EFFECTS OF COLD WEATHER CONSTRUCTION ON THE COMPRESSIVE STRENGTH OF CONCRETE MASONRY WALLS

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INTRODUCTION

Masonry walls may be exposed to low temperatures in winter construction when inadequate protective enclosures are provided or when heating equipment does not function properly. If this exposure occurs prior to the mortar attaining significant strength, the affected walls may be considered unsatisfactory and the contractor may be required to replace them. As a result projects will be delayed and costs increased appreciably. However, if subsequent to the low temperature exposure the masonry is exposed to normal temperature and curing conditions, the strength may increase significantly. It is therefore important to carefully assess the effects of exposure to low temperatures before remedial measures are defined.

This paper reviews current practices related to cold weather masonry construction and describes a study conducted at the University of Alberta into the effects of low temperature exposure on the compressive strength of concrete block masonry walls. In this study test specimens were exposed to a period of cold weather exposure which began at various times after construction. They were then transferred to a warmer environment, cured for a period of time and then tested to failure. This procedure permitted an assessment of the gain in strength resulting from improved curing conditions subsequent to cold weather exposure.

GENERAL

Present Canadian Standards such as A371-M 1980 (1) require that materials be protected from rain, ice and snow. When the temperature is less than 5°C sand and mixing water must be heated and at no time should the temperature of units be less than -7°C.

Uncompleted masonry must be covered and protected from freezing during the early stages. As temperature is reduced insulating blankets or even auxiliary heating must be furnished to allow hydration to proceed.

Winter construction practice for masonry structures in the USSR is described in Reference (2). The majority of construction is undertaken using the freezing method for the mortar. In this method the mortar, after freezing, exhibits a high strength that is retained until thawing sets in. No special treatment is considered for structures up to three stories. Limitations are placed on the eccentricity of applied loads however; the maximum load eccentricity permitted is 0.25 times the actual wall thickness.

In this freezing method care must be taken in design to ensure that the mortar possesses sufficient strength and stability at the thawing stage. Based on strength methods the mortar joint at the thawing stage must still be capable of carrying the imposed load. For buildings in excess of three stories or for extremely low temperature, curing using heat based on economic considerations is provided in the lower portions. Also additives to promote hyration and higher class strengths of mortar are used. For design purposes the strength of winter masonry is shown in Figure (1) taken from Ref (2) . The final winter strength is shown to depend on the mean air temperature at the time of initial freezing; lowered initial temperature results in lowered strength. This reflects the reduced opportunity for hydration and also greater moisture loss from the mortar and unit due to sublimation thereby reducing the potential post thawing hydration. This deficit in the final strength of winter laid masonry is compensated for at the construction stage by using a better grade mortar than that which would be used in summer construction.

In Canada no extensive studies relating to winter masonry construction have been made. Suter (3) tested prism specimens using standard 200 mm clay bricks with type M mortar subjected to temperatures of approximately 20°C (RT) and -11°C (LT). Additionally tension and shear specimens were tested. The overall curing for the specimens was 7 days. Curing designated RT was at room temperature, RT/LT designated specimens cured at room temperature for a half week and at low temperatures for a half week, and, specimens LT were cured at low temperatures. Dry units and warm mortar were used for the LT specimens. The results of these tests are shown in Figure (2). Suter concluded that construction conditions, whether RT or LT, have no significant effect on strength in compression, tension or shear. He also observed that for both compression and tension the trend of the data was similar in that these strengths decreased as the curing conditions became more severe.

Davison (4) studied the effect of low temperatures on the volume of mortar as influenced by the moisture content of the mortar. Mortar samples were encased in rubber membranes and were immersed in a cylinder connected to a calibrated glass capillary tube. The change in volume was related to the height of the capillary column. Figures (3) and (4) show typical results. The larger moisture content mortar (Figure 3) exhibited larger volume changes with temperature variation than that mortar which had a low moisture content (Figure 4). Davison concluded that the amount of expansion which occurs in mortar when a newly laid-up masonry wall freezes will depend on the amount of "set" the mortar acquires and the amount of water extracted from it by suction of the units before freezing occurs. For moisture content of mortar less than six percent the expansion associated with freezing is neglible. Davison further indicated that good results achieved by masonry laid up without protection in cold weather are the result of enough setting time and sufficient reduction in the moisture content level to provide the mortar with sufficient strength and adequate void space to contain the expanded volume of ice formed when freezing occurs.

Portland Cement Association studies (5) confirmed that a very rapid loss of moisture occurs in the mortar immediately upon placement of mortar on a masonry unit; approximately 20% of the total mixing water is removed from the mortar closest to the unit within several minutes. Such a moisture reduction makes mortar less susceptible to freeze expansion. Other studies at the PCA laboratories using various depth probes, established clearly that mortar at a surface of a joint hydrates for a much shorter period than interior mortar due to reduced available moisture in the former.

EXPERIMENTAL PROGRAM

Forty-nine wall specimens were tested: 19 specimens in the 1981 winter program and 30 specimens in the 1982 winter program. All specimens were constructed of 200 mm lightweight concrete masonry units whose compressive strength was 7.5 MPa based on gross area or 15 MPa based on net area.

