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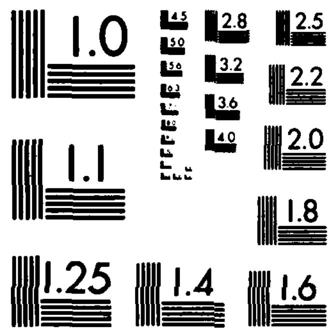
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Deteriorated concrete panels on buildings at Sondrestrom, Greenland

Charles Korhonen

Prepared for
SONDRESTROM AIR BASE, GREENLAND
and
OFFICE OF THE CHIEF OF ENGINEERS

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) On 22 July 1983 a dozen reinforced concrete buildings, built in 1954 at Sondrestrom Air Base in Greenland, were examined to determine why their concrete wall panels were cracked, spalled and rust stained. The investigation determined that structural and thermal movements caused most of this deterioration. Very little freeze-thaw deterioration was evident on the outside, but the most serious problem was that of frost damage within the wall cavities fed by moisture from the inside of each building. The visible surface defects can be repaired with breathable patching materials, but to achieve long-term success and to minimize wall-cavity frost damage, vapor migration through the walls must be properly controlled.		

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PREFACE

This report was prepared by Charles Korhonen, Research Civil Engineer, of the Civil Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory.

The study was conducted for the Base Civil Engineer at Sondrestrom Air Base, Greenland, on MIPR number 83-01. The study was also conducted as part of DA Project 4A762730AT42, Design, Construction and Operations Technology for Cold Regions, Technical Area C, Cold Regions Maintenance and Operations of Facilities, Work Unit 006, Maintenance and Rehabilitation of Military Facilities in Cold Regions.

The author thanks Tony Husbands of the U.S. Army Engineer Waterways Experiment Station for his assistance in examining these buildings and in recommending the repair procedures in this report. Wayne Tobiasson and Stephen Flanders of CRREL technically reviewed this report.

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ILLUSTRATIONS

CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM Metric Practice Guide (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	By	To obtain
degrees Fahrenheit	$t_{°C} = (t_{°F}-32)/1.8$	degrees Celsius
inches	0.0254*	meters
lbf/in^2 (psi)	6894.757	pascals

*Exact

DETERIORATED CONCRETE PANELS ON BUILDINGS AT SONDRESTROM, GREENLAND

Charles Korhonen

INTRODUCTION

The exterior walls of reinforced concrete buildings at Sondrestrom Air Base (SAB) in Greenland have deteriorated to the point that some remedial repairs are needed. At the request of the U.S. Air Force and with the assistance of Tony Husbands of the U.S. Army Waterways Experiment Station (WES), I examined the extent of this deterioration on 22 July 1983 to determine its cause and to recommend appropriate concrete patching and repair procedures.

The buildings were constructed in 1954 using a frame of reinforced concrete columns, bents and beams, to which reinforced concrete roof and wall panels were attached. These elements were prefabricated in Zeist, Holland, shipped to Greenland, and erected on insulated floor slabs poured directly on grade or on floor slabs elevated slightly above grade (Sondrestrom is in an area of discontinuous permafrost).

The exterior walls are of cavity construction. The outer leaf, made of one-story-high concrete panels supported and keyed into precast grade beams, is separated from the inner leaf by a 2-in. air space. As originally built, the inner leaf consisted of either prefinished, unreinforced, light-weight concrete panels or 2x4 wood framing sheathed with gypsum board and insulated with blocks of foamed glass. Many of these walls have been remodeled to make them more thermally efficient.

I visually examined both the inside and outside of a dozen buildings, documented signs of distress, and took chips of concrete for laboratory analysis. This report details visual and laboratory findings and presents repair recommendations.

LABORATORY ANALYSIS

To determine its make-up, several chips of concrete from various building walls and from unused wall panels stored since 1954 near the SAB runway

(Fig. 1) were sent to WES for analysis. A microscopic examination showed that this concrete is highly susceptible to freeze-thaw deterioration in the presence of water because it was non-air-entrained. Air entraining is generally acknowledged to greatly increase the resistance to freeze-thaw deterioration.

Figure 1. Unused wall panels stored near the runway.

