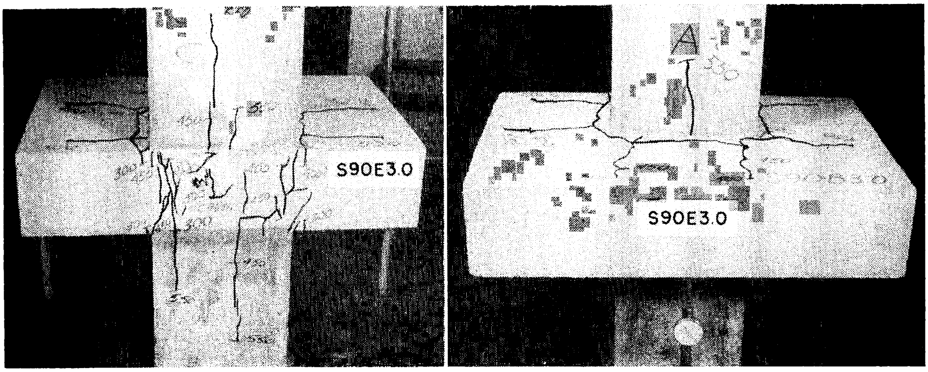


Fig. 11—Typical cracking for edge column specimens, Type E (slab series)

In Specimens S40C2.0, S45C1.5, and S30C1.5, cracks extending from the perimeter of the columns, did not form. Typical cracking patterns are shown in Fig. 10 and 11 for the Type C and Type E specimens, respectively.

Ultimate failure of all Type C and Type E specimens occurred either in the slab portion flush with the column face or faces, or in the bottom column or top column. In Specimens S40E2.0 and S50E2.0, failure occurred at the junction of the bottom column and slab.

For the interior column specimens, Type I, four stages of cracking were observed as shown by a typical example in Fig. 12. Cracking first took place on the vertical faces on the outside perimeter of the over hanging slab indicating that tensile stresses were present on these faces. These tensile stresses were caused by the lateral internal compressive stresses,

TABLE 3—MEASURED AND COMPUTED QUANTITIES—SLAB SERIES AND BEAM SERIES

Specimen No.	Concrete strength,* psi			f'_{cc}† / f'_{ct}	Tensile strength of column steel, psi		Location‡ of failure	P_{test}, lb	f'_{cp}§, psi	P_{test}** / P_{calc}
	f'_{cc} Bottom	f'_{cc} Top	f'_{ct}		Yield strength	Ultimate strength				
Slab series — Type S										
S75S3.0	5330	6090	2180	2.44	48,360	80,380	S	415,000	3250	1.00
S60S2.4	5190	5150	1960	2.63	46,300	78,400	S	376,000	2910	0.99
S50S2.0	5210	5310	2180	2.39	43,330	74,440	S	416,000	3350	1.02
S37S1.5	3180	3020	1960	1.54	45,270	78,570	S	390,000	3060	1.03
								Average	....	1.01
								Std. deviation		0.011
Slab series — Type C										
S90C3.0	8120	7540	2470	3.05	44,930	77,190	S & BC	480,000	3970	0.90
S75C3.0	7420	7560	2690	2.76	44,700	77,530	S & BC	516,000	4330	0.95
S60C3.0	5510	5380	1280	4.20	46,310	80,640	S	385,000	3010	1.03
S60C2.0	6630	6750	3600	1.84	44,320	76,800	S & BC	550,000	4670	0.96
S50C2.0	5710	5540	2550	2.17	46,080	80,640	S	450,000	3670	0.97
S40C2.0	4590	3510	1510	2.32	45,390	75,110	S	367,000	2840	1.17
S45C1.5	3990	4290	2730	1.46	42,690	76,030	BC	440,000	3600	0.92
S37C1.5	3580	3270	2300	1.42	44,980	78,080	TC	400,000	3170	0.98
S30C1.5	2840	2390	1530	1.57	43,850	75,870	TC	300,000	2210	0.94
								Average	....	0.98
								Std. deviation		0.076