Ready-mixed, ready-to-use type S mortar was used in the 1981 test specimens. This mortar had a compressive strength of 9.30 MPa. Type N mortar prepared in the laboratory in accordance with Canadian Standard Association Standard A179-1977 "Mortar and Grout for Unit Masonry" (6) was used in the 1982 test specimens. The average compresive strength of this mortar was 5.48 MPa. Mortar test specimens were cured under standard conditions and tested at 28 days.

All specimens were five courses high with each course consisting of a 200 x 300 x 400 unit and a 200 x 300 x 200 unit laid in running bond. The walls were constructed on pallets to facilitate transportation. Photo 1 shows a wall specimen under construction.

In each of the two winter programs all test specimens except one series were constructed in the laboratory at a temperature of 20°C. The exception was a series of specimens which was constructed outside using masonry units which had been exposed to outside temperatures for a number of days. Groups of specimens constructed in the laboratory were moved outside at specific times varying from immediately to 48 hours after completion of construction. In each program a group of control specimens remained in the laboratory.

The average outside temperature during the 1981 winter program was -10°C and the temperature never rose above 0°C. The average outside temperature during the 1982 winter program was -17°C with a high of -6°C and a low of -26°C.

All specimens remained outside for at least 15 days and then were moved into the laboratory. In the 1981 program the specimens, after thawing, remained in the laboratory for at least 15 days before testing. In the 1982 program the specimens remained in the laboratory for at least 28 days before testing and were subjected to a daily fine water spray to promote hydration of the mortar joint.

Table 1 summarizes the pertinent information about the test specimens. Photo 2 shows a test specimen during its outside exposure.

Specimens were tested to failure in compression in a one million pound testing machine in the I.F. Morrison Structural Engineering Laboratory at the University of Alberta.

TEST RESULTS

The mode of failure for all wall specimens was splitting of the masonry units at the cross webs. Photo 3 shows a typical wall failure.Test results are presented in Table 2 and Figures 5 and 6.

The mortar used in the 1981 series was premixed and contained a retarder specifically developed to allow mortar to remain fresh for up to 36 hours without the need to retemper. The strengths achieved by the wall specimens in the 1981 series were in accordance with the mortar strength. Ready mixed mortar normally has a higher air content than laboratory mixed mortar. Although this may result in a reduction in ready mixed mortar cube strength, the presence of air voids provides space for expansion of water upon freezing without disruption of the mortar itself.

The mortar used in fabricating the 1982 series walls was mixed as required in the laboratory. Mortar cube strengths ranged from 4.7 to 6.2 MPa. The actual values are shown in Table 2 and are plotted in Figure 6. The wall stengths achieved were less than the 1981 series; the differences reflect differences in mortar strengths.

Since the primary objective of these preliminary tests on walls was to determine detrimental effects of freezing, the exposure and curing conditions were chosen to represent actual field conditions. Minimal or no curing was provided for the walls after exposure to freezing. Also prior to exposure to freezing the specimens were kept in the laboratory without provision of moisture. During the winter season the relative humidity of the laboratory seldom exceeds 30 percent. A rapid loss of moisture from the mortar occurs not only due to suction but also due to evaporation. Such a loss of moisture inhibits extended hydration and strength gain in the mortar joint. This phenomenom can be readily seen in Figure 5 and 6 where the longer curing time before freezing exposure resulted in a reduced final wall strength. The effect was most pronounced for the control specimens which were stored in the laboratory for the entire period. Because the walls in the 1981 series were stored in the laboratory after exposure with no additional provision of water to promote hydration the wall strengths achieved upon testing was reduced significantly where the specimen was "cured" for 12 to 24 hours before exposure.

The walls from the 1982 series exhibited a lesser effect of strength reduction with increased curing time (Figure 6). A significant difference for these walls as compared to the previous series, was the daily spraying of the surface beginning 3 days after the end of exposure until the time of test. The effect of the spraying was to furnish moisture and lower evaporation of moisture from within thereby improving hydration and strength gain of the mortar joint.

In both series some wall specimens were built outside using warm mortar and allowed to freeze. The strengths achieved by these walls exceeded those of the control specimens which were stored continuously within the laboratory. Rapid moisture loss in the case of the control specimens is the most probable the reason for their lower final strength.

CONCLUSIONS AND RECOMMENDATIONS

The results obtained from these preliminary tests indicate that exposure of concrete block masonry walls to freezing conditions does not impair significantly the final strength of such walls providing further hydration of the mortar is possible following freezing.

The most significant factor affecting the strength of concrete masonry walls is moisture loss from the mortar especially by evaporation under conditions of low relative humidity. Little or no hydration occurs when the relative humidity of mortar reduces to values less than 70 to 80 percent. Although walls in which the mortar is frozen may lose water due to sublimation this effect is not as significant as loss of moisture to a dry atmosphere.

It is recommended that particular attention be given to reducing the loss of moisture from within mortar for any condition of exposure. Further research is required to determine detrimental and other effects of freezing on concrete masonry walls.

