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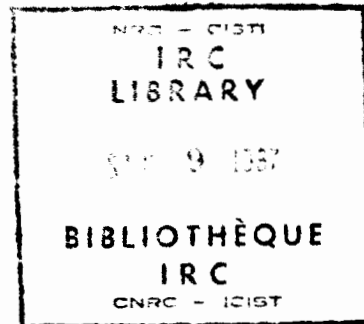
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construction

**Fire resistance of reinforced
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Test results**

T.T. Lie and J.L. Woollerton

Internal Report No. 569

Date of issue: July 1988



This is an internal report of the Institute for Research in Construction. Although not intended for general distribution, it may be cited as a reference in other publications.

Canada

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1 INTRODUCTION

1.1 BACKGROUND [1]

Studies on columns were started a few years ago for the purpose of updating the fire resistance ratings for reinforced concrete columns in the National Building Code of Canada [2, 3]. These ratings were related to full scale test results obtained in about 1920. Since that time, design procedures have changed and the safety factor has decreased. This indicates a need for revision of these ratings.

Facilities for testing columns have been constructed recently at the National Research Council of Canada. Using these facilities, it is possible to study experimentally the influence of the various factors that determine the fire resistance of columns. It is also possible to validate the mathematical models that have been developed for the prediction of the fire resistance of reinforced concrete columns.

The present study was an extension of the previous studies [2, 3]. It was undertaken in cooperation with the Portland Cement Association. Its main objectives were:

- a) To generate measured fire resistance data on reinforced concrete columns designed in accordance with current ACI 318-83 or CSA-CAN A23.3-M84 Building Codes.
- b) To develop general methods for the calculation of the fire resistance of concrete columns and walls for a wide range of applications.

1.2 PROGRAM

The National Research Council and the Portland Cement Association jointly worked out a three-phase program to study the behaviour of 41 full size reinforced concrete columns exposed to fire. The effect of the following variables on fire resistance was investigated:

- a) area of cross-section
- b) shape of cross-section (square, rectangular, circular)
- c) thickness of concrete cover
- d) percentage of longitudinal reinforcing steel
- e) lateral reinforcement: tied or spiral
- f) concrete mixture (type of aggregate)
- g) concrete strength
- h) moisture content of concrete (relative humidity)
- i) end conditions
- j) axial or rotational restraint
- k) load intensity
- l) load eccentricity
- m) fire exposure intensity.

The studied effects included:

- a) column temperatures
- b) column deflections
- c) time to failure
- d) residual strength when exposed to short-duration fires.

Mathematical models, capable of simulating these conditions, were developed and programmed for computer processing by NRC prior to the start of the joint research program. By comparing calculated results with those obtained during testing, the validity of the mathematical models can be verified.

A general description of the specimens and the test conditions follows. The third chapter contains in-depth descriptions of each test: all study parameters, visual test observations, drawings and photographs of the specimens, and numerical results.

Please note that where any original measurements were made in imperial units, these values appear in parentheses following the converted value in metric units. Sizes of reinforcing bars are left in imperial units, as there are no metric equivalents.

2 GENERAL DESCRIPTION OF SPECIMENS AND TESTS

2.1 TEST SPECIMENS - PROPERTIES

The basic properties of the 41 column specimens are listed in Tables 2.1a to d. Seven nearly identical reference specimens were tested under different loads, and these are indicated with an asterisk in the Tables. They differed only in measured concrete strength and relative humidity.

2.1.1 Dimensions

All columns were 3810 mm (12 ft 6 in.) long from endplate to endplate.

The reference cross-section was 305 x 305 mm (12 x 12 in.). Square sections of 203 mm (8 in.) and 406 mm (16 in.), rectangular sections of 305 x 457 mm (12 x 18 in.) and 203 x 915 mm (8 x 36 in.), and circular sections of 355 mm (14 in.) diameter were also used to investigate the effect of size and shape on fire resistance. Several 12 x 12 columns were built with brackets for eccentric loading.

All but one column had 38 mm (1.5 in.) cover to the tie bars, and 48 mm (1.875 in.) cover to the vertical steel. Column II-12 had 64 mm (2.5 in.) cover to the vertical steel.

2.1.2 Materials

a) Cement:

Type I Cement, a general purpose cement for construction of reinforced concrete structures, was used.

b) Aggregate:

3 types were used: siliceous sand and gravel from Eau Claire, Wisconsin; carbonate sand and gravel from Elgin, Illinois; and lightweight expanded shale manufactured by the Solite Corporation. The maximum size of the aggregate was 19 mm (3/4 in.). The petrographic information, given in Tables 2.2 and 2.3, was obtained following the procedures of ASTM C295-65 [4]. Sieve analyses were conducted, and gradation curves aggregates are shown in Figures 2.1 and 2.2. Other information needed for proportioning the mix, such as specific gravity, moisture content, unit weight, and fineness modulus of the aggregates is listed in Table 2.4.

c) Steel:

Deformed bars meeting requirements of ASTM Designation A615-80 [5] were used for main and tie bars. The longitudinal steel in the columns were symmetrical arrangements of No. 6, 7, 8 or 10 bars. All ties were No. 3 bars. A tensile test was performed for each bar size to determine yield and ultimate strength, and the results are listed in Table 2.6.

2.1.3 Concrete Mix

Several trial mixes for determining optimum proportions were made to produce a 34.5 MPa (5000 psi) strength non-air-entrained concrete for most columns. The lightweight columns were air-entrained, and some mixes were designed for higher strength. Batch quantities and measured properties of fresh concrete are given in Table 2.5.

The average 28-day concrete strengths were 39 MPa for siliceous (not including high-strength), 36 MPa for carbonate, and 36 MPa for lightweight aggregate concrete. Cylinders were tested at 28 days and on the test date, and the results are given in Table 2.1.

2.1.4. Fabrication

The columns were cast in specially designed forms. The reinforcement cage was assembled by welding the longitudinal bars to a steel end plate. Chromel-alumel thermocouples were secured to the reinforcing steel at specified locations after the cage was properly positioned in the form. In order to avoid any possible dislocation of the thermocouples during casting, a careful working plan was followed as described below.

2.1.5 Reinforcing Bars and Steel Plates

The standard cross-section (12 x 12 in.) had 2.19% steel reinforcement, with four No. 8 bars. As a variation, one column had double this amount of steel. Drawings of the main reinforcing bars and cross-sections are provided in Chapter 3.

The column length was 3810 mm (12 ft 6 in.) measured from end plate to end plate. The longitudinal reinforcing bars were cut to 3800 mm and machined at both ends to the diameters (measured by micrometer) shown in the figures entitled "Finishing Detail" in Chapter 3.

The dimensions of the end plates are also shown in these figures. Holes with a diameter 1.6 mm (1/16 in.) greater than that of the machined ends were drilled through the plates to accommodate the longitudinal bars. This information is summarized in Table 2.7.

The main bars and ties were tied together to complete the steel cage. The cage then was placed vertically on a leveled end plate in such a way that the machined segments of the bars were positioned in the holes.

2.1.6 Welding

The provisions of AWS Designation D12.1-75 [6] were followed when welding plates and bars. To prevent any possible brittle failure during welding, these members were preheated with a propane torch to 288°C (550°F). The side fillet weld was done around bars on the inner face of the bottom plate. McKay E10018-D2 and DYTRON-579 welding rods were used. Both types of welding rods have tensile strength of 835 MPa (120 ksi). Mild-steel welding rods were used to fill up the holes on the outer faces of the plate, drilled to accommodate the reinforcing bars. The rough surface of the welded joints on the outer face of the plate were ground to a smooth finish.

The welding of the top steel plate was performed after the casting of the columns. Before positioning the top plate, a 6 mm (1/4 in.) layer of mortar was spread over the top of the column to ensure good contact between steel plate and concrete. The mortar was made of 1 part of cement and 3 parts of siliceous sand. Using the same procedure as for the bottom plate, the top plate was welded on the outer side to the bars and smoothed.

2.1.7 Forms

Forms were made of smooth plywood, with the front side left open for depositing fresh concrete. As the casting progressed upwards, window pieces made of plywood were bolted to the form to close the opening.

2.1.8 Thermocouples

Butt-welded chromel-alumel thermocouples with a thickness of 0.91 mm were used to make thermocouple frames for measuring concrete temperatures at several locations in different cross sections of the columns. Each frame consisted of a number of thermocouples tied to steel rods that were firmly secured to the main reinforcing bars.

For the first series, temperatures were measured at three levels: at one-quarter height, at mid-height and at three-quarter height of the column. At mid-height, the temperatures were measured along the whole length of an axis and a diagonal of the section; at the other two levels, the temperatures were measured only along half of the axis and half of the diagonal of the section.

For all other columns, only the frame at mid-height, or a similar one, was used.

In addition, a number of thermocouples were mounted on the reinforcing steel bars and ties of all columns. Exact location and numbering of thermocouples is shown in the third chapter.

2.1.9 Concrete Placement

Concrete was mixed in a 0.17 m^3 (6 cu ft) tilting drum mixer. Shovels and scoops were used to deposit concrete in the form. A small internal vibrator was carefully applied to consolidate the concrete. As the casting progressed upward, the window pieces were successively closed and tightly bolted to the form to avoid possible mortar leaks. The top surface of the column was screeded and finished with a small wood float.

Lifting hooks were embedded on opposite sides of the specimen at 0.8 m (2 ft 7 in.) from the top of the column. A humidity well was positioned at mid-point for measuring relative humidity at mid-depth of the columns [7].

2.1.10 Curing

Concrete was cured under damp burlap for 7 days at 21 to 24°C (70 to 75°F). Forms were then stripped, and most columns conditioned in an atmosphere controlled at the same temperature and 30 to 40% relative humidity. In calculations, their moisture content was assumed to be 5% by volume.

Four columns, tested at a near-oven-dry condition, were kiln-dried at about 93°C (200°F) and 0 to 5% relative humidity. They were removed from the kiln periodically to cool at 23°C (73°F) so that the relative humidity in the concrete could be measured. After the desired moisture condition was reached, the columns were wrapped in plastic to prevent any change. The moisture content of these columns was assumed to be 0%.

The welding of the top steel plate was performed after the casting of the columns. Before positioning the top plate, a 6 mm (1/4 in.) layer of mortar was spread over the top of the column to ensure good contact between steel plate and concrete. The mortar was made of 1 part of cement and 3 parts of siliceous sand. Using the same procedure as for the bottom plate, the top plate was welded on the outer side to the bars and smoothed.

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2.2 TEST APPARATUS

The tests were carried out by exposing the columns to heat in a furnace specially built for testing loaded columns and walls. The test furnace was designed to produce the conditions to which a member might be exposed during a fire, i.e. temperatures, structural loads, and heat transfer. It consists of a steel framework supported by four steel columns, with the furnace chamber inside the framework (Figure 2.3). The characteristics and instrumentation of the furnace are described in detail in reference [8]. Only a brief description of the furnace and the main components is given here.

2.2.1 Loading Device

Three hydraulic jacks produce forces along the three principal axes. The jack acting along the axis of the test column is located at the bottom of the furnace chamber. The plate on top of this jack can be used as a platform to which the column can be attached.

2.2.2 Furnace Chamber

The furnace chamber has a floor area of 2642 x 2642 mm (8 ft 8 in.) and is 3048 mm (10 ft) high. The interior faces of the chamber are lined with insulating materials that efficiently transfer heat to the specimen. There are 32 propane gas burners in the furnace chamber, arranged in eight columns containing four burners each. The total capacity of the burners is 4700 kW (16 million Btu/h). Each burner can be adjusted individually, which allows for a high degree of temperature uniformity in the furnace chamber. The pressure in the furnace chamber is also adjustable. It was set somewhat lower than atmospheric pressure.

2.2.3 Instrumentation

The furnace temperatures are measured with the aid of eight chromel-alumel thermocouples. The junction of each thermocouple was located 305 mm (1 ft) from the test specimen, at various heights. Two thermocouples were placed opposite each other at intervals of 610 mm (2 ft) along the height of the furnace chamber. The location of their junctions and their numbering are shown in Figure 2.4. Thermocouples 4 and 6 were located at a height of 610 mm (2 ft) from the floor, thermocouples 2 and 8 at 1220 mm (4 ft), thermocouples 3 and 5 at 1830 mm (6 ft) and thermocouples 1 and 7 at 2440 mm (8 ft). The temperatures measured by the thermocouples are averaged automatically and the average temperature used as the criterion for controlling the furnace temperature.

The loads are controlled and measured using pressure transducers. The accuracy of controlling and measuring loads is about 20 kN (5 kips) at lower load levels and relatively better at higher loads.

The axial deformation of the test specimen is determined by measuring the displacement of the jack that supports the column. The displacement is measured using transducers with an accuracy of 0.002 mm.

2.3 TEST CONDITIONS AND PROCEDURES

The columns were installed in the furnace by bolting their end plates to a loading head at the top and a hydraulic jack at the bottom. Most end conditions were fixed-fixed, but different effective lengths were achieved in some tests by pinning one or both ends of the column, or allowing horizontal translation at the top. In two tests (III-2 and III-3), the columns were full restrained against thermal expansion by controlling the load. [9]

Before each test, the moisture condition in the centre of the column was measured with a Monfore humidity gauge [7]. The readings are recorded in Table 2.1.

2.3.1. Loading

All loads were applied at least 40 minutes before the test, in 4 or more stages. They varied from zero to higher than the maximum allowable [10, 11], which was calculated based on the assumption that only the dead and part of the live load are present during a fire. All other loads, such as wind and earthquake, were neglected. The test loads were then used in the mathematical models for the calculation of theoretical fire resistance.

The fire response of columns to eccentric load was also examined using both the regular cross-section and specially designed columns with brackets. In some tests, the initial rotation (after loading) was held constant during fire exposure; in others, the column was free to rotate.

2.3.2 Fire Exposure

Most columns were subjected to the standard ASTM-E119 (ULC-S101) temperature-time curve [12, 13]. In testing for residual strength, columns T-1 and T-2 were exposed to only the first hour and the first two hours, respectively, of the standard fire. They were cooled at a controlled temperature, then loaded to failure after 24 hours. [14]

Another column (II-4) was exposed to a high-intensity fire which simulated a hydrocarbon oil pool fire. To check the accuracy of the calculated initial strength, one column (III-13) underwent a room-temperature crush.

2.3.3 Recording of results

Readings were taken at each thermocouple location at intervals of 5 or 10 minutes. Axial strain was also measured. In addition, for some tests, horizontal displacement or angle of rotation was recorded.

The columns were considered to have failed, and the tests were terminated, when the hydraulic jack, which has a maximum speed of 76 mm/min (3 in./min), could no longer maintain the load.

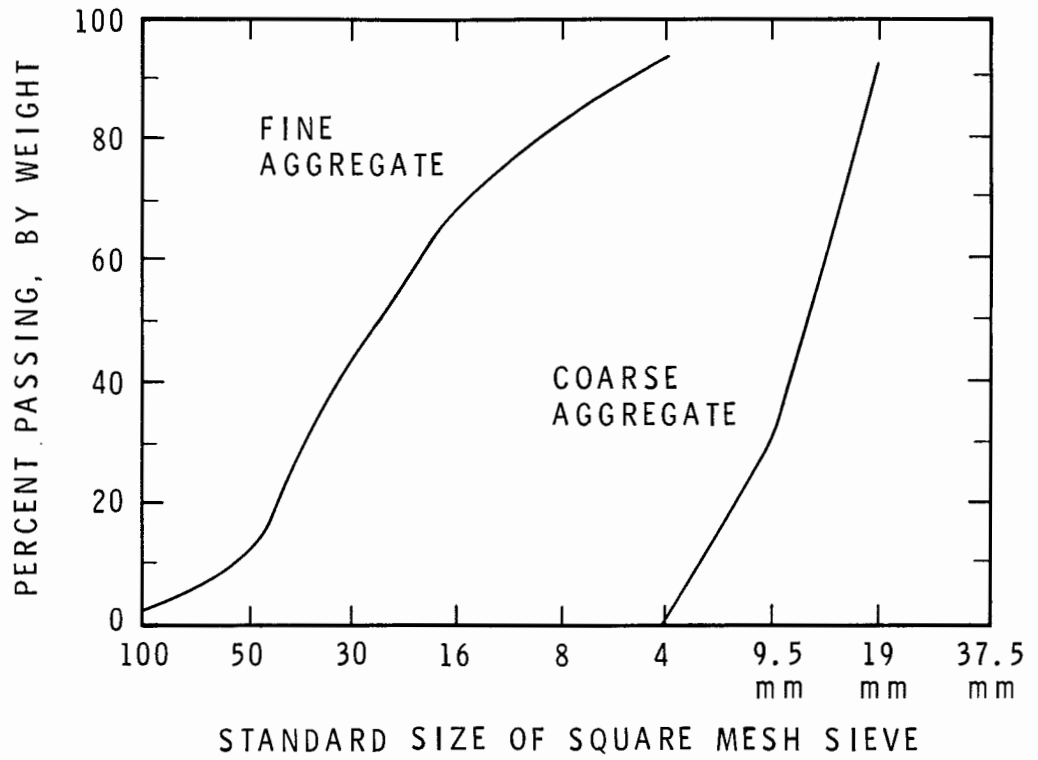


Figure 2.1 Gradation Curves for Siliceous Aggregate

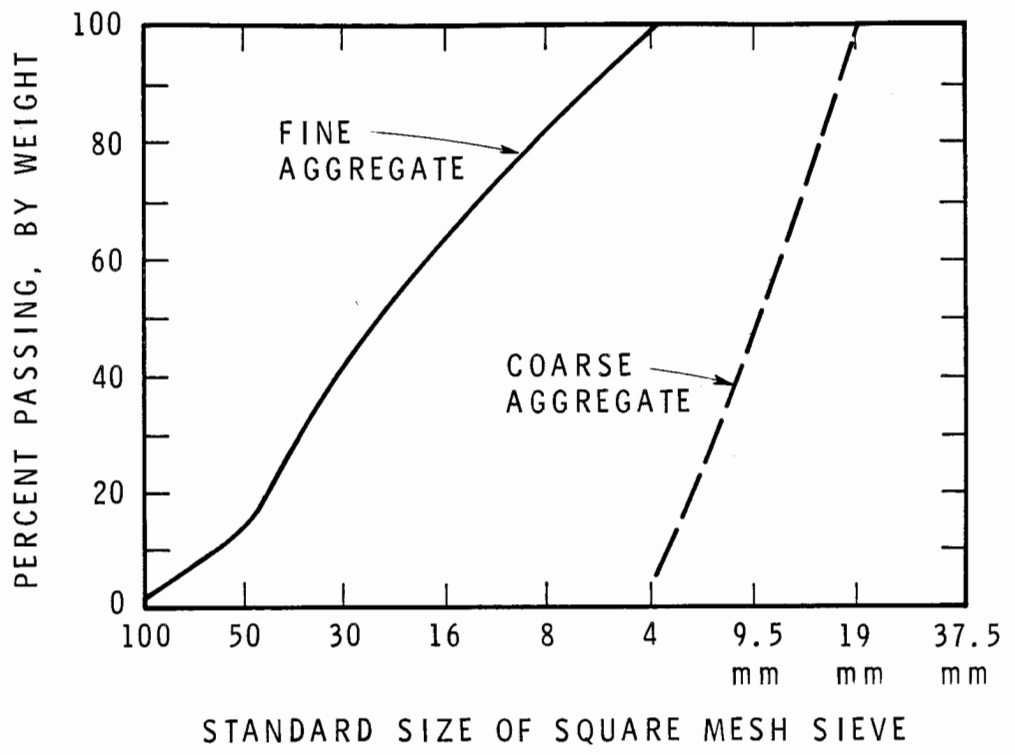


Figure 2.2 Gradation Curves for Carbonate Aggregate

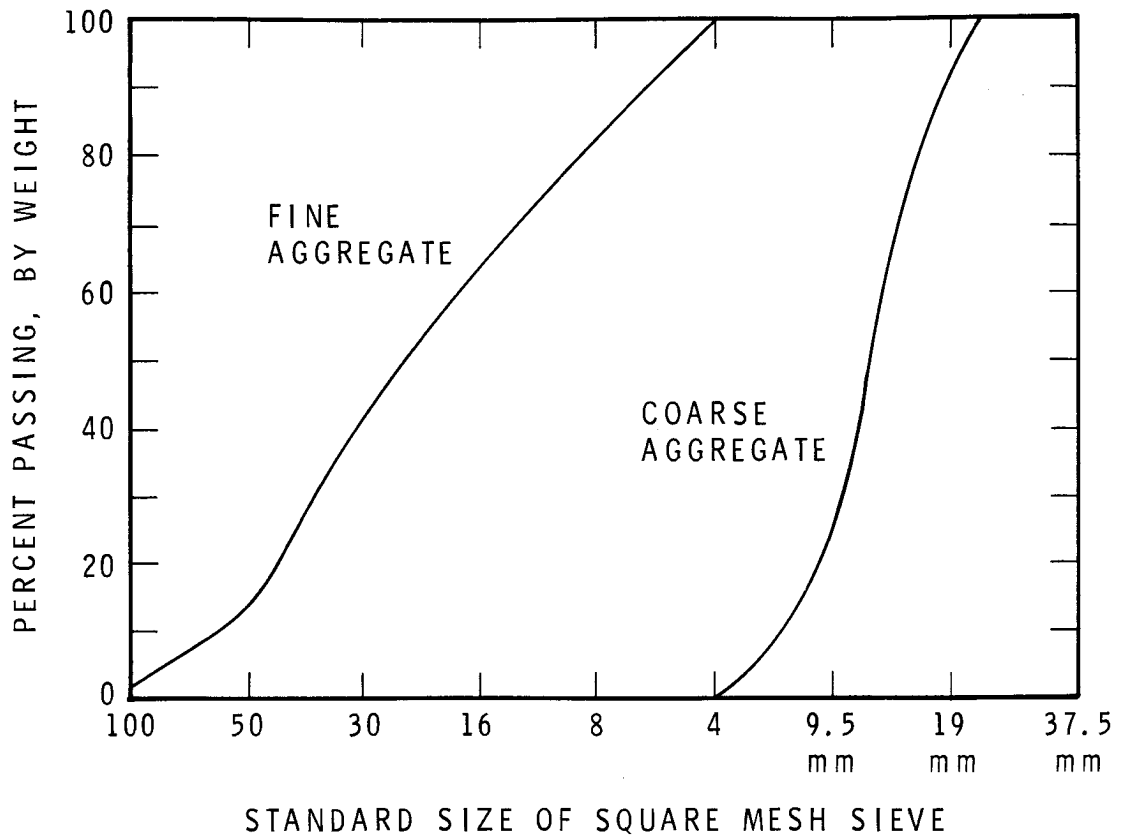


Figure 2.3 Gradation Curves for Lightweight Aggregate

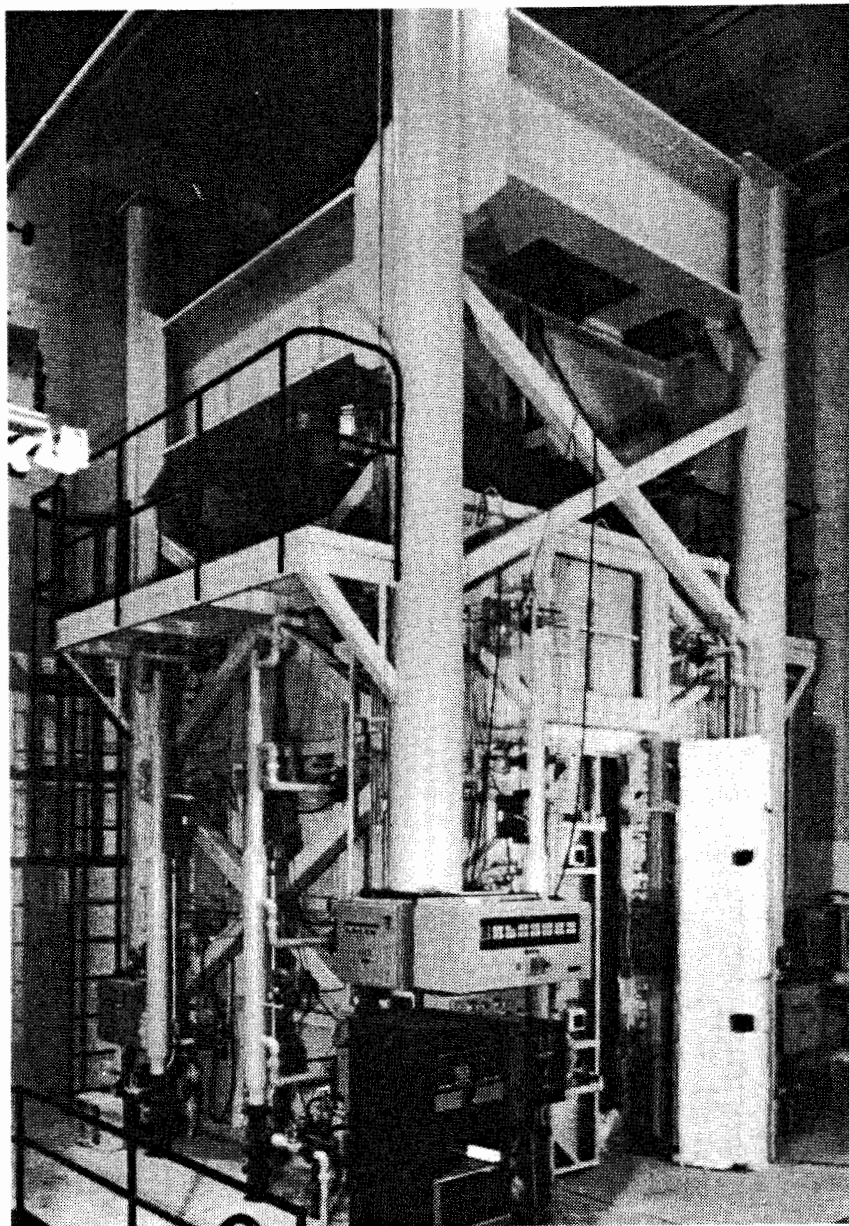


Figure 2.4 Column Furnace

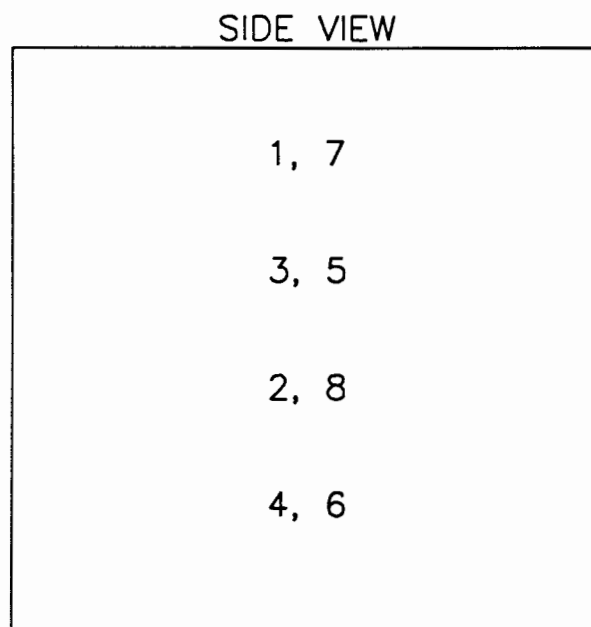
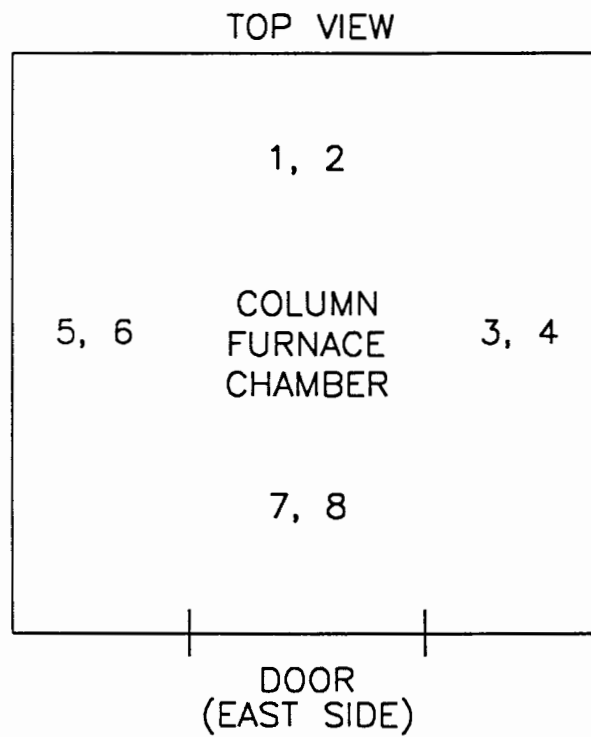


Figure 2.5 T/C Locations for Furnace Temperatures

Tables 2.1a to 2.1d Summaries of Test Parameters and Results

Table 2.1a Series I

Column #	Group	Test Purpose	X-Section in.	Steel %	Aggregate	R.H. %	fc' (MPa) 28 day	test	Load kN	Failure Mode	Failure (hrs) Theory	Actual
1*	a	Standard, dry	12 x 12	2.19	Siliceous	5	34.2		0	None		4:00
2*	a	Load, dry	12 x 12	2.19	Siliceous	15	31.0	36.9	1333	C*	2:25	2:50
3*	a	Load	12 x 12	2.19	Siliceous	70	34.8	34.2	800	C	3:23	3:38
4*	a	Load	12 x 12	2.19	Siliceous	63	31.7	35.1	711	C	3:30	3:40
5	g	Size, dry	16 x 16	2.47	Siliceous	9	35.7	40.7	0	None		5:00
6	g	Size, dry	8 x 8	2.75	Siliceous	29	34.8	42.3	169	B*	2:12	3:00
7*	a	Load	12 x 12	2.19	Siliceous	74	35.3	36.1	1067	C	2:40	3:28
8*	a	Load	12 x 12	2.19	Siliceous	74	33.5	34.8	1778	C	2:00	2:26
9*	a	Load	12 x 12	2.19	Siliceous	75	36.8	38.3	1333	C	2:40	3:07
10	b	Aggregate	12 x 12	2.19	Carbonate	75	33.6	40.9	800	C	5:20	8:30
11	b	Aggregate	12 x 12	2.19	Carbonate	75	33.5	36.9	1067	C	4:16	6:06
12	b	Aggregate	12 x 12	2.19	Carbonate	76	34.2	39.9	1778	C	2:47	3:36

Table 2.1b Series II

Column #	Group	Test Purpose	Section in.	Steel %	Aggregate	R.H. %	fc' (MPa) 28 day	test	Load initial (kN)	maximum (kN)	Failure Mode	Failure (hrs) Theory	Actual
1	e	Fixed-hinged, free translation	12 x 12	2.19	Siliceous	65	40.3	41.6	342		C		5:40
2	e	Full axial restraint	12 x 12	2.19	Siliceous	75	43.2	43.6	1044	2049	C	3:17	3:21
3	e	Full axial restraint	12 x 12	2.19	Siliceous	75	37.2	35.4	916	1914	C	3:18	3:30
4	d	High-strength concrete	12 x 12	2.19	Siliceous	75	53.2	52.9	1178		C	3:20	3:47
5	d	High-strength concrete	12 x 12	2.19	Siliceous	75	51.4	49.5	1067		C	3:32	3:54
6	c	Aggregate	12 x 12	2.19	Lightweight	79	34.2	46.6	1076		B		3:08
7	c	Aggregate	12 x 12	2.19	Lightweight	80	38.1	42.5	947		C		4:19
8	f	% Steel	12 x 12	4.38	Siliceous	61	41.4	42.6	978		C	3:40	4:12
9	f	% Steel	12 x 12	4.38	Siliceous		38.1	37.1	1333		C	3:10	3:45
10	g	Load	16 x 16	2.47	Siliceous	80	38.4	38.8	2418		C	4:00	4:22
11	g	% Steel	16 x 16	3.97	Siliceous	75	36.8	38.4	2795		C	4:40	4:45
12	g	% Steel/Load, thicker cover	16 x 16	3.97	Siliceous	68	42.6	46.2	2978		None†	5:08	3:33

Table 2.1c Series III

Column #	Group	Test Purpose	X-Section in.	Steel %	Aggregate	R.H. %	fc' (MPa)		Load (kN)	Failure Mode	Failure (hrs)	
							28 day	test			concentric	eccentric
1	i	Fixed-hinged	12 x 12	2.19	Siliceous	60	35.2	39.6	800	C	3:05	4:02
2	i	Fixed-hinged	12 x 12	2.19	Siliceous	64	35.2	39.3	1000	C	2:48	3:40
3	k	Eccentric load (0.96")	12 x 12	2.19	Carbonate	56	35.7	39.9	1000	B		3:01
4	j	Fire intensity	12 x 12	2.19	Carbonate	45	37.1	37.6	1067	C		5:28
5	h	Shape - rectangular	12 x 18	2.22	Siliceous	65	44.2	42.5	1413	C	5:40	5:56
6	h	Shape - mini-wall	8 x 36	1.22	Siliceous	58	39.2	42.1	756	C		5:35
7	l	Eccentric load	12 x 12b	2.19	Siliceous	44	40.2	42.1	1022	49 - 32	B	2:50
8	l	Eccentric load, rotation const.	12 x 12b	2.19	Siliceous	32	39.7	42.8	987	43 - 8	B	3:45
9	l	Eccentric load, rotation const.	12 x 12b	2.19	Siliceous	41	38.8	44.5	889	43 - 22	B	3:30
10	l	Eccentric load, load constant	12 x 12b	2.19	Siliceous	64	39.7	38.8	993	44	B	2:47
11	h	Shape - circular	14 Ø	2.34	Siliceous	78	39.3	41.6	1431	C		4:05
12	h	Shape - circular	14 Ø	2.34	Siliceous	76	37.0	42.4	444	C		3:40
13	j	Room-temperature crush	12 x 12	2.19	Siliceous	60	38.5	40.7	3833	C	--	--
14	k	Eccentric load (0.96")	12 x 12	2.19	Siliceous	25	40.0	37.9	1178	B		3:03

Table 2.1d T Series

Column #	Group	Test Purpose	X-Section in.	Steel %	Aggregate	R.H. %	fc' (MPa)		Load (kN)	Failure Mode	Residual Strength (kN)	
							28 day	test			Theory	Actual
T-1	j	Residual strength - 1-hr fire	12 x 12	2.19	Siliceous	87	32.1	38.9	993	C	2470	2671
T-2	j	Residual strength - 2-hr fire	12 x 12	2.19	Siliceous	82	35.3	41.8	1022	C	1725	1987
T-3	i	Hinged-hinged	12 x 12	2.19	Siliceous	57	37.2	41.6	1022	C		<u>Failure (hrs)</u> 3:41

* Failure Mode: C - Compression B - Buckling

† Test was stopped due to air fan burnout

Table 2.2 Petrography of Sand and Gravel used as Siliceous Aggregate

Component	<u>Composition of Sieve Fraction, Percent on Sieve of Size Indicated</u>											Percent Passing through No. 200
	19 mm	12.5 mm	9.5 mm	6 mm	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	No. 200	
Granite	37.9	32.9	25.5	31.3	27.0	27.6	12.3	7.4	1.9	4.4	0.6	--
Quartzite	21.6	29.2	34.8	24.6	24.5	20.0	12.3	12.6	10.9	3.1	2.2	--
Quartz	6.3	3.1	4.9	4.8	5.5	18.8	52.2	62.0	73.1	79.5	74.2	92.0
Chert ^a	10.8	7.0	5.2	8.1	9.8	5.9	7.7	3.5	2.0	0.8	2.8	2.0
Sandstone-Quartz Conglomerate	1.9	0.8	3.1	5.1	5.5	8.3	--	--	--	--	--	--
Rhyolite-Dacite	13.9	6.2	2.2	5.1	7.2	4.1	0.8	2.6	1.6	0.8	0.9	--
Feldspar	--	--	--	--	--	--	1.3	5.0	6.6	5.0	10.8	4.0
Diorite	1.9	1.4	3.1	1.8	1.2	--	--	--	--	--	--	--
Graywacke ^b	1.3	9.5	5.8	5.4	4.3	6.5	2.3	1.5	0.3	--	0.6	--
Gneiss-Schist	2.5	5.1	10.5	9.3	7.5	4.1	6.4	1.8	0.9	1.1	0.6	--
Basalt	1.9	4.5	4.0	3.9	6.9	3.2	2.6	2.4	0.7	--	0.3	--
Misc. Igneous Rocks and Opaque Minerals ^c	--	0.3	0.9	0.6	0.6	1.5	2.1	1.2	2.0	5.3	7.0	2.0
Particle Shape	19 to 6 mm (%)			No. 4 to No. 16 (%)			No. 30 to No. 200 (%)					
Subrounded to rounded	30			20			10					
Subrounded to subangular	40			40			40					
Angular	30			40			50					

^a "Ironstone," made up of jasper and hematite, is included in the chert classification.

^b Includes metagraywacke.

^c The miscellaneous igneous rocks were severely altered and positive identification was impossible. The opaque minerals occurred in the No. 50 and smaller sieve sizes and were largely magnetite.

Table 2.3 Petrography of Sand and Gravel used as Carbonate Aggregate

Component	<u>Composition of Sieve Fraction, Percent on Sieve of Size Indicated</u>											Percent Passing through No. 200
	19 mm	12.5 mm	9.5 mm	6 mm	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	No. 200	
Carbonate	91.1	87.4	87.3	85.6	87.6	80.5	79.6	64.4	46.1	36.4	65.0	92.0
Chert	3.6	4.2	5.2	7.6	6.1	8.9	11.0	--	--	--	--	--
Granite	1.1	1.2	3.5	1.8	2.4	3.6	2.4	--	--	--	--	--
Basalt	2.1	3.0	1.4	2.6	2.6	3.4	2.0	1.2	--	--	--	--
Gabbro	0.3	--	--	0.2	0.5	0.2	0.7	0.3	--	--	--	--
Quartzite	1.8	3.9	1.4	1.3	0.3	3.0	4.3	--	--	--	--	--
Gneiss-Schist	--	0.3	1.2	0.9	0.5	0.4	--	--	--	--	--	--
Quartz-Chalcedony	--	--	--	--	--	--	--	26.5	45.1	52.5	27.2	4.0
Feldspar	--	--	--	--	--	--	--	7.6	8.8	11.1	6.1	0.5
Misc. Igneous and Clays	--	--	--	--	--	--	--	--	--	--	1.7	3.5

Particle Shape	<u>19 to 6 mm (%)</u>		<u>No. 4 to No. 200 (%)</u>	
	<u>Carbonates</u>	<u>Silicates</u>	<u>Carbonates</u>	<u>Silicates</u>
Rounded	--	--	--	30
Subangular to subrounded	80	100	75	60
Angular	--	--	--	10
Angular to subangular	20	--	25	--

Table 2.4 Physical Properties of Aggregates

	Siliceous	Carbonate
Specific gravity of sand	2.63	2.67
Specific gravity of gravel	2.57	2.67
Moisture content of sand, %	4.0	3.0
Moisture content of gravel, %	1.0	1.0
Saturated surface dry density of gravel, kg/m ³ (lb/ft ³)	1678 (104.9)	1712 (107.0)
Fineness modulus of fine aggregate	2.96	3.00
Fineness modulus of coarse aggregate	1.73	1.53

Table 2.5 Approximate Batch Quantities

Item	Siliceous Aggregate Concrete	Carbonate Aggregate Concrete	Lightweight Aggregate Concrete
Cement, kg/m ³	307	346	418
Coarse Aggregate, kg/m ³	1054	1065	534
Sand, kg/m ³	871	816	747
Water, kg/m ³	154	193	114
Air Entraining Agent (Darex), ml/L ³			0.194
Superplasticizer (Pozzolith 84), ml/L ³		6.86	1.45
Average Air Content, %	1.7	1.9	7.0
Average Unit Weight, kg/m ³	2400	2400	1840
Average Compressive Strength at 28 days, MPa	39	36	36
Average Slump, mm	83	76	78

Table 2.6 Tensile Strength of Steel

Bar #	Yield Stress MPa (ksi)	Ultimate Strength MPa (psi)
3	427 (61.8)	671 (97.3)
6	442 (64.1)	721 (105)
7	414 (60) minimum	not tested
8	444 (64.3)	730 (106)
10	414 (60) minimum	not tested

Table 2.7 Reinforcing Bars and Steel Plates

Column Size (in.)	Machining		Plates Dimensions	
	Diameter mm (in.)	Depth mm (in.)	mm	(in.)
12 x 12	19 (3/4)	19 (3/4)	533 x 533 x 25	21 x 21 x 1
8 x 8	13 (1/2)	19 (3/4)	533 x 533 x 25	21 x 21 x 1
16 x 16	19 (3/4)	32 (1 1/4)	864 x 864 x 38	34 x 34 x 1 1/2
12 x 18	16 (5/8)	32 (1 1/4)	533 x 864 x 38	21 x 34 x 1 1/2
8 x 36	13 (1/2)	19 (3/4)	1016 x 533 x 25	40 x 21 x 1
14 diameter	16 (5/8)	19 (3/4)	533 x 533 x 25	21 x 21 x 1
With bracket	19 (3/4)	32 (1 1/4)	864 x 634 x 38	34 x 25 x 1 1/2

3 TEST DESCRIPTIONS AND RESULTS

This chapter contains results and observations from each of the 41 tests. They are presented according to test purpose and major characteristics, as follows:

- a) standards
- b) carbonate aggregate
- c) lightweight aggregate
- d) high-strength concrete
- e) restraint
- f) doubled reinforcement
- g) size and extra steel
- h) shape
- i) end conditions
- j) other than standard fire
- k) eccentric load
- l) eccentric load with constraints

The basic characteristics of the specimens have been given in Table 2.1; these will be reiterated for each test, with explanations where necessary. Also, diagrams of the specimens and thermocouple locations are presented here.

3.1 STANDARD TESTS

Specimen Properties:

Cross-Section: 305 x 305 mm (12 x 12 in.)
 Length: 3810 mm (12 ft 6 in.)
 Aggregate: Siliceous
 Reinforcement: 2.19% as four No. 8 bars.

Elevation, Cross-Section and Finishing Detail:	Figure 3.1.1
Layout of Thermocouple Frames in Concrete:	Figure 3.1.2
Locations of Thermocouples in Frames:	Figure 3.1.3
Locations of Thermocouples on Reinforcing Bars:	Figure 3.1.4

3.1.1 Series I, Column I

Test purpose:	Reference Column, Unloaded, Dry Condition.
Date tested:	September 19, 1979.
Loading:	none.

Measured Properties:

Cylinder strength:	34.2 MPa at 28 days.
Relative humidity:	5%.

Results:

Test duration: 4 hours.
 Temperatures: Tables 3.1.1 and 3.1.2a to d.

Note: temperatures measured in the column after about 3 hours are not reliable due to large axial expansion of the column and consequent strain on the thermocouple wires. Some thermocouples were damaged in transit and did not function from the beginning of the test.

Observations

0:00 Horizontal hairline cracks were observed on the surface of the specimen before the test.
 1:30 Narrow longitudinal cracks 10 to 15 cm long were observed on two sides of the column.

Figure 3.1.5 shows the column in the furnace chamber after the test. The cracks in the column were too narrow to be seen in this picture.

3.1.2 Series I, Column 2

Test purpose: Reference Column, Dry Condition.
 Date tested: June 19, 1981.
 Loading: 1333 kN, Concentric.

Measured Properties:

Cylinder strengths: 31.0 MPa at 28 days.
 36.9 MPa on test date.
 Relative humidity: 15%.

Results:

Test duration: 2 hours 50 minutes.
 Temperatures: Tables 3.1.3 and 3.1.4a to d.
 Axial deformations: Table 3.1.5

Observations

0:50 Hairline cracks were observed on all faces.
 2:10 Wider cracks could be seen on all faces, from 15 to 30 cm in length , and from 1.5 to 5 mm in width.
 2:30 The rate of contraction of the column increased rapidly.
 2:50 The column failed suddenly, unable to maintain the applied load. Cracks and falling off of the cover were observed as illustrated in Figure 3.1.6.

3.1.3 Series I, Column 3

Test purpose: Reference Column, Load Effect.
 Date tested: April 25, 1980.
 Loading: 800 kN, Concentric.

Measured Properties:

Cylinder strengths: Compressive strength: 34.8 MPa at 28 days.
 34.2 MPa on test date.
 Relative humidity: 70%.

Results:

Test duration: 3 hours 38 minutes.
 Temperatures: Tables 3.1.6 and 3.1.7a to d.
 Axial deformations: Table 3.1.8

Observations

0:18 Water oozed out on the cast column surface, 45 cm from the furnace bottom, and dried in 5 min.
 0:28 On the E surface, crack A extended 10 to 13 cm. New crack B developed about 5 cm from crack A towards the centerline of the columns.
 0:45 About 10 cm from the top end of crack A, a new crack C formed. At this time, cracks became visible on the N and S faces of the column.
 1:00 Many fine cracks were seen on the N face. More were seen on the W face.
 2:26 Cracks A, B, and C formed a continuous crack about 6 to 10 mm wide.
 3:16 Crack ABC increased in width to about 25 mm.
 3:38 Column failed as a result of crushing of the concrete with local buckling of the reinforcing bars. Figure 3.1.7 is a sketch of the deformed bars.

3.1.4 Series I, Column 4

Test purpose: Reference Column, Load Effect.
 Date tested: March 19, 1980.
 Loading: 711 kN, Concentric.

Measured Properties:

Cylinder strengths: 31.7 MPa at 28 days.
 35.1 MPa on test date.
 Relative humidity: 63%.

Results:

Test duration: 3 hours 40 minutes.
 Temperatures: Tables 3.1.9 and 3.1.10a to d.
 Axial deformations: Table 3.1.11

Observations

- 0:45 A vertical crack, 10 to 12.5 cm long, appeared on the E face at 45 cm from the bottom.
- 1:00 Long hairline vertical cracks that followed the main reinforcing steel located in the SE corner were seen on both S and E surfaces.
- 3:00 The cracks on the E face were 30 m long and 3 to 6 mm wide.
- 3:40 Failure by crushing of the concrete and buckling of the main reinforcing bars. Figure 3.1.8 shows part of the column in the furnace after concrete has been removed to expose the reinforcing bars.

3.1.5 Series I, Column 7

Test purpose:	Reference Column, Load Effect.
Date tested:	July 11, 1980.
Loading:	1067 kN, Concentric.

Measured Properties:

Cylinder strengths:	35.3 MPa at 28 days. 36.1 MPa on test date.
Relative humidity:	74%.

Results:

Test duration:	3 hours 28 minutes.
Temperatures:	Tables 3.1.12 and 3.1.13a to d.
Axial deformations:	Table 3.1.14

Observations

- 0:31 Four vertical cracks 10 to 15 cm long appeared on the E face of the column.
- 0:56 Another crack formed 10 cm below one of the cracks on the same face.
- 1:05 A long vertical crack was seen on the N face, and a long hairline crack appeared on the W face.
- 1:07 Two cracks on the E face (0:56) extended and joined together.
- 1:15 The crack on the N face widened.
- 1:33 The long crack on the E face widened to about 1.5 mm. The concrete temperature was about 760°C near the exposed surface and 1150°C at the center. The steel temperature was near 427°C.
- 1:50 Some hairline cracks were seen on the S face. The long E face crack was 3 mm wide.
- 2:12 Column expansion due to heating reached its maximum and stabilized.
- 3:04 The long E face crack was 6 mm wide.
- 3:07 Zero column expansion was recorded.
- 3:13 Electrical power was lost ; gas to the burners was automatically shut off.
- 3:15 Power came back on and the fire resumed. Cracks on the S face appeared to be about 10 mm wide, and the long E face crack about 13 mm wide.
- 3:28 Hydraulic pressure suddenly dropped and column failed due to crushing of concrete and buckling of steel. Figure 3.1.9 shows the column at the end of the test.

3.1.6 Series I, Column 8

Test purpose: Reference Column, Load Effect.
 Date tested: September 12, 1980.
 Loading: 1778 kN, Concentric.

Measured Properties:

Cylinder strengths: 33.5 MPa at 28 days.
 34.8 MPa on test date.
 Relative humidity: 74%.

Results:

Test duration: 2 hours 26 minutes.
 Temperatures: Tables 3.1.15 and 3.1.16a to d.
 Axial deformations: Table 3.1.17

Observations

0:27 Two short vertical cracks appeared on the lower part of the E face.
 0:43 A hairline crack was seen on the upper S face, two cracks A and B became visible on the upper E face, and a hairline crack appeared on the N surface.
 1:03 Cracks A and B extended to join and form AB, 35 cm long.
 1:05 Three more cracks were detected on the S face.
 1:17 Column expansion reached its maximum value and stabilized.
 1:21 Crack AB lengthened to 45 cm. A new crack appeared on the E face.
 1:40 Crack AB widened to 20 mm and extended to 60 cm.
 1:45 Crack C, about 90 cm long, was observed on the W face.
 2:07 Crack AB was now about 10 mm wide.
 2:26 Explosive failure occurred due to crushing of the concrete. Pieces of concrete 60 to 120 cm long and 10 to 20 cm wide fell from cracks AB and C. Figure 3.1.10 is a photo of the top of the column after the test.

3.1.7 Series I, Column 9

Test purpose: Reference Column, Load Effect.
 Date tested: February 5, 1981.
 Loading: 1333 kN, Concentric.

Measured Properties:

Cylinder strengths: 36.8 MPa at 28 days.
 38.3 MPa on test date.
 Relative humidity: 75%.

Results:

Test duration:	3 hours 7 minutes.
Temperatures:	Tables 3.1.18 and 3.1.19a to d.
Axial deformations:	Table 3.1.20

Observations

- 0:30 A crack developed on the N side, about 60 cm from the ceiling.
- 2:00 Cracks developed on all sides of the column, the largest being more than 90 cm long and nearly 6 mm wide.
- 3:07 Failure in compression (Figure 3.1.11).

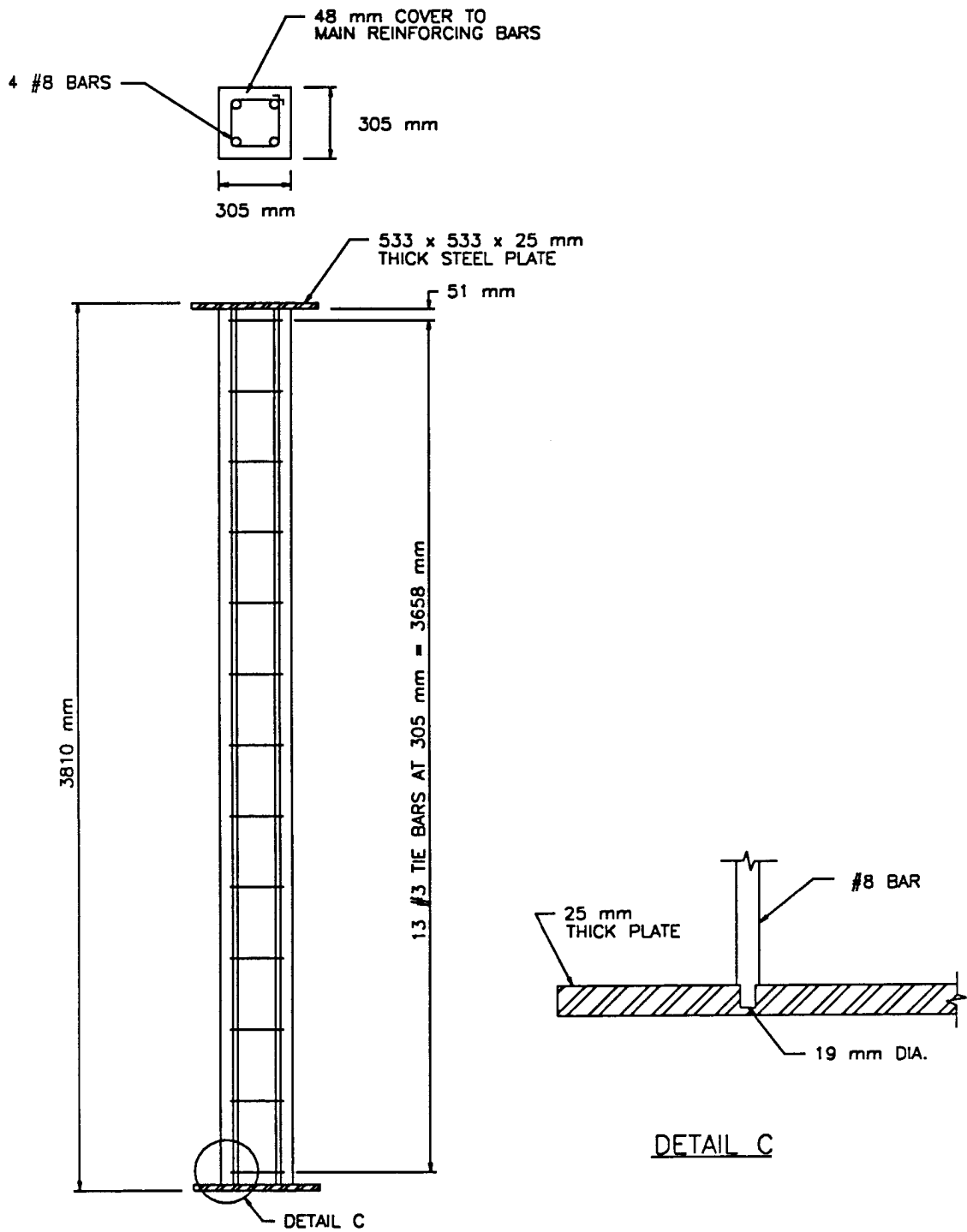


Figure 3.1.1 Elevation, Cross-Section and Finishing Detail: 12 x 12 Section with 2.19% Steel

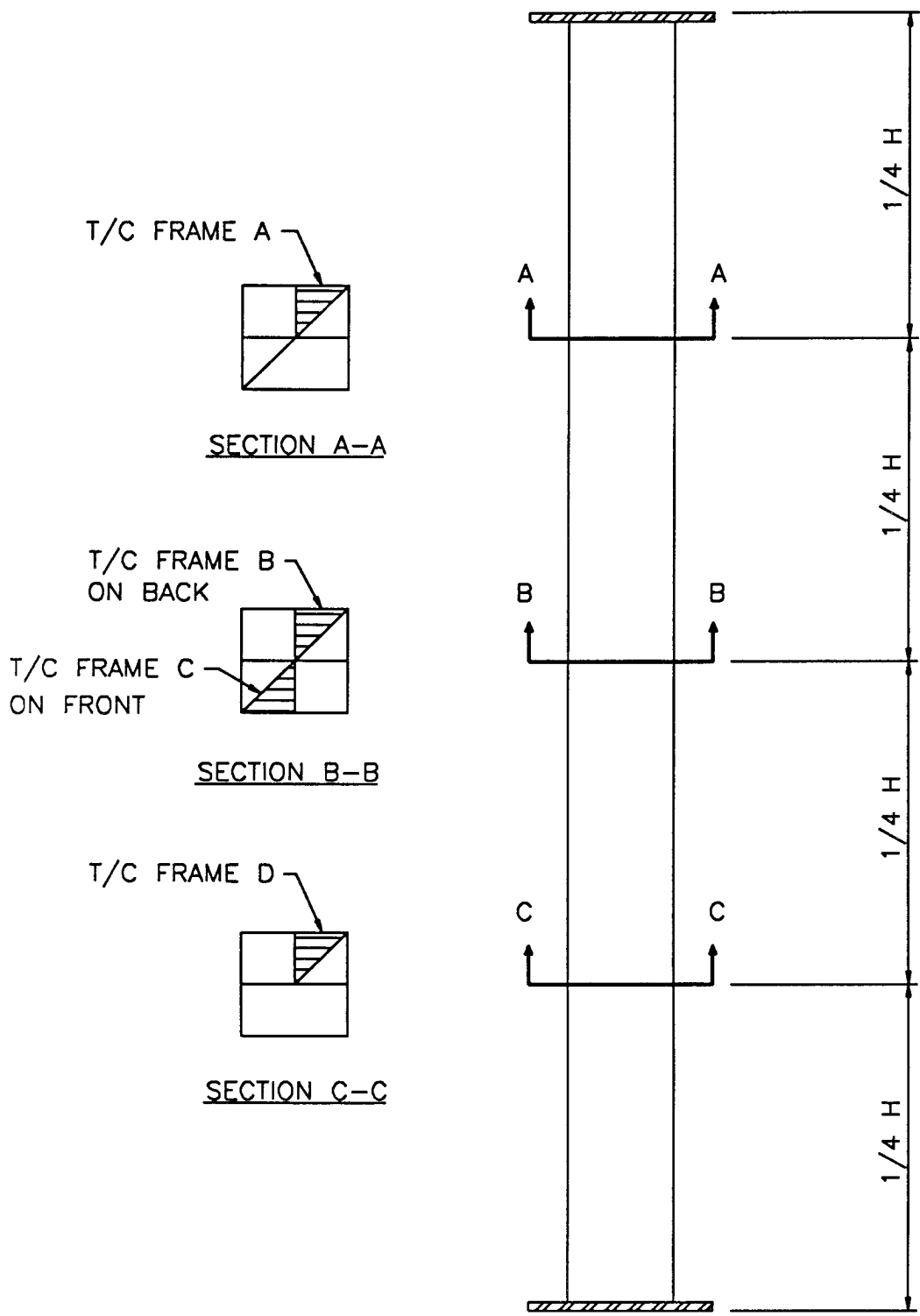


Figure 3.1.2 Layout of T/C Frames in Concrete: Series I Sections

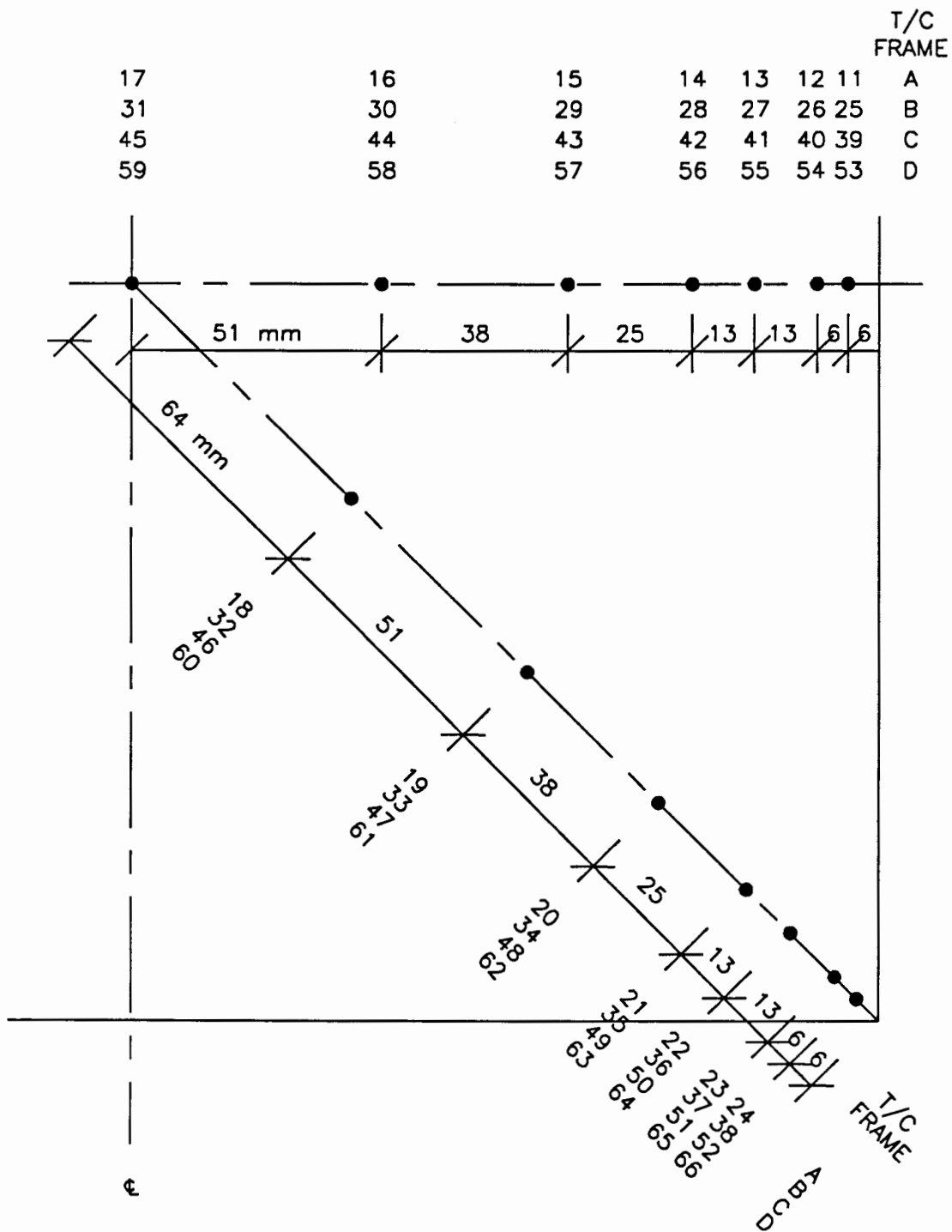


Figure 3.1.3 Locations of T/C's in Frames: 12 x 12 Section, Series I

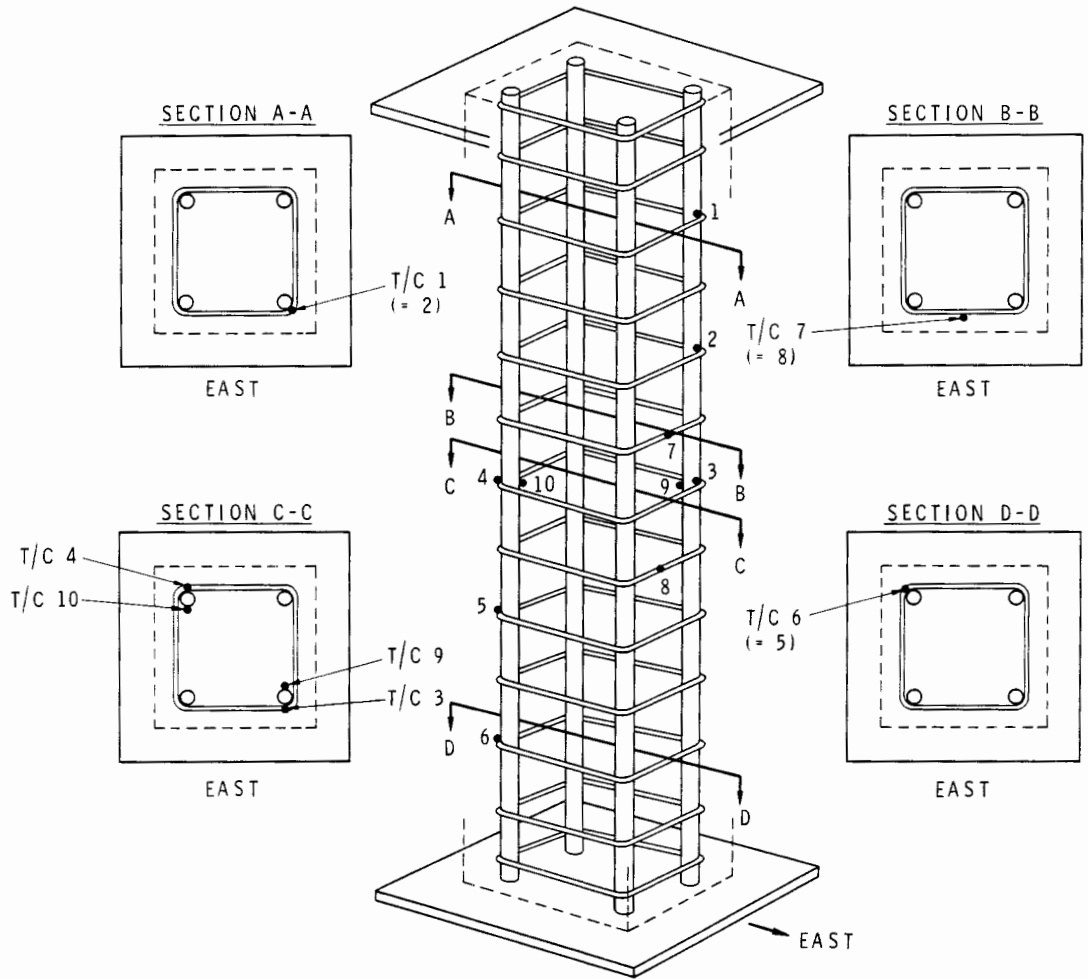


Figure 3.1.4 Locations of T/C's on Reinforcing Bars: 12 x 12 Section, Series I

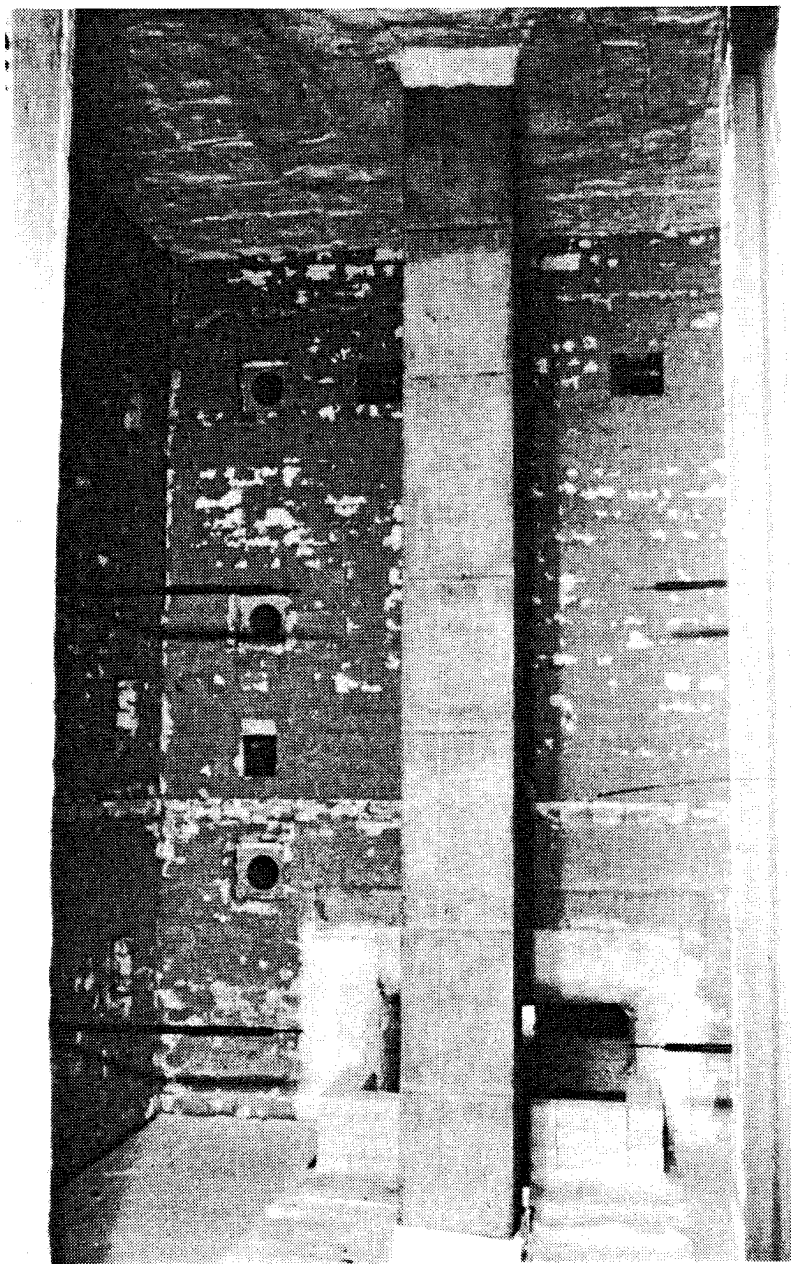


Figure 3.1.5 Series I Column 1 After Test

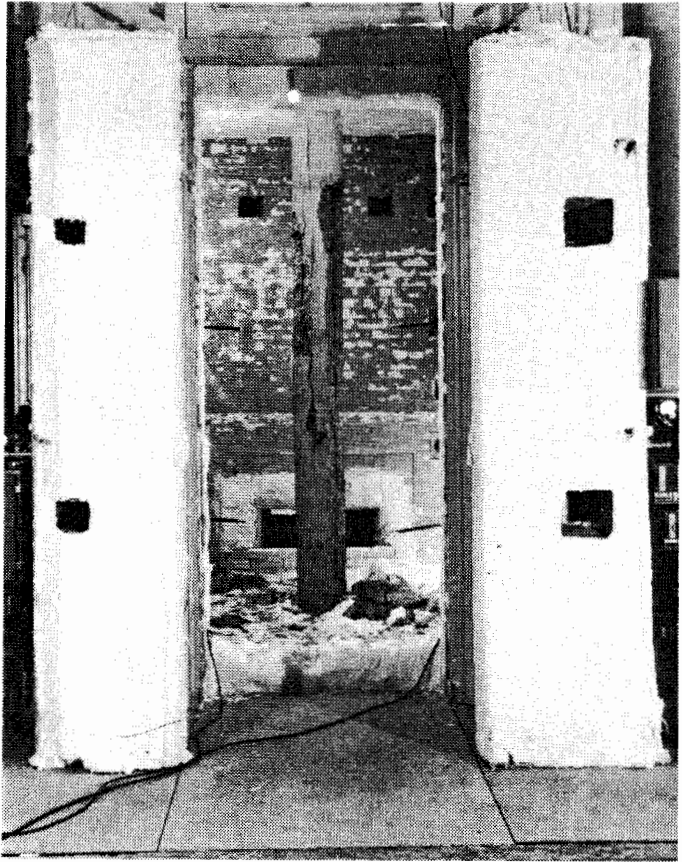


Figure 3.1.6 Series I Column 2 at failure (2:50)

