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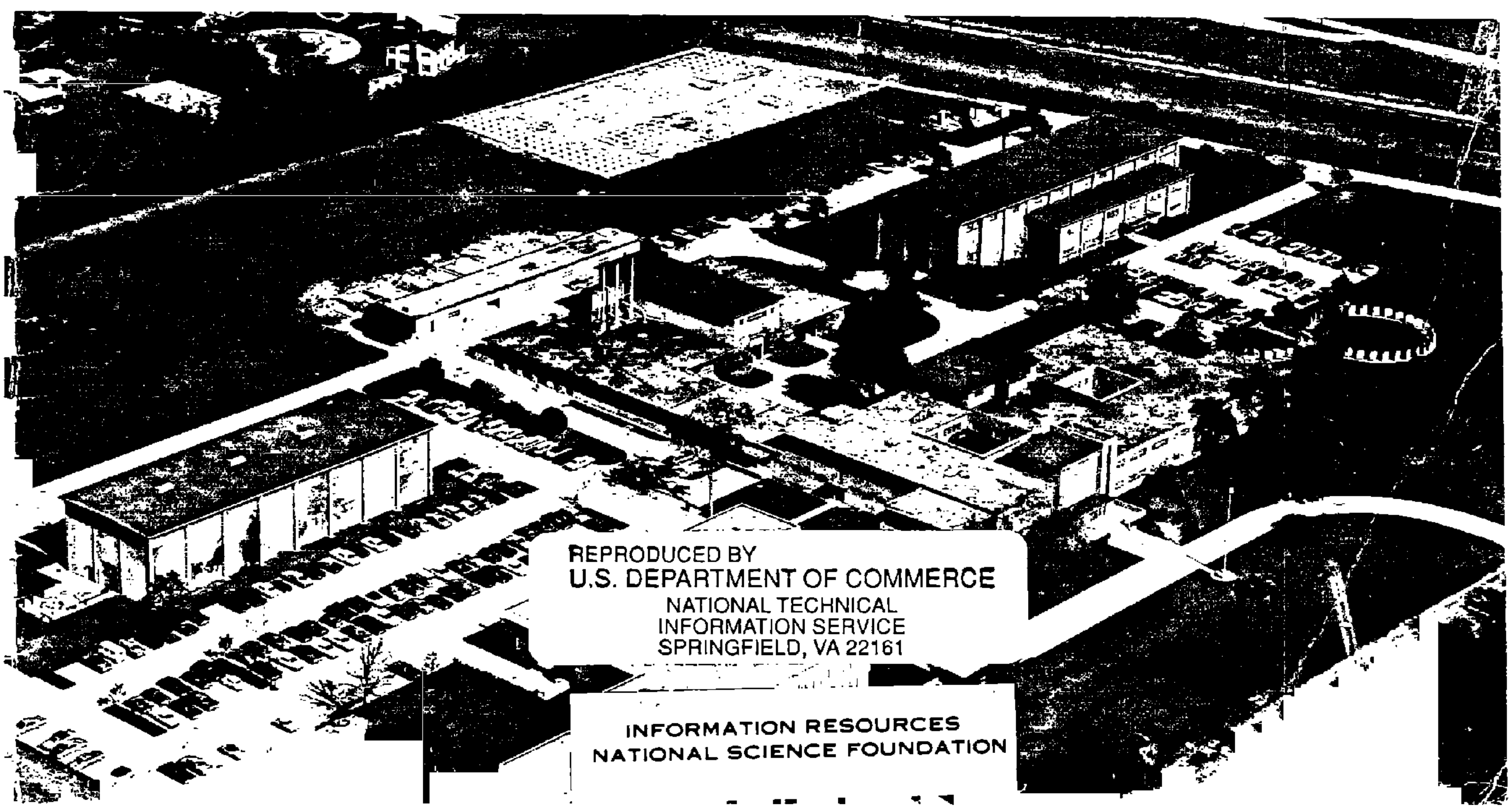
SEISMIC BEHAVIOR OF LIGHTWEIGHT CONCRETE COLUMNS



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Sixteen full-scale, column-beam assemblies, which represented a portion of a frame subjected to simulated seismic loading, were tested. Controlled test parameters included concrete type, column size, amount of main column steel, size and spacing of column confining hoops, and magnitude of column axial load. The columns were subjected to constant axial load and slow moment reversals at increasing inelastic deformations. Test data showed that properly designed lightweight concrete columns maintained ductility and strength when subjected to large inelastic deformations from load reversals. Confinement requirements for normal weight concrete columns were shown to be applicable to\lightweight concrete columns up to thirty percent of the design strength. Supplementary crossties engaging the column steel could be used to confine the core of lightweight and normal weight concrete columns.

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SEISMIC BEHAVIOR OF LIGHTWEIGHT CONCRETE COLUMNS

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SEISMIC BEHAVIOR OF LIGHTWEIGHT CONCRETE COLUMNS

by

B. G. Rabbat, J. I. Daniel, T. L. Weinmann and N. W. Hanson*

HIGHLIGHTS

In earthquake regions, columns in building frames are normally designed to maintain strength even after large inelastic deformations have occurred. Properly designed columns will perform satisfactorily during earthquakes. The experimental investigation described in this report was conducted to develop design information for columns subjected to simulated seismic forces.

Test Program

Sixteen full-scale column-beam assemblies were tested. They represented a portion of a frame subjected to simulated seismic loading. Controlled test parameters included concrete type, column size, amount of main column steel, size and spacing of column confining hoops, and magnitude of column axial load. The columns were subjected to constant axial load and slow moment reversals at increasing inelastic deformations.

Conclusions

Based on the results of the experimental investigation, the following conclusions are made:

1. Lightweight concrete columns with properly detailed reinforcement provided ductility and maintained strength when subjected to inelastic deformations from moment reversals.

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2. Properly detailed columns made with lightweight concrete performed as well as columns made with normal weight concrete when subjected to moment reversals.
3. Supplementary crossties engaging the column steel performed very satisfactorily in confining the column core. These crossties had a 135° hook at one end and a 90° hook at the other end. Crossties were alternated end for end along the column steel.
4. Requirements for column confinement in ACI 318-77 are conservative for normal weight concrete columns with axial loads up to 30% of the column design strength. These requirements can also be extended to lightweight concrete columns.
5. Simultaneous hinging of columns above and below a joint resulted in pinching of the load-deformation hysteresis loops.
6. In all specimens with column hinging, measured column strength exceeded the calculated nominal flexural strength.
7. As long as the nominal shear in the joint was less than $15\sqrt{f'_c}$ psi ($1.25\sqrt{f'_c}$ MPa), damage of the joint was avoided.

Recommendations

Based on test results of this investigation, and the above conclusions, the following is recommended:

1. Properly designed lightweight concrete columns may be used in ductile moment resisting frames for seismic resistance.
2. Current confinement requirements of ACI 318-77 for normal weight concrete columns can be extended to lightweight concrete columns with axial loads up to 30% of the column design strength.
3. Supplementary crossties engaging the column steel may be used to confine the column core of lightweight and

normal weight concrete columns. These crossties have a 135° hook at one end and a 90° hook at the other end. These crossties should be alternated end for end along the column steel.

4. Further research is needed to clarify the boundaries between mechanism of column hinging and that of joint distress.

INTRODUCTION

Columns in building frames are normally designed to neither hinge, crush, shear, or otherwise lose their capacity to support the building. However, columns in buildings subjected to an earthquake sometimes hinge, crush, or shear. This experimental study was conducted to develop design information on hinging in columns. Lightweight and normal weight concretes were used in specimens representing a portion of a frame subjected to simulated seismic loading. Tests were performed on 16 full-size frame joint assemblies.

The usual seismic resistant design of ductile frame buildings[(1-3)*] provides a relative condition of a strong column and weak beams at any junction. The intent is to encourage hinging in the beams as the primary location to absorb extreme displacements forced on the frame by seismic forces. Selna, Martin, Park, and Wyllie[(4)] examined design aspects of columns in frames. They expressed concern that a greater multiplier in the relative strength of column and beams is needed to encourage beam hinging. That is, the summation of column moment capacities at a joint must be greater than the summation of beam moment capacities. However, in "gravity load dominated frames," it is possible for hinging to occur in the column.[(5)]

The possibility of column hinging, and the continuing evidence of damage in poorly designed columns during earthquakes have prompted research of column hinging. Testing has been

*Supercript numbers in parentheses denote references at the end of this report.

directed toward understanding the function of lateral ties as (1) confinement for the column core, (2) means of preventing buckling of main steel, and (3) reinforcement for shear.

Sheikh and Uzumeri[6] subjected square columns to axial loading. One of their conclusions was "concrete, when confined with rectangular ties and well distributed longitudinal steel, exhibits a very significant strength gain as well as increased ductility." In addition to confining the concrete, the ties also controlled buckling of the longitudinal bars. Spacings of ties for confinement were sufficient for buckling control.

Tests involving shear reversals in columns were reported by Wight and Sozen.[7] They examined procedures for design of transverse reinforcement. Shear and confinement functions were identified for the transverse reinforcement. When insufficient transverse reinforcement was used, data indicated a progressive decrease in strength and stiffness under repeated reversals of hinging. However, when there was sufficient transverse reinforcement to confine the concrete and also to carry the total shear, the columns maintained strength and stiffness. Axial compressive load in the column specimens reduced the effect of repeated cycles of hinging.

Many other tests[8-22] have also indicated the usefulness of ties for confinement and to delay buckling of longitudinal steel. One important variable that has not been studied concerns anchorage of the main column reinforcement. Studies of beam hinging[23] at a frame joint have identified loss of anchorage of beam reinforcement as an important source of any reduction of stiffness. Similar conditions of high tensile force on one side and compressive force on the other side of the joint on the same column reinforcing bar may disturb anchorage. Correct anchorage and other appropriate end conditions can be represented in a complete frame joint test specimen as used in this test program.

Objectives

The specific objectives of the test program are:

1. To develop design recommendations based on laboratory tests for seismic resistant design of lightweight concrete columns in ductile moment-resisting frame buildings and structural wall-frame buildings.
2. To determine column design details necessary to ensure the ductile behavior required to prevent catastrophic collapse.

Scope

Test specimens represent, at full scale, the intersection of beams and column of a frame. The portion of column above and below the joint approximates half story height. Strength of the column was designed to be less than that of the beams or the joint so that inelastic bending occurred in the column as seismic frame displacements were simulated. Different amounts of longitudinal reinforcement and confinement reinforcement in the form of rectangular hoops and supplementary ties were provided in two different column sizes. Concretes were made with two different lightweight aggregates and also a normal weight aggregate. Axial column load was maintained at several selected levels during each test. Range of variables for the columns were as follows:

Column size - 15x15 in. (381x381 mm) and 15x20 in. (381x508 mm)

Longitudinal reinforcement - 1.47, 1.56, and 1.84%

Confinement reinforcement - 0.75, 1.5, and 3.0%

Axial load - 10, 20, 30, and 60% of column design strength

EXPERIMENTAL PROGRAM

This section gives a brief description of the test specimens and test procedure. A more detailed description is given in Appendix A.

Test Specimens

Sixteen full-scale columns were tested. Each test specimen represented a portion of the building frame at the joint between column and beams. The column portion extended from approximately mid-heights of the stories above and below the joint as shown in Fig. 1.

In most specimens, height of column portion projecting above and below the joint was proportioned so that the column moment immediately above the joint equaled the column moment immediately below the joint. However, in Specimens NC3, LC11, LC12, and LC13, height of the top column portion was increased while the height of the bottom column portion was decreased. The purpose was to force hinging into the top column. Ratio of bottom to top column moments for each specimen as well as test program variables are given in Table 1.

Reinforcement Details and Materials

Reinforcing steel used in each column is listed in Table 1. Reinforcement details are shown in Fig. 2. Columns containing two different size bars had the larger size bars placed in the corners. The reinforcement conformed to ASTM Designation A615 Grade 60.[24]

Column hoop and supplementary crosstie arrangements are illustrated in Fig. 2. "Candystick" supplementary crossties had a 135° hook with a 10-diameter extension at one end and a 90° hook with a six-diameter extension at the other end. Crossties were alternated end for end along the column longitudinal reinforcement. Crossties were fitted tightly around column bars without difficulty. In all specimens, bar size for supplementary crossties was similar to that of the confining hoops. The confining hoops had 135° hooks with a 10 diameter extension.

As the objective of this investigation was to determine required confinement to obtain ductile behavior of the column, the joint was overdesigned and yielding of the beam reinforcing steel was avoided. Clear concrete cover was maintained at 1-1/2 in. (38 mm) in columns and beams.

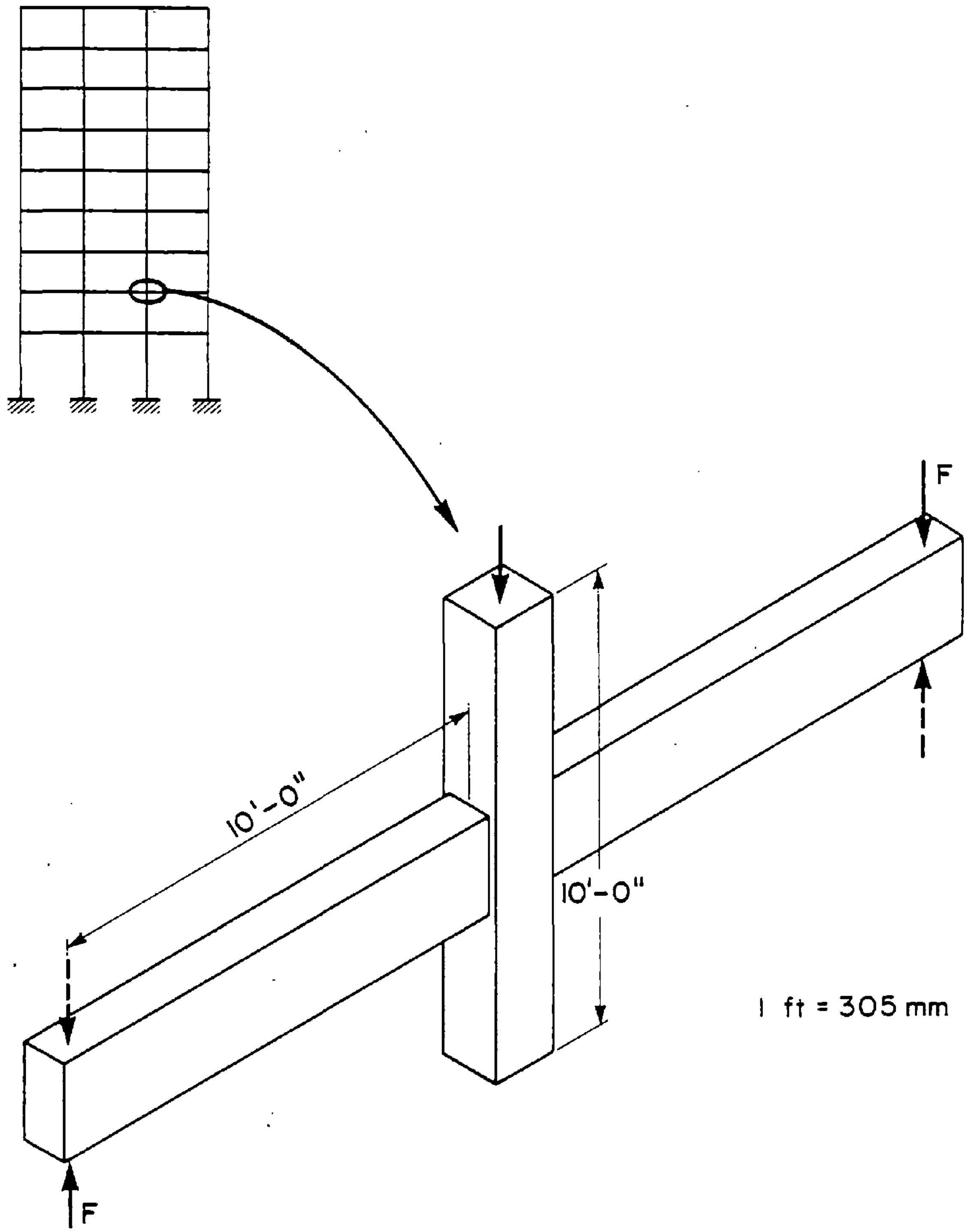


Fig. 1 Test Specimen

TABLE 1 - TEST PROGRAM VARIABLES

Specimen	Concrete Type	Column Size (in.)	Column Steel		Confining Hoops			Initial Axial Column Load, % of ϕ P_o**	Top to Bottom Column Moment Ratio
			Bars*	%	Bar No.	Spacing (in.)	%		
LC1	Lightweight 1	15x15	4 No. 7 & 4 No. 6	1.84	4	2	3.19	10	1.00
LC3	Lightweight 1	15x15	4 No. 7 & 4 No. 6	1.84	3	4-3/4	0.74	10	1.00
LC4	Lightweight 1	15x15	4 No. 7 & 4 No. 6	1.84	4	4	1.60	10	1.00
LC6	Lightweight 1	15x15	4 No. 7 & 4 No. 6	1.84	4	4	1.60	20	1.00
LC12	Lightweight 1	15x15	4 No. 7 & 4 No. 6	1.84	4	4	1.60	30	0.74
LC10	Lightweight 2	15x15	4 No. 7 & 4 No. 6	1.84	3	4-3/4	0.74	10	1.00
LC9	Lightweight 2	15x15	4 No. 7 & 4 No. 6	1.84	4	4	1.60	10	1.00
NC1	Normal Weight	15x15	4 No. 7 & 4 No. 6	1.84	4	4	1.60	10	1.00
NC3	Normal Weight	15x15	4 No. 7 & 4 No. 6	1.84	4	4	1.60	10	0.74
LC7	Lightweight 1	15x15	8 No. 6	1.56	4	4	1.60	10	1.00
LC8	Lightweight 2	15x15	8 No. 6	1.56	4	4	1.60	10	1.00
LC11	Lightweight 2	15x15	8 No. 6	1.56	4	4	1.60	10	0.83
NC2	Normal Weight	15x15	8 No. 6	1.56	4	4	1.60	10	1.00
LC5	Lightweight 1	15x20	10 No. 6	1.47	4	3-1/2	1.57	10	1.05
LC13	Lightweight 1	15x20	10 No. 6	1.47	4	4	1.37	10	0.77
LC2	Lightweight 1	15x15	4 No. 10 & 4 No. 9	4.04	3	2-1/4	1.56	10	1.00

*Where two different column bar sizes are used, the larger bars are placed in the corners.

**P_o = Column Axial Load Design Strength   1 in. = 25.4 mm

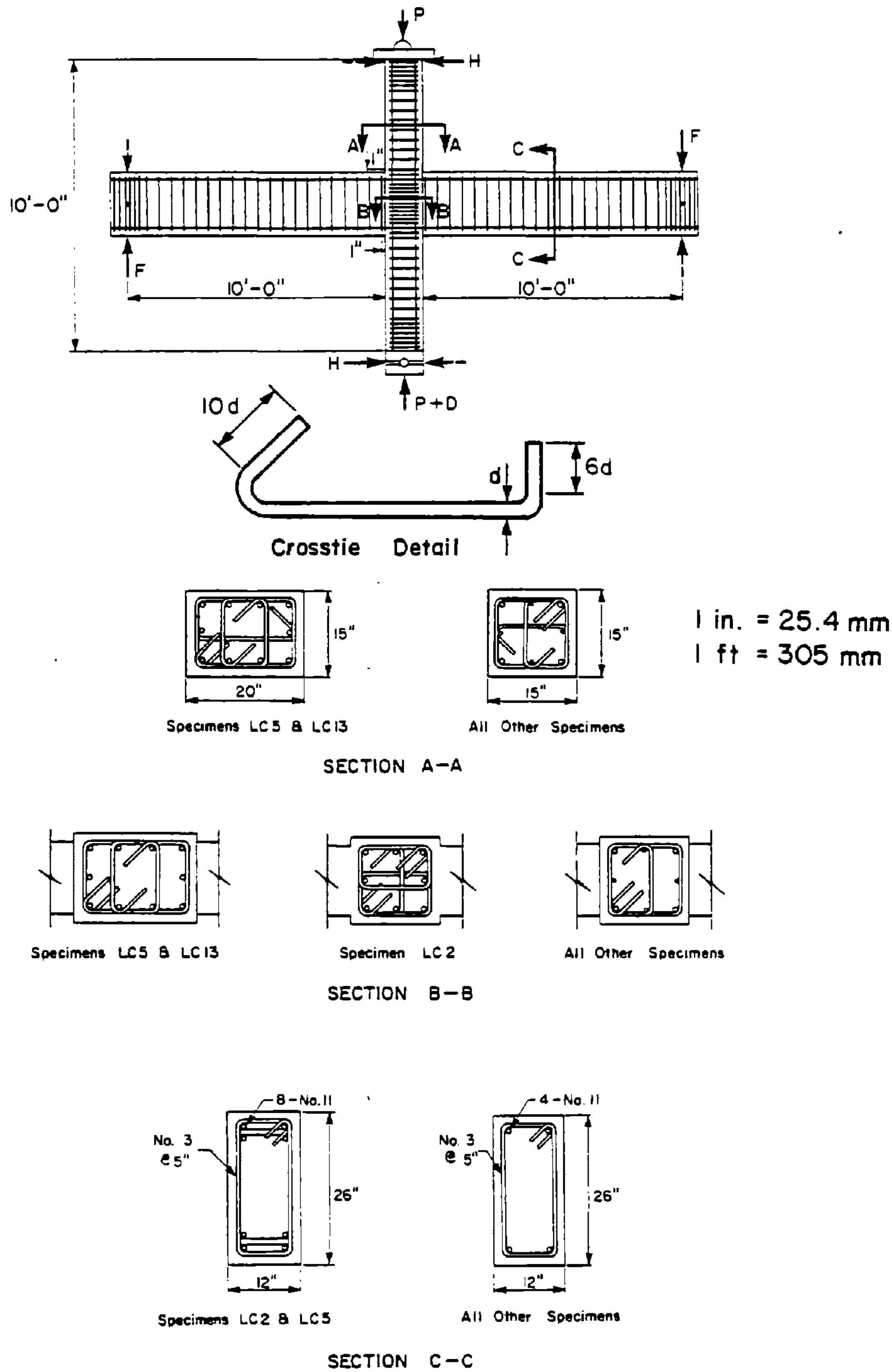


Fig. 2 Reinforcement Details

Three concrete mixes were used to manufacture the columns. Two were lightweight concretes and one was normal weight concrete. Type I portland cement was used in all mixes. Sand and gravel were from Elgin, Illinois. Lightweight Aggregate 1 consisted of an expanded clay produced on the west coast of the United States, while Lightweight Aggregate 2 consisted of an expanded shale produced on the east coast. Fresh unit weights of concrete made from Lightweight Aggregates 1 and 2 were 117 and 122 lb/ft^3 (18.4 and 19.1 kN/m^3), respectively. Both lightweight aggregates have been used extensively for structural applications.

Specimen Manufacture

The column reinforcing cage was assembled first. It was placed vertically in the form. The beam steel was then inserted through the joint and beam stirrups tied in place. Before casting, loading ducts and pipes for attaching external instrumentation were placed in position.

Casting of each specimen was completed within one working day. Each specimen required 13 concrete batches. The first two batches were placed to cast the bottom column early in the morning. The concrete was directed into the lower column through the joint in the space immediately below the bottom flexural reinforcement of the beam. The next nine batches were used to cast the beams and joint. Casting started from the ends of the beams with alternate batches placed in opposite beams. The last batches filled the joint. This occurred approximately two hours after placing concrete in the bottom column. This amount of time was adequate to allow plastic shrinkage to occur in the bottom column. The top column concrete was placed late in the afternoon. Two concrete batches were needed to cast the top column.

The same concrete type and mix proportions were used in the beams and columns of each specimen. One exception was Specimen LC9, where accidentally a leaner concrete mix was placed in the joint and beams. The mix was later duplicated. Concrete compressive strength and splitting tensile strength are reported below under the heading "Material Properties."

Beams and column were covered with a sheet of polyethylene for three days. Control cylinders were cured in a similar manner. Specimens and cylinders were then stripped and moved to the test location. Testing began approximately 14 days after casting.

Test Setup

The overall test setup is shown in Fig. 3. The specimen column was centered in a one-million pound (4.45 MN) capacity testing machine. The lower column end rested on a pin pivot. The upper column end contacted the spherically seated head of the movable platten of the testing machine. At the end of each beam, load was applied by a double-acting ram. Three separate hydraulic systems were used during each test. The first was used to apply the column axial load. The other two systems were one for each of the two double-acting rams applying load to the beams. Equal and opposite loads were applied to each beam.

Instrumentation

Each specimen was instrumented externally and internally. External measurements included column load, beam loads, column drifts, column rotations, and beam deflections. In some specimens, the lateral joint movement and/or the joint shear distortion were also measured. Internal measurements included strains of main column steel and column confining hoops. Details of instrumentation are presented in Appendix A.

Loads

Column axial load was controlled manually. It was maintained constant on the testing machine dial. Beam loads were determined by averaging the load in two tension-compression load cells.

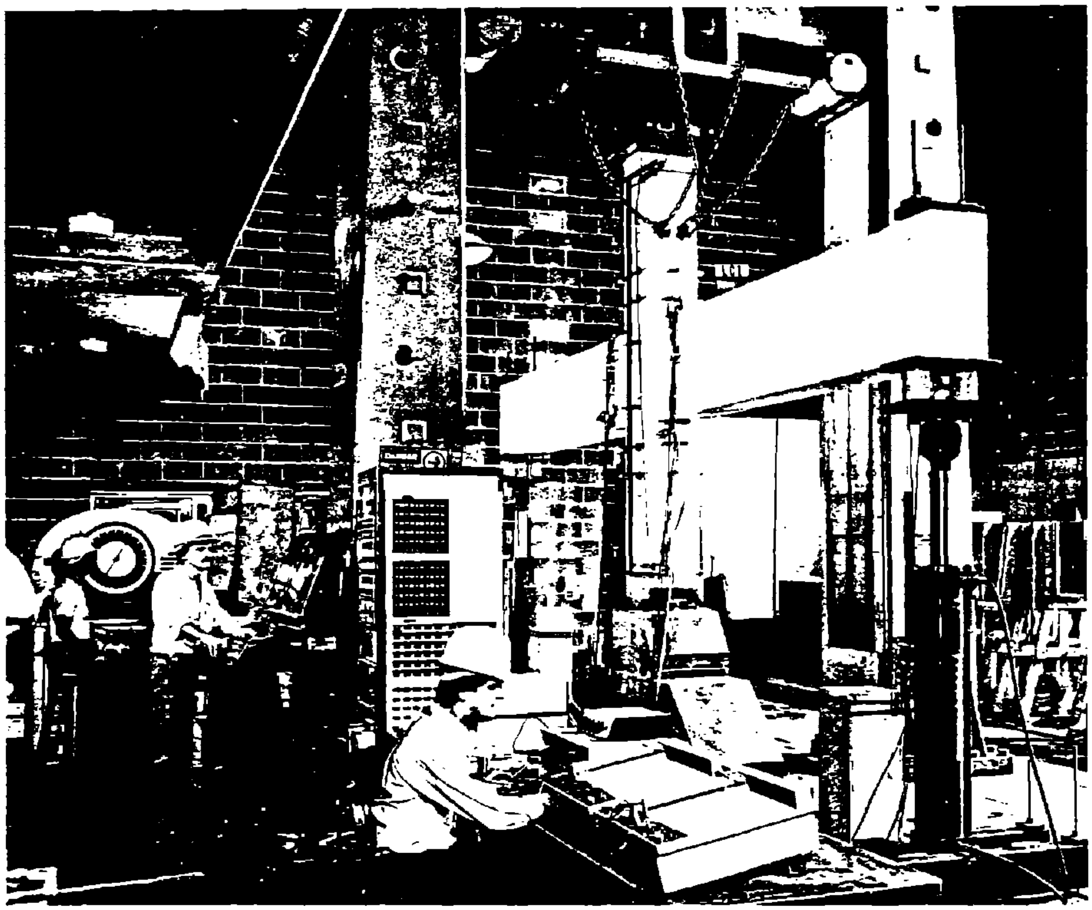


Fig. 3 Test Setup

Column drift

Top and bottom column "drifts" were measured using a vertical rigid arm connected to the joint as illustrated in Fig. 4. When the beam ends were loaded, the joint rotated. Therefore, the vertical arm also rotated. Lateral movements of the top and bottom ends of this arm relative to the columns were used as an indication of the column drift.

Distance between the joint center and top and bottom drift sensors were 58.5 and 43.5 in. (1.49 and 1.10 m), respectively, for Specimens NC3, LC12 and LC3, and 55.5 and 46.5 in. (1.41 and 1.18 m), respectively, for Specimen LC11. For all other specimens, these distances were 51 in. (1.30 m) for both top and bottom drift sensors.

Column rotation

Column rotations were measured above and below the joint over distances of 10 and 20 in. (25 and 51 mm) for Specimens LC5 and LC13, and over distances of 7-1/2 and 15 in. (190 and 381 mm) for all other specimens. Linear potentiometers mounted between frame works on the column were connected to the beam to sense column rotation.

Beam deflection

Vertical deflection of each beam was measured at a distance of 9 ft 8 in. (2.95 m) away from the column face.

Horizontal joint movement

The lateral movement of the joint was measured in Specimens LC12, LC13, and NC3. A potentiometer was secured to the top of a rigid arm clamped to the pedestal supporting the column. The end of the potentiometer's plunger was connected to a threaded rod projecting out of the joint as shown in Fig. 4.

Joint shear distortion

Shear distortion of the joint was measured in Specimens LC13 and NC3. Two potentiometers were mounted diagonally across the

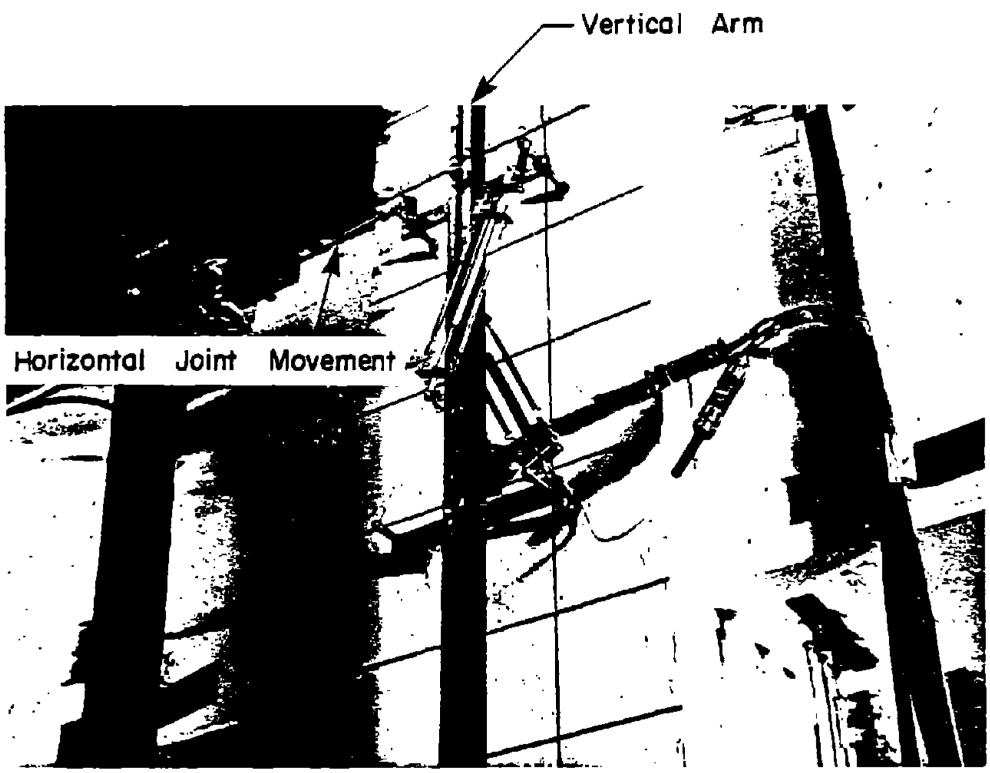


Fig. 4 Joint Instrumentation

joint as shown in Fig. 4. The change in the length of diagonals was used to calculate the joint shear distortion.

Reinforcement strains

Internal instrumentation included measurement of strains on the column steel and confining hoops. Details are given in Appendix A.

Data Acquisition

Loads, deformations, and steel strains were recorded at selected points along the load cycles by a digital data acquisition system. This system printed the data and simultaneously stored it in a desk computer. The on-line computer provided a tabulation of data within seconds of recording the readings.

Continuous plots of loads versus drift were recorded on X-Y plotters. The applied beam loads were expressed as column moments computed at a section immediately above or below the joint.

Test Procedure

After placing the specimen in the test setup and attaching all instrumentation, an axial load was applied to the column. This axial load was maintained constant while the beams were loaded. When one beam end was pulled down, the other beam end was pushed up. Then the beams were unloaded and the loading sequence reversed. This resulted in reversal of the moments in the beams and consequently in the columns. Several cycles of load reversals were applied to the beams. Therefore, column stubs above and below the joint were subjected to a constant axial load and to moment reversals. Specimens that survived the scheduled cycles of moment reversals were then subjected to a higher axial load followed by additional cycles of moment reversals.

Column axial load

The load applied to each column represented a fraction of the column axial load design strength as shown in Table 2. The column design strength, P_o, was defined by the following equation:

$$P_o = \phi\,(0.85\, f'_c\, (A_g - A_{st}) + A_{st} f_y) \qquad (1)$$

where ϕ = capacity reduction factor (0.7)

A_g = gross area of section, sq in.

A_{st} = area of reinforcement, sq in.

f'_c = specified compressive strength of concrete, psi

f_y = specified yield strength of reinforcement, psi

Beam loads

After applying the constant axial load to the column, the beams were loaded to produce cycles of moment reversals in the column. On the first cycle, the beams were loaded to attain calculated column yield moment. Subsequent beam loading cycles were controlled by column deformation as discussed below.

Column yield moment, in the presence of an axial force, was computed based on Navier's hypothesis of "plane section before bending remains plane after bending." A computer program was used to determine the yield moment and nominal flexural strength of each column. Calculations were made using equilibrium of forces and strain compatibility. Concrete compressive strength was assumed to be 5000 psi (35 MPa). Concrete tensile strength was ignored. Reinforcing steel yield stress was assumed to be 60 ksi (419 MPa).

Beam loads at positive and negative peaks of the first loading cycle were applied to obtain calculated yield moment in the column. The largest value of either top or bottom column drift measured at the first positive peak was defined as "yield drift." This yield drift was used as a deformation control for all subsequent cycles. Multiples of the yield drift were imposed on the column to produce the drift ductilities as shown in the loading schedule of Fig. 5. Drift ductility was defined

TABLE 2 - LOADING SCHEDULE

Specimen	Axial Column Load, % of ϕP_o	Number of Cycles @ Ductility
LC1	10	Basic Loading Cycles*
	20	2 @ 2, 2 @ 4, 3 @ 8
	30	2 @ 4, 3 @ 8
	60	2 @ 4, 1 @ 7.5
LC3	10	Basic Loading Cycles
	20	2 @ 4, 2 @ 8
	30	2 @ 8
LC4	10	Basic Loading Cycles
	20	2 @ 4, 2 @ 8
	30	2 @ 4, 2 @ 8
	60	2 @ 4, 0.5 @ 6.3
LC6	20	Basic Loading Cycles
	30	2 @ 4, 2 @ 8
	60	2 @ 8
LC12	30	Basic Loading Cycles
LC10	10	Basic Loading Cycles
	20	2 @ 4, 2 @ 8
LC9	10	Basic Loading Cycles
	20	2 @ 4, 2 @ 8
NC1	10	Basic Loading Cycles
	20	2 @ 4, 2 @ 8
	30	2 @ 4, 2 @ 8
	60	2 @ 4, 1 @ 5.5
NC3	10	Basic Loading Cycles
	20	2 @ 4, 2 @ 8
	30	2 @ 4, 2 @ 8
	60	2 @ 4, 1 @ 8
LC7	10	Basic Loading Cycles
	20	2 @ 4, 2 @ 8
	30	2 @ 4, 2 @ 8
	60	2 @ 4, 1 @ 6
LC8	10	Basic Loading Cycles
	20	2 @ 4, 2 @ 8
	30	2 @ 4, 2 @ 8
	60	2 @ 4, 1 @ 8
LC11	10	Basic Loading Cycles
	20	2 @ 4, 2 @ 8
	30	2 @ 4, 2 @ 8
	60	2 @ 4, 1 @ 8
NC2	10	Basic Loading Cycles
	20	2 @ 4, 2 @ 8
	30	2 @ 4, 2 @ 8
	60	2 @ 4, 1 @ 6
LC5	10	Basic Loading Cycles
	30	1 @ 8
LC13	10	Basic Loading Cycles
	20	2 @ 4, 2 @ 8
	30	2 @ 8
LC2	10	2 @ 1, 6 @ 2, 4 @ 4, 0.5 @ 6

*Basic Loading Cycles: 2 @ 1, 6 @ 2, 4 @ 4, 3 @ 8

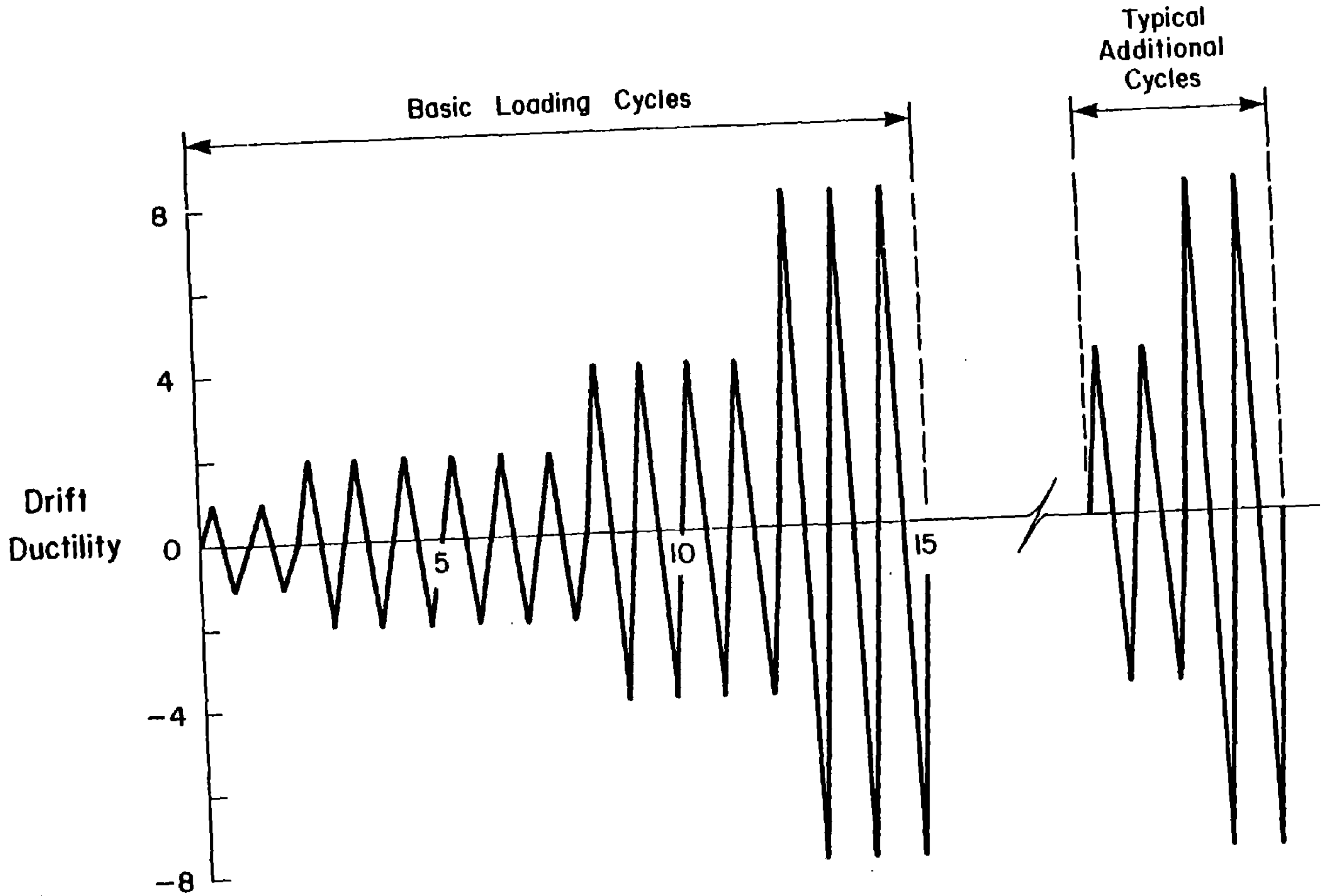


Fig. 5 Loading Schedule

as the ratio of the largest value of either top or bottom column drift in any cycle to yield drift.

While the column axial load was maintained constant, the fifteen basic loading cycles were applied as follows: two cycles at ductility 1, six cycles at ductility 2, four cycles at ductility 4, and three cycles at ductility 8. This loading schedule pattern was suggested by Wight and Sozen.(25) This pattern of ever increasing deformation in each group of cycles is not intended to represent any specific major earthquake. For specimens that survived the basic loading cycles, the column axial load was increased, and additional cycles of load reversals were applied as summarized in Table 2.

SUMMARY OF TEST RESULTS

This section contains a summary of properties of materials used in each specimen. Response of specimens is discussed in terms of behavior modes and load-deformation characteristics. Flexural strength history of columns is summarized.

Material Properties

Yield stress and strength of reinforcing steel used in each specimen were determined from coupons. These properties are listed in Table 3. Compressive and splitting tensile strengths of the concrete were determined from 6x12-in. (152x305-mm) cylinders. Control cylinders were taken from concrete placed immediately below and above the joint. The average strengths determined from these cylinders are also listed in Table 3.

Behavior of Specimens

Behavior of specimens is discussed based on four observed modes. These behavior modes are depicted in Fig. 6 where photographs of specimens are shown at the end of the basic loading cycles. Photographs of the same specimens at the end of test are shown in Fig. 7.

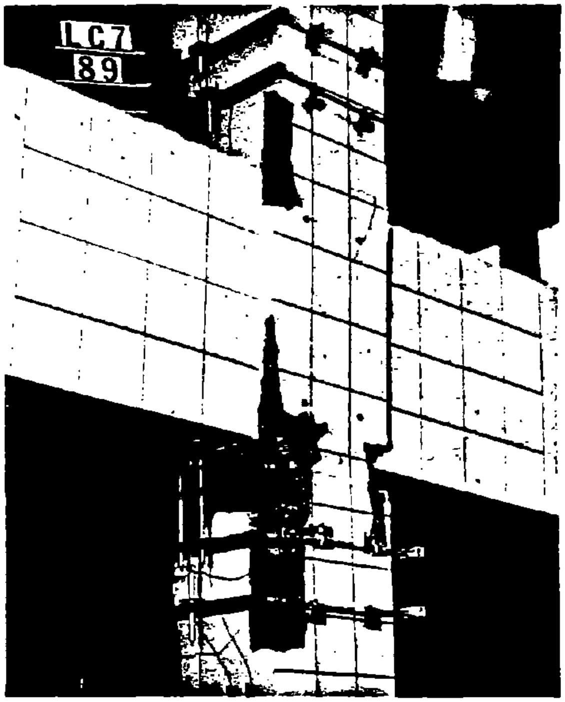
In behavior Mode A, one plastic hinge occurred in either the top or bottom column, immediately above or below the joint.

TABLE 3 - MATERIAL PROPERTIES

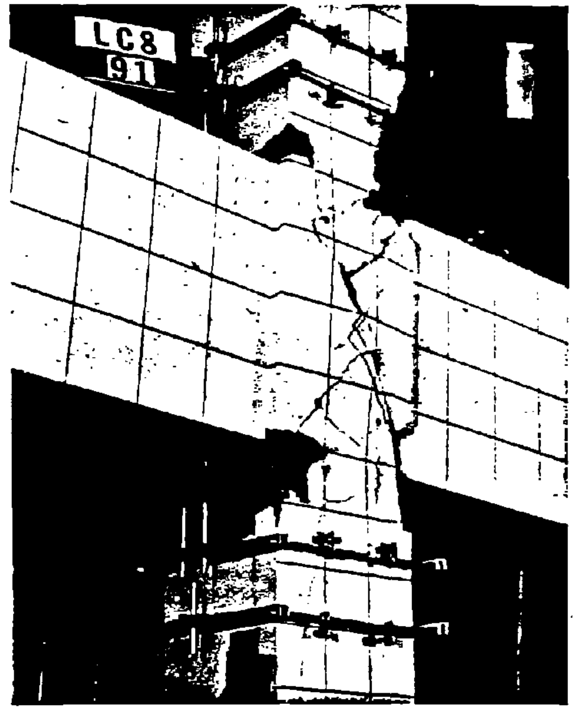
Specimen	No. 3 Bar (ksi)		No. 4 Bar (ksi)		No. 6 Bar (ksi)		No. 7 Bar (ksi)		No. 9 Bar (ksi)		No. 10 Bar (ksi)		Concrete (psi)	
	f_y	f_{su}	f_y	f_{su}	f_y	f_{su}	f_y	f_{su}	f_y	f_{su}	f_y	f_{su}	f'_c	f_{ct}
LC1	-	-	63.9	104.4	61.9	106.0	64.9	110.9	-	-	-	-	5050	430
LC3	69.9	105.0	-	-	63.4	106.4	67.3	110.6	-	-	-	-	5470	460
LC4	-	-	63.9	104.4	63.9	105.7	64.8	111.3	-	-	-	-	5980	410
LC6	-	-	61.0	106.8	63.6	105.7	64.6	109.2	-	-	-	-	6210	410
LC12	-	-	67.8	109.0	64.3	107.3	64.4	107.9	-	-	-	-	5000	410
LC10	71.0	107.3	-	-	64.2	105.8	64.8	109.1	-	-	-	-	5120	470
LC9	-	-	67.8	109.0	66.1	107.1	66.4	112.5	-	-	-	-	4860	490
NC1	-	-	63.9	104.4	64.7	106.8	66.5	112.3	-	-	-	-	5340	510
NC3	-	-	67.8	109.0	64.5	106.4	64.4	108.8	-	-	-	-	4710	500
LC7	-	-	67.8	109.0	63.8	106.2	-	-	-	-	-	-	5300	370
LC8	-	-	67.8	109.0	67.0	108.2	-	-	-	-	-	-	5210	500
LC11	-	-	67.8	109.0	65.4	108.2	-	-	-	-	-	-	5060	470
NC2	-	-	67.8	109.0	63.4	105.4	-	-	-	-	-	-	5160	540
LC5	-	-	63.9	104.4	63.2	104.9	-	-	-	-	-	-	5820	380
LC13	-	-	67.8	109.0	64.2	106.4	-	-	-	-	-	-	4740	420
LC2	69.9	105.0	-	-	-	-	-	-	64.8	104.8	67.4	105.5	6150	430

f_y = Yield Stress f_{su} = Ultimate Strength 1000 psi = 1 ksi = 6.895 MPa

f'_c = Concrete Compressive Strength f_{ct} = Splitting Tensile Strength

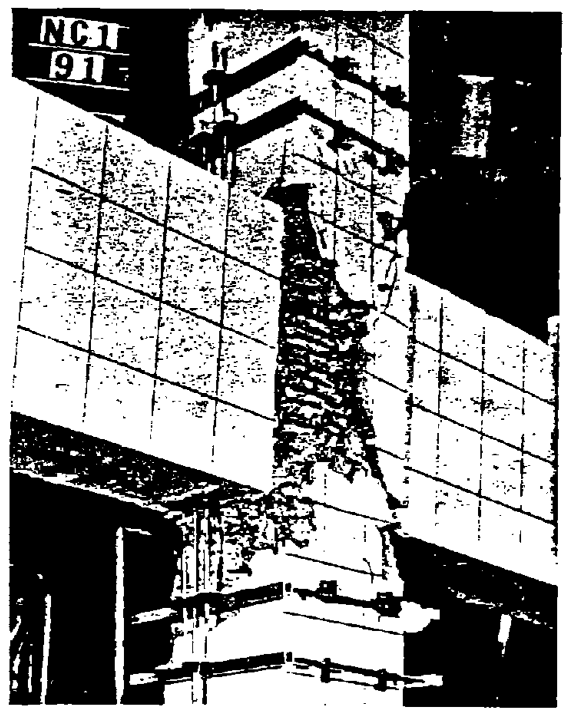


(a) One Column (Bottom) Hinging



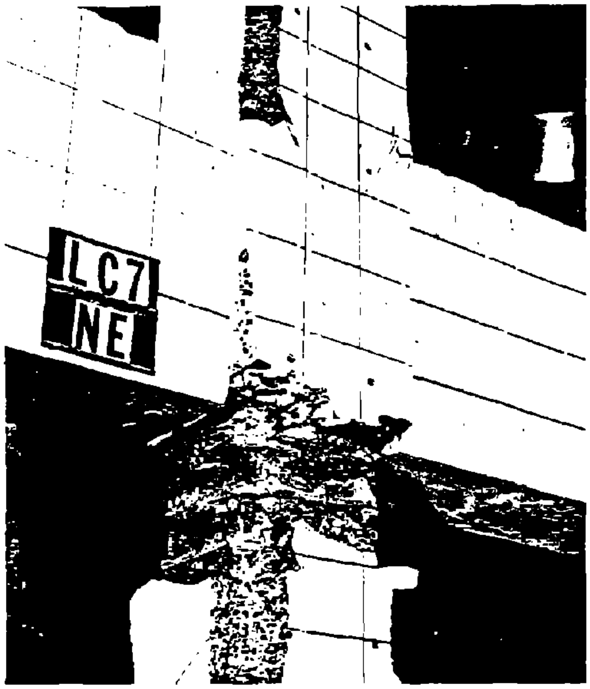
(b) Top and Bottom Columns Hinging

(c) Joint Damaged

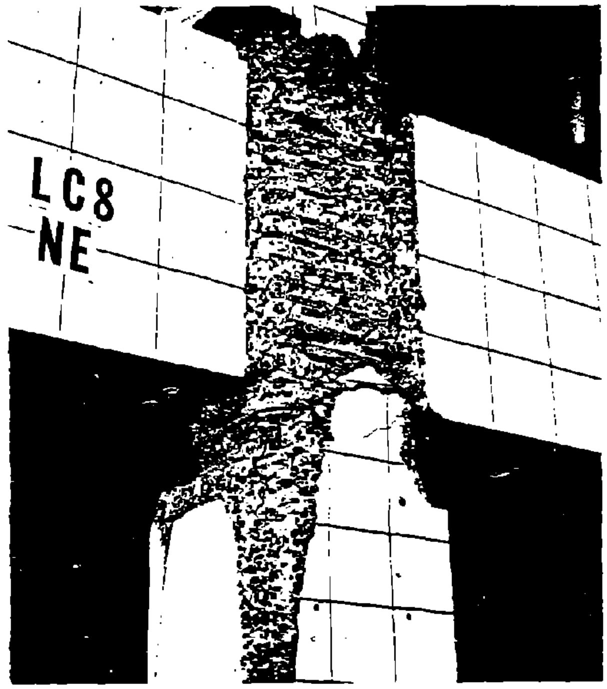


(d) Hinge Penetrating Joint

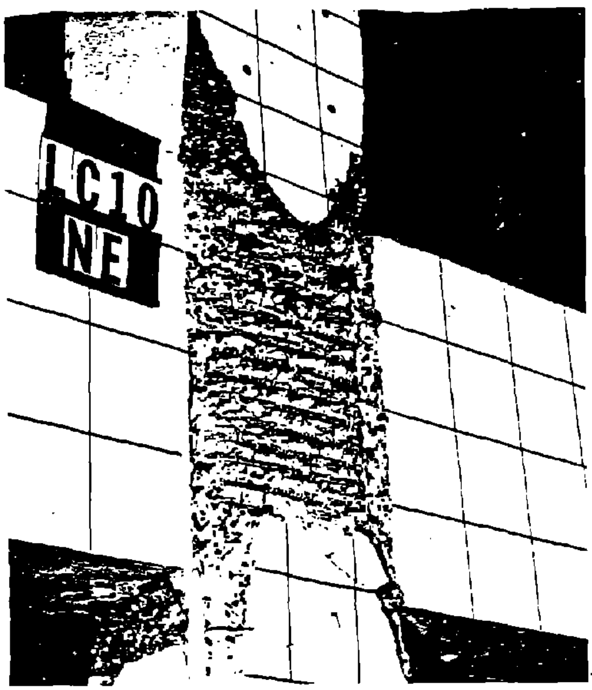
Fig. 6 Conditions of Specimens after Basic Loading Cycles



(a) Mode A - One Column Hinging



(b) Mode B - Both Columns Hinging



(c) Mode C - Joint Damaged

(d) Mode D - Hinge Penetratin Joint

Fig. 7 Behavior Modes

This is depicted in Fig. 8.a where hysteresis loops for column moment versus drift are plotted for both top and bottom columns of Specimen LC1. The loops shown are for the basic loading cycles. It is obvious that hinging occurred in the top column where the loops are largest. In fact as cycles at higher yield ductility were applied, the top column hysteresis loops became larger while the bottom column loops become smaller. In such cases, most of the energy was dissipated by the hinge. Figures 6.a and 7.a indicate a bottom column hinge. This behavior mode was observed in Specimens LC1, LC4, LC7, LC11, LC12, NC2 and NC3.

In behavior Mode B, plastic hinges occurred simultaneously in the top and bottom columns, as shown in Figs. 6.b and 7.b. Hysteresis loops of Fig. 8.b attest that about equal energy was dissipated by top and bottom columns. For Specimen LC8, shown in Fig. 8.b, bottom column drift was slightly larger. As a result, size of the bottom column loops at Ductility 8 was slightly larger than that of the top column. Specimens LC3 and LC8 behaved in a similar manner.

Specimens where all the damage occurred in the joint are classified under behavior Mode C. In these specimens, very little cracking and spalling of the concrete shell was observed in the columns, as shown in Figs. 6.c and 7.c. All the damage was concentrated in the joint. The hysteresis loops of Fig. 8.c indicate similar drift in top and bottom columns. Pinching of the loop characterized by smaller area within the loops was observed in these specimens. Specimens grouped under behavior Mode C include LC2, LC5, LC9, LC10 and LC13.

Behavior Mode D includes specimens where a partial column hinge penetrated the joint as shown in Figs. 6.d and 7.d. In these specimens, large cracks formed in the joint starting at the beam-column intersections and extending diagonally for a few inches towards the center of the joint. The hysteresis loops of behavior Mode D resemble those of Mode C shown in Fig. 8.d. Included under behavior Mode D are Specimens LC6 and NC1.

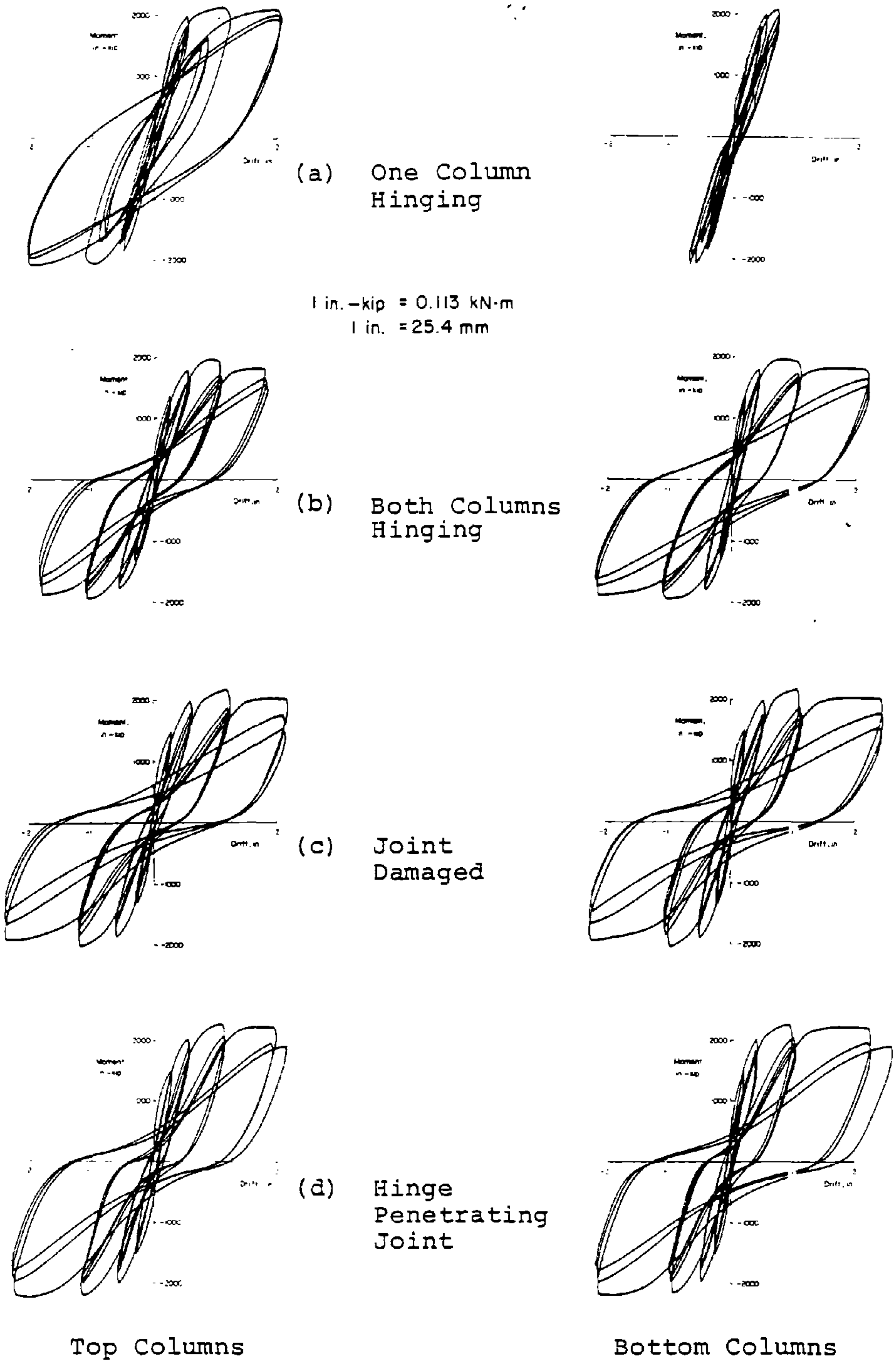


Fig. 8 Hysteresis Loops of Basic Loading Cycles for Different Behavior Modes

Column Flexural Strength History

In this section, flexural strength maintained by the columns is examined. Maintained flexural strength is defined in this report as the ratio of the smallest peak moment to first peak moment for consecutive cycles of equal drift ductility under a constant column axial load. Flexural strengths maintained by the test specimens are summarized in Table 4. The table also shows the behavior mode classification of each specimen.

There is no generally accepted limit for tolerable strength reduction in seismic resistance. It would not be unreasonable to state that a structural element maintaining 80% or more of flexural strength under consecutive repeated cycles of equal ductility is adequate for seismic designs. Table 4 indicates that most specimens maintained better than 80% strength during the basic loading cycles. All specimens suffering damage in the joint, behavior Mode C, maintained less than 80% of their strength at Ductility 4. For Specimen LC10, this occurred at Ductility 2. Specimen LC12 had early strength loss due to the sudden spalling of the concrete shell under high axial load. In Specimen LC3, up to Cycle 11 at Ductility 4, the top column drift controlled loading. On the first negative cycle at scheduled Ductility 8, the bottom drift increased rapidly and accidentally a ductility of 13 was imposed on the specimen. This probably caused the maintained strength to drop to 0.76 in subsequent cycles.

Maximum column strength measured during the basic loading cycles is compared to the calculated nominal flexural strength of each specimen in Table 5. The calculated strength was computed based on the design concrete compressive strength of 5000 psi (34.5 MPa) and steel with yield stress of 60 ksi (414 MPa) and including strain hardening. Although the behavior mode varied among specimens, the measured flexural strength exceeded the calculated nominal flexural strength.

TABLE 4 - MAINTAINED FLEXURAL STRENGTH

Specimen	Column Load %	Ductility				Column Load %	Ductility		Column Load %	Ductility		Behavior Mode
		1	2	4	8		4	8		4	8	
LC1	10	0.87	0.83	0.83	0.93	20	0.98	0.94	30	1.00	0.95	A
LC3	10	0.97	0.86	0.87	0.76	20	0.81	0.79	-	-	-	B
LC4	10	0.92	0.80	0.90	0.87	20	0.95	0.93	30	0.91	0.93	A
LC6	20	0.94	0.84	0.88	0.84	30	0.99	0.87	-	-	-	D
LC12	30	0.94	0.71	0.87	0.67	-	-	-	-	-	-	A
LC10	10	0.87	0.74	0.75	0.69	20	0.58	0.82	-	-	-	C
LC9	10	0.85	0.81	0.77	0.75	20	0.73	0.90	-	-	-	C
NC1	10	0.97	0.81	0.84	0.81	20	0.80	0.90	30	0.74	0.87	D
NC3	10	0.92	0.86	0.87	0.90	20	1.00	0.98	30	0.96	0.95	A
LC7	10	0.95	0.92	0.92	0.88	20	0.96	0.94	30	0.94	0.92	A
LC8	10	0.91	0.86	0.85	0.86	20	1.00	0.96	30	0.83	0.94	B
LC11	10	0.93	0.86	0.86	0.90	20	0.98	0.97	30	1.00	0.96	A
NC2	10	0.92	0.82	0.90	0.90	20	1.00	0.93	30	1.00	0.96	A
LC5	10	1.00	0.82	0.78	0.67	-	-	-	-	-	-	C
LC13	10	0.93	0.83	0.79	0.72	20	0.80	0.90	-	-	-	C

TABLE 5 - MEASURED VERSUS CALCULATED COLUMN FLEXURAL STRENGTH

Specimen	Flexural Strength, in.-kip		Measured / Calculated
	Measured	Calculated	
LC1	2144	2040	1.05
LC3	2325	2040	1.14
LC4	2216	2040	1.09
LC6	2477	2290	1.08
LC12	2900	2650	1.09
LC10	2252	2040	1.10
LC9	2098	2040	1.03
NC1	2329	1950	1.19
NC3	2386	1950	1.22
LC7	1954	1765	1.11
LC8	2034	1765	1.15
LC11	2091	1765	1.18
NC2	2077	1690	1.23
LC5	3200	3160	1.01
LC13	3906	3254	1.20

1 in.-kip = 0.113 kN·m

DISCUSSION OF TEST RESULTS

In this section, effect of confining hoops, column axial load, and type of concrete on the hysteretic behavior of the columns is discussed. Shear resisted by the joints is summarized.

Effect of Column Confinement

The amount of confinement used in the tested columns varied between 0.74 and 3.19%. This percentage represents the ratio of volume of hoop reinforcement to total volume of column core. Specimens containing different amounts of confinement but similar in all other respects included Specimens LC3, LC4, and LC1. Confinement in these specimens was 0.74, 1.60, and 3.19%, respectively. Amount of confinement required by ACI 318-77 (1) is 2.02% for normal weight concrete.

Moment versus drift loops for Specimens LC3, LC4 and LC1 are plotted in Fig. 9 for column axial loads of 10%, 20% and 30% of the column axial load design strength. During the basic loading cycles, a large amount of energy was dissipated as depicted by the large size of the hysteretic loops. As mentioned earlier, in the early part of Specimen LC3 test, the top column drift controlled loading. On the first negative cycle at Ductility 8, the bottom drift increased rapidly and accidentally a ductility of 13 was imposed on the specimen. This may have prompted the strength degradation during the last two negative cycles of Specimen LC3.

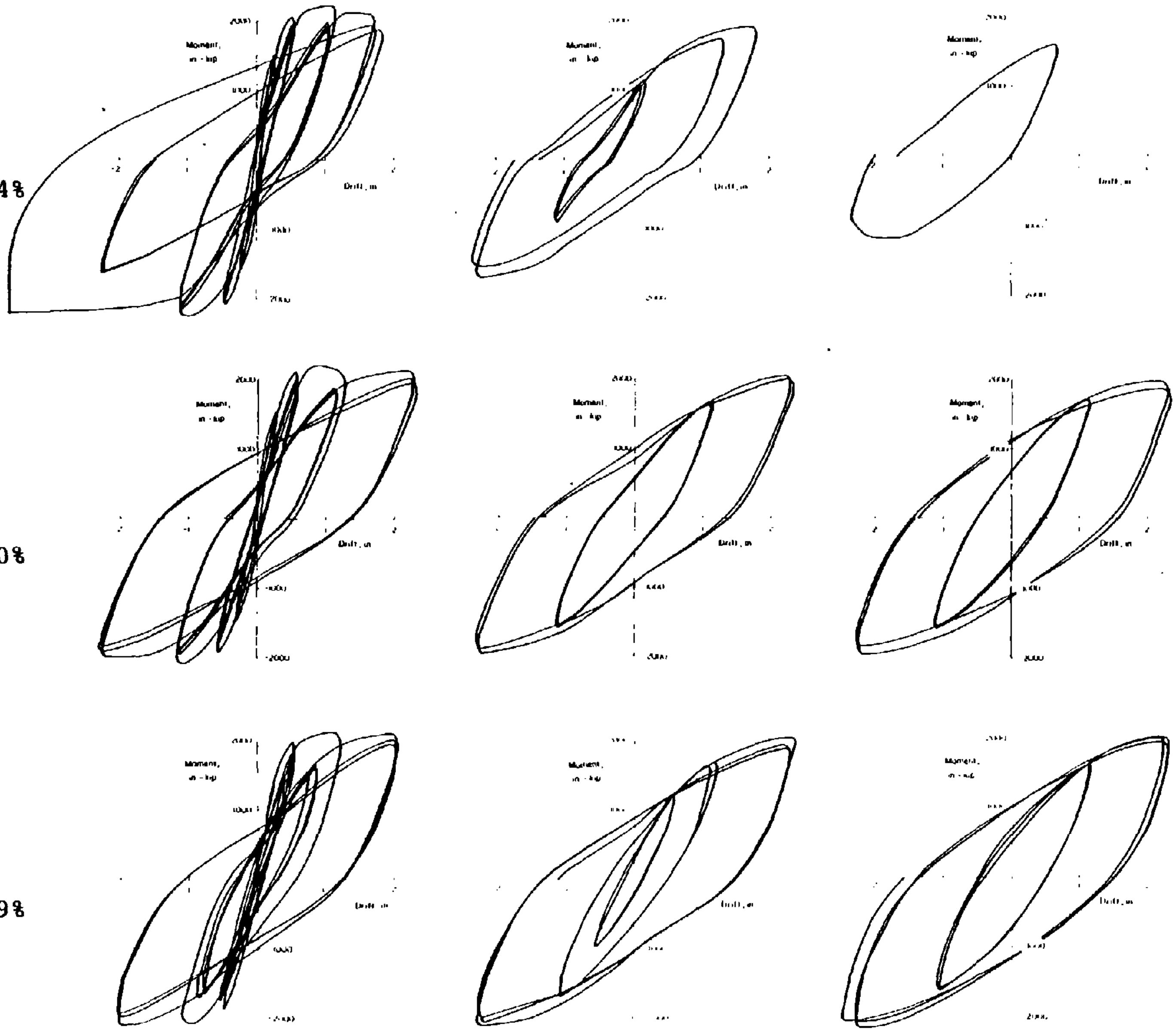
Hysteretic loops at 20% column axial load, in Fig. 9, indicate adequate energy absorption and adequacy of the confining hoops for the three specimens. At 30% column axial load, the amount of energy absorbed by Specimen LC3 decreased. However, it should be emphasized that the specimen had already been subjected to 19 cycles of load reversals. This simulates the effect of several severe earthquakes. Also, in all these specimens the column hinged during the basic loading cycles under 10% axial load. A different behavior would be expected had the

(a) Specimen LC3 - Confinement = 0.74%

1 in-kip = 0.113 kN·m
1 in. = 25.4 mm

(b) Specimen LC4 - Confinement = 1.60%

(c) Specimen LC1 - Confinement = 3.19%



Axial Load = 10% 20% 30%

Fig. 9 Effect of Amount of Hoop Confinement columns been subjected initially to higher axial load. This is discussed in the next section.

Specimens LC9 and LC10 had same column steel as Specimens LC3, LC4 and LC1. However, Specimens LC9 and LC10 were manufactured with Lightweight Concrete 2. Column confinement was 0.74% for Specimen LC10 and 1.6% for Specimen LC9. A comparison of the behavior of these two specimens as far as effect of column confining hoops is not possible as they both were damaged in the joint (behavior Mode C).

The minimum amount of confinement used in these tests was sufficient to provide substantial ductile behavior.

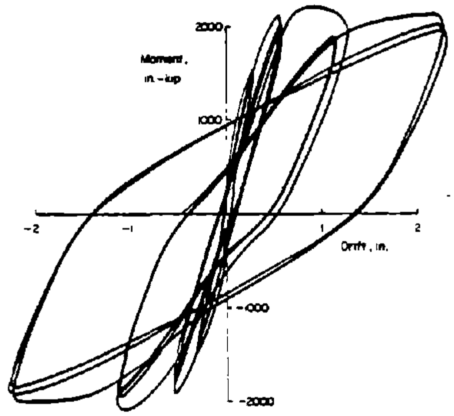
Effect of Column Axial Load

Specimens LC4, LC6, and LC12 had similar column steel and confinement, and were manufactured with Lightweight Concrete 1. The columns were initially loaded to 10, 20, and 30% of the column axial load design strength, respectively. In addition, the top column of Specimen LC12 was 7.5 in. (191 mm) taller and the bottom column was 7.5 in. (191 mm) shorter than those of the other two specimens.

Hysteretic loops for basic loading cycles of Specimens LC4, LC6, and LC12 are shown in Fig. 10. As would be expected, the flexural capacity of the column increased with increased column load. However, strength degradation was also higher as the column load increased. As the top column of Specimen LC12 was taller than that of Specimens LC4 and LC6, the top drift arm was also longer. This explains the larger measured top drift for Specimen LC12 in Fig. 10.c.

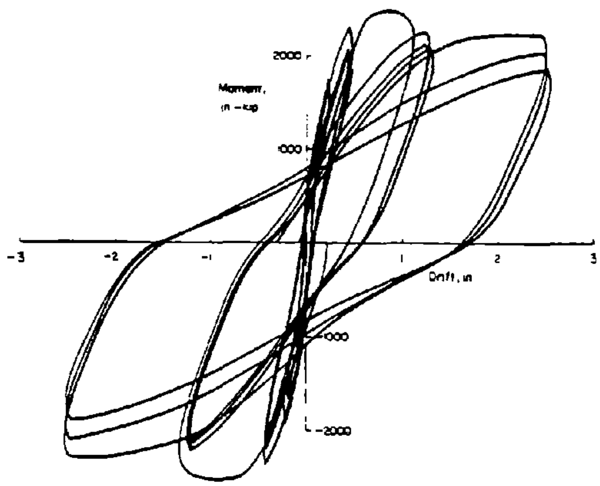
Effect of Column Size

Columns tested in this investigation were either 15x15 in. (381x381 mm) or 15x20 in. (381x508 mm) in size. The two 15x20-in. (381x508-mm) columns did not hinge but suffered damage in the joint. Therefore, it is not possible to draw conclusions regarding the effect of column size.

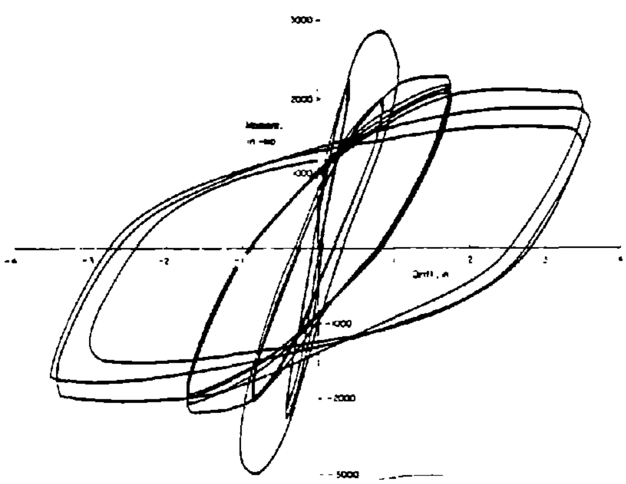


(a) Specimen LC4 -
Column Load = 10%

1 in.-kip = 0.113 kN·m
1 in. = 25.4 mm



(b) Specimen LC6 -
Column Load = 20%



(c) Specimen LC12 -
Column Load = 30%

Fig. 10 Effect of Magnitude of Column Axial Load

Effect of Concrete Type

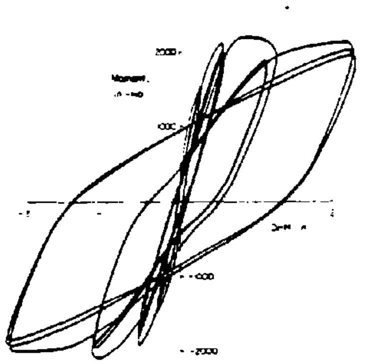
Three types of concretes were used to manufacture the specimens: Lightweight Concrete 1, Lightweight Concrete 2, and normal weight concrete. Comparisons are made between the behavior of columns manufactured with the three concretes based on the moment versus drift plots of Figs. 11 and 12. The plots shown in Fig. 11 are for columns containing 1.84% vertical reinforcement, while those of Fig. 12 are for 1.56% column steel. All the specimens plotted in these two figures had 1.6% confining hoops, except Specimen LC10 of Fig. 11.b which had 0.74% confinement.

Hysteresis loops of Fig. 11.a depict excellent energy absorption in the column of Specimen LC4 manufactured with Lightweight Concrete 1. On the other hand, hysteresis loops of Specimens LC10 and NC1, manufactured with Lightweight Concrete 2 and normal weight, respectively, denote some pinching. Specimen NC1 was duplicated. However, the top and bottom column heights were altered to force hinging in the top column. Hysteresis loops of this repeat specimen, Specimen NC3, are shown in Fig. 11.d. This plot denotes large loops that depict excellent energy absorption.

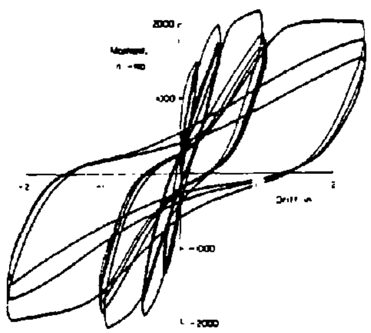
Moment versus drift plots for four specimens are shown in Fig. 12. Two lightweight concretes and one normal weight concrete are represented. In Specimen LC8, top and bottom columns hinged. Specimen LC11 was a repeat of Specimen LC8, except that hinging was forced in the top column by changing columns height. Figs. 12.a and 12.c for columns manufactured with two lightweight concretes denote as good energy absorption as the normal weight column of Fig. 12.d. The above comparisons indicate that lightweight concrete and normal weight concrete columns have comparable seismic behavior.

Joint Shear

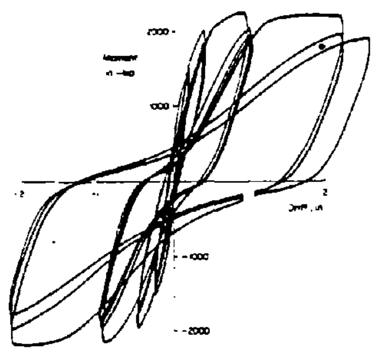
This investigation was conducted to determine seismic behavior of columns. However, as discussed earlier, columns did not hinge in all cases. Four behavior modes were observed. Modes C



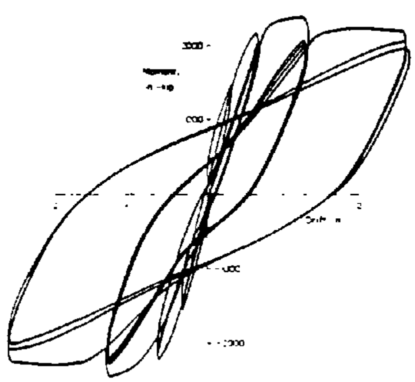
(a) Specimen LC4 - Lightweight Concrete 1



(b) Specimen LC10 - Lightweight Concrete 2

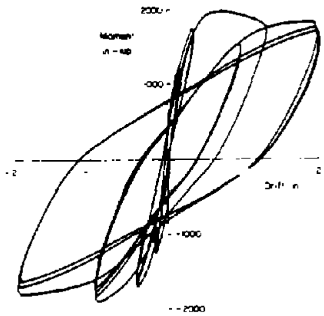


(c) Specimen NC1 - Normal Weight Concrete $M_{top} = M_{bottom}$



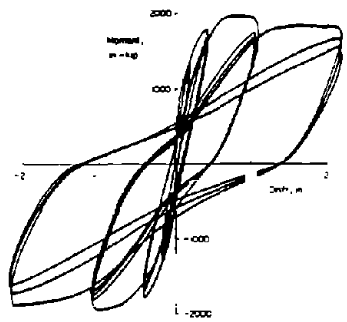
(d) Specimen NC3 - Normal Weight Concrete $M_{bottom}/M_{top} = 0.74$

Fig. 11 Effect of Concrete Type - Column Steel = 1.84%

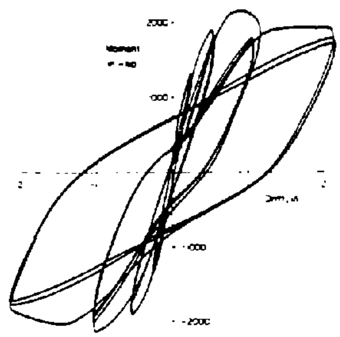


(a) Specimen LC7 - Lightweight Concrete 1

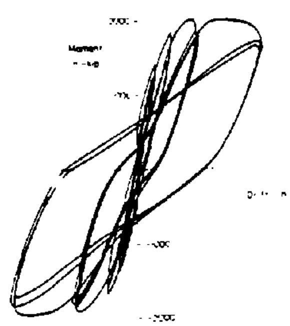
1 in.-kip = 0.113 kN·m
1 in. = 25.4mm



(b) Specimen LC8 - Lightweight Concrete 2 $M_{bottom} = M_{top}$



(c) Specimen LC11 - Lightweight Concrete 2 $M_{bottom}/M_{top} = 0.83$



(d) Specimen NC2 - Normal Weight Concrete $M_{top} = M_{bottom}$

Fig. 12 Effect of Concrete Type - Column Steel = 1.56%

and D concerned joint damage. For this reason, it is of interest to consider magnitude of joint shear. Table 6 summarizes the maximum horizontal shear force, V_j, computed in the joint during the basic loading cycles.

Also shown in Table 6 are the normalized shear stresses. In the third column, they are normalized with respect to the gross column area. In the last column of the table, the shear stress is normalized with respect to width of the column, b, and distance from the extreme compressive fibers to the tensile steel, d. The following discussion makes reference to values listed in the last column.

Range of normalized shear stress for the different behavior modes was (1) Mode A: 13.7 to 18.1, (2) Mode B: 14.3 and 15.6, (3) Mode C: 16.0 to 18.2, and (4) Mode D: 16.0 and 16.3. These values do not show any particular trend, although it seems that as long as the nominal shear is less than 15.0 $\sqrt{f'_c}$ psi (1.25 $\sqrt{f'_c}$ MPa), damage of the joint can be avoided.

CONCLUDING REMARKS

Sixteen full-size joint assemblies were tested to determine the seismic behavior of lightweight and normal weight concrete columns. A brief description of the test program, conclusions, and recommendations are given at the beginning of this report under the heading "HIGHLIGHTS."

