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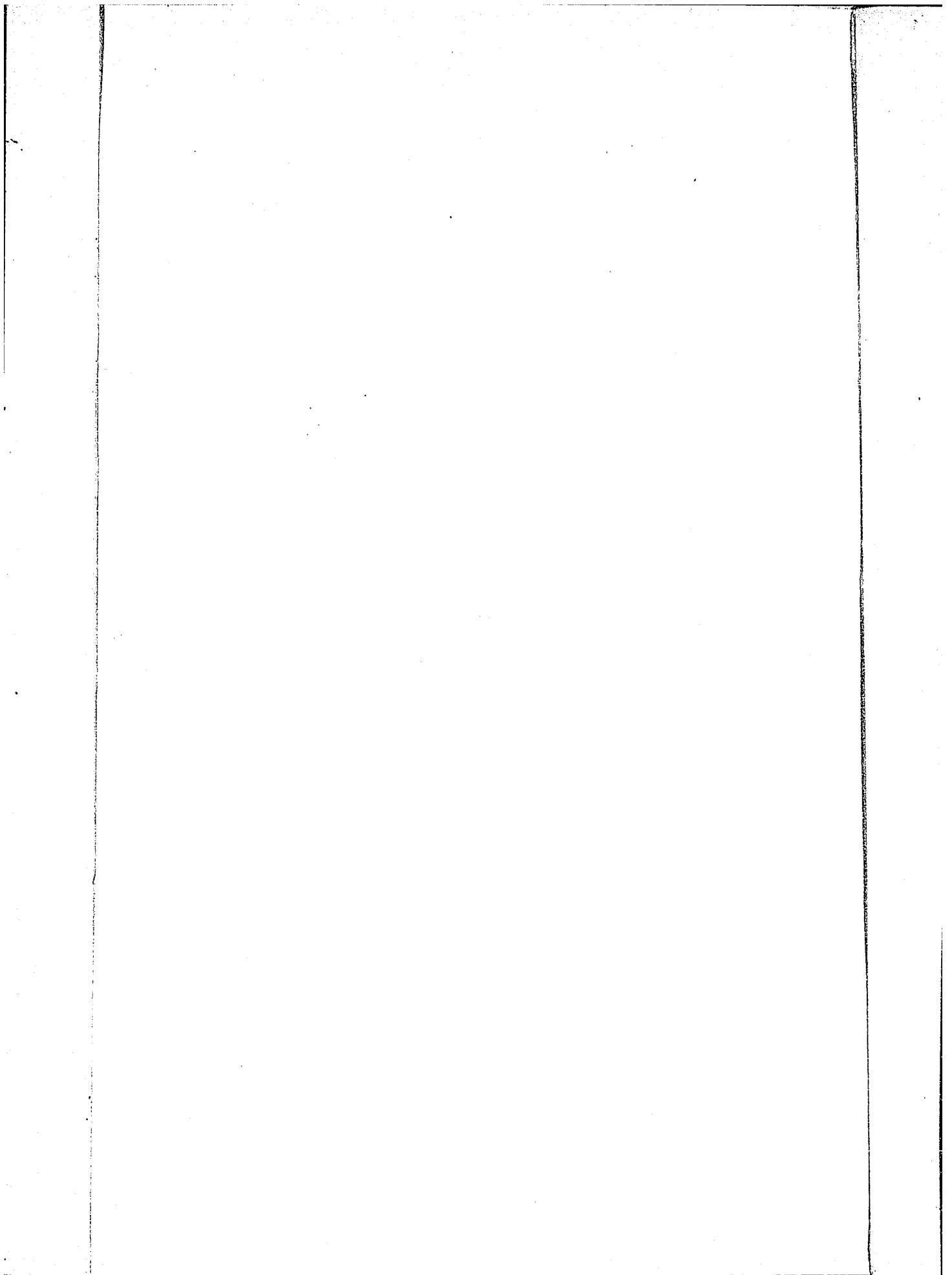
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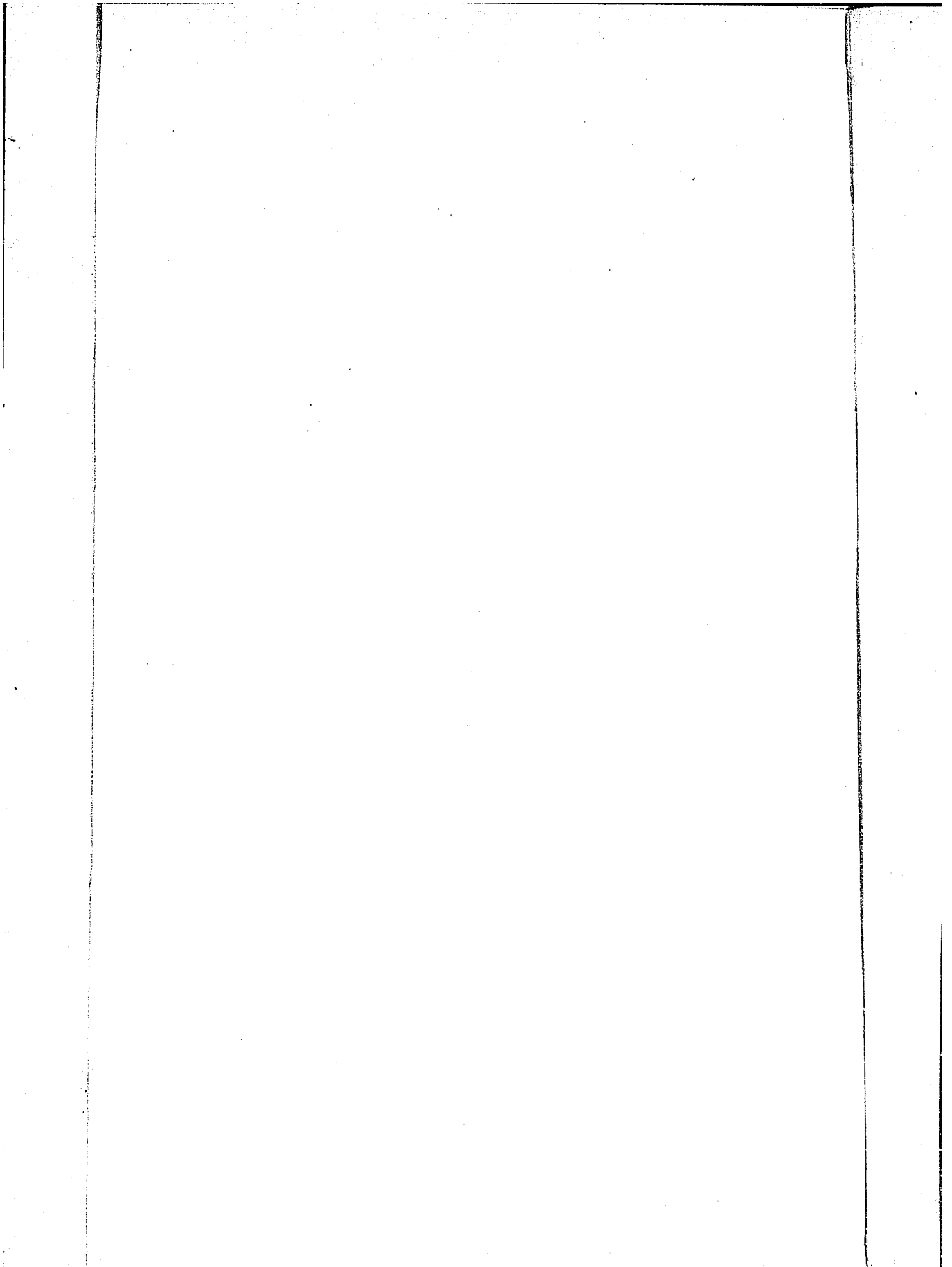
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AN INVESTIGATION OF THE LOW
TEMPERATURE PROPERTIES OF PLAIN
AND REINFORCED CONCRETE SLABS

BY
Satyendra Kumar Jain

A Thesis
Presented to
the Faculty of Graduate Studies
University of Ottawa
Ottawa
Canada

In Partial Fulfillment
of the Requirements for the Degree of
Master of Applied Science
in Civil Engineering

December 1968



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ABSTRACT

AN INVESTIGATION OF THE LOW TEMPERATURE PROPERTIES OF PLAIN AND REINFORCED CONCRETE SLABS

by

Satyendra Kumar Jain

The object of this investigation was to determine the behavior of plain and reinforced cement concrete with regard to temperature in the range from -100°F to $+140^{\circ}\text{F}$. The effects of temperature, strength of concrete, percentage of steel, and arrangement of steel on the coefficient of thermal expansion were studied.

Results at the age of 15 days and 30 days are not satisfactory partly due to experimental error. However, the results at the age of 84 days are very satisfactory. Below freezing point of water the coefficient of thermal expansion of plain concrete is 2.44×10^{-6} per degree F for w/c ratio 0.708 and 3.43×10^{-6} per degree F for w/c ratio 0.434. For reinforced concrete with 5.5% steel these values are 3.82×10^{-6} per degree F for w/c ratio 0.708 and 4.68×10^{-6} per degree F for w/c ratio 0.434.

Above freezing point of water the coefficient of thermal expansion of plain concrete is 3.14×10^{-6} per degree F for w/c ratio 0.708 and 4.03×10^{-6} per degree F for w/c ratio 0.434. For reinforced concrete with 5.5% steel these values are 4.49×10^{-6} per degree F for w/c ratio 0.708 and 5.37×10^{-6} per degree F for w/c ratio 0.434.

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The author expresses his sincere appreciation to Professor Carl Berwanger, Civil Engineering Department, University of Ottawa for his guidance and helpful criticism.

The experimental work reported herein forms a part of the continuing research into the low-temperature properties of structural materials being conducted by Professor Carl Berwanger at the University of Ottawa. The research is funded through grants held by Professor Carl Berwanger from the National Research Council of Canada.

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CHAPTER I

INTRODUCTION TO TOTAL SUBJECT AND ITS RELEVANCE TO MODERN PRACTICE

1.1 General: It is well known that cement concrete is strong in compression but weak in tension. To strengthen it in tension steel reinforcement is normally used. Steel reinforcement has a high strength both in tension and in compression and has a coefficient of thermal expansion close to that of concrete. The latter property gives low internal stresses due to temperature variation. Unfortunately this difference between the coefficient of thermal expansion of steel and that of cement does not remain constant with temperatures in the range from -100°F to $+140^{\circ}\text{F}$. One of the reasons for the difference in values of the coefficient of thermal expansion is the presence of water in the pores in the concrete.

Change of season causes large variation in temperature. Generally in Canada construction is done in summer at temperatures of about 65°F and above. Later it is subjected to natural environmental temperatures which, many times, are as low as -50°F or even lower.

To completely solve the problems involved in the behavior of plain concrete with temperature the following all need to be known:

- (1) Variation of the coefficient of thermal expansion of plain concrete with temperature and age of concrete.
- (2) Effect of the water/cement and/or aggregate/water ratios on the variation of the coefficient of thermal expansion for plain concrete.
- (3) Effect of different steel percentages and arrangements on the coefficient of thermal expansion for reinforced concrete. Are any non elastic effects present?
- (4) Effect of stress level on the variation of the coefficient of thermal expansion.
- (5) Variation of the modulus of elasticity and crushing strength of concrete with temperature.
- (6) Variation of the coefficient of thermal expansion of concrete with temperature for different aggregates and cements.

CHAPTER II

HISTORICAL REVIEW

2.1 Historical note: The concept of composite construction dates back to the late nineteenth century. Earlier steel beams and concrete slabs were bonded by friction force only. Some tests on these composite sections were conducted in the 1920's. In 1923 tests were conducted at McGill University by H. M. MacKay, P. Gillespie, and C. Lelau (1) on two steel I-beams encased in concrete and concrete slab. Truscon Steel Company (2) and R. A. Caughey (3) reported their tests on composite beam in 1923 and 1929 respectively. It was then noticed that natural friction was all right for static loading and for beams encased in concrete. H. Eiserbeck (5), Ruch (6), M. Gary (7), and A. Gassener (8) investigated the effect of temperature on setting and hardening properties of cement and fresh concrete.

Professor Dr. Ing Chr E Morsch (9) gave two theories for temperature stresses. These are (1) bending moment due to the temperature difference between inside and outside of the wall and (2) cracks due to temperature difference and propagation of these cracks. G. Ehlers (10) has plotted graphs for

the theories of E. Morsch and for the results obtained by Rousch (11). The results of Rousch give a slightly higher bending moment and stresses than those given by the second theory proposed by Morsch. For about the next 40 years not much was done on thermal expansion stresses.

E. J. Callan (12) has studied thermal expansion of aggregates and concrete durability in 1952; however, his studies are not related to problems listed in Chapter I.

J. A. Cran (13) investigated the effect of temperatures, concrete strength and percentage of steel used as reinforcement on thermal expansion of plain and reinforced concrete in 1963. The temperature range was from -30°F to $+75^{\circ}\text{F}$. His conclusions are:

- (1) The coefficient of thermal expansion is approximately constant for temperatures from -30°F to $+75^{\circ}\text{F}$.
- (2) The coefficient of thermal expansion for symmetrically reinforced slabs may be taken as that of the plain concrete, although it was found that the coefficient of thermal expansion of this type of slab increases about 6% when the steel percentage is

increased from zero to 5.5%. It was found that the coefficient of thermal expansion of different concrete samples from the same batch could vary more than this amount (6%). Therefore, this increase in the coefficient of thermal expansion is insignificant.

- (3) In case of asymmetrical slabs, as the steel percentage increases from zero to 5.5%, the coefficient of thermal expansion of the face opposite to the steel decreases about 2% while that of the face near the steel increases about 19%.
- (4) For plain concrete of a given age, a modest increase in the coefficient of thermal expansion accompanied a decrease of the w/c ratio.

The first of the above conclusions is not correct. This is proven by the results of the investigation carried out by the author. J. A. Cran did not have control over the age of the tests, and his results are based on the varying age specimens. Results of J. A. Cran are not very accurate due to inaccuracy in measurements in tests. His first conclusion is that the coefficient of thermal expansion is approximately constant for temperatures from

-30°F to +75°F. The author has found two distinct values of the coefficient of thermal expansion, one below and another above the freezing temperature of water. J. A. Cran's remaining conclusions give only a qualitative picture of behavior of the concrete with regard to the coefficient of thermal expansion. He has made investigation on problems 1, 2, 3, and 5 as listed on page 2. He has not investigated problems 4 and 6.

The conclusions of G. E. Monfore (14) on the physical properties of concrete at low temperatures are as follows:

- (1) All moist concretes probably increase somewhat in elastic modulus and considerably in strength as the concrete is cooled from room temperature to a temperature that would be associated with the storage of liquified natural gases. The absolute strength of a given concrete at a given low temperature will depend on the cement content, the water/cement ratio of the mix, the nature of aggregates, the age, and the moisture conditions.
- (2) The coefficient of thermal expansion of concrete at low temperatures is not as sensi-

tive to the mix design and moisture conditions as are the elastic modulus and strength of concrete.

His study is based on air entrained concrete with 5.3 to 7.8% air.

J. W. Dougill (15) has outlined the effect of the chemical changes besides thermal incompatibility. Many researchers have suggested that the reaction having the greatest effect on strength is that in which the calcium hydroxide in the cement paste is decomposed. This reaction does not normally occur below 900°F, and it may be assumed that chemical effects are of secondary significance below this temperature.

G. E. Monfore and A. E. Lentz (14) have reported that volume changes in moist concrete due to subfreezing cooling are greatly influenced by the behavior of the water contained in the concrete. Much of this water is located in such minute pores and has so much dissolved material that it does not act as ordinary bulk water. For instance, Verbeck and Klieger (16) have shown that as the temperature of concrete is decreased below 32°F, the amount of water which is frozen out progressively increases. Thus under subfreezing temperatures there are two

opposite effects. Ice already formed will contract with cooling, but additional ice formed during this further cooling will cause the coefficient of expansion for a temperature range from 75°F to -250°F to vary from 3.3×10^{-6} per degree F for the light weight aggregate concrete to 4.5×10^{-6} per degree F for the 7 Bag/cyd. sand and gravel concrete.

G. L. England and A. D. Ross (17) found that the coefficients of thermal expansion for sealed and unsealed specimens are 5.8×10^{-6} per degree F and 6.6×10^{-6} per degree F respectively, the latter value declining as drying progressed. A typical 1:2:4 concrete mix was chosen for all tests, with a water/cement ratio of 0.45 by weight. The compressive strength of four-inch cubes at an age of fourteen days was 5,500 p.s.i. The temperature range was 68°F to 285°F.

G. E. Monfore and A. E. Lentz (14) gave a combined figure for effect of temperature and aggregate type on the coefficient of thermal expansion of concrete. They found the coefficient of thermal expansion varying between 3.3×10^{-6} per degree F for normal weight aggregate in temperature range from -75°F to +200°F. They have not commented on the other aspects of the temperature studies as

listed in Chapter I.

G. L. England and A. D. Ross (17) also did not comment on various aspects of temperature studies as listed in Chapter I.

CHAPTER III

OBJECT OF INVESTIGATION

The object of this investigation was to experimentally determine:

- (1) Variation with temperature of the coefficient of thermal expansion of plain and reinforced concrete at various ages.
- (2) The effect of water cement ratio on the variation of the coefficient of thermal expansion.
- (3) The effect of steel percentage and arrangement on the coefficient of thermal expansion for reinforced concrete. From the results for reinforced concrete the coefficient of thermal expansion for the concrete was to be compared to the results for the plain concrete. If there is no significant difference between the coefficient obtained from all the tests it can be concluded only the effects considered in the elastic theory are important.

The following range of variables was used in this investigation:

- (1) Strength of concrete from 4000 p.s.i. to

7000 p.s.i.

- (2) Amount of steel from zero percent to 5.5%.
- (3) Range of temperature from -100°F to $+140^{\circ}\text{F}$.
- (4) Arrangement of reinforcement (symmetrical and asymmetrical).

CHAPTER IV

THEORY

The following assumptions are made in the theoretical development:

- (a) Concrete behaves as a homogeneous mass at low stress levels.
- (b) There is perfect bond between concrete and reinforcing steel because the strains are low.
- (c) Plane sections remain plane to give linear stress and strain diagrams.
- (d) Coefficient of thermal expansion of steel is greater than that of concrete.

