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# Condition and Durability of Segmental Concrete Block Retaining Walls Along Roadways in Minnesota

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This research project assesses the nature and extent of premature deterioration of segmental concrete block retaining walls (SCBRWs) along roadways in the Minneapolis-St. Paul area.

Researchers conducted a two-stage condition survey on 104 SCBRWs. The first stage, a general distress survey, focused on determining the type, severity, and extent of distresses present. The second stage, a peak winter survey, assessed the extent of snow/ice cover and exposure to winter sun.

According to research results, only 7 percent of the SCBRWs surveyed were in poor or very poor condition. But researchers observed many distress types in 50 percent or more of the walls surveyed, including freeze-thaw damage, scaling, manufacturing flaws, and efflorescence.

Freeze-thaw damage and scaling were most highly associated with decreases in overall wall condition. Efflorescence and freeze-thaw damage were found to be at least partly dependent upon SCBRW age and block manufacturer. Durability problems appear to be directly related to the lack of durability of the block units, which suggests problems with the use of inadequate mix designs, non-durable aggregate, and/or inadequate curing procedures.

The report includes recommendations to address possible deficiencies in manufacturing processes and quality.


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# Condition and Durability of Segmental Concrete Block Retaining Walls Along Roadways in Minnesota

## Final Report

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# EXECUTIVE SUMMARY


Segmental concrete block retaining walls (SCBRWs) along roadways are a relatively new innovation in the transportation field, and the metropolitan area of the Twin Cities of Minneapolis and St. Paul, Minnesota has pioneered their use. An assessment of the nature and extent of premature deterioration of SCBRWs in the Twin Cities was undertaken in response to recent reports of inadequate durability in the SCBRW inventory. Objectives of the present study were 1) determination of the proportion of SCBRWs along roadways in the Twin Cities exhibiting visible signs of distress, 2) qualitative assessment of the types and severity of the observed distresses, and 3) identification of factors that may be affecting the durability of the walls. A two-stage condition survey was conducted on 104 SCBRWs in the Twin Cities metropolitan area, with the first stage (general distress survey) focusing on type, severity and extent of the various types of distresses. The second stage (peak winter survey) was conducted to assess the extent of snow and ice cover, as well as the exposure to sunlight.

A review of literature was carried out to provide a baseline on current knowledge regarding the freeze-thaw durability of concrete masonry. The review revealed the following observations and conclusions: 1) The mechanisms of freeze-thaw damage in SCBRWs and the parameters affecting it do not appear to have been well established (Scott, 1996). 2) A conceptual model which identifies extent of curing and gel and capillary pore structures (MacDonald and Lukenan, 2000) seems to explain in a rational manner the variability in freeze-thaw resistance. 3) Until more is known regarding the mechanisms of freeze-thaw damage in SCBRWs, the durability requirements for concrete paving units should be adopted for use with SCBRWs. 4) A coordinated research effort is needed to identify mix designs tailored for known exposure conditions, and these mixes need to be verified by laboratory freeze-thaw tests that have been developed and calibrated to match exposure conditions determined by field monitoring of SCBRWs.

A database of 104 SCBRWs was compiled with the assistance of representatives from the Minnesota Department of Transportation (Mn/DOT), Dakota and Hennepin Counties, and various block producers. Criteria for the selection included: 1) walls constructed in 1994 or

earlier, 2) pairs of walls located at the same intersection and constructed during the same year, but facing different directions or representing new manufacturing and construction practices, and 3) privately owned walls identified by industry.  Data was collected from each wall in the following four categories: 1) project identification/location information, 2) environmental data, 3) design/construction data, 4) concrete block data, 5) maintenance records.  In the general distress survey (Stage 1), each wall was assigned a subjective distress rating with values ranging from 0 to 5, with the highest value indicating no visible distress.  Furthermore, each of 19 distress types was assessed visually with the aid of a *Distress Manual* developed in the course of this project (Appendix E).  Also, a global positioning system (gps) receiver was used to collect the latitudinal and longitudinal coordinates of each wall.  The peak winter survey (Stage 2) was done at the peak of winter to obtain information concerning snow, ice and deicing sand/salt accumulations, as well as exposure to sunlight.

Among the major findings of this study is that only 7% of the SCBRWs surveyed were in poor or very poor condition.  However, the following distress types were observed in 50% or more of the walls surveyed: freeze-thaw damage, fraying/spalling, scaling, position guide damage, embedded vegetation growth, manufacturing flaws, efflorescence, wash-through and open joints.  The presence of freeze-thaw damage and scaling were most highly associated with decreases in overall wall condition.  It further appears that the onset of freeze-thaw deterioration begins with local discoloration where saturating conditions are the greatest.  Later stages of freeze-thaw damage exhibit cracks that open and deteriorate to scaling.

Efflorescence and freeze-thaw damage were also among the distress types found to be at least partly dependent upon SCBRW age and block manufacturer.  It is further concluded that when durability problems exist, they are directly related to lack of durability of the units, thereby indicating that these problems are largely due to improper mix designs, nondurable aggregate, and/or inadequate curing procedures.  It is recommended that manufacturers investigate and improve the durability of materials and mixtures for SCBRW units, as well as curing procedures.  Block units should be tested to determine the source of the durability problems, and SCBRW field installations should be instrumented to accurately assess field exposure conditions for the development of realistic acceptance/rejection tests for predicting field performance potential.

# CHAPTER 1
# INTRODUCTION

## 1.1 Problem Statement

The use of modular concrete masonry units for segmental retaining walls along roadways is a relatively new innovation in the transportation field. The Twin Cities of Minneapolis and St. Paul, Minnesota have pioneered the use of segmental concrete block retaining walls (SCBRWs), with several hundred walls having been constructed along Twin Cities roadways since the mid-1980s. Subsequently, viable markets have opened for SCBRWs in other cities throughout the U.S. Recently, premature damage (generally attributed to freeze-thaw action), has been noted, primarily in the cap units. These instances of premature damage have been observed as early as five years after construction, thus raising concerns about the durability of modular concrete masonry units for use in retaining walls along roadways. Yet, reports of similar patterns of damage to SCBRWs in other U.S. cities are scarce.