TABLE 3 (Cont.)—SLAB SERIES AND BEAM SERIES

Specimen No.	Concrete strength,* psi f'_{cc} Bottom	f'_{cc} Top	f'_{cf}	f'_{cc}† / f'_{cf}	Tensile strength of column steel, psi Yield strength	Ultimate strength	Location‡ of failure	P_{test}, lb	f'_{cp}§, psi	P_{test}** / P_{calc}
					Slab series — Type E					
S90E3.0	8060	7610	2440	3.12	44,420	76,050	BS & BC	568,000	4850	0.96
S75E3.0	6800	7700	2380	2.86	45,640	79,360	BS	534,000	4480	0.96
S60E3.0	6340	5190	1720	3.01	46,770	80,410	BS	442,000	3560	1.01
S60E2.0	6600	6540	3470	1.89	44,930	76,500	BS	582,000	4970	0.94
S50E2.0	5120	5380	2350	2.18	45,480	81,200	BS & BC	453,000	3690	0.96
S40E2.0	3970	3360	1390	2.42	44,650	77,910	BS & BC	363,000	2820	1.11
S45E1.5	3450	3670	2560	1.35	43,780	74,650	BC	446,000	3650	1.05
S37E1.5	3420	3020	1990	1.52	44,000	75,350	TC	400,000	3190	1.05
S30E1.5	2400	2290	1470	1.56	45,390	78,110	BC	347,000	2650	1.12
								Average	....	1.02
								Std.	deviation	0.066
					Slab series — Type I					
S90I3.0	7400	7400	2480	2.98	46,870	80,740	TC & S	700,000	6110	0.95
S75I3.0	7440	7750	3220	2.31	42,730	74,320	BC	739,000	6550	0.97
S75I3.0	6280	6260	2300	2.72	44,240	76,180	TC	650,000	5630	1.01
S60I3.0	6570	6840	2080	3.17	43,640	75,110	BC	690,000	6050	1.05
S60I2.0	6620	6810	3430	1.93	45,450	78,860	TC	700,000	6140	0.98
S50I2.0	5890	6120	3090	1.91	45,000	77,500	BC	580,000	4940	0.90
S50I2.0	4990	5260	2210	2.26	43,330	74,440	BC	550,000	4660	1.01
S40I2.0	4590	3760	2460	1.53	45,160	76,730	TC	432,000	3490	0.94
S45I1.5	4990	4970	2870	1.73	44,520	77,170	TC	600,000	5150	1.06
S37I1.5	3940	3270	2200	1.49	44,240	76,960	TC	450,000	3680	1.09
S30I1.5	3710	3790	1940	1.91	43,150	76,250	BC	445,000	3640	1.03
								Average	....	1.00
								Std.	deviation	0.034
					Beam series — Type E					
B90E3.0	8030	7230	2600	2.78	45,890	77,850	BB	452,000	3670	0.97
B75E3.0	6720	7110	3140	2.14	45,390	78,800	BB	400,000	3170	0.75
B60E3.0	6180	5640	2020	2.79	45,280	77,650	BB & B	400,000	3170	1.06
B60E2.0	5160	5010	2820	1.77	46,140	79,350	BB	488,000	4020	1.01
B50E2.0	5090	4740	2200	2.16	46,410	80,580	BB	392,000	3070	0.98
B40E2.0	3420	3300	1510	2.19	45,150	77,470	BB	344,000	2620	1.16
B45E1.5	4930	4560	2570	1.77	42,655	77,550	BB	451,000	3710	1.02
B37E1.5	4470	4280	2300	1.86	46,030	78,250	BB	428,000	3430	1.05
B30E1.5	2580	1910	1720	1.11	45,760	79,790	TC	296,000	2140	1.08
								Average	....	1.01
								Std.	deviation	0.095
					Beam series — Type I					
B60I2.0	4050	4780	2160	1.88	45,500	76,980	BC	542,000	4570	1.11
B50I2.0	4360	3790	2070	1.84	43,340	74,500	TC	496,000	4150	1.08
B40I2.0	3380	3410	1730	1.95	45,020	77,810	BC	450,000	3670	1.07
								Average	....	1.09
								Std.	deviation	0.083
							Over-all average	....		1.01
							Over-all standard deviation			0.075

*f'_{cc} bottom column—29-day compressive strength; f'_{cc} top column—27-day compressive strength; f'_{cf} — 28-day compressive strength.

†Concrete strength, f'_{cc}, top or bottom column, whichever is lower used in ratio.

‡B—beam between slab and column; BB—junction of bottom column and beam; BC—bottom column; BS—junction bottom column and slab; S—slab between column stubs; TC—top column.

§$f'_{cp} = (P_{test} - A_s f_y)/CA_c$. Computed concrete strength in the column at the maximum load where $C = 0.85$.

**$P_{calc} = A_s f_y + A_c C f'_{cp}$. Calculated load on the specimen where $C = 0.85$ and the value f'_{cp} as given by equations on Fig. 15 through 20.

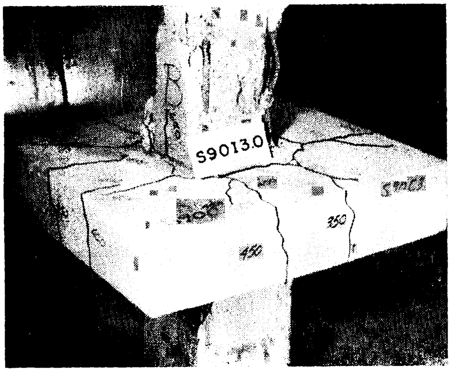


Fig. 12—Typical cracking for interior column specimens, Type I (slab series)

or internal pressure, subjected to the overhanging floor concrete when the floor concrete intersecting the column was loaded axially. The remaining three stages of cracking were as follows: vertical cracks of stage one progressing inward, in line with the slab reinforcement to the perimeters of the top and bottom columns; cracking of the slab around the perimeters of the top and bottom columns; and cracks appearing in the column stubs adjacent to the slab surface.