No assumptions have been made about the values of α_s , α_c , α_{RC} , E_s , E_c , and E_{RC} and whether they remain constant or not in the temperature range from -100°F to $+140^\circ\text{F}$ is not known. (For a description of notations, refer to the list of notations.) In fact, it is the object of this investigation to determine these values.

Symmetric reinforcement: In Figure 1 a symmetrically reinforced slab of length l is subjected to a decrease in temperature of ΔT . The reduction in length of concrete and steel are given by:

$$\Delta l_c = \alpha_c \Delta T l \quad \dots \quad 1$$

FIGURE 1 SYMMETRICALLY REINFORCED SLAB

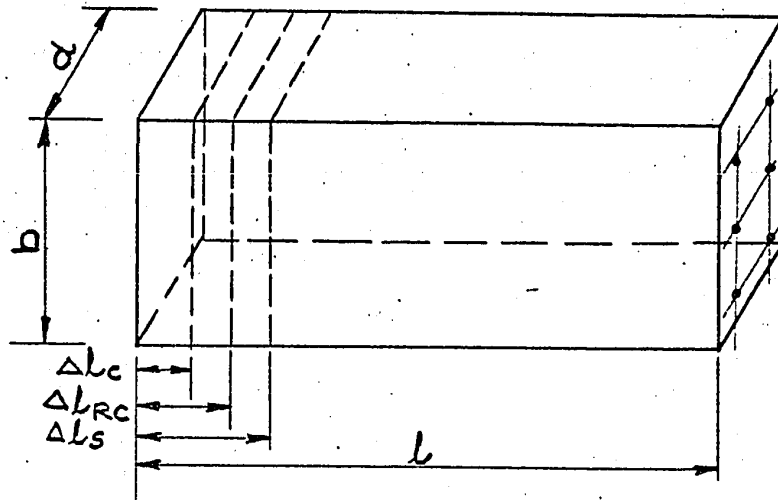
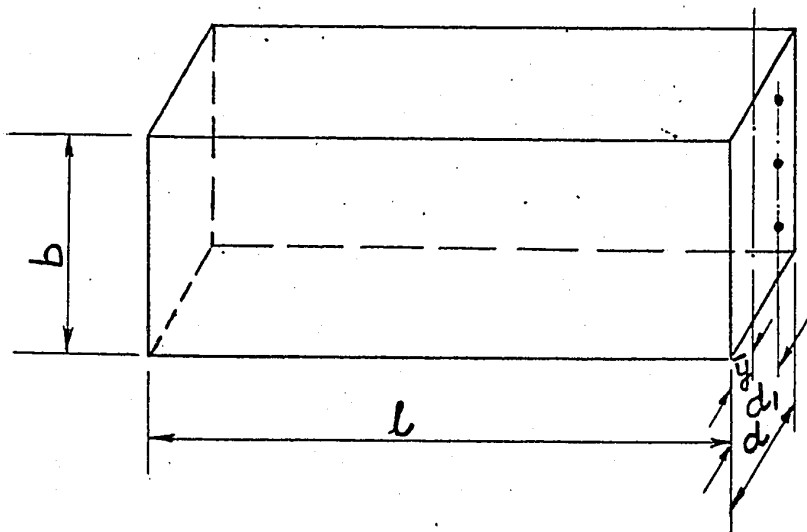


FIGURE 2 ECCENTRICALLY REINFORCED SLAB



$$\Delta l_s = \alpha_s \Delta T l \quad \dots 2$$

Since α_s is greater than α_c , for a particular value of l and ΔT , Δl_s is also greater than Δl_c . However, the steel and the concrete are bonded together, and this results in internal stresses. The combined effect of change in length of steel and concrete is given by:

$$\Delta l_{RC} = \alpha_{RC} l \Delta T = \alpha_s l \Delta T - \frac{F_s l}{A_{st} E_s} = \alpha_c l \Delta T + \frac{F_c l}{A_c E_c} \quad \dots 3$$

Also from equilibrium

$$F_s = F_c \quad \dots 4$$

Unsymmetric reinforcement: In figure 2 the force induced in concrete and steel is not concentric. This results in bending stresses and strains. Therefore, net change in the length of an asymmetrically reinforced concrete slab at any distance y from neutral axis is given by:

$$\alpha_c l \Delta T + \frac{F_c l}{A_c E_c} + \frac{F_c l (d_1 - \bar{y}) y}{E_c I} \quad \dots 5$$

A positive or negative sign in the last part of the expression 5 depends upon whether we are considering y below or above the neutral axis respectively.

Concrete shortening at $y = d_1 - \bar{y}$ below the neutral

axis is equal to the shortening of the steel. This gives

$$\alpha_s l \Delta T - \frac{F_s l}{A_{st} E_s} = \alpha_c l \Delta T + \frac{F_c}{E_c} \left[\frac{l}{A_c} + \frac{(d_1 - \bar{y})^2}{I} \right]$$

.....6

Also, strains at the face of the concrete nearest to the steel and farthest from the steel are respectively

$$\alpha_c \Delta T + \frac{F_c}{E_c A_c} + \frac{F_c (d_1 - \bar{y}) (d - \bar{y})}{E_c I}$$

.....7

and

$$\alpha_c \Delta T + \frac{F_c}{A_c E_c} - \frac{F_c (d_1 - \bar{y}) (\bar{y})}{E_c I}$$

.....8

Equations 3, 7 and 8 show the effect of percentage of steel on shortening of reinforced concrete slabs. In the case of symmetrically reinforced slabs, the shortening of reinforced concrete slab is slightly more than that of the plain concrete slab for the same decrease in temperature ΔT .

CHAPTER V

EXPERIMENTAL INVESTIGATION

The experimental program was simply to make a number of specimens with 5 different water/cement ratios with various ratios of symmetrical and unsymmetrical steel reinforcement. All specimens were placed in the temperature cabinet and kept at constant temperature. At the selected ages the temperature in the cabinets was slowly taken through the desired temperature cycle; the coefficient of thermal expansion being measured at each specified temperature.

5.1

Description of the test specimens: All test specimens were 3" thick, 4" wide and 12" long. This size was chosen due to the following reasons:

- (a) For simpler calculations the gauge length has been chosen as 10 inches. This fixes the minimum length at 12 inches, giving 1 inch extra at the ends of each target.
- (b) Width and depth had been so adjusted that steel percentage may be varied from zero percent to 5.5% in steps of 0.5%. Normal maximum percentage of steel in actual construction never exceeds 4.5%. The details

of bar sizes that had been used are listed in Table 1. Width and depth had been so chosen that a convenient number of convenient size bars could be used.

- (c) Twelve slab specimens (3" x 4" x 12"), four prisms (3" x 3" x 12") and six cylinders (6" x 12") needed about 2.5 cubic feet of concrete. The capacity of the mixer available in laboratory is 3 cubic feet. Twelve slab specimens, 4 prisms and 6 cylinders had been cast from one batch of concrete. Symmetrical slabs had the same steel bars on both faces of the slabs, whereas asymmetrical slabs had steel only on one face (see Figures 1 and 2). Each type of slab had 5 concrete strengths. Series A, B, C, D, and E represent symmetrical slabs, and series M, N, P, Q, and R represent asymmetrical slabs. The mix design of these series has been tabulated in Table 2. These proportions of aggregates have been arrived at from Figures 3 and 4 (graphs of mix design). Figures 3 and 4 are based on A.C.I. mix design method. The design strength had been based on seven days wet cured strength which is the case in the field. The number

TABLE 1

Reinforcement used in Various Specimens

Width of specimens: 4 inches Depth of specimens: 3 inches

symmetrically reinforced

asymmetrically reinforced

slabs

slabs

specimen number	steel	% steel $\frac{A_s}{bd} \times 100$	specimen number	steel	% steel $\frac{A_s \times 100}{bd}$
1	0	0	1	0	0
2	2-D3	0.5	2	2-D3	0.5
3	4-D3	1.0	3	2-D4 1-D3	1.0
4	6-D3	1.5	4	2-D7.2 1-D3.0	1.5
5	4-D4 2-D3	1.9	5	2-D8.5 1-D7.2	2.0
6	6-D5.2	2.5	6	2-D11 1-D8.5	2.5
7	4-D7.2 2-D3	3.0	7	1-D15 2-D11	3.0
8	6-D7.2	3.5	8	2-D15 1-D11	3.5
9	4-D8.5 2-D7.2	4.0	9	3-D15	4.0
10	4-D11 2-D5.2	4.5			
11	4-D11 2-D8.5	5.0			
12	6-D11	5.5			

All steel used is U.S.S. deformed steel wire conforming to
ASTM specification no. A 305-56T.

Table 2

Concrete Mix for Various Series of Specimens

Series	w/c Ratio	Cement lbs	Water lbs	Coarse Aggre- gate lbs ⁺	Fine Aggre- gate lbs ⁺
A & M	0.798	45.0	35.8	186.0	170.0
B & N	0.708	50.6	35.8	186.0	166.7
C & P	0.621	57.8	35.8	186.0	160.0
D & Q	0.532	67.2	35.8	186.0	151.0
E & R	0.434	82.2	35.8	186.0	137.8

⁺For grading of aggregates, see Table 3.

of specimens cast for the various series is tabulated in Table 4.

Deformed reinforcement bars had been used in all specimens. Control cylinders and prisms had been cast from the same batch of concrete as slab specimens and the same conditions of casting had been attempted.

5.2

Preparation of the test specimens: All slab specimens and control specimens (prisms and cylinders) had been cast in the structural laboratory of the Civil Engineering Department at the University of Ottawa. Moulds had been specially designed to be used for 3" x 4" x 12" or 4" x 4" x 12" test specimens. These moulds had small grooves to hold the reinforcing bars during casting. Each mould was used to cast two specimens at a time. Coarse and fine aggregates had been procured locally. These aggregates had been sieved and stored in different bins according to their sizes. Both fine and coarse aggregates had been sampled to give the best concrete mix. The sampling percentages of fine and coarse aggregates are given in Table 3. For fine aggregates the fineness modulus is 2.7. Aggregates had been sieved and recombined in the laboratory in propor-

TABLE 3

Grading of Coarse and Fine Aggregates⁺⁺

Sieve Size	% Retained by Cumulative Weight	% Retained on each Sieve by Weight	Percentage Proportion used by Weight
FINE AGGREGATE			
No 8	10	10	10
No 16	30	20	20
No 30	56	26	30
No 50	80	24	25
No 100	$\frac{94}{270}$ F.M.=2.7	$\frac{14}{94\%}$	$\frac{15}{100\%}$
COARSE AGGREGATE			
3/4"	5	5	5
1/2"	33	28	30
3/8"	63	30	30
No 4	95	$\frac{32}{95}$	$\frac{35}{100}$

⁺⁺ Aggregates have been sieved and recombined in the laboratory in proportion to fall in the middle of ASTM limits (C-33-64). Coarse aggregate was 100% Nepean Limestone.

TABLE 4

Number of specimens cast for each series:

Series	No. of Slabs 4"x3"x12"	No. of Cylinders 6"x12"	No. of Prisms 3"x3"x12"	Remarks
A	12	4	4	
B	12	6	4	
C	10	6	4	Slab no.11&12 not used.
D	10	6	4	Slab no.8&10 not used.
E	12	6	4	
M	9	6	4	
N	12	6	4	Two of each of no. 7, 8 & 9 are used.
P	12	6	4	Two of each of no. 7, 8 & 9 are used.
Q	10	6	4	Two of each of no. 6&7 used.No.9 not used.
R	12	6	4	Two of each of no. 7, 8 & 9 used.

Cylinders, prisms and slabs have been cast from the same batch for one series.

tions to fall in the middle of ASTM limit (C 33-64). Deformed steel wires corresponding to ASTM specification number A 305-56T from United States Steel International Company Limited having various diameters had been used. Tri-X high early strength Portland Cement had been used.

All casting had been done in the morning hours of the day in shade under normal temperature (about 65°F) and humidity. The whole process of casting took 45 to 60 minutes. All aggregates had been well mixed dry in the mixer, then water had been added and the mixing continued for about 2 to 3 minutes. All moulds had been well cleaned and oiled before pouring of concrete into them. All reinforcing bars had been kept away from the oil. Four thermocouple wires had been inserted; one in each of the slab specimens with 0%, 1.5%, 3.5%, and 5.5% steel. These thermocouple wires measured temperature at centres of cross section of slab specimens. Concrete was well compacted by hand and given a smooth finish. All specimens were covered with burlap two hours after casting and stored in the laboratory for 24 hours. The specimens were then removed from the moulds. All slab specimens and control prisms and cylinders were properly marked regarding percentage

of steel and date of casting. Then they were kept immersed in fresh water at room temperatures for seven days. No special control of humidity had been made at any stage of this investigation, because this control is hardly effected in the field. After seven days of wet curing, all specimens were dried in air inside the laboratory until tested. Special strain guage Advance wires with a 0.001" diameter were used to mark the targets. These targets were marked at 10 inch separations.

The lowest count of the microscope was 20×10^{-6} inches, and this necessitated the use of very fine targets made from 1×10^{-3} inch diameter. Advance wire was used. Cross marks had been made with this wire at ten inch guage lengths. Backgrounds of these cross marks had been painted white to illuminate the target. These targets had been fixed on the specimens with Armstrong A-2 adhesive with activator type A.

5.3 Extensometer: The extensometer was an optical instrument used to measure the change in the distance between two points. This was a high precision instrument and required great care in handling. Different parts and specifications are listed below.

5.3.1 Parts of the extensometer: In Figure 5 there is a photograph of the extensometer. This instrument was used to measure the deformation of specimens from outside the cold chamber. Following are the different parts of the extensometer (see Figure 5).

- (a) optical bench assembly - 8 feet long.
- (b) co-ordinate motion carriage assembly
- (c) basic bar assembly
- (d) filler micrometer microscopes
- (e) steel ball, 1/4" diameter (not shown in Figure 5)
- (f) spirit level accuracy 5×10^{-4} inch in 10 inches (not shown in Figure 5)

Two optical bench assemblies had been placed one on each side of the chamber. This avoided transferring and relevening of the bench from one side to another.

5.3.2 Specifications of extensometer microscopes:

- (a) Relay system magnification 0.5 X
- (b) Objective magnification 10 X
- (c) Eyepiece magnification 10 X
- (d) Total magnification 50 X
- (e) One division on Filar drum 0.00002 inch
- (f) One revolution of Filar drum 0.002 inch

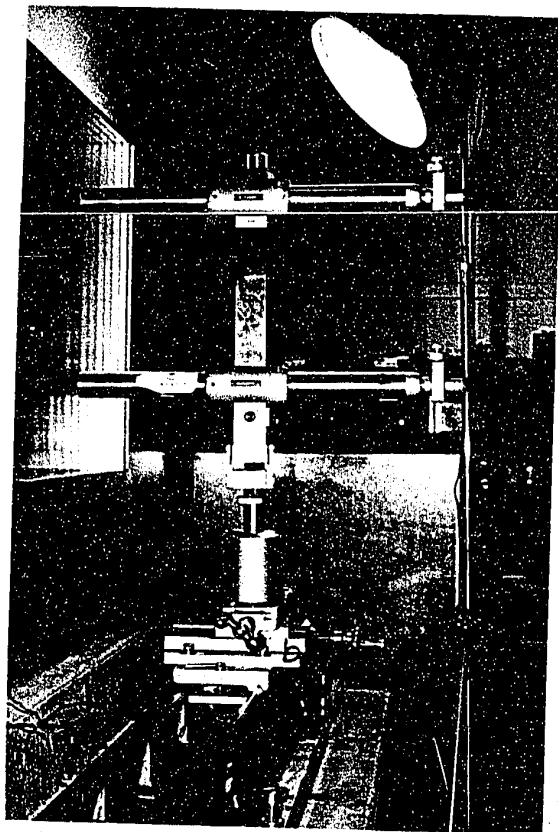


FIGURE 5

Various Parts of the Optical Extensometer

- (a) Optical bench assembly
- (b) Co-ordinate motion carriage assembly
- (c) Basic bar assembly
- (d) Filar micrometer microscopes

(g) Filar micrometer measuring range	0.08	inch
(h) Diameter of field of view	0.08	inch
(i) Mechanical working distance	15.5	inches
(j) Variable separation of microscopes	2 to 12	inches
(k) Lower microscope (minimum height above table)	19.5	inches
(l) Upper microscope (maximum height above table)	33.25	inches

5.3.3 Specifications of co-ordinate motion carriage:

(a) Longitudinal motion range	6	inches
(b) Cross motion range	4	inches
(c) One division on divided drum	0.001	inch

5.3.4 Setting up of extensometer: The optical benches were placed on the concrete pedestal, and a coating of rust veto A-2 was removed by kerosene oil. These benches were then coated with light machine oil from time to time. A small piece of sheet metal was placed under eight levelling screws. The co-ordinate motion carriage assembly was attached to the optical bench. The assembly was then levelled in both directions using the spirit level. After levelling all of the levelling screws were locked. This levelling of the bench was repeated before the

testing of each series and verified after the completion of the test. A quarter inch diameter steel ball was placed in the conical hole at the bottom of the socket located on top of the carriage assembly. Then the basic bar assembly (c in Figure 5) was inserted into the socket (b in Figure 5) to let it rest on the ball. The bar was clamped into the socket with knurled head clamp screw located on the side of the socket. Then microscopes (d in Figure 5) were mounted on the basic bar and clamped in position after making adjustments to match with targets on specimens.

5.4 Temperature measurement: A standard Honeywell potentiometer was used to read the temperature from the thermocouples. Model number 2736 reads temperature directly from -100°F to $+200^{\circ}\text{F}$. However, Honeywell Guarded Null detector model 3970 was changed from standard equipment. This was a pointer type indicator and was easy and more accurate to use. Figure 6 shows the potentiometer on the lower right.