The present state of knowledge regarding the durability of SCBRWs is incomplete. For instance, the number of walls affected, extent and severity of damage, and rate of deterioration of SCBRWs in the Twin Cities is unknown. It is uncertain whether the damage is the consequence of poor freeze-thaw durability of the modular concrete masonry units, or if there are other factors that are contributing to the rapid rates of deterioration. An assessment of the nature and extent of the damage to SCBRWs is needed before action can be taken to mitigate the observed damage.

## 1.2 Research Objective and Approach

The overall goal of the project was to determine the extent of any durability problems observed in a representative set of segmental concrete block retaining walls along roadways in the Twin Cities, and to gain additional insight into the nature of the deterioration. The specific objectives of this research were: 1) to determine the proportion of walls along roadways showing outward signs of distress; 2) to qualitatively assess the type and severity of observed durability distresses and to quantify the extent of observed distresses; and 3) to identify factors that may be affecting the durability of the walls. The extent of deterioration was to be quantified in terms of the number of walls affected, the proportion of area affected on each wall, and the severity of damage in these walls. The rate of deterioration was to be addressed using information supplied by the owner and block supplier (e.g., age of the wall and units).

To achieve these objectives, a two-stage condition survey was conducted on 104 SCBRWs in Minnesota. Stage 1 (general distress survey) was performed to determine the type, severity level and percentage of wall affected with each type of distress, while stage 2 (peak winter survey) assessed the extent of snow and ice cover and incident sunlight on the SCBRWs.

### 1.3 Benefits

The results of these surveys will provide Mn/DOT with a good indication of the extent of deterioration problems observed in a representative set of SCBRWs along roadways in the Twin Cities. In addition, the surveys provide additional insight into the materials-related distress problems present. This preliminary information should be confirmed at a later date using laboratory-based forensic investigation techniques, supplemented by realistic estimates of freeze-thaw exposure conditions obtained from field monitoring of existing SCBRWs. A better knowledge of the source of the current field problems will lead to the selection or development of a test (or suite of tests) and field monitoring studies that can be used to more accurately predict SCBRW durability in field installations.

# CHAPTER 2
# LITERATURE REVIEW

## 2.1 Background

The durability of segmental concrete block retaining walls under cycles of freezing and thawing has recently come in to question in many parts of North America. It is generally recognized that cycles of freezing and thawing can be detrimental to the microstructure of concrete masonry with different stages of exposure leading to discoloration, erosion, delamination, cracking, and eventual disintegration of the units. The mechanisms leading to this deterioration and the factors that affect the rate of deterioration need to be known so that constituent materials, mix designs, production methods and installation procedures can be selected so as to extend the life of SCBRWs to match the expectations for comparable highway structures. For example, the Minnesota Department of Transportation (Mn/DOT) expects a 75-year service life from SCBRWs.

At first glance, the problem of freeze-thaw damage appears to be a simple one, with porous materials absorbing water when the temperature is above freezing. Subsequent freezing produces a volumetric expansion of water as it is transformed to its solid state. Frozen water in fully saturated pores or capillaries, not having room to expand, will exert large pressures on the porous medium. If the medium lacks sufficient tensile strength, microcracks will form and propagate as the cycles of freezing and thawing are repeated. However, the roles of 1) size and distribution of pores, 2) internal pressures and 3) soluble salts appear to greatly complicate the mechanisms of freeze-thaw damage. The level of complexity is further exacerbated by environmental factors such as histories of temperature and humidity.

In a certain sense, the freeze-thaw durability of concrete masonry products has often been viewed as a special case of the freeze-thaw durability of concrete products in general, and the latter has long been a concern in the construction industry. Unfortunately, there are important differences between wet-cast concrete products, in which sufficient mixing water is added to make the wet mixture flow, and dry-cast concrete masonry products, in which the water content is sufficiently low for the molded product to maintain its shape upon ejection from the mold.

Concrete masonry products owe their cost-effectiveness to the dry-casting method, in which large machines are able to manufacture (i.e., mix, consolidate and mold) concrete masonry units in a matter of seconds. However, the resulting microstructure of concrete masonry is quite different from that for west cast concrete, given the differences in production methods, and the mechanisms of freeze-thaw damage for concrete masonry cannot be taken directly from the knowledge base for wet-cast concrete. The resistance of concrete masonry to freezing and thawing, as well as the mechanisms of damage under such environmental action, are known to be quite complex, and many variables are known to affect its durability. Furthermore, some empirical observations on the freeze-thaw durability of concrete masonry appear to conflict with those for wet-cast concrete, such as the roles of absorption and compressive strength.

This chapter is not intended as a comprehensive literature review on the freeze-thaw durability of concrete masonry products, such as the one compiled by Snyder and Janssen (1992) on the durability of wet-cast concrete products. Snyder and Janssen provide a review and summary of 556 technical papers and reports. Rather, this chapter is a selective review of research specific to the durability of segmental concrete block retaining wall units, as well as a limited sampling of papers on concrete masonry durability and mechanisms of freeze-thaw damage in concrete and other porous materials. The chapter provides a brief summary of this technical literature which is subdivided into the following five categories: 1) mechanisms of freeze-thaw damage in porous materials; 2) freeze-thaw durability research on general concrete masonry products, 3) freeze-thaw durability research on concrete paving units, 4) freeze-thaw durability research on SCBRW units, and 5) research on freeze-thaw durability test methods.

## 2.2 Mechanisms of Freeze-Thaw Damage

### 2.2.1 Litvan (1980)

Litvan (1980) presents a phenomenological description of the basic mechanism of freeze-thaw damage in porous materials. This mechanism is compatible with observations made in compiling the experimental database on freeze-thaw damage. These observations include the following: 1) the severity of damage is directly proportional to water content, 2) damage is enhanced with increasing cooling rates, 3) very high or very low porosity gives best performance (intermediate porosity as in hydrated cement paste gives the worst performance), 4) the spherical bubbles introduced by air-entraining admixtures provide excellent performance, 5) damage is most severe if the liquid is a solution rather than a pure liquid, and 6) a 5% solution is the worst concentration.