TABLE 6 - MAXIMUM JOINT SHEAR

Specimen	Maximum Shear* V_j (kips)	$\frac{V_j}{bh\sqrt{f'_c}}$	$\frac{V_j}{bd\sqrt{f'_c}}$
LC1	203	12.7	15.5
LC3	217	13.0	15.6
LC4	209	12.0	14.6
LC6	234	13.2	16.0
LC12	238	15.0	18.1
LC10	213	13.2	16.0
LC9**	198	15.0	18.2
NC1	220	13.4	16.3
NC3	196	12.7	15.4
LC7	185	11.3	13.7
LC8	192	11.8	14.3
LC11	181	11.3	13.7
NC2	196	12.1	14.7
LC5	333	14.5	16.8
LC13	319	15.4	17.6
LC2	415	23.5	28.4

*During Basic Loading Cycles   1 kip = 4.45kN

**f'_c (Joint) = 3440 psi = 23.7 MPa

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Fabrication and testing of specimens were performed by the technical staff of the department under the direction of R. K. Richter, Laboratory Foreman. The lead technican on the project was G. J. Naiweem, Expert Technician.

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APPENDIX A - EXPERIMENTAL PROGRAM

Details of the experimental program including specimen geometry, reinforcement details, material properties, fabrication, and testing are given in this appendix.

Test Specimens

Sixteen full-scale columns were tested. Each test specimen represented a portion of the building frame at the joint between column and beams. The column portion extended from approximately mid-heights of the stories above and below the joint as shown in Fig. A1. In most specimens, height of column portion projecting above and below the joint was proportioned such that the column moment immediately above the joint equalled the column moment immediately below the joint. However, in Specimens NC3, LC11, LC12, and LC13, height of the top column portion was increased while the height of the bottom column portion was decreased. The purpose was to force hinging into the top column. Ratio of bottom to top column moments for each specimen as well as test program variables are given in Table A1.

Reinforcement Details

Main column steel and column confining hoops used in each specimen are summarized in Table A1. Reinforcement details are shown in Fig. A2.

Main column steel consisted of eight bars in 15x15-in. (381x381-mm) columns and ten bars in 15x20-in. (381x508-mm) columns. Columns containing two different size bars had the larger size bars placed in the corners. Column hoop and supplementary crosstie arrangements are illustrated in Fig. A2. "Candystick" supplementary crossties had a 135° hook with a 10-diameter extension at one end and a 90° hook with a six-diameter extension at the other end. Crossties were alternated end for end along the column longitudinal reinforcement. Cross-ties were fitted tightly around column bars at the middle of each

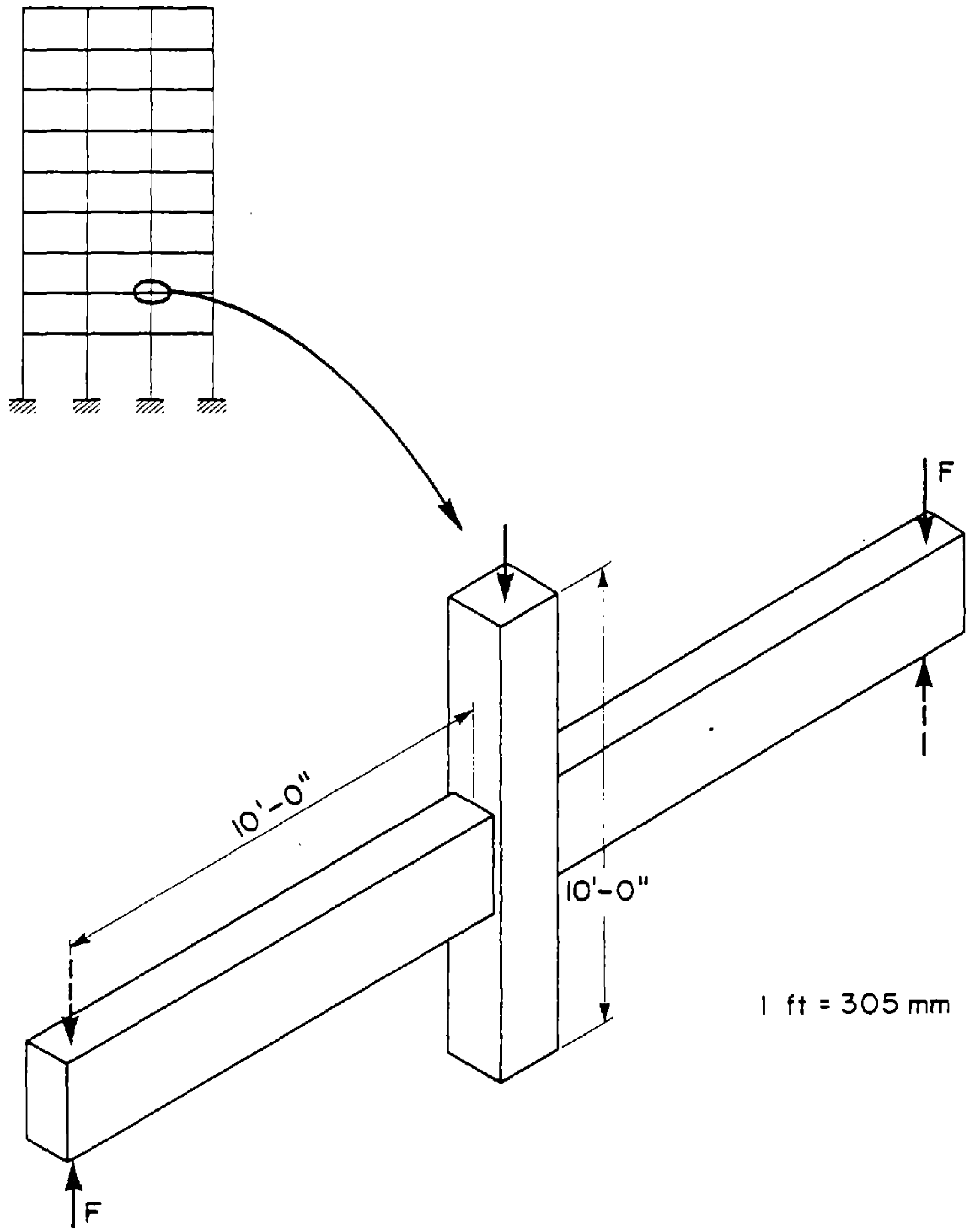


Fig. A1 Test Specimen

TABLE A1 - TEST PROGRAM VARIABLES

Specimen	Concrete Type	Column Size (in.)	Column Steel		Confining Hoops			Initial Axial Column Load, % of ϕP_o**	Top to Bottom Column Moment Ratio
			Bars*	%	Bar No.	Spacing (in.)	%		
LC1	Lightweight 1	15x15	4 No. 7 & 4 No. 6	1.84	4	2	3.19	10	1.00
LC3	Lightweight 1	15x15	4 No. 7 & 4 No. 6	1.84	3	4-3/4	0.74	10	1.00
LC4	Lightweight 1	15x15	4 No. 7 & 4 No. 6	1.84	4	4	1.60	10	1.00
LC6	Lightweight 1	15x15	4 No. 7 & 4 No. 6	1.84	4	4	1.60	20	1.00
LC12	Lightweight 1	15x15	4 No. 7 & 4 No. 6	1.84	4	4	1.60	30	0.74
LC10	Lightweight 2	15x15	4 No. 7 & 4 No. 6	1.84	3	4-3/4	0.74	10	1.00
LC9	Lightweight 2	15x15	4 No. 7 & 4 No. 6	1.84	4	4	1.60	10	1.00
NC1	Normal Weight	15x15	4 No. 7 & 4 No. 6	1.84	4	4	1.60	10	1.00
NC3	Normal Weight	15x15	4 No. 7 & 4 No. 6	1.84	4	4	1.60	10	0.74
LC7	Lightweight 1	15x15	8 No. 6	1.56	4	4	1.60	10	1.00
LC8	Lightweight 2	15x15	8 No. 6	1.56	4	4	1.60	10	1.00
LC11	Lightweight 2	15x15	8 No. 6	1.56	4	4	1.60	10	0.83
NC2	Normal Weight	15x15	8 No. 6	1.56	4	4	1.60	10	1.00
LC5	Lightweight 1	15x20	10 No. 6	1.47	4	3-1/2	1.57	10	1.05
LC13	Lightweight 1	15x20	10 No. 6	1.47	4	4	1.37	10	0.77
LC2	Lightweight 1	15x15	4 No. 10 & 4 No. 9	4.04	3	2-1/4	1.56	10	1.00

*Where two different column bar sizes are used, the larger bars were placed in the corners.
**P_o = Column axial load design strength. 1 in. = 25.4 mm

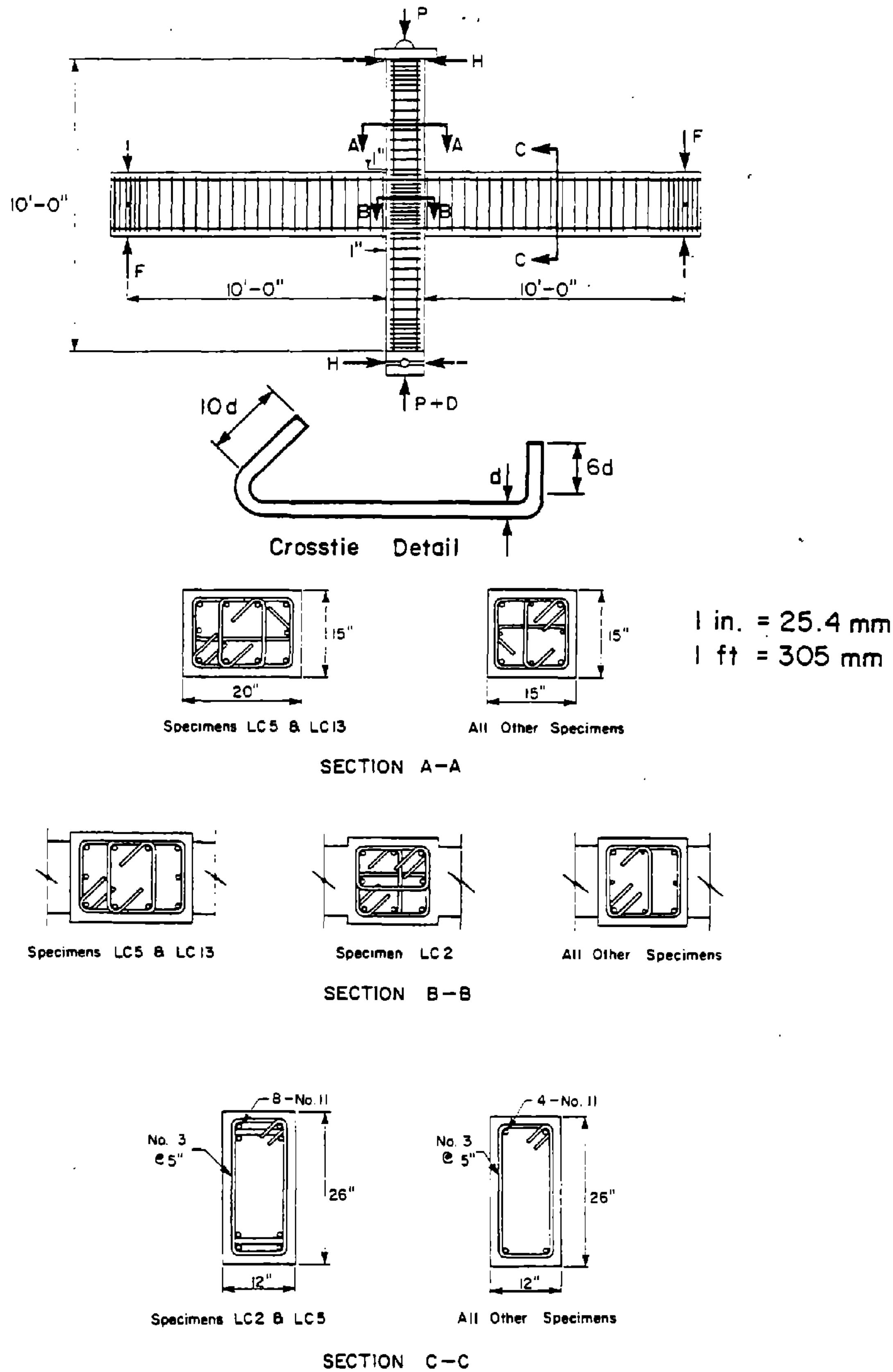


Fig. A2 Reinforcement Details

face without difficulty. In all cases, bar size for supplementary crossties was similar to that of the confining hoops. The confining hoops had a 135° hook with a 10-diameter extension.

As the objective of this investigation was to determine required confinement to obtain ductile behavior of the column, the joint was overdesigned and yielding of the beam reinforcing steel was avoided. Details of the joint reinforcement are shown in Fig. A2. Beam reinforcement consisted of No. 11 bars as shown also in Fig. A2. Clear concrete cover was maintained at 1-1/2 in. (38 mm) in columns and beams. Reinforcing cage for Specimen LC2 is shown in Fig. A3.

Material Properties

Properties of reinforcing steel used in each test specimen are summarized in Table A2. The reinforcement conformed to ASTM Designation A615 Grade 60.(24)

Three concrete mixes were used to manufacture the columns. Two were lightweight concretes and one was normal weight concrete. Each mix was designed for a concrete compressive strength, f'_c, of 5000 psi (34.5 MPa) at 14 days and a slump of 3 ± 1/2 in. (76 ± 13 mm). Mix proportions for the three concretes are shown in Table A3.

Type I cement was used in all mixes. Sand and gravel were from Elgin, Illinois. Lightweight Aggregate 1 consisted of an expanded clay produced on the west coast of the United States. Lightweight Aggregate 2 consisted of an expanded shale produced on the east coast. Fresh unit weights of concrete made from Lightweight Aggregates 1 and 2 were 117 and 122 lb/ft^3 (18.4 and 19.1 kN/m^3), respectively. Both lightweight aggregates have been used extensively for structural applications.

The concrete was mixed in a six cu ft tilting drum mixer. Three 6x12-in. (152x305-mm) control cylinders were taken from the batch placed in the column immediately below the joint. Another three cylinders were taken from the batch placed in the column immediately above the joint. Of the six cylinders, three

Fig. A3 Reinforcing Steel Cage

TABLE A2 - REINFORCEMENT PROPERTIES

Specimen	No. 3 Bar (ksi)		No. 4 Bar (ksi)		No. 6 Bar (ksi)		No. 7 Bar (ksi)		No. 9 Bar (ksi)		No. 10 Bar (ksi)	
	f_y	f_{su}	f_y'	f_{su}	f_y	f_{su}	f_y	f_{su}	f_y	f_{su}	f_y	f_{su}
LC1	-	-	63.9	104.4	61.9	106.0	64.9	110.9	-	-	-	-
LC3	69.9	105.0	-	-	63.4	106.4	67.3	110.6	-	-	-	-
LC4	-	-	63.9	104.4	63.9	105.7	64.8	111.3	-	-	-	-
LC6	-	-	61.0	106.8	63.6	105.7	64.6	109.2	-	-	-	-
LC12	-	-	67.8	109.0	64.3	107.3	64.4	107.9	-	-	-	-
LC10	71.0	107.3	-	-	64.2	105.8	64.8	109.1	-	-	-	-
LC9	-	-	67.8	109.0	66.1	107.1	66.4	112.5	-	-	-	-
NC1	-	-	63.9	104.4	64.7	106.8	66.5	112.3	-	-	-	-
NC3	-	-	67.8	109.0	64.5	106.4	64.4	108.8	-	-	-	-
LC7	-	-	67.8	109.0	63.8	106.2	-	-	-	-	-	-
LC8	-	-	67.8	109.0	67.0	108.2	-	-	-	-	-	-
LC11	-	-	67.8	109.0	65.4	108.2	-	-	-	-	-	-
NC2	-	-	67.8	109.0	63.4	105.4	-	-	-	-	-	-
LC5	-	-	63.9	104.4	63.2	104.9	-	-	-	-	-	-
LC13	-	-	67.8	109.0	64.2	106.4	-	-	-	-	-	-
LC2	69.9	105.0	-	-	-	-	-	-	64.8	104.8	67.4	105.5

f_y = Yield Stress f_{su} = Ultimate Strength 1000 psi = 1 ksi = 6.895 MPa

TABLE A3 - CONCRETE MIX PROPORTIONS

Ingredients	Lightweight Concrete 1	Lightweight Concrete 2	Normal Weight Concrete
Cement (lb), Type I	641	450	478
Sand* (lb)	1444	1393	1579
1/4 in. to 3/8 in. Gravel (lb)	-	-	860
3/8 in. to 3/4 in. Gravel (lb)	-	-	860
Lightweight Aggregate 1* (lb)	761	-	-
Lightweight Aggregate 2* (lb)	-	1000	-
Air Entrainment Agent (liter)	0.98	0.73	-
Water (lb)	359	290	275

*Saturated Surface Dry, SSD   1 lb = 4.448N   1 in. = 25.4 mm cylinders were tested for compresssive strength and three for splitting tensile strength.

Concrete cylinders were tested on the first day of the column test. Each column test was conducted over two consecutive days. Age of concrete and compressive and splitting tensile strengths of individual cylinders are listed in Table A4. Average strengths are also shown.

Concrete type used in each specimen is identified in Table A1. Same concrete type and mix proportions were used in the beams and columns of each specimen. One exception was Specimen LC9, where accidently a leaner concrete mix was placed in the joint and beams. This mix contained 76% of the intended amount of cement. The mix was later duplicated for determination of concrete properties. The average compressive strength of the concrete was 3440 psi (23.7 MPa) as determined from three cylinders. Similarly, the average splitting tensile strength was 340 psi (2.34 MPa).

Fabrication

The column reinforcing cage was assembled first. It was placed vertically in the form. The beam steel was then inserted through the joint and beam stirrups tied in place. Before casting, loading ducts and pipes for attaching external instrumentation were placed in position. Locations of instrumentation pipes are shown in Fig. A4.

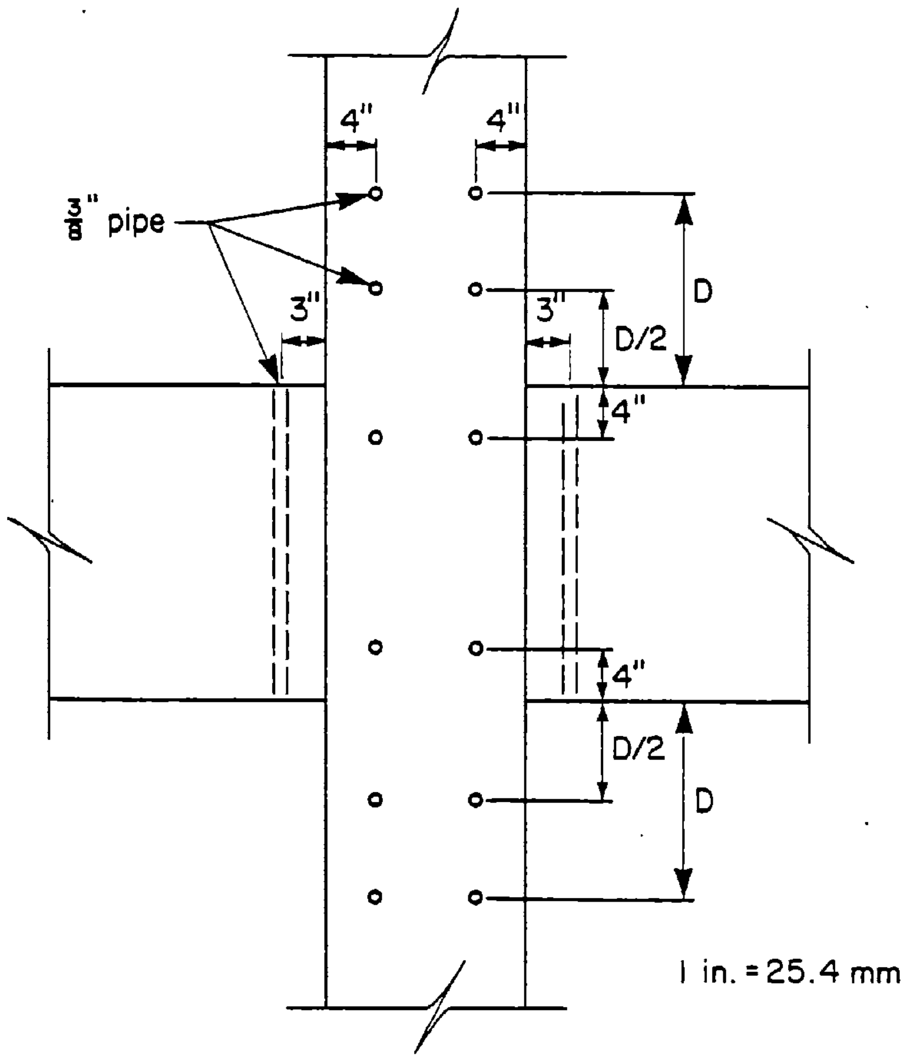
Casting of each specimen was completed within one working day. Each specimen required 13 concrete batches. The first two batches cast the bottom column early in the morning. The concrete was placed through the joint in the space immediately below the bottom flexural reinforcement of the beam. The next nine batches were placed in the beams and joint starting from the ends of the beams with alternate batches in opposite beams. The last batches filled the joint. This occurred approximately two hours after placing concrete in the bottom column. This time was adequate to allow plastic shrinkage to occur in the

TABLE A4 - CONCRETE PROPERTIES

Specimen	Age (days)	Compressive Strength of Concrete, f'_c (psi)			Splitting Tensile Strength, f_{ct} (psi)			$\frac{f_{ct}}{\sqrt{f'_c}}$
		Bottom Column*	Top Column*	Average	Bottom Column*	Top Column*	Average	
LC1	19	5380	4550, 5220	5050	480, 480	340	430	6.1
LC3	13	4400, 5840	6160	5470	450	440, 480	460	6.2
LC4	14	5530	6170, 6230	5980	370, 460	390	410	5.3
LC6	13	5260	6360, 7020	6210	350, 400	465	410	5.2
LC12	14	5480	4580, 4930	5000	340, 460	420	410	5.8
LC10	17	4910	5210, 5230	5120	440, 480	480	470	6.6
LC9**	13	5070, 5090	4630, 4630	4860	500	490	490	7.0
NC1	14	5540, 5640	4840	5340	570	450, 520	510	7.0
NC3	13	4600	4700, 4820	4710	470, 470	550	500	7.3
LC7	14	5120, 5220	5560	5300	420	340, 350	370	5.1
LC8	15	5220, 5380	5040	5210	540	470, 500	500	6.9
LC11	14	5390	4870, 4910	5060	420, 490	490	470	6.6
NC2	14	5620	4900, 4960	5160	530, 570	520	540	7.5
LC5	18	6180, 6400	4880	5820	360	380, 400	380	5.0
LC13	14	5110	4500, 4610	4740	370, 460	430	420	6.1
LC2	20	6530, 5900	6010	6150	430	390, 480	430	5.5

*Individual Cylinders 1000 psi = 6.895 MPa

**Concrete in the Joint and Beams of Specimen LC9: f'_c = 3440 psi, f_{ct} = 340 psi



D = 20 in. for Specimens LC5 and LC13
D = 15 in. for all other Specimens

Fig. A4 Locations of Instrumentation Pipes bottom column. The top column concrete was placed late in the afternoon. Two concrete batches were needed to cast the top column.

Beams and column were covered with a sheet of polyethylene and allowed to cure for three days. Control cylinders were cured in a similar manner. Specimens and cylinders were then stripped and moved to the test location. Testing began approximately 14 days after casting. Age of concrete at testing time is shown in Table A4.

Test Setup

The overall test setup is shown in Fig. A5. The specimen column was centered in a one-million pound capacity testing machine. The lower column end rested on a pin pivot. The upper column end contacted the spherically seated head of the movable platten of the testing machine. Uniform contact on the top of the column was insured by use of a thin layer of high strength plaster.

The lower column end was similarly bedded in plaster to the upper plate of the pin pivot. The pivot assembly consisted of two grooved 4-in. (102-mm) thick steel plates separated by a 2-1/4-in. (57-mm) diameter high strength steel rod acting as the pivot. The pivot assembly was supported at the proper height above the machine base by a concrete pedestal.

At the end of each beam, the load was applied by a double-acting ram. The base of the ram was secured to the laboratory floor. The top of the ram piston was connected to a swivel head that was fastened to the bottom of two tension-compression load cells. The tops of the load cells were, in turn, clamped to the bottom of the beam. The rams had a 36-in. (914-mm) stroke.

Three separate hydraulic systems were used during each test. The first was used to apply the column axial load. The other two systems were used for each of the two double-acting rams applying load to the beams. The rams' piston area for the push cycle was larger than that for the pull cycle. Since equal and

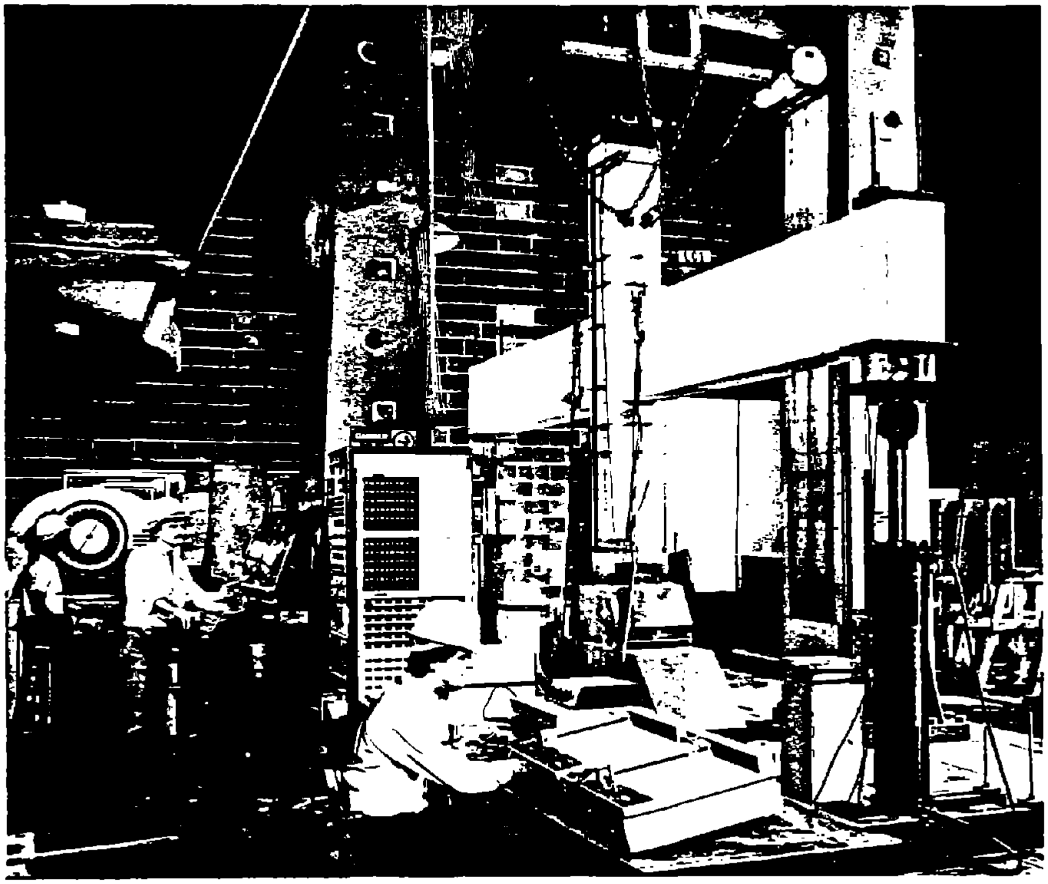


Fig. A5 Test Setup

opposite loads were applied to each beam, two separate hydraulic systems were needed.

Instrumentation

Each specimen was instrumented externally and internally. External measurements included column load, beam loads, column drifts, column rotations, and beam deflections. In some specimens, the lateral joint movement and/or the joint shear distortion were also measured. Internal measurements included strains of main column steel and column confining hoops.

Loads

Column axial load was determined from the load measuring capsule of the testing machine. The load was read visually on the dial of the machine console. The million-pound machine is calibrated annually. Each beam's load was determined by averaging the load in two tension-compression load cells.

Column drift

Top and bottom column "drifts" were measured using a vertical rigid arm connected to the joint as illustrated in Fig. A6. When the beam ends were loaded, the joint rotated. Therefore, the vertical arm also rotated. Lateral movements of the top and bottom ends of this arm relative to the columns were used as an indication of the column drift (approximately half-story drift).

Prior to casting, pipes were embedded in the specimens as shown in Fig. A4. After stripping, a threaded rod was inserted through each pipe. The rod was tightly bolted against the pipe at both ends. Portions of the threaded rod projecting beyond the nuts were used to fasten the different instrumentation devices. For example, the drift arm was bolted to two brackets; each bracket was then fastened to two threaded rods. Lateral movement of the top and bottom ends of the drift arm were sensed through 12-in. (305-mm) stroke potentiometers mounted on frames secured to the top and bottom of the column. Bottom drift

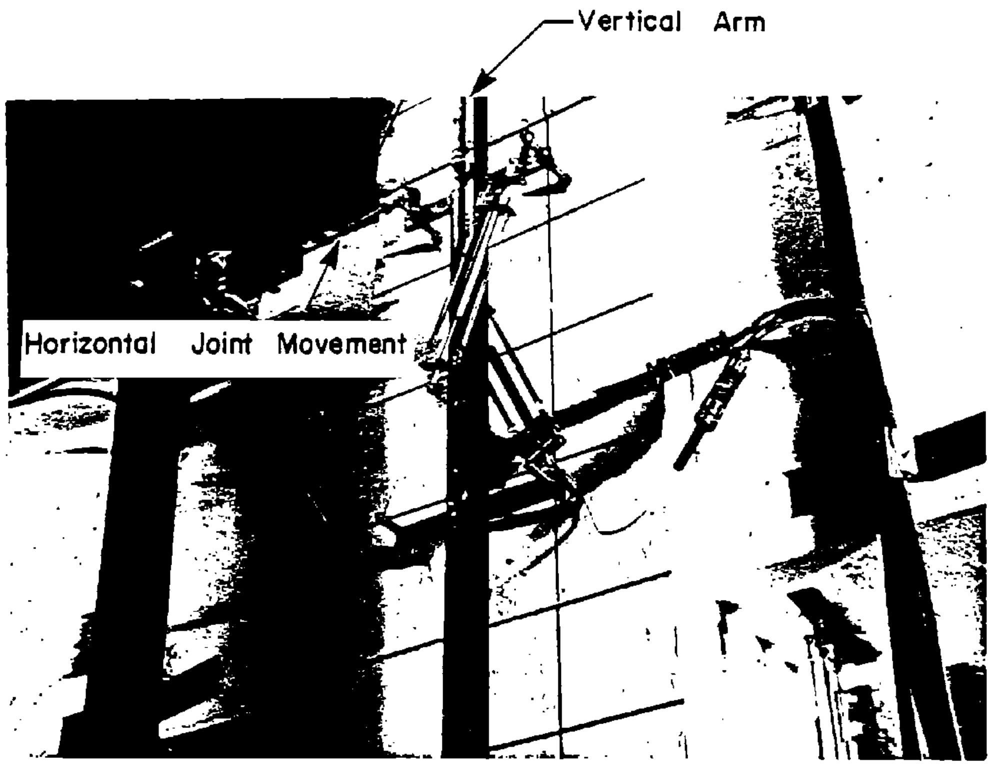


Fig. A6 Joint Instrumentation

potentiometer is shown in Fig. A7. Distance between the joint center and top and bottom drift potentiometers were 58.5 and 43.5 in. (1.49 and 1.10 m) respectively for Specimens NC3, LC12 and LC3, and 55.5 and 46.5 in. (1.41 and 1.18 m) respectively for Specimen LC11. For all other specimens, these distances were 51 in. (1.30 m) for both top and bottom drift potentiometers.

Column rotation

Column rotations were measured above and below the joint over distances of 10 and 20 in. (25 and 51 mm) for Specimens LC5 and LC13, and over distances of 7-1/2 and 15 in. (190 and 381 mm) for all other specimens. Fig. A8 depicts the rotation frames used in the bottom column. Linear potentiometers with 4-in. (102-mm) stroke sensed relative movement between frames and the beam for calculation of column rotations.

Beam deflection

Vertical deflection of each beam at a distance of 9 ft 8 in. (2.95 m) away from the column face was measured using 36-in. (914-mm) stroke linear potentiometers.

Horizontal joint movement

The arrangement used to measure the horizontal joint movement is shown in Fig. A6. The lateral movement of the joint was measured in Specimens LC12, LC13, and NC3, using a 12-in. (305-mm) potentiometer. The potentiometer was secured to the top of a rigid arm clamped to the pedestal supporting the column. The end of the potentiometer's plunger was connected to one of the top threaded rods projecting out of the joint.

Joint shear distortion

Shear distortion of the joint was measured in Specimens LC13 and NC3. Two 4-in. (102-mm) potentiometers were mounted diagonally across the joint. The change in the length of diagonals

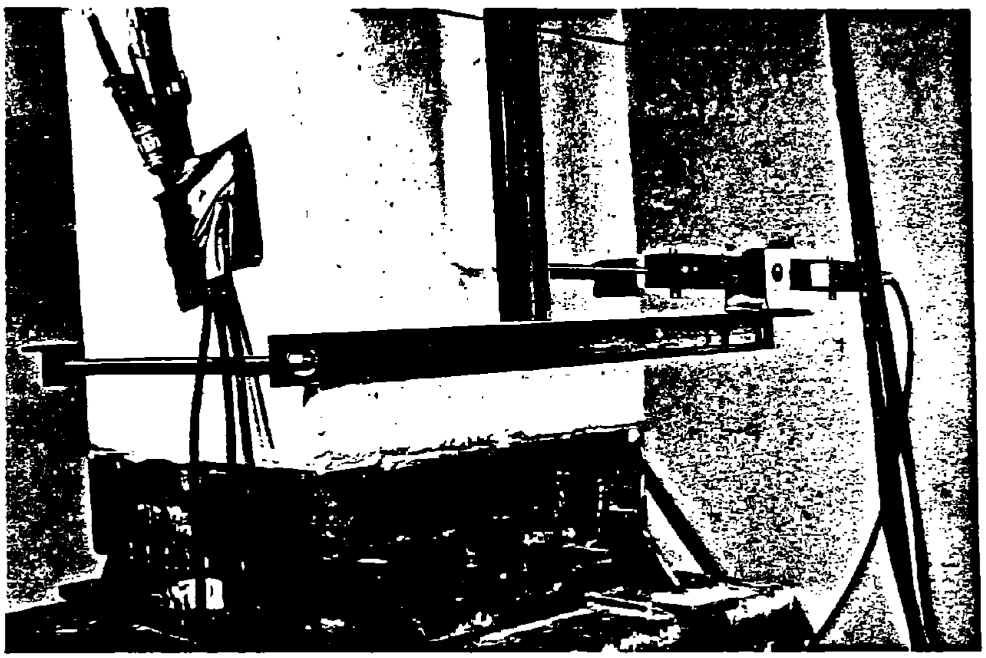


Fig. A7 Bottom Drift Potentiometer

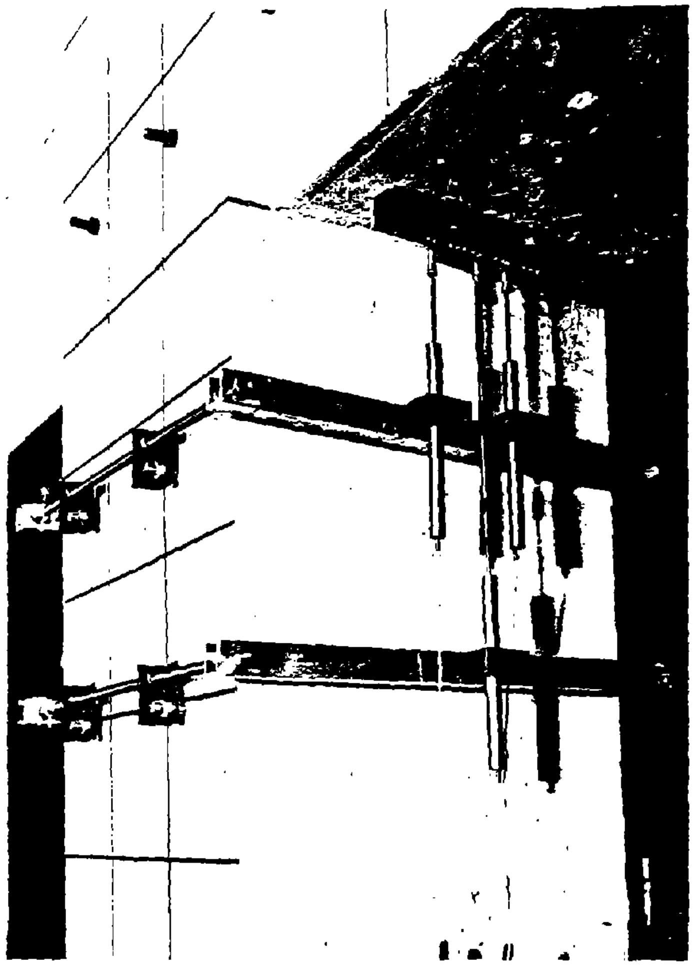


Fig. A8 Bottom Column Rotation Measurements was used to calculate the shear distortion as illustrated in Fig. A9.

Reinforcement strains

Internal instrumentation included measurement of strains on the column steel and confining hoops. Electrical resistance strain gages were attached to the surface of the reinforcement before testing. In each specimen, two column bars were each instrumented with nine gages. Strain gage locations and identification are shown in Fig. A10. In addition, three confining hoops above and three below the joint were instrumented each with two gages as identified in Fig. A11.

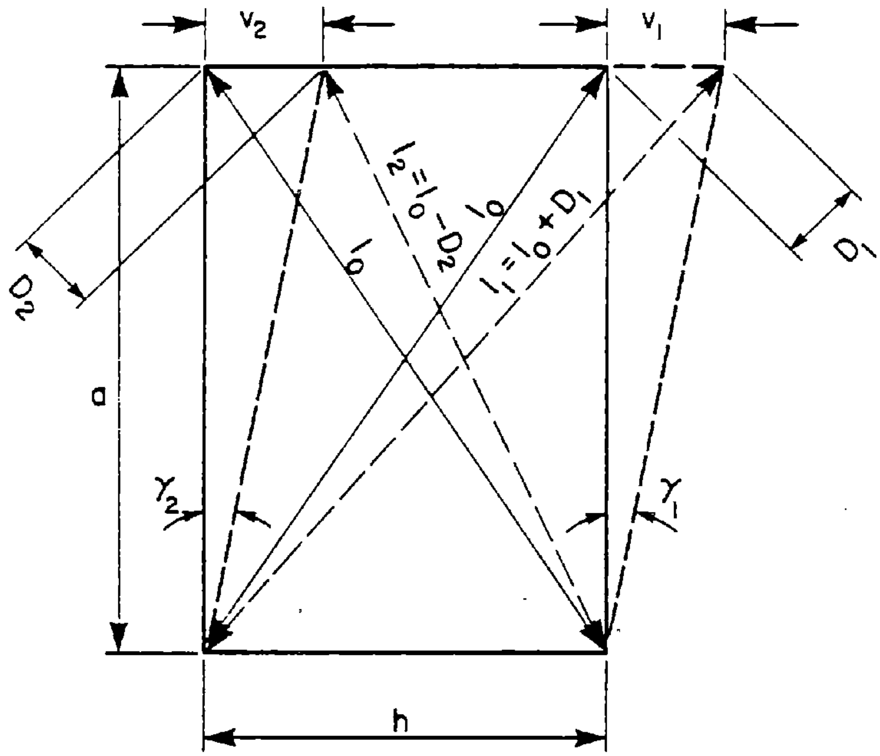
Data Acquisition

Loads, deformations, and steel strains were recorded at selected points along the load cycles by a digital data acquisition system. This system printed the data and simultaneously stored it on magnetic tape. The on-line computer provided a tabulation of data within seconds of recording the readings.

Continuous plots of loads and deformations were recorded on X-Y plotters. The applied beam loads were expressed as column moments. These moments were a function of specimen geometry and applied beam loads. As the test setup provided a statically determinate system, the column moment was directly proportional to the applied beam loads. The column moments were computed at a section immediately above or below the joint. The following continuous plots were recorded.

Moment versus drift

For each specimen, moment versus drift was plotted separately for each of the top and bottom columns, i.e. the column portions above and below the joint. These plots were used to control the imposed deformations as discussed under "Test Procedure." The moment was proportional to the sum of loads in the four load cells. Column drift was measured as explained above.



$$\text{Shear Distortion } \gamma = \frac{\gamma_1 + \gamma_2}{2} = \frac{v_1 + v_2}{2a}$$

$$= \frac{\sqrt{l_1^2 - a^2} - \sqrt{l_2^2 - a^2}}{2a}$$

Fig. A9 Equation for Shear Distortion

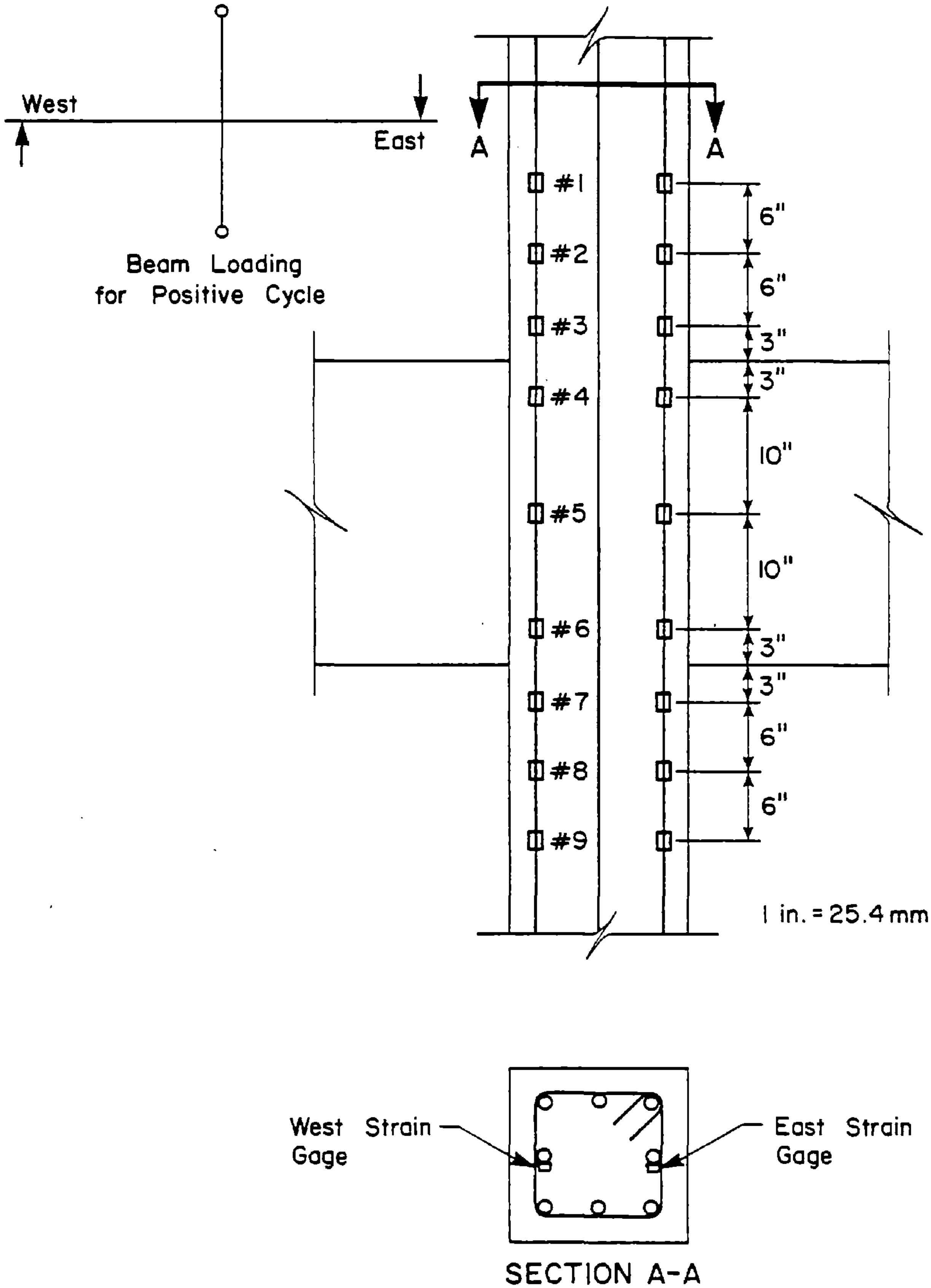


Fig. A10 Locations of Strain Gages on Instrumented Column Steel

Specimen	Hoop Distance Above and Below the Joint, in.		
	#1	#2	#3
LC1	1.00	5.00	9.00
LC3	1.00	5.75	15.25
LC4	1.00	5.00	9.00
LC6	1.00	5.00	9.00
LC12	1.00	5.00	9.00
LC10	1.00	5.75	10.50
LC9	1.00	5.00	9.00
NC1	1.00	5.00	9.00
NC3	1.00	5.00	9.00
LC7	1.00	5.00	9.00
LC8	1.00	5.00	9.00
LC11	1.00	5.00	9.00
NC2	1.00	5.00	9.00
LC5	1.00	4.50	11.50
LC13	1.00	5.00	9.00
LC2	1.00	5.50	10.00

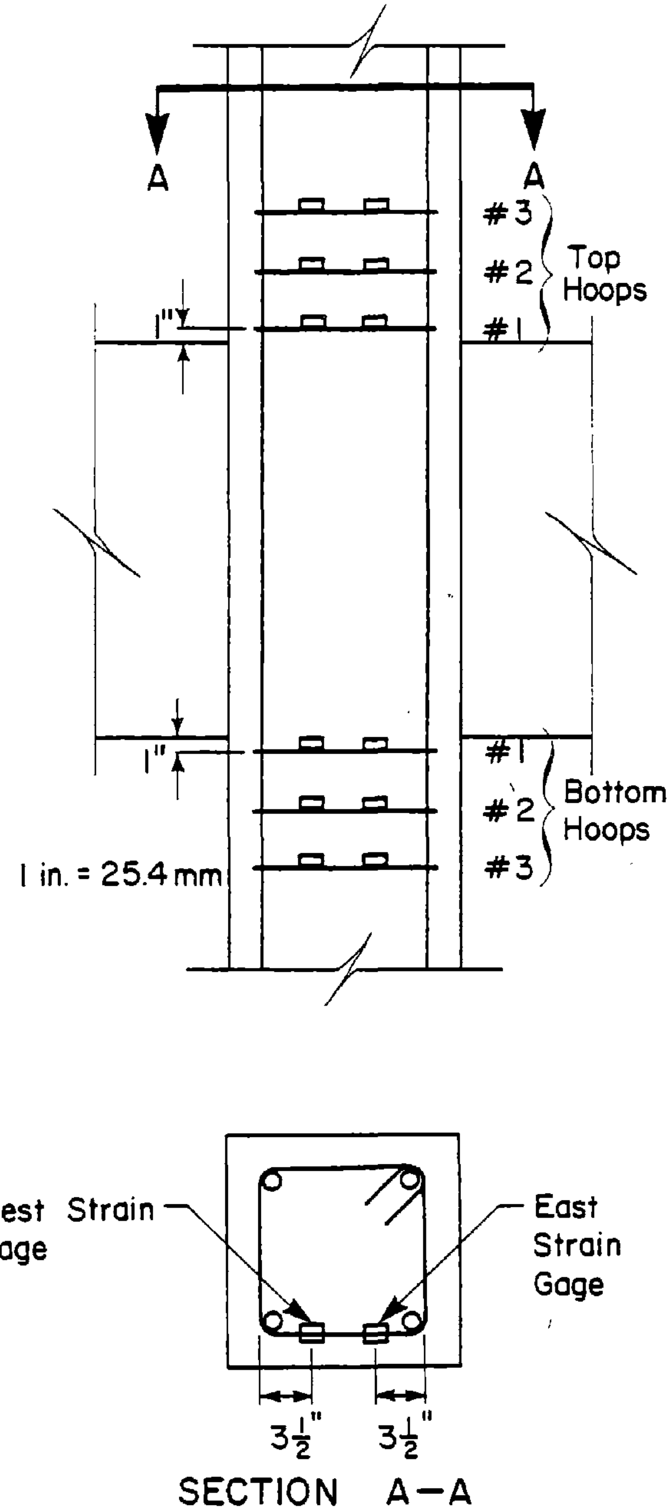


Fig. A11 Locations of Strain Gages on Instrumented Confining Hoops

Moment versus rotation

For each specimen, a continuous plot of moment versus column rotation was recorded separately for the top and bottom columns. The rotation depicted the change in angle between the ends of a column segment immediately above or below the joint. The segment height was 7.5 in. (190 mm) in 15x15-in. (381x381-mm) columns, and 10 in. (254 mm) in 20x20-in. (508x508-mm) columns. Significant plots are reported in Appendix B.

Test Procedure

After placing the specimen in the test setup and attaching all instrumentation, an axial load was applied to the column. This axial load was maintained constant while the beams were loaded. When one beam end was under a down load, the other beam end was subjected to an up load. Then the beams were unloaded and the loading sequence was reversed. This resulted in reversal of the moments in the beams and consequently in the columns. Several cycles of load reversals were applied to the beams. Therefore, the column stubs above and below the joint were subjected to a constant axial load and to moment reversals. Specimens that survived the scheduled cycles of moment reversals were then subjected to a higher axial load, followed by additional cycles of moment reversals.

Column axial load

The load applied to each column represented a fraction of the column axial load design strength. Axial load levels applied to each specimen are shown in Table A5. The column design strength was defined by the following equation:

$$P_o = \phi (0.85 f'_c (A_g - A_{st}) + A_{st} f_y) \quad \text{(A1)}$$

where ϕ = capacity reduction factor (0.7)

A_g = gross area of section, sq in.

A_{st} = area of reinforcement, sq in.

f'_c = specified compressive strength of concrete, psi

f_y = specified yield strength of reinforcement, psi

TABLE A5 - LOADING SCHEDULE

Specimen	Axial Column Load, % of ϕP_o	Number of Cycles @ Ductility
LC1	10	Basic Loading Cycles*
	20	2 @ 2, 2 @ 4, 3 @ 8
	30	2 @ 4, 3 @ 8
	60	2 @ 4, 1 @ 7.5
LC3	10	Basic Loading Cycles
	20	2 @ 4, 2 @ 8
	30	2 @ 8
LC4	10	Basic Loading Cycles
	20	2 @ 4, 2 @ 8
	30	2 @ 4, 2 @ 8
	60	2 @ 4, 0.5 @ 6.3
LC6	20	Basic Loading Cycles
	30	2 @ 4, 2 @ 8
	60	2 @ 8
LC12	30	Basic Loading Cycles
LC10	10	Basic Loading Cycles
	20	2 @ 4, 2 @ 8
LC9	10	Basic Loading Cycles
	20	2 @ 4, 2 @ 8
NC1	10	Basic Loading Cycles
	20	2 @ 4, 2 @ 8
	30	2 @ 4, 2 @ 8
	60	2 @ 4, 1 @ 5.5
NC3	10	Basic Loading Cycles
	20	2 @ 4, 2 @ 8
	30	2 @ 4, 2 @ 8
	60	2 @ 4, 1 @ 8
LC7	10	Basic Loading Cycles
	20	2 @ 4, 2 @ 8
	30	2 @ 4, 2 @ 8
	60	2 @ 4, 1 @ 6
LC8	10	Basic Loading Cycles
	20	2 @ 4, 2 @ 8
	30	2 @ 4, 2 @ 8
	60	2 @ 4, 1 @ 8
LC11	10	Basic Loading Cycles
	20	2 @ 4, 2 @ 8
	30	2 @ 4, 2 @ 8
	60	2 @ 4, 1 @ 8
NC2	10	Basic Loading Cycles
	20	2 @ 4, 2 @ 8
	30	2 @ 4, 2 @ 8
	60	2 @ 4, 1 @ 6
LC5	10	Basic Loading Cycles
	30	1 @ 8
LC13	10	Basic Loading Cycles
	20	2 @ 4, 2 @ 8
	30	2 @ 8
LC2	10	2 @ 1, 6 @ 2, 4 @ 4, 0.5 @ 6

*Basic Loading Cycles: 2 @ 1, 6 @ 2, 4 @ 4, 3 @ 8

Beam loads

After applying the constant axial load to the column, the beams were loaded to produce cycles of moment reversals in the column. On the first cycle, the beams were loaded to attain calculated yield moment in the column. Subsequent beam loading cycles were controlled by column deformation as discussed below.

Column yield moment, in the presence of an axial force, was computed based on Navier's hypothesis of "plane section before bending remains plane after bending." A computer program was used to determine the yield moment and nominal flexural strength of each column. Calculations were made using equilibrium of forces and strain compatibility. Concrete compressive strength was assumed to be 5000 psi (35 MPa). Concrete tensile strength was ignored. Reinforcing steel yield stress was assumed to be 60 ksi (419 MPa).

Beam loads at positive and negative peaks of the first loading cycle were applied to obtain calculated yield moment in the column. The largest value of either top or bottom column drift measured at the first positive peak was defined as "yield drift." This yield drift was used as a deformation control for all subsequent cycles. Multiples of the yield drift were imposed on the column to produce the drift ductilities as shown in the loading schedule of Fig. A12. Drift ductility was defined as the ratio of the largest value of either top or bottom column drift in any cycle to yield drift.

While the column axial load was maintained constant, the fifteen basic loading cycles were applied as follows: two cycles at ductility 1, six cycles at ductility 2, four cycles at ductility 4, and three cycles at ductility 8. This loading schedule pattern was suggested by Wight and Sozen.[25] This pattern of ever increasing deformation in each group of cycles is not intended to represent any specific major earthquake. For specimens that survived the basic loading cycles, the column axial load was increased, and additional cycles of load reversals were applied as summarized in Table A5.

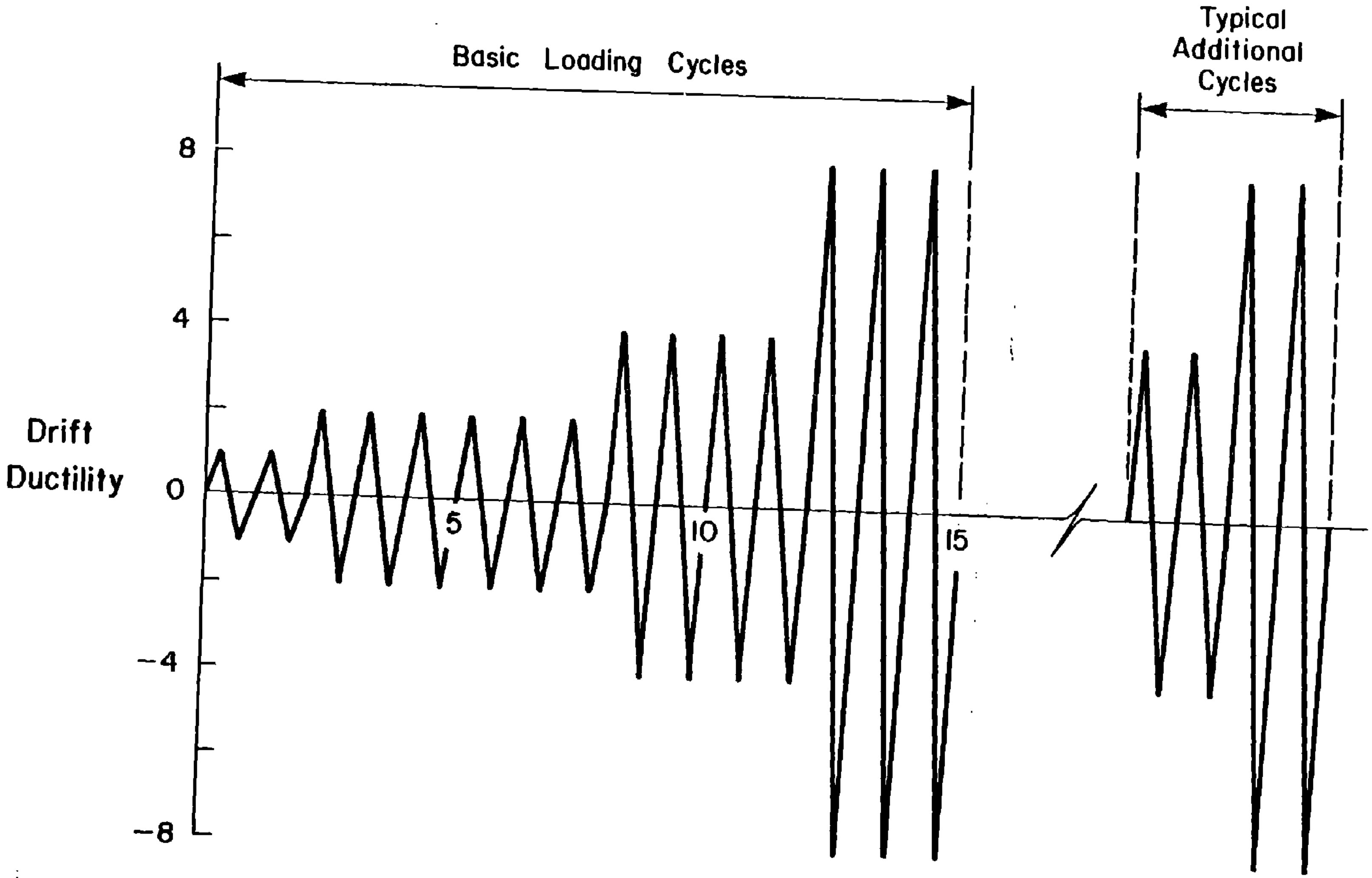


Fig. A12 Loading Schedule

Equal and opposite loads were applied to the beams. These loads were controlled by monitoring hydraulic pressure to each ram using pressure cells. One hydraulic system was used for each ram. The hydraulic pressure in each ram was plotted on an X-Y plotter. Each axis represented one ram. At all times, the hydraulic pressures were proportional to the reciprocal of the push-pull ram piston areas. Four way valves allowed the hydraulic pressure to be switched from a push cycle to a pull cycle.

Test results for each specimen are given in detail in Appendix B.

APPENDIX B - TEST RESULTS

This appendix contains test results for all specimens. Presentation of test data is first described. Test results for each specimen are then presented in detail.

Data Presentation

For each specimen, the following material is presented in this appendix:

1. Summary of column details
2. Column moment history
3. Column moment versus drift relationships
4. Tabulated test results

Specimen behavior is discussed under "Column moment versus drift relationships."

Column moment history

The column moment history of each test specimen is depicted in a figure. Applied column moment is plotted versus cycle number. Applied column moment is computed from measured beam loads and specimen geometry, at a section immediately above or below the joint. Measured column moment corresponding to first positive peak is shown on each figure. Applied column axial load and drift ductility are indicated at the top of the figure for the different cycles. The level of applied column axial load is given as a percent of the calculated axial load design strength. Drift ductility is defined as measured column drift divided by the drift measured at first positive peak. Column drift was measured as discussed in Appendix A under "Instrumentation."

Column moment versus drift relationships

A continuous plot of moment versus drift is presented for each specimen at each column axial load level. For those specimens where a plastic hinge formed in the top and bottom columns simultaneously, plots of moment versus top and bottom drifts are presented. When hinging occurred in either the top or bottom

column only, plots of moment versus drift are presented for the hinged column. However, for Specimen LC1, moment was plotted versus both top and bottom drifts to illustrate the bottom column behavior as a hinge developed in the top column. All plots of moment versus drift were continuously recorded during testing using X-Y plotters.

The maximum measured column moment within the basic loading cycles is compared with the calculated nominal flexural strength for each column. Calculated nominal flexural strengths were determined using sectional analysis based on equilibrium of forces, strain compatibility, design material properties, and an unspalled cracked section. Strain hardening of the steel was included. The material properties used for specimen design were (1) concrete compressive strength equal to 5000 psi (35 MPa) and (2) yield strength of the steel equal to 60,000 psi (414 MPa). Measured reinforcing steel and concrete properties for each specimen are reported in Tables A2 and A4.

Photographs at the end of Cycles 12 and 15 are shown for each specimen. These correspond to last cycles at Ductilities 4 and 8, respectively, within the basic loading cycles.

Continuous plots of moment versus rotation for top and bottom columns were recorded for each specimen. Very close similarities were observed between the loops of these plots and the loops of column moment versus drift plots. For this reason, moment versus rotation relationships are only reported for Specimen LC1.

Tabulated results

Test data recorded at cycle peaks are tabulated for each specimen. The following data are provided:

1. Column moment
2. Top column drift
3. Bottom column drift
4. East beam deflection
5. West beam deflection

6. Calculated rotation over distances D and D/2 above and below the joint, where D is the column width.
7. All reinforcement strains

In addition, Specimens LC12, LC13, and NC3 were instrumented to measure horizontal joint movement. Specimens LC13 and NC3 were instrumented to measure joint shear distortion. Horizontal joint movement and joint shear distortion measurements are reported in the appropriate tables. Moments listed exclude secondary P-Delta effects due to horizontal joint movement. These secondary effects are also excluded from plotted moments.

All tabulated data correspond to cycle peaks. These data were recorded as described under the section "Data Acquisition" in Appendix A. Data judged meaningless were replaced with a dash in the tabulation.

Specimen LC1

Specimen LC1 was constructed of Lightweight Concrete 1. This specimen was heavily confined with No. 4 hoops spaced at 2 in. (51 mm). This corresponds to a volume of hoop reinforcement to concrete core of 3.19%. Other column details are given in Table A1.

Column moment history

The column was subjected to 30 cycles of moment reversals as shown in Fig. B1. The test began with a column axial load of 83.2 kips (370 kN). This corresponded to 10% of the column design strength. This axial load was maintained constant throughout the basic loading cycles. Column axial load was subsequently increased to 20%, 30%, and 60% of the column design strength as shown in Fig. B1.

Column moment versus drift relationships

Top column moment versus drift relationships are shown in Fig. B2. The first positive peak column moment was 1567 in.-kip (177 kN·m). The corresponding top column drift was 0.28 in.

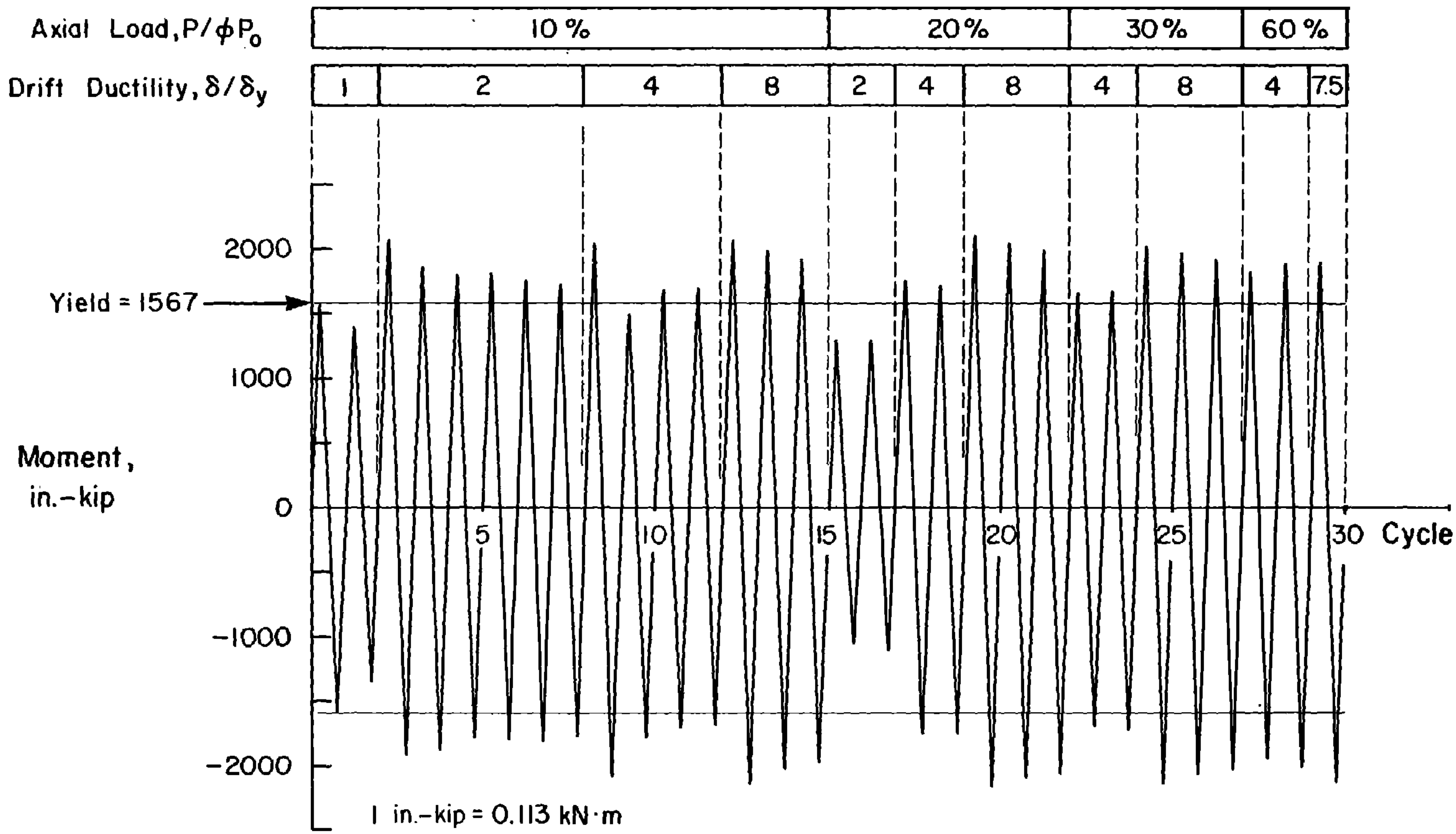
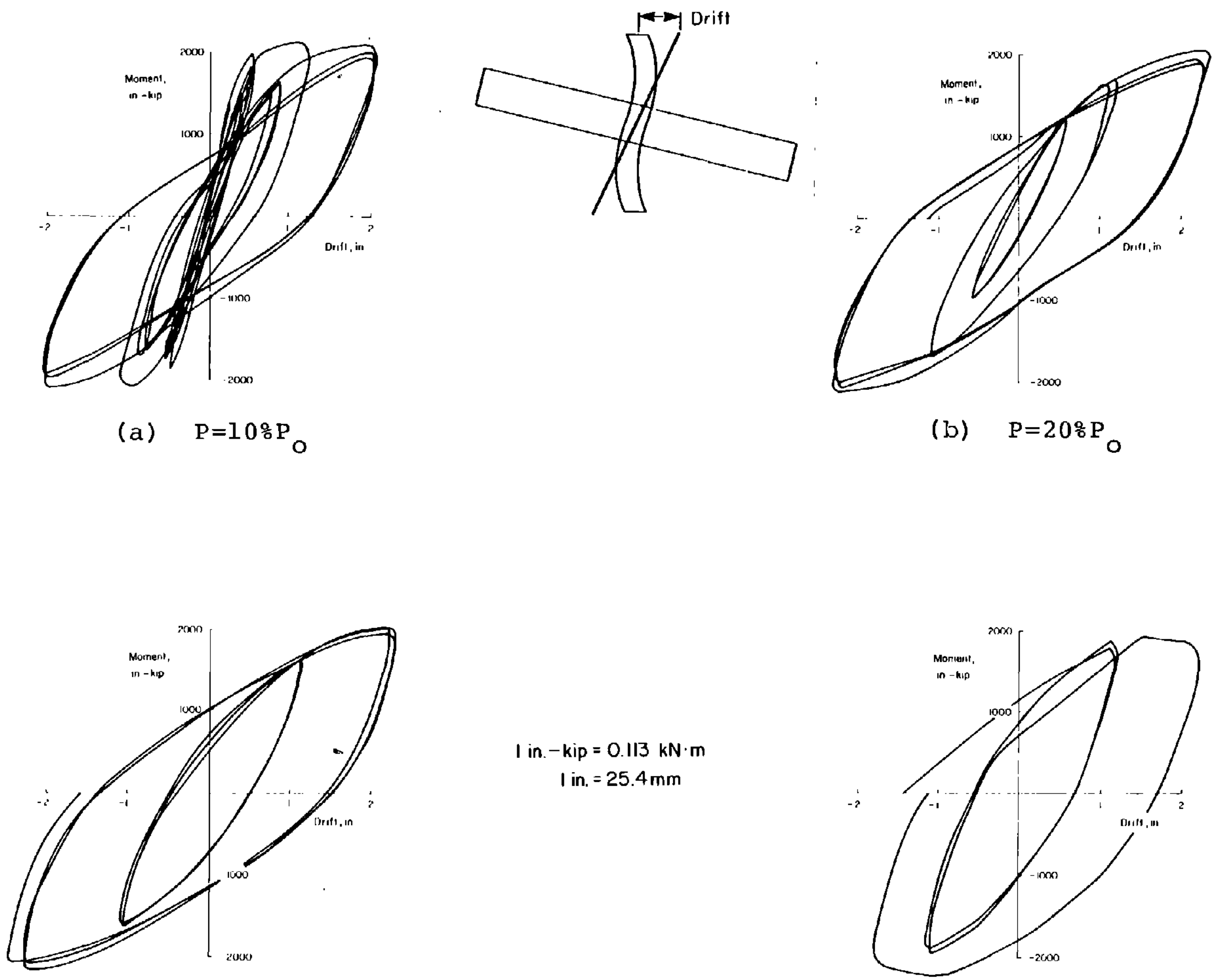


Fig. B1 Column Moment History for Specimen LC1



(a) $P=10\%P_o$ (b) $P=20\%P_o$

(c) $P=30\%P_o$ (d) $P=60\%P_o$

Fig. B2 Top Column Moment versus Drift for Specimen LC1

(7.1 mm). Bottom column drift measured at the first positive peak was 0.26 in. (6.6 mm). Top column drift was greater than bottom column drift throughout the test. Bottom column moment versus drift is plotted in Fig. B3. This plot indicates a decrease in hysteresis loop size as hinging developed in the top column.

The maximum measured moment within the basic loading cycles was 2144 in.-kip (242 kN·m). It occurred at the negative peak of Cycle 13. The calculated monotonic nominal flexural strength was 2040 in.-kip (230 kN·m) based on an unspalled cracked section. The maximum measured moment was approximately 5% greater than calculated.

Photographs of Specimen LC1 at the end of Cycles 12 and 15 are shown in Figs. B4 and B5, respectively.

During Cycle 30, the column moment capacity dropped and the test was ended. No buckling of the column bars or opening of the 90° hook in the supplementary crossties were observed throughout the test. The high amount of confining reinforcement helped maintain the column integrity while allowing large inelastic cycles of moment reversals.

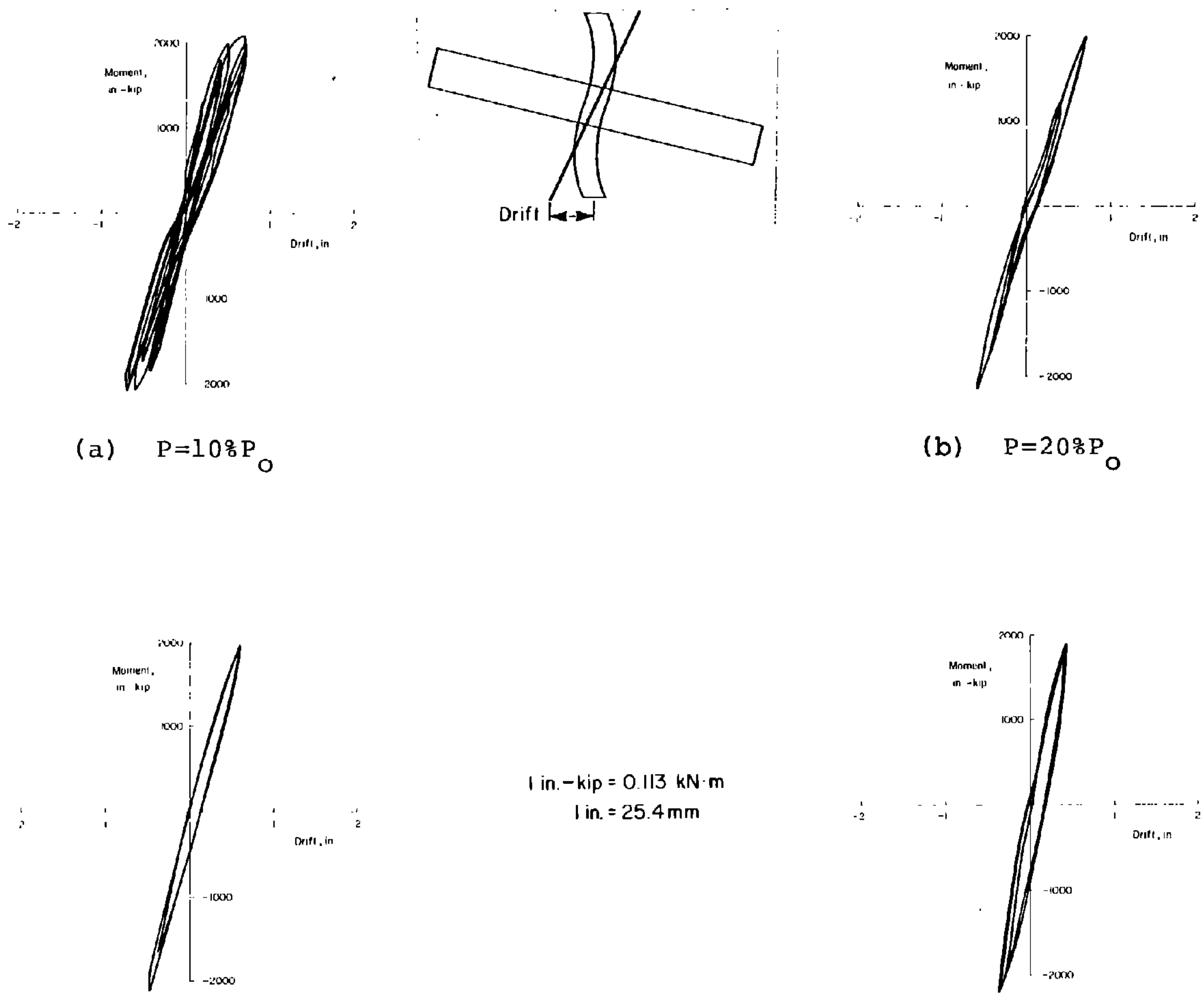
Column moment versus rotation relationships

Top column moment versus rotation relationships are shown in Fig. B6. Rotation in this plot was measured over a distance of 7.5 in. (190 mm) directly above the joint. This distance encompassed the majority of the hinging region.

A comparison of Figs. B2 and B6 indicates a large similarity in the shape of the hysteresis loops for moment versus drift and moment versus rotation for the top column. Similar behavior was observed in other specimens for both top and bottom columns. Because of this similarity, only plots of column moment versus drift will be reported for subsequent specimens.

Tabulated results

Tabulated values of column moment, top and bottom column drifts, and east and west beam deflections recorded at cycle



(a) P=10%P_o

(b) P=20%P_o

(c) P=30%P_o

(d) P=60%P_o

Fig. B3 Bottom Column Moment versus Drift for Specimen LC1

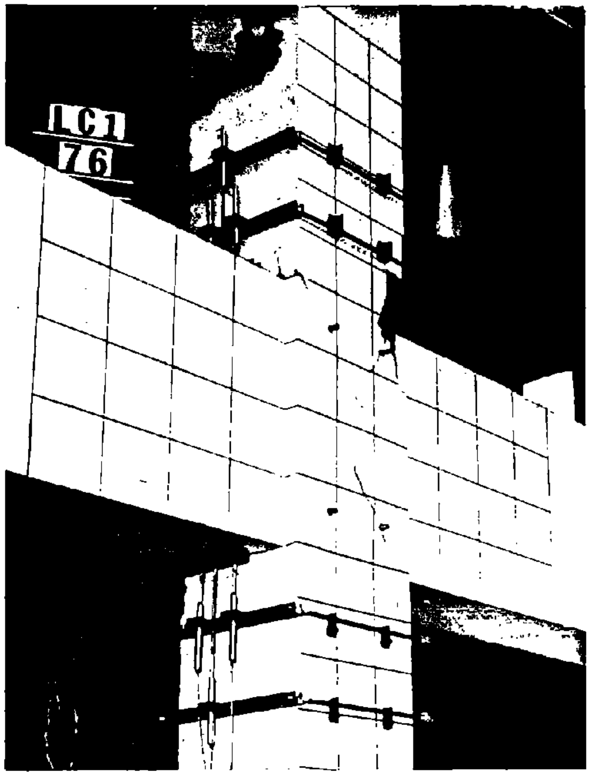


Fig. B4 Specimen LC1 after Cycle 12

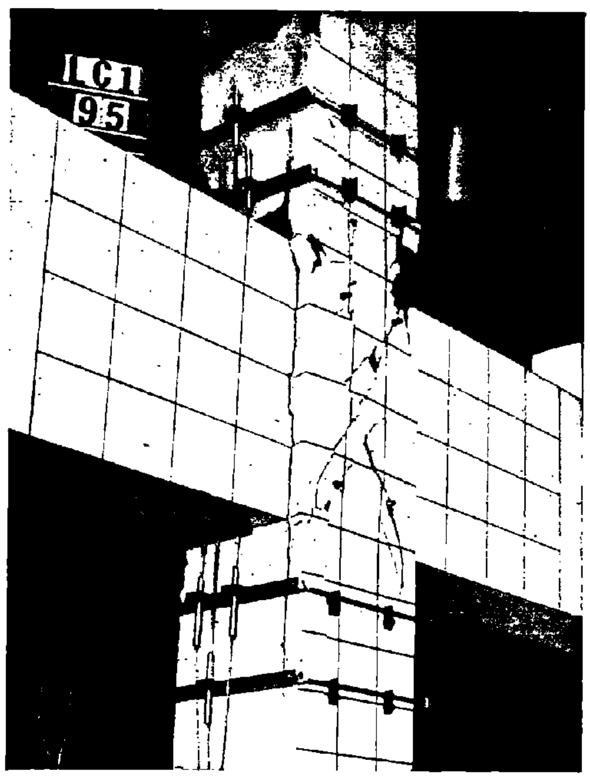


Fig. B5 Specimen LC1 after Cycle 15

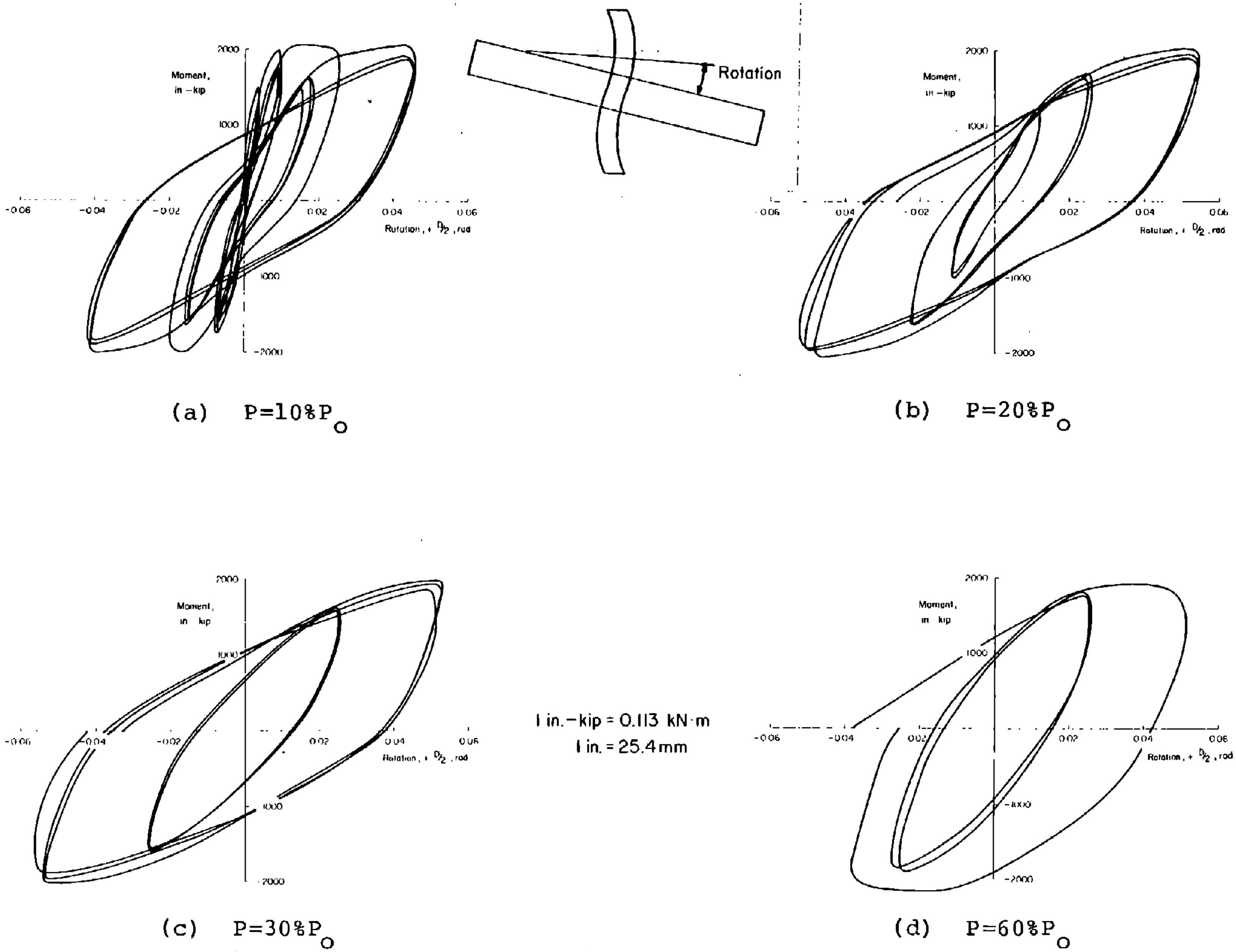


Fig. B6 Top Column Moment versus Rotation for Specimen LC1

peaks are given in Table B1. Column rotations measured at cycle peaks are listed in Table B2. Reinforcement strains recorded at cycle peaks are presented in Tables B3 and B4 for column steel and Tables B5 and B6 for column confining hoops. Locations of strain gages are identified in Figs. A10 and A11 for column steel and confining hoops, respectively.