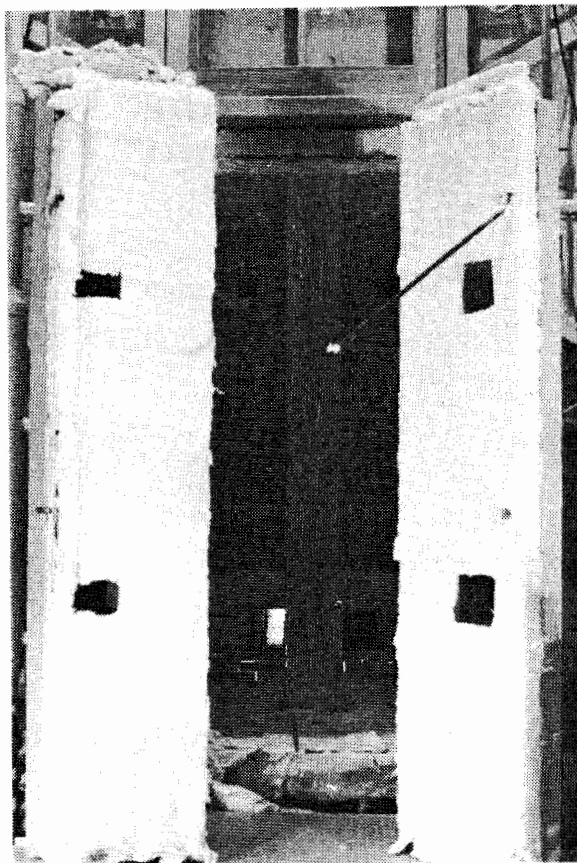


Figure 3.1.7 Series I Column 3 - deformed reinforcing bars

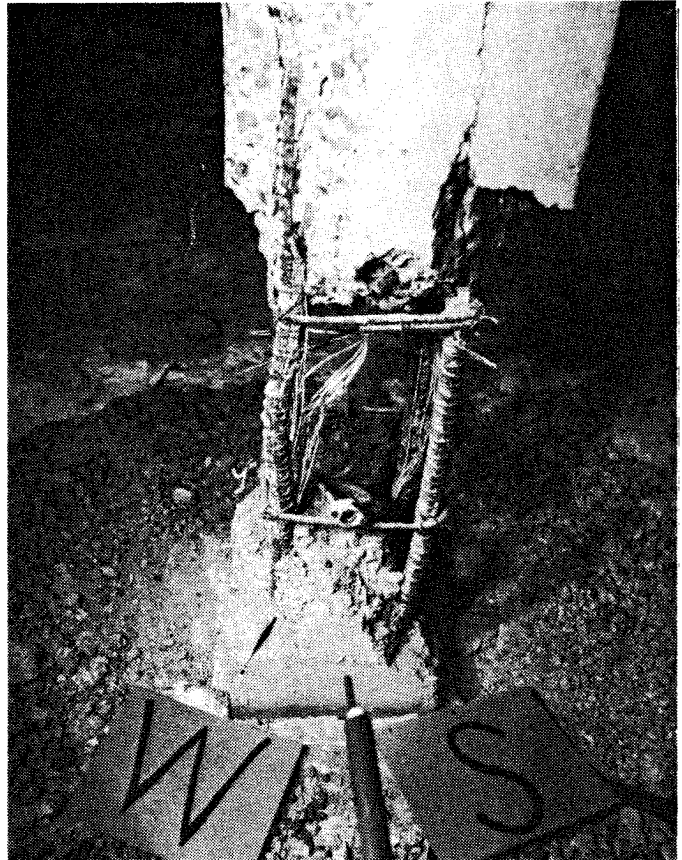


Figure 3.1.8 Series I Column 4 After Test, concrete removed to show rebars

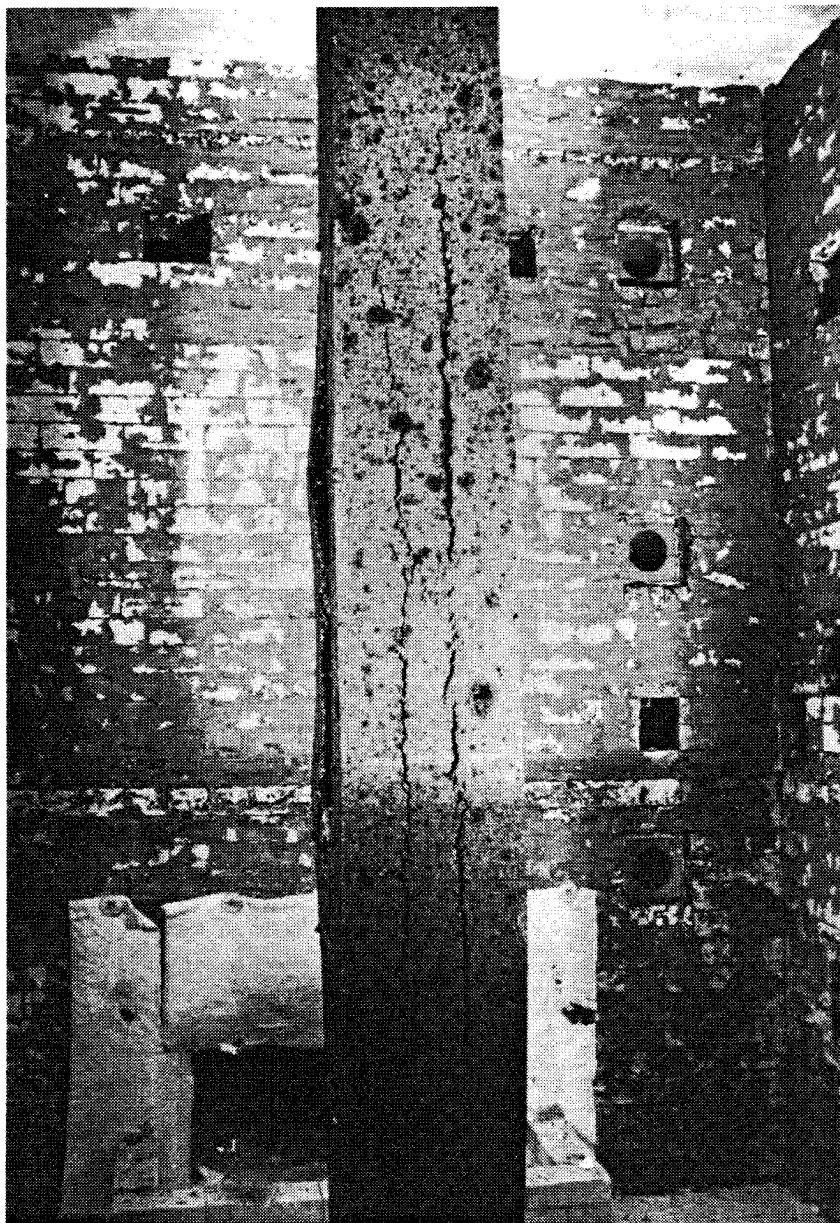


Figure 3.1.9 Series I Column 7 After Test

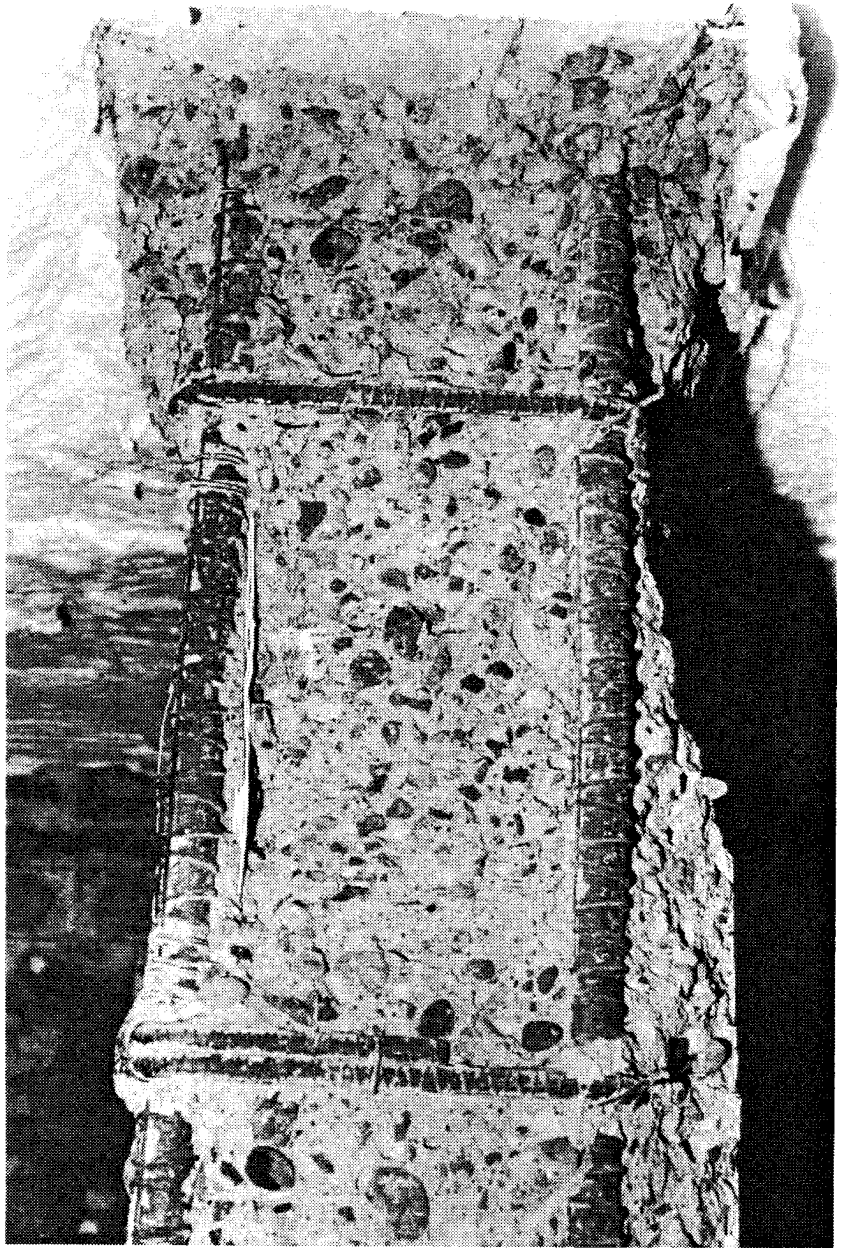


Figure 3.1.10 Series I Column 8 - top After Test



Figure 3.1.11 Series I Column 9 After Test

Table 3.1.1 Steel Temperatures, Series I Column 1

Minutes	Temperature (°C) Measured at Thermocouple #:										Furnace	
	1	2	3	4	5	6	7	8	9	10		
0	24	24	24	24	24	24	24	24	24	24	24	24
5	27	27	27	27	27	27	27	27	27	27	27	373
10	41	46	43	38	32	32	54	35	38	32	32	660
20	107	113	113	116	96	96	129	91	104	82	82	786
30	138	160	135	179	160	129	196	127	124	113	113	839
40	188	213	185	238	221	177	252	177	168	157	157	875
50	238	260	235	291	277	232	299	227	213	204	204	906
60	285	310	282	332	324	282	341	277	260	254	254	929
70	332	357	329	377	368	329	377	329	304	296	296	946
80	377	399	374	421	410	371	413	366	346	341	341	968
90	413	438	413	449	454	407	443	407	385	379	379	982
100	463	482	446	474	485	443	482	443	435	416	416	988
110	485	504	488	510	516	477	502	477	457	449	449	999
120	518	535	521	532	543	510	529	513	491	482	482	1007
130	554	571	560	557	577	538	560	538	529	510	510	1016
140	582	599	588	582	599	568	585	566	554	538	538	1018
150	607	627	613	607	624	593	610	593	582	566	566	1024
160	632	654	641	638	646	624	632	616	607	593	593	1027
170	654	685	663	663	671	654	654	638	635	618	618	1032
180	674	710	691	688	691	691	677	663	663	643	643	1038

Table 3.1.2a Concrete Temperatures in Frame A, Series I Column 1

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
5	107	82	54	41	27	27	27	27	27	24	41	24	43	63	373
10	204	154	99	60	35	27	27	27	38	46	93	93	129	218	660
20	391	307	199	132	71	35	29	35	88	121	160	241	316	468	786
30	516	421	293	199	113	77	46	93	121	224	260	366	454	602	839
40	593	502	363	260	141	110	79	110	157	307	357	463	549	677	875
50	649	557	418	310	171	110	107	110	199	363	418	529	627	741	906
60	691	604	468	354	204	118	107	113	243	416	468	588	688	782	929
70	729	643	510	391	241	135	107	135	285	460	516	641	732	810	946
80	760	677	543	427	271	163	110	166	327	499	552	685	766	846	968
90	785	704	577	460	299	188	138	191	363	532	591	718	793	866	982
100	804	729	607	488	329	213	160	218	399	566	621	746	816	879	988
110	824	752	635	516	357	235	182	243	429	599	649	768	829	891	999
120	841	771	660	541	385	260	204	266	474	627	677	771	818	885	1007
130	857	788	682	566	413	285	232	293	491	654	699	752	774	841	1016
140	871	813	699	593	438	316	254	321	516	657	727	746		787	1018
150	882	821	713	610	460	329	277	346	538	713	741			768	1024
160	891	835	721	632	482	354	302	366	563	729	757				1027
170	902	846	732	652	507	377	324	391	588	729					1032
180	913	863	741	677	529	407	346	413	613	760					1038

Table 3.1.2b Concrete Temperatures in Frame B, Series I Column 1

Minutes	Temperature (°C) Measured at Thermocouple #:												Furnace	
	25	28	29	30	31	32	33	34	35	36	37	38		
0	24	24	24	24	24	24	24	24	24	24	24	24	24	24
5	141			24	24	24	24	27	43	60	82	121		373
10	316	38		24	24	24	27	49	93	127	218	302		660
20	566	124	93	27	27	27	82	121	241	318	466	560		786
30	677	196	99	54	29	57	102	224	366	454	599	691		839
40	752	254	110	77	60	99	143	307	460	549	679	754		875
50	802	302	143	99	99	99	191	363	529	627	743	804		906
60	838	343	174	107	99	113	238	416	588	685	782	838		929
70	860	385	210	129	99	135	282	460	641	732	813	860		946
80	871	418	246	157	118	160	321	499	682	766	846	877		968
90	891	454	274	182	138	188	360	532	718	793	866	891		982
100	896	482	307	207	163	218	393	566	746	816	879	896		988
110	913	510	338	235	188	263	432	599	768	829	891	913		999
120	921	532	368	260	213	371	468	627	771	816	885	921		1007
130	927	557	393	293	238	532	532	654						1016
140	927	582	421	327	260	635	621	685						1018
150	929	607	449	371	288	691	682	710						1024
160	932	638	477	421	313	718	718	732						1027
170	935	663	516	474	343	746	732	746						1032
180	932	688	552	513		754	743	754						1038

Table 3.1.2c Concrete Temperatures in Frame C, Series I Column 1

Minutes	Temperature (°C) Measured at Thermocouple #:										Furnace	
	42	44	45	46	47	48	49	50	51	52		
0	24	24	24	24	24	24	24	24	24	24	24	24
5	38	24	24	24	27	43		79	121	143	373	
10	52	24	24	24	32	60		166	263	371	660	
20	146	32	24	35	102	166	260	357	496	599	786	
30	207	54	32	60	127	260	402	521	649	732	839	
40	263	91	52	88	166	329	482	602	721	788	875	
50	327	107	82	113	224	402	566	660	788	829	906	
60	366	124	107	132	266	449	616	732	821	857	929	
70	413	154	124	163	302	488	657	768	852	885	946	
80	443	177	135	182	352	538	702	807	871	910	968	
90	477	196	154	204	385	566	727	829	882	921	982	
100	510	224	177	235	427	607	752	849	879	929	988	
110	538	246	196	260	454	635	768	868	871	941	999	
120	571	274	218	282	482	657	777	882	863	952	1007	
130	593	299	246	316	513	685	788	896	863	963	1016	
140	607	324	266	338	535	704	788	907	841	966	1018	
150	643	352	296	379	566	724	768	913	829	968	1024	
160	663	371	316	427	593	741		916	782	968	1027	
170	685	399	343	510	633	746		899	774	954	1032	
180	696	463		613	696	746		829	757	899	1038	

Table 3.1.2d

Concrete Temperatures in Frame D, Series I Column 1

Minutes	Temperature (°C) Measured at Thermocouple #:											Furnace	
	53	54	55	56	57	58	59	60	62	63	65		
0	24	24	24	24	24	24	24	24	24	24	24	24	24
5	82	68	57	32	24	24	24	24	24	35	68	116	373
10	218	157	93	52	29	24	24	24	24	79	149	207	660
20	407	307	188	121	63	27	24	32	149	293	518	786	839
30	543	441	249	204	113	82	49	107	248	385	635	839	839
40	616	510	360	257	141	107	77	107	349	521	724	875	875
50	649	563	407	299	174	107	107	107	371	582	771	906	906
60	710	616	460	349	218	118	107	132	446	637	802	929	929
70	741	649	496	382	246	133	107	163	499	696	832	946	946
80	774	691	538	413	274	160	121	188	532	727	782	968	968
90	793	713	566	454	313	191	149	221	574	760	793	982	982
100	810	732	593	482	341	218	171	246	604	779	799	988	988
110	829	754	629	513	371	246	193	279	629	802	796	999	999
120	843	774	649	538	399	274	221	352	662	824	782	1007	1007
130	863	789	671	560	418	293	246	443	682	832	760	1016	1016
140	871	804	691	588	449	324	274	563	707		741	1018	1018
150	882	816	720	610	482	343	296	629	724		732	1024	1024
160	896	829	729	638	538	368	316	666	732		732	1027	1027
170	899	835	741	663		402	343	693	738		743	1032	1032
180	899	827	741	682		443	371	704	743		749	1038	1038

Table 3.1.3

Steel Temperatures, Series I Column 2

Minutes	Temperature (°C) Measured at Thermocouple #:										Furnace
	1	2	3	4	5	6	7	8	9	10	
0	21	21	20	20	20	20	21	20	20	21	21
5	35	31	29	28	27	25	35	33	27	26	524
10	56	48	45	40	41	37	65	63	37	33	667
15	103	88	82	82	80	75	101	105	66	58	725
20	121	110	110	104	109	99	123	145	107	90	769
25	144	132	131	113	114	120	149	178	112	107	806
30	172	157	154	135	138	143	175	210	129	116	834
35	199	182	179	158	161	166	199	241	152	132	861
40	228	207	206	182	186	190	223	269	175	154	884
45	256	233	232	207	212	215	247	297	199	176	917
50	283	260	259	231	237	239	271	323	223	198	934
55	311	287	287	256	262	264	295	348	247	221	936
60	337	313	313	280	287	289	318	370	270	243	948
70	386	363	362	326	334	334	361	411	315	287	963
80	429	408	405	367	377	377	399	446	355	328	962
90	468	449	444	404	416	415	433	477	393	365	972
100	502	485	481	439	453	448	464	504	429	399	983
110	534	517	514	472	487	478	494	530	462	431	993
120	561	544	543	502	519	506	521	554	494	462	1007
130	588	569	572	528	547	532	546	581	522	490	1019
140	614	596	607	554	575	556	571	608	548	515	1029
150	643	623	647	582	604	583	601	632	576	540	1036
160	677	652	683	611	641	608	639	656	603	567	1042
170	715	725	708		702	628	653	681	631	596	1047

Table 3.1.4a Concrete Temperatures in Frame A, Series I Column 2

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0	22	22	22	22	22	22	22	22	22	21	21	21	21	21	21
5	127	93	53	37	26	23	22	23	28	42	81	116	242	178	524
10	222	164	101	65	33	24	22	24	37	86	150	207	349	304	667
15	303	229	139	99	46	26	23	28	64	129	217	294	452	404	725
20	373	288	182	128	64	31	25	36	102	160	280	370	529	482	769
25	434	342	223	159	94	43	28	54	108	203	337	433	594	547	806
30	487	388	260	187	104	58	35	64	117	251	390	489	648	597	834
35	530	428	293	213	111	66	43	72	133	291	435	538	693	625	861
40	566	463	324	238	120	73	53	81	152	327	475	583	732	699	884
45	607	498	353	262	135	82	72	92	173	360	511	626	772	739	917
50	640	529	381	286	150	93	84	104	195	391	545	663	804	755	934
55	663	554	407	309	165	103	93	110	217	420	579	696	823	794	936
60	685	578	430	330	181	111	99	118	238	446	610	723	841	816	948
70	720	618	473	368	211	133	111	146	281	491	665	767	816	843	963
80	742	648	508	402	241	158	122	174	321	530	704	799	770	858	962
90	764	674	538	433	269	180	144	199	358	564	733	822	758	865	972
100	786	698	566	462	298	204	165	225	393	595	759	842	748	775	983
110	805	720	593	489	326	228	187	251	425	623	781	860	748	775	993
120	826	741	619	515	354	253	210	276	456	649	801	877	751	777	1007
130	847	763	645	539	380	278	234	301	485	673	820	889	753	779	1019
140	865	783	668	564	406	303	258	326	512	695	837	895	753	780	1029
150	880	801	691	589	432	331	290	349	536	716	851	906	753	783	1036
160	893	816	710	615	460	372	347	371	559	601	857	768	763	777	1042
170	903	829	729	645	491	448	433	391	584	754	763	761	767	793	1047

Table 3.1.4b Concrete Temperatures in Frame B, Series I Column 2

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace
	25	26	27	28	29	30	31	32	33	34	35	36	37	
0	21	21	21	20	21	21	21	21	21	21	21	21	21	21
5	125	90	53	35	25	22	21	22	25	39	74	115	186	524
10	231	167	104	73	33	23	22	23	31	86	155	224	340	667
15	317	238	153	103	50	26	22	27	53	128	230	323	445	725
20	389	301	201	135	82	31	24	35	84	166	300	404	528	769
25	452	358	247	171	101	49	33	50	106	216	363	473	599	806
30	502	406	287	202	108	65	43	71	111	264	420	531	655	834
35	544	446	321	230	115	78	53	86	123	306	471	582	706	861
40	580	482	353	256	131	87	63	95	142	343	517	630	746	884
45	619	517	382	281	147	93	72	101	162	376	556	671	786	917
50	651	549	410	305	162	101	81	109	182	407	597	709	820	934
55	674	575	436	328	177	107	91	118	202	436	632	738	840	936
60	695	599	459	349	193	115	102	130	222	462	662	762	858	948
70	729	639	500	386	223	136	108	154	261	508	711	802	885	963
80	750	667	532	418	253	159	125	179	300	548	746	828	889	962
90	770	692	560	448	282	184	150	205	336	583	773	847	893	972
100	779	713	588	476	312	210	173	218	371	613	796	863	776	983
110	778	734	614	503	341	236	197	258	404	642	818	876	773	993
120	785	755	638	528	368	262	221	285	436	667	836	887	786	1007
130	819	776	663	553	395	288	246	311	466	692	855	897	811	1019
140	835	795	685	577	421	314	270	337	494	715	871	906	940	1029
150	846	812	706	601	447	340	294	361	520	736	885	906	954	1036
160	827	-17	724	625	473	368	320	385	545	755	785		964	1042
170	715	682	667	644	504	397	354	409	574	659	674			1047

Table 3.1.4c Concrete Temperatures in Frame C, Series I Column 2

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace
	39	40	41	42	43	44	45	46	47	48	49	51	52	
0	21	21	21	21	21	21	21	21	21	21	21	23	22	21
5	144	99	51	36	26	22	21	22	28	42	86	194	276	524
10	266	191	104	72	33	23	22	24	41	98	166	363	472	667
15	358	266	154	108	50	26	23	27	78	132	248	472	577	725
20	433	332	204	148	99	33	25	35	109	175	315	545	652	769
25	494	388	250	185	108	53	29	57	119	222	371	606	709	806
30	541	434	291	219	109	64	40	77	140	264	422	655	751	834
35	582	473	327	250	112	73	55	86	161	304	471	710	789	861
40	618	507	358	277	129	81	66	93	185	341	514	750	826	884
45	659	541	388	303	146	90	74	103	210	375	552	721	867	917
50	691	573	417	328	163	102	83	103	234	406	593	741	891	934
55	712	597	444	351	180	105	99	110	259	435	628	755	900	936
60	733	619	466	372	196	116	103	124	282	462	657	771	914	948
70	766	657	507	409	228	140	109	153	327	509	708	791	934	963
80	785	684	538	441	258	163	129	179	368	549	744			962
90	804	708	567	470	288	186	152	205	405	584	771			972
100	824	730	593	497	317	211	173	232	440	616	795			983
110	841	751	619	523	346	236	197	258	472	643	808			993
120	860	772	643	547	374	262	221	285	501	668	749			1007
130	879	794	667	573	402	287	245	310	528	692	755			1019
140	896	813	690	599	429	312	268	335	553	714	759			1029
150	910	831	711	621	456	336	293	360	579	735	758			1036
160	921	845	729	643	482	359	316	383	604	754	751			1042
170					509	383	340	406	621					1047

Table 3.1.4c Concrete Temperatures in Frame C, Series I Column 2

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace
	39	40	41	42	43	44	45	46	47	48	49	51	52	
0	21	21	21	21	21	21	21	21	21	21	21	23	22	21
5	144	99	51	36	26	22	21	22	28	42	86	194	276	524
10	266	191	104	72	33	23	22	24	41	98	166	363	472	667
15	358	266	154	108	50	26	23	27	78	132	248	472	577	725
20	433	332	204	148	99	33	25	35	109	175	315	545	652	769
25	494	388	250	185	108	53	29	57	119	222	371	606	709	806
30	541	434	291	219	109	64	40	77	140	264	422	655	751	834
35	582	473	327	250	112	73	55	86	161	304	471	710	789	861
40	618	507	358	277	129	81	66	93	185	341	514	750	826	884
45	659	541	388	303	146	90	74	103	210	375	552	721	867	917
50	691	573	417	328	163	102	83	103	234	406	593	741	891	934
55	712	597	444	351	180	105	99	110	259	435	628	755	900	936
60	733	619	466	372	196	116	103	124	282	462	657	771	914	948
70	766	657	507	409	228	140	109	153	327	509	708	791	934	963
80	785	684	538	441	258	163	129	179	368	549	744			962
90	804	708	567	470	288	186	152	205	405	584	771			972
100	824	730	593	497	317	211	173	232	440	616	795			983
110	841	751	619	523	346	236	197	258	472	643	808			993
120	860	772	643	547	374	262	221	285	501	668	749			1007
130	879	794	667	573	402	287	245	310	528	692	755			1019
140	896	813	690	599	429	312	268	335	553	714	759			1029
150	910	831	711	621	456	336	293	360	579	735	758			1036
160	921	845	729	643	482	359	316	383	604	754	751			1042
170					509	383	340	406	621					1047

Table 3.1.4d Concrete Temperatures in Frame D, Series I Column 2

Minutes	Temperature (°C) Measured at Thermocouple #:												Furnace
	53	54	55	56	57	58	59	60	61	62	63	66	
0	22	22	22	22	22	22	22	20	21	20	20	20	21
5	123	88	53	34	25	23	22	22	26	39	75	252	524
10	234	173	108	65	32	23	22	23	36	90	159	451	667
15	324	248	158	102	46	26	23	26	69	135	239	566	725
20	401	316	208	136	72	31	25	34	106	176	309	651	769
25	468	376	256	172	98	55	31	55	111	232	365	710	806
30	520	426	298	204	109	73	42	72	125	281	414	755	834
35	563	467	333	232	116	81	54	83	148	324	462	794	861
40	602	506	366	256	131	86	63	93	172	363	507	830	884
45	643	543	398	277	146	92	72	103	197	396	547	843	917
50	676	576	427	299	162	101	81	111	221	427	590	849	934
55	696	602	452	320	177	109	92	120	245	454	625		936
60	717	624	474	338	193	116	103	133	268	480	654		948
70	749	661	512	371	222	133	115	159	311	525	704		963
80	768	687	542	401	252	158	125	186	352	565	740		962
90	789	711	569	430	281	185	150	214	390	599	769		972
100	810	732	596	459	311	212	174	242	425	630	793		983
110	823	753	621	488	340	238	198	269	456	657	815		993
120		774	645	516	370	264	222	295	486	682	834		1007
130		795	641	550	403	290	249	321	512	705	852		1019
140		814	678	592	448	315	285	346	536	726	869		1029
150		830	706	638	500	339	342	370	560		883		1036
160		830	724	670	546	363	414	394	585				1042
170			738	691	577	394	468	420	606				1047

Table 3.1.5

Deflections, Series I Column 2

Minutes	Expansion, mm
0	0.0
5	0.5
10	1.0
20	2.0
30	2.6
40	3.2
50	3.7
60	4.1
70	4.5
80	4.7
90	4.8
100	4.8
110	4.7
120	4.1
130	3.1
140	1.8
150	0.0
160	-2.2
165	-3.9

Table 3.1.6

Steel Temperatures, Series I Column 3

Minutes	Temperature (°C) Measured at Thermocouple #:										Furnace	
	1	2	3	4	5	6	7	8	9	10		
0	20	20	20	20	20	20	20	20	20	20	20	20
5	22	20	20	20	20	20	25	22	20	20	20	446
10	41	36	28	32	29	27	52	44	26	24	24	687
20	111	111	87	114	109	107	127	116	109	91	91	812
30	125	120	94	115	117	122	165	149	109	109	109	845
40	167	166	120	150	152	164	220	209	134	125	125	875
50	215	218	154	195	203	217	274	263	180	162	162	921
60	264	269	185	243	254	269	323	311	228	207	207	932
70	311	315	214	289	302	316	365	352	274	250	250	946
80	353	356	241	331	344	357	403	388	315	290	290	960
90	391	394	241	369	384	395	438	421	351	327	327	988
100	427	429	230	405	421	429	471	452	379	361	361	974
120	493	493	267	471	486	492	525	503	442	454	454	1010
140	555	547	306	529	540	544	574	552	498	483	483	1027
160	650	603	375	582	591	594	622	603	551	535	535	1039
180	716	664	494	631	651	641	664	649	603	585	585	1050
200	746	721	560	677	703	686	697	696	650	638	638	1061
218	754	741	619	719	722	723	720	762	691	693	693	1076

Table 3.1.7b Concrete Temperatures in Frame B, Series I Column 1

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace
	25	27	28	29	30	31	32	33	34	35	36	37	38	
0	20	20	20	20	20	20	20	20	20	20	20	20	20	20
5	20	31	21	20	20	20	20	21	23	43	74	118	158	446
10	145	68	39	21	20	20	20	23	51	101	151	238	325	687
20	330	143	105	53	22	20	27	102	133	224	338	489	539	812
30	443	233	133	101	52	28	55	108	213	348	440	616	663	845
40	519	302	179	108	75	48	77	113	301	448	507	702	771	875
50	574	354	222	124	88	70	93	151	365	523	569	766	807	921
60	620	397	260	148	104	94	111	196	418	586	624	810	826	932
70	653	433	294	175	119	109	128	239	463	637	672	839	878	946
80	681	462	323	200	131	119	144	279	501	677	704	864	858	960
90	709	489	350	224	141	128	158	313	534	711	751	891	880	988
100	735	515	376	247	155	131	176	346	566	743	804	746	899	974
120	767	558	427	293	196	146	222	407	621	782	805	731	919	1010
140	806	612	486	347	247	200	275	464	667	824	789	750	938	1027
160	840	660	541	398	301	264	328	517	707	856	803	765	953	1039
180	868	702	590	438	352	406	378	573	742	863	816	767	872	1050
200	870	716	640	481	444	465	428	658	771	880	692	794	792	1061
218	605	737	731	616	538	721	513	707	715	716	710	710	764	1076

Table 3.1.7d Concrete Temperatures in Frame D, Series I Column 3

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	53	54	55	56	57	58	59	60	61	62	63	64	65	66	
0	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
5	70	48	29	20	20	20	20	20	20	20	34	55	95	132	446
10	144	105	64	36	20	20	20	20	21	47	105	148	243	344	687
20	342	245	151	107	47	20	20	21	98	128	242	366	510	325	812
30	462	357	242	150	96	51	26	46	108	211	376	505	637	121	845
40	527	421	301	193	103	65	42	63	114	287	458	581	709	702	875
50	600	494	371	250	119	86	65	88	162	376	553	678	784	733	921
60	647	541	419	291	145	103	83	108	206	432	620	734	824	765	932
70	680	578	457	325	170	112	122	122	248	477	669	759	851	786	946
80	708	611	489	351	193	127	113	137	288	515	707	747	875	788	960
90	737	641	516	371	218	141	125	154	324	547	738	751	902	785	988
100	763	669	541	387	239	159	134	174	355	579	769	763	924	787	974
120	794	703	583	436	287	196	150	220	418	631	804	772	759	777	1010
140	831	749	638	504	348	247	197	271	479	679	846	785	761	781	1027
160	862	787	683	557	403	300	254	324	530	719	875	785	790	781	1039
180	848	815	722	605	458	351	306	379	576	753	773	781	809	771	1050
200	747	810	754	663	600	424	391	421	620	785	755	769	828	757	1061
218	763	809		763	719	563	561	466	656				846		1076

Table 3.1.8

Deflections, Series I Column 3

Minutes	Expansion, mm
0	0.0
5	0.3
10	1.5
20	2.4
30	2.8
40	3.3
50	3.8
60	3.9
75	5.3
90	6.0
105	6.4
120	6.6
145	6.0
160	4.9
170	4.0
180	2.9
190	1.3
200	-0.9
210	-3.8
218	-7.2

Table 3.1.9

Steel Temperatures, Series I Column 4

Minutes	Temperature (°C) Measured at Thermocouple #:										Furnace	
	1	2	3	4	5	6	7	8	9	10		
0	21	21	21	21	21	21	21	21	21	21	21	21
5	27	27	27	21	21	21	32	21	24	21	21	496
10	38	35	35	24	22	21	49	38	27	21	21	691
20	121	121	110	113	115	103	121	119	93	104	104	779
30	129	121	121	121		117	154	148	110			838
40	163	152	154	163	147	152	204	218	121	134	134	877
50	216	204	202	218	196	272	249	271	157	185	185	952
60	285	271	263	271	249	259	307	317	207	233	233	927
70	329	318	304	319	299	309	343	356	246	278	278	941
80	371	360	343	362	343	353	377	391	282	319	319	952
90	407	399	382	399	383	392	407	422	318	355	355	963
100	438	432	413	433	420	427	435	451	352	388	388	982
120	495	493	471	495	487	491	485	506	413	449	449	1010
140	557	552	532	547	544	544	538	536	474	503	503	1016
160	610	607	585	597	599	593	593	616	527	550	550	1038
180	663	660	641	651	661	640	641	687	582	598	598	1052
200	710	710	693	712	711	682	677	727	621	643	643	1066
220	746	721	716	741	749		721	746	685	685	685	1077

Table 3.1.10a Concrete Temperatures in Frame A, Series I Column 4

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
5	107	71	46	32	24	24	21	21	21	27	41		91	51	496
10	168	116	77	46	27	24	21	21	29	66	107	158	263	164	691
20	349	249	163	121	63	27	24	32	99	152	265	380	523	363	779
30	466	346	235	149	102	57	32	57	110	241	392	512	649	485	838
40	541	421	304	213	104	68	52	79	127	329	494	611	737	571	877
50	596	482	363	263	121	85	68	102	163	399	568	686	789	632	952
60	663	546	427	310	141	118	88	118	204	454	639	744	834	679	927
70	691	579	463	349	171	124	116	132	243	496	683	774	855	708	941
80	716	610	493	377	193	129	127	143	282	532	718	801	877	736	952
90	738	635	518	399	218	141	132	163	316	566	747	826	895	759	963
100	757	660	538	418	235	154	135	185	349	593	772	848	913	783	982
120	799	702	585	460	277	188	149	232	410	652	820	889	948	828	1010
140	829	735	638	516	335	232	191	279	468	696	856		958	859	1016
160	866	760	688	568	399	291	246	332	521	735	883			889	1038
180		793	724	618	449	341	299	382	571	768				914	1052
200	893		760	663	499	391	346	429	621	802					1066
220	907		793	699	546	441	404	477	668						1077

Table 3.1.10b

Concrete Temperatures in Frame B, Series I Column 4

Minutes	Temperature (°C) Measured at Thermocouple #:											Furnace	
	25	26	27	28	29	30	31	32	33	34	35		
0	21	21	21	21	21	21	21	21	21	21	21	21	21
5	51	39		21	21	21	21	21	21	21	21	36	496
10	164	112	65	38	21	21	21	21	21	46	108	691	
20	363	268	103	111	53	21	21	22	82	136	258	779	
30	485	377	244	158	97	46	25	52	107	226	381	838	
40	571	464	323	231	108	69	47	74	118	318	481	877	
50	632	526	383	287	137	86	63	92	157	391	554	952	
60	679	580	437	335	167	104	87	111	198	448	625	927	
70	708	616	477	374	196	121	111	128	238	492	672	941	
80	736	647	511	407	226	134	119	143	276	528	707	952	
90	759	674	540	437	253	145	125	161	312	558	735	963	
100	783	699	568	464	279	161	133	182	346	588	754	982	
120	828	743	622	516	331	206	156	232	408	644	806	1010	
140	859	774	669	563	386	258	201	287	468	694	844	1016	
160	889	807	710	611	439	311	260	341	522	733	873	1038	
180	914		748	655	489	360	311	393	572	771	896	1052	
200			782	693	533	407	357	447	622	802		1066	
220			811	725	573	452	405	516	668	822		1077	

Table 3.1.10c

Concrete Temperatures in Frame C, Series I Column 4

Minutes	Temperature (°C) Measured at Thermocouple #:										Furnace	
	40	41	42	43	44	45	46	47	48	49		
0	21	21	21	21	21	21	21	21	21	21	21	21
5	53	33	21	21	21	21	21	21	21	21	21	496
10	142	92	51	21	21	21	21	21	32	88	88	691
20	324	194	117	46	21	21	21	71	121	246	246	779
30	422	275	163		35	32	43	96	210	279	279	838
40	487	336	222		54	46	63	107	310	479	479	877
50	538	415	296	124	82	71	96	168	410	591	591	952
60	591	438	317	138	91	79	102	188	438	624	624	927
70	622	475	353	171	104	102	121	232	488	671	671	941
80	649	505	381	196	118	107	135	266	521	704	704	952
90	673	530	404	218	129	113	149	302	554	735	735	963
100	696	553	426	246	149	118	174	343	588	760	760	982
120	747	606	478	293	185	141	218	399	641	804	804	1010
140	788	660	536	357	241	188	274	460	691	843	843	1016
160	827	706	589	413	293	246	329	510	729	871	871	1038
180	860	748	637	463	343	296	377	560	763	896	896	1052
200	887	783	679	510	391	343	427	610	796	916	916	1066
220			713	563	441	407	474	652				1077

Table 3.1.10d

Concrete Temperatures in Frame D, Series I Column 4

Minutes	Temperature (°C) Measured at Thermocouple #:											Furnace	
	54	55	56	57	58	59	60	61	62	63	64		
0	21	21	21	21	21	21	21	21	21	21	21	21	21
5	21	21	21	21	21	21	21	21	21	21	21	38	496
10	99	46	24	21	21	21	21	21	21	21	49	93	691
20	252	135	102	38	21	21	21	71	116	235	341	341	779
30	368	224	141	93	38	21	41	99	191	368	485	485	838
40	449	299	204	96	57	32	54	107	288	471	588	588	877
50	510	357	266	107	74	52	79	135	360	346	663	663	952
60	557	404	302	135	91	71	102	185	341	621	727	727	927
70	593	446	343	160	107	93	113	224	327	663	757	757	941
80	624	482	377	185	121	116	129	266	357	702	788	788	952
90	649	510	407	213	129	116	143	307	377	724	810	810	963
100	677	538	435	241	146	121	160	338	407	746	829	829	982
120	704	566	466	266	166	124	185	368	466	768	854	854	1010
140	729	593	491	293	191	141	213	399	524	788	871	871	1016
160	768	643	538	352	241	191	266	463	524		902	902	1038
180	802	685	588	402	293	246	316	518	538		927	927	1052
200	838	721	632	454	346	296	368	566	568		941	941	1066
220	862	757	674	488	396	343	416	613	593				1077

Table 3.1.10d

Concrete Temperatures in Frame D, Series I Column 4

Minutes	Temperature (°C) Measured at Thermocouple #:											Furnace	
	54	55	56	57	58	59	60	61	62	63	64		
0	21	21	21	21	21	21	21	21	21	21	21	21	21
5	21	21	21	21	21	21	21	21	21	21	21	38	496
10	99	46	24	21	21	21	21	21	21	21	49	93	691
20	252	135	102	38	21	21	21	71	116	235	341	779	779
30	368	224	141	93	38	21	41	99	191	368	485	838	838
40	449	299	204	96	57	32	54	107	288	471	588	877	877
50	510	357	266	107	74	52	79	135	360	346	663	952	952
60	557	404	302	135	91	71	102	185	341	621	727	927	927
70	593	446	343	160	107	93	113	224	327	663	757	941	941
80	624	482	377	185	121	116	129	266	357	702	788	952	952
90	649	510	407	213	129	116	143	307	377	724	810	963	963
100	677	538	435	241	146	121	160	338	407	746	829	982	982
120	704	566	466	266	166	124	185	368	466	768	854	1010	1010
140	729	593	491	293	191	141	213	399	524	788	871	1016	1016
160	768	643	538	352	241	191	266	463	524		902	1038	1038
180	802	685	588	402	293	246	316	518	538		927	1052	1052
200	838	721	632	454	346	296	368	566	568		941	1066	1066
220	862	757	674	488	396	343	416	613	593			1077	1077

Table 3.1.11

Deflections, Series I Column 4

Minutes	Expansion, mm
0	0.0
5	0.4
10	1.1
20	2.7
30	3.2
40	3.7
50	4.5
60	4.9
75	5.9
90	6.7
105	7.4
120	7.6
135	7.6
150	7.0
165	5.9
180	4.4
195	2.2
210	-1.7
220	-3.9

Table 3.1.12

Steel Temperatures, Series I Column 7

Minutes	Temperature (°C) Measured at Thermocouple #:										Furnace
	1	2	3	4	5	6	7	8	9	10	
0	21	21	21	21	21	20	21	21	21	21	20
5	25	26	25	24	25	23	32	35	23	22	534
10	47	50	46	38	41	38	67	72	38	30	689
20	123	119	120	116	119	123	127	121	119	97	770
30	121	141	129	119	125	126	195	170	117	111	844
40	162	197	177	158	167	170	257	221	157	132	865
50	214	252	229	203	218	220	305	265	205	169	908
60	264	304	278	249	267	269	346	307	251	212	928
70	311	352	324	294	312	314	384	345	295	255	934
80	352	395	365	336	354	355	417	380	335	295	958
90	391	435	402	374	392	392	448	414	370	332	976
100	427	471	437	411	427	426	476	446	404	367	984
110	462	505	470	446	461	459	503	473	436	400	986
120	494	533	501	479	491	489	527	498	466	432	1011
130	523	559	530	509	520	517	551	526	495	462	1013
140	550	585	557	536	546	543	576	554	522	490	1019
150	577	609	585	561	572	568	601	580	547	516	1025
160	603	633	616	586	598	592	626	608	575	539	1045
170	627	656	650	611	626	615	648	638	600	563	1040
180	650	676	683	636	657	637	670	675	624	587	1048
190	673	697	709	663	688	659	693	709	649	610	1060
200	696	714	720	689	714	681	709	720	677	633	1047
205	705	720	719	698	721	689	714	719	690	643	1066

Table 3.1.13a Concrete Temperatures Measured in Frame A, Series I Column 7

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0	20	21	21	21	21	21	21	22	21	21	21	21	21	21	20
5	112	77	43	29	23	22	21	22	23	30	62	101	158	219	534
10	203	141	91	58	30	22	22	22	33	71	132	193	305	400	689
20	370	276	162	114	67	32	24	51	115	141	274	379	513	602	770
30	496	387	245	164	108	76	40	79	113	226	390	501	641	726	844
40	567	461	312	215	126	104	60	91	133	319	490	595	720	780	865
50	627	518	363	256	146	110	83	103	173	385	561	671	760	831	908
60	667	558	405	292	172	116	101	118	216	438	623	699	722	858	928
70	699	593	441	322	199	128	115	131	255	481	671	712	751	786	934
80	726	622	471	349	225	139	121	144	291	516	706	740	769	789	958
90	751	649	500	376	251	153	123	161	325	547	739	760	783	786	976
100	779	680	530	405	278	172	129	184	359	578	769	776	790	790	984
110	796	702	556	435	304	193	138	210	392	608	793	780	789	786	986
120	820	728	584	463	331	216	157	235	424	634	812	784	788	785	1011
130	839	750	612	491	357	240	182	261	454	658	831	788	784	786	1013
140	855	770	637	518	384	266	209	288	483	681	848	788	778	786	1019
150	869	789	660	542	410	292	237	314	510	701	863	786	777	783	1025
160	884	807	682	565	435	317	263	340	535	721	876	783	780	779	1045
170	898	823	702	588	459	342	289	365	559	740	889	780	778	774	1040
180	895	837	721	610	482	366	314	389	583	757	901	776	776	766	1048
190	873	845	741	632	505	389	339	415	606	774	877	771	787	754	1060
200	850	821	743	650	527	415	369	449	628	787	759	764	756	734	1047
205	866	835	751	658	539	430	388	472	638	787	750	760	751	724	1066

Table 3.1.13b Concrete Temperatures Measured in Frame B, Series I Column 7

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	25	26	27	28	29	30	31	32	33	34	35	36	37	38	
0	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20
5	124	88	46	32	22	21	21	21	22	29	60	90	158	211	534
10	226	162	98	61	30	22	21	22	31	65	131	178	312	397	689
20	391	306	180	121	65	32	24	47	110	132	269	362	518	601	770
30	521	423	268	170	109	63	37	70	108	220	390	491	648	726	844
40	589	495	338	225	123	98	72	93	117	288	484	583	721	741	865
50	653	556	392	273	154	106	93	106	161	368	557	661	783	744	908
60	697	599	438	317	188	110	101	114	208	422	618	713	820	767	928
70	729	637	480	357	222	117	107	127	253	466	669	753	848	780	934
80	761	670	516	393	253	130	117	141	295	503	705	783	862	797	958
90	788	700	548	427	281	147	126	162	333	536	736	812	771	801	976
100	814	730	581	458	306	166	133	184	369	568	765	837	783	801	984
110	828	749	607	486	329	187	141	209	401	599	785	769	786	795	986
120	852	774	632	513	355	208	154	234	433	624	804	776	788	794	1011
130	867	793	657	539	384	234	178	260	463	647	821	778	784	792	1013
140	882	811	679	563	413	261	210	288	491	669	836	779	778	789	1019
150	892	828	700	588	439	289	238	314	516	689	844	777	773	787	1025
160	776	844	719	612	464	316	265	341	540	709	768	777	771	785	1045
170	778	859	738	634	488	343	295	366	563	727	767	783	771	782	1040
180	823	872	755	655	512	372	340	392	587	743	764	872	767	779	1048
190	885	887	772	672	542	418	438	424	612	751	757	861	763	775	1060
200	854	856	766	688	594	503	566	486	638	741	731	839	743	759	1047
205	856	866	771	695	625	552	609	534	653	706	727	830	735	749	1066

Table 3.1.13c Concrete Temperatures Measured in Frame C, Series I Column 7

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	39	40	41	42	43	44	45	46	47	48	49	50	51	52	
0	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20
5	149	98	52	33	23	21	21	21	23	33	68	113	189	257	534
10	275	176	106	64	32	22	21	22	34	78	134	212	357	456	689
20	468	342	197	116	81	40	24	59	119	147	278	411	558	651	770
30	585	444	262	129	96	55	39	64	104	218	394	538	696	774	844
40	646	513	331	180	110	72	57	78	119	299	495	631	758	738	865
50	702	569	381	223	130	95	80	98	157	357	569	704	816	777	908
60	739	611	422	264	159	110	99	114	199	401	630	750	844	797	928
70	764	646	459	301	188	117	106	128	240	423	679	787	845	864	934
80	792	675	490	335	218	127	112	139	279	440	715	816	839	885	958
90	817	703	522	368	248	145	119	161	317	467	748	844	837	903	976
100	841	731	552	401	277	165	127	186	352	494	778	871	825	924	984
110	852	749	580	431	305	186	139	210	384	519	802	884	782	932	986
120	757	772	607	462	332	208	156	235	416	544	822	877	787	951	1011
130	760	791	634	491	360	233	181	261	448	566	842	786	794	963	1013
140	761	808	659	520	387	260	209	288	479	586	858	782	861	973	1019
150	762	821	682	547	414	289	236	316	507	605	872	782	888	975	1025
160	760	825	704	579	440	321	263	350	535	624	886	783	908	964	1045
170	752	819	724	613	467	367	292	410	561	644	898	777	912	962	1040
180	738	796	743	648	496	438	326	511	587	664	907	766	910	963	1048
190	818	754	759	680	539	527	372	608	614	699	902	745	882	951	1060
200	783	742	755	696	605	608	431	673	649	717	832	725	804	855	1047
205	782	738	759	702	635	635	462	692	667	722	794	723	819	803	1066

Table 3.1.13d Concrete Temperatures Measured in Frame D, Series I Column 7

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	53	54	55	56	57	58	59	60	61	62	63	64	65	66	
0	21	21	20	20	20	20	21	21	21	21	21	21	21	21	20
5	114	78	45	31	23	22	22	21	22	32	61	103	159	212	534
10	212	143	89	57	30	23	22	22	30	70	132	202	313	395	689
20	374	269	164	106	63	34	26	45	112	138	270	393	526	598	770
30	488	367	241	154	102	72	51	79	107	247	393	521	654	720	844
40	560	441	305	202	116	82	65	87	122	340	497	617	726	777	865
50	619	502	357	244	142	100	93	102	157	405	570	430	747	746	908
60	659	543	398	281	168	113	106	111	196	456	632	659	769	772	928
70	685	575	432	313	192	122	113	122	235	498	679	724	770	783	934
80	715	604	461	341	216	132	119	140	274	532	713	751	787	791	958
90	741	633	490	369	241	149	127	163	310	563	744	767	796	793	976
100	767	664	521	399	268	170	134	188	344	595	773	772	795	792	984
110	784	686	548	428	296	193	144	213	377	625	795	766	784	787	986
120	810	714	576	457	324	218	164	238	409	651	815	767	779	786	1011
130	830	739	606	487	352	244	193	264	440	672	831	770	777	785	1013
140	849	763	634	516	380	271	221	292	470	664	840	773	845	784	1019
150	866	784	660	542	407	298	248	318	499	680	852	774	859	783	1025
160	882	804	683	567	433	324	274	344	528	696	862	773	885	781	1045
170	895	819	705	593	458	348	300	370	557	711	840	768	853	779	1040
180	905	753	724	616	482	372	324	395	589	717	725	758	850	769	1048
190	916	765	743	639	505	395	347	427	619	719	736	751	852	756	1060
200	890	753	744	656	526	418	369	475	641	722	740	744	835	746	1047
205	911	763	754	665	536	429	380	500	652	723	744	742	835	745	1066

Table 3.1.14

Deflections, Series I Column 7

Minutes	Expansion, mm
0	0.0
5	0.3
10	0.7
20	2.3
30	2.7
40	3.0
50	3.7
60	4.1
75	5.0
90	5.7
105	6.0
120	6.0
130	5.9
140	5.5
150	5.0
160	4.2
170	2.8
180	1.4
190	-0.4
200	-4.0
205	-4.7

Table 3.1.15

Steel Temperatures, Series I Column 8

Minutes	Temperature (°C) Measured at Thermocouple #:										Furnace
	1	2	3	4	5	6	7	8	9	10	
0	20	20	19	18	15	14	20	17	19	18	16
5	26	27	25	22	19	17	35	34	23	20	621
10	47	62	64	35	31	28	80	85	42	28	725
15	96	109	102	97	78	80	113	119	90	71	780
20	108	114	107	119	118	119	116	145	102	109	823
25		119	115				138	196	105		852
30	116	137	129				167	237	114		863
35	132	161	150	132	124	121	193	270	129	117	901
40	151	188	177	149	143	137	220	299	151	128	890
45	173	216	203	168	166	159	244	324	174	144	881
50	196	243	229	190	191	183	264	345	199	164	891
55	220	267	255	211	214	206	284	364	224	185	906
60	243	288	279	234	237	230	302	382	247	206	907
70	286	327	323	278	280	273	337	416	291	248	926
80	326	361	363	319	319	312	371	446	331	288	946
90	364	393	400	356	354	348	404	477	367	324	973
100	400	424	435	391	389	382	437	507	401	358	989
110	434	454	469	423	421	414	468	533	434	390	995
120	467	483	500	455	452	444	498	558	466	421	1023
130	496	513	530	486	480	473	524	584	495	452	1022
140	524	545	562	516	507	500	548	608	522	481	1030
145	536	563	582	529	519	514	560	620	535	495	1033

Table 3.1.16a Concrete Temperatures Measured in Frame A, Series I Column 8

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0	20	20	20	20	20	20	20	20	20	20	20	20	20	19	16
5	126	96	47	31	22	20	20	20	23	33	67	118	177	268	621
10	231	173	104	66	30	21	20	21	33	84	141	222	341	465	725
15	330	256	130	98	49	24	21	27	84	127	207	331	461	585	780
20	414	331	178	123	72	33	23	42	105	143	280	417	547	665	823
25	480	392	221	146	103	50	28	47		174	342	486	614	715	852
30	524	437	258	173	104	62	37	57		224	397	540	661	856	863
35	566	476	291	200	104	71	46	66	116	279	446	585	708		901
40	602	511	323	228	107	77	55	75	132	321	492	632	744		890
45	609	527	349	254	117	84	63	86	149	357	528	656	747		881
50	628	546	372	276	130	92	72	97	167	386	555	681	669		891
55	647	566	393	296	145	99	81	107	186	411	582	704	716		906
60	663	585	413	315	159	107	91	117	207	433	608	723	736		907
70	695	620	448	349	186	122	109	131	246	472	650	755	761		926
80	721	649	479	377	208	135	120	145	284	505	685	782	776		946
90	757	684	509	404	229	146	129	159	318	535	718	815	788		973
100	783	712	537	430	250	159	136	179	350	567	749	844			989
110	803	736	563	455	274	177	141	201	381	598	774	867			995
120	823	755	589	482	302	199	150	223	412	628	796	883			1023
130	840	775	614	508	331	222	165	246	441	656	817				1022
140	856	793	638	533	360	247	192	271	470	677	834				1030
145	853	802	649	545	374	259	207	283	483	685	840				1033

Table 3.1.16b Concrete Temperatures Measured in Frame B, Series I Column 8

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	25	26	27	28	29	30	31	32	33	34	35	36	37	38	
0	18	18	18	18	19	19	19	19	19	18	18	18	18	18	16
5	142	86	47	29	20	19	19	19	21	31	73	120	198	292	621
10	265	164	104	65	30	19	19	19	29	99	147	240	377	496	725
15	368	246	143	100	49	22	19	23	64	121	228	353	490	605	780
20	452	318	193	118	74	30	22	35	95	142	299	434	564	672	823
25	518	378	239	145	94	48	27	45	95	197	363	501	633	710	852
30	555	423	280	180	113	65	36	55	100	248	421	552	674	745	863
35	595	460	314	209	119	81	55	65	106	283	470	601	721	793	901
40	619	491	344	233	123	92	78	75	113	315	514	646	755	810	890
45	622	505	366	255	138	100	90	86	123	346	545	666	756		881
50	642	524	386	274	153	104	96	97	138	382	573	689	774	820	891
55	661	544	406	293	167	109	103	108	157	414	601	711	791	835	906
60	679	563	426	313	183	112	107	116	178	438	626	729	805	846	907
70	712	598	463	350	215	119	113	131	219	479	668	763	833	868	926
80	740	630	496	383	246	132	118	140	255	512	702	790	855	889	946
90	780	667	529	415	274	146	123	154	290	544	736	824	890	920	973
100	808	699	561	447	301	164	128	175	322	577	767	852	912	936	989
110	830	726	592	475	328	184	138	198	354	607	791	870	928	948	995
120	853	750	620	502	354	207	158	222	384	635	810		941		1023
130		773	647	528	380	232	184	247	412	660	822		951		1022
140		791	671	553	406	258	209	272	441	682					1030
145		797		566	419	271	222	285	454	692					1033

Table 3.1.16c Concrete Temperatures Measured in Frame C, Series I Column 8

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	25	26	27	28	29	30	31	32	33	34	35	36	37	38	
0	18	18	18	18	19	19	19	19	19	18	18	18	18	18	16
5	142	86	47	29	20	19	19	19	21	31	73	120	198	292	621
10	265	164	104	65	30	19	19	19	29	99	147	240	377	496	725
15	368	246	143	100	49	22	19	23	64	121	228	353	490	605	780
20	452	318	193	118	74	30	22	35	95	142	299	434	564	672	823
25	518	378	239	145	94	48	27	45	95	197	363	501	633	710	852
30	555	423	280	180	113	65	36	55	100	248	421	552	674	745	863
35	595	460	314	209	119	81	55	65	106	283	470	601	721	793	901
40	619	491	344	233	123	92	78	75	113	315	514	646	755	810	890
45	622	505	366	255	138	100	90	86	123	346	545	666	756		881
50	642	524	386	274	153	104	96	97	138	382	573	689	774	820	891
55	661	544	406	293	167	109	103	108	157	414	601	711	791	835	906
60	679	563	426	313	183	112	107	116	178	438	626	729	805	846	907
70	712	598	463	350	215	119	113	131	219	479	668	763	833	868	926
80	740	630	496	383	246	132	118	140	255	512	702	790	855	889	946
90	780	667	529	415	274	146	123	154	290	544	736	824	890	920	973
100	808	699	561	447	301	164	128	175	322	577	767	852	912	936	989
110	830	726	592	475	328	184	138	198	354	607	791	870	928	948	995
120	853	750	620	502	354	207	158	222	384	635	810		941		1023
130		773	647	528	380	232	184	247	412	660	822		951		1022
140		791	671	553	406	258	209	272	441	682					1030
145		797		566	419	271	222	285	454	692					1033

Table 3.1.16d Concrete Temperatures Measured in Frame D, Series I Column 8

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	53	54	55	56	57	58	59	60	61	62	63	64	65	66	
0	15	15	15	15	15	16	16	14	14	14	14	13	13	13	16
5	125	83	44	26	18	16	16	15	18	25	69	117	189	271	621
10	237	156	104	60	26	17	16	16	37	75	144	234	360	470	725
15	338	234	134	94	46	20	17	38	106	114	223	345	470	573	780
20	420	305	185	116	80	45	26	67	111	115	288	421	532	630	823
25	481	359	228	134	94	54	30			153	353	493	599	693	852
30	519	400	267	162	101	58	36			188	413	549	644	726	863
35	562	439	300	188	107	64	44	71	116	220	460	597	684	767	901
40	591	472	331	212	108	73	53	77	133	250	502	643	722	784	890
45	597	488	354	235	117	82	62	86	153	280	534	663	728		881
50	615	507	374	254	132	93	71	95	174	307	561	686	747		891
55	631	525	392	273	149	102	81	104	195	332	586	707	765		906
60	645	541	410	289	164	109	94	109	215	354	608	725	780		907
70	673	571	440	318	190	113	110	122	253	393	646	755			926
80	699	599	469	345	215	122	115	139	289	427	683	778			946
90	735	635	500	374	242	137	118	160	323	460	718	807			973
100	763	667	531	404	270	159	126	182	356	492	750	834			989
110	786	694	560	434	298	182	135	206	389	523	776				995
120	810	717	588	463	326	207	157	231	421	551	797				1023
130	827	741	616	492	353	232	184	257	453	577	816				1022
140	832	760	641	518	381	258	211	283	483	601	832				1030
145		770	653	530	394	271	223	296	498	612	838				1033

Table 3.1.17

Deflections, Series I Column 8

Minutes	Expansion, mm
0	0.0
5	0.2
10	0.4
20	1.1
30	1.1
40	1.1
50	1.1
60	1.1
70	0.8
80	0.7
90	0.4
100	-0.2
110	-0.7
122	-1.7
130	-2.7
140	-4.3
145	-5.5

Table 3.1.18

Steel Temperatures, Series I Column 9

Minutes	Temperature (°C) Measured at Thermocouple #:										Furnace
	1	2	3	4	5	6	7	8	9	10	
0	8	5	2	2	-3	0	4	0	2	2	9
1	19	13	10	8	1	5	12	10	8	7	126
5	24	17	13	11	4	8	15	13	11	10	230
10	34	26	20	19	11	16	27	27	16	15	570
15	57	49	40	36	29	35	59	64	31	27	714
20	102	101	85	92	91	91	103	103	71	75	777
25	115	110	101	115	114	110	122	126	93	114	819
30	119	121	111	117	106	110	139	155	105	104	855
35	135	142	129	122	115	119	180	194	121	106	863
40	160	169	150	140	131	140	213	228	136	122	880
45	190	197	172	164	155	168	242	257	154	143	897
50	219	225	196	189	184	197	269	284	176	166	913
55	246	252	220	214	213	225	294	309	199	190	924
60	273	278	245	239	240	252	317	331	223	213	942
70	322	327	295	285	293	302	359	372	271	257	951
80	367	372	342	328	342	347	397	406	317	298	963
90	408	413	385	367	387	387	431	438	360	336	979
100	445	451	425	403	427	423	462	468	399	371	991
110	480	485	461	437	464	457	493	495	435	404	1002
120	514	518	494	470	498	488	521	521	468	436	1012
130	543	550	524	502	531	516	547	545	498	467	1022
140	572	588	552	537	558	542	572	569	526	497	1030
150	599	628	580	583	584	570	598	595	550	524	1038
160	630	675	610	637	610	605	623	622	578	549	1046
170	663	764	642	683	634	644	646	652	604	575	1054
180	698	766	674	715	657	682	667	684	629	600	1062
187	744		698	730	673	704	689	706	662	620	1051

Table 3.1.19a Concrete Temperatures in Frame A, Series I Column 9

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0	7	7	6	6	6	6	6	7	7	7	7	6	6	6	9
1	35	29	22	15	10	7	7	59	52	40	32	18	13	8	126
5	49	39	28	19	13	8	7	87	72	53	41	23	16	9	230
10	132	95	58	30	16	10	8	233	181	116	80	37	20	11	570
15	232	162	109	56	25	12	9	399	318	200	140	74	30	13	714
20	333	238	150	94	41	16	11	529	442	296	208	108	62	18	777
25	417	311	207	114	69	26	14	616	533	379	277	117	100	36	819
30	482	369	257	124	83	39	21	687	603	446	341	160	105	49	855
35	524	414	298	149	91	49	29	730	658	506	400	186	102	56	863
40	559	450	333	175	102	58	38	756	699	552	449	212	108	64	880
45	590	481	364	200	112	67	48	783	732	595	491	241	124	73	897
50	618	510	391	224	123	77	57	807	760	633	527	270	144	84	913
55	642	535	416	246	136	88	66	829	782	666	557	298	164	97	924
60	665	559	440	267	149	99	76	849	805	695	589	324	184	107	942
70	700	601	482	307	179	118	106	862	843	741	643	373	223	126	951
80	726	632	515	342	208	133	125	875	867	774	684	418	261	144	963
90	750	659	544	373	235	146	132	889	889	803	717	456	297	160	979
100	774	685	571	402	261	162	133	900	909	829	746	490	331	179	991
110	795	708	597	429	287	181	136	906	925	851	772	522	363	200	1002
120	815	730	622	458	313	201	144	905	936	870	794	551	396	225	1012
130	835	752	647	486	340	225	169	903	946	886	813	578	428	251	1022
140	852	772	670	513	368	251	198	795	954	894	831	602	459	278	1030
150	868	791	692	538	395	278	226	795	960	877	846	626	487	306	1038
160	870	810	693	563	422	304	252	789	958	881	858	648	514	332	1046
170	770	827	653	588	447	329	278	785	783	892	724	671	539	359	1054
180	768	834	675	611	472	354	302	779	764	817	734	691	563	389	1062
187	674	348	686	618	681	660	628	367	359	709	710	687	689	404	1051

Table 3.1.19b Concrete Temperatures in Frame B, Series I Column 9

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	25	26	27	28	29	30	31	32	33	34	35	36	37	38	
0	3	2	2	2	2	2	2	2	2	2	3	3	4	3	9
1	24	20	13	10	6	4	3	4	8	14	22	29	38	43	126
5	43	32	19	13	7	4	4	5	10	18	32	45	66	79	230
10	137	100	49	26	10	5	4	6	15	37	80	126	199	250	570
15	258	189	103	62	20	7	5	8	29	90	146	228	360	432	714
20	374	282	143	91	38	12	7	14	77	126	224	338	490	562	777
25	462	361	209	116	67	21	10	26	99	155	296	425	582	653	819
30	527	421	257	133	79	33	16	39	101	211	359	494	655	718	855
35	568	462	294	156	89	44	25	51	106	272	416	550	702	754	863
40	602	494	326	179	102	55	36	62	118	320	465	600	-73	785	880
45	631	523	354	201	113	65	46	73	139	360	507	642	523	748	897
50	658	550	380	223	123	76	56	85	163	393	543	681	608	766	913
55	680	574	404	243	134	87	67	97	186	424	580	712	617	781	924
60	702	596	425	263	147	99	79	110	209	452	612	739	638	795	942
70	733	630	464	300	175	116	100	129	254	500	667	783	719	805	951
80	756	657	497	334	204	127	112	142	296	538	707	812	598	805	963
90	779	682	527	366	233	142	123	161	335	572	739	838	620	804	979
100	801	706	553	395	261	161	132	186	371	603	767	862	643	801	991
110	821	728	581	424	287	181	141	210	405	631	792	881	665	796	1002
120	840	750	609	454	314	205	154	235	437	657	814	898	690	795	1012
130	859	773	638	485	342	230	172	260	467	681	834	913	715	793	1022
140	876	794	666	516	370	256	200	286	496	703	851	926	733	792	1030
150	892	814	691	544	398	282	229	312	522	724	867	938	741	787	1038
160	908	832	714	572	426	309	257	337	547	742	882	949	777	838	1046
170	782	848	735	598	451	335	283	362	572	760	896	959	778	933	1054
180	756	855	755	624	470	360	308	386	596	777	903	967	779	955	1062
187	754	858	682	644	494	383	753	405	615	790	913	971	797	962	1051

Table 3.1.19c Concrete Temperatures in Frame C, Series 1 Column 9

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	39	40	41	42	43	44	45	46	47	48	49	50	51	52	
0	3	3	2	2	2	2	2	2	2	2	3	5	5	5	9
1	26	22	15	11	6	3	3	4	9	15	26	36	47	55	126
5	43	34	21	15	8	4	3	4	12	21	37	54	78	96	230
10	129	94	47	28	11	5	4	6	17	39	85	129	206	273	570
15	255	181	102	64	20	7	4	8	31	98	155	249	402	499	714
20	370	275	142	103	37	11	6	14	90	126	243	368	524	617	777
25	457	352	193	121	72	20	10	33	109	165	310	451	599	685	819
30	523	414	237	153	80	33	16	43	106	232	363	520	669	748	855
35	563	454	268	177	84	43	25	52	103	285	404	578	718	782	863
40	595	485	297	201	97	53	35	61	116	328	439	628	754	811	880
45	624	514	326	227	102	63	46	70	135	365	469	669	785	835	897
50	651	540	353	251	105	72	55	81	158	397	502	703	812	855	913
55	674	566	376	270	118	82	65	93	182	426	576	732	834	776	924
60	696	590	398	291	131	92	75	105	204	452	606	757	855	788	942
70	728	629	442	334	161	109	100	117	246	497	656	798	880	800	951
80	753	658	477	369	188	121	111	128	287	534	693	825	890	801	963
90	777	684	508	398	214	132	115	147	326	567	727	848	896	802	979
100	799	708	535	426	240	150	124	174	362	599	765	744	795	802	991
110	719	730	561	452	267	173	133	200	395	627	778	722	797	905	1002
120	731	751	587	478	294	195	149	226	427	652	802	722	800	919	1012
130	743	772	614	507	323	220	173	252	458	676	823	718	801	930	1022
140	738	793	642	535	353	247	201	280	488	698	836	733	802	937	1030
150	757	812	668	563	382	274	229	307	515	719	852	752	799	949	1038
160	760	829	691	590	411	301	256	333	541	739	750	770	797	961	1046
170	768	839	713	614	438	327	282	360	566	757	748	787	792	961	1054
180	775	840	733	637	464	352	307	395	591	773	742	798	782	730	1062
187	769	856	748	655	484	372	326	491	621	777	722	825	765	729	1051

Table 3.1.19d

Concrete Temperatures in Frame D, Series I Column 9

Minutes	Temperature (°C) Measured at Thermocouple #:										Furnace
	53	54	55	56	57	58	59	60	61	62	
0	0	0	0	0	0	0	0	-1	-1	-1	9
1	21	15	10	6	2	0	0	0	3	7	126
5	45	30	16	10	4	0	0	0	5	12	230
10	149	101	49	25	9	1	0	1	11	29	570
15	284	187	103	83	22	4	1	3	26	86	714
20	398	283	149	106	52	9	3	10	98	121	777
25	484	362	208	128	90	22	7	32	114	150	819
30	547	416	246	159	94	36	14	46	106	202	855
35	584	457	284	190	97	46	23	54	105	251	863
40	616	491	316	218	103	56	34	62	114	294	880
45	644	521	345	243	107	66	44	71	128	332	897
50	670	548	372	268	120	75	53	79	150	365	913
55	693	573	397	291	135	85	63	88	174	396	924
60	715	597	421	314	152	95	73	99	198	423	942
70	747	634	464	354	184	113	96	118	243	472	951
80	770	662	497	387	213	130	116	139	286	512	963
90	793	687	525	416	239	144	127	156	324	547	979
100	814	709	550	441	263	156	134	173	358	580	991
110	832	729	574	464	286	174	136	195	390	613	1002
120	849	750	598	489	310	196	142	218	422	642	1012
130	867	772	625	516	338	221	163	243	456	670	1022
140	883	794	651	543	367	247	193	270	487	733	1030
150	898	813	676	570	396	275	222	297	515	705	1038
160	758	832	700	597	424	302	250	324	542	721	1046
170	762	849	721	621	451	328	276	349	568	739	1054
180	767	863	741	644	475	353	301	374	595	708	1062
187	854	764	756	661	494	371	319	393	614	714	1051

Table 3.1.20

Deflections, Series I Column 9

Minutes	Expansion, mm
0	0.0
5	0.1
10	0.5
20	1.7
30	2.5
40	2.7
50	3.3
60	3.7
70	4.1
80	4.2
90	3.9
100	3.8
110	3.8
120	3.8
130	4.0
140	4.0
150	3.1
160	2.0
170	0.4
180	-1.9
185	-3.4

3.2 EFFECT OF CARBONATE AGGREGATE

Specimen Properties:

Cross-Section: 305 x 305 mm (12 x 12 in.)
 Length: 3810 mm (12 ft 6 in.)
 Aggregate: Carbonate
 Reinforcement: 2.19% as four No. 8 bars.

Elevation, Cross-Section and Finishing Detail: Figure 3.1.1
 Layout of Thermocouple Frames in Concrete: Figure 3.1.2
 Locations of Thermocouples in Frames: Figure 3.1.3
 Locations of Thermocouples on Reinforcing Bars: Figure 3.1.4

3.2.1 Series I, Column 10

Test purpose: Effect of Carbonate Aggregate.
 Date tested: December 14, 1981.
 Loading: 800 kN, Concentric.

Measured Properties:

Cylinder strengths: 33.6 MPa at 28 days.
 40.9 MPa on test date.
 Relative humidity: 75%.

Results:

Test duration: 8 hours 30 minutes.
 Temperatures: Tables 3.2.1 and 3.2.2a to d.
 Axial deformations: Table 3.2.3

Observations

2:05 Small hairline cracks 50 to 75 mm long were observed on the E face of the column. Small cracks then appeared on other faces.
 2:30 The maximum expansion of 14 mm was reached.
 4:30 All major cracks had developed, and progressively worsened.
 5:00 Cracks on the E face were about 30 cm long and 6 mm wide. Cracks on other faces had also worsened.
 6:30 Column started to contract (from initial zero).
 7:00 Steel temperature exceeded 760°C (1400°F).
 8:00 Steel temperature reached 816°C (1500°F).
 8:10 The contraction was 20 mm and accelerated.
 8:30 Contraction was 24 mm as the column failed in compression with a mild crushing sound (Figure 3.2.1).

- 3:08 Cracks on N face were 60 cm long and 3 mm wide.
- 3:25 Cracks on E face widened to 6.5 mm.
- 3:28 Cracks on N face were 6 to 10 mm wide.
- 3:32 Cracks on N and S faces widened to 13 mm.
- 3:35 Cracks on E face reached 90 cm long and 13 mm wide. The column failed in compression. Concrete cover ruptured on all sides near the upper quarter point. A diagonal crack developed through the core of the column at the centre of the failed portion, and all main bars buckled (Figure 3.2.3).