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5. Isberner, A.W., "Specifications and Selection of Materials for Masonry Mortars and Grouts" R and D Bulletin RD 024.01 M Portland Cement Association, Skokie, Illinois, 1974.

6. "CSA Standard A179-1977M Mortar and Grout for Unit Masonry". Canadian Standards Association, Rexdale, Ontario.

TABLE 1 - TEST SPECIMENS

Test Series	Number of Specimens	Curing Time Prior To Low Temperature Exposure hours	Temperature at time of Exposure
1981 Program			
A-81	3	control	-
B-81	2	0	-10°C
C-81	3	2	-10°C
D-81	2	5	-10°C
E-81	3	12	-10°C
F-81	3	24	-10°C
G-81	3	built outside	-10°C
1982 Program			
A-82	5	control	-
B-82	5	2	- 6°C
C-82	5	6	-18°C
D-82	5	17	-19°C
E-82	5	48	-21°C
F-82	5	built outside	-26°C

TABLE 2

TEST RESULTS

Test Series	Mortar Strength MPa	Failure Load kN	Average Failure Load kN	Average Compressive Strength MPa	Wall Strength / Mortar Strength
1981 Program					
A-81	9.30	523 444 433	467	7.87	0.85
B-81	9.30	638 725	681	11.49	1.24
C-81	9.30	491 579 678	583	9.82	1.06
D-81	9.30	535 671	603	10.17	1.09
E-81	9.30	610 558 612	594	10.00	1.08
F-81	9.30	509 551 505	522	8.80	0.95
G-81	9.30	471 499 520	497	8.37	0.90

Table 2

continued

Test Series	Mortar Strength MPa	Failure Load kN	Average Failure Load kN	Average Compressive Strength MPa	Wall Strength / Mortar Strength
1982 Program					
A-82	6.2	460 268 345 362 345	356	6.00	0.97
B-82	4.7	529 476 538 416 390	470	7.92	1.69
C-82	5.0	353 510 448 424 354	418	7.05	1.41
D-82	6.1	413 483 403 454 417	434	7.30	1.20
E-82	5.0	353 466 435 283 397	387	6.52	1.30
F-82	5.9	346 515 414 393 350	404	6.80	1.15

