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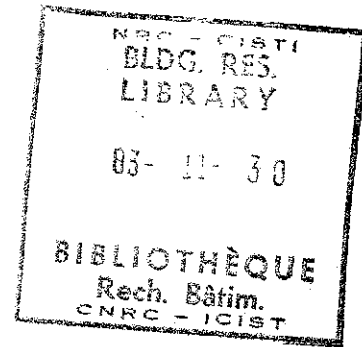
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FIRE TESTS ON REINFORCED CONCRETE COLUMNS, SPECIMEN NO. 3

by T.T. Lie and T.D. Lin

ANALYSED



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NATIONAL RESEARCH COUNCIL OF CANADA
DIVISION OF BUILDING RESEARCH

DBR INTERNAL REPORT NO. 480

FIRE TESTS ON REINFORCED CONCRETE COLUMNS, SPECIMEN NO. 3

by T.T. Lie and T.D. Lin

Checked by: T.Z.H.

Approved by: L.W. Gold

Date: October 1983

Prepared for: Record Purposes

ABSTRACT

Results of a fire test on a reinforced concrete column are given. The test is one of a series of twelve tests carried out in the first phase of a joint study on the fire performance of concrete columns by the National Research Council Canada and the Portland Cement Association. The column was made with siliceous aggregate. Its section size was 305 × 305 mm (12 × 12 in.). It was tested to study the influence of load on the fire resistance of the column.

FIRE TESTS ON REINFORCED CONCRETE COLUMNS
SPECIMEN NO. 3

by

T.T. Lie and T.D. Lin*

Tests were carried out on a series of reinforced concrete columns as part of a study to develop methods for the determination of the fire resistance of such columns. The study was a cooperative effort between the National Research Council Canada and the Portland Cement Association. In the first phase of the study, 12 columns were tested. The columns were designed and manufactured by PCA in Skokie, U.S.A., and tested in the NRCC laboratories in Canada. The specimens, method of testing and test results are described in successive reports.

This report deals with specimen No. 3 which was tested to study the influence of load on the fire resistance of the column.

TEST SPECIMEN

The test specimen consisted of a square tied reinforced concrete column. Details of the specimen and its fabrication follow.

Dimensions

Section Size: 305 × 305 mm (12 × 12 in.)
Height: 3810 mm (12 ft 6 in.)

Materials

Cement: Type I, a general purpose cement for the construction of reinforced concrete structures.

Aggregate: Siliceous sand and gravel from Eau Claire, Wisconsin. The maximum size of the aggregate was 19 mm (3/4 in.). The gradation curve is shown in Figure 1. Petrographic information on the aggregate, obtained according to ASTM C295-79¹ is given in Table 1. The physical properties of the aggregate are given in Table 2.

Steel reinforcement: Deformed 25M (No. 8) longitudinal reinforcing bars and 10M (No. 3) ties, meeting the requirements of ASTM Designation A615-60² were used. The yield stress of the 25M bars was 443.7 MPa (64.3 ksi) and that of the 10M bars 426.5 MPa (61.8 ksi). The ultimate strengths of the 25M and 10M bars were 730 MPa (105.8 ksi) and 671 MPa (97 ksi) respectively.

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Concrete mix: The concrete mix was designed to produce a 34.5 MPa (5000 psi) strength non-air-entrained concrete. A water-cement ratio of 0.6 was used. The slump was 97 mm (3.83 in.). Batch quantities are given in Table 3 and measured properties of the concrete in Table 4.

Fabrication

Casting

The column was cast in a specially designed form. At the start of the casting the front side of the form was left open for depositing fresh concrete. The concrete was mixed in a 0.17 m³ (6 ft³) tilting drum mixer. Shovels and scoops were used to deposit concrete in the form. A small internal vibrator was applied to consolidate the concrete. As the casting progressed upwards, the window pieces were successively closed and tightly bolted to the form to avoid possible moisture leaks. Lifting hooks were embedded on opposite sides of the test specimen at 800 mm (2 ft 7 1/2 in.) from the top of the column. A cylindrical humidity well³ with a diameter of 4 mm (5/32 in.) was positioned at mid-height of the column for measuring the relative humidity at mid-depth.

Reinforcing cage

The reinforcing cage was assembled by welding each end of four longitudinal main reinforcing bars to a steel end plate. The bars were cut to 3800 mm (12 ft 5 1/2 in.) and machined at both ends, for a length of 19 mm (3/4 in.) to a diameter of 19 mm (3/4 in.). Figure 2 shows details of the finished bars. The dimensions of the end plates were 533 × 533 × 25 mm (21 × 21 × 1 in.). In each corner of the plate, 20.6 mm holes (13/16 in.) were drilled to accommodate the longitudinal bars. The holes were spaced 92.1 mm (3 5/8 in.) from the centerlines of the plates. In this way a column was obtained with a section of 305 × 305 mm (12 × 12 in.) and a cover of 47.6 mm (1 7/8 in.) to the main reinforcing bars and 38.1 mm (1 1/2 in.) to the stirrups. The main bars and stirrups were tied together to complete the steel cage which, including the steel plates, was 3810 mm (12 ft 6 in.) long.

Welding

The provisions of AWS Designation D12.1-75⁴ were followed when welding plates and bars. These members were preheated with a propane torch to 288°C (550°F), to prevent any possible brittle failure during welding. 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 834.9 MPa (121 000 psi). Mild-steel welding rods were used to fill up the 6 mm (1/4 in.) deep holes on the outer faces of the plate. The rough surfaces of the welded joints on the outer faces of the plate were ground to a smooth finish.

The top steel plate was welded after the columns were cast. 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 and concrete. The mortar was made of one part cement and three parts 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.

Curing

The concrete was cured under damp burlap for seven days at 21 to 24°C (70 to 75°F). The form was then stripped, and the column conditioned in an atmosphere controlled at 21 to 24°C (70 to 75°F) and 30 to 40% relative humidity. The column was removed from the kiln periodically to cool at 23°C (73°F) so that the relative humidity in the concrete could be measured. Moisture content in the column during the drying period is given below.

Days after casting	Relative humidity centre of column (%)
89	92
293	80

Two hundred ninety-three days after the casting of the column, the desired moisture condition was reached, and the column was wrapped in plastic to prevent change of its moisture content.

Thermocouples

Butt-welded chromel-alumel thermocouples with a thickness of 0.912 mm (0.0359 in.) were used to make thermocouple frames for measuring concrete temperatures at different locations in various 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. Temperatures were measured at three levels; i.e., 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 a centerline and diagonal of the section; at the other two levels, the temperatures were measured only along half of the centerline and half of the diagonal of the section. The location of the thermocouples in the concrete and their numbering are shown in Figures 3 and 4.

In addition, a number of thermocouples were mounted on the reinforcing steel bars and ties. The locations of the thermocouples on the steel are shown in Figure 5 and in more detail in Figure 6.

All thermocouples were installed in such a way that the wire followed an isotherm over a distance of at least 12.7 mm (1/2 in.) from the junction.

Test Apparatus

The test was carried out by exposing the column to heat in a furnace specially built for the testing of loaded columns and walls. The test furnace was designed to produce the conditions to which a member might be exposed during a fire; for example, fire temperatures, structural loads, and heat transfer. It consists of a steel framework supported by four steel columns with the furnace chamber inside the framework (Fig. 7). The characteristics and instrumentation of the furnace are described in detail in reference 5. Only a brief description of the furnace and the main components will be given here.

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.

Furnace Chamber

The furnace chamber has a floor area of 2642×2642 mm (8 ft 8 in. \times 8 ft 8 in.) and is 3048 mm (10 ft) high. It is made of insulating materials that will produce a high heat transfer 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 (16×10^6 Btu/h). Each burner can be adjusted individually to obtain a high temperature uniformity in the furnace chamber. The pressure in the furnace chamber is also adjustable. It was set somewhat lower than atmospheric pressure.

Instrumentation

The furnace temperatures were measured with 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 every 610 mm (2 ft) along the height of the furnace chamber. The locations of their junctions and their numbering are shown in Figure 8. Thermocouples Nos. 4 and 6 were located at a height of 610 mm (2 ft) from the floor, thermocouples Nos. 2 and 8 at 1220 mm (4 ft), thermocouples Nos. 3 and 5 at 1830 mm (6 ft) and thermocouples Nos. 1 and 7 at 2440 mm (8 ft). The temperatures measured by the thermocouples were averaged automatically, and the average temperature was used as the criterion for controlling the furnace temperature.