Litvan indicates that complete saturation of a porous body can only be achieved at a temperature of 0° C or higher. At lower temperatures, the degree of saturation decreases due to differences in the vapor pressures of supercooled liquid and ice. As temperature drops for a fully saturated porous body, either some water must leave the pores, or mechanical damage must take place. Upon cooling a body with a high degree of saturation, the amount of excess water (i.e., water that can no longer be absorbed), may be produced at a rate greater than it can exit. Solid, amorphous (non-crystalline) ice is formed, further reducing the ability of water to exit Upon thawing, some of the water that had migrated out of the pores will reenter to re-saturate the solid.

Environmental changes worsen damage, including fast rates of cooling and rates of wetting and drying. Moisture content in-situ may be the most important factor in freeze-thaw durability, yet very little is known about it, as well as sources of saturation including condensation. Efforts to evaluate moisture content in-situ have been poor, and in many freeze-thaw tests, the water content is low by necessity because the saturation period is short. Low porosity is desirable, and for hydrated cement pastes that implies low water-cement ratios. Surface coatings are potentially detrimental because they do not prevent saturation through condensation, but they hinder egress of water.

### 2.2.2 Grimm (1985)

Grimm (1985) provides a comprehensive literature review on the durability of clay brick. While durability aspects that are discussed pertain to clay masonry, some aspects also affect concrete masonry. Grimm distinguishes between florescence, the salt residue that remains when water with dissolved salts evaporates, efflorescence, the stain on the surface of masonry from the deposit of florescence, and cryptofluorescence, the residue that remains in the internal pore/void structure of masonry units. Cryptoflorescence can adversely affect durability as large internal pressures are generated by the salt crystallization. Osmotic pressures in masonry can be as high a 10.3 MPa (1500 psi).

2.2.3 Stark (1989)

Stark (1989) illustrated the damage associated with duration of freeze-thaw cycles by conducting freeze-thaw tests on wet-cast concrete samples with both long cycles (one per week) and short cycles (two per day). The samples were manufactured using a mixed sand/gravel aggregate, type I portland cement and vinsol resin as air-entraining admixture. Wet mixes were designed with air contents between 2.7% and 5.2%. Markedly higher reductions in freeze-thaw durability were noted during the long cycles than the short ones. The theoretical explanation for this phenomenon is taken from Helmuth who postulates that water or saline solution is drawn to ice crystals growing in air voids or capillary pores. The longer the period during which the gradient exists, the longer the period during which moisture can diffuse to existing ice. Thus, greater ice buildup during longer periods increases internal pressure producing damage.

2.2.4 Pigeon and Langlois (1992)

Pigeon and Langlois (1992) studied the effects of water-to-cement (W/C) ratio, type of cement, type of coarse aggregate, duration of curing and air-void spacing factor on the freeze-thaw durability of high-performance concretes. Concrete compression strengths varied from 80-100 MPa (11,600-14,500 psi). It was observed that the limiting W/C ratio below which air entraining agents are not needed to protect concrete against freeze-thaw damage is in the range of 0.25 to 0.30. Laboratory freeze-thaw tests demonstrate that when W/C ratio is less than 0.30, the resistance to deicer salts is very good. Adequate consolidation was achieved in the wet-cast mixes by using superplasticizers to increase the flow of the mix in spite of the low W/C ratio.

## 2.3 Freeze-Thaw Durability Research on Concrete Masonry

2.3.1 Kuenning and Carlson (1956)

Kuenning and Carlson (1956) studied the influence of curing and drying conditions on the physical properties of concrete masonry. They found that these have little influence on freeze-thaw durability, but that the addition of air entraining admixtures improved durability except in the driest mixes (i.e., with the lowest W/C ratios). It is noted that the mixes used in this study were conisderably “wetter” (had a considerably higher water content) than do mixes presently, with W/C ratios in excess of 0.7. Therefore, these mixes share more in common with wet-cast concrete than do contemporary concrete masonry products. Sand and gravel were observed to produce the most durable concrete masonry units.

### 2.3.2 Copeland (1966)

Copeland (1966) summarizes experiences with concrete block masonry units exposed to cycles of freezing and thawing prior to 1966. He raises the issue of changes in block production methods and their impact on masonry unit durability. Changes in production methods are associated with molding and consolidation techniques, curing time and temperature, reductions in cement and water contents, and partial replacement of portland cement with other cementitious materials (fly ash, silica fume, lime). While some of these concerns are not applicable more than three decades later, others still are, and new ones have come to light such as the use of admixtures.

Copeland (1966) recognizes that much of the traditional durable performance of concrete masonry units is due to the fact that “concrete masonry exterior walls above grade seldom become thoroughly saturated except temporarily near the outer surface.” However, the author urges caution because “there are situations where moisture continues to permeate into the concrete and cannot escape. Eventually, the pores and voids become more or less completely filled with water. Then the concrete is vulnerable to serious damage from alternate freezing and thawing.” Copeland reviews data from two experimental studies, by now dated because of the concrete masonry materials used. However, some interesting observations are made: 1) initial rate of absorption, not absorption, appears to be more important to durability, and, 2) some limestone aggregates have very poor freeze-thaw resistance.

### 2.3.3 Shideler and Toennies (1967)

Shideler and Toennies (1967) studied the freeze-thaw durability of blocks from a variety of manufacturers in the U.S., as well as units manufactured in the laboratory-made units. They considered a number of variables including type of aggregate (lightweight: pumice, expanded shale, expanded slate, expanded slag, granulated slag and steam boiler cinders; normal-weight: sand/gravel combination), pozzolanic material content, air entraining admixture and (high-temperature) curing method (low-pressure: steam; high-pressure: autoclaving). They used two types of freeze-thaw tests ("slow water": freeze in water and thaw in air; "slow air": freeze in air and thaw in water). The air-entraining admixture produced a more durable block in all cases. Silica replacement reduced the durability of low-pressure (steam) cured block. However, no correlation was found between durability and a several important parameters related to porosity, including absorption, rate of absorption and ratio of voids to amount of "freezable water".

#### 2.3.4 Redmond (1969)

Redmond (1969) tested concrete masonry units under freeze-thaw cycles. He included various types of aggregates (sand-gravel, expanded slate) and curing methods (high-pressure or autoclaving, and low-pressure or kiln), as well as fly ash replacements. The sand-gravel mixes performed poorly, especially when cured under high-pressure. The fly ash mixes with expanded slate and high-pressure cured did not perform well either. Redmond recommended a minimum net area compression strength of 3000 psi for the most severe exposures (i.e., horizontal faces).