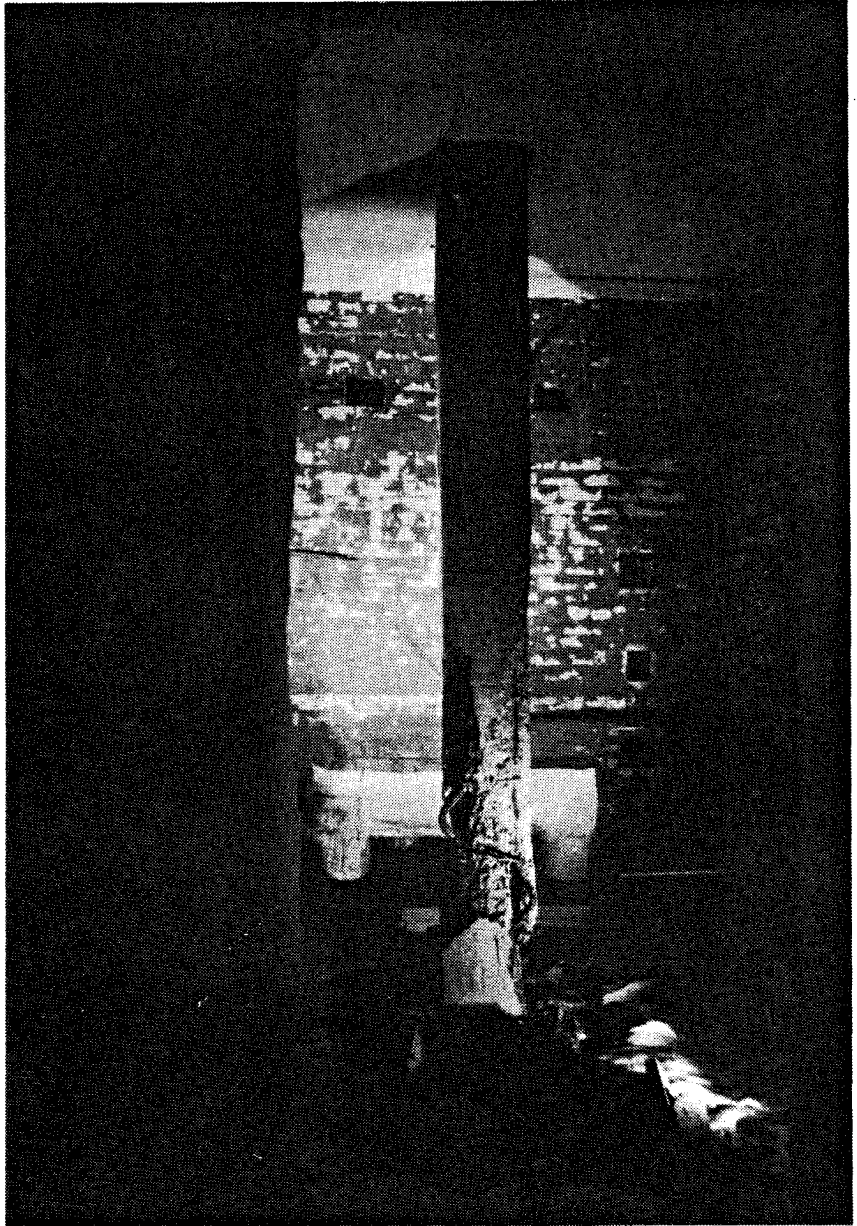


Figure 3.2.1 Series I Column 10 After Test

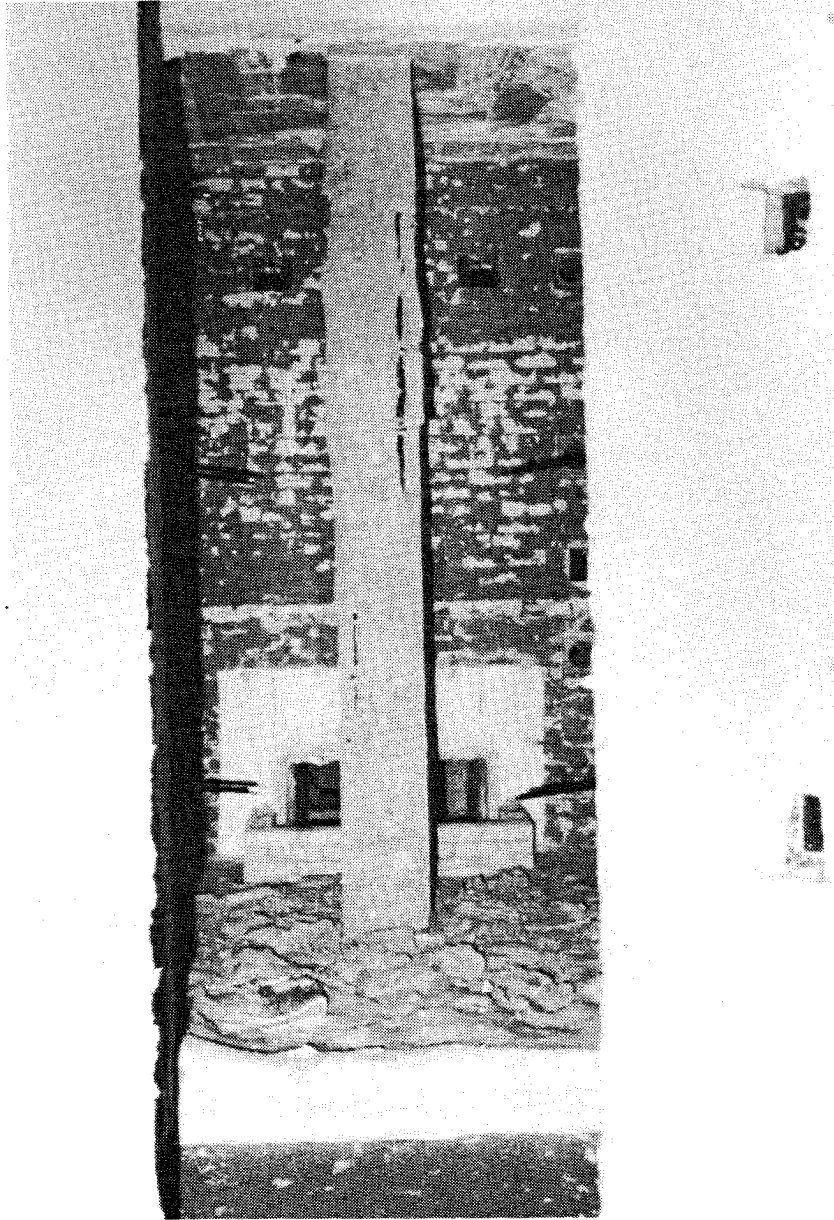


Figure 3.2.2 Series I Column 11 After Test

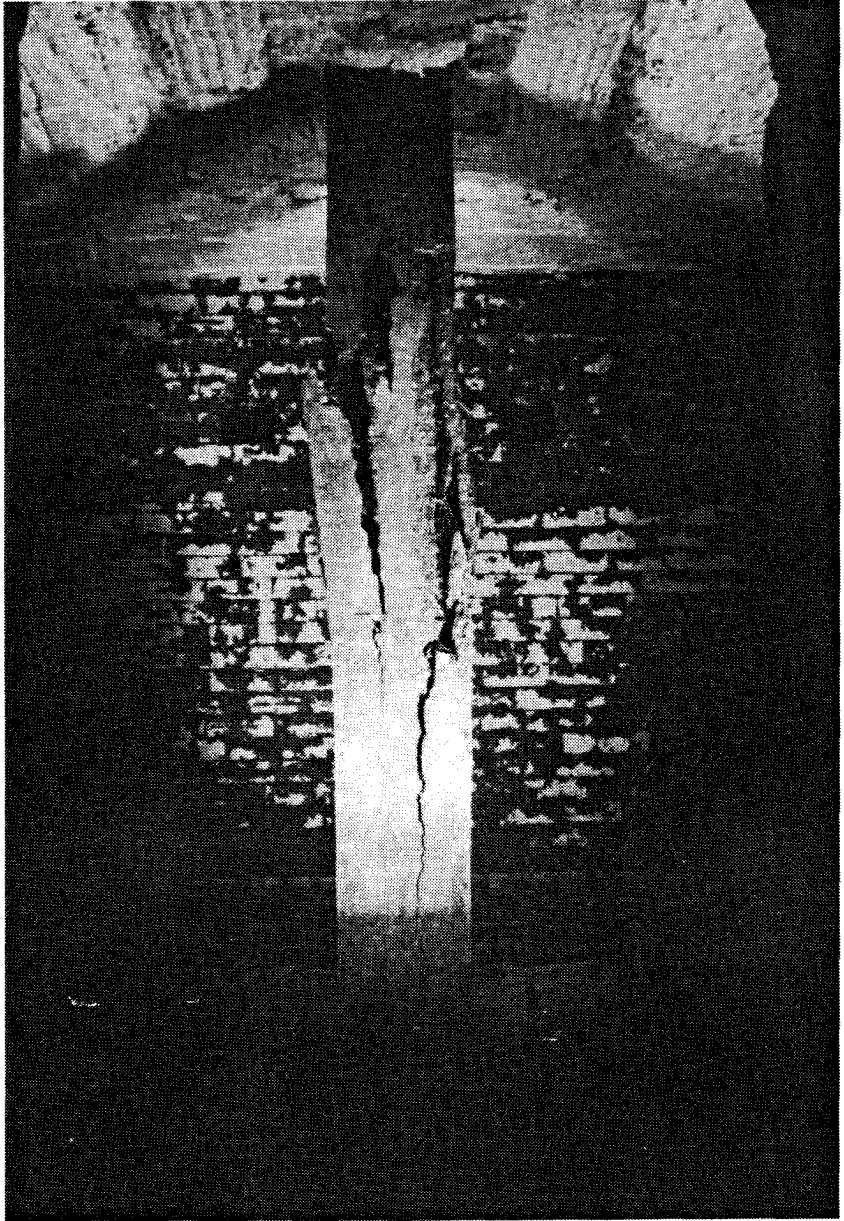


Figure 3.2.3 Series I Column 12 After Test

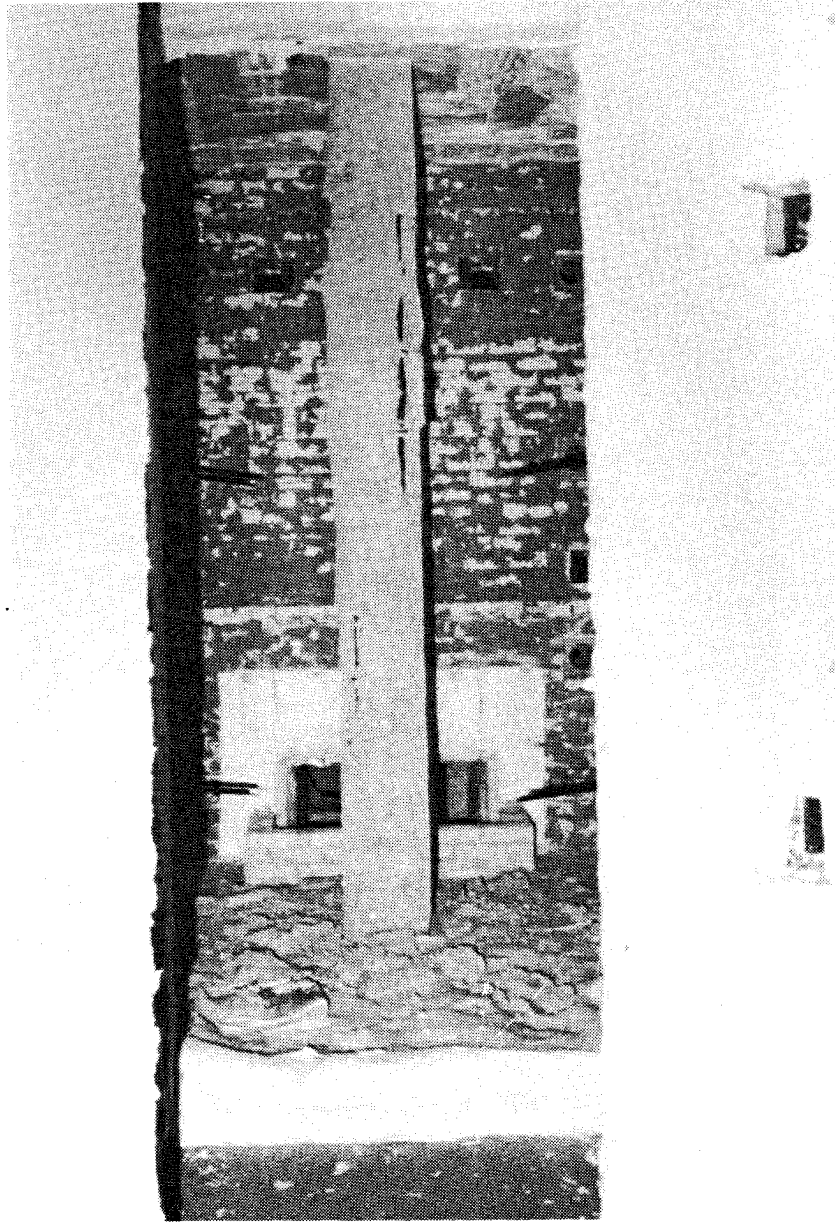


Figure 3.2.2 Series I Column 11 After Test

Table 3.2.1

Steel Temperatures, Series I Column 10

Minutes	Temperature (°C) Measured at Thermocouple #:									Furnace
	1	2	3	5	6	7	8	9	10	
0	19	18	16	12	5	17	15	16	17	13
5	28	25	24	18	12	28	30	21	20	596
10	45	41	44	33	25	59	66	31	28	692
20	107	104	106	106	121	131	92	95	436	780
30	127	121	139	117	181	192	109	107	558	841
40	170	170	190	154	242	244	145	134	631	875
50	221	222	245	203	292	291	192	175	678	907
60	269	270	296	253	334	336	237	218	712	933
80	351	348	374	335	398	412	318	295	764	966
100	413	407	431	398	445	472	381	360	810	1002
120	464	455	478	449	484	516	434	415	841	1029
140	506	496	518	491	518	549	478	462	849	1021
160	541	529	550	525	546	575	515	502	863	1032
180	569	557	577	554	572	599	545	535	879	1042
200	593	580	601	578	593	620	571	562	891	1049
220	614	600	623	599	613	640	593	585	908	1063
240	634	619	651	617	632	657	613	606	928	1082
260	656	637	668	634	649	672	632	626	948	1103
280	679	656	679	650	664	680	649	647	963	1115
300	698	672	684	667	676	684	658	667	975	1130
320	710	686	690	685	684	693	672	684	974	1141
340	721	696	699	699	690	702	685	697	967	1148
360	732	707	725	713	696		693	709	925	1174
380		716		725				721		1187
400				731				733		1198
420				752				743		1217

Table 3.2.2a Concrete Temperatures in Frame A, Series I Column 10

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0	19	19	19	18	19	19	19	18	19	18	18	18	18	17	13
5	160	99	49	35	23	19	19	19	23	34	68	118	179	256	596
10	273	179	99	71	32	20	19	20	30	73	137	215	314	417	692
20	313	178	132	74	28	22	33	85	137	261	387	506	604	442	780
30	423	263	202	109	63	33	68	104	227	375	510	623	712	559	841
40	502	332	260	125	75	52	79	123	311	470	595	692	768	628	875
50	555	385	308	157	86	70	93	159	377	540	649	736	810	672	907
60	593	429	350	192	102	94	109	198	426	585	687	772	848	706	933
80	646	495	417	253	128	118	135	270	493	638	741	834	901	758	966
100	688	543	467	300	160	133	174	331	536	684	787	875	943	803	1002
120	718	579	507	345	198	155	217	383	571	720	822	906	964	833	1029
140	736	606	540	389	245	205	264	430	600	747	841	918	956	843	1021
160	753	630	567	430	294	255	312	471	624	766	854	931	962	858	1032
180	771	653	593	468	340	302	355	506	645	784	867	944	969	874	1042
200	787	673	615	500	381	344	395	536	665	797	876	953	969	886	1049
220	804	691	635	527	418	382	430	561	682	811	890	968	970	903	1063
240	823	709	654	551	451	416	462	584	700	827	909	986		918	1082
260	842	727	671	571	480	448	490	603	717	843	929	1001		914	1103
280	857	744	688	589	505	477	515	621	730	856	943				1115
300	873	759	703	604	527	502	540	639	741	862	949				1130
320	884	770	716	620	547	527	569	657	744		932				1141
340	891	777		636	566	553	605	675	737						1148
360	885	777		654	591	608	645	691	730						1174
380				667				673	700	722					1187
400								692	708	721					1198
420								712	721	726					1217

Table 3.2.2b Concrete Temperatures in Frame B, Series I Column 10

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	25	26	27	28	29	30	31	32	33	34	35	36	37	38	
0	15	15	15	15	15	16	16	16	16	16	16	16	16	16	13
5	161	99	46	28	18	16	16	16	19	112	66	30	185	269	596
10	280	183	101	62	26	17	16	18	27	216	136	77	333	437	692
20	319	180	123	68	26	19	29	84	394	272	117	525	617	448	780
30	426	262	180	94	51	32	56	105	520	390	179	637	719	559	841
40	501	331	239	108	78	52	78	122	599	478	239	700	777	629	875
50	553	386	289	134	93	71	98	160	649	541	299	743	822	675	907
60	590	429	330	163	105	95	115	201	687	583	351	780	857	706	933
80	644	494	395	220	129	110	144	274	738	639	429	835	912	756	966
100	686	543	448	273	164	131	183	338	779	679	488	874	959	801	1002
120	717	581	493	324	210	167	234	393	814	716	536		981	832	1029
140	735	610	529	374	259	216	283	442	834	746	574		976	842	1021
160	753	634	559	418	307	264	329	485	848	767	603		987	857	1032
180	772	656	585	457	351	310	373	520	863	787	627		998	872	1042
200	788	676	608	491	391	352	411	550	875	801	649		1004	883	1049
220	805	695	630	521	427	389	447	576	890	815	669		1016	899	1063
240	817	713	649	547	460	423	479	598	908	828	686		1025	914	1082
260	808	729	666	571	491	456	507	618	921	836	701		1029	918	1103
280		740	681	596	523	488	536	637			706				1115
300		742	694	627	562	525	571	658			705				1130
320			703	660	605	575	617	678			708				1141
340			710	686	648	627	659	694			714				1148
360			717	705	681	668	687	706			723				1174
380			723	716	700	692	700	712			729				1187
400			731	724	715	707	709				736				1198
420			739	731	726	719	718								1217

Table 3.2.2c Concrete Temperatures in Frame C, Series I Column 10

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace
	39	41	42	43	44	45	46	47	48	49	50	51	52	
0	16	16	16	16	16	16	16	16	16	16	16	16	16	13
5	168	58	33	19	16	16	17	20	34	80	122	198	272	596
10	290	113	73	27	18	16	18	31	87	158	232	357	453	692
20	213	137	103	27	19	35	92	160	306	415	547	633	404	780
30	298	206	94	55	31	73	107	260	425	535	650	727	523	841
40	371	268	102	70	51	84	131	339	512	607	710	779	593	875
50	426	319	129	95	79	99	171	400	569	657	752	821	641	907
60	468	359	157	102	103	103	212	446	608	693	788	852	672	933
80	528	419	213	127	107	137	285	510	665	747	839	897	726	966
100	571	467	270	169	126	181	348	554	707	789	873	939	770	1002
120	606	510	324	213	163	231	403	590	739	819	895	963	800	1029
140	632	544	373	262	212	284	452	620	763	835	908	961	814	1021
160	653	571	418	310	261	333	493	643	781	847	920	970	831	1032
180	673	594	456	354	308	376	527	663	796	860	939	984	848	1042
200	691	616	490	393	350	415	555	681	808	872	951	995	862	1049
220	709	636	520	429	388	449	577	697	822	889	968	1011	880	1063
240	725	654	550	463	423	479	597	713	837	907	986	1029	900	1082
260	735	670	587	501	466	507	615	729	849	925	1001	1044	920	1103
280	733	683	629	554	527	535	635	742		932			931	1115
300	722	696	664	615	598	574	656	743						1130
320	717	707	691	662	653	624	676	728						1141
340	719	717	708	690	685	665	689	707						1148
360	725	727	720	707	703	688	697	698						1174
380	730	735	730	719	715	701	703	699						1187
400	739	745	741	732	728	712	712	709						1198
420	752	757	754	748	742	723	721	722						1217

Table 3.2.2d

Concrete Temperatures in Frame D, Series I Column 10

Minutes	Temperature (°C) Measured at Thermocouple #:											Furnace	
	53	54	55	56	57	58	59	60	61	62	63		
0	6	6	7	7	7	7	7	7	7	7	7	7	13
5	136	92	40	22	11	8	8	8	12	27	69	596	
10	244	171	96	56	19	9	8	9	23	83	148	692	
20	307	177	119	78	20	12	24	85	152	293	399	780	
30	416	262	184	101	63	29	52	108	242	414	524	841	
40	493	334	243	108	75	48	79	143	324	507	606	875	
50	546	389	291	125	87	67	103	186	389	568	656	907	
60	575	407	284	127	106	106	112	228	437	609	689	933	
80	632	489	388	200	125	111	146	305	503	662	736	966	
100	674	539	441	255	159	133	185	369	551	704	782	1002	
120	704	575	485	308	204	163	234	422	591	738	814	1029	
140	724	606	524	360	253	207	284	469	623	765	832	1021	
160	743	631	555	407	302	258	331	508	647	783	845	1032	
180	762	653	582	448	348	306	374	539	668	800	859	1042	
200	778	672	604	483	388	348	412	567	686	816	871	1049	
220	795	691	624	512	424	386	447	589	702	831	886	1063	
240	814	709	643	537	457	421	480	609	719	846	904	1082	
260	830	727	661	559	487	456	514	628	734	860	922	1103	
280	841	741	676	578	516	495	555	648	749	866	933	1115	
300		749	689	597	553	547	599	668	760			1130	
320		750	697	622	599	605	636	687	760			1141	
340		746	703	650	644	653	664	703	748			1148	
360		745	709	674	675	684	684	714	735			1174	
380		747	716	692	695	703	698	722	730			1187	
400		752	728	708	713	718	707	730	732			1198	
420		762	743	724	730	735	716	738	738			1217	

Table 3.2.3

Deflections, Series I Column 10

Minutes	Expansion, mm
0	0.0
5	0.4
10	1.2
20	3.6
30	4.5
40	5.1
50	5.8
60	6.9
70	7.8
80	8.6
90	9.3
100	10.0
120	10.8
140	11.1
160	11.1
180	10.9
200	10.3
220	9.4
240	8.2
260	6.5
280	4.4
300	2.2
330	-1.2
360	-4.3
390	-7.2
420	-10.0
450	-13.2
480	-18.2
510	-26.0

Table 3.2.4

Steel Temperatures, Series I Column 11

Minutes	Temperature (°C) Measured at Thermocouple #:										Furnace	
	1	2	3	4	5	6	7	8	9	10		
0	20	20	20	20	20	20	20	20	20	20	20	20
5	28	24	24	25	20	15	30	27	20	20	20	564
10	46	43	45	60	37	33	67	62	30	26	26	686
20	107	108	105	125	109	112	133	132	87	101	101	787
30	135	131	139	217	135	133	209	188	115	112	112	840
40	182	182	189	269	186	183	273	250	150	122	122	881
50	233	233	245	318	242	243	323	302	201	162	162	902
60	282	284	297	353	294	297	363	345	248	202	202	924
70	324	333	342	378	339	343	396	381	290	241	241	947
80	361	372	381	411	377	383	426	412	327	277	277	965
90	392	406	414	438	410	417	452	441	361	311	311	977
100	420	436	442	463	438	446	473	465	389	342	342	987
110	446	462	467	486	463	472	493	487	415	369	369	999
120	470	485	491	505	485	495	511	506	438	395	395	1011
140	512	525	531	540	524	534	544	541	481	442	442	1031
160	547	558	565	572	557	566	573	571	518	486	486	1044
180	577	586	593	600	586	595	599	598	550	523	523	1062
200	602	611	619	625	611	619	622	623	577	555	555	1071
220	625	635	643	649	635	641	644	647	601	580	580	1090
240	646	658	667	673	661	660	666	670	622	603	603	1098
260	666	680	687	693	686	678	685	687	651	624	624	1111
280	686	695	681	696	699	694	694	693	666	646	646	1117
300	703	702	681	693	701	708	665	693	676	666	666	1119
320	716	701	682	687	705	718	693	698	685	683	683	1127
340	727	692	689	691	705	725	692	705	690	692	692	1131
360	730	693	693	700	708	726	696	708	696	698	698	1130
365	730	693	695	703	711	729	697	710	697	701	701	1130

Table 3.2.5a Concrete Temperatures in Frame A, Series I Column 11

Minutes	Temperature (°C) Measured at Thermocouple #:												Furnace	
	11	12	13	15	16	17	18	19	20	21	22	24		
0	20	20	20	20	20	20	20	20	20	20	20	20	20	20
5	108	71	43	20	20	20	20	21	31	66	111	229	564	
10	196	131	89	26	20	20	20	29	68	132	205	392	686	
20	356	254	157	56	25	20	27	94	132	257	387	600	787	
30	472	357	235	98	71	36	61	110	216	373	515	702	840	
40	548	434	304	113	81	54	77	126	302	468	598	763	881	
50	595	488	357	129	95	71	95	162	368	535	651	803	902	
60	629	528	399	151	107	96	111	201	416	572	687	837	924	
70	658	1060	434	179	122	121	127	238	452	604	716	866	947	
80	681	586	463	205	135	135	140	271	480	635	744	888	965	
90	698	605	486	228	147	142	152	298	503	660	766	905	977	
100	712	621	505	249	159	142	167	325	521	677	785	907	987	
110	727	636	524	271	176	142	187	353	537	691	801	921	999	
120	743	652	543	295	196	152	210	381	554	706	816	930	1011	
140	772	683	580	345	243	201	258	434	587	732	841	938	1031	
160	799	710	610	392	292	253	306	480	617	755	863	986	1044	
180	822	733	636	433	338	301	350	518	644	776	883	1007	1062	
200	841	755	660	469	379	342	390	549	667	791	903	1030	1071	
220	863	777	683	501	416	381	426	575	688	807	928	1057	1090	
240	882	797	704	528	450	415	459	597	707	823	949	1075	1098	
260	898	815	723	552	480	448	488	616	723	838	965	1070	1111	
280	910	830	740	572	507	481	513	635	740	850	980	1001	1117	
300	908	839	751	591	533	515	536	652	755	860	982	917	1119	
320	880	827	753	609	559	557	557	669	766	870	958	901	1127	
340	833	806	742	630	590	601	582	684	768	862	908	797	1131	
360	792	778	728	652	625	640	615	695	754	823	818	716	1130	
365	706	705	701	689	627	642	687	697	691	680	706	675	1130	

Table 3.2.5b Concrete Temperatures in Frame B, Series I Column 11

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	25	26	27	28	29	30	31	32	33	34	35	36	37	38	
0	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
5	124	87	45	28	20	20	20	20	20	27	62	96	170	240	564
10	230	167	97	62	26	20	20	20	27	70	131	187	317	412	686
20	391	303	186	124	61	25	20	28	99	130	266	368	528	620	787
30	493	398	269	186	97	53	30	61	111	227	389	498	641	717	840
40	570	470	335	239	116	79	52	82	128	280	486	584	705	776	881
50	618	523	389	287	139	97	72	97	174	325	553	638	748	817	902
60	653	562	431	327	167	110	93	113	220	373	595	676	784	852	924
70	682	592	464	358	192	122	107	129	260	412	626	706	818	882	947
80	705	616	491	383	216	135	115	145	296	447	651	731	843	907	965
90	723	634	510	402	237	148	125	160	327	477	672	752	862	926	977
100	740	650	527	420	258	164	135	178	354	501	691	771	875	941	987
110	757	666	544	441	280	183	145	198	380	522	708	788	887	954	999
120	776	684	563	465	305	206	161	222	406	542	724	804	901	970	1011
140	809	718	602	513	357	254	207	272	457	578	755	831	932	993	1031
160	837	749	635	551	406	302	257	321	499	610	782	853	960	1013	1044
180	860	775	662	581	448	348	305	365	534	641	805	872	982	1031	1062
200	875	797	686	607	484	390	347	405	563	663	823	893	999	1047	1071
220	878	818	703	631	516	436	386	442	589	683	842	917	1023	1069	1090
240	840	832	711	653	544	502	422	474	611	701	858	930	1039	1069	1098
260	800	837	718	672	571	567	465	502	630	716	870	938	1037	720	1111
280	801	808	726	684	609	593	528	530	648	723	866	930	992	697	1117
300	802	760	732	688	654	642	611	565	663	717	831	880	883	726	1119
320	761	733	731	696	688	678	671	613	675	704	771	802	772	726	1127
340	735	726	727	708	707	702	702	659	682	698	722	739	727	717	1131
360	726	727	723	718	718	714	717	688	688	699	702	716	710	709	1130
365	715	730	722	720	722	715	719	688	691	702	705	720	708	712	1130

Table 3.2.5c Concrete Temperatures in Frame C, Series I Column 11

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace	
	39	40	41	42	43	44	45	46	47	48	49	50	51	52		
0	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
5	162	104	55	30	20	20	20	20	20	35	80	131	223	306	564	
10	286	197	108	67	26	20	20	20	31	91	165	255	404	491	686	
20	468	352	218	133	65	25	20	36	95	171	328	453	607	681	787	
30	573	455	306	197	98	51	32	59	107	267	454	571	700	761	840	
40	642	530	378	260	103	69	60	88	122	343	538	638	756	826	881	
50	682	577	435	313	122	86	80	98	167	405	592	685	797	860	902	
60	716	614	479	357	154	103	98	102	213	450	631	718	830	888	924	
70	746	645	514	393	184	113	107	117	257	486	661	745	856	911	947	
80	770	670	542	423	211	128	111	138	296	517	681	771	875	917	965	
90	788	689	565	448	233	145	116	157	331	542	707	792	894	876	977	
100	803	705	581	469	254	162	128	176	360	563	725	808	911	782	987	
110	819	720	595	488	278	182	100	197	387	582	740	823	927	778	999	
120	834	735	610	508	306	204	158	222	413	598	755	836	942	781	1011	
140	862	763	644	546	364	253	207	276	461	629	785	860	969	761	1031	
160	887	789	675	578	414	303	256	327	502	657	809	883	995	781	1044	
180	909	812	700	606	457	350	304	372	537	681	831	909	1015	969	1062	
200	926	831	722	632	493	391	347	413	566	698	851	933	1032	1010	1071	
220	948	852	744	656	525	428	386	449	591	695	869	956	1052	1016	1090	
240	963	870	762	676	551	461	421	481	612	701	884	973	1062	1003	1098	
260	972	883	777	692	573	492	455	512	631	715	898	967	1063	1030	1111	
280	958	882	784	701	592	525	492	547	649	727	905	931	1044	985	1117	
300	888	841	765	699	616	571	547	597	664	728	884	887	976	908	1119	
320	790	772	732	697	649	630	616	648	679	715	824	805	857	797	1127	
340	735	730	715	704	678	676	668	678	688	702	758	742	756	728	1131	
360	717	715	709	708	693	695	691	696	700	722	713	712	712	707	1130	
365	718	717	711	713	696	695	694	700	700	699	698	699	700	706	1130	

Table 3.2.5d Concrete Temperatures in Frame D, Series I Column 11

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	53	54	55	56	57	58	59	60	61	62	63	64	65	66	
0	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
5	116	80	36	21	20	20	20	20	20	23	58	97	169	252	564
10	219	153	94	50	20	20	20	20	20	75	135	196	327	437	686
20	392	295	170	104	60	20	20	31	95	142	147	382	540	642	787
30	513	407	259	149	101	73	34	72	110	252	180	512	648	735	840
40	589	486	329	198	112	77	52	84	122	338	198	596	709	791	881
50	632	537	382	242	131	92	72	98	160	400	271	646	743	831	902
60	666	573	423	280	157	105	95	200	200	445	465	682	777	865	924
70	696	603	457	311	182	113	112	122	236	479	616	712	813	897	947
80	721	628	486	337	208	127	122	139	269	506	652	733	836	920	965
90	741	648	508	358	233	144	129	161	298	528	680	760	856	936	977
100	756	663	527	380	256	162	138	184	326	546	698	780	870	952	987
110	772	679	545	406	280	181	146	206	353	562	715	797	882	966	999
120	788	695	565	435	306	201	159	228	381	578	731	813	897	980	1011
140	818	725	600	488	358	250	206	277	434	608	758	838	929	1001	1031
160	845	752	630	529	406	299	257	326	479	636	748	858	957	1008	1044
180	869	778	656	561	448	346	305	371	516	659	775	876	961	960	1062
200	890	801	680	588	485	386	347	410	547	680	623	898	983	751	1071
220	913	825	705	614	516	424	386	446	1073	701	613	926	1020	829	1090
240	933	843	726	637	543	457	420	478	596	721	636	946	1028	878	1098
260	950	861	745	658	566	488	453	506	616	738	653	932	1031	845	1111
280	963	876	761	677	586	513	482	530	635	754	664	936	1024	876	1117
300	966	886	777	695	604	536	508	548	653	767	680	957	993	919	1119
320	943	878	788	707	622	557	536	580	669	773	700	927	917	823	1127
340	887	837	790	715	641	580	568	611	683	768	729	862	836	841	1131
360	824	784	776	717	662	612	608	642	689	753	730	779	786	809	1130
365	830	784	776	720	665	616	611	642	691	758	728	763	787	822	1130

Table 3.2.6

Deflections, Series I Column 11

Minutes	Expansion, mm
0	0.0
5	0.5
10	1.0
20	2.9
30	3.7
40	4.2
50	4.8
60	5.5
70	6.1
80	6.6
90	7.2
100	7.5
120	7.8
140	7.9
160	7.9
180	7.1
200	5.8
220	4.0
240	1.6
260	-1.5
280	-5.0
300	-8.8
320	-12.6
340	-16.1
360	-19.6
365	-20.6

Table 3.2.7

Steel Temperatures, Series I Column 12

Minutes	Temperature (°C) Measured at Thermocouple #:										Furnace
	1	2	3	4	5	6	7	8	9	10	
0	19	20	19	18	16	13	21	20	18	18	91
5		24	24		20	15	34	31	21	20	589
10		39	44		35	25	70	73	31	28	680
15	82	88	89	82	80	69	109	113	60	57	738
20	105	106	107	104	102	106	140	142	98	92	792
25	107	109	116	110	109	109	176	175	108	106	820
30	121	124	134	118	113	108	210	209	108	109	847
35	137	142	159	135	132	117	242	240	122	112	873
40	155	163	185	157	156	133	271	267	142	128	894
45	177	187	211	182	179	154	298	291	166	149	903
50	199	211	236	207	201	177	321	312	189	171	904
55	222	236	260	231	224	200	341	331	212	194	918
60	243	261	282	254	246	224	359	348	234	215	929
65	263	286	304	276	267	246	376	363	256	236	926
70	283	308	323	296	287	266	391	378	276	256	947
75	288	328	342	316	306	286	405	391	295	275	954
80	297	346	359	333	323	304	418	404	312	293	960
85	306	363	374	350	340	322	431	416	329	310	969
90	316	379	389	365	356	339	443	427	344	325	976
95	318	393	402	379	370	354	454	438	359	340	981
100	332	407	415	393	384	368	464	449	372	354	989
105	346	420	427	405	397	382	474	459	385	367	994
110	348	432	439	417	410	395	484	470	397	379	1005
115	357	444	450	429	422	408	493	480	410	391	1007
120	367	455	461	440	434	419	502	489	421	403	1013

Table 3.2.8a Concrete Temperatures in Frame A, Series I Column 12

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0	33	29	24	21	19	17	17	17	19	22	29	36	43	49	91
5	129	89	47	30	21	17	17	17	22	35	73	123	186	266	589
10	223	158	94	58	28	19	17	19	30	74	136	221	316	417	680
15	305	223	128	90	41	21	18	21	52	118	201	315	424	530	738
20	383	287	170	115	58	26	20	27	83	142	263	396	516	618	792
25	445	343	211	139	83	36	24	40	101	187	323	463	580	671	820
30	494	390	249	167	98	55	30	55	110	240	379	519	626	712	847
35	533	429	283	195	102	64	39	65	108	284	427	565	664	746	873
40	566	463	314	222	108	69	48	72	119	324	468	602	694	772	894
45	592	492	343	247	114	75	57	78	135	358	504	629	717	791	903
50	609	515	368	269	125	83	65	86	154	387	531	650	733	803	904
55	625	534	389	290	137	93	73	96	173	413	553	667	747	818	918
60	641	551	408	308	151	103	86	105	193	435	570	683	761	833	929
65	652	565	426	326	165	110	110	113	212	454	586	697	774	839	926
70	664	577	441	341	178	117	118	122	231	471	600	709	788	853	947
75	675	589	455	354	190	125	125	132	249	486	612	720	800	864	954
80	685	600	467	365	201	133	129	141	266	499	624	731	810	873	960
85	694	609	479	376	212	139	131	149	282	511	634	741	821	883	969
90	703	618	489	387	223	145	132	156	298	522	644	751	830	893	976
95	712	627	499	397	235	151	131	164	313	531	654	761	839	901	981
100	720	635	509	408	246	159	129	172	328	541	663	772	847	909	989
105	729	643	519	420	258	168	132	180	342	550	671	781	854	919	994
110	737	651	529	431	271	177	138	189	355	559	679	779	861	926	1005
115	745	659	538	442	283	188	142	199	369	568	687	799	868	932	1007
120	753	667	547	453	295	199	152	209	382	576	694	806	874	939	1013

Table 3.2.8b Concrete Temperatures in Frame B, Series I Column 12

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	25	26	27	28	29	30	31	32	33	34	35	36	37	38	
0	25	24	21	18	16	15	15	15	17	20	26	31	37	42	91
5	118	89	47	28	18	16	16	16	20	32	71	117	200	271	589
10	209	155	101	58	26	17	16	17	28	74	141	214	344	434	680
15	289	222	133	95	41	20	21	21	51	107	207	310	458	550	738
20	363	286	179	110	62	25	19	31	95	137	272	394	551	640	792
25	425	343	226	141	84	41	24	53	105	188	336	463	612	693	820
30	474	391	267	172	95	53	32	61	105	235	393	519	656	732	847
35	515	431	304	199	105	63	42	69	107	275	443	564	691	762	873
40	548	466	335	225	113	71	51	76	118	312	487	600	720	789	894
45	573	494	363	249	122	80	59	84	133	344	522	628	741	809	903
50	591	516	387	270	131	88	68	93	151	372	549	650	757	822	904
55	607	534	407	290	142	96	77	102	171	396	571	667	772	837	918
60	622	551	426	308	155	104	87	111	191	418	589	683	786	850	929
65	634	564	442	324	168	111	97	120	210	438	605	696	797	856	926
70	645	577	456	338	181	118	106	130	228	455	618	706	809	869	947
75	656	588	469	340	193	125	112	139	245	471	630	717	821	879	954
80	666	598	481	362	205	131	111	147	262	485	642	728	831	889	960
85	675	607	491	372	215	137	121	153	278	498	652	737	841	898	969
90	683	615	501	381	226	142	126	160	293	509	661	747	850	906	976
95	691	623	509	390	236	148	130	166	306	520	670	757	857	914	981
100	699	630	518	400	247	155	134	173	320	529	678	767	865	922	989
105	706	638	526	410	258	163	136	181	333	539	686	776	872	930	994
110	714	645	535	421	269	172	140	192	345	548	693	784	879	937	1005
115	721	653	544	432	280	182	145	202	358	556	700	792	886	944	1007
120	729	660	553	443	292	192	151	213	371	563	707	800	893	950	1013

Table 3.2.8d Concrete Temperatures in Frame D, Series I Column 12

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace
	53	54	55	56	57	58	59	60	61	62	63	64	66	
0	21	19	16	14	12	11	11	11	13	16	21	25	39	91
5	96	66	35	21	14	12	12	12	15	26	62	107	254	589
10	172	125	80	44	20	13	12	13	25	87	126	200	418	680
15	243	182	116	73	31	15	13	16	57	101	157	293	535	738
20	309	236	151	104	52	21	15	26	97	121	156	377	621	792
25	365	286	188	110	76	38	20	45	105	174	186	445	674	820
30	413	330	224	129	88	52	28	58	105	220	233	500	710	847
35	452	367	257	150	96	59	38	66	110	254	262	544	744	873
40	486	400	286	169	104	67	47	73	124	287	289	582	1151	894
45	513	427	312	187	111	904	56	80	143	318	322	609		903
50	532	449	334	204	119	82	65	90	163	346	341	631		904
55	549	468	354	222	131	91	75	102	183	370	355	650		918
60	564	485	371	239	142	100	86	106	203	392	370	666		929
65	576	500	388	255	154	110	99	112	222	412	388	680		926
70	587	513	402	270	166	118	110	121	240	430	404	692		947
75	598	525	416	284	177	125	117	131	258	446	419	703		954
80	608	537	429	297	189	130	120	138	275	460	432	713		960
85	618	547	441	310	201	133	122	147	291	473	445	722		969
90	627	557	452	323	213	139	124	156	307	486	457	731		976
95	636	566	463	335	225	145	129	166	322	498	470	739		981
100	645	575	474	348	237	154	134	177	336	509	482	748		989
105	653	584	484	360	248	164	138	189	350	519	494	757		994
110	661	593	494	372	260	175	145	200	364	529	505	766		1005
115	669	601	504	385	272	186	153	212	377	538	516	774		1007
120	676	609	513	397	284	198	163	223	389	547				1013

Table 3.2.9

Deflections, Series I Column 12

Minutes	Expansion, mm
0	0.0
5	0.4
10	0.7
20	1.7
30	2.1
40	2.3
50	2.5
60	2.5
70	2.5
80	2.5
90	2.5
100	2.5
110	2.3
120	2.0
130	1.6
140	1.0
150	0.3
160	-0.7
170	-1.9
180	-3.4
190	-5.3
200	-7.6
210	-10.2
215	-11.9

3.3 EFFECT OF LIGHTWEIGHT AGGREGATE

Specimen Properties:

Cross-Section: 305 x 305 mm (12 x 12 in.)
 Length: 3810 mm (12 ft 6 in.)
 Aggregate: Lightweight
 Reinforcement: 2.19% as four No. 8 bars.

Elevation, Cross-Section and Finishing Detail: Figure 3.1.1
 Layout of Thermocouple Frames in Concrete: Figure 3.3.1
 Locations of Thermocouples in Frames: Figure 3.3.2
 Locations of Thermocouples on Reinforcing Bars: Figure 3.3.3

3.3.1 Series II, Column 6

Test purpose: Effect of Lightweight Aggregate.
 Date tested: June 19, 1984.
 Loading: 1076 kN, Concentric.

Measured Properties:

Cylinder strengths: 34.2 MPa at 28 days.
 46.6 MPa on test date.
 Relative humidity: 79%.

Results:

Test duration: 3 hours 8 minutes.
 Temperatures: Tables 3.3.1 and 3.3.2.
 Axial deformations: Table 3.3.3

Observations

1:40 Fine cracks developed on the E and S faces of the column.
 2:10 A crack on the E face increased in length to 45 cm.
 2:20 Maximum crack width on the E face was 3 mm. Small cracks also developed on the N and W faces. Figure 3.3.1 shows all faces.
 2:58 60 cm long cracks developed in the lower quarter of the E and S faces.
 2:59 A corner piece of concrete about 75 cm long fell off the SE corner at quarter height, exposing a main reinforcing bar directly to the fire.
 3:08 The column buckled and failed (Figure 3.3.4).

3.3.2 Series II, Column 7

Test purpose: Effect of Lightweight Aggregate.
 Date tested: October 24, 1984.
 Loading: 947 kN, Concentric.

Measured Properties:

Cylinder strengths:	38.1 MPa at 28 days. 42.5 MPa on test date.
Relative humidity:	80%.

Results:

Test duration:	4 hours 19 minutes.
Temperatures:	Tables 3.3.4 and 3.3.5.
Axial deformations:	Table 3.3.6

Observations

- 1:40 Fine crack developed on the E face of the column.
- 2:20 Small cracks developed on the other faces.
- 3:40 Cracks expanded to 13 mm, but no spalling was observed.
- 4:19 The column failed in compression.

Figure 3.3.5 shows the column after the test.

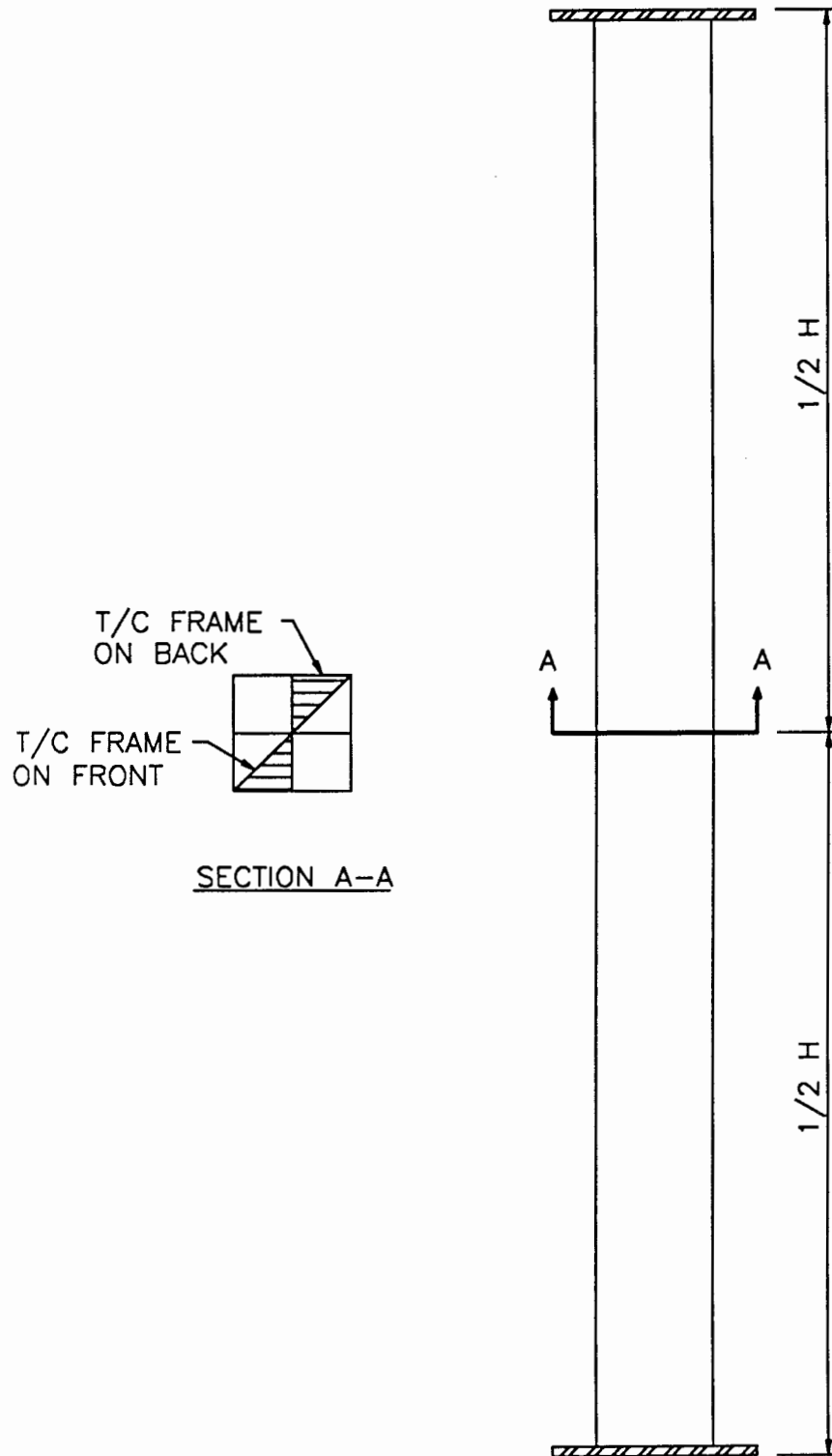


Figure 3.3.1 Layout of T/C Frames in Concrete: Series II and III Square Sections

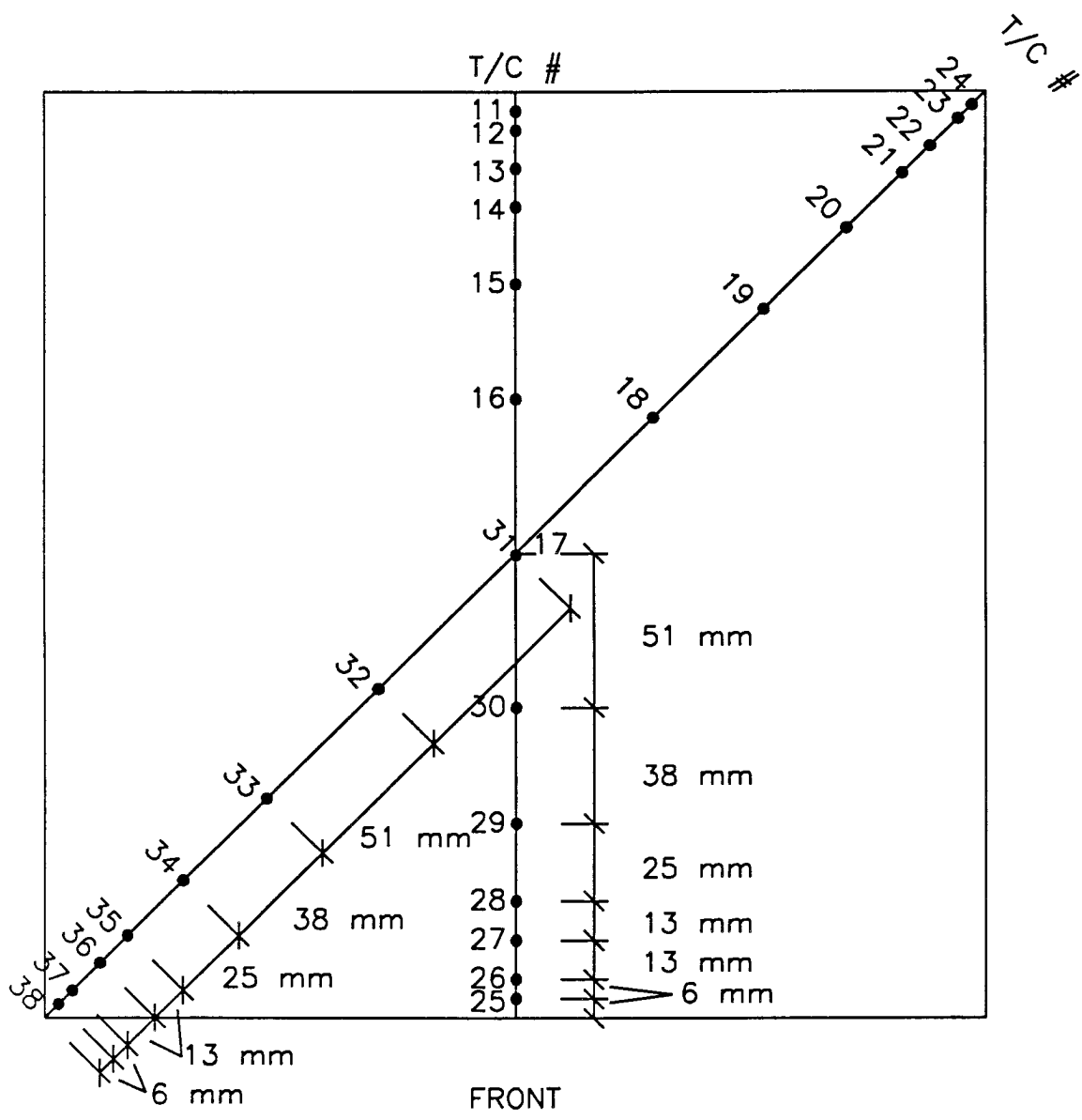


Figure 3.3.2 Locations of T/C's in Frames: Standard 12 x 12 Section, Series II and III

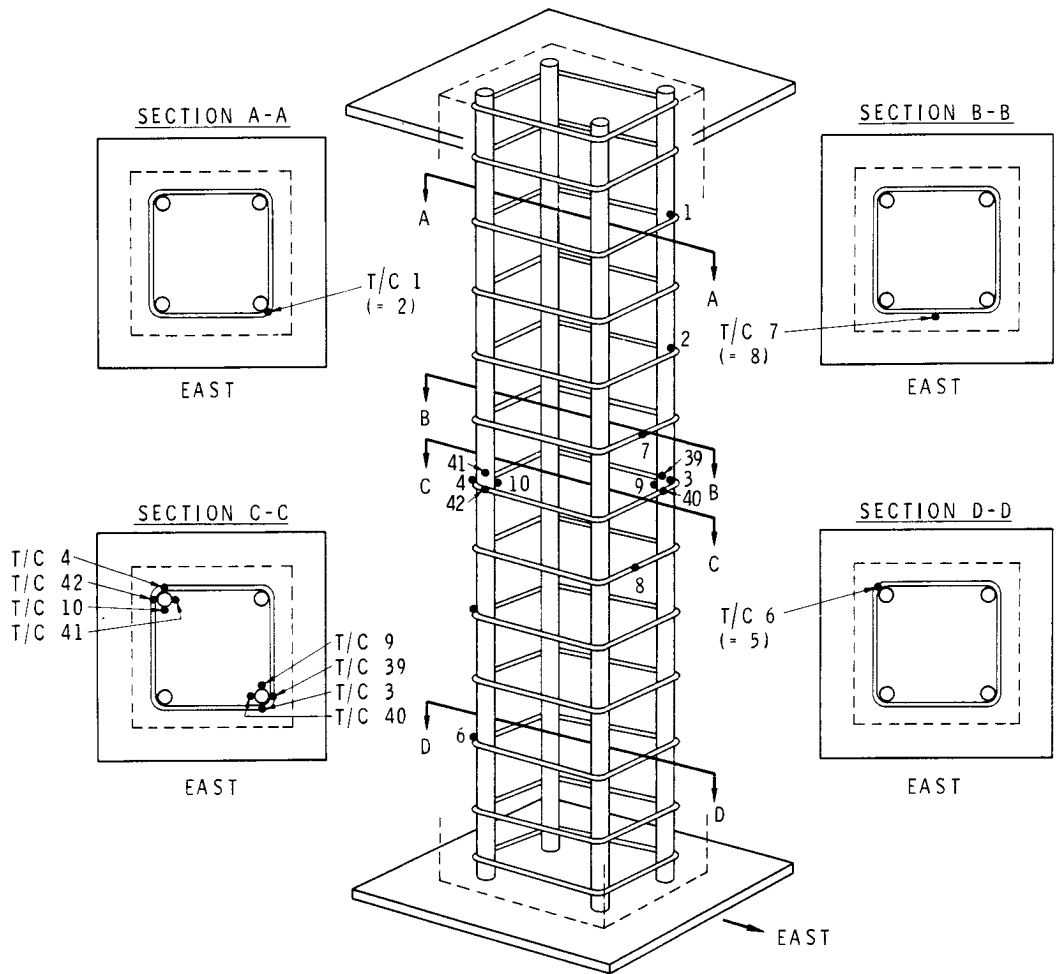


Figure 3.3.3 Locations of T/C's on Reinforcing Bars: Standard 12 x 12 Section, Series II and III

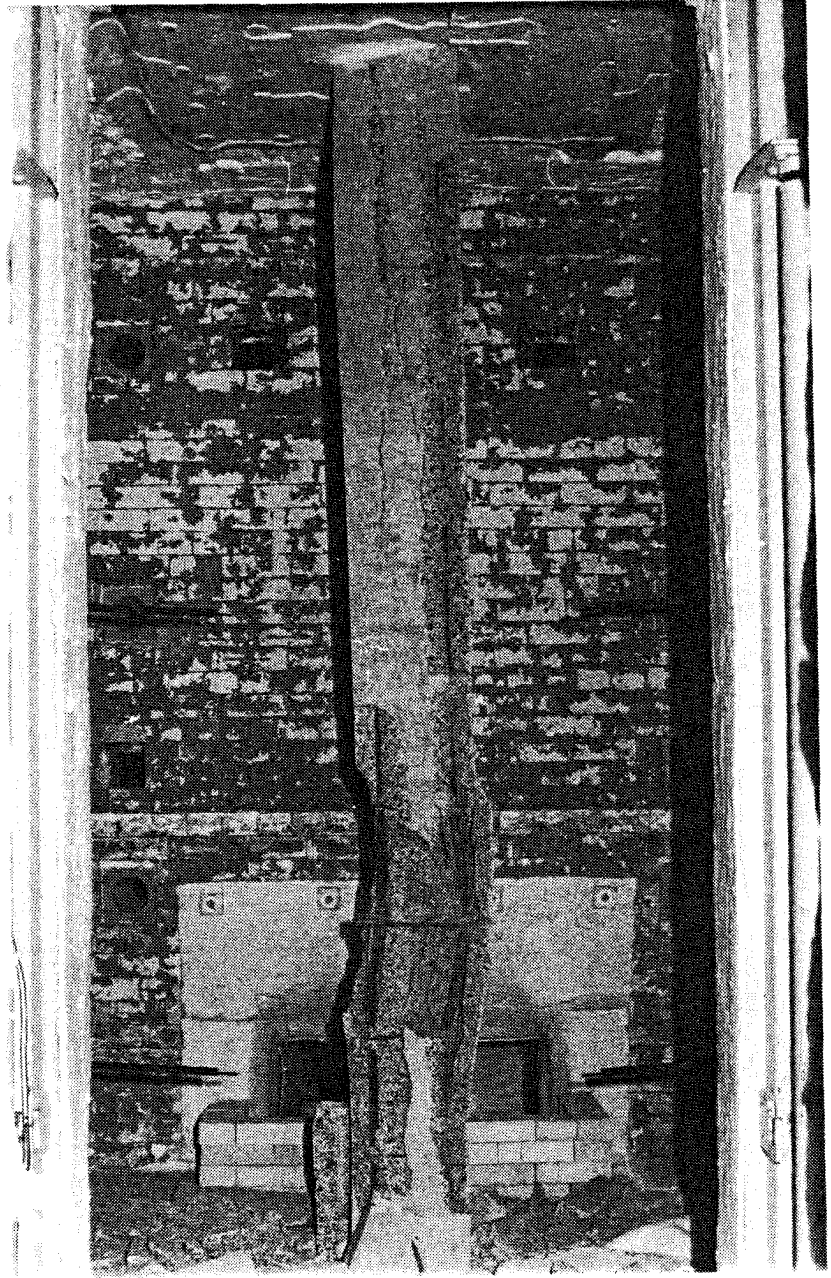


Figure 3.3.4 Series II Column 6 After Test

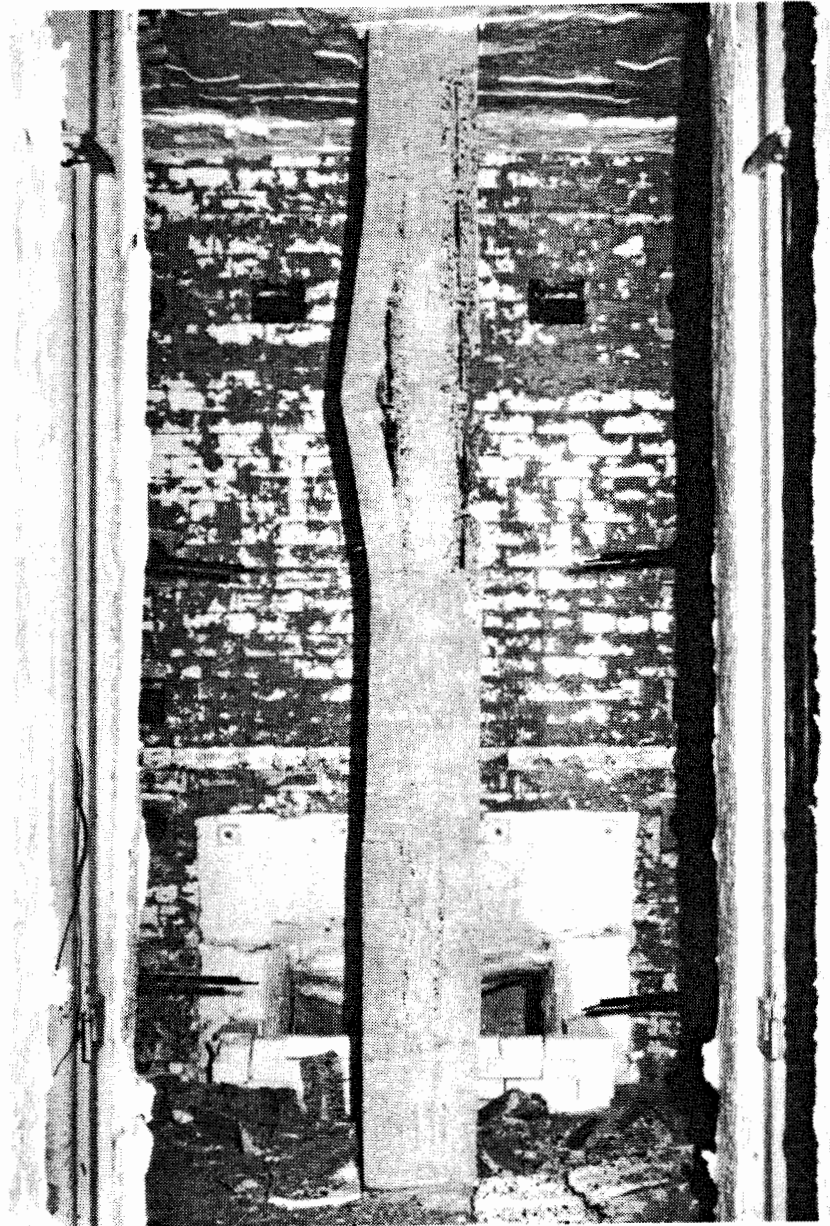


Figure 3.3.5 Series II Column 7 After Test

Table 3.3.1 Steel Temperatures, Series II Column 6

Minutes	Temperature (°C) Measured at Thermocouple #:											Furnace
	1	2	3	4	5	6	7	8	9	41	42	
0	23	23	23	23	23	23	23	23	23	22	22	72
5	25	24	24	24	23	24	27	28	24	23	23	569
10	34	34	34	31	30	30	46	51	32	30	29	677
15	76	66	70	60	56	53	71	82	63	59	54	733
20	99	101	97	94	85	88	99	110	89	95	88	778
25	107	107	108	108	108	108	110	113	107	108	103	805
30	116	116	116	109	111	110	117	127	115	109	106	836
35	129	134	131	115	115	115	132	149	126	115	111	851
40	147	154	150	129	122	126	149	171	142	129	124	866
45	166	174	170	145	132	142	166	193	160	146	138	883
50	186	194	191	163	146	160	187	213	179	164	154	896
55	207	213	214	181	162	179	207	233	201	182	171	901
60	228	234	236	201	180	199	225	253	222	201	189	914
70	269	275	277	239	219	239	247	289	262	240	227	932
80	307	314	314	277	256	277	279	323	299	278	263	950
90	341	350	349	311	291	313	311	354	334	325	298	966
100	373	383	381	343	324	346	341	382	366	406	330	979
110	403	411	410	373	354	375	369	407	395	508	360	987
120	431	438	437	401	381	402	396	432	422	584	388	1001
130	458	462	461	428	407	427	420	454	447	622	414	1007
140	484	483	482	453	431	451	449	476	467	632	439	1018
150	508	504	503	476	454	474	473	497	488	642	463	1035
160	530	524	523	499	476	495	496	517	508	648	485	1035
170	550	543	543	519	496	515	516	535	528	631	506	1043
180	570	561	561	539	515	534	535	553	546	635	526	1055
185	579	570	570	548	524	543	545	561	555	640	536	1062

Table 3.3.2 Concrete Temperatures, Series II Column 6

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0	26	24	23	23	23	22	23	22	22	22	22	23	27	30	72
5	161	102	48	31	23	22	23	22	23	27	62	111	219	281	569
10	270	176	100	65	29	23	22	23	41	71	123	193	368	425	677
15	377	259	137	99	43	24	23	25	81	111	192	292	477	522	733
20	455	330	175	123	64	28	23	31	97	133	257	382	554	598	778
25	510	386	218	147	90	42	24	42	107	155	312	448	609	648	805
30	556	430	256	170	98	50	28	54	109	192	368	504	654	695	836
35	588	467	289	196	102	54	35	61	116	235	419	550	692	727	851
40	611	495	318	221	107	58	41	67	126	270	463	589	721	752	866
45	632	519	343	242	112	63	47	73	135	292	500	621	746	776	883
50	649	538	359	254	115	69	54	79	139	295	528	645	766	795	896
55	664	555	375	267	120	78	64	86	151	328	552	665	784	812	901
60	678	570	395	289	128	91	78	94	163	358	577	686	801	828	914
70	708	603	436	331	151	111	100	111	210	402	616	721	827	853	932
80	733	631	469	364	179	118	109	126	251	439	647	749	847	875	950
90	752	652	496	392	204	127	115	142	283	470	672	771	861	890	966
100	767	670	519	415	227	140	119	157	309	496	694	789	874	902	979
110	781	687	540	438	250	152	123	169	336	519	712	804	888	913	987
120	797	704	559	458	270	163	130	181	360	541	729	818	903	928	1001
130	810	719	576	476	290	175	138	192	383	560	745	832	916	938	1007
140	828	737	594	495	310	189	148	205	407	580	763	848	932	953	1018
150	844	753	612	513	330	204	158	223	430	598	778	863	946	968	1035
160	854	767	630	533	350	221	169	243	453	616	792	875	953	971	1035
170	866	780	646	551	370	239	181	262	475	632	804	885	961	978	1043
180	877	794	663	569	392	258	196	282	498	649	816	895	967	980	1055
185	885	802	673	581	406	269	203	293	512	658	822	900	972	986	1062

Table 3.3.2
(continued)

Minutes	25	26	27	28	29	30	31	32	33	34	35	36	37	Furnace
0	25	24	23	22	22	22	22	22	22	22	22	23	28	72
5	139	107	50	30	23	22	22	22	23	29	73	123	236	569
10	236	184	102	59	28	22	22	22	32	70	145	223	400	677
15	325	260	135	99	40	23	22	25	87	114	209	325	514	733
20	395	326	178	113	56	25	23	34	100	132	290	413	589	778
25	444	377	217	130	74	29	25	49	104	154	359	483	640	805
30	487	419	254	158	96	57	30	48	105	186	415	537	683	836
35	521	455	288	186	104	73	37	53	103	194	458	581	716	851
40	546	484	318	213	111	80	44	64	104	197	490	614	738	866
45	569	509	345	238	116	84	50	77	107	201	513	638	758	883
50	590	531	369	260	123	85	59	87	121	235	532	657	774	896
55	609	552	391	281	130	87	68	101	145	295	555	676	791	901
60	625	569	410	299	138	92	76	112	169	337	580	694	805	914
70	653	597	440	324	148	104	89	119	209	391	624	729	833	932
80	673	617	460	335	155	114	101	128	247	427	653	756	854	950
90	682	625	460	323	156	119	113	128	280	457	678	776	870	966
100	704	648	499	382	195	121	118	126	303	479	698	792	882	979
110	722	667	524	411	225	130	120	135	335	505	718	808	894	987
120	740	685	544	433	248	142	127	158	363	529	736	823	909	1001
130	756	701	563	453	269	156	135	176	388	551	754	837	922	1007
140	775	719	582	475	290	169	145	192	416	575	774	847	938	1018
150	792	735	598	493	309	182	156	213	452	596	791	840	953	1035
160	804	748	615	512	328	198	170	236	506	621	802	826	958	1035
170	817	761	631	530	348	218	192	258	562	652	801	817	956	1043
180	830	773	648	550	370	248	228	289	611	739	867	769	776	1055
185	839	781	658	563	385	270	254	317	660	788	858	776	796	1062

Table 3.3.3

Deflections, Series II Column 6

Minutes	Expansion, mm
0	0.0
10	0.6
20	1.8
30	2.3
40	2.5
50	3.0
60	3.6
70	4.0
80	4.4
90	4.8
100	5.1
110	5.4
120	5.6
130	5.8
140	5.8
150	5.8
160	5.8
170	5.8
180	5.3
185	4.8

Table 3.3.4 Steel Temperatures, Series II Column 7

Minutes	Temperature (°C) Measured at Thermocouple #:											Furnace
	1	2	3	4	5	6	7	8	9	11	12	
0	18	23	15	14	12	12	16	13	15	18	15	149
5	19	24	17	15	14	13	23	18	16	143	88	602
10	29		28	24	23	20	48	39	24	252	161	690
15	64		70	53	50	42	88	71	52	342	231	748
20	95	85	99	90	84	75	115	104	83	423	299	783
25	101	88	104	108	105	96	132	118	100	483	354	813
30	105	93	117	109	113	104	153	135	108	532	398	842
35	120	106	133	116	118	109	178	155	114	566	432	861
40	136	120	152	128	133	120	205	177	128	595	463	876
45	155	137	174	143	151	134	229	199	146	618	490	891
50	175	155	198	160	172	152	247	220	166	639	514	900
55	197	174	222	179	194	171	263	241	186	657	535	912
60	219	195	245	200	216	190	283	260	207	672	553	924
70	263	236	290	241	260	228	320	296	250	700	584	941
80	304	272	332	281	301	265	352	329	292	724	610	953
90	343	305	369	317	338	301	381	359	329	746	633	968
100	379	335	403	350	372	335	407	387	363	765	655	980
110	412	362	432	381	403	367	431	413	394	785	676	993
120	442	387	461	414	433	395	454	439	425	802	696	1001
140	496	433	514	469	490	449	498	488	480	832	729	1022
160	539	473	559	513	536	495	542	532	528	858	754	1043
180	578	516	601	554	572	535	590	574	572	886	784	1062
200	613	552	637	594	607	572	630	612	612	910	806	1076
220	645	586	670	632	639	605	666	646	646	909	803	1091
240	674	615	701	668	669	636	697	678	678	840	780	1105
255	695	635	711	694	690	658	711	700	700	775	762	1114

Table 3.3.5 Concrete Temperatures, Series II Column 7

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
0	14	14	13	13	13	13	14	14	15	19	22	30	21	17	149
5	41	22	14	13	13	13	14	21	67	32	239	353	186	120	602
10	98	50	20	13	13	13	22	63	142	36	376	511	302	205	690
15	131	88	33	15	13	17	62	104	198	45	473	606	389	286	748
20	175	114	55	20	14	28	96	130	272	46	551	674	459	353	783
25	217	139	80	33	16	47	106	149	339	42	609	720	510	404	813
30	255	158	97	58	21	54	109	183	394	41	653	763	555	446	842
35	289	181	105	70	28	59	113	212	441	40	685	791	587	480	861
40	321	207	112	77	37	67	119	235	479	40	717	815	614	511	876
45	349	233	121	83	58	75	130	265	511	40	742	835	635	537	891
50	374	256	131	88	77	81	146	295	540	41	764	851	654	560	900
55	396	277	141	94	87	87	162	323	567	41	784	867	672	581	912
60	416	296	151	100	92	93	177	343	591	42	800	881	687	598	924
70	451	330	171	109	98	104	206	377	628	44	828	902	714	629	941
80	480	359	193	118	104	113	241	424	659	45	850	918	740	656	953
90	507	385	215	127	107	127	284	467	692	47	871	935	765	680	968
100	531	410	240	138	111	144	318	500	718	48	889	948	791	703	980
110	554	433	264	150	120	158	349	530	740	49	906	962	814	723	993
120	576	456	288	163	130	171	379	557	760	51	921	971	833	743	1001
140	613	497	331	192	154	197	431	604	791	54	948	993	859	776	1022
160	646	531	373	227	176	234	479	644	816	57	970	1016	859	805	1043
180	679	574	427	263	197	279	526	685	841	60	989	1033	833	801	1062
200	712	611	521	305	225	321	566	716	864	62	1007	1041	834	807	1076
220	740	654	587	382	272	372	603	743	886	64	1013	1033	825	784	1091
240	753	700	622	526	369	672	706	733	781	66	895	787	817	772	1105
255	742	724	651	616	468	752	769	748	757	67	761	741	812	772	1114

Table 3.3.6

Deflections, Series II Column 7

Minutes	Expansion, mm
0	0.0
10	0.8
20	2.2
30	2.8
40	3.0
50	3.6
60	4.2
70	4.9
80	5.2
90	5.7
100	6.1
110	6.5
120	6.7
130	6.9
140	7.0
150	7.0
160	7.0
170	6.8
180	6.3
185	6.1
190	5.7
195	5.4
200	5.1
205	4.8
210	4.4
215	4.1
220	3.6
225	3.2
230	2.6
235	2.0
240	1.3
245	0.6
250	0.3
255	0.1

3.4 EFFECT OF HIGH-STRENGTH CONCRETE

Specimen Properties:

Cross-Section: 305 x 305 mm (12 x 12 in.)
 Length: 3810 mm (12 ft 6 in.)
 Aggregate: Siliceous
 Reinforcement: 2.19% as four No. 8 bars.