The loads were controlled and measured with the aid of pressure transducers. The accuracy of controlling and measuring loads was about 5% at lower load levels and better at higher loads.

The axial deformation of the test specimen was determined by measuring the displacement of the jack that supported the column. The

displacement was measured using transducers with an accuracy of 0.002 mm.

Test Conditions and Procedures

The column was installed in the furnace by bolting its end plates to a loading head at the top and a hydraulic jack at the bottom. For this purpose eight 19 mm (3/4 in.) bolts, spaced regularly around the column at a distance of 63.5 mm (2 1/2 in.) from the sides were used at each end.

On the day of the test the moisture condition in the centre of the column was measured with a Monfore gauge³. The relative humidity measured prior to the start of the test was 70%. The ambient temperature at the start of the test was 20°C (68°F).

The column was cast on 14 July, 1977 and tested on 25 April, 1980. It was subjected to a load of 800 kN (180 kips) applied about one hour before the test. At the test date, the cylinder strengths of the concrete measured on two cylinders were 34.2 MPa (4961 psi) and 34.0 MPa (4952 psi) respectively.

During the test, the column was exposed to heating controlled so that the average temperature in the furnace followed as closely as possible the ASTM-E119⁶ or ULC-S101⁷ standard temperature-time curve. This curve can be approximately described by the following equation:⁸

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

where

T_f = temperature in °C, and
 τ = time in h

or by

$$T_f = 68 + 1350 [1 - \exp(-3.79553\sqrt{\tau})] + 306.74\sqrt{\tau}$$

where

T_f = temperature in °F

During the test, temperatures in the furnace and in the column were measured at the locations described earlier. The column was considered to have failed and the test was terminated when the hydraulic jack, which has a maximum speed of 76 mm/min (3 in./min) could no longer maintain the load.

TEST RESULTS

Measured Temperatures and Deformations

In Table 5, the steel temperatures are given for various times. The temperatures measured in the concrete sections are given in Tables 6A-D.

In Table 7, the average furnace temperature and in Table 8, the measured axial deformation of the column are given for various times during the test.

Observations

The observations made during the test after various exposure times are given below.

<u>Test Time</u> <u>Hr:Min</u>	<u>Observations</u>
0:0	Fire started.
0:18	Water oozed out on the cast column surface, 450 mm (18 in.) from the furnace bottom. However, it dried in about 5 min (Fig. 9).
0:28	Crack A extended 100-125 mm (4-5 in.). New crack B developed about 50 mm (2 in.) from crack A towards the centerline of the columns.
0:45	About 100 mm (4 in.) from the top end of crack A, a new crack C formed. At this time, cracks D and E became visible on the north and south faces of column, respectively.
1:00	Numerous fine cracks were observed on the north face of the column. Cracks were also seen on the west face.
2:26	Cracks A, B, and C of the east surface formed a long continuous crack, ABC, about 6 to 10 mm (1/4 to 3/8 in.) wide.
3:16	Crack ABC increased in width to about 25 mm (1 in.).
3:38	Column failed as a result of crushing of the concrete with local buckling of the reinforcing bars. A schematic view of the column at the end of the fire test is shown in Figure 10.

Figure 11 shows a schematic view of the main bars. In Figure 12 the column is shown after the test.

DISCUSSION OF RESULTS

The method described in reference 9 was used to calculate the temperatures of the main reinforcing steel, and the temperatures at various depths in the concrete sections. For the reinforcing steel, the temperature at the center has been chosen as representative of the average temperature of the steel. The two average temperatures

obtained from measurements on two reinforcing bars during the test are shown in Figure 13. These measurements were made with thermocouples Nos. 3 and 9 located on one bar opposite each other with respect to the center of one bar, and with thermocouples Nos. 4 and 10, located opposite each other on another bar (see Fig. 6).

The average measured steel temperature and the average steel temperature calculated according to the method described in reference 9 are compared in Figure 13. The comparisons show reasonably good agreement between the calculated temperatures and those measured with thermocouples Nos. 4 and 10. There is a larger difference, however, between the calculated temperatures and those measured with thermocouples Nos. 3 and 9. This difference is caused mainly by the substantially lower temperatures measured by thermocouple No. 3, as can be seen in Figure 14 where the temperatures measured by the individual thermocouples are shown.

In Figure 15 the temperatures shown were measured along a centerline in the concrete section at mid-height at various depths. The curves show good agreement between measured and calculated temperatures.

In Figure 16 the measured axial deformation during the test and those calculated using the method described in reference 9 are shown. There is good agreement between measured and calculated axial deformations. The measured failure time of 218 min. is somewhat higher than the predicted failure time of about 205 min.

The comparison of measured and calculated temperatures, deformations and failure times shows that although the predictions lie on the safe side, the differences between them and the measured values are relatively small.

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TABLE 1 PETROGRAPHY OF SAND AND GRAVEL USED AS AGGREGATE

Component	Composition of Sieve Fraction, Percent on Sieve of Size Indicated											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	--	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.

^bIncludes metagraywacke.

^cThe 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 PHYSICAL PROPERTIES OF AGGREGATE

Specific gravity of sand	2.63
Specific gravity of gravel	2.57
Moisture content of sand, %	4.0
Moisture content of gravel, %	1.0
Saturated surface dry unit weight of gravel, kg/m ³	1678
Fineness modulus of fine aggregate	2.96
Fineness modulus of coarse aggregate	1.73

TABLE 3 BATCH QUANTITIES

Item	Quantity (kg/m ³)
Cement	307.3
Coarse aggregate	1054.3
Sand	871.5
Water	153.7

TABLE 4 PROPERTIES OF THE CONCRETE

Property	Quantity
Air content, %	1.47
Density, kg/m ³	2412
Compressive strength at 28 days, MPa (cast date: July 14/77)	34.8

TABLE 5 MEASURED STEEL TEMPERATURES

Time (min)	Temperature (°C) Measured at Thermocouple No:									
	1	2	3	4	5	6	7	8	9	10
0	20	20	20	20	20	20	20	20	20	20
5	22	20	20	20	20	20	25	22	20	20
10	41	36	28	32	29	27	52	44	26	24
15	91	96	66	68	70	55	97	85	62	48
20	111	111	87	114	109	107	127	116	109	91
25	115	109	89	108	109	116	132	126	110	103
30	125	120	94	115	117	122	165	149	109	109
35	144	140	105	132	132	141	192	179	117	113
40	167	166	120	150	152	164	220	209	134	125
45	191	192	137	171	177	190	247	237	156	141
50	215	218	154	195	203	217	274	263	180	162
55	240	244	170	219	229	243	299	288	204	184
60	264	269	185	243	254	269	323	311	228	207
70	311	315	214	289	302	316	365	352	274	250
80	353	356	241	331	344	357	403	388	315	290
90	391	394	241	369	384	395	438	421	351	327
100	427	429	230	405	421	429	471	452	379	361
110	461	463	243	439	456	462	500	480	411	393
120	493	493	267	471	486	492	525	503	442	424
130	522	521	286	501	514	519	549	529	470	454
140	555	547	306	529	540	544	574	552	498	483
150	600	575	331	555	565	569	598	578	524	510
160	650	603	375	582	591	594	622	603	551	535
170	690	631	465	606	621	618	643	627	577	559
180	716	664	494	631	651	641	664	649	603	585
190	734	698	528	635	680	664	682	669	627	610
200	746	721	560	677	703	686	697	696	650	638
210	753	734	588	696	717	708	709	724	672	672
218	754	741	619	719	722	723	720	762	691	693