5.5 Refrigeration chamber: Figure 6 shows the chamber from the outside, and Figure 7 shows it from the inside including the mounting frame and specimens. This chamber was designed by Professor Carl Berwanger,

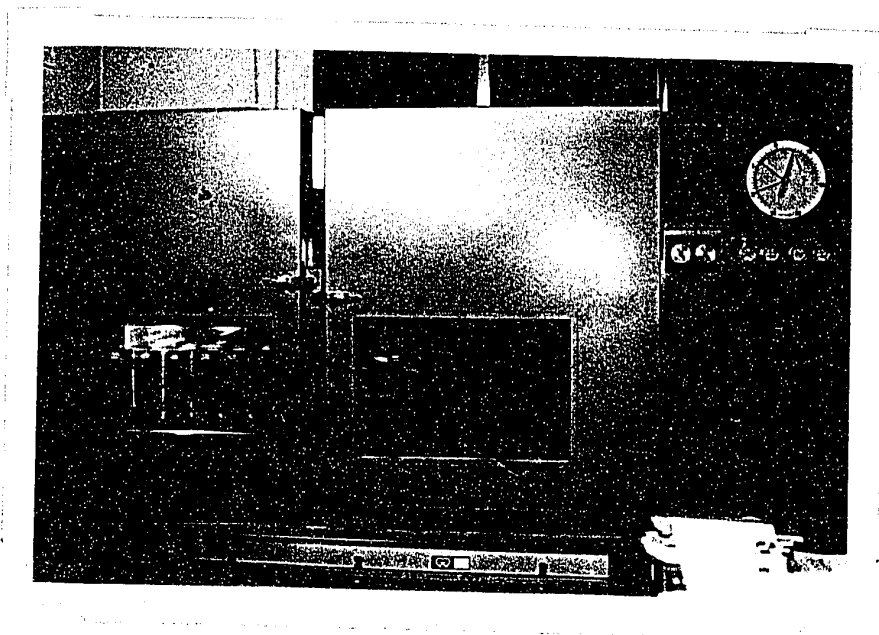


FIGURE 6

Outside view of cold chamber and potentiometer with slabs shown in position through viewing windows.

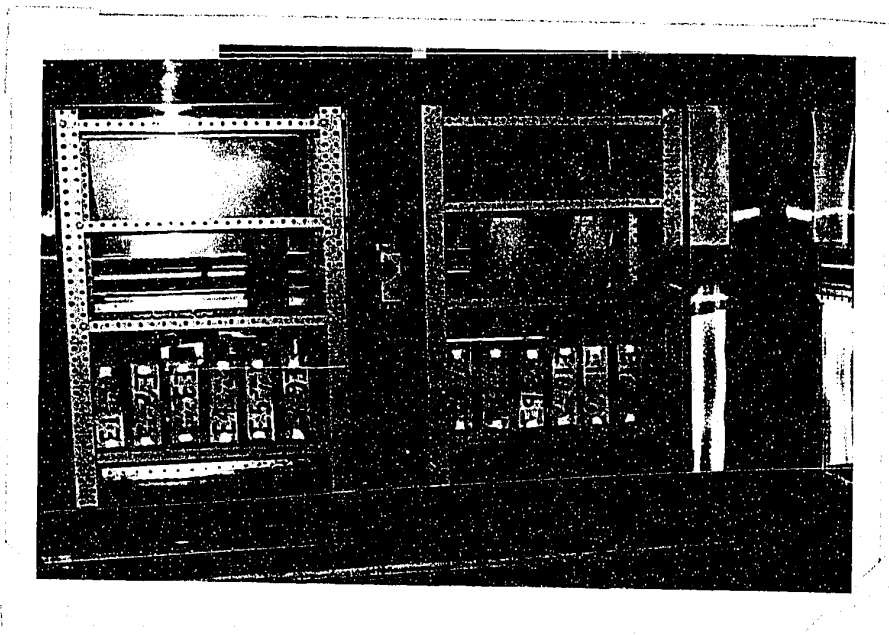


FIGURE 7

Inside view of cold chamber, mounting frame and specimens.

Department of Civil Engineering, University of Ottawa and manufactured by Webber Manufacturing Company, Incorporated; Indianapolis, Indiana, U.S.A. Various parts of the chamber are shown in Figure 8. (Appendix II)

5.6 Sonic test apparatus: A standard sonic test apparatus of M. Falk and Company Limited, England is used. Figure 9 shows the apparatus.

5.7 Compression testing machine: A standard compression testing machine of 300 kips maximum capacity had been used to determine the compressive strength and static Young's modulus of concrete used. Figure 10 shows test and testing machine.

5.8 Testing procedure:

5.8.1 Temperature tests: All specimens were assembled inside the chamber on the mounting frame shown in Figure 7. Thermocouple wires were connected to extension wires leading to the potentiometer outside the chamber. The chamber was sealed and the starting temperature (80°F and 32°F) was maintained inside. Initial readings on both targets were taken. Then the temperature was lowered to -100°F and then raised to +140°F in steps of 30°F. Readings were taken at all the temperatures. The temperatures were



FIGURE 9

Sonic test apparatus

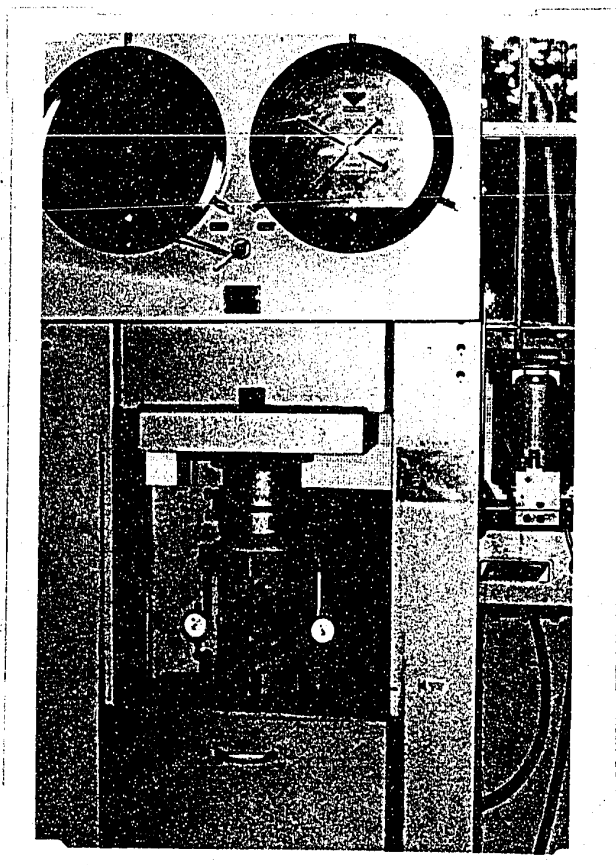


FIGURE 10

Compression testing machine with test cylinder in position.

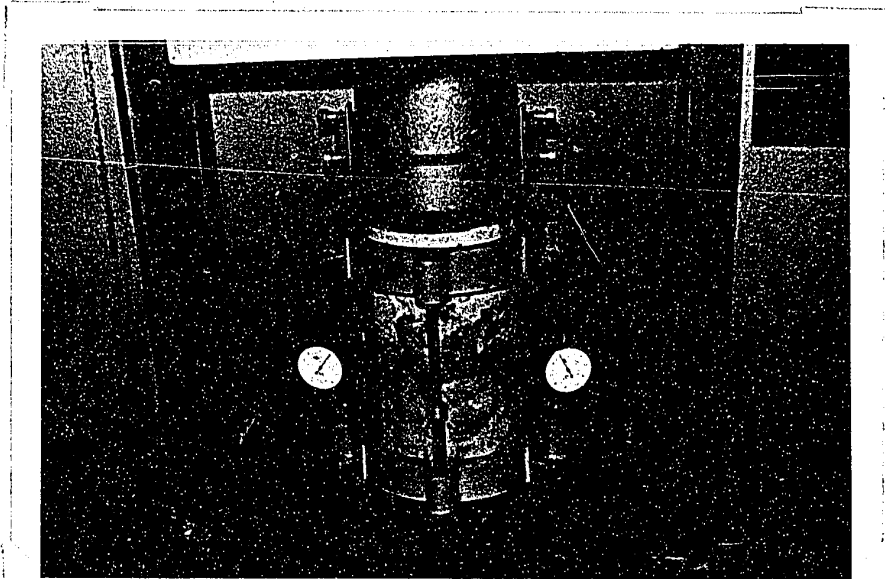


FIGURE 11

A cylinder under compression test.

noted from both potentiometer and temperature indicator of the cold chamber. These temperatures were in very close agreement. It took about two and a half hours to stabilize the temperature inside and outside the specimens.

All the data had been programmed for IBM 360 system model 65 computer. Fortran IV language had been used. This program calculated changes in temperatures and corresponding changes in the length of specimens between targets. This program then used these values of ΔT and Δl_{RC} from its memory and fitted a straight line by the least square curve fit. Figure 13 shows the flow chart of this program. A sample of computer output is given in Table 5. The slope of this straight line gives the value of the coefficient of thermal expansion. Strains have also been plotted against temperature. The sample plot of strain versus temperature is shown in Figure 12. This process was repeated for all ten series from A to E and M to R.

The time to test one series was 5 days, and age was calculated after 3 days from the beginning of the test. One control cylinder was tested before beginning the test and one after the end of the test. During the test this second cylinder was kept inside

the chamber and subjected to the same temperature changes as all the test specimens. A sonic test was done before and after the test. Sonic test samples were also kept inside the chamber and subjected to the same temperature changes.

5.8.2 Sonic tests: The weight of the samples was taken first, and prisms were then clamped in position for the resonance test (see Figure 9). Dial readings were taken at resonance. Corresponding to these dial readings, resonance frequencies had been written from the table supplied with the machine. The length of all prisms is 12 inches and width and thickness, 3 inches each. This was done twice for each series; once before beginning the test and again after the end of the test. A sample reading is shown in Table 6.

5.8.3 Compression tests: A 9 inch guage length was marked first leaving $1\frac{1}{2}$ inches cover on the top and bottom. Then the cylinder was capped with a sulphur compound for uniform application of the load. The cylinder was then clamped in the frame symmetrically to give symmetrical strains. Two dial guages were used and the average of the two readings was taken as strain reading till load of about 45% of maximum ultimate load. Then the dial guage and frame were

TABLE 6

Sample Reading of Sonic Test

Series C Age: 84 days

Size of specimen: 3"x3"x12"

Specimen No.	Weight lbs.	Dial Reading	Frequency (Resonance) cycles/second	Remarks
2	9.34	1944	6025	These tests were made after the temperature test.
3	9.39	1932	5910	
4	9.42	1902	5620	
2	9.35	1943	6020	These tests were made before the temperature test.
3	9.38	1933	5915	
4	9.41	1911	5700	

removed and the cylinder was loaded for the ultimate load. This was done before and after the test for each series. The cylinder which was tested after the temperature test was subjected to the same temperature changes as the specimen. A sample reading is shown in Table 7.

TABLE 7

Sample Readings for the Compression Test

Series D

Age: 84 days

Sample no. D4; Size: 6" diameter, 12" long

Maximum crushing load: 180 Kips

Gauge length: 9"

Load Kips	Gauge Reading Dial 1	($\times 10^{-4}$ in) Dial 2	Deformation ($\times 10^{-4}$ in)	Strain Micro-in/in
0	0	0	0	0
5	4.4	4.3	4.35	38.3
10	8.3	8.5	8.40	93.3
15	12.7	12.2	12.45	138.3
20	16.6	17.1	16.85	187.2
25	22.1	22.9	22.50	250.0
30	25.1	26.7	25.90	297.8
35	30.0	31.1	30.55	339.4
40	33.0	34.5	33.75	375.0
45	37.5	38.5	38.00	422.2
50	42.5	43.5	43.00	477.8
45	38.0	39.5	38.75	430.6
40	34.0	34.5	34.25	380.6
35	31.0	31.5	31.25	347.2
30	26.1	26.7	26.40	293.3
25	22.5	22.9	22.70	252.2

(TABLE 7 cont'd)

20	17.0	17.5	17.25	191.6
15	13.0	13.3	13.15	146.1
10	8.7	8.8	8.75	97.2
5	4.5	4.2	4.35	49.3
0	0	0	0	0

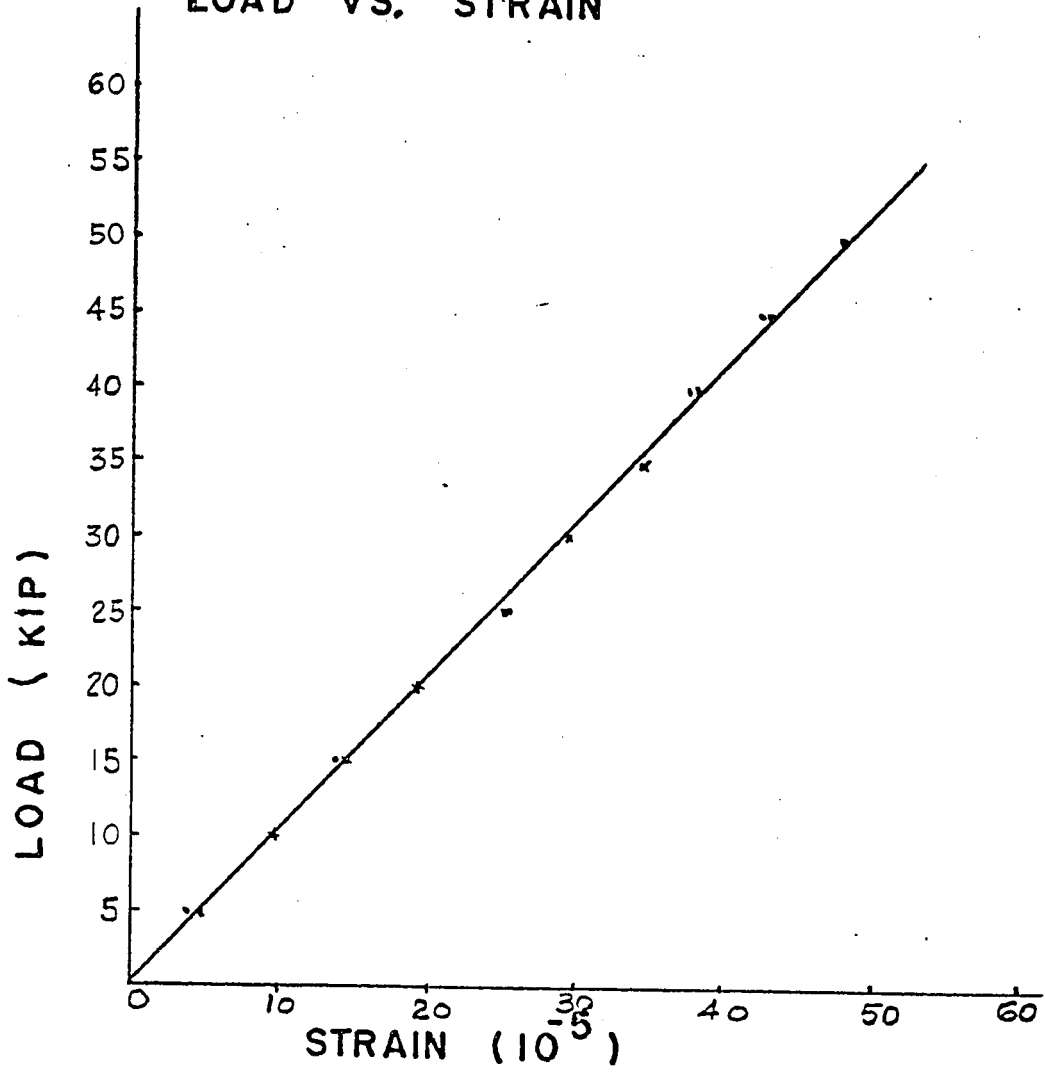
CHAPTER VI

RESULTS

6.1 Experimental data: Tables 6, 7, and 8 show samples of data that have been obtained from the tests. Table 6 lists samples of data obtained from sonic tests. The numbers in the frequency column are taken from the table supplied by the manufacturer of the test machine. Table 7 shows samples of the data obtained from the compression test. These data have been plotted on graph and the value of E_{static} and Ultimate Compressive Strength (f'_c) calculated. Figure 14 shows a typical plot of load versus deformation.

Table 8 shows specimen numbers specifying the steel percentage, initial and final temperature readings and initial and final readings on the extensometer matching with targets before and after the temperature change. The temperatures noted are averages of four potentiometer readings and two temperature dial readings (one from the pointer and the other from the graph plotted). This table also shows contraction or elongation of each specimen; the negative sign shows contraction and the positive sign, elongation.

FIGURE 14
LOAD VS. STRAIN



SAMPLE NO. D 4
AGE 84 DAYS

DIAMETER = 6" ULTIMATE LOAD = 180 KIPS

All the data recorded from the tests have been punched directly for computation and the program was so prepared as to make all necessary calculations and keep them in memory as required except for the compression tests for which calculations were done manually.

6.2 Calculations: Table 9 shows the results of calculations for a temperature test at the age of 15 and 30 days for series C, M, N, and D, E, P respectively. Many of the data obtained from the tests could not be used because results were very erratic. The tabulated values are only approximate and cannot be relied upon.

Tables 10a, 10b, 10c, and 10d show the results of temperature tests on B, C, D, and E series respectively at the age of 84 days. These results are very reliable and follow a very regular pattern. These values are computed by fitting a straight line to temperature change and deformation data by the least square fit method.

Tables 10a, 10b, 10c, and 10d show that a high w/c ratio and no steel gives a low coefficient of thermal expansion. As the w/c ratio is reduced and/or steel is increased, the value of the coefficient

TABLE 9

Summary of Results of Static and Dynamic Young's Modulus

Series	Age Days	f_c' p.s.i.	E_{static} $\times 10^6$ psi	$E_{dynamic}$ $\times 10^6$ psi	$\frac{E_{dynamic}}{E_{static}}$
A	15	4590	4.33	4.80	1.10
B	15	4400	4.45	4.80	1.08
C	15	4900	4.00	5.10	1.27
D	30	6065	3.93	5.20	1.32
E	30	6550	3.93	4.80	1.22
M	15	2770	3.66	4.90	1.34
N	15	3950	3.39	4.20	1.24
P	30	4990	4.49	4.80	1.07
B	84	4770	4.18	4.60	1.10
C	84	5480	4.10	4.50	1.10
D	84	6325	4.12	4.60	1.12
E	84	6770	3.88	4.80	1.24

of thermal expansion increases until it is very near to that of the steel alone. Also, there are two values of the coefficient of thermal expansion of concrete, one below the freezing point of water and the other above the freezing point. The difference in the two values is greater for high w/c ratio concrete and at a lower age. As already mentioned, this behavior is due to free moisture in the minute pores in the hardened concrete. The quantity of free moisture is more for concrete with a high w/c ratio. This reduces to a minimum value as time passes due to the process of evaporation.