Specimen LC3

Specimen LC3 was manufactured with Lightweight Concrete 1. Confining reinforcement consisted of No. 3 hoops spaced at 4-3/4 in. (121 mm). The amount of confinement was 0.74%. Other details of column steel are shown in Table A1.

Column moment history

Specimen LC3 was subjected to 21 cycles of moment reversals as shown in Fig. B7. During the basic loading cycles, the column was subjected to an axial load of 83.2 kips (370 kN) or 10% of the column design strength. For subsequent cycles, column axial load was increased to 20% and 30% of the column design strength as shown in Fig. B7.

Column moment versus drift relationships

Moment versus drift for both top and bottom columns are plotted in Figs. B8 and B9, respectively. The first positive peak column moment was 1598 in.-kip (181 kN·m). At this stage top and bottom drifts were 0.28 in. and 0.26 in. (7.1 and 6.6 mm), respectively.

Hysteresis loops for Cycles 1 through 12 were very similar for top and bottom columns. Both top and bottom columns hinged simultaneously with top column drift being slightly greater and controlling test progress for positive and negative cycles. However, during the negative half of Cycle 13, the bottom column drift increased faster than that of the top column. Expecting top column drift to control, the bottom column drift went undetected and an accidental bottom drift of 3.71 in. (94 mm) was

TABLE B1 - COLUMN MOMENT, COLUMN DRIFTS, AND BEAM DEFLECTIONS FOR SPECIMEN LC1

CYCLE	MOMENT (IN.-KIP)	DRIFT (IN.)		DEFLECTION (IN.)	
		TOP	BOTTOM	EAST	WEST
+ 1	1567	0.230	-0.257	1.459	-1.343
- 1	-1593	-0.322	0.265	-1.313	1.335
+ 2	1398	0.240	-0.226	1.301	-1.193
- 2	-1355	-0.232	0.220	-1.109	1.121
+ 3	2072	0.531	-0.505	2.284	-2.243
- 3	-1922	-0.498	0.365	-1.859	1.837
+ 4	1862	0.500	-0.453	2.129	-2.040
- 4	-1389	-0.522	0.445	-2.243	1.730
+ 5	1800	0.488	-0.439	2.063	-1.980
- 5	-1789	-0.508	0.401	-1.695	1.319
+ 6	1813	0.502	-0.447	2.105	-2.028
- 6	-1800	-0.510	0.399	-1.895	1.837
+ 7	1761	0.492	-0.439	2.063	-1.974
- 7	-1817	-0.520	0.405	-1.937	1.879
+ 8	1729	0.484	-0.433	2.035	-1.939
- 8	-1779	-0.516	0.401	-1.913	1.843
+ 9	2045	1.114	-0.717	3.358	-3.191
- 9	-2085	-1.048	0.613	-2.974	2.897
+ 10	1497	0.715	-0.475	2.344	-2.243
- 10	-1790	-0.886	0.499	-2.548	2.446
+ 11	1666	0.854	-0.537	2.662	-2.577
- 11	-1713	-0.822	0.473	-2.392	2.325
+ 12	1697	0.877	-0.553	2.704	-2.631
- 12	-1688	-0.800	0.461	-2.368	2.297
+ 13	2074	2.014	-0.739	4.533	-4.425
- 13	-2144	-2.010	0.651	-4.251	4.164
+ 14	1984	1.993	-0.737	4.437	-4.331
- 14	-2026	-2.036	0.621	-4.251	4.110
+ 15	1929	2.034	-0.747	4.407	-4.408
- 15	-1980	-2.062	0.603	-4.257	4.122
+ 16	1294	0.555	-0.419	1.835	-1.795
- 16	-1054	-0.576	0.202	-1.535	1.542
+ 17	1294	0.564	-0.419	1.829	-1.790
- 17	-1116	-0.568	0.222	-1.559	1.593
+ 18	1759	1.140	-0.567	2.908	-2.859
- 18	-1753	-1.128	0.421	-2.788	2.714
+ 19	1730	1.135	-0.559	2.884	-2.798
- 19	-1754	-1.110	0.419	-2.752	2.714
+ 20	2105	2.280	-0.687	4.626	-4.504
- 20	-2166	-2.276	0.573	-4.515	4.465
+ 21	2045	2.259	-0.665	4.557	-4.539
- 21	-2098	-2.278	0.553	-4.473	4.418
+ 22	1990	2.250	-0.647	4.503	-4.485
- 22	-2068	-2.296	0.539	-4.521	4.425
+ 23	1666	1.114	-0.479	2.782	-2.660
- 23	-1696	-1.129	0.341	-2.692	2.708
+ 24	1677	1.147	-0.487	2.824	-2.678
- 24	-1724	-1.110	0.353	-2.698	2.714
+ 25	2022	2.235	-0.587	4.443	-4.211
- 25	-2140	-2.260	0.473	-4.377	4.393
+ 26	1976	2.307	-0.565	4.461	-4.301
- 26	-2070	-2.276	0.445	-4.347	4.402
+ 27	1919	2.291	-0.579	4.377	-4.271
- 27	-2039	-2.442	0.441	-4.551	4.628
+ 28	1829	1.114	-0.417	2.704	-2.416
- 28	-1950	-1.128	0.240	-2.573	2.750
+ 29	1889	1.146	-0.415	2.728	-2.416
- 29	-2013	-1.100	0.261	-2.609	2.774
+ 30	1899	2.114	-0.425	3.379	-3.645
- 30	-2136	-1.722	0.345	-3.376	3.364

1 in.-kip = 0.113 kN·m 1 in. = 25.4mm

TABLE B2 - COLUMN ROTATIONS FOR SPECIMEN LC1

CYCLE	ROTATION (RADIANS)			
	ABOVE JOINT		BELOW JOINT	
	+D	+D/2	-D	-D/2
+ 1	0.00600	0.00420	-0.00509	-0.00375
- 1	-0.00552	-0.00454	0.00347	0.00354
+ 2	0.00537	0.00416	-0.00490	-0.00347
- 2	-0.00466	-0.00375	0.00272	0.00310
+ 3	0.01242	0.01029	-0.01053	-0.00813
- 3	-0.00929	-0.00750	0.00564	0.00533
+ 4	0.01166	0.00984	-0.00974	-0.00752
- 4	-0.00983	-0.00788	0.00695	0.00643
+ 5	0.01177	0.00953	-0.00946	-0.00748
- 5	-0.00932	-0.00771	0.00612	0.00568
+ 6	0.01166	0.00980	-0.00957	-0.00775
- 6	-0.00949	-0.00784	0.00623	0.00574
+ 7	0.01135	0.00953	-0.00941	-0.00756
- 7	-0.00963	-0.00795	0.00636	0.00585
+ 8	0.01118	0.00939	-0.00920	-0.00736
- 8	-0.00966	-0.00791	0.00630	0.00588
+ 9	0.02319	0.02360	-0.01570	-0.01331
- 9	-0.02396	-0.01929	0.01675	0.00994
+ 10	0.01794	0.01540	-0.00958	-0.00889
- 10	-0.02008	-0.01524	0.00872	0.00774
+ 11	0.02157	0.01825	-0.01194	-0.00983
- 11	-0.01850	-0.01517	0.00815	0.00741
+ 12	0.02319	0.01834	-0.01211	-0.01024
- 12	-0.01600	-0.01476	0.00805	0.00723
+ 13	0.05316	0.04626	-0.01627	-0.01395
- 13	-0.05092	-0.04094	0.01094	0.01099
+ 14	0.05100	0.04529	-0.01557	-0.01343
- 14	-0.05163	-0.04214	0.01103	0.01005
+ 15	0.05152	0.04556	-0.01557	-0.01354
- 15	-0.05229	-0.04256	0.01084	0.01001
+ 16	0.01291	0.01268	-0.00857	-0.00756
- 16	-0.01394	-0.01183	0.00392	0.00420
+ 17	0.01332	0.01244	-0.00841	-0.00754
- 17	-0.01367	-0.01175	0.00427	0.00473
+ 18	0.02799	0.02554	-0.01139	-0.00968
- 18	-0.02753	-0.02290	0.00774	0.00734
+ 19	0.02778	0.02549	-0.01114	-0.00980
- 19	-0.02733	-0.02298	0.00784	0.00733
+ 20	0.05875	0.05315	-0.01374	-0.01234
- 20	-0.05865	-0.04816	0.01019	0.00945
+ 21	0.05819	0.05286	-0.01347	-0.01203
- 21	-0.05949	-0.05064	0.00991	0.00929
+ 22	0.05843	0.05298	-0.01340	-0.01173
- 22	-0.05947	-0.05186	0.00961	0.00881
+ 23	0.02766	0.02583	-0.00980	-0.00841
- 23	-0.02873	-0.02695	0.00638	0.00607
+ 24	0.02878	0.02607	-0.00969	-0.00837
- 24	-0.02626	-0.02654	0.00656	0.00616
+ 25	0.05747	0.05266	-0.01144	-0.00959
- 25	-0.05900	-0.05332	0.00846	0.00763
+ 26	0.05903	0.05311	-0.01127	-0.00957
- 26	-0.06096	-0.05444	0.00803	0.00731
+ 27	0.05837	0.05178	-0.01102	-0.00949
- 27	-0.06579	-0.05912	0.00764	0.00726
+ 28	0.02685	0.02439	-0.00722	-0.00579
- 28	-0.03105	-0.02817	0.00335	0.00287
+ 29	0.02696	0.02416	-0.00719	-0.00574
- 29	-0.03045	-0.02620	0.00259	0.00307
+ 30	0.05366	0.04770	-0.00696	-0.00553
- 30	-0.04714	-0.03908	0.00474	0.00445

TABLE B3 - WEST COLUMN STEEL STRAINS FOR SPECIMEN LC1

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	-741	-866	1733	-249	-	-	1726	-471	1015
- 1	1928	2076	-710	2336	-	-	-753	1799	-499
+ 2	-667	-786	1526	-233	-	-	1523	242	911
- 2	1572	1729	-591	1978	-	-	-656	2160	-419
+ 3	-1130	-1299	2719	-277	-	-	6763	-301	1726
- 3	1892	5452	-1327	8024	-	-	450	2010	-1162
+ 4	-1420	-148	2103	2020	-	-	5193	-250	1123
- 4	1918	6316	-1294	8273	-	-	536	2634	-1133
+ 5	-1415	269	1995	2330	-	-	4892	554	1053
- 5	1737	5780	-1287	7876	-	-	642	2569	-1147
+ 6	-1425	314	2030	2493	-	-	4967	-128	1072
- 6	1712	5800	-1316	7906	-	-	635	2757	-1195
+ 7	-1415	411	1935	2586	-	-	4715	410	1005
- 7	1754	6008	-1317	3116	-	-	657	2712	-1202
+ 8	-1415	497	1362	2661	-	-	4529	2561	953
- 8	2253	6454	-742	8560	-	-	1243	3502	-647
+ 9	-1387	-2655	6319	2989	-	-	8140	-2537	1776
- 9	2970	12366	85	14520	-	-	1180	12237	-917
+ 10	-1076	-464	3824	3195	-	-	5050	12711	1174
- 10	2654	9875	252	12130	-	-	1213	17917	-862
+ 11	-1238	-912	4382	3211	-	-	5575	3919	1372
- 11	2516	9023	321	11471	-	-	1214	13992	-859
+ 12	-1195	-688	4490	3294	-	-	5669	2692	1464
- 12	2536	8608	400	11336	-	-	1271	-	-805
+ 13	-1605	-2513	6435	2605	-	-	8236	-850	1889
- 13	9322	22193	316	26234	-	-	1316	17117	-929
+ 14	-817	-1615	5906	2812	-	-	7514	463	1736
- 14	3599	21115	19	26462	-	-	1353	9311	-943
+ 15	-731	-1130	5798	3034	-	-	7361	-1274	1702
- 15	8807	21352	313	26978	-	-	1263	7133	-1079
+ 16	-59	1372	2783	5760	-	-	4098	843	340
- 16	2382	6155	599	10940	-	-	1436	3576	-921
+ 17	-147	1159	2734	5457	-	-	3970	-	323
- 17	2941	6045	604	10767	-	-	1432	3764	-911
+ 18	-1700	-1329	2694	3402	-	-	3936	-1573	-66
- 18	3791	9259	-697	13842	-	-	143	3325	-2071
+ 19	-1775	-1277	2507	3506	-	-	3716	-1273	-139
- 19	3675	9150	-698	13541	-	-	137	3267	-2055
+ 20	-2647	-3162	3261	1527	-	-	4422	-4306	152
- 20	7393	20542	-914	24163	-	-	-19	2356	-2173
+ 21	-2576	-1984	3155	6027	-	-	4313	-	211
- 21	7241	20182	-918	22298	-	-	-20	-	-2163
+ 22	-2517	-947	2972	9369	-	-	4155	-	175
- 22	7205	20303	-837	21253	-	-	19	-	-2143
+ 23	-2105	757	1534	11333	-	-	2743	-	-516
- 23	3084	10154	-878	16774	-	-	-116	-	-2111
+ 24	-2174	513	1523	11697	-	-	2652	-	-601
- 24	2849	9666	-1029	16419	-	-	-252	-	-2230
+ 25	6310	-	1702	9068	-	-	2325	-	-540
- 25	7055	-	-1347	18473	-	-	-491	-	-2459
+ 26	12278	-	1609	11984	-	-	2761	-	-536
- 26	6277	-	-1304	17946	-	-	-430	-	-2424
+ 27	44265	-	1569	25273	-	-	2723	-	-531
- 27	9992	-	-1265	25791	-	-	-371	-	-2331
+ 28	44165	-	94	26636	-	-	963	-	-1510
- 28	33573	-	-1651	30267	-	-	-1051	-	-2531
+ 29	44332	-	-47	16383	-	-	694	-	-1457
- 29	-37200	-	-1749	57545	-	-	-1093	-	-2517
+ 30	-	-	-	-	-	-	-	-	-
- 30	-	-	-	-	-	-	-	-	-

TABLE B4 - EAST COLUMN STEEL STRAINS FOR SPECIMEN LC1

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	1510	1824	1835	1844	516	49	-558	-589	-554
- 1	-675	902	-887	-304	437	1353	1368	1761	1309
+ 2	1427	1617	1657	1606	495	56	-502	-509	-528
- 2	-581	242	-785	-267	325	1094	1176	1394	1065
+ 3	1939	6309	8271	8622	783	241	-654	-967	-990
- 3	-1442	279	-81	2370	149	1913	1610	2109	1277
+ 4	1473	5658	7089	7814	453	103	-989	-1167	-1248
- 4	-1432	320	-41	2956	355	7160	2063	3160	1390
+ 5	1380	5441	6726	7602	385	3607	-885	-963	-1243
- 5	-1432	447	61	2928	50	6204	1777	2850	1107
+ 6	1418	5596	6927	7774	390	3763	-695	-476	-1252
- 6	-1458	446	91	2981	30	5160	1750	2899	1085
+ 7	1468	5407	6522	7553	365	3802	-895	-374	-1242
- 7	-1391	456	111	3075	26	6249	1778	3036	1124
+ 8	1340	5264	6405	7396	344	3823	-908	-339	-1243
- 8	-847	1055	673	3668	590	6307	2363	3547	1651
+ 9	2325	13304	14951	15219	1134	4597	-582	-17	-905
- 9	-1339	242	-733	4616	630	8479	6434	7220	1936
+ 10	1854	8271	7897	10793	802	3895	430	1700	-799
- 10	-1272	281	-1450	4410	453	7275	4691	6174	1663
+ 11	2088	9925	10627	12175	902	4053	342	2041	-677
- 11	-1287	448	-1300	4400	403	6965	4251	6352	1555
+ 12	2197	10263	10413	12453	989	4192	397	2238	-610
- 12	-1226	632	-1108	4542	442	6963	4204	6265	1601
+ 13	8839	24104	25968	27730	1498	4596	268	1873	-866
- 13	-835	840	-4835	6247	497	8672	6475	7554	2047
+ 14	8685	23660	23151	28066	1580	4697	444	1932	-920
- 14	-752	4955	-2749	7112	346	9438	5665	7574	1374
+ 15	8708	24023	22762	28760	1531	4830	493	2223	-949
- 15	-762	22217	-571	8177	159	8185	5509	7148	1682
+ 16	3168	49972	6224	13498	593	3220	682	2140	-1048
- 16	-112	50574	2115	8352	-529	4260	2674	4103	99
+ 17	3073	54415	6029	13081	420	3197	578	2594	-1050
- 17	-122	57194	2106	8731	-499	4321	2658	4399	137
+ 18	3980	52671	9483	16465	-125	2573	-571	1503	-2095
- 18	-1759	62875	-613	6505	-1275	4635	2599	4417	-115
+ 19	3759	59316	9213	15917	-160	2601	-659	1387	-2103
- 19	-1760	76267	-788	6282	-1251	4611	2516	4466	-95
+ 20	5902	40555	21513	38452	147	2835	-928	1042	-2273
- 20	-2619	87539	-3053	5980	-1230	5659	3293	5143	259
+ 21	6995	60710	19005	29088	241	2931	-806	1326	-2155
- 21	-2801	98588	-1342	7834	-1329	5289	2972	4903	136
+ 22	6861	76831	17600	29305	271	3005	-802	1314	-2115
- 22	-2817	96696	17098	8939	-1336	5169	2825	4952	127
+ 23	2871	55895	8893	18556	-407	1983	-1032	1321	-2149
- 23	-2428	77319	24478	9367	-1699	3103	1410	3325	-698
+ 24	2811	51276	8965	18085	-455	1983	-1119	1135	-2145
- 24	-2625	64253	33252	9072	-1794	3037	1283	3282	-776
+ 25	5364	64439	14782	26439	-236	2080	-1492	818	-2419
- 25	14093	78629	50901	2366	-1974	3345	1470	3566	-646
+ 26	5383	46483	30686	28269	-202	2041	-1419	931	-2364
- 26	36343	54698	62601	9610	-2034	3066	1316	3413	-719
+ 27	5495	60005	31714	28145	-153	2050	-1334	1008	-2283
- 27	73202	31948	69670	10526	-2070	2890	1221	3320	-754
+ 28	78418	43367	60623	17544	-1078	-183	-2112	96	-2606
- 28	-	55277	89559	3853	-2867	-615	-665	1155	-1598
+ 29	83990	54964	84115	15591	-1167	-1172	-2275	-15	-2564
- 29	-	55406	-	7315	-2347	-1549	-751	1238	-1524
+ 30	-	-	-	-	-	-	-	-	-
- 30	-	-	-	-	-	-	-	-	-

TABLE B5 - TOP COLUMN HOOP STRAINS FOR SPECIMEN LC1

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	25	119	30	-12	109	13
- 1	-133	117	-257	-119	62	-28
+ 2	9	124	-483	-26	127	7
- 2	-74	138	-383	-75	103	-2
+ 3	-116	513	11	-143	303	-120
- 3	-475	-52	-410	-557	-149	-435
+ 4	-452	159	-617	-479	-42	-477
- 4	-433	-32	-584	-571	-138	-439
+ 5	-461	139	-676	-482	-36	-437
- 5	-438	-47	-628	-565	-119	-448
+ 6	-476	138	-595	-491	-32	-503
- 6	-476	-67	-577	-587	-134	-474
+ 7	-490	115	-721	-502	-46	-517
- 7	-476	-62	-683	-599	-129	-493
+ 8	-506	99	-750	-517	-55	-537
- 8	31	469	-166	-104	405	67
+ 9	193	755	-156	112	599	-65
- 9	6	680	-71	-93	439	88
+ 10	124	517	-262	73	478	-105
- 10	41	537	-103	-30	365	88
+ 11	115	531	-226	62	504	-125
- 11	55	533	-113	-26	346	99
+ 12	179	666	-143	133	581	-59
- 12	94	553	-59	35	383	128
+ 13	421	1527	1318	239	1214	-194
- 13	193	977	37	294	869	257
+ 14	450	1453	33	137	1154	-408
- 14	340	925	-132	251	836	134
+ 15	299	1371	-39	84	1000	-539
- 15	253	794	-312	213	807	-8
+ 16	370	558	330	259	595	-135
- 16	318	607	158	541	437	188
+ 17	331	537	338	239	557	-260
- 17	327	510	251	546	482	167
+ 18	-610	-27	-352	-785	-206	-1253
- 18	-800	-282	-621	-572	-326	-609
+ 19	-643	-57	-338	-801	-211	-1243
- 19	-737	-292	-537	-578	-325	-601
+ 20	-746	466	-127	-888	107	-1394
- 20	-654	-17	-706	-574	78	-525
+ 21	-640	569	305	-755	209	-1341
- 21	-644	-11	-779	-574	112	-658
+ 22	-579	592	508	-701	245	-1361
- 22	-604	22	-	-559	161	-684
+ 23	-237	-45	548	-476	118	-1356
- 23	-404	33	-451	-303	-55	-676
+ 24	-183	-26	516	-499	111	-1337
- 24	-506	-76	-457	-444	-179	-857
+ 25	-255	362	392	-672	130	-1633
- 25	-	10	-	-568	161	-999
+ 26	-	3926	1227	-568	313	-1653
- 26	-	153	-	-622	253	-1023
+ 27	-	-	-	-509	415	-1640
- 27	-	-	-	-622	1025	-1009
+ 28	-	-	-	233	1540	-1146
- 28	-	-	-	204	4647	-133
+ 29	-	-	-	381	5250	-1130
- 29	-	-	-	362	4890	-472
+ 30	-	-	-	-	-	-
- 30	-	-	-	-	-	-

TABLE B6 - BOTTOM COLUMN HOOP STRAINS FOR SPECIMEN LC1

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	-	-	-	-	709	879
- 1	-	-	-	-	-163	-184
+ 2	-	-	-	-	-106	-355
- 2	-	-	-	-	264	-361
+ 3	-	-	-	-	94	1129
- 3	-	-	-	-	541	401
+ 4	-	-	-	-	325	1728
- 4	-	-	-	-	-249	1578
+ 5	-	-	-	-	-43	2100
- 5	-	-	-	-	-116	1396
+ 6	-	-	-	-	-118	1629
- 6	-	-	-	-	-81	1253
+ 7	-	-	-	-	-109	1345
- 7	-	-	-	-	45	1877
+ 8	-	-	-	-	68	1336
- 8	-	-	-	-	554	2028
+ 9	-	-	-	-	448	-
- 9	-	-	-	-	303	-
+ 10	-	-	-	-	402	-
- 10	-	-	-	-	586	-
+ 11	-	-	-	-	313	-
- 11	-	-	-	-	540	-
+ 12	-	-	-	-	426	-
- 12	-	-	-	-	647	-
+ 13	-	-	-	-	490	-
- 13	-	-	-	-	640	-
+ 14	-	-	-	-	482	-
- 14	-	-	-	-	613	-
+ 15	-	-	-	-	445	-
- 15	-	-	-	-	480	-
+ 16	-	-	-	-	225	-
- 16	-	-	-	-	350	-
+ 17	-	-	-	-	144	-
- 17	-	-	-	-	319	-
+ 18	-	-	-	-	-777	-
- 18	-	-	-	-	-732	-
+ 19	-	-	-	-	-879	-
- 19	-	-	-	-	-777	-
+ 20	-	-	-	-	-960	-
- 20	-	-	-	-	-807	-
+ 21	-	-	-	-	-905	-
- 21	-	-	-	-	-825	-
+ 22	-	-	-	-	-916	-
- 22	-	-	-	-	-819	-
+ 23	-	-	-	-	-830	-
- 23	-	-	-	-	-806	-
+ 24	-	-	-	-	-800	-
- 24	-	-	-	-	-896	-
+ 25	-	-	-	-	-855	-
- 25	-	-	-	-	-785	-
+ 26	-	-	-	-	-723	-
- 26	-	-	-	-	-625	-
+ 27	-	-	-	-	-589	-
- 27	-	-	-	-	-792	-
+ 28	-	-	-	-	-189	-
- 28	-	-	-	-	-403	-
+ 29	-	-	-	-	-20	-
- 29	-	-	-	-	-85	-
+ 30	-	-	-	-	-	-
- 30	-	-	-	-	-	-

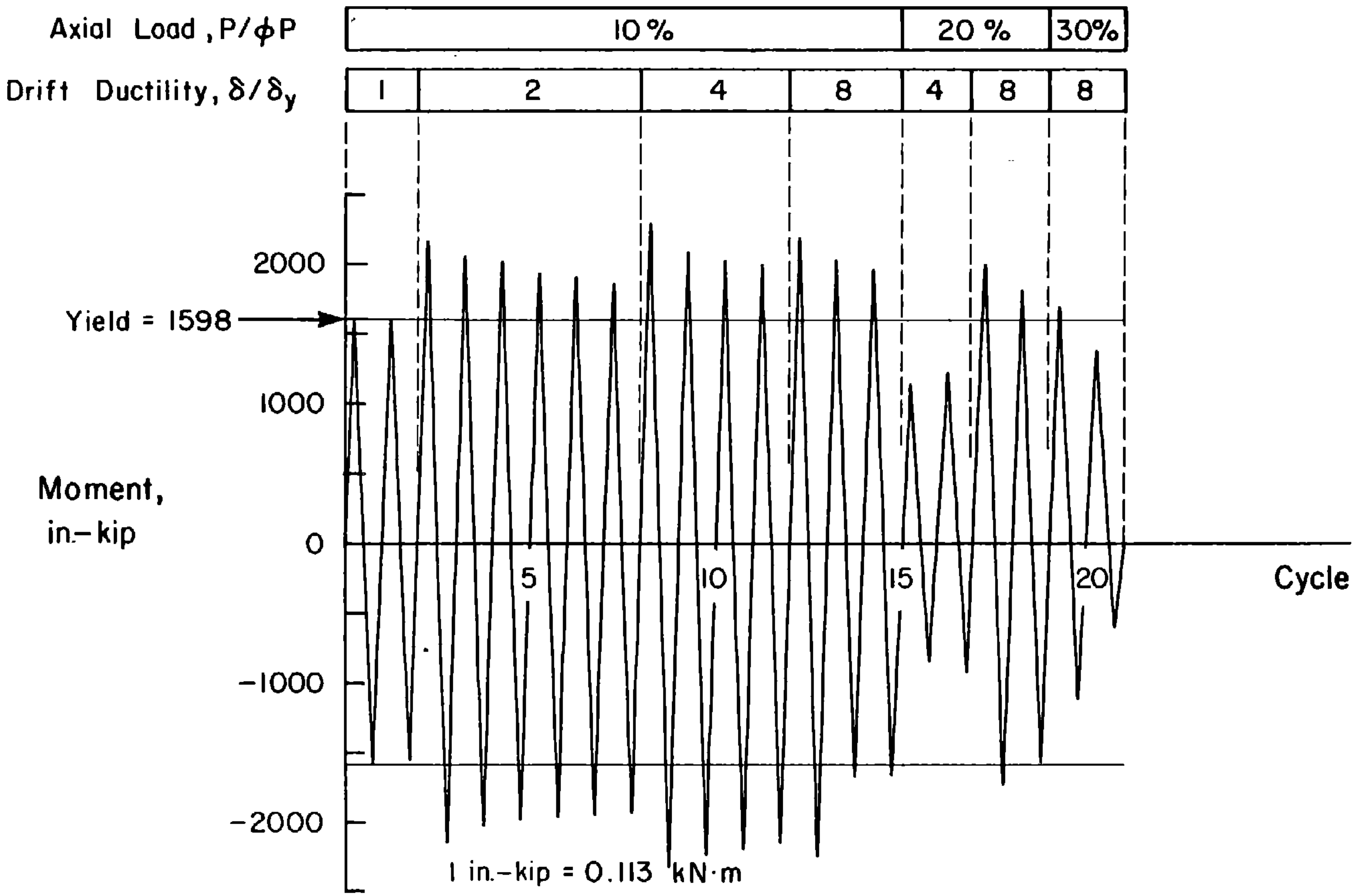
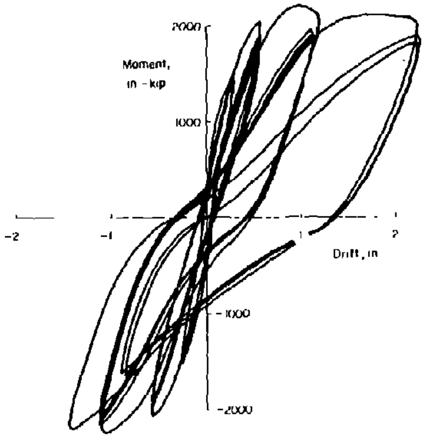
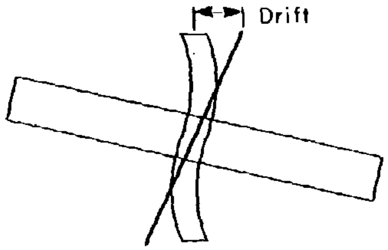
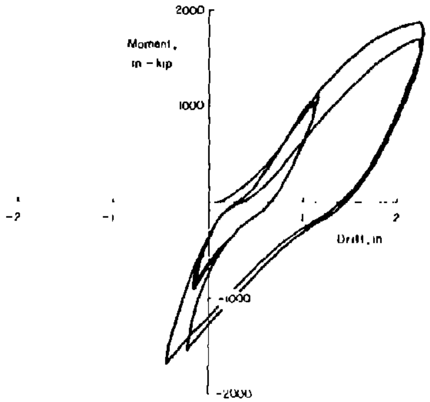


Fig. B7 Column Moment History for Specimen LC3

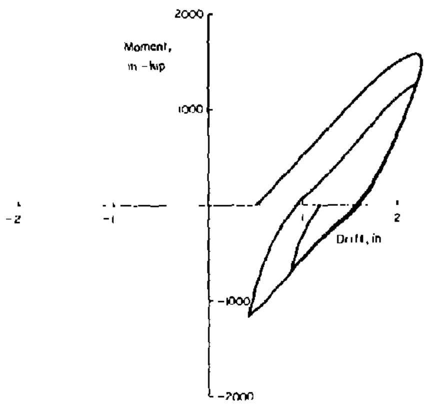




(a) P=10%P_o



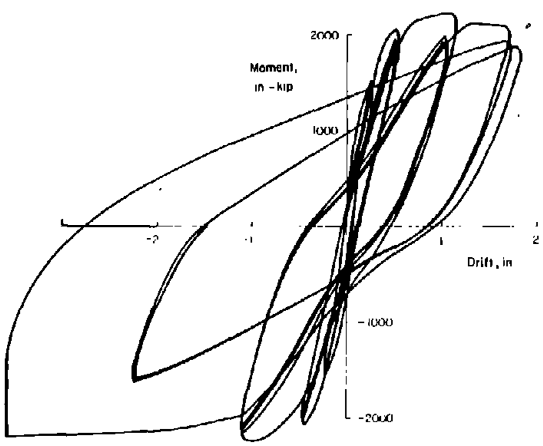
(b) P=20%P_o

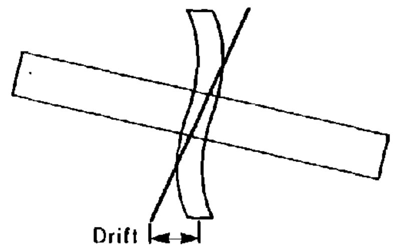


(c) P=30%P_o

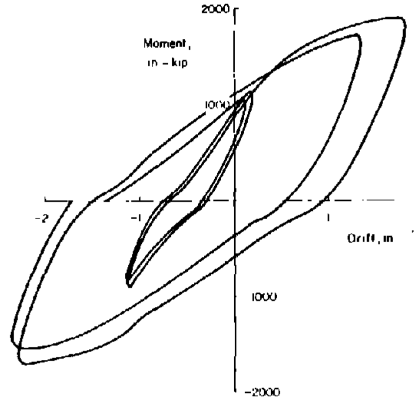
1 in.-kip = 0.113 kN·m
1 in. = 25.4 mm

Fig. B8 Top Column Moment versus Drift for Specimen LC3

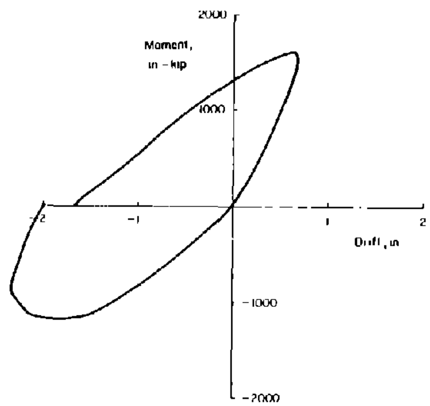




(a) $P=10\%P_o$



(b) $P=20\%P_o$



(c) $P = 30\%P_o$

1 in.-kip = 0.113 kN·m
1 in. = 25.4 mm

Fig. B9 Bottom Column Moment versus Drift for Specimen LC3

incurred as shown in Fig. B9(a). Following Cycle 12, top column drift controlled for positive peaks and bottom column drift controlled for negative peaks. This also explains the non-symmetrical shape of the hysteresis loops.

The maximum measured column moment was 2325 in.-kip (263 kN•m). It occurred at the negative peak of Cycle 9. The calculated column nominal flexural strength was 2040 in.-kip (230 kN•m). Maximum measured column moment was approximately 14% greater than calculated. Photographs of the specimen at the end of Cycles 12 and 15 are shown in Figs. B10 and B11, respectively.

During Cycles 20 and 21, column moment capacity decreased. Bottom column corner and midside bars buckled and the 90° hook of the supplementary crosstie opened as shown in Fig. B12. Although the top column was considerably spalled, no buckling of reinforcement was observed. Due to column steel buckling, the bottom column shortened and the drift arm was rubbing against the jig that secures the drift potentiometer to the column (see Fig. A7). The test was ended. Cycle 21 is not plotted in Fig. B9(c) due to unreliable data provided by the bottom drift arm. It should be emphasized that the 90° hook started unhooking only during Cycle 20. Four large inelastic load reversals had occurred beyond those of the basic loading cycles.

Tabulated results

Tabulated values of column moment, top and bottom drifts, and east and west beam deflections recorded at cycle peaks are presented in Table B7. Peak rotations are given in Table B8. Peak steel strains are listed in Tables B9 through B12.

<u>Specimen LC4</u>

Specimen LC4 was manufactured using Lightweight Concrete 1. This specimen was similar to Specimen LC1 except one-half the amount of confining reinforcement was used. The column core was confined with No. 4 hoops spaced at 4 in. (102 mm). This corresponds to a confinement of 1.60%.

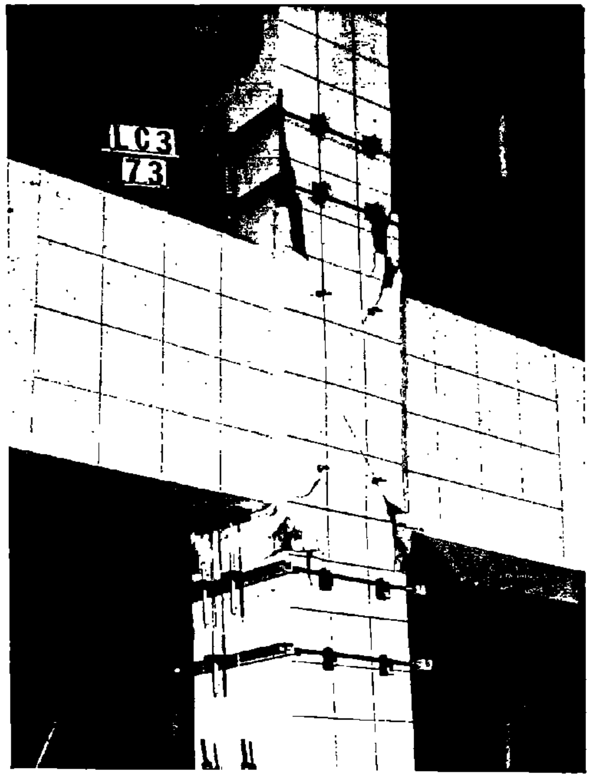


Fig. B10 Specimen LC3 after Cycle 12

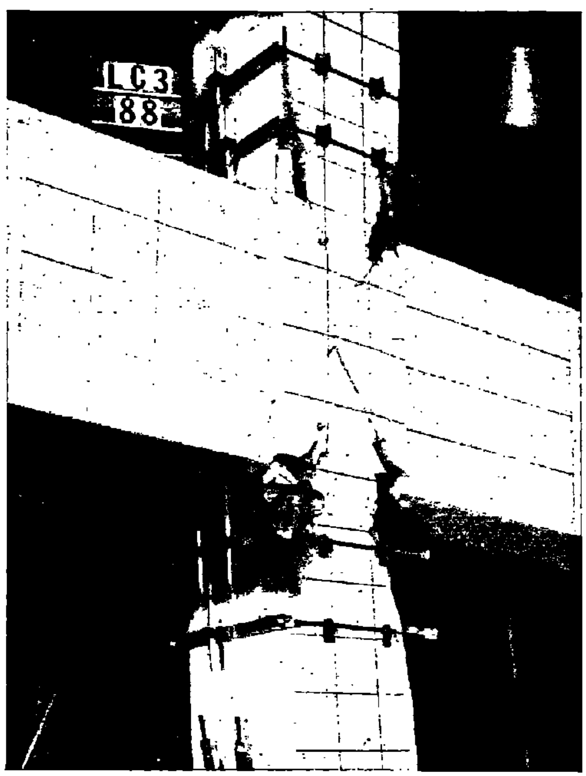


Fig. B11 Specimen LC3 after Cycle 15

Fig. B12 Unhooking of Crosstie
at End of Test

TABLE B7 - COLUMN MOMENT, COLUMN DRIFTS, AND BEAM DEFLECTIONS FOR SPECIMEN LC3

CYCLE	MOMENT IN.-KIPS	DRIFT IN.		DEFLECTION IN.	
		TOP	BOTTOM	EAST	WEST
+ 1	1593	0.233	-0.259	1.409	-1.300
- 1	-1523	-0.249	0.217	-1.169	1.250
+ 2	1604	0.239	-0.261	1.445	-1.294
- 2	-1559	-0.257	0.225	-1.153	1.252
+ 3	2168	0.587	-0.523	2.313	-2.169
- 3	-2150	-0.547	0.459	-2.151	2.147
+ 4	2056	0.593	-0.503	2.269	-2.171
- 4	-2035	-0.541	0.444	-2.093	2.081
+ 5	2013	0.597	-0.518	2.260	-2.165
- 5	-1934	-0.547	0.438	-2.075	2.061
+ 6	1983	0.577	-0.495	2.199	-2.102
- 6	-1966	-0.547	0.441	-2.069	2.067
+ 7	1907	0.574	-0.490	2.183	-2.070
- 7	-1951	-0.549	0.448	-2.069	2.061
+ 8	1962	0.576	-0.500	2.165	-2.046
- 8	-1939	-0.549	0.442	-2.063	2.052
+ 9	2293	1.171	-1.117	3.759	-3.740
- 9	-2326	-1.099	1.067	-3.777	3.553
+ 10	2085	1.119	-1.041	3.455	-3.603
- 10	-1237	-1.115	1.088	-3.807	3.510
+ 11	2025	1.122	-1.035	3.463	-3.551
- 11	-2199	-1.117	1.025	-3.753	3.507
+ 12	1995	1.131	-1.029	3.478	-3.585
- 12	-2152	-1.117	1.085	-3.736	3.495
+ 13	2193	2.229	-1.680	5.709	-5.852
- 13	-2249	-1.444	3.713	-7.539	7.084
+ 14	2037	2.254	-1.706	5.582	-5.387
- 14	-1677	-0.386	2.229	-4.327	4.485
+ 15	1964	2.244	-1.906	5.325	-5.751
- 15	-1666	-0.634	2.213	-4.737	4.405
+ 16	1141	1.138	-0.125	2.195	-2.046
- 16	-947	-0.113	1.119	-1.649	1.939
+ 17	1211	1.165	-0.194	2.330	-2.171
- 17	-833	-0.138	1.113	-1.979	1.954
+ 18	1995	2.274	-1.758	5.357	-5.911
- 18	-1732	-0.421	2.229	-4.101	3.972
+ 19	1814	2.258	-1.335	5.442	-5.195
- 19	-1571	-0.200	2.275	-3.752	3.744
+ 20	1695	2.251	-0.550	4.675	-4.221
- 20	-1119	0.469	2.190	-1.898	2.733
+ 21	1330	2.213	1.781	3.023	-2.155
- 21	-605	0.912	2.143	-1.649	2.134

1 in.-kip = 0.113 kN·m   1 in. = 25.4mm

TABLE B8 - COLUMN ROTATIONS FOR SPECIMEN LC3

CYCLE	ROTATION (RADIANS)			
	ABOVE JOINT		BELOW JOINT	
	+D	+D/2	+D	+D/2
+ 1	0.00248	0.00232	-0.00243	-0.00254
- 1	-0.00553	-0.00228	0.00196	0.00265
+ 2	0.00320	0.00378	-0.00322	-0.00340
- 2	-0.00435	-0.00388	0.00399	0.00414
+ 3	0.00645	0.00834	-0.00791	-0.00778
- 3	-0.01068	-0.00956	0.00896	0.00796
+ 4	0.00845	0.00859	-0.00805	-0.00783
- 4	-0.01083	-0.00967	0.00882	0.00782
+ 5	0.00835	0.00962	-0.00812	-0.00784
- 5	-0.01057	-0.00953	0.00869	0.00775
+ 6	0.00800	0.00820	-0.00788	-0.00746
- 6	-0.01050	-0.00967	0.00879	0.00792
+ 7	0.00779	0.00817	-0.00784	-0.00736
- 7	-0.01050	-0.00967	0.00889	0.00796
+ 8	0.00775	0.00813	-0.00794	-0.00732
- 8	-0.01052	-0.00967	0.00875	0.00792
+ 9	0.02226	0.01963	-0.02236	-0.01979
- 9	-0.02320	-0.01946	0.02387	0.01834
+ 10	0.02216	0.01918	-0.02096	-0.01882
- 10	-0.02353	-0.01928	0.02439	0.01956
+ 11	0.02219	0.01949	-0.02067	-0.01812
- 11	-0.02321	-0.01889	0.02427	0.01983
+ 12	0.02237	0.01935	-0.02083	-0.01811
- 12	-0.02311	-0.01858	0.02413	0.01973
+ 13	0.05163	0.03710	-0.03779	-0.03349
- 13	-0.03041	-0.02417	0.05654	0.04658
+ 14	0.05297	0.04139	-0.03907	-0.03592
- 14	-0.01734	-0.01441	0.05538	0.04455
+ 15	0.05276	0.04163	-0.04215	-0.04009
- 15	-0.01603	-0.01317	0.05614	0.04504
+ 16	0.02579	0.02285	-0.00977	-0.00989
- 16	0.00072	-0.00043	0.02753	0.02059
+ 17	0.02542	0.02303	-0.00174	-0.01142
- 17	0.00016	-0.00074	0.02730	0.02236
+ 18	0.05554	0.04525	-0.04173	-0.04341
- 18	-0.00531	-0.00650	0.05959	0.04751
+ 19	0.05615	0.04602	-0.02891	-0.03145
- 19	-0.00081	-0.00169	0.05200	0.05147
+ 20	0.05777	0.04789	-0.01096	-0.01274
- 20	0.01532	0.01270	0.06199	0.05579
+ 21	0.05422	0.04589	0.01962	0.02087
- 21	0.02691	0.02313	0.06492	0.06453

TABLE B9 - WEST COLUMN STEEL STRAINS FOR SPECIMEN LC3

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	-	-754	-933	-433	533	1931	1400	1711	1600
- 1	-	1871	1931	2397	501	-251	-647	-763	-543
+ 2	-	-752	-737	-318	500	1934	1499	1745	1630
- 2	-	1962	1818	2419	541	-239	-593	-761	-643
+ 3	-	-594	-1007	-102	1034	8651	4359	5645	3472
- 3	-	8050	3482	9700	1049	3050	-132	574	-931
+ 4	-	1082	519	2599	815	8750	4355	6556	2313
- 4	-	7884	8210	9615	979	3513	-13	333	-393
+ 5	-	1279	561	3058	750	8755	4305	5468	2169
- 5	-	7746	8326	9565	352	3708	48	951	-386
+ 6	-	1441	788	3272	559	8427	4255	6066	2145
- 6	-	7730	7992	9563	341	3801	68	579	-889
+ 7	-	1511	833	3297	618	8315	3977	5959	2103
- 7	-	7697	7942	9555	390	3865	93	1005	-915
+ 8	-	1553	878	3501	579	8283	3934	5394	3066
- 8	-	7595	7941	9502	512	3915	133	1024	-883
+ 9	-	1148	-1322	3671	833	15015	10267	13368	5975
- 9	-	13474	15802	16533	1254	4532	-35	183	-35
- 10	-	735	-1905	4734	754	15013	10134	12133	5513
- 10	-	13503	15302	15938	1235	5191	563	353	133
+ 11	-	937	-1775	5473	711	15059	9361	13078	5477
- 11	-	13299	14893	17035	1220	5429	575	441	173
+ 12	-	1045	-1607	5967	565	15080	9691	11929	5433
- 12	-	13215	14773	17202	1200	5649	759	523	213
+ 13	-	-1815	-10926	6167	731	21371	15313	19161	9516
- 13	-	16751	17056	20579	1373	5157	-12555	-5156	-379
+ 14	-	-2119	-3487	3537	969	25218	6656	20407	12482
- 14	-	13251	7277	16838	1116	-	-5154	-3231	480
+ 15	-	-3395	-5270	3673	931	25964	7646	18575	11877
- 15	-	9754	6405	15610	1939	-	-2850	-2202	551
- 16	-	-844	-3244	7313	-37	-	493	3933	4083
- 16	-	3335	355	10433	-153	-	-1701	-717	1001
+ 17	-	-1235	-3372	7064	-89	-	573	3040	4344
- 17	-	2236.	5	10466	-70	-	-1721	-738	943
+ 18	-	-5744	-11652	6893	580	-	5852	15671	.1564
- 18	-	4441	-1405	12535	509	-	-2578	-2011	-125
+ 19	-	-7355	-13318	6432	404	-	5586	11983	9140
- 19	-	2214	-3817	12584	416	-	-1139	-1177	47
- 20	-	-3758	-14307	4490	-151	-	1892	6133	5674
- 20	-	-3355	-3195	8630	-524	-	-632	-1563	233
+ 21	-	-10039	-14273	3946	-516	-	700	1342	3071
- 21	-	-5748	-10932	6519	-316	-	-421	-3551	757

TABLE B10 - EAST COLUMN STEEL STRAINS FOR SPECIMEN LC3

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	1330	1758	1737	1867	584	-259	-765	-713	-595
- 1	-641	-686	-747	-309	422	1603	1523	1573	1353
+ 2	1455	1840	1825	1942	691	-211	-740	-739	-584
- 2	-637	-682	-741	-303	455	1532	1534	1550	1272
+ 3	2125	7854	5459	9275	1053	101	-956	-982	-790
- 3	-851	1171	-423	3109	759	3823	2612	5567	3311
+ 4	2043	7877	6092	10410	974	4105	-1255	301	-734
- 4	-853	1423	-283	3838	628	6557	2469	5297	2132
+ 5	2003	7314	6239	10451	952	4532	-1275	426	-785
- 5	-847	1590	-180	4125	556	8441	2418	5161	2133
+ 6	1905	7292	5946	10059	907	4589	-1275	535	-764
- 6	-851	1615	-160	4238	514	8392	2399	5106	2115
+ 7	1866	7236	5359	9946	867	4784	-1285	573	-758
- 7	-847	1644	-131	4416	511	8358	2379	5057	2096
+ 8	1822	7138	5818	9898	877	4845	-1290	503	-756
- 8	-848	1677	-103	4532	471	8296	2351	5009	2067
+ 9	2356	13322	.5703	17403	1223	4915	-1730	41	-914
- 9	-1059	691	919	5521	923	15351	15816	11050	4200
+ 10	2166	12368	15091	17052	1055	4530	-1076	105	-430
- 10	-1081	1064	948	6201	438	15028	-	11072	4321
+ 11	2142	12216	15090	17120	1051	5240	-	166	-439
- 11	-1110	1178	950	6488	562	16019	-	10833	4308
+ 12	2123	12126	15097	17222	1041	5755	-	380	-425
- 12	-1120	1289	1033	6814	517	16114	-	10725	4265
+ 13	13393	21551	28731	28917	1318	6239	-	-1099	-753
- 13	-153	2188	2146	9850	655	43674	-	22949	-
+ 14	13198	-	27025	28853	1067	10713	-	-5322	-507
- 14	616	3236	3393	11996	486	-	-	13435	-
+ 15	12920	-	25943	28664	1024	11210	-	-5727	-579
- 15	857	3758	3906	13270	570	-	-	9268	11584
+ 16	5697	-	10344	17930	54	13399	-	-3517	1950
- 16	1259	4459	4120	11787	-546	-	-	725	5152
+ 17	5805	-	10431	17039	44	13672	-	-4131	1910
- 17	1142	4283.	3666	11337	-501	-	-	421	5036
+ 18	11156	-	23521	25544	594	9440	-	-10201	-2037
- 18	799	4445	3941	11580	326	-	-	6392	23363
+ 19	10778	-	21977	24542	529	10390	-	-9406	-344
- 19	1136	5396	3917	12254	397	-	-	4914	5773
+ 20	9911	-	19518	22259	175	10665	-	-9859	699
- 20	1363	-	6469	13122	-232	-	-	-1303	6380
+ 21	9769	-	16964	20097	53	11943	-	-9013	1395
- 21	3921	-	10094	14043	-468	-	-	-4499	4418

TABLE B11 - TOP COLUMN HOOP STRAINS FOR SPECIMEN LC3

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	-42	-22	172	-	262	413
- 1	-64	175	232	-	508	377
+ 2	-75	-1	277	-	331	526
- 2	-105	197	438	-	583	300
+ 3	-71	592	507	-	590	1191
- 3	-126	748	903	-	1516	492
+ 4	-54	703	571	-	651	1266
- 4	-126	699	880	-	1394	427
+ 5	-51	710	570	-	548	1262
- 5	-123	589	374	-	1354	486
- 6	-44	580	555	-	519	1213
- 6	-120	590	865	-	1334	462
+ 7	-42	674	550	-	610	1201
- 7	-116	689	858	-	1321	491
+ 8	-31	620	547	-	610	1191
- 8	-110	639	854	-	1296	491
+ 9	-45	1183	771	-	1448	1622
- 9	-97	1340	1192	-	1929	821
+ 10	27	1407	805	-	1341	1625
- 10	16	1551	1195	-	1731	923
- 11	52	1379	802	-	1316	1613
- 11	20	1523	1179	-	1645	960
- 12	49	1370	803	-	1307	1507
- 12	23	1502	1170	-	1585	962
+ 13	661	2170	1322	-	1991	1716
- 13	162	1865	1314	-	1789	1019
+ 14	735	2327	1151	-	1913	1416
- 14	391	1465	1299	-	1040	824
+ 15	573	2436	1128	-	1829	1300
- 15	476	1411	1294	-	1007	828
- 16	530	1126	691	-	793	503
- 16	609	887	461	-	321	403
- 17	525	1314	707	-	780	529
- 17	637	906	501	-	369	426
+ 18	505	4053	1170	-	2136	1172
- 18	755	2502	1068	-	1187	330
+ 19	545	4240	1216	-	2125	1128
- 19	371	3050	1059	-	1343	317
+ 20	834	7331	1373	-	2234	1072
- 20	1286	6211	951	-	1756	791
- 21	775	7053	1338	-	2139	1033
- 21	1199	6371	956	-	1898	691

TABLE B12 - BOTTOM COLUMN HOOP STRAINS FOR SPECIMEN LC3

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	13	1925	50	-78	142	-3
- 1	-59	-1087	184	12	126	36
+ 2	4	239	129	-87	183	32
- 2	-61	-347	200	2	113	47
+ 3	-5	2787	596	15	793	322
- 3	-15	785	442	15	302	282
+ 4	13	5391	522	51	799	410
- 4	9	1104	463	24	293	312
+ 5	23	5988	520	65	799	433
- 5	10	1393	474	22	294	321
+ 6	14	6152	595	70	754	414
- 6	-	1551	453	30	295	325
+ 7	22	6419	590	59	755	413
- 7	8	1673	488	30	293	327
+ 8	22	6705	581	45	766	410
- 8	8	1879	487	36	294	331
+ 9	49	13425	994	125	1739	663
- 9	-31	4137	923	114	1126	586
+ 10	98	13798	998	220	1545	707
- 10	26	5306	997	164	1144	629
+ 11	97	13637	1023	228	1487	711
- 11	23	5351	1014	152	1146	653
+ 12	78	13575	1018	233	1452	714
- 12	12	5264	1024	142	1150	664
+ 13	145	14527	1343	298	2120	1112
- 13	1546	13068	1577	556	2684	1635
+ 14	549	18835	1862	430	3179	1047
- 14	744	19012	941	642	1951	1151
+ 15	596	19078	1745	446	2293	1057
- 15	683	19275	921	597	1822	1115
+ 16	759	19118	620	744	1384	501
- 16	872	18570	604	774	1191	514
+ 17	754	19941	588	817	1396	492
- 17	863	18579	609	790	1237	647
+ 18	953	18437	1373	917	2707	1156
- 18	1294	19657	1402	1399	1932	1205
+ 19	1042	18481	1325	1219	2615	1123
- 19	1191	20314	1333	1799	2220	1108
+ 20	1104	19904	1310	1553	-	956
- 20	-1257	19977	1197	2500	-	970
+ 21	154	17932	1094	1510	-	299
- 21	-1192	19782	1026	2442	-	77

Column moment history

The column was subjected to 25-1/2 cycles of moment reversals as shown in Fig. B13. The test began with an axial load equal to 10% of the column design strength. This column axial load was maintained constant throughout the basic loading cycles. Subsequently, column axial load was increased to 20%, 30%, and 60% of the column design strength and additional cycles of moment reversals were applied.

Column moment versus drift relationships

Top column moment versus drift relationships are presented in Fig. B14. The first positive peak column moment was 1611 in.-kip (182 kN·m). It occurred at a top column drift of 0.28 in. (7.1 mm). The corresponding bottom column drift was 0.25 in. (6.4 mm). Bottom column moment versus drift relationships are shown in Fig. B15. A comparison of Figs. B14 and B15 indicates that hinging occurred in the top column throughout the test.

The maximum measured moment was 2216 in.-kip (250 kN·m). It occurred at the positive peak of Cycle 13. The calculated nominal flexural strength was 2040 in.-kip (230 kN·m). Therefore, maximum measured moment was approximately 9% greater than calculated. Photographs of Specimen LC4 at the end of Cycles 12 and 15 are shown in Figs. B16 and B17, respectively.

In the top column, the main midside bar on the compression face buckled during Cycle 25. The 90° hook in the supplementary crosstie also was observed to open. During the first half of Cycle 26, the moment capacity dropped when a drift ductility of 8 was imposed on the column. The test was ended after completion of the first half of Cycle 26.

Tabulated results

Tabulated values of column moment, top and bottom column drifts, and east and west beam deflections are listed in Table B13. Column rotations are presented in Table B14. Reinforcement strains for column steel and confinement steel are shown in Tables B15 through B18.

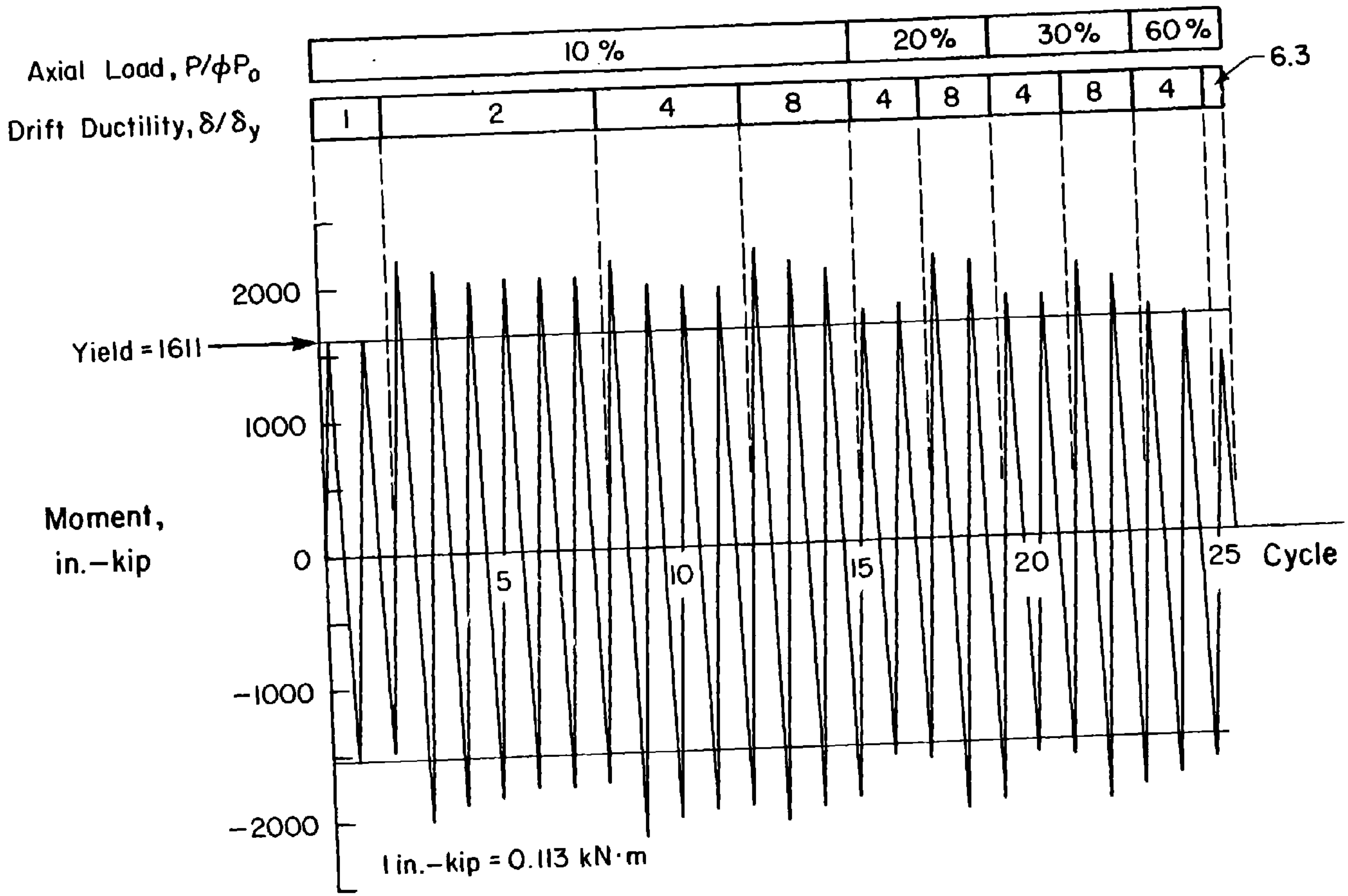
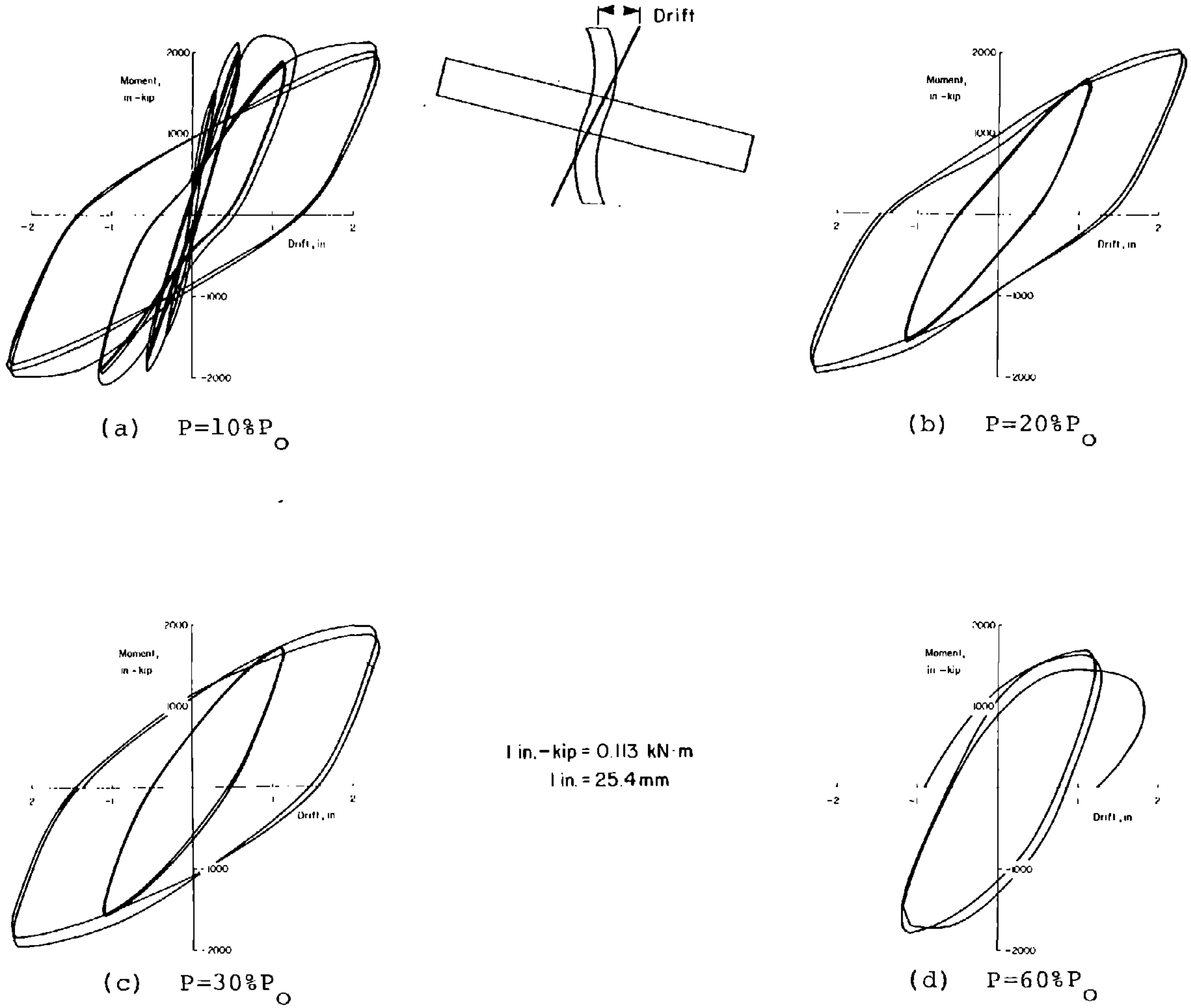


Fig. B13 Column Moment History for Specimen LC4



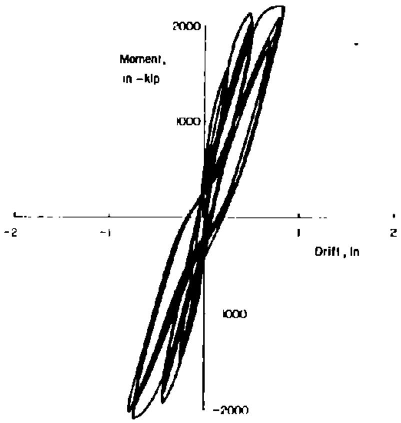
(a) P=10%P_o

(b) P=20%P_o

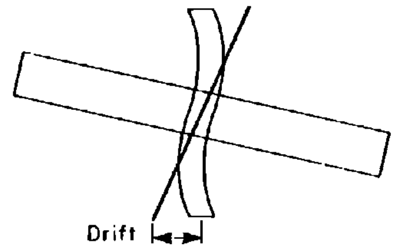
(c) P=30%P_o

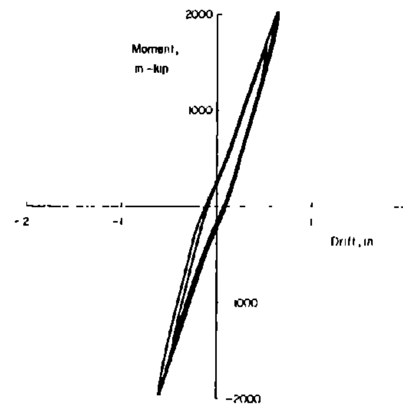
(d) P=60%P_o

Fig. B14 Top Column Moment versus Drift for Specimen LC4

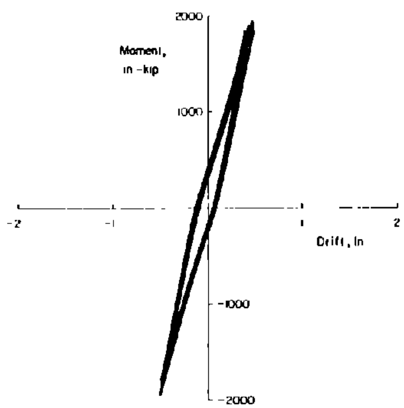


(a) $P=10\%P_o$



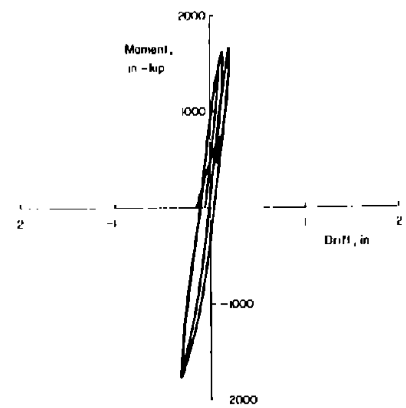


(b) $P=20\%P_o$



(c) $P=30\%P_o$

1 in.-kip = 0.113 kN·m
1 in. = 25.4 mm



(d) $P=60\%P_o$

Fig. B15 Bottom Column Moment versus Drift for Specimen LC4

Fig. B16 Specimen LC4 after Cycle 12

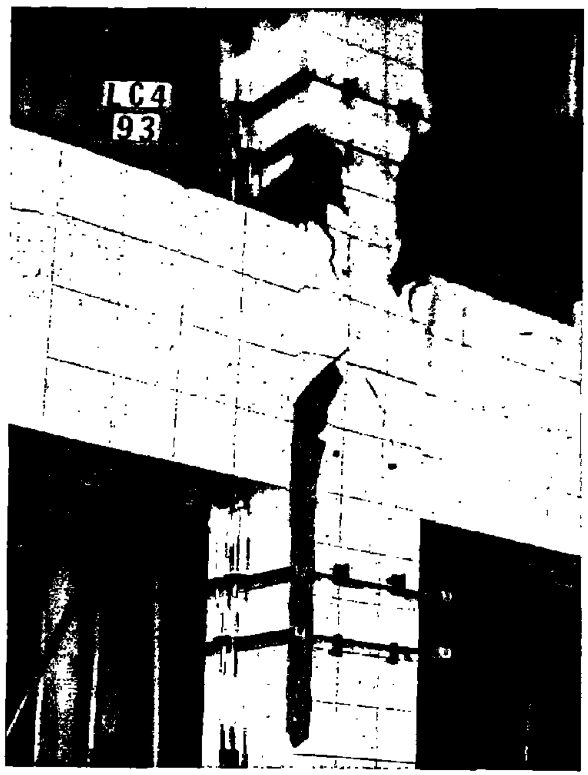


Fig. B17 Specimen LC4 after Cycle 15

TABLE B13 - COLUMN MOMENT, COLUMN DRIFTS, AND BEAM DEFLECTIONS FOR SPECIMEN LC4

CYCLE	MOMENT (IN.-KIP)	DRIFT (IN.)		DEFLECTION (IN.)	
		TOP	BOTTOM	EAST	WEST
+ 1	1611	0.381	-0.246	1.338	-1.341
- 1	-1526	-0.301	0.244	-1.312	1.319
+ 2	1603	0.399	-0.232	1.356	-1.365
- 2	-1481	-0.287	0.238	-1.300	1.307
+ 3	2206	0.579	-0.504	2.177	-2.284
- 3	-2014	-0.561	0.446	-2.007	2.117
+ 4	2117	0.584	-0.494	2.323	-2.272
- 4	-1895	-0.561	0.437	-1.971	2.057
+ 5	2027	0.575	-0.430	2.287	-2.219
- 5	-1842	-0.555	0.431	-1.929	2.033
+ 6	2044	0.592	-0.507	2.323	-2.278
- 6	-1781	-0.541	0.422	-1.869	1.979
+ 7	2043	0.601	-0.513	2.353	-2.314
- 7	-1783	-0.549	0.424	-1.893	1.996
+ 8	2036	0.610	-0.519	2.371	-2.330
- 8	-1752	-0.541	0.419	-1.857	1.972
+ 9	2156	1.248	-0.824	3.554	-3.574
- 9	-2169	-1.133	0.755	-3.165	3.187
+ 10	1969	1.141	-0.699	3.222	-3.238
- 10	-2030	-1.127	0.726	-3.105	3.107
+ 11	1954	1.153	-0.691	3.218	-3.274
- 11	-1981	-1.125	0.716	-3.088	3.098
+ 12	1935	1.156	-0.689	3.237	-3.268
- 12	-1957	-1.127	0.710	-3.082	3.111
+ 13	2216	2.274	-0.858	4.898	-5.037
- 13	-2080	-2.254	0.788	-4.700	4.729
+ 14	2114	2.257	-0.818	4.828	-4.959
- 14	-1984	-2.276	0.738	-4.730	4.724
+ 15	2048	2.333	-0.799	4.850	-4.983
- 15	-1919	-2.270	0.704	-4.670	4.737
+ 16	1735	1.148	-0.529	2.954	-2.920
- 16	-1609	-1.115	0.462	-2.819	2.926
+ 17	1766	1.161	-0.521	2.969	-2.944
- 17	-1650	-1.137	0.472	-3.243	2.957
+ 18	2128	2.289	-0.665	4.697	-4.713
- 18	-2033	-2.274	0.612	-4.575	4.712
+ 19	2072	2.335	-0.637	4.730	-4.737
- 19	-1972	-2.302	0.596	-4.575	4.701
+ 20	1806	1.152	-0.445	2.956	-2.948
- 20	-1621	-1.105	0.373	-2.699	2.876
+ 21	1804	1.155	-0.419	2.902	-2.800
- 21	-1649	-1.099	0.369	-2.747	2.861
+ 22	2039	2.291	-0.484	4.539	-4.443
- 22	-1992	-2.234	0.514	-4.366	4.372
+ 23	1927	2.313	-0.426	4.500	-4.183
- 23	-1892	-2.255	0.504	-4.275	4.437
+ 24	1708	1.187	-0.218	2.880	-2.594
- 24	-1814	-1.145	0.219	-2.365	2.738
+ 25	1549	1.223	-0.145	2.747	-2.440
- 25	-1711	-1.113	0.269	-2.341	2.558
+ 26	1310	1.763	-0.095	3.145	-2.794
- 26	1330	1.763	-0.095	3.145	-2.794

1 in.-kip = 0.113 kN·m   1 in. = 25.4mm

TABLE B14 - COLUMN ROTATIONS FOR SPECIMEN LC4

CYCLE	ROTATION RADIANS			
	ABOVE JOINT		BELOW JOINT	
	+D	-D/2	-D	-D/2
+ 1	0.00534	0.00372	-0.00525	-0.00373
- 1	-0.00667	-0.00437	0.00526	0.00307
+ 2	0.00657	0.00432	-0.00531	-0.00429
- 2	-0.00671	-0.00431	0.00529	0.00313
+ 3	0.01310	0.00911	-0.01095	-0.00855
- 3	-0.01235	-0.00909	0.00938	0.00653
- 4	0.01352	0.00941	-0.01086	-0.00907
- 4	-0.01236	-0.00923	0.00922	0.00642
+ 5	0.01312	0.00935	-0.01064	-0.00994
- 5	-0.01213	-0.00912	0.00901	0.00528
+ 6	0.01351	0.00958	-0.01097	-0.00929
- 6	-0.01132	-0.00887	0.00880	0.00614
+ 7	0.01361	0.00975	-0.01111	-0.00946
- 7	-0.01201	-0.00905	0.00886	0.00615
- 8	0.01397	0.00999	-0.01123	-0.00955
- 8	-0.01186	-0.00894	0.00875	0.00617
+ 9	0.03127	0.02160	-0.01565	-0.01510
- 9	-0.02582	-0.02106	0.01510	0.01288
+ 10	0.02942	0.02124	-0.01585	-0.01377
- 10	-0.02589	-0.02075	0.01547	0.01242
+ 11	0.02979	0.02139	-0.01579	-0.01377
- 11	-0.02593	-0.02072	0.01530	0.01246
- 12	0.03003	0.02171	-0.01563	-0.01363
- 12	-0.02528	-0.02137	0.01525	0.01242
+ 13	0.06125	0.04389	-0.01902	-0.01575
- 13	-0.05731	-0.04491	0.01747	0.01453
+ 14	0.05999	0.04596	-0.01828	-0.01627
- 14	-0.05916	-0.04720	0.01690	0.01404
+ 15	0.05979	0.04730	-0.01780	-0.01594
- 15	-0.05945	-0.04826	0.01633	0.01357
- 16	0.02919	0.02587	-0.01252	-0.01175
- 16	-0.02999	-0.02426	—	0.00895
+ 17	0.02995	0.02526	-0.01239	-0.01197
- 17	-0.03035	-0.02511	0.01077	0.00915
+ 18	0.05992	0.05090	-0.01513	-0.01422
- 18	-0.06107	-0.05130	0.01408	0.01137
- 19	0.06189	0.05463	-0.01475	-0.01393
- 19	-0.06148	-0.05216	0.01379	0.01119
+ 20	0.03068	0.02921	-0.01081	-0.01103
- 20	-0.03081	-0.02486	0.00932	0.00729
- 21	0.03054	0.02976	-0.01041	-0.01071
- 21	-0.03052	-0.02444	0.00949	0.00795
- 22	0.06169	0.05779	-0.01171	-0.01189
- 22	-0.06065	-0.04963	0.01154	0.00904
+ 23	0.06291	0.06007	-0.01069	-0.01125
- 23	-0.05981	-0.04784	0.01103	0.00856
+ 24	0.03334	0.03537	-0.00603	-0.00673
- 24	-0.02923	-0.02193	0.00659	0.00422
- 25	0.03451	0.03531	-0.00499	-0.00529
- 25	-0.02962	-0.02188	0.00625	0.00405
+ 26	0.04711	0.04661	-0.00273	-0.00416
- 26	0.04711	0.04661	-0.00273	-0.00416

TABLE B15 - WEST COLUMN STEEL STRAINS FOR SPECIMEN LC4

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	-537	-651	-834	-338	481	514	1303	1334	908
- 1	1642	3203	3258	3189	1599	2358	-53	631	710
+ 2	-702	-543	-767	-350	553	677	2403	1359	958
- 2	464	1517	1796	1758	375	-1138	126	-542	-498
+ 3	-422	-306	-1022	-154	1040	5093	8124	2136	1443
- 3	768	3423	3060	8340	873	1852	2604	-927	-594
+ 4	-570	-357	-1277	2710	893	4412	9391	2042	1352
- 4	908	3707	3369	9218	882	324	7699	-377	-554
+ 5	-480	-196	-1283	3131	786	2652	10032	1952	1291
- 5	1491	4635	4333	9023	1851	1487	6100	173	513
+ 6	-	938	-234	4434	1857	3164	9603	3134	2512
- 6	1328	4583	4323	3891	1935	450	5654	241	634
+ 7	208	953	-243	4539	1819	3166	10004	3138	2509
- 7	1352	4614	4387	3939	1931	105	7024	232	634
+ 8	50	990	-146	4630	1814	4234	10445	3150	2513
- 8	1251	4568	4376	3859	1913	318	9082	254	553
+ 9	-32	-722	-8463	4457	1947	5305	13579	4906	2591
- 9	1953	10152	16185	13547	2330	2314	11534	31	502
+ 10	-159	-138	-6591	4369	1643	4027	13001	4350	2482
- 10	1429	9759	14766	13024	2264	4772	14193	31	488
+ 11	-53	-52	-6763	4701	1613	3860	14036	4389	2474
- 11	1837	9735	14318	13015	2253	719	15564	47	488
+ 12	-58	-92	-6829	4784	1452	3744	13760	4259	2333
- 12	1425	9617	13872	13013	2179	652	15347	-46	372
+ 13	-	-555	-17599	5034	1580	-	-	5597	2351
- 13	-	15991	20323	30230	2664	-	-	15	292
+ 14	-	-101	-12272	5329	1414	-	-	5493	3394
- 14	-	16435	13844	32596	2575	-	-	133	320
+ 15	-	16514	6957	-	17519	-	-	22342	20670
- 15	-	15943	10522	-	2702	-	-	203	312
+ 16	-	17575	13230	-	17209	-	-	20340	20279
- 16	-	8447	4021	-	1365	-	-	129	325
+ 17	-	15023	11600	-	15540	-	-	18927	18717
- 17	-	8443	1920	-	1959	-	-	122	400
+ 18	-	13388	5121	-	14213	-	-	17929	17389
- 18	-	14354	5979	-	2377	-	-	-61	431
+ 19	-	1978	-1863	-	9110	-	-	11924	11437
- 19	-	15700	7993	-	6658	-	-	4460	5304
+ 20	-	6022	2470	-	4437	-	-	5948	6372
- 20	-	9539	2787	-	2690	-	-	1215	1751
+ 21	-	3211	-311	-	1604	-	-	3952	3171
- 21	-	9140	2535	-	2632	-	-	1186	1739
+ 22	-	1893	224	-	1574	-	-	4062	3158
- 22	-	16974	4951	-	5356	-	-	2139	4131
+ 23	-	5135	2003	-	4131	-	-	6552	5243
- 23	-	24413	11517	-	12369	-	-	10177	10378
+ 24	-	15554	10684	-	11200	-	-	12341	12330
- 24	-	19157	11544	-	11895	-	-	10519	10918
+ 25	-	3645	-	-	-300	-	-	1163	1554
- 25	-	18232	-	-	12352	-	-	11427	11771
+ 26	-	3915	-	-	-548	-	-	550	654
- 26	-	3915	-	-	-548	-	-	550	675

TABLE B16 - EAST COLUMN STEEL STRAINS FOR SPECIMEN LC4

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	1428	1934	1351	2203	624	-402	-369	-781	-626
- 1	677	548	-	941	1743	3433	3024	2606	2536
+ 2	1481	1970	4156	2207	750	-394	-851	-757	-619
- 2	-540	-610	1745	-547	486	1933	1633	1431	1177
+ 3	2169	9583	9584	11230	1205	-334	-1205	-1045	-640
- 3	-370	1932	2845	9020	759	9452	3540	2295	1957
+ 4	2141	9713	9347	11707	1168	3363	-667	-1023	-914
- 4	-360	2015	3336	9785	635	9149	3905	2142	1914
+ 5	2147	9297	9835	11394	1081	3765	-802	-1014	-794
- 5	136	3142	4135	5077	1533	9966	4771	3023	2779
+ 6	3266	10615	10049	12744	2134	4979	320	47	353
- 6	212	3355	4291	5322	1516	9588	4699	3008	2790
+ 7	3261	10740	10125	12909	2167	5053	319	31	340
- 7	231	3447	4128	5575	1512	9662	4695	3003	2774
+ 8	3251	10820	10147	13051	2188	5099	315	27	345
- 8	207	3555	4389	5759	1489	9571	4635	2978	2743
+ 9	4252	15319	14483	18635	2391	5074	-513	-100	288
- 9	-130	1465	3671	5986	1700	12561	11700	9058	3160
+ 10	4089	13805	13015	17359	2194	3893	144	1453	199
- 10	-171	1323	3154	6200	1493	12277	10756	9136	3034
+ 11	4069	13785	13050	18125	2160	4077	242	1537	132
- 11	-190	1337	3113	6361	1423	12216	10416	8177	2976
+ 12	3963	13579	12982	18370	2068	4356	206	1582	53
- 12	-302	1309	3099	6469	1255	12044	10199	7955	2831
+ 13	12266	-	18233	41457	2362	4913	40	1528	-3
- 13	529	531	-1555	7369	1127	13533	11682	8974	2941
+ 14	12381	-	13227	39743	2571	5487	331	1779	21
- 14	685	457	-2515	6016	1017	13186	10851	8399	2833
+ 15	28597	-	25919	40605	13626	21946	16871	18354	16351
- 15	806	436	-2111	3329	375	12720	10133	7857	2740
+ 16	23038	37415	20677	30025	17986	20675	16778	18346	16344
- 16	918	4751	-393	2003	409	8702	5502	5219	1357
+ 17	21481	25695	19013	27461	16540	19416	15198	15843	15360
- 17	845	4792	-456	957	455	8915	5438	5219	2044
+ 18	23682	33820	19956	32153	15561	18217	13393	15158	13870
- 18	129	3304	-4565	-6224	475	10127	6837	5972	2289
+ 19	18291	23791	12721	24414	10699	13566	8839	10405	9441
- 19	4317	2482	1206	-8409	4679	14236	10814	10045	6704
+ 20	10466	13904	6853	7430	5824	7651	3914	5640	4134
- 20	1491	2150	35	-10733	1244	7581	4738	5299	2794
+ 21	7436	10344	4019	3165	2857	4838	948	2720	1337
- 21	1254	2070	159	-11319	1234	7729	4635	5364	2814
+ 22	12283	18971	5327	9214	3271	4930	739	2560	1171
- 22	2203	-5616	1490	-17302	3405	10585	7555	7158	5314
+ 23	13212	19350	7569	8213	6008	7541	3628	5402	4070
- 23	10403	-3691	9919	-15220	13545	17370	14526	14691	12137
+ 24	17362	10334	14058	-1362	11128	14295	10673	12617	11504
- 24	10662	-3304	12051	-17503	10511	14036	12003	12540	11384
+ 25	7260	-630	2766	-14567	1312	1160	-777	1376	154
- 25	11660	-6179	-	-17306	11212	13759	12658	14249	12533
+ 26	2534	-	-	-17282	373	387	-412	1099	-96
- 26	2534	-	-	-17282	373	387	-412	1099	-96

TABLE B17 - TOP COLUMN HOOP STRAINS FOR SPECIMEN LC4

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	-56	-15	730	-153	-30	-19
- 1	1524	1331	4443	1291	1398	1298
+ 2	-103	-27	-1133	15	-16	-41
- 2	99	-70	2044	160	70	-74
+ 3	-97	239	1258	318	21	-35
- 3	237	7	1258	465	230	139
+ 4	-132	267	5443	480	86	-30
- 4	202	41	16933	619	253	122
+ 5	-130	273	-	663	92	-30
- 5	1112	1017	-	1377	1265	1069
+ 6	906	1337	-	1539	1211	1024
- 6	1150	1076	-	1458	1327	1115
+ 7	899	1452	-	1777	1206	1009
- 7	1139	1062	-	5031	1327	1111
+ 8	905	1349	-	5876	1319	1310
- 8	1119	1065	-	3426	1326	1101
+ 9	850	1371	-	9991	1385	1512
- 9	1134	1499	-	15118	1645	1506
+ 10	614	1632	-	11523	1281	1490
- 10	1012	1430	-	16183	1508	1496
+ 11	559	1074	-	12179	1302	1515
- 11	971	1410	-	16484	1432	1487
+ 12	487	1006	-	12644	1208	1423
- 12	842	1318	-	17131	1361	1388
+ 13	132	909	-	-	1760	1854
- 13	730	1319	-	-	1001	1736
+ 14	520	844	-	-	1593	1843
- 14	568	1153	-	-	951	1741
+ 15	15615	16683	-	-	17555	17868
- 15	538	1046	-	-	1045	1747
+ 16	16618	16801	-	-	17113	17649
- 16	631	767	-	-	1301	1404
+ 17	15242	15444	-	-	15810	16299
- 17	544	797	-	-	1337	1460
+ 18	13959	14312	-	-	14721	15335
- 18	755	950	-	-	1513	2014
+ 19	9683	10026	-	-	10498	11372
- 19	4865	4975	-	-	5994	14411
+ 20	4885	5393	-	-	5136	7324
- 20	1718	1721	-	-	3117	26479
+ 21	2130	2566	-	-	2391	3190
- 21	1667	1701	-	-	3133	39363
+ 22	2505	2841	-	-	2572	11441
- 22	5838	4130	-	-	10759	29187
+ 23	5436	3327	-	-	5293	9334
- 23	11150	-	-	-	46744	3943
+ 24	15074	-	-	-	13463	13601
- 24	13193	-	-	-	14259	9211
+ 25	3636	-	-	-	2443	10571
- 25	14212	-	-	-	15193	7996
+ 26	7405	-	-	-	2653	13985
- 26	7405	-	-	-	2653	13985

TABLE B18 - BOTTOM COLUMN HOOP STRAINS FOR SPECIMEN LC4

C CLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
- 1	-78	177	196	-69	-	108
- 1	1172	1472	1424	1347	-	1432
+ 2	-132	191	330	-71	-	129
- 2	-243	80	65	-4	-	38
+ 3	266	347	485	-76	-	254
- 3	152	342	323	-38	-	58
- 4	270	368	521	-33	-	270
- 4	176	361	334	-13	-	84
- 5	266	360	511	-36	-	277
- 5	1013	1311	1325	1030	-	1072
- 6	1221	1315	1622	1135	-	1375
- 6	1091	1367	1384	1098	-	1139
- 7	1211	1309	1624	1129	-	1375
- 7	1064	1367	1382	1099	-	1140
- 8	1044	1315	1634	1135	-	1395
- 8	988	1368	1382	1099	-	1144
- 9	949	1624	1337	1165	-	1557
- 9	1288	1516	1555	1079	-	1160
- 10	1110	1535	1738	1150	-	1473
- 10	1106	1487	1545	1048	-	1147
+ 11	987	1521	1734	1161	-	1474
- 11	1106	1491	1555	1049	-	1153
+ 12	871	1409	1515	1055	-	1366
- 12	1010	1392	1451	939	-	1055
+ 13	900	1530	1567	1034	-	1394
- 13	1128	1469	1504	971	-	1059
+ 14	1012	1541	1594	1077	-	1379
- 14	1217	1443	1493	972	-	1362
- 15	16189	17451	17500	17911	-	17367
- 15	1267	1409	1478	953	-	1057
- 16	16154	17225	17133	17858	-	17051
- 16	1267	1179	1239	957	-	1025
+ 17	14721	15979	15915	16457	-	15749
- 17	1522	1210	1272	974	-	1046
- 18	13201	14569	14590	15014	-	14461
- 18	1292	1317	1359	955	-	1066
- 19	9591	10231	10381	10759	-	12362
- 19	5124	5520	5586	5419	-	5290
- 20	4802	5223	5189	5236	-	5257
- 20	1955	2259	2410	2254	-	2210
- 21	1951	2427	2395	2290	-	2474
- 21	1934	2265	2409	2245	-	2236
- 22	1916	2417	2404	2257	-	2464
- 22	4034	4584	4662	4600	-	4498
+ 23	5032	5135	5101	5129	-	5205
- 23	10925	11797	11745	11430	-	12723
+ 24	12306	13263	13252	12910	-	15123
- 24	11279	12732	12732	12314	-	14322
+ 25	5031	1574	1718	1409	-	1349
- 25	12535	13503	13461	12575	-	14939
- 25	1508	1069	1316	1042	-	1398
- 25	1508	1069	1316	1042	-	1398

Specimen LC6

Specimen LC6 was similar to Specimen LC4 in every respect. However, the column of Specimen LC6 was subjected to a higher axial load at the beginning of the test.