A chemical analysis of the concrete revealed a very low chloride content of 0.02%. This amount should not induce the embedded reinforcing steel to corrode, since chloride usually does not create corrosion problems until its quantity has reached at least 0.1% by weight of cement in the concrete (American Concrete Institute 1983a).

A careful visual examination of the concrete chips showed a good bond between the aggregate and the cement paste. No signs of alkali-silica reaction were evident. In general the laboratory results indicate that, other than not being air entrained, this concrete has no serious problems built into it; it is structurally sound.

FIELD STUDY

A detailed visual examination showed that the concrete wall panels are deteriorating because of corrosion, foundation movements, thermal stresses and frost action.

Corrosion

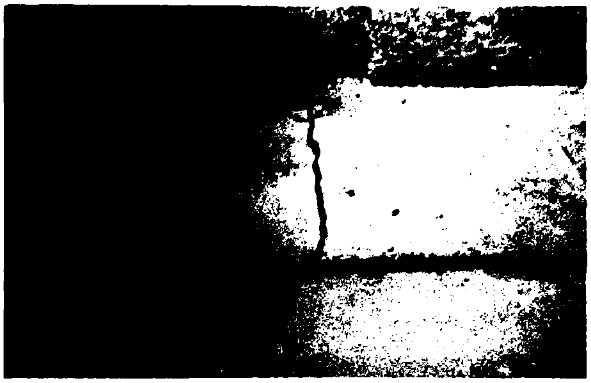
Usually when one thinks of corrosion in concrete, visions of rusted reinforcing steel come to mind. Figure 2 suggests that this is the case, as rust streaks are evident on the exterior surfaces of these buildings. However, a closer look shows that the rust is emanating from a point source, not from

Figure 2. Typical rust streak. Note the dark, iron-rich stone at its center.

cracks corresponding to reinforcement locations. I chipped out several of these areas and in each case found a rusted, iron-rich stone. Chipping deeper revealed even more of this material, except that it was not rusted at depths greater than about 3/8 in. Unless it begins to expose more and more aggregate, this near-surface rusting is not a structural problem.

Structural movement

My measurements and observations suggest that most of these buildings have settled differentially. Cracks and separations in the structural framework at several locations were evidence of this. For example, in the corner of one building a section of grade beam (Fig. 3a) had cracked and separated from the floor slab by as much as 1/4 in. but had remained in contact with the floor along the rest of its length. In another case, an equipment support rod that was securely bolted to the ceiling and floor had bowed (Fig. 3b). A comparison of the bowed and unbowed rod heights showed that the ceiling-to-floor distance had decreased by 1/16 in. These and similar movements are considered responsible for developing shear forces within many of the concrete panels, causing them to crack across their widths. Figure 4 shows a typical panel-wide crack. The diagonal nature of these cracks indicates a shear-type failure mode.



a. Grade beam cracked and separated from floor, leaving a 1/4-in. crack.

b. Bowed equipment support rod, representing a 1/16-in. movement.

Figure 3. Measurements that suggest buildings have settled differentially.

However, it is difficult on the basis of only one site visit to predict if the foundations are still moving. (Monitoring devices should be installed on several cracks to determine that.) But because these cracks are reported to have developed shortly after the buildings were constructed and because they have remained tight (Fig. 4), I do not expect these cracks to worsen significantly in the near future.

Figure 4. Panel-wide crack.

Thermal stress

As the temperature changes, the concrete panels that clad these buildings are constantly expanding and contracting. To accommodate this movement each wall panel has been separated by a 3/8-in. joint, weather sealed with a flexible metal waterstop. Some joints have also been filled with a rigid, cement mortar. Wherever this mortar has been used, the panels have not been free to expand. As a result, stresses have built up to the point where the panel edges have developed two types of cracks along these joints: short hairline cracks perpendicular to the panel edge (Fig. 5a) and diagonal cracks at the panel corners (Fig. 5b).

