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by

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ABSTRACT

Experiments were carried out to determine the fire resistance of hollow steel columns filled with high strength concrete (HSC). The results of eight full-scale fire resistance experiments are described in this report. The main study variables were the column dimensions, load intensity and concrete reinforcement. These studies were conducted as part of a research program aimed at determining the fire performance of HSC-filled hollow steel columns.

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1. INTRODUCTION

Steel hollow structural section (HSS) columns are very efficient structurally in carrying compression loads and moments and are widely used around the world in the construction of framed structures in office and industrial buildings. Often these sections are filled with concrete to enhance the load-bearing capacity. The two components of the composite column complement each other ideally, in that the steel casing confines the concrete laterally allowing it to develop its optimum compressive strength, while the concrete, in turn, enhances resistance to elastic local buckling of the steel wall.

Another advantage of concrete filling is that it also increases the fire resistance of the column without the need for external fire protection for the steel. This increases usable space in the building. Properly designed concrete-filled columns can lead economically to the realization of architectural and structural design with visible steel without any restrictions on fire safety [1, 2].

In recent years, high strength concrete (HSC) has become an attractive alternative to traditional normal strength concrete (NSC), since it further increases the load-carrying capacity of HSS columns [3, 4]. As well, the high stiffness of HSC prevents elastic local buckling in the steel wall while the confinement within the steel HSS, enhances the ductility, which sometimes is a major concern for HSC. These advantages have led to the increased use of HSC-filled HSS columns [5].

The benefits from the use of HSC filling can be maximised if the external fire protection is eliminated. The enhancement of fire resistance of HSS columns, leading to the use of unprotected concrete-filled HSS columns, has been established for NSC filling (concrete strength below 55 MPa) by a number of studies [2, 6, 7]. However, there is little information available in the literature on the fire performance of HSS columns filled with HSC (strength above 55 MPa). Further, the behaviour of HSC at elevated temperatures is significantly different from that of NSC [4, 8].

To develop test data on HSC-filled HSS columns, fire resistance experiments were carried out on HSC-filled steel columns. In this report, results of the fire resistance experiments of HSS columns filled with HSC concrete are presented for three types of concrete filling (plain, bar reinforced and steel fibre reinforced).

2. TEST SPECIMENS

2.1 Dimensions

All columns were 3810 mm long from end plate to end plate and were of various cross sectional sizes. The outside diameter, D, of the circular columns ranged from 203.2 mm to 406.4 mm while the square columns were of 203.2 mm sides. The wall thickness (t) ranged from 4.78 mm to 12.70 mm. The dimensions of each column are listed in Table 1. Six columns had a circular cross-section; the remaining two columns had square cross section. The HSS columns were filled with one of the three types of concrete, namely plain concrete (PC), bar reinforced concrete (RC) and steel fibre reinforced concrete (FC).

2.2 Materials

2.2.1 Steel

Steel hollow structural sections (HSS) meeting the requirements of CSA Standard G40.20-M81 [9], Class H, were used. The sections were made with Grade 300W steel, which had a minimum yield strength of 300 MPa. The sections were supplied by Stelco Inc. The end plates were constructed using mild steel.

2.2.2 Concrete

Five batches of concrete mix were supplied by Dufferin Concrete, from Ottawa. RC-filled HSS columns C-62, C-70 and SQ-14 were cast from the first batch, while the two FC-filled HSS columns C-36 and SQ-11 were cast from the second batch of concrete. The remaining three columns were each cast from individual batches. The mixes were made with general purpose Type 10 and Type 30 Portland cement, carbonate stone and silica based sand. In columns C-46 and C-47, silica fume was added to the mix in order to achieve a higher concrete strength. RIBTEC[1] steel fibre's of XOREX type, supplied by Ribbon Technology Corporation [10], were used as reinforcement in Batches 2 and 3. The fibre's, which were 50 mm long and 0.9 mm equivalent diameter, had an aspect ratio of 57. The percentage of steel fibre's in the concrete mix was 1.8% by mass. Superplasticizer, Mighty 150 and Daracem 100[1], and retarding admixtures, Daratard 17[1], were added to some mixes to improve workability. Batch quantities of the concrete and the columns fabricated from each batch are given in Table 1. The 28-day cylinder compressive strengths ranged from 68.4 to 90.5 MPa.

2.3 Fabrication

2.3.1 Steel Column

The hollow steel sections were fabricated by cutting the supplied sections to 3797 mm in length. Steel end plates were then welded to both section extremities, with special attention being given to the centering and perpendicularity of the end plates. The total column length was 3810 mm including end plates.

The hollow steel sections and end plates were joined by a fillet weld added around the outside diameter of the hollow steel section. AWS 5.18 Type E705-6 welding rods were used for both welds. Figures 1 and 2 shows elevation and cross-sectional details of a typical column.

Before assembly, a hole was cut in each plate to provide an opening through which the concrete was poured. The hole was approximately 25 mm smaller in diameter than the inside diameter of the section. This construction provided a 13 mm lip to transfer the load from the steel plate to the concrete filling. The end plate connection detail is shown in Figure 3.

Five small holes were drilled in the wall of the steel sections. Two pairs, 15.9 mm in diameter, located 457 mm from each end of the columns, were provided as vent holes for the water vapour produced during the experiment. The fifth hole, 25 mm in diameter, located near the top end plate, was used for entry of thermocouple wires.

2.3.2 Reinforcement

For the RC-filled HSS columns C-62, C-70 and SQ-14, the reinforcing bars were tied together to form a steel cage, which was placed inside the column. Deformed bars, meeting the

[1]Certain commercial products are identified in this paper in order to adequately specify the experimental details. In no case does such identification imply recommendation or endorsement by the National Research Council of Canada, nor does it imply that the product or material identified is the best available for the purpose.

CSA Standard G40.20-M81 [9] with minimum yield strength of 400 MPa, were used for the main reinforcing and tie bars. The diameter of the main reinforcing bars was 19.5 mm. The diameter of the ties was 6.4 mm.

The main reinforcing bars were tied together to complete the steel cage. The main bars were cut 10 mm shorter than the column length. The steel cage was then placed into the column with special care to ensure appropriate centering.

The longitudinal reinforcement consisted of 4-16mm main rebars, while 6.4 mm ties, provided at a spacing of 295 mm, formed the lateral reinforcement. The cover to the main reinforcing bars was 23 mm. For columns C-62 and C-70, the longitudinal reinforcement consisted of 4-16mm main rebars with a tie diameter of 6.4 mm and a spacing of 254 mm. Typical reinforcement details are shown in Figure 2.

For FC-filling, steel fibre's, 1.77 percent by mass, were mixed with the concrete.

2.3.3 Concrete Placement

The concrete was mixed in a truck mixer. The steel fibre's were added to the fresh concrete and mixed for approximately 5 minutes to provide uniform dispersion. The columns were put in an upright position and filled with the concrete. A concrete placement bucket and a funnel were used to deposit the concrete in the steel column. An internal vibrator was used to consolidate the concrete inside the column. The top surface of the column was finished with a small trowel. The section was sealed at both ends with plastic sheet and tape to avoid possible moisture leaks. The columns were left upright for 28 days, then stored horizontally at room temperature, with no particular curing measures being taken, until the test date. In general, six months or more elapsed between the time a column was poured and the time it was tested. However, for Column C-46, the curing period was limited to five months.

Before most tests, the moisture condition in the center of a column section was measured by inserting a Vaisala[1] moisture sensor in a hole drilled in the concrete through one of the vent holes. A moisture content corresponding to approximately 55 to 85% relative humidity was measured.

2.3.4 Instrumentation

Type K chromel-alumel thermocouples, with a thickness of 0.91 mm, were used for measuring concrete temperatures at several locations across the mid-height section of the columns. The thermocouples were tied to a steel rod that was secured to a bar running along the longitudinal axis of the column. The bar was fixed at both ends of the column as shown in Figure 4. In addition, a thermocouple was attached to the steel wall of each column at mid-height. Also, an additional four thermocouples were mounted on rebars and ties in RC-filled HSS columns. The thermocouple locations in various columns are shown in Figures 5 to 8. In these figures 'd' represents the inside diameter of the HSS column.

3. 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 conditions to which a member might be exposed during a fire, i.e., temperatures, structural loads and heat transfer. It consisted of a steel framework supported by four steel columns, with the furnace chamber inside the framework (Figure 9). The characteristics and instrumentation of the furnace are described in detail in Reference [11]. Only a brief description of the furnace and the main components is given here.

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[1] ibid

3.1 Loading Device

A hydraulic jack with a capacity of 9778 kN produces a load along the axis of the test column. The jack is located at the bottom of the furnace chamber. Eccentric loads can be applied by means of hydraulic jacks, one at the top and one at the bottom of the column, located at a distance of 508 mm from the axis of the column. The capacity of the top jack is 587 kN and that of the bottom jack is 489 kN.

3.2 Furnace Chamber

The furnace chamber has a floor area of 2642 x 2642 mm and is 3048 mm high. The interior of the chamber is lined with insulating materials that efficiently transfer heat to the specimen. The ceiling and floor insulation protects the column end plates from fire. It should be noted that only 3200 mm of the column is exposed to fire.

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. 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 and was set somewhat lower than atmospheric pressure.

3.3 Instrumentation

The furnace temperatures were measured with the aid of eight Type K chromel-alumel thermocouples. The thermocouple junctions were located 305 mm from the test specimen, at various heights. Two thermocouples were placed opposite each other at intervals of 610 mm along the height of the furnace chamber. The locations of their junctions and their numbering are shown in Figure 10. Thermocouples 4 and 6 were located at a height of 610 mm from the floor, Thermocouples 2 and 8 at 1220 mm, Thermocouples 3 and 5 at 1830 mm and Thermocouples 1 and 7 at 2440 mm. The temperatures measured by the thermocouples were averaged automatically and the average temperature was used to control the furnace temperature.

The loads were controlled by servo-controllers and measured with pressure transducers. The accuracy of controlling and measuring loads is about 4 kN at lower load levels and relatively better at higher loads.

The axial deformation of the test columns was determined by measuring the displacement of the jack that supports the column. The rotation of the end plates of the columns was determined by measuring the displacement of the plates at a distance of 500 mm from the center of the hinge at the top and bottom respectively. The displacements were measured using transducers with an accuracy of 0.002 mm.

4. TEST CONDITIONS AND PROCEDURES

4.1 End Conditions

All columns were tested with both ends of the column fixed, i.e. restrained against rotation and horizontal translation. For this purpose, eight 19 mm diameter bolts spaced regularly around the column, were used at each end to bolt the end plate to the loading head at the top and the hydraulic jack at the bottom.

4.2 Loading

All columns were tested under a concentric load. The applied load on the columns ranged from 24 to 52% of the factored compressive resistance of the columns (C_{rc}) or 39 to 100% of the factored compressive resistance of the concrete core (C'_r), determined according to

CSA Standard CSA/CAN-S16.1-M89 [12]. The factored compressive resistances of each column, as well as the applied loads, are given in Table 1. The factored compressive resistances of the columns were calculated using the effective length factors, K, recommended in CSA/CAN-S16.1-M89 for the given end conditions, i.e. 0.65 for fixed ends.

All loads were applied approximately 45 minutes before the start of the test and were maintained until a condition was reached at which no further increase of the axial and rotational deformations could be measured. This condition was selected as the initial condition of the column deformations. The load was maintained constant throughout the test.

4.3 Fire Exposure

The ambient temperature at the start of each test was approximately 20°C. During the test, the column was exposed to heating controlled in such a way that the average temperature in the furnace followed, as closely as possible, the CAN/ULC-S101 [13] or ASTM-E119 [14] standard temperature-time curve. This curve can be calculated using the following equation:

$$T_f = 20 + 750\,[1 - \exp(-3.79553\sqrt{t})] + 170.41\sqrt{t}$$

where: t = time in hours
T_f = temperature of furnace in °C

4.4 Recording of Results

The furnace, concrete, steel and reinforcement temperatures, as well as axial deformations of the columns, were recorded at one-minute intervals.

4.5 Failure Criterion

The columns were considered to have failed, and the tests were terminated, when the axial hydraulic jack, which has a maximum speed of 76 mm/min, could no longer maintain the load. Generally, the failure of the columns, which was determined by visual observation, was in compression. However, bending was observed for Column C-36, C-47 and C-62. These columns failed by buckling.

5. RESULTS AND DISCUSSION

The results of the eight column tests are summarized in Table 1, in which the column characteristics, test conditions, fire resistances and failure modes are given for each column. The furnace, concrete and steel temperatures recorded during the tests, as well as the axial deformations of the column specimens, are given in Tables A1 to A16 and plotted in Figures A1 to A8, in Appendix A. Positive axial deformation values indicate expansion of the column. Figures B1 to B8 in Appendix B show photographs of the column specimens just after the fire resistance tests.

Data from the tests (Table 1) indicate that the best fire performance can be obtained with a steel-fibre reinforced concrete filling.

The increased fire resistance of fibre-reinforced HSC-filled columns, as compared to plain HSC-filled columns or bar reinforced HSC-filled columns, can be attributed to superior mechanical properties and fire endurance of fibre-reinforced concrete. Results from the experimental studies carried out to determine mechanical properties at elevated temperatures [15, 16] indicate that the compressive strength of fibre-reinforced concrete increases with temperature up to about 400°C. The steel fibre's prevented early cracking and also contributed to the compressive strength of concrete at elevated temperatures.

Although the data from the steel-fibre reinforced columns seems to indicate that a greater concrete core diameter enhances the fire resistance, the bar reinforced columns do not clearly follow this trend. Due to small number of test samples it is not possible to draw specific conclusions. Further research, using both experimental and numerical studies, is needed to establish design methodologies for fire resistance evaluation of HSC-filled steel columns [17]. The authors recommend such studies be carried out in order to develop design equations for incorporation in codes and standards.

The reinforcement bars do not seem to have much effect on the fire performance of the columns if compared to plain HSC-reinforced columns.