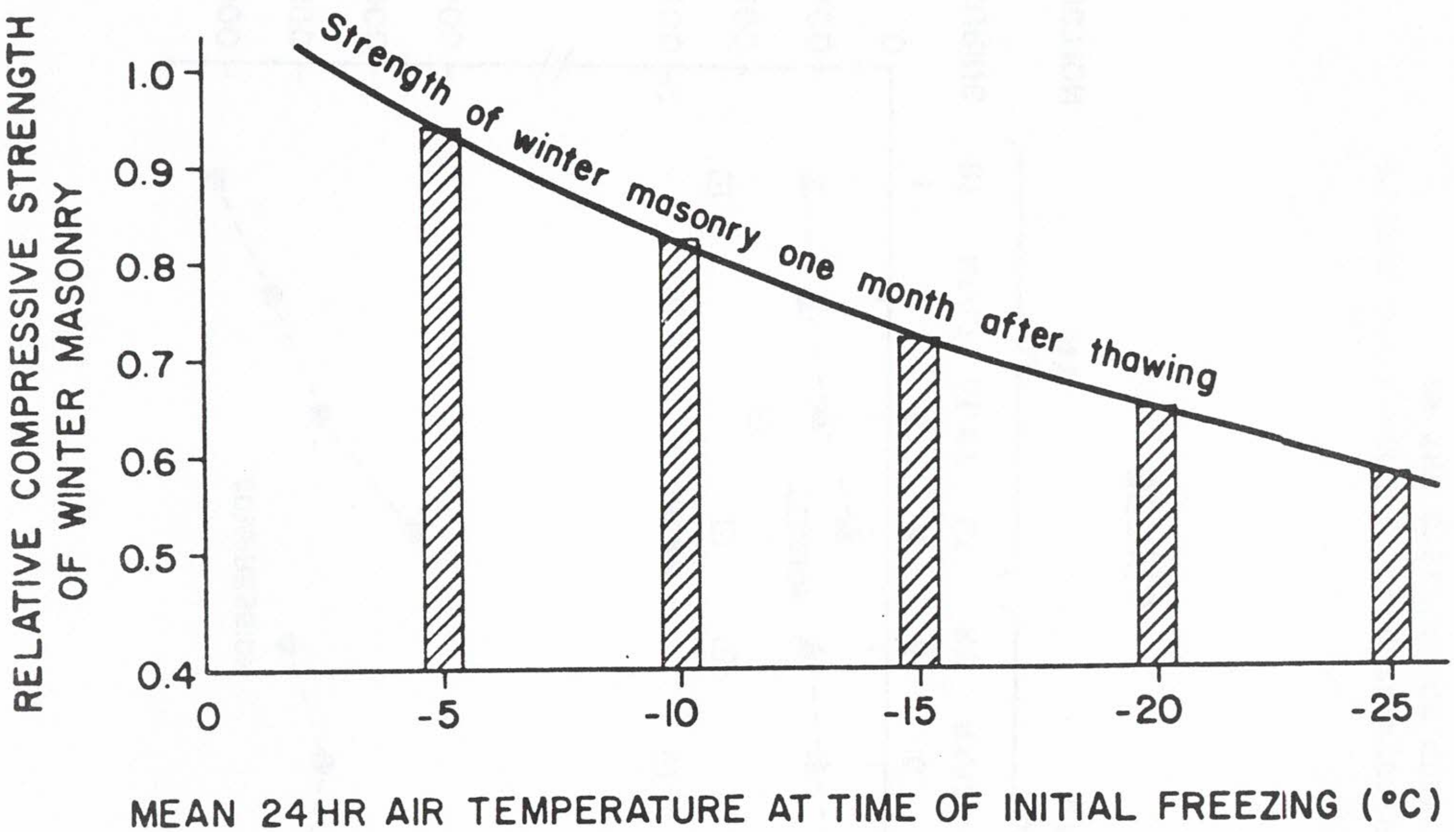

FIGURE 1 - EFFECT OF INITIAL FREEZING TEMPERATURE ON STRENGTH OF WINTER MASONRY

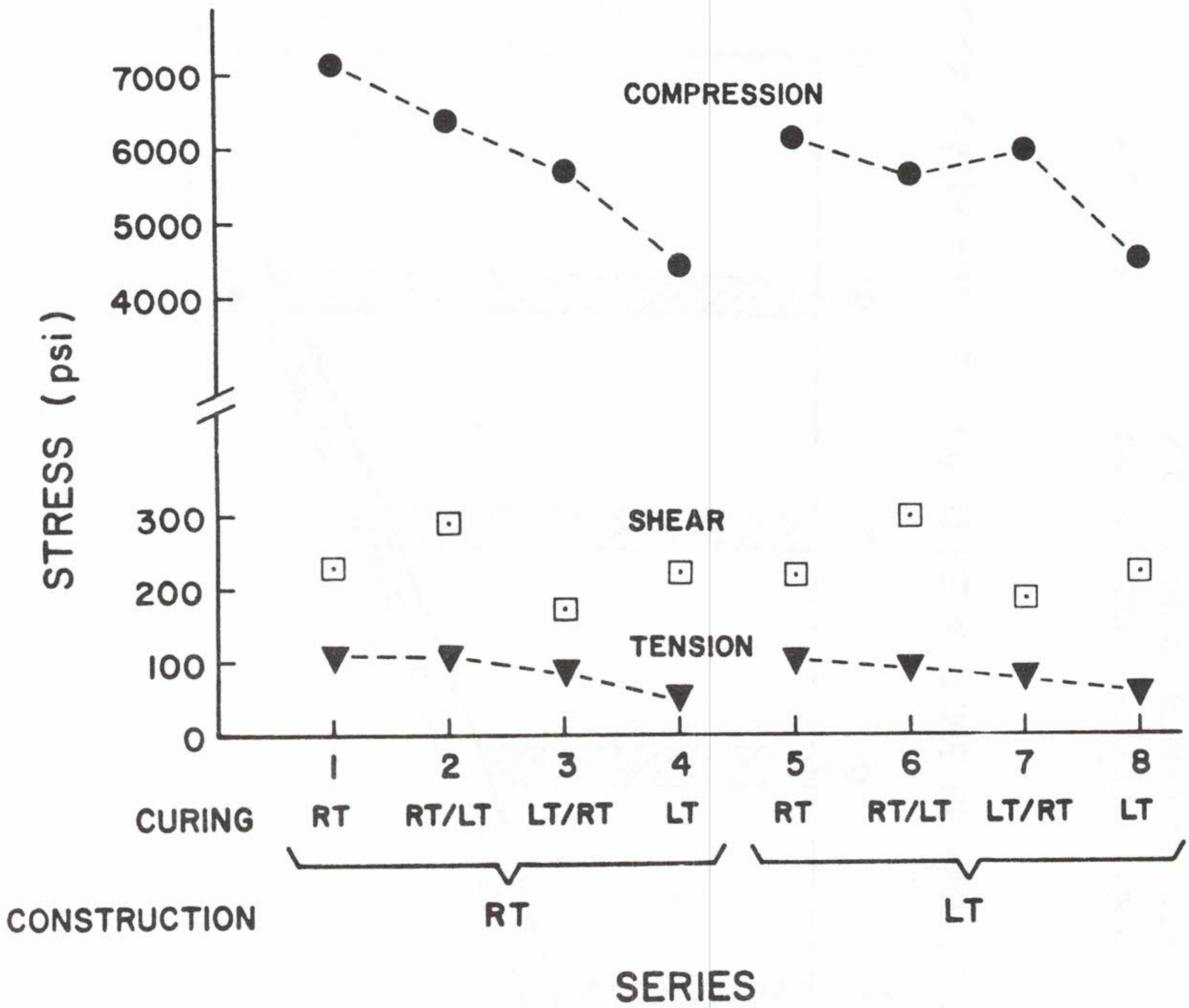