Table 10 shows the effect of w/c ratio on the coefficient of thermal expansion of the concrete for various percentages of reinforcing steel. Again there are two values, one below the freezing temperature of water and the other above the same. We find that as the strength increases, the expansion coefficient also increases, though rather slowly.

Table 8 shows a comparison of static and dynamic Young's modulus of elasticity of concrete of various strength and at various ages. The results show that $E_{dynamic}$ is greater than E_{static} . Both of these moduli increase with an increase in strength and also at a greater age. Table 8 also shows that

TABLE 10

Summary of the Results of the Coefficient
of Thermal Expansion

Series	Age	w/c ratio	No. of specimens tested for determina- tion of RC	$\alpha_{RC} \times 10^{-6}$		Remarks
				Below 32°F	Above 32°F	
C	15	0.621	5	2.55	4.70	
M	15	0.798	8	0.90	2.59	face near the steel
N	15	0.708	7	1.0	2.07	face near the steel
D	30	0.532	7	2.16	4.24	
E	30	0.434	9	1.88	2.93	
P	30	0.621	8	2.20	4.04	face near the steel

TABLE 10a

Summary of the Results of the Coefficient
of Thermal Expansion

Series B Age: 84 days w/c ratio = 0.708

Specimen No.	% age steel	$\alpha_{RC} (x10^{-6}/^{\circ}F)$		Remarks
		Below 32 ^o F	Above 32 ^o F	
B1	0.0	2.44	3.14	
B2	0.5	2.53	2.91	
B3	1.0	2.63	3.36	
B4	1.5	2.85	3.46	
B5	2.0	1.74	2.49	
B6	2.5	3.00	3.37	
B7	3.0	3.15	4.58	
B8	3.5	3.26	3.77	
B9	4.0	3.41	3.04	
B10	4.5	3.54	4.19	
B11	5.0	2.10	3.09	
B12	5.5	3.82	4.49	

TABLE 10b

Summary of the Results of the Coefficient
of Thermal Expansion

Series C		Age: 84 days		w/c ratio = 0.621	
Specimen No.	% age steel	$\alpha_{RC} (x10^{-6}/^{\circ}F)$		Remarks	
		Below 32 ^o F	Above 32 ^o F		
C1	0.0	3.45	3.61		
C2	0.5	3.35	3.68		
C3	1.0	3.53	3.78		
C4	1.5	2.49	3.80		
C5	2.0	3.93	4.28		
C6	2.5	3.79	4.08		
C7	3.0	4.03	4.25		
C8	3.5	4.19	4.44		
C9	4.0	4.28	4.35		
C10	4.5	4.56	4.71		

TABLE 10c

Summary of the Results of the Coefficient
of Thermal Expansion

Series D Age: 84 days w/c ratio = 0.532

Specimen No.	% age steel	$\alpha_{RC} (x10^{-6}/^{\circ}F)$		Remarks
		Below 32°F	Above 32°F	
D1	0.0	3.36	3.87	
D2	0.5	3.45	3.85	
D3	1.0	3.56	4.06	
D4	1.5	3.62	4.13	
D5	2.0	3.47	4.21	
D6	2.5	3.84	4.26	
D7	3.0	3.82	—	
D9	4.0	—	4.64	
D11	5.0	4.36	4.41	
D12	5.5	4.48	4.60	

TABLE 10d

Summary of the Results of the Coefficient
of Thermal Expansion

Series E Age: 84 days w/c ratio = 0.434

Specimen No.	% age steel	α RC ($\times 10^{-6}/^{\circ}\text{F}$)		Remarks
		Below 32 $^{\circ}\text{F}$	Above 32 $^{\circ}\text{F}$	
E1	0.0	3.43	4.03	
E2	0.5	3.50	4.56	
E3	1.0	3.63	4.22	
E4	1.5	3.71	4.29	
E5	2.0	3.83	4.43	
E6	2.5	3.97	4.55	
E7	3.0	4.11	4.70	
E8	3.5	4.23	5.31	
E9	4.0	4.37	4.24	
E10	4.5	4.29	5.10	
E11	5.0	4.63	5.23	
E12	5.5	4.68	5.37	

a maximum of the values of $E_{\text{dynamic}}/E_{\text{static}}$ ratio lies between 1.10 and 1.25.

In Table 11 the experimental values of the coefficient of thermal expansion are tabulated. Using these values of the coefficient of thermal expansion of concrete and theory of Chapter IV, the values of $\frac{E_c}{f'_c}$ have been calculated. These values have been compared with J. A. Cran's experimentally obtained values of $\frac{E_c}{f'_c}$ in Table 12.

Symmetrical series A and all asymmetrical series were not tested at the age of 84 days. Each value given on Table 10a through Table 10d and Table 11 is the least square average of sixteen readings.

TABLE 12

Summary of Results Obtained by Theory Using
Experimental Values of the Coefficient of
Thermal Expansion of Reinforced Concrete

$$E_s = 30 \times 10^6 \text{ p.s.i.} \quad \alpha_s = 6 \times 10^{-6} \text{ per degree F}$$

Temperature °F	$\frac{E_c}{f_c}$ (J.A.Cran) Age 69 Days $\times 10^3$		$\frac{E_c}{f_c}$ (S.K.Jain) Age 84 Days $\times 10^3$			
			w/c = 0.708 $f'_c=4770$ p.s.i.	w/c = 0.621 $f'_c=5480$ p.s.i.	w/c = 0.532 $f'_c=6325$ p.s.i.	w/c = 0.434 $f'_c=6770$ p.s.i.
-30°	2.0	1.5				
-15°	1.9	1.4				
0°	1.8	1.4	0.9	0.9	1.0	1.0
+15°	1.8	1.4				
+32°	1.8	1.4				
+45°	1.8	1.4				
+60°	1.8	1.4	0.8	0.8	0.9	0.9
+75°	1.8	1.4				

CHAPTER VII

CONCLUSIONS

(1) There are two values of the coefficient of thermal expansion for concrete and reinforced concrete, one below freezing and the other above the freezing temperature of water.

(2) Below freezing point of water the coefficient of thermal expansion of plain concrete is 2.44×10^{-6} per degree F for w/c ratio 0.708 and 3.43×10^{-6} per degree F for w/c ratio 0.434. For reinforced concrete with 5.5% steel these values are 3.82×10^{-6} per degree F for w/c ratio 0.708 and 4.68×10^{-6} per degree F for w/c ratio 0.434.

(3) Above freezing point of water the coefficient of thermal expansion of plain concrete is 3.14×10^{-6} per degree F for w/c ratio 0.708 and 4.03×10^{-6} per degree F for w/c ratio 0.434. For reinforced concrete with 5.5% steel these values are 4.49×10^{-6} per degree F for w/c ratio 0.708 and 5.37×10^{-6} per degree F for w/c ratio 0.434.

(4) The value of static Young's Modulus of elasticity varies between 4.0×10^6 p.s.i. and 4.5×10^6 p.s.i. for concrete with a w/c ratio from 0.708 to 0.434.

(5) The dynamic Young's Modulus of elasticity is always greater than the static Young's Modulus of elasticity, and its values vary from 4.5×10^6 p.s.i. to 5.2×10^6 p.s.i. for a w/c ratio from 0.708 to 0.434.

(6) The dynamic Young's Modulus of elasticity is on the average 20% greater than the static Young's Modulus of elasticity.

(7) The coefficient of thermal expansion shows a greater variation with a change in steel percentage and/or a w/c ratio below the freezing temperature of water than above the same.

(8) The suggested one value of the coefficient of thermal expansion of reinforced concrete for design purpose where finer accuracy is not desired is 4.5×10^{-6} per degree F.

The suggested one value of the coefficient of thermal expansion is an average value which can be used for most of the designs for various w/c ratios of concrete at different ages of concrete and different percentages of steel. G. E. Monfore and A. E. Lentz (14) also suggested the average value as 4.5×10^{-6} per degree F. G. L. England and A. D. Ross gave the values of the coefficient of thermal expansion for sealed and unsealed specimens as 5.8×10^{-6}

and 6.6×10^{-6} per degree F respectively. In the author's opinion these values are high.

In Table 11 a comparison has been made between experimental values of the coefficient of thermal expansion and back calculated values of the same from the average of values of E_c computed using theory of Chapter IV. These values compare very well for most of the cases. However, there is some variation at some places, because the experimental values at these places are not good. In fact these experimental values account for whatever little difference exists elsewhere. Calculation of the coefficient of thermal expansion of reinforced concrete from the values of the coefficient of thermal expansion of plain concrete gives reasonable results. In general it can be summarized that results are very good in this investigation.

CHAPTER VIII

RECOMMENDATIONS

It is recommended to make the following studies in order to solve the problem involved in the behavior of plain concrete with temperature:

- (1) Effect of temperature on ultimate compressive strength of the concrete and Young's Modulus of concrete with different w/c ratios, aggregate/water, and aggregate/cement ratios.
- (2) Effect of stress level on the properties mentioned in (1).
- (3) Influence of age and percentage of steel on both (1) and (2) above.

APPENDIX I

NOTATION

- α_s = Coefficient of thermal expansion of steel
- α_c = Coefficient of thermal expansion of concrete
- $\alpha_{R.C.}$ = Coefficient of thermal expansion of reinforced concrete
- E_s = Young's modulus of steel
- E_c = Young's modulus of concrete
- $E_{R.C.}$ = Young's modulus of reinforced concrete
- l = Length of specimen
- ΔT = Change in temperature
- Δl_c = Change in concrete length
- Δl_s = Change in steel length
- $\Delta l_{R.C.}$ = Change in reinforced concrete length
- F_s = Force in steel due to temperature change
- F_c = Force in concrete due to temperature change
- A_{st} = Area of steel
- A_c = Area of concrete
- y = Distance from neutral axis
- d_1 = Effective depth of specimen
- \bar{y} = Depth of neutral axis from concrete face having no reinforcement
- I = Moment of inertia of section about neutral axis
- E_{static} = Static Young's modulus

E_{dynamic} = Dynamic Young's modulus

f'_c = Ultimate compressive strength per unit area

b = Width of specimen

d = Depth of specimen

Table 5

CALCULATION OF COEFFICIENT OF THERMAL EXPANSION BY LEAST SQUARE FIT

SERIES = B1

CALCULATION BELOW FREEZING TEMPERATURE

CHANGE IN TEMPERATURE CHANGE IN LENGTH
IN DEGREE F IN 2E-03 INCHES

-31.0000	-0.2700
-62.0000	-0.6400
-91.0000	-1.0200
-130.0000	-1.5000
-107.0000	-1.2100
-75.0000	-0.8500
-46.0000	-0.4900
-17.0000	-0.1300

COEFFICIENT OF THERMAL EXPANSION = 2.44 E-06

CALCULATION ABOVE FREEZING TEMPERATURE

CHANGE IN TEMPERATURE CHANGE IN LENGTH
IN DEGREE F IN 2E-03 INCHES

14.0000	0.3200
46.0000	0.7900
75.0000	1.2400
105.0000	1.6900
89.0000	1.4600
62.0000	1.0400
30.0000	0.5700
1.0000	0.0100

COEFFICIENT OF THERMAL EXPANSION = 3.14 E-06

Table 5

CALCULATION OF COEFFICIENT OF THERMAL EXPANSION BY LEAST SQUARE FIT

SERIES = R2

CALCULATION BELOW FREEZING TEMPERATURE

CHANGE IN TEMPERATURE CHANGE IN LENGTH
IN DEGREE F IN 2E-03 INCHES

-31.0000	-0.3700
-62.0000	-0.7500
-91.0000	-1.1400
-130.0000	-1.6400
-107.0000	-1.3700
-75.0000	-0.9900
-46.0000	-0.6100
-17.0000	-0.2300

COEFFICIENT OF THERMAL EXPANSION = 2.53 E-06

CALCULATION ABOVE FREEZING TEMPERATURE

CHANGE IN TEMPERATURE CHANGE IN LENGTH
IN DEGREE F IN 2E-03 INCHES

14.0000	0.2400
46.0000	0.7500
75.0000	1.2200
105.0000	1.7200
89.0000	1.4800
62.0000	2.0300
30.0000	1.5500
1.0000	0.0700

COEFFICIENT OF THERMAL EXPANSION = 2.91 E-06

Table 5

CALCULATION OF COEFFICIENT OF THERMAL EXPANSION BY LEAST SQUARE FIT

SERIES = B3

CALCULATION BELOW FREEZING TEMPERATURE

CHANGE IN TEMPERATURE CHANGE IN LENGTH
IN DEGREE F IN 2E-C3 INCHES

-31.0000	-0.3800
-62.0000	-0.6600
-91.0000	-1.1400
-130.0000	-1.6600
-107.0000	-1.3800
-75.0000	-0.9800
-46.0000	-0.5800
-17.0000	-0.1800

COEFFICIENT OF THERMAL EXPANSION = 2.63 E-06

CALCULATION ABOVE FREEZING TEMPERATURE

CHANGE IN TEMPERATURE CHANGE IN LENGTH
IN DEGREE F IN 2E-C3 INCHES

14.0000	0.3100
46.0000	0.8400
75.0000	1.3300
105.0000	1.8200
89.0000	1.5700
62.0000	1.1000
30.0000	0.6000
1.0000	0.0600

COEFFICIENT OF THERMAL EXPANSION = 3.36 F-06

Table 5

CALCULATION OF COEFFICIENT OF THERMAL EXPANSION BY LEAST SQUARE FIT

SERIES = R4

CALCULATION BELOW FREEZING TEMPERATURE

CHANGE IN TEMPERATURE CHANGE IN LENGTH
IN DEGREE F IN 2E-03 INCHES

-31.0000	-0.4000
-62.0000	-0.8900
-91.0000	-1.2900
-130.0000	-1.8300
-107.0000	-1.5300
-75.0000	-1.1100
-46.0000	-0.6900
-17.0000	-0.2400

COEFFICIENT OF THERMAL EXPANSION = 2.85 E-06

CALCULATION ABOVE FREEZING TEMPERATURE

CHANGE IN TEMPERATURE CHANGE IN LENGTH
IN DEGREE F IN 2E-03 INCHES

14.0000	0.2600
46.0000	0.7700
75.0000	1.2900
105.0000	1.8100
89.0000	1.5500
62.0000	1.0500
30.0000	0.5300
1.0000	-0.00

COEFFICIENT OF THERMAL EXPANSION = 3.46 F-06

Table 5
 CALCULATION OF COEFFICIENT OF THERMAL EXPANSION BY LEAST SQUARE FIT

SERIES = B5

CALCULATION BELOW FREEZING TEMPERATURE

CHANGE IN TEMPERATURE CHANGE IN LENGTH
 IN DEGREE F IN 2E-03 INCHES

-31.0000	-0.4100
-62.0000	-0.7500
-91.0000	-1.2900
-130.0000	-1.8500
-107.0000	-1.5300
-75.0000	-1.9500
-46.0000	-1.5100
-17.0000	-1.0800

COEFFICIENT OF THERMAL EXPANSION = 1.74 E-06

CALCULATION ABOVE FREEZING TEMPERATURE

CHANGE IN TEMPERATURE CHANGE IN LENGTH
 IN DEGREE F IN 2E-03 INCHES

14.0000	-0.5600
46.0000	-0.0300
75.0000	0.5000
105.0000	1.0200
89.0000	0.7600
62.0000	0.2700
30.0000	-0.2700
1.0000	0.1100

COEFFICIENT OF THERMAL EXPANSION = 2.49 E-06

Table 5

CALCULATION OF COEFFICIENT OF THERMAL EXPANSION BY LEAST SQUARE FIT

SERIES = B-6

CALCULATION BELOW FREEZING TEMPERATURE

CHANGE IN TEMPERATURE CHANGE IN LENGTH
IN DEGREE F IN 2E-03 INCHES

-31.0000	-0.4200
-62.0000	-0.8400
-91.0000	-1.3000
-130.0000	-1.8800
-107.0000	-1.5600
-75.0000	-1.1000
-46.0000	-0.6400
-17.0000	-0.1800

COEFFICIENT OF THERMAL EXPANSION = 3.00 E-06

CALCULATION ABOVE FREEZING TEMPERATURE

CHANGE IN TEMPERATURE CHANGE IN LENGTH
IN DEGREE F IN 2E-03 INCHES

14.0000	0.3600
46.0000	0.9000
75.0000	1.4300
105.0000	1.6700
89.0000	1.7100
62.0000	1.1900
30.0000	0.6400
1.0000	-0.0100

COEFFICIENT OF THERMAL EXPANSION = 3.37 E-06

Table 5

CALCULATION OF COEFFICIENT OF THERMAL EXPANSION BY LEAST SQUARE FIT

SERIES = B7

CALCULATION BELOW FREEZING TEMPERATURE

CHANGE IN TEMPERATURE CHANGE IN LENGTH
IN DEGREE F IN 2E-03 INCHES

-31.0000	-0.4400
-62.0000	-0.9000
-91.0000	-1.3800
-130.0000	-1.9800
-107.0000	-1.6400
-75.0000	-1.1600
-46.0000	-0.6800
-17.0000	-0.2000

COEFFICIENT OF THERMAL EXPANSION = 3.15 E-06

CALCULATION ABOVE FREEZING TEMPERATURE

CHANGE IN TEMPERATURE CHANGE IN LENGTH
IN DEGREE F IN 2E-03 INCHES

14.0000	0.3600
46.0000	1.3200
75.0000	1.8700
105.0000	2.4200
89.0000	2.1300
62.0000	1.5800
30.0000	0.9800
1.0000	-0.00

COEFFICIENT OF THERMAL EXPANSION = 4.58 E-06

Table 5

CALCULATION OF COEFFICIENT OF THERMAL EXPANSION BY LEAST SQUARE FIT

SERIES = BR

CALCULATION BELOW FREEZING TEMPERATURE

CHANGE IN TEMPERATURE CHANGE IN LENGTH
IN DEGREE F IN 2E-03 INCHES

-31.0000	-0.4600
-62.0000	-0.9800
-91.0000	-1.4800
-130.0000	-2.1000
-167.0000	-1.7500
-75.0000	-1.2500
-46.0000	-0.7500
-17.0000	-0.2900

COEFFICIENT OF THERMAL EXPANSION = 3.27 E-06

CALCULATION ABOVE FREEZING TEMPERATURE

CHANGE IN TEMPERATURE CHANGE IN LENGTH
IN DEGREE F IN 2E-03 INCHES

14.0000	0.2900
46.0000	0.8700
75.0000	1.4400
105.0000	2.0200
89.0000	1.7500
62.0000	1.1900
30.0000	0.5800
1.0000	0.1000