Failures for Type I specimens occurred either in the top column or the bottom column.

Beam series — For the edge column and interior column specimens, Types E and I, three stages of cracking were observed as shown by typical examples in Fig. 13 and 14, respectively. The first two stages for the Type E and Type I specimens were similar to the first two stages of cracking for the Type E and Type I specimens of the slab series, respectively. Splitting of the beams from the bottom of the slab constituted the third stage of cracking.

Typical failures of the Type E specimens occurred either in the bottom column or in the bottom of the beam next to the column. Specimen B30E1.5 failed in the top column. Typical failures of the Type I specimens occurred in either the top column or bottom column.

ANALYSIS

Ultimate load capacities

Without intersecting floor concrete — The ultimate strength of a short tied column without intersecting floor concrete, subjected to axial loads, is usually considered to be the sum of the ultimate strength, $CA_c f'_{cc}$, of the net concrete area, and the load, $A_s f_y$, required to stress the column

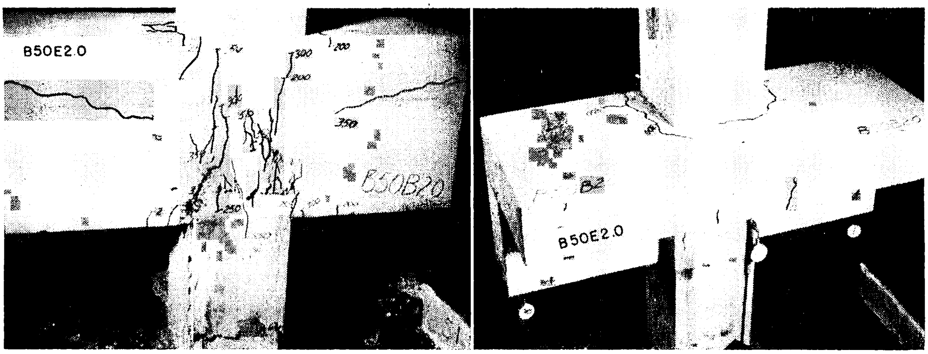


Fig. 13—Typical cracking for edge column specimens, Type E (beam series)

reinforcement to its yield point. The ultimate load, P, which the column can carry may then be computed as follows:

$$P = CA_c f'_{cc} + A_s f_y \qquad (1)$$

where C is the ratio of the concrete stress on an axially loaded column to the column concrete compressive strength as determined by 6 x 12-in. cylinders.

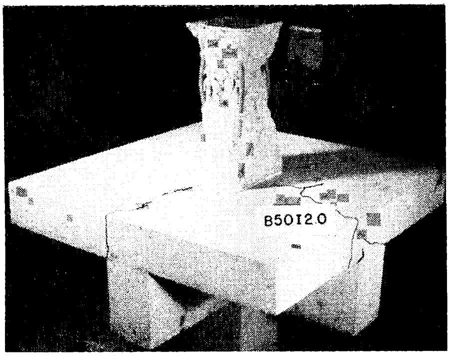


Fig. 14—Typical cracking for interior column specimens, Type I (beam series)

The ultimate load capacities for columns without intersecting floor concrete, computed from Eq. (1) with $C = 0.85$,* are compared in Table 2 with the test data. The average ratio of the test to calculated values is 1.00, with a standard deviation of 0.049.

With intersecting floor concrete — In computing the ultimate load of a column, when a sufficient length of the central portion of the column concrete is replaced by the weaker strength floor concrete, the value of f'_{cc} in Eq. (1) should be that of the weaker floor concrete strength, f'_{cf}. However, as the length of the floor section is reduced and restraints provided on the section in the form of slab or slab and beam reinforcement, column reinforcement, surrounding floor concrete, and surrounding column concrete, there will appear to be an apparent increase in strength of the floor concrete above the value expected on the basis of known cylinder strength. This apparent strength, f'_{cp}, may be expressed as follows:

$$f'_{cp} = F(f'_{cf}, f'_{cc}, R_l, R_e, G, p_c, \text{ and } p_f) \qquad (2)$$

Other variables may influence the magnitude of f'_{cp} but the ones listed seem to be the important ones. Therefore, in computing the ultimate load of a column, with the usual thickness of intersecting floor concrete, the value of f'_{cc} in Eq. (1) should be that of the apparent strength of the floor concrete, f'_{cp}. Using the value of 0.85 for C and f'_{cp} for f'_{cc} in Eq. (1) the ultimate load of a tied column with intersecting floor concrete may be computed as follows:

$$P = 0.85 A_c f'_{cp} + A_s f_y \qquad (3)$$

To use Eq. (3), the value of f'_{cp} must be known. Sufficient information is not available to develop a general expression for f'_{cp} involving all the variables listed in Eq. (2). However, expressions for f'_{cp} were

*ACI Committee 318, "Building Code Requirements for Reinforced Concrete (ACI 318-56)," ACI Journal, V. 27, No. 9, May 1956 (*Proceedings* V. 52), p. 984.

developed for each type of specimen from the limited data obtained in this investigation.