TABLE 6A CONCRETE TEMPERATURES MEASURED WITH THERMOCOUPLES IN FRAME A

Time (min)	Temperature (°C) Measured at Thermocouple No:													
	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	20
5	79	59	34	23	20	20	20	20	20	25	47	81	*	175
10	145	116	71	44	23	20	20	20	25	57	108	159	*	328
15	233	175	116	80	35	20	20	20	60	112	162	258	*	478
20	313	243	146	111	57	25	20	35	100	130	235	350	*	553
25	379	303	188	132	91	40	22	49	104	156	295	419	*	635
30	424	348	226	148	101	59	29	56	103	202	351	475	*	685
35	464	387	260	174	105	79	39	65	109	239	402	522	*	730
40	498	420	292	204	111	86	51	75	119	270	444	564	*	766
45	527	451	322	231	120	91	61	85	131	300	481	606	*	795
50	554	480	349	257	129	94	68	94	146	326	514	641	*	821
55	580	506	375	280	141	95	75	102	165	351	543	673	*	825
60	602	529	398	301	150	102	89	111	186	373	571	700	*	758
70	638	567	439	340	178	119	113	126	228	415	621	740	*	771
80	669	603	475	375	206	133	121	135	267	453	660	773	*	774
90	700	635	507	406	232	144	127	153	303	486	694	802	*	674
100	729	666	537	435	257	157	134	175	337	516	726	831	*	659
110	733	679	561	462	282	176	130	198	368	545	751	839	*	657
120	765	707	584	485	307	196	146	221	397	569	771	861	*	668
130	784	730	610	510	333	218	163	244	426	594	797	883	*	689
140	802	750	634	532	359	243	189	269	455	614	818	900	*	696
150	819	769	656	554	385	269	217	295	483	629	836	914	*	694
160	835	786	677	577	410	295	244	320	508	646	852	925	*	689
170	840	803	696	598	434	320	270	345	531	662	867	933	*	693
180	850	818	714	619	458	344	295	369	553	683	873	898	*	699
190	862	832	732	638	481	368	319	392	576	701	755	900	*	706
200	874	845	748	657	503	391	342	414	598	716	749	897	*	711
210	887	850	764	676	525	415	367	436	620	721	748	884	*	712
218	893	854	772	685	535	429	383	446	631	644	749	828	*	714

*Measurement not reliable

TABLE 6B CONCRETE TEMPERATURES MEASURED WITH THERMOCOUPLES IN FRAME B

Time (min)	Temperature (°C) Measured at Thermocouple No:													
	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
5	20	51	31	21	20	20	20	20	21	23	43	74	118	158
10	145	106	68	39	21	20	20	20	23	51	101	151	238	325
15	247	170	114	76	32	20	20	20	45	103	159	249	386	495
20	330	236	143	105	53	22	20	27	102	133	224	338	489	539
25	398	295	189	115	92	34	21	41	103	155	288	398	565	589
30	443	340	233	133	101	52	28	55	108	213	348	440	616	663
35	484	380	270	156	104	65	38	67	108	263	402	475	662	723
40	519	414	302	179	108	75	48	77	113	301	448	507	702	771
45	547	443	330	201	114	81	58	85	129	335	489	540	736	801
50	574	469	354	222	124	88	70	93	151	365	523	569	766	807
55	600	494	377	242	135	96	83	102	174	393	555	597	791	810
60	620	515	397	260	148	104	94	111	196	418	586	624	810	826
70	653	*	433	294	175	119	109	128	239	463	637	672	839	878
80	681	*	462	323	200	131	119	144	279	501	677	704	864	858
90	709	*	489	350	224	141	128	158	313	534	711	751	891	880
100	735	*	515	376	247	155	131	176	346	566	743	804	746	899
110	735	*	536	401	270	173	136	197	377	597	764	803	714	886
120	767	*	558	427	293	196	146	222	407	621	782	805	731	919
130	787	*	585	456	319	220	171	248	436	645	805	803	740	927
140	806	*	612	486	347	247	200	275	464	667	824	789	750	938
150	824	*	637	515	375	274	230	302	492	688	841	791	758	943
160	840	*	660	541	398	301	264	328	517	707	856	803	765	953
170	855	*	682	565	418	327	322	353	541	725	860	807	762	958
180	868	*	702	590	438	352	406	378	573	742	863	816	767	872
190	876	*	719	613	456	384	467	402	616	758	873	794	782	836
200	870	*	716	640	481	444	465	428	658	771	880	692	794	792
210	841	*	719	678	537	516	500	463	688	776	879	697	791	754
218	605	*	737	731	616	538	721	513	707	715	716	710	710	764

*Measurement not reliable

TABLE 6C CONCRETE TEMPERATURES MEASURED WITH THERMOCOUPLES IN FRAME C

Time (min)	Temperature (°C) Measured at Thermocouple No:													
	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
5	103	76	41	26	20	20	20	20	20	27	58	95	147	193
10	194	140	92	58	24	20	20	20	25	65	128	174	295	387
15	322	238	126	96	39	20	20	20	53	119	189	293	465	550
20	414	322	178	116	68	28	20	27	97	134	268	384	555	612
25	479	384	224	134	83	36	21	40	109	176	335	455	628	682
30	514	422	262	168	88	46	28	51	106	238	397	512	676	725
35	548	457	295	199	93	55	37	59	104	284	449	562	723	767
40	581	489	326	220	98	62	52	65	109	315	486	592	747	787
45	611	518	355	250	103	73	76	76	128	357	534	653	793	828
50	638	544	378	263	105	89	87	86	149	387	570	691	820	853
55	661	567	399	281	110	99	96	98	169	414	606	722	843	874
60	678	588	422	305	119	105	100	109	188	440	637	712	855	883
70	709	623	464	351	161	112	112	122	227	484	685	765	837	902
80	737	656	499	386	189	122	116	133	264	520	721	763	800	919
90	761	686	530	416	214	134	118	146	299	533	732	779	883	944
100	790	713	559	444	237	148	121	164	332	582	782	790	904	963
110	702	720	581	469	262	165	130	187	365	614	800	784	890	939
120	724	751	604	492	289	186	143	211	397	635	814	787	916	976
130	737	773	629	518	319	212	168	237	427	659	837	789	919	975
140	734	792	653	543	351	239	195	263	457	681	855	788	921	978
150	702	810	677	569	382	267	223	290	486	700	870	785	938	937
160	696	827	699	594	411	295	249	317	514	718	884	782	935	941
170	758	842	719	617	439	321	275	340	541	726	897	777	912	949
180	776	857	738	639	465	347	301	378	572	739	906	772	779	955
190	775	869	754	660	491	373	326	435	611	719	902	762	771	963
200	780	*	765	679	517	406	351	523	657	744	840	744	747	960
210	727	*	770	697	551	446	317	614	700	743	789	735	734	905
218	*	*	*	718	582	534	417	639	753	769	*	744	*	*

*Measurement not reliable

TABLE 6D CONCRETE TEMPERATURES MEASURED WITH THERMOCOUPLES IN FRAME D

Time (min)	Temperature (°C) Measured at Thermocouple No:													
	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
5	70	48	29	20	20	20	20	20	20	20	34	55	95	132
10	144	105	64	36	20	20	20	20	21	47	105	148	243	344
15	249	171	108	73	28	20	20	20	40	102	166	263	406	523
20	342	245	151	107	47	20	20	21	98	128	242	366	510	325
25	415	310	199	121	89	33	20	34	102	153	312	445	586	106
30	462	357	242	150	96	51	26	46	108	211	376	505	637	121
35	505	399	281	178	100	62	36	57	108	261	430	553	686	697
40	527	421	301	193	103	65	42	63	114	287	458	581	709	702
45	571	466	344	228	110	75	56	77	140	342	517	641	756	708
50	600	494	371	250	119	86	65	88	162	376	553	678	784	733
55	627	519	396	271	131	95	74	100	184	405	588	709	808	753
60	647	541	419	291	145	103	83	108	206	432	620	734	824	765
70	680	578	457	325	170	112	102	122	248	477	669	759	851	786
80	708	611	489	351	193	127	113	137	288	515	707	747	875	788
90	737	641	516	371	218	141	125	154	324	547	738	751	902	785
100	763	669	541	387	239	159	134	174	355	579	769	763	924	787
110	760	677	560	409	261	176	140	197	387	609	789	763	853	771
120	794	703	583	436	287	196	150	220	418	631	804	772	759	777
130	813	728	611	472	317	220	170	245	449	656	827	781	762	780
140	831	749	638	504	348	247	197	271	479	679	846	785	761	781
150	847	769	661	532	376	274	226	298	506	700	861	786	776	781
160	862	787	683	557	403	300	254	324	530	719	875	785	790	781
170	875	803	703	582	430	326	280	349	553	737	883	783	804	778
180	848	815	722	605	458	351	306	379	576	753	773	781	809	771
190	730	818	738	628	506	379	335	398	599	769	764	776	816	761
200	747	810	754	663	600	424	391	421	620	785	755	769	828	757
210	760	806	765	707	682	502	498	443	640	798	751	763	831	751
218	763	809	*	763	719	563	561	466	656	*	*	*	846	*