COEFFICIENT OF THERMAL EXPANSION = 3.77 E-06

Table 5

CALCULATION OF COEFFICIENT OF THERMAL EXPANSION BY LEAST SQUARE FIT

SERIES =B9

CALCULATION BELOW FREEZING TEMPERATURE

CHANGE IN TEMPERATURE CHANGE IN LENGTH
IN DEGREE F IN 2F-03 INCHES

- 31.0000 -0.4900
- 62.0000 -1.0100
- 91.0000 -1.5300
- 130.0000 -2.1700
- 107.0000 -1.8200
- 75.0000 -1.3000
- 46.0000 -0.7800
- 17.0000 -0.2600

COEFFICIENT OF THERMAL EXPANSION = 3.41 E-06

CALCULATION ABOVE FREEZING TEMPERATURE

CHANGE IN TEMPERATURE CHANGE IN LENGTH
IN DEGREE F IN 2E-03 INCHES

- 14.0000 -0.6600
- 46.0000 -0.0600
- 75.0000 0.6000
- 105.0000 1.1800
- 89.0000 0.8700
- 62.0000 0.2300
- 30.0000 -0.4000
- 1.0000 0.0300

COEFFICIENT OF THERMAL EXPANSION = 3.04 E-06

Table 5
CALCULATION OF COEFFICIENT OF THERMAL EXPANSION BY LEAST SQUARE FIT

SERIES = B1C

CALCULATION BELOW FREEZING TEMPERATURE

CHANGE IN TEMPERATURE CHANGE IN LENGTH
 IN DEGREE F IN 2E-03 INCHES

-31.0000	-0.4200
-62.0000	-0.9600
-91.0000	-1.5100
-130.0000	-2.1700
-107.0000	-1.8300
-75.0000	-1.2900
-46.0000	-0.7500
-17.0000	-0.2100

COEFFICIENT OF THERMAL EXPANSION = 3.54 E-06

CALCULATION ABOVE FREEZING TEMPERATURE

CHANGE IN TEMPERATURE CHANGE IN LENGTH
 IN DEGREE F IN 2E-03 INCHES

14.0000	0.4100
46.0000	1.0300
75.0000	1.6500
105.0000	2.2500
89.0000	1.9200
62.0000	1.3400
30.0000	0.7000
1.0000	0.0200

COEFFICIENT OF THERMAL EXPANSION = 4.19 E-06

CALCULATION OF COEFFICIENT OF THERMAL EXPANSION BY LEAST SQUARE FIT

SERIES = R11

CALCULATION BELOW FREEZING TEMPERATURE

CHANGE IN TEMPERATURE IN DEGREE F CHANGE IN LENGTH IN 2E-03 INCHES

-31.0000	-0.5100
-62.0000	-1.0700
-91.0000	-1.6000
-130.0000	-2.2800
-107.0000	-1.9100
-75.0000	-2.4700
-46.0000	-1.9100
-17.0000	-1.3500

COEFFICIENT OF THERMAL EXPANSION = 2.10 E-06

CALCULATION ABOVE FREEZING TEMPERATURE

CHANGE IN TEMPERATURE IN DEGREE F CHANGE IN LENGTH IN 2E-03 INCHES

14.0000	-0.6900
46.0000	-0.0200
75.0000	0.6200
105.0000	1.2400
89.0000	0.9000
62.0000	0.2800
30.0000	-0.3900
1.0000	0.0900

COEFFICIENT OF THERMAL EXPANSION = 3.09 E-06

CALCULATION OF COEFFICIENT OF THERMAL EXPANSION BY LEAST SQUARE FIT

SERIES = P12

CALCULATION BELOW FREEZING TEMPERATURE

CHANGE IN TEMPERATURE CHANGE IN LENGTH
IN DEGREE F IN 2E-03 INCHES

-31.0000	-0.5900
-62.0000	-1.1800
-91.0000	-1.7600
-130.0000	-2.4600
-107.0000	-2.0600
-75.0000	-1.4800
-46.0000	-0.9000
-17.0000	-0.3200

COEFFICIENT OF THERMAL EXPANSION = 3.82 F-06

CALCULATION ABOVE FREEZING TEMPERATURE

CHANGE IN TEMPERATURE CHANGE IN LENGTH
IN DEGREE F IN 2E-03 INCHES

14.0000	0.3400
46.0000	1.0300
75.0000	1.6900
105.0000	2.3500
89.0000	1.9900
62.0000	1.3900
30.0000	0.6900
1.0000	-0.0100

COEFFICIENT OF THERMAL EXPANSION = 4.49 F-06

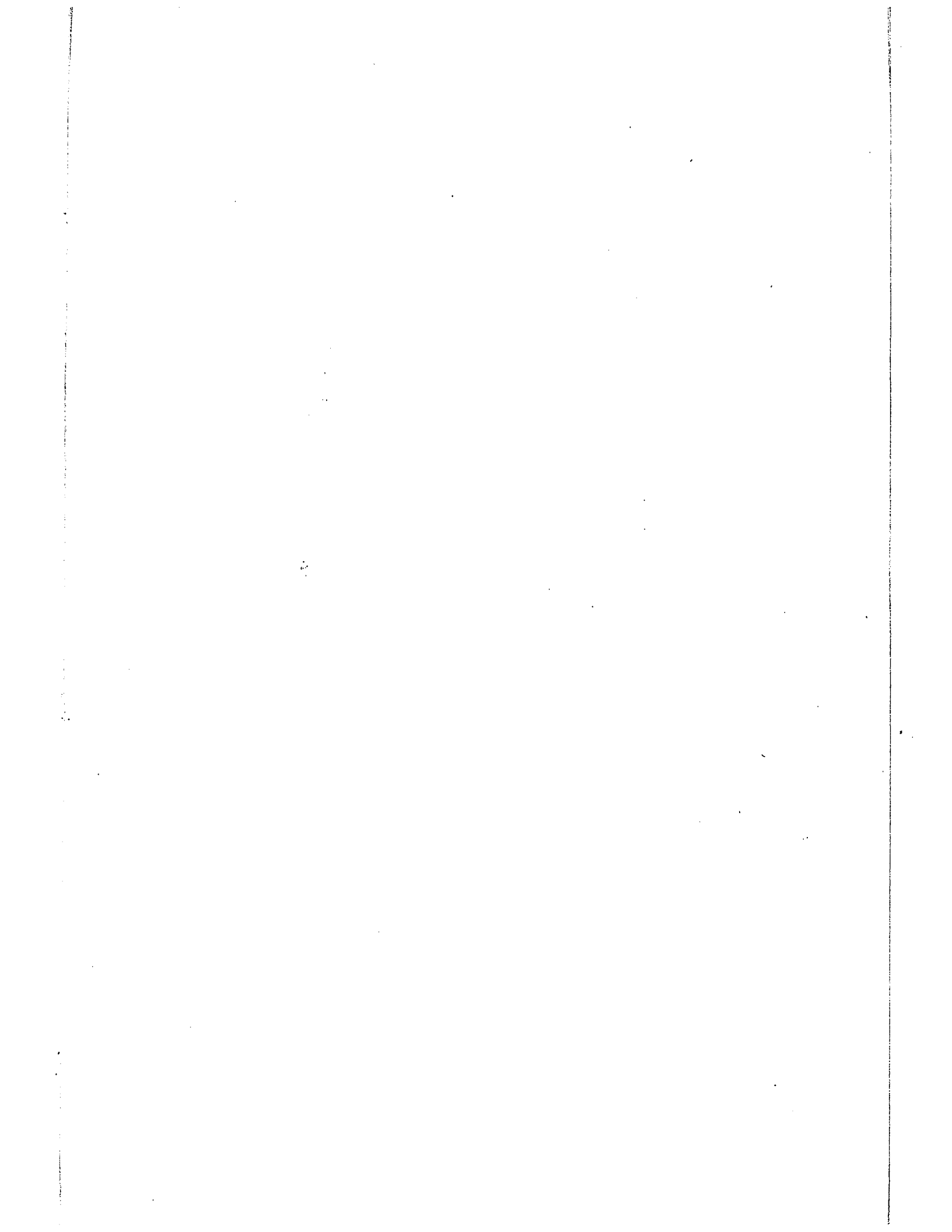
NOTE TO USERS

Oversize maps and charts are microfilmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

This reproduction is the best copy available.

UMI



LEGEND

- (A) INSULATION
- (B) 3" - I BEAM SKID
- (C) FLOOR SUPPORTS
- (D) COOLING COILS
- (E) 24" x 36" WINDOW
- (F) AIR OUTLET
- (G) HEATING ELEMENT
- (H) DOOR LATCHES
- (I) REFRIGERATION GAUGES
- (J) TOGGLE SWITCHES (MASTER, COOLING, HEATING, FAN AND LIGHT)
- (K) HONEYWELL CONTROLLER RECORDER
- (L) FAN MOTOR
- (M) FAN BLADE
- (N) AIR INLET
- (O) DOOR HINGES
- (P) 2" ϕ PORT HOLE
- (Q) LIGHT
- (R) WATER INLET AND OUTLET
- (S) WINDOW FRAME 1"
- (T) ELECTRICAL JUNCTION BOX

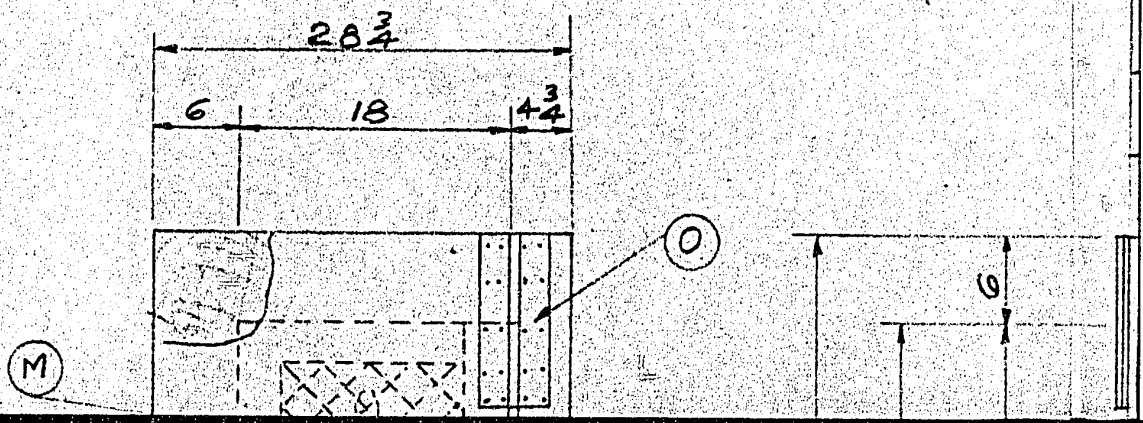
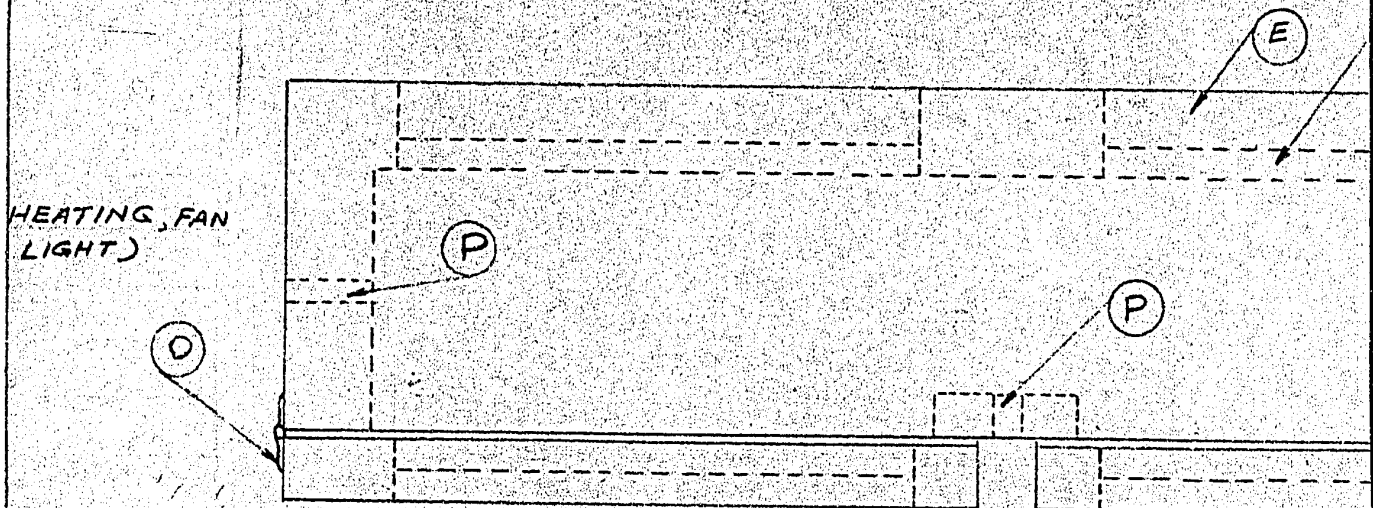
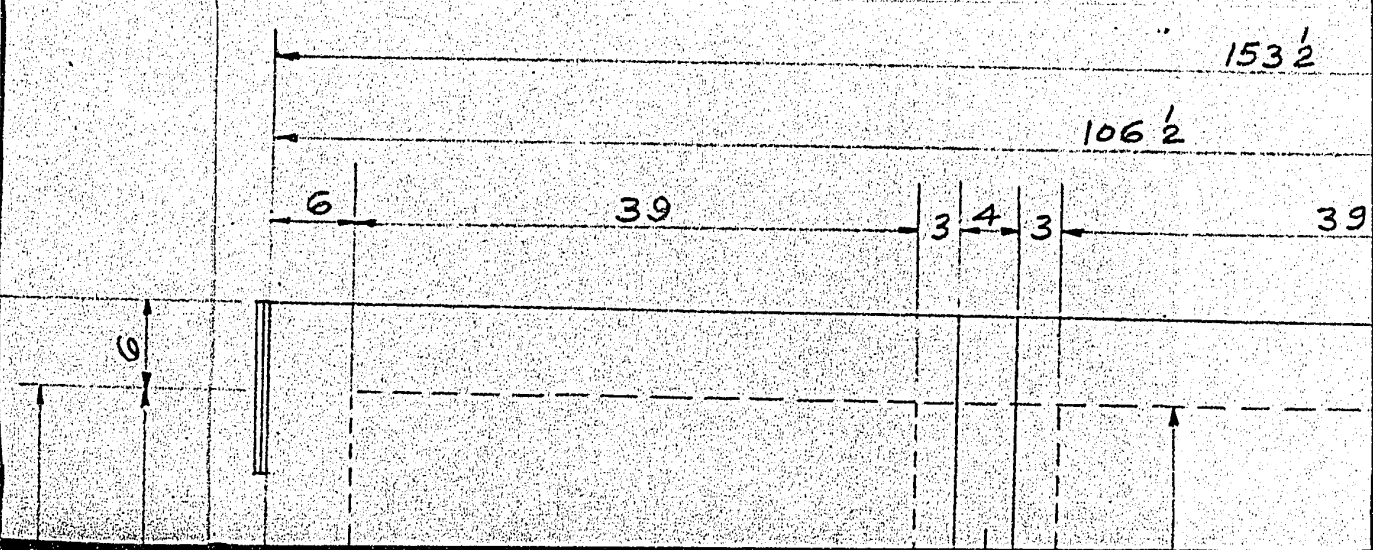


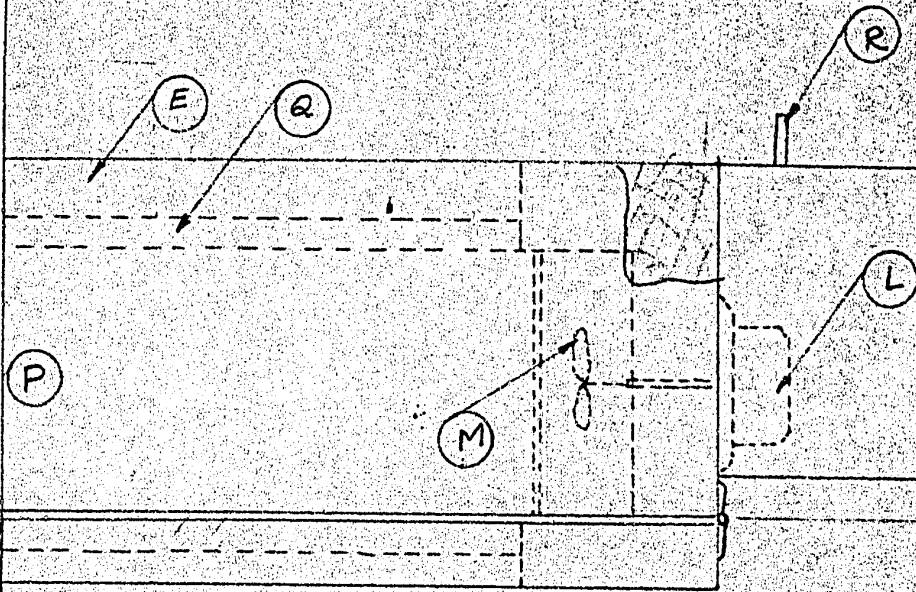
FIGURE 1: SCHEMATIC DIAGRAM OF REF



TOP VIEW



PLAN OF REFRIGERATION CHAMBER



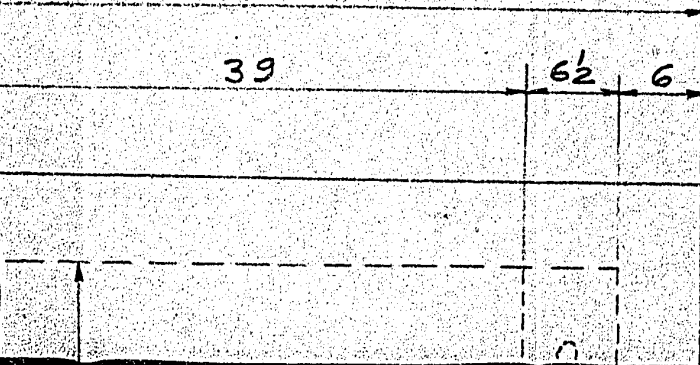
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06 1/2