The stress σ developed in such a restrained member due to a change in temperature can be estimated by multiplying the member's modulus of elasticity E by its coefficient of thermal expansion α and the change in temperature ΔT it is subjected to ($\sigma = E\,\alpha\,\Delta T$). If we assume that 1) the concrete panels were installed at 55°F and attain a summer temperature of 85°F, 2) their coefficient of thermal expansion is $6.5\text{x}10^{-6}$ in./in.°F, and 3) their modulus of elasticity is $4\text{x}10^{6}$ psi, then the stress would be 780 psi; this is too small to crack structurally sound concrete. But this assumes, of course, that the 780 psi is uniformly distributed, which, obviously, it is not. Both kinds of stress cracks do not occur together on the same panel but are part of an active process that can easily be solved by removing the cement mortar between panels.

a. Hairline cracks along panel edges.

b. Diagonal cracks that have spalled off panel corners.

Figure 5. Stress cracks along the vertical joints between some wall panels.

Frost action

Frost damage is rare on these buildings. About the only place it is noticeable is on the grade beams (Fig. 6). This is somewhat surprising because the laboratory results showed that this concrete is susceptible to freeze-thaw deterioration. The main reason why this concrete has survived the low temperatures so well is that the climate at Sondrestrom is very dry.* Dry concrete, whether it is entrained with air or not, is not deteriorated by freezing.

The interior surfaces of the exterior wall panels, on the other hand, appear to be significantly more affected by frost action. I first became aware of this when building occupants described seeing water streaming out of the walls onto the floors during warm

Figure 6. Minor freeze-thaw deterioration. The lime deposits indicate wetting.

*The Air Force Weather Service reports a mean annual precipitation of 6 in. at Sondrestrom.

spring days. If ice had formed within the wall cavities during the winter, as this suggests, did it also damage the concrete there?

To determine if it did, I probed into several weepholes and peered into other larger holes previously cut into the walls. In many cases the weepholes were filled with chips of concrete (Fig. 7a), and the back sides of those panels that could be reached through the larger holes (Fig. 7b) were much rougher than the back sides of the panels stored near the runway (Fig. 1). This convinced me that the wall cavities were being eroded by frost action fed by interior building moisture.

a. The c [illegible] of concrete in the foı [illegible] and came out of this weepnole.

b. Reaching inside holes such as this one revealed that the back sides of some panels were very rough.

Figure 7. Evidence of wall-cavity frost damage.

Not all the buildings were equally eroded. When I probed the weepholes of several barracks buildings, I found more debris from some buildings than from others. The as-built drawings showed that there are four different wall cross sections for this type of building. Two of them, built in 1954, were described earlier in this report. A third wall type consists of some of the original walls retrofitted in 1976 with inside insulation and a vapor retarder. In 1981 the wall cavities of a few of the 1976 walls were filled with insulation, creating the fourth wall type.

Figure 8 compares the vapor pressure profile through each of these walls as outlined in ASHRAE (1981). It was assumed that the walls were exposed to indoor conditions of 70°F and 30% relative humidity and outdoor conditions of