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Table 1: Summary of test parameters and results

Col. No.	Reinforcement	HSS Dim.		Concrete Strength		Factored Res.		Test load C	Load Intensity		Failure Mode	Fire Resistance
		core	wall	28 day	Test day	C'r	Crc		C/C'r	C/Crc		
-	-	mm	mm	MPa	MPa	kN	kN	kN	-	-	-	min
C-36	S-Fibre’s	219.1	4.78	90.10	98.1	1149	1987	600	0.52	0.30	B	174
C-46	Plain concrete	273.1	6.35	90.50	82.2	2094	3827	1050	0.50	0.27	C	48
C-47	Plain concrete	273.1	6.35	82.40	107.0	2679	4408	1050	0.39	0.24	B	51
C-62	Bars 2.3 %	219.1	4.78	81.70	not measured	1073	1912	900	0.84	0.47	B	43
C-69	S-Fibre’s	406.4	6.35	68.40	76.2	3693	6118	3200	0.87	0.52	C	259
C-70	Bars 2.5 %	406.4	12.70	81.70	93.2	4005	8685	4000	1.00	0.46	C	75
SQ-11	S-Fibre’s	203.2	6.35	90.10	99.5	1236	2777	900	0.73	0.32	C	128
SQ-14	Bars 2.2 %	203.2	6.35	81.70	not measured	1152	2693	1150	1.00	0.43	C	89

Column No.
- C — Circular Column
- SQ — Square Column

Reinforcement
- S-Fibre’s — Steel Fibre’s
- SF — Silica Fume
- Bars — Reinforcement Bars X %

Factored Resistance
- C'r — Factored compressive resistance of concrete core of the column according to CAN3-S16.1-M89
- Crc — Factored compressive resistance of concrete-filled HSS column according to CAN3-S16.1-M90

Failure Mode
- B — Buckling
- C — Compression

Table 2: Concrete mix batch quantities for filling in HSS columns

No.	Column No.		Unit	C-62 C-70 SQ-14	C-36 SQ-11	C-69	C-46	C-47
Batch				1	2	3	4	5
1	Cement	Type 10	kg/m^3	500	500	500	-	-
		Type 30	kg/m^3	-	-	-	500	500
2	Silica Fume		kg/m^3	50	50	50	30	30
3	Sand		kg/m^3	700	700	700	700	700
4	Gravel	1/2"	kg/m^3	-	-	-	440	440
		3/8"	kg/m^3	1100	1100	1100	330	330
		1/4"	kg/m^3	-	-	-	330	330
5	Water		kg/m^3	140	140	140	135	135
6	Superplasticizer		l/m^3	8	8	8	-	-
7	Retarder		l/m^3	1.2	1.2	1.2	-	-
-	Water / (Cement +SF)		-	2.6	2.6	2.6	2.5	2.5
8	Steel Fibre’s		kg/m^3	-	45	45	-	-
9	28 Day Compressive Strength		MPa	81.7	90.1	68.4	90.5	82.4

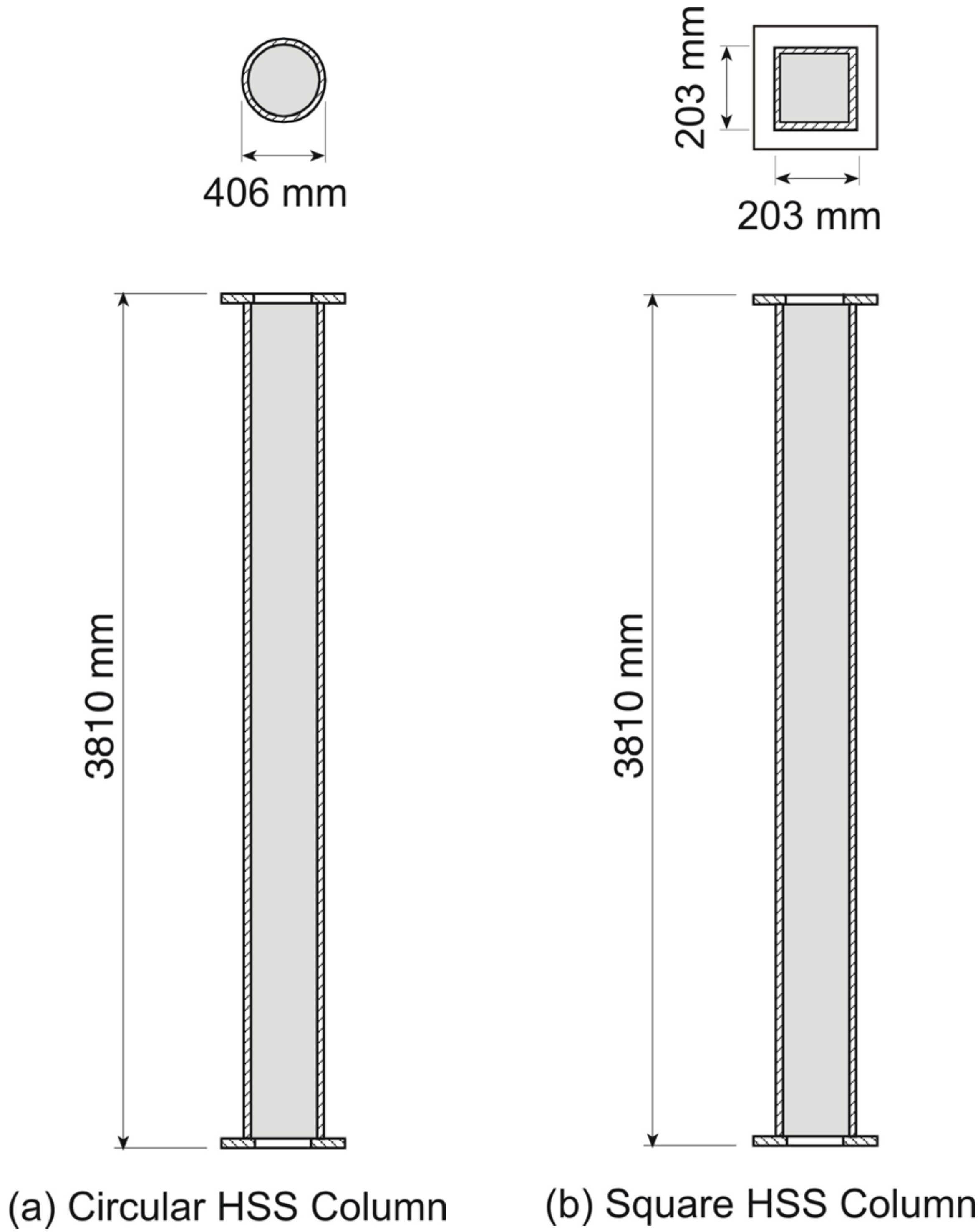

Fig. 1 Typical elevation and cross-section of circular and of square PC- and FC-filled HSS columns

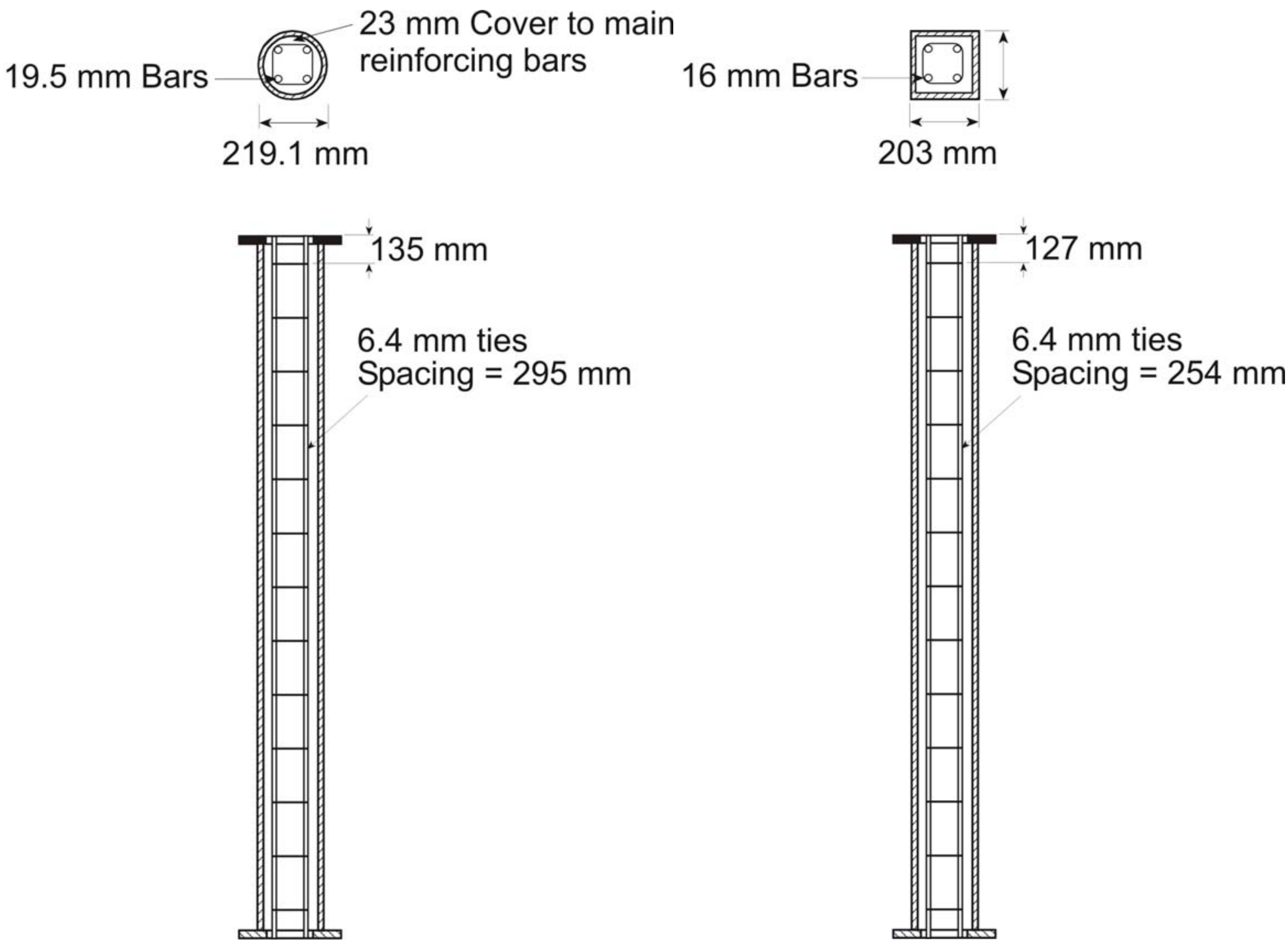

Fig. 2 Typical elevation and cross-section of circular and of square RC-filled HSS columns (C-62, C-70, SQ-14)

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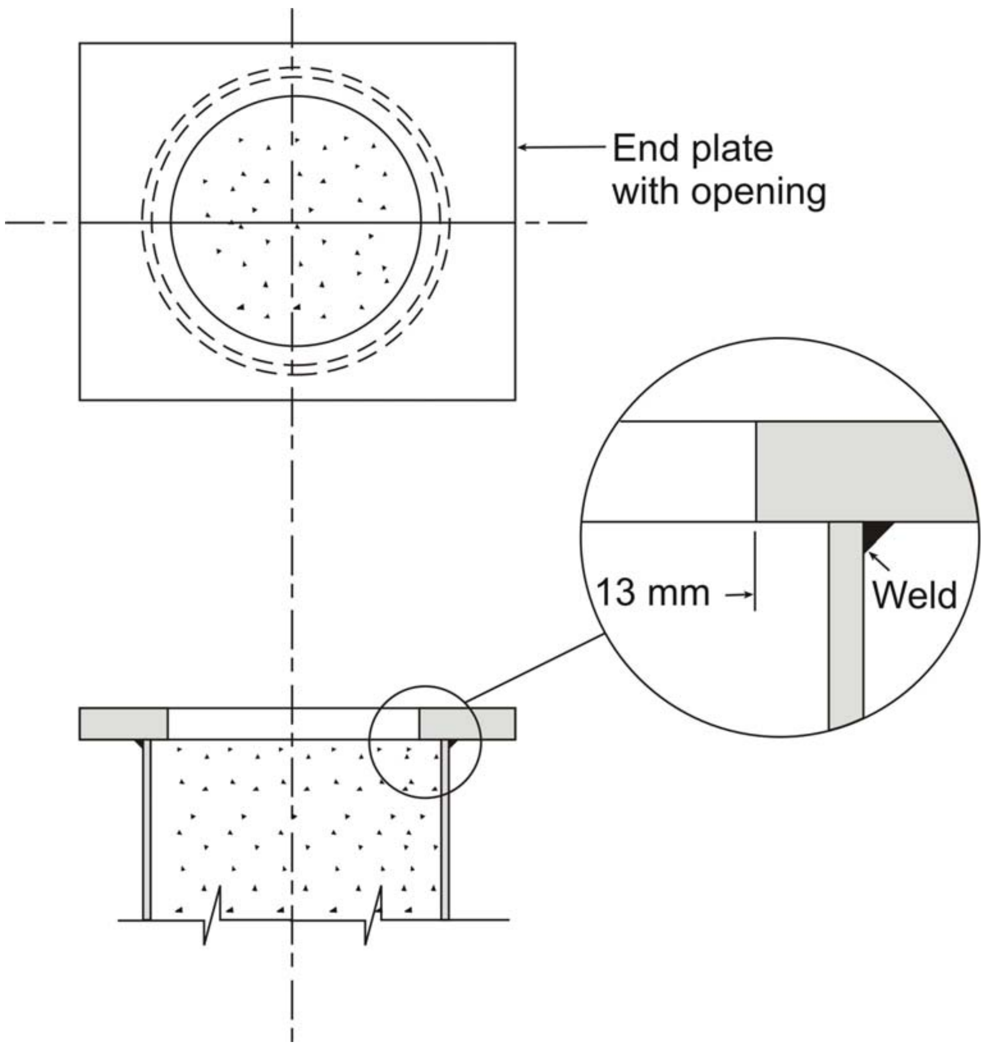