#### 2.3.5 Pfeiffenberger and Schellie (1985)

Pfeiffenberger and Schellie (1985) produced a durable concrete mix that can be used to produce concrete masonry products in a contemporary block machine. The mix included silica fume for dense packing of the microstructure of the mix, a superplasticizer, and a proprietary water repellent admixture. Resistance to freeze-thaw cycles, measured using ASTM C67, indicated freeze-thaw resistance in excess of the specification.

#### 2.3.6 Edgell et al. (1999)

Edgell et al. (1999) tested brick masonry panels in a unidirectional freeze-thaw test setup. They included Types S and N mortars with and without air-entraining admixture. Only the panels with Type S mortar with air-entraining admixture survived the freeze-thaw cycles. No panels with Type N mortar and air-entraining admixture were tested.

### 2.4 Freeze-Thaw Durability Research on Concrete Masonry Paving Units

#### 2.4.1 Clarke (1980)

Clarke (1980) reported on a major study to investigate the durability of concrete masonry paving units in Europe for the purpose of establishing specifications for freeze-thaw resistance.

Experimental variables in the mix design included cement content, moisture content, aggregate-to-cement (A/C) ratio, water-to-cement (W/C) ratio, and type of aggregate. The tests comprised single units saturated in 3% saline solution (sodium chloride).

Of the parameters studied, absorption, density and initial surface absorption had only weak correlation with weight loss during the freeze-thaw cycles. Compressive strength had a slightly better correlation than the other parameters, but it was not sufficient to serve as an accurate predictor of durability of concrete paving units. For the concrete mixes and aggregates studied, W/C ratio offered the strongest correlation with durability. Mixes with a W/C ratio above 0.30 exhibited freeze-thaw deterioration that increased rapidly with increasing number of cycles, whereas mixes with W/C ratios less than 0.30 exhibited the same freeze-thaw behavior. In spite of these observations, a minimum compression strength requirement for paving units of 50 MPa (7250 psi) is recommended.

Comparison of the freeze-thaw performance of concrete paving units with that of wet-cast specimens cut from pavement slabs meeting stringent freeze-thaw requirements, as well as to the performance of pavements exposed to winter conditions suggests that the freeze-thaw test can be comparable to actual exposure to winter conditions.

#### 2.4.2 Schoenfeld (1982)

Schoenfeld (1982) tested and compared concrete block paving units from different manufacturers to determine the effectiveness of a property specification developed by the NCMA for concrete block paving units. Among the properties included in this specification were unit compression strength, unit weight, absorption, saturation coefficient, tensile strength and freeze-thaw durability. Schoenfeld concluded that a compression strength in the range of 8,500 to 10,000 psi was found to be an adequate measure of freeze-thaw durability. Furthermore, the least durable units also had the highest absorption (6.1% vs. an average of 3.6%) and the lowest tensile strength (330 psi vs. an average of 500 psi).

### 2.4.3 Harrison (1993)

Harrison (1993) reported on a large effort to compare a variety of freeze-thaw testing techniques to characterize the durability of a wide cross-section of concrete paving units in Europe. These techniques included standard freeze-thaw tests, environmental rigs, and field exposure tests. It was observed that total water content of the units after 1 hour of water absorption is a better indicator of weight loss after 100 freeze-thaw cycles in saline solution, than maximum absorption capacity. Furthermore, weight loss (after 100 cycles) was observed to decrease approximately linearly unit weight (weight density).

Harrison indicated that the use of fly ash generally reduced freeze-thaw resistance. Furthermore, freeze-thaw resistance did not correlate well with physical parameters such as compression strength, tensile strength, flexural strength, fracture mechanics parameter or abrasion. Freeze-thaw resistance correlated best with "total porosity combined with pore volume between sizes 0.05 to 0.3 mm expressed as a volume per volume of paste. A strong correlation was observed between weight loss in freeze-thaw tests and water uptake.

From the exposure tests, freeze-thaw distress was observed to increase with amount of deicing salt used, number of freeze-thaw cycles, duration of the cycles, amount of rainfall, depth of snow cover, and environmental conditions conducive to high saturation. A hypothesis for freeze-thaw damage is proposed in which "the main cause of damage is due to the ice formed from mobile water and differential expansion between ice and the hydrate structure during thawing." From the exposure tests, the worst exposure condition identified is "squeeze" freezing, in which the base of the unit remains frozen but the surface thaws and then re-freezes, and under conditions with a high degree of saturation. In an environment of high humidity, moisture condenses on the thawed surface, leading to high saturation levels upon refreezing.

### 2.4.4 Ghafoori and Mathis (1997)

Ghafoori and Mathis (1997) studied the influence of cement content on durability of concrete masonry paver units under freeze-thaw action in saline solution. Cement content was varied so as to generate water-to-cement (W/C) ratios by weight from 0.21 to 0.29, and aggregate-to-cement (A/C) ratios by weight from 3:1 to 8:1. Compression strength and density were observed to increase with increasing cement content, while permeability and porosity decreased. In general, freeze-thaw durability increased with increasing cement content, and a recommendation was made to change ASTM requirements for pavers by increasing the minimum compression strength from 8000 psi to 8900 psi, and decreasing the maximum absorption from 5% to 4%.

## 2.5 Freeze-Thaw Durability Research on SCBRW Units

### 2.5.1 Devalapura et al. (1994)

Devalapura et al. (1994) provides a summary of general design concepts for segmental concrete block retaining walls. Durability of the segmental units is identified as a necessary requirement for adequate service life of such walls, and 1991 recommendations from the NCMA on minimum compression strength and maximum absorption capacity are mentioned. Manufacturer estimates of a 30 to 50 year life for these units are given, but validation of the required freeze-thaw durability is not provided.

### 2.5.2 Bremner and Ries (1996)

Bremner and Ries (1996) conducted freeze-thaw tests according to ASTM C1262 tests of concrete block for segmental retaining walls made using normal weight and lightweight mixes. They found little difference in their freeze-thaw resistance. They observed only a slight increase in rate of decay with increasing absorption, and a modest increase in resistance with increasing unit compression strength.