Column moment history

The column of Specimen LC6 was subjected to 21 cycles of moment reversals as shown in Fig. B18. The test began with a column axial load of 166 kips (738 kN) or 20% of the column design strength. Subsequent to the basic loading cycles, the column axial load was increased to 30% and 60% of the column design strength as shown in the figure.

Column moment versus drift relationships

Top and bottom column moment versus drift plots are shown in Figs. B19 and B20, respectively. Hinging was predominant in the bottom column throughout the test. In addition, considerable diagonal cracks were observed in the joint with some large ones occurring at the corners of the beam-column intersection. Pinching observed in the hysteresis loops of Fig. B19(b) is attributed to joint shear distortion.

The first positive peak column moment was 1824 in.-kip (206 kN·m). It occurred at a top column drift of 0.31 (7.8 mm). The corresponding bottom column drift was 0.22 in.(5.6 mm). The maximum recorded moment was 2477 in.-kip (280 kN·m) and occurred at the negative peak of Cycle 9. The calculated nominal flexural strength was 2290 in.-kip (259 kN·m). The maximum recorded moment was approximately 8% greater than calculated.

Photographs of Specimen LC6 at the end of Cycles 12 and 15 are shown in Figs. B21 and B22, respectively. Propagation of diagonal cracks into the joint can be seen.

Loss of moment capacity was observed during Cycle 21. At this stage the column was subjected to an applied axial load of 500 kips (2224 kN) or 60% of the design axial strength and a drift ductility of 8. No significant buckling of the main column steel was noticed. However, unhooking of the 90° bend in a

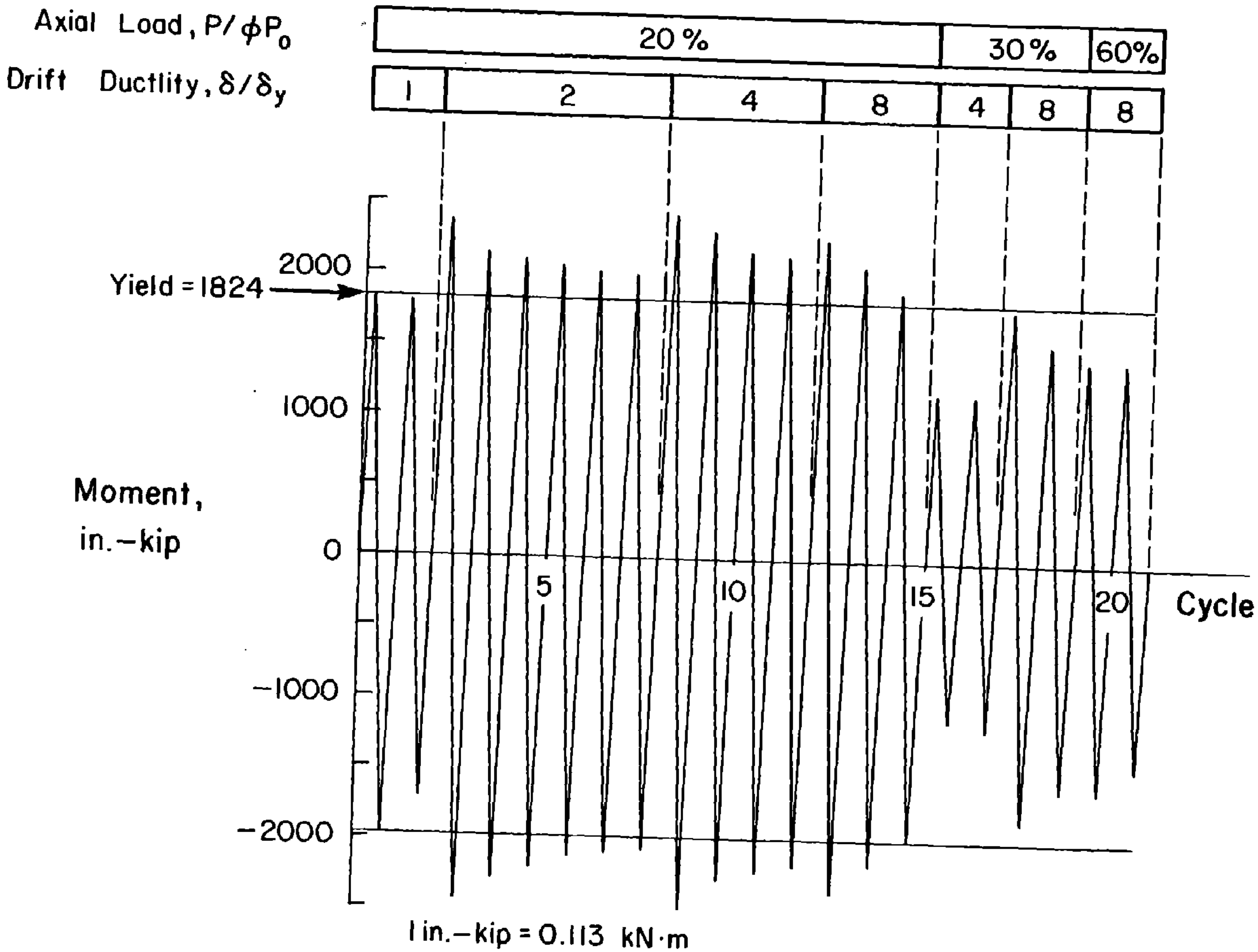
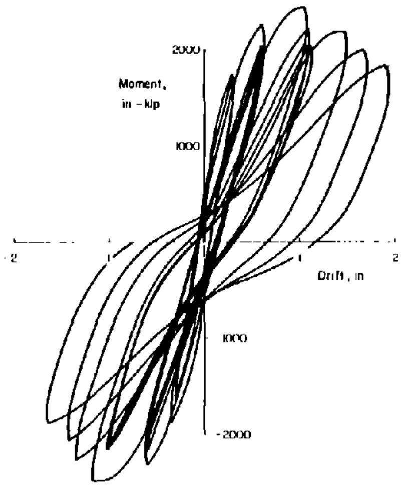
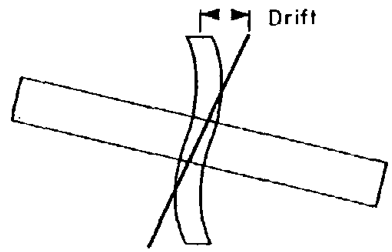
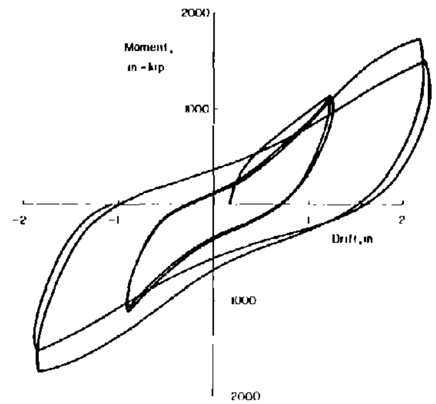


Fig. B18 Column Moment History for Specimen LC6

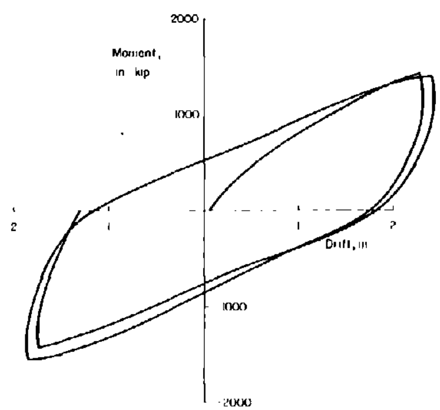


(a) P=20%P_o





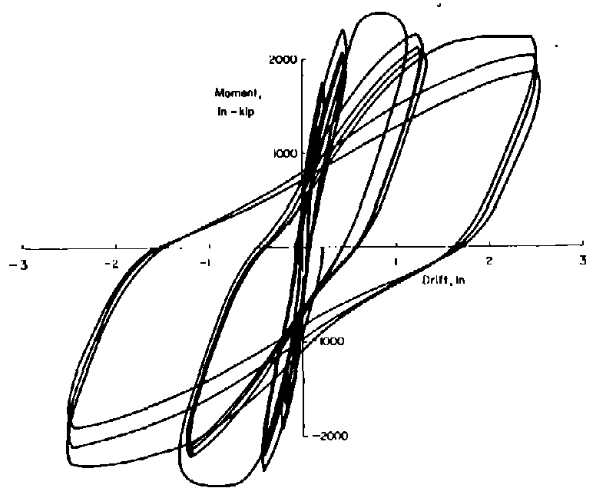
(b) P=30%P_o



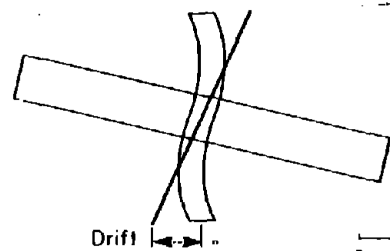
(c) P=60%P_o

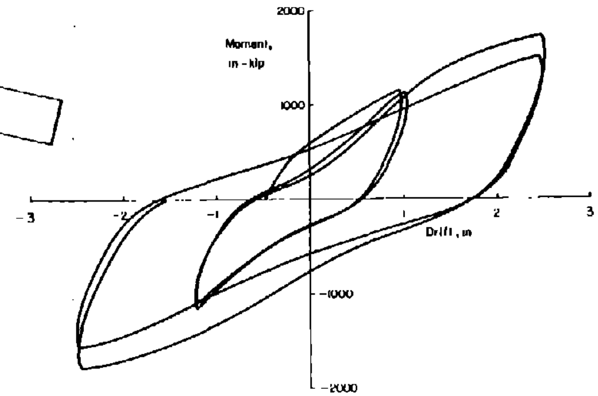
1 in.-kip = 0.113 kN·m
1 in. = 25.4 mm

Fig. B19 Top Column Moment versus Drift for Specimen LC6

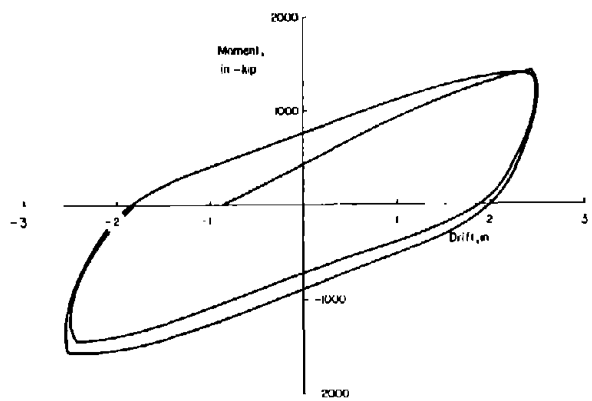


(a) P=20%P_O





(b) P=30%P_O



1 in.-kip = 0.113 kN·m
1 in. = 25.4 mm

(c) P=60%P_O

Fig. B20 Bottom Column Moment versus Drift for Specimen LC6

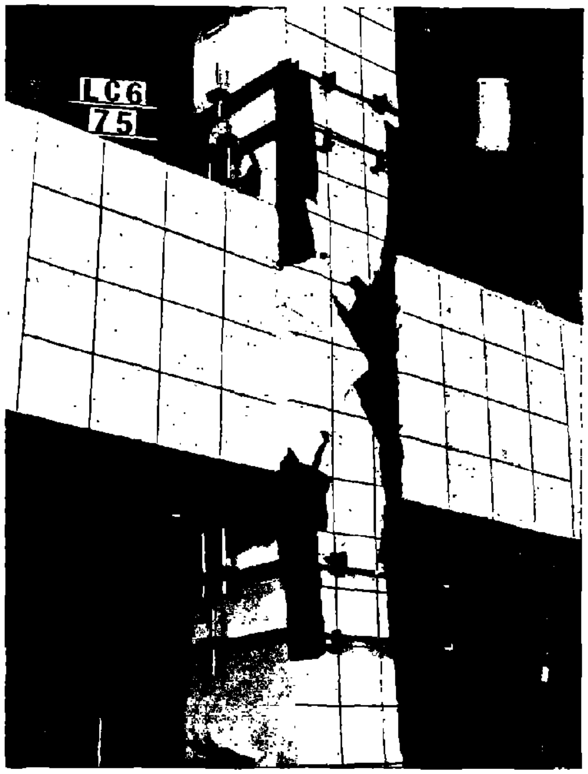


Fig. B21 Specimen LC6 after Cycle 12

Fig. B22 Specimen LC6 after Cycle 15

supplementary crosstie was observed in the bottom column during Cycle 20.

Tabulated results

Tabulated values of column moment, top and bottom column drifts, and east and west beam deflections are listed in Table B19. Column rotations above and below the joint are shown in Table B20. Reinforcement strains are presented in Tables B21 through B24.

<u>Specimen LC12</u>

Specimen LC12 had the same column steel and hoop reinforcement as Specimens LC4 and LC6. However, the column of Specimen LC12 was subjected to a higher axial load at the beginning of the test than the columns of Specimens LC4 and LC6. In addition, the column lengths were changed for Specimen LC12 to force hinging into the top column. Height of the top column was increased while that of the bottom column was decreased. As a result, the ratio of bottom column moment to top column moment was 0.74. Because of unequal column moments, sidesway of the joint was anticipated. Therefore, instrumentation was installed to measure this horizontal movement.

Column moment history

The column of Specimen LC12 was subjected to 15 cycles of moment reversals as shown in Fig. B23. The test was conducted at an applied column axial load of 250 kips (1112 kN) or 30% of the column design strength.

Column moment versus drift relationships

A plot of top column moment versus drift is shown in Fig. B24. The plotted moment excludes P-Delta effects due to horizontal joint movement. As anticipated, hinging occurred in the top column. Few cracks appeared in the bottom column and measured drift was minimal throughout the test. Therefore, the

TABLE B19 - COLUMN MOMENT, COLUMN DRIFTS, AND BEAM DEFLECTIONS FOR SPECIMEN LC6

CYCLE	MOMENT (IN.-KIP)	DRIFT (IN.)		DEFLECTION (IN.)	
		TOP	BOTTOM	EAST	WEST
+ 1 - 1	1824 -1834	0.305 -0.329	-0.323 0.342	1.517 -1.295	-1.332 1.441
+ 2 - 2	1793 -1711	0.318 -0.279	-0.230 0.210	1.514 -1.089	-1.380 1.252
+ 3 - 3	2372 -2435	0.598 -0.537	-0.461 0.441	2.401 -2.022	-2.256 2.220
+ 4 - 4	2144 -2182	0.596 -0.597	-0.439 0.423	2.266 -1.963	-2.116 2.152
+ 5 - 5	2097 -2207	0.605 -0.595	-0.441 0.413	2.254 -1.932	-2.126 2.121
+ 6 - 6	2055 -2118	0.610 -0.579	-0.439 0.401	2.251 -1.913	-2.135 2.051
+ 7 - 7	2019 -2092	0.604 -0.581	-0.427 0.399	2.224 -1.807	-2.106 2.041
+ 8 - 8	1993 -2065	0.606 -0.577	-0.429 0.399	2.220 -1.807	-2.100 2.019
+ 9 - 9	2430 -2477	1.053 -1.157	-1.063 1.295	3.811 -3.980	-3.737 3.965
+ 10 - 10	2314 -2269	1.055 -0.995	-1.238 1.215	3.971 -3.604	-3.977 3.675
+ 11 - 11	2172 -2212	1.048 -0.980	-1.228 1.223	3.915 -3.574	-3.881 3.663
+ 12 - 12	2146 -2164	1.083 -0.976	-1.279 1.230	4.025 -3.580	-3.571 3.680
+ 13 - 13	2270 -2354	1.446 -1.327	-2.457 2.473	5.915 -5.730	-6.135 5.680
+ 14 - 14	2281 -2154	1.608 -1.404	-2.465 2.475	6.243 -5.903	-6.375 5.812
+ 15 - 15	1902 -1959	1.365 -1.504	-2.493 2.460	5.572 -6.029	-5.633 6.023
+ 16 - 16	1166 -1130	1.201 -0.876	-0.946 1.230	3.560 -3.385	-3.239 3.403
+ 17 - 17	1175 -1187	1.225 -0.850	-0.956 1.230	3.626 -3.096	-3.215 3.488
+ 18 - 18	1784 -1832	2.140 -1.865	-2.465 2.455	6.793 -6.106	-6.609 6.219
+ 19 - 19	1549 -1610	2.199 -1.825	-2.437 2.474	6.779 -6.142	-6.537 6.350
+ 20 - 20	1440 -1613	2.235 -1.786	-2.423 2.461	6.595 -5.867	-6.039 6.504
+ 21 - 21	1439 -1453	2.361 -1.718	-2.417 2.455	6.692 -5.511	-5.855 6.482

1 in.-kip = 0.113 kN·m   1 in. = 25.4mm

TABLE B20 - COLUMN ROTATIONS FOR SPECIMEN LC6

CYCLE	ROTATION (RADIANS)			
	ABOVE JOINT		BELOW JOINT	
	+D	+D/2	-D	-D/2
+ 1	0.00592	0.00439	-0.00495	-0.00374
- 1	-0.00624	-0.00453	0.00481	0.00398
+ 2	0.00608	0.00462	-0.00538	-0.00410
- 2	-0.00531	-0.00413	0.00410	0.00330
+ 3	0.01132	0.00890	-0.00947	-0.00757
- 3	-0.01114	-0.00899	0.00829	0.00685
+ 4	0.01115	0.00862	-0.00916	-0.00755
- 4	-0.01138	-0.00903	0.00805	0.00668
+ 5	0.01111	0.00869	-0.00920	-0.00765
- 5	-0.01123	-0.00913	0.00795	0.00655
+ 6	0.01113	0.00867	-0.00915	-0.00764
- 6	-0.01090	-0.00886	0.00745	0.00631
+ 7	0.01098	0.00863	-0.00909	-0.00752
- 7	-0.01094	-0.00886	0.00748	0.00624
+ 8	0.01105	0.00869	-0.00910	-0.00754
- 8	-0.01090	-0.00886	0.00744	0.00624
+ 9	0.02051	0.01718	-0.02464	-0.02135
- 9	-0.02328	-0.01977	0.03066	0.02596
+ 10	0.02120	0.01755	-0.02895	-0.02512
- 10	-0.01954	-0.01704	0.02831	0.02447
+ 11	0.02058	0.01713	-0.02833	-0.02595
- 11	-0.01921	-0.01677	0.02844	0.02450
+ 12	0.02092	0.01743	-0.02930	-0.02583
- 12	-0.01911	-0.01652	0.02977	0.02473
+ 13	0.02744	0.02369	-0.05778	-0.05293
- 13	-0.02537	-0.02271	0.06104	0.05378
+ 14	0.02996	0.02672	-0.05485	-0.05045
- 14	-0.02637	-0.02409	0.05911	0.05339
+ 15	0.03284	0.02993	-0.05239	-0.04983
- 15	-0.02890	-0.02695	0.05543	0.05111
+ 16	0.02297	0.01956	-0.01789	-0.01788
- 16	-0.01517	-0.01515	0.02597	0.02597
+ 17	0.02075	0.01946	-0.01810	-0.01800
- 17	-0.01539	-0.01525	0.02590	0.02592
+ 18	0.03555	0.03345	-0.04589	-0.04448
- 18	-0.03078	-0.02952	0.05056	0.04826
+ 19	0.03615	0.03456	-0.04345	-0.04280
- 19	-0.03047	-0.02961	0.04948	0.04783
+ 20	0.03397	0.03348	-0.04101	-0.04059
- 20	-0.02833	-0.02731	0.04810	0.04828
+ 21	0.03479	0.03437	-0.03758	-0.03726
- 21	-0.02666	-0.02616	0.04771	0.04849

TABLE B21 - WEST COLUMN STEEL STRAINS FOR SPECIMEN LC6

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	-390	-1009	-963	-444	-36	1581	1456	1361	1033
- 1	1343	1901	1517	2108	317	-202	-1010	-761	-835
+ 2	-344	-1009	-919	-456	6	1638	1444	1373	1053
- 2	1348	1496	1288	1677	254	-245	-917	-373	-813
+ 3	-1020	-1251	-1159	-281	423	7281	4035	2350	1833
- 3	1735	2880	3065	9155	656	3318	-639	-1226	-1117
+ 4	-963	-1139	-1019	2331	210	5797	3752	1956	1583
- 4	1719	2826	3411	9006	336	3239	-603	-1174	-1058
+ 5	-954	-1124	-978	2754	112	6639	3595	1903	1536
- 5	1555	2745	3387	8830	316	3334	-552	-1153	-1335
+ 6	-939	-1126	-976	2916	42	6467	3466	1840	1480
- 6	1552	2595	3199	8341	754	3280	-499	-1125	-1011
+ 7	-935	-1114	-964	2957	-7	6279	3273	1770	1419
- 7	1548	2537	3184	8249	737	3334	-473	-1117	-1003
+ 8	-933	-1105	-964	3116	-31	6251	3342	1755	1403
- 8	1519	2542	3138	8128	719	3269	-452	-1112	-995
+ 9	-1165	-1517	-1663	2993	153	11323	13173	8849	2180
- 9	2106	10114	12490	15402	952	3147	-8394	-4060	-1744
+ 10	-978	-391	-973	3139	134	13994	10236	6899	2185
- 10	1900	7759	9573	13076	746	3721	-8107	-3265	-1803
+ 11	-934	-346	-885	3375	16	13573	7958	8583	3095
- 11	1326	7230	9092	12823	647	3991	-7956	-3219	-1347
+ 12	-937	-220	-851	3603	-76	13751	7240	8639	2074
- 12	1783	7131	3918	12852	607	4087	-7827	-3101	-1862
+ 13	-946	-372	-779	4645	312	22443	14471	16881	2657
- 13	1367	9373	11031	16523	524	6218	-16675	-4103	-2272
+ 14	-910	-63	-31	10209	333	21602	3461	14945	2654
- 14	1674	7125	9719	18964	383	5393	-14211	-3569	-1964
+ 15	-328	131	453	27700	365	19825	-2357	13610	3477
- 15	1527	6258	18475	41352	379	3966	-11506	-1908	5181
+ 16	895	558	193	14361	-441	11373	-5979	7134	5665
- 16	1862	2728	3754	49004	-144	4017	-5411	517	3425
+ 17	5702	538	-20	16914	-497	10458	-7097	4346	10415
- 17	4116	2759	3821	40873	-105	3699	-9389	-244	9762
+ 18	4946	-9	3	23385	103	14604	-5517	12615	15639
- 18	4366	4316	19760	32176	235	-555	-10192	-1579	30649
+ 19	7623	338	398	25646	119	12553	-6132	10394	21534
- 19	2959	3437	7521	94444	137	-2123	-9672	-1501	31030
+ 20	11374	17457	-1055	17797	-740	6005	-7051	4463	37396
- 20	12759	1716	2230	73139	-1048	-13717	-10093	-3350	-
+ 21	14606	81255	-344	-15770	-4577	-2776	-7904	2849	56833
- 21	13854	23319	1517	24971	-5005	-12676	-10047	-3597	43946

TABLE B22 - EAST COLUMN STEEL STRAINS FOR SPECIMEN LC6

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	-305	1833	1700	1970	315	-365	-1009	-944	-895
- 1	-307	-947	-909	-433	211	1554	1114	1254	1031
+ 2	49	1793	1776	1873	359	-369	-975	-933	-997
- 2	-53	-860	-549	-556	124	1173	890	959	767
+ 3	-256	5760	8088	8934	914	-160	-1332	-1219	-1151
- 3	49	119	559	2159	379	4365	2303	2042	1774
+ 4	-53	5338	7380	8270	918	1315	-1301	-1136	-1063
- 4	-307	278	537	2352	265	4441	2095	1857	1587
+ 5	-257	5226	7192	8120	917	1398	-1304	-1125	-1057
- 5	100	365	594	2454	179	4289	2015	1775	1510
+ 6	49	5130	7035	8035	915	1405	-1318	-1123	-1059
- 6	-2	421	725	2440	118	4023	1866	1639	1382
+ 7	-53	4972	6786	7802	836	1401	-1315	-1112	-1049
- 7	-307	398	686	2438	34	3959	1838	1611	1355
- 8	-206	4931	6735	7753	883	1401	-1314	-1110	-1041
- 8	-206	419	693	2442	59	3899	1801	1573	1322
- 9	-104	10442	11295	12651	1133	1135	-3031	-1930	-1321
- 9	-205	384	-522	3099	275	14027	15336	11688	1499
- 10	304	9796	11549	13304	376	,3005	-10777	-1318	-1511
- 10	-52	785	-412	3164	145	13514	11825	10560	2331
- 11	-205	9642	10512	12725	651	3525	-10998	-1144	-1544
- 11	-205	948	-422	3277	102	13834	10969	10380	2285
+ 12	-205	9528	10380	12875	545	3745	-11307	-1060	-1573
- 12	-409	703	-389	3400	74	14113	10550	10223	2246
- 13	-307	10109	13851	16835	490	3522	-21074	-1600	-1715
- 13	-358	348	-281	4433	345	29045	24494	-	3387
- 14	-104	9106	11952	17807	208	4379	-17244	-	-1529
- 14	-307	1086	17	4702	123	38113	30045	-	7544
- 15	-409	7990	11195	18857	92	4549	-14491	-	-1199
- 15	-409	1214	231	4839	58	26821	14643	-	5313
- 16	-2	4250	5895	11693	-192	4186	-4951	-	-671
- 16	49	1616	437	1824	-814	12301	2073	-	2512
+ 17	-256	4177	5516	9832	-249	3301	-5915	-	1438
- 17	-256	1595	333	1158	-828	11738	1530	-	9542
- 18	-104	6218	6353	15747	-246	-3	-13735	-	22153
- 18	-53	1261	-151	952	-270	20605	5466	-	4309
- 19	-53	5001	6964	14593	-194	-2060	-12647	-	5733
- 19	-154	1275	51	334	-277	17848	2994	-	1638
- 20	49	3199	2545	3439	-1378	-14433	-	-	12591
- 20	-1	1829	-1089	-16805	-3992	-876	-7135	-	57678
+ 21	202	2588	1841	-10536	-4290	-25040	-	-	31133
- 21	-103	1425	-1162	-26100	-6102	-13050	-	-	54473

TABLE B23 - TOP COLUMN HOOP STRAINS FOR SPECIMEN LC6

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1 - 1	-40 102	387 565	54 269	55 -35	4 182	275 5
+ 2 - 2	-52 62	600 408	72 218	50 -19	28 183	283 18
+ 3 - 3	36 36	3355 3640	122 641	19 80	46 334	503 31
+ 4 - 4	36 50	3326 3274	174 634	79 108	83 365	506 47
+ 5 - 5	37 62	3704 3711	188 620	86 107	92 375	506 53
+ 6 - 6	35 70	3846 3952	193 600	91 104	96 377	523 56
+ 7 - 7	30 58	3783 3386	194 595	93 100	97 376	435 55
+ 8 - 8	33 71	3305 4191	194 585	93 100	103 377	492 54
+ 9 - 9	373 412	3916 3803	294 593	204 824	144 692	537 189
+ 10 - 10	541 429	4205 4307	272 589	317 761	250 693	646 172
+ 11 - 11	550 426	4841 4409	258 580	361 761	282 700	632 167
+ 12 - 12	564 439	5064 4515	260 574	386 763	302 706	628 155
+ 13 - 13	706 609	5191 5696	282 600	599 887	324 736	553 159
+ 14 - 14	716 667	6447 6594	300 614	848 836	369 717	671 159
- 15 - 15	718 587	10063 25013	441 2533	551 723	417 696	647 155
- 16 - 16	412 551	10313 9900	1512 1961	688 433	361 549	293 231
- 17 - 17	402 524	12504 13475	1840 1692	579 422	354 553	235 236
- 18 - 18	506 650	16700 28707	18375 5985	697 406	425 664	479 241
- 19 - 19	446 605	12942 31349	21397 16820	669 397	440 523	401 358
- 20 - 20	358 475	17895 25003	16055 8742	1549 1743	541 315	383 471
- 21 - 21	475 544	10881 13574	21516 22032	3359 3868	620 901	354 706

TABLE B24 - BOTTOM COLUMN HOOP STRAINS FOR SPECIMEN LC6

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
- 1	-32	-215	104	503	-10	30
- 1	-135	-169	130	538	19	-55
- 2	-64	-169	145	562	-2	10
- 2	-112	-195	141	434	33	-78
- 3	-87	-152	394	311	22	114
- 3	-83	-206	327	-1375	165	5
- 4	-72	-189	409	-800	50	133
- 4	-71	-153	337	-1067	171	1
+ 5	-79	-271	410	-424	55	125
- 5	-74	-237	341	-754	167	-5
+ 6	-87	-358	409	-653	53	111
- 6	-82	-297	337	117	161	-21
+ 7	-66	-382	400	-343	55	77
- 7	-75	-316	338	-955	158	-34
+ 8	-93	-341	400	-354	53	78
- 8	-81	-250	315	-575	154	-48
+ 9	-100	-225	945	-457	328	713
- 9	178	924	1103	-1205	831	1107
+ 10	76	613	1222	120	481	1077
- 10	211	934	1034	-508	719	1116
+ 11	98	597	1290	-231	434	1022
- 11	211	943	1051	-450	673	1166
+ 12	115	614	1326	502	403	1027
- 12	224	959	1075	-442	645	1079
+ 13	421	706	1373	1836	533	1433
- 13	629	1298	1550	-1995	391	1679
- 14	451	495	1798	3213	464	1189
- 14	915	1105	1606	-1939	734	1583
+ 15	527	487	1727	3639	441	1054
- 15	1235	1209	1478	-1757	531	1434
+ 16	516	379	1071	14193	331	468
- 16	599	902	999	2227	125	759
- 17	455	369	1035	4397	323	457
- 17	705	912	958	1512	145	742
+ 18	541	572	1425	17144	451	758
- 18	1169	1187	1371	11561	358	1216
+ 19	2397	441	1335	28343	459	710
- 19	7160	1158	1364	18711	227	1108
- 20	3256	567	1218	-	522	919
- 20	18239	1935	1509	-	712	1092
+ 21	21316	394	1364	-	-	1106
- 21	44513	2332	1584	-	-	1051

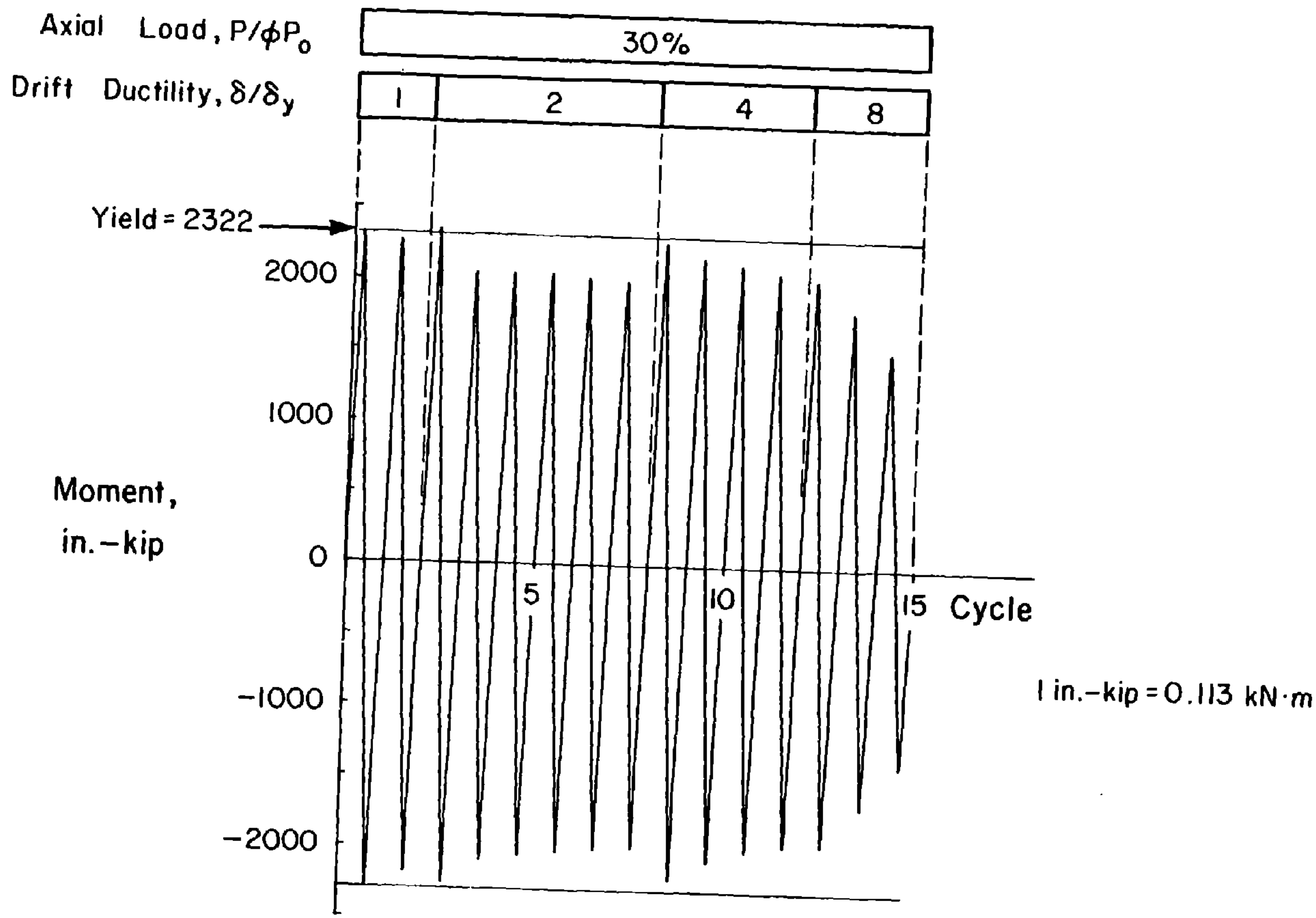


Fig. B23 Column Moment History for Specimen LC12

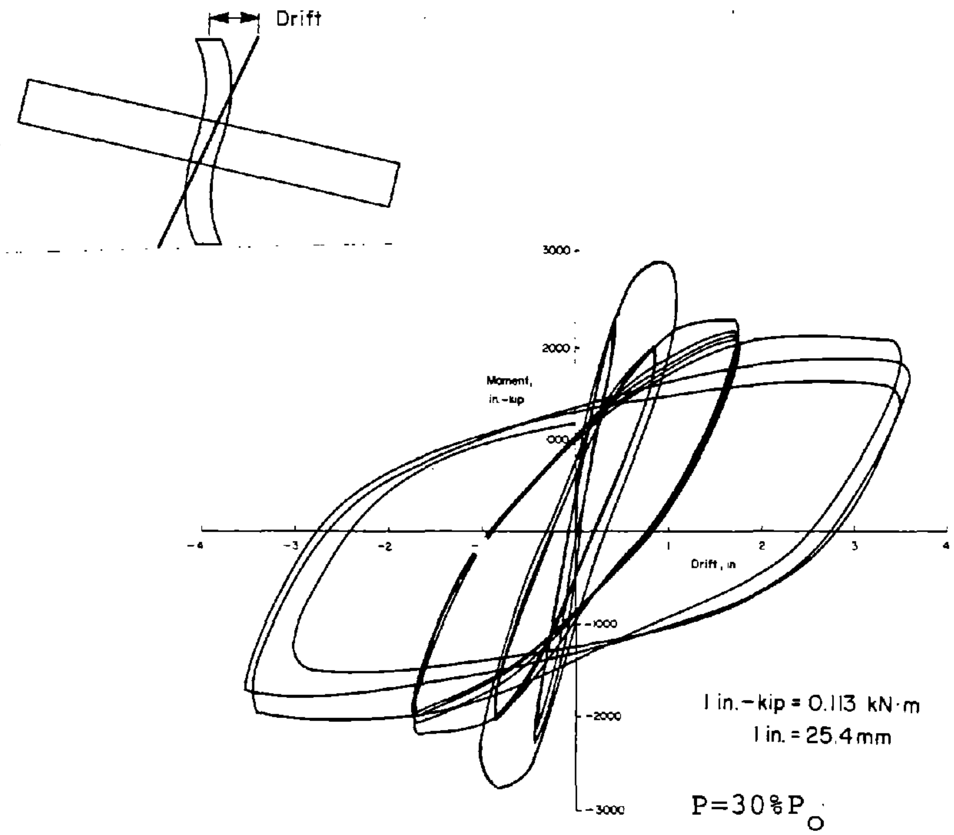


Fig. B24 Top Column Moment versus Drift for Specimen LC12

bottom column moment versus drift plot is not shown. Few cracks were observed in the joint.

The first positive peak column moment was 2322 in.-kip (262 kN·m). It occurred at a peak top drift of 0.43 in. (10.9 mm). The maximum measured top column moment was 2990 in.-kip (338 kN·m) and occurred at the negative peak of Cycle 3. The calculated nominal flexural strength was 2650 in.-kip (299 kN·m). The maximum measured moment was approximately 4.5% greater than calculated nominal flexural strength.

The peak moment for Cycle 3 shown in Fig. B24, does not correspond with the recorded peak moment tabulated. Prior to reaching the target top drift of 0.86 in. (21.8 mm), corresponding to a drift ductility of 2, the concrete shell of the column spalled. The column response following this spalling and under the relatively high column axial load was a sudden drop of moment capacity and rapid increase of deformation. This action prevented the digital recording of the actual peak data for Cycle 3. However, peak moments plotted in Fig. B24 are correct since these values were continuously recorded using X-Y plotters.

Photographs of Specimen LC12 at the end of Cycles 12 and 15 are shown in Figs. B25 and B26, respectively.

The main column bars were observed to buckle during Cycle 14. In addition, the 90° hook in the supplementary crossties was observed to open. A 30% drop in moment resisting capacity occurred during Cycle 15 and the test was ended. A photograph showing a buckled column bar and the opening of a supplementary crosstie at test end is presented in Fig. B27.

Tabulated results

Tabulated values of top column moment, top and bottom column drifts, east and west beam deflections, and horizontal joint movement are presented in Table B25. Moments listed exclude secondary P-Delta effects due to horizontal joint movement. Column rotations are shown in Table B26. Reinforcement strains

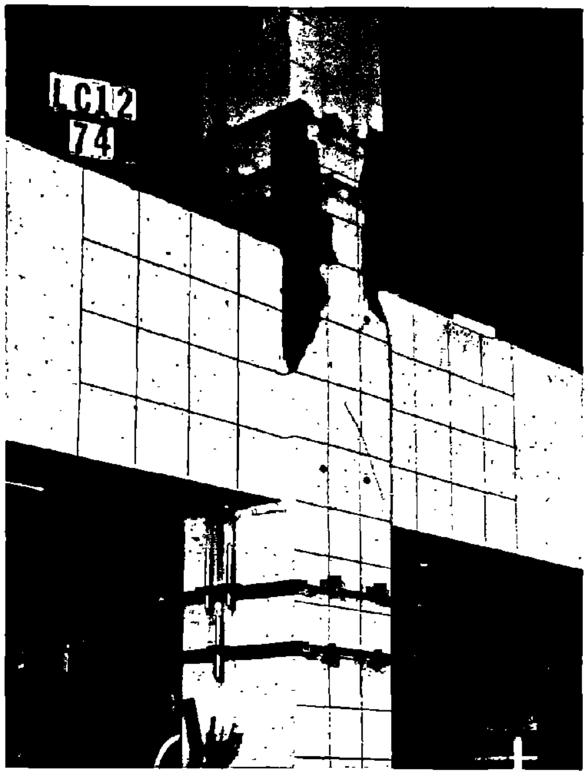


Fig. B25 Specimen LC12 after Cycle 12

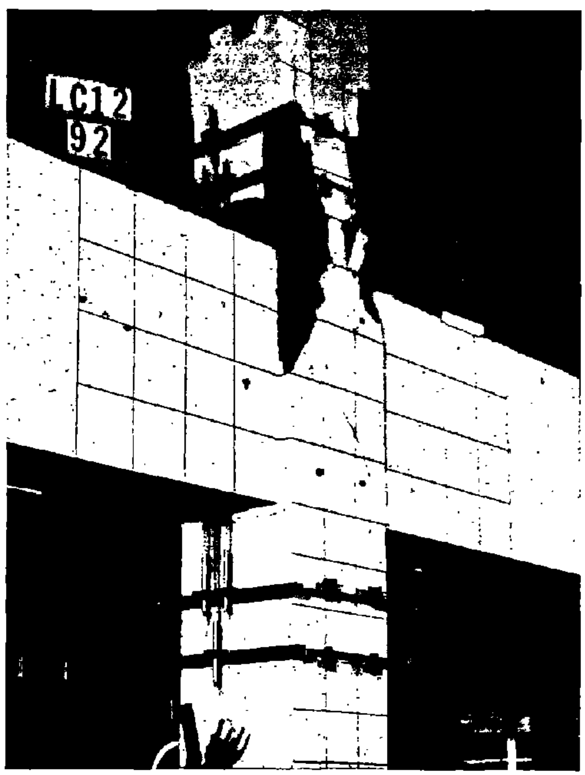


Fig. B26 Specimen LC12 after Cycle 15

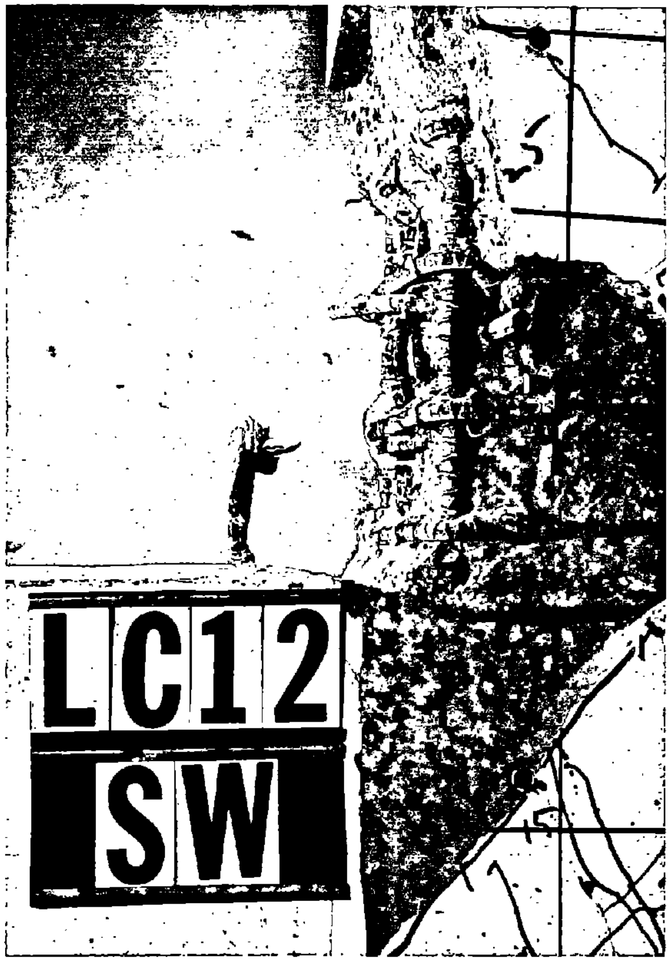


Fig. B27 Buckled Column Bar and Opening of Supplementary Crosstie in Specimen LC12 at Test End

TABLE B25 - COLUMN MOMENT, COLUMN DRIFTS, BEAM DEFLECTIONS, AND HORIZONTAL JOINT MOVEMENT FOR SPECIMEN LC12

CYCLE	MOMENT (IN.-KIP)	DRIFT (IN.)		DEFLECTION (IN.)		HORIZONTAL JOINT MOVEMENT (IN.)
		TOP	BOTTOM	EAST	WEST	
+ 1	2322	0.431	-0.112	1.554	-1.389	0.373
- 1	-2250	-0.401	0.142	-1.281	1.493	-0.340
+ 2	2258	0.447	-0.125	1.551	-1.425	0.378
- 2	-2137	-0.407	0.149	-1.255	1.471	-0.337
+ 3	2349	1.122	-0.232	2.673	-2.334	0.785
- 3	-2258	-0.960	0.228	-2.064	2.314	-0.570
+ 4	2045	0.889	-0.152	2.189	-1.939	0.635
- 4	-2090	-0.846	0.170	-1.866	2.077	-0.610
+ 5	2043	0.889	-0.153	2.160	-1.928	0.636
- 5	-2063	-0.960	0.170	-1.869	2.080	-0.518
+ 6	2043	0.909	-0.158	2.210	-1.958	0.546
- 6	-2029	-0.850	0.182	-1.839	2.052	-0.610
+ 7	2023	0.916	-0.158	2.218	-1.953	0.649
- 7	-2008	-0.852	0.190	-1.845	2.051	-0.611
+ 8	2001	0.904	-0.160	2.186	-1.928	0.640
- 8	-1991	-0.958	0.190	-1.845	2.040	-0.610
+ 9	2278	1.761	-0.199	3.297	-3.074	1.182
- 9	-2207	-1.728	0.220	-2.968	3.130	-1.177
+ 10	2171	1.751	-0.186	3.231	-3.044	1.175
- 10	-2084	-1.755	0.202	-2.953	3.075	-1.185
+ 11	2126	1.756	-0.178	3.213	-3.038	1.182
- 11	-2006	-1.724	0.172	-2.898	3.021	-1.169
+ 12	2063	1.777	-0.170	3.235	-3.038	1.194
- 12	-1972	-1.724	0.170	-2.876	3.014	-1.170
+ 13	2030	3.504	-0.168	5.346	-5.383	-
- 13	-1954	-3.411	0.190	-4.930	4.932	-
+ 14	1807	3.549	-0.132	5.206	-5.106	-
- 14	-1687	-3.405	0.162	-4.781	4.769	-
+ 15	1530	3.456	-0.110	4.949	-4.966	-
- 15	-1357	-3.373	0.140	-4.564	4.157	-

1 in.kip = 0.113 kN·m 1 in. = 25.4mm

TABLE B26 - COLUMN ROTATIONS FOR SPECIMEN LC12

CYCLE	ROTATION (RADIANS)			
	ABOVE JOINT		BELOW JOINT	
	-D	+D/2	-D	-D/2
+ 1	0.00696	0.00600	-0.00112	-0.00237
- 1	-0.00701	-0.00429	0.00187	0.00120
+ 2	0.00741	0.00650	-0.00154	-0.00276
- 2	-0.00713	-0.00422	0.00135	0.00110
+ 3	0.02188	0.01830	-0.00279	-0.00508
- 3	-0.01847	-0.01240	0.00270	0.00346
+ 4	0.01776	0.01507	-0.00192	-0.00316
- 4	-0.01714	-0.01091	0.00215	0.00193
+ 5	0.01776	0.01517	-0.00195	-0.00337
- 5	-0.01742	-0.01053	0.00372	0.00187
+ 6	0.01843	0.01555	0.00022	-0.00346
- 6	-0.01725	-0.00996	0.00252	0.00177
+ 7	0.01847	0.01565	-0.00146	-0.00343
- 7	-0.01728	-0.01005	0.00209	0.00188
+ 8	0.01820	0.01547	-0.00200	-0.00334
- 8	-0.01746	-0.01022	0.00195	0.00174
+ 9	0.03775	0.03018	-0.00247	-0.00393
- 9	-0.03717	-0.02309	0.00219	0.00222
+ 10	0.03796	0.03130	-0.00229	-0.00377
- 10	-0.03772	-0.02914	0.00202	0.00231
+ 11	0.03835	0.03212	-0.00217	-0.00356
- 11	-0.03732	-0.02897	0.00208	0.00198
+ 12	0.03883	0.03290	-0.00214	-0.00351
- 12	-0.03743	-0.02935	0.00207	0.00181
+ 13	0.07997	0.06686	-0.00193	-0.00345
- 13	-0.07822	-0.05972	0.00236	0.00214
+ 14	0.08200	0.06951	-0.00135	-0.00302
- 14	-0.07820	-0.06122	0.00208	0.00153
+ 15	0.08041	0.06430	-0.00106	-0.00258
- 15	-0.05828	-0.04454	0.00185	0.00148

of both column steel and confining hoops are given in Tables B27 through B30.

Specimen LC10

Specimen LC10 was manufactured as a duplicate of Specimen LC3 using Lightweight Concrete 2. The column confining reinforcement consisted of No. 3 hoops spaced at 4.75 in. (121 mm). This corresponds to 0.74% confinement. Other column reinforcement details are presented in Table A1.

Column moment history

Specimen LC10 was subjected to 19 cycles of moment reversals as shown in Fig. B28. The test began with a column axial load of 83.2 kips (370 kN). This corresponds to 10% of the column design strength. Following the basic loading cycles, the axial load was increased to 20% of the column design strength as shown in Fig. B28.

Column moment versus drift relationships

Top and bottom column moment versus drift relationships for Specimen LC10 are shown in Figs. B29 and B30, respectively. Compared to Specimen LC3, Specimen LC10 was observed to lose moment capacity at a faster rate as cycles were repeated at a given drift ductility. Very few cracks formed in either the top or bottom column. Excessive cracking and spalling occurred in the joint. Photographs of Specimen LC10 at the end of Cycles 12 and 15 are shown in Figs. B31 and B32, respectively. A photograph of the joint after the test is shown in Fig. B33.

Pinching of the hysteresis loops as depicted in Figs. B29 and B30 is an indication of excessive joint shear distortion as well as debonding of reinforcement.[23] The maximum joint shear force that occurred during the basic loading cycles was 213 kips (947 kN). This corresponded to a nominal effective shear stress of $16\sqrt{f'_c}$ psi ($1.32\sqrt{f'_c}$ MPa) in the joint. Further details concerning specimen joint shear are provided in the main body of the report in the section entitled "Joint Shear."

TABLE B27 - WEST COLUMN STEEL STRAINS FOR SPECIMEN LC12

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	-1162	-1432	-1538	-1363	-344	770	502	379	125
- 1	1293	1541	1700	2130	313	-335	-1052	-936	-533
+ 2	-1166	-1438	-1608	-1129	-347	751	475	391	136
- 2	1367	1587	1630	2045	365	-384	-1031	-912	-811
+ 3	-1323	-4256	-8986	-1835	-403	333	645	574	280
- 3	2148	6259	6468	6282	617	-296	-1162	-1004	-689
+ 4	-1557	-3654	-7605	-1301	-471	624	414	400	143
- 4	2005	5253	4475	5275	489	-370	-1101	-917	-835
+ 5	-1664	-3744	-7954	-1355	-503	613	406	355	146
- 5	2013	5282	4230	5294	483	-369	-1095	-915	-820
+ 6	-1683	-3331	-8222	-1391	-538	593	400	395	147
- 6	1984	5103	3787	5177	472	-379	-1051	-921	-819
+ 7	-1518	-3873	-8407	-1316	-570	568	386	385	137
- 7	1933	5093	3607	5179	472	-381	-1091	-917	-814
+ 8	-1583	-3846	-8421	-1342	-593	538	367	356	127
- 8	1975	5032	3403	5155	461	-385	-1086	-915	-811
+ 9	-2025	-6495	-16406	-2323	-537	725	493	481	103
- 9	5333	12473	10654	11781	742	-252	-1122	-943	-940
+ 10	-2390	-7319	-15460	-2035	-708	619	434	402	144
- 10	5571	12159	9048	12545	737	-262	-1070	-905	-839
+ 11	-2108	-7815	-16374	-2038	-758	558	349	351	108
- 11	5543	11596	7776	13663	752	-256	-1044	-862	-789
+ 12	-2117	-8311	-17201	-2090	-799	517	326	330	91
- 12	5745	11337	7032	12855	777	-253	-1234	-875	-760
+ 13	-3139	-34825	-31134	-4715	-971	140	66	111	-37
- 13	12075	22191	18829	15623	1093	-95	-946	-801	-733
+ 14	-2141	-27390	-	-2065	-1032	17	-26	33	-93
- 14	11357	17427	-	25477	1034	-120	-852	-739	-655
+ 15	1461	-	-	5216	-1072	-125	-144	-82	-153
- 15	3135	-	-	-	938	-201	-765	-665	-617

TABLE B28 - EAST COLUMN STEEL STRAINS FOR SPECIMEN LC12

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	1341	1613	1516	1383	522	-594	-1045	-930	-853
- 1	-1135	-1413	-1467	-922	-321	571	203	570	67
+ 2	1350	1630	1560	1847	526	-557	-1024	-911	-841
- 2	-1136	-1417	-1480	-967	-351	577	193	436	44
+ 3	2151	7934	8413	3153	704	-266	-1155	-953	-833
- 3	-2012	-3872	-6774	-5	-379	587	423	530	73
+ 4	1892	5269	4512	6015	484	-417	-1011	-870	-825
- 4	-1955	-3950	-7570	-11	-501	424	293	501	35
+ 5	1916	5156	4061	5969	474	-410	-1015	-847	-831
- 5	-2039	-4048	-8010	10	-553	387	374	505	15
+ 6	1951	5297	4009	6080	469	-406	-1020	-842	-834
- 6	-2017	-4014	-8115	20	-579	347	349	475	8
+ 7	1951	5253	3795	6090	460	-400	-1019	-820	-832
- 7	-2039	-4017	-8291	40	-598	336	346	425	2
+ 8	1919	5075	3381	5967	429	-410	-1016	-822	-839
- 8	-2030	-4013	-8462	35	-609	322	336	466	5
+ 9	4953	12414	13993	12577	745	-279	-1066	-869	-872
- 9	-1232	-6137	-15872	-151	-694	368	373	501	19
+ 10	7641	12249	10222	13019	720	-258	-1017	-927	-834
- 10	-3190	-6278	-16238	-51	-752	272	190	433	-13
+ 11	5918	12207	9117	12859	708	-264	-1005	-916	-821
- 11	-3111	-7041	-16869	97	-788	221	161	398	-27
+ 12	5158	12160	8687	12553	733	-247	-989	-808	-809
- 12	-3112	-7982	-17668	365	-822	173	132	362	-37
+ 13	14447	25115	24736	15919	1003	-102	-900	-715	-756
- 13	-5091	-17134	-	-	-1003	-74	-6	147	-115
+ 14	15587	23117	22000	-	903	-125	-515	-660	-654
- 14	-6451	-	-	-	-1074	-252	-97	72	-165
+ 15	14575	-	-	-	791	-157	-742	-589	-536
- 15	-1345	-	-	-	-1104	-442	-177	-46	-219

TABLE B29 - TOP COLUMN HOOP STRAINS FOR SPECIMEN LC12

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	-74	138	148	-10	101	56
- 1	-29	-146	143	-21	155	122
+ 2	-74	141	154	-14	100	96
- 2	-39	-134	153	-8	161	132
+ 3	45	695	509	33	125	266
- 3	74	-13	426	54	915	702
+ 4	14	580	507	136	224	523
- 4	50	3	509	66	880	538
+ 5	-9	574	520	139	245	553
- 5	65	23	540	75	369	540
+ 6	-42	680	529	157	248	574
- 6	54	18	554	94	349	539
+ 7	-70	689	528	169	249	594
- 7	49	49	568	99	837	553
+ 8	-93	700	524	171	257	614
- 8	44	64	575	95	331	565
+ 9	-373	1199	1115	531	389	1013
- 9	277	371	1230	23	1299	1119
+ 10	-378	1241	991	510	452	1206
- 10	314	391	1339	-98	1210	1119
+ 11	-399	1104	961	502	416	1270
- 11	303	386	1338	-109	1091	1083
+ 12	-396	1147	938	492	376	1393
- 12	253	357	1315	-84	934	1084
+ 13	-691	-	1063	108	746	1978
- 13	296	373	1983	-323	1570	1318
+ 14	-556	-	-153	141	-	1719
- 14	-301	-	1827	-364	-	715
+ 15	-1175	-	-738	-241	-	2372
- 15	-1031	-	1325	-303	-	136

TABLE B30 - BOTTOM COLUMN HOOP STRAINS FOR SPECIMEN LC12

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	59	-40	1	-38	66	132
- 1	4	48	168	34	-52	45
+ 2	40	-50	-4	-11	55	122
- 2	5	43	154	40	-44	45
+ 3	35	-12	11	-35	78	126
- 3	21	55	158	82	17	72
+ 4	33	-21	9	-14	89	119
- 4	12	49	149	63	-	53
+ 5	30	-27	6	-16	79	133
- 5	20	46	145	58	-1	58
+ 6	27	-26	3	-18	88	117
- 6	19	45	144	56	-3	55
+ 7	36	-25	1	-24	73	113
- 7	21	43	139	55	-4	51
+ 8	28	-25	6	-22	61	117
- 8	22	47	144	56	-1	57
+ 9	25	-22	-4	-36	78	112
- 9	13	42	129	60	11	57
+ 10	32	-22	-1	-26	80	107
- 10	23	39	129	57	6	55
+ 11	31	-27	-2	-25	77	105
- 11	22	43	119	52	2	45
+ 12	31	-26	1	-30	74	106
- 12	20	39	121	51	1	46
+ 13	36	-22	15	-46	63	102
- 13	16	29	107	52	-	41
+ 14	50	-22	22	-19	62	97
- 14	19	26	94	47	11	35
+ 15	47	-20	28	-13	57	79
- 15	5	15	88	31	19	42

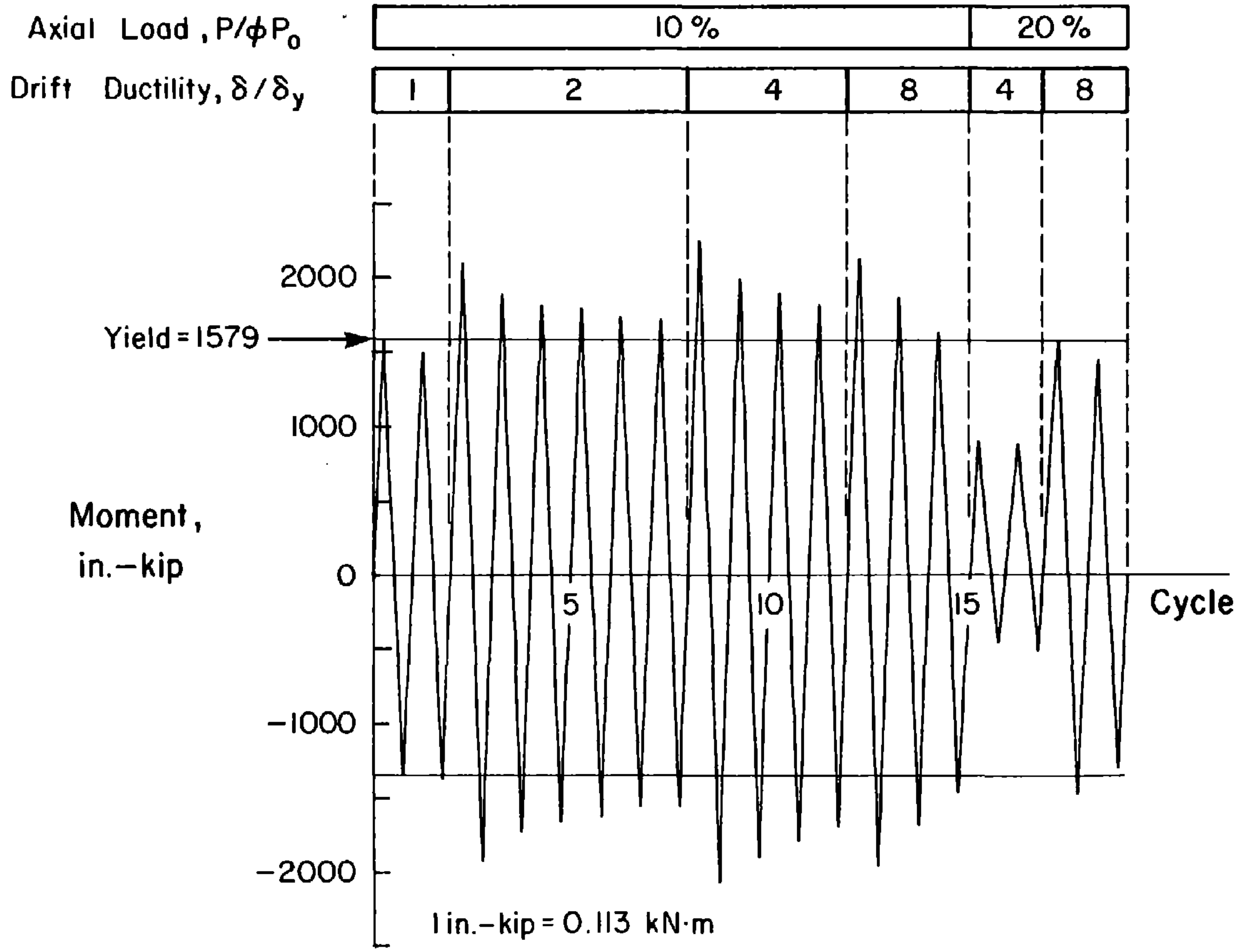
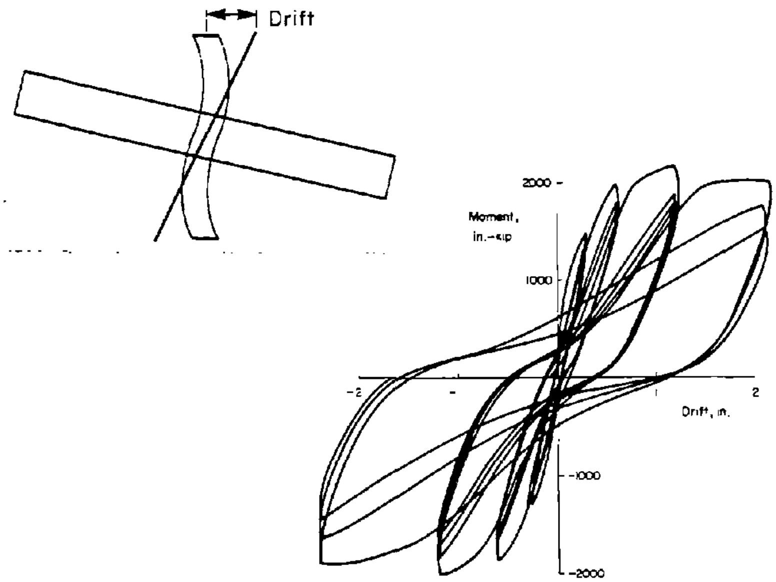
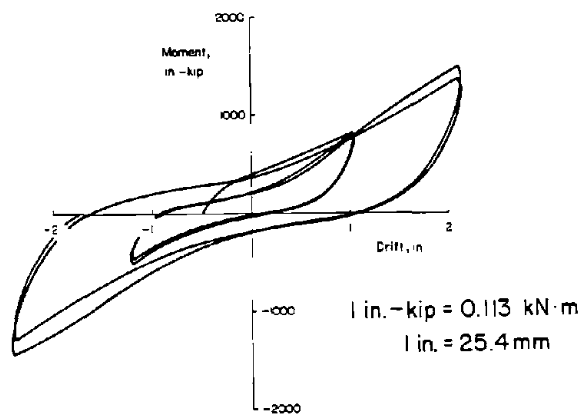


Fig. B28 Column Moment History for Specimen LC10

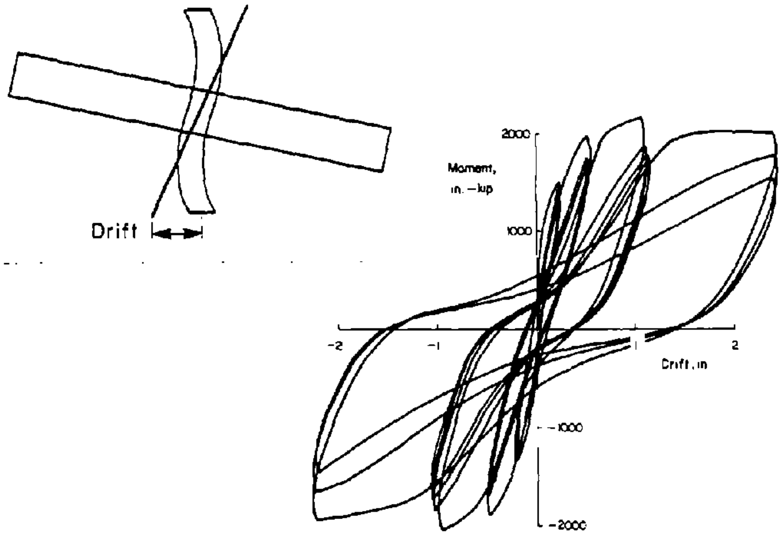


(a) P = 10%P_o

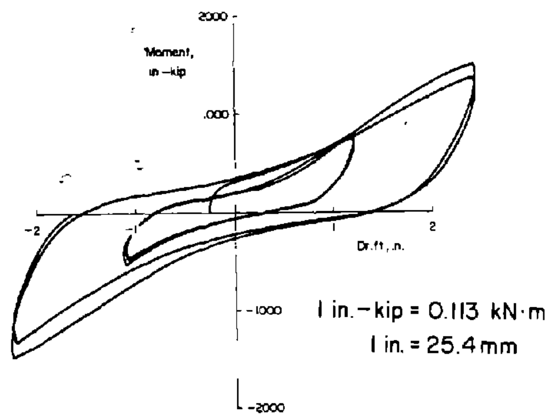


(b) P=20%P_o

Fig. B29 Top Moment Column versus Drift for Specimen LC10



(a) $P=10\%P_o$



(b) $P=20\%P_p$

Fig. B30 Bottom Column Moment versus Drift for Specimen LC10

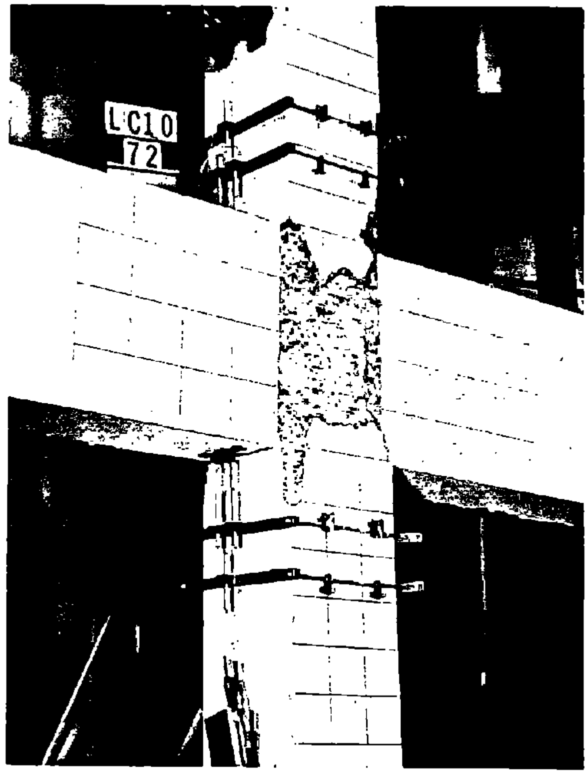


Fig. B31 Specimen LC10 after Cycle 12

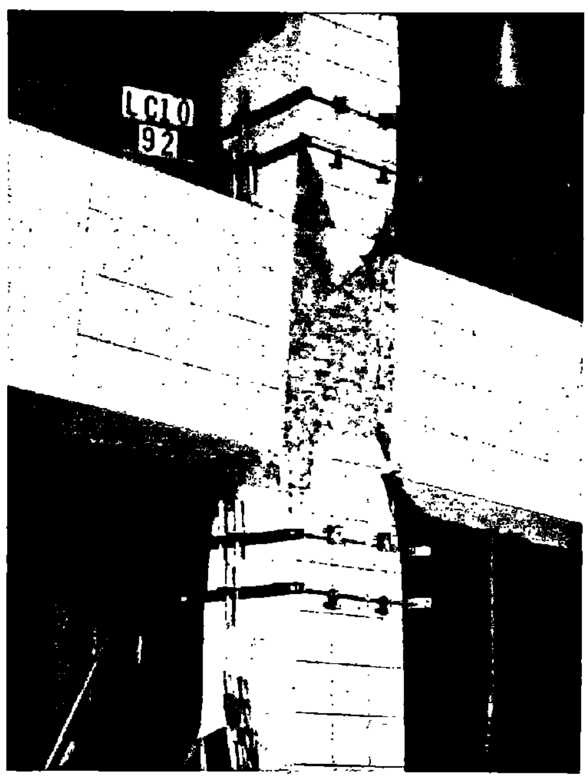


Fig. B32 Specimen LC10 after Cycle 15

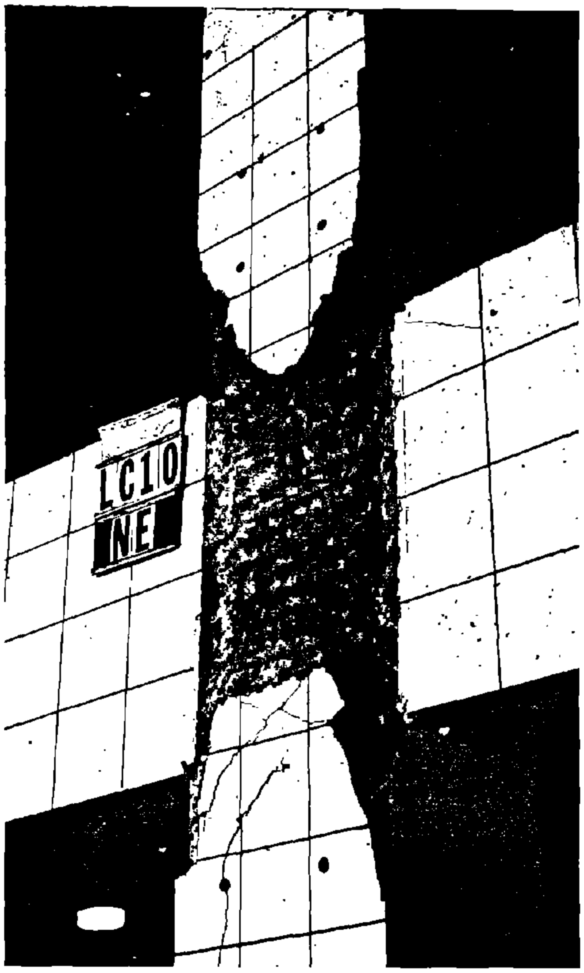


Fig. B33 Specimen LC10 at End of Test

The first positive peak column moment was 1579 in.-kip (178 kN·m). It occurred at a top drift of 0.30 in. (7.7 mm). The maximum measured column moment was 2252 in.-kip (254 kN·m) and occurred at the positive peak of Cycle 9. The calculated column nominal flexural strength was 2040 in.-kip (230 kN·m). Therefore, maximum measured column moment was approximately 10% greater than calculated.