*Measurement not reliable

TABLE 7 AVERAGE FURNACE TEMPERATURE

Time (Min)	Average Temperature (°C)	Time (Min)	Average Temperature (°C)
0	20	90	988
5	446	100	974
10	687	110	966
15	768	120	1010
20	812	130	1018
25	827	140	1027
30	845	150	1033
35	865	160	1039
40	875	170	1046
45	903	180	1050
50	921	190	1057
55	931	200	1061
60	932	210	1070
70	946	218	1076
80	960		

TABLE 8 MEASURED AXIAL DEFORMATION OF COLUMN

Time (min)	Deformation (mm)	Time (min)	Deformation (mm)	Time (min)	Deformation (mm)
0	0	90	6.0	180	2.9
5	0.3	105	6.4	185	2.1
10	1.5	120	6.6	190	1.3
15	1.6	135	6.4	195	-0.1
20	2.4	145	6.0	200	-0.9
25	2.6	150	5.7	205	-2.1
30	2.8	155	5.3	210	-3.8
40	3.3	160	4.9	215	-5.7
50	3.8	165	4.5	218	-7.2
60	3.9	170	4.0		
75	5.3	175	3.4		

(-) sign indicates contraction of column past initial starting position

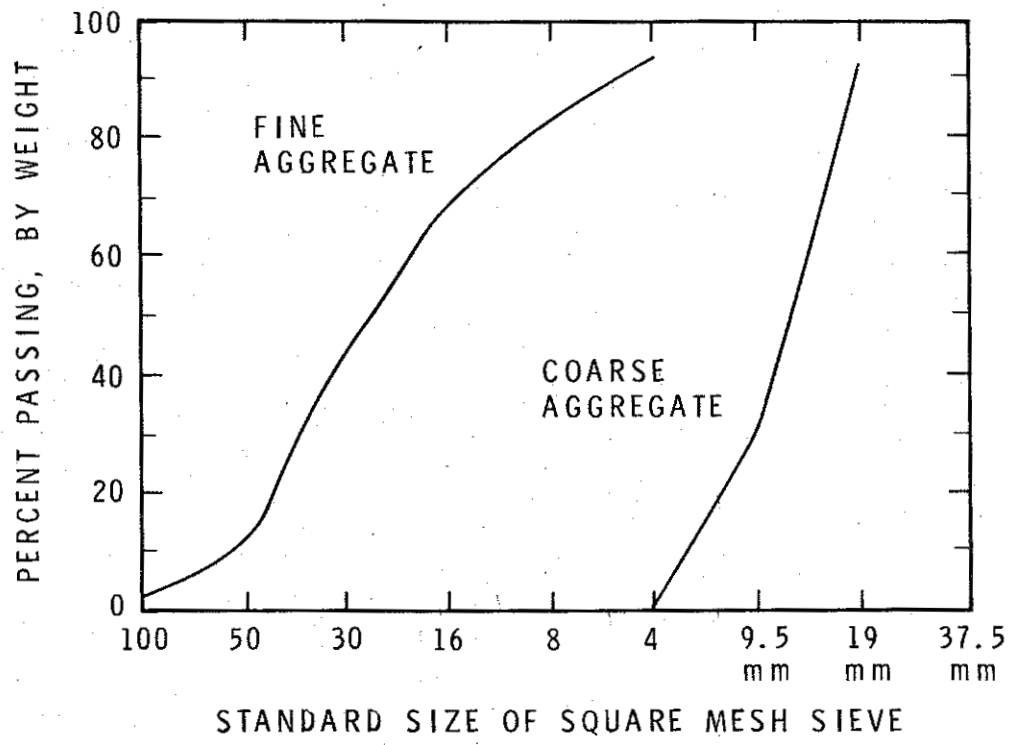


FIGURE 1
 GRADATION CURVES OF SILICEOUS AGGREGATE

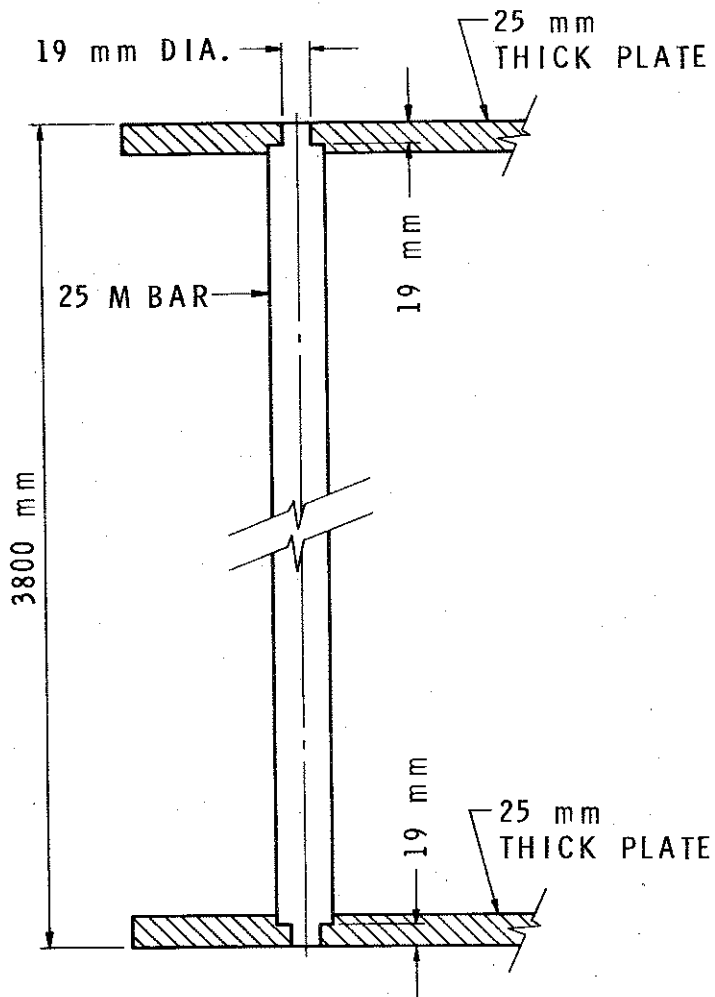


FIGURE 2
MAIN REINFORCING BARS

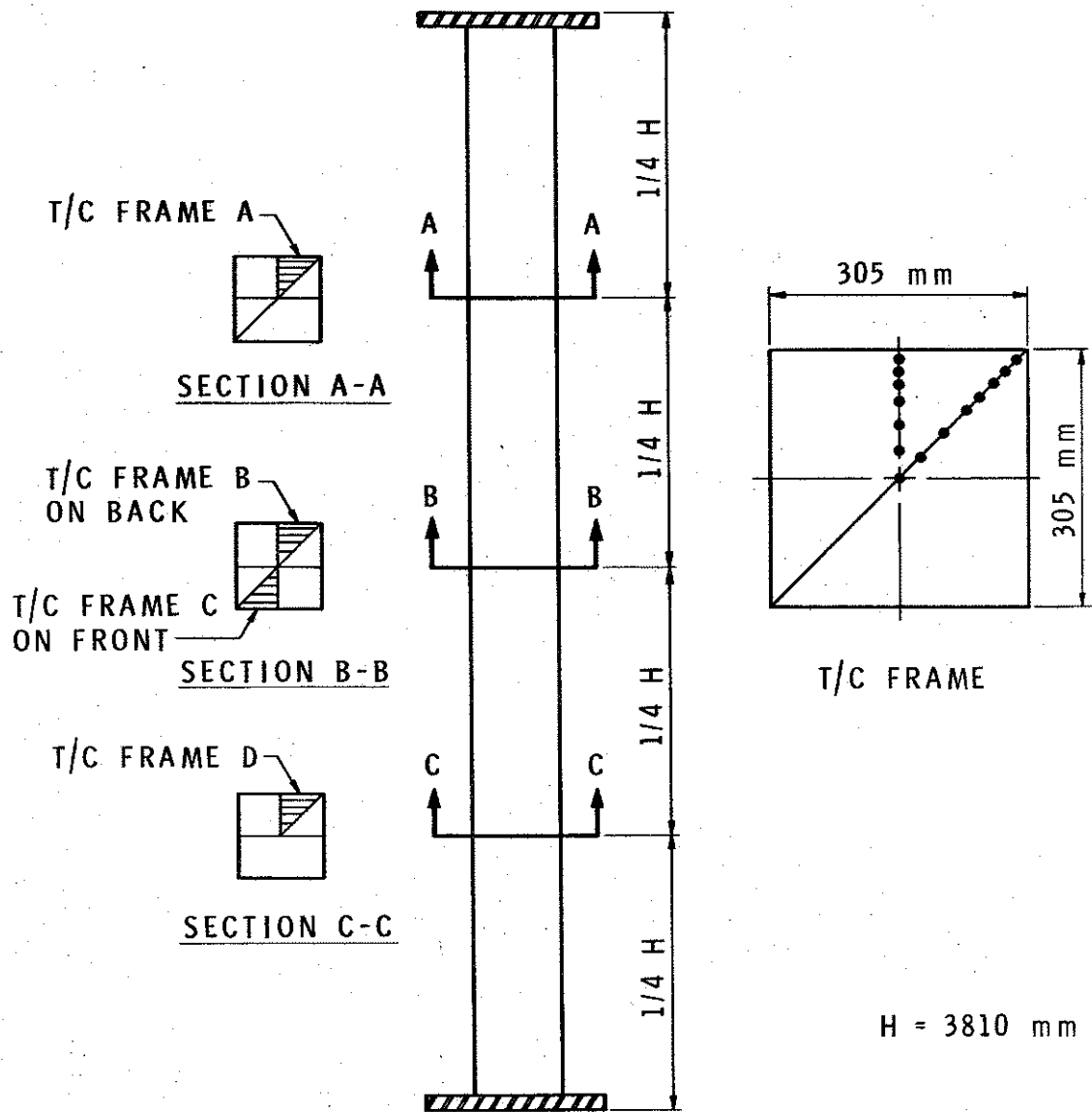


FIGURE 3
LAYOUT OF THERMOCOUPLE FRAMES

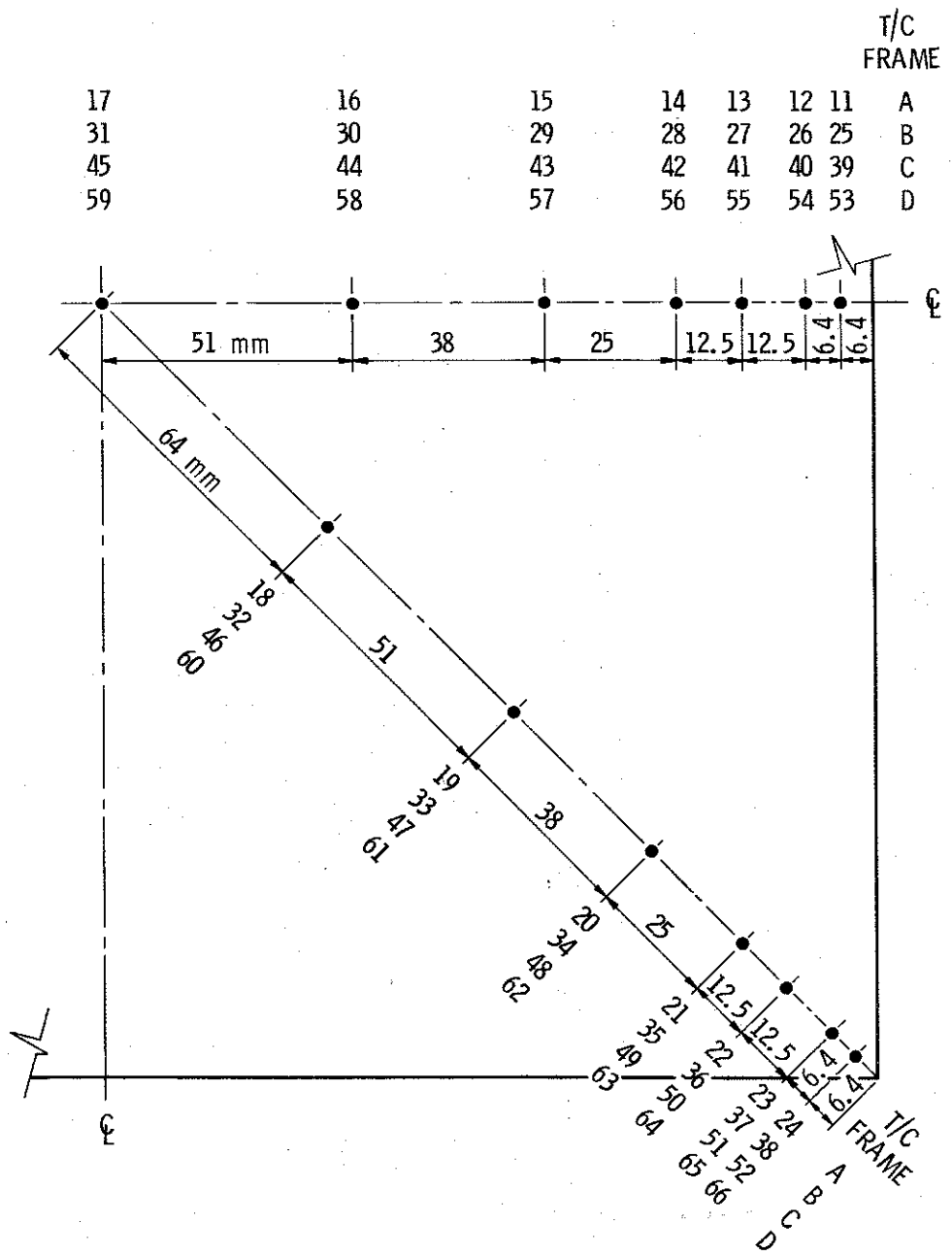


FIGURE 4
 LOCATION AND NUMBERS OF THERMOCOUPLES IN A SECTION

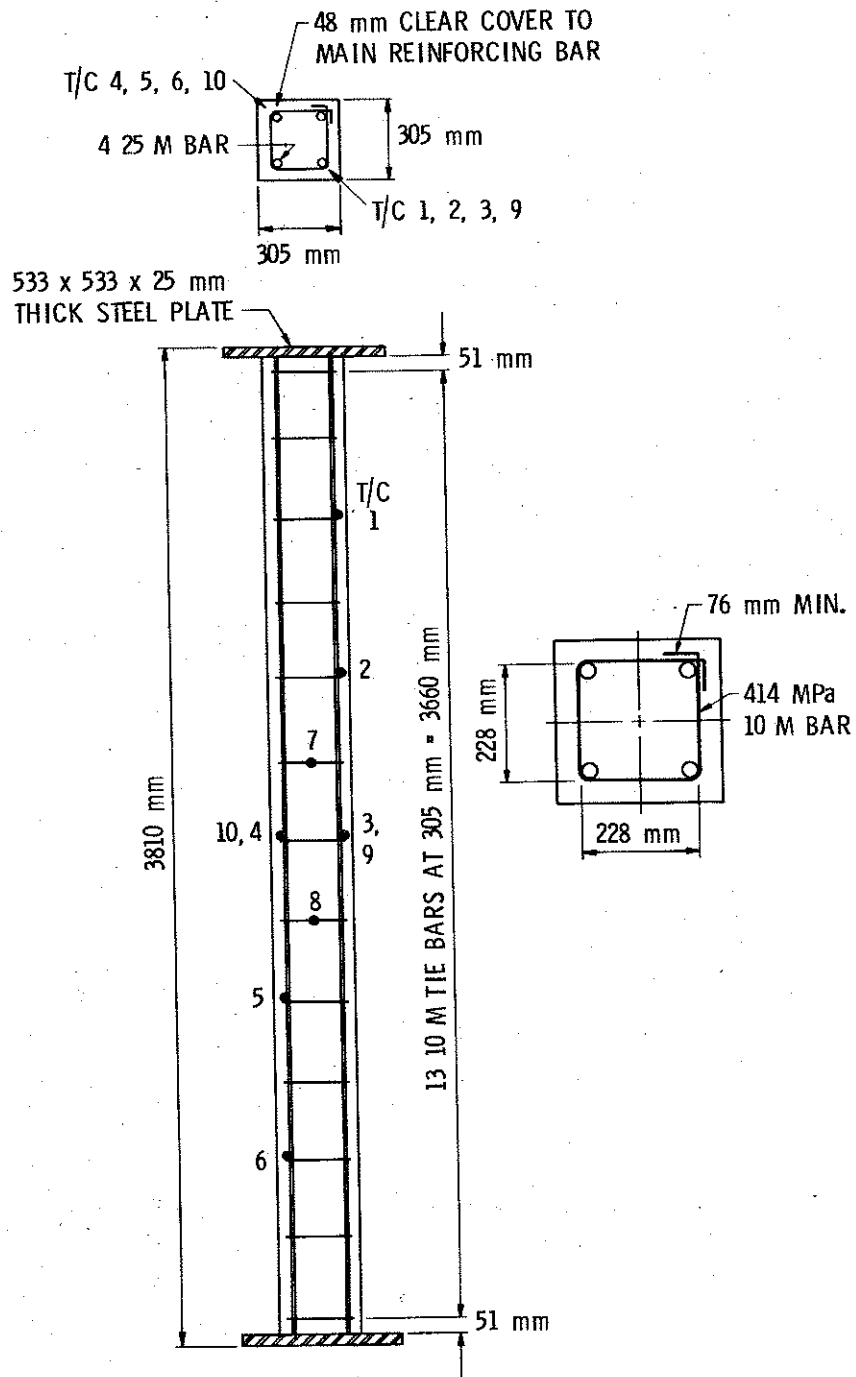


FIGURE 5
THERMOCOUPLES ON REINFORCING BARS

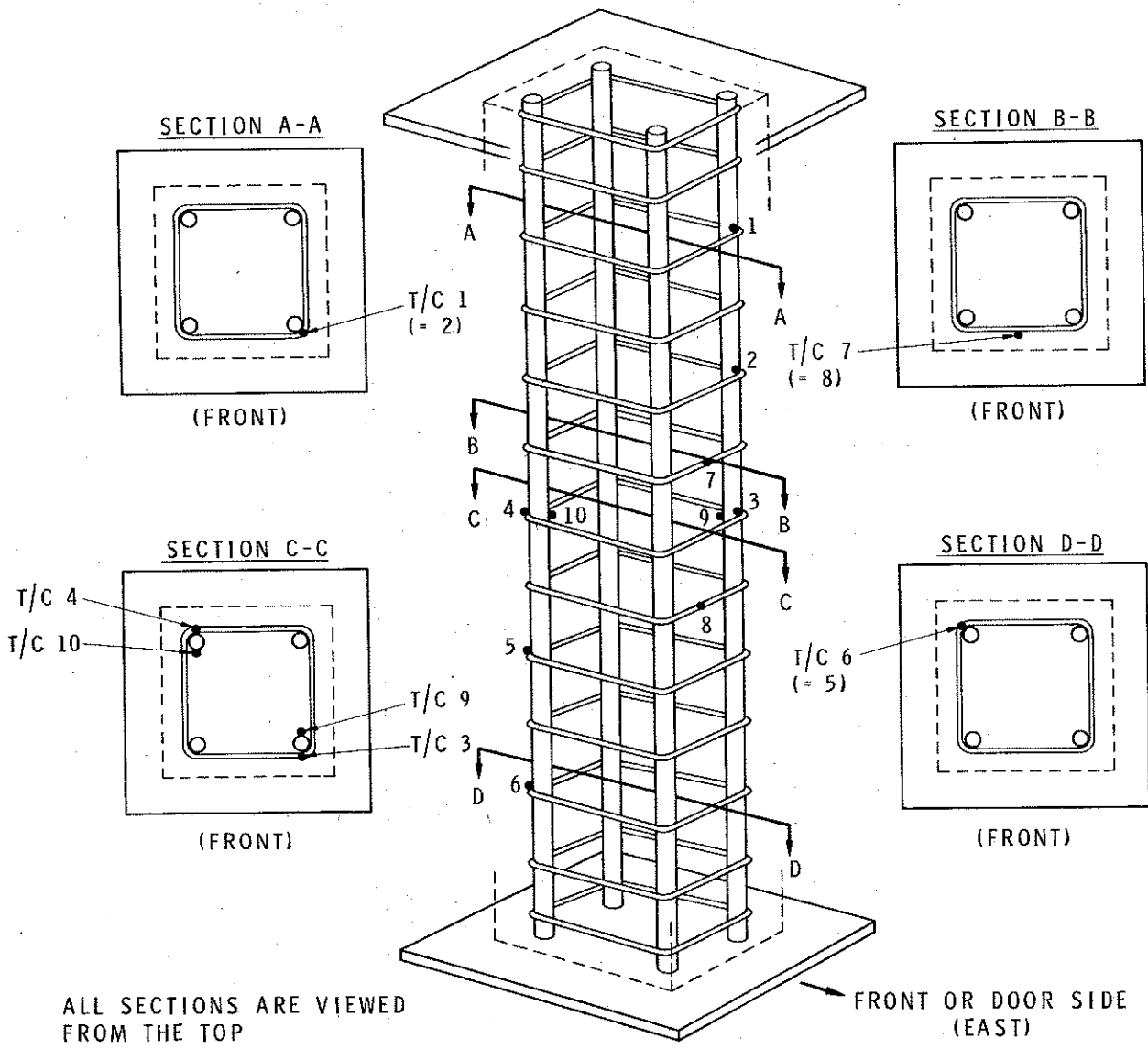


FIGURE 6
THERMOCOUPLES ON REINFORCING BARS (305 mm x 305 mm COLUMN)