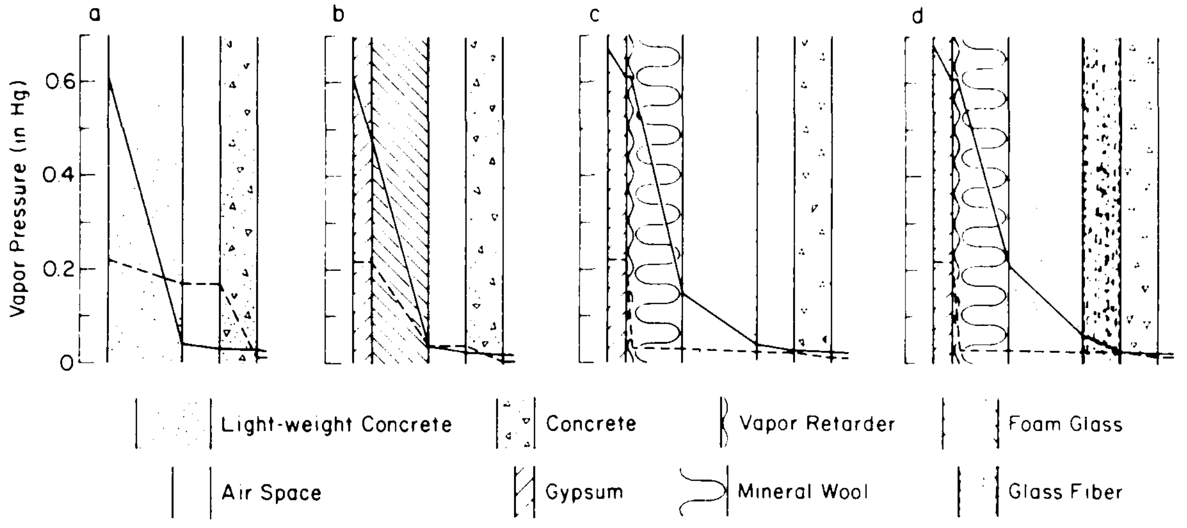


Figure 8. Vapor pressure profiles through four wall cross sections. Moisture condenses when the actual vapor pressure (dotted line) exceeds the vapor pressure of saturated air (solid line). The warm side of each wall is on the left.

-10°F and 70% relative humidity. As can be seen, condensation is more likely to occur in the two walls without a warm-side vapor retarder (Fig. 8a,b). It was in these walls that I found the most debris. Also, it was on these buildings that the wall panels seemed to be a bit more cracked. Thus, it appears that much of the deterioration of these buildings can be alleviated by adding a vapor retarder on the warm side of the walls.

A vapor retarder does not completely stop moisture, particularly in retrofit situations, where it is often extremely difficult to achieve continuity. Air leakage through cracks around doors and windows and through splits and joints in the vapor retarder can be a particularly important means of vapor transport from the inside of the buildings into the walls. This means of vapor transfer can be, and in older buildings often is, more dominant than the flow produced by vapor pressure alone. The addition of cavity insulation (Fig. 8d) could help to reduce air leakage by tightening the walls to air flow, which in turn may reduce erosion. Tightening the walls could also increase erosion by reducing the amount of water that could escape by ventilation. Which effect cavity insulation will have is difficult to predict, but it will be interesting to compare the performance of these buildings over the next several years.

Currently no exterior concrete panel appears to be severely eroded, but because this process goes unnoticed, there is reason for concern.

RECOMMENDATIONS

Although no defect identified on these buildings is considered to be an immediate threat, remedial measures are needed to slow panel deterioration. The visible defects (rust, cracks and spalls) can be repaired with commercially available patching materials and conventional repair procedures. To be effective, the patches must be sufficiently permeable to vapor to allow building moisture to escape. The frost damage in the wall cavities can be controlled by making the inside of the wall more vapor resistant.

Patching

Since rust is limited to near-surface pieces of aggregate, further rusting can be eliminated by chipping out all rusted material and patching the resulting holes with an acrylic-latex-modified concrete (Fig. 9). A solution of oxalic acid and water can be used to wash off the remaining rust stains. It is best when working with acids to experiment with light applications to determine the success of various strengths of solution. Also, the surrounding concrete should be wetted to minimize etching.

The cracks that run the width of many panels (Fig. 4) and those that occur at the vertical edge of other panels (Fig. 5a) can be cosmetically repaired with a coating. Several paint-like cement-based products are available that will adhere very well if the concrete surface is first sandblasted.

Before any cosmetic repairs are made, all cement mortar between panels must be removed to avoid further stress cracking. If a sealant must still be used in those joints, an elastomeric material would be best. Polysulfides, polyurethanes and silicones are excellent choices for working joints because

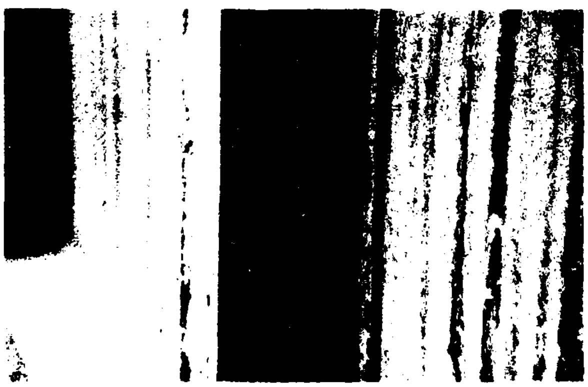


Figure 9. Hole remaining after an iron-rich stone has been chipped out.

they will return to their original shape even in very cold weather. To be effective, the sealant should not completely fill the joint. There is a definite correlation between sealant depth and joint width (Fig. 10). As an elastic material is stretched, it begins to thin, producing the greatest strain at the top and bottom surfaces. For the elastomeric sealants mentioned above, the allowable working strain is ± 25% (Maslow 1974). As shown in Figure 10, a 3/8-in. joint subjected to a 0.05-in. movement produces a 25% strain in a 1-in.-thick bead of sealant. However, to avoid even approaching this strain, the sealant should not be placed any deeper than 3/4 in. A polyethylene-foam backer rod should first be inserted to the proper depth in the joint, both to create the desired sealant cross section and to prevent the sealant from sticking on its bottom side.