The top drift measurement controlled the test progression until Cycle 13 at which time the bottom drift measurement became larger and was used as the control parameter. Throughout the test, both top and bottom drifts were approximately the same since the majority of the deformation took place in the joint. Loss of moment capacity was observed during Cycle 19 under a column axial load equal to 20% of the design strength.

Tabulated results

Tabulated values of column moment, top and bottom drifts, and east and west beam deflections are given in Table B31. Column rotations are listed in Table B32. Reinforcement strains are given in Tables B33 through B36.

Specimen LC9

The reinforcement of Specimen LC9 was similar to that of Specimen LC4. Specimen LC9 was manufactured using Lightweight Concrete 2. The column confining reinforcement was No. 4 hoops spaced at 4 in. (102 mm). This corresponds to 1.60% confinement. Detailed information concerning column reinforcement for Specimen LC4 is contained in Table A1.

As reported in Appendix A, under "Material Properties," weaker concrete was accidentally placed in the beams and joint of Specimen LC9. Average concrete compressive strength, f'_c, in the beam and joint was 3440 psi (23.7 MPa), while for top and bottom columns, average concrete compressive strength was 4860 psi (33.5 MPa).

TABLE B31 - COLUMN MOMENT, COLUMN DRIFTS, AND BEAM DEFLECTIONS FOR SPECIMEN LC10

CYCLE	MOMENT (IN.-KIP)	DRIFT (IN.)		DEFLECTION (IN.)	
		TOP	BOTTOM	EAST	WEST
+ 1	1579	0.303	-0.234	1.363	-1.271
- 1	-1349	-0.261	0.220	-1.015	1.163
+ 2	1500	0.311	-0.328	1.363	-1.253
- 2	-1375	-0.295	0.342	-1.111	1.244
+ 3	2103	0.608	-0.525	2.413	-2.332
- 3	-1929	-0.616	0.513	-2.060	2.116
+ 4	1885	0.608	-0.525	2.323	-2.172
- 4	-1732	-0.606	0.505	-1.983	2.105
+ 5	1813	0.608	-0.525	2.293	-2.225
- 5	-1563	-0.606	0.513	-1.977	2.279
+ 6	1793	0.616	-0.527	2.299	-2.231
- 6	-1627	-0.599	0.511	-1.941	2.066
+ 7	1737	0.616	-0.525	2.299	-2.214
- 7	-1564	-0.600	0.511	-1.923	2.051
+ 8	1718	0.616	-0.527	2.257	-2.213
- 8	-1561	-0.600	0.513	-1.917	2.042
+ 9	2252	1.219	-1.058	3.846	-3.827
- 9	-2071	-1.197	1.003	-3.464	3.513
+ 10	1990	1.209	-1.094	3.697	-3.777
- 10	-1902	-1.205	1.069	-3.535	3.633
+ 11	1898	1.199	-1.112	3.670	-3.753
- 11	-1795	-1.205	1.086	-3.529	3.577
+ 12	1817	1.197	-1.114	3.564	-3.743
- 12	-1698	-1.217	1.093	-3.470	3.529
+ 13	2123	2.154	-2.403	6.415	-6.663
- 13	-1964	-2.404	2.263	-6.366	6.371
+ 14	1964	2.075	-2.413	6.426	-6.751
- 14	-1590	-2.416	2.235	-6.456	6.371
+ 15	1629	2.098	-2.339	6.382	-6.626
- 15	-1468	-2.412	2.219	-6.336	6.223
+ 16	897	1.026	-1.198	3.432	-3.388
- 16	-461	-1.215	1.091	-3.058	3.233
+ 17	833	1.041	-1.192	3.401	-3.388
- 17	-510	-1.225	1.114	-3.141	3.280
+ 18	1578	2.117	-2.421	6.339	-6.446
- 18	-1430	-2.422	2.258	-6.131	6.347
+ 19	1446	2.111	-2.401	6.373	-6.422
- 19	-1300	-2.404	2.235	-6.062	6.235

1 in.-kip = 0.113 kN·m 1 in. = 25.4mm

TABLE B32 - COLUMN ROTATIONS FOR SPECIMEN LC10

CYCLE	ROTATION (RADIANS)			
	ABOVE JOINT		BELOW JOINT	
	+D	+D/2	-D	-D/2
+ 1	0.00573	0.00525	-0.00492	-0.00333
- 1	-0.00551	-0.00333	0.00522	0.00354
+ 2	0.00566	0.00558	-0.00467	-0.00400
- 2	-0.00603	-0.00411	0.00573	0.00425
+ 3	0.01202	0.01077	-0.00972	-0.00839
- 3	-0.01211	-0.00892	0.01070	0.00810
+ 4	0.01182	0.01054	-0.00984	-0.00840
- 4	-0.01164	-0.00872	0.01040	0.00794
+ 5	0.01175	0.01048	-0.00963	-0.00825
- 5	-0.01161	-0.00859	0.01033	0.00792
+ 6	0.01178	0.01059	-0.00963	-0.00837
- 6	-0.01144	-0.00859	0.01009	0.00790
+ 7	0.01171	0.01056	-0.00954	-0.00835
- 7	-0.01144	-0.00860	0.01006	0.00786
+ 8	0.01154	0.01051	-0.00953	-0.00835
- 8	-0.01132	-0.00854	0.01009	0.00785
+ 9	0.02375	0.02063	-0.01963	-0.01742
- 9	-0.02313	-0.01853	0.01900	0.01620
+ 10	0.02211	0.01979	-0.01950	-0.01789
- 10	-0.02224	-0.01876	0.01994	0.01733
+ 11	0.02161	0.01947	-0.01930	-0.01795
- 11	-0.02275	-0.01839	0.01983	0.01735
+ 12	0.02142	0.01946	-0.01944	-0.01827
- 12	-0.02224	-0.01804	0.01952	0.01709
+ 13	0.03925	0.03446	-0.04484	-0.04162
- 13	-0.04093	-0.03527	0.03945	0.03503
+ 14	0.03687	0.03434	-0.04491	-0.04267
- 14	-0.03974	-0.03506	0.03967	0.03563
+ 15	0.03504	0.03432	-0.04303	-0.04165
- 15	-0.03572	-0.03461	0.03728	0.03480
+ 16	0.01913	0.01964	-0.02123	-0.02391
- 16	-0.01924	-0.01731	0.01743	0.01565
+ 17	0.01995	0.01941	-0.02163	-0.02234
- 17	-0.01948	-0.01745	0.01795	0.01703
+ 18	0.03439	0.03347	-0.04225	-0.04170
- 18	-0.03704	-0.03363	0.03578	0.03391
+ 19	0.03440	0.03357	-0.04206	-0.04184
- 19	-0.03637	-0.03329	0.03462	0.03304

TABLE B33 - WEST COLUMN STEEL STRAINS FOR SPECIMEN LC10

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	-550	-717	-795	-358	357	1544	1495	1474	1200
- 1	1241	1615	1153	1739	557	-167	-691	-600	-514
+ 2	-613	-713	-714	-431	395	1476	1441	1400	1143
- 2	1317	1704	1311	1870	630	-157	-727	-625	-533
+ 3	-811	-949	-1015	-400	839	5021	3149	2462	2036
- 3	1977	4282	2197	8115	977	1525	-838	-883	-740
+ 4	-779	-136	-1361	2178	606	4757	3053	2223	1831
- 4	1958	4006	2096	7615	853	1565	-742	-819	-679
+ 5	-771	-50	-1367	2501	505	4529	2980	2101	1732
- 5	1803	3879	2043	7419	812	1586	-705	-803	-665
+ 6	-762	-22	-1362	2792	468	4465	2840	2071	1713
- 6	1745	3756	2003	7256	793	1587	-682	-793	-555
+ 7	-751	16	-1346	2939	421	4330	2735	1992	1646
- 7	1705	3560	1958	7131	759	1595	-661	-783	-644
+ 8	-751	36	-1342	2947	408	4275	2678	1955	1620
- 8	1671	3595	1930	7045	747	1586	-657	-786	-646
+ 9	-341	-462	-1529	3067	704	9954	9764	6123	1292
- 9	2176	7530	-	13487	1015	2763	-38	-120	-998
+ 10	-396	15	-	4371	516	10035	8960	5469	2054
- 10	2025	7132	-	12983	813	4325	334	-90	-381
+ 11	-383	167	-	5080	409	7773	8319	5100	1938
- 11	1313	6607	-	12535	708	4543	670	20	-961
+ 12	-373	227	-	5444	373	9621	8016	4907	1877
- 12	1311	6142	-	12142	653	4619	915	91	-838
+ 13	-1034	-160	-	6181	849	20017	16549	12428	1913
- 13	2167	9319	-	10364	876	2347	1639	-100	-1053
+ 14	-395	155	-	9234	766	21029	17030	10373	1665
- 14	1304	-737	-	19323	693	10376	3073	132	-919
+ 15	-327	539	-	11548	738	19901	14331	8351	1342
- 15	1553	5493	-	11897	607	12848	4029	467	-873
+ 16	-543	1124	-	6730	-271	14054	7624	3594	518
- 16	-45	1351	-	12544	-736	7946	4109	911	-550
+ 17	-543	1184	-	6294	-369	12235	7299	3462	553
- 17	7	1371	-	11585	-765	7268	4012	345	-679
+ 18	-519	435	-	9967	437	15215	10885	6404	1670
- 18	389	4535	-	18074	155	7842	3739	143	-1044
+ 19	-573	487	-	9062	423	15558	9972	5518	1467
- 19	115	4109	-	15335	1	7424	3851	253	-989

TABLE B34 - EAST COLUMN STEEL STRAINS FOR SPECIMEN LC10

CYCLE	STRAIN MILLIONTHS								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	1416	1729	1458	1877	487	-152	-741	-565	-529
- 1	-559	-665	-668	-337	209	1444	1301	1372	311
+ 2	1397	1639	1455	1773	567	-112	-731	-544	-501
- 2	-589	-670	-707	-322	291	1497	1366	1322	307
+ 3	2231	2730	2476	7810	1032	121	-1059	-901	-718
- 3	-753	-736	-1303	3237	573	6540	2630	1978	1797
- 4	2113	2607	2439	7547	958	3041	-883	-795	-659
- 4	-749	-738	-1205	3835	427	5917	2357	1639	1584
+ 5	2054	2513	2374	7232	925	3168	-844	-541	-639
- 5	-737	-718	-1202	3041	370	5680	2246	1504	1515
- 6	2033	2497	2365	7233	517	3232	-838	-851	-643
- 6	-727	-702	-1193	3169	321	5517	2164	1443	1464
+ 7	1982	2421	2298	7050	385	3255	-813	-883	-622
- 7	-715	-591	-1133	3252	396	5362	2677	1372	1408
+ 8	1946	2376	2251	6924	341	3273	-798	-867	-633
- 8	-720	-658	-1185	3294	260	5291	2240	1357	1380
- 9	2579	8050	11182	12811	1158	3719	-1337	-1332	-521
- 9	-975	47	-107	4738	422	10571	7639	4208	2314
- 10	2316	6636	9540	11731	876	5326	-499	-817	-763
- 10	-949	309	165	5348	351	10439	7395	4019	1893
- 11	2225	6064	8715	11258	759	5742	-154	-827	-745
- 11	-932	309	375	5719	305	10055	6894	3770	1792
+ 12	2158	5793	8325	11045	720	5911	102	-787	-739
- 12	-594	384	540	5981	270	9681	6415	3510	1635
+ 13	2983	9405	15457	18635	986	5186	-3748	-2455	-1150
- 13	-964	289	1445	10401	582	-	16074	8269	2120
+ 14	2557	7475	13310	18310	784	-	-2615	-1832	-1135
- 14	-901	614	2558	11350	525	-	14976	5868	1937
+ 15	2250	6295	11521	17908	713	-	3110	-1557	-1387
- 15	-735	766	3255	12133	-	-	12631	5542	1709
+ 16	511	3356	6242	12317	-	-	6002	-660	-565
- 16	-441	1258	3229	8953	-	-	3391	1358	147
+ 17	459	2795	5999	11277	-	-	2255	-768	-973
- 17	-474	1205	3191	8447	-	-	9999	1383	179
+ 18	1430	4416	8117	13375	-	-	1795	-1848	-1272
- 18	-864	561	2924	9387	-	-	6389	3477	1189
+ 19	1249	3974	7449	13371	-	-	4612	-1759	-1231
- 19	-804	609	3065	8735	-	-	4646	2732	987

TABLE B35 - TOP COLUMN HOOP STRAINS FOR SPECIMEN LC10

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	-117	213	189	298	74	19
- 1	124	47	107	-52	176	-7
+ 2	-103	243	229	316	102	24
- 2	171	72	132	-46	248	4
+ 3	9	678	673	357	308	236
- 3	190	253	404	15	640	285
+ 4	-7	734	634	305	405	346
- 4	161	255	400	9	542	318
+ 5	-7	800	674	285	408	353
- 5	150	233	400	5	656	325
+ 6	-5	820	678	273	415	359
- 6	145	230	375	8	656	331
+ 7	-5	817	664	272	415	362
- 7	140	251	357	4	651	322
+ 8	-7	816	659	260	414	358
- 8	140	237	325	2	643	328
+ 9	266	1255	1010	315	1208	540
- 9	479	503	552	312	1042	669
+ 10	241	1148	839	321	1137	676
- 10	382	627	558	297	931	651
+ 11	222	1092	841	325	1173	635
- 11	343	618	553	251	931	522
+ 12	311	1052	914	316	1147	690
- 12	316	608	549	245	900	598
+ 13	-	1249	1083	616	1439	832
- 13	-	811	683	565	1072	753
+ 14	-	1240	914	528	1519	902
- 14	-	859	725	535	1035	759
- 15	-	1012	772	530	1299	854
- 15	-	744	698	469	1103	794
+ 16	-	518	309	134	598	405
- 16	-	342	269	102	590	431
+ 17	-	478	295	106	514	382
- 17	-	314	259	88	538	423
+ 18	-	717	421	432	864	524
- 18	-	560	581	104	969	492
+ 19	-	-	390	315	798	590
- 19	-	-	551	11	934	483

TABLE B36 - BOTTOM COLUMN HOOP STRAINS
FOR SPECIMEN LC10

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
- 1	-	-13	19	270	138	115
- 1	-	49	46	507	40	193
- 2	-	-14	23	857	158	250
- 2	-	73	68	812	51	58
- 3	-	89	168	1018	629	931
- 3	-	461	451	531	178	361
+ 4	-	193	236	274	638	1179
- 4	-	488	472	334	188	563
- 5	-	193	255	275	523	1073
- 5	-	493	491	453	192	627
- 6	-	300	264	405	636	1052
- 6	-	499	495	436	192	628
+ 7	-	198	370	134	527	1149
- 7	-	491	498	456	193	543
- 8	-	198	375	438	523	1072
- 8	-	491	498	800	191	294
+ 9	-	402	382	377	1294	1539
- 9	-	517	332	573	451	541
+ 10	-	507	468	1407	1123	1342
- 10	-	345	378	1789	541	274
+ 11	-	527	481	1426	1050	1212
- 11	-	305	575	1413	562	264
+ 12	-	534	493	1024	1011	1083
- 12	-	764	862	843	578	277
+ 13	-	1341	774	1143	1309	1012
- 13	-	1286	1028	1860	1311	395
+ 14	-	1342	849	2014	1579	1304
- 14	-	1181	977	1681	1318	589
+ 15	-	1213	923	.159	1411	927
- 15	-	1035	914	1941	1188	433
+ 16	-	653	467	911	690	411
- 16	-	430	526	1645	535	270
+ 17	-	612	447	1489	662	371
- 17	-	429	524	1499	590	263
+ 18	-	931	753	1933	1121	713
- 18	-	831	847	1867	974	383
+ 19	-	946	755	1912	1055	712
- 19	-	759	817	1907	897	365

Column moment history

This test consisted of 19 cycles of moment reversals as shown in Fig. B34. The basic loading cycles were applied under a column axial load equal to 10% of the column design axial strength. For subsequent cycles, the column axial load was increased to 20% of the design strength.

Column moment versus drift relationships

Top and bottom moment versus drift relationships are presented in Figs. B35 and B36, respectively. The behavior of Specimen LC9 was very similar to that of Specimen LC10. Minor cracking occurred in the columns. Excessive concrete spalling and shear distortion occurred in the joint. This is reflected in the pinching of the moment-drift hysteresis loops of Figs. B35 and B36. Based on the joint's concrete compressive strength, the maximum nominal effective shear stress in the joint was $18.2\sqrt{f'_c}$ psi ($1.51\sqrt{f'_c}$ MPa). More information is provided under the section entitled "Joint Shear" in the main body of this report.

The first positive peak column moment was 1513 in.-kip (171 kN·m). The corresponding top drift was 0.37 in. (9.3 mm). The maximum measured column moment was 2098 in.-kip (237 kN·m). It occurred at the positive peak of Cycle 9. The calculated column nominal flexural strength was 2040 in.-kip (230 kN·m). Maximum measured column moment was approximately 3% greater than calculated nominal flexural strength. However, the column flexural capacity may not have been reached since the joint controlled specimen capacity.

Photographs at the end of Cycles 12 and 15 are shown in Figs. B37 and B38, respectively. Condition of Specimen LC9 at the end of the test looked very similar to that of Specimen LC10 shown in Fig. B33.

Tabulated results

Values of column moment, top and bottom column drifts, and east and west beam deflections are given in Table B37. Column

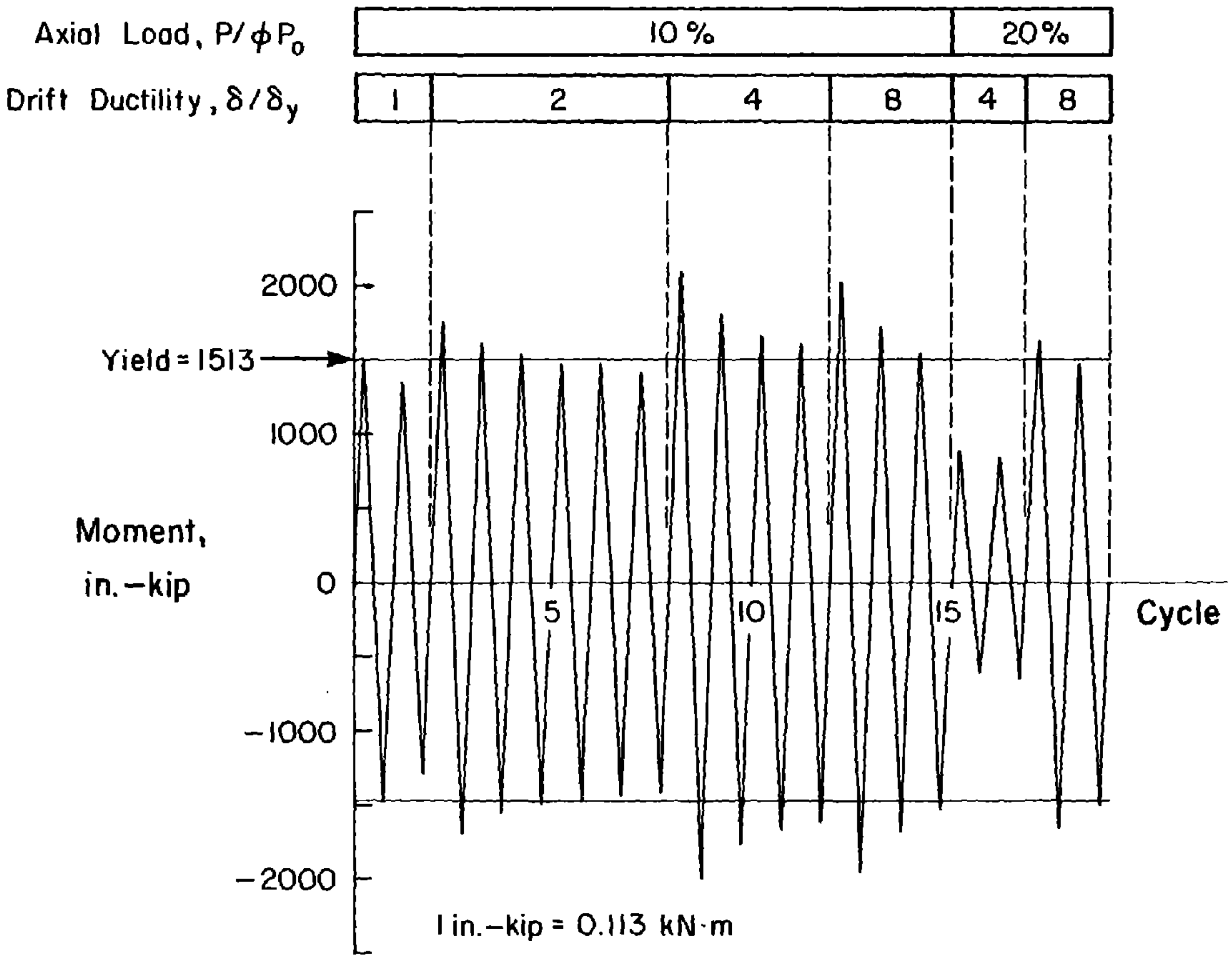
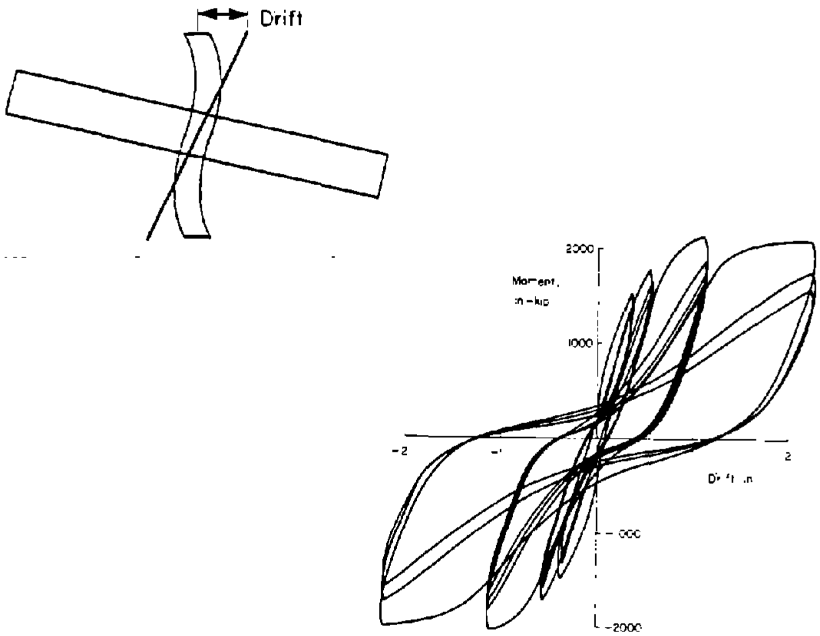
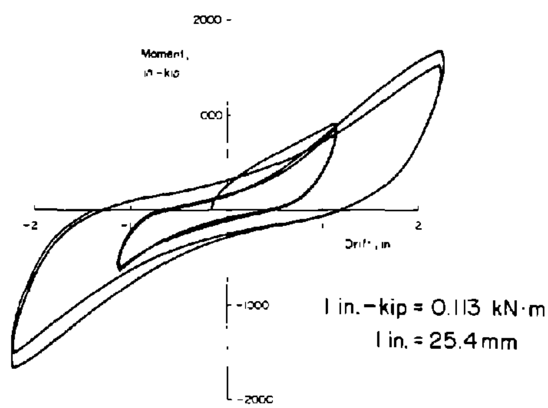


Fig. B34 Column Moment History for Specimen LC9

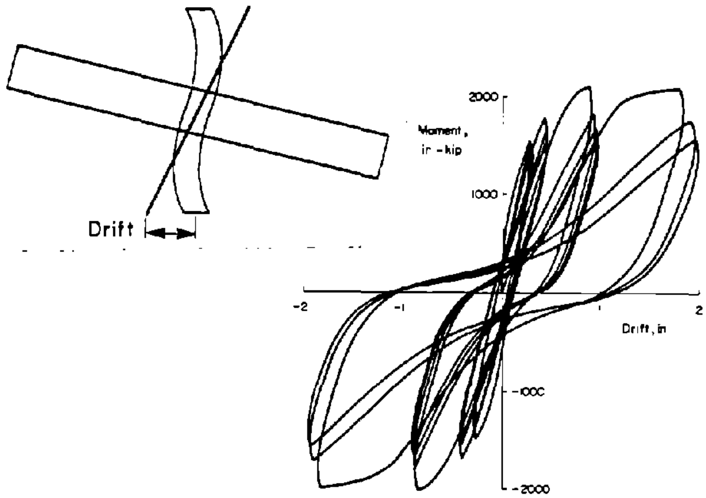


(a) P=10%P_o

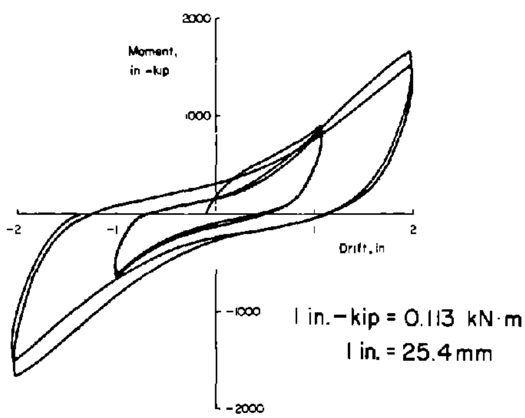


(b) P=20%P_o

Fig. B35 Top Column Moment versus Drift for Specimen LC9



(a) $P=10\%P_o$



b) $P=20\%P_o$

Fig. B36 Bottom Column Moment versus Drift for Specimen LC9

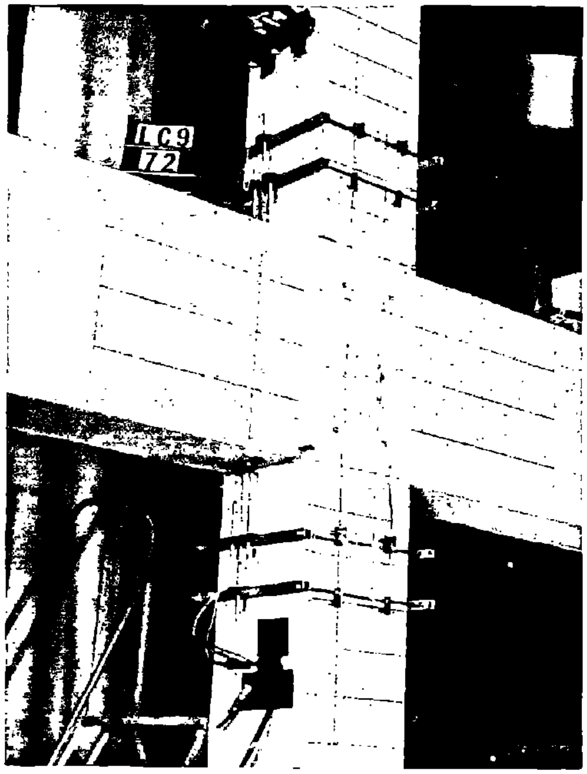


Fig. B37 Specimen LC9 after Cycle 12

Fig. B38 Specimen LC9 after Cycle 15

TABLE B37 - COLUMN MOMENT, COLUMN DRIFTS, AND BEAM DEFLECTIONS FOR SPECIMEN LC9

CYCLE	MOMENT (IN.-KIP)	DRIFT (IN.)		DEFLECTION (IN.)	
		TOP	BOTTOM	EAST	WEST
+ 1	1513	0.367	-0.297	1.559	-1.475
- 1	-1470	-0.381	0.297	-1.350	1.466
+ 2	1347	0.365	-0.271	1.457	-1.391
- 2	-1290	-0.359	0.261	-1.254	1.349
+ 3	1757	0.570	-0.445	2.078	-1.995
- 3	-1695	-0.565	0.431	-1.804	1.938
+ 4	1613	0.579	-0.447	2.035	-1.957
- 4	-1557	-0.565	0.433	-1.792	1.838
+ 5	1534	0.575	-0.439	1.977	-1.907
- 5	-1501	-0.565	0.429	-1.762	1.862
+ 6	1472	0.573	-0.437	1.941	-1.899
- 6	-1470	-0.563	0.431	-1.744	1.853
+ 7	1476	0.581	-0.447	1.977	-1.889
- 7	-1440	-0.563	0.431	-1.738	1.846
- 8	1415	0.574	-0.439	1.941	-1.871
- 8	-1421	-0.563	0.431	-1.744	1.834
+ 9	2058	1.132	-0.878	3.332	-3.274
- 9	-1999	-1.143	0.866	-3.082	3.187
+ 10	1813	1.140	-0.928	3.229	-3.184
- 10	-1770	-1.137	0.892	-3.022	3.099
+ 11	1668	1.133	-0.944	3.147	-3.134
- 11	-1667	-1.131	0.906	-2.998	3.073
+ 12	1609	1.136	-0.958	3.142	-3.100
- 12	-1616	-1.143	0.928	-3.016	3.061
+ 13	2037	2.259	-1.804	5.542	-5.612
- 13	-1955	-2.246	1.853	-5.327	5.417
+ 14	1729	2.271	-1.914	5.601	-5.708
- 14	-1688	-2.228	1.929	-5.315	5.360
+ 15	1551	2.251	-1.954	5.615	-5.702
- 15	-1530	-2.226	1.955	-5.257	5.354
+ 16	889	1.125	-1.073	3.076	-3.088
- 16	-613	-1.143	1.303	-2.717	2.753
- 17	847	1.125	-1.064	3.040	-3.010
- 17	-548	-1.143	1.303	-2.717	2.770
+ 18	1633	2.261	-1.988	5.625	-5.678
- 18	-1653	-2.254	2.040	-5.245	5.419
+ 19	1475	2.246	-1.982	5.620	-5.666
- 19	-1503	-2.240	2.058	-5.291	5.399

1 in.-kip = 0.113kN·m   1 in. = 25.4mm

rotations are shown in Table B38. Reinforcing steel strains are listed in Tables B39 through B42.

Specimen NC1

Specimen NC1 was similar to Specimens LC4 and LC9 except that it was manufactured with normal weight concrete. Column confinement consisted of No. 4 hoops spaced at 4 in. (102 mm). This corresponds to 1.60% confinement.

Column moment history

The columns of Specimen NC1 were subjected to 26 cycles of moment reversals as shown in Fig. B39. During the basic loading cycles, the column axial load equaled 10% of the column design axial strength. For subsequent cycles, the column axial load was increased to 20%, 30%, and 60% of the column design strength as shown in Fig. B39.

Column moment versus drift relationships

Top and bottom moment versus drift relationships are shown in Figs. B40 and B41, respectively. Specimen NC1 experienced joint shear distortion as indicated by pinching of the hysteresis loops shown in the figures. During the basic loading cycles, the maximum nominal effective shear stress in the joint was $16.3\sqrt{f'_c}$ psi ($1.35\sqrt{f'_c}$ MPa). Additional information concerning joint shear is provided in the main body of the report.

The first positive peak column moment was 1576 in.-kip (178 kN·m). It occurred at a top drift of 0.29 in. (7.3 mm). The maximum measured column moment was 2329 in.-kip (263 kN·m). It was recorded during the positive peak of Cycle 9. Calculated nominal flexural strength of the column was 1950 in.-kip (220 kN·m). Therefore, maximum measured column moment was 19% greater than calculated nominal flexural strength.

Photographs at the end of Cycles 12 and 15 are shown in Figs. B42 and B43, respectively. Severe diagonal shear cracks and spalling of the concrete shell within the joint can be seen in these photos.

TABLE B38 - COLUMN ROTATIONS FOR SPECIMEN LC9

CYCLE	ROTATION (RADIANS)			
	ABOVE JOINT		BELOW JOINT	
	-D	+D/2	-D	-D/2
+ 1	0.00738	0.00525	-0.00613	-0.00444
- 1	-0.00761	-0.00546	0.00617	0.00448
+ 2	0.00732	0.00570	-0.00582	-0.00434
- 2	-0.00723	-0.00512	0.00532	0.00448
+ 3	0.01116	0.00859	-0.00897	-0.00677
- 3	-0.01103	-0.00804	0.00831	0.00669
+ 4	0.01108	0.00861	-0.00825	-0.00675
- 4	-0.01094	-0.00807	0.00827	0.00665
+ 5	0.01093	0.00848	-0.00863	-0.00660
- 5	-0.01088	-0.00810	0.00829	0.00659
+ 6	0.01073	0.00836	-0.00844	-0.00648
- 6	-0.01086	-0.00808	0.00824	0.00658
+ 7	0.01086	0.00848	-0.00855	-0.00660
- 7	-0.01081	-0.00798	0.00821	0.00653
+ 8	0.01062	0.00827	-0.00839	-0.00649
- 8	-0.01070	-0.00794	0.00820	0.00655
+ 9	0.02136	0.01756	-0.01590	-0.01283
- 9	-0.02175	-0.01738	0.01526	0.01287
+ 10	0.02002	0.01653	-0.01573	-0.01287
- 10	-0.02095	-0.01683	0.01509	0.01287
+ 11	0.01912	0.01584	-0.01555	-0.01294
- 11	-0.02043	-0.01669	0.01497	0.01297
+ 12	0.01882	0.01549	-0.01547	-0.01274
- 12	-0.02039	-0.01663	0.01509	0.01310
+ 13	0.03939	0.03464	-0.02836	-0.02543
- 13	-0.03890	-0.03336	0.02907	0.02851
+ 14	0.03778	0.03344	-0.03031	-0.02519
- 14	-0.03695	-0.03215	0.02937	0.02152
+ 15	0.03687	0.03265	-0.03083	-0.03322
- 15	-0.03609	-0.03178	0.02951	0.02136
+ 16	0.01934	0.01684	-0.01817	-0.02222
- 16	-0.01753	-0.01649	0.01504	0.00910
+ 17	0.01975	0.01658	-0.01761	-0.02178
- 17	-0.01767	-0.01673	0.01499	0.00910
+ 18	0.03530	0.03209	-0.03075	-0.03337
- 18	-0.03482	-0.03132	0.02985	0.02275
+ 19	0.03601	0.03199	-0.03119	-0.03404
- 19	-0.03414	-0.03101	0.02982	0.02282

TABLE B39 - WEST COLUMN STEEL STRAINS FOR SPECIMEN LC9

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	-569	-723	1672	-153	132	1479	1440	1464	1170
- 1	1313	1791	-651	-103	989	-317	-671	-591	-532
+ 2	-600	-675	380	251	247	393	1260	1292	1019
- 2	1130	1557	3596	-49	850	-524	-616	-540	-456
+ 3	-766	-659	-19	301	475	1714	1301	1944	1595
- 3	1734	2210	4331	-52	1289	-225	-761	-707	-593
+ 4	-743	-839	-1340	-103	273	1437	1723	1757	1444
- 4	1533	2073	3711	-204	1104	-317	-707	-663	-552
+ 5	-716	-313	11	49	311	1527	1600	1533	1336
- 5	1559	1376	3930	-153	1153	-257	-631	-653	-541
+ 6	-702	-803	-1429	-153	272	1051	1521	1550	1267
- 6	1528	1326	3245	-153	1138	-475	-667	-643	-532
+ 7	-711	-813	-1386	-1	247	1012	1545	1571	1283
- 7	1502	1850	3144	-153	1120	-503	-551	-617	-537
+ 8	-686	-786	-1828	102	233	931	1452	1479	1208
- 8	1467	1846	3298	-103	1102	-459	-643	-629	-521
+ 9	-644	-1135	-2294	-204	605	3012	2521	2495	2035
- 9	2114	5309	6558	-204	1461	3443	-1037	-906	-724
+ 10	-873	334	-4464	-153	301	7432	2314	2201	1742
- 10	1871	5466	5363	-1	1308	3726	-961	-851	-665
+ 11	-630	507	-4123	-204	183	7217	3145	2030	1503
- 11	1757	5097	4592	-204	1253	3716	-906	-821	-637
+ 12	-816	561	-5315	-204	105	6571	3035	1915	1501
- 12	1691	4867	4333	-204	1204	3706	-869	-804	-622
+ 13	-1046	-183	-5833	151	424	11903	8544	2703	2007
- 13	2176	3787	11125	100	1752	5992	874	-1121	-753
+ 14	-963	323	-4053	49	313	11912	9361	2-06	1635
- 14	1871	7301	6217	100	1500	6607	1988	-1347	-674
+ 15	-309	531	-3357	49	156	11306	7769	2131	1500
- 15	1539	5426	4327	-1	1374	6432	3471	-937	-531
+ 16	-695	1200	-	102	-584	3595	4701	554	175
- 16	-90	2696	-	-50	-290	5017	1775	-746	-433
+ 17	-587	1153	-	103	-640	7452	4063	495	137
- 17	-67	1589	-	152	-290	4649	1716	-762	-451
+ 18	-1037	335	-	51	-173	9935	6157	1552	959
- 18	1217	4875	-	-51	971	5501	1666	-1155	-931
+ 19	-971	405	-	-102	-195	9324	5668	1477	833
- 19	1016	4253	-	-	783	5.67	1634	-1114	-837

TABLE B40 - EAST COLUMN STEEL STRAINS FOR SPECIMEN LC9

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	1071	1455	2062	3244	629	-137	-757	-663	-555
- 1	-533	-591	-317	-845	291	1753	1336	1551	1323
+ 2	1016	1354	1866	1973	613	-177	-667	-608	-516
- 2	-506	-561	-807	-847	199	1450	1129	1298	1107
+ 3	1518	2042	2524	6551	915	-103	-845	-780	-662
- 3	-556	-745	-1092	1066	345	2203	1736	1762	1699
+ 4	1458	1956	2267	6288	888	-106	-733	-744	-627
- 4	-540	-732	-1059	1225	249	2000	1634	1773	1516
+ 5	1385	1831	2215	5925	346	-75	-757	-720	-602
- 5	-631	-727	-1051	1301	189	1936	1563	1685	1442
+ 6	1337	1750	2136	5662	320	-103	-737	-703	-585
- 6	-527	-722	-1082	1329	163	1834	1523	1646	1404
+ 7	1355	1730	2163	5715	871	-116	-758	-721	-593
- 7	-621	-713	-1080	1345	138	1774	1485	1605	1368
+ 8	1239	1679	2243	5434	804	-133	-715	-638	-572
- 8	-616	-713	-1075	1346	123	1734	1462	1575	1339
+ 9	1926	2499	8734	10287	1153	-48	-1052	-1093	-809
- 9	-317	-1091	-524	1453	315	8491	2417	2425	2055
+ 10	1710	2248	6734	9164	977	2394	-1096	-1032	-733
- 10	-762	-1053	-424	1537	157	7314	2214	2181	1809
+ 11	1598	2097	5939	8406	691	3220	-1040	-996	-631
- 11	-735	-1035	-331	1666	103	7425	2098	2046	1657
+ 12	1519	2005	5454	7967	857	3294	-1011	-981	-677
- 12	-727	-1030	-276	1730	67	7181	2038	1975	1627
+ 13	2038	8025	7636	16643	1420	4141	-1015	-1195	-835
- 13	-945	-257	50	4308	244	9250	9357	2502	2038
+ 14	1805	6729	6259	15091	1151	5035	713	-1215	-759
- 14	-881	26	345	4890	167	4930	8414	2259	1753
+ 15	1657	5849	5236	14221	1045	4110	1455	-1276	-713
- 15	-643	136	551	5031	113	2623	7585	2075	1581
+ 16	317	2503	2119	8986	-18	1555	1142	-1106	-551
- 16	-533	513	334	3468	-584	1575	3251	107	33
+ 17	294	2402	2091	7684	-92	1571	1100	-1088	-542
- 17	-607	475	749	2963	-715	1405	3186	133	-7
+ 18	1219	4948	3660	11234	742	2437	1113	-1397	-825
- 18	-982	-101	192	2939	-238	712	6532	1759	1236
+ 19	1098	3647	2974	10569	663	732	1152	-1329	-775
- 19	-945	-52	356	2473	-304	76	5975	1560	1011

TABLE B41 - TOP COLUMN HOOP STRAINS FOR SPECIMEN LC9

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	-53	-	376	74	135	50
- 1	130	-	498	-23	130	-10
+ 2	-187	-	356	78	195	57
- 2	193	-	349	-12	175	2
+ 3	-75	-	613	138	362	117
- 3	638	-	472	26	257	107
+ 4	-15	-	489	124	379	158
- 4	654	-	402	14	255	132
+ 5	136	-	506	123	366	161
- 5	737	-	482	23	245	141
+ 6	125	-	453	120	351	158
- 6	713	-	371	32	244	144
+ 7	119	-	431	127	357	157
- 7	710	-	402	37	237	148
+ 8	116	-	438	122	341	150
- 8	700	-	341	33	234	151
+ 9	138	-	771	306	565	242
- 9	1016	-	413	134	382	466
+ 10	239	-	614	272	609	319
- 10	871	-	355	66	320	444
+ 11	254	-	645	231	550	319
- 11	789	-	317	37	296	426
+ 12	233	-	528	215	510	319
- 12	714	-	326	18	251	410
+ 13	567	-	940	567	873	454
- 13	1132	-	476	254	433	572
+ 14	626	-	1313	571	486	470
- 14	915	-	516	298	315	517
+ 15	662	-	1002	514	330	471
- 15	958	-	568	324	180	484
+ 16	843	-	735	462	48	229
- 16	1023	-	724	327	136	285
+ 17	795	-	726	460	38	224
- 17	1023	-	731	333	141	261
+ 18	952	-	1019	731	237	432
- 18	1125	-	1312	302	329	405
+ 19	832	-	955	742	228	413
- 19	1091	-	1124	298	220	379

TABLE B42 - BOTTOM COLUMN HOOP STRAINS FOR SPECIMEN LC9

CYCLE	STRAIN MILLIONTHS					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	59	-15	-355	-18	40	82
- 1	-37	32	-405	57	85	217
+ 2	43	-9	-456	-9	59	106
- 2	-21	58	-557	52	71	176
+ 3	84	2	-132	-17	132	132
- 3	-39	112	-51	121	155	319
+ 4	85	12	-405	-4	137	196
- 4	-27	112	-425	113	142	289
+ 5	89	16	-253	5	130	187
- 5	-23	108	-355	111	135	274
+ 6	86	17	-51	11	139	182
- 6	-22	107	-355	108	132	257
+ 7	82	18	100	6	131	186
- 7	-18	103	-355	104	129	259
+ 8	83	17	-203	17	129	181
- 8	-17	102	-102	101	127	256
+ 9	84	52	-102	122	271	354
- 9	-11	254	-405	98	278	509
+ 10	59	88	-355	91	267	340
- 10	-23	254	-203	56	278	455
+ 11	32	97	-405	32	261	324
- 11	-28	244	-405	58	261	429
+ 12	14	97	-405	74	252	308
- 12	-28	239	-506	58	253	409
+ 13	54	182	-253	295	403	459
- 13	224	369	-304	324	468	529
+ 14	189	183	-152	350	331	384
- 14	317	344	-304	353	444	500
+ 15	210	193	-253	340	389	351
- 15	290	310	-203	335	408	453
+ 16	221	32	101	200	216	143
- 16	132	170	50	247	157	72
+ 17	213	30	202	195	207	125
- 17	182	135	-51	257	156	71
+ 18	257	161	-152	251	254	265
- 18	269	300	-253	385	344	407
+ 19	274	157	-304	234	267	242
- 19	232	267	101	369	316	160

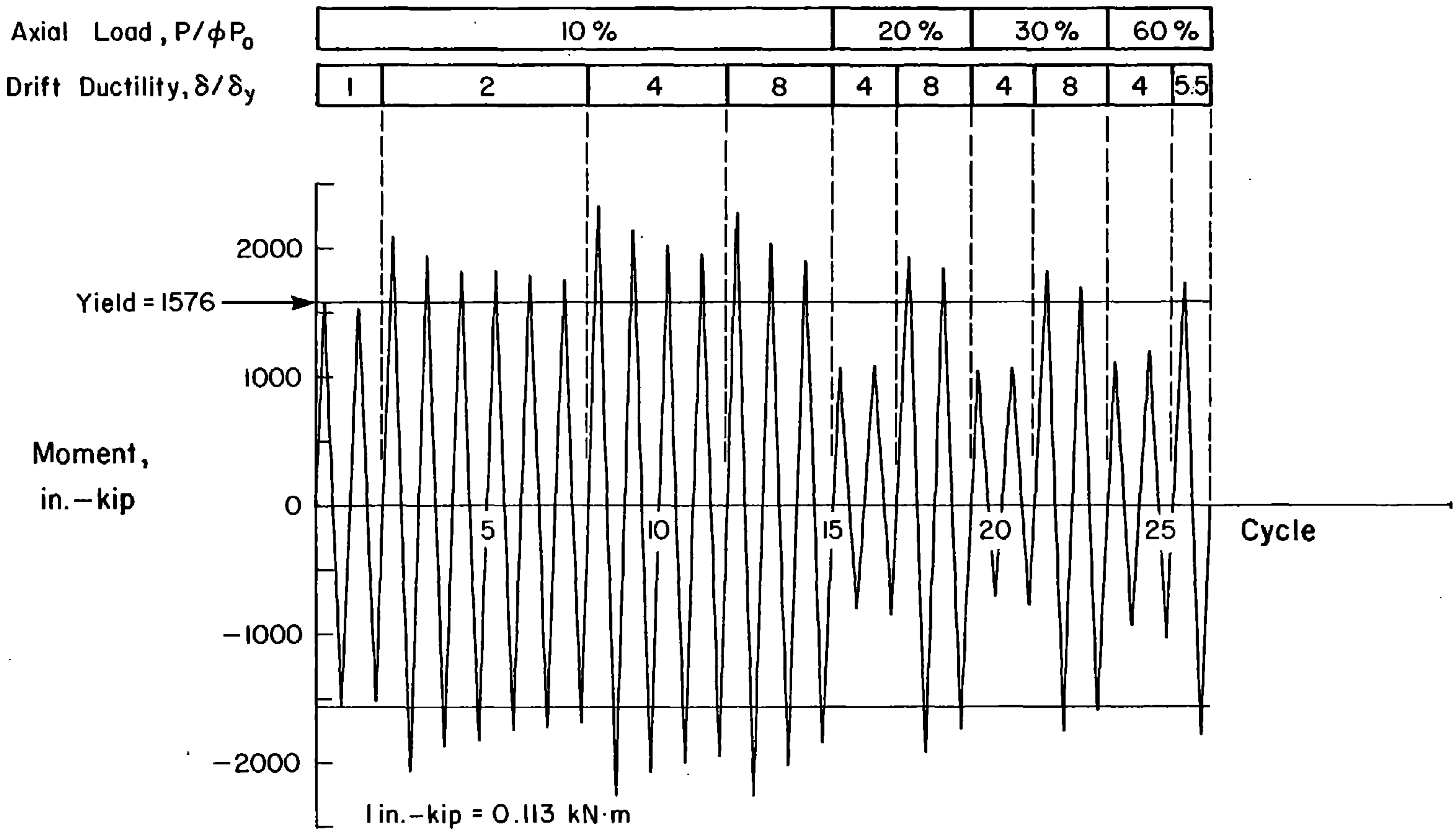
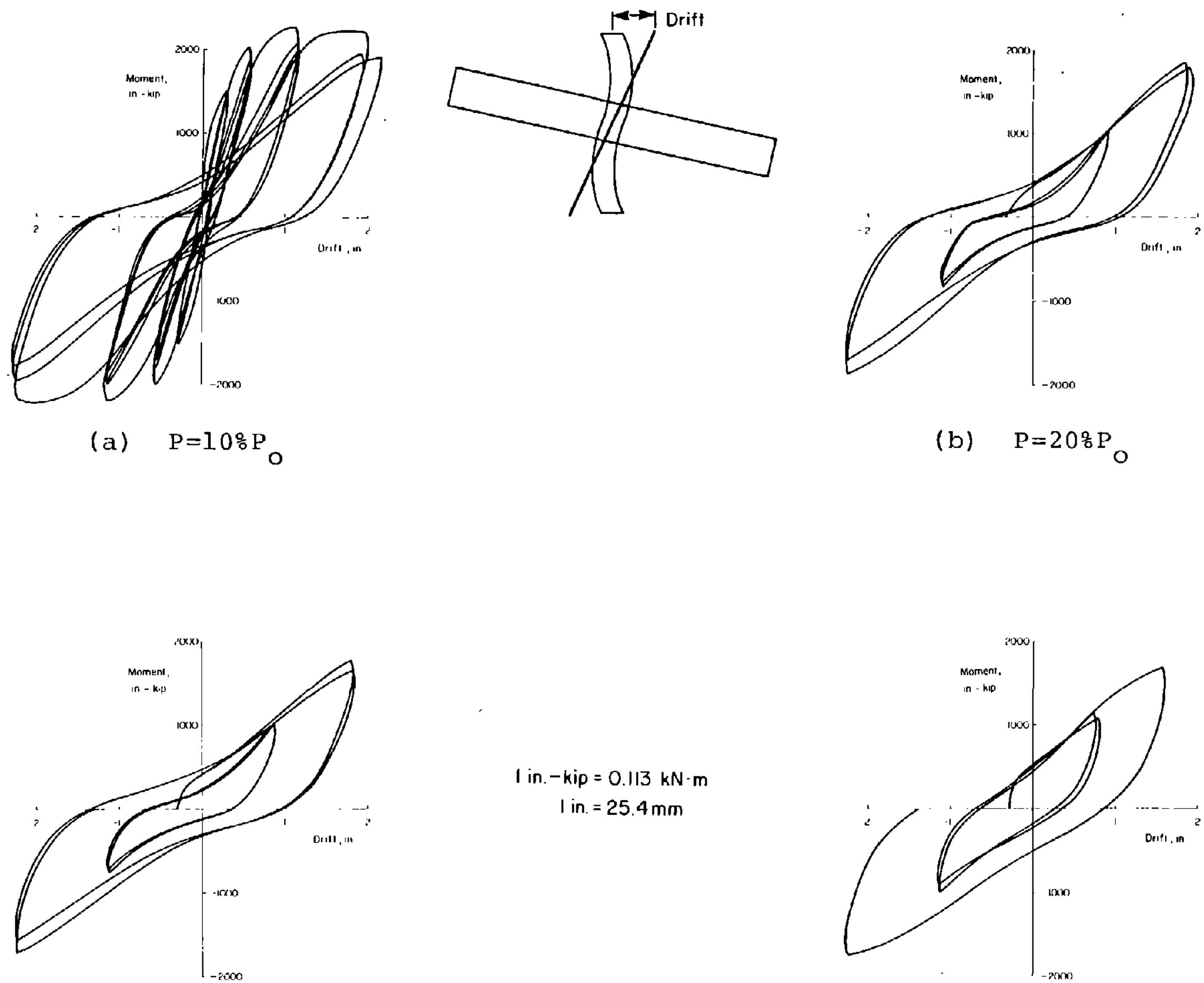


Fig. B39 Column Moment History for Specimen NC1



(a) P=10%P_o (b) P=20%P_o

(c) P=30%P_o (d) P=60%P_o

Fig. B40 Top Column Moment versus Drift for Specimen NC1

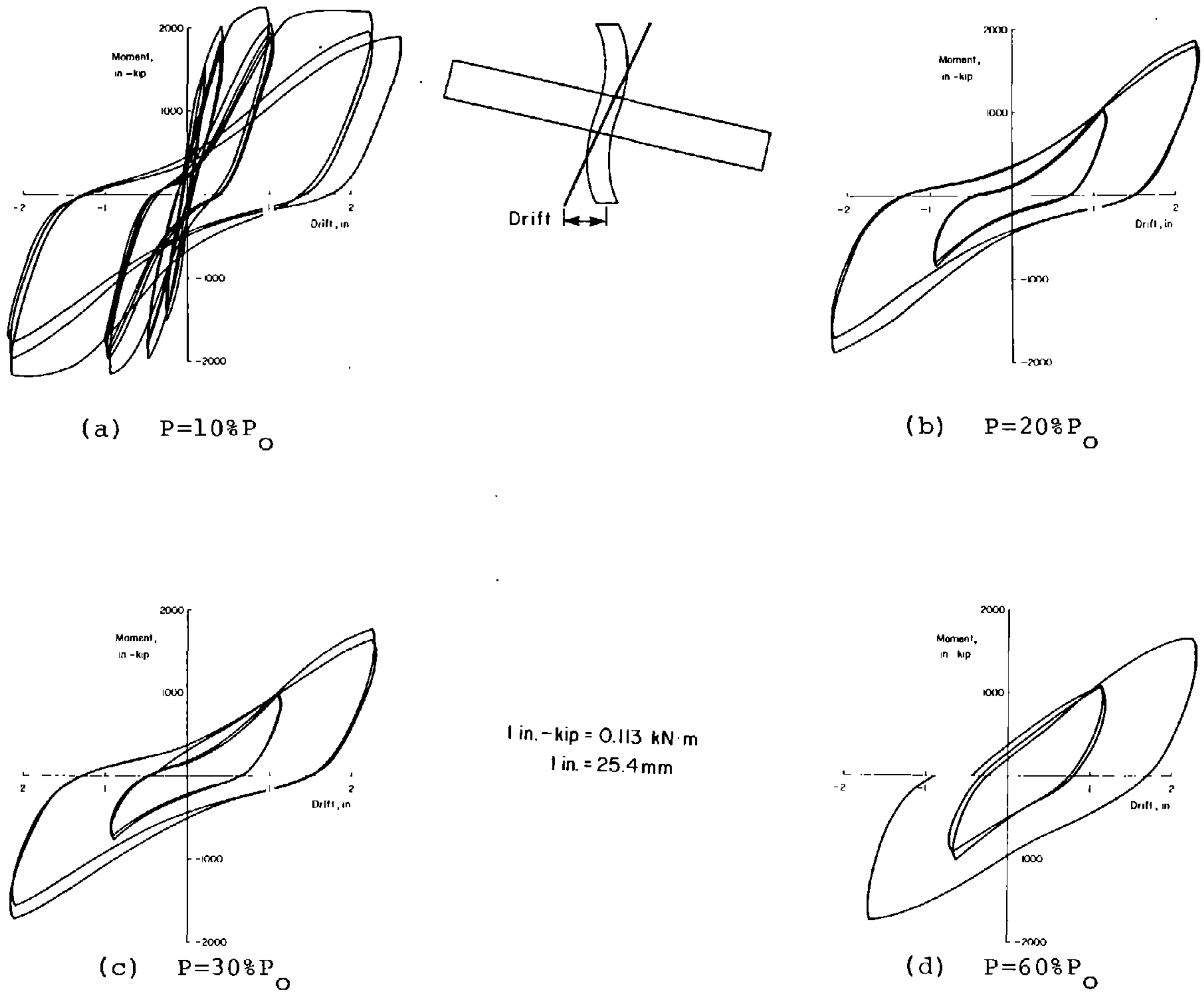


Fig. B41 Bottom Column Moment versus Drift for Specimen NC1

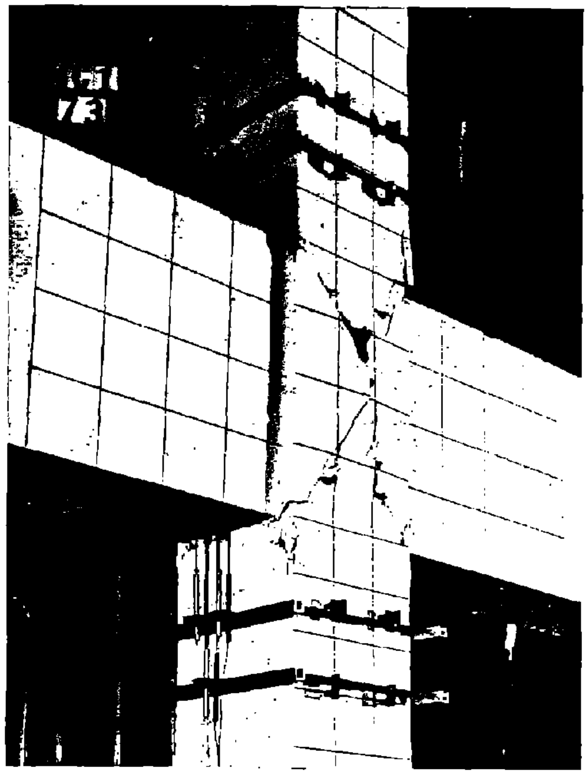


Fig. B42 Specimen NC1 after Cycle 12

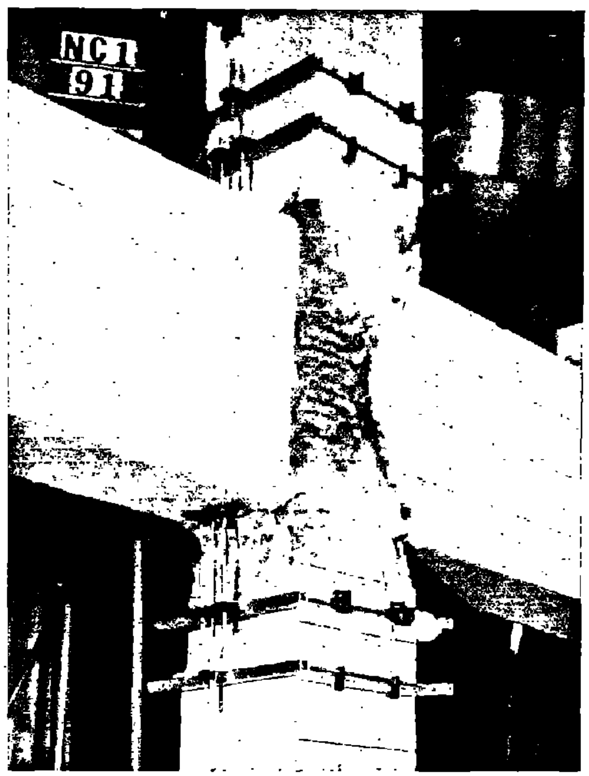


Fig. B43 Specimen NC1 after Cycle 15

Tabulated results

Values for column moment, top and bottom column drifts, and east and west beam deflections are listed in Table B43. Column rotations are shown in Table B44. Reinforcement strains are given in Tables B45 through B48.

Specimen NC3

Specimen NC3 was a repeat of Specimen NC1. However, column lengths were changed to force hinging into the top column. The top column length was increased 7.5 in. (190 mm) while the bottom column was shortened 7.5 in. (190 mm). This resulted in a bottom column moment to top column moment ratio of 0.74.

Column moment history

Specimen NC3 was subjected to 26 cycles of moment reversals as presented in Fig. B44. The moment history was identical to Specimen NC1. Due to the change in column lengths, hinging occurred in the top column. As a result of unequal column moments, sidesway of the joint was anticipated and instrumentation was added to measure the horizontal movement.

Column moment versus drift relationships

The top column of Specimen NC3 hinged. A record of moment versus drift is plotted in Fig. B45. The hysteresis loops are relatively fat depicting considerable energy dissipation capacity. For the bottom column, very small drift was measured. Bottom column moment versus drift hysteresis loops were very small and similar to those shown in Fig. B3 for Specimen LC1. Therefore, they are not reproduced here.

The first positive peak top column moment was 1501 in.-kip (169 kN·m). The corresponding top drift was 0.33 in. (8.3 mm). Because of the increase in top column height, the drift arm was longer. For this reason, the yield drift was larger than for Specimen NC1. The maximum measured top column moment was 2386 in.-kip (270 kN·m). It occurred at the negative peak of Cycle 9. Measured maximum moment was 22% greater than calculated nominal flexural strength.

TABLE B43 - COLUMN MOMENT, COLUMN DRIFTS, AND BEAM DEFLECTIONS FOR SPECIMEN NC1

CYCLE	MOMENT (IN.-KIP)	DRIFT (IN.)		DEFLECTION (IN.)	
		TOP	BOTTOM	EAST	WEST
+ 1 - 1	1576 -1567	0.287 -0.243	-0.206 0.242	1.374 -1.129	-1.229 1.343
+ 2 - 2	1529 -1529	0.309 -0.261	-0.199 0.253	1.403 -1.165	-1.235 1.361
+ 3 - 3	2093 -2071	0.586 -0.549	-0.427 0.483	2.311 -2.342	-2.189 2.243
+ 4 - 4	1937 -1877	0.591 -0.541	-0.415 0.473	2.242 -1.923	-2.099 2.129
+ 5 - 5	1819 -1933	0.578 -0.549	-0.397 0.471	2.165 -1.933	-2.015 2.105
+ 6 - 6	1924 -1747	0.595 -0.537	-0.417 0.461	2.193 -1.963	-2.039 2.061
+ 7 - 7	1789 -1729	0.600 -0.541	-0.425 0.463	2.183 -1.957	-2.033 2.029
+ 8 - 8	1753 -1693	0.597 -0.529	-0.417 0.461	2.165 -1.927	-2.009 2.015
+ 9 - 9	2329 -2256	1.158 -1.127	-0.972 0.930	3.733 -3.350	-3.552 3.492
+ 10 - 10	2141 -2075	1.175 -1.115	-1.024 0.930	3.771 -3.320	-3.588 3.427
+ 11 - 11	2023 -2000	1.160 -1.109	-1.018 0.938	3.694 -3.297	-3.622 3.406
+ 12 - 12	1954 -1949	1.161 -1.109	-1.018 0.950	3.666 -3.314	-3.593 3.427
+ 13 - 13	2275 -2259	1.975 -2.234	-2.216 2.117	6.079 -6.342	-6.326 6.111
+ 14 - 14	2039 -2023	1.936 -2.238	-2.204 2.118	6.101 -6.277	-6.322 6.220
+ 15 - 15	1907 -1845	1.942 -2.244	-2.234 2.140	6.185 -6.247	-6.388 6.123
+ 16 - 16	1063 -806	0.918 -1.101	-1.118 0.940	3.360 -2.920	-3.334 3.099
+ 17 - 17	1092 -853	0.920 -1.089	-1.104 0.932	3.256 -2.870	-3.298 3.075
+ 18 - 18	1937 -1935	1.855 -2.246	-2.244 2.165	6.056 -6.127	-6.152 6.333
+ 19 - 19	1845 -1735	1.916 -2.252	-2.244 2.166	6.262 -6.044	-6.295 6.287
+ 20 - 20	1053 -710	0.895 -1.129	-1.114 0.910	3.404 -2.664	-3.172 3.023
+ 21 - 21	1070 -774	0.905 -1.129	-1.124 0.900	3.433 -2.658	-3.173 3.021
+ 22 - 22	1829 -1753	1.825 -2.254	-2.249 2.109	6.122 -5.739	-6.032 6.155
+ 23 - 23	1699 -1592	1.829 -2.156	-2.251 2.096	6.181 -5.567	-5.966 6.110
+ 24 - 24	1122 -927	0.833 -1.135	-1.146 0.893	3.300 -2.801	-2.734 2.716
+ 25 - 25	1205 -1023	0.774 -1.127	-1.124 0.545	3.210 -1.947	-2.556 2.599
+ 26 - 26	1735 -1780	1.592 -2.254	-2.134 1.563	5.743 -4.994	-5.151 5.567

1 in.-kip = 0.113 kN·m   1 in. = 25.4mm

TABLE B44 - COLUMN ROTATIONS FOR SPECIMEN NC1

CYCLE	ROTATION (RADIANS)			
	ABOVE JOINT		BELOW JOINT	
	+D	+D/2	-D	-D/2
- 1	0.00593	0.00433	-0.00564	-0.00373
- 1	-0.00597	-0.00370	0.00510	0.00414
+ 2	0.00633	0.00456	-0.00613	-0.00409
- 2	-0.00616	-0.00353	0.00536	0.00429
+ 3	0.01140	0.00952	-0.01114	-0.00801
- 3	-0.01171	-0.00829	0.00979	0.00841
+ 4	0.01153	0.01001	-0.01122	-0.00788
- 4	-0.01120	-0.00775	0.00937	0.00811
- 5	0.01104	0.01001	-0.01081	-0.00755
- 5	-0.01118	-0.00770	0.00937	0.00815
+ 6	0.01130	0.01016	-0.01096	-0.00732
- 6	-0.01082	-0.00737	0.00908	0.00798
+ 7	0.01137	0.01044	-0.01096	-0.00759
- 7	-0.01031	-0.00740	0.00908	0.00800
+ 8	0.01114	0.01029	-0.01088	-0.00772
- 8	-0.01061	-0.00739	0.00899	0.00791
+ 9	0.02359	0.01927	-0.02308	-0.01714
- 9	-0.02312	-0.01755	0.01880	0.01740
- 10	0.02359	0.02069	-0.02396	-0.01804
- 10	-0.02230	-0.01712	0.01868	0.01750
+ 11	0.02297	0.02059	-0.02337	-0.01770
- 11	-0.02176	-0.01639	0.01861	0.01730
+ 12	0.02277	0.02039	-0.02322	-0.01773
- 12	-0.02171	-0.01685	0.01865	0.01750
+ 13	0.04223	0.03126	-0.05357	-0.03392
- 13	-0.04674	-0.03464	0.04550	0.03395
- 14	0.04103	0.03476	-0.05293	-0.04127
- 14	-0.04548	-0.03594	0.04323	0.03895
+ 15	0.04035	0.03540	-0.05270	-0.04263
- 15	-0.04409	-0.03632	0.04176	0.03909
+ 16	0.01895	0.01837	-0.02801	-0.02534
- 16	-0.02046	-0.01744	0.01558	0.01612
+ 17	0.01862	0.01897	-0.02732	-0.02446
- 17	-0.02000	-0.01691	0.01529	0.01560
+ 18	0.03644	0.03466	-0.05132	-0.04351
- 18	-0.04157	-0.03624	0.03965	0.04021
- 19	0.03324	0.03655	-0.05186	-0.04291
- 19	-0.04061	-0.03609	0.03816	0.03944
+ 20	0.01839	0.01874	-0.02788	-0.11047
- 20	-0.01934	-0.01708	0.01253	-0.09304
+ 21	0.01916	0.01861	-0.02773	-0.[illegible]1073
- 21	-0.01937	-0.01695	0.01263	-0.09133
+ 22	0.03445	0.03165	-0.05060	-0.11381
- 22	-0.03679	-0.03519	0.03503	-0.08101
+ 23	0.03405	0.03333	-0.05083	-0.11399
- 23	-0.03823	-0.03506	0.03390	-0.08244
- 24	0.01380	0.01413	-0.03691	-0.11451
- 24	-0.01619	-0.01619	0.00614	-0.10200
- 25	0.01326	0.01255	-0.03631	-0.11561
- 25	-0.01825	-0.01621	0.00542	-0.10324
+ 26	0.03643	0.03564	-0.04924	-0.12620
- 26	-0.03649	-0.03394	0.02191	-0.09651

TABLE B45 - WEST COLUMN STEEL STRAINS FOR SPECIMEN NC1

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	-592	-632	-541	53	812	1761	1395	1591	1341
- 1	1782	2044	1796	2086	698	75	-510	-512	-467
+ 2	-547	-697	-585	96	823	1737	1419	1575	1347
- 2	1844	2020	1813	1959	698	98	-531	-514	-470
+ 3	-696	-869	-716	513	1292	3240	2469	5753	2207
- 3	2641	3447	3517	9280	1118	4970	-846	1071	-639
+ 4	-726	1533	-743	4132	1017	8739	2307	5270	2004
- 4	2457	7733	3415	9689	966	5159	-845	1215	-612
+ 5	-713	1822	-711	4422	886	8278	2131	4864	1850
- 5	2417	7636	3387	8591	937	5206	-841	1254	-609
+ 6	-717	1851	-691	4554	870	8261	2134	4861	1851
- 6	2311	7175	3225	8290	861	5220	-820	1295	-598
+ 7	-720	1919	-681	4629	834	8161	2089	4767	1316
- 7	2290	6666	3202	8226	863	5240	-816	1311	-597
+ 8	-712	1946	-660	4660	796	8098	2033	4661	1770
- 8	2249	6632	3133	8110	839	5237	-810	1335	-539
+ 9	-365	1526	-793	5174	1317	13872	13920	9841	2570
- 9	4924	12910	14911	14404	1377	5592	1190	1296	-866
+ 10	35	1119	96	5720	1084	13573	13766	9739	2168
- 10	4567	11556	13551	13920	1034	6205	1423	1619	-879
+ 11	131	1249	288	6357	962	13177	13872	9157	2231
- 11	4331	11137	12827	13596	904	6545	1575	1737	-892
+ 12	158	1314	440	6756	905	13006	12505	6852	2164
- 12	4324	11191	12513	13527	849	5316	1731	1814	-892
+ 13	-56	643	-738	7544	1363	26142	29706	13114	7554
- 13	10361	21539	25873	24265	1098	11573	1422	1394	-457
+ 14	1335	85	-285	12732	1122	36892	26846	8837	7431
- 14	9505	13565	22088	23321	772	14731	2155	1671	-482
+ 15	1473	135	541	14353	1052	-	25350	7509	7156
- 15	8464	16065	19565	23005	605	-	3992	1697	-451
+ 16	1904	1239	3311	13136	144	-	10347	5730	2330
- 16	3753	4413	6800	15571	-451	-	5203	2779	-13
+ 17	1786	1059	2721	12398	32	-	3973	5729	2744
- 17	3755	4357	6406	14957	-456	-	5100	2824	-40
+ 18	1076	-145	-387	12335	693	-	30114	5790	5673
- 18	6317	10937	13691	19544	327	-	3217	2225	-593
+ 19	1065	-240	-360	12112	606	-	18955	5525	5232
- 19	5681	9019	11481	19084	251	-	3620	2031	-643
+ 20	1400	729	1385	9394	-426	-	3697	5358	1381
- 20	3793	3521	3946	11476	-924	-	4329	2728	-314
+ 21	1269	512	959	8408	-512	-	8366	5310	1925
- 21	2971	2959	3752	10574	-897	-	4115	2677	-379
+ 22	520	-470	-1056	8534	235	-	14633	6155	4002
- 22	4371	5965	7372	14549	-135	-	2236	2058	-988
+ 23	595	-460	-1063	6008	159	-	12912	5579	-
- 23	3365	4932	5017	11630	-215	-	2095	2131	-
+ 24	85	-593	-1900	-1038	-1501	-	4725	4112	-
- 24	1254	872	-6	441	-1958	-	1423	2472	-
+ 25	-5435	-757	-2371	-3311	-1311	-	4008	-109	-
- 25	1095	871	-579	-1439	-2254	-	352	2443	-
+ 26	-	-2130	-	-4118	-4350	-	5453	5410	-
- 26	516	1516	-71	571	-4363	-	-1938	1697	-

TABLE B46 - EAST COLUMN STEEL STRAINS FOR SPECIMEN NC1

CYCLE	STRAIN - MILLIONTHS								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	1443	1886	1957	2273	361	-117	-603	-574	-402
- 1	-538	-698	-505	237	402	1545	1597	1518	1238
+ 2	1465	1836	1996	2224	501	-96	-512	-505	-461
- 2	-602	-713	-631	349	415	1578	1593	1511	1237
+ 3	2154	6065	9140	10732	927	229	-658	-632	-635
- 3	-788	501	1887	5642	666	7868	3830	3455	1995
+ 4	3045	5843	8918	10619	967	3784	-100	-279	-584
- 4	-771	752	2189	6153	524	7119	3435	3049	1755
+ 5	1922	5409	8196	10150	937	3950	-52	-329	-637
- 5	-774	784	3277	5332	494	6998	3365	2975	1711
+ 6	1937	5454	8262	10210	961	4038	-34	-230	-533
- 6	-760	843	2352	6193	442	5743	3185	2815	1618
+ 7	1902	5353	8052	10094	950	4071	-25	-221	-534
- 7	-762	861	2403	6453	423	5673	3141	2783	1599
+ 8	1867	5227	7866	9982	943	4066	-8	-225	-533
- 8	-754	384	2434	6495	404	6560	3075	2727	1558
+ 9	2607	11218	15463	15908	1397	4325	-515	-641	-636
- 9	-901	931	2515	7670	708	10915	12234	8646	2199
- 10	2440	5989	14984	16277	1303	4451	-265	424	-773
- 10	-990	1151	2575	8353	571	10777	-11179	7702	2020
+ 11	2310	8772	13901	15792	1174	4384	-15	567	-786
- 11	-897	1190	2602	3799	456	10524	10606	7251	1923
- 12	2242	8301	13392	15585	1079	5129	189	623	-795
- 12	-893	1221	2595	9079	459	10502	10428	7021	1891
+ 13	5379	10656	12467	25750	1300	5153	-3142	-554	-345
- 13	-598	-1455	8089	14312	1040	22557	-	-	3110
+ 14	4944	8350	8608	25519	986	10192	919	-637	-151
- 14	-674	-1173	6641	16465	848	22066	7220	-	2901
+ 15	4635	7190	7782	26153	769	11518	2691	-408	-731
- 15	-660	-839	6025	16542	772	21937	4019	7798	2661
+ 16	1840	2755	7989	20397	-23	9681	4943	653	-914
- 16	-303	235	8564	15203	-359	13221	3414	3565	393
+ 17	1788	2744	7740	18535	-91	9320	5531	1151	-915
- 17	-353	215	8416	15031	-371	12836	3450	3540	909
+ 18	3434	4481	7198	22796	311	9203	1724	369	-1111
- 18	-1003	-1002	6598	15685	431	13700	4612	6317	2208
- 19	3227	4141	5943	23045	326	8526	1390	45	-1002
- 19	-674	-948	6609	15781	271	17393	4210	5483	1593
- 20	1094	2031	7906	16611	-481	5054	4446	625	-1042
- 20	-646	-100	8643	10962	-908	3070	2368	2652	416
+ 21	1091	2034	7668	13766	-531	4651	5157	1075	-838
- 21	-690	-156	8963	10202	-926	7714	3385	2658	486
+ 22	2195	2967	7299	16717	-55	4210	1722	349	-1199
- 22	-1165	-1110	7963	10219	-145	12426	4612	4238	1603
- 23	1922	2630	7381	15609	-95	2528	1113	-29	-1121
- 23	-1125	-1009	9181	9410	-251	16557	2825	3759	1476
+ 24	-395	555	9192	4219	-4157	-5362	960	-2	-1368
- 24	-1591	-902	9202	-4423	-5636	-3748	2975	1950	-702
+ 25	-452	662	9959	-2740	-5615	-6933	1135	374	-1234
- 25	-1765	-953	9116	-6934	-6830	-4961	3211	1695	-421
+ 26	223	1573	8059	-3213	-5027	-10547	-1863	-2094	-
- 26	-2785	-2214	7131	-10084	-6160	-4320	1122	907	-321

TABLE B47 - TOP COLUMN HOOP STRAINS FOR SPECIMEN NC1

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	478	-56	10	59	-	-
- 1	391	-51	438	95	-	-
+ 2	519	-573	26	61	-	-
- 2	412	-19	462	95	-	-
+ 3	545	-130	159	157	-	-
- 3	240	586	621	230	-	-
+ 4	555	339	229	146	-	-
- 4	284	818	584	207	-	-
+ 5	555	654	215	131	-	-
- 5	295	868	584	206	-	-
+ 6	555	488	230	131	-	-
- 6	315	908	563	196	-	-
+ 7	554	530	238	127	-	-
- 7	314	930	559	192	-	-
+ 8	555	545	244	122	-	-
- 8	320	940	553	199	-	-
+ 9	469	1375	545	224	-	-
- 9	422	1402	915	318	-	-
+ 10	657	1569	514	112	-	-
- 10	525	1491	375	245	-	-
+ 11	671	1592	591	35	-	-
- 11	555	1530	347	219	-	-
+ 12	656	1590	581	65	-	-
- 12	531	1575	636	207	-	-
+ 13	699	2179	1084	119	-	-
- 13	770	2045	1635	178	-	-
+ 14	858	2188	885	147	-	-
- 14	771	1965	1450	307	-	-
+ 15	923	2185	844	184	-	-
- 15	827	1954	1315	434	-	-
+ 16	660	2053	250	48	-	-
- 16	608	1860	520	165	-	-
+ 17	723	2063	255	98	-	-
- 17	585	1873	539	141	-	-
+ 18	964	2215	723	226	-	-
- 18	771	1855	1200	350	-	-
+ 19	1087	2226	730	319	-	-
- 19	845	1860	1148	395	-	-
+ 20	722	2118	309	171	-	-
- 20	706	1864	473	155	-	-
+ 21	761	2117	310	237	-	-
- 21	720	1853	508	185	-	-
+ 22	1005	2285	525	371	-	-
- 22	920	1860	1114	460	-	-
+ 23	1007	2325	625	425	-	-
- 23	996	1904	1069	517	-	-
+ 24	571	2265	498	233	-	-
- 24	559	2069	519	389	-	-
+ 25	610	2331	536	148	-	-
- 25	650	2052	569	334	-	-
+ 26	742	2556	712	500	-	-
- 26	330	2256	1143	401	-	-

TABLE B48 - BOTTOM COLUMN HOOP STRAINS FOR SPECIMEN NC1

CYCLE	STRAIN MILLIONTHS					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	154	-1	250	-13	109	-32
- 1	-60	175	-16	140	141	153
+ 2	159	30	374	-21	119	11
- 2	-50	199	-	155	112	174
+ 3	120	57	315	34	340	112
- 3	-16	438	146	137	279	327
+ 4	215	91	315	99	374	148
- 4	-9	432	164	131	262	306
+ 5	204	85	191	116	360	148
- 5	-6	436	178	191	253	307
+ 6	205	85	196	145	365	151
- 6	-7	421	173	200	242	308
+ 7	202	85	289	160	363	151
- 7	-4	431	173	206	237	294
+ 8	197	35	235	162	350	148
- 8	-3	416	174	203	232	294
+ 9	52	278	482	217	574	513
- 9	275	501	299	215	578	454
+ 10	-17	315	515	299	446	524
- 10	245	426	305	333	550	513
+ 11	-14	315	502	329	395	504
- 11	246	393	305	213	525	519
+ 12	-9	309	495	354	362	493
- 12	250	380	306	316	516	527
+ 13	127	564	1188	314	447	1463
- 13	426	355	1163	493	883	1725
+ 14	206	828	1300	385	335	1186
- 14	640	354	1106	424	736	1600
+ 15	242	714	1290	527	256	1339
- 15	775	358	1046	520	644	1519
+ 16	372	196	768	526	367	432
- 16	493	235	339	541	151	565
+ 17	305	229	725	556	418	432
- 17	496	329	355	496	200	666
+ 18	294	563	1275	617	440	1160
- 18	727	403	1030	435	565	1458
+ 19	315	538	1266	734	513	1117
- 19	763	417	960	394	513	1371
+ 20	428	115	736	522	655	453
- 20	701	423	421	563	258	499
+ 21	467	136	742	581	648	463
- 21	701	417	427	522	269	523
+ 22	474	411	1294	584	347	1006
- 22	303	564	934	405	513	1156
+ 23	541	417	1395	521	929	960
- 23	932	583	900	492	583	1309
+ 24	1042	325	600	593	1061	875
- 24	1150	711	725	300	749	798
+ 25	1208	330	651	557	1128	951
- 25	1149	742	751	790	765	842
+ 26	1352	519	1285	353	1917	1630
- 26	925	1143	1117	349	344	1439

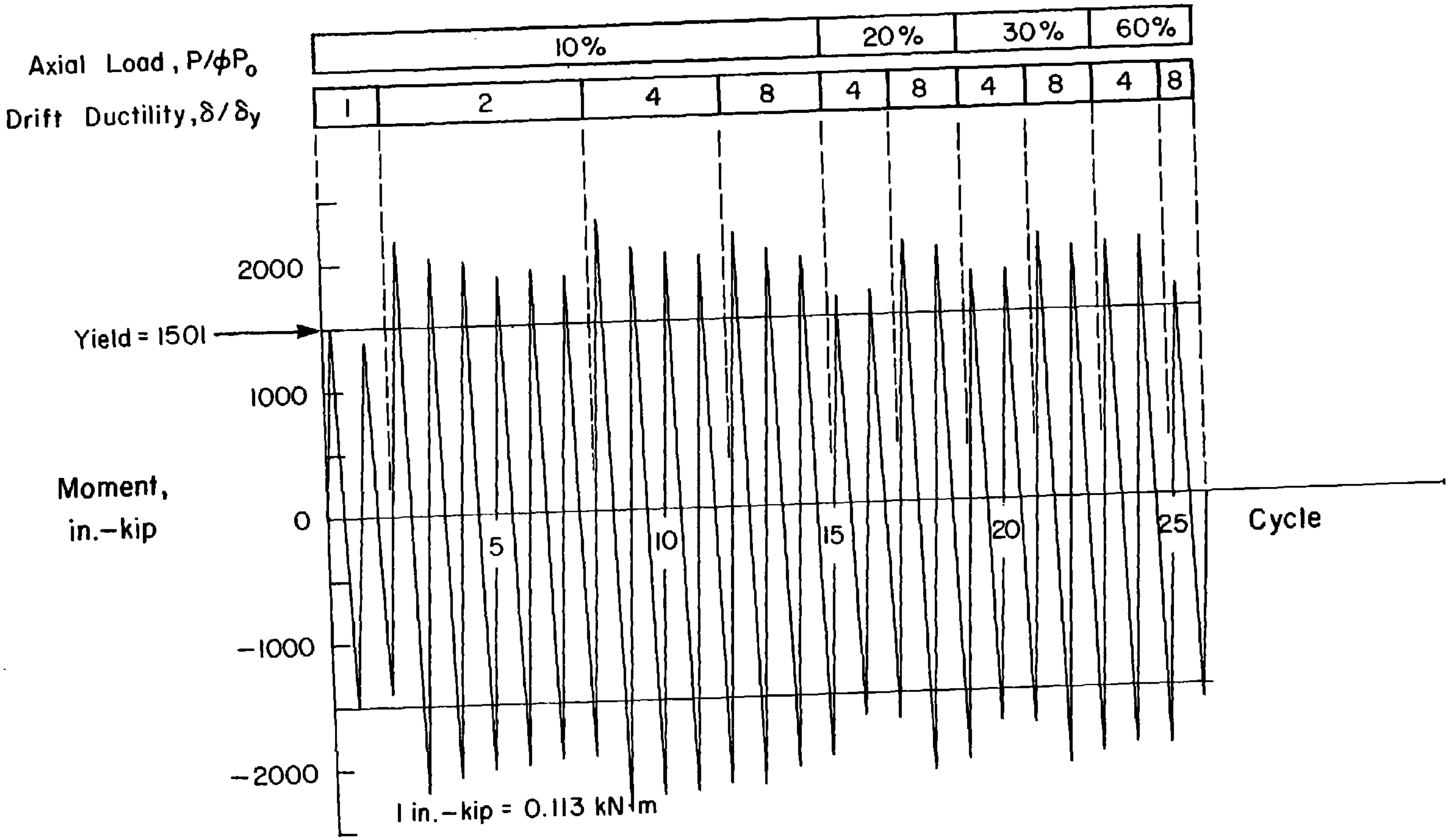


Fig. B44 Column Moment History for Specimen NC3

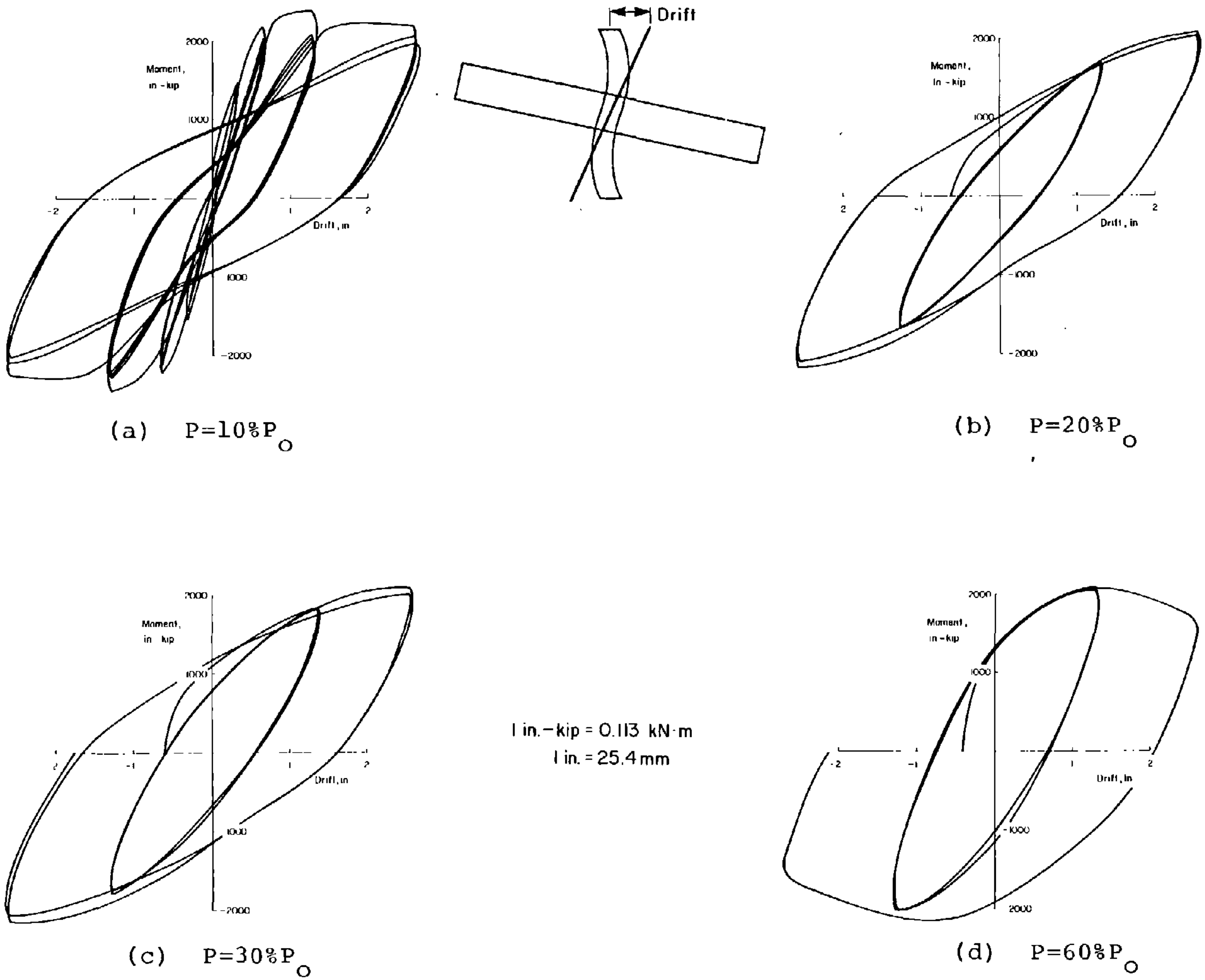


Fig. B45 Top Column Moment versus Drift for Specimen NC3

Some unhooking of the 90° hook of the supplementary crossties started during Cycle 23. Slight buckling of column reinforcement did not occur until Cycle 26. This specimen lost load carrying capacity during Cycle 26 as shown in Fig. B45(d).