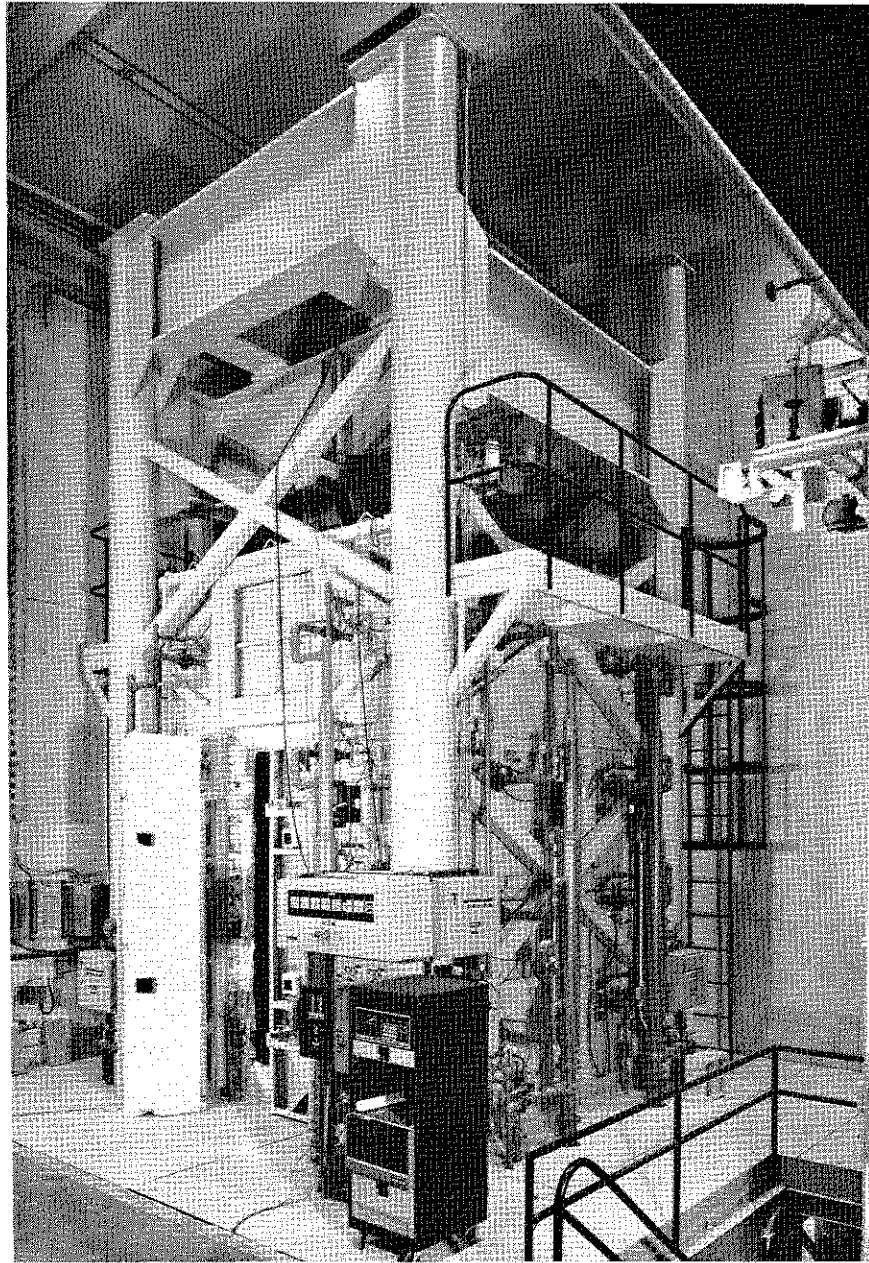


FIGURE 7
TEST FURNACE

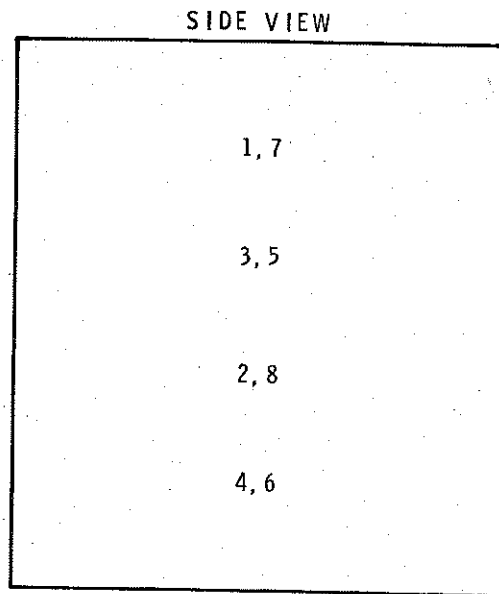
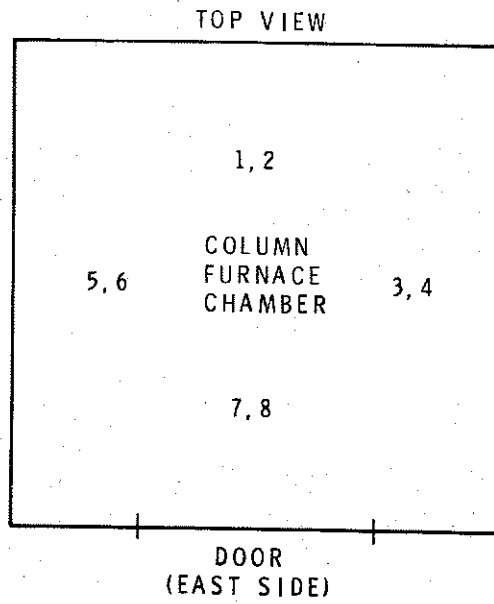