FIGURE 2 - EFFECT OF COLD TEMPERATURE ON THE STRENGTH OF CLAY MASONRY

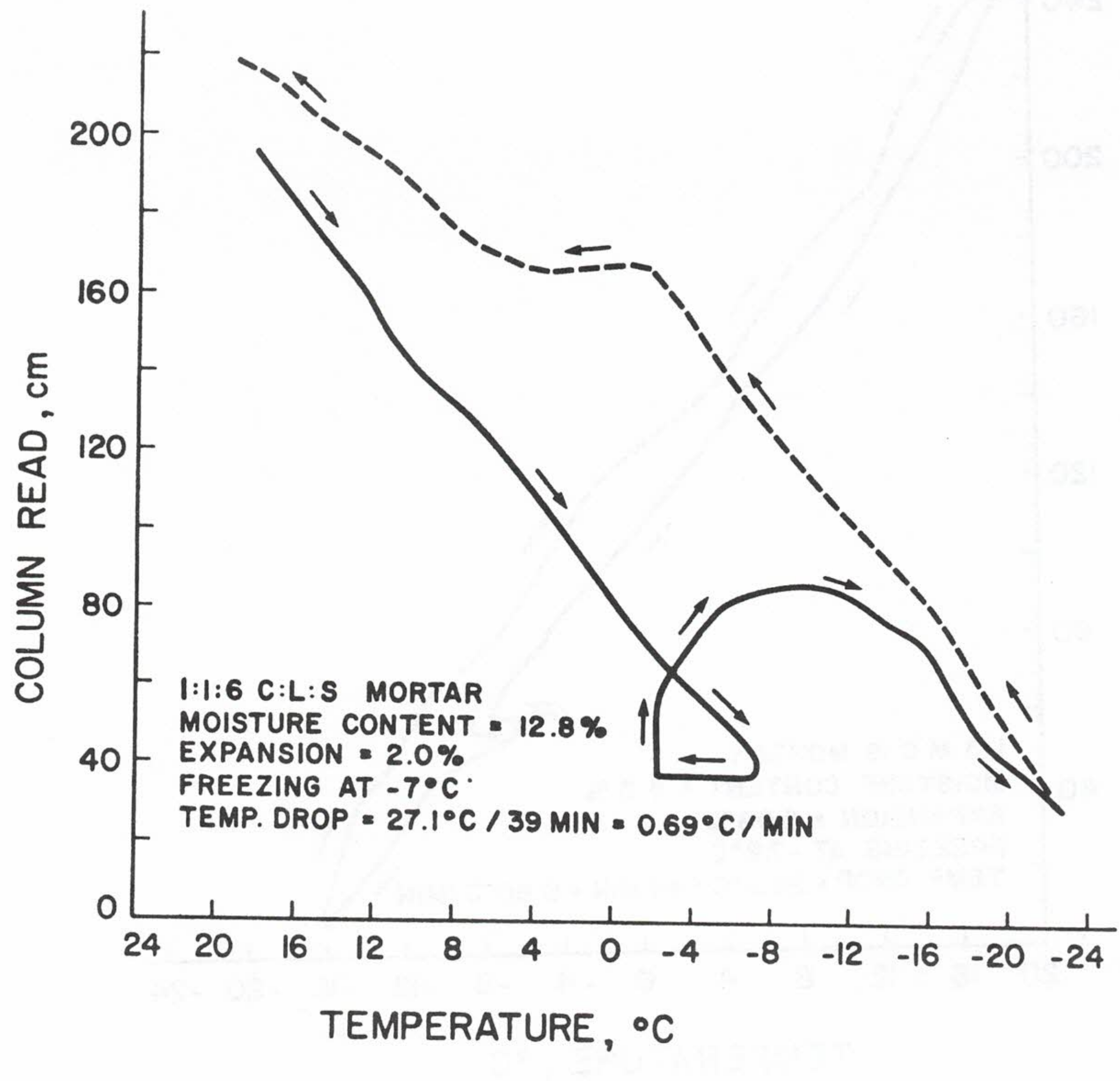

FIGURE 3 - VOLUME CHANGE DUE TO FREEZING