Photographs at the end of Cycles 12 and 15 of the basic loading cycles are shown in Figs. B46 and B47, respectively.

Tabulated results

Tabulated values of top column moment, top and bottom column drifts, east and west beam deflections, and horizontal joint movements are listed in Table B49. Moments listed exclude secondary moments due to horizontal joint movement. Column rotations, shear diagonal movements, and calculated joint shear distortions are given for peak cycles in Table B50. Shear Diagonal Movements D_1 and D_2, and the shear distortion equation are identified in Fig. A9. Reinforcement strains are shown in Tables B51 through B54.

Specimen LC7

Specimen LC7 was constructed using Lightweight Concrete 1. The main column reinforcement consisted of 8-No. 6 bars. Confining reinforcement consisted of No. 4 hoops spaced at 4 in. (102 mm). This corresponds to a volume of hoop reinforcement to concrete core of 1.60%. Other reinforcement details are provided in Table A1.

Column moment history

The column of Specimen LC7 was subjected to 26 cycles of moment reversals as shown in Fig. B48. During the basic loading cycles, the applied column axial load was 80.7 kip (359 kN). This corresponds to 10% of the column axial design strength. This axial load level was then increased to 20%, 30%, and 60% of the column design strength, and additional loading cycles were applied as shown in Fig. B48.

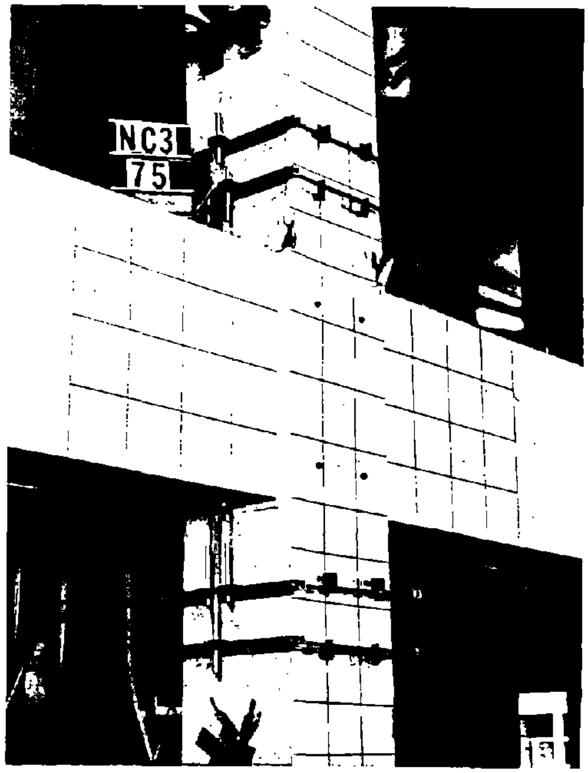


Fig. B46 Specimen NC3 after Cycle 12

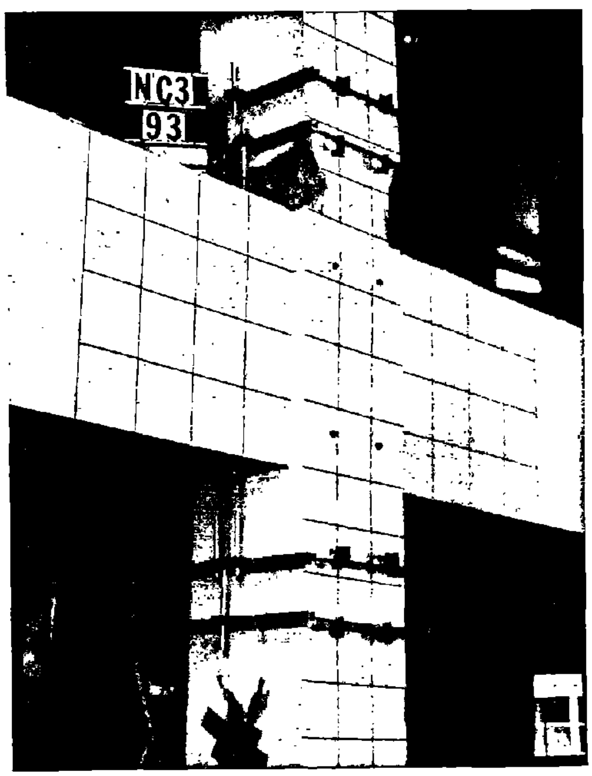


Fig. B47 Specimen NC3 after Cycle 15

TABLE B49 - COLUMN MOMENT, COLUMN DRIFTS, BEAM DEFLECTIONS, AND HORIZONTAL JOINT MOVEMENT FOR SPECIMEN NC3

CYCLE	MOMENT (IN.-KIP)	DRIFT (IN.)		DEFLECTION (IN.)		HORIZONTAL JOINT MOVEMENT (IN.)
		TOP	BOTTOM	EAST	WEST	
+ 1	1501	0.325	-0.066	1.064	-0.951	-0.293
- 1	-1508	-0.321	0.066	-0.847	0.961	0.250
+ 2	1357	0.329	-0.066	1.025	-0.834	-0.277
- 2	-1398	-0.311	0.063	-0.871	0.926	0.240
+ 3	2187	0.672	-0.173	1.835	-1.639	-0.477
- 3	-2194	-0.654	0.184	-1.632	1.765	0.430
+ 4	2033	0.674	-0.190	1.759	-1.539	-0.465
- 4	-2077	-0.654	0.180	-1.609	1.723	0.421
+ 5	2004	0.681	-0.178	1.793	-1.509	-0.469
- 5	-2025	-0.648	0.180	-1.599	1.715	0.413
+ 6	1882	0.658	-0.174	1.716	-1.567	-0.447
- 6	-1995	-0.652	0.184	-1.599	1.714	0.416
+ 7	1933	0.678	-0.178	1.770	-1.591	-0.459
- 7	-1955	-0.644	0.182	-1.573	1.593	0.409
+ 8	1873	0.665	-0.174	1.727	-1.567	-0.447
- 8	-1936	-0.640	0.182	-1.556	1.685	0.408
+ 9	2309	1.321	-0.233	2.719	-2.515	-0.865
- 9	-2386	-1.335	0.244	-2.568	2.713	0.840
+ 10	2082	1.306	-0.216	2.589	-2.443	-0.852
- 10	-2164	-1.323	0.238	-2.551	2.550	0.832
+ 11	2086	1.281	-0.218	2.532	-2.455	-0.870
- 11	-2242	-1.357	0.222	-2.581	2.629	0.830
+ 12	2011	1.309	-0.216	2.564	-2.473	-0.883
- 12	-2165	-1.347	0.221	-2.571	2.621	0.829
+ 13	2180	2.602	-0.236	4.117	-4.074	-1.721
- 13	-2203	-2.631	0.242	-4.059	4.069	1.569
+ 14	2040	2.620	-0.210	4.066	-4.066	-1.729
- 14	-2073	-2.631	0.232	-4.029	4.015	1.670
+ 15	1969	2.558	-0.205	4.094	-4.098	-1.748
- 15	-1996	-2.521	0.212	-3.975	3.972	1.662
+ 16	1647	1.301	-0.148	2.407	-2.230	-0.870
- 16	-1575	-1.315	0.142	-2.240	2.372	0.840
+ 17	1687	1.319	-0.148	2.425	-2.293	-0.888
- 17	-1714	-1.307	0.144	-2.251	2.377	0.838
+ 18	2072	2.593	-0.176	4.019	-3.918	-1.719
- 18	-2129	-2.523	0.192	-3.915	3.979	1.694
+ 19	2022	2.577	-0.176	3.965	-3.918	-1.709
- 19	-2042	-2.613	0.174	-3.902	3.935	1.589
+ 20	1822	1.394	-0.130	2.520	-2.377	-0.940
- 20	-1750	-1.307	0.104	-2.213	2.381	0.875
+ 21	1927	1.366	-0.128	2.486	-2.335	-0.930
- 21	-1778	-1.309	0.113	-2.226	2.384	0.872
+ 22	2102	2.575	-0.141	3.955	-3.898	-1.741
- 22	-2105	-2.619	0.142	-3.861	3.928	1.739
+ 23	2000	2.589	-0.128	3.917	-3.858	-1.729
- 23	-2019	-2.643	0.130	-3.856	3.917	1.744
+ 24	2021	1.312	-0.079	2.513	-2.275	-0.956
- 24	-1958	-1.315	0.072	-2.417	2.225	0.932
+ 25	2053	1.332	-0.070	2.529	-2.299	-0.970
- 25	-1974	-1.297	0.073	-2.174	2.378	0.921
+ 26	1671	2.570	-0.056	3.931	-3.672	-1.796
- 26	-1612	-2.613	0.092	-3.920	3.757	1.783

1 in.-kip = 0.113 kN·m   1 in. = 25.4mm

TABLE B50 - COLUMN ROTATIONS, SHEAR DIAGONAL MOVEMENTS, AND SHEAR DISTORSIONS FOR SPECIMEN NC3

CYCLE	ROTATION (RAD)				SHEAR DIAGONAL MOVEMENT (IN.)		SHEAR DISTORTION (RAD)
	ABOVE JOINT		BELOW JOINT				
	+D	+D/2	-I	-D/2	D1	D2	
+ 1	0.00540	0.00282	-0.00167	-0.00167	0.012	-0.008	0.00154
- 1	-0.00523	-0.00271	0.00278	0.00191	-0.010	0.013	-0.00180
+ 2	0.00520	0.00319	-0.00173	-0.00170	0.010	-0.008	0.00145
- 2	-0.00510	-0.00247	0.00285	0.00191	-0.012	0.013	-0.00202
+ 3	0.01091	0.00773	-0.00455	-0.00419	0.021	-0.016	0.00282
- 3	-0.01131	-0.00746	0.00582	0.00417	-0.026	0.034	-0.00467
+ 4	0.01087	0.00797	-0.00448	-0.00429	0.021	-0.015	0.00282
- 4	-0.01123	-0.00740	0.00576	0.00414	-0.028	0.035	-0.00495
+ 5	0.01077	0.00807	-0.00444	-0.00419	0.020	-0.016	0.00277
- 5	-0.01122	-0.00741	0.00575	0.00418	-0.031	0.036	-0.00523
+ 6	0.01025	0.00776	-0.00431	-0.00405	0.019	-0.016	0.00272
- 6	-0.01126	-0.00739	0.00577	0.00420	-0.032	0.036	-0.00536
+ 7	0.01057	0.00797	-0.00441	-0.00415	0.019	-0.016	0.00277
- 7	-0.01113	-0.00731	0.00572	0.00416	-0.031	0.036	-0.00523
+ 8	0.01026	0.00787	-0.00431	-0.00408	0.019	-0.016	0.00276
- 8	-0.01112	-0.00720	0.00565	0.00415	-0.031	0.036	-0.00523
+ 9	0.02402	0.01913	-0.00590	-0.00539	0.023	-0.020	0.00339
- 9	-0.02582	-0.01964	0.00722	0.00535	-0.040	0.047	-0.00682
+ 10	0.02429	0.02033	-0.00516	-0.00487	0.021	-0.019	0.00304
- 10	-0.02590	-0.01971	0.00703	0.00521	-0.040	0.046	-0.00673
+ 11	0.02432	0.02040	-0.00499	-0.00470	0.020	-0.016	0.00282
- 11	-0.02618	-0.01978	0.00689	0.00529	-0.039	0.047	-0.00674
+ 12	0.02490	0.02095	-0.00502	-0.00465	0.020	-0.016	0.00284
- 12	-0.02623	-0.01967	0.00637	0.00528	-0.040	0.047	-0.00679
+ 13	0.05415	0.03972	-0.00554	-0.00505	0.025	-0.021	0.00360
- 13	-0.05682	-0.03728	0.00712	0.00555	-0.049	0.056	-0.00821
+ 14	0.05458	0.04201	-0.00519	-0.00487	0.025	-0.020	0.00348
- 14	-0.05716	-0.03780	0.00673	0.00527	-0.049	0.055	-0.00811
+ 15	0.05509	0.04402	-0.00512	-0.00475	0.023	-0.020	0.00321
- 15	-0.05691	-0.03797	0.00659	0.00509	-0.049	0.056	-0.00825
+ 16	0.02521	0.02298	-0.00332	-0.02313	0.013	-0.019	0.00249
- 16	-0.02787	-0.01841	0.00449	0.00359	-0.032	0.033	-0.00513
+ 17	0.02603	0.02320	-0.00347	-0.00330	0.012	-0.019	0.00246
- 17	-0.02775	-0.01867	0.00458	0.00377	-0.033	0.033	-0.00513
+ 18	0.05426	0.04446	-0.00412	-0.00393	0.018	-0.025	0.00317
- 18	-0.05772	-0.04197	0.00536	0.00449	-0.042	0.042	-0.00660
+ 19	0.05426	0.04558	-0.00410	-0.00364	0.016	-0.023	0.00300
- 19	-0.05775	-0.04303	0.00529	0.00439	-0.036	0.039	-0.00587
+ 20	0.02362	0.02597	-0.00292	-0.00282	0.009	-0.022	0.00241
- 20	-0.02920	-0.02140	0.00360	0.00306	-0.019	0.014	-0.00253
+ 21	0.02825	0.02569	-0.00235	-0.00289	0.006	-0.022	0.00217
- 21	-0.02911	-0.02143	0.00361	0.00307	-0.021	0.014	-0.00277
+ 22	0.05478	0.04750	-0.00336	-0.00310	0.003	-0.025	0.00257
- 22	-0.05879	-0.04424	0.00417	0.00361	-0.028	0.022	-0.00395
+ 23	0.05542	0.04790	-0.00313	-0.00293	0.005	-0.022	0.00205
- 23	-0.05945	-0.04485	0.00390	0.00334	-0.025	0.021	-0.00350
+ 24	0.02871	0.02810	-0.00173	-0.00177	0.001	-0.023	0.00193
- 24	-0.02933	-0.02241	0.00226	0.00208	-0.014	-0.000	-0.00111
+ 25	0.02921	0.02762	-0.00172	-0.00158	0.001	-0.025	0.00217
- 25	-0.02604	-0.01929	0.00227	0.00194	-0.014	0.001	-0.00119
+ 26	0.05891	0.04714	-0.00154	-0.00116	0.002	-0.026	0.00220
- 26	-0.05599	-0.06465	0.00225	0.00175	-0.015	0.003	-0.00140

1 in. = 25.4mm

TABLE B51 - WEST COLUMN STEEL STRAINS FOR SPECIMEN NC3

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	-556	-594	-652	-245	-37	883	2311	420	439
- 1	1431	1652	1511	1737	223	-97	646	-374	-307
+ 2	-551	-580	-621	-304	-16	846	2575	395	410
- 2	1358	1504	1410	1625	233	-102	775	-367	-364
+ 3	-848	-920	-944	-197	194	1670	3730	1311	1131
- 3	2358	2612	2501	7621	876	20	799	-572	-496
+ 4	-676	-1066	-1311	1484	258	1601	1730	1300	1135
- 4	2313	2509	2432	7506	837	35	-4240	-558	-483
+ 5	-873	-1077	-1347	1736	254	1505	1822	1177	1096
- 5	2275	2473	2401	7465	901	44	-3656	-554	-431
+ 6	-856	-1065	-1363	1967	255	1433	1562	1126	1018
- 6	2261	2461	2392	7452	903	49	-4140	-552	-430
+ 7	-873	-1085	-1386	1960	256	1461	1792	1155	1065
- 7	2217	2416	2351	7328	897	49	-5134	-547	-478
+ 8	-865	-1078	-1393	2007	250	1404	1495	1119	1025
- 8	2201	2402	2339	7291	899	51	-4513	-544	-474
+ 9	-1031	-1429	-1965	2063	323	1765	2231	1432	1304
- 9	6543	10262	15091	14721	1232	189	-3707	-650	-558
+ 10	31	-329	-1974	2251	272	1519	2140	1289	1179
- 10	6574	10125	14185	14415	1212	195	-3316	-628	-536
+ 11	341	-769	-1926	2521	243	1553	2213	1235	1145
- 11	6709	10287	14310	14810	1255	205	-3481	-611	-519
+ 12	369	-706	-1926	2687	244	1553	2133	1233	1137
- 12	6737	10263	14189	14847	1247	204	-3628	-606	-515
+ 13	-154	-2185	-9471	2341	234	1611	2374	1289	1179
- 13	13451	20853	26810	23955	1458	290	-2957	-610	-525
+ 14	-536	-2657	-9491	2656	194	1531	2493	1203	1096
- 14	13584	19902	25171	24715	1464	285	-2601	-580	-501
+ 15	-464	-2838	-9150	2964	134	1460	2542	1147	1040
- 15	13383	19270	24014	25110	1445	235	-2323	-569	-494
+ 16	-134	-1703	-3606	4017	-126	552	1691	522	373
- 16	6314	8476	8188	11096	302	-45	-1942	-565	-534
+ 17	-166	-1935	-4506	4111	-120	597	1871	539	401
- 17	5847	8351	8005	11087	900	-49	-1807	-615	-544
+ 18	-391	-3904	-13169	3156	-130	313	2127	651	501
- 18	12539	18036	19279	23562	1190	52	-1633	-690	-506
+ 19	-987	-4727	-13157	3352	-302	734	3248	621	477
- 19	12562	17468	17366	23889	1164	51	-1461	-677	-596
+ 20	-670	-3820	-7726	4646	-389	165	1654	218	70
- 20	6483	7420	3961	13512	616	-183	-1054	-706	-639
+ 21	-762	-4050	-3312	4695	-415	130	592	198	50
- 21	6320	7272	3728	13424	506	-293	-3972	-731	-547
+ 22	-2124	-7740	-15067	3631	-522	169	629	159	36
- 22	11560	15738	13987	22691	907	-188	-3130	-768	-690
+ 23	-2428	-8315	-11458	4137	-532	171	896	169	39
- 23	11772	14825	14280	23237	870	-197	-2693	-746	-670
+ 24	-4297	-7351	-7560	4765	-1035	-331	-1119	-332	-454
- 24	2196	3324	1717	11759	-217	-1021	-2169	-1071	-1000
+ 25	-6670	-	-3500	4171	-1212	-357	-650	-453	-515
- 25	312	-	-112	10867	-206	-1321	-5910	-1127	-1053
+ 26	-3751	-	-	3867	-1399	-1237	-4715	-533	-556
- 26	5504	-	-	13655	-150	-961	-462	-1071	-1035

TABLE B52 - EAST COLUMN STEEL STRAINS FOR SPECIMEN NC3

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	1510	1657	1307	1725	295	178	-461	-430	-342
- 1	-533	-554	-539	-237	5	1213	905	762	241
+ 2	1493	1647	1360	1685	328	272	-439	-414	-337
- 2	-510	-544	-537	-263	16	1208	856	762	358
+ 3	2359	2272	2405	7594	921	383	-630	-577	-531
- 3	-303	-685	-1020	1754	180	2066	1666	1571	1165
+ 4	2262	3158	2401	7543	957	-1078	-641	-567	-499
- 4	-804	-660	-1083	1971	211	844	1573	1498	1122
+ 5	2230	3363	2373	7629	1021	-510	-642	-568	-505
- 5	-624	-616	-1108	2090	222	1113	1546	1473	1109
+ 6	2111	3223	2272	7246	969	-900	-615	-645	-488
- 6	-606	-633	-1125	2157	230	903	1535	1465	1109
+ 7	2160	3323	2327	7471	1012	-1207	-629	-561	-533
- 7	-301	-615	-1114	2189	225	228	1497	1433	1033
+ 8	2094	3234	2264	7256	988	-923	-616	-551	-495
- 8	-797	-605	-1139	2216	216	794	1477	1414	1069
+ 9	2487	11309	13031	13255	1321	-122	-718	-775	-593
- 9	-1251	-247	-33	2697	241	1756	1631	1751	1345
+ 10	2398	11126	13077	13577	1277	28	-654	-717	-543
- 10	-1285	-159	-319	2765	207	1558	1745	1682	1287
+ 11	2375	11121	13124	13379	1246	-1129	-632	-695	-506
- 11	-1281	-104	-232	2754	156	689	1708	1645	1279
+ 12	2384	11197	13461	14236	1272	-887	-530	-693	-510
- 12	-1297	-23	-286	3095	143	1032	1687	1524	1265
+ 13	10418	21684	27259	25015	1510	-213	-646	-736	-540
- 13	-990	-2475	-7989	3112	57	1425	1617	1553	1314
+ 14	10919	21067	25399	26895	1531	18	-505	-639	-517
- 14	-829	-3137	-9447	3344	-25	1385	1505	1440	1115
+ 15	11130	10648	14645	28215	1557	119	-588	-527	-510
- 15	-746	-3609	-9341	3302	-85	1338	1430	1370	1056
+ 16	6185	8210	5140	15424	1166	-100	-652	-709	-544
- 16	-386	-2341	-5629	4188	-308	626	637	551	332
+ 17	6085	3272	5720	15291	1135	-52	-655	-722	-553
- 17	-407	-2506	-6922	4253	-327	680	638	586	349
+ 18	9826	18072	21444	26464	1449	103	-725	-799	-617
- 18	-1111	-6356	-14529	2349	-350	321	799	744	471
+ 19	10242	17337	18536	27154	1426	139	-713	-738	-505
- 19	-1117	-5817	-15152	3817	-423	577	743	695	430
+ 20	6294	7687	2889	16934	1040	-174	-790	-835	-661
- 20	-771	-3663	-10142	5164	-517	150	114	122	-29
+ 21	5936	7373	3164	16402	982	-1517	-807	-839	-657
- 21	-819	-3791	-10478	5150	-633	-888	120	130	-13
+ 22	9378	16035	15200	25152	1217	-735	-841	-891	-712
- 22	-1854	-6503	-	4243	-714	-163	158	169	8
+ 23	9910	15847	-	-	1232	-404	-815	-860	-611
- 23	-1975	-5067	-	5028	-738	-105	129	119	-13
+ 24	4341	5284	-	-	429	-931	-1225	-1125	-1050
- 24	-1330	-5210	-	4636	-1299	-1060	-679	-607	-571
+ 25	2321	4111	-	13454	273	-1063	-1313	-1267	-1314
- 25	-5234	-	-	3384	-1393	-2115	-782	-687	-822
+ 26	4647	-	-	-	292	-1378	-1244	-1131	-1222
- 26	-6896	-	-	1619	-1459	-1199	-941	-754	-713

TABLE B53 - TOP COLUMN HOOP STRAINS FOR SPECIMEN NC3

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	-58	88	-44	135	743	57
- 1	138	68	43	-65	377	22
+ 2	-78	92	-24	138	979	70
- 2	165	59	50	-63	948	43
+ 3	5	305	51	212	1795	238
- 3	313	171	215	-44	3343	318
+ 4	-27	359	100	250	2262	257
- 4	183	185	223	-43	2148	349
+ 5	-26	367	121	255	2332	301
- 5	172	185	235	-41	2243	373
+ 6	-37	355	128	245	2418	294
- 6	154	182	238	-42	2201	389
+ 7	-35	364	138	253	2449	303
- 7	156	178	239	-38	2237	395
+ 8	-41	353	139	243	2471	396
- 8	154	177	241	-37	2212	402
+ 9	115	498	512	525	3157	559
- 9	141	523	658	206	2526	790
+ 10	-125	304	537	445	3165	678
- 10	53	492	734	192	2436	790
+ 11	-73	357	607	418	3236	729
- 11	104	570	775	196	2642	816
+ 12	-85	342	623	337	3209	765
- 12	92	566	795	157	2543	807
+ 13	-539	314	1463	322	3511	1891
- 13	139	716	2054	-183	2107	1404
+ 14	-517	31	1352	222	3300	1310
- 14	57	612	1942	-337	2107	1339
+ 15	-407	38	1316	141	3351	1805
- 15	38	549	1950	-303	2236	1329
+ 16	-155	241	628	15	2552	1340
- 16	-5	141	1246	-140	2919	659
+ 17	-189	236	666	23	2665	1329
- 17	-4	153	1210	-136	2675	660
+ 18	-448	334	1305	185	3257	1343
- 18	152	529	1774	-130	2957	1338
+ 19	-396	248	1347	193	3165	1944
- 19	132	410	1745	-28	2926	1323
+ 20	-51	503	678	-20	2913	1705
- 20	71	326	1398	93	3060	862
+ 21	-83	526	679	-34	2950	1551
- 21	31	253	1371	114	2740	571
+ 22	-169	714	1172	99	3358	2036
- 22	346	558	1536	214	3385	1375
+ 23	-16	761	1050	-53	3056	2218
- 23	191	709	1973	307	3451	1329
+ 24	337	1446	755	-278	1455	2402
- 24	193	-	2029	1058	-	1330
+ 25	1391	-	1303	12	-	2523
- 25	143	-	3115	1206	-	1910
+ 26	1377	-	-	-119	-	2778
- 26	-117	-	-	3278	-	1519

TABLE B54 - BOTTOM COLUMN HOOP STRAINS FOR SPECIMEN NC3

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
- 1	—	36	-25	-25	39	13
- 1	5	-3	12	99	-17	141
- 2	-7	41	-30	-23	47	24
- 2	-5	1	6	119	-17	153
- 3	-8	138	12	-19	137	94
- 3	-16	55	12	271	14	404
- 4	-5	134	35	-32	156	110
- 4	-16	66	22	266	24	396
+ 5	-16	131	45	-41	155	117
- 5	-19	71	23	252	26	398
+ 6	-13	122	52	-34	152	116
- 6	-22	77	27	261	29	398
+ 7	-14	125	55	-38	157	122
- 7	-23	73	33	254	30	394
+ 8	-13	120	56	-36	154	121
- 8	-25	79	32	254	31	393
+ 9	16	150	107	-37	199	179
- 9	-9	122	40	315	52	498
+ 10	28	138	101	-24	190	165
- 10	1	123	42	313	55	433
+ 11	51	167	106	1	203	166
- 11	23	153	52	326	72	436
+ 12	53	163	108	—	204	170
- 12	27	151	54	326	71	479
+ 13	52	161	123	-5	206	178
- 13	25	147	62	311	55	463
+ 14	54	148	117	1	196	166
- 14	24	131	60	290	50	430
+ 15	53	137	112	3	196	163
- 15	23	122	50	282	54	415
+ 16	40	72	57	57	35	100
- 16	25	56	52	159	15	214
+ 17	45	72	52	64	38	105
- 17	30	53	31	175	15	223
+ 18	46	77	72	54	103	121
- 18	24	70	31	200	30	258
+ 19	55	76	72	64	103	118
- 19	25	56	37	135	28	257
+ 20	61	29	30	91	66	133
- 20	21	61	137	108	2	142
+ 21	57	31	36	98	67	132
- 21	14	60	142	109	1	143
+ 22	72	27	41	104	66	155
- 22	17	66	142	128	5	157
+ 23	66	39	42	124	67	136
- 23	15	61	143	124	2	147
+ 24	122	50	113	124	105	223
- 24	116	128	319	217	55	151
+ 25	127	51	126	145	114	239
- 25	55	131	139	139	53	178
+ 26	117	72	158	145	113	228
- 26	56	131	222	195	44	188

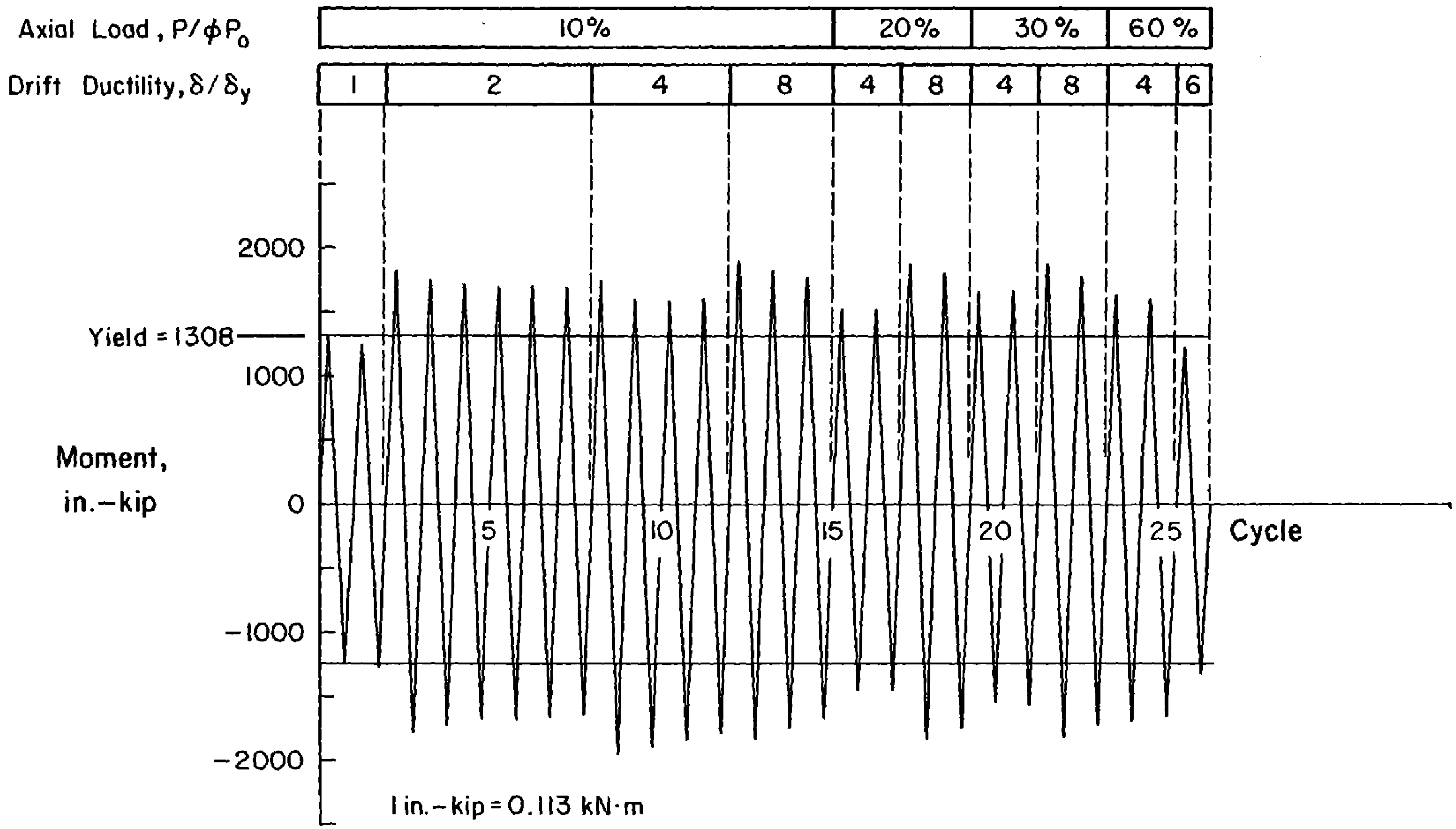


Fig. B48 Column Moment History for Specimen LC7

Column moment versus drift relationships

Bottom column moment versus drift relationships are shown in Fig. B49. Hinging occurred in the bottom column, therefore the top column moment versus drift relationships were omitted.

The first positive peak column moment was 1308 in.-kip (148 kN·m). It occurred at a top drift of 0.24 in. (6.2 mm). The top drift measurement controlled test progress during the first 8 cycles. During Cycle 9, a definite hinge started to form in the bottom column and the remainder of the test was controlled by the bottom drift measurement.

The maximum measured column moment was 1954 in.-kip (221 kN·m). It occurred at the negative peak of Cycle 9. Calculated column flexural strength was 1765 in.-kip (199 kN·m). Maximum measured column moment was approximately 11% greater than calculated nominal flexural strength.

Specimen LC7 lost its load carrying capacity during Cycle 26 as shown in Fig. B49(d) and the test was ended. This specimen exhibited considerable energy dissipation capacity as exemplified by the fat hysteresis loops. During Cycle 26, the main column steel buckled between the confining hoops in the bottom column. The 90° hook of some supplementary crossties opened under forces produced by bowing of the column steel.

Photographs at the end of Cycles 12 and 15 are shown in Figs. B50 and B51, respectively.

Tabulated results

Tabulated values of moment, top and bottom column drifts, and east and west beam deflections are provided in Table B55. Column rotations are shown in Table B56. Reinforcing steel strains are listed in Tables B57 through B60.

Specimen LC8

Specimen LC8 was similar to Specimen LC7 but was manufactured with Lightweight Concrete 2.

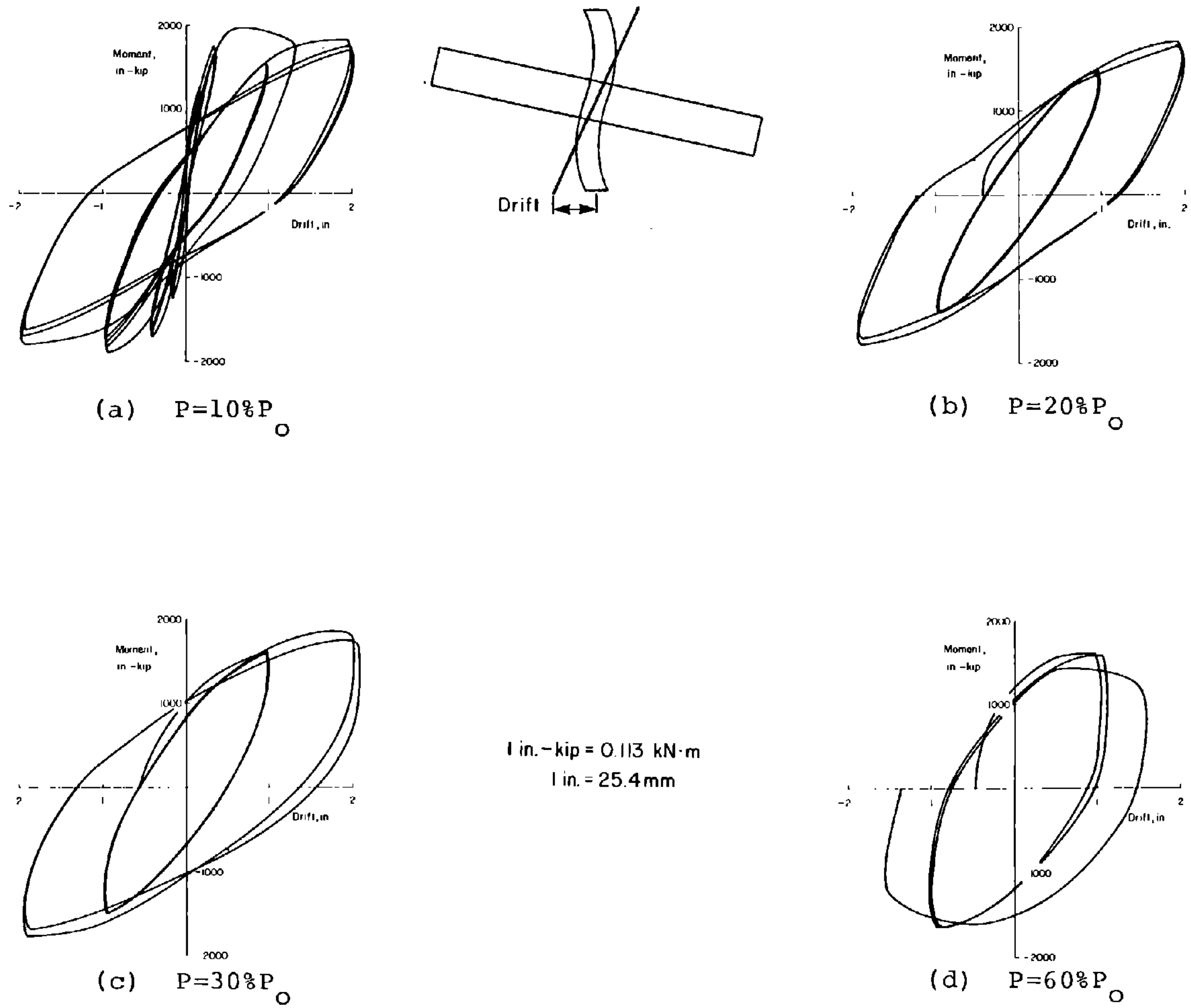


Fig. B49 Bottom Column Moment versus Drift for Specimen LC7

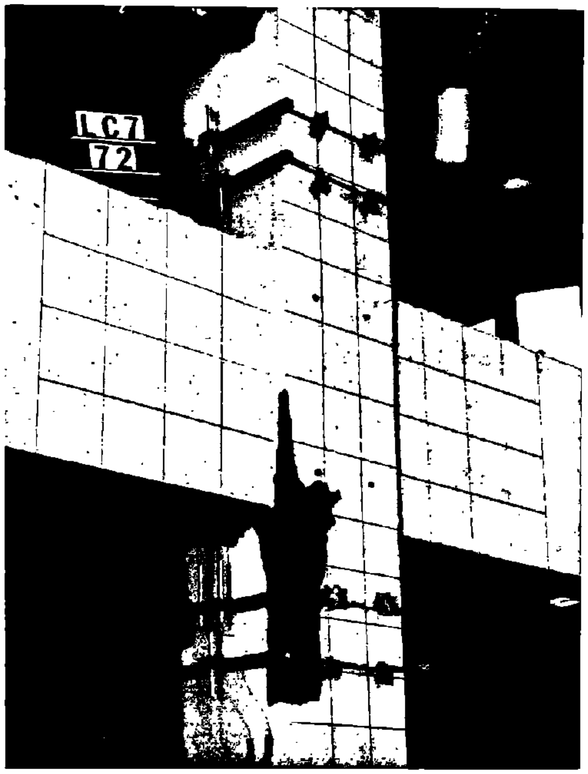


Fig. B50 Specimen LC7 after Cycle 12

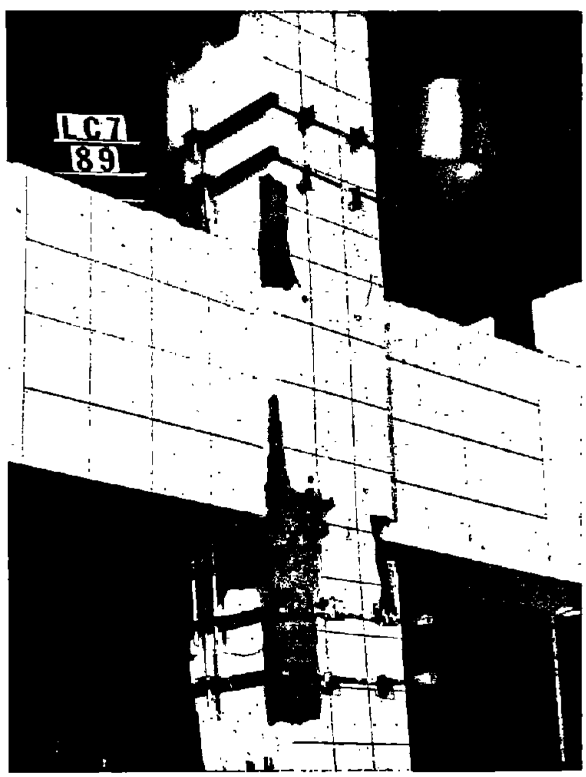


Fig. B51 Specimen LC7 after Cycle 15

TABLE B55 - COLUMN MOMENT, COLUMN DRIFTS, AND BEAM DEFLECTIONS FOR SPECIMEN LC7

CYCLE	MOMENT (IN.-KIP)	DRIFT (IN.)		DEFLECTION (IN.)	
		TOP	BOTTOM	EAST	WEST
+ 1 - 1	1308 -1243	0.241 -0.217	-0.179 0.183	1.105 -0.955	-1.043 1.035
+ 2 - 2	1243 -1274	0.223 -0.225	-0.173 0.190	1.099 -0.935	-1.049 1.045
+ 3 - 3	1827 -1796	0.499 -0.485	-0.383 0.407	1.941 -1.736	-2.003 1.734
+ 4 - 4	1752 -1727	0.501 -0.465	-0.369 0.415	1.893 -1.750	-1.949 1.712
+ 5 - 5	1719 -1680	0.503 -0.479	-0.361 0.409	1.881 -1.750	-1.949 1.694
+ 6 - 6	1697 -1686	0.533 -0.455	-0.361 0.417	1.857 -1.756	-1.942 1.714
+ 7 - 7	1701 -1676	0.511 -0.487	-0.363 0.415	1.893 -1.756	-1.949 1.703
+ 8 - 8	1694 -1645	0.511 -0.479	-0.361 0.407	1.887 -1.726	-1.943 1.681
+ 9 - 9	1742 -1954	0.653 -0.896	-1.297 0.966	3.390 -3.076	-3.653 2.895
+ 10 - 10	1558 -1873	0.690 -0.918	-0.968 0.974	2.843 -3.062	-2.992 2.913
+ 11 - 11	1592 -1843	0.698 -0.924	-0.970 0.974	2.849 -3.076	-2.986 2.907
+ 12 - 12	1605 -1790	0.701 -0.904	-0.981 0.966	2.879 -3.022	-3.029 2.871
+ 13 - 13	1896 -1832	0.935 -0.985	-1.974 1.940	4.471 -4.413	-4.797 4.239
+ 14 - 14	1829 -1752	0.885 -0.918	-1.986 1.952	4.443 -4.354	-4.797 4.122
+ 15 - 15	1772 -1674	0.957 -0.872	-1.994 1.913	4.425 -4.210	-4.767 4.030
+ 16 - 16	1526 -1455	0.571 -0.565	-0.982 0.974	2.717 -2.532	-2.758 2.536
+ 17 - 17	1518 -1456	0.543 -0.573	-0.955 0.956	2.634 -2.502	-2.639 2.488
+ 18 - 18	1874 -1634	0.699 -0.716	-1.954 1.909	4.193 -4.055	-4.177 4.002
+ 19 - 19	1905 -1753	0.655 -0.692	-1.936 1.905	4.168 -4.019	-4.371 3.930
+ 20 - 20	1665 -1545	0.473 -0.493	-0.980 0.956	2.711 -2.472	-2.686 2.506
+ 21 - 21	1668 -1570	0.465 -0.497	-0.988 0.966	2.717 -2.505	-2.662 2.561
+ 22 - 22	1879 -1819	0.547 -0.577	-2.006 1.913	4.113 -3.920	-4.151 3.976
+ 23 - 23	1781 -1724	0.511 -0.531	-2.073 1.894	4.212 -3.733	-4.197 3.840
+ 24 - 24	1637 -1592	0.311 -0.317	-0.983 0.963	2.711 -2.125	-2.362 2.564
+ 25 - 25	1606 -1557	0.273 -0.305	-0.985 0.953	2.687 -2.001	-2.155 2.581
+ 26 - 26	1329 -1325	0.100 -0.247	-1.509 1.473	3.104 -2.105	-2.524 3.151

1 in.-kip = 0.113 kN.m   1 in. = 25.4mm

TABLE B56 - COLUMN ROTATIONS FOR SPECIMEN LC7

CYCLE	ROTATION (RADIANS)			
	ABOVE JOINT		BELOW JOINT	
	-D	+D/2	-D	-D/2
+ 1	0.00506	0.00347	-0.00463	-0.00259
- 1	-0.00498	-0.00387	0.00324	0.00316
+ 2	0.00506	0.00331	-0.00440	-0.00256
- 2	-0.00484	-0.00371	0.00325	0.00313
+ 3	0.01046	0.00768	-0.00870	-0.00590
- 3	-0.00972	-0.00785	0.00750	0.00654
+ 4	0.01042	0.00764	-0.00851	-0.00567
- 4	-0.00980	-0.00785	0.00754	0.00651
+ 5	0.01034	0.00761	-0.00853	-0.00569
- 5	-0.00965	-0.00780	0.00739	0.00642
+ 6	0.01031	0.00761	-0.00851	-0.00563
- 6	-0.00973	-0.00781	0.00743	0.00657
+ 7	0.01043	0.00768	-0.00854	-0.00570
- 7	-0.00972	-0.00781	0.00741	0.00657
+ 8	0.01053	0.00770	-0.00860	-0.00574
- 8	-0.00964	-0.00779	0.00735	0.00643
+ 9	0.01563	0.01436	-0.03427	-0.02169
- 9	-0.01954	-0.01690	0.02120	0.01921
+ 10	0.01494	0.01125	-0.02600	-0.01795
- 10	-0.02026	-0.01767	0.02131	0.01949
- 11	0.01510	0.01125	-0.02587	-0.01781
- 11	-0.02025	-0.01777	0.02121	0.01976
- 12	0.01527	0.01138	-0.02650	-0.01819
- 12	-0.01982	-0.01736	0.02132	0.01991
+ 13	0.02039	0.01534	-0.05379	-0.03757
- 13	-0.02164	-0.01892	0.04530	0.04159
+ 14	0.01914	0.01439	-0.05493	-0.03914
- 14	-0.02015	-0.01772	0.04540	0.04184
+ 15	0.01880	0.01413	-0.05446	-0.03993
- 15	-0.01893	-0.01670	0.04721	0.04127
+ 16	0.01216	0.00900	-0.02704	-0.02081
- 16	-0.01273	-0.01113	0.02430	0.02143
+ 17	0.01151	0.00858	-0.02647	-0.02073
- 17	-0.01242	-0.01077	0.02379	0.02090
+ 18	0.01460	0.01104	-0.05465	-0.04194
- 18	-0.01598	-0.01367	0.04871	0.04238
+ 19	0.01395	0.01045	-0.05583	-0.04044
- 19	-0.01503	-0.01295	0.04692	0.04300
+ 20	0.00962	0.00705	-0.02967	-0.02348
- 20	-0.01023	-0.00903	0.02585	0.02220
+ 21	0.00948	0.00697	-0.03010	-0.02384
- 21	-0.01043	-0.00910	0.02535	0.02368
+ 22	0.01074	0.00805	-0.05972	-0.04654
- 22	-0.01218	-0.01067	0.05127	0.04419
+ 23	0.00972	0.00731	-0.06342	-0.05013
- 23	-0.01114	-0.00976	0.05085	0.04404
+ 24	0.00494	0.00339	-0.03493	-0.02887
- 24	-0.00627	-0.00505	0.02835	0.02348
+ 25	0.00406	0.00277	-0.03437	-0.02865
- 25	-0.00536	-0.00473	0.02603	0.02241
- 26	0.00257	0.00170	-0.05042	-0.03910
- 26	-0.00452	-0.00379	0.03375	0.03757

TABLE B57 - WEST COLUMN STEEL STRAINS FOR SPECIMEN LC7

CYCLE	STRAIN MILLIONTHS.								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	-570	-626	-652	-328	423	1363	1508	1452	1120
- 1	1359	1485	1284	1608	577	-230	-573	-692	-601
+ 2	-533	-560	-580	-317	402	1348	1457	1399	1087
- 2	1411	1546	1339	1665	615	-236	-592	-706	-616
+ 3	-740	-602	-743	153	569	6210	6220	2659	1985
- 3	2301	3006	2320	7559	1050	2728	929	-947	-848
+ 4	-733	-579	-1069	2912	462	6251	6087	2582	1884
- 4	2159	3120	2279	7569	1012	2977	1098	-930	-837
+ 5	-731	-633	-1107	3372	410	6219	6007	2542	1344
- 5	2203	3110	2234	7487	983	3047	1178	-915	-530
+ 6	-725	-603	-1116	3560	376	6154	5937	2510	1819
- 6	2214	3182	2254	7573	593	3098	1232	-916	-635
+ 7	-730	-586	-1128	3692	359	6138	5964	2514	1812
- 7	2196	3196	2240	7547	982	3119	1276	-912	-836
+ 8	-731	-571	-1138	3788	358	6132	5970	2514	1812
- 8	2147	3151	2193	7435	961	3134	1313	-906	-829
+ 9	-779	-524	-924	4166	549	15059	19332	15152	7506
- 9	4593	10456	12560	12313	1029	3861	1923	15	71
+ 10	390	471	260	4149	314	12250	13737	10675	5837
- 10	5127	10794	11009	12529	919	4160	1257	[illegible]	132
+ 11	542	550	481	4624	293	12260	13362	10526	5744
- 11	5077	10763	11029	12406	875	4329	762	-133	131
+ 12	604	751	630	4992	294	12475	13411	10559	5793
- 12	4947	10444	10740	12084	824	4436	390	-239	153
+ 13	448	641	778	5540	600	23720	28710	21524	10189
- 13	5132	11203	11614	12732	746	4141	-5371	-2306	-657
+ 14	540	777	951	5957	733	25107	26326	21091	10800
- 14	4791	10219	10637	11946	605	3909	-5007	-2261	-703
+ 15	581	340	1049	6223	778	26021	25299	20391	10916
- 15	4556	9509	9913	11420	516	3586	-4239	-1858	-546
+ 16	497	756	356	5484	232	13965	8634	8627	5912
- 16	3009	5197	4917	8238	-22	3529	-2856	-1039	-515
+ 17	-88	391	198	5352	216	13167	8242	8251	5616
- 17	2959	4942	4587	7960	-59	3319	-3078	-1142	-375
+ 18	304	472	56	5583	553	23617	21672	18028	9488
- 18	3588	6526	6302	9091	50	1143	-7551	-8504	-1384
+ 19	354	501	100	5575	567	24157	20710	17853	9636
- 19	2360	5930	5657	8580	-62	297	-7978	-3560	-1376
+ 20	300	503	-157	5025	103	12752	6615	6125	5569
- 20	2227	1602	2974	6662	-482	930	-5326	-2414	-1308
+ 21	262	433	-293	4917	86	12190	6646	7900	5396
- 21	2249	3568	2887	6605	-500	545	-5773	-2722	-1321
+ 22	173	336	-373	5089	421	21848	18461	17290	8745
- 22	2471	3999	3341	6936	-501	-2218	-11736	-6838	-2552
+ 23	213	389	-371	4587	538	22552	17208	17098	9209
- 23	2274	3637	2999	6026	-586	-2776	-13103	-7990	-3038
+ 24	-356	-25	-510	2558	-308	7815	-198	3251	3985
- 24	761	1420	573	3284	-1836	-5254	-14340	-11358	-4591
+ 25	-417	-49	-764	1392	-371	4691	-2481	-265	2487
- 25	590	1330	597	1453	-1725	-7001	-18196	-15513	-5374
+ 26	-390	117	-535	1537	-313	4518	-2565	-596	1521
- 26	489	1075	317	491	-1899	-3851	-24351	-15616	-6345

TABLE B58 - EAST COLUMN STEEL STRAINS FOR SPECIMEN LC7

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	1350	1642	1551	1638	376	-240	-719	-745	-642
- 1	-536	-683	-627	-358	474	1409	1227	1073	679
+ 2	1257	1566	1506	1522	406	-241	-658	-683	-577
- 2	-553	-698	-652	-368	534	1480	1287	1124	952
+ 3	2119	6140	7245	7207	850	-71	-953	-985	-832
- 3	-748	754	973	2365	851	7229	3311	2327	2022
+ 4	2078	6130	7372	7379	820	3112	-519	-965	-806
- 4	-747	957	1207	2875	795	7188	3413	2236	1954
+ 5	2041	6161	7340	7362	800	3346	-455	-964	-805
- 5	-749	1064	1320	3084	758	7093	3371	2251	1927
+ 6	2016	6147	7312	7363	795	3443	-421	-959	-806
- 6	-753	1124	1395	3223	759	7134	3422	2274	1939
+ 7	2010	6203	7398	7443	805	3509	-417	-974	-816
- 7	-753	1167	1446	3313	749	7100	3412	2261	1922
+ 8	2007	6224	7428	7463	799	3556	-193	-975	-819
- 8	-739	1222	1502	3384	712	6978	3343	2210	1876
+ 9	3846	9580	12609	11157	313	2754	-7727	-4712	-1783
- 9	-27	672	1207	3591	957	13729	12817	11644	3109
+ 10	3262	7527	9519	9558	563	2632	-5673	-2347	-1855
- 10	5	567	1018	3964	911	14031	12044	11486	3267
+ 11	3244	7503	9540	9586	547	3111	-5419	-2671	-1971
- 11	26	587	912	4058	381	14176	11590	11417	3365
+ 12	3266	7581	9641	9685	541	3437	-5311	-2573	-2071
- 12	46	719	829	4139	865	14123	11213	11345	3445
+ 13	4038	10343	13540	12479	779	3436	-12675	-6442	-2714
- 13	55	324	911	4547	1099	26038	22531	22661	10419
+ 14	3799	9562	12396	11943	579	3869	-10917	-6757	-2391
- 14	108	947	935	4764	1160	27049	19451	21929	10698
+ 15	3696	9230	11908	11705	473	4321	-9915	-5501	-2297
- 15	148	1032	991	4930	1173	27050	16817	20385	10415
+ 16	2349	5134	5932	8105	-46	4472	-4905	-4232	-1853
- 16	51	886	147	4022	600	14805	5617	7305	5213
+ 17	2307	4920	5063	7542	-36	4612	-5811	-4594	-1899
- 17	51	951	5	4038	612	14589	5041	7404	4998
+ 18	2766	6057	6606	8630	-16	3397	-14158	-10737	-2904
- 18	-127	617	-316	4262	1013	26313	13251	18118	9627
+ 19	2624	5652	5944	8243	-111	3239	-14218	-11383	-2944
- 19	-96	542	-342	4313	1059	27225	12201	17425	9612
+ 20	1695	3647	3090	6260	-479	4377	-9375	-7516	-2277
- 20	-116	558	-658	3673	427	15722	2345	5166	-396
+ 21	1692	3564	2827	6154	-519	4545	-10293	-8641	-2487
- 21	-146	516	-750	3668	437	15906	2126	5119	-606
+ 22	1541	3853	3133	6395	-553	3280	-20083	-17570	-2604
- 22	-251	569	-974	3671	804	27129	3675	14499	9590
+ 23	1613	3411	2519	5825	-646	3732	-22684	-20059	-3827
- 23	-229	432	-910	3575	833	27175	3993	12475	9719
+ 24	494	1509	355	2017	-1639	4033	-20225	-18964	-4656
- 24	-573	-104	-1594	1443	-127	10544	-9930	-5216	2782
+ 25	146	1300	-16	1475	-1693	3096	-24229	-23440	-5914
- 25	-930	-199	-1684	329	-143	12169	-15144	-9646	1376
+ 26	-72	963	-389	472	-1865	2830	-	-30843	-5122
- 26	-844	-70	-1566	695	-139	12927	-	-9538	-45

TABLE B59 - TOP COLUMN HOOP STRAINS FOR SPECIMEN LC7

CYCLE	STRAIN MILLIONTHS					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
- 1 - 1	-4 -75	135 195	-34 -38	49 -50	14 35	-2 -12
- 2 - 2	-18 -88	118 216	3 -38	41 -51	27 37	-6 -14
+ 3 - 3	29 175	436 247	-7 52	50 9	97 362	33 31
+ 4 - 4	44 279	519 311	36 72	50 18	144 397	34 38
- 5 - 5	40 269	519 295	58 38	58 18	147 424	29 44
+ 6 - 6	39 272	519 235	55 35	46 19	148 417	23 44
+ 7 - 7	33 269	519 275	58 86	46 18	149 418	21 44
+ 8 - 8	33 257	520 165	58 85	42 14	150 413	18 44
- 9 - 9	106 554	835 527	121 157	50 49	255 811	28 231
+ 10 - 10	30 503	789 601	115 192	45 29	292 815	54 242
+ 11 - 11	85 475	733 575	115 191	40 15	295 832	51 247
+ 12 - 12	94 446	789 545	102 187	35 5	285 305	49 243
- 13 - 13	34 462	873 561	105 194	45 -1	336 856	39 234
+ 14 - 14	78 406	908 510	106 182	35 -10	322 791	38 247
+ 15 - 15	74 359	877 478	131 176	30 -12	319 738	34 238
+ 16 - 16	-6 151	417 302	130 116	18 -50	209 362	19 110
+ 17 - 17	-5 135	424 392	127 131	15 -53	321 368	38 111
- 18 - 18	-3 202	583 331	111 143	15 -57	248 513	25 141
+ 19 - 19	-13 176	546 312	137 142	15 -66	241 478	34 142
+ 20 - 20	-7 95	115 241	200 120	26 -81	178 318	53 171
+ 21 - 21	-18 38	226 141	195 128	26 -34	188 228	54 170
+ 22 - 22	-27 105	181 140	185 133	22 -95	202 235	49 170
- 23 - 23	-38 78	214 114	200 111	38 -95	198 250	53 173
- 24 - 24	3 12	35 -23	358 318	17 3	127 259	205 354
+ 25 - 25	34 -7	35 -39	157 324	37 2	148 265	331 154
+ 26 - 26	-8 9	68 -38	355 345	53 17	131 256	245 143

TABLE B60 - BOTTOM COLUMN HOOP STRAINS FOR SPECIMEN LC7

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	10	-7	75	-1034	-25	-
- 1	-75	145	145	825	-224	49
+ 2	-	-3	58	-309	-3	25
- 2	-80	151	151	377	-224	62
+ 3	41	59	213	2282	159	9
- 3	-65	231	207	2567	57	248
+ 4	35	97	221	2950	154	47
- 4	-61	231	201	3310	118	247
+ 5	36	95	223	3109	201	55
- 5	-59	231	197	3418	130	248
+ 6	32	91	221	3342	197	58
- 6	-52	237	197	3592	140	252
+ 7	30	88	221	3528	203	64
- 7	-62	236	196	3759	143	249
+ 8	25	84	220	3629	201	64
- 8	-61	230	190	3822	140	244
+ 9	131	257	226	4769	736	443
- 9	57	1250	430	4689	635	569
+ 10	194	220	206	3871	516	400
- 10	78	1154	478	4387	615	573
+ 11	239	220	196	4044	513	405
- 11	97	1092	471	4505	591	559
+ 12	257	221	187	4396	523	400
- 12	137	1022	437	3271	559	534
+ 13	551	487	197	4103	1176	677
- 13	679	1692	548	4951	1148	803
+ 14	555	565	74	4097	-	595
- 14	709	1551	394	4383	-	574
+ 15	525	614	-13	4149	-	527
- 15	733	1571	158	5227	-	415
+ 16	526	481	-93	4952	-	431
- 16	334	760	217	5752	-	49
+ 17	535	451	-136	5202	-	413
- 17	825	742	206	6164	-	55
+ 18	663	773	-93	3585	-	528
- 18	1080	1459	440	5599	-	330
+ 19	552	304	-171	5357	-	588
- 19	586	461	420	8293	-	243
+ 20	618	778	-214	12341	-	506
- 20	617	313	274	12643	-	73
+ 21	950	747	-183	12133	-	591
- 21	757	-73	309	12732	-	76
+ 22	1253	-	3	12455	-	733
- 22	939	-	932	13051	-	276
+ 23	1398	-	-	12346	-	772
- 23	924	-	-	13125	-	132
+ 24	1345	-	-	12449	-	1109
- 24	1773	-	-	12518	-	606
+ 25	2466	-	-	12525	-	1226
- 25	1925	-	-	13624	-	752
+ 26	2341	-	-	12316	-	-
- 26	2495	-	-	14011	-	-

Column moment history

Specimen LC8 was subjected to 26 cycles of moment reversals as shown in Fig. B52. Both Specimens LC7 and LC8 were subjected to the same moment history except for Cycle 26. Due to loss of moment resisting capacity, a drift ductility of six was imposed on Specimen LC7 during Cycle 26, whereas a drift ductility of eight was imposed on Specimen LC8 during Cycle 26.

Column moment versus drift relationships

Top and bottom column moment versus drift relationships for Specimen LC8 are shown in Figs. B53 and B54, respectively. Hinging occurred in both the top and bottom columns. In addition, this specimen experienced joint shear distortion. Column hinges propagated into the joint region. Some pinching of hysteresis loops was observed during the basic loading cycles. This pinching became more evident during subsequent cycles.

The first positive peak column moment was 1429 in.-kip (161 kN·m). It corresponded to a top drift of 0.27 in. (6.9 mm). The maximum measured column moment was 2034 in.-kip (230 kN·m). It occurred at the negative peak of Cycle 9. The calculated column flexural strength was 1765 in.-kip (199 kN·m). Maximum measured column moment was approximately 15% greater than calculated.

Specimen LC8 lost load carrying capacity during Cycle 26 and the test was ended. Photographs of the specimen at the end of Cycles 12 and 15 are provided in Figs. B55 and B56, respectively.

Tabulated results

Values of moment, top and bottom column drifts, and east and west beam deflections are listed in Table B61. Column rotations are shown in Table B62. Steel strains are provided in Tables B63 through B66.

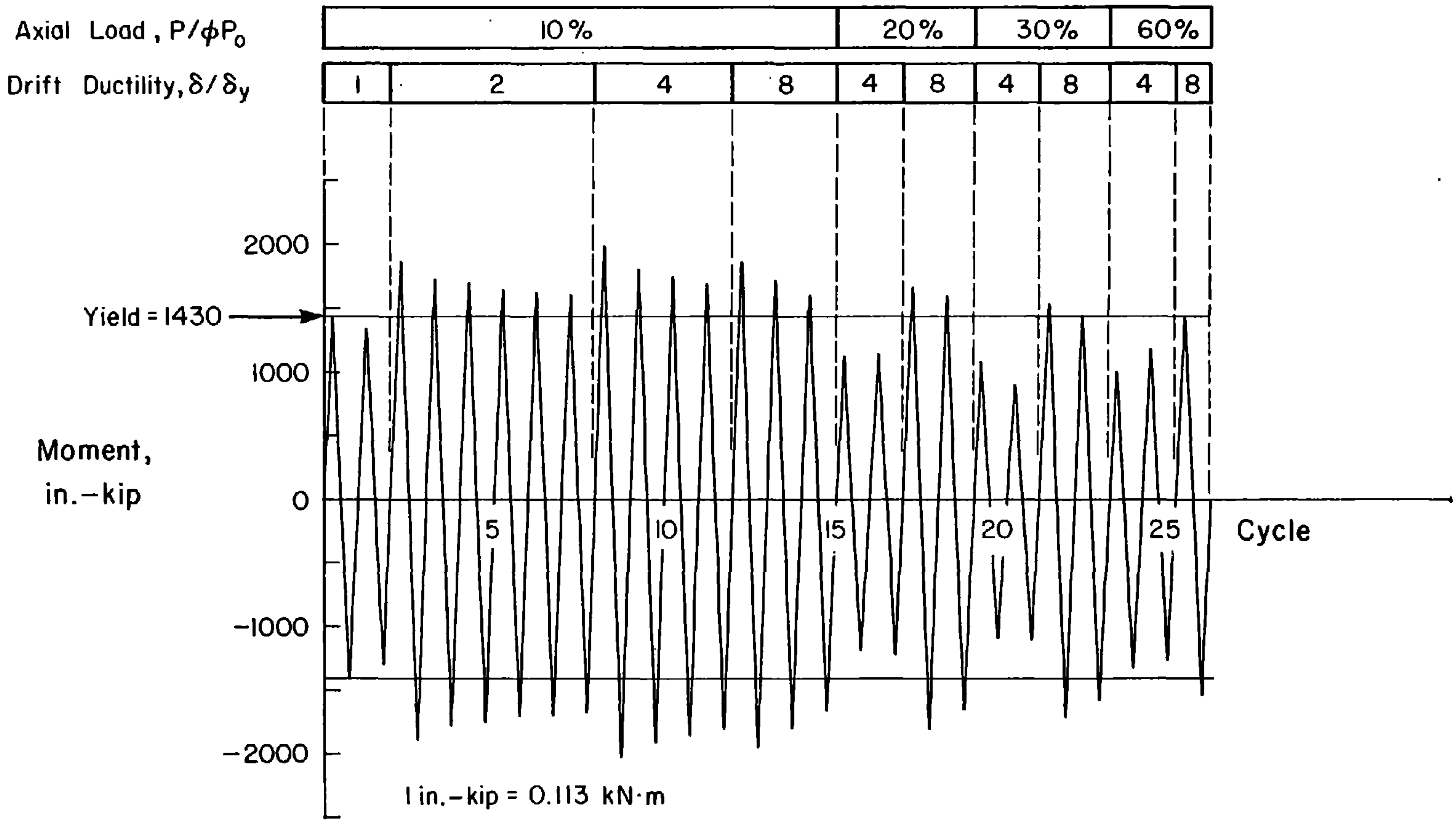
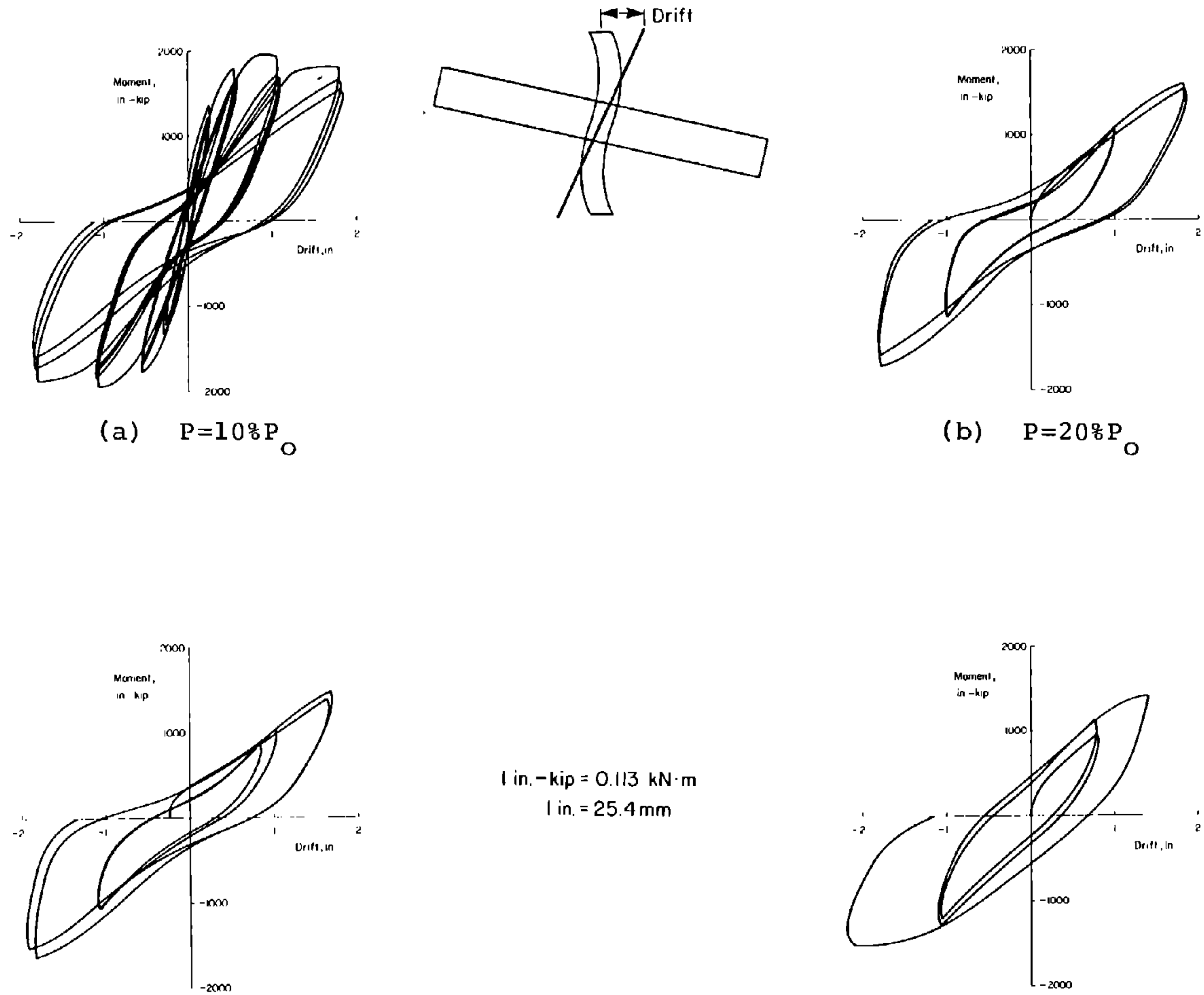


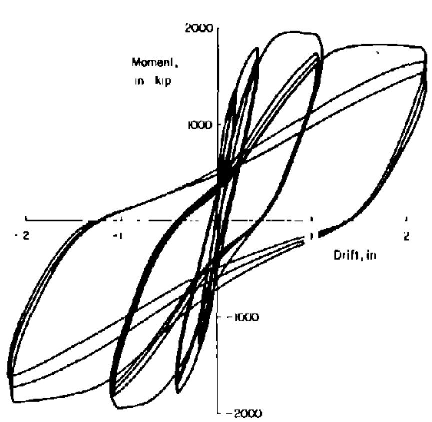
Fig. B52 Column Moment History for Specimen LC8

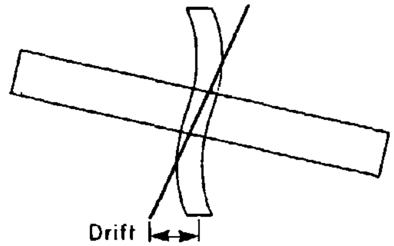


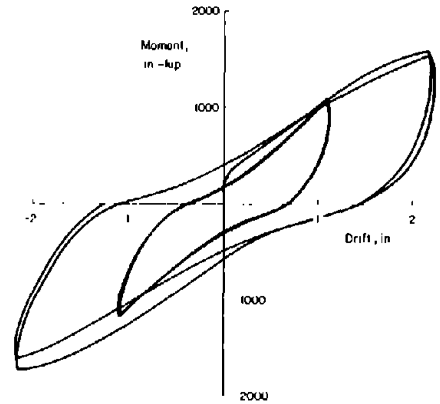
(a) P=10%P_O (b) P=20%P_O

(c) P=30%P_O (d) P=60%P_O

Fig. B53 Top Column Moment versus Drift for Specimen LC8

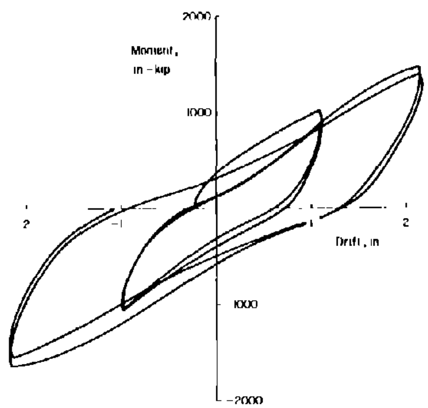




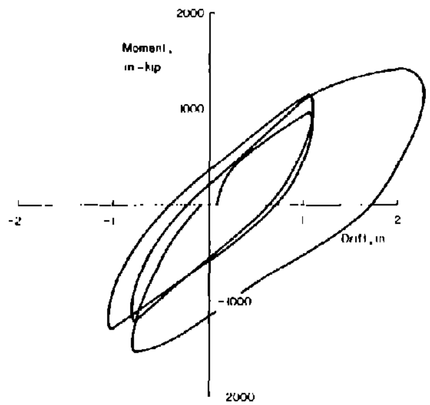


(a) P=10%P_o

(b) P=20%P_o



1 in.-kip = 0.113 kN·m
1 in. = 25.4 mm



(c) P=30%P_o

(d) P=60%P_o

Fig. B54 Bottom Column Moment versus Drift for Specimen LC8

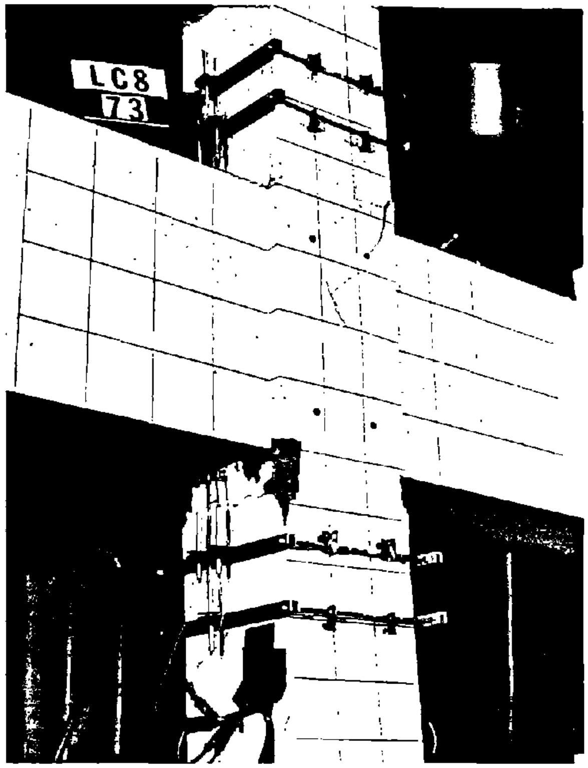


Fig. B55 Specimen LC8 after Cycle 12

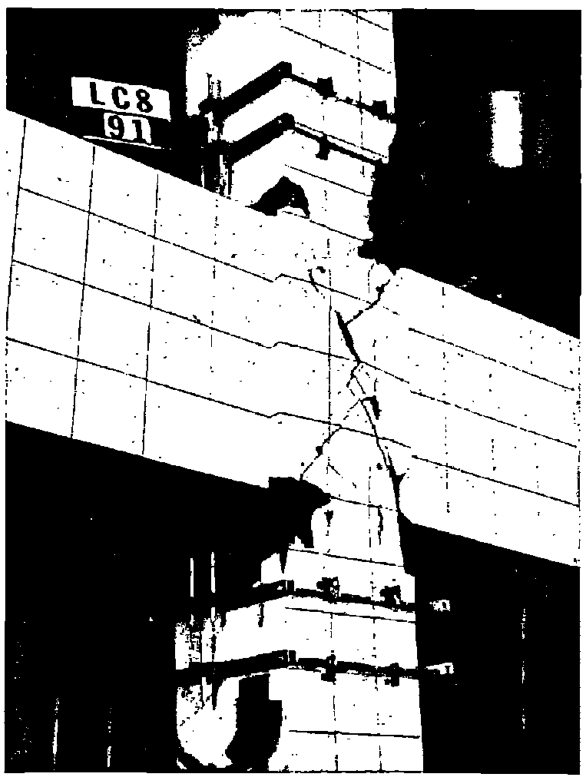


Fig. B56 Specimen LC8 after Cycle 15

TABLE B61 - COLUMN MOMENT, COLUMN DRIFTS, AND BEAM DEFLECTIONS FOR SPECIMEN LC8

CYCLE	MOMENT IN.-KIP	DRIFT IN.		DEFLECTION IN.	
		TOP	BOTTOM	EAST	WEST
+ 1	1429	0.271	-0.202	1.278	-1.247
- 1	-1412	-0.237	0.188	-1.147	1.187
+ 2	1341	0.251	-0.212	1.188	-1.253
- 2	-1300	-0.251	0.158	-1.069	1.061
+ 3	1374	0.546	-0.439	2.096	-2.133
- 3	-1391	-0.559	0.407	-1.971	1.951
+ 4	1729	0.543	-0.419	2.019	-2.091
- 4	-1782	-0.553	0.397	-1.917	1.951
+ 5	1702	0.556	-0.427	2.030	-2.093
- 5	-1757	-0.553	0.407	-1.923	1.961
+ 6	1646	0.549	-0.421	2.001	-2.063
- 6	-1707	-0.547	0.391	-1.887	1.925
+ 7	1639	0.550	-0.421	2.001	-2.057
- 7	-1703	-0.553	0.399	-1.881	1.936
+ 8	1610	0.552	-0.419	2.001	-2.039
- 8	-1630	-0.547	0.391	-1.881	1.919
+ 9	1939	1.073	-1.058	3.447	-3.622
- 9	-2034	-1.099	1.044	-3.518	3.403
+ 10	1804	1.088	-1.050	3.386	-3.592
- 10	-1910	-1.105	1.074	-3.529	3.441
+ 11	1749	1.099	-1.050	3.366	-3.556
- 11	-1658	-1.105	1.090	-3.559	3.454
+ 12	1693	1.100	-1.046	3.329	-3.520
- 12	-1802	-1.099	1.092	-3.559	3.451
+ 13	1864	1.792	-2.146	5.575	-5.870
- 13	-1954	-1.823	2.108	-5.797	5.613
+ 14	1718	1.809	-2.158	5.579	-5.876
- 14	-1799	-1.849	2.136	-5.805	5.642
+ 15	1506	1.833	-2.150	5.554	-5.840
- 15	-1660	-1.867	2.145	-5.799	5.556
+ 16	1127	1.007	-1.098	3.053	-3.156
- 16	-1187	-1.019	1.074	-3.285	3.310
+ 17	1142	1.003	-1.083	3.051	-3.142
- 17	-1225	-1.029	1.062	-3.314	3.339
+ 18	1657	1.835	-2.144	5.521	-5.714
- 18	-1807	-1.917	2.115	-5.745	5.699
+ 19	1594	1.842	-2.190	5.525	-5.780
- 19	-1656	-1.843	2.134	-5.685	5.687
+ 20	1080	1.035	-1.086	3.150	-3.166
- 20	-1093	-1.089	0.966	-3.058	3.225
+ 21	901	0.850	-1.090	2.598	-2.572
- 21	-1109	-1.089	0.970	-3.052	3.229
+ 22	1537	1.699	-2.130	5.117	-5.151
- 22	-1711	-1.847	2.123	-5.420	5.821
+ 23	1441	1.672	-2.138	5.046	-5.331
- 23	-1584	-1.927	2.119	-5.584	5.547
+ 24	1203	0.812	-1.059	2.497	-2.117
- 24	-1326	-1.065	1.028	-2.195	3.709
+ 25	1160	0.792	-1.066	2.616	-2.301
- 25	-1251	-1.069	0.738	-2.723	3.223
+ 26	1425	1.407	-2.178	4.892	-4.431
- 26	-1541	-2.143	0.779	-1.971	4.704