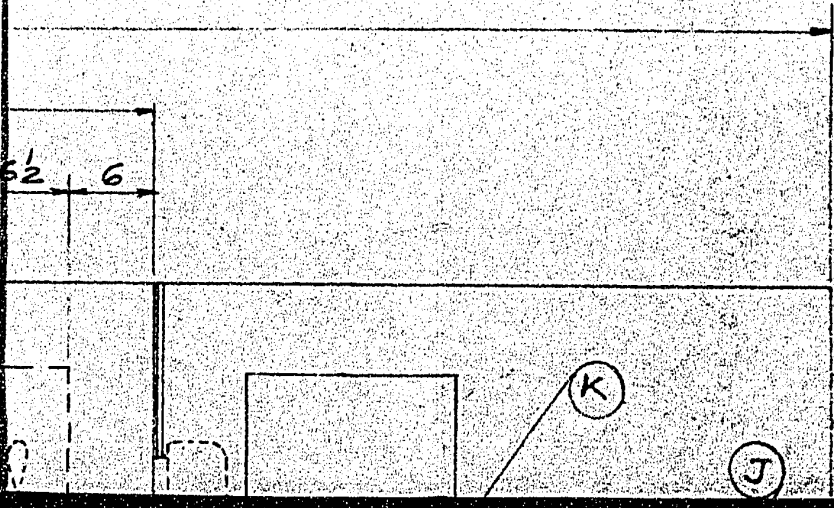
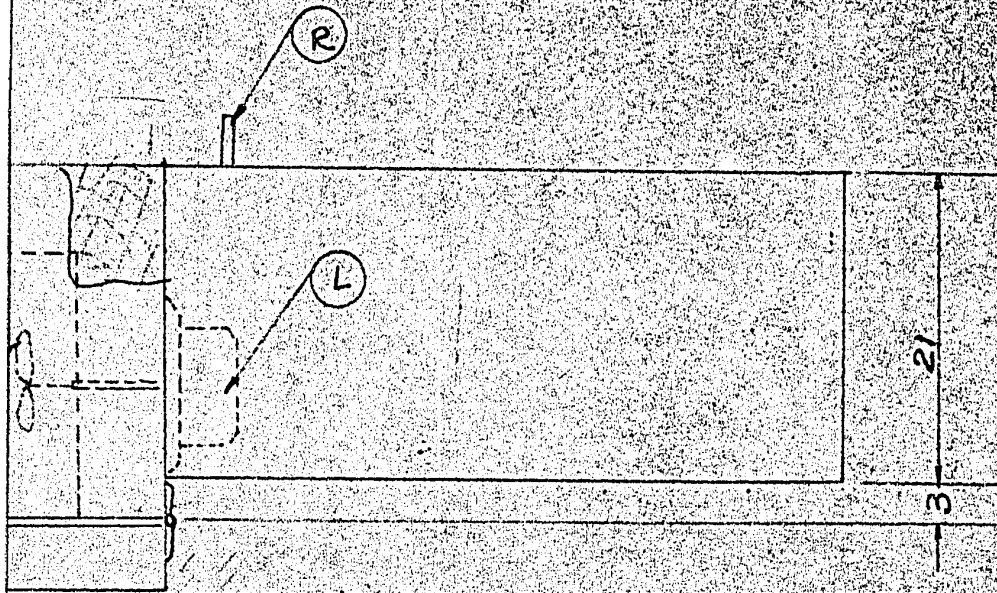
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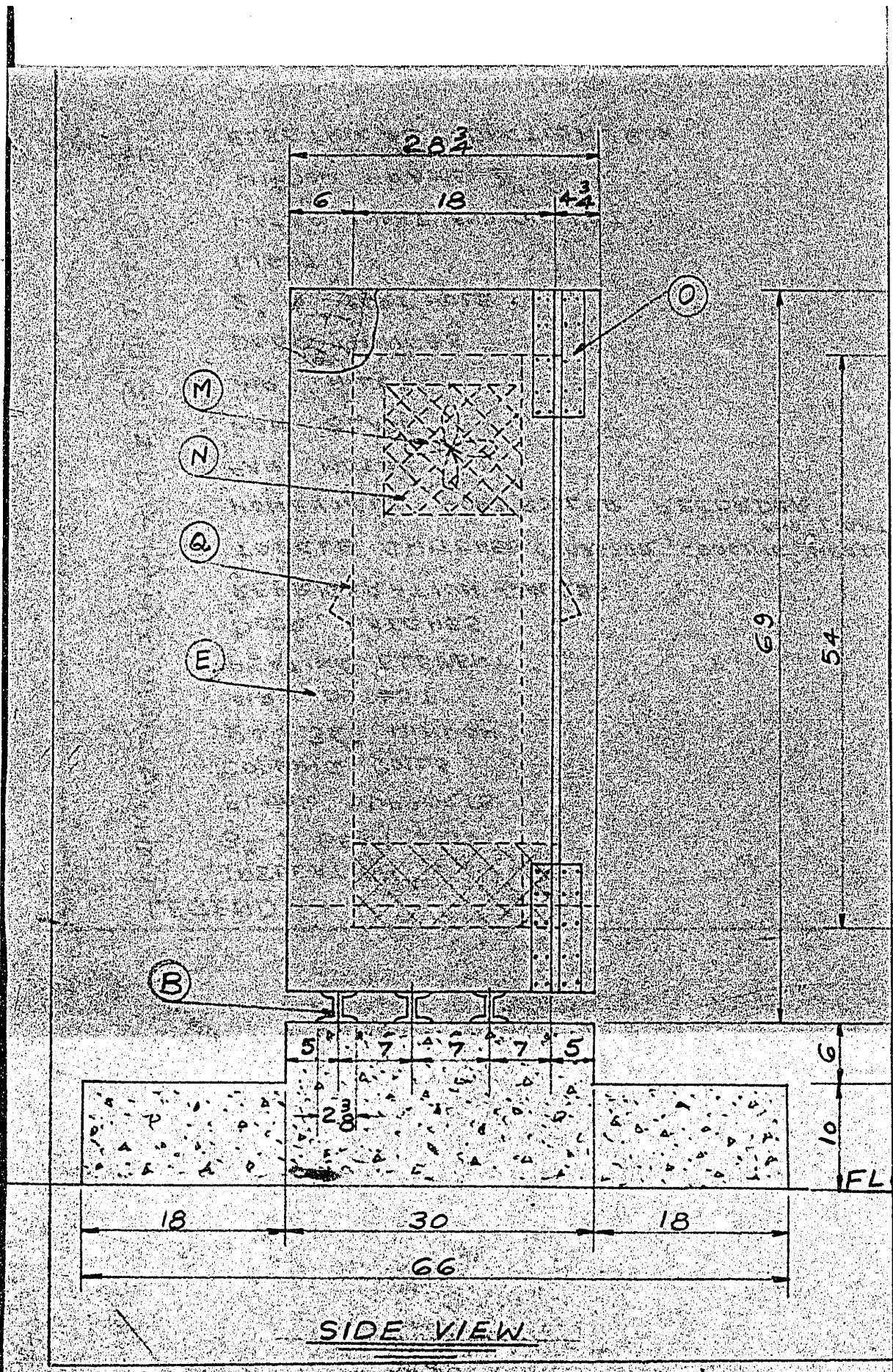
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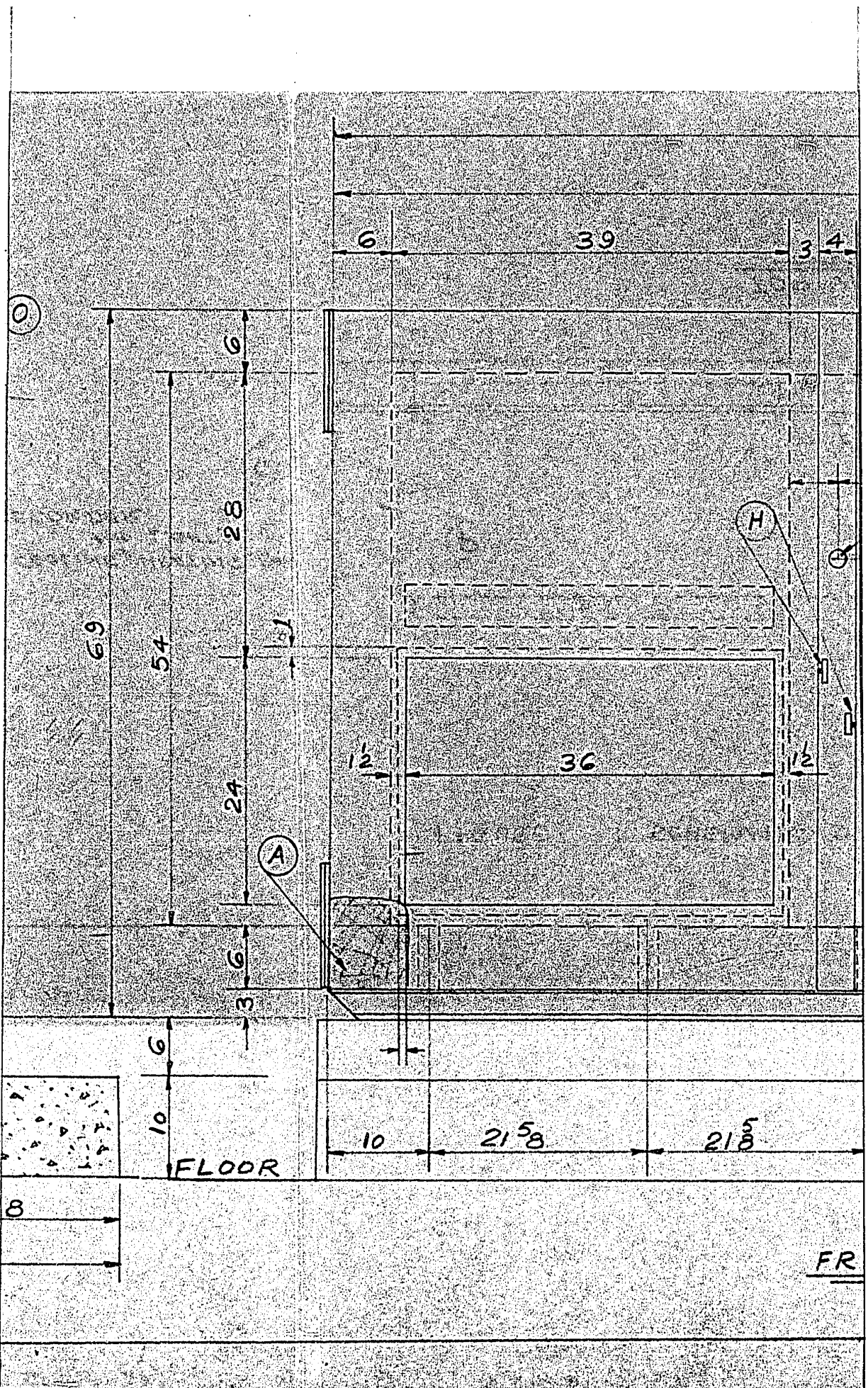


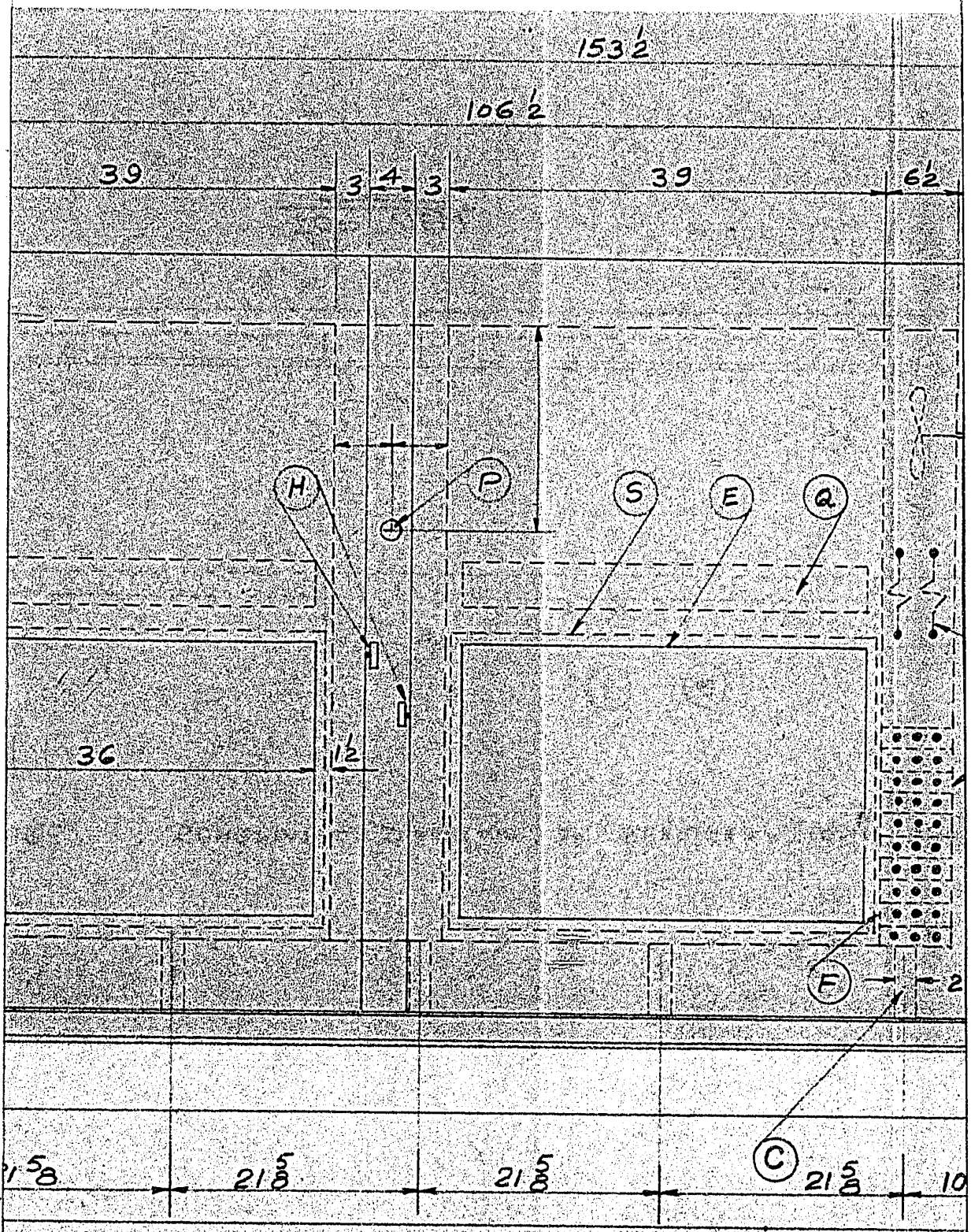
HAMBER



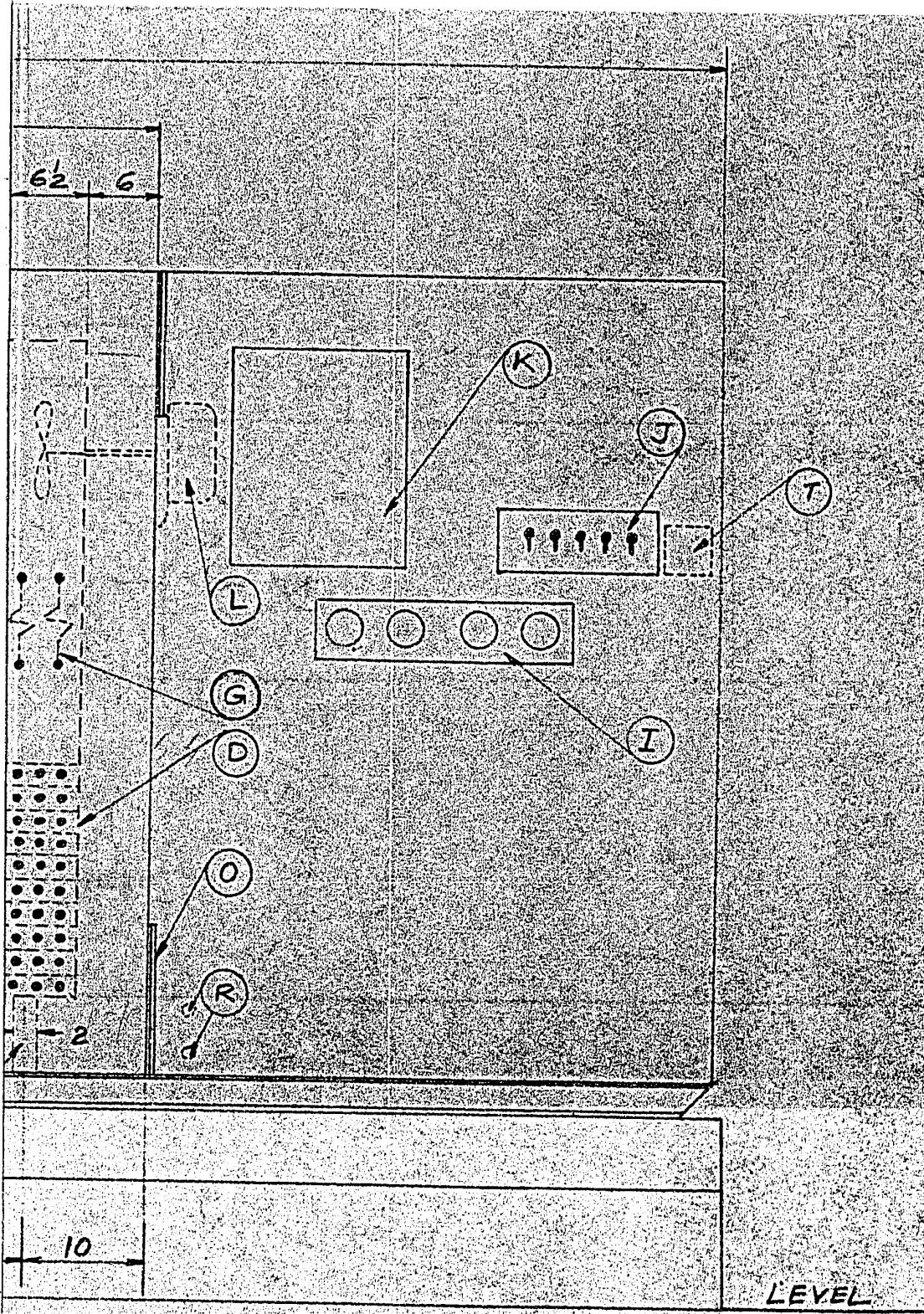


SIDE VIEW





FRONT VIEW



ORIGINAL WEBBER M/F. CO. #4134 A
 FIGURE 8 COPIED BY : S.K. JAIN
 ALL DIMENSIONS ARE IN INCH

Table 8

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CALCULATION OF CHANGE IN TEMPERATURE, CHANGE IN LENGTH AND
COEFFICIENT OF THERMAL EXPANSION

SERIES D AGE= 84.00DAYS COMPRESSIVE STRENGTH= 6325.0CP.S.J.