For any *one particular type* of specimen studied in this investigation, the lateral restraint, the end restraint, the geometry of the specimen, the percentage of column reinforcement, and the percentage of slab or slab and beam reinforcement remained constant. Therefore, Eq. (2) indicates that the apparent floor concrete strength, f'_{cp}, is only a function of the floor strength, f'_{cf}, and the column strength, f'_{cc}, or:

$$f'_{cp} = F\ (f'_{cf}, f'_{cc})$$

Empirical equations for f'_{cp} were developed from the test data of the different types of specimens investigated, and are given in Fig. 15 through 20. In these figures, the ratio of the maximum apparent concrete strength to the floor concrete strength, f'_{cp}/f'_{cf}, was plotted against the ratio of the column concrete strength to the floor concrete strength, f'_{cc}/f'_{cf}. The apparent concrete strength, f'_{cp}, in the ratio f'_{cp}/f'_{cf}, was evaluated, for each specimen tested, by using Eq. (3) with P equal to P_{test}. The term f'_{cc} in the ratio f'_{cc}/f'_{cf}, represents the bottom or top column concrete strength, whichever was lower, as determined from 6 x 12-in. cylinders.

The data on each figure were divided into two distinct failure types, column failures and joint failures. For a given type of specimen the type of failure depended on either the column strength or the ratio of the column concrete strength to floor concrete strength.

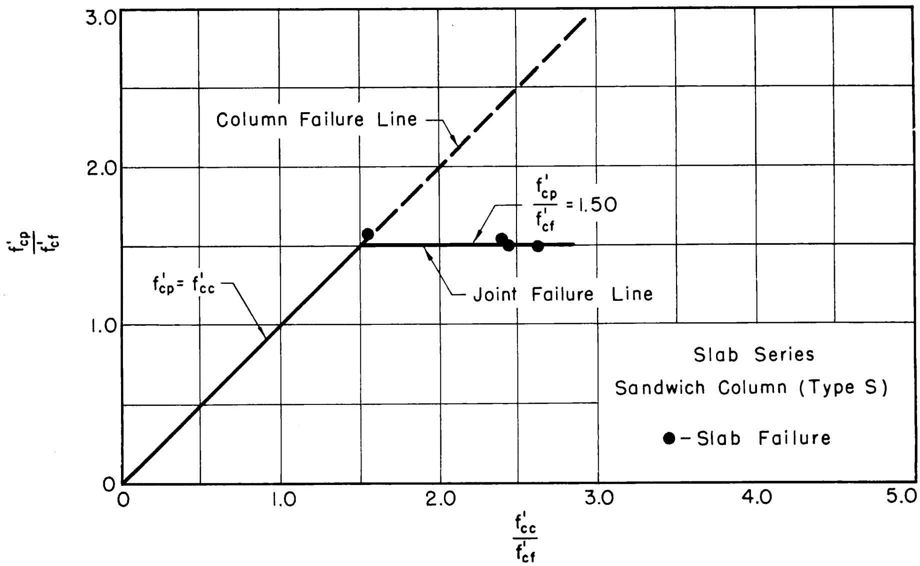


Fig. 15—Effect of f'_{cc}/f'_{cf}, sandwich column specimens, Type S (slab series)

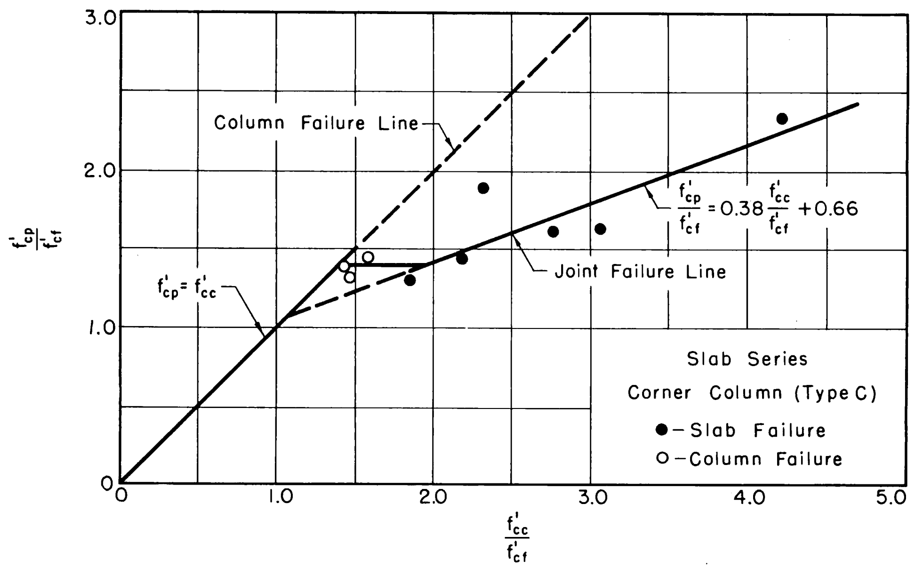


Fig. 16—Effect of f'_{cc}/f'_{cf}, corner column specimens, Type C (slab series)