FIGURE 8
LOCATION AND NUMBERS OF
THERMOCOUPLES IN COLUMN
FURNACE CHAMBER

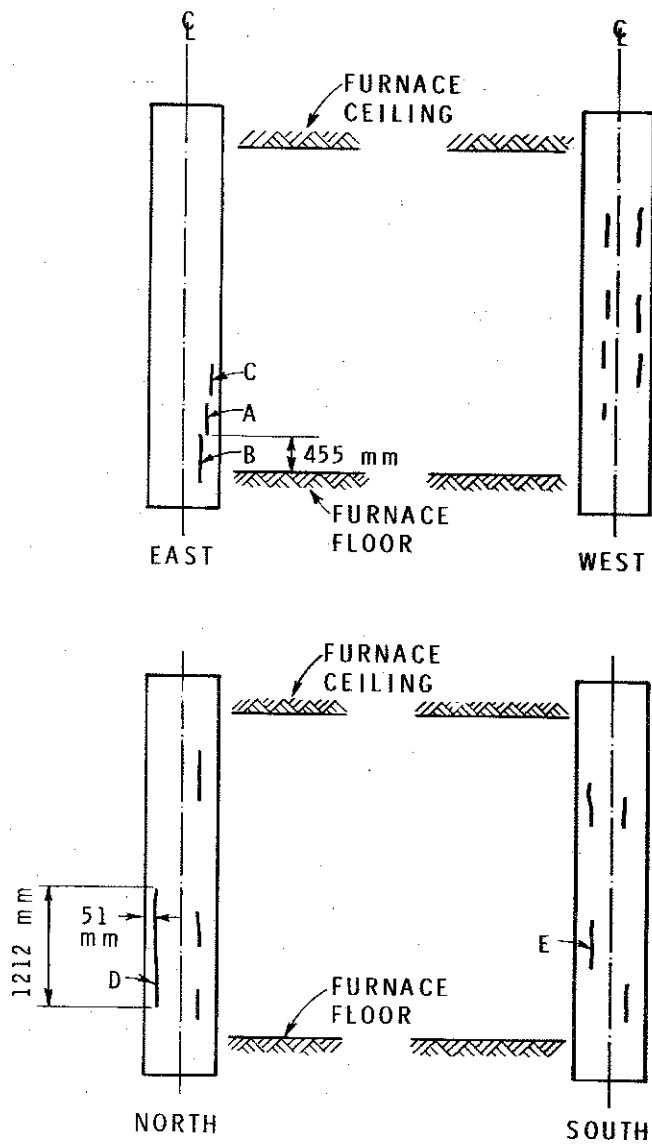


FIGURE 9
 CRACKS IN COLUMN AT 1 h TEST TIME

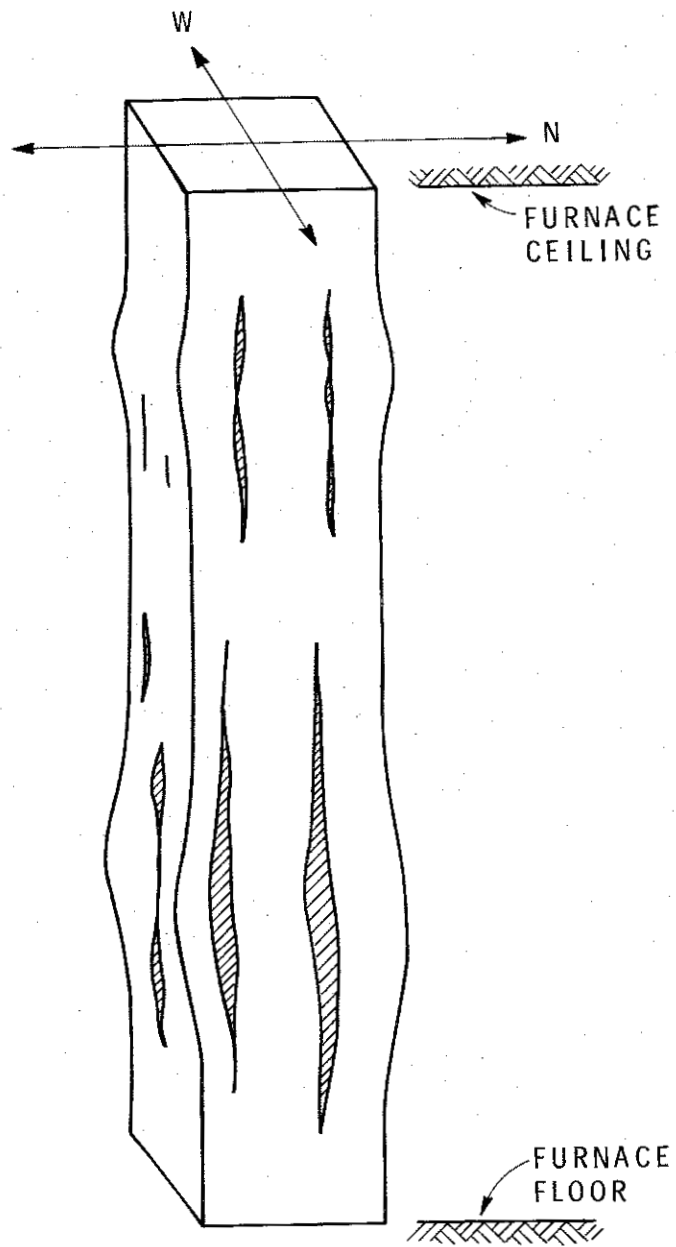


FIGURE 10
SCHEMATIC VIEW OF COLUMN AT END
OF TEST

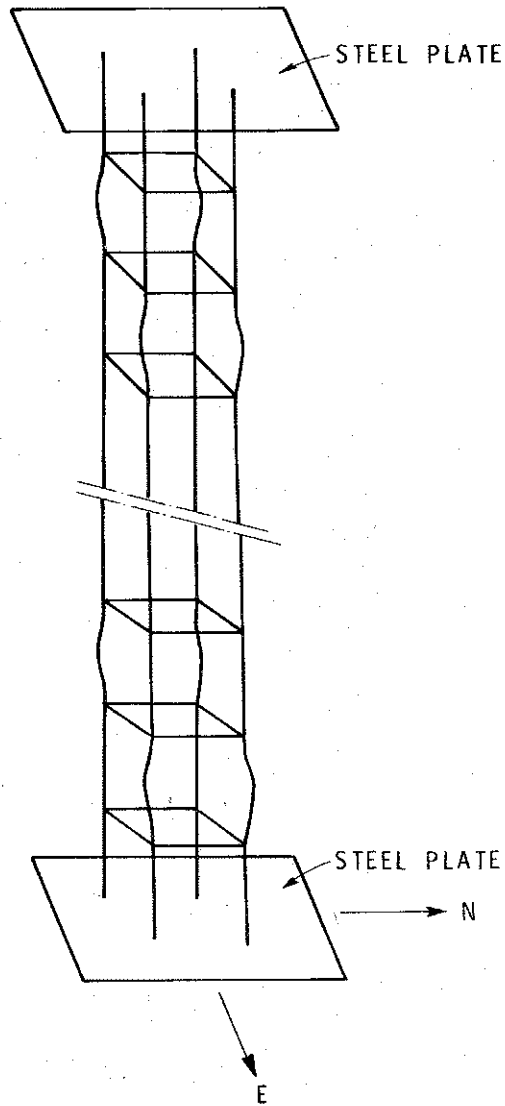


FIGURE 11
SCHEMATIC VIEW OF REINFORCING
BARS OF COLUMN AFTER FIRE TEST

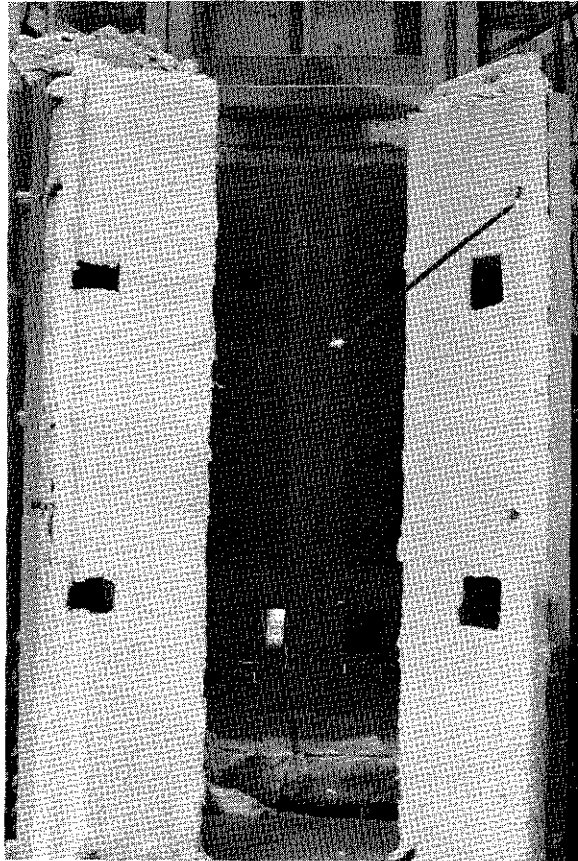


FIGURE 12
COLUMN SPECIMEN
AFTER TEST