SPECIMEN IDENTITY	INITIAL TEMP.	INITIAL TOP	INITIAL BOTTOM	FINAL TEMP.	FINAL TOP	FINAL BOTTOM	ELONGATION	COEFFICIENT OF EXPANSION
D1	31.0	0.0	-8.27	1.0	0.0	-7.76	-0.5100	3.4000
D1	31.0	0.0	-11.54	1.0	0.0	-11.03	-0.5100	3.4000
D2	31.0	0.0	-9.05	1.0	0.0	-8.52	-0.5300	3.5333
D2	31.0	0.0	9.75	1.0	0.0	10.27	-0.5200	3.4667
D3	31.0	0.0	-11.35	1.0	0.0	-10.80	-0.5500	3.6667
D3	31.0	0.0	-5.65	1.0	0.0	-5.10	-0.5500	3.6667
D4	31.0	0.0	-12.23	1.0	0.0	-11.68	-0.5500	3.6667
D4	31.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
D5	31.0	0.0	-11.03	1.0	0.0	-10.47	-0.5600	3.7333
D5	31.0	0.0	0.03	1.0	0.0	0.59	-0.5600	3.7333
D6	31.0	0.0	-8.95	1.0	0.0	-8.38	-0.5700	3.8000
D6	31.0	0.0	3.91	1.0	0.0	4.48	-0.5700	3.8000
D7	31.0	0.0	-3.55	1.0	0.0	-3.03	-0.5200	3.4667
D7	31.0	0.0	-3.55	1.0	0.0	-2.97	-0.5800	3.8667
D9	31.0	0.0	7.45	1.0	0.0	8.07	-0.6200	4.1333
D9	31.0	0.0	0.30	1.0	0.0	0.91	-0.6100	4.0667
C11	31.0	0.0	-6.65	1.0	0.0	-5.99	-0.6600	4.4000
C11	31.0	0.0	-3.57	1.0	0.0	-2.91	-0.6600	4.4000
C12	31.0	0.0	-4.97	1.0	0.0	-4.29	-0.6800	4.5333
C12	31.0	0.0	-1.63	1.0	0.0	-0.95	-0.6800	4.5333

Table 0

83

CALCULATION OF CHANGE IN TEMPERATURE, CHANGE IN LENGTH AND
COEFFICIENT OF THERMAL EXPANSION

SERIES 0 AGE= 84.00DAYS COMPRESSIVE STRENGTH= 6325.00P.S.I.

SPECIMEN IDENTITY	INITIAL TEMP.	INITIAL TOP	INITIAL READING BOTTOM	FINAL TEMP.	FINAL TOP	FINAL READING BOTTOM	FLONGATION	COEFFICIENT OF EXPANSION
D1	31.0	0.0	-8.27	-30.0	0.0	-7.25	-1.0200	3.3443
D1	31.0	0.0	-11.54	-30.0	0.0	-10.52	-1.0200	3.3443
D2	31.0	0.0	-9.05	-30.0	0.0	-8.00	-1.0500	3.4426
D2	31.0	0.0	9.75	-30.0	0.0	10.79	-1.0400	3.4098
D3	31.0	0.0	-11.35	-30.0	0.0	-10.26	-1.0900	3.5738
D3	31.0	0.0	-5.65	-30.0	0.0	-4.56	-1.0900	3.5738
D4	31.0	0.0	-12.23	-30.0	0.0	-11.14	-1.0900	3.5738
D4	31.0	0.0	0.0	-30.0	0.0	0.0	0.0	0.0
D5	31.0	0.0	-11.03	-30.0	0.0	-9.91	-1.1200	3.6721
D5	31.0	0.0	0.03	-30.0	0.0	1.15	-1.1200	3.6721
D6	31.0	0.0	-8.95	-30.0	0.0	-7.81	-1.1400	3.7377
D6	31.0	0.0	3.91	-30.0	0.0	5.05	-1.1400	3.7377
D7	31.0	0.0	-3.55	-30.0	0.0	-2.45	-1.1000	3.6066
D7	31.0	0.0	-3.55	-30.0	0.0	-2.39	-1.1600	3.8033
D9	31.0	0.0	7.45	-30.0	0.0	8.67	-1.2200	4.0000
D9	31.0	0.0	0.30	-30.0	0.0	1.54	-1.2400	4.0656
D11	31.0	0.0	-6.65	-30.0	0.0	-5.33	-1.3200	4.3279
D11	31.0	0.0	-3.57	-30.0	0.0	-2.24	-1.3300	4.3607
D12	31.0	0.0	-4.97	-30.0	0.0	-3.61	-1.3600	4.4590
D12	31.0	0.0	-1.63	-30.0	0.0	-0.27	-1.3600	4.4590

Table 0

CALCULATION OF CHANGE IN TEMPERATURE, CHANGE IN LENGTH AND
 COEFFICIENT OF THERMAL EXPANSION

SERIES D AGE= 84.00DAYS COMPRESSIVE STRENGTH= 6325.0CP.S.I.

SPECIMEN IDENTITY	INITIAL TEMP.	INITIAL TOP	INITIAL READING BOTTOM	FINAL TEMP.	FINAL TOP	FINAL READING BOTTOM	ELONGATION	COEFFICIENT OF EXPANSION
C1	31.0	0.0	-8.27	-60.0	0.0	-6.74	-1.5300	3.3626
D1	31.0	0.0	-11.54	-60.0	0.0	-10.00	-1.5400	3.3846
C2	31.0	0.0	-9.05	-60.0	0.0	-7.48	-1.5700	3.4505
C2	31.0	0.0	9.75	-60.0	0.0	11.31	-1.5600	3.4286
C3	31.0	0.0	-11.35	-60.0	0.0	-9.72	-1.6300	3.5824
C3	31.0	0.0	-5.65	-60.0	0.0	-4.01	-1.6400	3.6044
C4	31.0	0.0	-12.23	-60.0	0.0	-10.59	-1.6400	3.6044
C4	31.0	0.0	0.0	-60.0	0.0	0.0	0.0	0.0
D5	31.0	0.0	-11.03	-60.0	0.0	-9.35	-1.6800	3.6923
C5	31.0	0.0	0.03	-60.0	0.0	1.71	-1.6800	3.6923
C6	31.0	0.0	-8.95	-60.0	0.0	-7.14	-1.8100	3.9780
C6	31.0	0.0	3.91	-60.0	0.0	5.62	-1.7100	3.7582
C7	31.0	0.0	-3.55	-60.0	0.0	-1.87	-1.6800	3.6923
C7	31.0	0.0	-3.55	-60.0	0.0	-1.81	-1.7400	3.8242
C9	31.0	0.0	7.45	-60.0	0.0	9.29	-1.8400	4.0440
C9	31.0	0.0	0.30	-60.0	0.0	2.16	-1.8600	4.0879
D11	31.0	0.0	-6.65	-60.0	0.0	-4.67	-1.9800	4.3516
D11	31.0	0.0	-3.57	-60.0	0.0	-1.58	-1.9900	4.3736
C12	31.0	0.0	-4.97	-60.0	0.0	-2.93	-2.0400	4.4835
C12	31.0	0.0	-1.63	-60.0	0.0	0.42	-2.0500	4.5055

Table 8

CALCULATION OF CHANGE IN TEMPERATURE, CHANGE IN LENGTH AND
COEFFICIENT OF THERMAL EXPANSION

SERIES D AGF= 84.00DAYS COMPRESSIVE STRENGTH= 6325.CCP.S.I.

SPECIMEN IDENTITY	INITIAL TEMP.	INITIAL TOP	INITIAL BOTTOM	FINAL TEMP.	FINAL TOP	FINAL BOTTOM	ELONGATION	COEFFICIENT OF EXPANSION
C1	31.0	0.0	-8.27	-95.0	0.0	-6.14	-2.1300	3.3810
C1	31.0	0.0	-11.54	-95.0	0.0	-9.40	-2.1400	3.3968
C2	31.0	0.0	-9.05	-95.0	0.0	-6.86	-2.1900	3.4762
C2	31.0	0.0	9.75	-95.0	0.0	11.92	-2.1700	3.4444
C3	31.0	0.0	-11.35	-95.0	0.0	-9.09	-2.2600	3.5873
C3	31.0	0.0	-5.65	-95.0	0.0	-3.38	-2.2700	3.6032
D4	31.0	0.0	-12.23	-95.0	0.0	-9.96	-2.2700	3.6032
D4	31.0	0.0	0.0	-95.0	0.0	0.0	0.0	0.0
C5	31.0	0.0	-11.03	-95.0	0.0	-8.90	-2.1300	3.3810
C5	31.0	0.0	0.03	-95.0	0.0	2.37	-2.3400	3.7143
D6	31.0	0.0	-8.95	-95.0	0.0	-6.48	-2.4700	3.9206
D6	31.0	0.0	3.91	-95.0	0.0	6.28	-2.3700	3.7619
D7	31.0	0.0	-3.55	-95.0	0.0	-1.20	-2.3500	3.7302
C7	31.0	0.0	-3.55	-95.0	0.0	-1.13	-2.4200	3.8413
C9	31.0	0.0	7.45	-95.0	0.0	-10.03	17.4800	-27.7460
D9	31.0	0.0	0.30	-95.0	0.0	2.88	-2.5800	4.0952
C11	31.0	0.0	-6.65	-95.0	0.0	-3.90	-2.7500	4.3651
C11	31.0	0.0	-3.57	-95.0	0.0	-0.81	-2.7600	4.3810
D12	31.0	0.0	-4.97	-95.0	0.0	-2.14	-2.8300	4.4921
C12	31.0	0.0	-1.63	-95.0	0.0	1.21	-2.8400	4.5079

Table 8

CALCULATION OF CHANGE IN TEMPERATURE, CHANGE IN LENGTH AND COEFFICIENT OF THERMAL EXPANSION

SERIES D AGE= 84.00DAYS COMPRESSIVE STRENGTH= 6325.00P.S.I.

SPECIMEN IDENTITY	INITIAL TEMP.	INITIAL TEMP. TOP	INITIAL READING BOTTOM	FINAL TEMP.	FINAL TEMP. TOP	FINAL READING BOTTOM	ELONGATION	COEFFICIENT OF EXPANSION
D1	31.0	0.0	-8.27	-75.0	0.0	-6.50	-1.7700	3.3396
C1	31.0	0.0	-11.54	-75.0	0.0	-9.75	-1.7900	3.3774
C2	31.0	0.0	-9.05	-75.0	0.0	-7.22	-1.8300	3.4528
C2	31.0	0.0	9.75	-75.0	0.0	11.57	-1.8200	3.4340
D3	31.0	0.0	-11.35	-75.0	0.0	-9.45	-1.9000	3.5849
D3	31.0	0.0	-5.65	-75.0	0.0	-3.74	-1.9100	3.6038
D4	31.0	0.0	-12.23	-75.0	0.0	-10.32	-1.9100	3.6038
C4	31.0	0.0	0.0	-75.0	0.0	0.0	0.0	0.0
C5	31.0	0.0	-11.03	-75.0	0.0	-9.07	-1.9600	3.6981
D5	31.0	0.0	0.03	-75.0	0.0	1.99	-1.9600	3.6981
C6	31.0	0.0	-8.95	-75.0	0.0	-6.85	-2.1000	3.9623
C6	31.0	0.0	3.91	-75.0	0.0	5.91	-2.0000	3.7736
C7	31.0	0.0	-3.55	-75.0	0.0	-1.58	-1.9700	3.7170
C7	31.0	0.0	-3.55	-75.0	0.0	-1.52	-2.0300	3.8302
C9	31.0	0.0	7.45	-75.0	0.0	9.60	-2.1500	4.0566
D9	31.0	0.0	0.30	-75.0	0.0	2.57	-2.2700	4.2830
C11	31.0	0.0	-6.65	-75.0	0.0	-4.34	-2.3100	4.3585
C11	31.0	0.0	-3.57	-75.0	0.0	-1.25	-2.3200	4.3774
C12	31.0	0.0	-4.97	-75.0	0.0	-2.59	-2.3800	4.4906
C12	31.0	0.0	-1.63	-75.0	0.0	0.76	-2.3900	4.5094

Table C

CALCULATION OF CHANGE IN TEMPERATURE, CHANGE IN LENGTH AND
COEFFICIENT OF THERMAL EXPANSION

SERIES D AGF= 84.CODAYS COMPRESSIVE STRENGTH= 6325.CCP.S.I.

SPECIMEN IDENTITY	INITIAL TEMP.	INITIAL TOP	INITIAL BOTTOM	FINAL TEMP.	FINAL TOP	FINAL BOTTOM	ELONGATION	COEFFICIENT OF EXPANSION
D1	31.0	0.0	-8.27	-42.5	0.0	-7.21	-1.0600	2.8844
D1	31.0	0.0	-11.54	-42.5	0.0	-10.26	-1.2800	3.4830
D2	31.0	0.0	-9.05	-42.5	0.0	-7.74	-1.3100	3.5646
D2	31.0	0.0	9.75	-42.5	0.0	11.05	-1.3000	3.5374
D3	31.0	0.0	-11.35	-42.5	0.0	-9.99	-1.3600	3.7007
D3	31.0	0.0	-5.65	-42.5	0.0	-4.28	-1.3700	3.7279
D4	31.0	0.0	-12.23	-42.5	0.0	-10.87	-1.3600	3.7007
D4	31.0	0.0	0.0	-42.5	0.0	0.0	0.0	0.0
D5	31.0	0.0	-11.03	-42.5	0.0	-9.63	-1.4000	3.8095
D5	31.0	0.0	0.03	-42.5	0.0	1.48	-1.4500	3.9456
D6	31.0	0.0	-8.95	-42.5	0.0	-7.42	-1.5300	4.1633
D6	31.0	0.0	3.91	-42.5	0.0	5.34	-1.4300	3.8912
D7	31.0	0.0	-3.55	-42.5	0.0	-2.16	-1.3900	3.7823
D7	31.0	0.0	-3.55	-42.5	0.0	2.10	-5.6500	15.3741
D9	31.0	0.0	7.45	-42.5	0.0	9.00	-1.5500	4.2177
D9	31.0	0.0	0.30	-42.5	0.0	1.95	-1.6500	4.4898
D11	31.0	0.0	-6.65	-42.5	0.0	-5.00	-1.6500	4.4898
D11	31.0	0.0	-3.57	-42.5	0.0	-1.97	-1.6000	4.3537
D12	31.0	0.0	-4.97	-42.5	0.0	-3.27	-1.7000	4.6258
D12	31.0	0.0	-1.63	-42.5	0.0	0.08	-1.7100	4.6531

Table 8

CALCULATION OF CHANGE IN TEMPERATURE, CHANGE IN LENGTH AND
COEFFICIENT OF THERMAL EXPANSION

SERIES D AGE= 84.00DAYS COMPRESSIVE STRENGTH= 6325.00P.S.I.

SPECIMEN IDENTITY	INITIAL TEMP.	INITIAL TOP	INITIAL READING BOTTOM	FINAL TEMP.	FINAL TOP	FINAL READING BOTTOM	ELONGATION	COEFFICIENT OF EXPANSION
C1	31.0	0.0	-8.27	-14.0	0.0	-7.52	-0.7500	3.3333
C1	31.0	0.0	-11.54	-14.0	0.0	-10.78	-0.7600	3.3778
C2	31.0	0.0	-9.05	-14.0	0.0	-8.26	-0.7900	3.5111
C2	31.0	0.0	9.75	-14.0	0.0	10.53	-0.7800	3.4667
C3	31.0	0.0	-11.35	-14.0	0.0	-10.53	-0.8200	3.6444
D3	31.0	0.0	-5.65	-14.0	0.0	-4.82	-0.8300	3.6889
D4	31.0	0.0	-12.23	-14.0	0.0	-11.42	-0.8100	3.6000
D4	31.0	0.0	0.0	-14.0	0.0	0.0	0.0	0.0
D5	31.0	0.0	-11.03	-14.0	0.0	-10.19	-0.8400	3.7333
D5	31.0	0.0	0.03	-14.0	0.0	0.84	-0.8100	3.6000
D6	31.0	0.0	-8.95	-14.0	0.0	-7.99	-0.9600	4.2667
D6	31.0	0.0	3.91	-14.0	0.0	4.77	-0.8600	3.8222
D7	31.0	0.0	-3.55	-14.0	0.0	-2.74	-0.8100	3.6000
D7	31.0	0.0	-3.55	-14.0	0.0	1.52	-5.0700	22.5333
D9	31.0	0.0	7.45	-14.0	0.0	8.38	-0.9300	4.1333
D9	31.0	0.0	0.30	-14.0	0.0	1.33	-1.0300	4.5778
D11	31.0	0.0	-6.65	-14.0	0.0	-5.66	-0.9900	4.4000
D11	31.0	0.0	-3.57	-14.0	0.0	-2.67	-0.9000	4.0000
D12	31.0	0.0	-4.97	-14.0	0.0	-3.95	-1.0200	4.5333
D12	31.0	0.0	-1.63	-14.0	0.0	-0.60	-1.0300	4.5778

Table 8

CALCULATION OF CHANGE IN TEMPERATURE, CHANGE IN LENGTH AND COEFFICIENT OF THERMAL EXPANSION

SERIES D AGF= 84.00DAYS COMPRESSIVE STRENGTH= 6325.0CP.S.I.