### 2.5.3 Bowser et al. (1996)

Bowser et al. (1996) conducted ASTM C666 tests of concrete block for segmental retaining walls made using normal weight and high-strength lightweight mixes with silica fume, fly ash and admixtures. They observed that even though absorption was higher for the lightweight mixes, durability was also higher. The replacement of portland cement with fly ash and/or silica fume decreased the durability of normal weight units, while it increased that of some lightweight units. Both of these effects appear to be related to changes in the air-void system, and possibly increases in alkalinty, of the various mixes with the addition of the fines. A fatty acid waterproofer was also shown to improve durability.

### 2.5.4 Scott (1996)

Scott (1996) tested SCBRW units from manufacturers throughout the United States and Canada, with a variety of properties including aggregate type, cement content, absorption, and compression strength. Weak correlations were observed between freeze-thaw durability and several unit characteristics, and most of these were determined to be statistically insignificant. In particular, absorption characteristics and aggregate were not found to be statistically related to durability. A general observation was made regarding increased freeze-thaw durability with higher compression strength, even though a single value for the minimum strength required for freeze-thaw resistance could not be identified from the units tested. In addition, four units were sampled for air content, the least durable unit of which had more than 15% air content according to ASTM C457-90, while the rest had less than 9% air.

In order to gain more useful information in future studies, Scott recommends freeze-thaw testing of SCBRW units under more controlled conditions to establish the influence of important parameters. For example, more units should be tested from a given mix design and from a given manufacturer, and more property data from the manufacturer (type and source of aggregates, cement content, admixtures, etc.) should be obtained. In other words, Scott is advocating a more empirical approach to defining SCBRW durability for a given mix design, manufacturer, aggregate source, and curing conditions.

### 2.5.5 NCMA (1996a)

NCMA (1996a) conducted tests of a variety of concrete masonry units including segmental retaining wall units to evaluate freeze-thaw resistance using ASTM C1262 tests, as well as to correlate this resistance to other properties of the units. The number of cycles defining freeze-thaw resistance was seen to increase modestly with density and unit compression strength, while increased absorption was shown to decrease freeze-thaw resistance slightly. It was further noted that the number of cycles to freeze-thaw failure in 3% saline solutions was approximately one-fifth to one-tenth (10% to 20%) the number of cycles for failure in pure water.

2.5.6 NCMA (1996b)

NCMA (1996b) conducted tests of concrete masonry units manufactured using various different mix design to correlate freeze-the resistance with mix design parameters. Variables included type of aggregate (limestone and sand-and-gravel), type of admixture (superplasticizer or water repellant), cement content and freeze-thaw medium (pure water of 3% saline solution). Both compression strength and density were observed to increase with cement content, but absorption was relatively insensitive to cement content. Freeze-thaw resistance was seen to increase with cement content and, to a lesser degree, with the admixtures. It was noted, once again, that the data indicates that the number of cycles to failure in saline was roughly 10% to 20% of that for freeze-thaw failure in fresh water. Furthermore, the number of cycles to freeze-thaw failure never appears to have exceeded 50.

2.5.7 MacDonald et al. (1999)

MacDonald et al. (1999) summarize a petrographic analysis of thin sections cut from concrete masonry units for segmental retaining walls that were used in a Mn/DOT testing program on freeze-thaw durability. Two types of pore structures are typically identified in concrete products, one which has well-defined and uniformly-sized, spherical pores and which is typical in air-entrained wet-cast concrete products, and another which has randomly-oriented, irregularly shaped pores and which often forms during compaction in dry-cast concrete products. Pore structures of both types were identified in the retaining wall units tested for Mn/DOT, but no correlation was found between the pore structures and freeze-thaw durability. However, units not passing the Mn/DOT freeze-thaw requirements established in 1998 were also observed to have a higher degree of unhydrated cementitious particles. Degree of hydration, as impacted by curing, is postulated as the factor most critical for freeze-thaw durability of the units, with higher degrees of hydration leading to a more favorable pore-size distribution for durability in the cement paste.

2.5.8 MacDonald and Lukkania (2000)

In a subsequent paper, MacDonald and Lukkania (2000) refine their hypothesis concerning the influence of microstructure on freeze-thaw resistance. They propose a two-phase model that recognizes two types of void systems, the capillary and gel pore systems (capillary porosity) and the void system formed by compaction (compaction porosity). MacDonald and Lukkania recognize the importance of proper curing which leads to a capillary pore system that is well segmented and has small capillary diameters. These factors reduce the amount of water available for freezing and provide better freeze-thaw resistance regardless of the characteristics of the compaction porosity. This model explains earlier observations by MacDonald et al. (1999) that freeze-thaw resistance does not correlate well with the two types of pore structures, as well as the general variability that has been observed by many researchers regarding the freeze-thaw resistance of segmental retaining wall units.

## 2.6 Research on Freeze-Thaw Durability Test Methods

### 2.6.1 Ritchie and Davidson (1968)

Ritchie and Davidson (1968) measured changes in moisture content and temperature of masonry materials (clay brick, concrete brick, sandstone and mortar) exposed along vertical surfaces to the weather for a two-year duration at two Canadian locations (Halifax, Nova Scotia and Ottawa, Ontario) for two years. Moisture content was influenced primarily by type of masonry (with materials with higher water absorption having the higher moisture contents upon freezing), direction of exposure (east and north were the worst exposures), geographical location (Halifax exhibited higher moisture contents than Ottawa) and season of the year. Measured unit temperatures depended upon geographical location, direction of exposure, and on daily and seasonal changes in air temperature. The number of freeze-thaw cycles was influenced by the direction of exposure and by geographical location, and as many as 50 to 80 freeze-thaw cycles were recorded per winter. A larger number of freeze-thaw cycles were recorded when thermocouples were placed closer to the surface rather than the center of the brick.

Ritchie and Davidson observed that the rate of freezing and the moisture content when frozen differed considerably from those used in standard laboratory tests for freeze-thaw resistance. They made the following recommendations for laboratory freeze-thaw tests to better simulate actual exposure conditions: 1) slow freezing rates (about 10°F/hr), 2) moisture contents not exceeding the 24 hr immersion test, and 3) 100 freeze-thaw cycles per year as the threshold for acceptable resistance.