Fig. 3   End plate connection details for a typical column

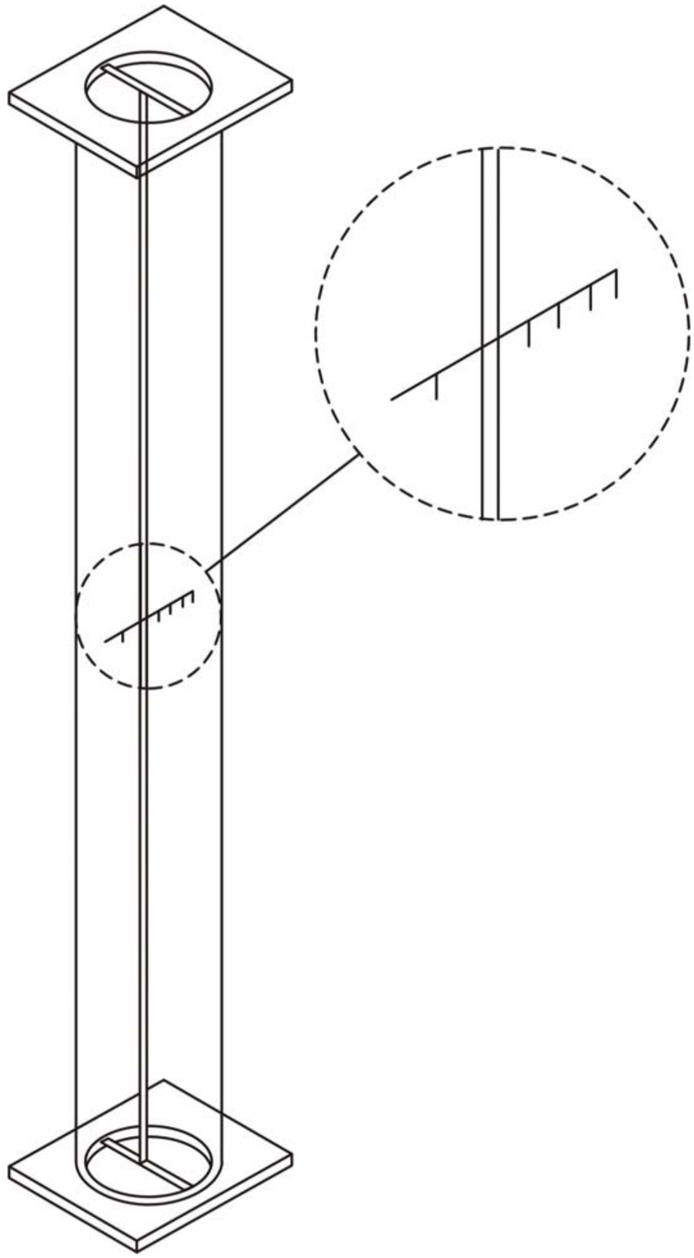


Fig. 4   Layout of thermocouple frame in a column

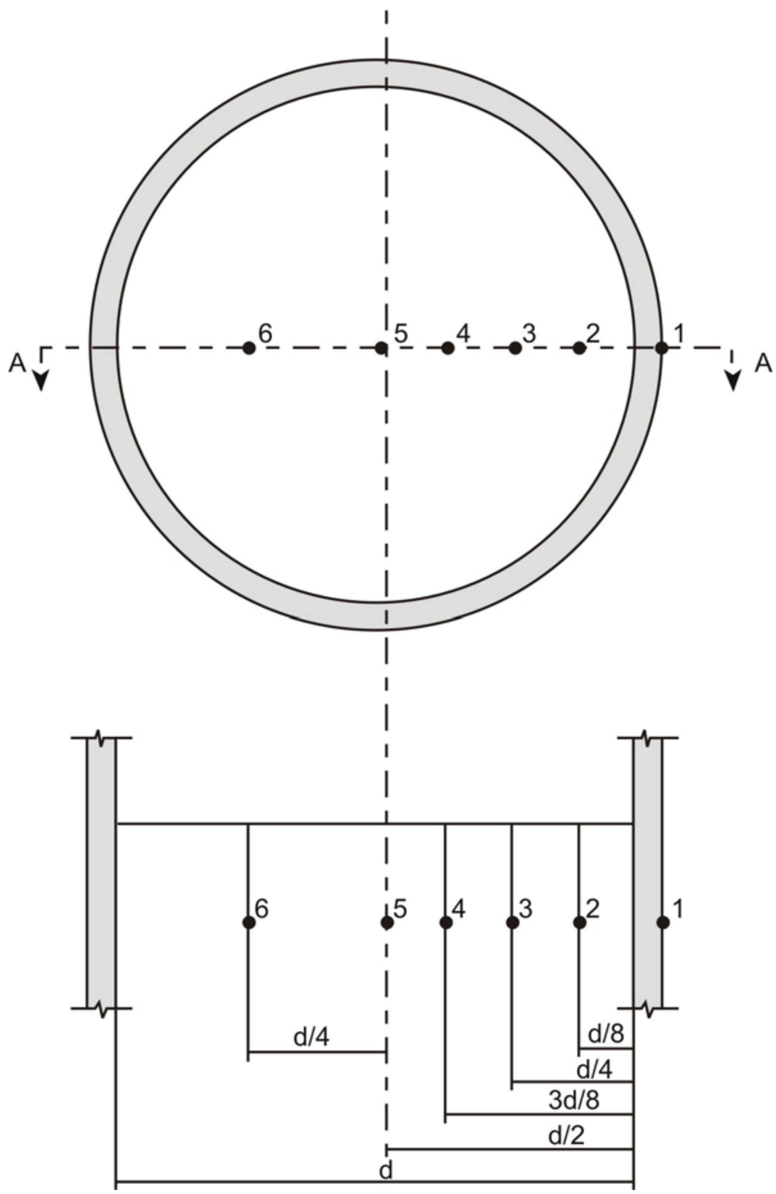


Fig. 5 Location and numbering of thermocouple locations in PC- and FC-filled circular HSS columns (C-36, C-46, C-47, C-69)

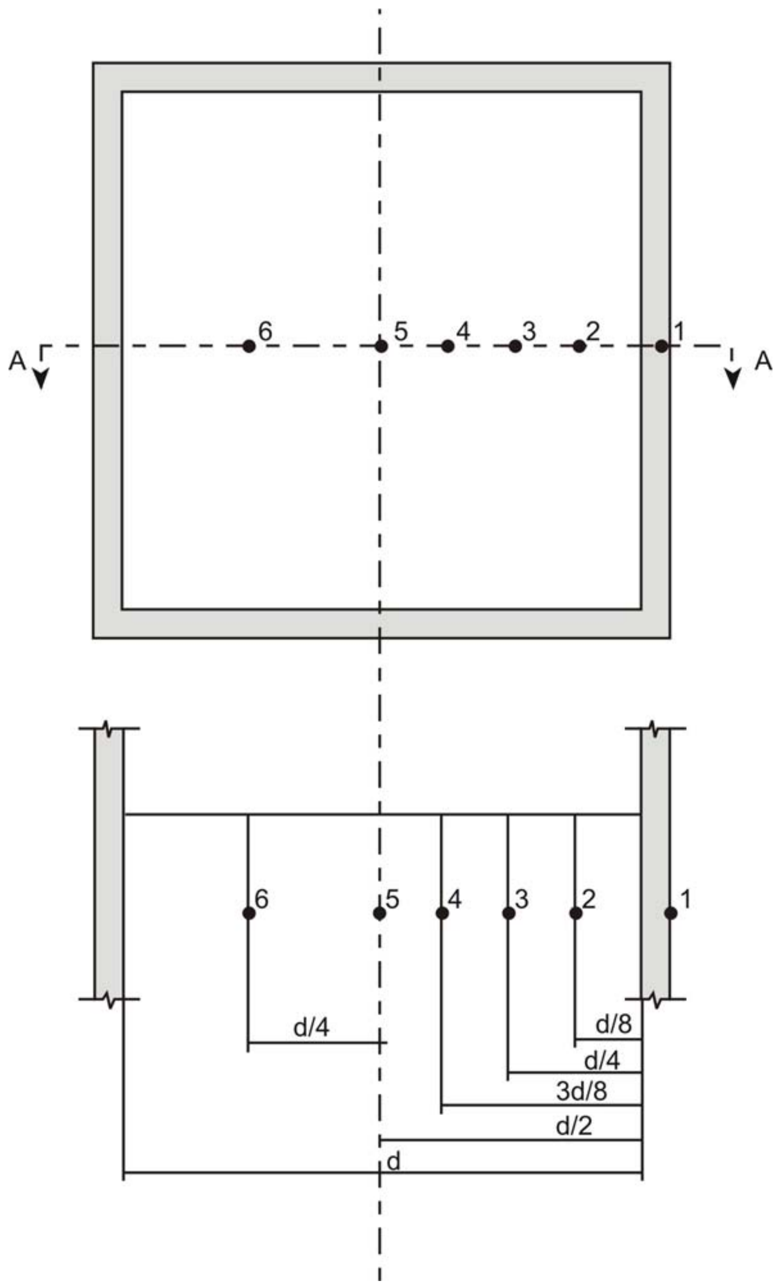


Fig. 6 Location and numbering of thermocouple locations in FC-filled square HSS column SQ-11

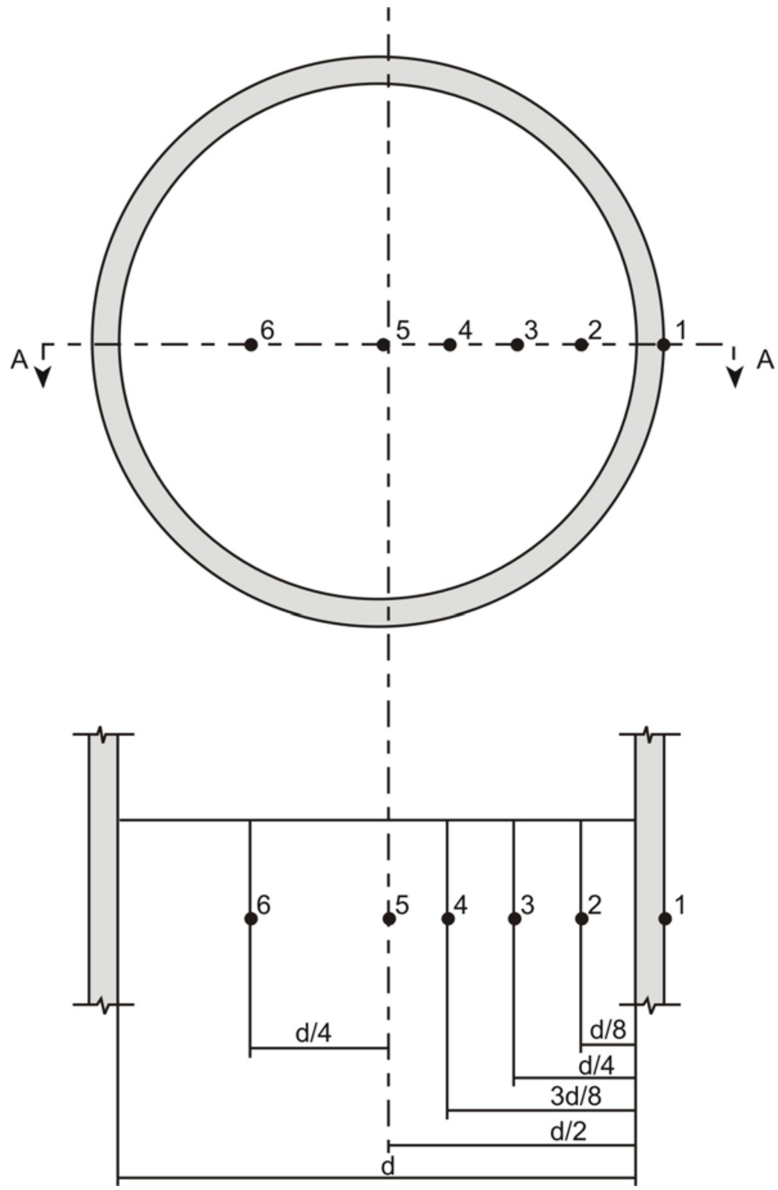


Fig. 7 Location and numbering of thermocouple locations in RC-filled circular HSS columns C-62 and C-70

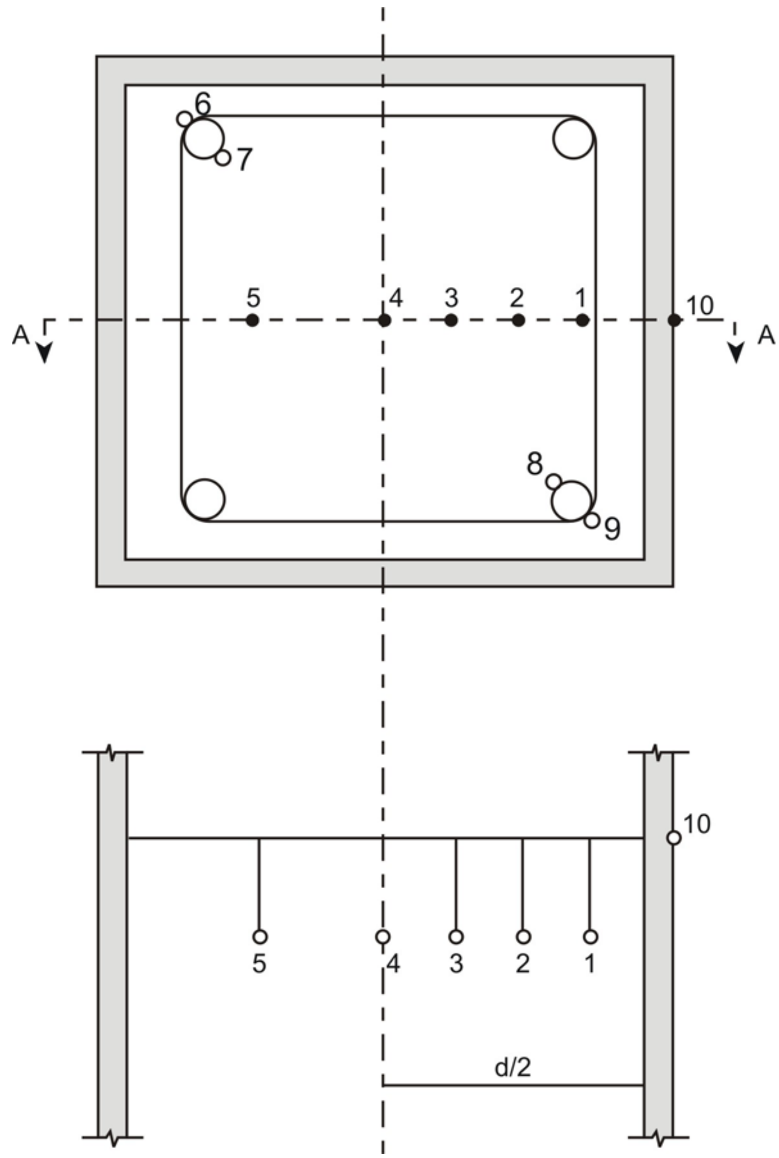
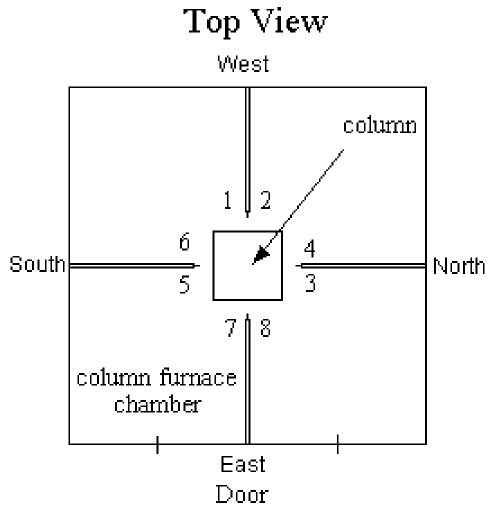