If the specimen failed in the column, the apparent floor concrete strength, f'_{cp}, in Eq. (3) was equal to the column concrete strength, f'_{cc}. For this case, a 45-deg column failure line was constructed on each figure. In Fig. 15 through 20, it can be seen that all specimens which failed in the column lie close to the column failure line.

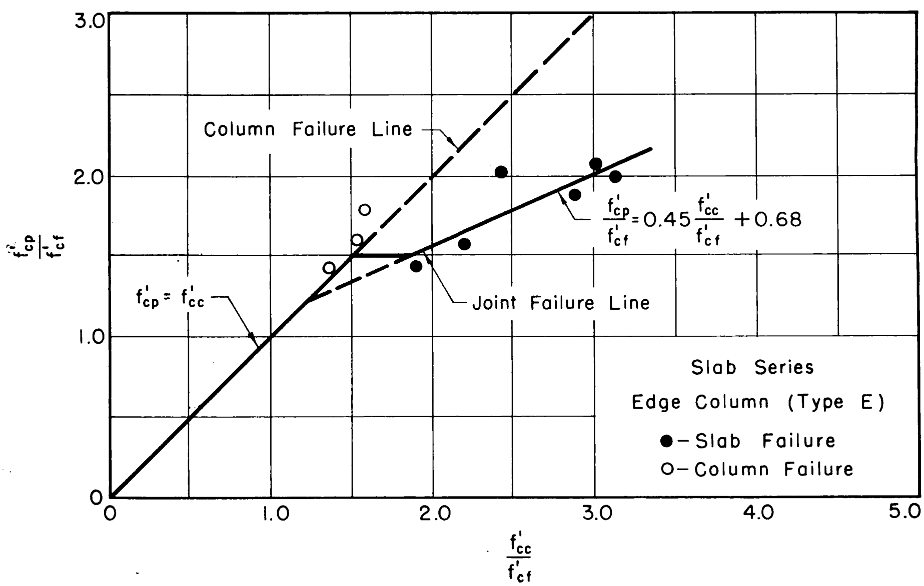


Fig. 17—Effect of f'_{cc}/f'_{cf}, edge column specimens, Type E (slab series)

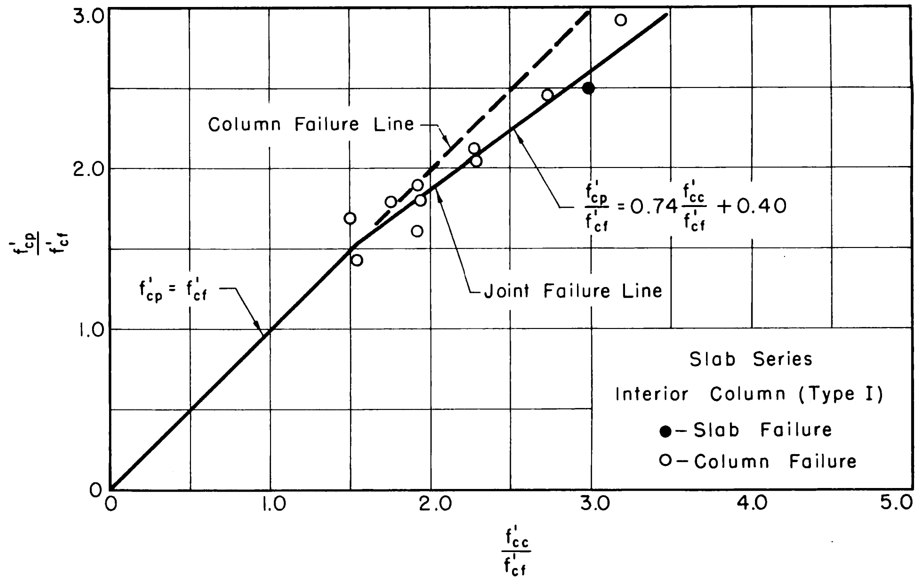


Fig. 18—Effect of f'_{cc}/f'_{cf}, interior column specimens, Type I (slab series)

If the specimen failed in the floor, or joint, the apparent floor concrete strength, f'_{cp}, was less than the column concrete strength f'_{cc}. In this case, a decrease in the load-carrying capacity resulted as compared with a column of the same column concrete strength with no intersecting floor concrete, as indicated in Fig. 15 through 19 by the joint failure lines.