2.6.2 Bessey and Harrison (1969)

Bessey and Harrison (1969) conducted a comparative study on various durability tests for calcium silicate (sand-lime) bricks. The tests included 1) exposure of partially-submerged brick to the elements in metal trays over a period of as long as 30 years, 2) burial of the brick in well-drained and undrained soil pits over a period of up to 20 years, 3) exposure of small, free-standing brick wallettes, and 4) accelerated freezing tests in the laboratory of brick submerged in saline solution (subjected to 10 cycles of freezing and thawing). Results from this study indicate that freeze-thaw durability is closely associated with compression strength, and that a minimum strength of 20 MPa guarantees adequate durability for calcium-silicate brick. The laboratory freeze-thaw test was found to correlate well with the tray exposure tests.

2.6.3 Dreijer (1980)

In a paper summarizing properties and testing methods for concrete paving units in Europe, Dreijer (1980) notes that resistance to sandblasting does not ensure resistance to freezing and thawing cycles.

2.6.4 Bruning (1987)

Bruning (1987) conducted a comparative study of test methods for the freeze-thaw resistance of brick walls. The tests comprised brick wallettes subjected to a constant ambient temperature on one face, and controlled cycles of temperature on the opposite face. The cycles included freezing temperatures and thawing, the latter which may include spraying with water. Standard procedures for testing freeze-thaw resistance in Great Britain, Germany, the Netherlands, Finland and the Soviet Union were included in the study. Exposure tests in Finland over one winter were also used to verify the accuracy of the test methods. Bruning concludes that the testing of brick for freeze-thaw resistance requires one-sided (unidirectional) freezing with the temperature history (i.e., the freezing and thawing) applied only on one face of the brick.

2.6.5 Van der Klugt (1989)

Van der Klugt (1989) developed a “sand tray” test for unidirectional freeze-thaw action that correlates well with observed damage to brick masonry in-situ. Loose brick was placed on gravel in a tray with a perforated base. Polystyrene foam insulation was used to line the inside of the tray, and the brick was subjected to a partial vacuum prior to immersion to allow a greater degree of saturation. Damage patterns for brick tested in this setup resembled those observed in the field, including delamination of the face of the brick rather than disintegration of the units.

### 2.6.6 Berra et al. (1993)

Berra et al. (1993) present a simple device for measuring deterioration: a dial gage mounted on plate with a adjustable clamp stand for the measurement of surface erosion in masonry units due to decay and deterioration. The device essentially measures the depth of surface erosion. Results for this device correlate well with those obtained using a laser sensor. However, Harrison (1993) concludes, on the basis of his exposure tests of concrete pavers, that the depth of surface abrasion is not a good indicator of degree of freeze-thaw damage.

### 2.6.7 Taylor-Firth and Laycock (1998)

Taylor-Firth and Laycock (1998) developed a climatic simulator for testing masonry panels under realistic profiles of temperature and humidity on one side (exterior) while maintaining constant temperature and humidity on the other side (interior). The emphasis of the research is to demonstrate the simulation of realistic climatic conditions and its importance for the study of durability and weathering effects. The limited research results presented pertain to masonry panels made using cored clay brick units under fresh water humidity. It was noted that "popout" damage was observed to begin at approximately 50 cycles.

### 2.6.8 Anand et al. (1998)

Anand et al. (1998) used linear finite element analysis of individual bricks under unidirectional (one face only) and omnidirectional (all four faces) freezing and thawing to study the generation of internal stresses under standard freeze-thaw tests. They observed similar behavior for clay brick in both cases, and they identified pockets of compression as the clay brick froze and tension as the clay brick thawed. The maximum magnitude of computed tensile stresses approached the tensile strength of the brick.

## 2.7 Implications on the Expected Performance of SCBRWs

The literature reviewed as part of this research project does not present a very clear nor cohesive vision of the mechanisms of freeze-thaw damage for SCBRWs and the parameters affecting it. However, some interesting and useful implications can be drawn. First, observations by MacDonald and Lukkania (2000) on the microstructure of SCBRW units and the role of curing, as well as their rational conceptual model, are very promising developments. Yet, these issues need further study and validation before they can be applied universally to SCBRW units.

Second, the requirements for freeze-thaw resistance of concrete paving units, developed from extensive research in North America and Europe (Harrison, 1993; Ghafoori and Mathis, 1997), is not likely to differ much from those SCBRW units. In particular, certain climatic conditions are sufficient to produce full saturation of masonry units, even on vertical faces (Ritchie and Davidson, 1968). Furthermore, "squeeze freezing", as described by Harrison (1993), poses highly damaging conditions that are likely to be present in many SCBRW applications. Consequently, until more is known regarding the freeze-thaw resistance and exposure conditions for SCBRWs, durability requirements should be adopted from concrete pavers. These latter requirements are based on a large database of laboratory and field performance tests, and they have served concrete pavers well (Clarke, 1980; Schoenfled, 1982).

Third, actual exposure conditions for SCBRWs are likely to be very different from those in laboratory freeze-thaw tests (Ritchie and Davidson, 1968). Thus, laboratory tests have to be carefully tailored to specific exposure conditions to be realistic representations of weathering at an accelerated rate. Faithful simulation of actual exposure requires simulation of boundary conditions, temperature histories and humidity histories (Bruning, 1987; Taylor-Firth and Laycock, 1998). Such an effort is likely to be complex, time-consuming and expensive.

In conclusion, the concept of tailored mix designs, coupled with laboratory freeze-thaw tests that are calibrated to known exposure conditions, is a viable approach. (These tests need not simulate actual exposure conditions, rather the need only to produce similar degrees of freeze-thaw damage as field exposure specimens. This procedure has been used for concrete pavers, and it appears to have worked well for many years. However, it entails coordinated research effort to develop superior mix designs and curing procedures, improved laboratory test methods and supporting field exposure tests.

# CHAPTER 3
# DESCRIPTION OF RESEARCH PROGRAM

## 3.1 Compilation of Database

The project team met with individuals representing the Minnesota Department of Transportation, Dakota County Highway Department, Hennepin County Transportation Department and the modular block industry to identify suitable SCBRWs for inclusion in the condition surveys. These representatives provided listings of walls constructed between 1980 and 2000. This list was reduced by the project team into a list of 104 SCBRW candidates for study using the following criteria: i) constructed in 1994 or earlier, thereby, allowing time for the effects of the environment to influence the wall condition; ii) pairs of walls located at the same intersection and constructed during the same year (dating 1995 or later), but facing in different directions or representing new manufacturing and construction practices; and iii) privately owned walls identified by industry. Table 3.1 presents the SCBRWs included in the condition surveys along with the year of construction, wall face direction, F/C (face-to-curb) offset and masonry block manufacturer.