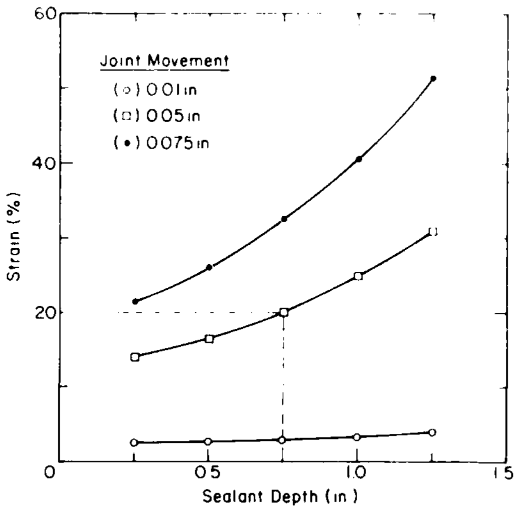


Figure 10. Relationship between movement, sealant strain and sealant depth for a 3/8-in.-wide joint. (After American Concrete Institute 1983b.)

Any spalling, as shown in Figures 5b and 6, can be patched with an acrylic-latex-modified concrete using the following procedure:

a) Remove all unsound concrete with a light-weight chipping hammer.

b) Clean chipped surface with high-pressure water or sandblasting to remove oils, grease, dirt, sealants and anything that would prevent good adhesion. If sandblasting, use compressed air to blow off any fines left behind.

c) Lightly dampen the surface with water without creating puddles.

d) Mix and place the patch material, closely following the manufacturer's instructions.

<u>Moisture control</u>

It is obvious from the erosion taking place in the wall cavities that water vapor, generated within the buildings, enters the walls faster than it can escape and condenses on the inside surface of the outer leaf. This erosion can be minimized by adding a vapor-resistant material to the inside wall surfaces. On some buildings this has already been done, so no further work is needed on them. Those that have a vapor retarder and cavity insulation may deteriorate somewhat faster than those with a vapor retarder but without cavity insulation. Insulating the outside wall surfaces may provide some relief by moving the dew point outside the concrete panels.

Coatings must be applied carefully to the outside surface of these buildings to avoid creating a vapor trap. To minimize this possibility the materials needed for repairing the concrete panels must be as breathable as the concrete. A cement-based material should work.

SUMMARY AND CONCLUSIONS

The investigation revealed that the reinforced concrete wall panels are gradually deteriorating. Since these buildings are nearly 30 years old, some of this deterioration is considered to be normal. The majority of the visible deterioration is attributed to structural and thermal movements, minor freeze-thaw damage, and some rusting of near-surface, iron-rich aggregate. The most serious problem is that of frost damage hidden within the wall cavities. Currently no wall panel has deteriorated significantly, but remedial action is needed to slow this process.

The visible surface defects can be repaired using commercially available materials and conventional patching procedures. The interior erosion of the wall cavities can be alleviated by adding a warm-side vapor retarder to minimize vapor migration through the walls. Although it is difficult to achieve vapor retarder continuity in a retrofit application, the value of adding a vapor retarder is demonstrated by the smaller amount of debris recovered in those buildings that were retrofitted in this way.

The wall cavities of some of the buildings have been insulated, which reduces any ventilation that may have normally occurred there. This may become a factor in increasing wall deterioration. If deterioration increases, then consideration should be given to adding exterior insulation in an attempt to minimize cavity condensation.

Caution must be exercised in using coating materials on the outside of these buildings. If they are not sufficiently permeable to vapor, vapor could become trapped within the wall panels. This could lead to additional frost damage, creating an even bigger problem than the coatings were intended to fix. Although information on the vapor permeability of concrete repair materials is limited, it is recommended that cement-based repair products be used, as these are likely to be as breathable as the concrete being repaired.

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