1 in.-kip = 0.113 kN.m   1 in. = 25.4mm

TABLE B62 - COLUMN ROTATIONS FOR SPECIMEN LC8

CYCLE	ROTATION - RADIANS			
	ABOVE JOINT		BELOW JOINT	
	-D	+D.I	-D	-D.I
+ 1	0.00604	0.00484	-0.00490	-0.00371
- 1	-0.00590	-0.00520	0.00500	0.00338
+ 2	0.00601	0.00481	-0.00493	-0.00372
- 2	-0.00545	-0.00483	0.00450	0.00304
+ 3	0.01229	0.00992	-0.00935	-0.00737
- 3	-0.01157	-0.01023	0.00951	0.00696
+ 4	0.01205	0.00962	-0.00951	-0.00730
- 4	-0.01149	-0.01017	0.00922	0.00626
+ 5	0.01219	0.00979	-0.00981	-0.00761
- 5	-0.01164	-0.01022	0.00926	0.00686
+ 6	0.01199	0.00958	-0.00962	-0.00747
- 6	-0.01142	-0.01001	0.00894	0.00669
+ 7	0.01183	0.00965	-0.00962	-0.00747
- 7	-0.01154	-0.01019	0.00907	0.00672
+ 8	0.01183	0.00952	-0.00961	-0.00737
- 8	-0.01146	-0.01003	0.00891	0.00655
+ 9	0.02363	0.01958	-0.02492	-0.01923
- 9	-0.02399	-0.02149	0.02474	0.01905
+ 10	0.02404	0.02024	-0.02492	-0.02055
- 10	-0.02453	-0.02179	0.02543	0.01956
+ 11	0.02401	0.02019	-0.02442	-0.02058
- 11	-0.02450	-0.02154	0.02565	0.01997
+ 12	0.02370	0.01997	-0.02400	-0.02027
- 12	-0.02456	-0.02147	0.02574	0.02014
+ 13	0.04095	0.03309	-0.05365	-0.04134
- 13	-0.04144	-0.03495	0.05154	0.04179
+ 14	0.04068	0.03463	-0.05378	-0.04353
- 14	-0.04166	-0.03517	0.05074	0.04299
+ 15	0.04049	0.03496	-0.05319	-0.04419
- 15	-0.04230	-0.03617	0.04963	0.04344
+ 16	0.02025	0.01885	-0.02793	-0.02451
- 16	-0.02461	-0.02192	0.02318	0.02191
+ 17	0.02002	0.01900	-0.02804	-0.02434
- 17	-0.02487	-0.02200	0.02320	0.02191
+ 18	0.03376	0.03553	-0.05455	-0.04700
- 18	-0.04286	-0.03758	0.04777	0.04342
+ 19	0.03889	0.03698	-0.05557	-0.04854
- 19	-0.04133	-0.03316	0.04663	0.04291
+ 20	0.01999	0.02012	-0.03109	-0.02311
- 20	-0.02527	-0.02257	0.01397	0.01911
+ 21	0.01570	0.01614	-0.02603	-0.02372
- 21	-0.02532	-0.02269	0.01997	0.01935
+ 22	0.03390	0.03320	-0.05148	-0.04641
- 22	-0.04369	-0.03929	0.04526	0.04396
+ 23	0.03324	0.03299	-0.05072	-0.04580
- 23	-0.04433	-0.04020	0.04398	0.04312
+ 24	0.01239	0.01122	-0.02378	-0.02142
- 24	-0.02766	-0.02522	0.01354	0.01917
+ 25	0.01390	0.01358	-0.01452	-0.02251
- 25	-0.02433	-0.02233	0.01463	0.01487
+ 26	0.02620	0.02659	-0.05279	-0.04678
- 26	-0.05090	-0.04879	0.01039	0.01193

TABLE B63 - WEST COLUMN STEEL STRAINS FOR SPECIMEN LC8

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	-	-657	-725	-180	117	1555	1455	1520	1282
- 1	-	1860	1662	1757	930	-41	-549	-519	-539
+ 2	-	-727	-665	-209	184	1495	1442	1555	1141
- 2	-	1602	1450	1515	760	-31	-599	-569	-498
+ 3	-	-904	-853	86	500	4694	2475	3670	2133
- 3	-	5323	4263	7190	1289	1577	-1114	-515	-760
+ 4	-	-32	-507	2376	411	4318	2336	3657	1972
- 4	-	5160	4600	6791	1229	1710	-1105	-453	-742
+ 5	-	59	-370	3274	381	4013	2286	3609	1936
- 5	-	5142	4674	6949	1314	1801	-1092	-409	-743
+ 6	-	151	-240	3437	362	3825	2177	3496	1854
- 6	-	4962	4517	6769	1199	1963	-1067	-377	-736
+ 7	-	209	-164	3527	361	3808	2147	3454	1837
- 7	-	4975	4579	6767	1209	1938	-1048	-363	-740
+ 8	-	191	-108	3592	347	3791	2052	3384	1796
- 8	-	-	4487	6668	1139	2000	-1029	-353	-737
- 9	-	-	-853	3726	707	11153	12770	10964	2519
- 9	-	-	12332	12444	1355	-	-849	119	-1050
+ 10	-	-	-1157	4851	531	-	11586	10271	2367
- 10	-	-	11673	-	1246	-	-1422	209	-1085
- 11	-	-	-973	5921	560	-	10570	9739	2291
- 11	-	-	11102	-	1233	-	-1494	293	-1113
- 12	-	-	-556	-	601	-	9703	9306	2235
- 12	-	-	10413	-	1173	-	-1362	358	-1122
+ 13	-	-	-3795	-	1088	-	21441	17408	5577
- 13	-	-	-	-	1346	-	-	-	-1441
+ 14	-	-	-	-	-	-	-	17135	5751
- 14	-	-	-	-	-	-	-	-	-1472
+ 15	-	-	-	-	-	-	-	-	5363
- 15	-	-	-	-	-	-	-	-	-2299
- 16	-	-	-	-	-	-	-	-	1084
- 16	-	-	-	-	-	-	-	-	-2273
- 17	-	-	-	-	-	-	-	-	486
- 17	-	-	-	-	-	-	-	-	-1318
+ 18	-	-	-	-	-	-	-	-	2595
- 18	-	-	-	-	-	-	-	-	-9571
- 19	-	-	-	-	-	-	-	-	-2564
- 19	-	-	-	-	-	-	-	-	-15667
+ 20	-	-	-	-	-	-	-	-	-5110
- 20	-	-	-	-	-	-	-	-	-22171
+ 21	-	-	-	-	-	-	-	-	-5937
- 21	-	-	-	-	-	-	-	-	-19055
+ 22	-	-	-	-	-	-	-	-	-11722
- 22	-	-	-	-	-	-	-	-	-19655
+ 23	-	-	-	-	-	-	-	-	-12645
- 23	-	-	-	-	-	-	-	-	-23846
- 24	-	-	-	-	-	-	-	-	-17351
- 24	-	-	-	-	-	-	-	-	-23010
+ 25	-	-	-	-	-	-	-	-	-19338
- 25	-	-	-	-	-	-	-	-	-17090
+ 26	-	-	-	-	-	-	-	-	-21217
- 26	-	-	-	-	-	-	-	-	-23493

TABLE B64 - EAST COLUMN STEEL STRAINS FOR SPECIMEN LC8

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
- 1	-	1793	1445	1146	519	-139	-656	-595	-392
- 1	-	-644	-572	-76	161	1701	1718	1485	810
+ 2	-	1746	1626	1311	648	-87	-606	-574	-261
- 2	-	-632	-425	-55	134	1477	1513	1307	916
+ 3	-	5660	2357	4086	1209	135	-813	-806	-430
- 3	-	675	-910	1448	418	6310	5996	2320	1430
+ 4	-	6300	2335	3928	1123	2156	442	-824	-385
- 4	-	837	-958	1592	331	5819	5514	2158	1345
+ 5	-	6249	2324	3384	1129	2416	576	-838	-388
- 5	-	921	-974	1704	313	5717	5419	2139	1336
+ 6	-	5821	2353	3783	1092	2532	695	-829	-365
- 6	-	981	-956	1748	254	5469	5149	2041	1302
+ 7	-	5351	2248	3742	1075	2600	758	-827	-342
- 7	-	1507	-935	1803	242	5412	5119	2043	1330
- 8	-	5849	2221	3695	1072	2541	803	-827	-323
- 8	-	1027	-927	1823	221	5291	4982	1997	1322
+ 9	-	10251	11164	5541	1410	2635	-1056	-1228	-412
- 9	-	537	970	2556	460	12877	14233	3438	1731
+ 10	-	10358	10787	-	1109	4333	-1185	-478	-530
- 10	-	672	1062	2890	430	12822	11680	6568	1756
+ 11	-	10059	10250	-	1016	5365	-841	-349	-565
- 11	-	745	1392	3124	444	11689	9936	8340	1752
+ 12	-	9725	9832	-	951	6026	-604	-	-577
- 12	-	300	-	3306	481	12517	9084	-	1761
- 13	-	16633	-	9723	-	6330	-9539	-	-728
- 13	-	723	-	4862	712	21986	-	-	4245
- 14	-	14858	-	9272	-	-	-3847	-	-304
- 14	-	915	-	-	-	42997	-	-	4445
+ 15	-	12937	-	-	-	-	-	-	-723
- 15	-	1058	-	-	-	-	-	-	4073
- 16	-	4153	-	-	-	-	-	-	-524
- 16	-	1401	-	-	-	-	-	-	1687
- 17	-	4158	-	-	-	-	-	-	-557
- 17	-	1408	-	-	-	-	-	-	1636
- 18	-	8359	-	-	-	-	-	-	-571
- 18	-	623	-	-	-	-	-	-	4017
- 19	-	7384	-	-	-	-	-	-	-584
- 19	-	820	-	-	-	-	-	-	1631
+ 20	-	2777	-	-	-	-	-	-	-312
- 20	-	1054	-	-	-	-	-	-	1275
- 21	-	2468	-	-	-	-	-	-	-150
- 21	-	1023	-	-	-	-	-	-	1245
+ 22	-	4658	-	-	-	-	-	-	-713
- 22	-	411	-	-	-	-	-	-	2983
- 23	-	3952	-	-	-	-	-	-	-727
- 23	-	288	-	-	-	-	-	-	2579
- 24	-	1155	-	-	-	-	-	-	-545
- 24	-	-1404	-	-	-	-	-	-	414
+ 25	-	405	-	-	-	-	-	-	-1141
- 25	-	-1326	-	-	-	-	-	-	175
+ 26	-	550	-	-	-	-	-	-	-1315
- 26	-	-9548	-	-	-	-	-	-	-22

TABLE B65 - TOP COLUMN HOOP STRAINS FOR SPECIMEN LC8

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	243	48	9	156	-	162
- 1	380	80	215	-52	-	-15
+ 2	3354	303	47	173	-	265
- 2	1546	193	308	-49	-	65
+ 3	3657	449	158	190	-	127
- 3	3903	345	377	-26	-	88
+ 4	3994	491	149	167	-	342
- 4	4146	345	364	-29	-	45
+ 5	4096	502	148	158	-	342
- 5	4147	349	361	-27	-	104
+ 6	4203	522	148	148	-	335
- 6	4264	340	351	-28	-	102
+ 7	4345	503	143	148	-	336
- 7	4500	340	347	-25	-	105
+ 8	4446	502	148	144	-	335
- 8	4593	335	341	-24	-	105
+ 9	5374	614	383	131	-	478
- 9	5763	614	478	147	-	206
+ 10	4895	440	369	118	-	515
- 10	4896	585	473	97	-	210
+ 11	5768	409	361	76	-	545
- 11	4905	558	470	92	-	217
+ 12	5769	396	348	55	-	549
- 12	5779	547	470	89	-	220
+ 13	5733	406	535	111	-	1018
- 13	5734	528	1001	37	-	397
+ 14	4983	350	687	79	-	995
- 14	5793	664	951	110	-	403
+ 15	5339	411	709	98	-	975
- 15	380	563	931	236	-	398
+ 16	6634	305	303	149	-	701
- 16	6357	329	612	329	-	332
+ 17	6803	167	346	143	-	712
- 17	6622	251	516	199	-	143
+ 18	6899	305	693	366	-	1017
- 18	9915	210	372	368	-	501
+ 19	11014	111	701	350	-	1112
- 19	9650	539	847	195	-	530
+ 20	10900	-233	393	260	-	793
- 20	9484	213	602	37	-	460
+ 21	10853	-411	345	224	-	633
- 21	9815	178	591	-3	-	465
+ 22	10452	-187	580	405	-	1037
- 22	-	453	858	330	-	601
+ 23	10224	-461	558	453	-	1353
- 23	-	-	835	241	-	596
+ 24	13410	361	515	393	-	641
- 24	13362	-	593	574	-	577
+ 25	10424	337	626	511	-	742
- 25	10458	-	514	311	-	577
+ 26	10533	144	740	354	-	323
- 26	-	-	1336	732	-	351

TABLE B66 - BOTTOM COLUMN HOOP STRAINS FOR SPECIMEN LC8

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	-129	31	253	52	36	-5
- 1	34	-41	51	25	4	136
- 2	-61	142	255	115	125	23
- 2	71	72	47	71	65	196
+ 3	-219	183	373	118	267	154
- 3	102	63	115	8	106	384
+ 4	-167	151	353	146	231	175
- 4	115	79	125	17	113	370
+ 5	-156	192	343	159	298	131
- 5	119	86	137	25	118	369
+ 6	-146	192	327	156	299	181
- 6	117	89	135	28	122	353
+ 7	-141	192	327	159	299	181
- 7	117	94	140	23	136	358
+ 8	-135	192	317	169	298	191
- 8	116	95	136	31	126	353
- 9	-161	492	491	21	492	567
- 9	279	372	547	-124	457	967
+ 10	-65	550	527	103	383	530
- 10	385	384	564	-78	438	571
+ 11	-34	556	517	92	361	517
- 11	288	408	568	-50	438	966
+ 12	-20	547	523	93	349	539
- 12	294	420	565	-30	442	865
+ 13	241	968	1414	-312	514	455
- 13	292	455	1206	55	190	1555
+ 14	170	851	1354	-439	505	430
- 14	117	353	1138	119	270	1514
+ 15	103	749	1291	-388	510	835
- 15	122	9	1034	155	246	835
+ 16	-26	384	355	-155	494	400
- 16	-114	382	441	119	99	735
+ 17	34	387	799	-165	482	449
- 17	-279	222	459	85	141	334
+ 18	234	817	1196	-351	915	862
- 18	1	549	916	318	612	1266
+ 19	246	1016	1240	-600	1267	951
- 19	-149	580	971	356	555	1409
+ 20	67	557	553	-312	1069	734
- 20	-59	736	-364	207	222	852
+ 21	-47	618	307	-262	579	673
- 21	-156	759	-502	184	250	331
+ 22	11	999	1149	-	1467	1024
- 22	-46	977	-809	-	500	1354
+ 23	-	987	1175	-	982	1037
- 23	-150	996	-2312	-	409	1272
- 24	-	1034	628	-	911	922
- 24	22	1138	-2008	-	461	879
+ 25	-	1175	770	-	769	1007
- 25	-207	1180	-1941	-	220	907
- 26	-	1486	1480	-	336	-492
- 26	-	1281	-1709	-	377	-463

Specimen LC11

Specimen LC11 was a repeat of Specimen LC8. In Specimen LC8, top and bottom columns were subjected to the same moment. Hinging occurred in both columns simultaneously. To avoid hinging of both top and bottom columns, top and bottom column lengths were altered. Height of the top column was increased by 4.5 in. (114 mm) and the bottom column was shortened by 4.5 in. (114 mm). This resulted in a bottom column to top column moment ratio of 0.83.

Column moment history

This specimen was subjected to 26 cycles of moment reversals as shown in Fig. B57. During the basic loading cycles, the column was subjected to an axial load of 80.7 kips (359 kN). This corresponds to 10% of the column axial load design strength.

Column moment versus drift relationships

As anticipated, hinging occurred in the top column of Specimen LC11. Top column moment versus drift relationships are shown in Fig. B58. Bottom column drift was very small. Bottom column moment versus drift hysteretic loops were similar to those for Specimen LC1 shown in Fig. B3.

Excellent energy dissipation capacity was observed throughout the test as exemplified by full hysteresis loops of Fig. B58. The first positive peak top column moment was 1333 in.-kip (151 kN·m). Corresponding top drift was 0.27 in. (6.7 mm). The maximum measured top column moment was 2091 in.-kip (236 kN·m). It occurred at the negative peak of Cycle 9. The calculated column nominal flexural strength was 1765 in.-kip (199 kN·m). Maximum measured top column moment was approximately 18% greater than calculated nominal flexural strength.

Specimen LC11 lost moment carrying capacity during Cycle 26 and the test was ended. First noticeable bowing of hoop reinforcement was observed during Cycle 23. During Cycle 26, buckling of the main column reinforcement occurred. In addition,

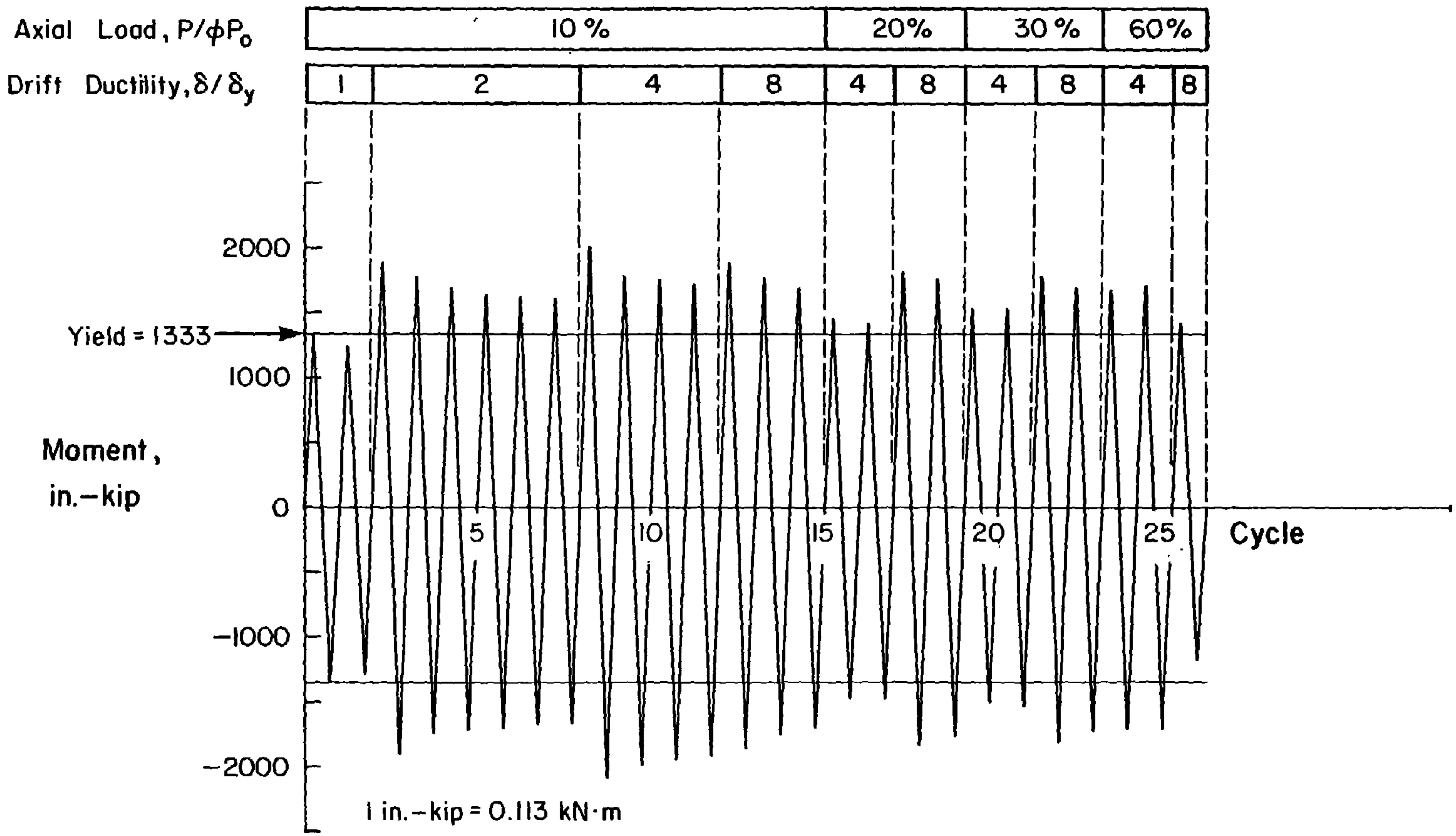


Fig. B57 Column Moment History for Specimen LC11

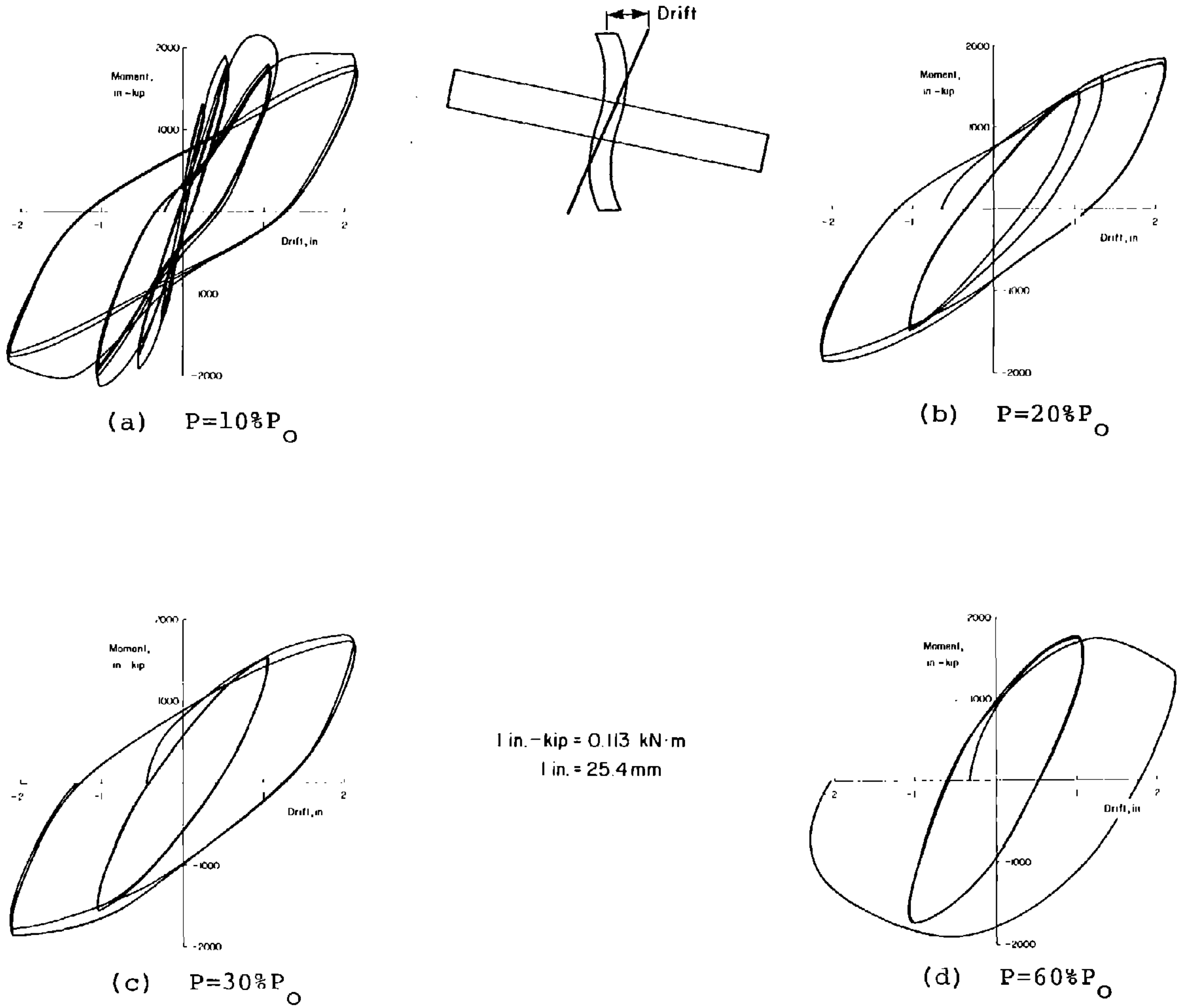


Fig. B58 Top Column Moment versus Drift for Specimen LC11

unhooking of the 90° leg of the supplementary crossties was noticed.

Photographs of the specimen at the end of Cycles 12 and 15 are shown in Figs. B59 and B60, respectively.

Tabulated results

Tabulated values of top column moment, top and bottom column drifts, and east and west beam deflections are presented in Table B67. Column rotations are shown in Table B68. All steel strains are listed in Tables B69 through B72.

Specimen NC2

Specimen NC2 was similar to Specimens LC7 and LC8 except that it was constructed of normal weight concrete.

Column moment history

Specimen NC2 was subjected to 26 loading cycles as shown in Fig. B61. The same basic moment history was applied to this specimen as was applied to Specimens LC7 and LC8.

Column moment versus drift relationships

Top and bottom column moment versus drift relationships are shown in Figs. B62 and B63, respectively. As depicted by the hysteresis loops, hinging occurred in the top column. Only minor drifts were recorded in the bottom column. However, during the negative half of Cycle 26, the bottom column shell suddenly spalled on the extreme compressive fiber side. As a result, the bottom drift controlled loading for the negative half of Cycle 26 as shown in Fig. B62(d).

The first positive peak column moment was 1327 in.-kip (150 kN·m). Corresponding top drift was 0.20 in. (5.1 mm). The maximum measured column moment during the basic loading cycle was 2077 in.-kip (235 kN·m). It occurred at the positive peak of Cycle 9. Calculated nominal flexural strength was 1690 in.-kip (191 kN·m). Therefore maximum measured moment was 23% greater than calculated.

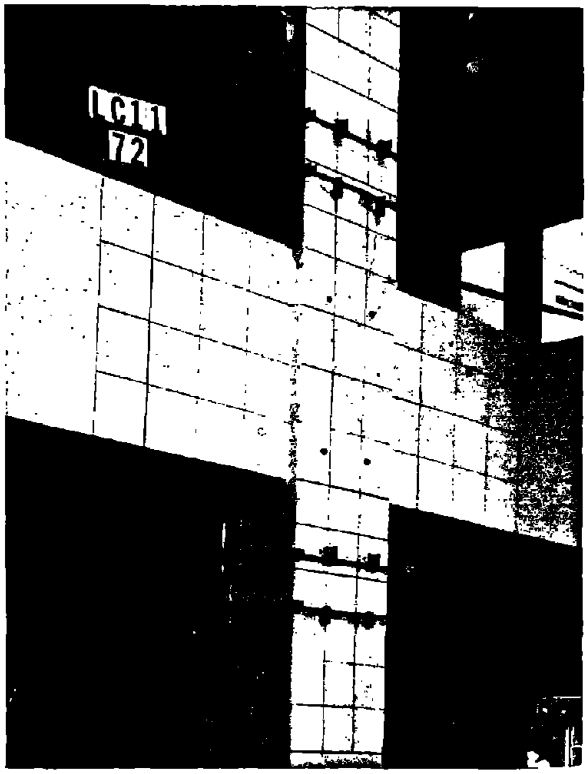


Fig. B59 Specimen LC11 after Cycle 12

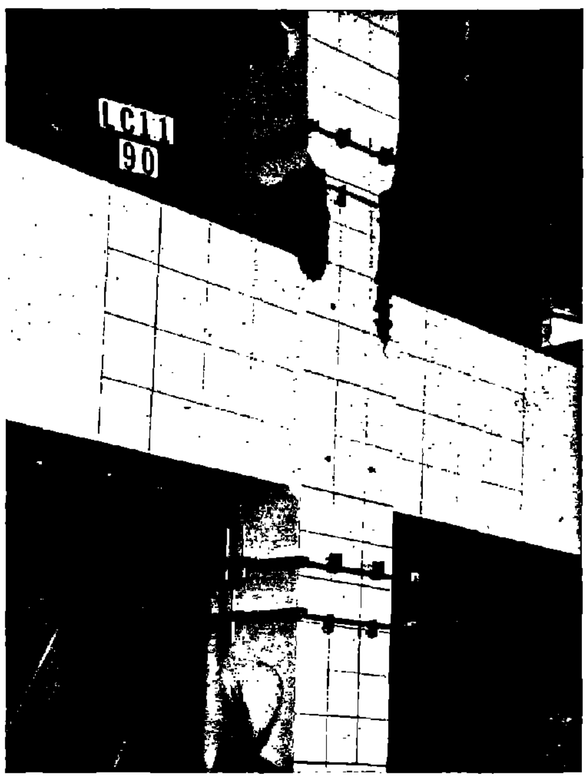


Fig. B60 Specimen LC11 after Cycle 15

TABLE B67 - COLUMN MOMENT, COLUMN DRIFTS, AND BEAM DEFLECTIONS FOR SPECIMEN LC11

CYCLE	MOMENT (IN.-KIP)	DRIFT (IN.)		DEFLECTION (IN.)	
		TOP	BOTTOM	EAST	WEST
+ 1 - 1	1333 -1349	0.365 -0.353	-0.090 0.132	1.015 -0.954	-0.931 1.025
+ 2 - 2	1241 -1286	0.359 -0.251	-0.086 0.130	0.985 -0.830	-0.857 1.013
+ 3 - 3	1899 -1906	0.551 -0.559	-0.220 0.287	1.857 -1.666	-1.703 1.948
+ 4 - 4	1777 -1747	0.557 -0.539	-0.218 0.271	1.815 -1.589	-1.703 1.757
+ 5 - 5	1695 -1723	0.549 -0.541	-0.210 0.273	1.762 -1.589	-1.679 1.754
+ 6 - 6	1641 -1708	0.545 -0.541	-0.203 0.281	1.732 -1.589	-1.619 1.756
+ 7 - 7	1621 -1674	0.537 -0.533	-0.200 0.279	1.714 -1.577	-1.619 1.739
+ 8 - 8	1615 -1670	0.539 -0.539	-0.200 0.279	1.738 -1.571	-1.619 1.739
+ 9 - 9	2010 -2091	1.120 -1.085	-0.309 0.387	2.747 -2.509	-2.578 2.680
+ 10 - 10	1786 -1990	1.077 -1.089	-0.259 0.375	2.544 -2.472	-2.415 2.635
+ 11 - 11	1759 -1947	1.100 -1.091	-0.257 0.379	2.568 -2.484	-2.458 2.635
+ 12 - 12	1719 -1915	1.093 -1.091	-0.257 0.375	2.533 -2.472	-2.416 2.631
+ 13 - 13	1888 -1856	2.138 -2.147	-0.291 0.399	3.939 -3.738	-3.819 3.939
+ 14 - 14	1774 -1752	2.173 -2.167	-0.279 0.359	3.887 -3.727	-3.337 3.858
+ 15 - 15	1694 -1695	2.153 -2.177	-0.271 0.347	3.820 -3.697	-3.777 3.846
+ 16 - 16	1453 -1477	1.046 -1.069	-0.178 0.222	2.198 -2.150	-2.165 2.299
+ 17 - 17	1420 -1460	1.056 -1.079	-0.166 0.229	2.216 -2.168	-2.117 2.195
+ 18 - 18	1816 -1833	2.144 -2.165	-0.230 0.281	3.735 -3.637	-3.675 3.817
+ 19 - 19	1764 -1771	2.138 -2.165	-0.213 0.269	3.681 -3.619	-3.640 3.752
+ 20 - 20	1532 -1506	1.073 -1.077	-0.132 0.190	2.245 -2.390	-2.067 2.323
+ 21 - 21	1515 -1538	1.065 -1.077	-0.130 0.188	2.216 -2.108	-2.257 2.332
+ 22 - 22	1781 -1811	2.134 -2.155	-0.172 0.220	3.635 -3.553	-3.556 3.758
+ 23 - 23	1700 -1725	2.127 -2.153	-0.150 0.210	3.606 -3.494	-3.478 3.712
+ 24 - 24	1677 -1787	1.079 -1.099	-0.082 0.129	2.275 -2.025	-2.333 2.354
+ 25 - 25	1715 -1714	1.071 -1.069	-0.060 0.140	2.249 -1.971	-1.879 2.310
+ 26 - 26	1422 -1131	2.158 -2.149	-0.060 0.112	3.485 -3.099	-3.333 3.449

1 in.-kip = 0.113 kN.m 1 in. = 25.4mm

TABLE B68 - COLUMN ROTATIONS FOR SPECIMEN LC11

CYCLE	ROTATION (RADIANS)			
	ABOVE JOINT		BELOW JOINT	
	+D	+D/2	-D	-D/2
- 1 - 1	0.00495 -0.00469	0.00364 -0.00357	-0.00321 0.00324	-0.00200 0.00261
+ 2 - 2	0.00527 -0.00462	0.00364 -0.00361	-0.00321 0.00312	-0.00303 0.00257
- 3 - 3	0.01107 -0.01020	0.00819 -0.00830	-0.00652 0.00662	-0.00430 0.00549
- 4 - 4	0.01111 -0.00983	0.00812 -0.00806	-0.00665 0.00655	-0.00423 0.00547
+ 5 - 5	0.01111 -0.00974	0.00816 -0.00794	-0.00635 0.00655	-0.00417 0.00546
- 6 - 6	0.01087 -0.00974	0.00793 -0.00807	-0.00614 0.00655	-0.00400 0.00548
- 7 - 7	0.01083 -0.00973	0.00789 -0.00793	-0.00612 0.00647	-0.00400 0.00532
+ 8 - 8	0.01087 -0.00971	0.00789 -0.00794	-0.00609 0.00649	-0.00400 0.00546
+ 9 - 9	0.02428 -0.02190	0.01900 -0.01779	-0.00847 0.00893	-0.00536 0.00718
- 10 - 10	0.02384 -0.02192	0.01893 -0.01775	-0.00751 -	-0.00519 0.00711
+ 11 - 11	0.02438 -0.02198	0.01948 -0.01790	-0.00757 0.00874	-0.00537 0.00729
+ 12 - 12	0.02434 -0.02190	0.01944 -0.01777	-0.00748 0.00874	-0.00527 0.00723
+ 13 - 13	0.05024 -0.04965	0.04095 -0.03521	-0.00814 0.00870	-0.00574 0.00745
+ 14 - 14	0.05142 -0.05048	0.04211 -0.03656	-0.00772 0.00812	-0.00572 0.00649
+ 15 - 15	0.05088 -0.05074	0.04149 -0.03749	-0.00759 0.00792	-0.00559 0.00637
- 16 - 16	0.02498 -0.02462	0.02094 -0.01996	-0.00530 0.00539	-0.00382 0.00443
+ 17 - 17	0.02519 -0.02452	0.02046 -0.01994	-0.00518 0.00543	-0.00383 0.00445
+ 18 - 18	0.05134 -0.05190	0.04199 -0.04106	-0.00660 0.00656	-0.00494 0.00542
+ 19 - 19	0.05108 -0.05226	0.04232 -0.04268	-0.00553 0.00531	-0.00483 0.00522
+ 20 - 20	0.02559 -0.02625	0.02154 -0.02292	-0.00446 0.00415	-0.00343 0.00353
- 21 - 21	0.02559 -0.02609	0.02117 -0.02320	-0.00447 0.00425	-0.00337 0.00365
- 22 - 22	0.05179 -0.05326	0.04533 -0.04507	-0.00513 0.00495	-0.00396 0.00420
+ 23 - 23	0.05226 -0.05336	0.04379 -0.04507	-0.00490 0.00466	-0.00371 0.00404
+ 24 - 24	0.02601 -0.02296	0.02222 -0.02541	-0.00234 0.00260	-0.00233 0.00206
+ 25 - 25	0.02592 -0.02630	0.02024 -0.02508	-0.00285 0.00261	-0.00212 0.00213
- 26 - 26	0.05532 -0.05543	0.04023 -0.04644	-0.00214 0.00185	-0.00184 0.00175

TABLE B69 - WEST COLUMN STEEL STRAINS FOR SPECIMEN LC11

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	-551	-678	-	-310	239	955	525	323	-
- 1	1136	1647	-	1612	458	-133	-514	125	-
+ 2	-520	-673	-	-328	248	923	514	25	-
- 2	1163	1585	-	1536	514	-123	-504	-75	-
+ 3	-786	-969	-	-144	518	1868	1551	330	-
- 3	1857	3630	-	7003	1098	202	-708	-537	-
+ 4	-316	-491	-	2018	335	1762	1512	-125	-
- 4	1746	3725	-	6549	1059	211	-670	-1094	-
+ 5	-321	-401	-	2370	184	1585	1480	-27	-
- 5	1591	3674	-	6437	1270	221	-671	-992	-
+ 6	-327	-343	-	2500	213	1545	1393	-233	-
- 6	1567	3673	-	6402	1283	230	-666	-1195	-
+ 7	-327	-317	-	2595	191	1532	1380	-587	-
- 7	1641	3630	-	6306	1083	233	-661	-1297	-
+ 8	-325	-307	-	2650	173	1492	1372	-687	-
- 8	1637	3629	-	5296	1085	237	-561	-1146	-
+ 9	-1013	-1101	-	2522	294	2084	1876	-76	-
- 9	2144	9453	-	10970	1472	531	-778	-1602	-
+ 10	-1035	-533	-	2622	13	1778	1523	-585	-
- 10	2072	9362	-	10503	1437	521	-748	-1960	-
+ 11	-1085	-388	-	2955	-53	1758	1515	-816	-
- 11	2047	9430	-	10344	1439	537	-735	-1851	-
+ 12	-1115	-236	-	3035	-123	1686	1567	-734	-
- 12	2012	9358	-	10181	1441	537	-723	-2153	-
+ 13	-1258	-939	-	2739	-164	1747	1554	-1150	-
- 13	7410	20053	-	14549	1562	653	-677	-2250	-
+ 14	-837	53	-	2088	-256	1546	1542	-734	-
- 14	7654	19291	-	14145	1551	531	-630	-2309	-
+ 15	-837	729	-	1835	-372	1543	1469	-885	-
- 15	7747	19177	-	13992	1672	547	-606	-2314	-
+ 16	-437	1779	-	2324	-667	575	632	-1133	-
- 16	4446	9812	-	7907	1219	125	-706	-2042	-
+ 17	-421	1333	-	2323	-639	505	590	-1530	-
- 17	4392	9592	-	7732	1201	121	-712	-1995	-
+ 18	-733	651	-	454	-669	842	856	-1577	-
- 18	7131	18110	-	13014	1529	328	-737	-2024	-
+ 19	-839	1225	-	-504	-733	763	820	-1567	-
- 19	7252	18115	-	12521	1534	329	-752	-2374	-
+ 20	-613	2377	-	706	-1033	-52	179	-1917	-
- 20	4270	3717	-	6579	975	-215	-889	-2731	-
+ 21	-529	2255	-	474	-1041	-19	152	-1764	-
- 21	4219	9553	-	6455	955	-216	-908	-2434	-
+ 22	-1909	-1085	-	-2218	-1105	-12	179	-1957	-
- 22	6671	16323	-	10497	1292	-18	-931	-2374	-
+ 23	-1955	-1594	-	-3189	-1136	-110	136	-2064	-
- 23	5754	15598	-	9482	1270	-22	-904	-2322	-
+ 24	-1839	-1673	-	-3803	-1763	-1355	-547	-2172	-
- 24	2179	5544	-	2298	332	-933	-1475	-2331	-
+ 25	-1591	-3375	-	-4787	-1304	-1522	-751	-2272	-
- 25	1556	4090	-	1277	223	-1025	-1542	-2677	-
+ 26	-4615	-5406	-	-5535	-1550	-1804	-995	-2374	-
- 26	3406	5889	-	3006	375	-908	-1147	-3029	-

TABLE B70 - EAST COLUMN STEEL STRAINS FOR SPECIMEN LC11

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	376	1447	1534	1633	579	-126	-542	-504	-396
- 1	-524	-624	-604	-221	-	1154	1055	913	483
+ 2	996	1409	1497	1562	757	-48	-521	-473	-375
- 2	-521	-627	-617	-227	12	1113	999	871	492
+ 3	1314	2315	2397	8041	1352	212	-771	-727	-588
- 3	-726	-921	-1112	2788	270	2140	1997	1930	1315
+ 4	1310	2155	2347	8224	1338	316	-744	-707	-566
- 4	-712	-907	-1192	3236	198	1936	1605	1754	1137
+ 5	1799	2206	2293	3127	1304	370	-719	-684	-542
- 5	-712	-912	-1209	3434	157	1890	1754	1719	1161
+ 6	1743	2122	2213	7910	1283	387	-703	-669	-532
- 6	-712	-913	-1217	3581	148	1360	1743	1704	1145
+ 7	1734	2091	2189	7923	1267	410	-699	-659	-531
- 7	-708	-912	-1218	3544	134	1819	1701	1662	1121
+ 8	1737	2094	2136	7842	1277	430	-700	-669	-531
- 8	-709	-913	-1223	3694	126	1811	1693	1654	1116
+ 9	2102	8953	12096	13744	1634	558	-832	-809	-648
- 9	-1878	-38	-211	4172	209	2726	2236	2206	1502
+ 10	2089	8496	11095	12941	1530	753	-761	-747	-588
- 10	-1104	97	-491	4346	133	2557	2139	2086	1421
+ 11	2125	8815	11160	13191	1527	811	-747	-737	-583
- 11	-1129	221	-531	4604	74	2461	2099	2049	1397
+ 12	2120	8770	10990	13050	1521	835	-734	-725	-576
- 12	-1151	292	-586	4765	31	2405	2044	1990	1160
+ 13	2439	20175	22193	22771	1777	939	-769	-775	-512
- 13	-1781	-2119	-3710	5080	-172	2221	1851	1825	1230
+ 14	5821	20105	19757	-	1750	970	-707	-730	-576
- 14	-2005	-1661	-9990	5457	-393	2035	1722	1595	1141
+ 15	6936	19484	17951	-	1750	1011	-678	-706	-558
- 15	-1867	-1334	-9711	-	-375	1933	1641	1503	1064
+ 16	4088	8592	3139	-	1258	511	-755	-729	-548
- 16	-1568	-65	-6638	-	-664	937	682	546	382
+ 17	3961	8307	3587	-	1174	575	-749	-738	-559
- 17	-1572	-238	-7013	-	-697	931	583	646	389
+ 18	6405	17324	15622	-	1567	774	-339	-814	-535
- 18	-3199	-2707	-13476	-	-733	1208	543	910	557
+ 19	6748	16985	12975	-	1554	772	-817	-817	-635
- 19	-2203	-2639	-13956	-	-779	1126	868	635	505
+ 20	4146	7447	-505	-	1139	348	-909	-851	-563
- 20	-1917	-1107	-10421	-	-1026	211	59	119	21
+ 21	3983	71.5	-415	-	1019	382	-928	-853	-635
- 21	-1954	-1310	-10796	-	-1013	325	78	149	37
+ 22	6904	14641	9719	-	1238	450	-965	-919	-726
- 22	-2829	-4191	-13634	-	-1073	153	165	335	73
+ 23	7462	14483	5610	-	1340	450	-927	-830	-795
- 23	-3391	-4447	-23082	-	-1115	346	95	171	17
+ 24	1119	4355	-	-	591	-339	-1111	-1119	-1041
- 24	-4605	-4525	-	-	-1325	-1133	-729	-474	-473
+ 25	1559	2946	-	-	394	-522	-1451	-1250	-1063
- 25	-5495	-5435	-	-	-1841	-1218	-761	-494	-467
+ 26	3250	7629	-	-	554	-449	-1335	-1139	-980
- 26	-8514	-7011	-	-	-1948	-1547	-1055	-717	-555

TABLE B71 - TOP COLUMN HOOP STRAINS FOR SPECIMEN LC11

CYCLE	STRAIN MILLIONTHS					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	-71	-26	36	11	-35	105
- 1	-33	-203	73	-77	37	82
+ 2	-31	-40	56	-3	-51	180
- 2	-36	-193	94	-79	32	93
+ 3	-50	-55	206	36	-3	353
- 3	9	-147	321	15	57	358
+ 4	-62	-39	161	49	41	379
- 4	-	-117	333	26	57	366
+ 5	-66	-25	266	47	42	393
- 5	-5	-101	342	27	54	372
+ 6	-63	-26	352	46	43	376
- 6	-1	-101	348	32	54	383
+ 7	-66	-15	257	42	47	377
- 7	-5	-101	347	31	57	377
+ 8	-63	-29	266	42	48	333
- 8	-6	-96	351	32	53	376
+ 9	-32	-45	656	108	118	759
- 9	325	-35	870	22	174	927
+ 10	-52	-60	737	114	94	739
- 10	305	-26	906	21	128	945
+ 11	-52	-74	748	120	89	750
- 11	331	-33	918	7	109	917
+ 12	-56	-79	734	109	92	749
- 12	261	-28	922	1	94	800
+ 13	-154	-272	1536	209	234	1746
- 13	-	-348	1597	-127	173	1349
+ 14	-	-481	1378	78	319	1922
- 14	-	-258	1546	-303	113	1352
+ 15	-	-502	1259	-19	232	1832
- 15	-	-213	1537	-415	112	1350
+ 16	-	79	472	-200	83	1299
- 16	-	-40	1090	-271	295	759
+ 17	-	11	499	-154	127	1260
- 17	-	-31	1079	-279	307	767
+ 18	-	-175	1202	84	254	1915
- 18	-	36	1649	-325	490	1383
+ 19	-	-11	1080	44	154	1980
- 19	-	56	1597	-322	495	1371
+ 20	-	549	551	-269	-54	1556
- 20	-	-19	1361	-71	597	942
+ 21	-	554	561	-233	-63	1511
- 21	-	3	1364	-56	505	973
+ 22	-	932	831	-5	-35	1964
- 22	-	345	1757	-133	551	1102
+ 23	-	1179	579	-157	-96	2116
- 23	-	156	1795	-36	335	1299
+ 24	-	333	900	-141	53	2065
- 24	-	702	1452	311	634	2081
+ 25	-	173	937	-131	336	2481
- 25	-	25	1503	174	398	2207
+ 26	-	-	1371	-250	1014	2494
- 26	-	-	2275	1116	108	-

TABLE B72 - BOTTOM COLUMN HOOP STRAINS FOR SPECIMEN LC11

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	-8	-51	19	62	20	33
- 1	-12	-9	18	50	33	-32
+ 2	-28	-56	13	55	42	35
- 2	-17	-9	23	40	38	-35
+ 3	-56	-12	23	73	242	50
- 3	-23	36	-6	93	134	50
+ 4	-47	-5	23	66	253	55
- 4	-29	107	-5	80	131	50
+ 5	-43	-5	38	62	272	60
- 5	-29	112	-3	79	140	56
+ 6	-49	-2	27	54	266	57
- 6	-28	116	-3	74	141	57
+ 7	-42	-5	31	55	273	60
- 7	-38	117	2	73	145	57
+ 8	-47	-1	27	53	276	60
- 8	-27	116	1	70	145	60
+ 9	-43	5	54	96	381	122
- 9	-33	239	1	94	186	122
+ 10	-26	25	49	75	343	108
- 10	-13	245	1	65	185	121
+ 11	-18	25	48	61	359	105
- 11	-7	256	6	64	188	122
+ 12	-16	21	47	74	356	105
- 12	-6	254	8	61	189	121
+ 13	-21	25	54	76	379	115
- 13	-7	264	4	75	193	115
+ 14	3	25	51	65	365	106
- 14	-2	244	3	74	192	105
+ 15	5	26	48	86	359	105
- 15	-1	234	8	73	188	102
+ 16	75	60	18	111	206	82
- 16	47	111	79	79	196	49
+ 17	81	56	15	113	210	81
- 17	53	136	71	61	194	49
+ 18	81	57	26	132	260	90
- 18	33	138	59	92	208	67
+ 19	82	46	23	133	249	86
- 19	31	128	59	88	203	60
+ 20	93	41	4	124	194	105
- 20	54	100	99	79	153	35
+ 21	99	32	3	134	139	105
- 21	54	95	99	82	142	36
+ 22	93	31	3	139	138	106
- 22	19	86	95	83	169	40
+ 23	43	25	7	135	191	102
- 23	14	82	91	34	165	32
+ 24	150	51	55	160	222	177
- 24	69	144	147	151	134	102
+ 25	143	50	51	161	219	159
- 25	57	141	156	146	133	102
+ 26	147	46	49	149	216	-51
- 26	53	117	116	146	193	-41

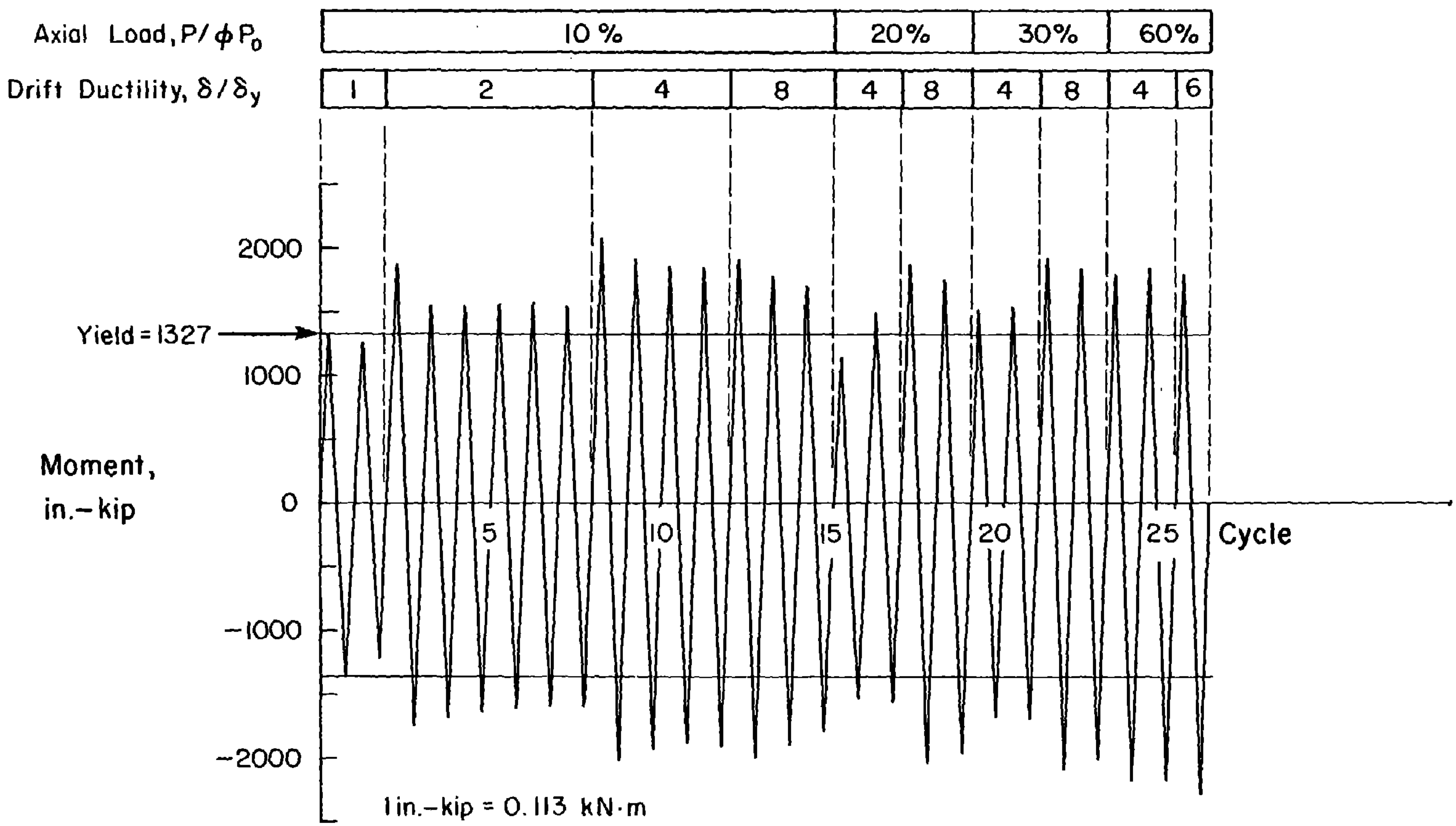


Fig. B61 Column Moment History for Specimen NC2

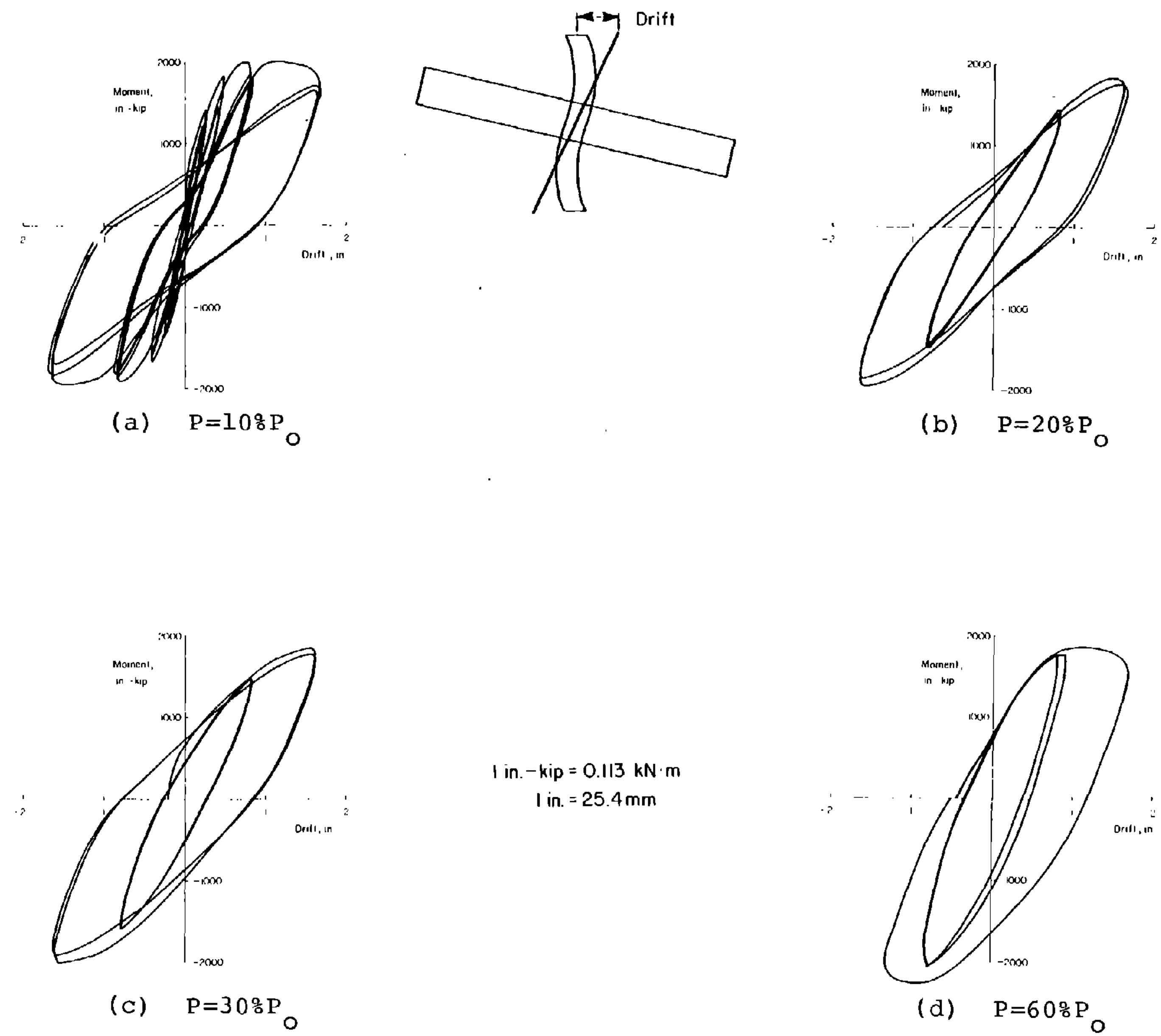


Fig. B62 Top Column Moment versus Drift for Specimen NC2

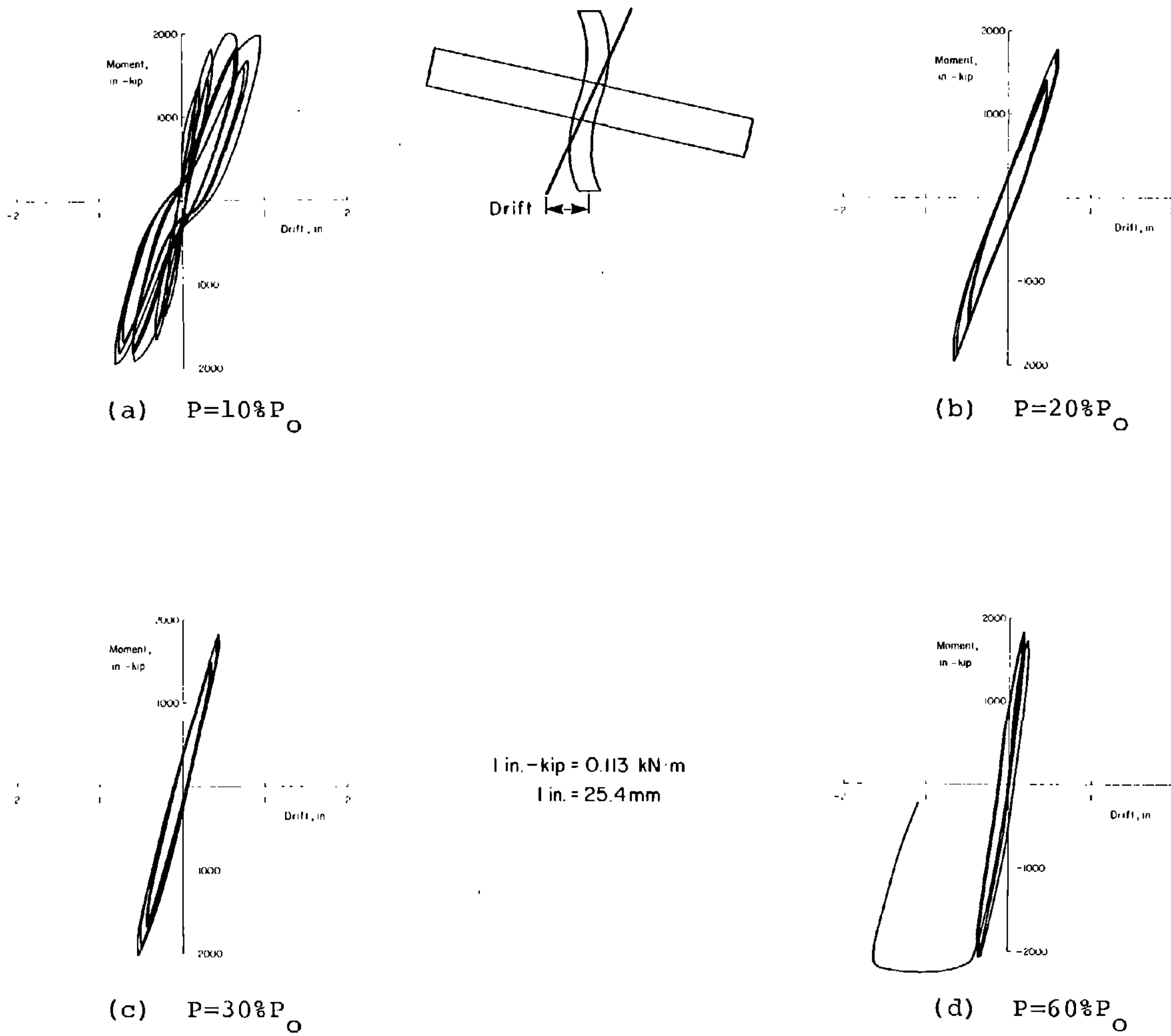


Fig. B63 Bottom Column Moment versus Drift for Specimen NC2

Photographs of Specimen NC2 at the end of Cycles 12 and 15 are shown in Figs. B64 and B65, respectively.

Tabulated results

Tabulated values of moment, top and bottom column drifts, and east and west beam deflections are shown in Table B73. Column rotations are listed in Table B74. Reinforcement strains are given in Tables B75 through B78.

Specimen LC5

Specimen LC5 was one of two specimens tested having a column size of 15x20 in. (381x508 mm). The large dimension was in the direction of bending. This specimen was constructed of Lightweight Concrete 1. The confining reinforcement consisted of No. 4 bars spaced at 3-1/2 in. (89 mm). This corresponds to 1.57% confinement. Complete reinforcement details are presented in Table A1. Note that the main beam reinforcement consisted of 4 No. 11 bars at both the top and bottom of the beam. This was needed to attain the nominal flexural strength of the column without yielding the beam reinforcement.

Column moment history

Specimen LC5 was subjected to 16 cycles of moment reversals as shown in Fig. B66. The column axial load level during the basic 15 loading cycles was 106 kip (472 kN). This axial load corresponds to 10% of the column axial design strength. The axial load level for Cycle 16 was increased to 30% of the column design strength as shown in Fig. B66.

Column moment versus drift relationships

Top and bottom column moment versus drift relationships are presented in Figs. B67 and B68, respectively. This specimen experienced significant joint shear distress. Pinching of the hysteresis loops, evident in the figures, is indicative of shear distortions within the joint region.

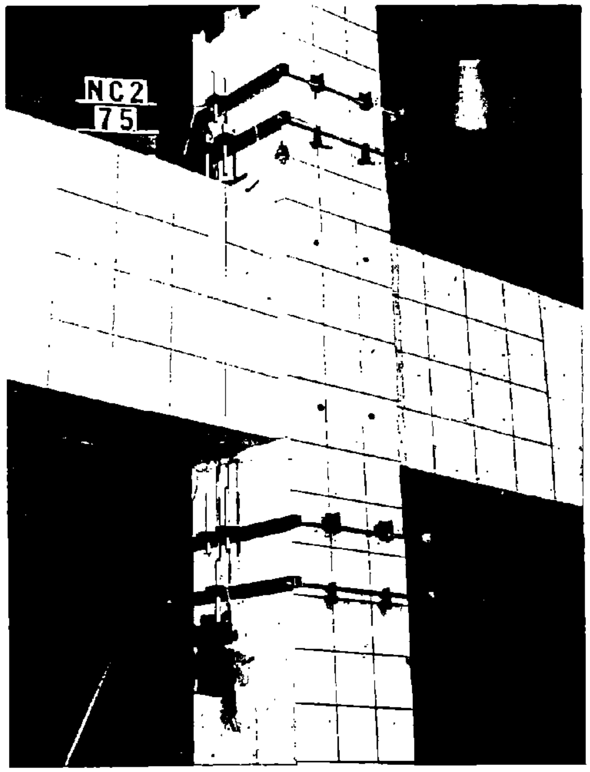


Fig. B64 Specimen NC2 after Cycle 12

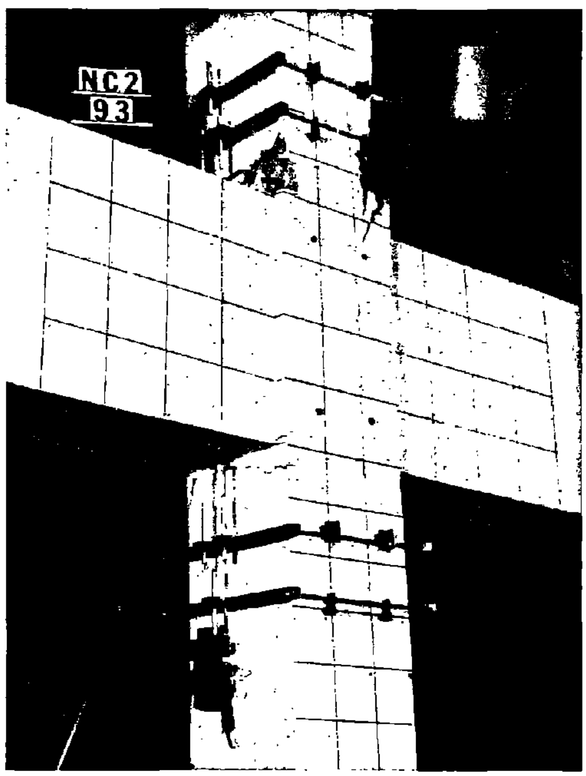


Fig. B65 Specimen NC2 after Cycle 15

TABLE B73 - COLUMN MOMENT, COLUMN DRIFTS, AND BEAM DEFLECTIONS FOR SPECIMEN NC2

CYCLE	MOMENT IN.-KIP	DRIFT (IN.)		DEFLECTION (IN.)	
		TOP	BOTTOM	EAST	WEST
- 1 - 1	1127 -1366	0.200 -0.211	-0.164 0.194	1.027 -1.033	-0.993 1.142
- 2 - 2	1365 -1216	0.227 -0.205	-0.184 0.185	1.111 -0.979	-1.013 1.091
+ 3 - 3	1979 -1753	0.473 -0.405	-0.385 0.333	1.929 -1.635	-1.833 1.745
+ 4 - 4	1552 -1684	0.413 -0.403	-0.323 0.335	1.648 -1.536	-1.601 1.733
+ 5 - 5	1545 -1645	0.415 -0.405	-0.325 0.335	1.554 -1.636	-1.583 1.713
+ 6 - 6	1553 -1513	0.425 -0.401	-0.331 0.327	1.672 -1.630	-1.613 1.704
- 7 - 7	1573 -1595	0.417 -0.399	-0.245 0.325	1.708 -1.506	-1.643 1.697
- 8 - 8	1544 -1598	0.435 -0.401	-0.339 0.333	1.672 -1.612	-1.619 1.706
+ 9 - 9	2077 -2035	0.797 -0.820	-0.591 0.595	2.691 -2.652	-2.776 2.679
+ 10 - 10	1912 -1935	0.915 -0.924	-0.583 0.605	2.664 -2.552	-2.746 2.671
+ 11 - 11	1855 -1889	0.816 -0.824	-0.671 0.613	2.634 -2.522	-2.698 2.665
+ 12 - 12	1847 -1911	0.835 -0.852	-0.671 0.627	2.555 -2.452	-2.722 2.773
+ 13 - 13	1910 -2204	1.637 -1.622	-0.952 0.832	4.244 -3.924	-4.251 3.945
+ 14 - 14	1782 -1907	1.642 -1.688	-0.830 0.786	3.829 -3.983	-4.035 3.942
+ 15 - 15	1703 -1797	1.649 -1.615	-0.791 0.735	3.778 -3.716	-3.981 3.749
+ 16 - 16	1148 -1519	0.321 -0.792	-0.471 0.465	4.513 -2.293	1.755 2.408
+ 17 - 17	1490 -1571	0.846 -0.778	-0.471 0.475	2.341 -2.293	-2.352 2.319
+ 18 - 18	1973 -2043	1.613 -1.600	-0.619 0.657	3.575 -3.567	-3.706 3.742
+ 19 - 19	1748 -1971	1.665 -1.630	-0.593 0.615	3.598 -3.531	-3.676 3.679
+ 20 - 20	1515 -1580	0.824 -0.772	-0.371 0.405	2.132 -2.198	-2.207 2.355
+ 21 - 21	1534 -1695	0.832 -0.782	-0.359 0.419	2.216 -2.263	-2.159 2.175
+ 22 - 22	1919 -2098	1.595 -1.573	-0.471 0.535	3.383 -3.492	-3.406 3.501
+ 23 - 23	1833 -2010	1.502 -1.506	-0.445 0.507	3.240 -3.458	-3.346 3.566
+ 24 - 24	1789 -2192	0.833 -0.773	-0.234 0.345	2.162 -2.191	-2.027 2.464
+ 25 - 25	1640 -2176	0.312 -0.773	-0.132 0.357	2.095 -2.192	-1.913 2.494
+ 26 - 26	1733 -2290	1.526 -1.243	-0.136 1.571	3.073 -4.441	-3.502 4.736

1 in.-kip = 0.113 kN.m   1 in. = 25.4mm

TABLE B74 - COLUMN ROTATIONS FOR SPECIMEN NC2

CYCLE	ROTATION (RADIANS)			
	ABOVE JOINT		BELOW JOINT	
	+D	+D/2	-D	-D/2
+ 1	0.00453	0.00316	-0.00354	-0.00270
- 1	-0.00501	-0.00346	0.00387	0.00290
+ 2	0.00511	0.00352	-0.00390	-0.00292
- 2	-0.00543	-0.00332	0.00364	0.00287
+ 3	0.01019	0.00738	-0.00650	-0.00503
- 3	-0.00990	-0.00563	0.00683	0.00516
+ 4	0.00886	0.00642	-0.00713	-0.00523
- 4	-0.00931	-0.00680	0.00684	0.00517
+ 5	0.00835	0.00641	-0.00714	-0.00512
- 5	-0.00981	-0.00671	0.00687	0.00515
+ 6	0.00896	0.00642	-0.00719	-0.00531
- 6	-0.00972	-0.00671	0.00682	0.00513
+ 7	0.00925	0.00668	-0.00737	-0.00544
- 7	-0.00965	-0.00667	0.00673	0.00513
+ 8	0.00909	0.00662	-0.00735	-0.00533
- 8	-0.00974	-0.00671	0.00682	0.00514
+ 9	0.01825	0.01378	-0.01520	-0.01174
- 9	-0.01968	-0.01523	0.01331	0.01209
+ 10	0.01865	0.01453	-0.01513	-0.01181
- 10	-0.01932	-0.01516	0.01323	0.01007
+ 11	0.01942	0.01468	-0.01476	-0.01177
- 11	-0.01963	-0.01520	0.01320	0.01027
+ 12	0.01875	0.01493	-0.01499	-0.01191
- 12	-0.02048	-0.01595	0.01335	—
+ 13	0.04163	0.03022	-0.02271	-0.01804
- 13	-0.04134	-0.02979	0.01934	0.01401
+ 14	0.04271	0.03234	-0.01904	-0.01544
- 14	-0.04387	-0.03164	0.01732	0.01324
+ 15	0.04321	0.03281	-0.01796	-0.01467
- 15	-0.04191	-0.03066	0.01620	0.01251
+ 16	0.02111	0.01689	-0.01136	-0.00971
- 16	-0.02068	-0.01433	0.01048	0.00802
+ 17	0.02191	0.01774	-0.01131	-0.00954
- 17	-0.02032	-0.01385	0.01051	0.00832
+ 18	0.04365	0.03434	-0.01450	-0.01214
- 18	-0.04237	-0.03118	0.01427	0.01034
+ 19	0.04546	0.03654	-0.01379	-0.01147
- 19	-0.04256	-0.03122	0.01359	0.01041
+ 20	0.02246	0.01902	-0.00904	-0.00802
- 20	-0.02021	-0.01370	0.00904	0.00690
+ 21	0.02268	0.01919	-0.00667	-0.00765
- 21	-0.02021	-0.01382	0.00933	0.00709
+ 22	0.04417	0.03621	-0.01056	-0.00943
- 22	-0.04193	-0.03015	0.01161	0.00896
+ 23	0.04439	0.03670	-0.01035	-0.00956
- 23	-0.04275	-0.03074	0.01132	0.00847
+ 24	0.02307	0.02095	-0.00509	-0.00512
- 24	-0.01965	-0.01403	0.00706	0.00523
+ 25	0.02286	0.01969	-0.00403	-0.00436
- 25	-0.01935	-0.01365	0.00734	0.00553
+ 26	0.04748	0.03827	-0.00390	-0.00430
- 26	-0.03333	-0.02151	0.04142	0.02951

TABLE B75 - WEST COLUMN STEEL STRAINS FOR SPECIMEN NC2

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	-543	-585	-548	-39	33	1558	1584	1346	1117
- 1	1433	1854	1509	1376	734	-56	-565	-585	-464
+ 2	-517	-536	-539	3	334	1541	1580	1361	1148
- 2	1251	1521	1611	1633	689	-33	-559	-566	-443
+ 3	-250	-335	-613	406	739	7714	6923	2524	3117
- 3	3056	4371	4275	6503	1304	3378	1325	-744	-599
+ 4	-664	215	-73	3798	546	6510	5478	2049	1692
- 4	2035	4503	4456	3539	1159	3510	1357	-748	-539
+ 5	-933	367	52	4198	515	6431	5388	2036	1684
- 5	1973	4450	4465	3447	1139	3566	1382	-744	-585
+ 6	-948	413	102	4380	456	6429	5403	2053	1792
- 6	1923	4460	4425	8340	1112	3591	1399	-739	-584
+ 7	-1009	425	133	4497	503	6509	5507	2058	1727
- 7	1883	4359	4399	8263	1101	3611	1417	-740	-584
+ 8	-1023	461	153	4547	487	6402	5378	2052	1296
- 8	1585	4394	4457	8309	1106	3637	1429	-742	-587
+ 9	-1203	397	396	5087	362	11559	11585	8089	2798
- 9	2143	10261	13907	13640	1493	4440	1175	981	-599
+ 10	-1332	511	778	4955	673	11479	11070	7510	2617
- 10	2122	5591	12508	13902	1416	4841	1319	1151	-593
+ 11	-1162	792	914	5377	573	11215	10651	7167	2536
- 11	2090	9613	13295	13842	1379	5102	1411	1235	-589
+ 12	-1393	388	1042	5691	512	11327	10748	7413	2536
- 12	2137	10217	13901	14454	1484	5338	1484	1239	-616
+ 13	-1854	-2010	-4608	5919	616	-	15099	9695	3677
- 13	7433	17066	-	23606	1651	-	-	1014	-352
+ 14	-1208	382	-	6264	351	-	12753	8012	3250
- 14	8087	8315	-	24703	1571	-	-	1051	-213
+ 15	3341	1184	-	6521	215	-	11744	7504	3069
- 15	7909	5145	-	23703	1535	-	-	1952	-189
+ 16	14243	1558	-	6280	-285	-	-	-403	1680
- 16	18132	4646	-	12667	306	-	-	894	-258
+ 17	55196	1393	-	6172	-254	-	-	4393	1773
- 17	56438	4674	-	12473	795	-	-	341	-275
+ 18	-	1619	-	5634	-193	-	-	5500	2343
- 18	20871	5337	-	22353	1347	-	-	585	-454
+ 19	-	1664	-	5602	-225	-	-	5035	2119
- 19	18719	5092	-	22599	1328	-	-	577	-443
+ 20	-	1913	-	6000	-613	-	-	3195	1075
- 20	-	3786	-	12302	552	-	-	-76	-464
+ 21	-	2133	-	5732	-652	-	-	3080	1056
- 21	-	3385	-	12221	547	-	-	440	-474
+ 22	-	2101	-	4758	-569	-	-	3639	1413
- 22	-	5052	-	20447	1530	-	-	301	-523
+ 23	-	2131	-	4549	-627	-	-	3348	1375
- 23	-	5015	-	20508	1046	-	-	232	-503
+ 24	-	2439	-	3340	-1537	-	-	1422	93
- 24	-	3317	-	3849	-122	-	-	-813	-1134
+ 25	-	3866	-	2263	-1574	-	-	554	-333
- 25	-	2551	-	7358	-133	-	-	-1150	-1354
+ 26	-	-1373	-	393	-1216	-	-	236	-363
- 26	-	4391	-	11311	36	-	-	-21213	-3297