Elevation, Cross-Section and Finishing Detail: Figure 3.1.1
 Layout of Thermocouple Frames in Concrete: Figure 3.3.1
 Locations of Thermocouples in Frames: Figure 3.3.2
 Locations of Thermocouples on Reinforcing Bars: Figure 3.3.3

3.4.1 Series II, Column 4

Test purpose: Effect of High-Strength Concrete.
 Date tested: August 9, 1983.
 Loading: 1178 kN, Concentric.

Measured Properties:

Cylinder strengths: 53.2 MPa at 28 days.
 52.9 MPa on test date.
 Relative humidity: 75%.

Results:

Test duration: 3 hours 47 minutes.
 Temperatures: Tables 3.4.1 and 3.4.2.
 Axial deformations: Table 3.4.3

Observations

1:00 A vertical hairline crack 10 cm long developed on the S face, 5 cm from the E corner.
 1:30 It grew to 45 cm. Cracks 5 to 15 cm long were seen on the other faces, near mid-height.
 1:45 All cracks extended, some to 60 cm.
 2:20 Cracks on the S face worsened, one being 75 cm long and 3 mm wide.
 2:45 Maximum crack width increased to 5 mm.
 3:15 3 15 cm long parallel cracks developed in the upper quarter of the W face
 3:40 Cracks widened rapidly: the worst opening was more than 6 mm.
 3:47 The column failed in compression (Figure 3.4.1)

3.4.2 Series II, Column 5

Test purpose: Effect of High-Strength Concrete.
 Date tested: March 23, 1984.
 Loading: 1067 kN, Concentric.

Measured Properties:

Cylinder strengths: 51.4 MPa at 28 days.
49.5 MPa on test date.
Relative humidity: 75%.

Results:

Test duration: 3 hours 54 minutes.
Temperatures: Tables 3.4.4 and 3.4.5.
Axial deformations: Table 3.4.6

Observations

- 1:00 A fine vertical crack developed on the S face at midheight.
1:20 It extended to 36 cm. Cracks 5 to 15 cm long were seen on the other faces, at midheight.
1:45 All cracks extended, some to 45 cm.
2:20 Cracks on the N face increased, with the largest 5 cm long and 6 mm wide.
3:40 Cracks widened rapidly, with one opening 13 mm wide.
3:54 The column failed in compression (Figure 3.4.2).

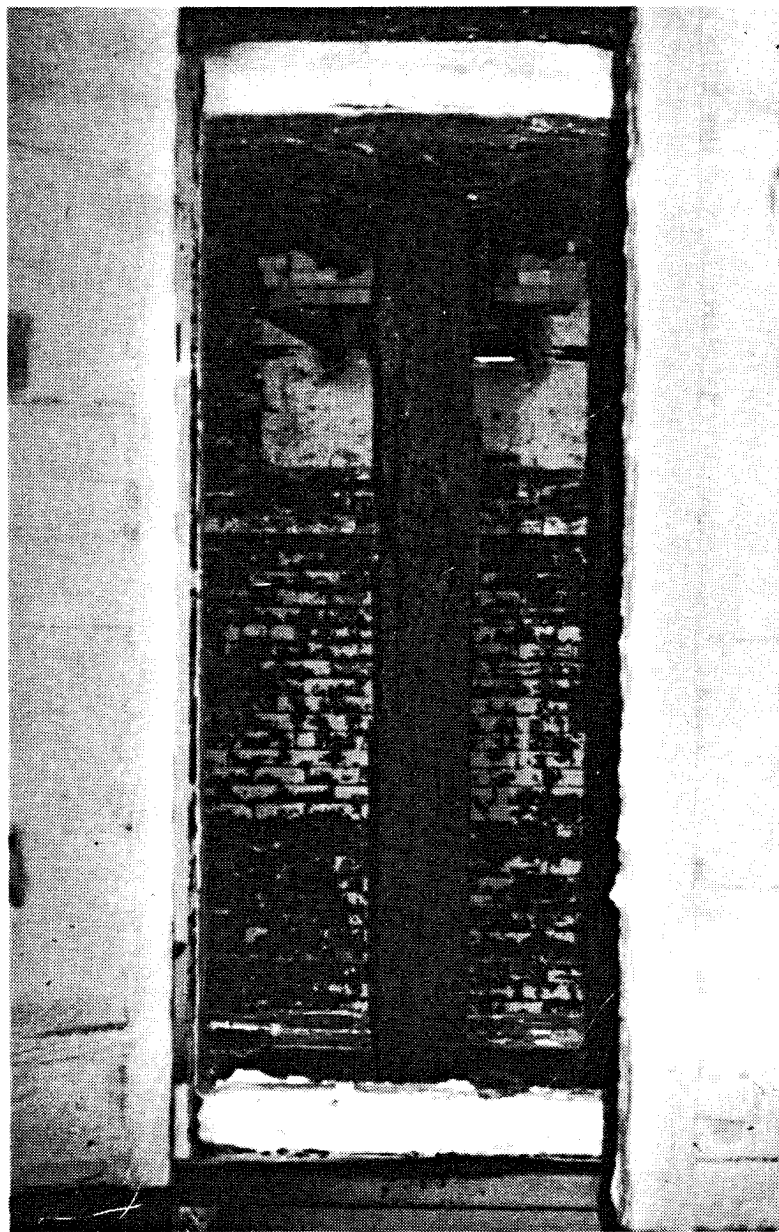


Figure 3.4.1 Series II Column 4 After Test

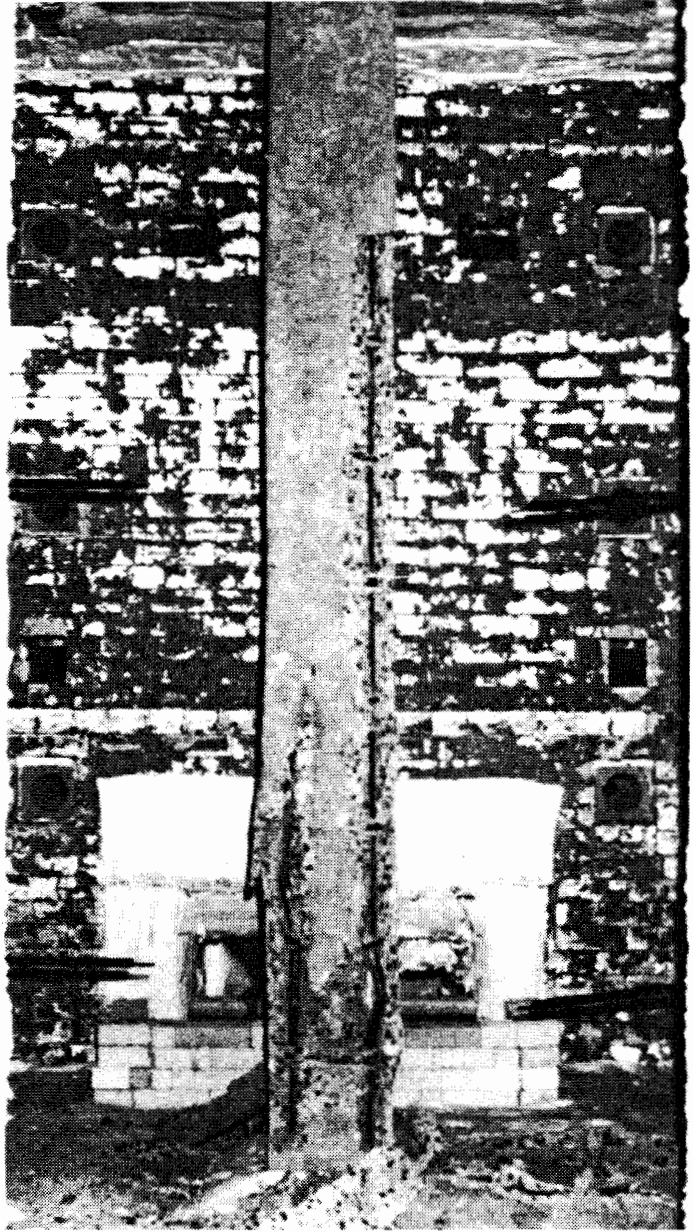


Figure 3.4.2 Series II Column 5 After Test

Table 3.4.1 Steel Temperatures, Series II Column 4

Minutes	Temperature (°C) Measured at Thermocouple #:												Furnace
	1	2	3	4	5	8	9	10	39	40	41	42	
0	30	32	35	39	28	23	20	25	21	20	20	21	165
5	68	101	178	263	129	31	21	50	26	23	23	24	571
10	131	182	304	431	211	58	29	96	44	34	34	39	662
15	194	276	410	555	300	92	41	135	82	65	66	78	728
20	261	356	497	638	375	117	63	167	113	101	102	113	773
25	320	424	567	700	438	132	79	204	115	820	819	824	811
30	369	482	626	741	484	160	91	243	127	806	802	811	833
35	408	532	672	780	526	196	99	282	145	107	103	116	849
40	447	573	705	804	560	226	106	317	167	144	141	157	866
45	486	608	734	826	590	254	116	348	190	161	159	177	874
50	520	637	752	832	610	278	128	374	213	181	178	198	867
55	550	663	780	865	637	299	140	395	237	203	198	220	903
60	580	689	799	883	661	319	153	416	260	226	219	242	918
70	631	731	834	910	704	356	178	455	306	272	262	286	936
80	675	767	853	923	735	388	204	489	348	313	302	327	949
90	710	797	826	940	763	417	228	518	388	352	340	366	962
100	740	823	786	948	787	443	253	545	425	392	380	407	971
110	766	844	788	963	806	469	279	571	459	427	415	444	984
120	789	863	789	973	825	492	303	595	491	460	448	484	997
130	811	882	784	980	843	516	329	619	521	490	479	550	1007
140	829	898	760	977	858	542	355	643	548	518	507	637	1016
150	843	913	739	918	865	577	382	666	575	544	534	699	1029
160	839	924	738	827	859	623	409	702	601	570	559	735	1039
170	806	918	747	782	848	671	436	691	627	595	588	753	1051
180	775	900	757	770	840	708	468	708	653	616	617	760	1055

Table 3.4.2

Concrete Temperatures, Series II Column 4

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	11	12	13	14	15	16	17	18	19	21	22	23	24	25	
0	29	27	25	23	21	19	18	19	22	25	23	22	22	21	165
5	135	95	55	33	23	19	19	19	24	29	27	25	25	25	571
10	224	159	103	62	31	20	19	21	32	46	41	40	41	42	662
15	315	229	138	94	46	22	19	24	60	89	77	78	77	84	728
20	393	294	181	119	67	27	21	32	100	116	114	111	113	113	773
25	460	354	226	146	100	35	25	47	114	124	115	115	114	114	811
30	514	407	265	171	104	46	31	58	111	136	121	124	121	121	833
35	555	453	301	197	106	56	39	67	118	155	135	140	135	135	849
40	585	489	333	224	115	65	48	75	132	177	154	159	154	154	866
45	613	521	361	249	127	76	56	84	151	201	176	179	175	177	874
50	630	544	386	270	139	86	64	94	171	226	201	201	197	201	867
55	658	568	407	290	151	95	74	104	192	251	226	224	219	225	903
60	682	589	427	308	164	102	84	113	212	274	251	248	242	249	918
70	716	627	464	342	191	116	100	131	252	318	298	295	286	296	936
80	744	660	498	374	218	130	111	148	288	358	341	339	329	339	949
90	773	688	529	403	244	145	121	164	322	396	380	380	370	380	962
100	801	714	556	430	268	160	133	181	354	430	416	418	407	418	971
110	821	734	582	454	291	177	143	202	385	463	451	453	443	454	984
120	841	755	606	478	314	195	156	226	414	493	482	485	477	487	997
130	859	776	630	502	338	216	172	256	446	521	511	515	507	518	1007
140	876	794	653	527	364	240	192	304	486	546	537	542	536	547	1016
150	891	813	677	554	391	268	215	368	534	572	562	569	563	574	1029
160	908	820	700	581	419	326	244	426	582	598	587	596	591	602	1039
170	920	797	721	606	446	459	291	463	621	623	612	621	617	627	1051
180	929	771	737	630	474	593	405	481	657	647	638	646	642	651	1055

Table 3.4.2
(continued)

Concrete Temperatures, Series II Column 4

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace
	26	27	28	29	30	31	32	33	34	35	36	37	38	
0	21	23	22	21	18	18	18	21	25	29	32	36	48	165
5	24	31	32	23	18	18	18	23	35	75	116	202	273	571
10	36	58	58	34	19	18	19	31	72	137	200	336	424	662
15	70	90	91	66	22	19	22	63	111	199	290	454	548	728
20	99	116	114	106	29	20	31	104	134	264	361	539	634	773
25	112	134	137	110	36	24	41	114	163	323	416	605	698	811
30	115	159	163	115	46	31	52	113	205	378	465	648	741	833
35	127	193	189	127	57	38	63	114	260	433	517	694	779	849
40	144	225	214	142	65	47	71	125	305	482	566	729	805	866
45	164	255	237	161	73	55	79	140	343	524	608	751	827	874
50	186	282	259	181	82	64	87	156	377	560	642	716	833	867
55	210	306	280	204	91	72	95	175	406	593	670	731	864	903
60	234	329	300	227	99	80	103	194	432	624	696	743	879	918
70	281	369	339	273	112	97	117	232	478	674	740	771	898	936
80	324	405	374	316	128	106	133	269	517	715	775	791	799	949
90	363	437	407	357	135	113	148	304	553	749	805	804	806	962
100	400	467	438	395	150	120	168	340	586	777	832	812	808	971
110	434	495	467	431	174	139	203	376	621	794	853	811	804	984
120	466	521	494	464	194	154	320	436	670	777	869	805	798	997
130	495	545	519	495	215	171	501	558	714	760	770	794	792	1007
140	522	569	543	523	239	192	619	661	741	763	765	773	789	1016
150	547	593	568	549	264	215	676	714	757	773	745	742	785	1029
160	573	615	593	576	289	245	692	741	764	784	738	736	773	1039
170	599	636	617	602	315	290	679	750	770	795	748	745	745	1051
180	622	655	640	626	341	354	654	745	776	803	759	754	736	1055

Table 3.4.3

Deflections, Series II Column 4

Minutes	Expansion, mm
0	0.0
10	0.4
20	1.8
30	2.4
40	2.8
50	3.4
60	4.1
70	4.6
80	5.2
90	5.7
100	6.1
110	6.4
120	6.5
130	6.5
140	6.5
150	6.4
160	6.1
170	5.6
180	4.9
185	4.5
190	4.1
195	3.4
200	2.8

Table 3.4.4

Steel Temperatures, Series II Column 5

Minutes	Temperature (°C) Measured at Thermocouple #:											Furnace
	1	2	3	4	5	6	7	8	40	41	42	
0	23	23	23	23	23	23	23	23	21	21	21	83
5	25	25	26	26	30	25	34	34	23	23	25	585
10	36	36	38	42	58	36	63	63	33	36	44	677
15	71	72	79	82	94	69	97	96	67	70	88	739
20	103	107	108	114	121	109	119	125	97	102	113	784
25	112	112	114	114	134	113	135	143	108	109	114	815
30	119	115	121	126	157	113	144	170	112	116	125	839
35	130	128	138	141	181	126	171	197	126	127	141	854
40	144	143	159	159	200	142	213	224	144	143	160	875
45	161	160	182	179	217	161	247	249	165	161	180	886
50	180	180	206	200	238	183	275	272	188	181	202	898
55	201	202	231	221	260	205	299	293	212	202	225	912
60	223	224	256	244	277	227	321	313	237	224	247	920
70	264	268	304	286	320	270	360	350	284	266	291	939
80	303	308	348	327	358	310	395	384	327	306	331	949
90	341	346	388	366	395	347	426	415	367	344	370	969
100	378	381	424	403	429	382	455	445	402	380	407	985
110	412	416	457	438	463	414	482	471	435	415	442	992
120	445	449	487	471	497	444	508	495	464	447	475	1002
130	476	480	514	501	527	473	533	519	490	478	506	1015
140	506	508	539	529	554	500	559	544	515	507	534	1023
150	533	534	562	555	580	526	585	569	537	533	561	1029
160	558	560	585	582	606	552	611	597	560	559	588	1039
170	585	586	609	610	631	577	634	632	584	587	615	1050
180	612	612	633	636	656	601	656	669	606	614	642	1062
200	662	659	683	684	704	645	697	721	650	674	699	1073
220	711	702	714	725	744	685	734	740	689	723	734	1095

Table 3.4.5 Concrete Temperatures, Series II Column 5
(continued)

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace
	25	26	27	28	29	31	32	33	34	35	36	37	38	
0	25	23	22	22	22	22	22	22	22	23	22	26	31	83
5	139	90	50	33	23	22	22	24	34	74	26	186	280	585
10	226	154	96	65	29	22	23	37	77	129	42	316	437	677
15	316	217	140	99	41	23	26	77	113	188	85	429	551	739
20	393	279	176	126	62	24	39	112	138	249	111	507	620	784
25	459	337	216	152	88	28	48	113	169	306	116	575	684	815
30	512	386	254	177	92	34	58	110	208	358	126	634	731	839
35	553	426	285	187	90	43	66	114	255	408	145	677	764	854
40	587	459	314	210	95	58	74	128	292	451	167	714	792	875
45	617	490	341	230	103	77	81	145	324	488	191	750	816	886
50	640	515	368	265	113	85	90	163	353	521	216	734	832	898
55	665	542	398	304	124	91	100	183	379	550	242	750	841	912
60	688	568	426	333	138	95	110	203	403	579	267	766	844	920
70	722	611	470	377	168	105	133	243	445	628	316	781		939
80	752	647	507	412	216	112	297	283	482	671	360	774		949
90	780	677	538	442	308	141	574	354	517	713	400	763		969
100	800	702	567	468	409	219	679	467	572	746	437	771		985
110	813	724	594	493	486	313	719	551	667	765	469	779		992
120	822	746	623	522	522	379	734	593	724	775	498			1002
130	828	765	660	566	525	406	742	614	752	782	525			1015
140	830	777	697	623	527	417	747	634	770		548			1023
150	837	789	726	670	542	432		656	780		573			1029
160	843	800	746	702	559	438		680	785		600			1039
170	849	811	758	724	576	443		704			629			1050
180	853	820	767	734	596	459		725			658			1062
200	854	828	779	734	634	536		738			701			1073
220				744	668	687		751			719			1095

Table 3.4.6

Deflections, Series II Column 5

Minutes	Expansion, mm
0	0.0
10	0.8
20	2.2
30	2.8
40	3.2
50	3.8
60	4.5
70	5.0
80	5.6
90	6.1
100	6.6
110	6.9
120	7.1
130	7.1
140	7.1
150	7.1
160	6.9
170	6.5
180	6.0
185	5.6
190	5.2
195	4.7
200	4.2
205	3.5
210	2.8
215	1.9
220	0.8
225	0.5
230	0.2

3.5 EFFECT OF END RESTRAINT

Specimen Properties:

Cross-Section: 305 x 305 mm (12 x 12 in.)
 Length: 3810 mm (12 ft 6 in.)
 Aggregate: Siliceous
 Reinforcement: 2.19% as four No. 8 bars.

Elevation, Cross-Section and Finishing Detail:	Figure 3.1.1
Layout of Thermocouple Frames in Concrete:	Figure 3.3.1
Locations of Thermocouples in Frames:	Figure 3.3.2
Locations of Thermocouples on Reinforcing Bars:	Figure 3.3.3

3.5.1 Series II, Column 1

Test purpose:	Effect of end restraint: fixed at the bottom and hinged at the top, free translation.
Date tested:	August 22, 1986.
Loading:	342 kN, Concentric.

Measured Properties:

Cylinder strengths:	40.3 MPa at 28 days. 43.2 MPa on test date.
Relative humidity:	65%.

Results:

Test duration:	5 hours 40 minutes.
Temperatures:	Tables 3.5.1 and 3.5.2.
Axial deformations:	Table 3.5.3

Observations

0:00 Column began to expand immediately after the fire was started.
 0:45 Hairline cracks were 7 to 10 cm long.
 1:40 Hairline cracks continued to propagate.
 2:10 Expansion reached a maximum of 20 mm, remaining constant for 30 min.
 3:05 Most cracks were 1 to 3 mm wide, with a larger crack (6 mm) on the S face.
 4:00 Several cracks 3 to 6 mm wide were noted on the S and E faces.
 5:00 These cracks began to open widely and concrete spalled at the edges, exposing parts of the reinforcing bars.
 5:40 The column could no longer carry the applied load (Figure 3.5.1).

3.5.2 Series II, Column 2

Test purpose: Effect of full restraint
 Date tested: February 17, 1984.
 Loading: 1044 to 2049 (maximum) kN, Concentric.

Measured Properties:

Cylinder strengths: 43.2 MPa at 28 days.
 43.6 MPa on test date.
 Relative humidity: 75%.

Results:

Test duration: 3 hours 21 minutes.
 Temperatures: Tables 3.5.4 and 3.5.5.
 Loads and Axial deformations: Table 3.5.6

Observations

- 0:20 One or two hairline cracks appeared on each face. The applied load reached a maximum of 2049 kN.
 0:35 Cracks on the E face extended to 15 cm long and 1 mm wide.
 1:20 Some cracks on E face extended to 45 cm.
 2:15 Cracks on the E face opened up, one to 65 cm long and 10 mm wide.
 2:30 Most cracks enlarged noticeably.
 2:56 The widest crack on the E face was 20 mm.
 3:15 Cracks on the E, S and N sided widened, some to 25 mm. The column shortened 3 mm.
 3:21 Failure due to crushing of the concrete and buckling of the steel bars. Figure 3.5.2 shows the column after the test and a closeup of the part that failed.

3.5.3 Series II, Column 3

Test purpose: Effect of full restraint
 Date tested: October 9, 1983.
 Loading: 916 to 1914 (maximum) kN, Concentric.

Measured Properties:

Cylinder strengths: 37.2 MPa at 28 days.
 35.4 MPa on test date.
 Relative humidity: 75%.

Results:

Test duration: 3 hours 30 minutes.
 Temperatures: Tables 3.5.7 and 3.5.8.
 Loads and Axial deformations: Table 3.5.9.

Observations

- 0:35 One or two hairline cracks appeared at midheight on each face. The applied load reached a maximum of 1914 kN.
- 1:00 All cracks had extended and widened. The largest, 45 cm long and 2 mm wide, was on the S face.
- 2:31 Furnace shutdown due to opening of the door. The load was 1300 kN.
- 2:52 Fire restarted. The load had decreased to 1120 kN and was controlled to follow a theoretically derived relation¹² that gives the load needed to fully restrain the column as a function of time.
- 3:17 Furnace shutdown. The load was held constant at 1103 kN.
- 3:30 Fire restarted and the load was controlled to follow the computed load until it had decreased to the original value of 916 kN.
- 3:35 Cracks rapidly worsened, some being 25 to 40 mm wide.
- 3:45 At 916 kN, the load was held constant. The column started to contract.
- 4:02 The column failed in compression (Figure 3.5.3).

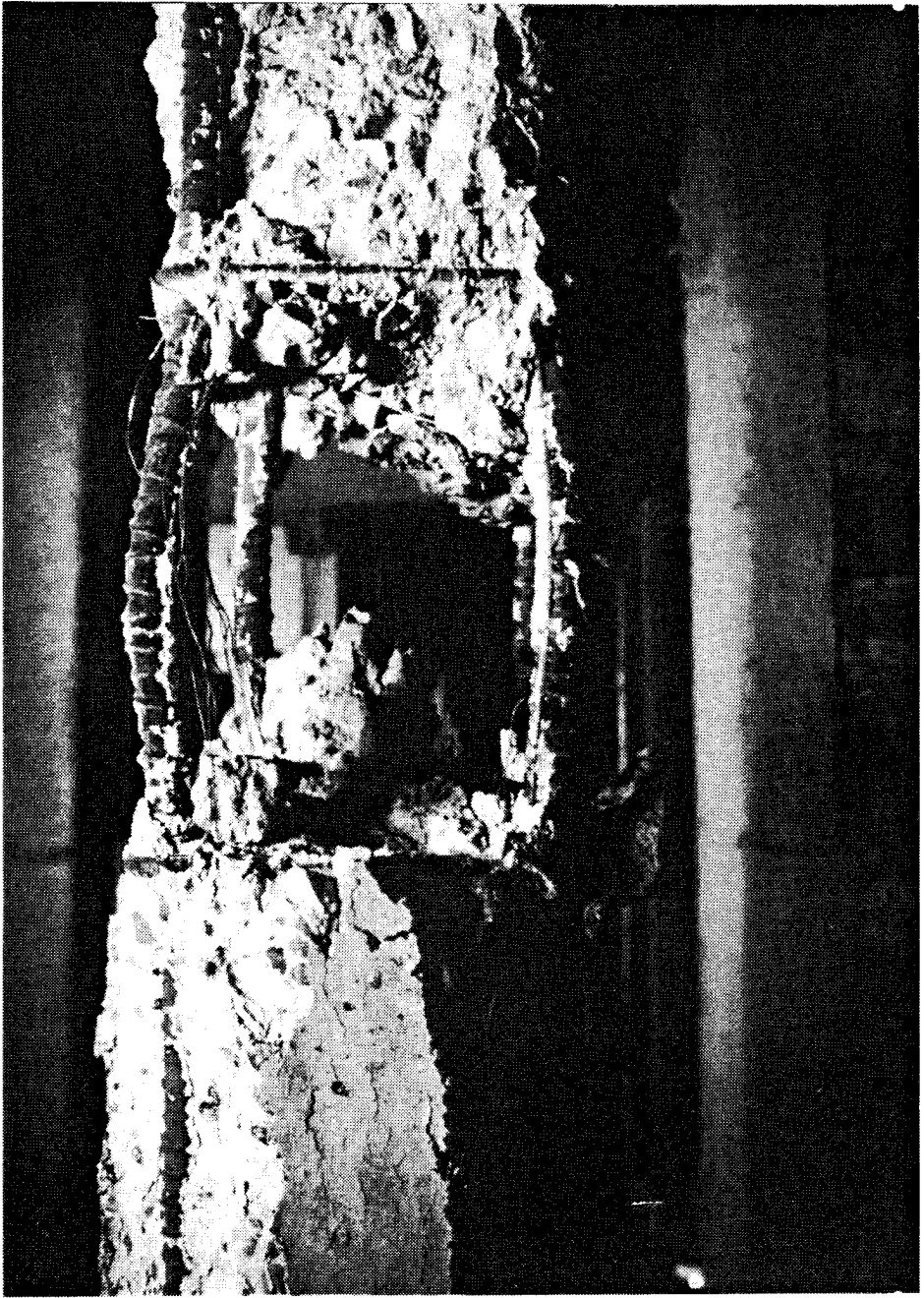


Figure 3.5.1 Series II Column 1 After Test

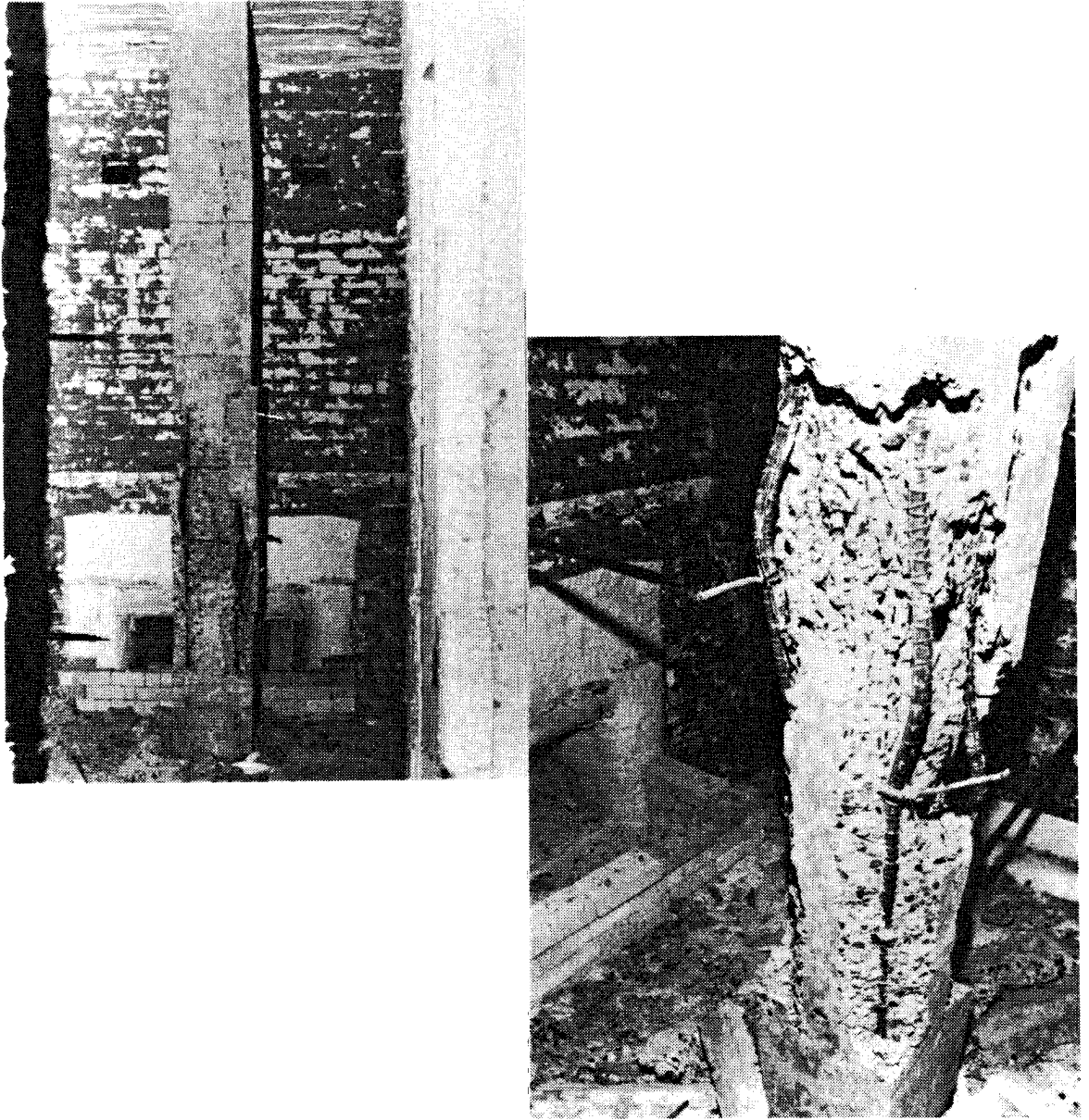


Figure 3.5.2 Series II Column 2 After Test

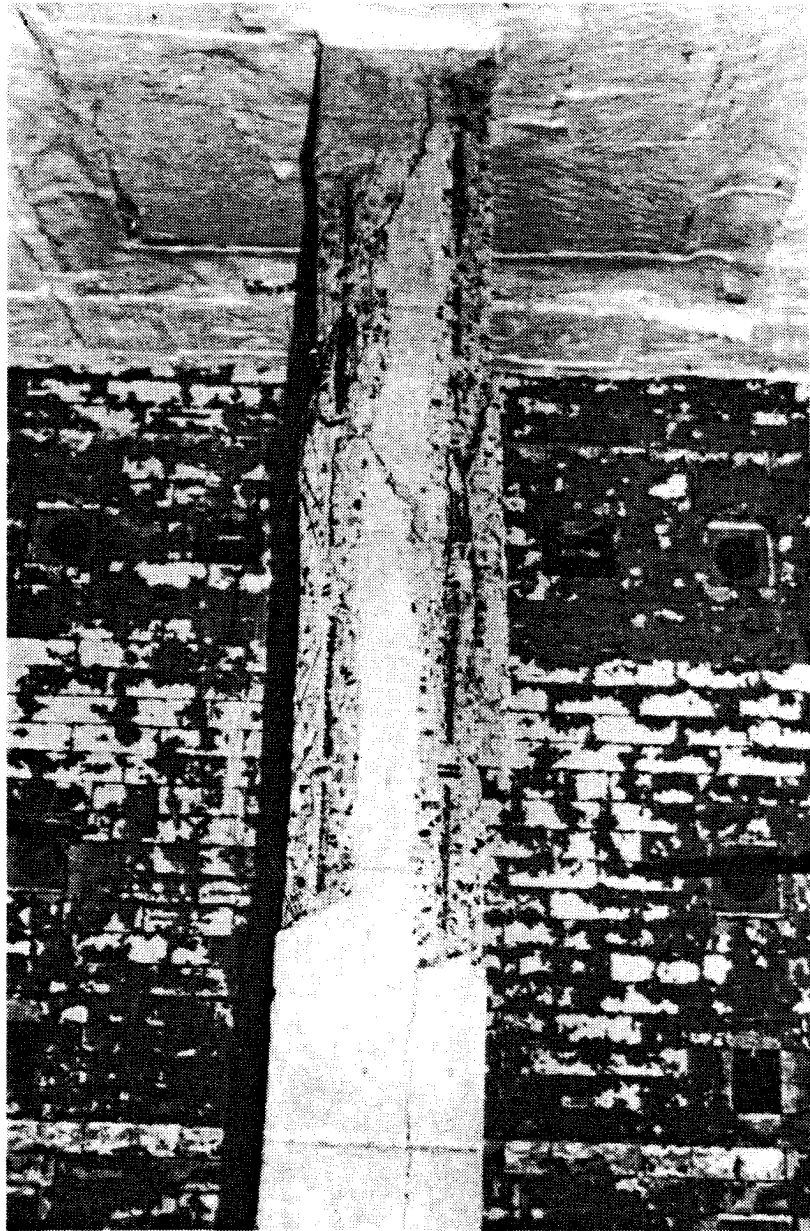


Figure 3.5.3 Series II Column 3 After Test

Table 3.5.1. Steel Temperatures, Series II Column 1

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	1	2	3	4	5	6	7	8	9	10	39	40	41	42	
0	20	19	19	19	18	18	19	19	21	20	18	19	19	19	207
5	26	23	25	23	22	21	30	33	19	22	24	22	24	21	587
10	46	40	46	39	39	34	59	64		34	43	38	41	34	685
15	93	84	92	82	90	75	96	105		73	96	82	95	77	742
35	145	139	157	141	143	136	182	208	144	127	156	140	143	125	854
40	167	161	183	164	164	157	203	235	168	148	182	164	166	145	875
50	217	209	235	213	213	206	248	283	218	195	233	212	216	190	901
60	266	258	286	263	262	257	294	325	268	243	285	263	266	236	920
70	312	305	334	309	308	304	335	363	316	288	333	310	312	280	938
80	355	349	378	352	351	347	373	399	359	331	379	355	356	323	955
90	395	388	418	392	390	386	406	432	398	370	418	394	396	362	969
105	450	444	472	448	444	440	454	480	452	426	474	449	452	416	986
110	467	461	489	465	461	458	469	494	469	443	491	466	469	434	992
120	501	494	521	497	495	491	497	522	500	477	525	499	504	468	1005
130	530	524	549	526	525	522	524	548	528	507	561	527	534	498	1015
140	558	550	577	554	553	549	549	576	552	535	615	552	564	527	1025
155	598	590	617	596	595	590	588	617	593	576	695	592	609	565	1039
170	636	628	655	634	634	629	625	653	630	615	739	631	648	606	1052
180	659	652	678	659	659	654	654	677	654	640	758	655	676	631	1059
195	692	685	706	692	693	686	705	712	685	675	769	687	717	666	1071
210	720	714	716	721	721	715	737	732	708	706	748	710	745	697	1083
225	734	734	728	708	724	736	756	715	707	730	727	716	735	705	1096
240	749	754	751	715	734	755	769	721	718	752	742	723	725	716	1105
270	789	779	782	760	770	796	781	766	766	774	778	761	758	754	1128
300	820	805	802	791	800	830	803	795	806	792	761	787	788	788	1151
330	849	820	828	822	851	856	846	843	833	836	787	822	827	823	1165

Table 3.5.2 Concrete Temperatures, Series II Column 1

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace
	11	12	13	14	15	16	17	18	19	20	21	22	24	
0	22	21	20	19	19	19	19	19	20	19	21	21	28	207
5	130	98	56	33	22	19	20	19	22	35	83	121	263	587
10	214	159	107	66	31	20	19	20	34	84	149	212	412	685
15	305	231	145	102	48	24	20	25	75	124	218	308	519	742
35	540	444	310	214	108	74	52	74	112	271	447	534		854
40	572	477	340	242	116	85	66	83	124	315	491	577	635	875
50	622	529	391	291	143	102	88	102	174	390	562	647	734	901
60	663	572	435	333	173	111	104	113	222	445	623	707	765	920
70		608	472	369	203	125	106	132	264	491	672	748	769	938
80	534	623	505	403	234	141	115	154	304	529	712	783	777	955
90	675	578	535	435	263	160	126	177	340	564	744	810	786	969
105	737	193	579	480	308	194	146	216	391	613	785	842	788	986
110	743	367	593	494	323	206	154	229	407	627	797	852	788	992
120	751	666		522	353	233	176	258	440	656	819	867	787	1005
130	755	707		547	382	261	204	286	471	680	838	856	771	1015
140	750	729		574	411	288	233	316	503	703	855	775	754	1025
155	755	756		612	452	329	275	395	585	734	875	761	763	1039
170	766	769	690	648	491	368	314	528	667	756	862	750	776	1052
180	771	764	706	699	516	393	339	577	682	767	768	765	779	1059
195	772	764	721	659	552	429	377	653	714	781	794	772	761	1071
210	757	738	716	682	626	483	428	726	744	751	755	765	741	1083
225	713	713	713	700	701	631	588	741	740	727	727	751	735	1096
240	711	716	714	719	713	705	693	736	723	729	725	730	725	1105
270	751	761	763	762	742	758	744	736	752	743	752	760	751	1128
300	773	793	795	772	776	786	782	776	788	758	771	785	777	1151
330	793	844	812	783	805	810	819	815	827	795	815	805	827	1165

Table 3.5.2 Concrete Temperatures, Series II Column 1
(continued)

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	25	26	27	28	29	30	31	32	33	34	35	36	37	38	
0	23	21	20	19	19	19	20	19	19	19	20	22	27	37	207
5	138	98	54	32	21	19	20	19	22	37	81	127	207	261	587
10	232	163	106	68	28	20	20	20	37	90	142	224	360	438	685
15	319	238	146	103	50	23	21	26	87	124	206	326	481	554	742
35	529	441	302	173	99	104	100	105	105	219	404	541	677	761	854
40	555	466	327	204	104	105	103	105	121	304	450	579	686	792	875
50	599	515	383	267	104	104	104	104	173	380	527	643	699	832	901
60	641	562	434	318	129	103	104	107	220	431	586	700	747	865	920
70	675	599	474	356	155	111	104	122	262	471	634	618	767	883	938
80	708	630	508	388	181	121	112	141	302	507	673	718	766	896	955
90		657	536	416	206	136	123	162	339	539	705	741	777	904	969
105	686	694	576	456	246	164	147	199	389	588	747	761	794	880	986
110	693	705	589	469	260	175	155	213	404	604	760	766	796	876	992
120	710	727	615	496	292	200	174	241	435	634	784	777	799	932	1005
130	725	748	640	522	325	227	197	268	464	662	807	786	799	944	1015
140	739	769	664	547	358	256	225	296	493	688	826	790	795	941	1025
155	755	797	697	586	403	298	265	336	531	720	852	791	794	799	1039
170	764	824	696	623	446	338	304	381	578	740	874	788	792	794	1052
180	766	836	707	646	473	365	329	450	644	739	886	775	791	798	1059
195	762	805	711	679	511	417	375	651	723	753	863	738	759	787	1071
210	729	752	702	712	562	599	553	730	754	767	761	749	734	741	1083
225	711	731	712	728	665	708	695	756	765	769	751	761	751	737	1096
240	723	737	733	747	719	741	736	759	764	763	763	759	762	749	1105
270	757	759	752	760	752	759	749	760	758	759	753	758	753	751	1128
300	783	784	776	788	777	780	776	773	762	760	757	764	763	766	1151
330	799	803	803	828	810	811	794	818	827	822	790	820	808	794	1165

Table 3.5.3

Deflections, Series II Column 1

Minutes	Expansion, mm
0	0.0
5	0.6
10	1.9
20	5.4
30	6.6
40	7.4
50	8.4
60	9.8
70	11.2
80	12.9
90	14.5
100	16.0
120	18.3
140	19.6
160	19.7
180	19.5
200	18.3
220	16.4
240	13.9
260	12.0
280	9.3
300	5.5
320	-0.2
340	-15.3

Table 3.5.4

Steel Temperatures, Series II Column 2

Minutes	Temperature (°C) Measured at Thermocouple #:												Furnace
	1	2	3	4	5	6	7	8	39	40	41	42	
0	21	20	18	17	11	9	19	15	17	16	16	16	72
5	30	25	24	24	20	18	36	32	24	19	19	20	596
10	54	47	50	43	46	45	76	68	56	35	34	40	687
15	107	99	96	99	100	98	112	105	97	75	81	95	739
20	111	110	111	111	112	112	137	135	110	102	101	108	777
25	116	112	114	111	117	107	170	161	117	102	106	110	814
30	128	125	130	124	137	126	209	192	136	106	109	120	841
35	148	144	152	141	162	146	244	222	161	122	123	137	863
40	172	166	177	162	190	168	275	249	187	141	142	158	864
45	200	190	203	187	219	194	303	273	214	163	166	183	884
50	227	215	229	213	246	219	327	296	240	185	189	209	900
55	253	239	254	238	273	244	349	318		207	213	234	906
60	279	263	279	263	298	269	370	340		229	236	258	912
70	325	307	325	310	345	315	407	378		273	281	305	935
80	365	347	366	353	386	357	440	414		314	322	348	950
90	402	385	404	392	424	397	470	447		352	361	388	965
100	437	420	438	428	459	436	497	476		387	396	424	969
110	471	452	469	462	492	472	521	503		421	429	458	984
120	502	482	499	493	523	502	544	529		453	461	490	1007
130	531	513	526	523	554	531	569	555		483	491	519	1007
140	558	540	552	550	585	559	593	581		511	518	546	1025
150	584	568	581	578	615	587	618	608		539	544	574	1021
160	612	598	610	608	644	615	640	632		568	571	604	1038
170	645	630	638	637	674	645	661	657		601	601	637	1048
180	681	665	665	664	702	673	682	681		644	631	673	1053
190	715	709	691	691	726	696	704	702		703	666	706	1068
200	743	760	715	713	748	715	724	718		727	699	730	1074

Table 3.5.5 Concrete Temperatures, Series II Column 2

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace
	11	12	13	14	15	16	17	18	19	20	21	22	24	
0	20	18	17	17	18	18	19	18	17	17	17	17	23	72
5	159	103	56	33	20	18	19	18	20	37	100	136	276	596
10	260	171	107	68	30	19	18	19	36	89	172	231	422	687
15	350	240	146	105	48	22	19	24	84	123	254	322	531	739
20	424	303	191	129	76	30	24	37	106	143	324	389	610	777
25	485	357	233	153	96	62	29	52	105	194	384	451	677	814
30	534	404	273	187	101	77	44	64	108	245	436	510	567	841
35	571	444	310	219	108	84	54	74	122	289	480	556	587	863
40	594	475	342	248	120	89	62	83	140	328	520	598	638	864
45	621	502	369	274	132	96	71	92	161	362	555	634	702	884
50	647	527	394	297	144	100	82	103	182	391	592	665	733	900
55	670	550	416	318	156	103	91	105	204	417	624	580	748	906
60	688	570	437	337	169	106	97	110	224	441	649	694	758	912
70	723	607	472	372	200	117	107	127	265	481	693	733	775	935
80	751	639	504	404	230	132	117	164	303	526	730	751	784	950
90	777		533	434	258	149	125	270	345	609	758	765	773	965
100	797		559	460	283	168	134	382	429	679	775	774	768	969
110	817		584	486	317	196	145	443	532	714	787	783	773	984
120	845		613	514	404	306	172	492	600	734	797	790	774	1007
130			657	560	576	561	272	621	649	738	773	753	750	1007
140			712	662	687	697	547	711	695	727	742	728	730	1025
150			742	722	727	737	707	741	728	734	738	732	735	1021
160			758	741	732	752	740	746	743	743	744	740	748	1038
170			773	754	741	759	754	749	758	757	760	748	755	1048
180			780	763	750	759	759	754	768	770	771	754	760	1053
190			785	771	759	758	759	752	774	773	764	760	763	1068
200			785	771	767	762	761	750	767	766	756	766	758	1074

Table 3.5.5
(continued)

Concrete Temperatures, Series II Column 2

Minutes	Temperature (°C) Measured at Thermocouple #:												Furnace
	25	26	27	28	29	31	32	33	34	35	36	37	
0	21	19	18	18	18	18	18	17	16	16	18	23	72
5	165	123	70	38	20	18	17	19	36	85	131	233	596
10	266	205	117	83	33	17	18	36	94	155	235	387	687
15	357	282	167	104	51	18	24	91	120	231	329	497	739
20	429	348	214	128	81	23	36	98	164	301	403	571	777
25	490	405	263	157	80	33	46	101	216	364	465	636	814
30	537	454	306	184	86	45	57	104	269	420	520	692	841
35	573	493	342	211	94	57	67	117	313	464	568	733	863
40	596	521	369	225	100	72	76	134	346	501	610	757	864
45	620	544	394	261	105	83	87	153	374	534	644	781	884
50	642	569	420	292	111	90	97	173	399	564	677	804	900
55	662	593	445	320	122								906
60	679	613	467	345	143			196	421	600	705	813	912
70	713	650	505	383	178								935
80	740	681	537	415	211								950
90	761	716	566	446	245			329	539	729	756	885	965
100	753	739	595	522	366			361	569	751	764	888	969
110	733	746	649	665	633			393	601	764	756		984
120	736	758	714	726	725			445	644	774	748		1007
130	750	765	742	738	747			578	692	785	801		1007
140	763	761	752	740	754			690	725	796			1025
150	768	759	752	749	763			737	746	806			1021
160	765	760	751	758	768			757	755	807			1038
170	762	768	757	768	774			769	761				1048
180	763	778	766	774	776			772					1053
190	767	784	774	776	776			769					1068
200	773	788	782	780	774			781					1074

Table 3.5.6

Loads and Deflections, Series II Column 2

Minutes	Load, kN	Expansion, mm
0	1044	0.0
10	1513	0.0
20	2049	0.0
30	1985	0.0
40	1967	0.0
50	1967	0.0
60	1935	0.0
70	1892	0.0
80	1846	0.0
90	1853	0.0
100	1767	0.0
110	1635	0.0
120	1413	0.0
130	1560	0.0
140	1413	0.0
150	1303	0.0
160	1167	0.0
170	1044	0.0
174	1044	-0.2
178	1044	-0.6
182	1044	-0.8
186	1044	-1.3
190	1044	-1.8
192	1044	-2.1
194	1044	-2.5
196	1044	-2.9
198	1044	-3.3
200	1044	-3.8

Table 3.5.7 Steel Temperatures, Series II Column 3

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace
	1	2	3	4	5	6	7	8	9	39	40	41	42	
0	15	14	12	12	12	11	15	16	12	17	11	11	12	60
5	15	16	15	14	14	13	21	20	14	17	12	11	14	571
10	34	35	35	30	29	27	54	52	31	45	29	24	36	681
15	81	88	95	94	85	76	100	93	78	92	77	87	98	740
20	113	109	110	108	106	105	118	113	107	111	102	103	107	788
25	112	111	106	102	102	103	134	125	106	117	106	100	101	811
30	125	127	123	112	102	113	178	158	116	136	113	104	115	840
35	145	144	141	126	118	123	214	190	135	158	130	115	134	849
40	170	163	165	146	140	140	245	220	157	183	152	132	156	871
45	197	186	191	169	164	162	273	246	181	210	177	152	180	894
50	224	210	219	192	188	187	298	271	206	238	203	174	204	899
55	250	236	246	216	212	212	321	294	232	265	231	196	228	912
60	274	261	272	239	236	237	341	317	256	290	257	219	252	923
70	320	309	321	285	281	284	379	357	303	338	305	264	298	945
80	362	353	366	328	323	327	412	393	346	381	348	306	340	955
90	400	393	405	367	362	366	443	426	385	419	387	345	380	972
100	436	429	440	404	398	402	471	457	420	454	422	381	416	984
110	469	463	471	439	432	436	496	485	452	486	454	416	451	984
120	499	494	503	473	463	468	520	510	481	515	484	449	484	1004
130	527	522	530	505	493	498	543	534	509	542	512	481	516	1013
140	552	548	558	534	520	525	566	558	534	569	537	511	545	1027
150	580	576	589	563	546	550	591	591	560	597	564	538	573	1034
160	606	602	611	590	573	576	606	620	587	620	591	566	599	503
170	615	607	617	597	581	584	587	594	598	621	601	580	603	381
180	606	595	605	589	573	574	564	566	590	606	593	576	591	972
200	624	614	617	608	590	586	621	618	601	627	603	591	615	864
220	657	646	650	640	622	619	630	626	635	654	637	626	644	1017
240	705	697	679	683	652	648	687	679	663	687	663	699	743	1102

Table 3.5.8 Concrete Temperatures, Series II Column 3

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace
	11	13	14	15	16	17	18	19	20	21	22	23	24	
0	16	13	12	9	9	9	9	10	8	9	8	10	17	60
5	136	56	26	11	9	9	9	12	29	83	129	203	265	571
10	239	113	65	22	10	9	10	27	83	156	233	349	429	681
15	339	160	103	42	15	10	15	82	129	229	338	470	550	740
20	418	211	123	71	25	12	41	107	152	295	418	547	628	788
25	481	259	151	91	45	19	48	105	200	355	484	618	668	811
30	528	301	184	99	65	34	60	107	255	409	539	674	719	840
35	564	336	216	105	75	48	72	117	304	459	589	717	754	849
40	596	367	245	114	82	57	80	133	348	501	632	330	785	871
45	622	393	271	126	88	65	87	151	385	538	669	674	757	894
50	646	418	295	139	95	73	94	172	415	572	704	715	793	899
55	667	440	317	153	101	82	103	195	441	604	728	728	752	912
60	683	461	338	167	109	91	112	218	464	631	569	740	765	923
70	632	499	375	195	126	103	132	261	504	678	726	804	778	945
80	690	531	408	221	140	117	147	301	539	715	751	844	780	955
90	719	561	437	247	152	126	165	337	573	748	751	848	783	972
100	741	589	464	273	169	132	188	371	606	766	754	842	784	984
110	747	615	490	299	191	141	235	413	645	772	765	760	779	984
120	758	639	516	326	214	160	336	480	688	774	762	758	765	1004
130	789	664	541	355	241	186	457	575	728	753	744	747	740	1013
140	799	687	567	383	268	214	615	686	743	751	744	752	752	1027
150	775	705	592	410	294	240	709	742	761	764	760	763	776	1034
160	661	669	599	435	323	267	604	639	733	795	746	733	730	503
170	633	601	571	454	351	293	570	619	686		693	681	684	381
180	621	605	551	463	374	318	542	597	643		647	643	642	972
200	853	635	624	494	417	362		811	728		722	728	829	864
220	671	648	636	533	476	401		643	720		697	705	657	1017
240	802	683	690	605	564	443		937	758		723	728	721	1102

Table 3.5.8
(continued)

Concrete Temperatures, Series II Column 3

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace
	25	26	27	28	29	30	31	32	33	34	35	36	37	
0	16	13	10	9	10	9	8	9	11	10	11	13	14	60
5	132	112	52	26	11	8	8	8	11	28	79	116	194	571
10	240	204	111	69	23	10	8	9	24	80	155	221	356	681
15	345	298	149	104	42	14	9	14	95	123	236	329	471	740
20	425	370	204	130	89	27	12	24	102	157	308	414	548	788
25	487	424	248	151	78	36	20	37	101	204	369	485	619	811
30	531	463	281	172	82	46	35	48	99	254	422	539	672	840
35	564	494	312	197	87	55	47	58	108	297	466	589	713	849
40	595	522	342	230	92	64	56	68	126	335	505	630	528	871
45	620	547	371	261	100	72	64	77	145	368	539	665	695	894
50	643	573	398	288	107	81	73	87	165	396	572	696	731	899
55	663	595	422	312	121	91	83	98	186	420	602	721	751	912
60	685	618	445	334	140	102	91	106	207	442	629	744	764	923
70	717	654	484	370	172	116	102	120	249	482	676	777	772	945
80	744	682	516	401	198	130	112	135	287	516	714	754	780	955
90	770	708	542	427	221	146	118	150	323	547	744	765	783	972
100	793	731	567	450	242	165	130	189	361	578	764	768	778	984
110	800	751	591	473	265	191	140	391	451	620	753	743	761	984
120	746	768	623	526	309	299	168	622	619	691	749	726	736	1004
130	720	762	681	653	480	561	324	715	704	728	748	736	728	1013
140	736	727	724	718	680	697	626	738	725	732	744	751	732	1027
150	750	724	745	733	732	729	718	743	733	737	743	756	737	1034
160	753	730	746	740	741	737	725	749	727	719	736	750	717	503
170	687	667	680	674	633	652	611	629	650	658	688	694	654	381
180	644	643	623	609	576	557	549	567	614	628	645	645	626	972
200	702	720	694	673	623	625	623	605	704	737	724	714	725	864
220	668	715	678	657	619	614	613	538	668	702	695	701	694	1017
240	731	768	733	719	696	681	688	606	743	769	748	700	768	1102

Table 3.5.9

Loads and Deflections, Series II Column 3

Minutes	Load, kN	Expansion, mm
0	916	0.0
10	1410	0.0
20	1892	0.0
30	1889	0.0
38	1910	0.0
50	1874	0.0
60	1902	0.0
70	1878	0.0
80	1892	0.0
90	1832	0.0
100	1814	0.0
110	1696	0.0
120	1649	0.0
130	1506	0.0
140	1413	0.0
150	1324	0.0
172	1117	-0.1
197	1103	0.0
210	1103	0.0
220	935	0.0
225	916	0.0
230	916	-0.8
240	916	-1.8
242	916	-5.3

3.6 EFFECT OF HEAVY REINFORCEMENT

Specimen Properties:

Cross-Section: 305 x 305 mm (12 x 12 in.)
 Length: 3810 mm (12 ft 6 in.)
 Aggregate: Siliceous
 Reinforcement: 4.38% as eight No. 8 bars.

Elevation, Cross-Section and Finishing Detail: Figure 3.6.1
 Layout of Thermocouple Frames in Concrete: Figure 3.3.1
 Locations of Thermocouples in Frames: Figure 3.6.2
 Locations of Thermocouples on Reinforcing Bars: Figure 3.6.3

3.6.1 Series II, Column 8

Test purpose: Effect of extra steel.
 Date tested: February 11, 1983.
 Loading: 978 kN, Concentric.

Measured Properties:

Cylinder strengths: 41.4 MPa at 28 days.
 42.6 MPa on test date.
 Relative humidity: 61%.

Results:

Test duration: 4 hours 12 minutes.
 Temperatures: Tables 3.6.1 and 3.6.2.
 Axial deformations: Table 3.6.3

Observations

1:11 The first hairline crack appeared at midheight on the E face.
 1:39 Longitudinal cracks 10 to 15 cm long were seen on the E, W, and N faces.
 2:58 Cracks on the N face widened, with a maximum width of 3 mm.
 3:19 Cracks began to develop on the S face.
 4:00 Cracks opened to 6 mm wide.
 4:12 The column failed in compression (Figure 3.6.4).

3.6.2 Series II, Column 9

Test purpose: Effect of extra steel.
 Date tested: April 26, 1984.
 Loading: 1333 kN, Concentric.

Measured Properties:

Cylinder strengths:	38.1 MPa at 28 days. 37.1 MPa on test date.
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Results:

Test duration:	3 hours 45 minutes.
Temperatures:	Tables 3.6.4 and 3.6.5.
Axial deformations:	Table 3.6.6.

Observations

1:00 A hairline crack 5 cm long appeared near midheight on the S face.
 1:20 Cracks 5 to 15 cm long were seen near midheight on the other faces.
 1:40 All cracks increased in length, with some about 35 cm long.
 2:20 Cracks on the N face increased in length to about 45 cm.
 2:45 Maximum crack width was about 6 mm.
 3:20 Two cracks 60 cm long developed in the upper quarter of the W face.
 3:30 Cracks widened rapidly, the widest being 13 mm.
 3:45 The column failed in compression (Figure 3.6.5)

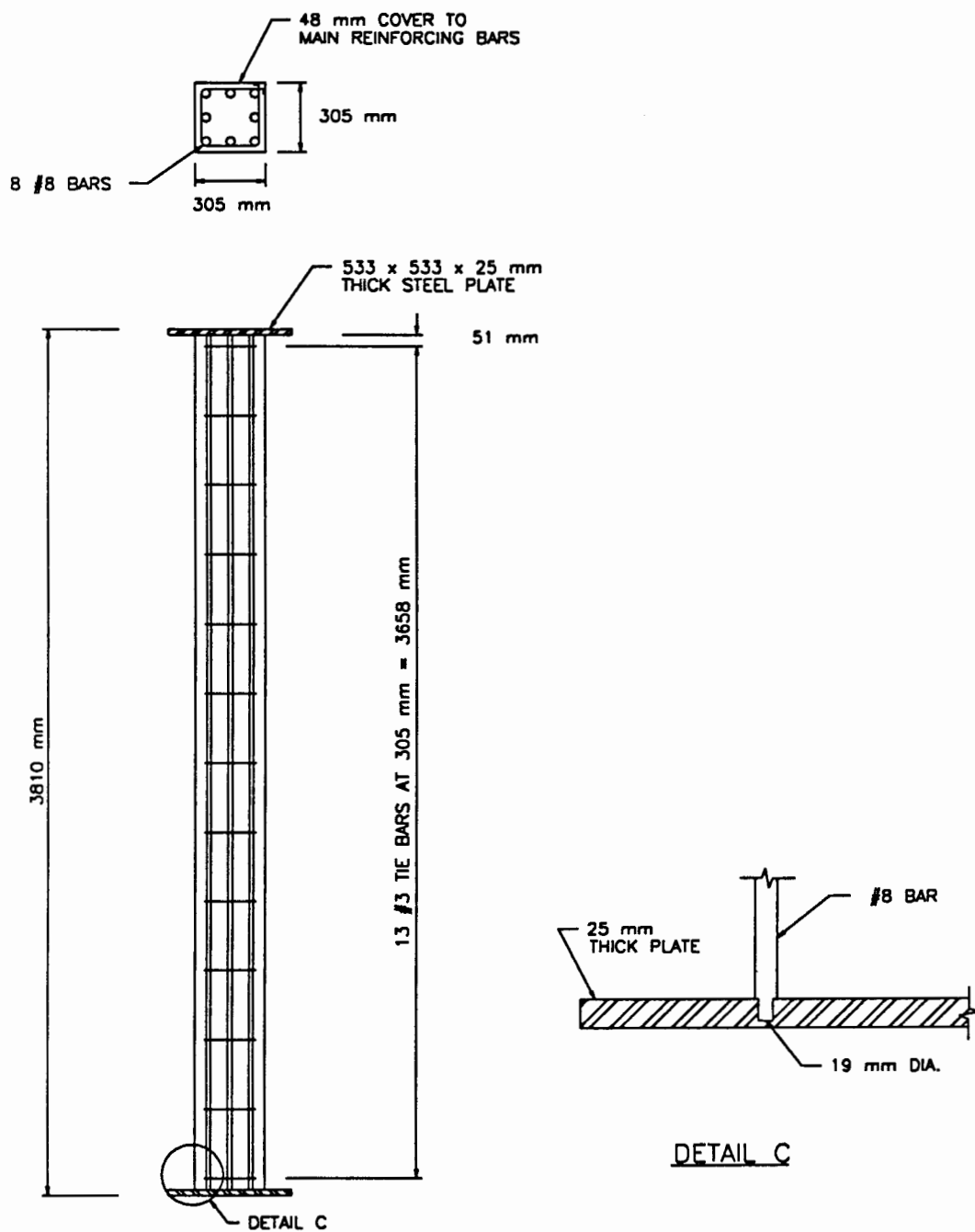


Figure 3.6.1 Elevation, Cross-Section and Finishing Detail: 12 x 12 Section with 4.38% Steel

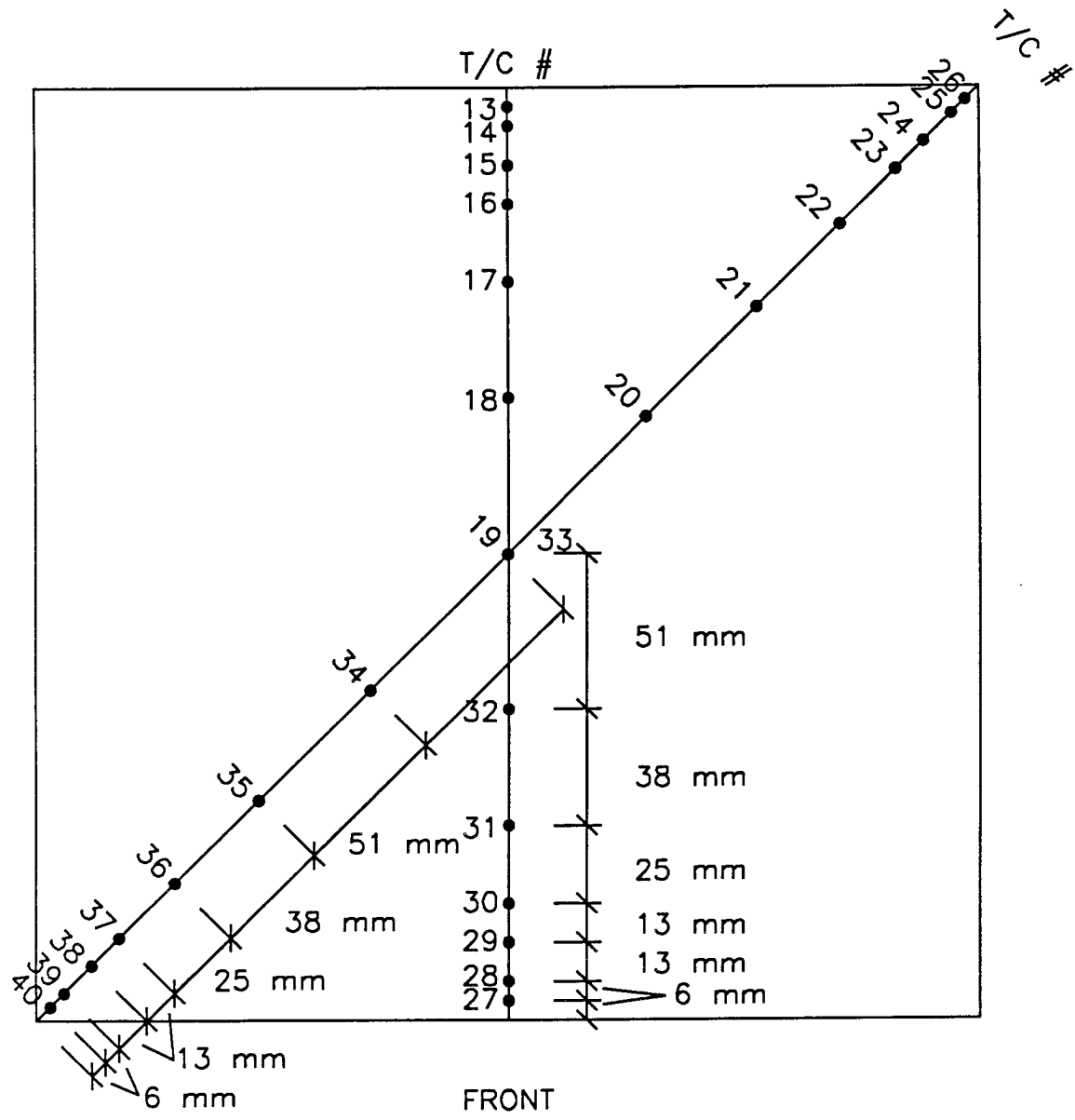


Figure 3.6.2 Locations of T/C's in Frames: 12 x 12 Section with 4.38% Steel

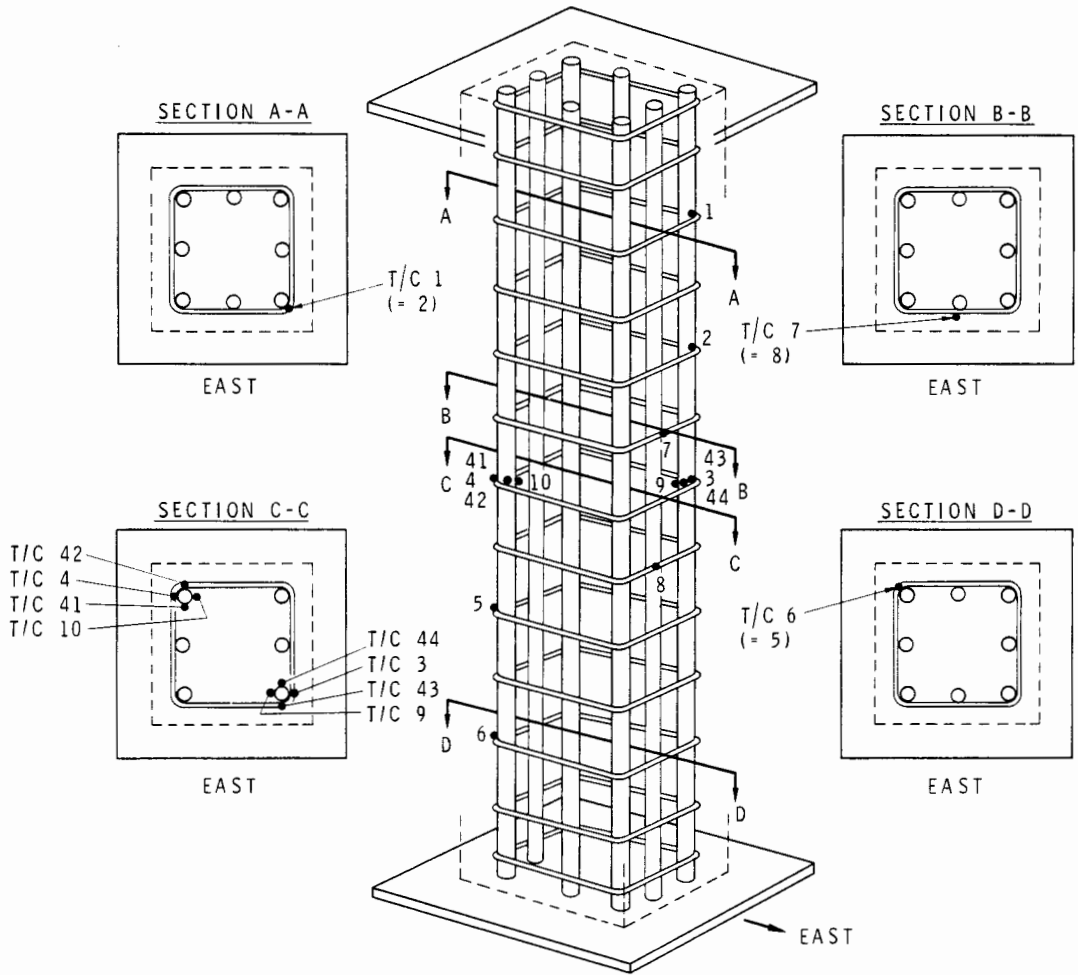


Figure 3.6.3 Locations of T/C's on Reinforcing Bars: 12 x 12 Section with 4.38% Steel

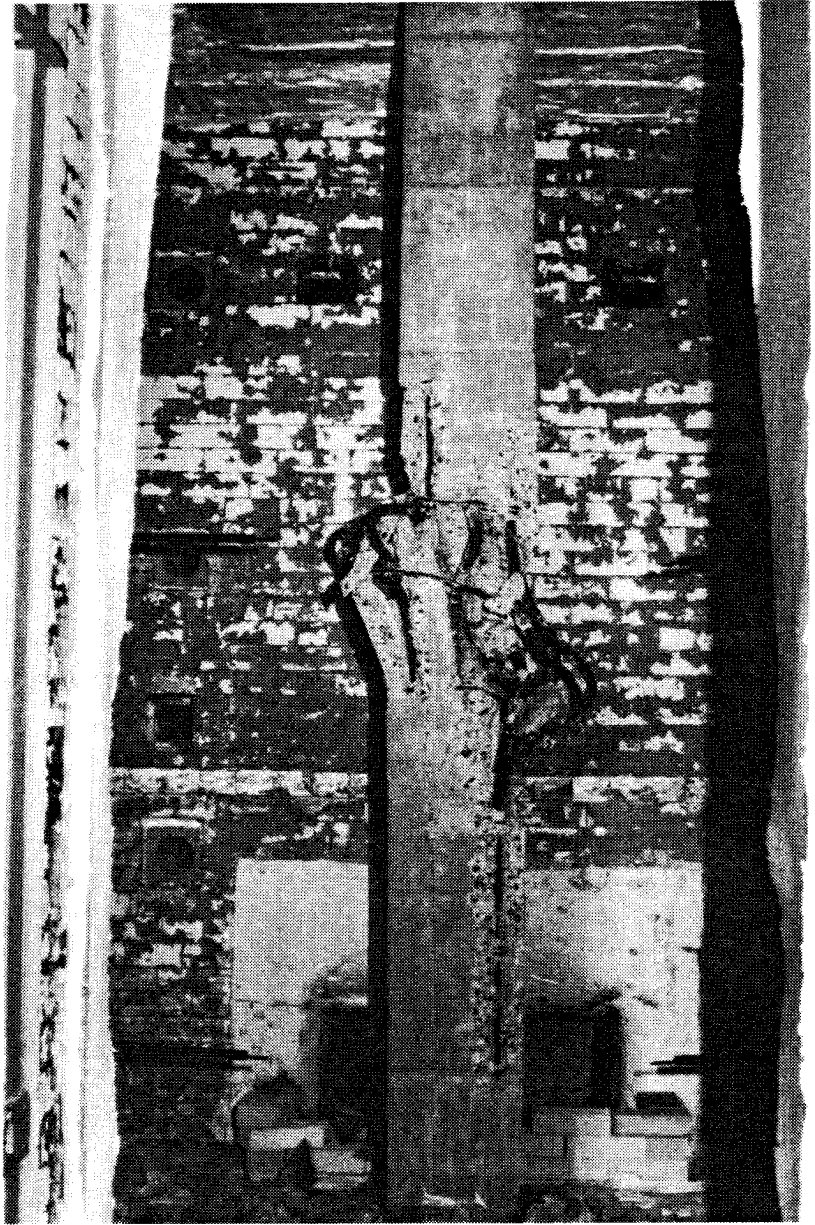


Figure 3.6.4 Series II Column 8 After Test

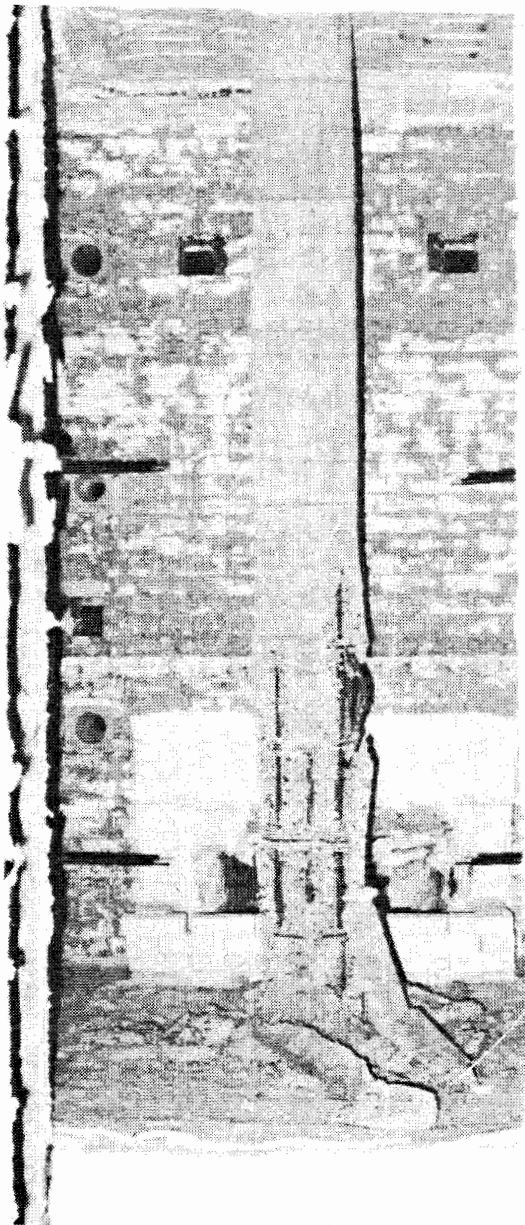


Figure 3.6.5 Series II Column 9 After Test

Table 3.6.1 Steel Temperatures, Series II Column 8

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	1	2	3	4	5	6	7	8	9	10	41	42	43	44	
0	20	18	15	14	4		17	12	12	15	13	13	14	14	373
5	27	24	25	21	10	6	35	25	21	19	18	20	24	20	571
10	49	46	50	39	29	27	69	51	41	33	34	38	50	40	675
15	96	88	106	84	69	68	103	83	93	69	72	83	111	104	738
20	113	116	123	113	107	112	125	109	119	105	106	113	123	120	781
25	117	123	127	114	114	116	150	129	121	113	112	112	129	117	816
30	131	136	147	126	118	129	184	145	134	115	113	121	147	130	838
35	150	155	172	147	132	149	222	175	155	127	129	140	171	151	858
40	173	179	200	170	151	174	253	204	180	146	149	163	198	177	881
45	198	206	230	193	174	199	280	229	208	167	171	186	226	205	886
50	223	233	258	218	198	225	305	251	235	189	194	210	255	233	894
55	248	259	286	241	223	250	327	272	262	212	216	233	282	260	907
60	274	283	312	264	247	274	348	292	288	233	239	256	309	287	914
70	321	330	360	306	292	321	386	328	336	276	281	299	357	335	934
80	365	373	403	346	332	364	420	361	379	316	322	340	400	378	954
90	405	412	443	383	368	404	451	392	418	354	359	377	440	417	968
100	441	448	479	418	402	442	479	422	454	389	395	413	476	453	980
110	475	482	513	453	434	477	505	450	488	423	429	447	510	487	993
120	507	514	544	485	465	509	530	478	520	456	462	481	541	519	1006
140	563	570	603	543	522	566	580	530	577	517	522	540	598	576	1019
160	619	626	662	597	573	618	629	581	633	571	577	596	652	636	1042
180	671	677	716	652	626	665	673	630	680	624	640	647	700	694	1055
200	716	720	726	708	675	705	710	675	712	672	704	693	726	716	1077
220	745	729	728	739	718	744	719	712	720	713	730	729	736	730	1097
240	787	756	758		739	770	736	726	751	723	736		756	758	1104
250	809	770	772		751	785	751	742	767	730	738		766	773	1114