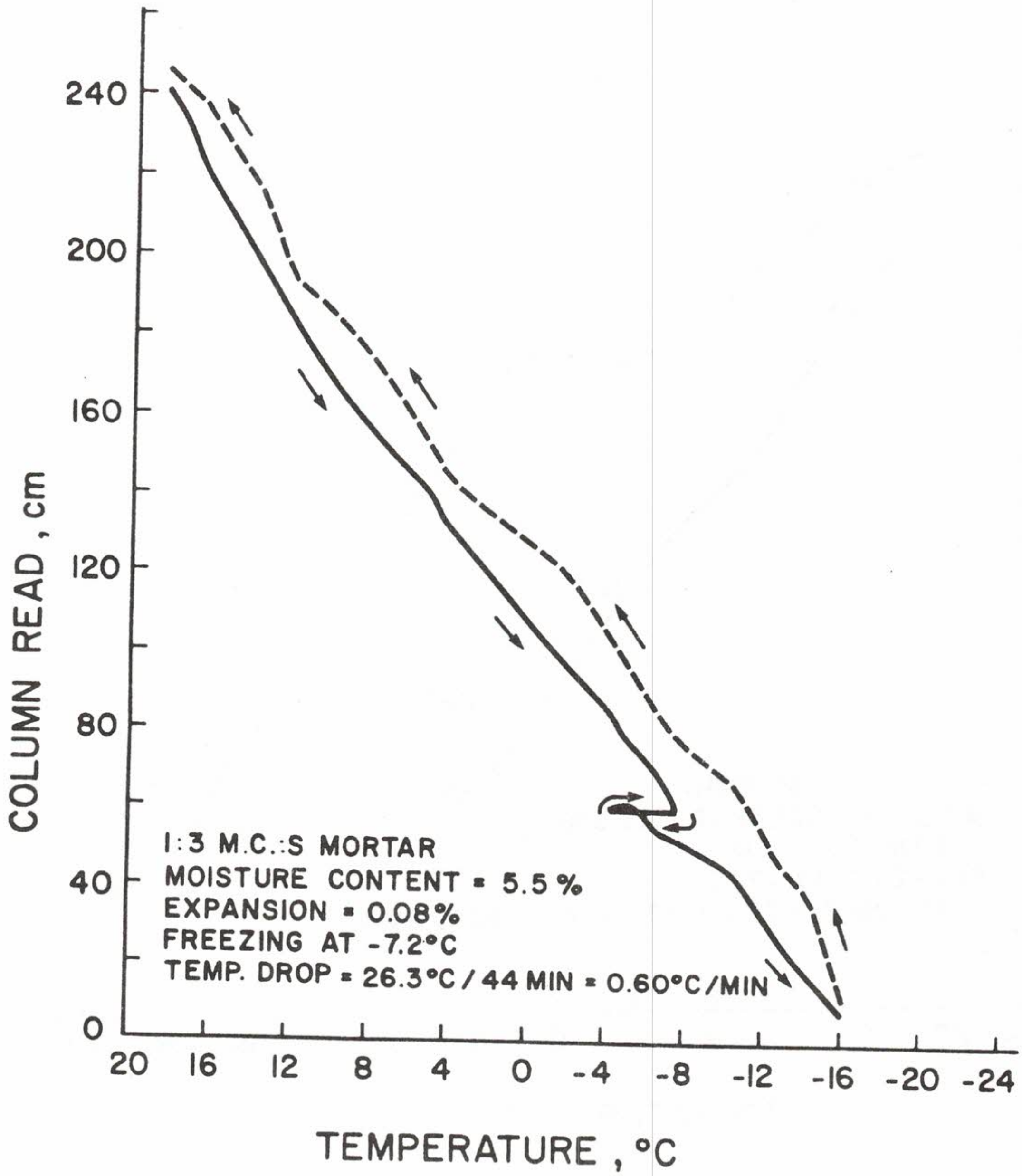

FIGURE 4 - VOLUME CHANGE DUE TO FREEZING

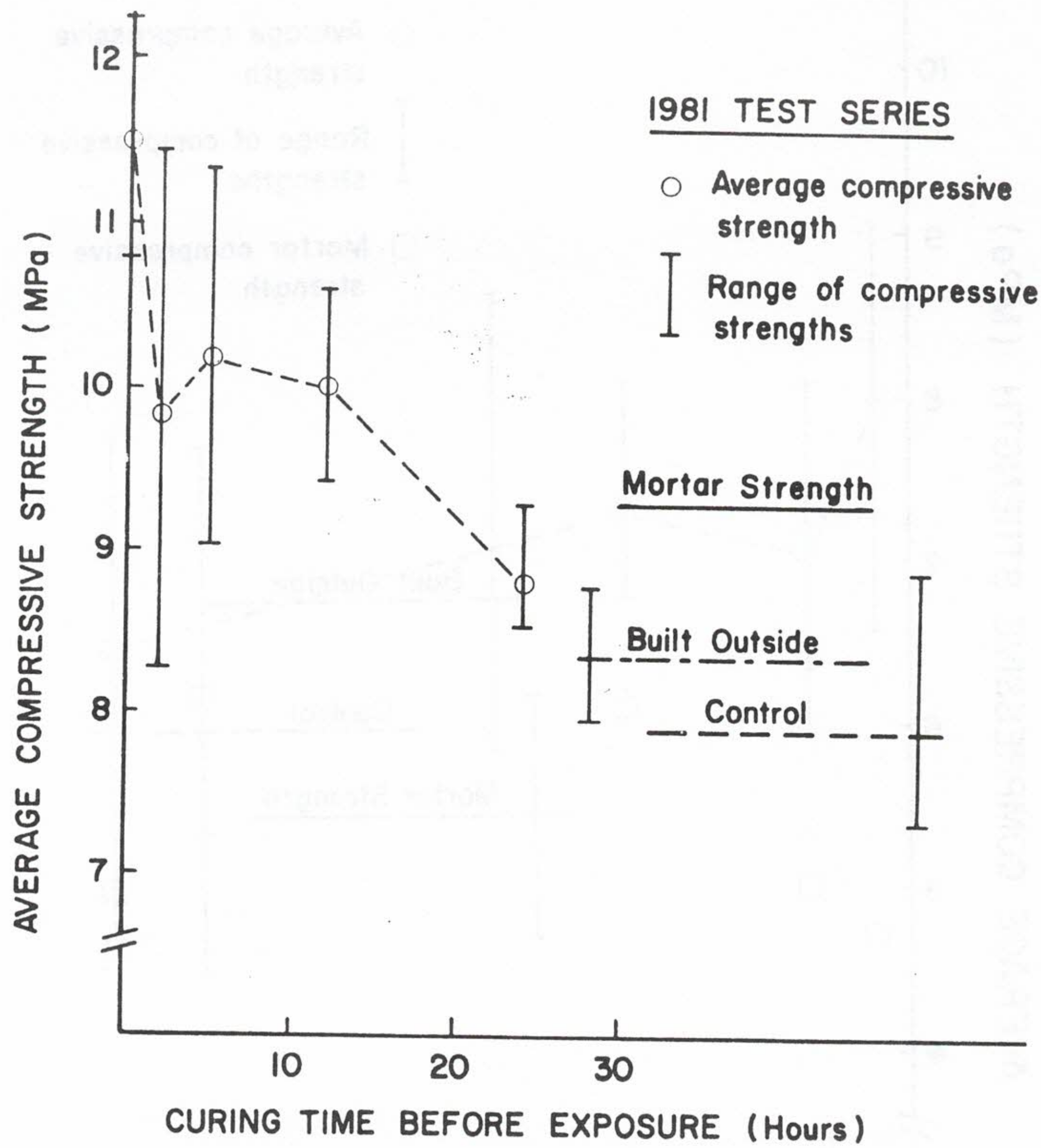

FIGURE 5 - WALL TEST RESULTS 1981 SERIES