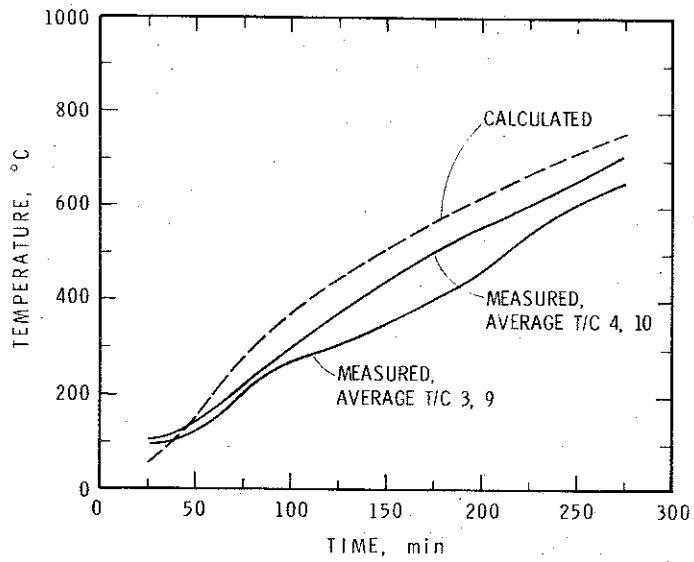


FIGURE 13
CALCULATED AND MEASURED AVERAGE
TEMPERATURES OF MAIN REINFORCING BARS

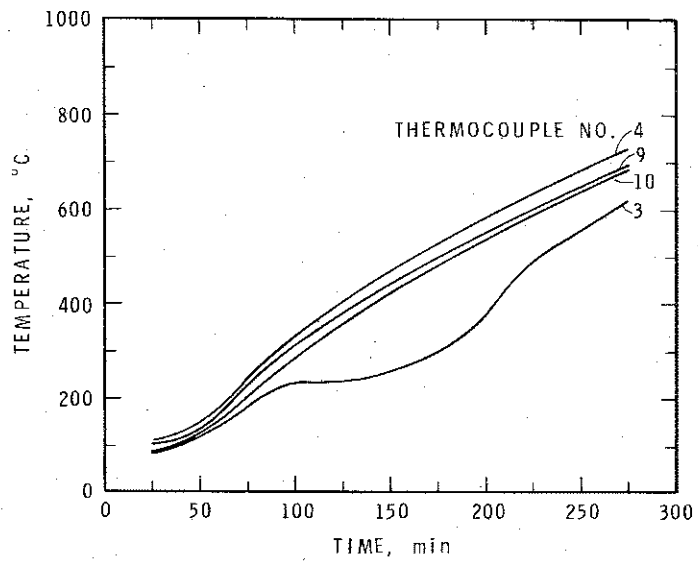


FIGURE 14
TEMPERATURES MEASURED ON MAIN REINFORCING
BARS

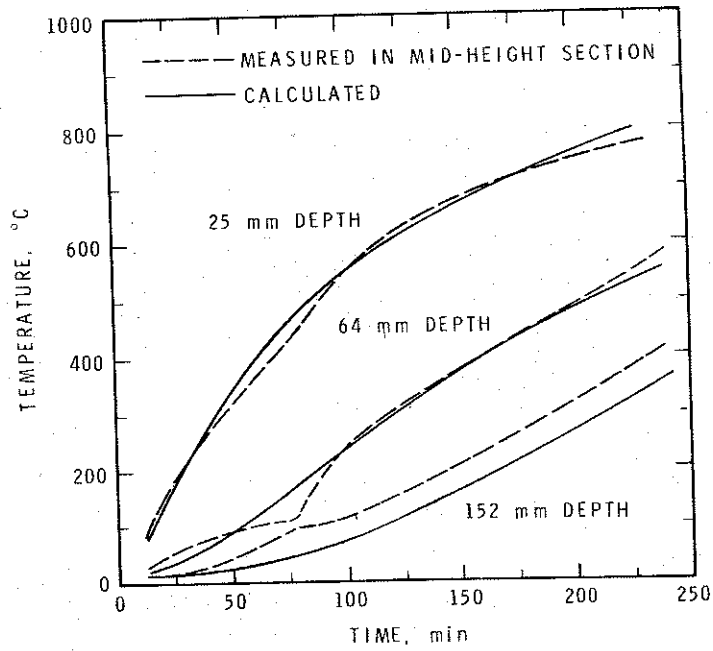


FIGURE 15
 CONCRETE TEMPERATURES IN MID-HEIGHT SECTION
 ALONG CENTRELINE AT VARIOUS DEPTHS

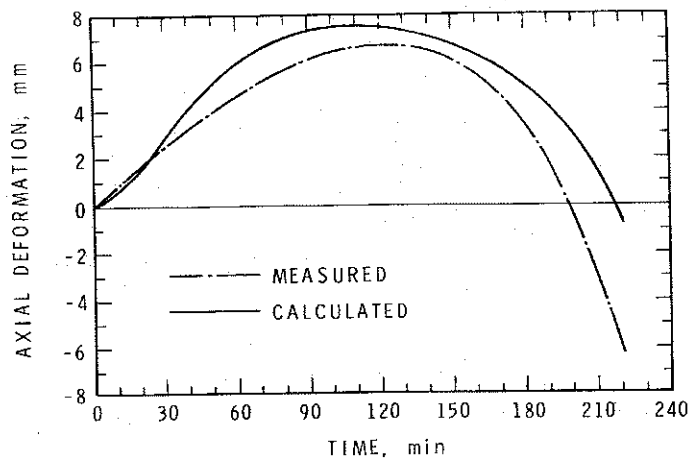


FIGURE 16
 AXIAL DEFORMATION AS A FUNCTION OF TIME