Table 3.6.2 Concrete Temperatures, Series II Column 8

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	13	14	15	16	17	18	20	21	22	23	24	25	26	27	
0	33	24	17	16	15	15	14	14	16	20	29	51	86	91	373
5	105	81	45	25	17	15	14	18	34	73	119	169	232	198	571
10	167	132	88	48	25	16	16	32	79	136	200	290	381	320	675
15	238	185	122	80	39	20	21	73	117	189	291	400	499	429	738
20	310	244	146	101	59	29	42	107	142	254	372	482	589	517	781
25	370	298	182	119	85	45	58	114	181	316	439	541	653	577	816
30	422	345	222	138	106	57	64	112	194	374	499	600	708	624	838
35	465	387	259	170	112	78	84	119	255	420	548	649	745	666	858
40	499	421	289	194	115	91	94	139	311	463	594	693	773	703	881
45	528	451	316	216	126	97	98	161	348	500	634	728	796	723	886
50	552	477	340	236	140	102	101	183	378	532	667	755	819	745	894
55	576	500	361	255	155	106	105	206	403	562	695	781	841	769	907
60	598	521	382	274	169	110	111	229	426	591	720	800	854	785	914
70	636	557	419	309	197	120	126	274	467	641	757	832	875	817	934
80	668	592	453	341	225	130	142	318	500	679	790	851	785	844	954
90	696	623	484	372	254	145	162	358	532	714	818	788	787	868	968
100	722	652	512	401	283	166	184	394	565	745	843	787	788	886	980
110	748	679	539	429	312	189	210	428	599	773	866	789	789	907	993
120	769	703	564	456	339	216	239	460	631	799	885	790		923	1006
140	813	749	616	507	394	272	296	517	679	839	919			951	1019
160	848	787	663	554	448	337	352	565	721	870	938			977	1042
180			703	619	571	563	405	616	754		955			1001	1055
200			729	719	714	706	483	681	761					1006	1077
220			742	740	731	735	673	720	726						1097
240			759	760	753	755	736	732	730						1104
250			767	772	761	766	759	749	750						1114

Table 3.6.3

Deflections, Series II Column 8

Minutes	Expansion, mm
0	0.0
10	1.1
20	3.1
30	4.0
40	4.6
50	5.5
60	6.5
70	7.7
80	8.9
90	10.0
100	11.1
110	12.1
120	12.9
130	13.7
140	14.3
150	14.6
160	14.8
170	14.8
180	14.8
185	14.6
190	14.3
195	13.9
200	13.4
205	12.9
210	12.0
215	11.0
220	9.9
225	8.7
230	7.2
235	5.6
240	3.7
245	1.6
250	-1.4
252	-69.4

Table 3.6.4 Steel Temperatures, Series II Column 9

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace
	1	2	3	4	5	6	7	8	9	41	42	43	44	
0	25	25	25	24	24	25	24	24	25	23	23	23	23	76
5	28	30	30	28	27	29	35	36	28	26	26	27	27	654
10	44	50	52	43	43	45	65	66	47	40	40	45	46	669
15	87	97	96	83	93	89	104	105	89	79	84	97	89	740
20	113	115	119	116	114	114	123	117	117	113	114	117	116	782
25	117	119	128	112	114	116	150	152	121	111	110	128	119	817
30	128	136	144	118	124	129	180	187	134	112	113	143	133	836
35	149	159	168	138	144	151	214	225	157	130	131	166	156	857
40	172	184	194	164	168	178	247	258	182	156	156	186	181	874
45	196	212	221	190	195	206	275	287	208	182	182	216	207	889
50	220	240	248	217	222	234	301	313	234	208	209	246	233	896
55	243	268	273	243	249	260	325	337	259	234	235	272	258	905
60	267	295	298	269	275	284	347	358	284	259	261	296	282	922
70	312	345	343	316	322	330	387	397	329	306	309	341	327	932
80	353	389	384	358	366	370	421	430	369	348	353	382	367	954
90	391	430	421	397	406	408	452	461	406	386	392	419	404	961
100	426	466	456	433	443	443	480	489	440	422	429	453	438	980
110	460	500	488	467	477	476	505	515	472	456	463	486	470	989
120	492	530	519	498	508	506	530	540	503	488	495	517	501	1006
130	521	557	548	527	535	534	553	566	532	518	525	545	530	1014
140	548	585	575	555	561	560	577	591	557	545	553	573	556	1019
150	575	611	603	583	588	587	601	615	586	572	581	600	584	1034
160	601	637	632	611	616	612	624	638	611	599	607	626	611	1043
170	627	661	664	639	646	635	647	659	636	624	634	651	641	1051
180	653	684	696	668	678	658	668	680	660	648	661	676	674	1055
200	703	723	725	709	728	701	708	715	701	689	707	715	716	1074
220	742	736	739	732	743	736	725	740	723	709	718	719	737	1092

Table 3.6.5 Concrete Temperatures, Series II Column 9

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
0	26	24	24	23	24	24	24	24	24	24	24	24	26	29	76
5	130	93	52	34	25	24	24	24	26	35	76	116	172	239	654
10	215	154	99	62	34	25	24	26	38	78	139	205	299	387	669
15	313	227	136	98	48	29	25	30	72	118	207	298	415	519	740
20	398	298	179	120	77	37	27	47	105	146	276	380	508	611	782
25	465	358	226	147	104	52	34	57	110	184	336	447	578	677	817
30	521	409	268	176	107	63	44	67	113	218	387	502	639	726	836
35	563	451	308	215	107	73	55	77	122	265	427	551	688	765	857
40	599	487	344	248	116	81	64	87	138	304	461	594	724	793	874
45	629	518	375	275	128	90	72	96	157	340	496	634	755	816	889
50	654	545	402	300	141	100	80	106	178	371	528	665	779	833	896
55	676	568	426	321	155	108	89	110	198	400	557	691	798	847	905
60	698	591	449	341	169	113	100	114	218	425	586	717	819	862	922
70	729	630	488	377	200	127	109	129	257	469	635	759	849		932
80	760	663	521	408	230	143	114	147	294	505	672	791	877		954
90	783	691	551	438	258	161	120	171	330	538	706	819	897		961
100	806	716	579	465	287	181	129	197	364	568	734	842	916		980
110	827	739	605	491	316	205	146	224	398	600	760	863	933		989
120	848	761	630	516	346	234	173	252	431	631	785	882	948		1006
130	863	780	654	539	375	263	203	281	462	659	808	899	958		1014
140	881	801	678	564	404	292	232	310	491	685	829	916	970		1019
150	896	819	699	588	431	319	261	338	517	708	846	928	978		1034
160	912	837	720	611	458	346	289	364	542	729	864	942	986		1043
170	927	855	740	633	484	374	314	390	567	750	880	954			1051
180	937	870	758	654	509	416	340	415	593	769	895	961			1055
200		895	791	693	565	610	391	473	647	784					1074
220				723	684	718	515	646	711						1092

Table 3.6.6

Deflections, Series II Column 9

Minutes	Expansion, mm
0	0.0
10	0.8
20	2.4
30	3.1
40	3.5
50	4.3
60	5.2
70	6.2
80	7.2
90	8.2
100	9.1
110	10.0
120	10.6
130	11.0
140	11.2
150	11.2
160	11.2
170	11.1
180	10.5
185	10.0
190	9.4
195	8.6
200	7.7
205	6.6
210	5.3
215	3.6
220	1.4
225	-2.2

3.7 EFFECT OF SIZE AND HEAVY REINFORCEMENT

3.7.1 Series I, Column 5

Test purpose: Effect of Larger Size and Dryness.
 Date tested: January 23, 1981.
 Loading: None.

Specimen Properties:

Cross-Section: 406 x 406 mm (16 x 16 in.)
 Length: 3810 mm (12 ft 6 in.)
 Aggregate: Siliceous
 Reinforcement: 2.47% as eight No. 8 bars.

Elevation, Cross-Section and Finishing Detail: Figure 3.7.1
 Layout of Thermocouple Frames in Concrete: Figure 3.1.2
 Locations of Thermocouples in Frames: Figure 3.7.2
 Locations of Thermocouples on Reinforcing Bars: Figure 3.7.3

Measured Properties:

Cylinder strengths: 35.7 MPa at 28 days.
 40.7 MPa on test date.
 Relative humidity: 9%.

Results:

Test duration: 5 hours.
 Temperatures: Tables 3.7.1 and 3.7.2a to d.
 Axial deformations: Table 3.7.3

The test lasted 5 hours, but temperatures measured in the column after 210 minutes are not reliable, due to excessive strain on the thermocouple wires caused by expansion of the unloaded column. Figure 3.7.4 shows the column after the test.

3.7.2 Series II, Column 10

Test purpose: Effect of Larger Size.
 Date tested: September 21, 1984.
 Loading: 2418 kN, Concentric.

Specimen Properties:

Cross-Section: 406 x 406 mm (16 x 16 in.)
 Length: 3810 mm (12 ft 6 in.)
 Aggregate: Siliceous
 Reinforcement: 2.47% as eight No. 8 bars.

Elevation, Cross-Section and Finishing Detail: Figure 3.7.1
 Layout of Thermocouple Frames in Concrete: Figure 3.3.1
 Locations of Thermocouples in Frames: Figure 3.7.5
 Locations of Thermocouples on Reinforcing Bars: Figure 3.7.6

Measured Properties:

Cylinder strengths: 38.4 MPa at 28 days.
38.8 MPa on test date.
Relative humidity: 80%.

Results:

Test duration: 4 hours 22 minutes.
Temperatures: Tables 3.7.4 and 3.7.5.
Axial deformations: Table 3.7.6.

Observations

1:35 Fine cracks were visible on all faces.
2:20 Maximum crack width on the E and W faces was 6 mm.
3:20 Two 60 cm long cracks developed in the lower quarter of the E and S faces.
3:58 Large cracks had developed on all faces. Cracks on the S and E faces had widened to 25 mm, exposing the corner reinforcing bar.
4:22 The column failed in compression (Figure 3.7.7).

3.7.3 Series II, Column 11

Test purpose: Effect of larger size with extra steel.
Date tested: August 8, 1984.
Loading: 2795 kN, Concentric.

Specimen Properties:

Cross-Section: 406 x 406 mm (16 x 16 in.)
Length: 3810 mm (12 ft 6 in.)
Aggregate: Siliceous
Reinforcement: 3.97% as eight No. 10 bars.

Elevation, Cross-Section and Finishing Detail: Figure 3.7.8
Layout of Thermocouple Frames in Concrete: Figure 3.3.1
Locations of Thermocouples in Frames: Figure 3.7.5
Locations of Thermocouples on Reinforcing Bars: Figure 3.7.6

Measured Properties:

Cylinder strengths: 36.8 MPa at 28 days.
38.4 MPa on test date.
Relative humidity: 75%.

Results:

Test duration: 4 hours 45 minutes.
Temperatures: Tables 3.7.7 and 3.7.8.
Axial deformations: Table 3.7.9.

Observations

- 1:40 Fine cracks developed on the E and S faces.
- 2:20 Cracks on the E face lengthened to 10 to 20 cm, with maximum width 3 mm. Small cracks also developed on the N and W faces.
- 3:00 Two 60 cm cracks developed on the lower quarter of the E and S faces.
- 3:20 Longest crack on the E face was 75 cm long. Others also lengthened.
- 4:00 Worst crack on the E face opened to 6 mm wide.
- 4:17 All cracks continued to widen. Worst crack on E face was 25 mm wide.
- 4:45 Failure in compression. Figure 3.7.9 shows the column after the test.

3.7.4 Series II, Column 12

Test purpose:	Effect of larger size with extra steel; thickness of concrete cover.
Date tested:	April 29, 1983.
Loading:	2978 kN, Concentric.

Specimen Properties:

Cross-Section:	406 x 406 mm (16 x 16 in.)
Length:	3810 mm (12 ft 6 in.)
Aggregate:	Siliceous
Reinforcement:	3.97% as eight No. 10 bars.
Concrete Cover to Vertical Steel:	63 mm (2.5 in.)

Elevation, Cross-Section and Finishing Detail:	Figure 3.7.8
Layout of Thermocouple Frames in Concrete:	Figure 3.3.1
Locations of Thermocouples in Frames:	Figure 3.7.5
Locations of Thermocouples on Reinforcing Bars:	Figure 3.7.6

Measured Properties:

Cylinder strengths:	42.6 MPa at 28 days. 46.2 MPa on test date.
Relative humidity:	68%.

Results:

Test duration:	3 hours 33 minutes.
Temperatures:	Tables 3.7.10 and 3.7.11.
Axial deformations:	Table 3.7.12.

Observations

- 0:28 A hairline crack developed near the upper quarter point of the E face.
- 0:40 It grew to 45 cm long, and more developed.
- 1:10 More developed near the edges of all faces, some 10 to 20 cm long.
- 2:15 Major cracks had a maximum width of 6 mm.
- 3:00 Most cracks became stable.
- 3:33 The combustion air fan motor burned out and the fire was automatically shut off. Figure 3.7.10 shows the column shortly after the test.

3.7.5 Series I, Column 6

Test purpose: Effect of Smaller Size and Dryness.
 Date tested: March 12, 1982.
 Loading: 169 kN, Concentric.

Specimen Properties:

Cross-Section: 203 x 203 mm (8 x 8 in.)
 Length: 3810 mm (12 ft 6 in.)
 Aggregate: Siliceous
 Reinforcement: 2.75% as four No. 6 bars.

Elevation, Cross-Section and Finishing Detail: Figure 3.7.11
 Layout of Thermocouple Frames in Concrete: Figure 3.1.2
 Locations of Thermocouples in Frames: Figure 3.7.12
 Locations of Thermocouples on Reinforcing Bars: Figure 3.7.13

Measured Properties:

Cylinder strengths: 34.8 MPa at 28 days.
 42.3 MPa on test date.
 Relative humidity: 29%.

Results:

Test duration: 3 hours.
 Temperatures: Tables 3.7.13 and 3.7.14a to d.
 Axial deformations: Table 3.7.15

The column buckled after 3 hours. Figure 3.7.14 shows the column after the test.

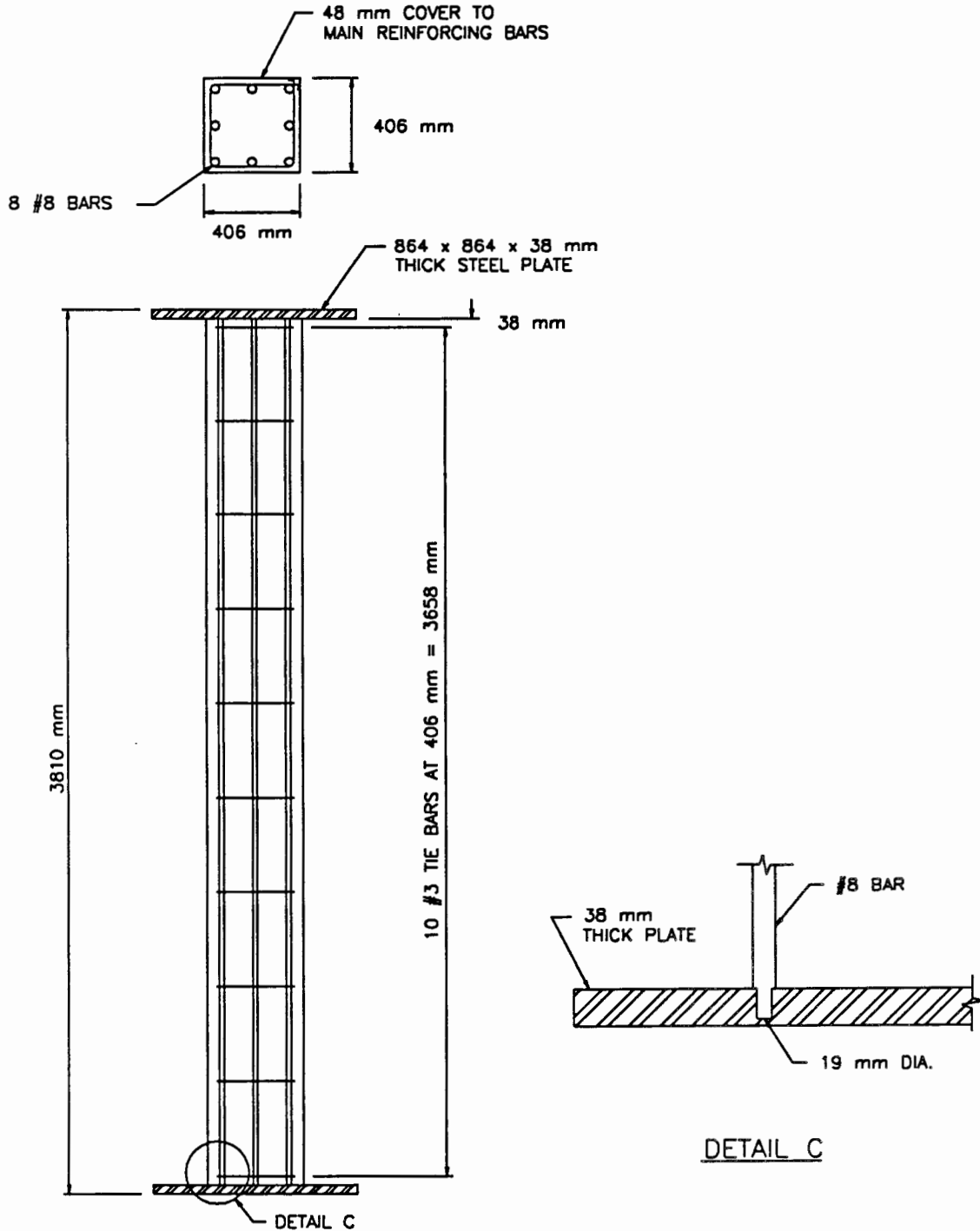


Figure 3.7.1 Elevation, Cross-Section and Finishing Detail: 16 x 16 Section with 2.47% Steel

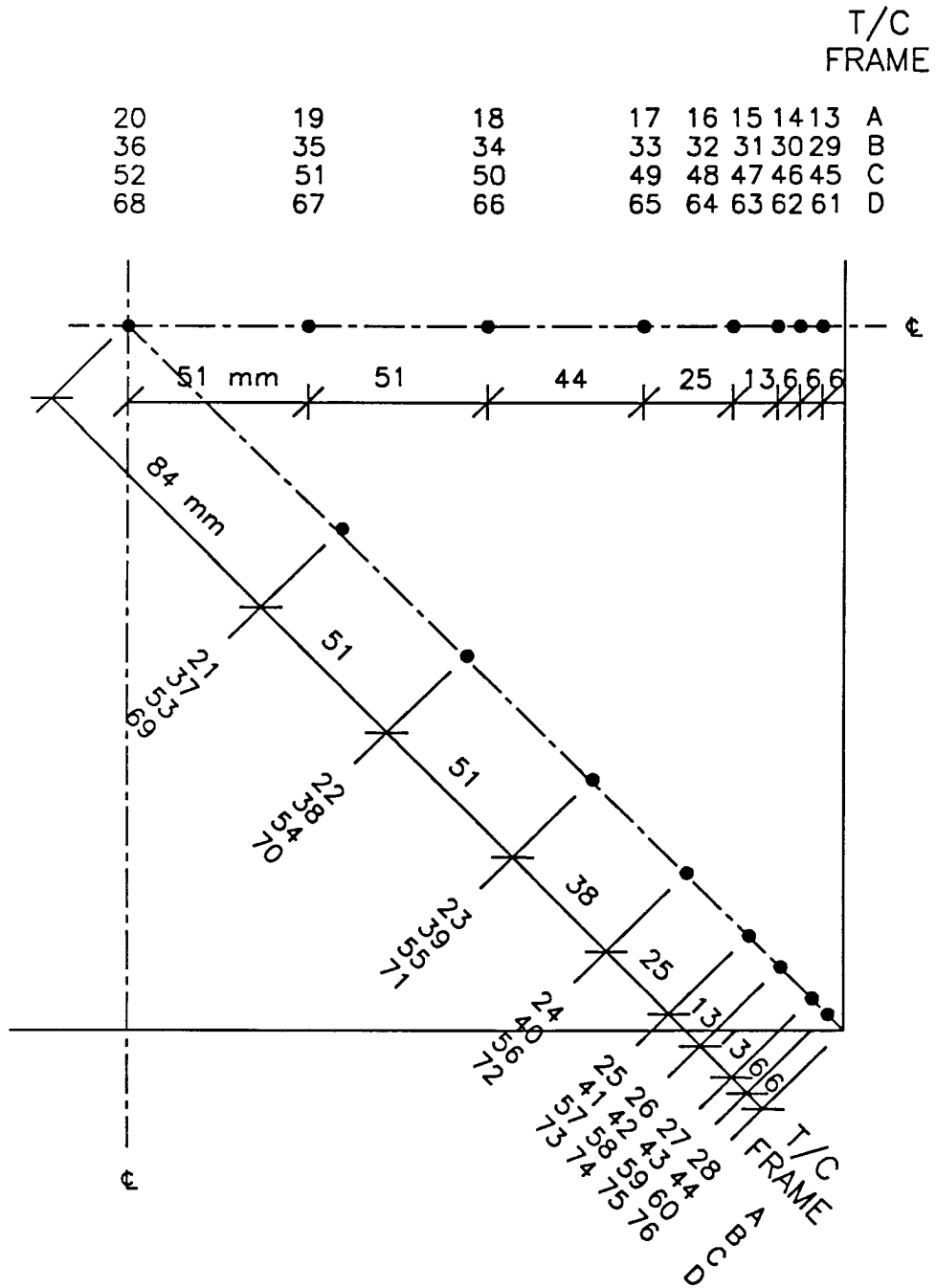


Figure 3.7.2 Locations of T/C's in Frames: Series I 16 x 16 Section with 2.47% Steel

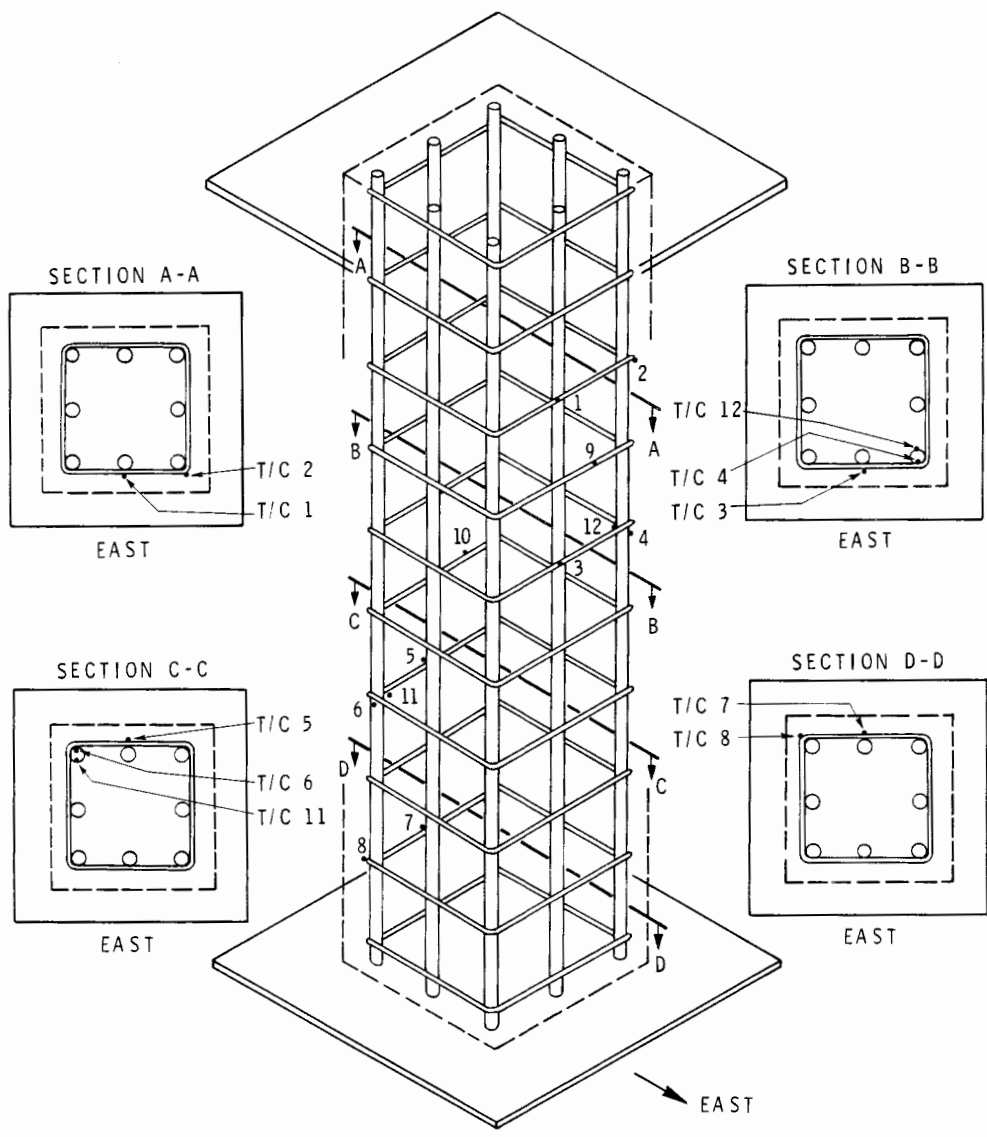


Figure 3.7.3 Locations of T/C's on Reinforcing Bars: Series I 16 x 16 Section with 2.47% Steel

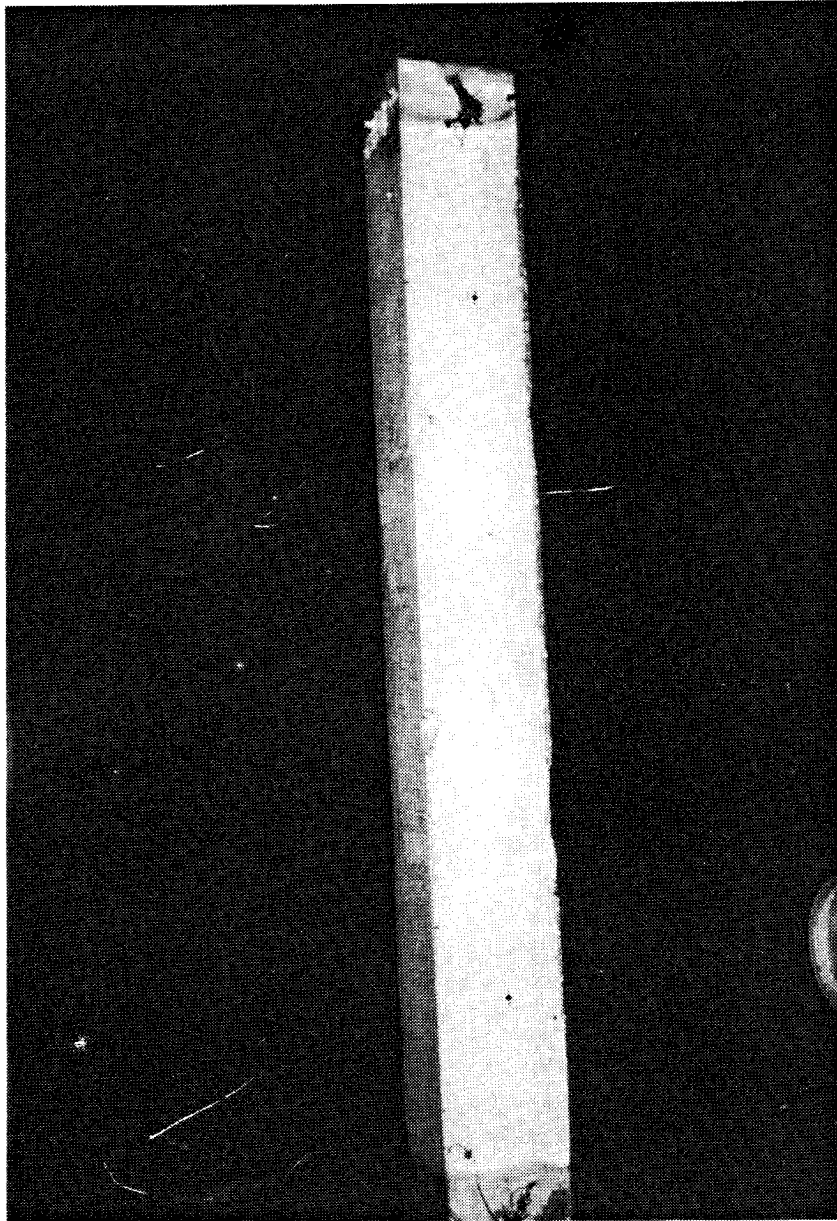


Figure 3.7.4 Series I Column 5 After Test

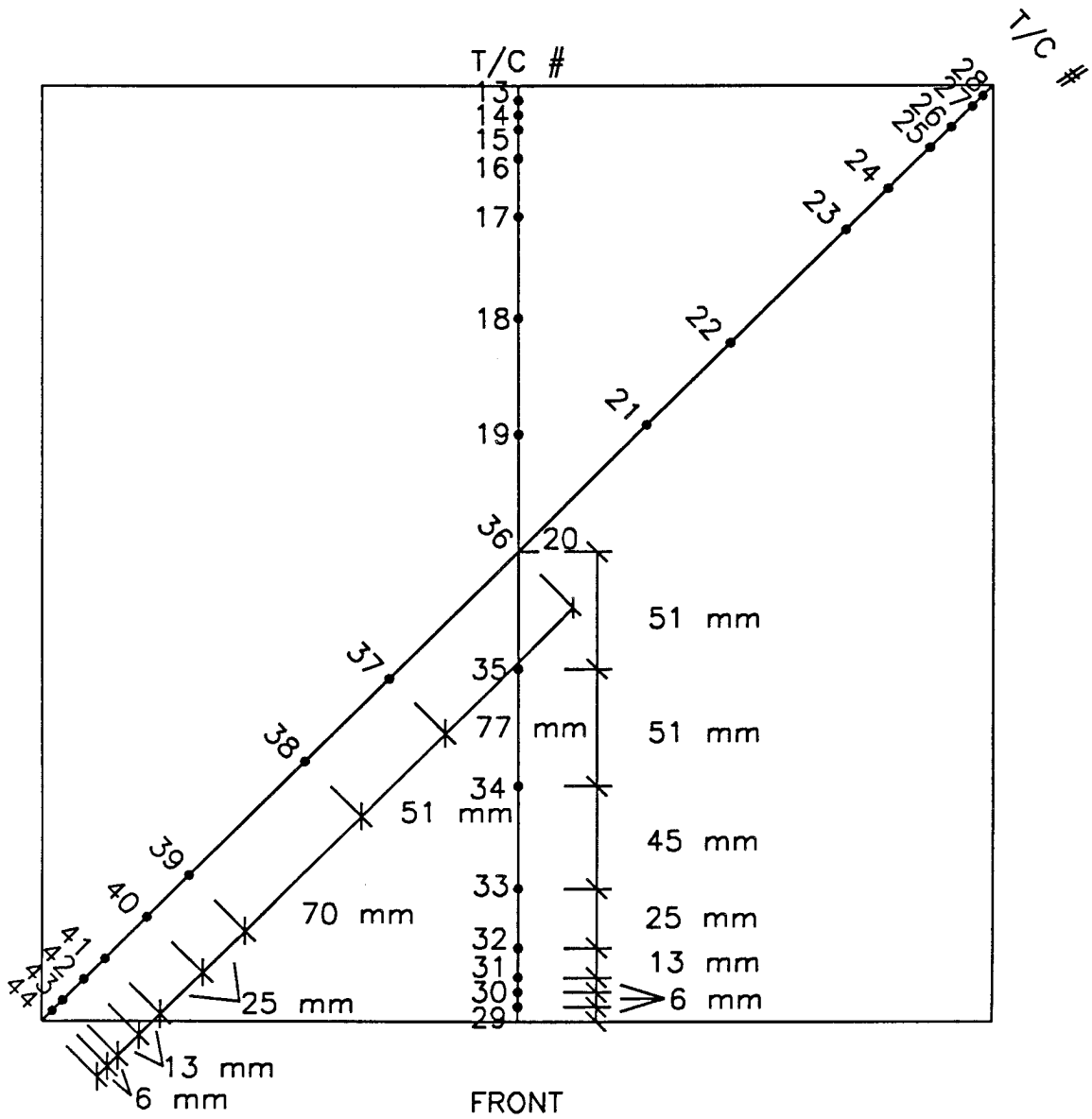


Figure 3.7.5 Locations of T/C's in Frames: Series II 16 x 16 Sections

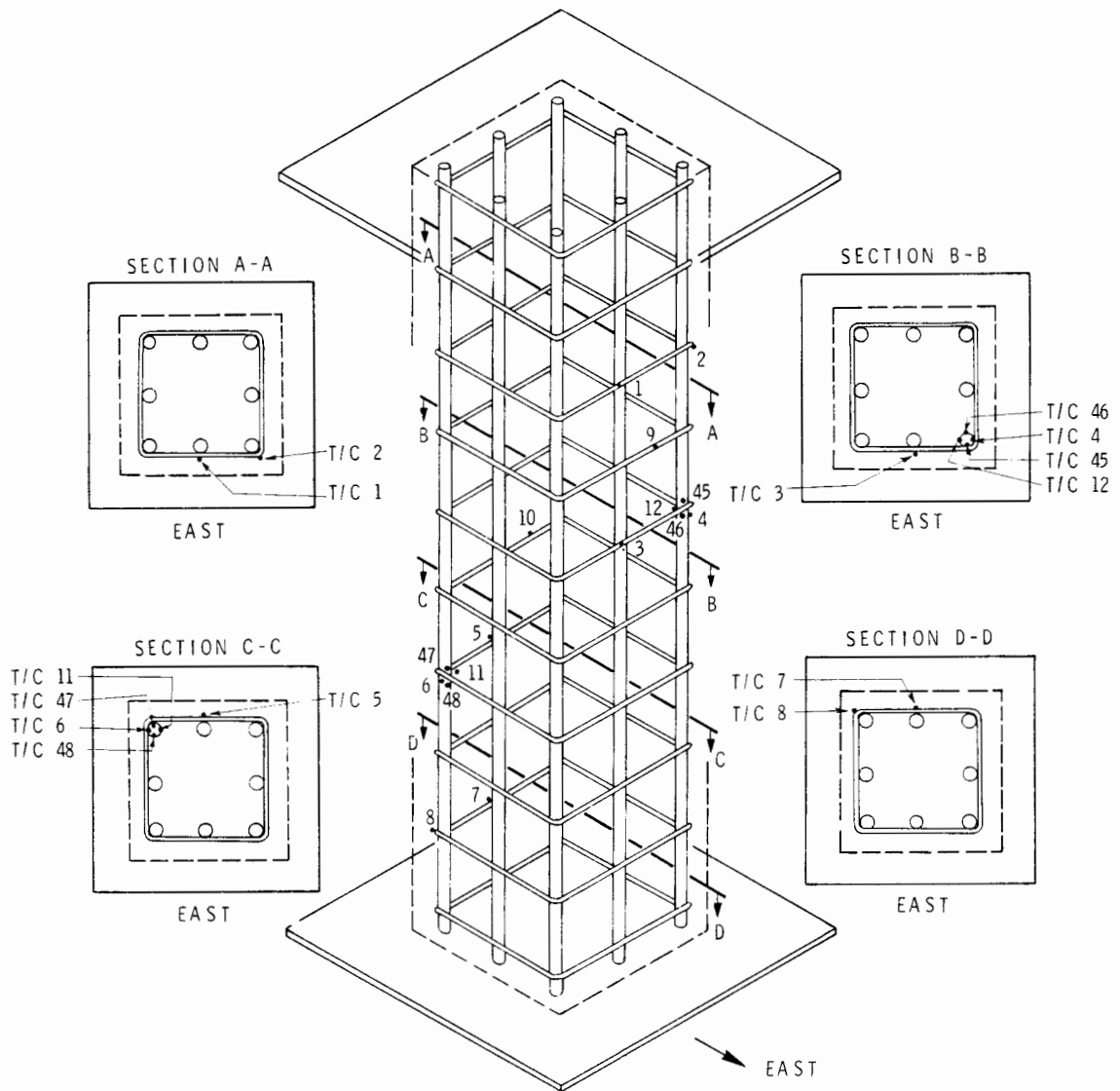


Figure 3.7.6 Locations of T/C's on Reinforcing Bars: Series II 16 x 16 Sections



Figure 3.7.7 Series II Column 10 After Test

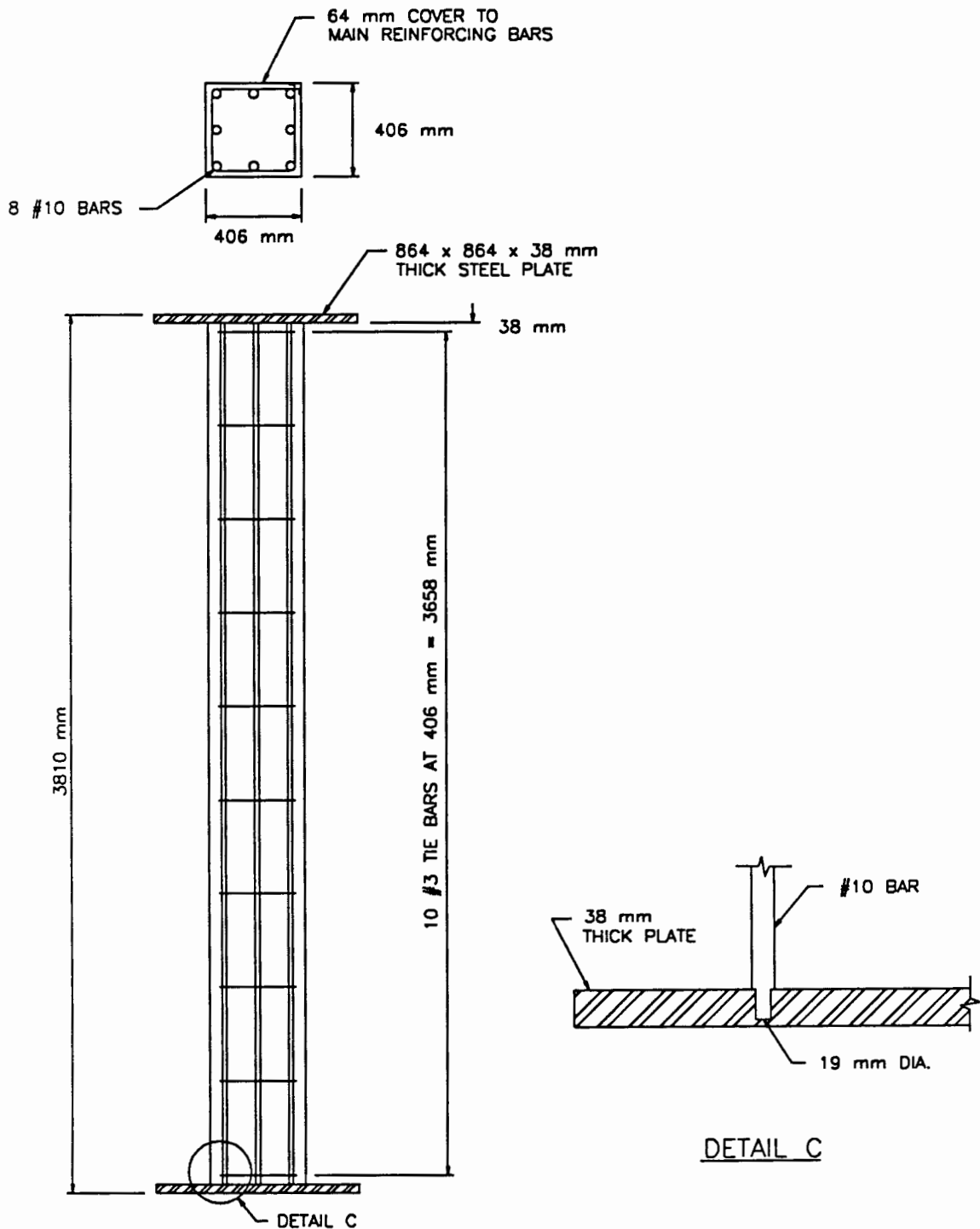


Figure 3.7.8 Elevation, Cross-Section and Finishing Detail: 16 x 16 Section with 3.97% Steel

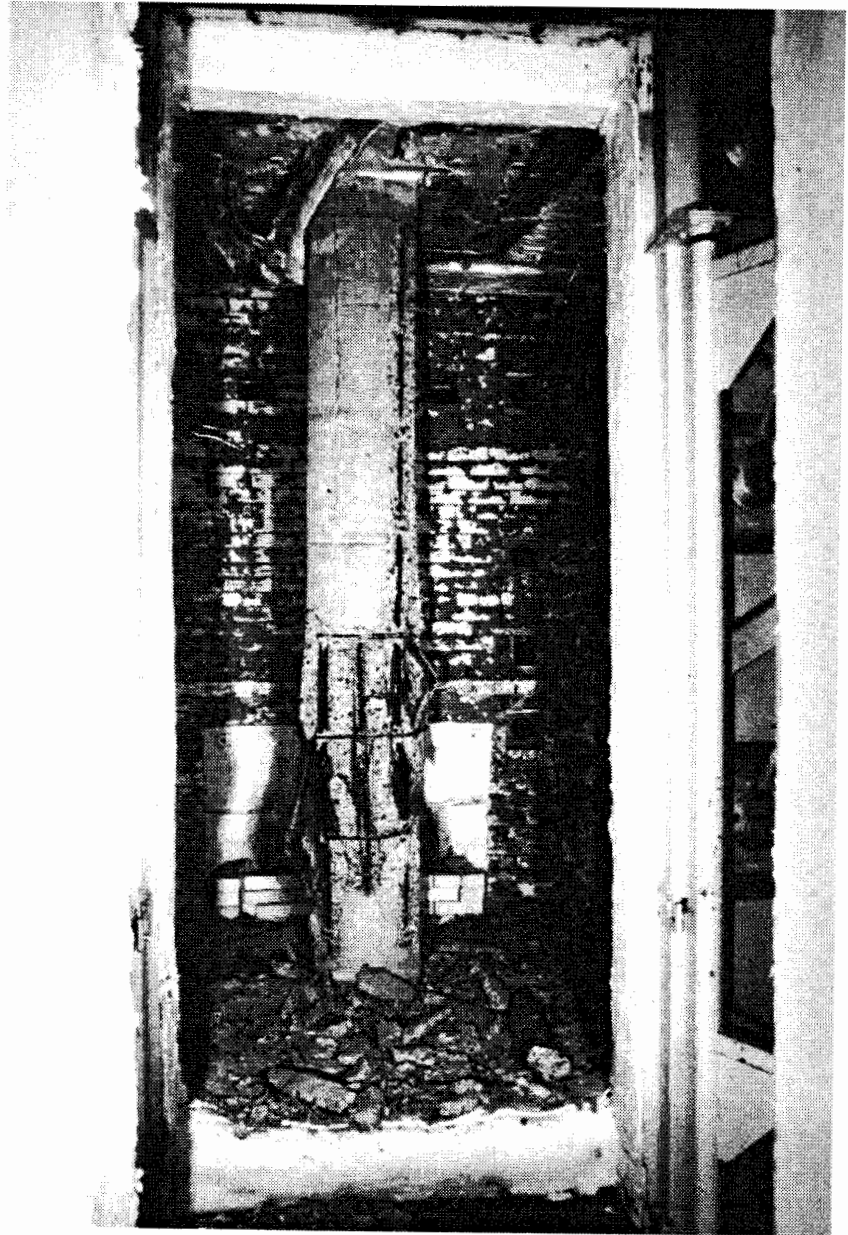


Figure 3.7.9 Series II Column 11 After Test



Figure 3.7.10 Series II Column 12 After Test

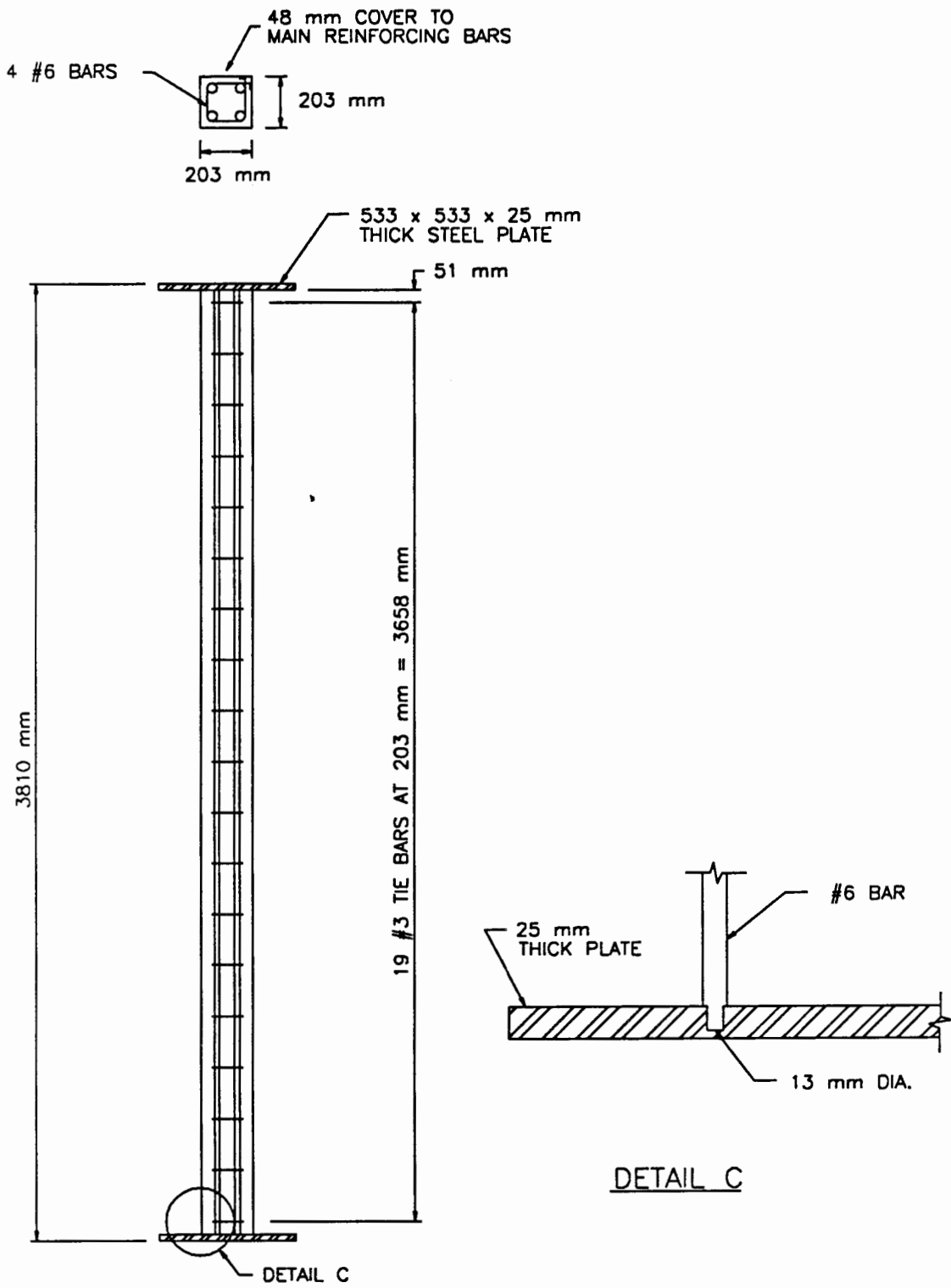


Figure 3.7.11 Elevation, Cross-Section and Finishing Detail: 8 x 8 Section

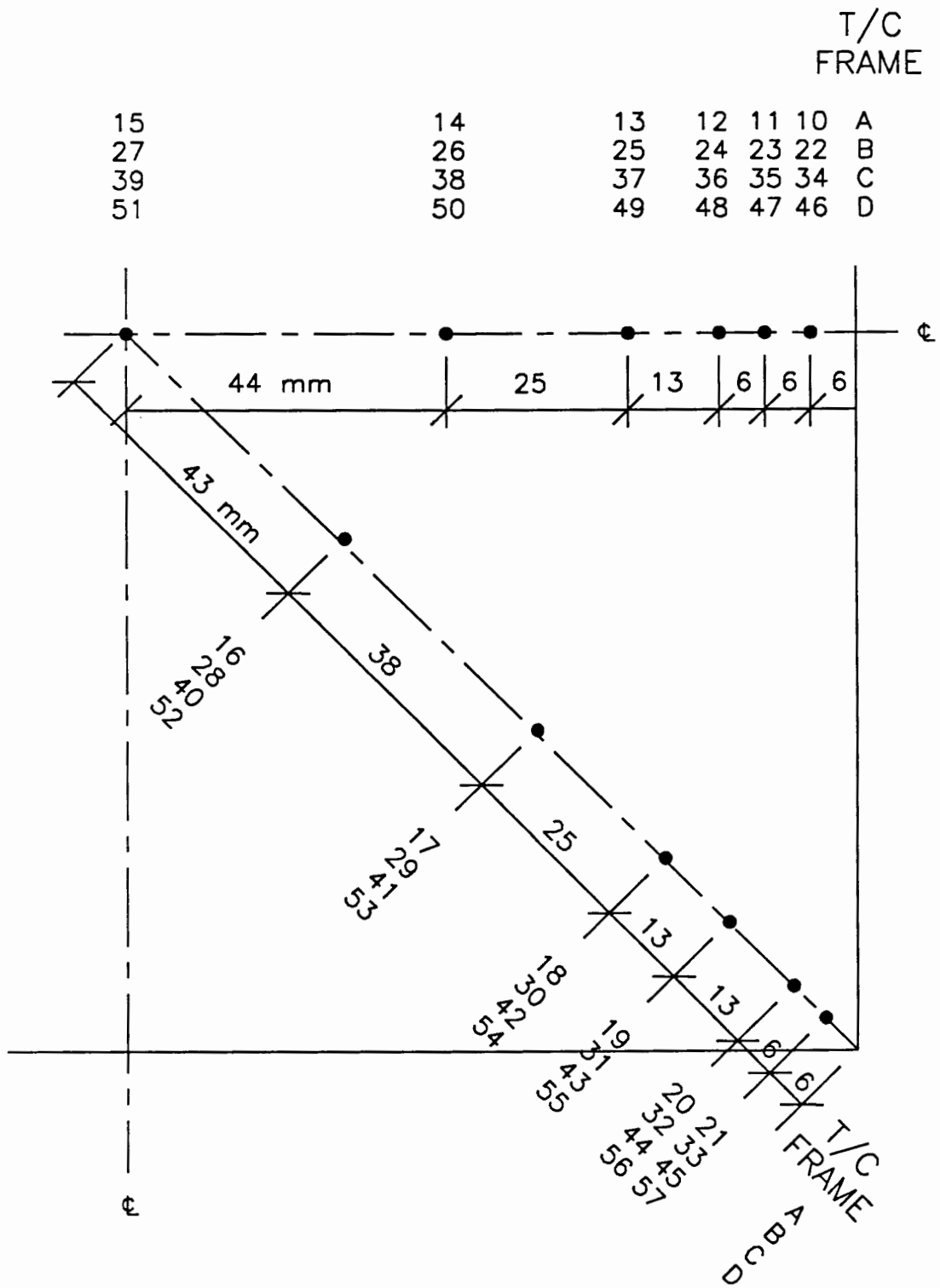


Figure 3.7.12 Locations of T/C's in Frames: 8 x 8 Section

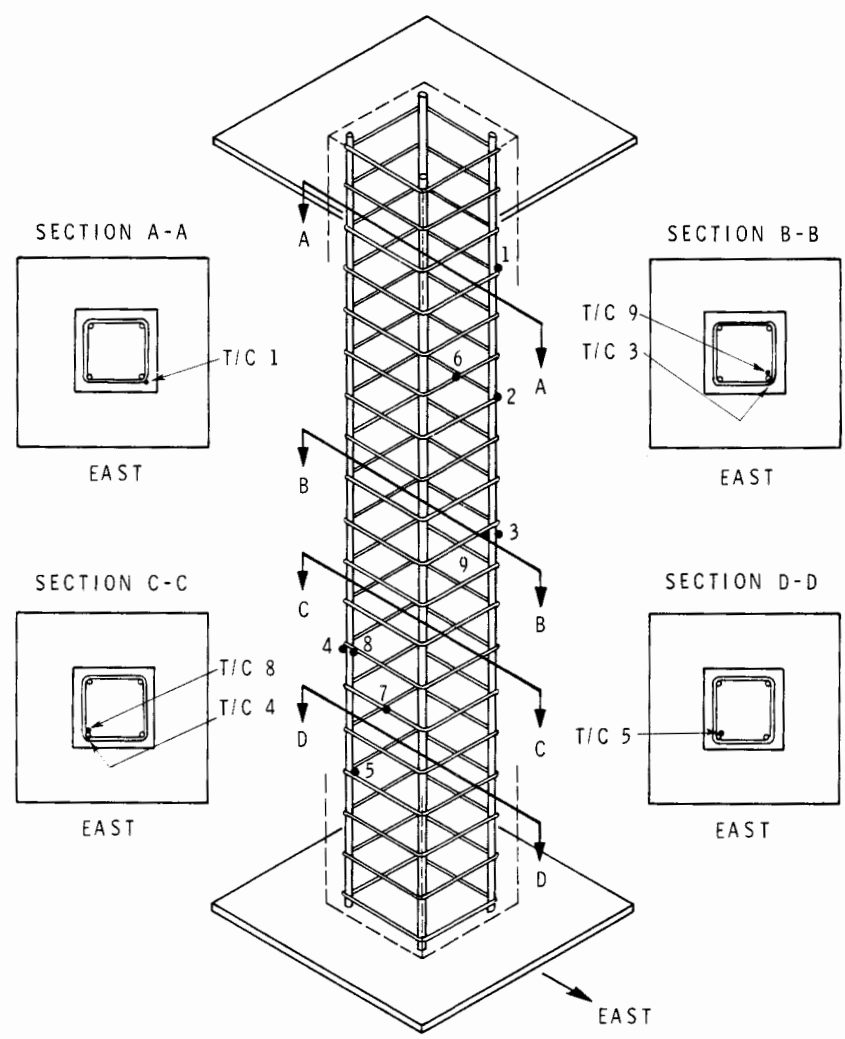


Figure 3.7.13 Locations of T/C's on Reinforcing Bars: 8 x 8 Section



Figure 3.7.14 Series I Column 6 After Test

Table 3.7.1

Steel Temperatures, Series I Column 5

Minutes	Temperature (°C) Measured at Thermocouple #:											Furnace	
	1	2	4	5	6	7	8	9	10	11	12		
0	19	19	19	19	19	19	19	19	19	19	19	19	19
5	35	36	29	19	21			35	27	26	22		323
10		47	40		31	21	27	50	39	31	30		476
15		66	56		43	32	41	77	61	40	44		645
20		99	93		82	53	79	108	97	62	81		736
25		117	113		108	78	108	151	126	96	110		796
30		138	125	109	108	101	112	188	156	104	122		836
35		159	151	131	125	127	143	224	186	118	145		871
40		182	179	151	150	147	170	256	206	137	169		887
45		208	208	171	177	166	197	286	243	160	195		908
50		233	239	190	204	185	224	313	269	183	220		916
55		259	265	209	231	204	256	337	293	206	244		934
60		284	293	227	257	222	276	358	316	230	268		948
70		330	346	261	306	257	325	401	357	277	310		967
80	194	372	394	292	352	288	371	440	395	322	347		981
90	267	409	438	320	394	316	412	177	428	363	380		994
100	313	445	478	345	432	342	451	509	459	401	411		1007
110	334	477	514	639	468	366	488	537	487	437	441		1016
120	369	508	545	391	501	389	521	566	514	471	469		1030
130	521	535	577	411	531	411	550	594	538	502	496		1039
140	627	562	611	431	558	431	578	622	565	535	520		1047
150	653	598	649	449	586	451	602	648	601	581	544		1054
160	674	618	687	468	625	471	624	676	645	642	567		1051
170	693	649	716	494	647	490	645	704	681	682	590		1047
180	708	679	731	539	676	507	663	723	703	704	612		1050
190	720	702	739	599	699	523	680	733	716	718	632		1054
200	730	719	742	646	712	538	696	738	718	725	652		1060
210	739	730		675	718	554	708	739		729	670		1065

Table 3.7.2a

Concrete Temperatures, Series I Column 5

Minutes	Temperature (°C) Measured at Thermocouple #:												Furnace
	14	15	16	18	21	22	23	24	25	26	27	28	
0	19	19	19	19	19	19	19	19	19	19	19	19	19
5	67	56	43	23	21	23	31	45	68	90	126	145	323
10	101	83	58	24	22	25	36	63	103	137	200	241	476
15	162	130	89	26	22	27	46	97	157	215	318	374	645
20	230	183	122	30	24	32	68	135	218	301	432	500	736
25	301	240	158	37	25	40	99	167	285	388	532	603	796
30	364	293	195	82	29	55	103	214	350	463	610	678	836
35	418	341	235	96	34	75	113	263	409	526	674	729	871
40	463	384	271	98	46	98	130	308	461	578	721	766	887
45	500	421	303	101	68	101	151	349	507	625	757	800	908
50	532	452	330	102	99	102	173	385	545	666	784	823	916
55	559	480	355	103	101	103	196	417	581	699	809		934
60	586	506	364	103	101	110	218	446	606	727	831		948
70	630	549		119	102	135	264	497	674	772	868		967
80	667	587		145	104	161	307	539	719	808	899		981
90	695	618		166	113	185	347	578	753	834	918		994
100	719	646		185	128	210	384	615	782	856	935		1007
110	741	670		205	144	233	419	647	808	876	949		1016
120	761	693		223	160	257	451	674	830	896	964		1030
130	781	713		242	176	280	481	699	851	913	976		1039
140	798	732		261	193	302	508	720	868	928	986		1047
150	814	748		279	211	323	532	740	884	939			1054
160	827	762		297	228	344	555	758	897	948			1051
170	833	771		315	246	364	579	773	905	948			1047
180	842	782		332	263	384	602	785	911				1050
190	851	792		349	279	403	623	796	917				1054
200	860	803		365	296	422	642	806	922				1060
210	870	814		381	312	440	659	815	928				1065

Table 3.7.2b Concrete Temperatures, Series I Column 5

Minutes	Temperature (°C) Measured at Thermocouple #:															Furnace
	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	
0	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
5	80	63	49	36	23	19	19	19	19	19	24	35	59	84	117	323
10	137	104	80	55	28	20	19	19	20	30	56	100	139	202		476
15	236	177	131	91	37	22	19	19	19	23	41	100	161	234	340	645
20	339	255	191	130	57	26	20	19	20	28	71	133	231	333	464	736
25	431	333	254	173	81	33	21	19	22	58	103	170	304	427	567	796
30	503	398	310		102	44	24	20	27	68	106	222	371	504	647	836
35	551	450	358	254	115	70	31	22	32	79	119	274	432	564	709	871
40	600	493	399	290	135	87	48	25	42	97	140	321	483	621	753	887
45	636	528	434	321	154	97	72	31	67	101	164	362	526	667	788	908
50	663	572	465	349	173	103	100	40	91	102	188	397	563	702	812	916
55	689	585	492	374	192	108	102	66	100	105	213	425	601	732	835	934
60	712	610	516	397	210	116	102	100	102	117	237	452	633	745	860	948
70	749	652	559	489	243	134	102	102	102	159	307	522	711	804		967
80	790	686	596	475	274	152	102	102	103	173	329	543	732	829		981
90	801	712	626	507	303	171			114	201	370	584	768	858		994
100	822	735	653	534	329	191	102		130	228	408	620	798			1007
110	841	755	656	560	354	211	111	102	146	254	443	651	825			1016
120	860	776	698	584	378	230	124	102	163	279	475	682	847			1030
130	877	795	719	607	400	250	140	115	181	303	505	710	867			1039
140	892	813	738	629	422	270	156	127	199	326	530	735	883			1047
150	905	829	755	649	444	289	172	141	217	318	553	758	899			1054
160	913	842	771	667	464	309	189	156	235	369	577	778	912			1051
170	915	848	781	681	483	328	205	172	254	389	601	796	920			1047
180	921	857	791	695	501	346	222	188	271	409	624	810	927			1050
190	927	866	802	708	518	364	240	205	289	428	644	823	932			1054
200	935	875	813	721	535	381	256	222	306	447	663	835	936			1060
210	942	885	824	733	550	398	272	238	323	465	681	846	939			1065

Table 3.7.2c Concrete Temperatures, Series I Column 5

Minutes	Temperature (°C) Measured at Thermocouple #:															Furnace
	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	
0	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
5	77	60	48	35	24	21	19	19	20	21	27	40	63	83	119	323
10	125	96	75	50	30	21	19	19	20	22	33	59	99	131	189	476
15	229	169	126	82	39	23	20	19	20	24	43	95	162	225	345	645
20	339	254	189	116	57	26	20	19	20	28	68	139	239	287	481	736
25	433	334	253	151	76	31	21	20	23	38	101	180	316	344	577	796
30	504	397	308	191	80	39	22	20	26	53	106	236	384	392	652	836
35	558	449	357	232	85	51	25	21	32	102	122	288	439	436	712	871
40	602	492	399	266	96	65	29	23	43	103	146	334	488	472	753	887
45	639	528	434	297	99	78	34	26	58	103	169	373	531	498		908
50	666	558	464	325		90	41	32	87	103	194	407	571	522	759	916
55	693	586	491	349		103	49	48	103	104	218	438	608	539	778	934
60	716	611	515	372		103	87	103	103	110	243	467	641	544	792	948
70	752	623	559	413	102	107	103	103	103	135	290		696	568	807	967
80	781	687	596	448	112	123	104		104	163	334	557	738	570	812	981
90	803	712	625	479	205	139	104		105	188	374	597	771			994
100	823	735	651	506	236	154	107		116	214	411	631	800			1007
110	842	755	674	530	253	170	115		132	239	445	662	826			1016
120	860	774	696	553	270	187	123		150	263	477	690	847			1030
130	877	791	716	576		205	134		168	287	505	716	867			1039
140	891	809	734	598		224	147	121	186	309	530	738	883			1047
150	904	823	752	618		242	161	138	204	331	555	761	897			1054
160	912	835	766	636		261	177	156	222	352	580	781	910			1051
170	914	839	776	652		280	193	173	240	382	604	798	917			1047
180	920	845	786	665		299	210	191	257	391	626	812	923			1050
190	926	851	793	678		309	229	212	275	410	646	824	929			1054
200	927	851	793	690		347	259	243	292	428	664	835	931			1060
210				699		401	331	308	309	445	677	845	931			1065

Table 3.7.2d Concrete Temperatures, Series I Column 5

Minutes	Temperature (°C) Measured at Thermocouple #:															Furnace
	61	62	63	64	65	66	67	68	69	70	71	72	73	74	76	
0	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
5	72	55	44	26	15	12						29	56	80	142	323
10	122	94	74	43	19	13					24	51	99	136	255	476
15	216	164	127	75	29	15					36	91	167	233	426	645
20	315	240	188	110	44	18				22	68	133	244	336	570	736
25	406	316	251	149	67	23				38	101	176	322	431	678	796
30	478	379	3005	180	93	32			22	97	106	233	392	509		836
35	533	430	352	219	101	43			32	99	123	284	454	570	733	871
40	575	473	394	265	104	58	21		13	61	145	327	507	625	762	887
45	613	510	431	294	129	82	27	21	55	101	167	363	550	671	785	908
50	643	541	462	323	147	94	37	28	68	101	191	395	591	708	785	916
55	670	569	490	349	164	99	59	36	92	102	214	423	627	739	792	934
60	694	595	515	372	181	102	86	83	101	103	238	449	659	765	801	948
70	732	639	557	413	214	106	96	99	102	122	283	496	711	808	815	967
80	762	674	595	449	244	126	100	100	102	148	324	538	750	841	819	981
90	784	700	625	480	272	146	102	101	103	174	362	575	782	864		994
100	806	724	651	508	299	165	103		118	199	397	611	809	882		1007
110	825	745	675	532	324	184	109	102	132	224	428	643	832	897		1016
120	845	766	697	555	348	203	119	102	148	247	458	673	853			1030
130	862	785	717	578	370	222	133	107	164	270	485	699	871			1039
140	877	802	735	599	393	240	147	120	180	292	510	723	887			1047
150	890	818	752	619	413	259	162	132	197	313	534	745	901			1054
160	899	831	767	637	433	277	177	146	214	334	556	765	912			1051
170	902	837	777	652	453	295	193	161	231	354	579	783	918			1047
180	908	845	787	666	471	313	209	176	249	374	601	798	922			1050
190	915	853	798	679	488	330	224	191	266	393	621	811	922			1054
200	922	862	808	692	504	346	240	207	283	412	640	824				1060
210	931	871	819	705	521	362	255	222	299	430	658	836				1065

Table 3.7.3 Steel Temperatures, Series II Column 10

Minutes	Temperature (°C) Measured at Thermocouple #:															Furnace
	1	2	3	4	5	6	7	8	9	11	12	45	46	47	48	
0	20	20	20	20	18	18	17	17	20	17	19	19	19	18	18	178
5	23	23	22	24	21	24	19	19	33	21	21	25	22	21	26	587
10	33	38	34	44	34	48	28	35	64	41	37	48	40	42	55	690
20	82	108	75	110	79	116	64	105	110	114	107	110	107	113	118	789
30	101	120	114	135	103	143	100	138	157	131	126	140	126	130	156	838
40	107	163	142	180	117	193	121	180	206	177	165	183	168	177	208	875
50	123	209	187	235	153	254	146	229	249	236	216	238	219	236	269	903
60	144	255	228	290	199	311	173	279	288	291	269	292	273	291	326	924
70	167	299	264	341	237	362	199	325	324	341	319	343	323	339	376	942
80	192	340	295	386	269	407	223	367	356	384	364	388	367	382	420	956
90	216	378	323	427	298	446	247	403	387	423	405	429	408	420	460	968
100	239	413	348	465	323	484	269	437	417	458	442	468	445	455	497	985
110	263	445	371	499	346	518	290	466	446	490	475	503	478	487	530	1000
120	286	475	393	528	368	549	310	489	474	520	506	533	508	517	560	1007
130	307	502	413	555	388	580	329	513	500	546	532	560	535	545	588	1012
140	329	527	432	582	407	614	348	536	524	577	557	585	559	576	618	1020
150	350	550	449	608	426	650	367	555	547	607	582	617	585	606	649	1034
160	370	576	465	631	443	691	385	577	571	636	605	655	609	636	682	1043
170	390	601	480	654	460	728	403	597	593	665	627	693	632	665	714	1054
180	410	625	496	678	476	754	420	615	614	693	648	722	658	693	738	1061
190	430	650	511	703	493	759	436	633	635	709	668	744	686	709	738	1070
200	450	675	525	724	509	761	453	651	655	725	686	761	711	723	739	1074
210	469	702	540	737	525	768	469	669	674	741	702	771	730	747	746	1090
220	489	715	553	733	540		484	685	692	749	709		736	752	754	1095
230	508	733	569	735	555		499	699	708	759	717		741	752	762	1098
240	527	769	583	750	571		513	709	723	772	743		747	754	771	1108
260	562	800	612	768	601		540	738	755	806	775		760	767	787	1112

Table 3.7.4 Concrete Temperatures, Series II Column 10

Minutes	Temperature (°C) Measured at Thermocouple #:																Furnace
	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
0	20	19	19	19	19	19	19	19	19	19	19	18	19	19	22	25	178
5	108	75	54	34	20	19	19	19	19	19	20	27	71	109	180	234	587
10	185	130	105	66	28	19	19	19	19	20	34	65	134	192	307	380	690
20	345	253	189	121	60	26	19	19	21	45	106	114	264	361	509	585	789
30	456	349	269	177	91	42	23	20	28	70	109	169	381	486	629	713	838
40	532	428	348	253	99	56	29	24	39	79	130	223	480	575	711	748	875
50	586	485	405	303	115	68	38	31	50	86	166	278	550	637	721	799	903
60	628	529	449	341	134	80	48	40	60	98	209	329	611	689	757	838	924
70	662	565	485	374	156	93	58	49	70	114	252	375	660	732	772	863	942
80	690	596	516	402	179	106	68	58	85	132	291	417	700	769	762	858	956
90	716	624	543	428	201	117	80	68	100	148	326	455	729	798	769	845	968
100	738	649	568	451	224	128	95	80	109	164	357	490	753	822	783	827	985
110	759	672	592	472	245	138	107	96	119	179	385	523	777	844	792	802	1000
120	777	692	613	492	265	147	115	107	126	194	410	552	799	863	798	802	1007
130	794	710	633	511	285	161	121	116	132	214	434	581	818	879	799	799	1012
140	703	725	650	527	304	176	126	122	138	234	456	605	834	891	798	795	1020
150	706	741	666	543	322	191	132	126	169	259	477	629	847	902	795	790	1034
160	712	756	682	560	339	204	138	132	418	361	497	672	845	904	787	755	1043
170	719	772	697	575	355	218	144	138	640	598	521	726	776	851	757	749	1054
180	728	788	713	591	372	231	150	143	713	724	575	755	738	771	764	779	1061
190	734	792	727	607	388	244	158	146	748	758	709	772	754	768	786	803	1070
200	743	722	744	625	405	258	168	148	751	777	756	774	761	770	782	814	1074
210	748	727	757	623	422	272	180	152	756	789	764	766	775	770	753	810	1090
220	754	733	771	637	440	287	192	158	771	783	765	766	790	768	757	785	1095
230	758	736	783	651	458	303	205	168	786	777	773	777	797	772	773	765	1098
240	762	740	795	665	475	320	220	182	796	786	784	789	796	786	787	774	1108
260	767	748	818	694	509	353	252	218		800	801	800	801	808	802	788	1112