The ratios of the maximum test load, P_{test}, to the calculated maximum load, P_{calc}, are listed for each specimen in Table 3. The value, P_{calc}, was computed by using Eq. (3) where f'_{cp} was given by the equations shown in Fig. 15 through 20. The over-all average ratio of the test to calculated values is 1.01, with an over-all standard deviation of 0.075. The ratios of the test to calculated loads agreed within 12 percent except for three specimens. These specimens were S40C2.0, B75E3.0, and B40E2.0 which had discrepancies of 17, 25, and 16 percents, respectively.

Effect of the ratio of column concrete strength to floor concrete strength

There were two important variables affecting the ultimate strength of the specimens tested in this investigation. These variables were the ratio of the column concrete strength to the floor concrete strength, f'_{cc}/f'_{cf}, and the type of specimen. For the types of specimens tested, the effect of the ratio f'_{cc}/f'_{cf} on the load-carrying capacity may be studied directly from Fig. 15 through 20.

The analysis indicates that up to some maximum critical value of f'_{cc}/f'_{cf}, there will be no reduction in column strength due to intersecting floor concrete. Up to this critical value of f'_{cc}/f'_{cf}, the apparent floor concrete strength, f'_{cp}, is equal to the column concrete strength, f'_{cc}, thus resulting in a column failure. For values of f'_{cc}/f'_{cf} greater than the critical value, there will be a reduction in the column load-carrying capacity as compared with a column of the same column concrete strength with no intersecting floor concrete. For this case, the apparent concrete strength f'_{cp} is less than f'_{cc}, thus resulting in a joint failure.

The analysis indicates that ratios of f'_{cc}/f'_{cf} of 1.50, 1.40, 1.50, and 1.54 for the Types S, C, E, and I specimens, respectively, of the slab series, and 1.39 for the Type E specimens of the beam series can be reached before the apparent concrete strength, f'_{cp}, becomes less than the column concrete strength, f'_{cc}. For the Type I specimens in the beam series the apparent concrete strength, f'_{cp}, is still equal to the column concrete strength, f'_{cc}, for a ratio of f'_{cc}/f'_{cf} of approximately 2.0

Effect of type of specimen

The effect that the type of specimen had on the load-carrying capacity of a column can be observed in Fig. 21, which consists of the curves shown in Fig. 15 through 20.

For ratios of f'_{cc}/f'_{cf} defining joint failures, the joint failure line for each type of specimen in the slab series and beam series, was at a different slope as shown in Fig. 21. A study of the figure indicates that the slope of the joint failure line increased as the number of sides of the specimen being restrained by overhanging floor concrete increased. The slopes of the joint failure lines were 0.00, 0.38, 0.45, and 0.74 for the

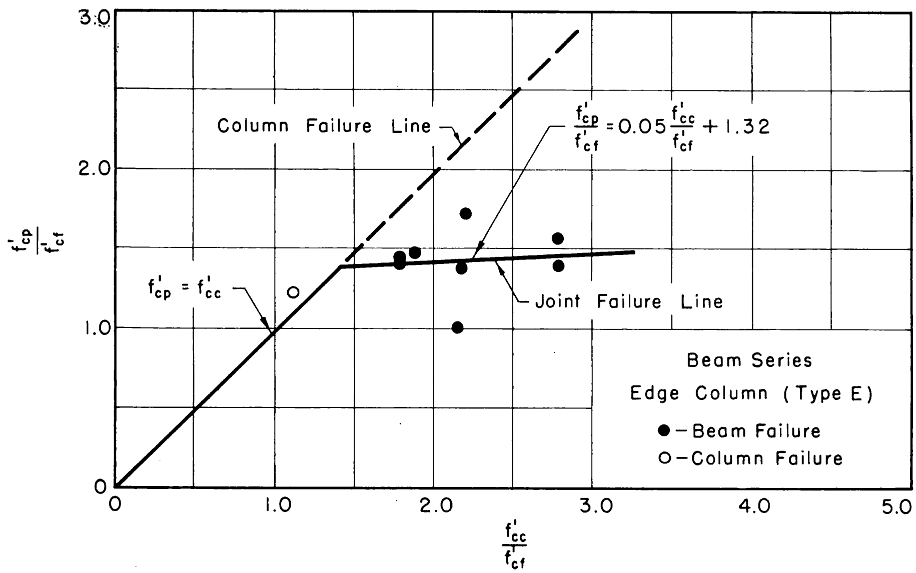


Fig. 19—Effect of f'_{cc}/f'_{cf}, edge column specimens, Type E (beam series)

Types S, C, E, and I specimens, respectively, of the slab series and 0.05, and 1.0 for the Types E and I specimens, respectively, of the beam series. It is interesting to note that Types C and E specimens of the slab series had a joint failure line slope of 0.00 for ratios of f'_{cc}/f'_{cf} less than 1.95 and 1.82, respectively.