Fig. 8 Location and numbering of thermocouple locations in RC-filled square HSS column SQ-14

Fig. 9 Column Test Furnace



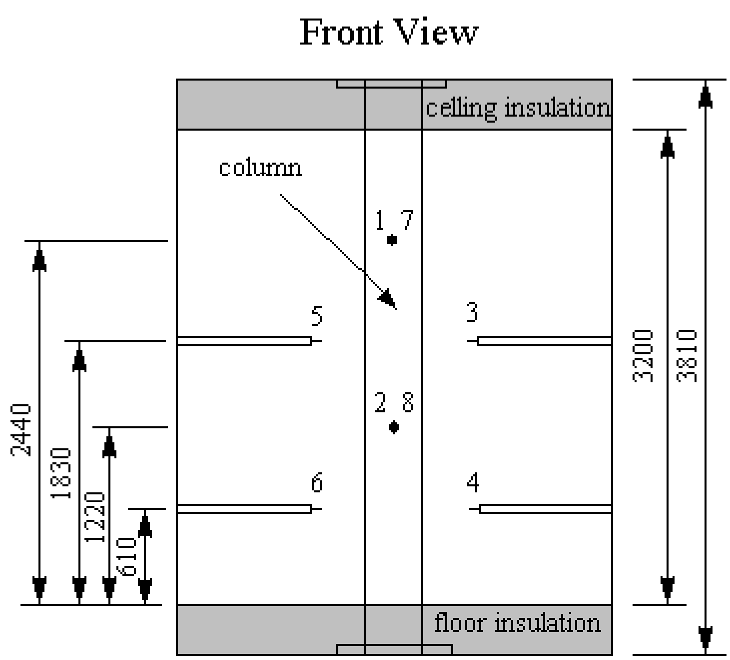


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Fig. A.8 Temperatures and Axial Deformation for Column for Column SQ-14

Table A.1: Temperatures in concrete for Column C-36
Note: °F = (°C x 9/5) + 32

Time	Std. Furn. Temp	Avg. Furn. Temp	**Temperatures (°C) at Thermocouple Number** (see Figure 5 for thermocouple locations)									
(min)	(°C)	(°C)	1	2	3	4	5	6	7	8	9	10
0	20	50	28	18	18	18	18	***	***	***	***	***
2	426	201	97	19	18	18	18	***	***	***	***	***
4	533	439	189	23	19	18	18	***	***	***	***	***
6	598	648	245	31	22	19	19	***	***	***	***	***
8	645	683	294	45	28	21	20	***	***	***	***	***
10	680	688	344	65	37	25	24	***	***	***	***	***
12	709	712	390	81	47	31	29	***	***	***	***	***
14	732	721	403	93	60	38	34	***	***	***	***	***
16	752	748	459	107	74	46	42	***	***	***	***	***
18	770	765	499	121	91	65	57	***	***	***	***	***
20	785	778	571	136	109	106	104	***	***	***	***	***
22	798	799	605	149	126	111	111	***	***	***	***	***
24	810	805	632	163	134	114	114	***	***	***	***	***
26	821	820	646	179	145	120	119	***	***	***	***	***
28	830	825	665	196	156	126	125	***	***	***	***	***
30	839	836	676	214	166	130	130	***	***	***	***	***
32	848	846	690	234	176	134	134	***	***	***	***	***
34	855	851	715	252	186	137	138	***	***	***	***	***
36	862	855	731	270	193	140	139	***	***	***	***	***
38	869	856	740	287	200	143	139	***	***	***	***	***
40	875	853	746	303	210	148	145	***	***	***	***	***
42	881	874	764	318	221	153	151	***	***	***	***	***
44	887	885	783	333	233	158	155	***	***	***	***	***
46	892	891	799	347	244	164	159	***	***	***	***	***
48	897	897	811	361	256	170	165	***	***	***	***	***
50	902	901	822	375	268	178	171	***	***	***	***	***
52	907	904	830	389	280	186	177	***	***	***	***	***
54	911	910	838	402	292	196	185	***	***	***	***	***
56	915	913	847	415	304	205	193	***	***	***	***	***

Table A.1: Temperatures in concrete for Column C-36 (cont'd)
Note: °F = (°C x 9/5) + 32

Time	Std. Furn. Temp	Avg. Furn. Temp	Temperatures (°C) at Thermocouple Number (see Figure 5 for thermocouple locations)									
(min)	(°C)	(°C)	1	2	3	4	5	6	7	8	9	10
58	920	917	856	428	315	214	202	***	***	***	***	***
60	924	921	865	440	327	224	212	***	***	***	***	***
64	931	930	883	463	349	243	231	***	***	***	***	***
68	938	931	895	485	370	263	252	***	***	***	***	***
72	945	943	911	505	391	282	271	***	***	***	***	***
76	951	950	921	523	411	302	289	***	***	***	***	***
80	957	952	929	540	431	320	307	***	***	***	***	***
84	963	960	940	556	449	339	325	***	***	***	***	***
88	969	968	951	571	467	357	343	***	***	***	***	***
92	974	971	955	585	484	376	360	***	***	***	***	***
96	979	976	965	600	500	394	378	***	***	***	***	***
100	984	984	973	613	517	412	395	***	***	***	***	***
104	989	991	977	625	531	430	412	***	***	***	***	***
108	994	984	977	637	544	446	429	***	***	***	***	***
112	999	992	986	649	557	462	445	***	***	***	***	***
116	1003	1009	1000	660	570	478	462	***	***	***	***	***
120	1007	1009	1011	671	583	495	477	***	***	***	***	***
124	1012	1009	1013	683	595	508	492	***	***	***	***	***
128	1016	1016	1017	693	606	521	507	***	***	***	***	***
132	1020	1017	1021	701	614	534	520	***	***	***	***	***
136	1024	1021	1027	710	624	550	533	***	***	***	***	***
140	1028	1024	1027	719	635	562	546	***	***	***	***	***
144	1032	1031	1037	728	645	574	557	***	***	***	***	***
148	1036	1035	1045	735	654	585	568	***	***	***	***	***
152	1039	1036	1058	743	663	596	578	***	***	***	***	***
156	1043	1040	1070	750	671	606	588	***	***	***	***	***
164	1050	1050	1067	764	686	624	606	***	***	***	***	***
172	1057	1053	1079	775	700	639	620	***	***	***	***	***

*** = not measured or measurement not reliable

Note: The test was terminated at 2 hours and 54 minutes

Table A.2: Axial deformations for Column C-36
Note: 1” = 25.4 mm

Time (min)	Axial Deformation (mm)
0	0.000
2	0.162
4	1.242
6	7.595
8	11.470
10	13.840
12	15.200
14	15.420
16	14.660
18	8.703
20	6.810
22	6.039
24	5.433
26	4.910
28	4.555
30	4.229
32	3.845
34	3.267
36	2.882
38	2.577
40	2.287
42	2.110
44	1.759
46	1.485
48	1.175
50	0.899
52	0.688
54	0.469
56	0.244
58	0.020
60	-0.183
64	-0.645
68	-1.173
72	-1.705
6	-2.340
80	-2.972
84	-3.664
88	-4.347
92	-5.154

Table A.2: Axial deformations for Column C-36 (cont'd)
Note: 1" = 25.4 mm

Time	Axial Deformation
(min)	(mm)
96	-6.021
100	-6.952
104	-7.980
108	-9.080
112	-10.200
116	-11.360
120	-12.640
124	-13.980
128	-15.300
132	-16.660
136	-18.070
140	-19.520
144	-20.990
148	-22.500
152	-24.070
156	-25.680
164	-29.480
172	-34.840

Table A.3: Temperatures in concrete for Column C-46
Note: °F = (°C x 9/5) + 32

Time	Std. Furn. Temp	Avg. Furn. Temp	Temperatures (°C) at Thermocouple Number (see Figure 5 for thermocouple locations)									
(min)	(°C)	(°C)	1	2	3	4	5	6	7	8	9	10
0	20	56	22	15	16	15	16	***	***	***	***	***
2	426	424	125	15	16	15	16	***	***	***	***	***
4	533	595	220	17	16	15	15	***	***	***	***	***
6	598	610	271	22	16	15	15	***	***	***	***	***
8	645	653	300	28	17	15	15	***	***	***	***	***
10	680	678	357	35	18	15	16	***	***	***	***	***
12	709	698	343	47	24	17	17	***	***	***	***	***
14	732	709	443	62	32	23	25	***	***	***	***	***
16	752	753	490	80	42	30	34	***	***	***	***	***
18	770	772	506	93	53	39	41	***	***	***	***	***
20	785	788	537	95	60	43	42	***	***	***	***	***
22	798	796	585	96	64	48	44	***	***	***	***	***
24	810	804	618	99	67	49	46	***	***	***	***	***
26	821	818	650	108	71	52	48	***	***	***	***	***
28	830	828	672	113	81	55	51	***	***	***	***	***
30	839	840	692	116	103	60	55	***	***	***	***	***
32	848	850	710	116	112	72	69	***	***	***	***	***
34	855	857	726	130	115	103	101	***	***	***	***	***
36	862	858	734	142	117	115	113	***	***	***	***	***
38	869	865	746	154	113	112	110	***	***	***	***	***
40	875	873	764	164	112	111	110	***	***	***	***	***
42	881	881	779	173	113	112	110	***	***	***	***	***
44	887	888	793	184	114	113	112	***	***	***	***	***
46	892	895	805	195	116	114	113	***	***	***	***	***
48	897	849	808	207	123	116	115	***	***	***	***	***

*** = not measured or measurement not reliable

Note: The test was terminated at 48 minutes

Table A.4: Axial deformations for Column C-46
Note: 1” = 25.4 mm

Time (min)	Axial Deformation (mm)
0	0.00
2	0.78
4	2.75
6	5.88
8	8.40
10	10.64
12	12.26
14	12.86
16	12.66
18	7.63
20	5.51
22	4.40
24	3.77
26	3.34
28	2.96
30	2.63
32	2.28
34	1.92
36	1.31
38	-3.81
40	-5.91
42	-8.07
44	-10.38
46	-14.13
48	-23.61

Table A.5: Temperatures in concrete for Column C-47
Note: °F = (°C x 9/5) + 32

Time	Std. Furn. Temp	Avg. Furn. Temp	**Temperatures (°C) at Thermocouple Number** (see Figure 5 for thermocouple locations)									
(min)	(°C)	(°C)	1	2	3	4	5	6	7	8	9	10
0	20	48	25	20	20	20	20	20	***	***	***	***
2	426	315	94	20	20	20	20	20	***	***	***	***
4	533	592	212	22	20	20	20	20	***	***	***	***
6	598	625	308	29	20	20	20	20	***	***	***	***
8	645	651	381	41	20	20	20	20	***	***	***	***
10	680	672	434	56	20	20	20	20	***	***	***	***
12	709	703	478	70	21	20	21	21	***	***	***	***
14	732	703	511	83	23	21	22	23	***	***	***	***
16	752	730	551	95	25	23	25	25	***	***	***	***
18	770	756	591	108	30	25	29	29	***	***	***	***
20	785	766	619	123	38	31	39	34	***	***	***	***
22	798	780	640	138	52	37	43	43	***	***	***	***
24	810	815	671	151	65	44	47	52	***	***	***	***
26	821	822	695	160	71	49	49	60	***	***	***	***
28	830	844	717	169	83	55	64	71	***	***	***	***
30	839	846	734	178	96	75	92	79	***	***	***	***
32	848	847	737	188	101	90	102	86	***	***	***	***
34	855	850	743	196	103	95	102	93	***	***	***	***
36	862	860	758	205	105	99	104	98	***	***	***	***
38	869	868	774	213	107	103	105	103	***	***	***	***
40	875	872	773	216	109	105	107	106	***	***	***	***
42	881	880	789	241	111	107	108	110	***	***	***	***
44	887	890	800	257	114	109	109	113	***	***	***	***
46	892	894	807	271	118	111	111	116	***	***	***	***
48	897	897	820	283	123	112	112	119	***	***	***	***
50	902	894	831	293	124	114	112	122	***	***	***	***

*** = not measured or measurement not reliable
Note: The test was terminated at 51 minutes

Table A.6: Axial deformations for Column C-47
Note: 1” = 25.4 mm

Time	Axial Deformation
(min)	(mm)
0	0.000
2	0.046
4	2.705
6	6.440
8	8.950
10	10.930
12	12.440
14	12.670
16	11.120
18	6.932
20	5.471
22	4.519
24	3.766
26	3.069
28	2.653
30	2.225
32	1.723
34	1.314
36	0.965
38	0.639
40	-1.303
42	-2.866
44	-4.117
46	-5.516
48	-8.543
50	-24.160

Table A.7: Temperatures in concrete for Column C-62
Note: °F = (°C x 9/5) + 32

Time	Std. Furn. Temp	Avg. Furn. Temp	**Temperatures (°C) at Thermocouple Number** (see Figure 7 for thermocouple locations)									
(min)	(°C)	(°C)	1	2	3	4	5	6	7	8	9	10
0	20	51	22	***	22	22	22	22	22	22	22	31
2	426	426	27	***	22	22	22	22	22	22	23	198
4	533	582	46	***	22	22	24	27	22	22	29	249
6	598	630	64	***	23	22	29	36	22	23	38	335
8	645	668	83	100	25	23	38	48	24	25	51	379
10	680	697	104	49	29	25	49	59	28	28	63	413
12	709	719	124	60	34	28	60	73	32	33	77	489
14	732	730	148	72	40	32	73	88	38	39	93	542
16	752	752	171	85	48	38	87	103	45	47	108	573
18	770	763	187	100	57	45	118	117	54	56	121	595
20	785	781	205	113	66	53	125	126	64	66	129	628
22	798	792	220	125	77	61	128	134	75	78	139	656
24	810	808	236	135	87	70	137	143	86	89	149	681
26	821	819	260	143	97	78	146	154	96	99	160	706
28	830	829	284	152	106	87	155	165	106	109	173	727
30	839	838	308	160	114	95	164	178	117	120	186	738
32	848	841	330	168	123	104	173	192	129	131	200	753
34	855	847	350	177	130	112	173	206	133	134	216	767
36	862	854	371	188	137	120	182	221	134	136	231	782
38	869	875	390	201	144	127	198	236	135	139	247	794
40	875	870	408	215	149	134	213	251	139	142	262	808
42	881	889	426	228	155	138	229	267	312	148	278	819