Table 3.7.4 Concrete Temperatures, Series II Column 10
(continued)

Minutes	Temperature (°C) Measured at Thermocouple #:																Furnace
	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	
0	22	20	19	18	18	18	18	18	18	18	18	19	19	20	26	36	178
5	130	88	65	38	20	18	18	18	18	18	19	33	76	121	196	258	587
10	230	149	112	77	31	19	18	18	18	19	33	78	142	214	349	413	690
20	410	285	220	130	70	28	19	18	20	42	108	136	282	391	549	609	789
30	509	378	301	188	95	45	22	20	30	67	106	234	398	511	673	782	838
40	573	444	368	250	111	59	29	24	43	77	132	299	489	605	1072	778	875
50	621	493	417	295	143	70	39	31	53	85	183	353	558	677	721	823	903
60	659	532	457	334	176	79	48	39	63	92	230	400	616	706	745	856	924
70	689	566	491	368	205	91	57	48	71	103	273	443	1239	703	758	871	942
80	715	597	521	398	232	104	66	57	82	116	311	481	690	732	772	805	956
90	738	624	549	425	257	116	77	67	94	133	345	515	692	753	784	792	968
100	761	649	575	450	280	128	88	79	106	152	373	546	716	768	793	800	985
110	782	672	600	474	303	139	100	92	117	173	396	573	737	780	799	804	1000
120	799	692	622	496	324	150	111	104	126	192	415	595	748	784	801	802	1007
130	815	711	643	516	344	161	117	113	135	210	429	614	750	786	801	799	1012
140	829	727	659	535	363	174	122	119	143	227	444	632	752	786	798	797	1020
150	842	743	676	552	380	188	129	125	151	243	459	648	751	786	794	795	1034
160	697	755	693	570	396	203	143	142	159	259	475	664	757	787	791	793	1043
170	693	755	707	587	413	221	186	206	181	292	492	681	759	785	787	787	1054
180	691	743	725	606	443	269	320	342	326	460	512	698	743	765	771	759	1061
190	700	729	737	640	520	408	524	500	609	659	551	735	745	741	742	744	1070
200	717	727	737	683	636	573	650	610	756	757	685	782	778	764	761	777	1074
210	744	734	734	725	720	676	711	677	799	791	756	807	805	788	786	804	1090
220	765	741	734	749	755	718	737	720	818	799	785	820	824	804	805	824	1095
230	778	751	743	768	770	733	741	739	825	802	797	827	832	808	815	837	1098
240	784	765	756	779	776	749	747	752	827	809	800	830	832	811	819	842	1108
260		791	772	790	781	778	769	776	825	817		828	825	821	823		1112

Table 3.7.5

Deflections, Series II Column 10

Minutes	Expansion, mm
0	0.0
10	0.3
20	1.2
30	1.6
40	1.9
50	2.1
60	2.4
70	2.7
80	3.0
90	3.3
100	3.5
110	3.7
120	3.8
130	3.8
140	3.8
150	3.8
160	3.8
170	3.8
180	3.8
190	3.6
200	3.4
205	3.3
210	3.1
215	3.0
220	2.8
225	2.6
230	2.4
235	2.2
240	2.0
245	1.8
250	1.5
255	1.2
260	0.8

Table 3.7.6

Steel Temperatures, Series II Column 11

Minutes	Temperature (°C) Measured at Thermocouple #:															Furnace
	1	2	3	4	5	6	7	8	9	11	12	45	46	47	48	
0	24	24	23	23	22	21	22	22	24	21	22	22	22	21	21	77
5	28	27	28	26	24	24	23	24	33	22	24	28	24	22	23	555
10	44	45	52	44	34	35	29	34	63	29	37	49	37	29	35	663
20	82	110	103	109	73	102	57	104	120	94	104	109	104	90	106	782
30	101	126	106	123	99	109	93	106	181	108	111	127	106	107	113	836
40	127	163	146	165	115	139	117	136	248	124	151	170	145	120	140	876
50	174	210	178	215	152	180	140	171	309	162	198	222	192	156	180	900
60	204	259	206	268	179	223	166	210	358	204	249	277	242	195	223	928
70	231	304	233	319	204	264	188	248	398	245	299	328	290	235	264	945
80	256	347	260	366	227	302	209	284	433	283	344	374	333	272	304	952
90	279	385	283	408	249	338	230	317	464	319	384	415	372	307	340	968
100	300	420	303	446	272	371	250	348	491	352	421	452	405	339	375	988
110	321	453	323	479	293	403	270	377	515	384	453	484	427	370	407	999
120	342	482	342	508	314	433	290	405	538	414	482	513	466	400	438	1007
130	362	510	361	534	333	461	308	432	559	442	509	539	492	428	467	1018
140	382	534	381	559	352	488	327	458	581	469	533	565	517	455	484	1027
150	400	557	399	583	369	513	345	482	601	494	555	591	539	480	519	1037
160	418	580	418	606	387	536	363	505	620	518	578	614	561	503	542	1046
170	436	601	437	629	404	559	380	527	638	539	600	635	583	525	564	1056
180	453	621	455	653	421	585	396	547	656	560	620	655	603	547	587	1064
200	488	660	491	699	454	646	428	587	689	604	657	693	642	591	631	1080
220	524	688	533	733	486	702	459	625	717	645	691	729	678	632	674	1098
240	562	736	631	734	516	731	489	660	741	681	707	741	701	669	715	1109
260	603	755	709	730	545	741	518	691	746	712	716	734	716	702	747	1130
280	650	793	754	754	596	750	546	720	760	725	733	739	742	717	759	1138
284	663	805	764	760	708		551	766	764	749	738	743	750	751	965	

Table 3.7.7 Concrete Temperatures, Series II Column 11

Minutes	Temperature (°C) Measured at Thermocouple #:															Furnace
	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	
0	25	23	22	22	22	22	22	22	22	22	22	21	22	23	26	77
5	123	91	57	41	23	22	22	22	22	22	23	32	70	101	173	555
10	210	150	107	77	32	23	22	22	22	22	30	77	135	178	298	663
20	394	296	205	149	78	31	23	22	23	37	102	132	269	351	492	782
30	514	408	299	218	111	55	26	23	30	57	105	213	386	478	609	836
40	588	484	374	291	143	68	34	28	41	71	109	306	482	566	695	876
50	643	544	439	353	193	78	43	35	51	83	134	372	553	641	754	900
60	686	591	486	398	228	90	52	43	62	99	166	425	614	696	797	928
70	720	629	524	436	261	102	62	52	75	116	201	469	652	708	829	945
80	747	662	557	468	289	115	73	62	91	130	235	507	687	737	855	952
90	774	690	588	496	312	128	86	74	103	141	264	541	728	758	877	968
100	797	714	614	517	277	136	101	95	112	151	288	572	756	773	893	988
110	812	729	629	530	309	143	117	113	122	164	320	601	779	785	905	999
120	829	747	649	549	350	154	126	120	132	182	352	627	801	792	912	1007
130	847	765	670	572	378	168	130	126	138	202	381	651	820			1018
140	862	782	689	592	397	184	135	132	144	225	410	673	838			1027
150	877	799	706	611	415	201	137	134	153	248	436	693	855			1037
160	889	815	722	628	431	217	144	136	163	267	460	710	870			1046
170	898	829	737	644	446	232	151	140	171	283	483	727	883			1056
180		843	752	659	461	247	159	146	181	298	505	742	891			1064
200		867	779	688	491	278	181	159	206	331	547	760	899			1080
220		874	806	715	531	311	205	176	260	371	593	754				1098
240			825	740	555	355	242	217	445	459	658	752				1109
260				748	622	465	365	372	625	604	706	756				1130
280					712	686	679	667	732	718	752	776				1138
284					729	711	709	694	745	731	759	780				

Table 3.7.7 Concrete Temperatures, Series II Column 11
(continued)

Minutes	Temperature (°C) Measured at Thermocouple #:															Furnace
	28	29	30	31	32	33	34	35	37	39	40	41	42	43	44	
0	28	26	24	23	22	21	21	21	21	21	22	23	25	29	34	77
5	230	123	96	70	44	23	21	21	21	22	35	70	111	171	235	555
10	375	222	169	127	86	34	22	21	21	30	83	134	199	314	407	663
20	599	404	318	240	155	65	31	22	23	100	143	273	388	533	619	782
30		515	420	331	222	102	50	25	29	103	246	397	516	654		836
40	742	586	494	406	305	101	61	33	40	111	328	487	608	710	741	876
50	778	645	554	469	368	117	71	42	50	141	392	554	670	764	773	900
60	755	690	604	516	412	137	84	51	60	180	442	615	717	750	842	928
70	763	721	640	551	445	158	98	60	72	216	481	662	757	770	872	945
80	778	746	669	583	473	179	110	75	82	250	516	701	789	783	894	952
90	791	769	694	609	495	200	121	90	93	283	547	732	816	789	915	968
100	799	788	714	630	515	221	131	103	105	312	578	759	838	795	931	988
110	804	803	730	648	531	242	143	115	118	345	607	783	858	800	941	999
120	808	820	747	666	547	263	156	123	130	373	631	805	876	802	951	1007
130	809	835	762	682	563	281	164	130	138	401	653	824	891		958	1018
140		848	775	696	578	302	171	135	148	427	675	841	905		963	1027
150		862	791	713	596	325	181	139	156	450	695	856	918		965	1037
160		872	806	728	612	345	196	144	163	472	714	867	929			1046
170			819	742	628	365	211	150	169	493	731					1056
180			834	757	644	384	223	155	175	512	747					1064
200			860	785	674	422	249	166	197	551	776					1080
220			885	812	703	461	282	188	224	593	803					1098
240			900	835	729	501	339	221	254	627	824					1109
260				849	747	542	476	663	287	657	840					1130
280					760	601	632	718	539	697						1138
284					961	640	652	746		716						

Table 3.7.8

Deflections, Series II Column 11

Minutes	Expansion, mm
0	0.0
10	0.4
20	1.3
30	1.8
40	2.1
50	2.5
60	3.0
70	3.4
80	4.0
90	4.4
100	4.9
110	5.3
120	5.5
130	5.7
140	5.9
150	6.0
160	6.1
170	6.1
180	6.1
190	6.1
200	6.1
205	5.9
210	5.9
215	5.8
220	5.7
225	5.5
230	5.3
235	5.1
240	4.9
245	4.6
250	4.2
255	3.8
260	3.3
265	2.8
270	2.2
275	1.6
280	0.9
285	-3.0

Table 3.7.9 Steel Temperatures, Series II Column 12

Minutes	Temperature (°C) Measured at Thermocouple #:																Furnace
	1	2	3	4	5	6	7	8	9	10	11	12	45	46	47	48	
0	22	21	21	18	19	19	20	19	22	19	19	20	20	20	19	19	55
10		25	23	19	22	23	23	37		25	21	22	24	22	21	22	
20		36	29	22	27	31	32	52		35	27	30	33	30	28	30	
30		52	39	27	37	44	45	107		54	38	42	47	43	39	43	568
40		101	59	38	55	76	87	175		98	65	79	91	80	67	75	625
50			88	61	87			469			97				99		936
60		113	108	93	114	104		569		131	102	104		105	102		922
70	106	134	109	116	125	124	108	633	123	175	118	108	115	107	113	125	935
80	125	135	126	127	148	154	436	701	142	213	142	131	144	126	139	155	985
90	146	201	147	150	178	188	178	746	170	247	171	168	184	165	172	188	990
100	169	239	173	175	207	223	220	787	196	281	204	208	227	204	206	224	1011
110	193	277	198	200	236	259	260	813	224	313	238	247	267	242	240	259	1011
120	216	313	222	223	264	293	297	837	249	344	272	282	304	278	273	293	1026
130	235	348	245	244	290	325	331	858	273	374	305	316	339	312	305	325	1035
140	258	381	267	264	314	356	363	878	298	402	336	348	371	343	335	356	1045
150	276	413	288	283	338	385	393						402	374	363	385	1053
160	296	444	309	301	359	411	423	911	349	454	392	407	432	402	390	411	1059
170	315	473	329	318	380	437	451	926	372	476	417	435	459	429	414	437	1067
180	335	500	348	335	399	461	477	937	395	498	441	460	485	455	438	461	1077
200	365	550	386	367	436	506	522	959	438	539	486	506	531	500	482	506	1094
220	416	596	423	397	480	547	561		504	593	426	544	570	539	522	547	785
240	450	622	451	416	500	581	587		530	612	555	571	592	566	552	579	555
255	461		458	416		584					563	575		570	560	581	485

Table 3.7.10 Concrete Temperatures, Series II Column 12

Minutes	Temperature (°C) Measured at Thermocouple #:															Furnace
	14	15	16	17	18	19	20	21	23	24	25	26	27	28	29	
0	23	21	20	20	19	20	19	20	19	19	20	22	24	27	23	55
10	60	50	37	24	20	20	20	20	24	32	54	69	86	100	60	
20	87	74	55	33	24	20	20	20	36	52	85	106	127	145	86	
30	168	136	99	49	30	21	20	22	59	88	151	197	252	294	165	568
40	260	203	136	75	44	24	21	26	105	138	222	302	386	456	264	625
50	513	386	225	115	64	29	24	35		169	356	513	691	820	532	936
60	601	486	312	139	86		30	45	139	244	484	640	786		609	922
70	656	546	372	176	101	51	39	60	222	326	564	720		878	661	935
80	711	601	419	209	101	62	51	74	282	398	638	777	795	931	718	985
90	746	645	461	241	101	72	63	84	331	459	701	824	805		756	990
100	775	677	496	270	107	81	77	91	373	511	750	840	806		788	1011
110	798	704	527	297	121	96	90	98	412	555	790				811	1011
120	820	727	553	323	145	103	100	105	446	598	821				833	1026
130	842	750	581	349	167	108	105	113	478	637	846				854	1035
140	860	771	606	374	184	112	109	123	506	670					871	1045
150			630	398	205	117	113	134	530	699					886	1053
160		809	653	421	225	125	117	145	554	725					901	1059
170		827	674	442	243	135	124	157	579	749					915	1067
180		843	693	462	262	146	134	170	604	770					928	1077
200			729	500	299	168	155	201	646	808					952	1094
220	736	730	744	534	335	194	175	235	685	839	769	772	749	779	838	785
240	628	628	643	534	369	226	194	271	627	789	710	721	695	720	644	555
255	569	571	584	519	387	250	208	292	617	723	669	677	656	675	563	485

Table 3.7.10 Concrete Temperatures, Series II Column 12
(continued)

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	30	31	32	33	34	35	36	37	39	40	41	42	43	44	
0	21	20	20	17	19	19	19	19	19	20	22	24	27	31	55
10	50	41	33	17	20	19	19	19	26	36	55	72	89	105	
20	72	60	48	18	22	19	19	19	39	57	85	108	129	148	
30	131	105	83	21	27	20	19	21	67	100	151	201	255	302	568
40	199	154	116	67	37	23	21	26	107	144	221	301	385	460	625
50	382	278	179	85	60	28	24	35		203	370	481	669	791	936
60	477	372	256	118	86	42	30	46		295	495	610	768	838	922
70	533	429	312	165	95	62	41	62	211	380	575	691	820		935
80	588	480	366	212	102	72	53	75	284	455	645	757	839		985
90	635	528	414	247	108	81	65	87	336	516	712	810			990
100	668	568	453	276	118	89	76	100	379	566	760	847			1011
110	699	602	485	302	130	98	90	107	417	611	796	873			1011
120	724	631	514	325	145	104	99	113	450	650	825	895			1026
130	747	656	538	346	161	111	104	120	481	685	849	913			1035
140	767	678	560	365	177	118	107	128	507	714	869	929			1045
150	785	698	582	385	193	125	110	136	536	739	888	942			1053
160	802	706	603	402	209	133	115	145	562	761	905	953			1059
170	818	734	622	419	225	141	123	157	586	781	920	962			1067
180	833	750	640	426	242	151	132	173	608	798	933	970			1077
200	859	781	675	468	277	174	152	208	648	830	959	983			1094
220	730	779	699	499	312	198	173	241	685	855	958	934	778	778	785
240	629	651	625	505	345	227	194	273	682	784	789	723	723	722	555
255	571	583	574	493	364	251	213	296	652	710	688	673	672	672	485

Table 3.7.11

Deflections, Series II Column 12

Minutes	Expansion, mm
0	0.0
10	0.1
20	0.4
30	0.7
40	1.3
50	1.6
60	2.0
70	2.3
80	2.6
90	3.1
100	3.5
110	4.0
120	4.4
130	4.9
140	5.3
150	5.8
160	6.1
170	6.5
180	6.7
190	6.9
200	7.0
205	7.0
210	7.0
215	7.0
220	7.0
225	6.9
230	6.8
235	6.6
240	6.5
245	6.3
250	6.1
255	5.9

Table 3.7.12

Steel Temperatures, Series I Column 6

Minutes	Temperature (°C) Measured at Thermocouple #:									Furnace
	1	2	3	4	5	6	7	8	9	
0	26	21	24	24	23	26	25	23	23	92
5	33	15	30	30	29	41	39	26	27	583
10	56		55	55	50	78	78	40	40	690
15	97		97	99	97	119	112	73	78	754
20	120		119	126	117	160	152	115	109	798
25	148		149	158	149	199	186	119	125	834
30	179	173	180	189	181	237	216	145	151	859
35	211	193	212	223	217	273	247	175	177	881
40	243	220	244	257	252	308	278	206	206	889
45	274	242	276	290	285	339	309	237	235	904
50	305	270	306	321	317	369	339	266	264	920
55	334	296	335	351	347	398	369	296	294	934
60	361	320	364	379	376	425	398	324	322	945
70	413	369	418	432	429	476	452	378	376	968
80	462	410	468	482	479	522	503	429	427	986
90	507	448	516	530	525	564	551	478	476	1001
100	548	482	558	572	567	607	596	522	520	1015
110	589	516	599	615	609	647	638	562	558	1027
120	629	547	638	654	649	684	677	605	601	1039
130	668	580	675	692	685	717	713	645	641	1042
140	702	606	704	723	714	736	735	682	679	1050
150	728	623	716	730	738	737	742	707	710	1056
160	746	633	735	740	760	738	753	730	726	1057
170	759	644	754	762	783	752	771	752	746	1062
180	774	670	773	780	802	772	788	772	770	1064

Table 3.7.13a Concrete Temperatures Measured in Frame A, Series I Column 6

Minutes	Temperature (°C) Measured at Thermocouple #:												Furnace
	10	11	12	13	14	15	16	17	18	19	20	21	
0	39	35	32	28	24	23	23	28	37	42	46	51	92
5	156	113	80	47	29	25	23	43	105	147	194	252	583
10	261	192	139	87	42	28	25	85	188	254	327	404	690
15	360	274	202	131	76	53	30	129	273	359	443	526	754
20	443	349	265	176	115	83	33	166	351	446	533	605	798
25	510	412	320	217	120	105	37	210	415	515	603	671	834
30	562	464	367	255	142	111	103	253	472	575	664	725	859
35	609	509	410	292	168	116	147	294	520	627	711	766	881
40	643	546	448	327	195	131	171	332	561	669	746	794	889
45	672	578	481	359	223	152	84	367	599	702	773	819	904
50	700	609	511	389	250	176	77	398	632	731	798	841	920
55	725	638	539	418	277	200	77	428	662	757	820	861	934
60	748	663	566	445	303	225	97	457	689	780	841	877	945
70	789	709	618	496	353	275	108	510	736	821	876	902	968
80	824	748	663	541	401	323	152	554	776	853	898	916	986
90	854	781	703	586	447	369	162	601	811	875	792	924	1001
100	880	813	738	628	490	411	173	644	840	891	794	934	1015
110	902	839	770	667	529	454	214	683	865	883	794	938	1027
120	922	864	800	702	565	495	466	717	887	888	794	936	1039
130	936	884	826	735	606	530	420	749	906	832	790	953	1042
140	946	899	844	763	643	553	454	775	913	859	778	962	1050
150	911	881	825	779	681	613	632	782	859	736	740	918	1056
160	807	793	772	756	714	688	647	755	778	726	722	802	1057
170	758	752	755	745	738	734	663	749	758	745	741	759	1062
180	763	764	765	762	757	761	719	766	771	767	764	772	1064

Table 3.7.13b Concrete Temperatures Measured in Frame B, Series I Column 6

Minutes	Temperature (°C) Measured at Thermocouple #:												Furnace
	22	23	24	25	26	27	28	29	30	31	32	33	
0	34	30	28	26	23	23	21	26	33	37	42	46	92
5	169	113	80	50	28	26	23	43	107	149	221	295	583
10	288	198	144	95	44	41	27	95	196	262	370	462	690
15	395	284	211	143	80	81	41	143	286	368	491	587	754
20	465	349	270	190	116	110	86	185	364	455	580	673	798
25	525	402	318	229	134	120	108	239	429	524	652	735	834
30	586	454	361	264	152	141	111	289	488	582	709	781	859
35	635	499	403	299	176	169	119	335	537	634	738	817	881
40	670	538	441	333	204	197	138	375	580	677	768	838	889
45	700	571	475	366	233	226	165	410	619	713	736	859	904
50	729	603	508	397	261	255	191	443	653	743	757	879	920
55	754	633	537	428	290	284	218	473	684	770	779	897	934
60	776	660	565	457	318	312	244	501	712	794	796	910	945
70	816	708	619	511	372	366	296	551	761	836	814	926	968
80	847	748	665	558	422	417	346	602	801	867	808	931	986
90	872	781	705	606	470	465	392	646	834	892	798	927	1001
100	893	809	740	647	513	509	436	686	862	914	785	914	1015
110	913	836	773	685	550	547	481	721	884	931	774	886	1027
120	934	863	804	720	591	588	521	752	905	948	767	826	1039
130	942	882	825	748	632	637	559	778	920	953	757	790	1042
140	885	864	791	748	671	686	654	773	887	883	750	751	1050
150	768	766	744	744	704	708	724	735	772	746	723	729	1056
160	744	737	744	755	727	727	750	735	727	725	721	734	1057
170	753	751	752	765	750	753	763	754	742	748	745	753	1062
180	766	769	768	777	769	775	776	769	764	771	769	773	1064

Table 3.7.13c Concrete Temperatures Measured in Frame C, Series I Column 6

Minutes	Temperature (°C) Measured at Thermocouple #:												Furnace
	34	35	36	37	38	39	40	41	42	43	44	45	
0	35	32	29	27	23	22	23	26	33	24	45	50	92
5	158	112	82	47	27	24	27	43	89	27	223	310	583
10	266	194	146	95	42	28	44	93	172	30	378	486	690
15	365	277	211	137	87	41	102	133	256	37	500	607	754
20	446	350	275	185	117	94	117	187	335	37	584	688	798
25	508	410	328	227	121	113	123	238	401	38	655	746	834
30	558	460	373	266	142	110	145	285	459	39	712	789	859
35	600	502	413	302	167	113	171	326	507	48	754	823	881
40	634	538	450	336	195	136	200	362	548	50	785	843	889
45	663	569	482	368	225	164	230	395	585	45	809	863	904
50	690	599	512	398	254	190	260	425	619	46	831	882	920
55	715	628	539	427	283	217	289	454	650	46	851	897	934
60	739	654	566	455	311	243	318	481	677	47	869	910	945
70	780	700	617	506	364	296	372	531	724	48	898	934	968
80	814	740	662	552	414	345	422	578	764	49	919	951	986
90	844	774	702	597	462	391	470	625	799	50	935	962	1001
100	870	806	738	640	506	436	515	665	829	51	941	975	1015
110	892	834	770	678	546	480	552	702	854	52	911	983	1027
120	909	851	795	714	598	521	595	735	877	53	787	985	1039
130	876	820	799	746	661	568	635	764	895	54	782	960	1042
140	780	753	759	747	705	671	673	769	880	55	757	873	1050
150	738	738	729	728	723	725	703	737	774	79	718	741	1056
160	735	746	741	737	738	738	724	743	731	59	732	731	1057
170	751	761	761	757	757	754	747	763	748	84	753	752	1062
180	771	775	774	770	774	767	769	776	768	66	772	768	1064

Table 3.7.13d

Concrete Temperatures Measured in Frame D, Series I Column 6

Minutes	Temperature (°C) Measured at Thermocouple #:												Furnace
	46	47	48	49	50	51	52	53	54	55	56	57	
0	32	30	28	25	23	22	23	26	31	34	39	42	92
5	165	119	85	46	27	23	26	40	95	140	219	294	583
10	280	207	151	93	50	27	44	92	182	255	379	476	690
15	377	296	222	137	85	44	83	134	270	365	504	603	754
20	459	374	289	184	114	76	109	179	352	456	593	687	798
25	524	437	345	226	125	101	114	230	419	528	662	746	834
30	576	488	392	265	152	108	136	277	473	586	715	789	859
35	618	531	434	303	180	116	165	321	517	637	755	823	881
40	651	566	471	338	209	138	193	360	556	678	783	842	889
45	680	598	503	370	239	163	222	396	594	710	807	860	904
50	709	628	533	401	268	188	250	428	628	739	831	879	920
55	733	656	561	430	296	213	278	458	659	763	852	894	934
60	756	681	590	458	323	239	305	486	688	786	871	900	945
70	797	726	641	511	375	290	358	535	738	827	902	898	968
80	832	763	685	556	424	339	407	582	779	860	925	893	986
90	858	797	724	602	471	385	455	628	814	884	943	870	1001
100	881	826	758	645	513	429	501	669	843	894	954	794	1015
110	903	852	789	683	550	472	557	709	859	762	939	765	1027
120	925	875	818	718	591	512	658	740	827	745	848	755	1039
130	930	891	843	750	630	543	733	759	782	758	787	763	1042
140	936	903	861	778	668	570	764	772	774	775	775	770	1050
150	896	876	852	787	703	627	778	783	781	788	779	773	1056
160	802	801	796	771	730	689	782	792	777	792	789	776	1057
170	771	773	765	768	754	741	788	816	784	805	807	788	1062
180	782	782	776	780	774	771	794	854	806	821	837	865	1064

Table 3.7.14

Deflections, Series I Column 6

Minutes	Expansion, mm
0	0.0
5	1.3
10	2.8
20	5.5
30	7.0
40	8.7
50	10.9
60	13.1
70	15.4
80	17.6
90	19.6
100	20.9
110	21.3
120	20.5
130	18.9
140	15.5
150	12.0
160	4.9
170	-2.6
180	-12.2

3.8 EFFECT OF SHAPE

3.8.1 Series II, Column 5

Test purpose: Effect of Rectangular Section.
 Date tested: June 20, 1985.
 Loading: 1413 kN, Concentric.

Specimen Properties:

Cross-Section: 305 x 457 mm (12 x 18 in.)
 Length: 3810 mm (12 ft 6 in.)
 Aggregate: Siliceous
 Reinforcement: 2.22% as eight No. 7 bars.

Elevation, Cross-Section and Finishing Detail: Figure 3.8.1
 Layout of Thermocouple Frames in Concrete: Figure 3.8.2
 Locations of Thermocouples in Frames: Figure 3.8.3
 Locations of Thermocouples on Reinforcing Bars: Figure 3.8.4

Measured Properties:

Cylinder strengths: 44.2 MPa at 28 days.
 42.5 MPa on test date.
 Relative humidity: 65%.

Results:

Test duration: Actual: 6 hours 36 minutes
 Corrected: 5 hours 56 minutes.
 (due to recurring interruptions in the fire test)
 Temperatures: Tables 3.8.1 and 3.8.2.
 Axial deformations: Table 3.8.3

Observations

0:35 The fire died out.
 0:39 Fire restarted.
 1:00 A 10 cm long crack developed on the S side.
 1:10 A 5 cm crack was visible on the E face. The fire died out.
 1:15 Fire restarted.
 1:25 Hairline cracks developed on all sides.
 1:30 Fire died out.
 1:35 Fire restarted.
 1:40 Cracks on the E and S faces extended to 20 cm long.
 2:10 Cracks on the E and S faces extended to 45 cm. Fire died out.
 2:15 Fire restarted.
 2:20 Maximum crack width on the E face was 3 mm. Small cracks developed on the other faces.
 3:00 60 cm cracks formed on the upper and lower third of the S and E faces.
 3:30 Maximum crack width was 13 mm; no spalling observed.
 3:50 Fire died out.
 3:55 Fire restarted.
 5:00 Cracks on the S face widened to 20 mm; no reinforcing bars were visible.

6:00 All cracks remained unchanged.
 6:36 Failure in compression (Figure 3.8.5).

3.8.2 Series III, Column 6

Test purpose: Effect of Rectangular Section (Mini-Wall).
 Date tested: June 27, 1986.
 Loading: 756 kN, Concentric.

Specimen Properties:

Cross-Section: 203 x 915 mm (8 x 36 in.)
 Length: 3810 mm (12 ft 6 in.)
 Aggregate: Siliceous
 Reinforcement: 1.22% as eight No. 6 bars.

Elevation, Cross-Section and Finishing Detail: Figure 3.8.6
 Layout of Thermocouple Frames in Concrete: Figure 3.8.7
 Locations of Thermocouples in Frames: Figure 3.8.8
 Locations of Thermocouples on Reinforcing Bars: Figure 3.8.9

Measured Properties:

Cylinder strengths: 39.2 MPa at 28 days.
 42.1 MPa on test date.
 Relative humidity: 58%.

Results:

Test duration: 5 hours 35 minutes
 Temperatures: Tables 3.8.4 and 3.8.5.
 Axial deformations: Table 3.8.6

Figure 3.8.10 shows the column after the test.

3.8.3 Series III, Column 11

Test purpose: Effect of Circular Section.
 Date tested: March 1, 1985.
 Loading: 1431 kN, Concentric.

Specimen Properties:

Cross-Section: 355 mm (14 in.) diameter
 Length: 3810 mm (12 ft 6 in.)
 Aggregate: Siliceous
 Reinforcement: 2.34% as six No. 7 bars.

Elevation, Cross-Section and Finishing Detail: Figure 3.8.11
 Layout of Thermocouple Frames in Concrete: Figure 3.8.12
 Locations of Thermocouples in Frames: Figure 3.8.13
 Locations of Thermocouples on Reinforcing Bars: Figure 3.8.14

Measured Properties:

Cylinder strengths: 39.3 MPa at 28 days.
41.6 MPa on test date.
Relative humidity: 78%.

Results:

Test duration: 4 hours 5 minutes
Temperatures: Tables 3.8.7 and 3.8.8.
Axial deformations: Table 3.8.9

Observations

0:40 Hairline cracks appeared.
0:53 A piece of concrete 30 x 15 cm by 1 cm thick, spalled off the S face at midheight.
1:00 Hairline cracks lengthened.
1:08 A vertical crack on the E face opened to nearly 2 mm.
1:38 The worst vertical crack on the E face widened to 3 mm and 60 cm long.
2:30 It reached 6 mm wide and 120 cm long.
3:00 All cracks remained unchanged.
3:10 Column began to contract.
3:40 All cracks increased in length and width.
4:00 The rate of contraction increased very rapidly.
4:04 Sudden failure in compression. Approximately 30% of the cover spalled off. (Figure 3.8.15)

3.8.4 Series III, Column 12

Test purpose: Effect of Circular Section.
Date tested: October 3, 1985.
Loading: 444 kN, Concentric.

Specimen Properties: Exactly as Series II, Column 11 (3.8.3).

Measured Properties:

Cylinder strengths: 37.0 MPa at 28 days.
42.4 MPa on test date.
Relative humidity: 76%.

Results:

Test duration: 3 hours 40 minutes
Temperatures: Tables 3.8.10 and 3.8.11.
Axial deformations: Table 3.8.12

Observations

- 0:15 Hairline cracks developed around the column.
0:30 Most cracks extended, the longest being 60 cm.
0:43 A piece of concrete 20 x 10 cm by 1 cm thick, spalled off the E face at midheight.
1:00 Some cracks widened to 6 mm.
1:08 A second piece of concrete 60 x 25 cm appeared to be falling off the E face
2:38 It fell off, exposing the spiral steel to fire.
3:00 All cracks increased in length and width.
3:05 Column began to contract.
4:04 Sudden failure in compression. (Figure 3.8.12)

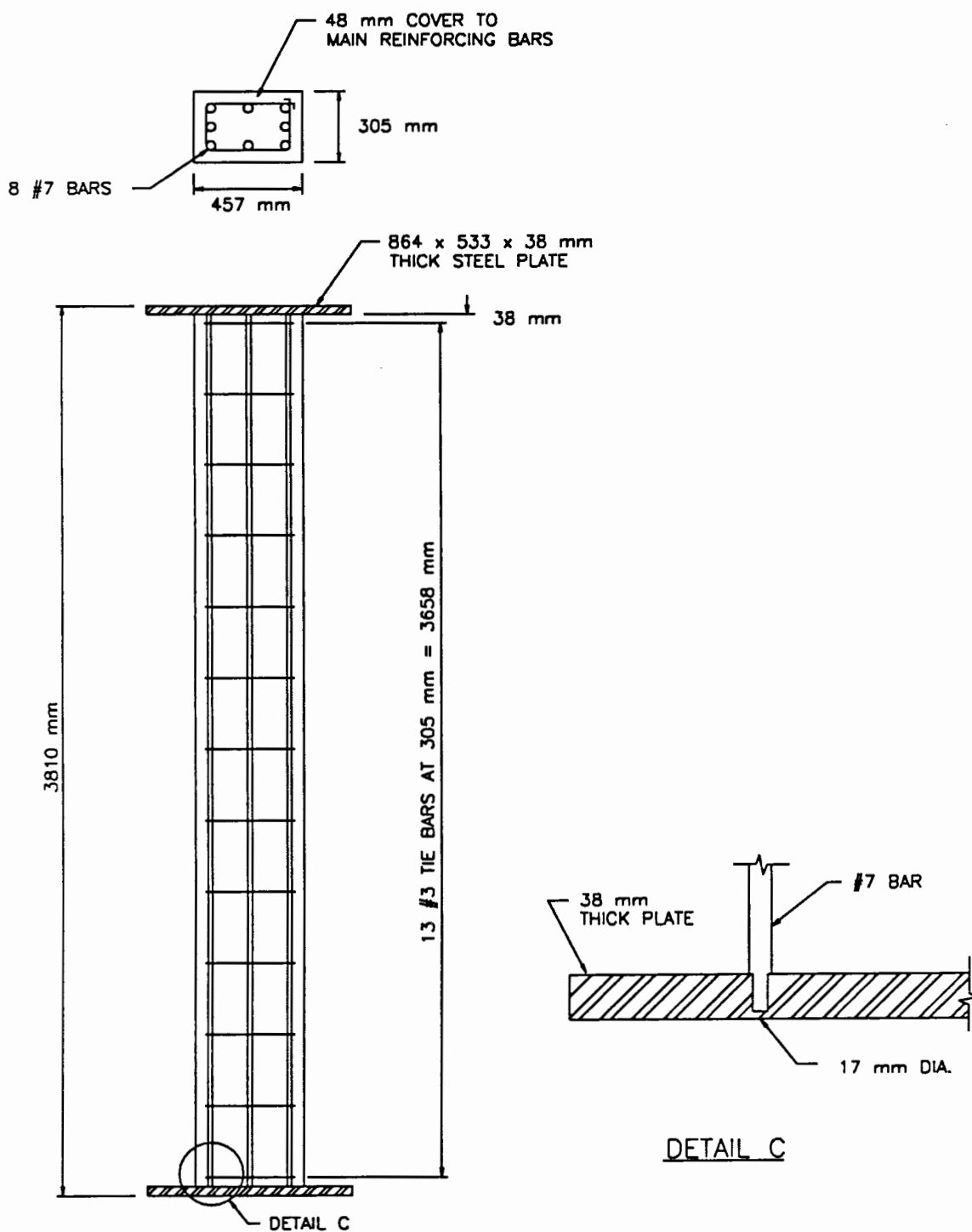


Figure 3.8.1 Elevation, Cross-Section and Finishing Detail: 12 x 18 Section

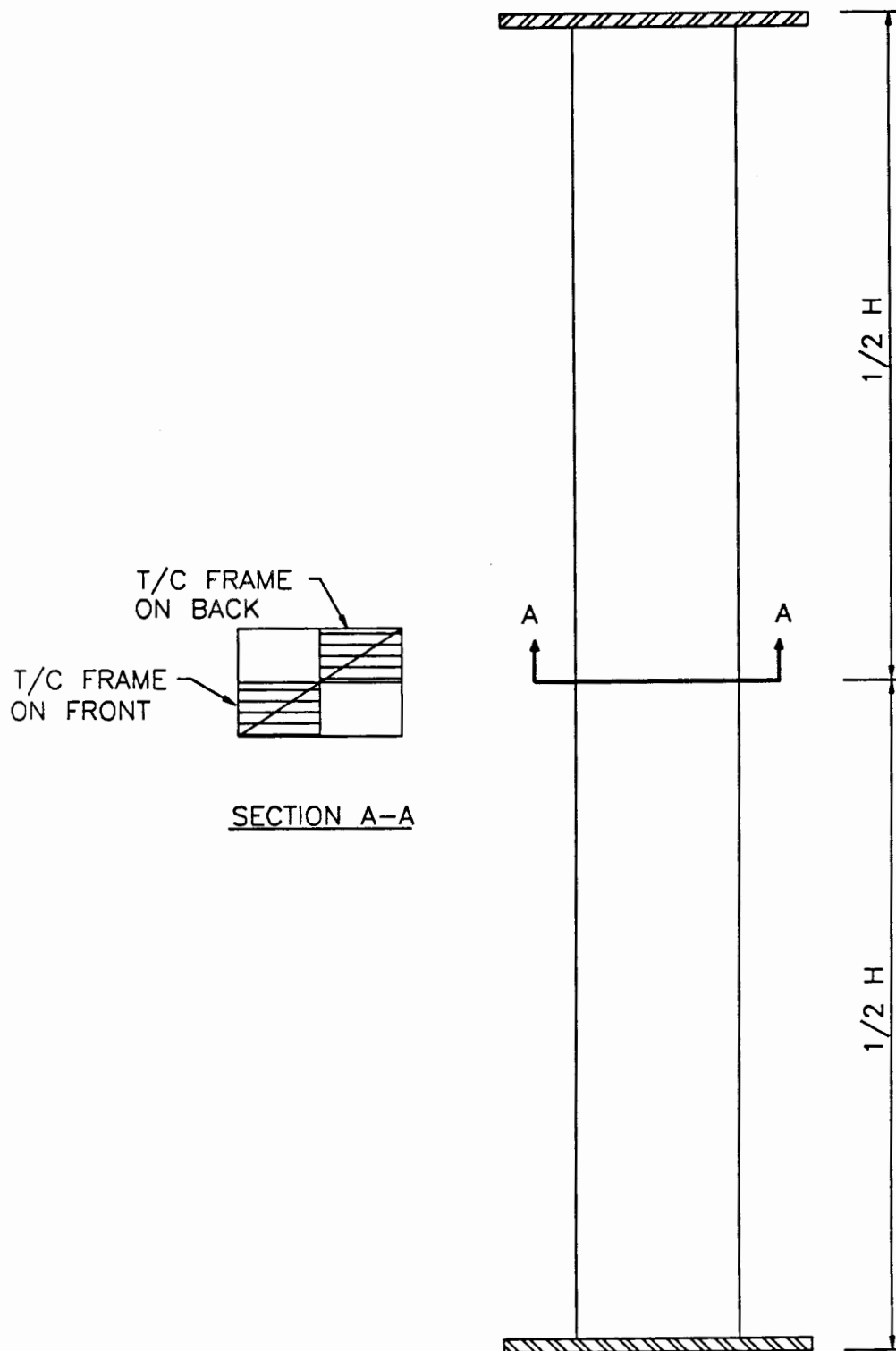


Figure 3.8.2 Layout of T/C Frames in Concrete: 12 x 18 Section

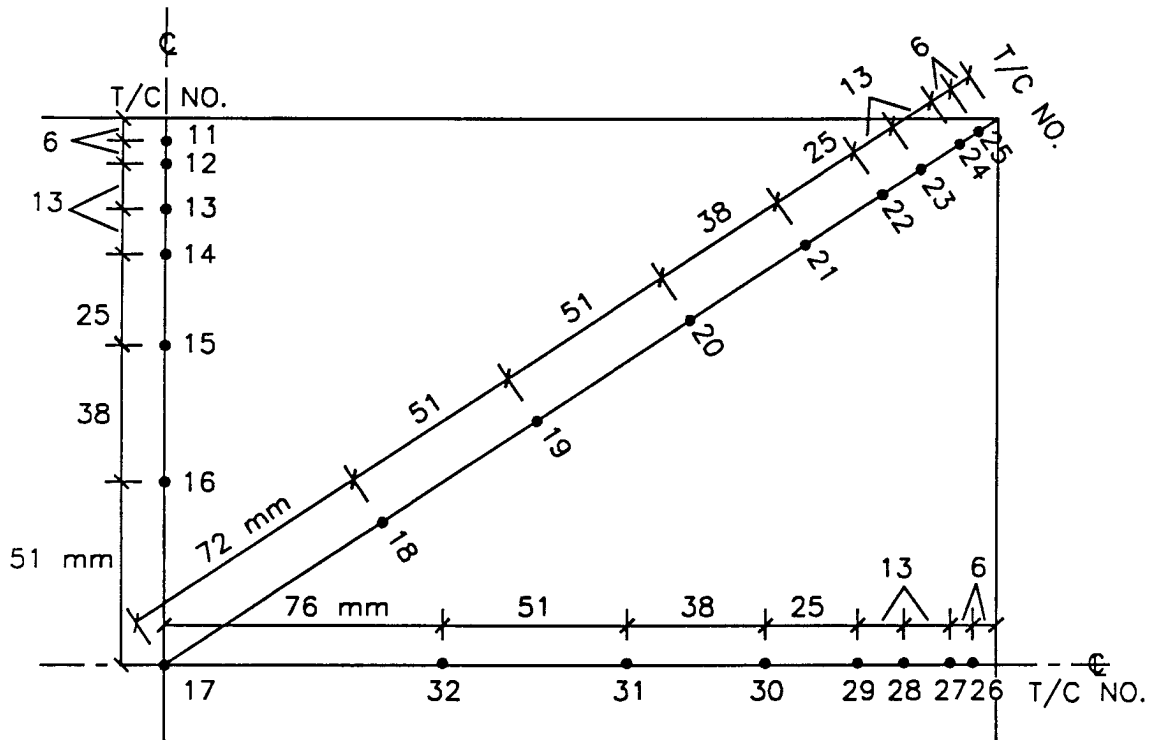


Figure 3.8.3 Locations of T/Cs in Frames: 12 x 18 Section

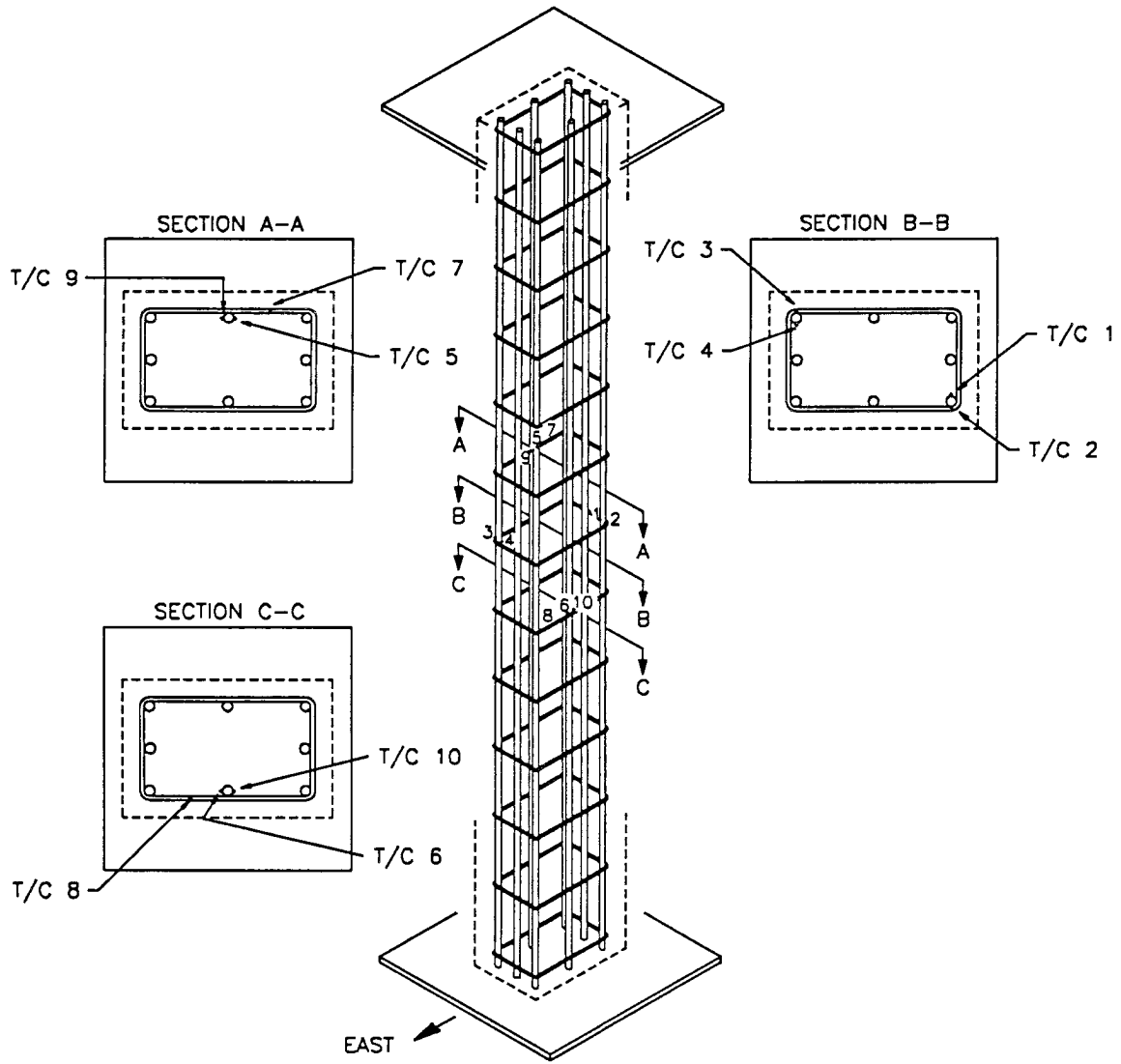


Figure 3.8.4 Locations of T/Cs on Reinforcing Bars: 12 x 18 Section



Figure 3.8.5 Series III. Column 5 After Test

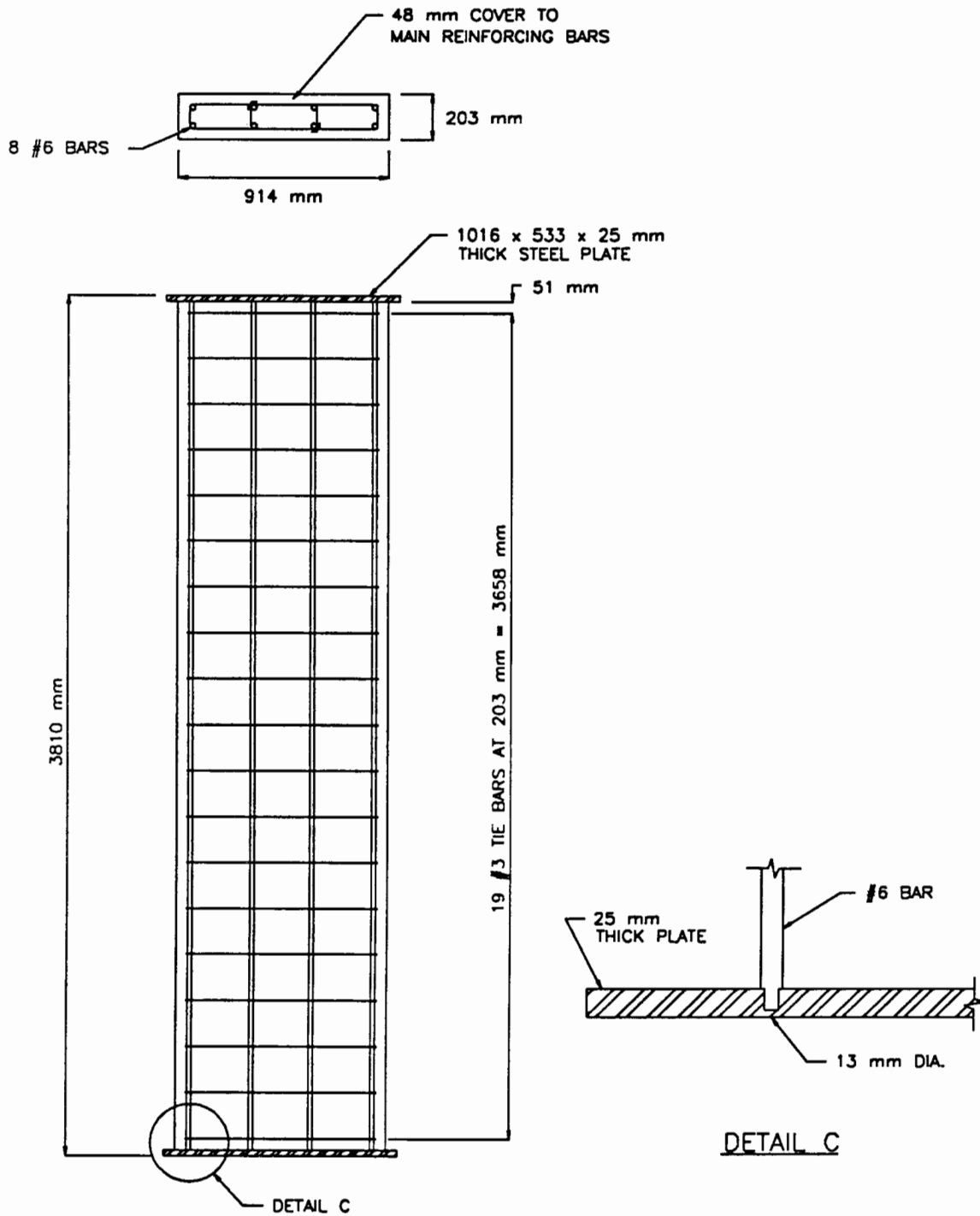


Figure 3.8.6 Elevation, Cross-Section and Finishing Detail: 8 x 36 Section

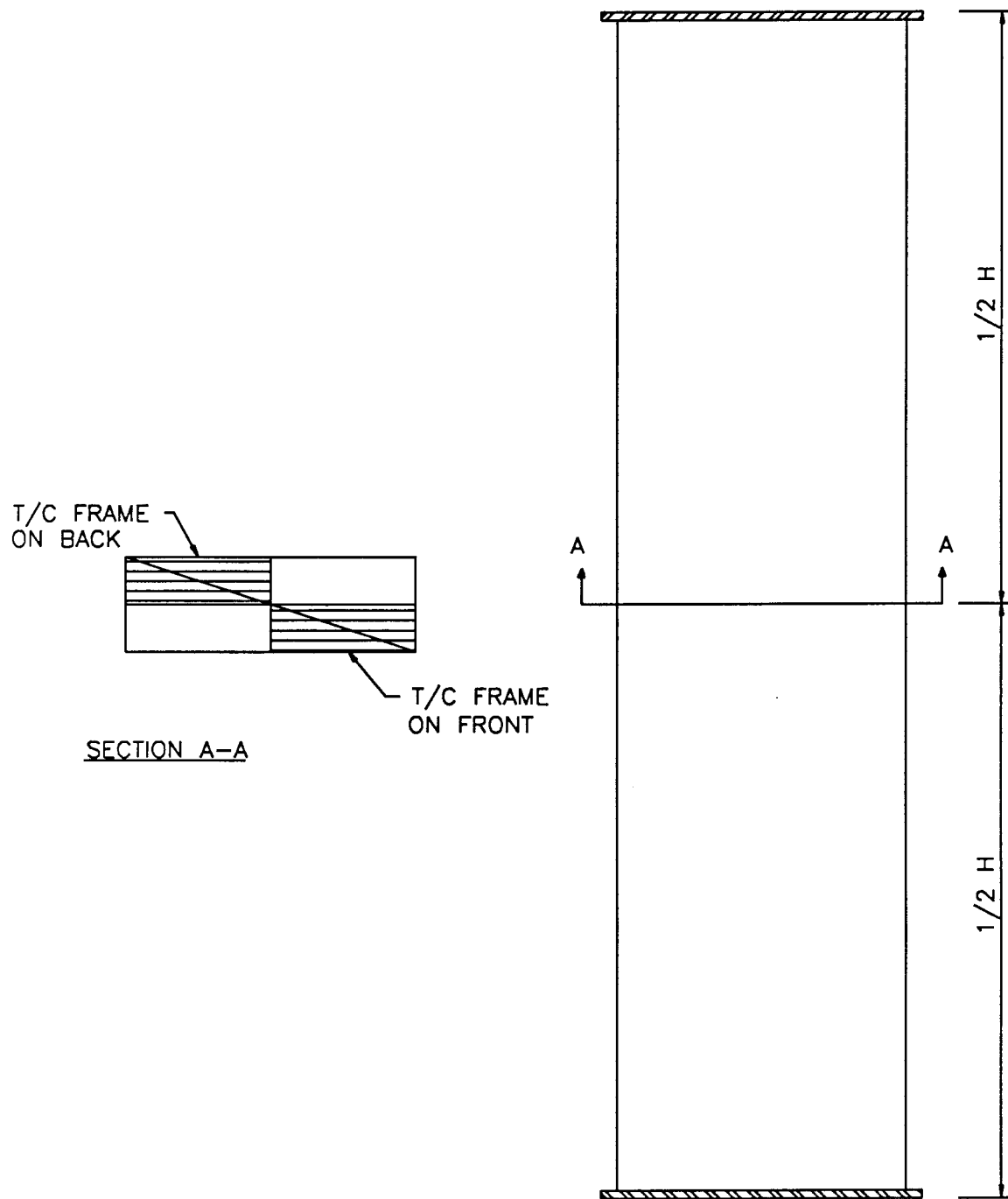


Figure 3.8.7 Layout of T/C Frames in Concrete: 8 x 36 Section

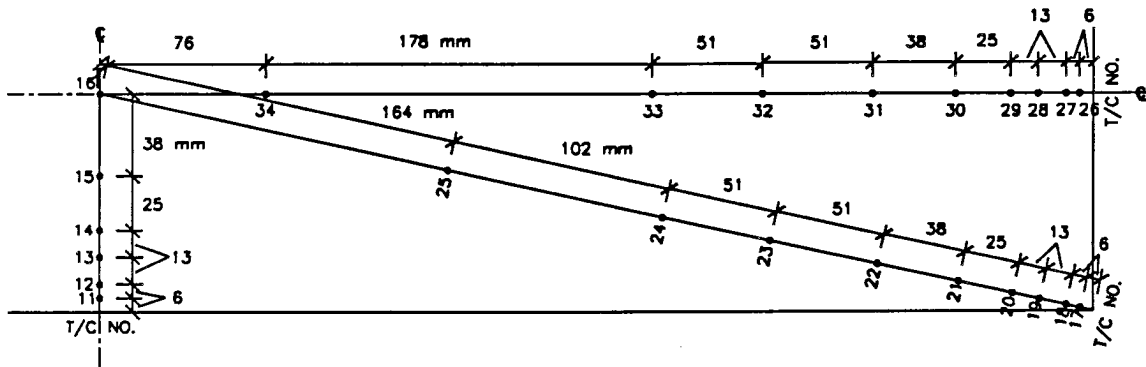


Figure 3.8.8 Locations of T/Cs in Frames: 8 x 36 Section

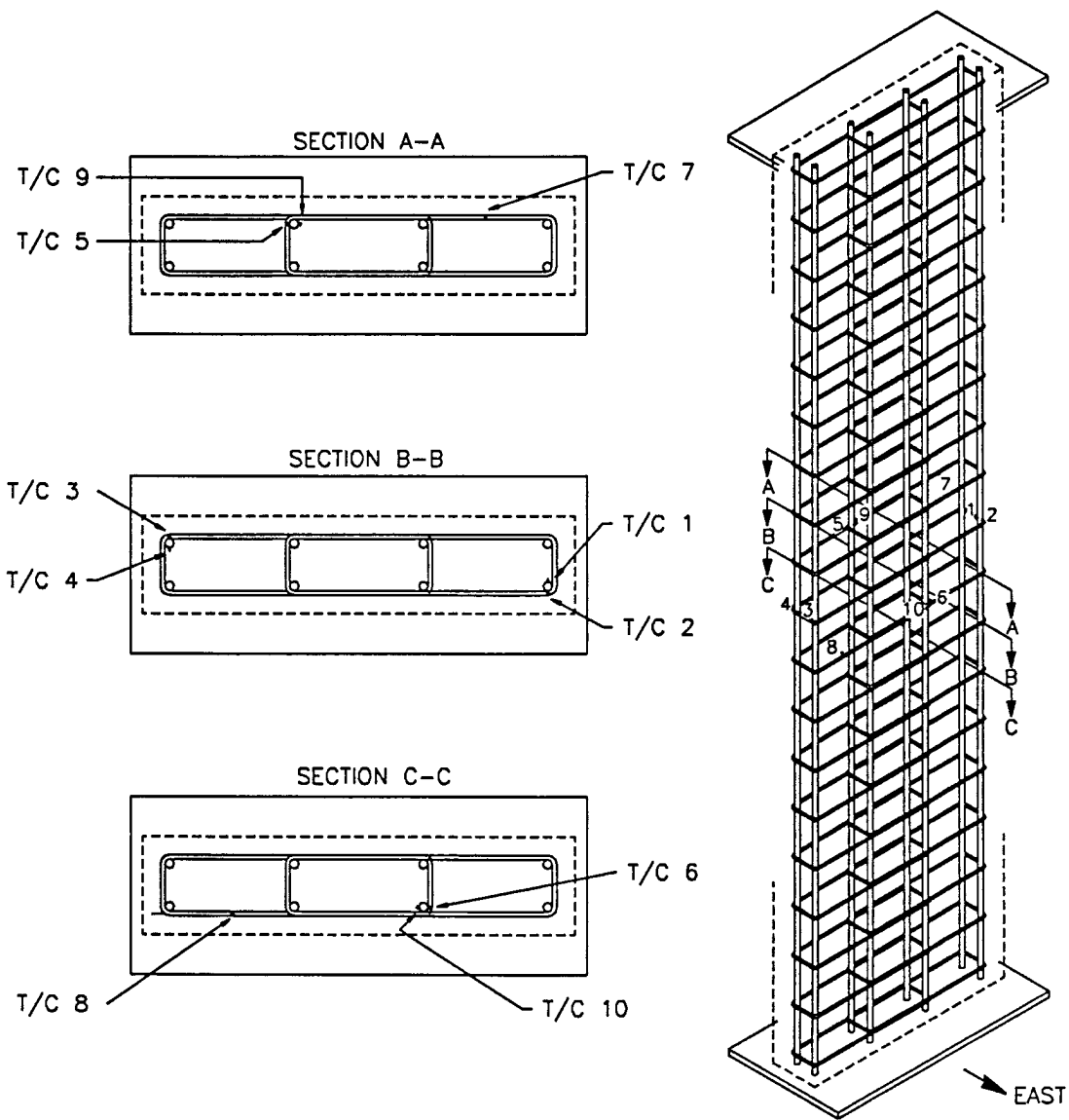


Figure 3.8.9 Locations of T/Cs on Reinforcing Bars: 8 x 36 Section



Figure 3.8.10 Series III Column 6 After Test

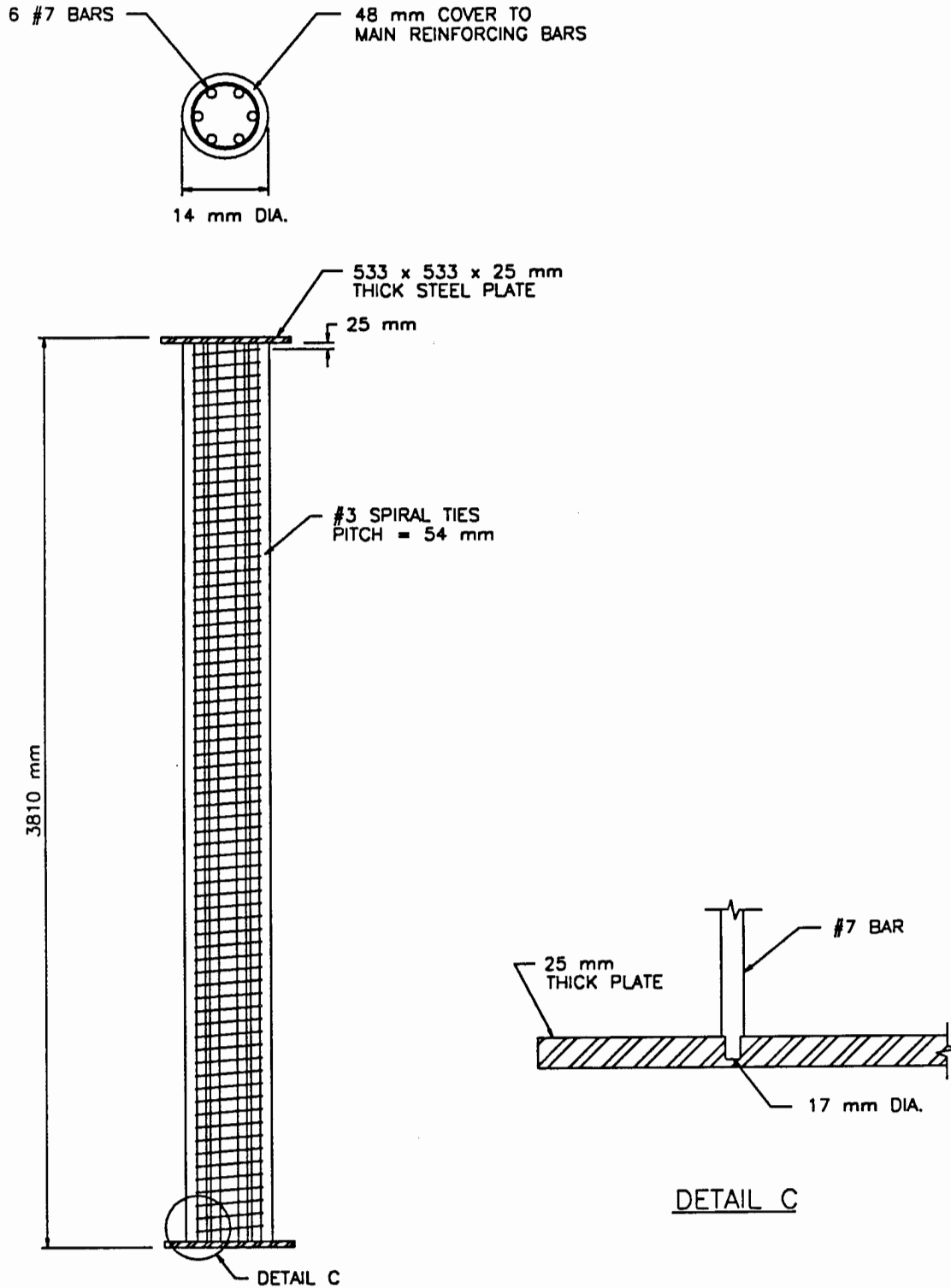


Figure 3.8.11 Elevation, Cross-Section and Finishing Detail: 14 Ø Section

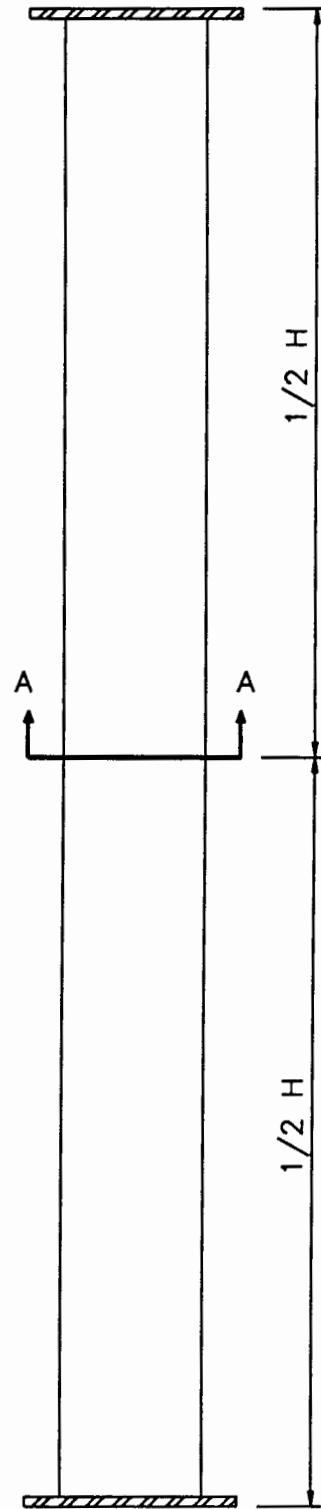
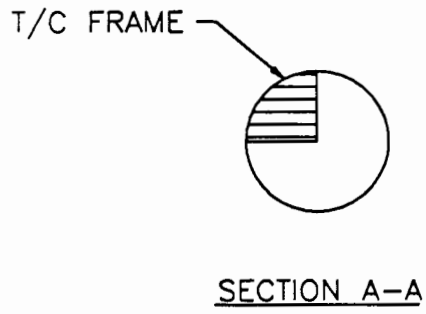


Figure 3.8.12 Layout of T/C Frames in Concrete: 14 Ø Section

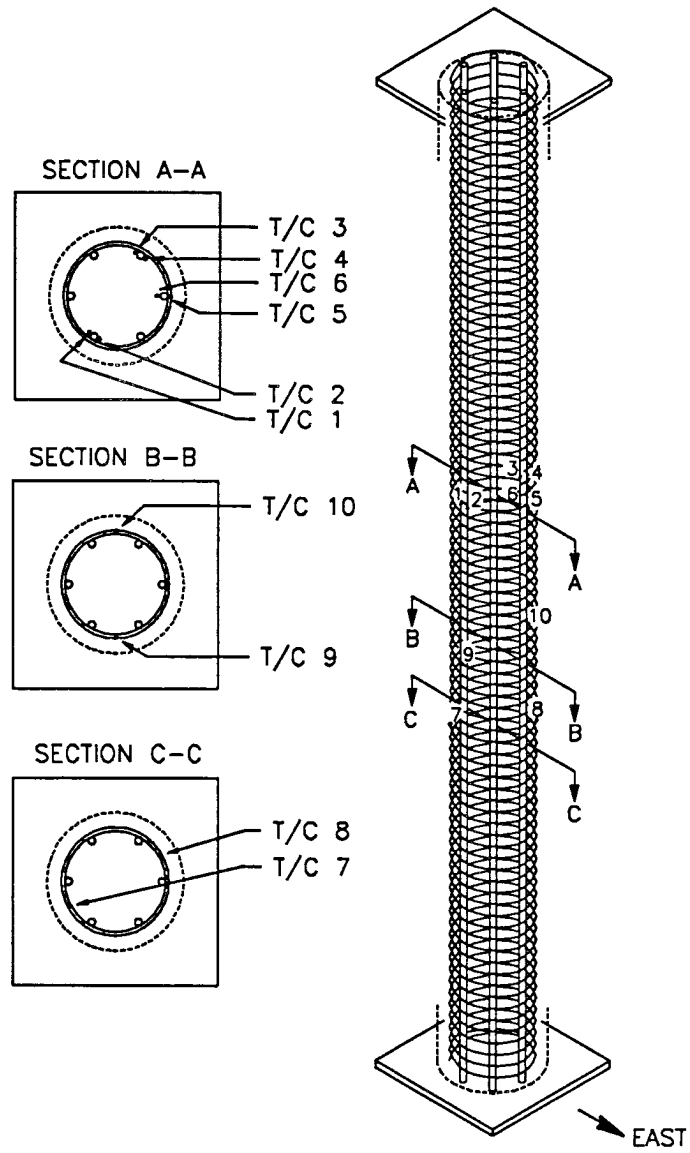


Figure 3.8.14 Locations of T/Cs on Reinforcing Bars: 14 Ø Section



Figure 3.8.15 Series III Column 11 After Test

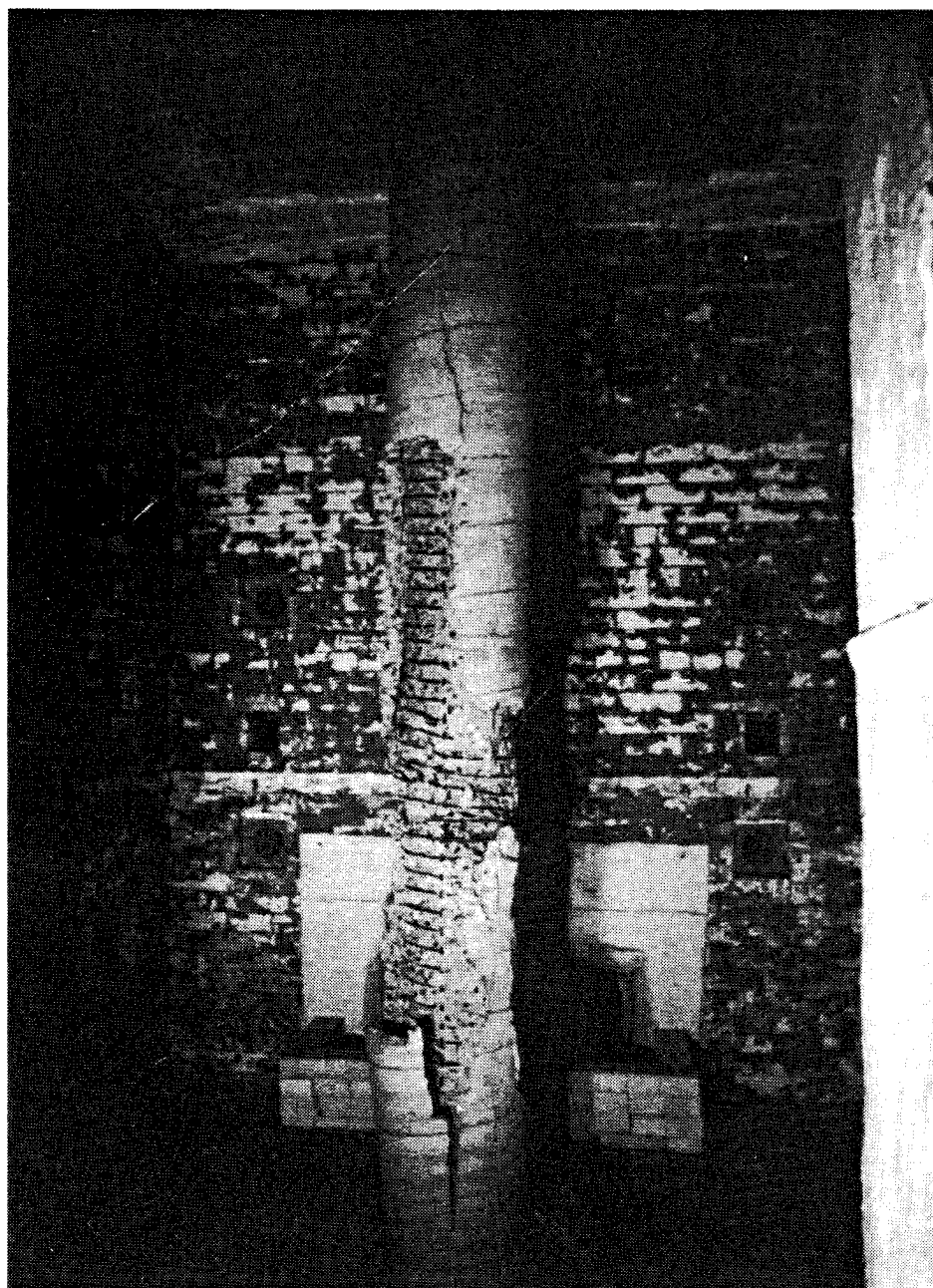


Figure 3.8.16 Series III Column 12 After Test

Table 3.8.1 Steel Temperatures, Series III Column 5

Minutes	Temperature (°C) Measured at Thermocouple #:									Furnace
	1	2	3	4	5	7	8	9	10	
0	18	18	18	18	19	19	17	19	18	107
5	20	21	22	21	20	25	27	20	19	585
10	32	36	49	39	28	47	56	29	30	674
20	108	120	119	115	71	107	126	73	78	796
30	120	127	105	111	121	136	167	121	120	840
40	163	178	118	128	132	203	239	133	152	794
50	200	217	132	147	148	235	272	151	179	819
60	237	257	183	189	183	265	306	186	205	833
80	319	343	311	304	248	326	375	253	265	881
100	394	417	395	387	299	379	433	304	319	880
120	459	480	463	455	343	428	485	348	368	865
140	495	516	501	492	370	458	516	375	398	875
150	511	532	518	509	383	472	530	389	412	880
165	533	553	541	533	403	493	549	408	432	881
180	553	573	563	554	422	512	569	428	452	884
195	574	593	584	576	442	530	589	447	471	893
210	594	612	605	597	460	547	611	465	489	862
230	615	631	626	618	482	565	636	487	510	888
250	635	651	648	639	503	587	664	508	530	889
270	654	670	670	659	523	607	688	528	549	891
290	671	686	688	677	542	625	703	546	568	894
310	683	694	701	691	559	640	710	564	588	894
330	692	700	712	703	577	657	719	582	613	898
350	698	702	721	713	596	673	725	599	644	900
365	701	705	724	716	611	684	728	611	664	898