SPECIMEN IDENTITY	INITIAL TEMP.	INITIAL TOP	INITIAL BOTTOM	FINAL TEMP.	FINAL TOP	FINAL BOTTOM	ELONGATION	COEFFICIENT OF EXPANSION
C1	31.0	0.0	-8.27	16.0	0.0	-8.03	-0.2400	3.2000
C1	31.0	0.0	-11.54	16.0	0.0	-11.29	-0.2500	3.3333
C2	31.0	0.0	-9.05	16.0	0.0	-9.78	-0.2700	3.6000
C2	31.0	0.0	9.75	16.0	0.0	10.00	-0.2500	3.3333
C3	31.0	0.0	-11.35	16.0	0.0	-11.07	-0.2800	3.7333
C3	31.0	0.0	-5.65	16.0	0.0	-5.36	-0.2900	3.8667
C4	31.0	0.0	-12.23	16.0	0.0	-11.98	-0.2500	3.3333
C4	31.0	0.0	0.0	16.0	0.0	0.0	0.0	0.0
C5	31.0	0.0	-11.03	16.0	0.0	-10.75	-0.2800	3.7333
D5	31.0	0.0	0.03	16.0	0.0	0.28	-0.2500	3.3333
D6	31.0	0.0	-8.95	16.0	0.0	-8.56	-0.3900	5.2000
D6	31.0	0.0	3.91	16.0	0.0	4.21	-0.3000	4.0000
D7	31.0	0.0	-3.55	16.0	0.0	-3.32	-0.2300	3.0667
D7	31.0	0.0	-3.55	16.0	0.0	0.94	-4.4900	59.8666
D9	31.0	0.0	7.45	16.0	0.0	7.76	-0.3100	4.1333
D9	31.0	0.0	0.30	16.0	0.0	0.71	-0.4100	5.4667
D11	31.0	0.0	-6.65	16.0	0.0	-6.32	-0.3300	4.4000
D11	31.0	0.0	-3.57	16.0	0.0	-3.33	-0.2400	3.2000
D12	31.0	0.0	-4.97	16.0	0.0	-4.63	-0.3400	4.5333
D12	31.0	0.0	-1.63	16.0	0.0	-1.28	-0.3500	4.6667

Table 8

CALCULATION OF CHANGE IN TEMPERATURE, CHANGE IN LENGTH AND
COEFFICIENT OF THERMAL EXPANSION

SERIES D AGE= 84.00DAYS COMPRESSIVE STRENGTH= 6325.00P.S.I.

SPECIMEN IDENTITY	INITIAL TEMP.	INITIAL TOP	INITIAL BOTTOM	FINAL TEMP.	FINAL TOP	FINAL BOTTOM	ELONGATION	COEFFICIENT OF EXPANSION
D1	31.0	0.0	-8.27	44.0	0.0	-8.56	0.2900	4.4615
D1	31.0	0.0	-11.54	44.0	0.0	-11.83	0.2900	4.4615
D2	31.0	0.0	-9.05	44.0	0.0	-9.32	0.2700	4.1539
D2	31.0	0.0	9.75	44.0	0.0	9.46	0.2900	4.4616
D3	31.0	0.0	-11.35	44.0	0.0	-11.64	0.2900	4.4615
D3	31.0	0.0	-5.65	44.0	0.0	-5.93	0.2800	4.3077
D4	31.0	0.0	-12.23	44.0	0.0	-12.55	0.3200	4.9231
D4	31.0	0.0	0.0	44.0	0.0	0.0	0.0	0.0
D5	31.0	0.0	-11.03	44.0	0.0	-11.34	0.3100	4.7692
D5	31.0	0.0	0.03	44.0	0.0	-0.32	0.3500	5.3846
D6	31.0	0.0	-8.95	44.0	0.0	-9.17	0.2200	3.3846
D6	31.0	0.0	3.91	44.0	0.0	3.60	0.3100	4.7692
D7	31.0	0.0	-3.55	44.0	0.0	-3.92	0.3700	5.6923
D7	31.0	0.0	-3.55	44.0	0.0	0.30	-3.8500	-59.2307
D9	31.0	0.0	7.45	44.0	0.0	7.11	0.3400	5.2308
D9	31.0	0.0	0.30	44.0	0.0	0.06	0.2400	3.6923
D11	31.0	0.0	-6.65	44.0	0.0	-7.03	0.3800	5.8462
D11	31.0	0.0	-3.57	44.0	0.0	-4.06	0.4900	7.5385
D12	31.0	0.0	-4.97	44.0	0.0	-5.35	0.3800	5.8462
D12	31.0	0.0	-1.63	44.0	0.0	-1.99	0.3600	5.5385

Table 8

CALCULATION OF CHANGE IN TEMPERATURE, CHANGE IN LENGTH AND COEFFICIENT OF THERMAL EXPANSION

SERIES D AGE= 84.00DAYS COMPRESSIVE STRENGTH= 6325.00P.S.I.

SPECIMEN IDENTITY	INITIAL TEMP.	INITIAL TOP	INITIAL BOTTOM	FINAL TEMP.	FINAL TOP	FINAL BOTTOM	ELONGATION	COEFFICIENT OF EXPANSION
C1	31.0	0.0	-8.27	76.0	0.0	-9.14	0.8700	3.8667
C1	31.0	0.0	-11.54	76.0	0.0	-12.41	0.8700	3.8667
C2	31.0	0.0	-9.05	76.0	0.0	-9.91	0.8600	3.8222
C2	31.0	0.0	9.75	76.0	0.0	8.87	0.8800	3.9111
C3	31.0	0.0	-11.35	76.0	0.0	-12.25	0.9000	4.0000
C3	31.0	0.0	-5.65	76.0	0.0	-6.54	0.8900	3.9556
C4	31.0	0.0	-12.23	76.0	0.0	-13.17	0.9400	4.1778
C4	31.0	0.0	0.0	76.0	0.0	0.0	0.0	0.0
C5	31.0	0.0	-11.03	76.0	0.0	-12.00	0.9700	4.3111
C5	31.0	0.0	0.03	76.0	0.0	-0.95	0.9800	4.3556
C6	31.0	0.0	-8.95	76.0	0.0	-9.81	0.8600	3.8222
C6	31.0	0.0	3.91	76.0	0.0	2.96	0.9500	4.2222
C7	31.0	0.0	-3.55	76.0	0.0	-4.58	1.0300	4.5778
C7	31.0	0.0	-3.55	76.0	0.0	-0.36	-3.1900	-14.1778
C9	31.0	0.0	7.45	76.0	0.0	6.44	1.0100	4.4889
C9	31.0	0.0	0.30	76.0	0.0	-0.66	0.9600	4.2667
C11	31.0	0.0	-6.65	76.0	0.0	-7.77	1.1200	4.9778
C11	31.0	0.0	-3.57	76.0	0.0	-4.80	1.2300	5.4667
C12	31.0	0.0	-4.97	76.0	0.0	-6.11	1.1400	5.0667
C12	31.0	0.0	-1.63	76.0	0.0	-2.75	1.1200	4.9778

Table 8

CALCULATION OF CHANGE IN TEMPERATURE, CHANGE IN LENGTH AND COEFFICIENT OF THERMAL EXPANSION

SERIES D AGE= 84.00DAYS COMPRESSIVE STRENGTH= 6325.0CP.S.I.

SPECIMEN IDENTITY	INITIAL TEMP.	INITIAL TOP	INITIAL BOTTOM	FINAL TEMP.	FINAL TOP	FINAL BOTTOM	ELONGATION	COEFFICIENT OF EXPANSION
C1	31.0	0.0	-8.27	106.0	0.0	-9.72	1.4500	3.8667
C1	31.0	0.0	-11.54	106.0	0.0	-12.99	1.4500	3.8667
C2	31.0	0.0	-9.05	106.0	0.0	-10.40	1.3500	3.6000
C2	31.0	0.0	9.75	106.0	0.0	8.28	1.4700	3.9200
C3	31.0	0.0	-11.35	106.0	0.0	-12.86	1.5100	4.0267
D3	31.0	0.0	-5.65	106.0	0.0	-7.15	1.5000	4.0000
D4	31.0	0.0	-12.23	106.0	0.0	-13.79	1.5600	4.1600
D4	31.0	0.0	0.0	106.0	0.0	0.0	0.0	0.0
D5	31.0	0.0	-11.03	106.0	0.0	-12.63	1.6000	4.2667
D5	31.0	0.0	0.03	106.0	0.0	-1.58	1.6100	4.2933
D6	31.0	0.0	-8.95	106.0	0.0	-10.45	1.5000	4.0000
D6	31.0	0.0	3.91	106.0	0.0	2.32	1.5900	4.2400
C7	31.0	0.0	-3.55	106.0	0.0	-5.24	1.6900	4.5067
D7	31.0	0.0	-3.55	106.0	0.0	-1.02	-2.5300	-6.7467
C9	31.0	0.0	7.45	106.0	0.0	5.74	1.7100	4.5600
C9	31.0	0.0	0.30	106.0	0.0	-1.36	1.6600	4.4267
C11	31.0	0.0	-6.65	106.0	0.0	-8.51	1.8600	4.9600
D11	31.0	0.0	-3.57	106.0	0.0	-5.54	1.9700	5.2533
C12	31.0	0.0	-4.97	106.0	0.0	-6.87	1.9000	5.0667
C12	31.0	0.0	-1.63	106.0	0.0	-3.51	1.8800	5.0133

Table 0
 CALCULATION OF CHANGE IN TEMPERATURE, CHANGE IN LENGTH AND
 COEFFICIENT OF THERMAL EXPANSION

SERIES	D	AGE=	84.0DAYS	COMPRESSIVE STRENGTH=	6325.0CP.S.I.			
SPECIMEN IDENTITY	INITIAL TEMP.	INITIAL TOP	READING BOTTOM	FINAL TEMP.	FINAL TOP	READING BOTTOM	ELONGATION	COEFFICIENT OF EXPANSION
C1	31.0	0.0	-8.27	135.0	0.0	-10.30	2.0300	3.9038
C1	31.0	0.0	-11.54	135.0	0.0	-13.57	2.0300	3.9038
C2	31.0	0.0	-9.05	135.0	0.0	-11.00	1.9500	3.7500
C2	31.0	0.0	9.75	135.0	0.0	7.68	2.0700	3.9808
C3	31.0	0.0	-11.35	135.0	0.0	-13.47	2.1200	4.0769
C3	31.0	0.0	-5.65	135.0	0.0	-7.76	2.1100	4.0577
C4	31.0	0.0	-12.23	135.0	0.0	-14.41	2.1800	4.1923
C4	31.0	0.0	0.0	135.0	0.0	0.0	0.0	0.0
D5	31.0	0.0	-11.03	135.0	0.0	-13.26	2.2300	4.2885
D5	31.0	0.0	0.03	135.0	0.0	-2.21	2.2400	4.3077
D6	31.0	0.0	-8.95	135.0	0.0	-11.09	2.1400	4.1154
C6	31.0	0.0	3.91	135.0	0.0	1.68	2.2300	4.2885
D7	31.0	0.0	-3.55	135.0	0.0	-5.90	2.3500	4.5192
C7	31.0	0.0	-3.55	135.0	0.0	-1.68	-1.8700	-3.5962
C9	31.0	0.0	7.45	135.0	0.0	5.05	2.4000	4.6154
C9	31.0	0.0	0.30	135.0	0.0	-2.06	2.3600	4.5385
C11	31.0	0.0	-6.65	135.0	0.0	-9.25	2.6000	5.0000
C11	31.0	0.0	-3.57	135.0	0.0	-6.28	2.7100	5.2115
D12	31.0	0.0	-4.97	135.0	0.0	-7.63	2.6600	5.1154
C12	31.0	0.0	-1.63	135.0	0.0	-4.27	2.6400	5.0769

Table 6
CALCULATION OF CHANGE IN TEMPERATURE, CHANGE IN LENGTH AND
COEFFICIENT OF THERMAL EXPANSION

SERIES D AGE= 84.00DAYS COMPRESSIVE STRENGTH= 6325.00P.S.I.

SPECIMEN IDENTITY	INITIAL TEMP.	INITIAL TOP	INITIAL READING BOTTOM	FINAL TEMP.	FINAL TOP	FINAL READING BOTTOM	ELONGATION	COEFFICIENT OF EXPANSION
C1	31.0	0.0	-8.27	120.5	0.0	-10.00	1.7300	3.8659
C1	31.0	0.0	-11.54	120.5	0.0	-13.28	1.7400	3.8883
C2	31.0	0.0	-9.05	120.5	0.0	-10.71	1.6600	3.7095
C2	31.0	0.0	9.75	120.5	0.0	7.97	1.7800	3.9777
C3	31.0	0.0	-11.35	120.5	0.0	-13.17	1.8200	4.0670
C3	31.0	0.0	-5.65	120.5	0.0	-7.46	1.8100	4.0447
C4	31.0	0.0	-12.23	120.5	0.0	-14.10	1.8700	4.1788
C4	31.0	0.0	0.0	120.5	0.0	0.0	0.0	0.0
C5	31.0	0.0	-11.03	120.5	0.0	-12.94	1.9100	4.2682
C5	31.0	0.0	0.03	120.5	0.0	-1.89	1.9200	4.2905
C6	31.0	0.0	-8.95	120.5	0.0	-10.77	1.8200	4.0670
C6	31.0	0.0	3.91	120.5	0.0	2.00	1.9100	4.2682
C7	31.0	0.0	-3.55	120.5	0.0	-5.57	2.0200	4.5140
C7	31.0	0.0	-3.55	120.5	0.0	-1.34	-2.2100	-4.9385
C9	31.0	0.0	7.45	120.5	0.0	5.40	2.0500	4.5810
C9	31.0	0.0	0.30	120.5	0.0	-1.71	2.0100	4.4916
C11	31.0	0.0	-6.65	120.5	0.0	-9.62	2.9700	6.6369
C11	31.0	0.0	-3.57	120.5	0.0	-5.91	2.3400	5.2290
C12	31.0	0.0	-4.97	120.5	0.0	-8.01	3.0400	6.7933
D12	31.0	0.0	-1.63	120.5	0.0	-3.89	2.2600	5.0503

CALCULATION OF CHANGE IN TEMPERATURE, CHANGE IN LENGTH AND COEFFICIENT OF THERMAL EXPANSION

SERIFS D AGE= P4.00DAYS COMPRESSIVE STRENGTH= 6325.0CP.S.I.

SPECIMEN IDENTITY	INITIAL TEMP.	INITIAL TOP	INITIAL BOTTOM	FINAL TEMP.	FINAL TOP	FINAL BOTTOM	ELONGATION	COEFFICIENT OF EXPANSION
E1	31.0	0.0	-8.27	89.5	0.0	-9.42	1.1500	3.9316
E1	31.0	0.0	-11.54	89.5	0.0	-12.70	1.1600	3.9658
D2	31.0	0.0	-9.05	89.5	0.0	-10.11	1.0600	3.6239
E2	31.0	0.0	9.75	89.5	0.0	8.56	1.1900	4.0684
E3	31.0	0.0	-11.35	89.5	0.0	-12.56	1.2100	4.1368
E3	31.0	0.0	-5.65	89.5	0.0	-6.85	1.2000	4.1026
D4	31.0	0.0	-12.23	89.5	0.0	-13.48	1.2500	4.2735
E4	31.0	0.0	0.0	89.5	0.0	0.0	0.0	0.0
E5	31.0	0.0	-11.03	89.5	0.0	-12.31	1.2800	4.3761
E5	31.0	0.0	0.03	89.5	0.0	-1.26	1.2900	4.4103
E6	31.0	0.0	-8.95	89.5	0.0	-10.13	1.1800	4.0342
D6	31.0	0.0	3.91	89.5	0.0	2.65	1.2600	4.3077
D7	31.0	0.0	-3.55	89.5	0.0	-4.91	1.3600	4.6496
D7	31.0	0.0	-3.55	89.5	0.0	-0.69	-2.8600	-9.7778
D9	31.0	0.0	7.45	89.5	0.0	6.10	1.3500	4.6154
D9	31.0	0.0	0.30	89.5	0.0	-1.02	1.3200	4.5128
E11	31.0	0.0	-6.65	89.5	0.0	-8.92	2.2700	7.7607
E11	31.0	0.0	-3.57	89.5	0.0	-5.18	1.6100	5.5043
E12	31.0	0.0	-4.97	89.5	0.0	-7.24	2.2700	7.7607
E12	31.0	0.0	-1.63	89.5	0.0	-3.23	1.6000	5.4701

CALCULATION OF CHANGE IN TEMPERATURE, CHANGE IN LENGTH AND COEFFICIENT OF THERMAL EXPANSION

SERIES D AGE= 84.00DAYS COMPRESSIVE STRENGTH= 6325.CCP.S.I.

SPECIMEN IDENTITY	INITIAL TEMP.	INITIAL TOP	INITIAL BOTTOM	FINAL TEMP.	FINAL TOP	FINAL BOTTOM	ELONGATION	COEFFICIENT OF EXPANSION
D1	31.0	0.0	-8.27	60.5	0.0	-8.84	0.5700	3.8644
D1	31.0	0.0	-11.54	60.5	0.0	-12.12	0.5800	3.0322
D2	31.0	0.0	-9.05	60.5	0.0	-9.52	0.4700	3.1864
D2	31.0	0.0	9.75	60.5	0.0	9.15	0.6000	4.0678
D3	31.0	0.0	-11.35	60.5	0.0	-11.95	0.6000	4.0678
D3	31.0	0.0	-5.65	60.5	0.0	-6.24	0.5900	4.0000
D4	31.0	0.0	-12.23	60.5	0.0	-12.86	0.6300	4.2712
D4	31.0	0.0	0.0	60.5	0.0	0.0	0.0	0.0
D5	31.0	0.0	-11.03	60.5	0.0	-11.68	0.6500	4.4068
D5	31.0	0.0	0.03	60.5	0.0	-0.63	0.6600	4.4746
D6	31.0	0.0	-8.95	60.5	0.0	-9.49	0.5400	3.6610
D6	31.0	0.0	3.91	60.5	0.0	3.29	0.6200	4.2034
D7	31.0	0.0	-3.55	60.5	0.0	-4.25	0.7000	4.7458
D7	31.0	0.0	-3.55	60.5	0.0	-0.05	-3.5000	-23.7288
D9	31.0	0.0	7.45	60.5	0.0	6.79	0.6600	4.4746
D9	31.0	0.0	0.30	60.5	0.0	-0.33	0.6300	4.2712
D11	31.0	0.0	-6.65	60.5	0.0	-8.18	1.5300	10.3729
D11	31.0	0.0	-3.57	60.5	0.0	-4.34	0.7700	5.2203
D12	31.0	0.0	-4.97	60.5	0.0	-6.48	1.5100	10.2373
D12	31.0	0.0	-1.63	60.5	0.0	-2.47	0.8400	5.6940

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