*** = not measured or measurement not reliable
Note: The test was terminated at 43 minutes

Table A.8: Axial deformations for Column C-62
Note: 1” = 25.4 mm

Time	Axial Deformation
(min)	(mm)
0	0.000
2	0.943
4	3.307
6	4.913
8	5.646
10	5.731
12	4.889
14	3.692
16	3.014
18	2.430
20	2.048
22	1.702
24	1.349
26	0.932
28	0.383
30	-0.859
32	-2.813
34	-4.829
36	-7.212
38	-9.808
40	-13.320
42	-26.990

Table A.9: Temperatures in concrete for Column C-69
Note: °F = (°C x 9/5) + 32

Time	Std. Furn. Temp	Avg. Furn. Temp	Temperatures (°C) at Thermocouple Number (see Figure 5 for thermocouple locations).									
(min)	(°C)	(°C)	1	2	3	4	5	6	7	8	9	10
0	20	51	29	15	16	16	16	16	***	***	***	***
2	426	445	162	15	16	16	16	16	***	***	***	***
4	533	564	268	15	16	16	16	16	***	***	***	***
6	598	622	344	15	16	16	16	16	***	***	***	***
8	645	656	409	15	16	16	16	16	***	***	***	***
10	680	692	473	15	16	16	16	16	***	***	***	***
12	709	719	523	16	16	16	16	16	***	***	***	***
14	732	725	556	16	16	16	16	16	***	***	***	***
16	752	749	594	16	16	16	16	17	***	***	***	***
18	770	771	615	17	16	16	16	17	***	***	***	***
20	785	784	644	18	16	16	16	18	***	***	***	***
22	798	799	675	19	16	16	16	18	***	***	***	***
24	810	802	701	21	16	16	16	19	***	***	***	***
26	821	820	724	22	17	16	16	20	***	***	***	***
28	830	820	737	24	17	17	17	22	***	***	***	***
30	839	835	751	26	18	17	17	23	***	***	***	***
32	848	844	760	28	19	17	17	25	***	***	***	***
34	855	854	773	31	20	18	17	26	***	***	***	***
36	862	862	785	33	21	19	18	28	***	***	***	***
38	869	865	795	36	23	19	18	31	***	***	***	***
40	875	873	807	39	24	20	19	33	***	***	***	***
42	881	874	816	42	26	21	20	35	***	***	***	***
44	887	884	828	45	29	23	21	38	***	***	***	***
46	892	893	839	49	31	24	22	41	***	***	***	***
48	897	897	847	53	34	26	24	44	***	***	***	***
50	902	891	853	56	37	28	25	47	***	***	***	***
52	907	902	864	60	40	32	27	50	***	***	***	***
54	911	908	871	64	43	35	29	54	***	***	***	***
56	915	916	880	68	46	40	31	59	***	***	***	***

Table A.9: Temperatures in concrete for Column C-69 (cont'd)
Note: °F = (°C x 9/5) + 32

Time	Std. Furn. Temp	Avg. Furn. Temp	**Temperatures (°C) at Thermocouple Number** (see Figure 5 for thermocouple locations)									
(min)	(°C)	(°C)	1	2	3	4	5	6	7	8	9	10
58	920	919	887	72	50	45	34	64	***	***	***	***
60	924	918	893	76	53	51	36	71	***	***	***	***
64	931	932	906	85	61	64	40	92	***	***	***	***
68	938	939	913	93	69	74	48	108	***	***	***	***
72	945	943	922	102	77	82	57	120	***	***	***	***
76	951	955	931	110	85	90	67	127	***	***	***	***
80	957	948	931	119	92	96	80	132	***	***	***	***
84	963	964	944	127	100	102	93	138	***	***	***	***
88	969	975	952	135	110	109	118	145	***	***	***	***
92	974	995	952	142	120	115	134	150	***	***	***	***
96	979	978	944	147	131	122	136	153	***	***	***	***
100	984	830	955	152	138	128	139	155	***	***	***	***
108	994	826	952	159	144	142	140	152	***	***	***	***
116	1003	842	964	165	143	141	140	151	***	***	***	***
124	1012	844	973	171	142	138	138	154	***	***	***	***
132	1020	1022	1007	180	144	135	134	159	***	***	***	***
140	1028	1018	998	191	146	133	131	168	***	***	***	***
148	1036	1035	1014	205	151	129	128	178	***	***	***	***
156	1043	1041	1021	220	158	126	125	192	***	***	***	***
164	1050	1048	1031	234	167	124	122	205	***	***	***	***
172	1057	1054	1055	249	177	123	120	218	***	***	***	***
180	1064	1062	1088	263	188	130	118	231	***	***	***	***
188	1071	1067	1102	277	200	138	121	245	***	***	***	***
196	1077	1076	1244	292	212	149	128	258	***	***	***	***
204	1084	1079	1184	305	225	161	137	271	***	***	***	***
220	1096	1090	1099	333	250	190	164	298	***	***	***	***
236	1108	1105	897	360	277	220	197	325	***	***	***	***
252	1119	1117	996	386	304	250	228	352	***	***	***	***

*** = not measured or measurement not reliable

Note: The test was terminated at 4 hours and 19 minutes

Table A.10: Axial deformations for Column C-69
Note: 1” = 25.4 mm

Time	Axial Deformation
(min)	(mm)
0	0.00
2	0.60
4	0.84
6	0.84
8	0.84
10	0.84
12	0.84
14	0.72
16	0.49
18	0.24
20	0.08
22	-0.05
24	-0.20
26	-0.32
28	-0.43
30	-0.57
32	-0.80
34	-0.97
36	-1.10
38	-1.20
40	-1.28
42	-1.40
44	-1.48
46	-1.56
48	-1.64
50	-1.74
52	-1.77
54	-1.87
56	-1.94
58	-2.00
60	-2.10
64	-2.29
68	-2.56
72	-2.86
76	-3.16
80	-3.53
84	-3.88
88	-4.25

Table A.10: Axial deformations for Column C-69 (cont'd)
Note: 1" = 25.4 mm

Time	Axial Deformation
(min)	(mm)
92	-4.70
96	-5.17
100	-5.55
108	-6.56
116	-7.34
124	-8.14
132	-8.84
140	-9.75
148	-10.41
156	-11.19
164	-11.99
172	-12.88
180	-13.73
188	-14.43
196	-15.34
204	-16.29
220	-18.40
236	-20.87
252	-24.12

Table A.11: Temperatures in concrete for Column C-70
Note: °F = (°C x 9/5) + 32

Time	Std. Furn. Temp	Avg. Furn. Temp	**Temperatures (°C) at Thermocouple Number** (see Figure 7 for thermocouple locations)									
(min)	(°C)	(°C)	1	2	3	4	5	6	7	8	9	10
0	20	55	17	17	17	17	16	17	17	17	17	25
2	426	421	17	17	17	17	16	17	17	17	17	104
4	533	560	17	17	17	17	16	17	17	17	17	168
6	598	602	17	17	17	17	16	17	17	17	17	227
8	645	637	17	17	17	17	16	17	17	17	17	289
10	680	670	18	18	17	17	16	17	17	18	18	348
12	709	695	20	18	18	17	16	17	17	19	20	402
14	732	699	23	20	19	17	16	19	18	21	22	445
16	752	732	27	22	20	18	16	42	26	23	25	489
18	770	771	36	25	22	18	16	77	54	26	28	534
20	785	785	47	28	24	19	17	84	68	29	32	574
22	798	795	53	33	27	21	17	92	73	32	36	605
24	810	808	59	39	31	23	18	99	83	36	41	629
26	821	820	67	46	35	26	19	110	95	41	46	654
28	830	826	74	54	41	28	20	114	103	46	51	679
30	839	834	82	62	47	31	21	112	106	51	57	701
32	848	845	92	67	54	37	23	108	103	57	62	720
34	855	856	99	73	62	41	25	107	102	63	68	736
36	862	858	108	81	68	51	27	107	103	70	75	745
38	869	869	111	91	78	94	29	108	104	77	83	751
40	875	874	113	102	88	106	31	108	104	85	91	761
42	881	880	114	107	103	107	34	109	105	93	100	774
44	887	885	113	111	110	110	36	111	107	105	111	783
46	892	892	111	113	109	108	42	109	107	108	112	793
48	897	897	111	113	109	108	45	108	106	109	113	805
50	902	898	113	114	109	108	48	108	106	110	114	814
52	907	903	118	116	109	108	51	108	106	111	116	823
54	911	906	125	118	110	109	54	109	107	112	118	832

Table A.11: Temperatures in concrete for Column C-70 (cont'd)
Note: °F = (°C x 9/5) + 32

Time	Std. Furn. Temp	Avg. Furn. Temp	**Temperatures (°C) at Thermocouple Number** (see Figure 7 for thermocouple locations)									
(min)	(°C)	(°C)	1	2	3	4	5	6	7	8	9	10
56	915	913	131	120	110	109	57	109	109	113	120	837
58	920	903	136	122	111	109	65	109	109	115	122	842
60	924	918	142	121	112	109	69	109	109	117	125	854
62	927	926	148	122	113	108	72	110	110	108	130	865
64	931	932	153	123	115	108	72	110	110	108	135	875
66	935	937	159	126	116	109	75	113	111	109	124	884
68	938	930	165	129	117	109	80	114	111	115	146	888
70	942	936	171	132	118	109	84	117	113	110	151	894
72	945	961	177	136	121	110	97	121	117	110	156	900
74	948	942	185	135	125	111	97	126	121	111	161	903

*** = not measured or measurement not reliable
Note: The test was terminated at 1 hour and 15 minutes

Table A.12: Axial deformations for Column C-70
Note: 1” = 25.4 mm

Time (min)	Axial Deformation (mm)
0	0.000
2	0.200
4	1.182
6	1.998
8	2.625
10	2.961
12	3.039
14	3.039
16	2.757
18	2.022
20	1.340
22	0.740
24	0.327
26	0.050
28	-0.247
30	-0.522
32	-0.741
34	-0.950
36	-1.252
38	-1.630
40	-1.936
42	-2.173
44	-5.048
46	-7.368
48	-8.738
50	-9.870
52	-10.880
54	-11.830
56	-12.750
58	-13.590
60	-14.740
62	-16.240
64	-17.990
66	-20.030
68	-22.090
70	-24.250
72	-26.910
74	-30.000

Table A.13: Temperatures in concrete for Column SQ-11
Note: °F = (°C x 9/5) + 32

Time	Std. Furn. Temp	Avg. Furn. Temp	**Temperatures (°C) at Thermocouple Number** (see Figure 6 for thermocouple locations)									
(min)	(°C)	(°C)	1	2	3	4	5	6	7	8	9	10
0	20	50	27	21	21	21	21	21	***	***	***	***
2	426	419	139	25	21	21	21	21	***	***	***	***
4	533	585	234	37	22	21	21	21	***	***	***	***
6	598	637	307	53	23	21	21	22	***	***	***	***
8	645	654	353	70	29	24	28	29	***	***	***	***
10	680	677	398	90	39	31	36	39	***	***	***	***
12	709	697	441	108	49	40	43	48	***	***	***	***
14	732	729	484	126	59	47	49	58	***	***	***	***
16	752	742	521	143	71	54	53	68	***	***	***	***
18	770	761	552	147	89	61	56	77	***	***	***	***
20	785	783	598	153	100	69	61	85	***	***	***	***
22	798	794	621	139	105	76	67	91	***	***	***	***
24	810	807	634	141	107	83	77	97	***	***	***	***
26	821	824	653	157	110	90	91	104	***	***	***	***
28	830	825	672	168	110	96	103	110	***	***	***	***
30	839	831	691	172	112	101	106	117	***	***	***	***
32	848	844	710	174	115	105	111	124	***	***	***	***
34	855	847	725	175	119	109	118	132	***	***	***	***
36	862	858	738	185	122	114	127	139	***	***	***	***
38	869	848	739	193	119	119	133	145	***	***	***	***
40	875	854	746	203	121	124	133	151	***	***	***	***
42	881	890	766	220	127	127	133	155	***	***	***	***
44	887	885	784	241	132	129	133	158	***	***	***	***
46	892	894	800	261	135	131	133	160	***	***	***	***
48	897	892	809	281	140	131	130	162	***	***	***	***
50	902	900	820	299	144	130	125	166	***	***	***	***
52	907	899	828	318	148	130	126	169	***	***	***	***
54	911	919	839	336	154	130	127	173	***	***	***	***

Table A.13: Temperatures in concrete for Column SQ-11 (cont'd)
Note: °F = (°C x 9/5) + 32

Time	Std. Furn. Temp	Avg. Furn. Temp	**Temperatures (°C) at Thermocouple Number** (see Figure 6 for thermocouple locations)									
(min)	(°C)	(°C)	1	2	3	4	5	6	7	8	9	10
56	915	915	847	353	159	132	129	178	***	***	***	***
58	920	918	855	370	165	135	130	183	***	***	***	***
60	924	924	864	386	172	137	132	190	***	***	***	***
64	931	938	876	417	188	142	135	207	***	***	***	***
68	938	934	884	447	205	149	141	225	***	***	***	***
72	945	936	895	473	223	157	150	246	***	***	***	***
76	951	957	901	499	244	169	161	266	***	***	***	***
80	957	948	908	522	265	186	176	286	***	***	***	***
84	963	957	917	543	286	207	194	305	***	***	***	***
88	969	969	929	562	307	229	215	324	***	***	***	***
92	974	976	942	580	329	251	237	343	***	***	***	***
96	979	997	954	596	350	273	258	362	***	***	***	***
100	984	1023	970	611	370	293	278	380	***	***	***	***
104	989	993	969	626	390	314	298	398	***	***	***	***
108	994	976	960	638	409	333	317	415	***	***	***	***
112	999	990	967	646	427	352	336	433	***	***	***	***
116	1003	1004	977	656	445	370	354	449	***	***	***	***
120	1007	1008	977	665	461	388	371	465	***	***	***	***
124	1012	1013	983	675	477	405	389	481	***	***	***	***
128	1016	1013	988	684	492	421	405	496	***	***	***	***

*** = not measured or measurement not reliable
Note: The test was terminated at 2 hours and 8 minutes

Table A.14: Axial deformations for Column SQ-11
Note: 1” = 25.4 mm

Time (min)	Axial Deformation (mm)
0	-0.04
2	1.17
4	5.39
6	8.89
8	11.29
10	13.36
12	14.98
14	15.86
16	16.08
18	14.76
20	10.07
22	6.84
24	5.14
26	3.83
28	2.80
30	2.02
32	1.34
34	0.58
36	-0.17
38	-0.84
40	-1.39
42	-1.89
44	-2.44
46	-2.94
48	-3.43
50	-3.89
52	-4.35
54	-4.78
56	-5.25
58	-5.74
60	-6.23
64	-7.31
68	-8.44
72	-9.59
76	-10.81
80	-12.15
84	-13.55
88	-15.07
92	-16.77