Table 3.8.2

Concrete Temperatures, Series III Column 5

Minutes	Temperature (°C) Measured at Thermocouple #:									Furnace
	11	12	13	14	15	16	17	18	19	
0	22	20	19	18	20	18	18	18	18	107
5	136	94	47	31	19	18	18	18	19	585
10	228	160	100	64	11	19	18	19	24	674
20	400	296	169	119	76	31	21	55	88	796
30	539	412	257	182	122	118	51	80	81	840
40	541	441	314	240	129	120	110	113	111	794
50	591	492	351	268	140	123	122	126	131	819
60	618	519	384	298	159	124	122	133	138	833
80	671	576	450	367	238	136	119	146	198	881
100	691	613	496	417	288	168	129	186	266	880
120	707	641	535	461	335	212	159	230	322	865
140	727	663	560	488	363	240	184	258	356	875
150	734	673	573	501	377	255	199	273	372	880
165	745	687	591	519	398	278	224	295	396	881
180	756	700	607	537	419	301	249	318	418	884
195	766	712	623	553	438	324	274	340	440	893
210	739	699	632	569	457	346	298	362	461	862
230	774	726	647	585	479	375	328	390	486	888
250	785	740	665	606	501	401	356	415	509	889
270	794	751	681	624	522	427	383	439	530	891
290	795	754	692	640	540	450	408	461	549	894
310	804	765	703	653	558	473	432	480	568	894
330	814	777	717	668	576	493	455	496	587	898
350	819	786	729	682	592	512	476	513	606	900
365	821	790	736	691	604	524	490	528	623	898

Table 3.8.2
(continued)

Concrete Temperatures, Series III Column 5

Minutes	Temperature (°C) Measured at Thermocouple #:									Furnace
	20	21	22	23	24	25	26	27	28	
0	18	19	19	21	23	26	22	20	18	107
5	22	41	81	129	188	230	153	109	58	585
10	48	103	155	221	324	382	248	176	111	674
20	113	169	302	415	514	587	433	316	188	796
30	119	183	414	542	640	713	541	390	234	840
40	132	173	431	554	635	690	530	400	274	794
50	148	204	468	600	685	738	578	442	306	819
60	180	330	523	639	715	763	607	470	339	833
80	290	461	638	723	781	821	674	549	432	881
100	368	527	689	757	803	727	706	601	494	880
120	433	584	722	712	810	724	725	640	546	865
140	469	617	745	724	826	731	747	669	580	875
150	486	631	755	728	831	735	756	681	596	880
165	509	650	767	735	838	739	768	698	617	881
180	530	667	778	739	846	741	781	714	637	884
195	549	683	788	741	851	743	791	729	656	893
210	569	696	786	738	814	738	764	719	667	862
230	590	707	795	732	850	730	799	747	685	888
250	612	724	807	733	857	732	810	761	703	889
270	633	738	815	734	860	735	818	773	719	891
290	651	749	816	735	853	735	818	776	729	894
310	666	755	817	734	858	733	826	786	739	894
330	679	764	820	734	859	730	834	797	753	898
350	690	765	732	733	839	718	838	804	763	900
365	693	758	682	728	714	703	829	802	766	898

Table 3.8.3

Deflections, Series III Column 5

Minutes	Expansion, mm
0	0.0
10	0.4
20	1.6
30	2.3
40	2.8
50	3.6
60	4.1
70	4.6
80	5.2
90	5.7
100	6.0
120	6.6
140	6.9
160	7.0
180	7.0
200	7.0
220	6.7
240	6.3
260	5.5
280	4.7
300	3.5
310	2.9
320	2.2
330	1.4
340	0.5
350	-0.6
360	-1.9
366	-6.1

Table 3.8.4

Steel Temperatures, Series III Column 6

Minutes	Temperature (°C) Measured at Thermocouple #:									Furnace
	1	2	3	4	5	6	7	8	10	
0	17	16	17	16	17	16	17	16	22	80
10	33	29	38	32	26	29	42	56		683
20	121	119	122	118	70	89	107	116	90	782
30	114	113	129	119	118	123	144	168	124	840
40	107	108	146	125	140	139	196	210	149	874
50	145	135	202	181	165	179	244	265	185	902
60	201	187	254	232	202	217	285	312	224	922
70	249	234	301	279	235	251	320	351	257	939
80	296	281	347	326	266	284	352	387	288	955
90	342	329	392	372	297	316	384	421	319	969
100	386	375	435	415	329	348	414	454	350	981
110	429	418	476	456	360	379	445	485	379	994
120	469	458	514	494	390	437	474	514	407	1006
130	506	495	548	529	419	468	503	541	433	1006
140	539	529	580	559	447	496	530	567	458	1029
150	571	559	613	593	473	523	555	594	481	1038
160	604	593	644	624	498	549	581	622	505	1043
170	635	624	673	654	522	575	607	656	527	1055
180	667	660	700	682	545	603	633	699	549	1065
200	717	722	724	716	642	707	702	724	630	1081
220	734	733	745	747	735	741	748	739	720	1093
240	771	772	783	786	773	783	775	778	770	1108
260	799	805	813	821	792	809	794	811	789	1121
280	835	858	848	887	788	840	803	860	788	1136
300	871	877	875	895	886	877	855	891	862	1145
320	894	897	913	918	911	910	921	918	889	1167
330	896	911	924	929			934	926	903	1169

Table 3.8.5 Concrete Temperatures, Series III Column 6

Minutes	Temperature (°C) Measured at Thermocouple #:											Furnace
	11	12	13	14	15	16	18	19	20	21	22	
0	19	18	17	17	27	17	20	19	18	17	17	80
10	176	129	85	54	19	18	261	189	150	107	64	683
20	333	254	156	109	73	35	483	386	319	207	130	782
30	452	361	239	162	116	81	600	508	445	293	151	840
40	524	437	306	220	134	144	679	597	522	328	181	874
50	561	487	360	272	150	149	727	657	582	405	237	902
60	599	529	403	315	185	146	771	708	641	480	300	922
70	645	571	444	352	216	156	808	752	689	534	349	939
80	685	608	481	386	248	185	838	788	730	582	395	955
90	719	642	515	418	280	219	864	818	764	627	440	969
100	747	672	545	449	311	252	885	844	794	667	483	981
110	772	699	573	478	342	284	903	866	820	702	523	994
120	795	724	600	506	372	315	919	886	844	732	557	1006
130	814	746	626	532	400	344	933	904	865	760	592	1006
140	834	767	651	557	428	372	946	919	884	785	625	1029
150	853	788	674	581	455	399	957	931	900	808	656	1038
160	870	808	697	606	480	425	967	941	915	829	685	1043
170	886	826	719	630	504	451	976	947	928	848	711	1055
180	902	844	740	654	526	475	984	952	940	866	737	1065
200	923	871	777	696	567	520	996		957	894	782	1081
220	929	894	807	725	611	558	997		961	906	814	1093
240				745	663	660						1108
260				750	713	729						1121
280				748	735	745						1136
300				761	753							1145
320				874	771							1167
330				891	786							1169

Table 3.8.5
(continued)

Concrete Temperatures, Series III Column 6

Minutes	Temperature (°C) Measured at Thermocouple #:											Furnace
	23	24	25	26	27	28	29	30	31	32	33	
0	17	16	16	21	19	17	17	19	21	18	18	80
10	35	24	22	216	160	98	61	29	23	19	19	683
20	105	77	50	409	325	194	136	108	80	56	36	782
30	129	116	103	451	346	144	109	110	103	93	88	840
40	159	138	141	293	230	120	104	117	130	129	132	874
50	189	156	151	537	451	279	180	127	137	139	144	902
60	223	182	173	602	520	350	238	158	139	141	146	922
70	255	207	203	640	565	403	287	201	155	148	152	939
80	289	236	235	688	613	460	346	252	191	168	178	955
90	325	268	267	731	660	516	407	302	234	199	212	969
100	362	302	299	771	701	565	462	351	275	238	244	981
110	397	335	330	804	736	610	507	396	315	274	276	994
120	431	367	360	834	767	649	547	436	353	309	308	1006
130	464	397	388	859	795	684	587	476	389	341	337	1006
140	495	427	416	881	821	715	623	511	423	372	365	1029
150	523	455	443	901	844	744	656	543	456	402	393	1038
160	549	482	468	917	865	770	687	573	487	431	420	1043
170	575	507	492		877	793	716	607	520	465	458	1055
180	603	531	515			790	734	649	585	545	551	1065
200	655	576	554			725	727	719	723	718	715	1081
220	699	622	594			764	758	759	774	771	766	1093
240	718	665	646			775	779	776	784	788	785	1108
260	722	707	706			786	814	787	787	783	834	1121
280	747	729	740			847	866	858	817	800	886	1136
300	772	752	764			897	903	901	869	901	917	1145
320	802	780	791			921	917	930	917	905		1167
330	816	792	846			925		928				1169

Table 3.8.6

Deflections, Series III Column 6

Minutes	Expansion, mm
0	0.0
10	1.8
20	4.4
30	6.4
40	7.4
50	8.2
60	9.1
70	10.0
80	11.0
90	12.1
100	13.1
110	14.2
120	15.1
130	16.0
140	16.7
150	17.2
160	17.6
170	17.8
180	18.0
190	18.1
200	18.1
210	17.8
220	17.4
230	16.8
240	16.2
250	15.3
260	14.0
270	12.3
280	10.3
290	7.8
300	4.8
310	0.9
320	-4.7
330	-14.8

Table 3.8.7

Steel Temperatures, Series III Column 11

Minutes	Temperature (°C) Measured at Thermocouple #:										Furnace
	1	2	3	4	5	6	7	8	9	10	
0	23	23	23	23	23	23	22	22	22	21	64
5	26	24	25	24	27	24	34	30	35	29	589
10	36	31	35	30	46	36	62	51	72	53	686
20	91	82	90	80	88	78	104	104	155	102	821
30	99	92	93	88	110	101	125	120	239	111	855
40	122	111	107	99	140	122	164	150	300	141	879
50	153	136	135	121	176	153	209	188	351	182	911
60	187	166	167	150	210	184	253	229	398	225	929
70	221	197	199	180	243	216	298	270	438	267	944
80	255	230	232	210	273	245	338	307	473	305	963
90	288	261	261	238	298	269	362	341	505	338	972
100	318	291	291	267	324	295	398	372	533	370	987
110	347	320	320	297	349	321	432	402	559	400	1000
120	375	347	349	326	375	347	464	432	585	429	1009
130	402	374	378	354	400	373	494	462	611	459	1017
140	429	400	406	382	427	399	523	492	636	487	1032
150	455	426	433	409	453	425	549	520	660	516	1040
160	480	452	459	435	480	452	574	546	684	540	1046
170	503	476	484	461	505	477	600	571	706	565	1058
180	526	499	508	485	529	502	625	597	727	590	1066
195	560	532	541	520	565	537	658	634	756	627	1072
210	593	563	574	552	599	570	690	668	786	662	1090
225	626	596	607	584	634	605	718	703	813	698	1102
240	657	628	640	617	666	640	742	730	831	733	1106
245	670	637	651	626	700	695	792	836	836	833	1061

Table 3.8.9

Deflections, Series III Column 11

Minutes	Expansion, mm
0	0.0
10	0.7
20	1.7
30	1.9
40	2.2
50	2.7
60	3.2
70	3.8
80	4.4
90	4.9
100	5.3
110	5.8
120	6.2
130	6.6
140	6.9
150	7.1
160	7.3
170	7.3
180	7.3
190	7.3
200	6.8
210	5.9
220	4.7
230	3.0
240	0.5
245	-23.4

Table 3.8.10

Steel Temperatures, Series III Column 12

Minutes	Temperature (°C) Measured at Thermocouple #:										Furnace
	1	2	3	4	5	6	7	8	9	10	
0	18	18	18	18	18	18	13	13	14	15	93
5	19	20	20	20	20	20	29	26	25	29	579
10	28	30	28	28	30	31	68	62	62	68	676
20	85	92	88	88	85	86	106	111	112	126	786
30	92	94	93	94	96	96	157	131	112	195	845
40	100	104	107	108	104	107	193	175	135	245	878
50	121	128	133	134	126	129	236	222	179	285	906
60	148	158	162	163	152	156	285	266	233	330	929
70	178	189	192	193	182	185	329	307	296	373	943
80	208	220	224	225	207	209	370	347	379	412	957
90	222	234	240	240	207	206	391	365	439	430	983
100	264	277	284	285	216	217	448	414	741	478	987
110	293	306	312	313	257	259	484	444	380	509	1005
120	321	335	339	340	289	290	519	474	881	539	1008
130	349	362	366	367	318	320	546	499	880	562	997
140	374	387	390	391	347	349	570	522	927	587	1026
150	400	413	414	415	377	380	602	549	917	617	1025
160	427	440	440	441	408	411	633	574	959	645	1048
170	454	466	465	466	438	441	665	599	920	674	1064
180	479	491	489	490	467	470	699	625	865	699	1063
190	504	516	512	513	494	497	732	649	853	720	1073
200	528	539	534	535	520	523	767	671	862	739	1079
210	550	562	556	556	545	549	825	692	965	758	1108
220	572	585	578	578	570	574	883	713	912	778	1098

Table 3.8.11 Concrete Temperatures, Series III Column 12

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace
	11	12	13	14	15	16	17	18	19	20	21	22	23	
0	15	18	17	16	16	16	17	17	17	17	18	19	28	93
5		91	51	31	18	16	17	17	20	39	70	109	187	579
10		157	108	69	29	18	17	19	34	84	131	185	308	676
20	391	299	196	123	82	32	18	40	90	140	240	353	527	786
30	504	407	294	195	95	55	25	51	102	199	321	468	637	845
40	579	486	369	255	119	72	39	62	132	254	389	540	706	878
50	633	542	426	303	148	92	53	82	163	300	440	593	758	906
60	676	591	472	349	181	117	89	114	196	342	483	635	800	929
70	710	629	511	386	214	140	116	137	222	372	517	669	830	943
80	746	663	540	384	207	155	124	153	250	407	552	704	901	957
90	756	670	547	397	212	160	127	158	266	423	565	713	858	983
100	717	707	590	382	285	174	154	187	319	469	605	748	725	987
110	723	729	616	345	314	196	153	221	361	509	642	780	727	1005
120	734	750	639	346	340	216	149	231	374	522	653	790	732	1008
130	715	742	644	353	366	238	157	253	399	539	656	778	710	997
140	736	771	667	389	391	261	168	274	422	561	684	812	735	1026
150	753	796	692	392	416	283	180	295	439	589	711	838	754	1025
160	762	814	712	415	443	307	197	317	463	614	733	852	766	1048
170	771	836	735	435	469	331	220	339	488	639	757	865	778	1064
180	774	855	756	466	493	355	248	361	513	663	780	842	784	1063
190	771	869	775	529	518	379	275	384	537	686	799	772	786	1073
200	768	883	792	559	542	403	304	406	559	706	818	778	790	1079
210	760	897	809	610	578	433	370	427	581	726	836	783	795	1108
220	786	883	814	730	669	524	570	448	604	546	852	787	798	1098

Table 3.8.12

Deflections, Series III Column 12

Minutes	Expansion, mm
0	0.0
5	0.2
10	0.6
20	1.6
30	1.8
40	2.0
50	2.4
60	2.9
70	3.5
80	4.1
90	4.7
100	5.2
110	5.6
120	6.0
130	6.3
140	6.6
150	6.8
160	6.9
170	7.0
180	7.0
190	6.6
200	5.8
210	4.5
220	2.5

3.9 EFFECT OF END CONDITIONS

Specimen Properties:

Cross-Section: 305 x 305 mm (12 x 12 in.)
 Length: 3810 mm (12 ft 6 in.)
 Aggregate: Siliceous
 Reinforcement: 2.19% as four No. 8 bars.

Elevation, Cross-Section and Finishing Detail: Figure 3.1.1
 Layout of Thermocouple Frames in Concrete: Figure 3.3.1
 Locations of Thermocouples in Frames: Figure 3.3.2
 Locations of Thermocouples on Reinforcing Bars: Figure 3.3.3

3.9.1 Series III, Column 1

Test purpose: Effect of end conditions: fixed-hinged.
 Date tested: December 3, 1985.
 Loading: 800 kN, Concentric.

Measured Properties:

Cylinder strengths: 35.2 MPa at 28 days.
 39.6 MPa on test date.
 Relative humidity: 60%.

Results:

Test duration: 4 hours 2 minutes.
 Temperatures: Tables 3.9.1 and 3.9.2.
 Axial deformations: Table 3.9.3

Observations

0:30 Hairline cracks on the S face were observed.
 1:40 Hairline cracks on the N face were observed.
 2:38 Cracks widened, some to 3 mm. Column started to contract.
 3:00 All cracks lengthened and widened.
 4:02 Sudden failure in compression (Figure 3.9.1).

3.9.2 Series III, Column 2

Test purpose: Effect of end conditions: fixed-hinged.
 Date tested: December 17, 1985.
 Loading: 1000 kN, Concentric.

Measured Properties:

Cylinder strengths: 35.2 MPa at 28 days.
39.3 MPa on test date.
Relative humidity: 64%.

Results:

Test duration: 3 hours 40 minutes.
Temperatures: Tables 3.9.4 and 3.9.5.
Axial deformations: Table 3.9.6

Observations

0:40 Hairline cracks on the S face were observed.
1:40 Hairline cracks on the N and W faces were observed.
2:10 Cracks widened, some to 3 mm. Column started to contract.
3:00 All cracks lengthened and widened.
3:40 Sudden failure in compression (Figure 3.9.2).

3.9.3 T Series, Column 3

Test purpose: Effect of end conditions: hinged-hinged.
Date tested: June 4, 1986.
Loading: 1022 kN, Concentric.

Measured Properties:

Cylinder strengths: 37.2 MPa at 28 days.
41.6 MPa on test date.
Relative humidity: 57%.

Results:

Test duration: 3 hours 41 minutes.
Temperatures: Tables 3.9.7 and 3.9.8.
Axial deformations: Table 3.9.9

Observations

2:10 Hairline cracks were visible on all sides; maximum expansion reached.
2:30 Contraction started.
3:41 Concrete had spalled at the edges of the top third, exposing the reinforcing bars (Figure 3.9.3). The column could no longer carry the load.



Figure 3.9.1 Series III Column 1 After Test

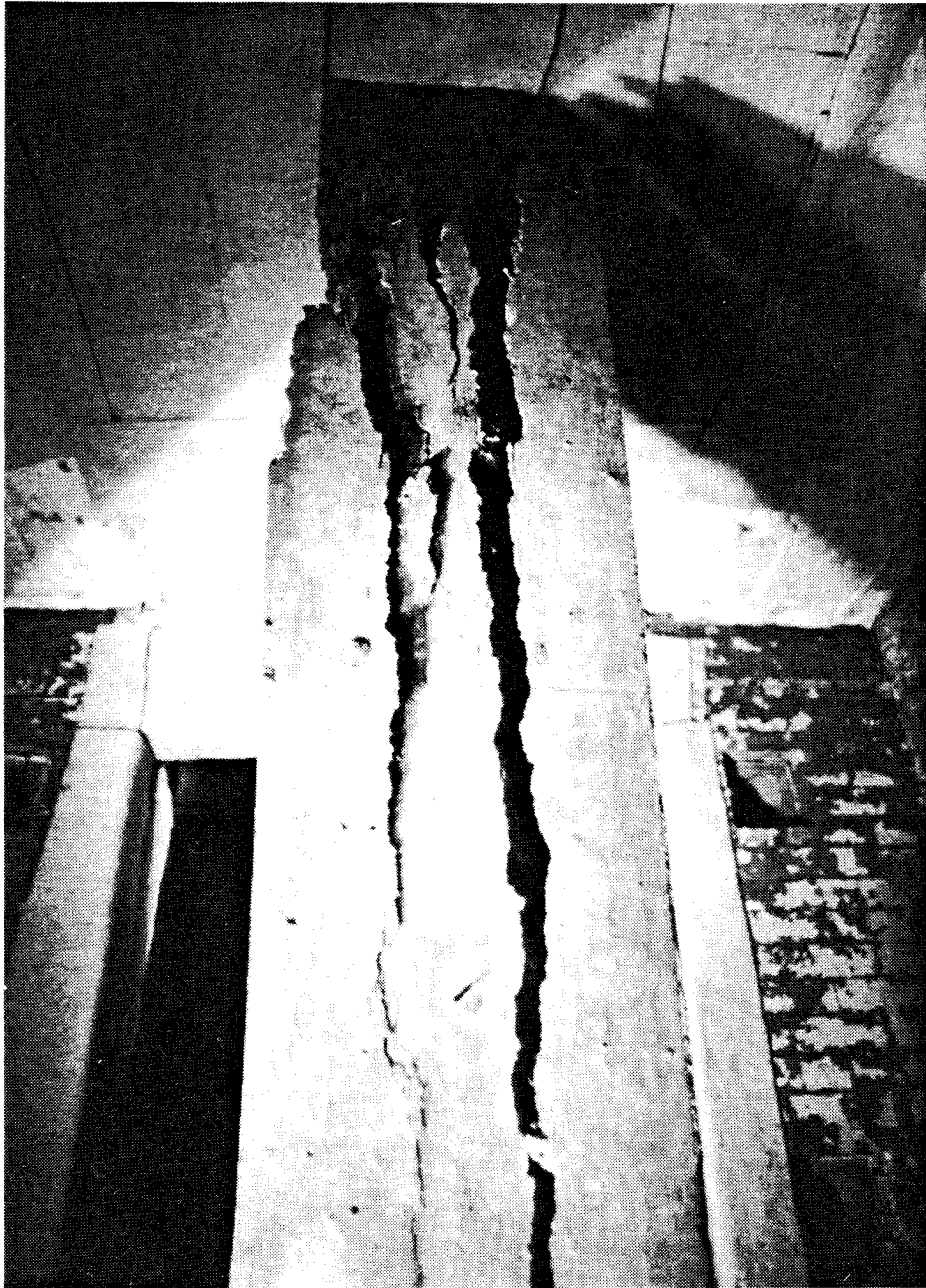


Figure 3.9.2 Series III Column 2 After Test

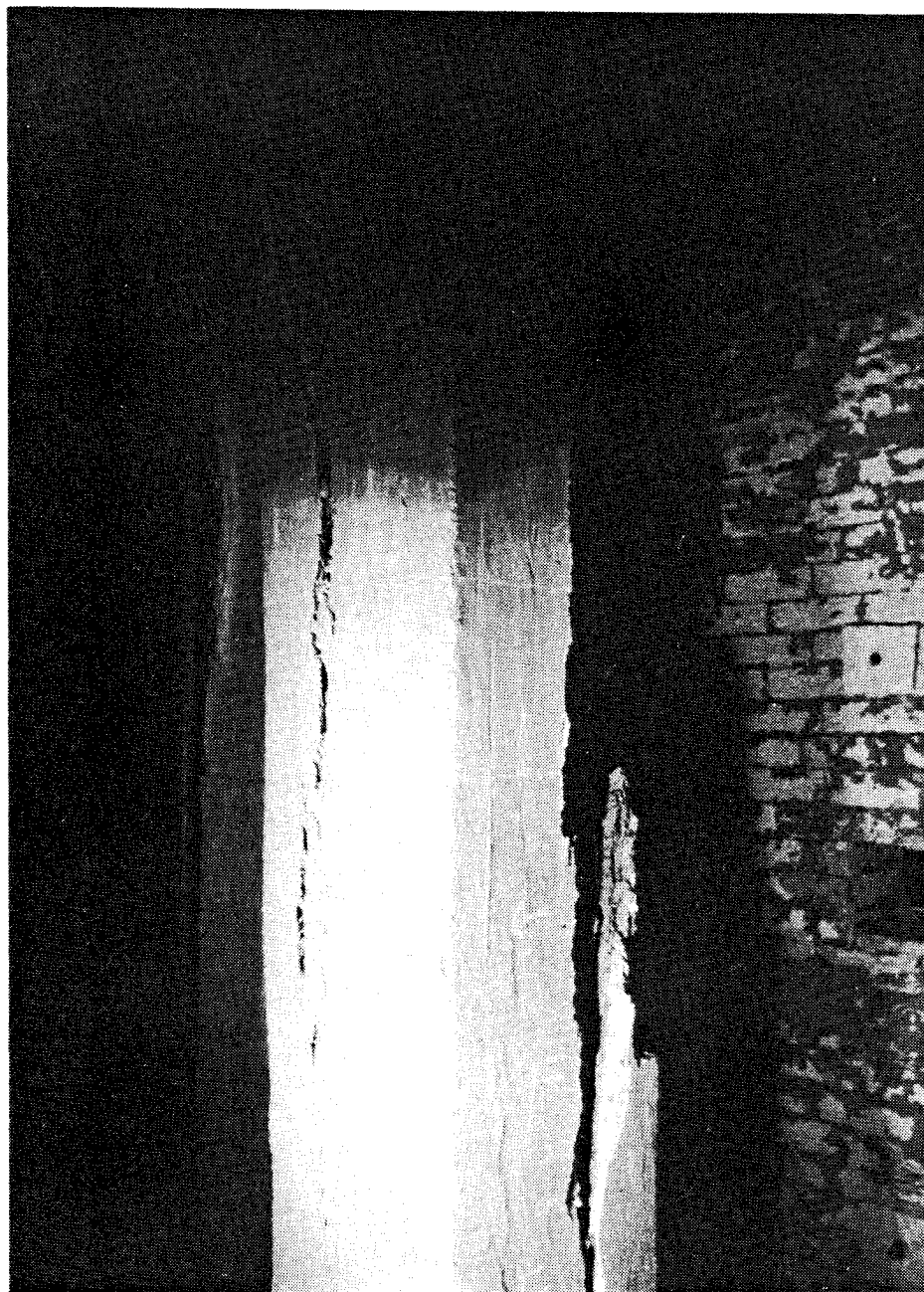


Figure 3.9.3 T Series Column 3 After Test

Table 3.9.1 Steel Temperatures, Series III Column 1

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace
	1	2	3	4	5	6	7	8	9	39	40	41	42	
0	19	17	11	10	1		15	22	11	11	10	11	11	153
5	23	21	15	16	6	1	26		14	14	15	17	14	595
10	40	39	33	36	27	16	57		28	26	32	36	28	688
15	87	79	85	76	66	47	103		75	62	74	91	72	747
20	109	110	107	106	111	105	130	114	102	101	106	108	99	785
25	113	113	111	111	111	109	144	125	110	109	111	114	110	817
30	129	128	126	116	124	106	181	139	116	108	112	130	114	849
35	150	150	146	134	141	118	219	162	132	120	130	151	130	859
40	174	175	167	154	162	135	252	177	152	135	151	173	149	879
45	201	200	190	174	184	155	280	192	173	152	172	197	170	892
50	228	225	214	196	207	176	306	209	196	172	193	221	192	905
55	254	250	238	219	230	199	329	229	218	192	216	245	214	916
60	278	273	262	242	252	223	351	246	241	215	239	269	236	929
70	324	317	307	288	293	269	390	309	285	259	285	314	280	946
80	365	357	349	331	331	312	424	340	326	302	327	355	320	961
90	402	394	387	372	367	352	455	380	365	342	367	393	358	976
100	436	428	423	410	400	388	484	409	401	379	404	429	393	983
110	468	461	457	445	430	423	510	444	436	414	439	463	427	1002
120	497	492	489	478	459	455	535	463	468	448	472	496	460	1007
130	524	520	518	508	487	487	559	385	498	480	503	526	490	1021
140	548	547	545	536	514	516	585	513	526	510	530	553	518	1026
150	573	574	573	564	540	542	610	525	552	537	557	582	543	1055
160	598	600	600	591	566	568	634	574	580	563	585	608	570	1053
180	646	649	651	646	617	618	677	622	631	618	637	657	622	1066
205	700	701	703	710	680	675	722	677	696	675	693	710	681	1075
220	726	725	712	735	713	706	728	702	712	705	725	709	705	1100
240	748	730	749	720	730	738	720	712	743	713	717	738	751	1111

Table 3.9.2 Concrete Temperatures, Series III Column 1

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0	14	12	11	10	11	11	12	11	11	11	11	11	15	18	153
5	117	85	47	25	13	11	12	11	12	23	64	90	155	211	595
10	206	157	98	58	23	12	12	12	20	65	135	171	281	366	688
15	298	228	146	99	42	15	12	16	44	109	204	264	396	489	747
20	385	300	189	128	69	22	15	36	84	138	277	350	479	575	785
25	455	361	237	155	95	34	22	66	97	172	340	418	542	639	817
30	514	414	280	188	108	54	30	64	102	231	398	478	604	704	849
35	556	457	318	219	119	72	40	70	110	282	451	529	653	736	859
40	592	493	351	249	137	83	53	78	122	324	496	574	693	764	879
45	622	522	382	276	158	90	64	88	137	359	533	615	724	787	892
50	647	548	410	301	177	97	73	101	154	390	567	650	750	807	905
55	669	571	434	324	194	103	83	109	172	418	600	679	773	825	916
60	691	594	457	344	210	111	93	116	192	442	629	706	795	842	929
70	726	633	498	383	241	126	107	131	230	484	679	749	830	849	946
80	756	665	533	418	270	140	111	146	268	519	716	780	857		961
90	782	694	564	451	297	154	122	166	304	551	747	809	880		976
100	804	720	595	481	322	170	134	191	338	581	774	835	897		983
110	827	744	623	509	348	193	149	215	370	609	797	855	912		1002
120	844	766	648	535	373	219	166	240	399	635	819	874	922		1007
130	865	788	673	560	398	245	189	266	428	659	838	890	930		1021
140	881	808	696	587	423	272	218	293	454	681	857	907	931		1026
150	897	826	717	612	448	300	246	319	479	702	872				1055
160	912	845	740	636	472	326	273	345	502	722	889				1053
180		875	779	681	519	379	325	395	548	759	916				1066
205		897	810	728	637	547	433	466	622	800					1075
220				737	712	657	611	601	691						1100
240					727	697	704	709	721						1111

Table 3.9.2 Concrete Temperatures, Series III Column 1
(continued)

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	25	26	27	28	29	30	31	32	33	34	35	36	37	38	
0	16	13	12	11	11	12	11	11	11	11	12	14	25	34	153
5	124	83	51	27	13	12	11	11	14	36	84	124	211	254	595
10	225	151	104	66	22	13	11	13	29	92	162	226	360	421	688
15	321	225	151	105	37	16	12	18	66	137	247	332	475	542	747
20	406	295	201	124	64	22	14	58	106	176	324	418	562	621	785
25	468	351	249	161	90	43	20	77	111	236	392	487	628	687	817
30	520	400	294	201	86	49	30	69	110	286	456	546	679	734	849
35	557	440	331	217	90	57	50	72	110	322	507	597	716	769	859
40	587	471	358	233	97	68	75	88	113	360	547	640	749	800	879
45	611	496	381	252	104	81	84	95	122	394	586	675	776	824	892
50	633	521	409	296	108	90	88	99	160	421	619	705	800	844	905
55	655	545	436	328	123	100	92	103	192	447	648	729		860	916
60	678	570	460	351	141	106	96	105	218	470	674	753		877	929
70	714	611	499	388	175	116	104	117	263	511	716	789		900	946
80	740	644	531	420	207	130	106	139	299	545	749	819		914	961
90		673	561	448	238	146	116	162	332	580	778	843		921	976
100		699	591	476	270	183	127	186	363	612	804	865		923	983
110		722	618	510	309	254	141	212	394	644	827	883		927	1002
120		742	644	560	372	333	165	240	424	672	847	899			1007
130		761	669	615	451	381	215	268	453	697	866	915			1021
140		778	744	653	513	392	291	296	481	721	884	929			1026
150		790	759	669	543	407	358	324	507	743	897	941			1055
160		799	770	679	556	428	401	351	532	763	914	954			1053
180			779	703	580	462	433	404	584	801	938	969			1066
205				734	618	511	468	486	643	839	942				1075
220				748	642	556	502	559	677						1100
240					782	730	715	658	712						1111

Table 3.9.3

Deflections, Series III Column 1

Minutes	Expansion, mm
0	0.0
10	1.3
20	3.8
30	4.6
40	5.0
50	5.7
60	6.8
70	7.8
80	8.9
90	9.8
100	10.6
110	11.2
120	11.5
130	11.5
140	11.6
150	11.3
160	10.7
170	10.0
180	9.2
190	8.2
205	7.7
210	5.6
220	3.6
230	1.0
240	-2.9

Table 3.9.4 Steel Temperatures, Series III Column 2

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace
	1	2	3	4	5	6	7	8	9	41	42	43	44	
0	0	-3	-4	-4	-6	-5	33	29	-4	-5	-4	-4	-4	173
5	3	2	1	1	0	0			-1	10	1	2	0	591
10	20	22	22	22	22	19			15		18	24	14	674
20	105	109	107	106	100	103	127	107	96	50	104	105	90	785
30	112	124	126	114	118	125	193	126	109	99	110	125	109	842
40	146	165	169	145	155	167	257	173	147	117	142	170	139	871
50	194	213	220	188	206	220	306	215	196	160	188	222	186	902
60	244	264	271	237	254	271	345	252	246	207	238	274	233	922
70	290	313	318	285	299	318	378	288	293	247	285	321	279	935
80	332	357	361	330	341	360	406	321	336	293	327	363	321	956
90	370	396	400	368	378	398	431	353	375	331	365	403	359	971
100	406	430	436	402	411	432	454	382	411	364	400	439	395	976
110	440	462	470	432	444	464	475	409	445	383	433	473	429	997
120	472	492	501	463	475	494	497	435	478	431	465	504	461	1002
130	502	520	530	493	505	520	520	461	507	443	495	532	491	1017
140	529	546	556	525	532	545	545	487	534	479	523	559	518	1029
150	556	574	584	552	557	569	569	512	559	518	549	587	542	1031
160	582	600	611	579	583	593	590	537	587	414	575	614	570	1046
170	608	626	636	605	609	617	610	561	613	313	602	640	597	1054
180	632	651	661	634	634	639	629	587	638	593	627	664	622	1060
190	656	675	684	665	657	660	646	611	661	631	652	687	646	1071
200	677	697	703	695	680	680	663	634	682	664	675	706	669	1078
220	717	728	720	729	720	714	677	679	704	712	716	722	700	1089

Table 3.9.5 Concrete Temperatures, Series III Column 2

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0	0	-2	-4	-4	-4	-4	-4	-4	-4	-4	-3	-2	1	5	173
5	82	55	16	6	-3	-4	-4	-4	-1	12	44	76	129	180	591
10	156	118	55	33	5	-4	-4	-3	12	57	116	161	240	320	674
20	307	237	133	102	35	5	-1	10	86	127	238	324	435	531	785
30	420	339	200	147	99	31	13	45	107	210	353	450	558	653	842
40	494	410	261	199	99	58	36	74	122	295	451	546	652	734	871
50	549	465	315	250	116	75	57	91	157	360	524	621	720	794	902
60	592	509	361	292	142	95	76	108	197	411	585	680	766	819	922
70	633	549	401	330	169	112	96	119	236	453	636	469	806		935
80	668	584	437	363	196	128	111	133	272	490	676	698	836		956
90	694	614	469	392	222	144	122	156	307	521	709	724	859		971
100	721	643	497	418	248	161	131	182	340	550	739	743	880		976
110	743	667	523	443	271	177	141	205	371	579	764	756	894		997
120	764	690	547	467	294	195	154	228	400	609	788	766	910		1002
130	786	713	571	491	319	216	173	252	428	637	809	771	926		1017
140	803	733	595	515	346	242	198	278	456	657	829	773	936		1029
150	823	755	620	539	374	270	227	305	482	680	847	774	949		1031
160	841	775	644	563	401	297	254	332	508	700	861		955		1046
170	859	794	666	587	428	324	284	359	532	721	876				1054
180	871	811	687	612	458	353	335	384	555	740	887				1060
190	881	827	705	640	517	403	469	409	581	758					1071
200			715	677	625	523	628	433	605	774					1078
220			730	722	719	683	722	518	656						1089

Table 3.9.5 Concrete Temperatures, Series III Column 2
(continued)

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	25	26	27	28	29	30	31	32	33	34	35	36	37	38	
0	4	0	-3	-4	-4						-3	-1	9	19	173
5	127	89	37	14	-1						62	18		226	591
10	232	170	96	54	9						142	206	338	378	674
20	411	320	191	124	66	5			75	155	288	376	537	588	785
30	524	418	278	185	96	21			81	242	417	500	662	714	842
40	594	486	353	252	101	58	30	68	106	329	502	590	530	717	871
50	648	541	409	306	120	78	55	87	138	395	571	662	741	748	902
60	686	583	451	350	145	96	76	106	178	455	631	713	771	773	922
70	721	619	486	386	172	99	104	112	212	489	677	752	779	781	935
80	752	650	517	417	201	114	114	136	247	518	708	779	780	788	956
90	774	673	544	443	223	121	111	149	280	542	740	805	789		971
100	796	698	569	466	244	145	123	169	305	568	766	834	792		976
110	816	719	592	491	270	158	125	188	329	588	784	850	795		997
120	834	741	618	518	300	194	134	205	359	625	799	863			1002
130	855	765	644	545	332	201	131	228	389	639	791	855			1017
140	871	785	669	574	366	230	181	295	438	649	830	877			1029
150	888	807	696	604	397	245	183	127	198	708	847	909			1031
160	905	817	711	630	427										1046
170	920		701	654	455										1054
180	931		712	677	482	355	321	383	547	767					1060
190	948		723	698	508	374	325	418	565	791					1071
200	956		732	718	532	407	350	433	587	790					1078
220			725	739	585	477	429	482	640	800					1089

Table 3.9.6

Deflections, Series III Column 2

Minutes	Expansion, mm
0	0.0
10	1.0
20	3.2
30	4.0
40	4.3
50	5.0
60	5.8
70	6.5
80	7.1
90	7.8
100	8.3
110	8.7
120	8.9
130	8.9
140	8.9
150	8.8
160	8.3
170	7.5
180	6.5
190	5.3
200	3.7
210	1.5
220	-2.3

Table 3.9.7

Steel Temperatures, T Series Column 3

Minutes	Temperature (°C) Measured at Thermocouple #:										Furnace
	1	2	3	4	5	6	7	8	9	10	
0	15	15	15	14	14	14	15	14	14	29	71
10	29	34	34	33	33	32	60	58	30	18	669
22	114	116	119	121	119	121	126	132	117		803
30	109	120	119	127	119	126	175	179	112	107	841
40	134	159	158	161	153	155	238	246	148	125	876
50	177	207	207	201	201	201	285	299	194	157	899
60	222	255	254	240	250	248	326	343	238	195	926
70	268	302	299	281	298	292	365	383	281	235	942
80	310	345	338	320	341	331	398	415	320	276	955
90	348	385	372	359	382	367	430	442	355	316	971
0	399	433	414	405	430	411	468	472	397	363	987
112	427	459	437	430	456	435	490	491	420	388	996
120	453	484	460	455	482		512	514	443	413	1007
135	501	525	502	500	525	505	549	555	485	458	1018
150	540	563	541	542	563		589	595	524	500	1057
164	576	599	577	579	599		631	631	557	536	1049
185	635	652	647	649	654	642	694	677	613	592	1061
200	667	683	694	693	692	679	723	707	648	628	1078
220	709	726	719	732	733	731	733	732	695	689	1092
221	713	728	733	753	733	733	736	733	696	692	1029

Table 3.9.8

Concrete Temperatures, T Series Column 3

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace
	11	12	13	14	15	16	17	18	19	20	21	22	23	
0	18	17	15	15	15	14	15	14	15	15	16	17	21	71
10	238	178	105	65	29	15	15	15	31	73	167	227	321	669
22	428	345	203	131	93	43	20	64	122	155	359	455	549	803
30	513	426	269	174	105	54	32	70	104	198	444	555	650	841
40	583	496	335	230	130	72	50	77	103	279	533	645	729	876
50	630	545	384	275	150	91	68	91	139	342	605	707	780	899
60	666	583	416	303	169	109	87	113	175	395	656	750	817	926
70	695	616	450	340	202	126	116	131	226	442	700	787	848	942
80	717	643	474	366	230	137	128	147	260	480	734	816	871	955
90	752	666	494	386	252	148	132	160	292	513	764	841	892	971
0	782	694	522	414	280	166	132	185	333	555	797	868	913	987
112	796	711	543	435	300	183	137	202	358	579	814	882	921	996
120	814	731	568	461	324	202	146	222	385	600	831	895	929	1007
135	844	768	614	507	367	240	181	262	428	638	859	917	940	1018
150	875	803	655	549	408	278	222	301	465	671	879	935		1057
164	894	832	691	589	444	314	258	336	500	702	898	954		1049
185	920	866	737	641	497	366	313	389	555	747	920	974		1061
200	940	889	766	673	529	401	354	423	588	773	934	985		1078
220		900	785	711	585	462	514	479	633	801	918			1092
221		898	786	700	587	464	518	479	633	801				1029

Table 3.9.9

Deflections, T Series Column 3

Minutes	Expansion, mm
0	0.0
10	0.9
22	3.0
30	3.2
40	3.5
50	4.2
60	5.0
70	5.6
80	6.3
90	3.6
98	7.2
108	7.6
120	7.8
128	7.9
140	7.9
150	7.9
158	7.6
168	6.9
178	6.1
190	4.8
200	3.2
210	1.0
220	-2.7
341	-4.2

3.10 EFFECT OF OTHER THAN STANDARD FIRE

Specimen Properties:

Cross-Section: 305 x 305 mm (12 x 12 in.)
 Length: 3810 mm (12 ft 6 in.)
 Aggregate: Siliceous
 Reinforcement: 2.19% as four No. 8 bars.

Elevation, Cross-Section and Finishing Detail: Figure 3.1.1
 Layout of Thermocouple Frames in Concrete: Figure 3.3.1
 Locations of Thermocouples in Frames: Figure 3.3.2
 Locations of Thermocouples on Reinforcing Bars: Figure 3.3.3

3.10.1 Series III, Column 4

Test purpose: Effect of high-intensity fire.
 Date tested: October 24, 1986.
 Loading: 1067 kN, Concentric.

Measured Properties:

Cylinder strengths: 37.1 MPa at 28 days.
 37.6 MPa on test date.
 Relative humidity: 45%.

Results:

Test duration: 5 hours 28 minutes.
 Temperatures: Tables 3.10.1 and 3.10.2.
 Axial deformations: Table 3.10.3

Observations

2:15 Hairline cracks 7 to 20 cm long visible on all sides; maximum expansion.
 2:45 Contraction began.
 3:30 Large cracks (6 to 13 mm wide) visible on three sides.
 4:45 Large cracks (6 to 30 mm wide and up to 45 cm long) visible on all sides.
 5:27 Concrete had spalled at the edges of the top third, exposing the reinforcing bars (Figure 3.10.1). Column could no longer maintain the applied load.

3.10.2 Series III, Column 13

Test purpose: Room-temperature crush to check column strength.
 Date tested: September 24, 1986.
 Loading: to failure at 3833 kN, Concentric.

Measured Properties:

Cylinder strengths: 38.5 MPa at 28 days.
40.7 MPa on test date.
Relative humidity: 60%.

Results:

Column failure occurred at the top bearing plate, as the top 30 cm of the column did not have ties. The failure mechanism was pure compression. (Figure 3.10.2).

3.10.3 T Series, Column 1

Test purpose: Residual strength after 1-hour fire.
Date tested: January 21, 1985.
Loading during fire: 993 kN, Concentric.

Measured Properties:

Cylinder strengths: 37.1 MPa at 28 days.
37.6 MPa on test date.
Relative humidity: 87%.

Results:

Failure Load: 2671 kN.
Temperatures: Tables 3.10.4 and 3.10.5.
Axial deformations: Table 3.10.6

Observations

Fire test:

0:57 Small hairline cracks on all faces and one vertical crack 25 cm long visible.
1:00 Controlled, linear cooling began.
1:50 Additional cracks on S face, full-length and transverse cracks on E face.
2:00 Additional cracks on all faces, all still less than 2 mm wide.
2:10 S face cracks widened to 3 mm, one 40 cm long; checkerboard cracking.
2:50 Extensive 3 mm cracking on E face, predominantly horizontal.

Load test after 24 hours: failure in compression at 2671 kN, characterized by sudden violent noise and expulsion of concrete. All bars buckled outward (Figure 3.10.3).

3.10.4 T Series, Column 2

Test purpose:	Residual strength after 2-hour fire.
Date tested:	May 22, 1985.
Loading during fire:	1022 kN, Concentric.

Measured Properties:

Cylinder strengths:	35.3 MPa at 28 days.
(concrete only)	41.8 MPa on test date.
Relative humidity:	82%.

Results:

Failure Load:	1987 kN.
Temperatures:	Tables 3.10.7 and 3.10.8.
Axial deformations:	Table 3.10.9

The column failed in compression at 1728 kN.

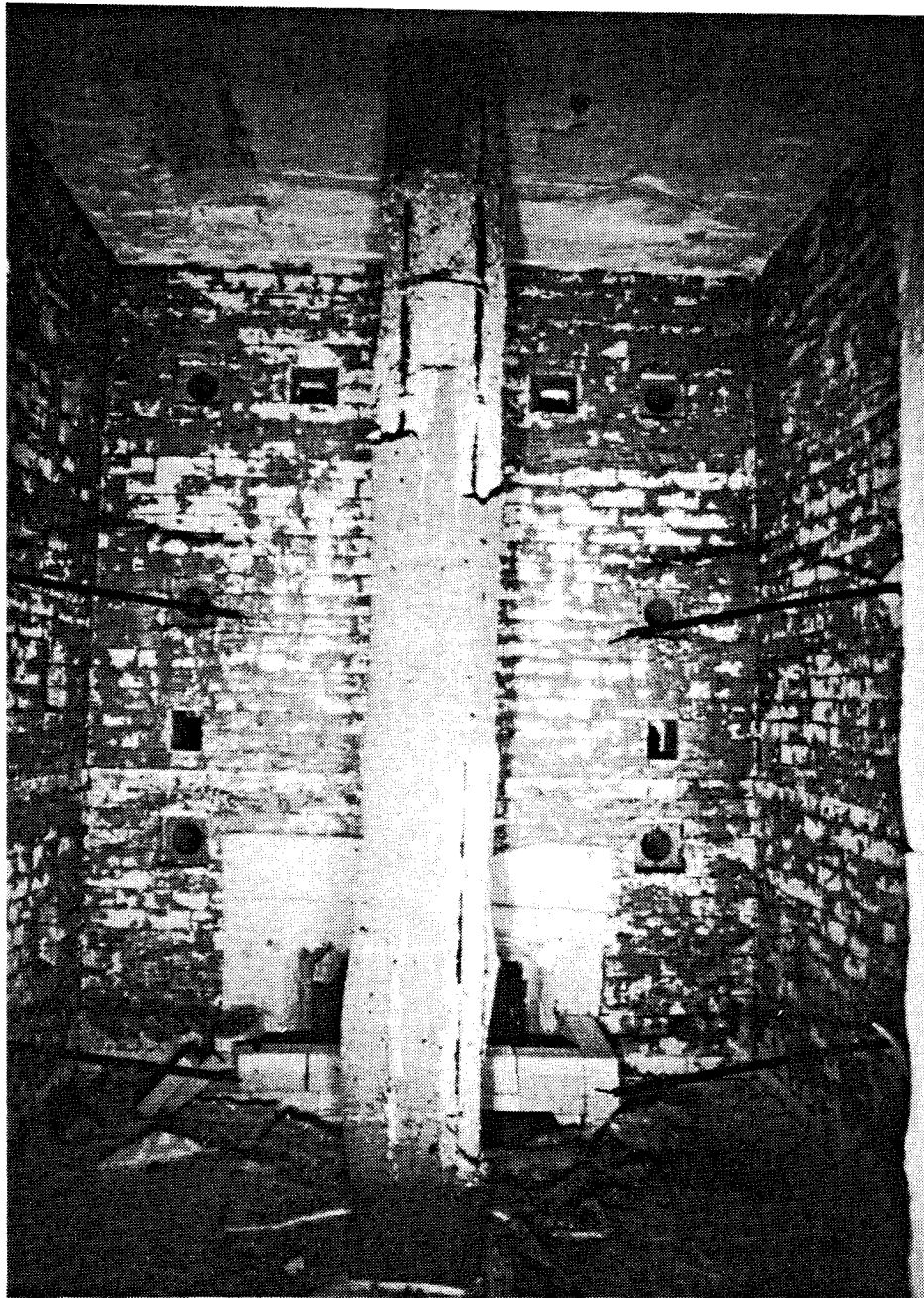


Figure 3.10.1 Series III Column 4 After Test

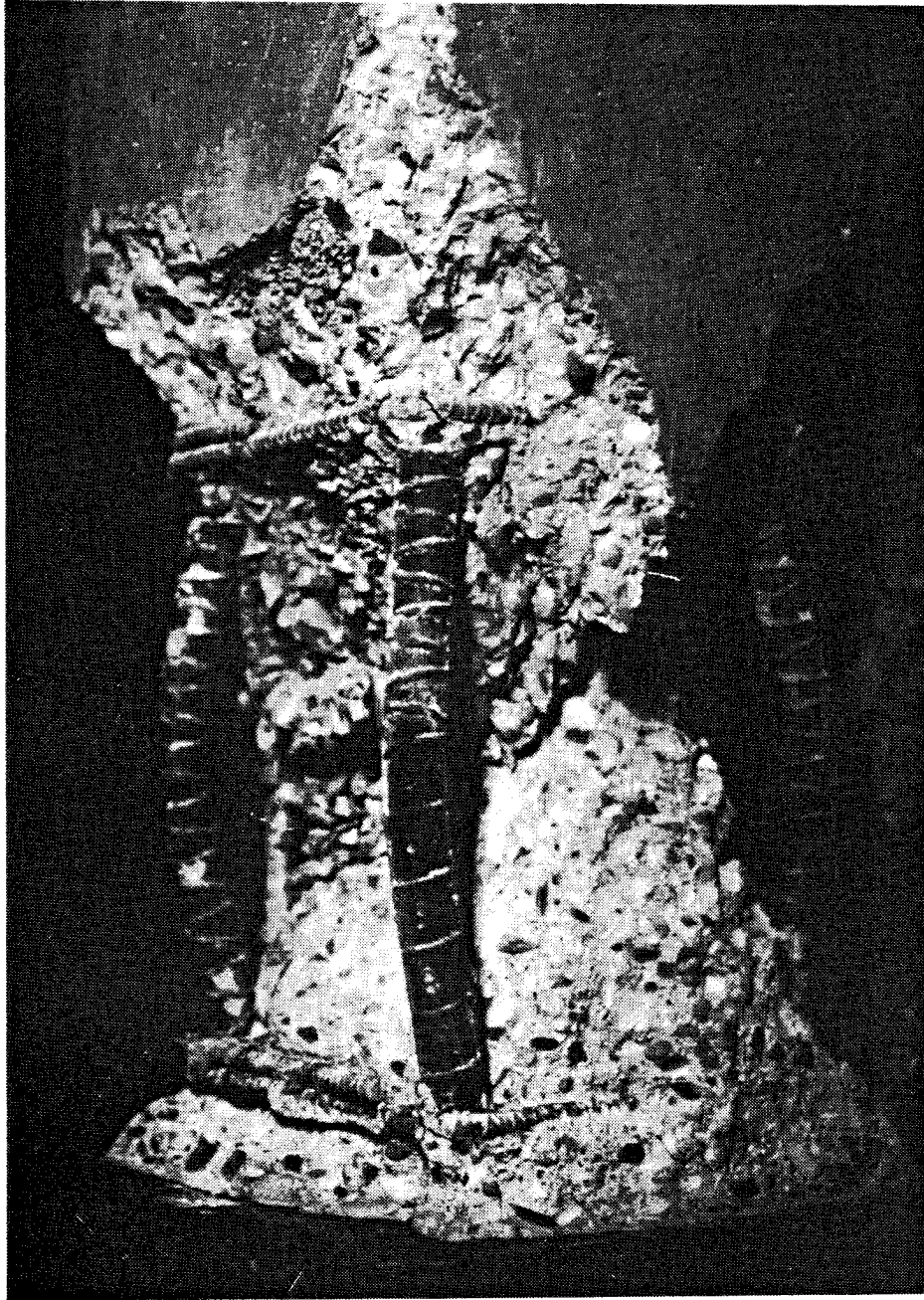


Figure 3.10.2 Series III Column 13 After Test

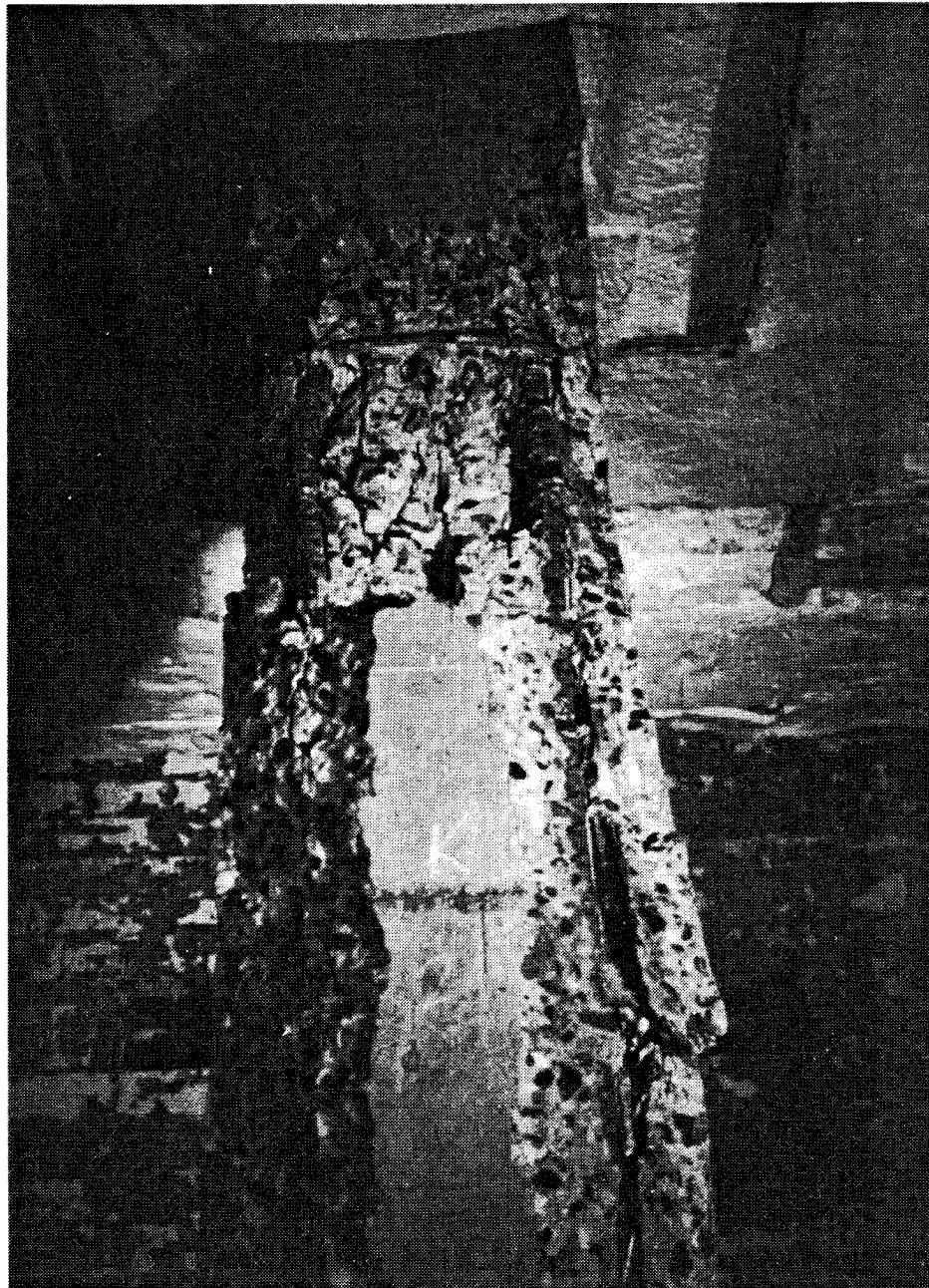


Figure 3.10.3 T Series Column 1 After Test

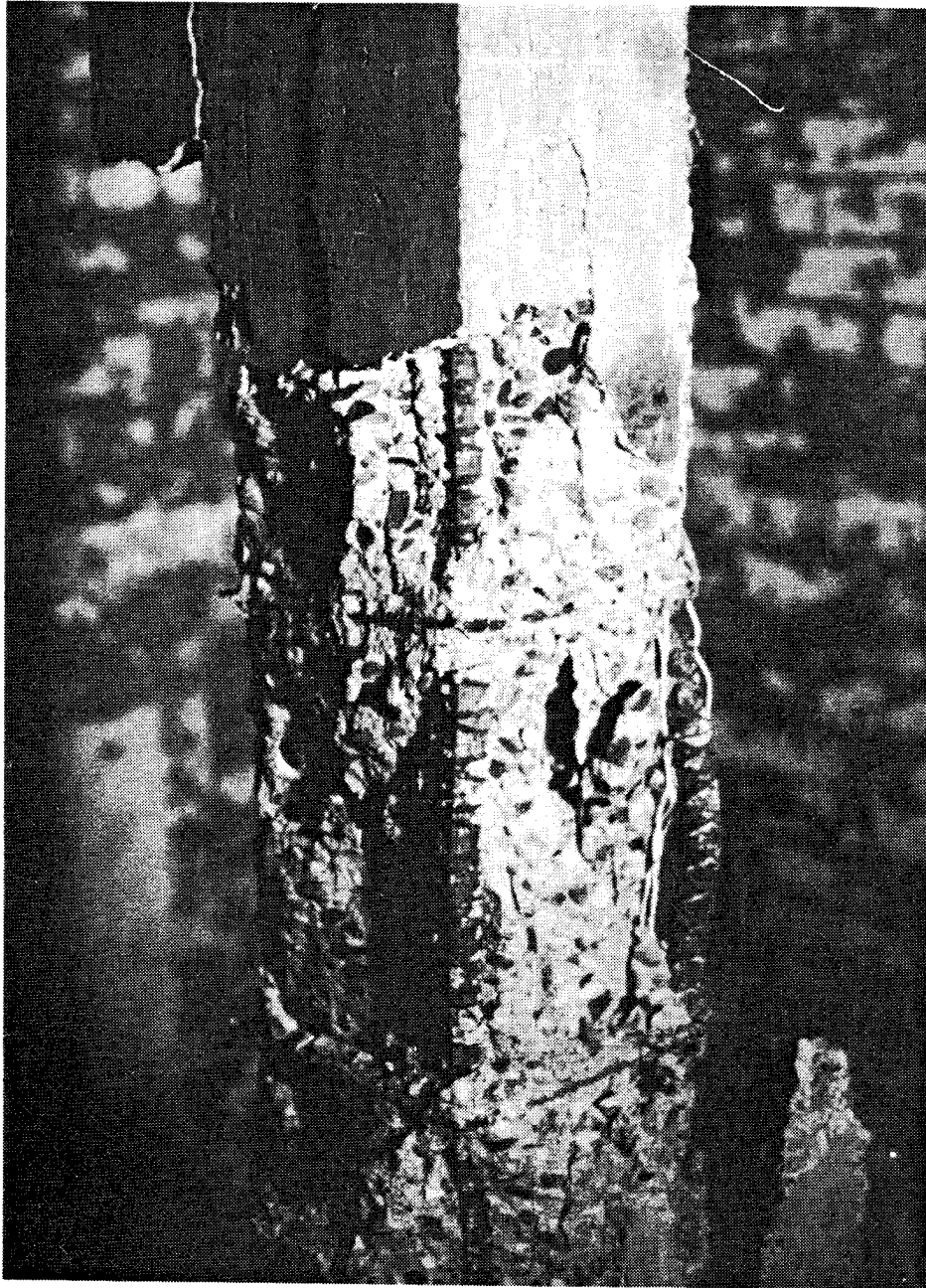


Figure 3.10.4 T Series Column 2 After Test

Table 3.10.1 Steel Temperatures, Series III Column 4

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace
	1	2	3	4	5	6	7	8	9	10	42	43	44	
0	19	19	19	19	18	19	19	23	15	19	19	19	18	179
5	22	22	22	22	21	20	30	21	18	21	22	23	32	775
10	37	47	70	63	49	45	74		36	33	55	76	70	953
20	101	102	101	99	101	95	128		101	90	101	102	133	1086
30	128	144	135	137	133	114	205	117	131	113	135	149	199	1109
40	176	204	188	199	195	158	265	155	185	157	193	206	255	1135
50	229	256	241	256	255	208	313	230	239	206	249	260	301	1165
60	278	306	289	306	309	256	323	249	289	253	298	307	341	1188
70	321	348	332	348	355	298	387	291	333	297	341	348	377	1199
80	358	384	368	386	393	336	416	329	371	337	379	384	409	1199
90	392	417	400	420	427	370	443	362	404	373	413	414	436	1203
100	422	446	429	450	456	399	466	391	434	406	444	442	461	1199
110	450	472	455	478	483	426	487	417	461	435	472	467	484	1200
120	476	496	479	502	507	451	505	443	485	462	497	491	505	1202
140	521	536	522	544	549	496	538	487	527	507	539	532	542	1190
160	558	569	558	579	584	534	567	526	562	544	574	567	574	1197
180	588	598	589	608	614	567	593	561	590	575	604	597	601	1199
200	614	623	615	634	641	595	617	590	615	601	631	623	626	1196
220	639	646	639	659	666	619	639	615	637	625	659	645	649	1198
240	664	668	660	683	690	640	659	636	660	649	685	666	670	1200
260	688	686	679	701	711	662	676	657	685	670	685	686	690	1201
280	710	700	700	703	719	711	694	704	715	687	699	739	703	1199
300	735	708	730	708	720	735	703	741	739	707	707	759	711	1203
320	758	725	734	717	726	738	731	736	778	720	715		714	1198
327	789	743	737	723	733	743	870		796	729	721		719	1191

Table 3.10.2

Concrete Temperatures, Series III Column 4

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace
	11	12	13	14	15	16	17	18	19	20	21	22	25	
0	22	21	20	19	19	19	20	19	19	19	19	20	23	179
5	178	109	24	33	21	19	20	19	20	31	69	116	195	775
10	424	255	139	91	33	21	19	20	43	102	171	290	446	953
20	658	469	281	175	86	42	22	38	89	202	386	559	633	1086
30	726	561	379	258	110	72	35	60	106	336	524	670	705	1109
40	774	617	442	315	138	91	54	83	148	422	603	731	756	1135
50	816	658	490	361	167	107	72	110	195	478	654	777	797	1165
60	854	692	529	401	199	128	95	133	240	518	691	819	833	1188
70	883	820	561	436	229	147	112	153	280	547	718	852	862	1199
80	887	743	587	466	257	165	119	170	315	568	741	878	887	1199
90	895	762	609	492	283	182	133	188	347	586	761	899	908	1203
100	905	777	627	514	308	201	156	210	377	602	778	921	922	1199
110	920	793	645	534	334	224	160	235	405	618	798	942	938	1200
120	931	806	660	552	359	249	176	260	432	634	816	959	950	1202
140	950	830	688	585	406	297	215	310	480	665	845	988	970	1190
160	969	851	712	613	449	344	267	357	519	691	870	1007	988	1197
180	982	869	734	638	486	388	316	400	552	713	892	1013	1002	1199
200	996	888	755	661	518	427	359	438	581	730	910		1016	1196
220	1006	904	775	682	546	462	398	473	610	734	927		1025	1198
240	1014	918	794	700	569	493	433	579	692	746				1200
260	1006	916	806	704	594	525	492	754	759	774				1201
280				713	639	580	540	804	792	783				1199
300				795	688	663	650							1203
320					721	717	709							1198
327						735	725							1191

Table 3.10.3

Deflections, Series III Column 4

Minutes	Expansion, mm
0	0.0
10	1.0
20	2.1
30	2.3
40	3.0
50	3.8
60	4.5
70	5.2
80	5.8
90	6.4
100	6.8
110	7.0
120	7.2
130	7.3
140	7.3
150	7.3
160	7.3
170	7.0
180	6.5
190	6.0
200	5.1
210	4.1
220	3.0
230	1.7
240	0.3
250	-1.2
260	-2.9
270	-4.6
280	-6.5
290	-8.3
300	-10.3
310	-12.5
320	-14.8
327	-18.4

Table 3.10.4 Loads and Deflections, Series III Column 13

Minutes	Load kN	Deflection* mm
0	444	0.0
10	667	0.6
20	889	1.5
30	1111	2.2
40	1333	2.9
50	1556	3.6
60	1778	4.2
70	2000	4.8
80	2222	5.7
90	2444	6.2
100	2667	6.7
110	2889	7.2
120	3111	7.8
130	3333	8.6
140	3556	9.2
150	3778	10.0
154	3867	20.8

* Compression positive

Table 3.10.5

Steel Temperatures, T Series Column 1

Hours	Temperature (°C) Measured at Thermocouple #:									Furnace
	1	2	3	4	5	6	7	8	9	
0.0	22	22	21	21	19	19	21	19	21	84
0.3	114	125	117	106	109	101	126	126	107	781
0.7	155	146	150	131	157	153	221	227	132	875
1.0	255	238	237	203	248	249	329	327	213	921
1.3	333	319	320	282	322	328	397	387	297	740
1.7	380	366	373	335	362	370	410	400	354	585
2.0	399	384	388	359	377	377	395	388	375	419
2.3	397	380	379	361	370	362	370	365	371	270
2.7	381	362	357	348	351	335	338	336	353	116
3.3	328	308	302	304	297	272	281	286	303	60
3.8	297	278	273	277	268	242	258	262	275	47
4.2	273	255	250	255	245	217	239	243	253	40
5.0	235	220	215	221	209	181	209	211	218	39
5.8	206	194	189	195	182	152	185	186	192	35
6.3	194	183	179	184	170	140	175	176	181	34
7.5	164	156	152	156	141	109	150	147	154	29
8.3	148	141	136	140	122	93	135	130	138	27
9.2	133	127	123	126	107	80	122	116	124	25
10.0	120	115	110	113	96	71	110	105	112	29
15.0	71	69	66	67	58	46	66	63	66	26
20.0	49	47	45	45	40	34	45	43	45	23
24.0	39	38	35	36	33	29	36	34	35	25
25.0	38	36	33	34	31	29	35	32	33	25
26.3	37	34	32	33	30	28	33	30	32	23

Table 3.10.6 Concrete Temperatures, T Series Column 1

Hours	Temperature (°C) Measured at Thermocouple #:														Furnace
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0.0	22	20	20	19	20	20	20	20	20	20	20	21	25	26	84
0.3	369	266	170	126	76	30	23	55	107	136	303	406	492	445	781
0.7	558	436	306	207	103	71	53	94	125	247	507	613	701	135	875
1.0	655	536	404	273	120	97	86	106	196	366	644	734	794	583	921
1.3	618	548	453	356	178	116	119	127	279	448	677	725	709	431	740
1.7	525	493	438	368	226	143	128	169	328	472	614	628	608	199	585
2.0	438	434	404	369	255	175	141	205	348	457	529	521	801		419
2.3	367	373	367	350	280	211	174	239	356	423	444	425	847		270
2.7	298	317	329	329	294	244	215	268	349	379	361	332	777		116
3.3	233	250	268	280	288	277	266	287	304	291	246	223	711		60
3.8	212	228	245	258	275	279	277	282	278	254	207	187	415		47
4.2	195	210	227	239	261	274	277	273	256	227	180	163			40
5.0	171	183	198	209	233	251	258	246	220	189	146	133			39
5.8	154	164	175	185	207	225	232	219	194	166	127	116			35
6.3	146	156	166	175	195	212	219	207	183	156	120	110			34
7.5	125	133	141	149	164	177	183	173	154	132	103	95			29
8.3	113	120	127	133	147	158	163	154	138	118	93	85			27
9.2	103	108	114	120	132	141	145	138	124	107	84	78			25
10.0	94	99	104	108	118	126	129	123	111	97	78	72			29
15.0	58	60	62	64	68	71	72	70	65	58	51	48			26
20.0	41	42	43	43	45	47	47	46	44	41	38	36			23
24.0	33	34	34	34	35	36	37	36	35	33	31	31			25
25.0	32	32	32	33	34	34	35	34	33	32	31	30			25
26.3	30	30	31	31	32	33	33	32	32	30	29	28			23

Table 3.10.7 Loads and Deflections, T Series Column 1

Hours:Minutes	Loads kN	Expansion mm
0:00	992	0.0
0:12	992	0.9
0:20	992	2.2
0:30	992	2.7
0:40	992	3.1
0:50	992	3.7
1:00	992	4.5
1:30	992	5.7
2:00	992	6.0
2:30	992	6.0
2:56	992	5.4
4:10	992	3.2
5:00	992	2.0
6:15	992	0.4
7:05	992	-0.6
8:20	992	-1.7
10:00	992	-2.9
12:05	992	-3.9
14:10	992	-4.5
16:15	992	-5.1
18:20	992	-5.4
22:05	992	-5.7
24:00	1009	-6.2
24:15	1196	-6.8
24:30	1384	-7.5
24:45	1571	-8.2
25:00	1759	-8.9
25:15	1946	-9.6
25:30	2134	-10.4
25:45	2321	-11.2
26:00	2509	-12.0
26:13	2671	-13.0

Table 3.10.8

Steel Temperatures, T Series Column 2

Hours	Temperature (°C) Measured at Thermocouple #:										Furnace
	1	2	3	4	5	6	7	8	9	10	
0.0	18	18	18	17	16	17	18	17	16	17	59
0.2	39	37	35	41	40	32	59	72	34	30	612
0.3		118	94	121	119	121	128	128	112	113	800
0.5	112	115	71	109	112		171	188	111	108	859
0.7	158	144	89	146	150		256	252	136	127	895
0.8	215	193	109	195	201	186	317	305	173	172	925
1.0	269	244	154	247	254	233	364	350	218	222	931
1.2	318	290	173	295	304	278	402	390	265	269	935
1.5		370	318	376	387	356	460	455	347	348	970
1.8	479	435	128	441	457	423	511	513	415	413	1000
2.0	500	465	103	472	489	456	533	538	447	443	1010
2.2	528	494	140	501	517	486	555	562	478	473	959
2.5	570	542	317	547	563	535	587	594	528	523	883
2.8	596	574	334	577	592	569	600	606	560	556	811
3.0	602	584	329	586	599	580	600	605	569	568	764
4.0	594	582	451	581	584	580	570	565	565	575	486
5.0	545	528	243	520	515	520	501	487	500	522	256
6.0	471	452	134	439	426		419	398	404	445	76
7.0	389	377	118	364	350	368	351	334	335	371	56
8.0	332	324	110	312	300		301	287	286	318	46
9.0	290	283	93	272	262		262	250	246	278	42
10.0	256	249	84	239	230		230	219	213	244	39
15.0	143	141	56	129	123	130	126	120	110	131	31
20.0	87	85	42	77	69		75	72	64	78	24
25.0	60	58	35	52	46	52	53	49	43	53	29
26.0	56	54	34	49	44	49	50	46	41	50	28
27.2	53	51	46	46	42	46	48	44	39	46	27

Table 3.10.9 Concrete Temperatures, T Series Column 2

Hours	Temperature (°C) Measured at Thermocouple #:														Furnace
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0.0	20	19	18	17	17	17	17	17	17	17	18	19	21	22	59
0.2	221	164	103	67	28	18	17	18	26	77	144	186	281	302	612
0.3	389	309	183	127	93	33	21	37	102	125	272	344	448	487	800
0.5	506	419	267	176	93	56	35	72	108	111	380	473	577	635	859
0.7	584	495	342	243	99	71	56	72	107	247	471	569	675	729	895
0.8	639	553	402	303	125	87	72	88	138	313	550	647	741	735	925
1.0	680	603	451	350	151	104	87	97	179	363	616	705	785	764	931
1.2	701	631	487	387	186	122	106	103	220	405	662	738	805	771	935
1.5	755	684	543	440	225	145	124	144	288	472	725	741	833	789	970
1.8	800	725	590	484	268	179	135	176	339	530	774	766	797	795	1000
2.0	819	744	613	507	295	200	146	202	367	562	786	774	788	795	1010
2.2	813	752	633	531	327	226	168	267	399	606	782	774	756	782	959
2.5	780	737	647	566	389	281	224	453	486	675	762	738	753	788	883
2.8	730	704	642	582	435	332	278	519	558	684	738	699	734	710	811
3.0	705	685	635	584	454	356	303	528	574	678	723	685	717	698	764
4.0	552	561	566	559	513	458	422	467	558	595	605	608	603	609	486
5.0	429	447	475	493	505	497	486	484	520	506	538	477	596	549	256
6.0	323	345	387	418	463	487	495	470	460	407	323	168	492	314	76
7.0	272	291	327	355	409	446	463	427	392	329	81	56	121	364	56
8.0	237	252	283	307	357	394	412	376	337	278	44				46
9.0	209	222	248	268	312	343	360	328	293	241					42
10.0	186	196	218	235	272	299	313	285	256	210					39
15.0		111	120	127	143	153	158	147	136	114					31
20.0		66	71	74	82	87	90	84	79	68					24
25.0			50	51	54	56	57	55	54	49					29
26.0			48	48	51	53	54	52	51	47					28
27.2			45	46	48	49	50	48	47	44					27

Table 3.10.10 Loads and Deflections, T Series Column 2

Hours:Minutes	Loads kN	Expansion mm
0:00	1022	0.0
0:15	1022	1.2
0:30	1022	2.3
0:30	1022	2.3
0:45	1022	2.8
1:00	1022	4.0
1:15	1022	4.6
1:30	1022	5.6
2:00	1022	6.5
2:30	1022	6.5
3:00	1022	5.6
3:30	1022	4.3
4:00	1022	2.2
4:30	1022	-0.6
5:00	1022	-2.9
6:00	1022	-6.6
7:00	1022	-9.9
8:00	1022	-12.6
9:00	1022	-14.7
10:00	1022	-16.4
12:00	1022	-19.0
14:00	1022	-20.8
16:00	1022	-22.0
20:00	1022	-23.9
24:00	1022	-24.5
25:45	1022	-24.8
26:00	1125	-26.3
26:15	1312	-27.1
26:30	1500	-28.1
26:45	1687	-29.0
27:00	1875	-30.1
27:09	1987	-32.3

3.11 EFFECT OF ECCENTRIC LOADING, REGULAR SECTIONS

Specimen Properties:

Cross-Section: 305 x 305 mm (12 x 12 in.)
 Length: 3810 mm (12 ft 6 in.)
 Aggregate: Siliceous
 Reinforcement: 2.19% as four No. 8 bars.