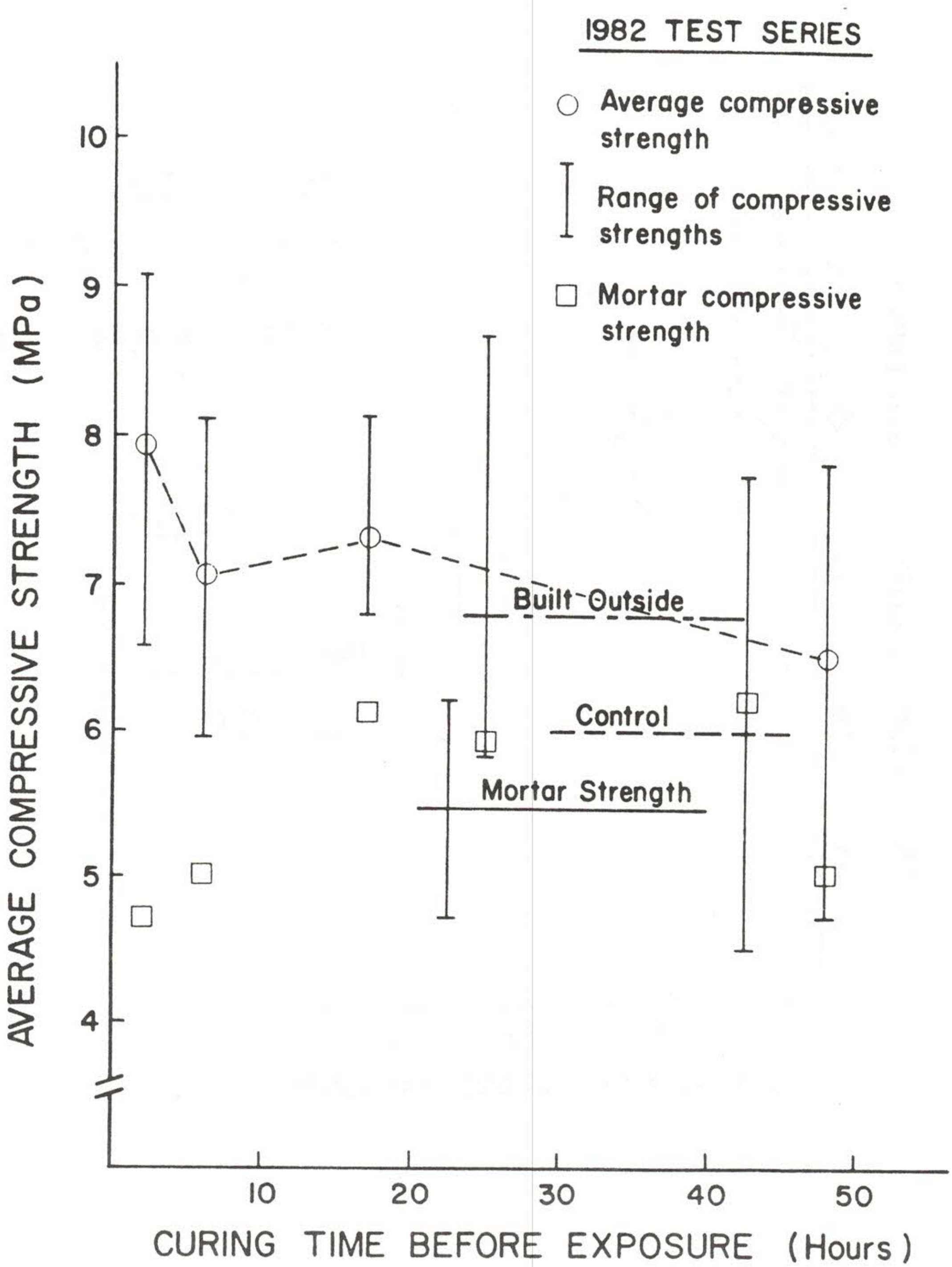

FIGURE 6 - WALL TEST RESULTS 1982 SERIES

PHOTO 1 - WALL SPECIMEN UNDER CONSTRUCTION