Table A.14: Axial deformations for Column SQ-11 (cont'd)
Note: 1" = 25.4 mm

Time	Axial Deformation
(min)	(mm)
96	-18.62
100	-20.65
104	-22.83
108	-25.00
112	-27.17
116	-29.63
120	-32.18
124	-35.07
128	-38.44

Table A.15: Temperatures in concrete for Column SQ-14
Note: °F = (°C x 9/5) + 32

Time	Std. Furn. Temp	Avg. Furn. Temp	**Temperatures (°C) at Thermocouple Number** (see Figure 8 for thermocouple locations)									
(min)	(°C)	(°C)	1	2	3	4	5	6	7	8	9	10
0	20	62	22	20	20	20	23	20	20	20	20	39
2	426	455	12	34	23	20	23	20	20	22	22	175
4	533	578	***	59	36	20	20	23	22	32	34	247
6	598	630	***	80	49	20	15	29	28	49	52	311
8	645	655	***	102	63	21	8	38	37	68	71	362
10	680	700	***	107	77	24	***	50	48	87	91	419
12	709	726	***	129	90	27	***	63	60	107	111	461
14	732	741	***	149	105	31	***	79	74	123	128	477
16	752	751	***	168	121	35	***	105	98	142	147	486
18	770	776	***	189	136	41	***	115	111	160	164	471
20	785	799	***	209	151	47	***	127	124	171	176	510
22	798	808	***	212	154	53	***	136	134	183	192	530
24	810	826	***	229	163	60	***	146	141	200	213	559
26	821	828	***	248	178	67	***	133	122	228	239	595
28	830	825	***	266	192	73	***	134	120	252	264	622
30	839	839	***	284	205	79	***	136	119	276	289	652
32	848	842	***	301	218	86	***	145	121	298	313	677
34	855	853	***	318	231	93	***	163	138	321	335	704
36	862	863	***	335	244	100	***	189	167	342	357	726
38	869	874	***	351	258	108	***	213	196	363	379	743
40	875	883	***	368	271	116	***	234	218	383	400	754
42	881	887	***	384	283	124	***	254	238	403	420	767
44	887	891	***	400	295	131	***	272	256	423	440	785
46	892	901	***	415	309	138	***	288	272	441	459	802
48	897	892	***	431	324	143	***	304	288	460	477	812
50	902	913	***	447	339	147	***	320	303	477	495	827
52	907	900	***	462	354	151	***	335	318	494	512	834
54	911	913	***	478	369	155	***	350	333	511	529	846

Table A.15: Temperatures in concrete for Column SQ-14 (cont'd)
Note: °F = (°C x 9/5) + 32

Time	Std. Furn. Temp	Avg. Furn. Temp	Temperatures (°C) at Thermocouple Number (see Figure 8 for thermocouple locations)									
(min)	(°C)	(°C)	1	2	3	4	5	6	7	8	9	10
56	915	920	***	493	383	158	***	365	347	527	544	854
58	920	927	***	507	397	162	***	379	362	542	559	862
60	924	930	***	521	411	165	***	393	376	556	573	869
62	927	933	***	535	424	168	***	407	390	570	587	875
64	931	934	***	547	437	171	***	420	403	583	599	880
66	935	925	***	560	449	176	***	434	417	595	611	882
68	938	929	***	571	461	183	***	447	430	606	622	888
70	942	939	***	583	473	192	***	459	443	617	632	895
72	945	935	***	594	484	203	***	471	456	628	642	898
74	948	945	***	604	495	214	***	483	468	638	652	907
76	951	938	***	614	506	225	***	495	480	648	661	910
78	954	949	***	624	517	237	***	506	492	657	670	915
80	957	961	***	634	529	249	***	517	503	666	678	922
82	960	959	***	643	539	261	***	527	513	674	686	924
84	963	959	***	652	551	274	***	538	524	682	694	928
86	966	967	***	661	561	286	***	547	534	690	701	933
88	969	972	***	669	572	300	***	557	544	697	708	938

*** = not measured or measurement not reliable
Note: The test was terminated at 1 hour and 29 minutes

Table A.16: Axial deformations for Column SQ-14
Note: 1” = 25.4 mm

Time (min)	Axial Deformation (mm)
0	0.00
2	0.95
4	2.97
6	5.08
8	7.65
10	9.99
12	10.88
14	11.04
16	10.06
18	5.01
20	3.56
22	2.85
24	2.28
26	1.67
28	1.05
30	0.48
32	-0.18
34	-0.85
36	-1.57
38	-2.22
40	-2.80
42	-3.35
44	-3.88
46	-4.36
48	-4.88
50	-5.35
52	-5.85
54	-6.41
56	-6.97
58	-7.56
60	-8.16
62	-8.83
64	-9.51
66	-10.20
68	-10.92
70	-11.68
72	-12.47
74	-13.11
76	-13.91

Table A.16: Axial deformations for Column SQ-14 (cont'd)
Note: 1" = 25.4 mm

Time	Axial Deformation
(min)	(mm)
78	-14.76
80	-15.68
82	-16.74
84	-18.00
86	-19.49
88	-21.81

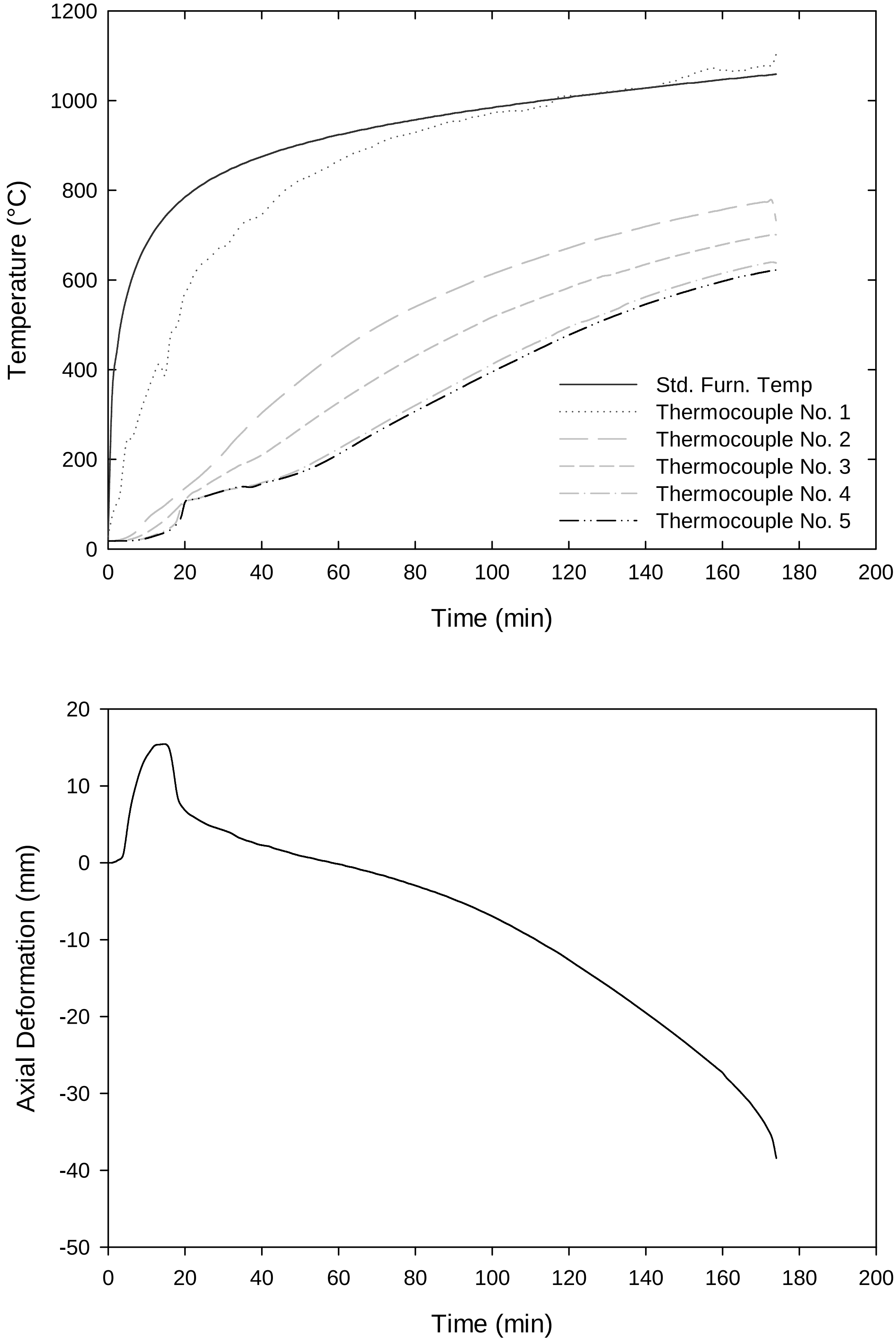


Fig. A.1: Temperatures and Axial Deformations for Column C-36

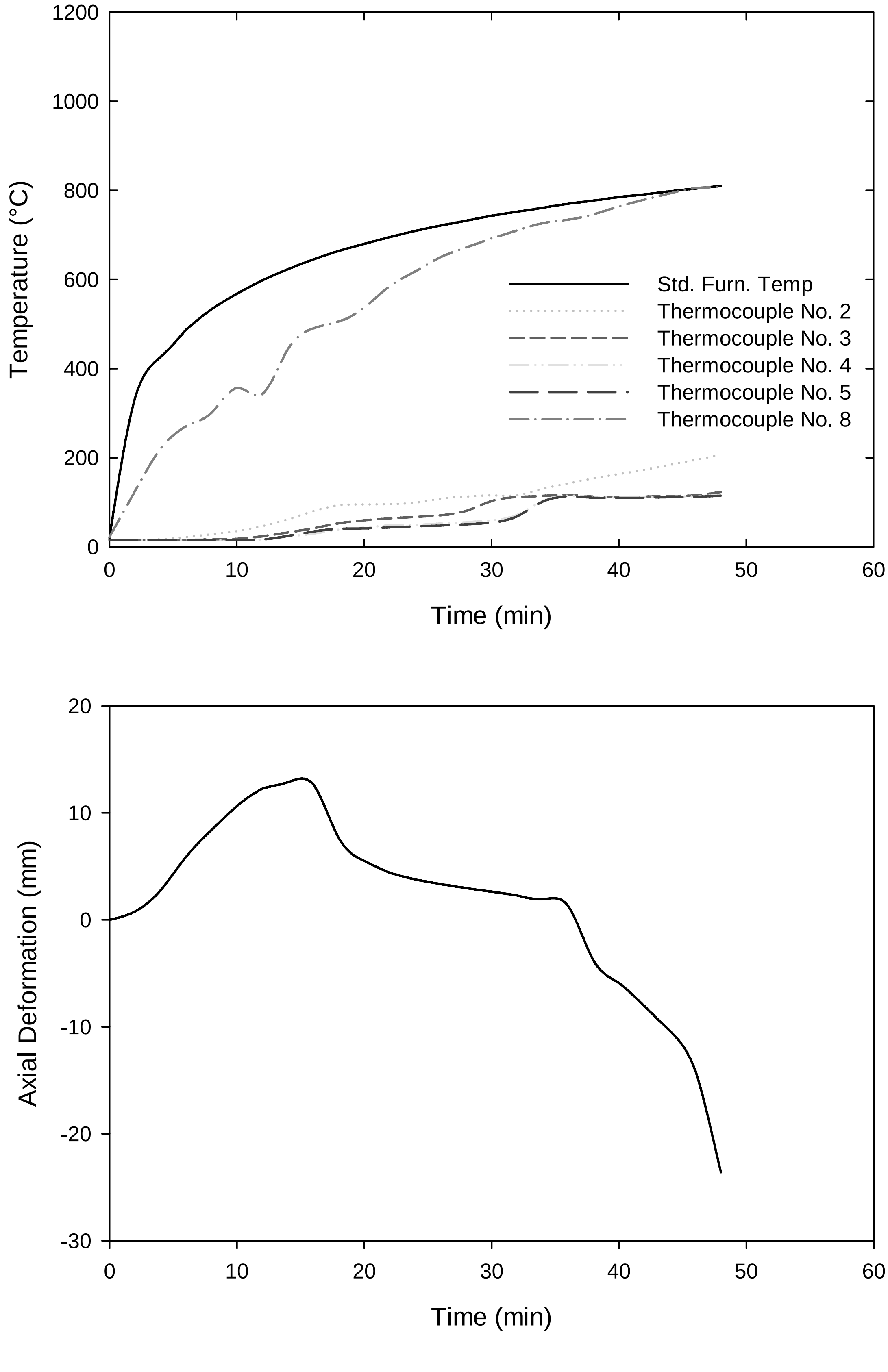
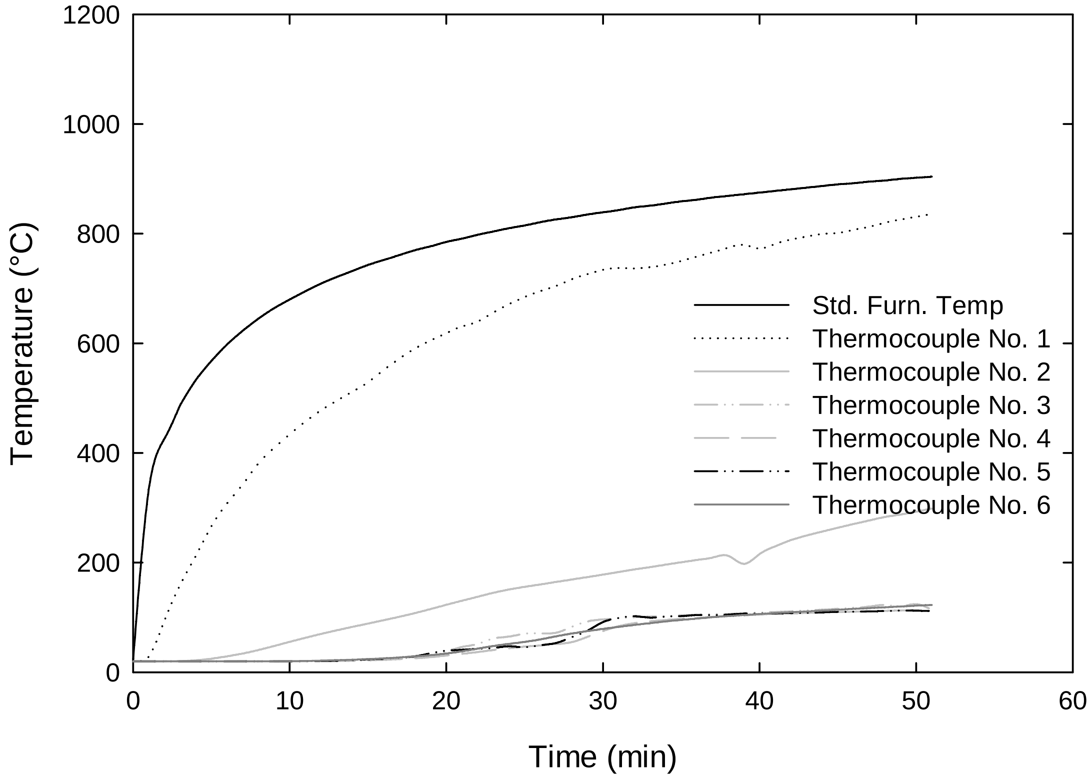