Elevation, Cross-Section and Finishing Detail: Figure 3.1.1
 Layout of Thermocouple Frames in Concrete: Figure 3.3.1
 Locations of Thermocouples in Frames: Figure 3.3.2
 Locations of Thermocouples on Reinforcing Bars: Figure 3.3.3

The columns were offset by 0.96" (25 mm) in the furnace, so that the loads were eccentric toward the back (west).

3.11.1 Series III, Column 3

Test purpose: Effect of eccentric loading.
 Date tested: June 19, 1987.
 Loading: 1000 kN, Eccentric at 25 mm from centre.

Measured Properties:

Cylinder strengths: 35.7 MPa at 28 days.
 39.9 MPa on test date.
 Relative humidity: 56%.

Results:

Test duration: 3 hours 1 minute.
 Temperatures: Tables 3.10.1 and 3.10.2.
 Axial deformations: Table 3.10.3

Figure 3.11.1 shows the column after the test.

3.11.2 Series III, Column 14

Test purpose: Effect of eccentric loading, dryness.
 Date tested: December 11, 1987.
 Loading: 1178 kN, Eccentric at 25 mm from centre.

Measured Properties:

Cylinder strengths: 40.0 MPa at 28 days.
 37.9 MPa on test date.
 Relative humidity: 25%.

Results:

Test duration: 3 hours 3 minutes.
Temperatures: Tables 3.10.4 and 3.10.5.
Axial deformations: Table 3.10.6

Observations

0:30 Small hairline cracks developed on the E and S faces.
1:00 These cracks increased to 3 mm.
1:30 3 mm cracks on E, S, and N faces; hairline crack near edge of W face.
2:00 More cracks developed, size constant.
2:15 First cracks opened to 6 mm; most still 3 mm.
2:30 Cracks lengthen on N and E faces.
2:45 Cracks on N and E faces 13 mm wide; W face still less than 3 mm.
2:56 25 mm cracks on E and N faces; 3 mm on W and S faces.

Figure 3.11.2 shows the column after the test.

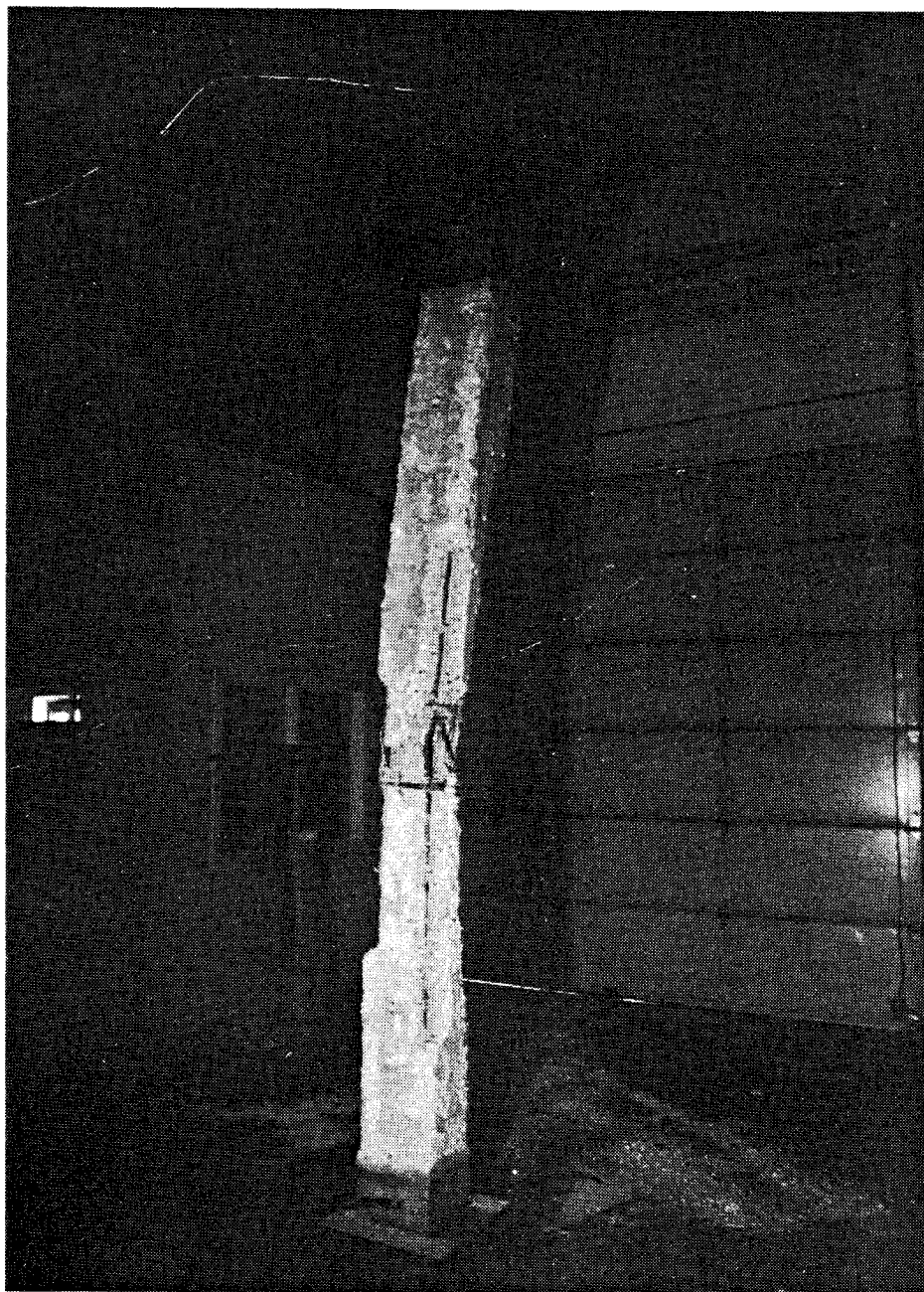


Figure 3.11.1 Series III Column 3 After Test

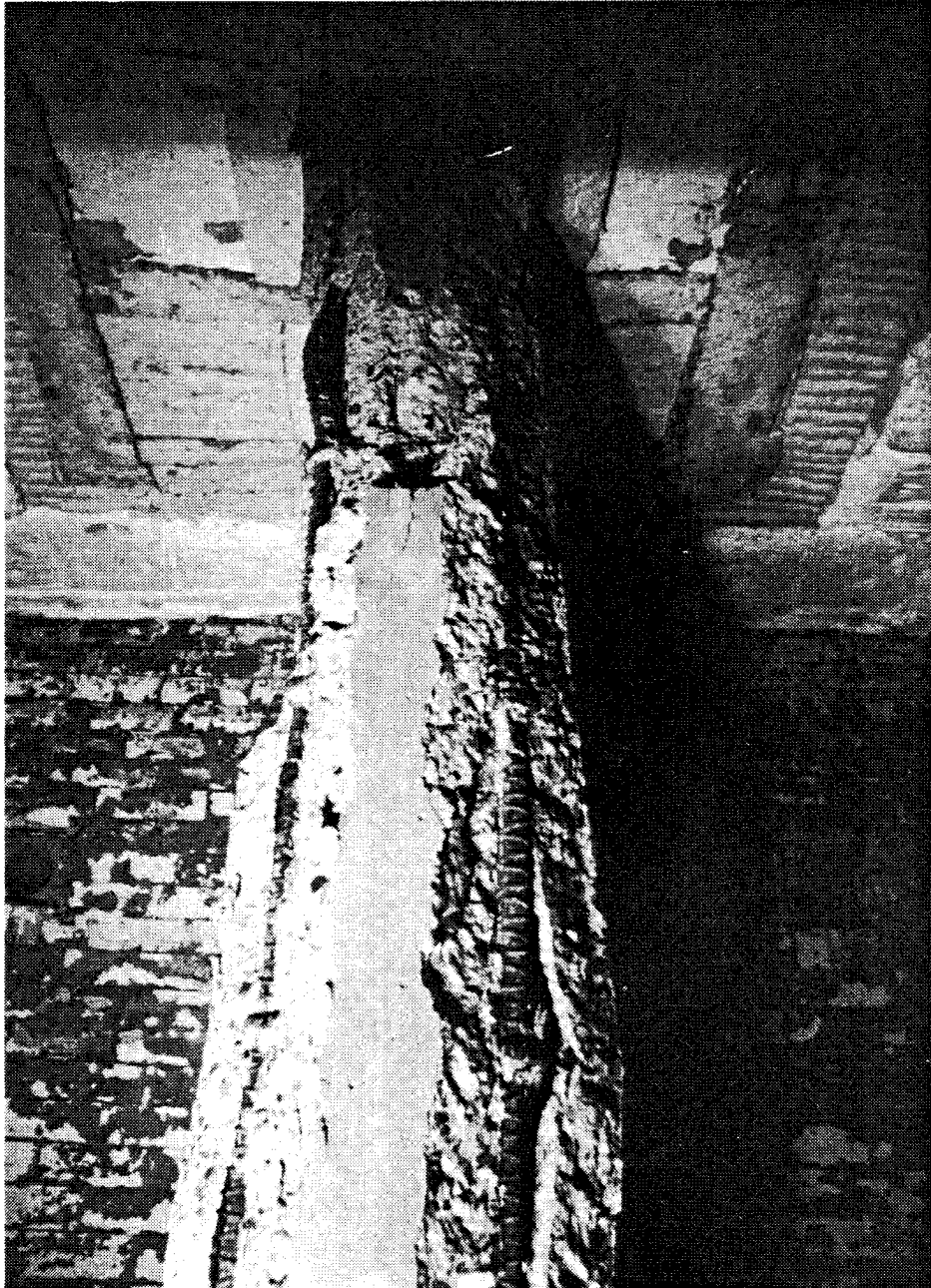


Figure 3.11.2 Series III Column 14 After Test

Table 3.11.1 Steel Temperatures, Series III Column 3

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	1	2	3	4	5	6	7	8	9	10	41	42	43	44	
0	23	23	26	23	23	25	23	25	25	27	24	23	22	24	71
5	28	29	26	24	27	23	33	31	23	25	20	26	24	25	574
10	44	45	41	36	37	39	64	64	35	33	12	33	23	35	687
15	83	81	85	70	70	82	103	108	69	57	-25	54	25	67	742
20	106	105	107	106	106	110	137	139	99	98	106	90	25	95	789
25	116	117	118	114	112	126	170	174	112	110	114	104	26	110	818
30	139	139	142	124	121	148	207	213	123	116	123	112	36	119	842
35	163	163	162	144	139	171	241	244	144	130	144	122	77	135	859
40	188	189	190	168	164	196	273	277	169	151	166	140	197	158	878
45	214	216	214	192	186	222	299	304	192	173	190	163	223	178	890
50	240	242	237	215	210	248	323	329	215	195	210	182	247	202	901
55	266	268	260	236	234	271	344	349	237	216	234	202	272	226	918
60	290	291	288	257	262	294	366	370	261	235	255	222	294	247	928
65	312	313	308	278	282	318	380	390	280	256	272	239	316	269	938
70	333	332	327	297	301	336	394	404	300	275	293	258	336	289	945
75	353	355	344	316	323	353	408	422	319	293	309	276	352	309	953
80	370	368	361	332	336	367	421	432	333	311	327	293		326	962
90	405	400	393	363	369	399	445	456	367	343	357	325		358	972
100	433	428	420	389	393	426	471	480	397	372	389	351		390	986
110	459	455	446	414	417	450	492	500	423	399	418	381		413	995
120	475	478	468	436	437	469	510	519	447	418	433	401		434	1006
130	498	503	493	460	461	495	533	534	467	447	459	423		456	1036
140	519	515	511	479	481	508	544	554	485	465	480	447		478	1032
150	535	532	528	499	504	523	562	563	507	484	501	470		498	1040
160	551	550	542	519	518	538	574	576	524	502	516	491		516	1027
170	565	564	561	539	536	554	588	589	541	520	536	506		537	1051
180	576	577	575	550	550	563	595	601	552	535	551	523		550	1085

Table 3.11.2 Concrete Temperatures, Series III Column 3

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0	29	23	27	24	24	27	24		26	26	26	24	29	27	71
5	124	78	47	34	28	24	27		25	34	71	100	134	186	574
10	241	152	98	63	32	26	24		30	83	155	202	269	355	687
15	342	221	146	102	41	29	24	47	46	132	232	300	386	474	742
20	431	291	189	137	62	33	25	53	78	169	309	391	478	565	789
25	500	351	235	162	89	40	27	67	98	223	380	461	550	627	818
30	554	405	277	192	107	64	38	77	108	276	441	511	599	671	842
35	593	445	316	223	109	77	49	85	112	323	493	552	637	700	859
40	625	479	347	251	112	83	58	92	120	361	533	592	666	726	878
45	646	507	375	278	122	89	69	97	135	396	566	616	693	744	890
50	665	531	400	302	133	96	78	104	151	424	589	637	711	760	901
55	684	549	423	324	144	103	85	114	168	446	606	659	725	781	918
60	695	570	441	346	154	113	98	125	185	467	624	677	742	796	928
65	712	582	461	363	169	123	107	133	202	485	641	686	755	809	938
70	722	595	475	381	180	131	108	141	221	502	650	701	763	820	945
75	733	610	489	393	196	138	111	151	236	515	660	712	774	829	953
80	743	621	503	408	209	148	119	159	255	525	673	718	788	845	962
90	766	641	529	437	235	162	135	179	289	546	695	738	808	858	972
100	782	656	547	458	262	179	148	198	318	568	710	757	827	875	986
110	800	672	566	479	287	198	159	220	345	586	726	772	841	886	995
120	816	691	583	498	309	216	174	246	370	594	743	787	849	896	1006
130	838	710	602	518	335	242	190	267	394	614	755	804	873	923	1036
140	846	718	613	538	357	259	208	287	417	623	769	815	879	929	1032
150	861	728	630	549	383	281	234	309	438	638	782	828	885	945	1040
160	871	742	641	567	401	308	256	332	459	650	797	837		956	1027
170	878	753	653	579	426	331	281	357	477	661	806	845		967	1051
180	901	765	664	590	445	350	301	374	495	671	817	863			1085

Table 3.11.2 Concrete Temperatures, Series III Column 3
(continued)

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	25	26	27	28	29	30	31	32	33	34	35	36	37	38	
0	27	27	23	26	25	25	25	23	25	23	24	27	27	29	71
5	115	76	47	31	26	23	24	26	24		56	82	130	176	574
10	224	153	100	66	31	25	24	25	32		130	178	274	358	687
15	311	223	139	106	44	27	24	26	56	126	198	279	399	488	742
20	390	286	184	131	70	30	25	32	87	154	265	364	496	576	789
25	447	342	229	162	105	84	29	54	106	205	335	436	563	633	818
30	492	391	270	200	111		42	77	113	251	400	492	611	676	842
35	532	430	309	233	111	95	54	83	115	296	451	540	649	708	859
40	564	465	343	264	115	93	64	85	126	333	495	573	676	734	878
45	589	493	370	289	121	95	72	94	140	368	528	602	699	755	890
50	611	515	394	311	135	98	80	99	157	393	554	621	715	773	901
55	626	537	413	334	146	99	89	107	176	417	577	641	734	790	918
60	644	555	433	353	163	105	105	110	195	434	594	655	747	802	928
65	654	571	447	369	173	108	107	118	213	451	607	666	757	819	938
70	666	579	463	380	185	110	108	129	232	465	624	678	773	833	945
75	677	591	473	395	198	118	107	138	245	476	635	687	782	844	953
80	686	601	487	410	210	126	109	145	264	487	643	702	794	851	962
90	705	622	510	430	234	141	123	160	293	509	665	720	812	869	972
100	723	639	531	453	262	165	140	181	325	531	686	741	835	893	986
110	735	653	545	472	287	184	154	200	349	543	698	755	849	907	995
120	745	665	563	489	308	197	171	222	370	551	708	768	860	913	1006
130	764	681	583	509	334	224	185	244	397	568	723	780	874	940	1036
140	776	694	592	529	358	248	209	271	417	579	736	795	889	942	1032
150	789	705	610	541	385	272	234	292	438	585	749	807	899	954	1040
160	797	720	619	557	405	296	260	313	460	593	759	823	907	966	1027
170	805	723	632	570	423	319	285	338	478	600	765	826	910	966	1051
180	826	742	643	581	442	338	308	360	498	608	779	840	938	993	1085

Table 3.11.3 Deflections, Series III Column 3

Minutes	Expansion, mm	Lateral Deflection at Midheight, mm
0	0.0	1.3
10	0.8	
20	2.8	
30	4.0	
40	4.3	
50	4.9	
60	5.5	10.0
70	6.0	
80	6.5	
90	6.9	15.0
100	7.1	
110	7.3	19.0
120	7.4	21.0
130	7.4	23.0
140	7.4	25.0
150	7.3	27.0
160	6.7	
170	5.5	
180	3.0	32.0

Table 3.11.4

Steel Temperatures, Series III Column 14

Minutes	Temperature (°C) Measured at Thermocouple #:										Furnace
	1	2	3	4	5	6	7	8	9	10	
0	26	25	22	24	18	15	25	19	25	22	64
4	26	25	24	22	19		31	26	25	25	567
10	46	41	40	36	34		69	57	37	32	685
20	112	110	108	113	110		130	124	105	101	782
30	130	126	126	120	122	115	193	179	118	110	843
40	175	170	166	155	151	150	261	242	157	128	878
50	225	219	216	202	200	198	318	296	207	168	905
60	276	268	264	253	246	248	360	344	253	214	930
64	295	287	283	271	264	264	377	358	272	231	933

Table 3.11.5

Concrete Temperatures, Series III Column 14

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace	
	11	12	13	14	15	16	17	18	19	20	21	22	23		24
0	27	24	22	24	22	22	24		24	23	24	23	27	33	64
4	122	82	44	29	24	23	23	23	23	28	57	87	148	234	567
10	242	181	112	66	33	23	25	23	33	83	154	222	337	464	685
20	399	321	207	118	72	34	24	62	91	147	305	401	535	642	782
30	517	435	297	162	87	50	42	126	106	244	423	507	658	755	843
40	592	512	370	221	106	69	58	110	129	333	518	612	736	795	878
50	641	562	424	267	131	91	73	106	165	394	593	684	790	768	905
60	679	604	468	309	163	107	103	130	207	440	653	734	828	763	930
64	692	617	481	323	173	112	108	141	221	457	676	755	842	772	933

Table 3.11.6 Deflections, Series III Column 14

Minutes	Expansion mm	Rotation of top degrees
0	0.0	0.0
10	0.4	0.4
20	2.1	1.4
30	2.6	2.1
40	2.9	2.1
50	3.4	3.2
60	3.9	4.0
70	4.4	4.0
80	4.8	5.9
90	5.3	5.9
100	5.5	8.4
110	5.6	8.4
120	5.6	8.4
130	5.6	11.4
140	5.4	11.4
150	4.9	14.3
160	4.0	17.9
170	2.8	23.2
180	0.7	33.7
183	-2.0	

3.12 EFFECT OF ECCENTRIC LOADING, SECTIONS WITH BRACKETS

Specimen Properties:

Cross-Section: 305 x 305 mm (12 x 12 in.), 406 mm (16 in.) extension.
 Length: 3810 mm (12 ft 6 in.)
 Aggregate: Siliceous
 Reinforcement: 2.19% as four No. 8 bars.

Elevation, Cross-Section and Finishing Detail: Figure 3.12.1
 Layout of Thermocouple Frames in Concrete: Figure 3.3.1
 Locations of Thermocouples in Frames: Figure 3.3.2
 Locations of Thermocouples on Reinforcing Bars: Figure 3.3.3
 Loading Scheme: Figure 3.12.2

The loads consisted of a constant concentric load applied from the bottom with a concentric reaction, and variable eccentric loads at both ends of the column.

3.12.1 Series III, Column 7

Test purpose: Effect of eccentric loading with gradual reduction of restraint against rotation.
 Date tested: October 9, 1987.
 Concentric Loading: 1022 kN
 Eccentric at 51 cm: Initial: 49 kN.
 Final: 32 kN.

Measured Properties:

Cylinder strengths: 40.2 MPa at 28 days.
 42.1 MPa on test date.
 Relative humidity: 44%.

Results:

Test duration: 2 hours 50 minutes.
 Temperatures: Tables 3.12.1 and 3.12.2.
 Loads and deformations: Table 3.12.3

Observations

1:20 Minor cracking on S and N faces.
 2:15 Minor cracking on all faces.
 2:30 Cracks were around 6 mm wide.
 2:50 The column buckled and failed (Figure 3.12.3).

3.12.2 Series III, Column 8

Test purpose: Effect of eccentric loading, rotation held constant by varying eccentric load.
 Date tested: April 24, 1987.
 Concentric Loading: 987 kN
 Eccentric at 51 cm: Initial: 43 kN.
 Final: 8 kN.

Measured Properties:

Cylinder strengths: 39.7 MPa at 28 days.
 42.8 MPa on test date.
 Relative humidity: 32%.

Results:

Test duration: 3 hours 45 minutes.
 Temperatures: Tables 3.12.4 and 3.12.5.
 Loads and deformations: Table 3.12.6

Observations

0:45 Small hairline cracks on S and E faces.
 1:00 Cracks were small (3 mm wide) and typical.
 1:36 Cracks on the W (compression) face were near the bottom bracket; wider (9 mm) cracks appeared on the top E (tension) face.
 2:14 All cracks were growing; one on the lower W face was 13 mm wide.
 3:05 That crack had widened to over 25 mm; all others were growing.
 3:45 The concrete cover exploded off the column on the lower W face, indicating a buckling failure (Figure 3.12.4).

3.12.3 Series III, Column 9

Test purpose: Effect of eccentric loading, rotation held constant by varying eccentric load.
 Date tested: March 31, 1987.
 Concentric Loading: 889 kN
 Eccentric at 51 cm: Initial: 43 kN.
 Final: 22 kN.

Measured Properties:

Cylinder strengths: 38.8 MPa at 28 days.
 44.5 MPa on test date.
 Relative humidity: 41%.

Results:

Test duration: 3 hours 29 minutes.
 Temperatures: Tables 3.12.7 and 3.12.8.
 Loads and deformations: Table 3.12.9

Observations

0:53 Parallel cracks on all but the W face.
 1:16 Width and length of these cracks had increased, largest on S face.
 2:00 E face tension cracks 9 mm, S face cracks about 25 mm wide.
 2:30 Still no significant new cracks; existing ones widening and lengthening.
 3:29 The SW corner buckled at midheight and the concrete cover on the W face spalled off completely, as did a large portion of the cover on the S and N faces. A horizontal flexural crack appeared at midheight on the E face (Figure 3.12.5).

3.12.4 Series III, Column 10

Test purpose: Effect of eccentric loading, loads constant.
 Date tested: August 28, 1987.
 Concentric Loading: 993 kN
 Eccentric at 51 cm: 44 kN.

Measured Properties:

Cylinder strengths: 39.7 MPa at 28 days.
 38.8 MPa on test date.
 Relative humidity: 64%.

Results:

Test duration: 2 hours 47 minutes.
 Temperatures: Tables 3.12.10 and 3.12.11.
 Loads and deformations: Table 3.12.12

Observations

1:30 Hairline cracking at one-third points on E, S and N faces, 30 - 45 cm long.
 2:30 More prominent cracks on the S, W and N faces, 3 to 5 mm wide.
 2:47 The column buckled and failed (Figure 3.12.6).

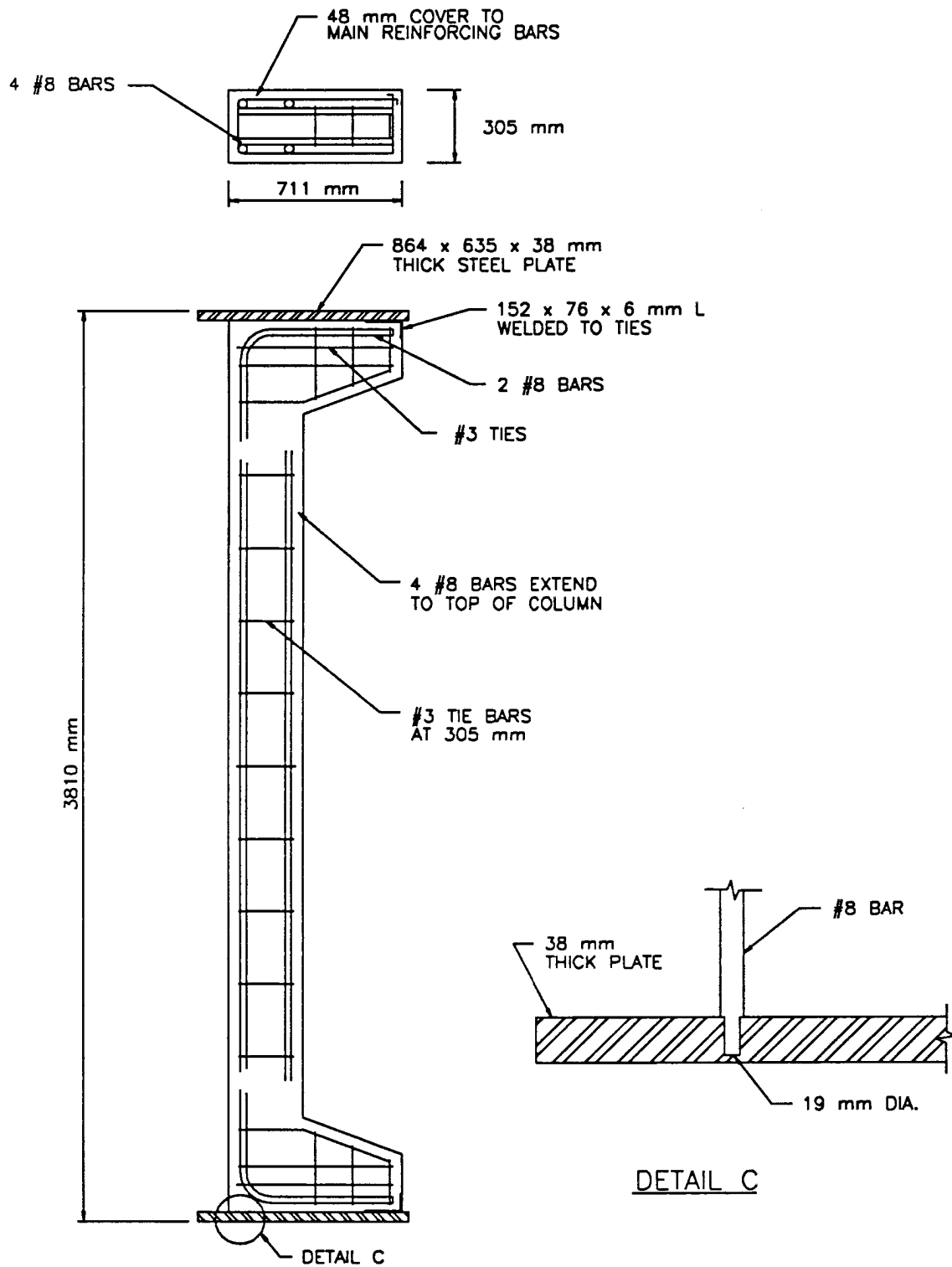


Figure 3.12.1 Elevation, Cross-Section and Finishing Detail: 12 x 12 Section with Brackets

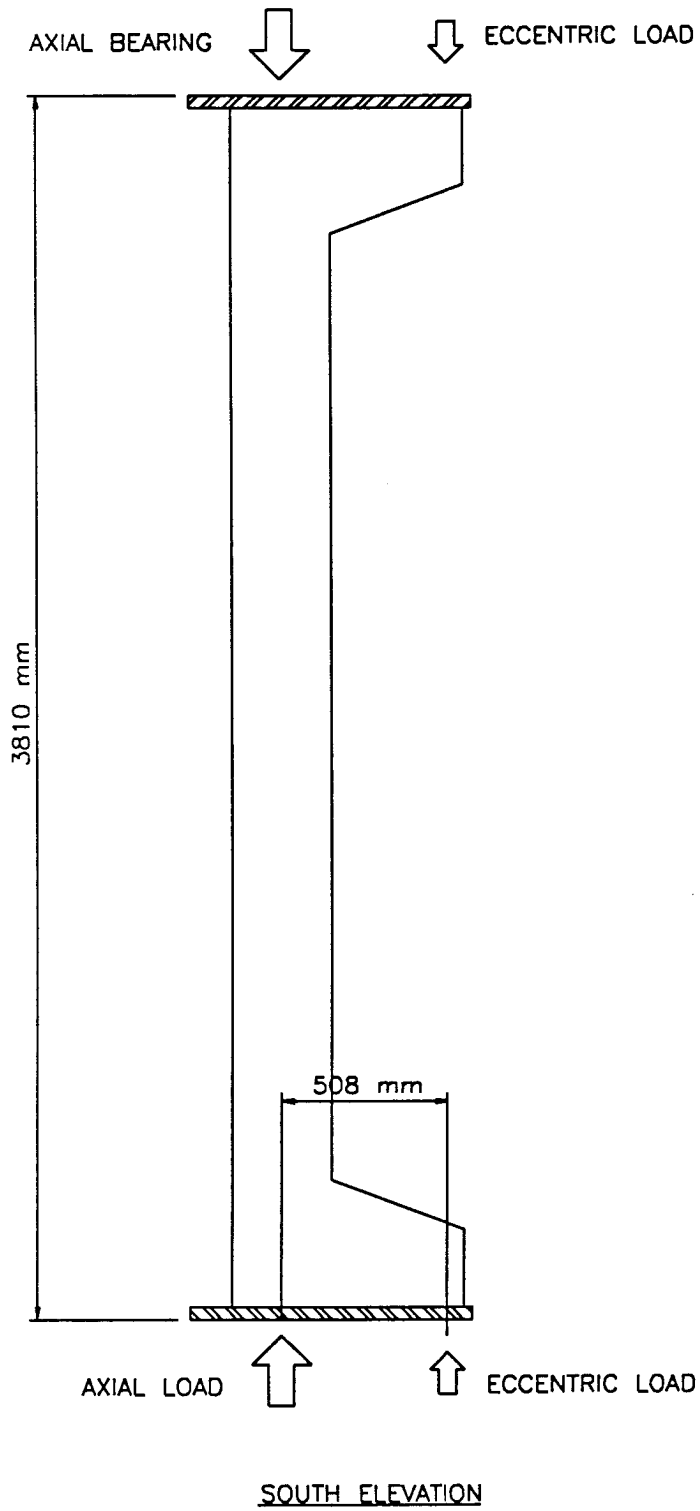


Figure 3.12.2 Loading Scheme: 12 x 12 Section with Brackets

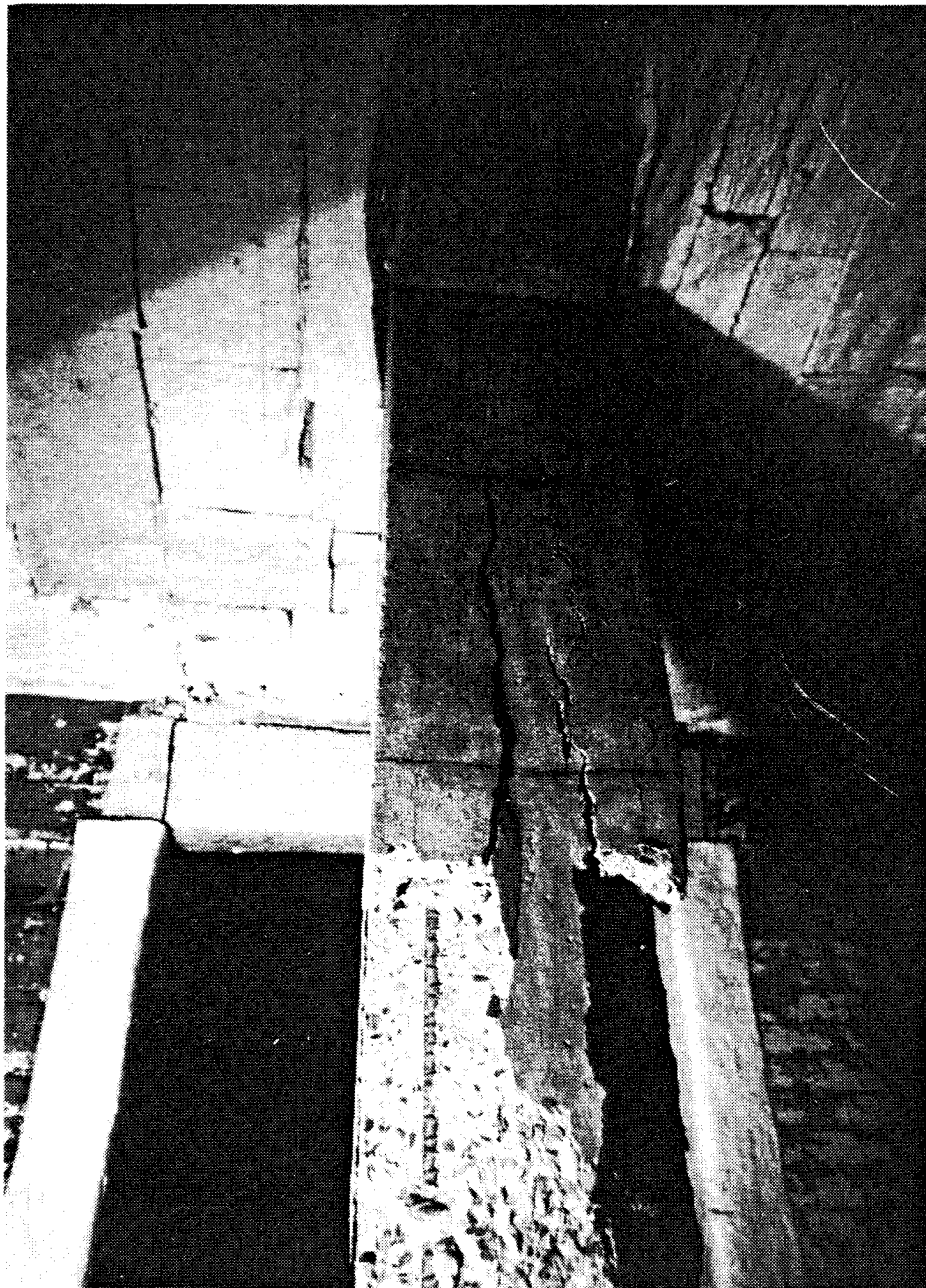


Figure 3.12.3 Series III Column 7 After Test

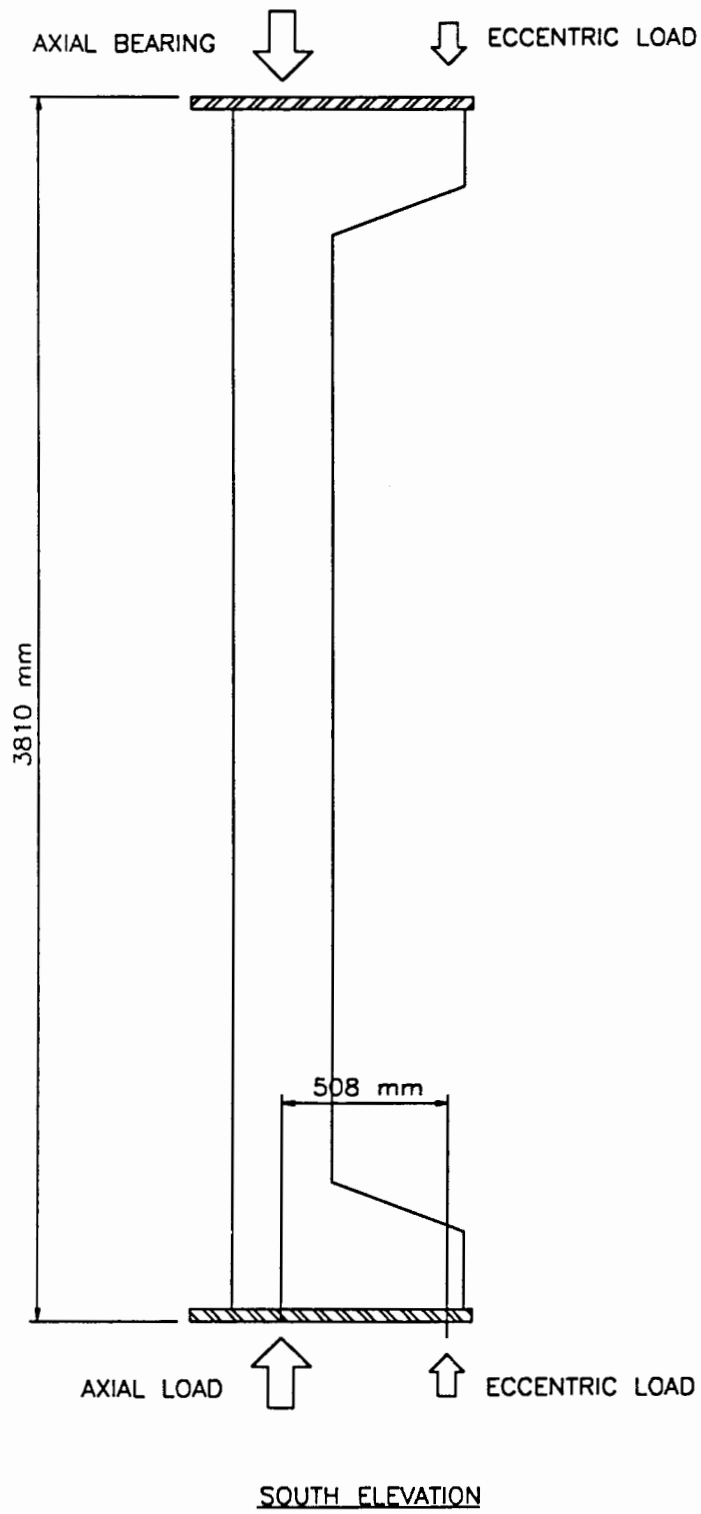


Figure 3.12.2 Loading Scheme: 12 x 12 Section with Brackets



Figure 3.12.4 Series III Column 8 After Test

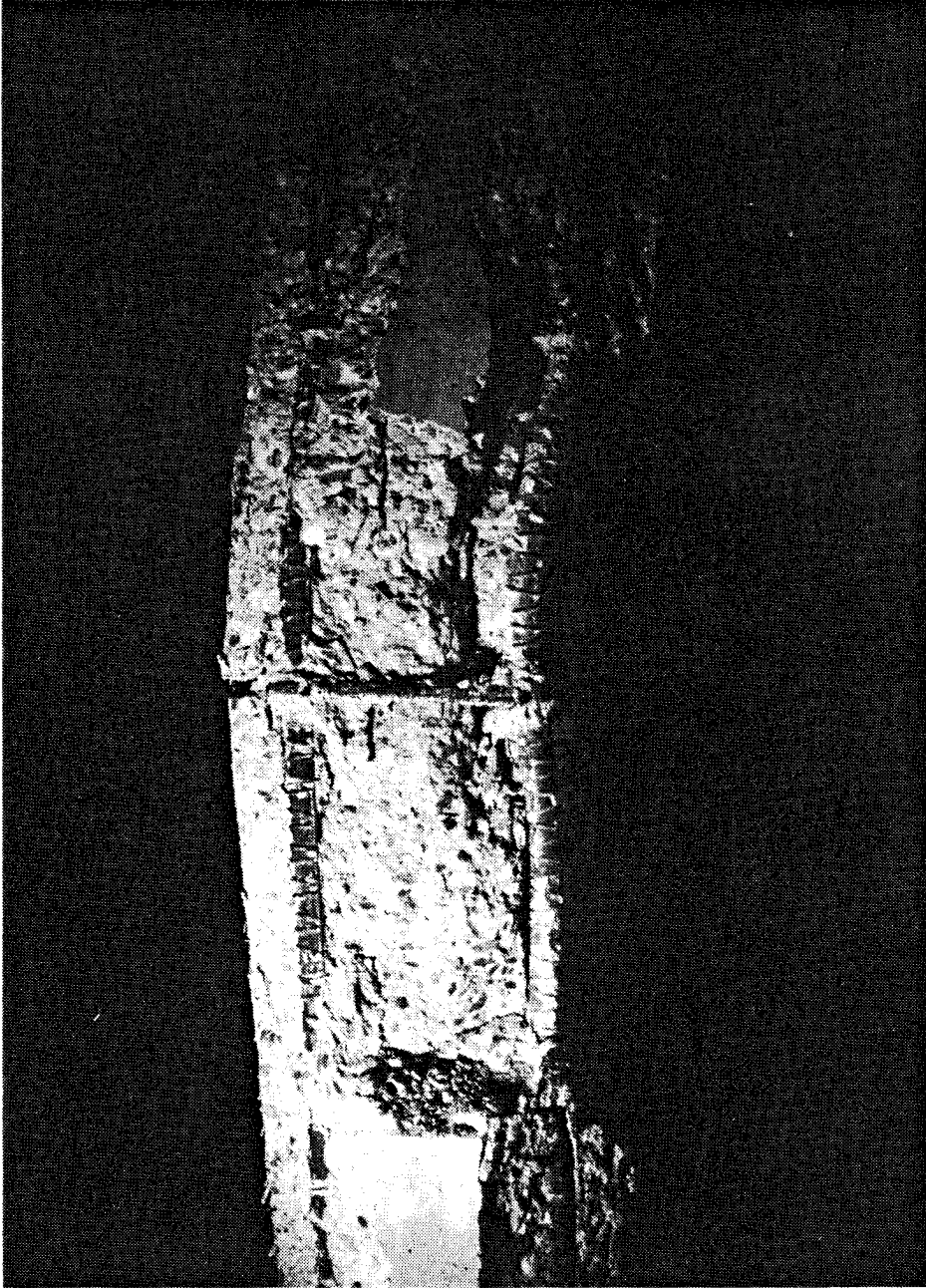


Figure 3.12.5 Series III Column 9 After Test

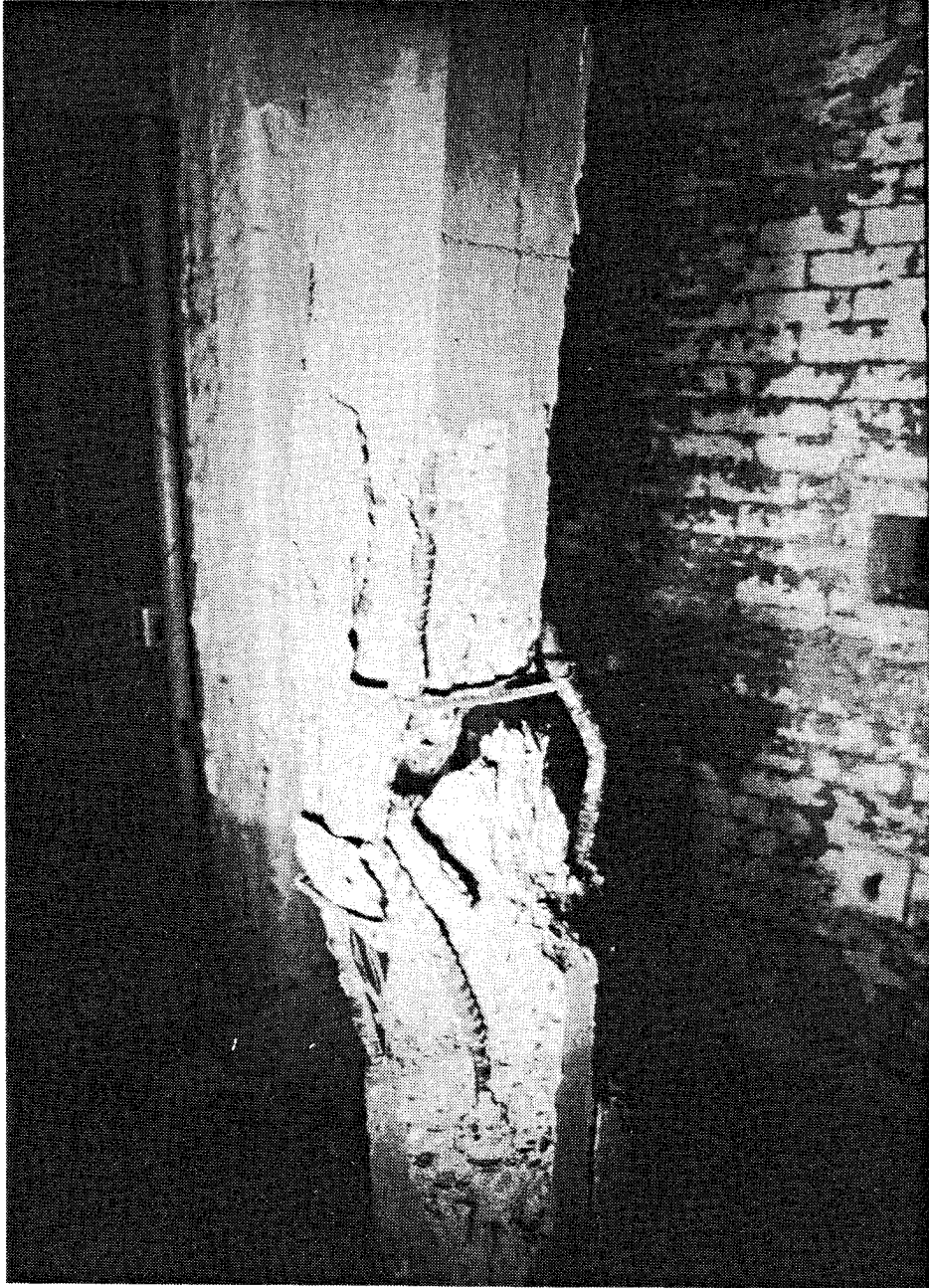


Figure 3.12.6 Series III Column 10 After Test

Table 3.12.1

Steel Temperatures, Series III Column 7

Minutes	Temperature (°C) Measured at Thermocouple #:										Furnace
	1	2	3	4	5	6	7	8	9	10	
0	17	14	16	12	14	10	17	11	17	32	57
4	16	14	14	13	12	12	16	16	14	32	556
10	38	33	35	30	34	32	47	52	32		685
20	115	112	116	108	111	119	116	119	110		783
30	131	125	135	116	142	123	163	166	124	113	842
40	176	166	175	147	194	166	232	227	162	136	879
50	227	219	224	195	248	217	288	280	210	180	905
60	276	271	273	242	299	267	335	326	258	224	925
70	324	320	317	285	346	309	375	365	300	267	944
80	365	368	355	332	386	353	414	401	342	306	958
90	403	409	388	368	423	390	444	435	374	342	973
100	437	444	418	403	454	423	472	465	403	373	983
110	473	479	450	433	484	459	495	491	435	399	997
120	503	510	480	466	512	490	520	517	464	429	1011
140	557	567	539	524	563	544	568	567	520	478	1030
160	609	621	594	577	612	596	623	619	574	521	1048

Table 3.12.2 Concrete Temperatures, Series III Column 7

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0	16	14	14	13	12	12	12	12	13	13	14	19	24	31	57
4	84	60	31	21	16	15	15	15	16	20	41	71	178	130	556
10	202	151	92	53	20	14	12	14	22	71	134	187	386	194	685
20	361	286	167	119	58	23	16	56	99	145	258	361	574	239	783
30	488	397	249	171	103	60	30	80	109	237	382	485	703	264	842
40	565	471	315	228	105	78	50	82	119	315	483	579	777	281	879
50	620	528	371	284	123	89	67	97	148	375	555	655	823		905
60	664	572	418	327	150	103	84	113	188	424	619	707	856		925
70	703	610	459	363	165	119	105	133	224	466	670	750			944
80	733	645	495	397	199	133	117	146	262	501	711	784			958
90	761	674	521	430	222	147	124	158	298	531	740	812			973
100	780	700	546	454	248	159	131	181	325	562	764	839			983
110	800	720	574	479	269	178	140	200	357	593	789	857			997
120	823	742	599	505	296	198	157	225	386	626	814	876			1011
140	858	783	643	548	352	247	196	274	447	678	846	905			1030
160	885	821	688	594	405	299	249	325	499						1048

Table 3.12.3 Deflections, Series III Column 7

Minutes	Expansion mm	End Rotation ($\Delta b - \Delta c$) degrees	Midheight Lateral Deflection* (Δm) mm
0	0.0	0.00	0.0
10	0.9	0.08	0.0
20	2.8	-0.38	4.5
30	3.3	-0.36	5.5
40	3.6	-0.55	6.3
50	4.2	-0.92	7.5
60	4.8	-1.55	9.5
70	5.4	-2.16	11.3
80	6.0	-2.86	13.3
90	6.5	-3.57	15.0
100	6.8	-4.35	17.0
110	7.1	-5.11	19.5
120	7.2	-5.57	21.0
130	7.2	-6.38	23.5
140	7.2	-6.70	25.0
150	6.8	-8.01	28.0
160	6.1	-10.18	35.0
170	2.4	-13.30	42.0

* Initial deflection was 2.0 mm

Table 3.12.4

Steel Temperatures, Series III Column 8

Minutes	Temperature (°C) Measured at Thermocouple #:										Furnace
	1	2	3	4	5	6	7	8	9	10	
0	25	23	24	24	25	23	25	24	23	22	66
4	23	25	25	24	23	23	28	27	22	24	563
10	46	44	42	46	47	41	62	68	38	37	684
20	115	115	118	118	104	126	126	132	115	110	792
30	129	131	132	129	126	127	172	180	119	116	837
40	175	178	177	166	167	165	238	241	158	178	874
50	231	231	229	217	217	211	293	293	207	193	905
60	279	280	278	267	264	245	336	335	255	248	929
70	329	325	324	314	310	281	377	376	303	293	944
80	371	367	368	360	356	316	413	410	344	336	959
90	412	405	407	398	393	352	445	445	382	369	973
100	446	441	440	430	428	376	472	470	418	403	987
110	479	475	474	462	461	397	500	500	451	435	999
120	506	504	499	488	490	423	525	523	476	464	1011
130	538	531	530	520	524	445	551	547	507	495	1018
140	564	556	556	545	549	460	576	572	534	521	1030
150	588	584	582	571	575	480	599	598	560	547	1038
160	616	609	610	600	605	512	626	622	587	573	1058
170	640	635	636	629	633	537	649	647	616	602	1057
180	661	660	663	655	657	584	673	672	652	623	1068
190	683	684	686	682	684	444	696	694	690	653	986
200	706	704	709	706	713	337	715	713	718	676	1083
210	725	723	727	728	735	274	727	726	734	702	1090
220	740	736	734	729	747	246	735	733	740	714	1096
224	742	743	732	736	757	253	738	740	737	721	1097

Table 3.12.5 Concrete Temperatures, Series III Column 8

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace
	11	12	13	14	15	16	17	19	20	21	22	23	24	
0	27	25	24	22	22	21	21	22	22	22	22	24	27	66
4	11	89	50	31	23	24	25	22	33	65	99	159	215	563
10	225	180	118	75	34	23	21	29	92	157	218	334	421	684
20	393	324	208	134	79	35	27	84	157	305	396	534	623	792
30	515	435	296	200	105	75	54	102	271	432	526	658	722	837
40	596	513	375	272	120	89	67	112	367	531	624	737	792	874
50	650	569	432	323	145	100	79	143	428	604	696	789	780	905
60	692	613	477	364	176	112	99	183	478	667	748	830	788	929
70	729	651	516	402	207	127	112	218	515	712	786	852	792	944
80	758	684	549	432	229	142	117	252	554	748	814	813	797	959
90	783	706	568	444	241	155	127	277	580	767	837	783	793	973
100	807	732	598	466	262	177	142	314	616	801	854	784	788	987
110	704	752	620	491	285	198	152	345	649	823	865	789	792	999
120	715	770	644	534	315	219	165	376	674	845	872	789	791	1011
130	733	792	668	614	355	247	189	409	695	865	842	784	792	1018
140	751	813	693	684	427	286	212	449	717	881	767	782	797	1030
150	764	831	716	725	560	394	243	503	738	890	754	761	784	1038
160	773	830	734	736	653	545	294	567	757	882	760	754	767	1058
170	774	796	747	745	707	649	421	605	771	866	763	753	761	1057
180	775	773	750	754	721	694	573	626	780	860	767	758	758	1068
190	774	774	755	755	722	713	661	645	777	848	763	752	742	986
200	763	780	763	753	726	718	699	668	734	787	743	734	732	1083
210	751	788	771	750	735	733	717	714	722	748	731	739	743	1090
220	753	785	767	753	743	743	731	756	744	764	744	751	759	1096
224	754	783	758	758	747	744	735	764	757	761	759	752	762	1097

Table 3.12.5 Concrete Temperatures, Series III Column 8

Minutes	Temperature (°C) Measured at Thermocouple #:													Furnace
	11	12	13	14	15	16	17	19	20	21	22	23	24	
0	27	25	24	22	22	21	21	22	22	22	22	24	27	66
4	11	89	50	31	23	24	25	22	33	65	99	159	215	563
10	225	180	118	75	34	23	21	29	92	157	218	334	421	684
20	393	324	208	134	79	35	27	84	157	305	396	534	623	792
30	515	435	296	200	105	75	54	102	271	432	526	658	722	837
40	596	513	375	272	120	89	67	112	367	531	624	737	792	874
50	650	569	432	323	145	100	79	143	428	604	696	789	780	905
60	692	613	477	364	176	112	99	183	478	667	748	830	788	929
70	729	651	516	402	207	127	112	218	515	712	786	852	792	944
80	758	684	549	432	229	142	117	252	554	748	814	813	797	959
90	783	706	568	444	241	155	127	277	580	767	837	783	793	973
100	807	732	598	466	262	177	142	314	616	801	854	784	788	987
110	704	752	620	491	285	198	152	345	649	823	865	789	792	999
120	715	770	644	534	315	219	165	376	674	845	872	789	791	1011
130	733	792	668	614	355	247	189	409	695	865	842	784	792	1018
140	751	813	693	684	427	286	212	449	717	881	767	782	797	1030
150	764	831	716	725	560	394	243	503	738	890	754	761	784	1038
160	773	830	734	736	653	545	294	567	757	882	760	754	767	1058
170	774	796	747	745	707	649	421	605	771	866	763	753	761	1057
180	775	773	750	754	721	694	573	626	780	860	767	758	758	1068
190	774	774	755	755	722	713	661	645	777	848	763	752	742	986
200	763	780	763	753	726	718	699	668	734	787	743	734	732	1083
210	751	788	771	750	735	733	717	714	722	748	731	739	743	1090
220	753	785	767	753	743	743	731	756	744	764	744	751	759	1096
224	754	783	758	758	747	744	735	764	757	761	759	752	762	1097

Table 3.12.6 Loads and Deflections, Series III Column 8

Minutes	Loads, kN		Deflections, mm		
	P2 top	P2 bottom	P1	P2 top	P2 bottom
0	43.4	42.9	0.00	0.00	0.00
5	44.5	46.0	0.38	0.00	0.38
10	42.6	47.6	0.94	-0.02	0.94
20	38.1	38.9	3.00	0.00	3.01
30	41.3	42.5	3.38	0.00	3.38
40	36.4	47.1	3.71	0.00	3.71
50	37.9	40.2	4.40	0.00	4.39
60	35.1	35.8	5.17	0.00	5.13
70	30.9	31.1	5.87	0.00	5.88
80	31.2	29.6	6.51	0.00	6.51
85	31.2	28.7	6.84	0.00	6.84
100	31.0	28.9	7.65	0.00	7.65
112	15.8	20.8	8.10	0.00	8.10
120	17.3	23.2	8.23	0.00	8.25
131	17.4	26.2	8.24	0.00	8.25
140	18.7	27.8	8.24	0.00	8.24
150	18.7	27.8	8.10	0.00	8.08
160	20.3	26.9	7.70	0.00	7.67
170	20.3	24.2	7.16	0.00	7.17
180	21.7	20.2	5.98	0.00	5.92
190	23.6	17.3	4.60	0.00	4.59
200	23.7	13.3	3.19	0.00	3.20
210	26.0	11.0	1.37	0.00	1.37
220	23.9	8.3	-1.67	0.00	-1.99
225	22.1	8.2			

Table 3.12.7

Steel Temperatures, Series III Column 9

Minutes	Temperature (°C) Measured at Thermocouple #:										Furnace
	1	2	3	4	5	6	7	8	9	10	
0	26	25	28	25	21	19	24	26	27	22	67
4	29	23	24	25	21	24	27	29	26	25	545
10	48	39	38	46	42	44	59	82	36	41	687
20	118	115	110	122	121	123	113	153	102	114	802
30	130	126	123	124	130	138	152	224	117	115	847
40	169	164	149	159	178	184	196	284	138	143	882
50	215	215	188	207	234	233	233	332	174	186	908
60	264	263	235	254	290	281	269	376	218	231	927
70	308	307	291	302	339	326	306	414	269	275	940
80	348	343	375	344	384	369	341	488	338	315	958
90	385	375	474	383	423	408	376	478	419	354	974
100	422	409	557	421	461	445	410	506	498	390	984
110	453	442	631	458	496	481	444	534	565	425	1000
120	484	482	693	493	525	512	477	561	619	458	1011
130	513	517	741	524	554	541	508	585	661	491	1020
140	540	550	770	557	584	567	540	613	694	523	1033
150	565	584	811	589	615	596	572	641	728	553	1043
160	588	617	827	622	636	623	613	661	769	584	1052
170	614	655	814	656	665	647	646	688	791	619	1059
180	636	687	833	693	692	673	673	709	812	653	1069
190	658	715	868	724	716	696	710	725	837	683	1075
200	679	747	893	746	741	718	864	739	858	708	1085
208	696	780	900	760	760	739	781	746	868	731	1084

Table 3.12.7

Steel Temperatures, Series III Column 9

Minutes	Temperature (°C) Measured at Thermocouple #:										Furnace
	1	2	3	4	5	6	7	8	9	10	
0	26	25	28	25	21	19	24	26	27	22	67
4	29	23	24	25	21	24	27	29	26	25	545
10	48	39	38	46	42	44	59	82	36	41	687
20	118	115	110	122	121	123	113	153	102	114	802
30	130	126	123	124	130	138	152	224	117	115	847
40	169	164	149	159	178	184	196	284	138	143	882
50	215	215	188	207	234	233	233	332	174	186	908
60	264	263	235	254	290	281	269	376	218	231	927
70	308	307	291	302	339	326	306	414	269	275	940
80	348	343	375	344	384	369	341	488	338	315	958
90	385	375	474	383	423	408	376	478	419	354	974
100	422	409	557	421	461	445	410	506	498	390	984
110	453	442	631	458	496	481	444	534	565	425	1000
120	484	482	693	493	525	512	477	561	619	458	1011
130	513	517	741	524	554	541	508	585	661	491	1020
140	540	550	770	557	584	567	540	613	694	523	1033
150	565	584	811	589	615	596	572	641	728	553	1043
160	588	617	827	622	636	623	613	661	769	584	1052
170	614	655	814	656	665	647	646	688	791	619	1059
180	636	687	833	693	692	673	673	709	812	653	1069
190	658	715	868	724	716	696	710	725	837	683	1075
200	679	747	893	746	741	718	864	739	858	708	1085
208	696	780	900	760	760	739	781	746	868	731	1084

Table 3.12.8

Concrete Temperatures, Series III Column 9

Minutes	Temperature (°C) Measured at Thermocouple #:												Furnace
	11	12	13	14	15	16	17	19	20	21	22	23	
0	28	27	23	21	22	25	27	27	26	25	36	27	67
4	118	86	43	25	23	24	21	23	31	49	76	208	545
10	263	203	116	70	385	25	24	32	94	146	195	415	687
20	432	340	200	124	89	38	23	90	157	275	360	593	802
30	551	451	294	182	105	67	40	105	251	394	489	687	847
40	612	513	361	239	115	77	54	120	342	493	582	764	882
50	659	563	414	285	142	94	71	148	410	562	655	813	908
60	703	605	459	326	170	111	90	181	462	626	710	847	927
70	737	645	497	362	196	125	117	218	506	673	752	869	940
80	767	680	533	395	218	143	131	252	541	713	787	789	958
90	796	715	565	427	239	159	137	283	574	744	816	790	974
100	823	754	600	461	265	178	137	310	602	770	839	795	984
110	845	781	630	496	296	198	142	341	631	797	860	799	1000
120	865	806	664	533	331	222	152	372	659	818	880	801	1011
130	882	832	472	565	367	250	176	405	681	835	893	807	1020
140	771	817	588	599	404	277	206	436	703	853	771	806	1033
150	781	778	694	633	438	308	235	469	722	873	767	807	1043
160	784	781	719	677	472	333	260	494	733	887	769	805	1052
170	788	779	735	640	502	360	289	521	750	897	770	804	1059
180	788	779	749	650	532	387	315	555	767	866	765	786	1069
190	787	776	758	679	561	418	345	606	780	761	763	774	1075
200	778	769	755	697	593	453	397	675	799	781	785	792	1085
208	756	744	744	711	641	510	477	727	804	805	793	825	1084

Table 3.12.9

Loads and Deflections, Series III Column 9

Minutes	Loads, kN		Deflections, mm		
	P2 top	P2 bottom	P1	P2 top	P2 bottom
0	0.00	43.4	42.9	0.00	0.00
5	0.38	44.5	46.0	0.38	0.00
10	0.94	42.6	47.6	0.94	-0.02
20	3.01	38.1	38.9	3.00	0.00
30	3.38	41.3	42.5	3.38	0.00
40	3.71	36.4	47.1	3.71	0.00
50	4.39	37.9	40.2	4.40	0.00
60	5.13	35.1	35.8	5.17	0.00
70	5.88	30.9	31.1	5.87	0.00
80	6.51	31.2	29.6	6.51	0.00
85	6.84	31.2	28.7	6.84	0.00
100	7.65	31.0	28.9	7.65	0.00
112	8.10	15.8	20.8	8.10	0.00
120	8.25	17.3	23.2	8.23	0.00
131	8.25	17.4	26.2	8.24	0.00
140	8.24	18.7	27.8	8.24	0.00
150	8.08	18.7	27.8	8.10	0.00
160	7.67	20.3	26.9	7.70	0.00
170	7.17	20.3	24.2	7.16	0.00
180	5.92	21.7	20.2	5.98	0.00
190	4.59	23.6	17.3	4.60	0.00
200	3.20	23.7	13.3	3.19	0.00
210	1.37	26.0	11.0	1.37	0.00
220	-1.99	23.9	8.3	-1.67	0.00
225		22.1	8.2		

Table 3.12.10

Steel Temperatures, Series III Column 10

Minutes	Temperature (°C) Measured at Thermocouple #:										Furnace
	1	2	3	4	5	6	7	8	9	10	
0	18	20	19	18	17	16	18	19	20	17	56
5	23	21	22	23	22	20	24	33	21	21	558
10	40	35	32	36	36	36	50	76	29	32	681
15	89	83	66	87	90	81	85	119	59	75	741
20	11	112	105	116	118	119	122	150	97	113	781
25	118	111	111	117	117	116	136	190	110	114	814
30	128	120	115	122	130	129	155	226	112	113	841
35	149	131	125	138	151	147	185	261	119	128	859
40	174	151	146	158	177	175	218	292	136	146	876
45	199	172	165	184	203	200	248	317	155	170	890
50	226	198	191	210	234	230	276	341	179	196	901
55	251	220	214	236	261	257	297	363	200	222	912
60	275	247	237	265	288	284	319	384	224	248	920
70	320	294	282	314	340	332	359	422	267	296	943
80	363	335	324	360	385	375	391	454	310	338	954
90	401	375	361	398	423	413	421	481	346	379	972
100	438	412	398	437	461	452	449	508	382	412	982
110	467	444	426	470	494	483	471	530	413	448	996
120	501	478	459	503	523	513	499	555	443	480	1009
130	528	508	489	530	549	541	520	580	473	508	1016
140	552	536	517	559	588	568	544	605	504	535	1027
150	576	560	540	583	608	594	565	628	530	560	1036
160	602	587	569	610	632	618	590	651	550	587	1034
165	615	598	578	621	644	629	602	662	561	598	1042

Table 3.12.11 Concrete Temperatures, Series III Column 10

Minutes	Temperature (°C) Measured at Thermocouple #:														Furnace
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0	22	21	20	18	16	16	18	19	19	17	19	21	24	27	56
5	128	78	49	27	21	19	18	17	19	32	70	108	181	240	558
10	221	139	95	52	24	17	19	20	30	77	145	195	318	392	681
15	311	205	134	92	38	23	20	30	63	123	213	289	416	505	741
20	387	266	174	124	66	28	23		95	146	286	370	484	572	781
25	450	323	215	140	85	37	28		103	188	344	430	546	640	814
30	502	372	256	166	89	47	34		106	244	405	490	608	684	841
35	543	412	293	196	93	57	44		112	296	459	533	656	727	859
40	577	446	326	225	102	65	53	85	125	337	505	577	694	764	876
45	609	479	356	252	115	75	61	92	143	373	542	618	728	792	890
50	634	505	382	273	127	83	70	103	162	401	580	648	759	814	901
55	655	529	405	294	138	93	79	113	185	427	611	679	780	834	912
60	674	551	426	314	149	106	89	126	204	451	640	707	800	850	920
70	711	590	465	347	176	119	107	145	244	492	690	748	833	881	943
80	741	624	499	378	200	134	113	155	280	527	726	779	860	899	954
90	767	652	525	404	227	148	123	174	316	558	758	810	885	918	972
100	789	675	550	429	251	163	137	196	350	588	785	835	903	934	982
110	811	699	577	457	298	180	146	220	382	615	807	854	919	952	996
120	830	721	603	481	305	203	161	247	412	641	829	874	932	965	1009
130	848	744	624	508	332	226	181	271	439	665	848	893	947	978	1016
140	865	766	646	532	361	248	206	294	467	691	867	908	944	986	1027
150	883	786	673	558	392	276	232	282	499	712	883	920		995	1036
160		800	678	582	416	301	260		522	735	898	937		996	1034
165		811		596	431	314	272		534	748	900				1042

Table 3.12.12 Deflections, Series III Column 10

Minutes	Expansion mm	End Rotation degrees	Midheight Lateral Deflection (Δm) mm
0	0.0	0.00	2.0
10	0.8	0.11	2.5
20	2.8	0.14	3.5
30	3.2	0.14	4.3
40	3.5	0.14	5.0
50	4.2	0.14	6.5
60	5.0	0.14	8.0
70	5.7	0.14	10.0
80	6.4	0.15	12.5
90	6.9	0.15	14.0
100	7.4	0.15	17.5
110	7.6	0.15	19.0
120	7.7	0.15	20.0
130	7.7	0.14	24.0
140	7.7	0.14	26.0
150	7.2	0.13	30.0
160	6.2	-0.07	40.0

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