In the Type S specimens of the slab series, the apparent concrete strength reached a uniform top limit of 1.50 f'_{cf} for ratios of f'_{cc}/f'_{cf} greater than 1.50. It is believed that the magnitude of the top limit will depend on the dimensions of the weaker concrete, and to some extent on the actual strength of the weaker concrete.

The data indicate that the efficiency of the Type E specimens of the slab series was greater than the Type E specimens of the beam series. The increase in efficiency may be explained in terms of the thickness of weaker concrete and the amount of lateral restraint on the weaker floor concrete. In the Type E specimens of the slab series the weaker concrete was restrained for its full depth on three sides, whereas, in the Type E specimens of the beam series the weaker concrete extended down the column shaft below the slab for the depth of the beam and was restrained on only two sides and a small portion of the third side.

The efficiency of the Type I specimens of the beam series was slightly greater than the Type I specimens of the slab series. However, broad conclusions should not be drawn because statistically there was an insufficient amount of test data for the Type I specimens of the beam

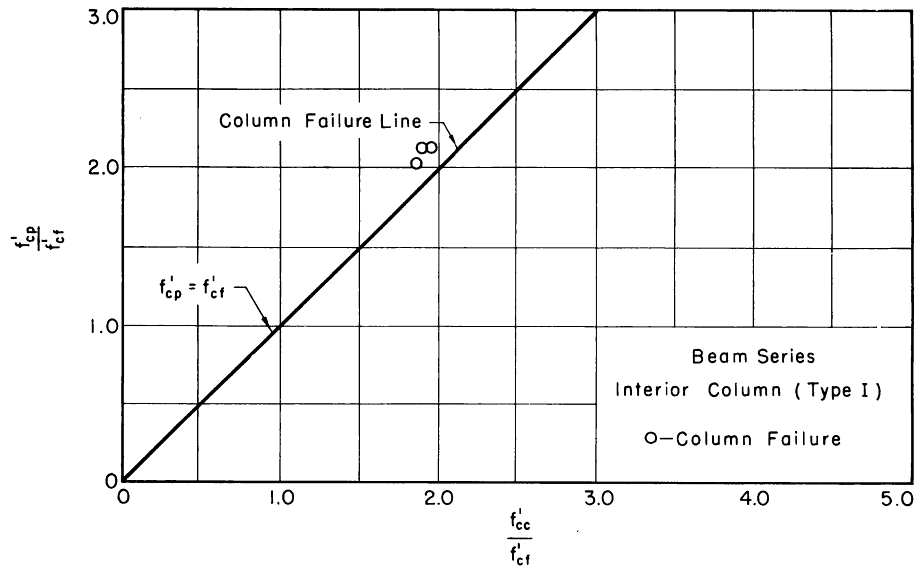


Fig. 20—Effect of f'_{cc}/f'_{cf}, interior column specimens, Type I (beam series)

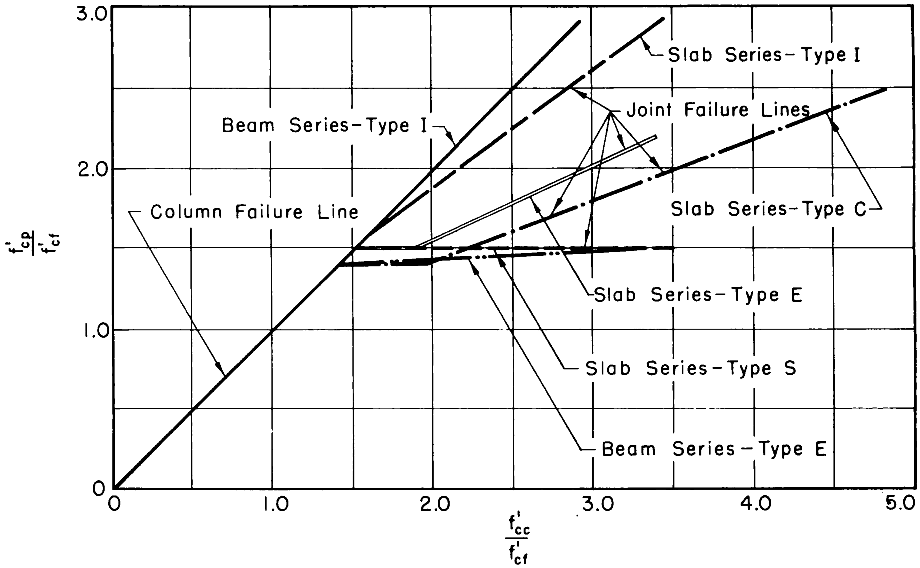


Fig. 21—Effect of type of specimen (slab series and beam series)

series to evaluate a joint failure line. An examination of Fig. 20 indicates that only three Type I specimens of the beam series, with approximately the same ratio of f'_{cc}/f'_{cf}, were tested. However, based on the data obtained, it may be possible that the restraint to the weaker concrete strength was greater in the Type I specimens of the beam series due to the extra projection of concrete and use of additional steel as compared to the restraint in the Type I specimens of the slab series.