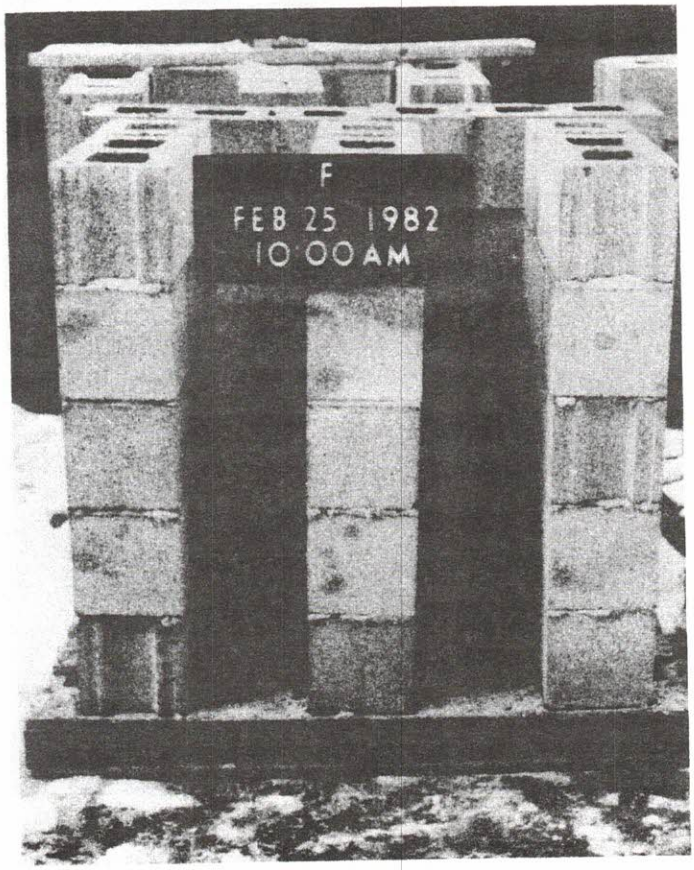

PHOTO 2 - SPECIMEN EXPOSED TO LOW TEMPERATURE

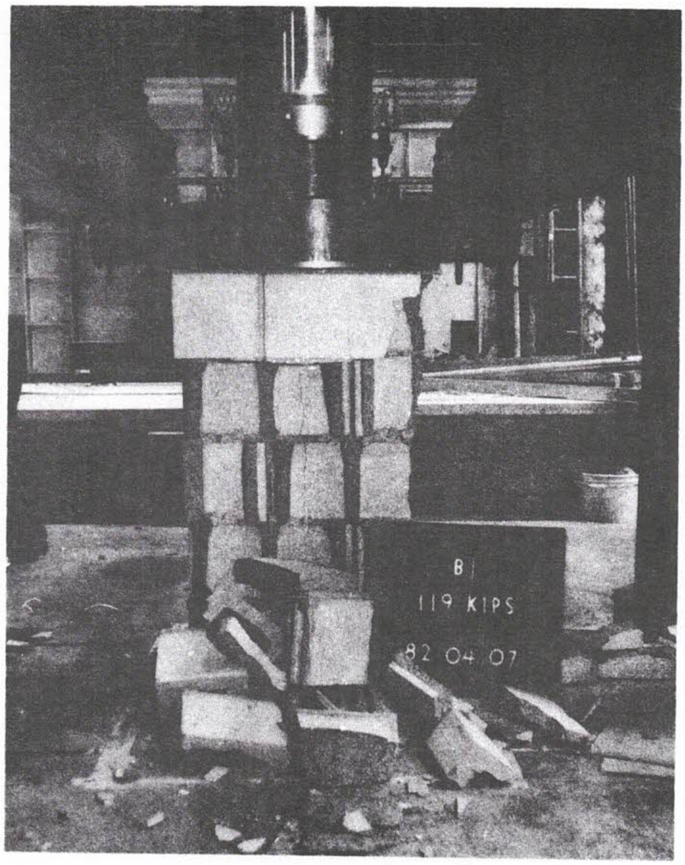

PHOTO 3 - TYPICAL FAILURE OF AXIALLY LOADED WALL