Fig. A.2: Temperatures and Axial Deformations for Column C-46



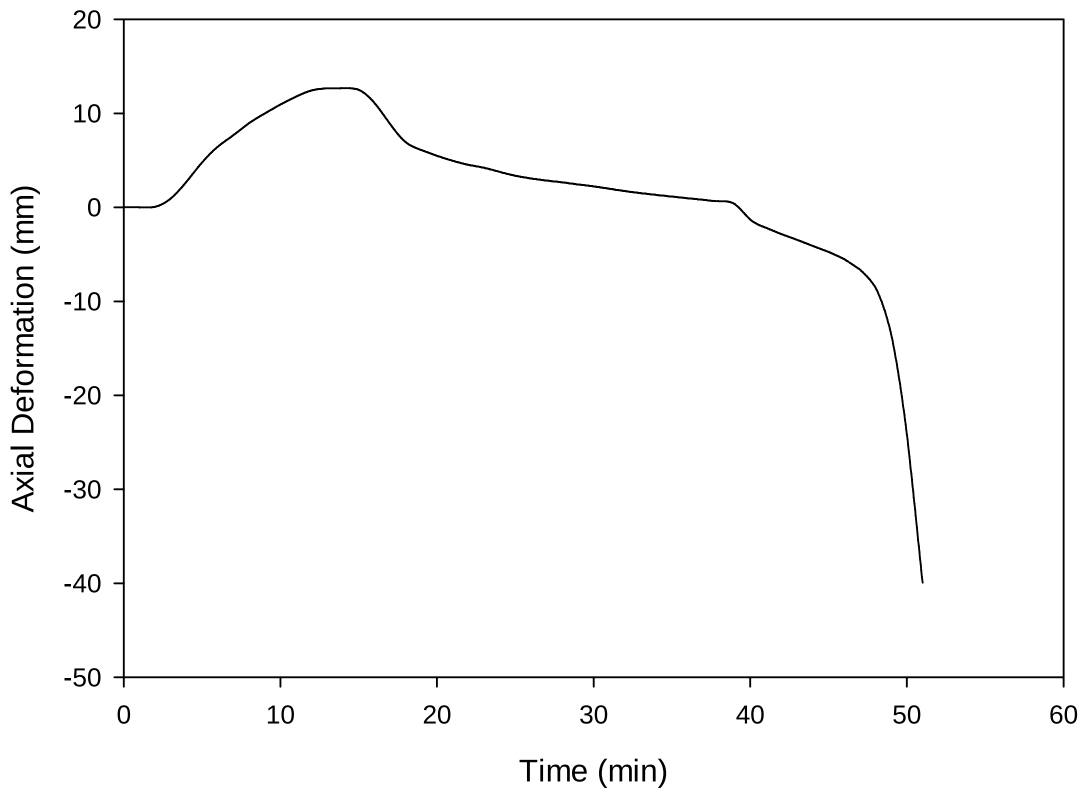
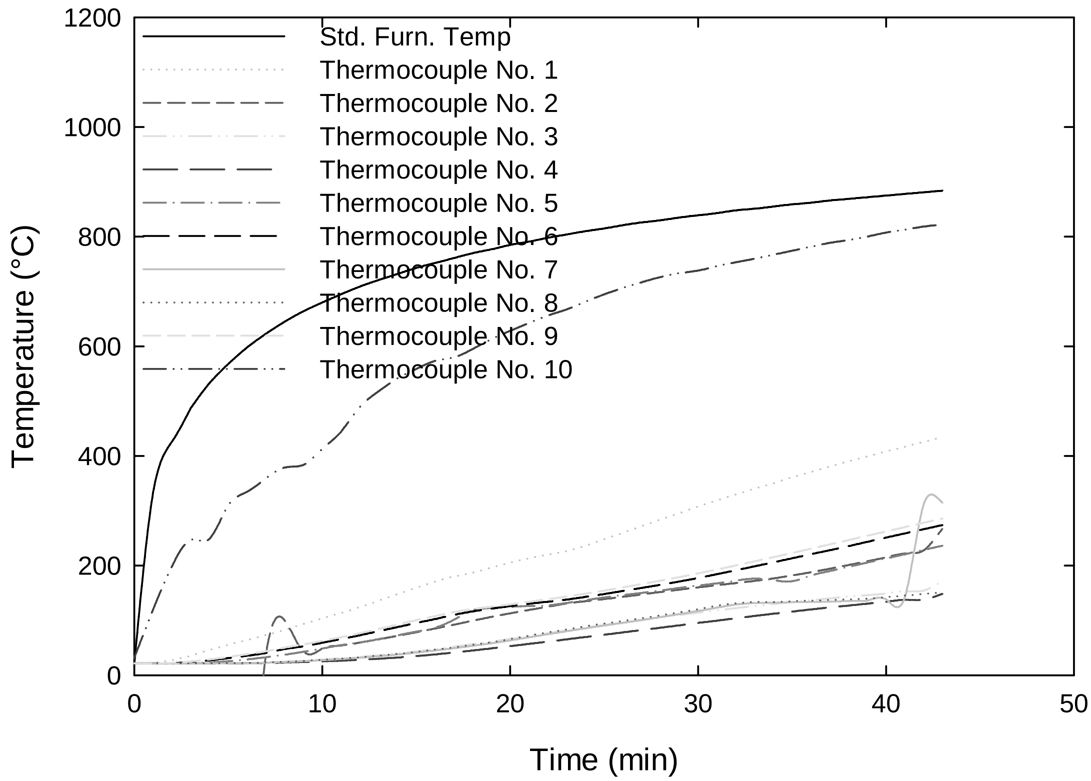