Data collection forms were developed to assist with the collection of design information kept for the 104 walls included in the condition surveys (see appendix A). These forms were split into the following data collection sections:

- Project Section Identification/Location Information
- Environmental Data
- SCBRW Design/Construction Data
- Concrete Block Data
- Maintenance Records

Appendix B presents the design data that could be collected for each of the walls included in the condition surveys. For proprietary reasons, the concrete block manufacturing data (e.g., mix designs, block casting/formation techniques, manufacturer test results, etc.) were not included in this appendix. The standard specifications followed during the construction of walls built in 1994, 1996 and 1998 are presented in appendix C.

Table 3.1. SCBRWs included in the condition surveys.

| Route No | Location | City | No. Surveys* | Face Direction | F/C Offset (ft) | Year Built |
|---|---|---|---|---|---|---|
| **DAKOTA COUNTY** | | | | | | |
| 26 | Bovey Ave. | Inver Gove Heights | 1 | N | 18 | 92 |
| 31 | Delores Lane (SW Quad Pilot Knob & Cliff Rd) | Eagan | 1 | E | 18 | 88 |
| 31 | Apple Valley, on Pilot Knob at Cliff Rd. (SE Quad) | Eagan | 1 | W | | 88 |
| 31 | Diffley Road (SW Quad, frontage Road, house #1440) | Eagan | 1 | E/W | | 88 |
| 32 | Fairway Hills Drive | Eagan | 1 | N | 18 | 88 |
| 38 | Gardenview Ave, North Side | Apple Valley | 2 | S | 18 | 92 |
| 38 | Gardenview Ave, South Side | Apple Valley | 2 | N | 6 | 92 |
| 38 | Havelock Trail | Apple Valley | 3 | N | 6 | 92 |
| 38 | Diamond Path | Apple Valley | 1 | N | 20 | 91 |
| 38 | Apple Valley, on McAndrews at Pilot Knob (NE Quad) | Apple Valley | 1 | W | | 91 |
| 38 | Apple Valley, on McAndrews at Pilot Knob (SE Quad) | Apple Valley | 1 | W | | 91 |
| 42 | East Side, Grove Street (Hastings) | Hastings | 1 | W | | 97 |
| 42 | West Side, Grove Street (Hastings) | Hastings | 1 | E | | 97 |
| 42 | Burnsville, Glendale Rd W ~~to Vernon Ave~~ (NW Quad) | Burnsville | 1 | S | 13 | 93 |
| 42 | Burnsville, Glendale Rd W ~~to Vernon Ave~~ (SW Quad) | Burnsville | 1 | N/W | Tier 1: 12<br>Tier 2: 16 | 93 |
| 46 | Church, Highview Ave. | Lakeville | 1 | N | 18 | 92 |
| 46 | Grove Trail | Lakeville | 1 | N | 18 | 92 |
| **HENNEPIN COUNTY** | | | | | | |
| 1 | 702' E of Sheridan Ave S | Bloomington | 1 | S | 12L | 93 |
| 5 | 343' E of Jidana Lane | Minnetonka | 1 | N | 9R | 94 |
| 6 | 825' E of CSAH 101 | Plymouth | 1 | S | 8L | 91 |
| 6 | 25' E of Garland Ln (W) | Plymouth | 1 | S | 10L | 91 |
| 6 | 481 E of Dunkirk Ln | Plymouth | 1 | S | 9L | 91 |
| 6 | 481 E of Dunkirk Ln | Plymouth | 1 | N | 10R | 91 |
| 6 | 52' E of Dunkirk Ln | Plymouth | 1 | S | 10R | 91 |
| 6 | 149' E of Yuma Ln | Plymouth | 1 | S | 10L | 91 |
| 6 | 530 E of Shenandoah Ln | Plymouth | 1 | S | 19L | 91 |
| 6 | 1103' E of Niagara Ln | Plymouth | 1 | S | 12L | 91 |
| 6 | 50' E of Juneau | Plymouth | 1 | S | 8L | 91 |
| 9 | SW Quad. Annapolis Ln | Plymouth | 1 | W | 11-20R | 96 |
| 9 | SE Quad. Annapolis Ln | Plymouth | 1 | E/S | 11R | 96 |
| 9 | SE Quad Gettysburg | New Hope | 1 | N/W | 8R/3R | 94 |
| 9 | 47' E of Flag Ave N | New Hope | 1 | N/W | 8R/3R | 94 |
| 9 | 430' E of Ensign Ave | New Hope | 1 | S | 8L | 94 |
| 9 | 40' E of Quebec Ave N | New Hope | 1 | N | 7R | 89 |
| 9 | 50' E of Quebec Ave N | New Hope | 1 | S | 7L | 89 |
| 9 | SW Quad. Oregon | New Hope | 1 | N | 7R | 89 |
| 9 | 278' E of Lake Rd | Robbinsdale | 1 | S | 7L | 92 |
| 10 | 275' E of I 494 On-Ramp | Maple Grove | 1 | S | 16L | 94 |
| 10 | 85' E of Jonquil Ln N | Plymouth | 1 | N | 10R | 94 |

*Number of general distress surveys performed at given wall location.