DESIGN CONSIDERATIONS

Design formulas

Based on the results of this limited investigation using sand and gravel concrete, *and assuming tentatively that the results are applicable to all tied columns,* the present ACI Code tied column formulas, both for working load design and ultimate strength design may be used for ratios of f'_{cc}/f'_{cf} up to 1.4 for corner and edge columns and for ratios of f'_{cc}/f'_{cf} up to 1.5 for interior columns.

For corner and edge columns, the data indicate that no substantial benefits may be obtained by increasing the column concrete strength beyond 1.4 times the floor concrete strength.

For interior columns it appears that approximately 75 percent of the column concrete strength above 1.5 times the floor concrete strength may be effective in sustaining load. For this case the value of f'_c to be used in both the working load and ultimate strength tied column formulas listed in the ACI Code* may be computed from the following equation:

$$f'_c = 1.50\, f'_{cf} + 0.75\ (f'_{cc} - 1.50\, f'_{cf}) \quad (4)$$

Using f'_c as given by Eq. (4) the following working design and ultimate strength tied column formulas are obtained:

$$P_a = A_g\ (0.14\, f'_{cc} + 0.067\, f'_{cf} + 0.80\, f_s p_g) \quad (5)$$

$$P = A_c\ (0.64\, f'_{cc} + 0.31\, f'_{cf}) + A_s f_y \quad (6)$$

The data indicate that Eq. (5) and (6) are applicable for ratios of f'_{cc}/f'_{cf} between 1.5 and 3.0 for interior slab intersected columns and for ratios of f'_{cc}/f'_{cf} between 1.5 and 2.0 for interior slab and beam intersected columns.

CONCLUSIONS

The following conclusions may be drawn from the results of this limited investigation on the effect of floor concrete on column strength.

1. Two types of failures were observed in these tests: column failures and joint or floor failures. The type of failure obtained in each specimen depended on either the column strength or on the ratio of the column concrete strength to the floor concrete strength.

2. The data and analysis indicate, that up to some critical value of the ratio of column concrete strength to floor concrete strength f'_{cc}/f'_{cf}, the 1956 ACI Building Code ultimate load column formula may be used in computing the ultimate load for tied columns with intersecting floor concrete. These critical ratios of f'_{cc}/f'_{cf} are 1.4 for corner and edge columns and 1.5 for interior columns.

3. For ratios of column concrete strength to floor concrete strength greater than the critical values, the ultimate strength of a tied column with intersecting floor concrete is a function of the amount of restraint offered to the floor portion of the column and also of the ratio of the column concrete strength to the floor concrete strength. For this case the ultimate strength may be computed from Eq. (3) which is a modified form of the present ultimate load column formula.

The above conclusions are based on a limited investigation in which only two variables were considered. These were the ratio of the column concrete strength to the floor concrete strength and the type of joint. Many items which might have considerable influence on the behavior of the specimens, such as the type of column (tied or spiral), column size and shape, percentage of column reinforcement, thickness of the floor, percentage of floor reinforcement, the height of the specimen,

*ACI Committee 318, "Building Code Requirements for Reinforced Concrete (ACI 318-56)," ACI JOURNAL, V. 27, No. 9, May 1956 (*Proceedings* V. 52), p. 984.

type of concrete (lightweight or normal weight), and the type of loading (axial or eccentric), were not considered. A broader investigation should be conducted in which the effects of the above variables, constant in this investigation, should be studied to provide a better understanding of the behavior involved and a more adequate basis for design.

ACKNOWLEDGMENT

This investigation was carried out as a project of the Engineering Experiment Station in the Department of Theoretical and Applied Mechanics at the University of Illinois, in cooperation with the Reinforced Concrete Research Council of the Engineering Foundation. Credit for initiating the investigation must be given to the late J. DiStasio, Sr., who planned the tests in cooperation with Dr. I. M. Viest, formerly research associate professor in the Department of Theoretical and Applied Mechanics, University of Illinois. A task committee consisting of J. DiStasio, Sr., chairman; R. C. Reese; and C. A. Willson, was appointed by the Council to provide supervision of the investigation. After the untimely death of Mr. DiStasio, Mr. Reese became chairman of the task committee.

Received by the Institute Jan. 29, 1960. Presented at the ACI 56th annual convention, New York, Mar. 17, 1960. Title No. 56-58 is a part of copyrighted Journal of the American Concrete Institute, V. 31, No. 11, May 1960. (Proceedings V. 56). Separate prints are available at 60 cents each.

American Concrete Institute, P.O. Box 4754, Redford Station, Detroit 19, Mich.

Discussion of this paper should reach ACI headquarters in triplicate by Aug. 1, 1960, for publication in Part 2, December 1960 JOURNAL.