Fig. A.3: Temperatures and Axial Deformations for Column C-47



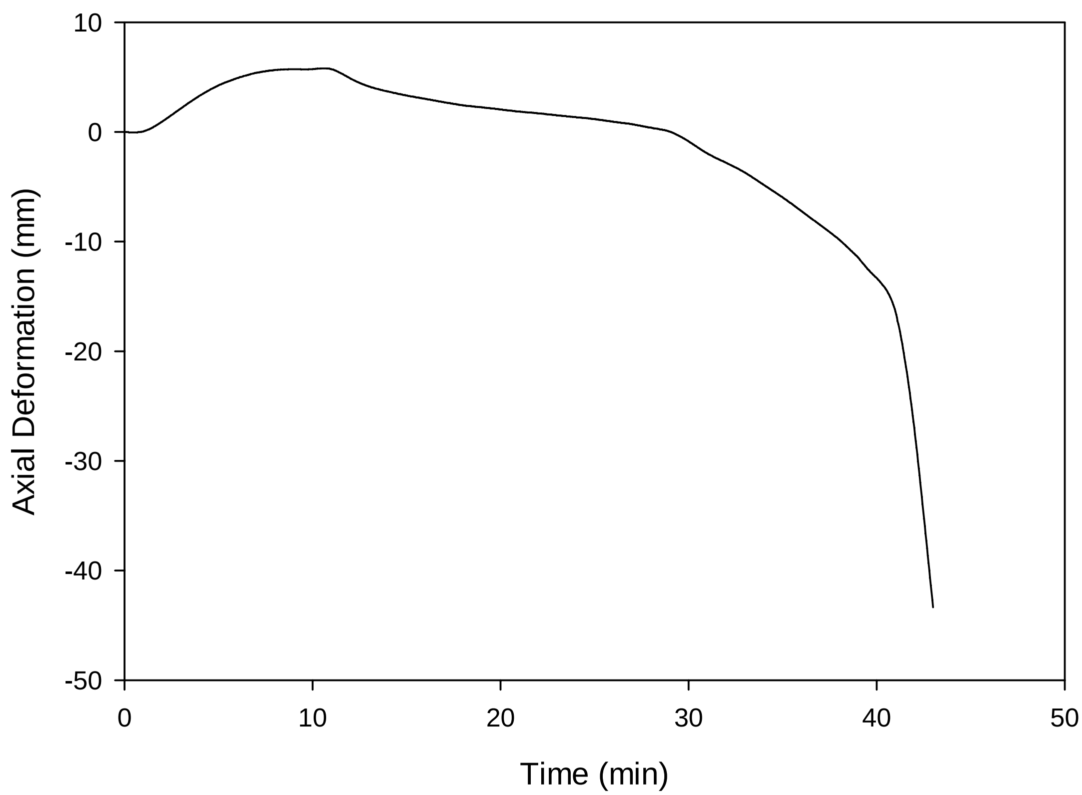


Fig. A.4: Temperatures and Axial Deformations for Column C-62

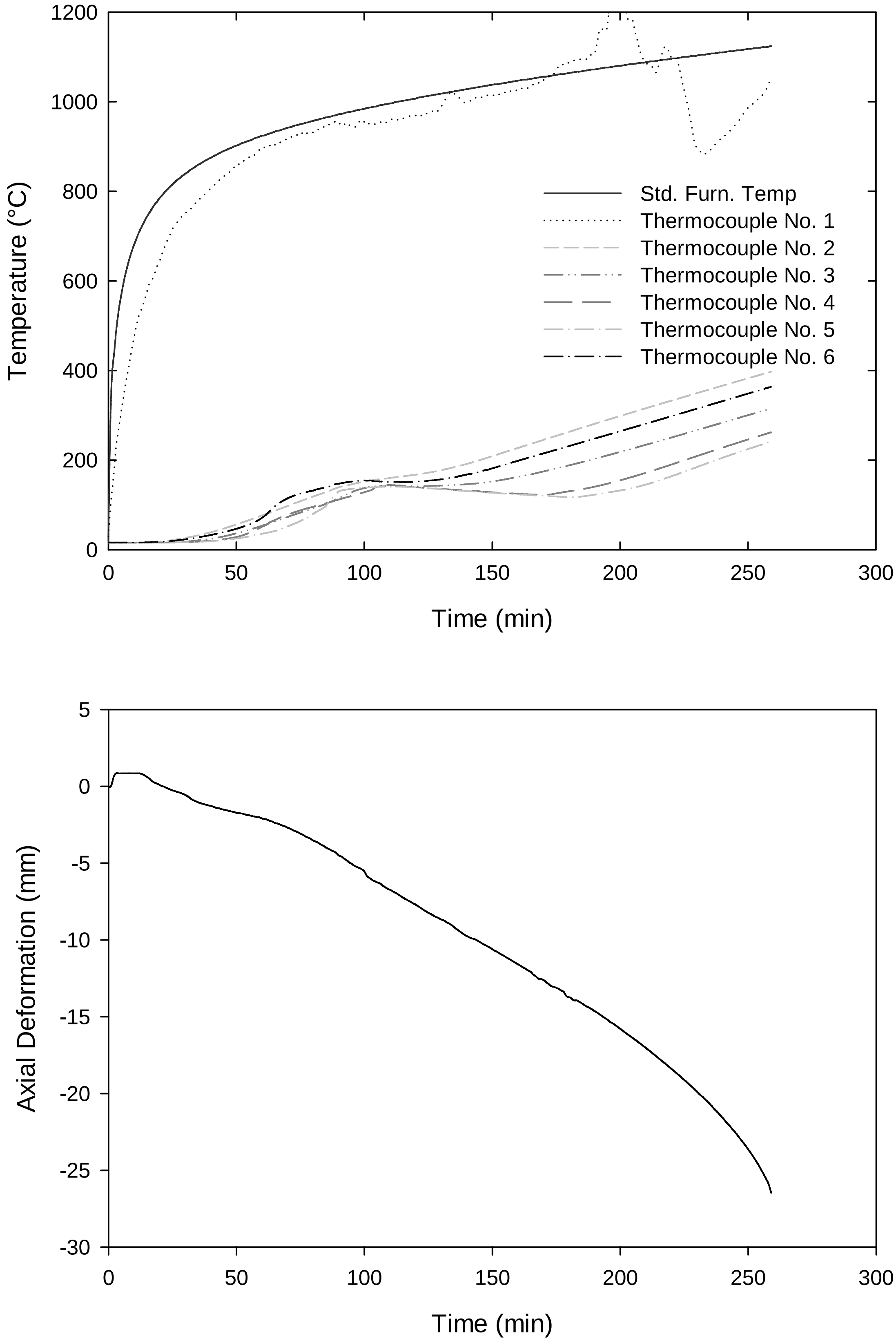


Fig. A.5: Temperatures and Axial Deformations for Column C-69

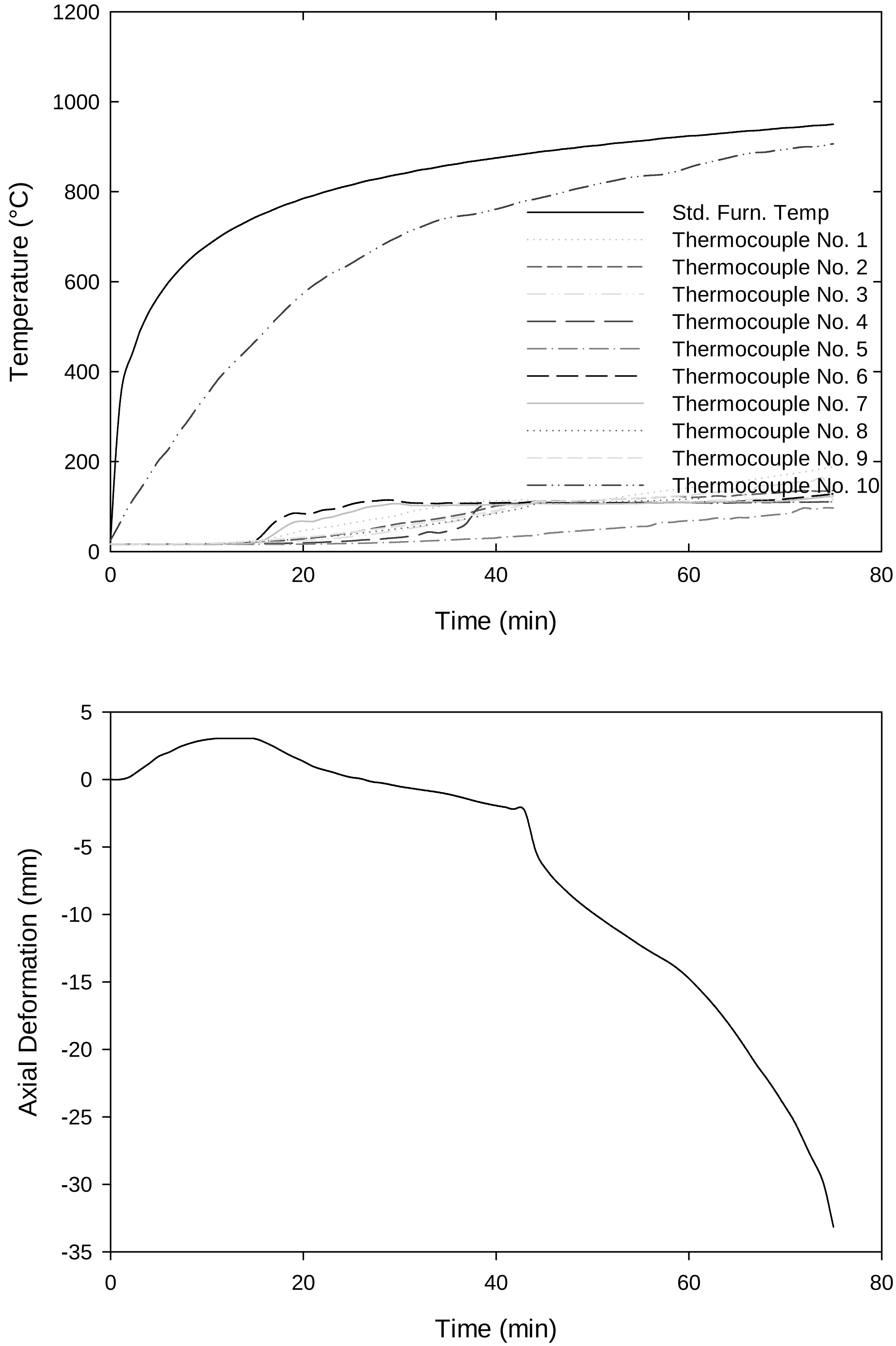
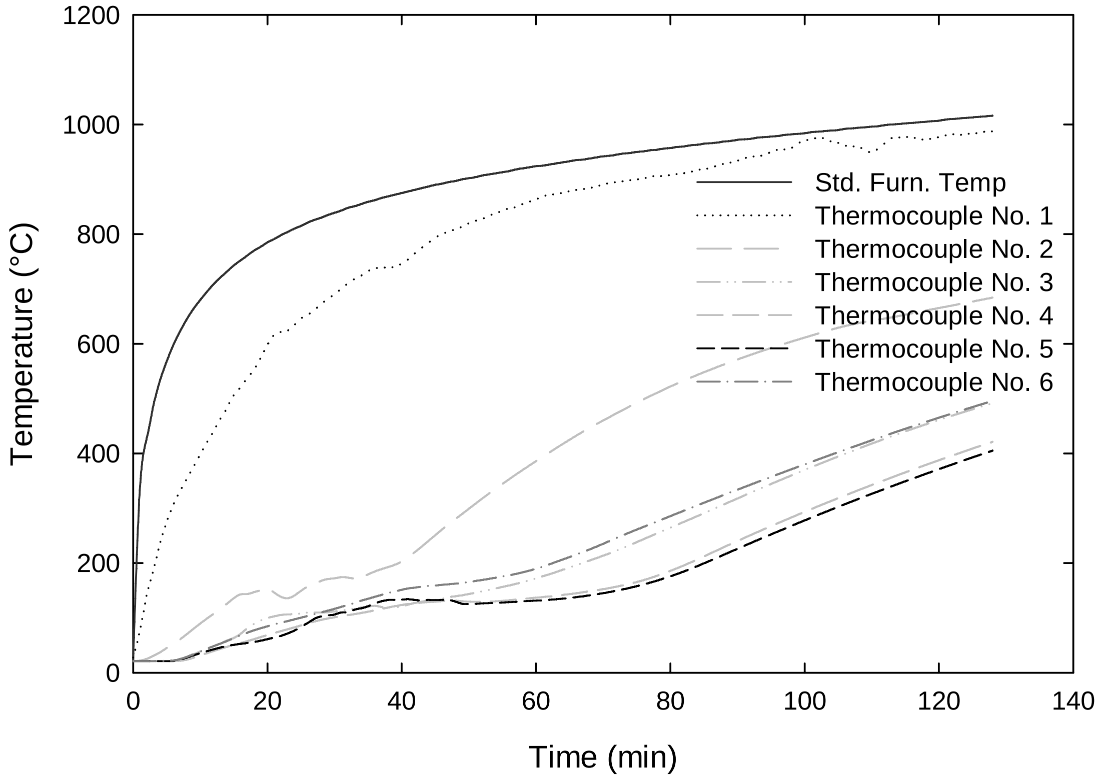


Fig. A.6: Temperatures and Axial Deformations for Column C-70



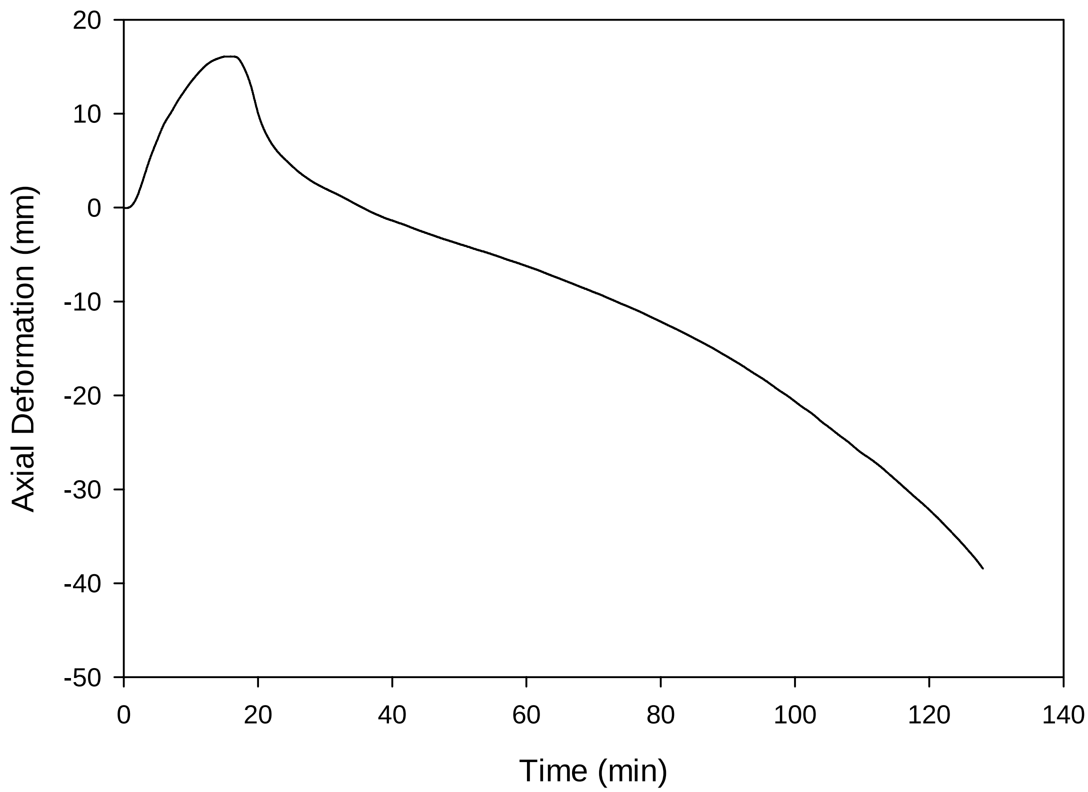
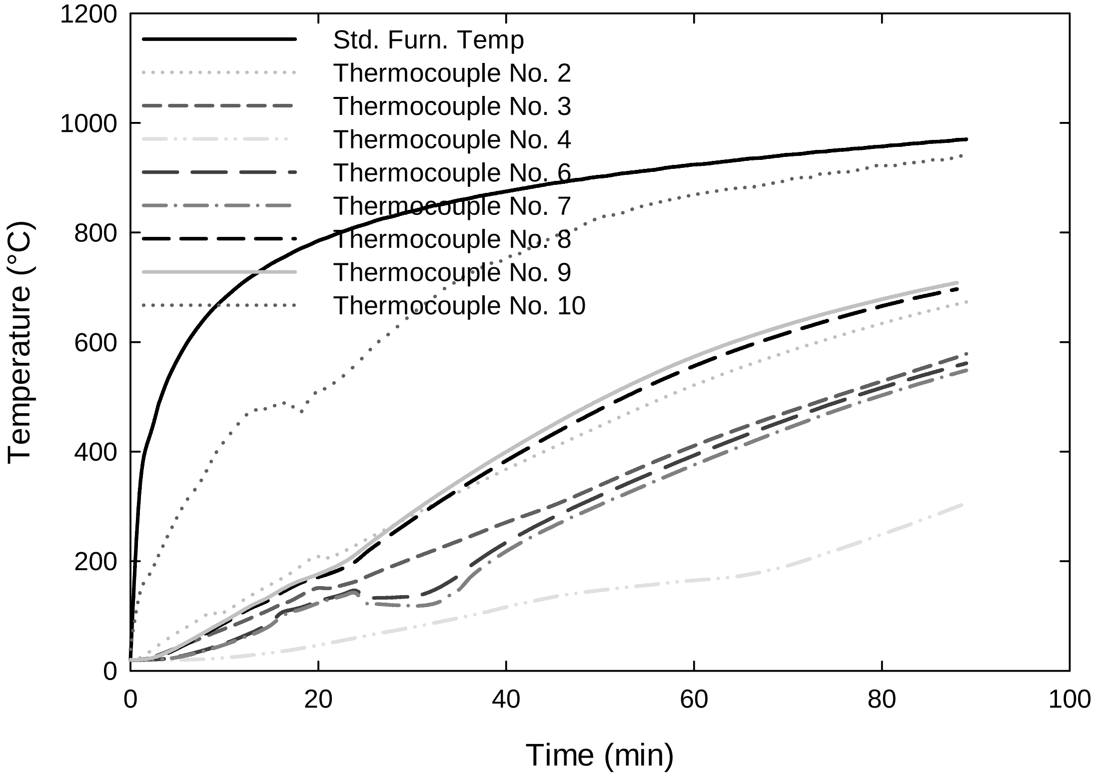


Fig. A.7: Temperatures and Axial Deformations for Column SQ-11



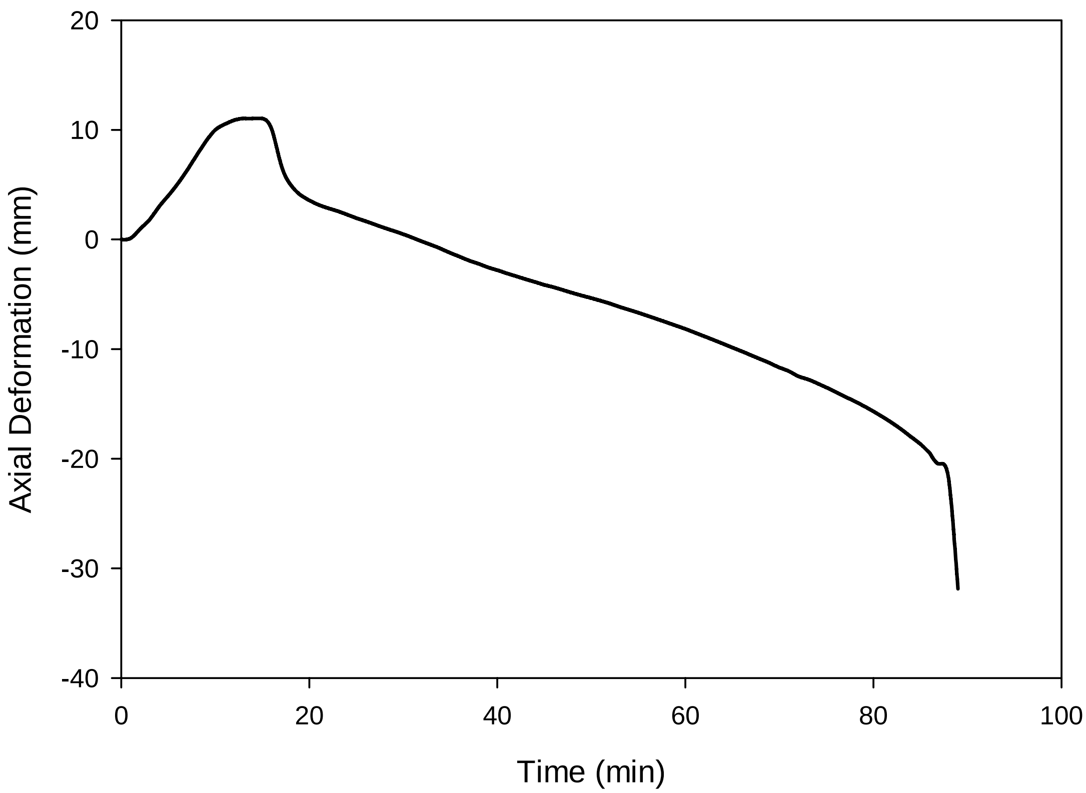


Fig. A.8: Temperatures and Axial Deformations for Column SQ-14

APPENDIX B

VIEW OF COLUMN SPECIMENS AFTER FIRE TEST

List of Figures

Fig. B.1 View of Column C-36 after Fire Endurance Test

Fig. B.2 View of Column C-46 after Fire Endurance Test

Fig. B.3 View of Column C-47 after Fire Endurance Test

Fig. B.4 View of Column C-62 after Fire Endurance Test

Fig. B.5 View of Column C-69 after Fire Endurance Test

Fig. B.6 View of Column C-70 after Fire Endurance Test

Fig. B.7 View of Column SQ-11 after Fire Endurance Test

Fig. B.8 View of Column SQ-14 after Fire Endurance Test