TABLE B76 - EAST COLUMN STEEL STRAINS FOR SPECIMEN NC2

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	1419	1733	1538	1840	-	-141	-637	-537	-511
- 1	-662	-714	-633	-134	-	1738	1531	1713	1232
+ 2	1447	1760	1567	1956	-	-135	-598	-551	-431
- 2	-646	-700	-635	-138	-	1508	1414	1513	1118
+ 3	2189	5421	3557	9857	-	43	-863	-920	-694
- 3	-356	121	-740	3295	-	5428	2697	2533	1998
+ 4	2009	4514	3112	8318	-	1874	-741	-833	-613
- 4	-871	320	-759	4201	-	5474	2687	2523	1922
+ 5	2000	4459	3113	8303	-	2040	-729	-836	-619
- 5	-877	332	-750	4130	-	5405	2644	2463	1889
+ 6	2024	4496	3157	8394	-	2111	-735	-848	-627
- 6	-876	343	-753	4204	-	5312	2593	2419	1843
+ 7	2066	4603	3242	8537	-	2153	-748	-862	-642
- 7	-876	355	-742	4245	-	5257	2564	2383	1831
+ 8	2024	4501	3178	8995	-	2163	-733	-852	-613
- 8	-891	364	-738	4301	-	5275	2583	2397	1836
+ 9	3638	9844	10734	13592	-	2411	-999	-1094	-734
- 9	-708	388	433	4772	-	10115	11030	8552	2457
+ 10	3431	9681	11220	13965	-	2954	-5	314	-867
- 10	-698	535	557	5068	-	10093	10641	8384	2266
+ 11	3083	9593	11090	13926	-	3360	174	515	-885
- 11	-693	641	695	5279	-	10031	10413	8250	2324
+ 12	3414	9802	11274	14182	-	3535	375	615	-900
- 12	-714	735	332	5477	-	10170	10535	8434	2329
+ 13	10631	30429	20642	21879	-	3965	-	462	-943
- 13	-413	-177	-1806	6259	-	13328	14774	10455	2501
+ 14	10741	30013	19624	22639	-	4352	250	594	-943
- 14	-366	44	-3954	6564	-	12591	13257	9694	2392
+ 15	10734	19330	18427	23195	-	4515	302	542	-945
- 15	-307	581	-3666	5713	-	11397	11959	8942	2260
+ 16	5518	12406	5552	13712	-	3652	121	509	-972
- 16	-226	1224	-2304	5655	-	7707	5518	5029	1202
+ 17	5565	15866	5617	13397	-	2497	-178	509	-958
- 17	-291	1147	-3040	5713	-	7576	5311	4965	1268
+ 18	9536	17281	15148	21173	-	3689	-571	265	-1057
- 18	-902	101	-8650	5165	-	9354	9025	6824	1336
+ 19	3747	18224	12484	22032	-	3544	-593	254	-1032
- 19	-1050	672	-5928	5027	-	3837	7375	6329	1733
+ 20	5042	3190	1003	12571	-	2801	-581	259	-1042
- 20	-901	111	-5710	5161	-	5991	3330	3719	713
+ 21	4330	7405	916	12564	-	2656	-975	209	-1040
- 21	-984	-34	-5972	5022	-	6005	3321	3800	814
+ 22	8479	22132	9500	19561	-	2304	-1208	[illegible]	-1131
- 22	-2749	-2733	-11527	3759	-	6779	4281	4539	1155
+ 23	8667	15554	7092	20016	-	2713	-1236	-	-1105
- 23	-3300	-1590	-11563	3580	-	6385	3725	4131	1049
+ 24	2751	4314	-300	10755	-	1299	-1739	-415	-1349
- 24	-5131	-5160	-11281	1762	-	3005	511	1547	-57
+ 25	951	2411	-4172	8814	-	320	-1363	-521	-1355
- 25	-6392	-6231	-12257	933	-	2554	372	1544	-42
+ 26	7532	9319	725	12648	-	754	-1301	-535	-1313
- 26	3179	-14781	-13521	-350	-	3852	13095	14818	2842

TABLE B77 - TOP COLUMN HOOP STRAINS FOR SPECIMEN NC2

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	64	108	15	-31	-6	117
- 1	4	-65	52	67	36	93
+ 2	-12	185	49	-63	35	163
- 2	-17	-55	71	38	71	72
+ 3	-59	454	111	-64	55	351
- 3	35	-15	300	31	359	30
+ 4	-73	424	97	-76	109	314
- 4	4	-12	219	77	303	35
+ 5	-93	435	99	-92	123	317
- 5	-16	-9	218	59	322	93
+ 6	-102	446	100	-95	126	324
- 6	-20	-10	220	50	329	39
+ 7	-108	459	103	-106	132	328
- 7	-25	-5	219	43	330	89
+ 8	-111	451	103	-111	132	333
- 8	-31	-5	220	42	335	92
+ 9	147	1073	403	26	367	525
- 9	398	263	442	33	740	293
+ 10	51	999	407	110	418	523
- 10	367	284	469	24	706	283
+ 11	53	975	405	106	412	513
- 11	345	265	463	19	397	279
+ 12	32	977	421	31	420	510
- 12	328	286	485	-	715	293
+ 13	391	1318	691	106	394	343
- 13	217	575	550	239	3945	513
+ 14	524	1163	564	120	558	346
- 14	343	556	416	166	4595	613
+ 15	566	1175	528	142	713	397
- 15	198	525	345	175	3136	551
+ 16	533	464	455	145	504	375
- 16	253	398	12	579	1661	475
+ 17	503	431	457	229	539	382
- 17	253	402	38	580	1599	495
+ 18	630	1134	531	232	309	561
- 18	252	675	338	654	2914	801
+ 19	692	996	661	306	383	595
- 19	303	736	234	756	2771	755
+ 20	617	755	531	515	330	325
- 20	393	519	100	559	1592	750
+ 21	665	527	544	531	973	352
- 21	359	527	129	933	1766	734
+ 22	836	980	355	469	1232	570
- 22	447	980	241	1100	3175	2780
+ 23	1344	362	937	575	1139	509
- 23	511	1005	223	2555	1535	1162
+ 24	1492	719	1276	1112	2252	577
- 24	921	1006	502	1377	2457	2361
+ 25	1153	791	1481	1111	2796	1159
- 25	336	1191	529	1949	2741	2751
+ 26	1144	2577	3911	1473	3188	1734
- 26	1187	2531	4574	1520	-	7355

TABLE B78 - BOTTOM COLUMN HOOP STRAINS FOR SPECIMEN NC2

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	-	15	105	-101	-30	59
- 1	-	-13	33	-19	-49	422
+ 2	-	50	107	-46	-11	103
- 2	-	3	33	6	-41	364
+ 3	-	144	300	-10	-14	297
- 3	-	116	130	-97	-17	344
+ 4	-	146	248	5	-1	357
- 4	-	127	112	-80	-15	606
+ 5	-	148	239	32	-8	268
- 5	-	130	109	-133	-22	593
+ 6	-	147	243	-35	-12	272
- 6	-	132	112	-128	-24	575
+ 7	-	148	245	-5	-11	280
- 7	-	128	111	-74	-25	566
+ 8	-	148	238	-36	-14	279
- 8	-	132	109	-97	-25	565
+ 9	-	254	570	550	247	710
- 9	-	422	333	347	240	580
+ 10	-	274	571	552	271	686
- 10	-	409	367	317	251	529
+ 11	-	262	564	543	265	675
- 11	-	405	361	319	251	608
+ 12	-	255	558	543	261	684
- 12	-	405	356	298	245	605
+ 13	-	364	779	400	396	940
- 13	-	476	416	242	352	707
+ 14	-	307	719	447	287	833
- 14	-	435	390	242	326	659
+ 15	-	286	631	330	272	771
- 15	-	399	355	209	303	628
+ 16	-	174	381	277	204	354
- 16	-	324	180	232	191	446
+ 17	-	179	404	305	204	411
- 17	-	272	191	213	201	462
+ 18	-	232	544	325	245	629
- 18	-	303	268	302	235	558
+ 19	-	225	522	329	251	605
- 19	-	266	246	327	225	542
+ 20	-	132	367	337	251	398
- 20	-	203	179	3360	134	403
+ 21	-	139	296	1027	263	313
- 21	-	309	181	604	190	421
+ 22	-	174	382	1977	266	420
- 22	-	334	207	1063	204	491
+ 23	-	174	361	317	275	408
- 23	-	231	207	2875	305	475
+ 24	-	206	130	390	421	493
- 24	-	393	319	462	134	328
+ 25	-	209	192	353	424	507
- 25	-	102	330	473	184	353
+ 26	-	328	301	367	430	505
- 26	-	2345	49166	436	1217	1445

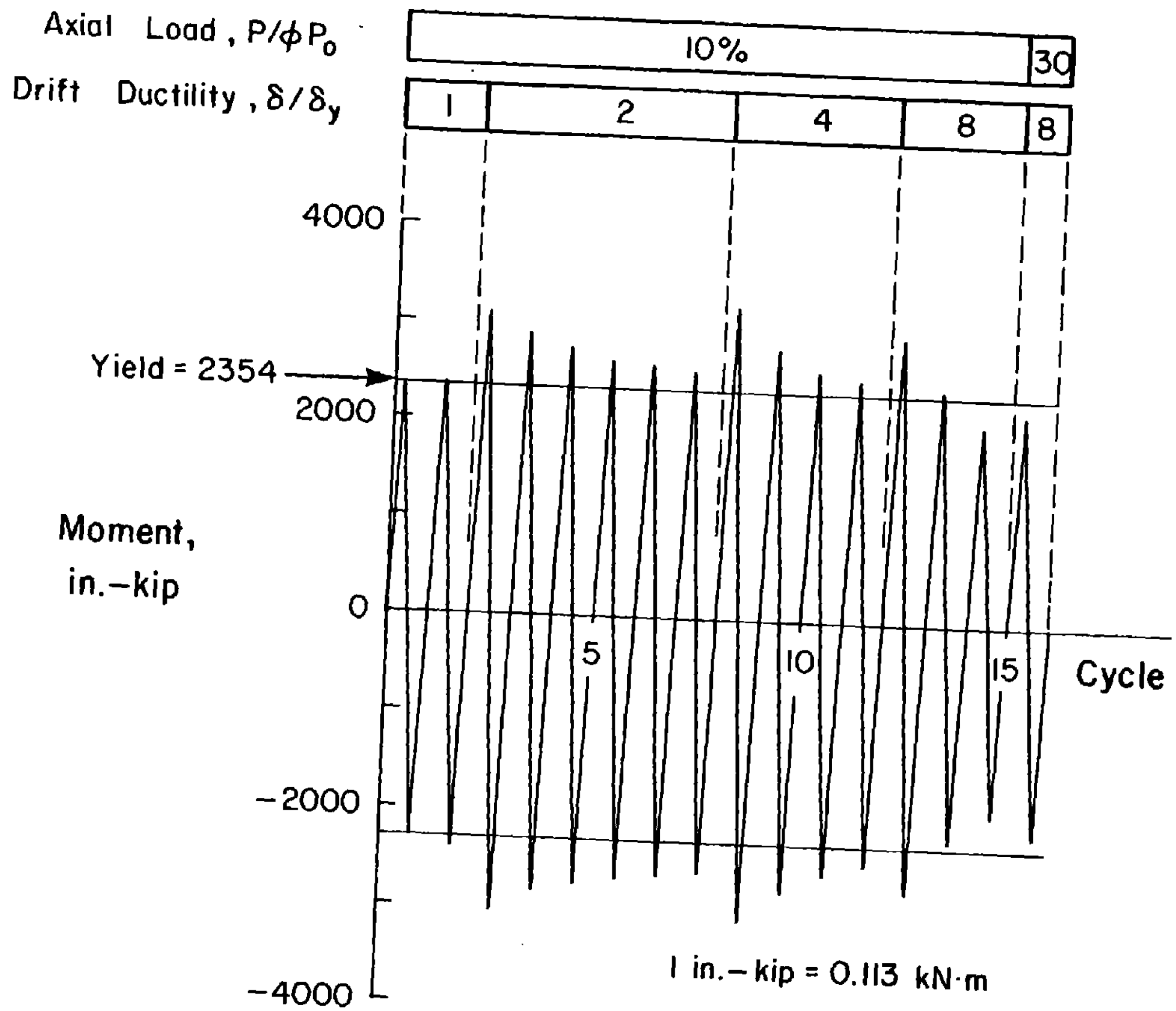
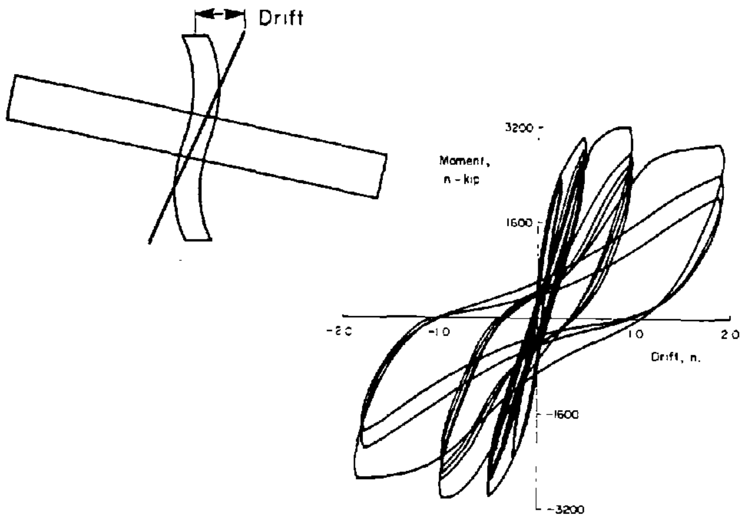
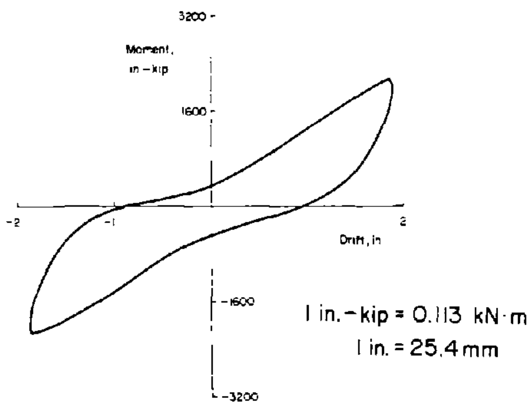


Fig. B66 Column Moment History for Specimen LC5

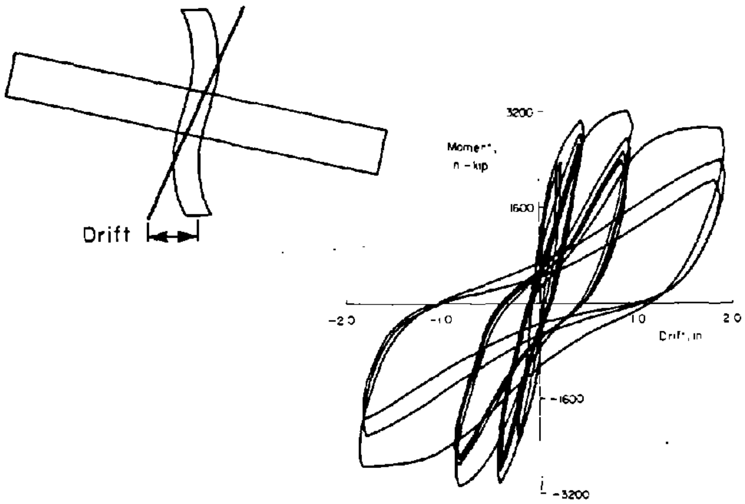


(a) P=10%P_o

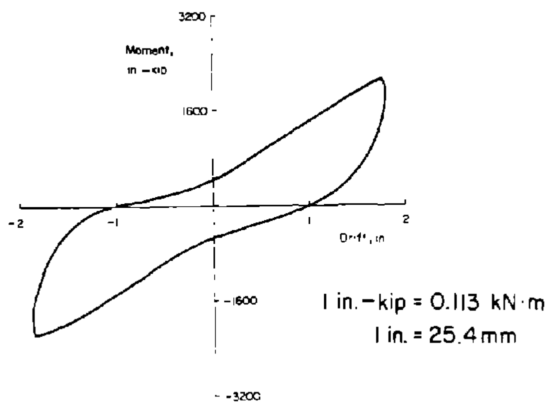


(b) P=30%P_o

Fig. B67 Top Column Moment versus Drift for Specimen LC5



(a) P=10%P_o



(b) P=30%P_o

Fig. B68 Bottom Column Moment versus Drift for Specimen LC5

The first positive peak column moment was 2354 in.-kip (266 kN·m). Corresponding top column drift was 0.24 in. (6.0 mm). The maximum measured column moment was 3200 in.-kip (362 kN·m). It occurred at the positive peak of Cycle 9. Calculated nominal flexural strength was 3160 in.-kip (357 kN m). The specimen was observed to lose capacity through shearing of the joint. The maximum nominal shear stress in the joint during the basic loading cycles was $16.8\sqrt{f'_c}$ psi ($1.38\sqrt{f'_c}$ MPa). Further information concerning joint shear is provided in the main body of the report.

Photographs of Specimen LC5 at the end of Cycles 12 and 15 are provided in Figs. B69 and B70, respectively. Notice the severe joint distress by the end of Cycle 15.

Tabulated results

Values for average of top and bottom column moment, top and bottom column drifts, and east and west beam deflections are listed in Table B79. Column rotations are given in Table B80. Steel strains are provided in Tables B81 through B84.

Specimen LC13

Specimen LC13 had a 15x20-in. (318x508-mm) column. Main column steel was similar to that of Specimen LC5. However, confining hoops of Specimen LC13 consisted of No. 4 hoops spaced at 4 in. (102 mm). This specimen had slightly less confinement than Specimen LC5. In addition, column lengths were changed to force a hinge to occur in the top column. The top column height was increased 7.5 in. (190 mm) and the bottom column height was decreased 7.5 in. (190 mm). This resulted in a bottom column to top column moment ratio of 0.77.

Column moment history

Specimen LC13 was subjected to 21 cycles of moment reversals as shown in Fig. B71. Column axial load during the basic loading cycles was equal to 10% of the column axial design strength.

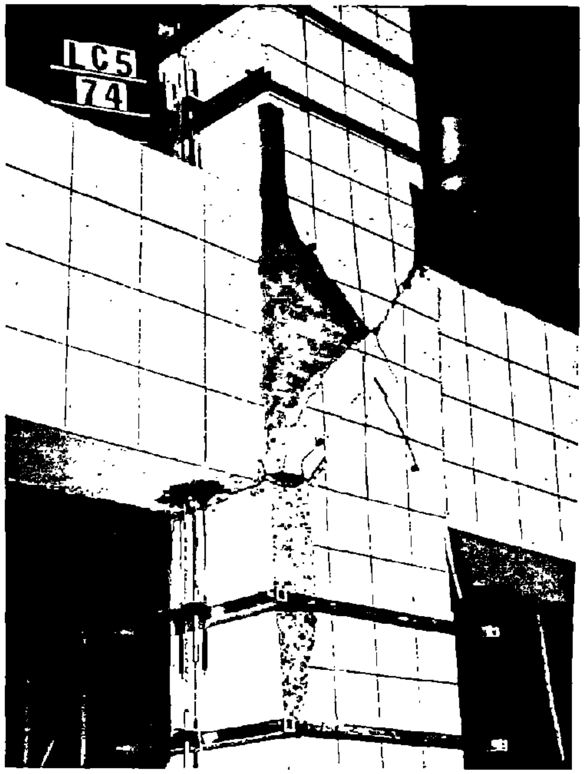


Fig. B69 Specimen LC5 after Cycle 12

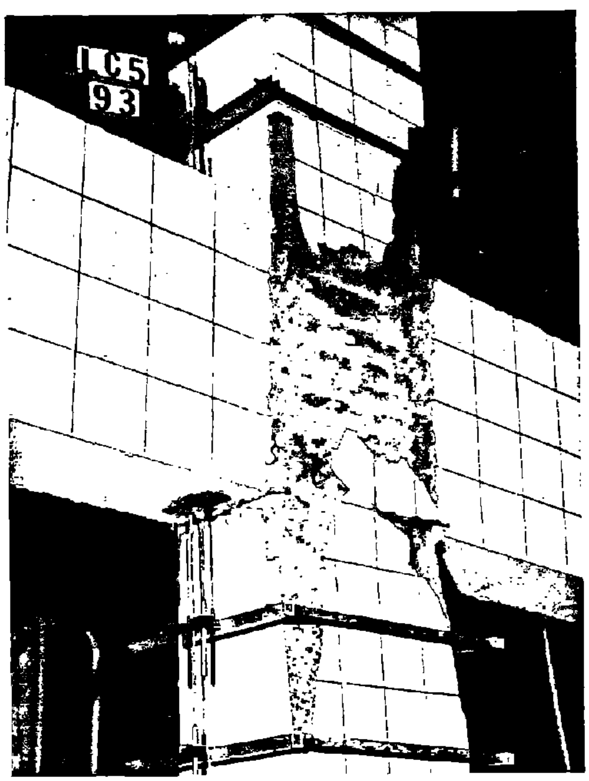


Fig. B70 Specimen LC5 after Cycle 15

TABLE B79 - COLUMN MOMENT, COLUMN DRIFTS, AND BEAM DEFLECTIONS FOR SPECIMEN LC5

CYCLE	MOMENT IN.-KIP	DRIFT (IN.)		DEFLECTION (IN.)	
		TOP	BOTTOM	EAST	WEST
+ 1	2354	0.235	-0.162	1.273	-1.295
- 1	-2331	-0.201	0.201	-1.230	1.259
+ 2	2366	0.235	-0.204	1.378	-1.403
- 2	-2404	-0.246	0.228	-1.409	1.391
+ 3	3100	0.489	-0.434	2.174	-2.303
- 3	-3052	-0.495	0.437	-2.150	2.201
+ 4	2985	0.495	-0.433	2.114	-2.237
- 4	-2934	-0.495	0.439	-2.090	2.195
+ 5	2746	0.499	-0.438	2.072	-2.153
- 5	-2753	-0.496	0.439	-2.048	2.123
+ 6	2627	0.496	-0.435	2.013	-2.117
- 6	-2694	-0.494	0.440	-2.035	2.105
+ 7	2537	0.495	-0.431	1.989	-2.075
- 7	-2646	-0.492	0.440	-2.007	2.081
+ 8	2534	0.493	-0.429	1.965	-2.039
- 8	-2606	-0.490	0.441	-1.983	2.059
+ 9	3200	0.985	-0.950	3.398	-3.634
- 9	-3097	-0.986	0.878	-3.237	3.329
+ 10	2785	0.931	-0.936	3.224	-3.412
- 10	-2760	-0.933	0.865	-3.177	3.157
+ 11	2566	0.975	-0.934	3.135	-3.292
- 11	-2598	-0.977	0.867	-3.123	3.105
+ 12	2484	0.990	-0.938	3.115	-3.268
- 12	-2489	-0.979	0.875	-3.117	3.097
+ 13	2916	1.851	-1.884	5.365	-5.590
- 13	-2778	-1.867	1.856	-5.595	5.558
+ 14	2398	1.863	-1.890	5.396	-5.666
- 14	-2221	-1.801	1.822	-5.470	5.454
+ 15	2050	1.841	-1.824	5.247	-5.455
- 15	-1951	-1.799	1.820	-5.411	5.414
+ 16	2167	1.831	-1.770	5.047	-5.157
- 16	-2159	-1.879	1.859	-5.446	5.313

1 in.-kip = 0.113 kN.m   1 in. = 25.4mm

TABLE B80 - COLUMN ROTATIONS FOR SPECIMEN LC5

CYCLE	ROTATION (RADIANS)			
	ABOVE JOINT		BELOW JOINT	
	+D	+D/2	-D	-D/2
+ 1	0.00481	0.00397	-0.00493	-0.00342
- 1	-0.00491	-0.00396	0.00449	0.00310
+ 2	0.00500	0.00418	-0.00531	-0.00373
- 2	-0.00560	-0.00461	0.00508	0.00357
+ 3	0.00978	0.00851	-0.00998	-0.00766
- 3	-0.01107	-0.00958	0.00886	0.00679
+ 4	0.00958	0.00842	-0.00987	-0.00751
- 4	-0.01075	-0.00934	0.00856	0.00665
+ 5	0.00927	0.00826	-0.00961	-0.00743
- 5	-0.01063	-0.00932	0.00839	0.00657
+ 6	0.00895	0.00796	-0.00943	-0.00730
- 6	-0.01045	-0.00925	0.00834	0.00652
+ 7	0.00892	0.00784	-0.00931	-0.00717
- 7	-0.01036	-0.00915	0.00829	0.00656
+ 8	0.00872	0.00778	-0.00914	-0.00714
- 8	-0.01031	-0.00904	0.00826	0.00730
+ 9	0.01732	0.01663	-0.01936	-0.01559
- 9	-0.01923	-0.01789	0.01560	0.01413
+ 10	0.01666	0.01594	-0.01757	-0.01447
- 10	-0.01858	-0.01731	0.01500	0.01380
+ 11	0.01596	0.01528	-0.01730	-0.01390
- 11	-0.01805	-0.01685	0.01471	0.01368
+ 12	0.01565	0.01507	-0.01711	-0.01377
- 12	-0.01780	-0.01668	0.01457	0.01361
+ 13	0.02769	0.02686	-0.03157	-0.02723
- 13	-0.03046	-0.02938	0.02984	0.02327
+ 14	0.02626	0.02591	-0.03077	-0.02682
- 14	-0.02945	-0.02760	0.02852	0.02737
+ 15	0.02434	0.02434	-0.02917	-0.02552
- 15	-0.02744	-0.02693	0.02779	0.02532
+ 16	0.02314	0.02351	-0.02631	-0.02364
- 16	-0.02639	-0.02677	0.02690	0.02595

TABLE B81 - WEST COLUMN STEEL STRAINS FOR SPECIMEN LC5

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	-662	-797	-665	-354	787	2054	1722	-	1329
- 1	1343	1371	1936	2221	975	-81	-792	-	-601
+ 2	-586	-745	-762	-189	366	2235	1387	-	1443
- 2	1548	2116	2210	2579	1200	9	-800	-	-602
+ 3	-904	-1004	-1075	167	1134	11583	9940	-	2134
- 3	2146	5963	10237	13338	1592	4276	1211	-	-849
+ 4	-728	518	546	4433	664	11295	9215	-	1946
- 4	1991	5604	9496	13024	1330	4791	1443	-	-815
+ 5	-777	631	842	5140	461	10815	8564	-	1835
- 5	1929	5435	9170	12903	1304	4961	1520	-	-809
+ 6	-753	774	991	5453	365	10451	8044	-	1752
- 6	1879	5299	8874	12724	1250	5059	1545	-	-799
+ 7	-743	824	1071	5551	334	10244	7779	-	1714
- 7	1936	5200	9666	12582	1108	5105	1572	-	-795
+ 8	-743	854	1138	5795	293	9959	7447	-	1653
- 8	1908	5104	9472	12430	1173	5146	1592	-	-787
+ 9	-952	141	867	6639	988	18245	16304	-	2252
- 9	2168	9108	15055	21678	1594	7821	1043	-	-1034
+ 10	-836	915	963	3018	508	17010	13558	-	1957
- 10	1992	8134	13504	20170	1331	8540	1251	-	-969
+ 11	-847	1170	1433	8852	298	16092	11953	-	1799
- 11	1971	7569	12431	19175	1194	9080	1465	-	-935
+ 12	-827	1250	1696	9333	277	15773	11257	-	1715
- 12	1787	7149	11717	18575	1133	9314	1597	-	-920
+ 13	-932	904	1910	10687	943	26209	-	-	2191
- 13	1995	8951	22799	-	1759	13838	-	-	-1058
+ 14	-792	1501	3242	14466	690	-	-	-	1771
- 14	1563	6792	25088	-	1260	-	-	-	2231
+ 15	-712	1684	3643	14610	593	-	-	-	10273
- 15	1330	5503	21644	-	936	-	-	-	21365
+ 16	-929	1109	1670	5738	-338	-	-	-	17734
- 16	376	3635	5521	-	-134	-	-	-	9342

TABLE B82 - EAST COLUMN STEEL STRAINS FOR SPECIMEN LC5

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	1417	1076	1885	2283	538	-21	-579	-655	-536
- 1	-715	-631	-830	-377	711	2011	1520	1555	1291
+ 2	1526	2302	1968	2508	336	-31	-797	-747	-558
- 2	-713	374	-840	-148	793	2259	1762	1655	1558
+ 3	2251	4863	9313	11427	1275	346	-1151	-1063	-778
- 3	-973	505	751	3515	612	11338	2566	5912	2223
+ 4	2145	3983	5783	10204	1241	4150	-1383	439	-757
- 4	-944	772	993	3683	541	10762	2413	5465	2048
+ 5	2220	3574	8133	9560	1142	-653	-1401	605	-737
- 5	-937	566	1081	3856	440	10438	2342	5267	1972
+ 6	1914	3256	7574	9136	1050	4825	-1335	705	-713
- 6	-929	1398	1115	3978	370	10159	2235	5103	1911
+ 7	1870	3083	7302	9031	1025	4919	-1390	747	-739
- 7	-918	543	1123	4091	324	9973	2244	4996	1867
+ 8	1799	2886	6952	8828	974	4973	-1400	768	-706
- 8	-911	450	1143	4145	290	9933	2211	4505	1835
+ 9	2432	5057	12979	11290	1453	5773	-1786	-176	-912
- 9	-1072	355	53	3277	642	16166	10727	9570	2690
+ 10	2158	4310	12082	8986	1047	6555	-500	1037	-650
- 10	-1013	431	289	3125	305	15232	5365	8327	2374
+ 11	1961	3823	11077	7584	897	6204	-321	1331	-603
- 11	-968	501	517	3190	179	14851	4392	7640	2210
+ 12	1901	3626	10578	7221	838	7044	-257	1391	-581
- 12	-949	518	692	3260	117	14511	3511	7139	2096
+ 13	2263	4842	12243	7450	1325	8550	-367	695	-738
- 13	-1005	503	2212	4253	756	26203	5240	10247	2479
+ 14	1757	3669	8550	6055	1319	13236	-155	1354	-580
- 14	-940	646	2953	3309	480	22052	3522	8037	2037
+ 15	1474	3124	7079	4254	527	14077	-83	1521	-489
- 15	-756	717	1263	4944	381	20194	2882	6929	1793
+ 16	159	2057	5168	3514	-291	9663	23	895	-717
- 16	-1064	473	1753	2631	-714	11407	2140	4361	779

TABLE B83 - TOP COLUMN HOOP STRAINS
FOR SPECIMEN LC5

CYCLE	STRAIN MILLIONTHS					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	-57	35	61	296	-34	30
- 1	-11	-88	-13	-26	57	86
+ 2	7	129	124	422	-10	77
- 2	54	17	22	86	105	134
+ 3	75	179	219	263	-51	92
- 3	70	-38	-1	182	193	167
+ 4	105	161	230	254	-40	96
- 4	66	-74	3	192	188	174
+ 5	90	155	225	232	-46	86
- 5	64	-74	2	178	189	173
+ 6	81	140	215	218	-44	82
- 6	59	-65	3	164	189	172
+ 7	59	136	215	203	-40	81
- 7	54	-64	3	147	184	170
+ 8	66	130	214	209	-40	80
- 8	54	-64	2	132	184	170
+ 9	161	191	292	658	-55	106
- 9	320	-23	7	350	259	222
+ 10	177	159	286	573	-30	137
- 10	326	8	20	318	251	222
+ 11	151	145	277	639	-10	136
- 11	303	28	27	275	245	218
+ 12	137	131	275	619	3	140
- 12	295	47	27	240	238	214
+ 13	160	144	322	1007	107	153
- 13	695	175	40	356	308	218
+ 14	152	114	306	936	187	172
- 14	639	152	71	253	167	229
+ 15	146	95	291	832	167	162
- 15	552	114	34	254	147	212
+ 16	125	148	305	654	30	137
- 16	366	-28	38	81	153	259

TABLE B84 - BOTTOM COLUMN HOOP STRAINS FOR SPECIMEN LC5

CYCLE	STRAIN MILLIONTHS					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	35	-35	-130	-89	77	56
- 1	-37	57	-207	36	-9	-9
+ 2	136	95	-87	73	157	112
- 2	-27	173	-189	135	42	60
+ 3	71	91	-120	154	359	215
- 3	-15	190	-231	175	66	141
+ 4	96	87	-147	111	361	225
- 4	-47	199	-251	170	91	135
+ 5	87	78	-162	109	341	212
- 5	-67	193	-254	159	95	132
+ 6	91	77	-192	107	331	202
- 6	-72	197	-252	155	96	132
+ 7	87	71	-182	98	326	203
- 7	-61	198	-238	165	97	132
+ 8	92	77	-177	108	311	193
- 8	-85	198	-221	163	101	136
+ 9	139	127	-74	291	716	149
- 9	-67	463	135	499	233	208
+ 10	281	234	199	254	543	308
- 10	-51	436	275	489	306	232
+ 11	255	239	247	226	450	270
- 11	-55	413	289	470	340	239
+ 12	261	249	250	216	407	260
- 12	-45	391	275	457	397	231
+ 13	541	667	196	581	575	255
- 13	1310	655	234	533	774	300
+ 14	675	551	193	495	566	299
- 14	7305	672	145	594	776	305
+ 15	6273	541	195	422	469	260
- 15	11039	516	138	637	721	304
+ 16	33915	574	51	223	284	277
- 16	13247	600	199	722	603	213

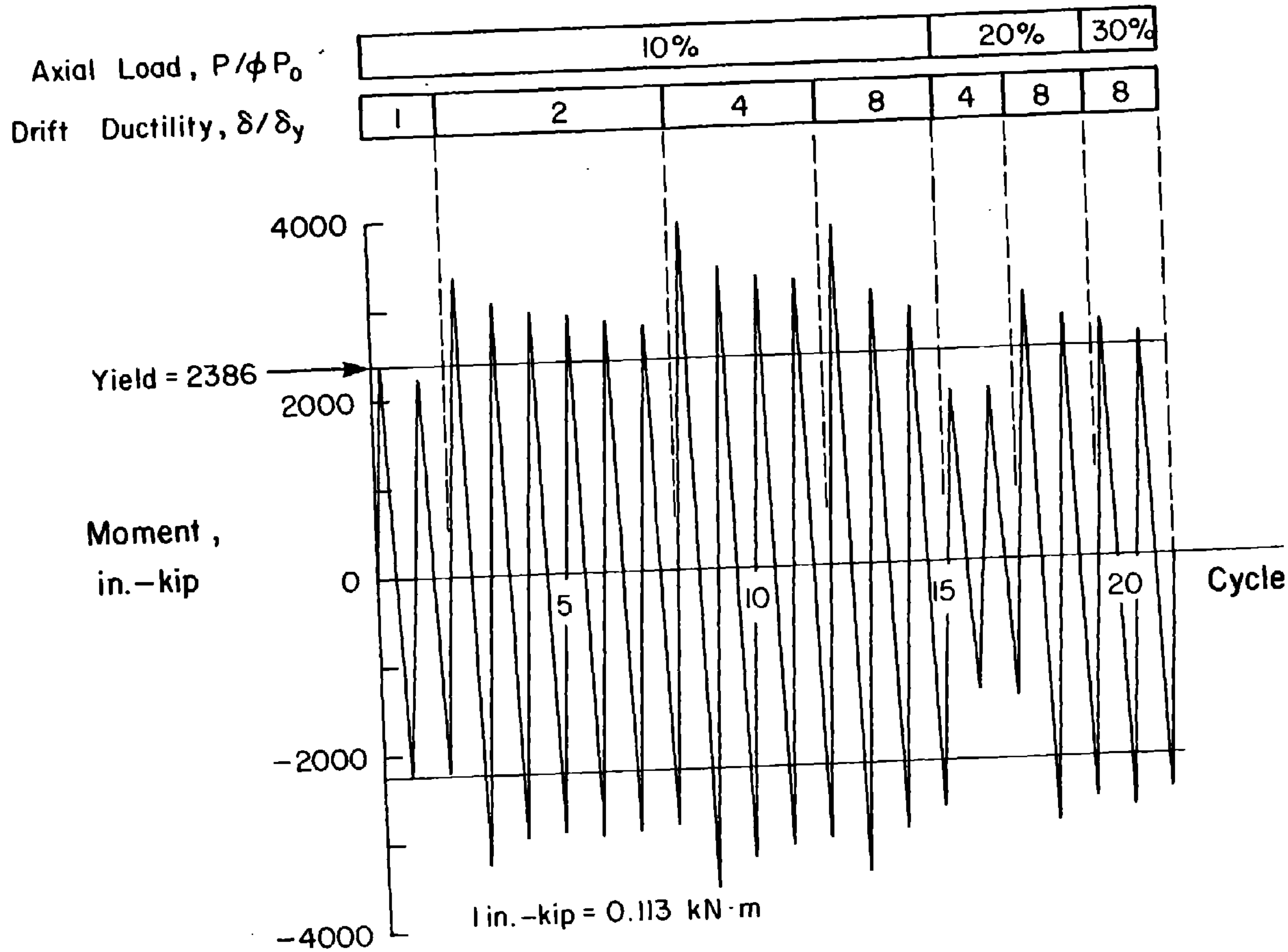


Fig. B71 Column Moment History for Specimen LC13

Column axial load was then increased to 20% and 30% of the column design strength and additional loading cycles were applied at each load level. As with Specimens LC12 and NC3, horizontal movement of the joint was anticipated. The specimen was instrumented to measure this movement.

Column moment versus drift relationships

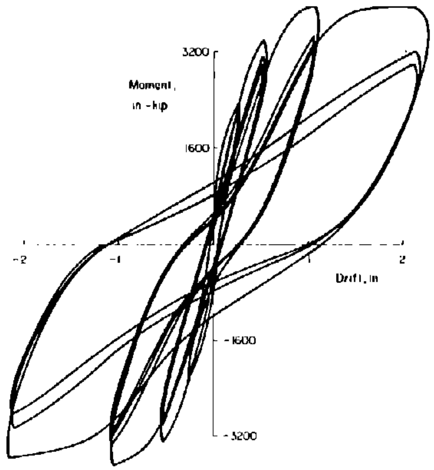
Top and bottom column moment versus drift relationships are shown in Figs. B72 and B73, respectively. The figures reflect the fact that the column moment immediately below the joint equalled 77% of the column moment immediately above the joint. A partial plastic hinge formed in the top column. However, considerable joint distress also occurred. Particularly large cracks formed in the joint, starting at the top column-beam intersections and extending diagonally towards the center of the joint. The bottom column drift was attributed to the joint shear distortion. Presence of shear distortions is indicated by pinching evident in both top and bottom hysteresis loops.

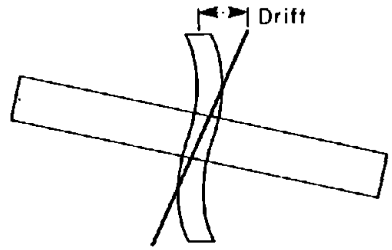
The first positive peak top column moment was 2424 in.-kip (274 kN·m). Corresponding top drift was 0.26 in. (6.7 mm). The maximum measured top column moment was 3906 in.-kip (9441 kN·m). It occurred at the positive peak of Cycle 9. The calculated nominal flexural strength of the column was 3254 in.-kip (368 kN·m). Therefore, the maximum measured moment was approximately 20% greater than calculated nominal flexural strength.

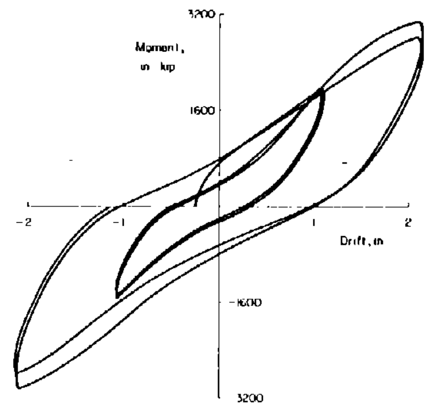
Due to the extensive joint damage, the test was ended after 21 cycles of loading. Photographs of the specimen at the end of Cycles 12 and 15 are shown in Figs. B74 and B75, respectively. Diagonal shear cracks running through the joint region are evident in Fig. B75.

Tabulated results

Tabulated values of top column moment, top and bottom column drifts, east and west beam deflections, and horizontal joint moment are shown in Table B85. Bottom column moment equalled

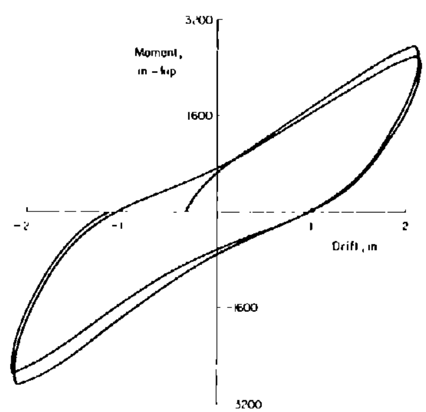






(a) $P=10\%P_o$

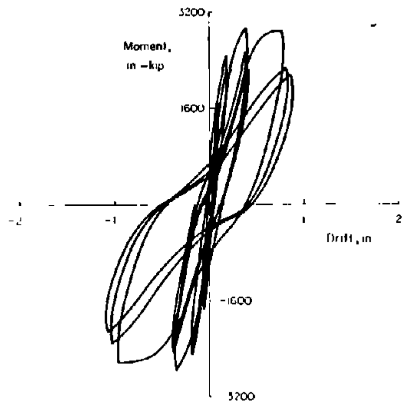
(b) $P=20\%P_o$

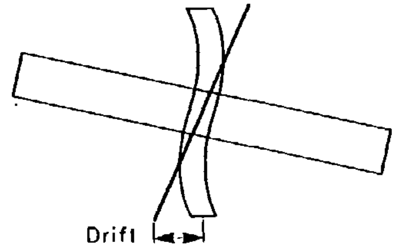


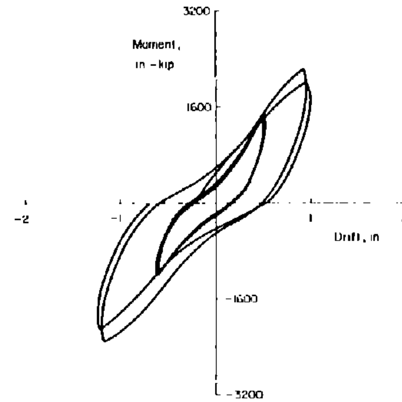
1 in.-kip = 0.113 kN·m
1 in. = 25.4 mm

(c) $P=30\%P_o$

Fig. B72 Top Column Moment versus Drift for Specimen LC13

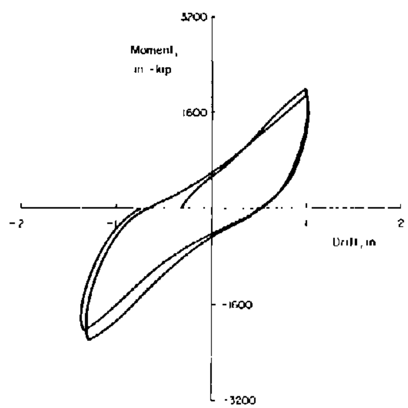






(a) P=10%P_o

(b) P=20%P_o



1 in.-kip = 0.113 kN·m
1 in. = 25.4 mm

(c) P=30%P_o

Fig. B7·3 Bottom Column Moment versus Drift for Specimen LC13

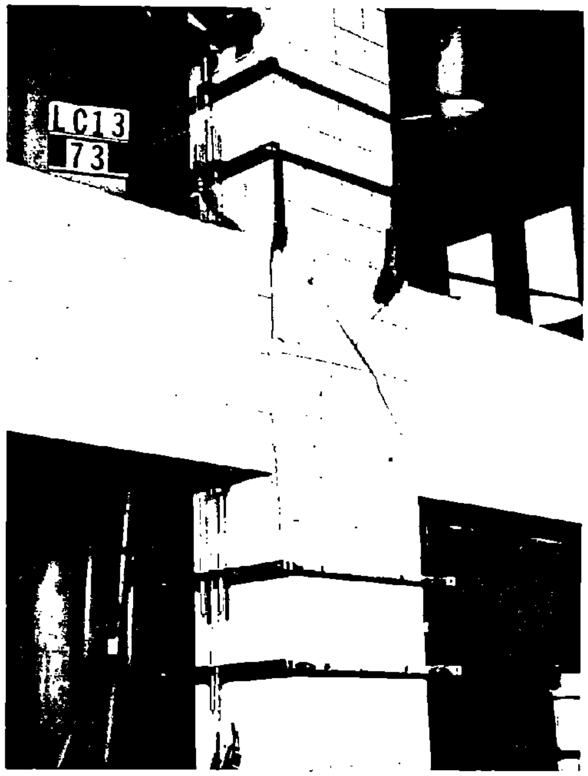


Fig. B74 Specimen LC13 after Cycle 12

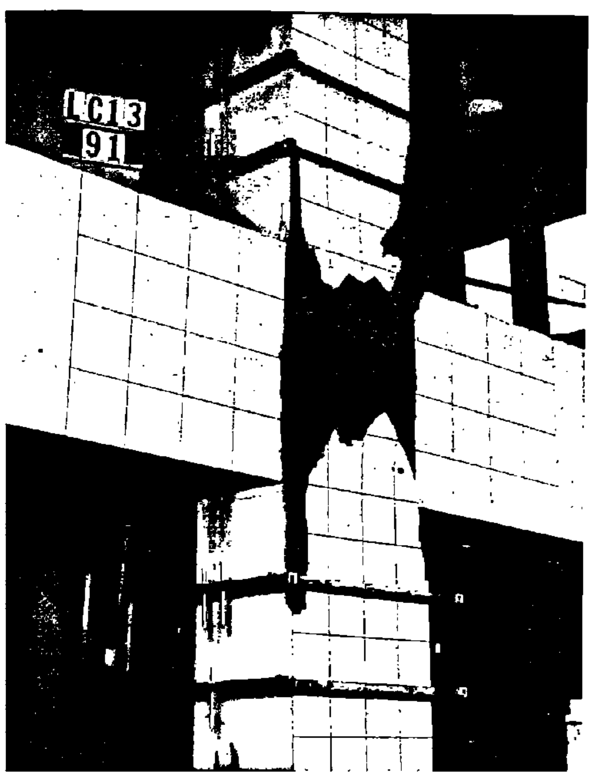


Fig. B75 Specimen LC13 after Cycle 15

TABLE B85 - COLUMN MOMENT, COLUMN DRIFTS, BEAM DEFLECTIONS, AND HORIZONTAL JOINT MOVEMENT FOR SPECIMEN LC13

CYCLE	MOMENT (IN.-KIP)	DRIFT (IN.)		DEFLECTION (IN.)		HORIZONTAL JOINT MOVEMENT (IN.)
		TOP	BOTTOM	EAST	WEST	
+ 1	1386	0.264	-0.083	1.352	-1.221	-0.103
- 1	-1246	-0.238	0.076	-1.073	1.232	0.092
+ 2	2232	0.262	-0.079	1.310	-1.197	-0.112
- 2	-2210	-0.242	0.079	-1.111	1.235	0.089
+ 3	3354	0.544	-0.182	2.158	-2.072	-0.497
- 3	-3251	-0.519	0.189	-1.958	2.093	0.460
+ 4	3073	0.541	-0.185	2.048	-2.003	-0.477
- 4	-2971	-0.515	0.188	-1.879	1.999	0.441
+ 5	2953	0.537	-0.197	2.034	-1.953	-0.465
- 5	-2913	-0.512	0.137	-1.873	2.005	0.435
+ 6	2901	0.512	-0.201	1.919	-1.958	-0.455
- 6	-2966	-0.539	0.131	-1.974	1.999	0.433
+ 7	2829	0.517	-0.157	1.913	-1.916	-0.455
- 7	-2919	-0.533	0.135	-1.933	2.011	0.433
+ 8	2767	0.520	-0.196	1.896	-1.962	-0.446
- 8	-2870	-0.529	0.138	-1.915	2.011	0.435
+ 9	3306	1.055	-0.369	3.167	-3.098	-0.753
- 9	-3591	-1.055	0.362	-2.948	3.034	0.714
+ 10	3397	1.059	-0.366	2.959	-2.882	-0.657
- 10	-3262	-1.055	0.391	-2.834	2.905	0.666
+ 11	3292	1.054	-0.392	2.922	-2.858	-0.677
- 11	-3140	-1.054	0.399	-2.834	2.880	0.671
+ 12	3233	1.061	-0.401	2.920	-2.858	-0.673
- 12	-3054	-1.054	0.408	-2.834	2.866	0.662
+ 13	3818	2.150	-0.762	4.729	-4.830	-1.201
- 13	-3462	-2.103	0.925	-4.805	4.791	1.005
+ 14	3091	2.108	-0.763	4.529	-4.611	-1.102
- 14	-2992	-2.101	1.023	-4.775	4.718	0.905
+ 15	2879	2.131	-0.843	4.601	-4.699	-1.054
- 15	-2760	-2.103	1.271	-4.763	4.726	0.853
+ 16	1923	1.101	-0.473	2.583	-2.616	-0.523
- 16	-1463	-1.046	0.502	-2.566	2.517	0.405
+ 17	1935	1.033	-0.473	2.565	-2.592	-0.511
- 17	-1541	-1.052	0.606	-2.625	2.547	0.407
+ 18	2999	2.126	-0.923	4.625	-4.679	-0.945
- 18	-2965	-2.091	1.156	-4.978	4.966	0.782
+ 19	2735	2.113	-0.951	4.594	-4.680	-0.897
- 19	-2704	-2.093	1.216	-4.984	4.972	0.733
+ 20	2670	2.108	-0.973	4.578	-4.615	-0.850
- 20	-2313	-2.093	1.292	-5.090	5.114	0.689
+ 21	2527	2.119	-0.936	4.535	-4.585	-0.827
- 21	-2615	-2.101	1.340	-5.104	5.133	0.655

1 in.-kip = 0.113 kN.m 1 in. = 25.4mm

77% of the tabulated top column moment. Column rotations, horizontal joint movements, and calculated joint shear distortions are listed in Table B86. Shear Diagonal Movements D_1 and D_2, and the shear distortion equation are illustrated in Fig. A9. Reinforcement strains are provided in Tables B87 through B90.

Specimen LC2

Specimen LC2 was manufactured using Lightweight Concrete 1. Column steel consisted of four No. 10 bars and four No. 9 bars. This corresponded to 4.04% of the gross column cross-sectional area. Other details including confinement steel are given in Table A1. This was the first specimen to be tested in the test program. Many problems were encountered. As a result, the usefulness of the test data is limited.

The column of Specimen LC2 was heavily reinforced causing very high shear stresses within the joint region. This resulted in a shear failure of the joint. The maximum joint shear force that occurred during basic loading cycles was 415 kips (1846 kN). This corresponded to a nominal effective shear stress of 28.5 $\sqrt{f'_c}$ psi (2.34 $\sqrt{f'_c}$ MPa). Design of subsequent specimens was changed to result in lower joint shear stresses.

Column moment history

Specimen LC2 was subjected to 12-1/2 cycles of moment reversals as shown in Fig. B76. The entire test was conducted at a column axial load equal to 10% of the column design strength. Due to heavy joint damage and problems with testing hardware, the test was ended after 12-1/2 cycles.

Tabulated results

Tabulated values of column moment, top and bottom drifts, and east and west beam deflections are given in Table B91. Column rotations are listed in Table B92. Reinforcement strains are given in Tables B93 through B96.

TABLE B86 - COLUMN ROTATIONS, SHEAR DIAGONAL MOVEMENTS, AND SHEAR DISTORTIONS FOR SPECIMEN LC13

CYCLE	ROTATION (RAD)				SHEAR DIAGONAL MOVEMENT (IN.)		SHEAR DISTORTION (RAD)
	ABOVE JOINT		BELOW JOINT				
	+D	+I/2	-D	-I/2	D1	D2	
+ 1	0.00526	0.00368	-0.00277	-0.00221	0.005	-0.018	0.00114
- 1	-0.00452	-0.00384	0.00264	0.00208	-0.016	0.012	-0.00141
+ 2	0.00511	0.00345	-0.00269	-0.00212	0.007	-0.018	0.00126
- 2	-0.00454	-0.00394	0.00286	0.00228	-0.016	0.013	-0.00151
+ 3	0.01006	0.00726	-0.00522	-0.00423	0.014	-0.032	0.00236
- 3	-0.00930	-0.00800	0.00556	0.00456	-0.041	0.037	-0.00398
+ 4	0.00991	0.00717	-0.00512	-0.00395	0.018	-0.032	0.00255
- 4	-0.00927	-0.00804	0.00530	0.00436	-0.041	0.042	-0.00423
+ 5	0.00977	0.00701	-0.00505	-0.00418	0.018	-0.034	0.00262
- 5	-0.00930	-0.00810	0.00532	0.00445	-0.044	0.045	-0.00450
+ 6	0.00951	0.00634	-0.00502	-0.00408	0.027	-0.029	0.00283
- 6	-0.00959	-0.00849	0.00545	0.00451	-0.040	0.053	-0.00474
+ 7	0.00935	0.00672	-0.00497	-0.00390	0.030	-0.031	0.00310
- 7	-0.00959	-0.00843	0.00544	0.00458	-0.041	0.054	-0.00431
+ 8	0.00915	0.00662	-0.00495	-0.00381	0.032	-0.037	0.00350
- 8	-0.00958	-0.00849	0.00543	0.00452	-0.043	0.054	-0.00491
+ 9	0.01847	0.01441	-0.00810	-0.00667	0.082	-0.093	0.00388
- 9	-0.01803	-0.01670	0.00817	0.00691	-0.122	0.107	-0.01163
+ 10	0.01765	0.01399	-0.00786	-0.00652	0.068	-0.107	0.00893
- 10	-0.01721	-0.01596	0.00806	0.00659	-0.122	0.085	-0.01054
+ 11	0.01734	0.01378	-0.00786	-0.00657	0.069	-0.135	0.01037
- 11	-0.01685	-0.01575	0.00817	0.00703	-0.126	0.098	-0.01090
+ 12	0.01734	0.01368	-0.00796	-0.00680	0.073	-0.137	0.01072
- 12	-0.01679	-0.01565	0.00819	0.00711	-0.130	0.092	-0.01127
+ 13	0.03652	0.02981	-0.01300	-0.01142	0.182	-0.243	0.02190
- 13	-0.03118	-0.02936	0.01631	0.01501	-0.260	0.243	-0.02559
+ 14	0.03512	0.02837	-0.01365	-0.01214	0.178	-0.234	0.02095
- 14	-0.02893	-0.02747	0.01718	0.01593	-0.238	0.285	-0.02911
+ 15	0.03425	0.02797	-0.01462	-0.01315	0.202	-0.253	0.02316
- 15	-0.02783	-0.02643	0.01757	0.01660	-0.302	0.307	-0.03094
+ 16	0.01768	0.01472	-0.00899	-0.00825	0.112	-0.159	0.01379
- 16	-0.01298	-0.01236	0.01027	0.00975	-0.187	0.171	-0.01817
+ 17	0.01704	0.01421	-0.00872	-0.00806	0.113	-0.162	0.01399
- 17	-0.01297	-0.01278	0.01033	0.00992	-0.190	0.169	-0.01823
+ 18	0.03208	0.02700	-0.01499	-0.01379	0.232	-0.287	0.02647
- 18	-0.02598	-0.02490	0.01898	0.01797	-0.345	0.335	-0.03459
+ 19	0.03126	0.02663	-0.01548	-0.01444	0.239	-0.306	0.02776
- 19	-0.02502	-0.02415	0.01961	0.01862	-0.363	0.353	-0.03641
+ 20	0.03002	0.02635	-0.01540	-0.01435	0.249	-0.328	0.02943
- 20	-0.02354	-0.02282	0.02034	0.01942	-0.407	0.360	-0.03907
+ 21	0.02950	0.02524	-0.01545	-0.01452	0.233	-0.352	0.02990
- 21	-0.02293	-0.02216	0.02090	0.02014	-0.438	0.362	-0.04082

1 in. = 25.4mm

TABLE B87 - WEST COLUMN STEEL STRAINS FOR SPECIMEN LC13

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	-740	-812	-770	-194	-31	1145	456	344	436
- 1	1090	1523	1474	1710	434	-117	-616	-567	-429
+ 2	-634	-781	-658	-305	23	1059	493	773	435
- 2	1177	1567	1504	1584	466	-98	-615	-573	-433
+ 3	-374	-1154	-1088	-913	369	1818	1292	1559	1191
- 3	2145	2507	2630	8605	1156	191	-639	-376	-679
+ 4	-920	-1075	-1194	1943	302	1633	1220	1419	1087
- 4	2054	2395	2636	8518	1166	242	-819	-800	-605
+ 5	-891	-1038	-1134	2420	217	1536	1171	1361	1047
- 5	2020	2363	2630	9509	1171	259	-812	-790	-597
+ 6	-875	-1023	-1169	3176	132	1467	1140	1309	1015
- 6	2060	2409	2720	9431	1226	273	-814	-800	-589
+ 7	-859	-1003	-1165	3440	141	1411	1119	1290	992
- 7	2031	2376	2704	9475	1212	279	-809	-792	-586
+ 8	-344	-983	-1150	3613	95	1355	1079	1233	949
- 8	2015	2156	2708	9496	1197	278	-812	-787	-586
+ 9	-1124	-1522	-1959	3837	374	2485	1754	1320	1453
- 9	2359	7610	10985	15061	1653	791	-991	-990	-741
+ 10	-1137	-494	-1373	4378	180	2208	1589	1641	1224
- 10	2227	7221	9545	14925	1580	851	-863	-912	-684
+ 11	-1114	-300	-1269	4800	-15	2130	1551	1539	1155
- 11	2166	7024	9113	14630	1552	895	-842	-387	-559
+ 12	-1103	-203	-1191	5120	-62	2086	1531	1565	1163
- 12	2128	6891	8858	14469	1520	928	-315	-970	-548
+ 13	-1765	-3143	-4852	5359	157	5058	1954	1865	1321
- 13	2601	10189	15493	24420	2349	4678	-467	-932	-709
+ 14	-1691	-3272	-3829	9339	-70	7553	2187	1502	1124
- 14	2294	8450	13533	23001	2134	5675	-376	-797	-627
+ 15	-1629	-2915	-3337	9214	-133	7895	2184	1507	1045
- 15	2257	7531	11320	20390	2049	6203	-196	-725	-591
+ 16	-1352	-305	-861	7482	-537	5091	882	387	119
- 16	514	2206	3575	11331	385	3575	-440	-543	-430
+ 17	-1234	-690	-1566	7070	-743	4214	628	330	99
- 17	589	2132	2414	10865	389	3226	-467	-562	-477
+ 18	-1725	-2172	-4705	5191	-691	5685	1587	894	495
- 18	1736	4641	5979	14799	1587	4677	-565	-902	-723
+ 19	-1604	-1977	-4202	2754	-644	5737	1575	739	397
- 19	1553	3799	4498	12090	1421	4605	-508	-330	-677
+ 20	-1651	-1906	-4571	-3192	-1015	4031	1093	388	62
- 20	961	2165	1439	4489	754	2196	-913	-1002	-909
+ 21	-1756	-1344	-4650	-7896	-1193	2692	316	332	7
- 21	32	1704	732	-145	562	1111	-	-969	-774

TABLE B88 - EAST COLUMN STEEL STRAINS FOR SPECIMEN LC13

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	1287	1735	1431	2007	748	69	-516	-513	-451
- 1	-644	-770	-731	-534	-14	1083	535	715	423
+ 2	1256	1606	1405	1813	775	59	-529	-710	-433
- 2	-550	-778	-752	-533	2	1093	529	706	467
+ 3	2232	2508	2403	3362	1453	383	-792	-1004	-655
- 3	-979	-1131	-1452	1650	134	1366	1155	1391	1372
+ 4	2161	2350	2312	9343	1448	414	-691	-979	-615
- 4	-924	-1143	-1471	1964	123	1762	1075	1200	1142
+ 5	2113	2279	2258	8159	1423	428	-673	-958	-593
- 5	-909	-1123	-1491	2147	93	1717	1045	1148	1113
+ 6	2041	2202	2229	7903	1365	408	-713	-857	-544
- 6	-913	-1153	-1502	2355	43	1753	1029	1300	1185
+ 7	2026	2177	2207	7785	1359	415	-699	-861	-536
- 7	-910	-1143	-1515	2378	32	1701	1022	1314	1157
+ 8	1968	2113	2145	7555	1326	405	-689	-791	-541
- 8	-909	-1146	-1524	2390	23	1658	1009	1319	1123
+ 9	2592	7827	8379	1753	1959	719	-951	-1122	-730
- 9	-1153	-979	-1993	1765	-40	2869	1400	1595	1475
+ 10	2339	6149	9313	-311	1756	915	-844	-883	-708
- 10	-1097	-709	-1763	1395	-155	2713	1353	1695	1318
+ 11	2344	5956	8210	208	1621	951	-615	-817	-689
- 11	-1067	-607	-1635	1379	-222	2643	1329	1657	1253
+ 12	2329	5948	8221	700	1645	973	-603	-900	-681
- 12	-1047	-542	-1519	1342	-252	2617	1320	1644	1232
+ 13	9143	11929	17544	443	3387	1749	-693	-826	-743
- 13	-354	-1204	-1431	471	-171	10620	1796	1914	1456
+ 14	8723	11065	16253	475	1571	5046	-644	-681	-651
- 14	14	-933	-792	-1904	-237	10732	1645	1879	1270
+ 15	6175	10244	14930	-694	1544	5977	-788	-590	-517
- 15	130	-764	-407	-4451	-167	10655	1814	1639	1172
+ 16	3851	3935	6013	-1952	494	4123	-844	-579	-515
- 16	674	-150	386	-4647	-733	5552	476	362	55
+ 17	3734	3671	5466	-1874	371	3965	-858	-591	-535
- 17	640	-339	244	-4600	-758	5379	488	372	73
+ 18	6174	7350	10228	-3095	1199	5151	-828	-336	-716
- 18	-15	-902	-893	-8660	-595	8750	1527	1062	683
+ 19	5373	6247	8930	-4302	1108	5244	-711	-1089	-661
- 19	51	-779	-738	-11900	-647	5193	1473	599	554
+ 20	4152	4455	6306	-6065	732	4026	-793	-1249	-729
- 20	-164	-901	-1157	-16317	-1105	5192	1091	-231	177
+ 21	3674	3796	5322	-	589	2015	-782	-1759	-701
- 21	-293	-896	-1167	-19263	-1291	5105	394	-558	137

TABLE B89 - TOP COLUMN HOOP STRAINS FOR SPECIMEN LC13

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	20	7	48	107	-35	48
- 1	36	-72	153	-9	51	53
+ 2	-12	-15	58	98	-19	53
- 2	15	-76	145	-17	70	32
+ 3	-32	-2	64	122	44	114
- 3	94	-65	225	-34	361	138
+ 4	-17	21	89	97	127	120
- 4	65	-60	211	-30	375	137
+ 5	-17	21	89	92	132	118
- 5	56	-59	207	-29	361	143
+ 6	66	125	100	113	117	149
- 6	134	44	218	-9	386	175
+ 7	55	115	100	107	119	149
- 7	115	28	213	-8	390	172
+ 8	20	84	94	98	118	134
- 8	35	4	206	-9	389	155
+ 9	-89	271	274	-64	89	215
- 9	40	163	295	108	587	236
+ 10	-67	185	251	-156	157	255
- 10	39	203	210	135	475	246
+ 11	-56	179	251	-182	161	256
- 11	50	212	205	145	455	249
+ 12	-52	178	257	-206	167	277
- 12	49	214	200	149	448	249
+ 13	157	361	454	-628	313	550
- 13	130	634	343	291	912	357
+ 14	334	295	461	-273	411	558
- 14	54	643	338	209	746	256
+ 15	350	263	449	-153	395	555
- 15	23	624	329	-228	648	-24
+ 16	226	163	328	-278	435	216
- 16	25	356	231	-243	113	-125
+ 17	232	142	253	-430	411	165
- 17	25	324	244	-258	121	-135
+ 18	431	193	483	-579	371	143
- 18	-13	524	313	-1044	352	-556
+ 19	449	135	485	-1699	462	-581
- 19	-19	484	327	-1708	156	-1187
+ 20	521	217	474	-1977	421	-662
- 20	-47	401	321	-2196	219	-1498
+ 21	526	124	481	-2871	498	-1237
- 21	-171	172	317	-2733	215	-2068

TABLE B90 - BOTTOM COLUMN HOOP STRAINS FOR SPECIMEN LC13

CYCLE	STRAIN MILLIONTHS					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	74	-47	-53	-75	23	86
- 1	-52	50	104	77	-21	59
+ 2	55	-57	-35	-56	22	83
- 2	-52	48	104	57	-20	67
+ 3	335	-54	103	-117	73	38
- 3	-47	122	135	302	22	245
+ 4	336	-44	120	-100	76	34
- 4	-35	113	131	270	22	220
+ 5	324	-44	117	-107	73	77
- 5	-36	112	130	270	22	210
+ 6	158	-4	117	-80	91	94
- 6	1	151	136	305	45	243
+ 7	344	-6	116	-86	56	90
- 7	-15	147	139	389	37	234
+ 8	321	-22	113	-108	73	82
- 8	-27	130	130	285	33	225
+ 9	505	-13	216	-147	120	138
- 9	-65	151	171	427	40	317
+ 10	450	-28	202	-152	105	117
- 10	-93	137	155	420	40	385
+ 11	444	-27	202	-157	101	113
- 11	-94	135	156	421	41	279
+ 12	446	-26	202	-162	97	114
- 12	-93	128	166	430	42	371
+ 13	535	-21	269	-255	167	154
- 13	30	156	205	575	95	397
+ 14	709	19	297	-253	143	149
- 14	33	138	202	732	103	378
+ 15	725	55	303	-300	125	154
- 15	7	127	202	720	111	357
+ 16	420	20	131	-126	117	143
- 16	-5	101	175	339	52	57
+ 17	356	13	131	-137	112	114
- 17	-73	101	182	350	50	57
+ 18	674	45	206	-315	112	169
- 18	40	133	257	785	106	108
+ 19	715	65	207	-349	127	-689
- 19	-70	135	243	772	112	-1324
+ 20	648	60	160	-349	158	-959
- 20	154	179	367	756	103	-969
+ 21	679	43	147	-193	157	-1547
- 21	-	197	357	742	-26	-1586

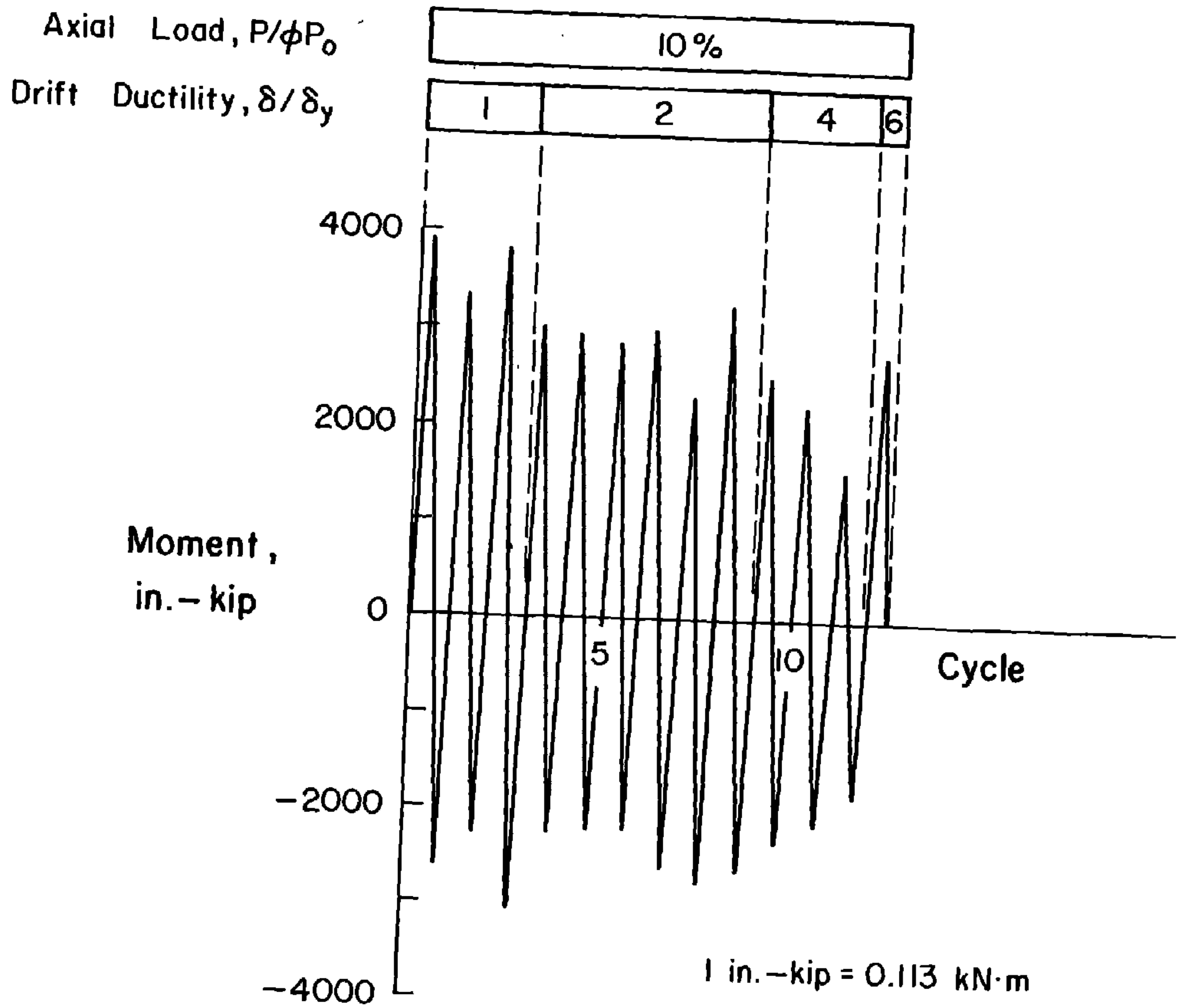


Fig. B76 Column Moment History for Specimen LC2

TABLE B91 - COLUMN MOMENT, COLUMN DRIFTS, AND BEAM DEFLECTIONS FOR SPECIMEN LC2

CYCLE	MOMENT (IN.-KIP)	DRIFT (IN.)		DEFLECTION (IN.)	
		TOP	BOTTOM	EAST	WEST
+ 1	3899	-0.567	-0.591	2.833	-2.824
- 1	-2642	0.853	0.595	-1.963	2.054
+ 2	3359	-0.713	-0.701	2.583	-2.734
- 2	-2579	0.902	0.803	-2.207	2.046
+ 3	3731	-1.137	-1.051	3.493	-3.737
- 3	-3015	1.345	0.937	-2.947	2.954
+ 4	3027	-0.912	-0.338	2.752	-3.058
- 4	-2246	1.099	0.315	-2.386	2.407
+ 5	2968	-0.649	-0.144	2.863	-3.040
- 5	-2135	1.187	-0.321	-2.423	2.392
+ 6	2878	-0.641	-0.544	2.786	-3.058
- 6	-2210	1.070	0.756	-2.386	2.344
+ 7	2998	-0.738	-0.302	2.939	-3.250
- 7	-3870	1.539	..271	-3.424	3.428
+ 8	2321	-0.481	-0.522	3.153	-2.439
- 8	-2792	1.312	-0.369	-3.871	3.842
+ 9	3627	—	—	4.982	-5.213
- 9	-2596	—	—	-4.951	4.854
+ 10	2524	—	—	3.672	-3.965
- 10	-3272	—	—	-5.464	5.344
+ 11	3239	—	—	3.245	-6.521
- 11	-2138	—	—	-6.263	6.209
+ 12	1873	—	—	2.410	-2.710
- 12	-1746	—	—	-6.174	6.132
+ 13	2806	—	—	6.118	-6.603
- 13	445	—	—	3.281	-3.395

1 in.-kip = 0.113 kN.m   1 in. = 25.4mm

TABLE B92 - COLUMN ROTATIONS FOR SPECIMEN LC2

CYCLE	ROTATION (RADIANS)			
	ABOVE JOINT		BELOW JOINT	
	+D	+D/2	-D	-D/2
+ 1	—	0.00962	-0.00979	-0.00832
- 1	—	-0.00548	0.00766	0.00587
+ 2	—	0.01099	-0.00963	-0.00790
- 2	—	-0.00546	0.00811	0.00620
+ 3	—	0.01814	-0.01377	-0.01207
- 3	—	-0.00823	0.01164	0.01051
+ 4	—	0.01744	-0.01133	-0.00979
- 4	—	-0.00530	0.00951	0.00919
+ 5	—	0.01870	-0.01151	-0.00997
- 5	—	-0.00516	0.00965	0.00936
+ 6	—	0.01909	-0.01145	-0.00995
- 6	—	-0.00469	0.00940	0.00925
+ 7	—	0.02084	-0.01200	-0.01048
- 7	—	-0.00969	0.01442	0.01410
+ 8	—	0.01731	-0.00900	-0.00739
- 8	—	-0.01240	0.01670	0.01684
+ 9	—	0.03313	-0.02139	-0.01961
- 9	—	-0.01782	0.02121	0.02360
+ 10	—	0.02724	-0.01696	-0.01672
- 10	—	-0.02145	0.02635	0.02744
+ 11	—	0.02246	-0.01455	-0.01431
- 11	—	-0.02681	0.03033	0.03284
+ 12	—	0.01674	-0.01147	-0.01095
- 12	—	-0.02741	0.03011	0.03305
+ 13	—	0.03835	-0.02939	-0.02935
- 13	—	0.02669	-0.01635	-0.01781

TABLE B93 - WEST COLUMN STEEL STRAINS FOR SPECIMEN LC2

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1	-1289	-1570	-	-	647	3892	2270	10941	1735
- 1	1362	1901	-	-	677	669	-1476	10377	630
+ 2	-1103	-1542	-	-	425	3938	1910	13716	1952
- 2	1944	1892	-	-	540	647	-1486	9740	784
+ 3	-1374	-2127	-	-	593	6930	2465	13801	3197
- 3	2499	2253	-	-	743	1671	-1569	12613	605
+ 4	-1175	-1971	-	-	250	5333	1308	13542	2206
- 4	1950	1740	-	-	485	1690	-1581	13644	911
+ 5	-1150	-1371	-	-	168	5150	1773	14004	2013
- 5	1324	1712	-	-	455	1597	-1657	9873	359
+ 6	-1136	-1840	-	-	153	5049	1723	14345	1992
- 6	1992	1851	-	-	458	1727	-1620	10133	1107
+ 7	-1362	-1798	-	-	238	5297	1997	15218	3089
- 7	2525	2291	-	-	715	1584	-2020	10162	1314
+ 8	-324	-1457	-	-	18	4286	1277	14483	2372
- 8	2501	2396	-	-	692	1335	-2068	10106	1157
+ 9	-1300	-2211	-	-	497	5893	2697	13563	2847
- 9	2293	2253	-	-	579	978	-2299	11333	1063
+ 10	-874	-1639	-	-	180	6390	1891	14354	2245
- 10	2025	2021	-	-	455	155	-2211	10175	1679
+ 11	-760	-1434	-	-	65	5728	1547	13773	2255
- 11	1957	1948	-	-	430	-1748	-2301	8155	1102
+ 12	-598	-1214	-	-	-56	3455	1295	13831	2374
- 12	1642	1644	-	-	291	-3619	-2473	4394	1109
+ 13	-1029	-1937	-	-	260	5698	2004	11757	2303
- 13	-39	-355	-	-	-403	1959	-562	10671	1540

TABLE B94 - EAST COLUMN STEEL STRAINS FOR SPECIMEN LC2

CYCLE	STRAIN (MILLIONTHS)								
	ABOVE JOINT			WITHIN JOINT			BELOW JOINT		
	#1	#2	#3	#4	#5	#6	#7	#8	#9
+ 1 - 1	- -	9333 8434	- -	- -	1539 741	10 1189	-431 2104	-1472 1850	3651 5504
+ 2 - 2	- -	9675 8751	- -	- -	1112 706	93 1244	-211 2109	-1316 1878	7713 7413
+ 3 - 3	- -	8559 7776	- -	- -	1242 564	139 1996	-443 2716	-1625 2334	8284 8695
+ 4 - 4	- -	8854 7571	- -	- -	741 214	387 1455	-72 2198	-1336 1654	9157 9309
+ 5 - 5	- -	8854 7723	- -	- -	721 270	403 1470	-36 2234	-1352 1518	9465 9745
+ 6 - 6	- -	8901 12272	- -	- -	644 360	414 1540	73 2370	-1310 1581	9617 10545
+ 7 - 7	- -	12989 12866	- -	- -	300 661	565 1953	592 3637	-1362 2295	11577 10341
+ 8 - 8	- -	12215 10468	- -	- -	573 660	571 1995	591 3771	-1099 2313	11531 9773
+ 9 - 9	- -	19180 16661	- -	- -	993 789	741 2319	36 4696	-1742 2321	11467 9975
+ 10 - 10	- -	11568 18249	- -	- -	479 485	570 2154	631 4186	-1403 2075	11773 10079
+ 11 - 11	- -	-8628 14754	- -	- -	439 432	650 2216	1084 4265	-1218 1967	11621 9976
+ 12 - 12	- -	8020 12389	- -	- -	325 192	515 1970	1377 3765	-1167 1638	12552 9976
+ 13 - 13	- -	-3240 -5347	- -	- -	973 -20	1036 956	695 1993	-1650 -750	10231 9665

TABLE B95 - TOP COLUMN HOOP STRAINS FOR SPECIMEN LC2

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	8073	-	1172	11261	-	1474
- 1	1390	-	1789	5120	-	605
+ 2	15673	-	2575	20685	-	1311
- 2	-1005	-	1569	6295	-	546
+ 3	17446	-	2408	23616	-	1407
- 3	2235	-	3913	9125	-	841
+ 4	14309	-	2296	22538	-	1127
- 4	399	-	2215	9434	-	793
+ 5	14412	-	2329	22741	-	1091
- 5	-2033	-	2486	9379	-	769
+ 6	14045	-	2392	22991	-	1055
- 6	197	-	3273	10561	-	775
+ 7	15217	-	3155	24546	-	1136
- 7	-1048	-	3677	11084	-	915
+ 8	14001	-	3117	24282	-	930
- 8	-1827	-	3339	11232	-	924
+ 9	18157	-	2863	27925	-	1377
- 9	-1534	-	3990	15741	-	999
+ 10	13934	-	3091	31310	-	919
- 10	-2662	-	3162	17131	-	954
+ 11	11730	-	2963	33629	-	804
- 11	-1839	-	3206	15759	-	939
+ 12	11675	-	3825	34547	-	586
- 12	-2353	-	2869	15741	-	-
+ 13	16357	-	3732	37582	-	384
- 13	15320	-	3476	30743	-	717

TABLE B96 - BOTTOM COLUMN HOOP STRAINS
FOR SPECIMEN LC2

CYCLE	STRAIN (MILLIONTHS)					
	WEST			EAST		
	#1	#2	#3	#1	#2	#3
+ 1	-13	352	616	-57	506	339
- 1	333	175	684	71	462	339
+ 2	478	474	788	-64	765	390
- 2	272	337	743	108	585	539
+ 3	520	694	1020	-53	954	503
- 3	184	350	917	148	723	698
+ 4	545	639	999	14	944	538
- 4	236	389	926	157	718	706
+ 5	537	526	1014	-18	944	544
- 5	272	411	950	316	745	693
+ 6	550	612	1022	9	945	538
- 6	423	488	1008	395	905	719
+ 7	580	709	1120	131	1133	558
- 7	494	561	1122	416	1042	980
+ 8	583	636	1086	256	1035	498
- 8	463	525	1104	452	1057	985
+ 9	746	952	1315	511	1315	663
- 9	475	674	1233	367	1175	1022
+ 10	954	734	1270	496	1219	580
- 10	537	627	1307	316	1132	906
+ 11	971	709	1223	521	1229	467
- 11	545	428	1201	379	1229	721
+ 12	959	356	1179	452	1153	509
- 12	217	-45	1137	399	1188	494
+ 13	974	223	1350	-391	1312	50
- 13	791	-57	1173	189	1147	-16