Table 3.1. SCBRWs included in the condition surveys (continued).

| Route No. | Location | City | No. Surveys* | Face Direction | F/C Offset (ft) | Year Built |
|---|---|---|---|---|---|---|
| **HENNEPIN COUNTY (CONTINUED)** | | | | | | |
| 10 | 300’ E of CSAH 61 (NE Quad) | Plymouth | 1 | S | 19L | 94 |
| 10 | 435’ E of CSAH 61 (SE Quad) | Plymouth | 1 | N | 16R | 94 |
| 10 | 656’ E of Deerwood Ln N (SE Quad) | Plymouth | 1 | N | 9R | 94 |
| 10 | 890’ E of Deerwood (NE Quad) | Plymouth | 2 | S | 16L | 94 |
| 10 | 500’ E of Trenton | Plymouth | 2 | S | 18L | 94 |
| 10 | 170’ E of Decatur Ave N | New Hope | 1 | S | 7L | 94 |
| 10 | SE Quad Boone Ave | New Hope | 1 | N/W | 9R | 93 |
| 10 | 31’ E of Sumter Ave N | New Hope | 1 | N | 8R | 93 |
| 12 | 747’ N of Noble Ave N | Champlin | 1 | E | 11L | 92 |
| 17 | 135’ N of W Fuller St | Edina | 1 | W | 6R | 89 |
| 17 | 423’ N of W 52nd St | Edina | 1 | E | 6L | 89 |
| 17 | 200’ N of W 49th St | Edina | 2 | E | 10L | 89 |
| 17 | 862’ N of W 37th St | St. Louis Park | 1 | E | 15L | 89 |
| 32 | 555’ N of Maple Ave S | Bloomington | 1 | W | 24R | 94 |
| 32 | 86’ N of W 78th St | Richfield | 1 | E | 9L | 94 |
| 34 | 881’ N of 102nd St | Bloomington | 1 | W | 10 | 91 |
| 35 | 495’ N of E 83rd St | Bloomington | 1 | E | 10L | 91 |
| 53 | At Queen NE Quadrant | Richfield | 1 | S | 7L7R | 87 |
| 61 | 138’ N of 42nd Pl N | Plymouth | 1 | E | 24R | 90 |
| 61 | At 46th Ave N | Plymouth | 1 | W | 21L | 92 |
| 61 | 200’ N of 54th Ave N | Plymouth | 1 | E | 29R | 90 |
| 61 | 25’ N of 66th Ave N | Maple Grove | 1 | E | 13R | 92 |
| 62 | 200’ E of CSAH 101 (SE Quad) | Eden Prairie | 1 | N | 13R | 96 |
| 62 | 200’ E of CSAH 101 (NE Quad) | Minnetonka | 1 | S | 12L | 96 |
| 62 | At Ellerdale Lane (North Side) | Minnetonka | 2 | S | T1: 16L<br>T2: 23L<br>T3: 30L<br>T4: 39L | 96 |
| 62 | E of Ellerdale Lane (South Side) | Eden Prairie | 1 | N | 16R | 96 |
| 70 | At Flag AveN | New Hope | 1 | S/W | 15L/4L | 92 |
| 70 | 130’ E of Decatur Ave N. | Golden Valley | 1 | N | 8L | 92 |
| 70 | 57’ E of Xylon Ave N | New Hope | 1 | S | 11L | 92 |
| 70 | 100’ E of Virginia Ave | New Hope | 1 | S | 9L | 92 |
| 70 | At NW Quad. Winnetka Ave N | New Hope | 1 | S | 8L | 92 |
| 70 | At Rhode Island Ave N | New Hope | 1 | S | 5L | 92 |
| 70 | 248’ E of Nevada Ave | New Hope | 1 | S | 8L | 92 |
| 70 | 29’ E of Louisiana Ave N | Crystal | 1 | S | 8L | 92 |
| 70 | 100’ E of Jersey | Crystal | 1 | S | 8L | 92 |
| 70 | 20’ E of Idaho Ave N | Crystal | 1 | S | 8L | 92 |
| 73 | At Oak Knoll Terrace N | Minnetonka | 1 | E | 1-4L | 89 |
| 101 | 130’ S of 24th Ave N | Plymouth | 3 | W | 12R | 92 |
| 101 | 90’ N of 82nd Ave N | Maple Grove | 1 | W | 27R | 93 |
| 101 | 90’ N of 82nd Pl N | Maple Grove | 1 | E | 27L | 93 |
| 101 | SE Quad. Weaver Lake Dr | Maple Grove | 1 | W | 6R | 94 |
| 101 | 100’ S of 87th Pl N | Maple Grove | 1 | E | 7L | 94 |
| 101 | 100’ S of 87th Pl N | Maple Grove | 1 | W | 12R | 94 |
| 156 | SW Quad. CSAH 70 | Golden Valley | 1 | E | 8L | 92 |

*Number of general distress surveys performed at given wall location.

Table 3.1. SCBRWs included in the condition surveys (continued).

| Route No. | Location | City | No. Surveys* | Face Direction | F/C Offset (ft) | Year Built |
|---|---|---|---|---|---|---|
| **HENNEPIN COUNTY (CONTINUED)** | | | | | | |
| 156 | 706’ N of CSAH 9 | New Hope | 1 | W | 13R | 94 |
| 156 | 894’ N of CSAH 9 (44th Ave.) | New Hope | 1 | W | 13R | 94 |
| 156 | 35’ N of 46th Ave N | New Hope | 1 | E | 13L | 94 |
| 156 | 208’ N of Angeline Dr | New Hope | 1 | W | 13R | 94 |
| **MN/DOT** | | | | | | |
| TH 55/100 | SW Frontage Road | Golden Valley | 1 | N | | 88 |
| I-394 | Ridgedale Entrance | Minnetonka | 2 | E | | 89 |
| I-394 | N Frontage Road @ Veterinary Clinic | Minnetonka | 2 | S | | 90 |
| I-35W/94 | NW of Ramp | Minneapolis | 1 | E | | 93? |
| I-94 | ~~Chicago/~~Western Ave. | St. Paul | 1 | N | | 91 |
| TH 9 | New London, Minnesota (Crow River) | New London | 2 | N/S | T1: 7<br>T2: 15 | 94 |
| I-90 | Hayward Rest Area | Hayward | 2 | N/S | | 92? |
| **PRIVATELY OWNED** | | | | | | |
| 31 | Extended Stay, NW Quad. Pilot Knob and Yankee Doodle | Eagan | 1 | N | | |
| 32 | RHS Building, SE Quad. 35E and Cliff Rd | Burnsville | 1 | S | | |
| | Shakopee Printing, Hwy 101 S of Valley Fair Entrance | Shakopee | 1 | N | | |
| | St. Hubert’s Church, Hwy 5 and SE quadrant Great Plains Rd | Chanhassen | 1 | W | | 98 |
| | Burnsville, corner of S. Cross and Burnhaven | Burnsville | 1 | W | | 89 |
| | Burnsville, behind K-Mart between Burnhaven and Irving | Burnsville | 1 | E/S | | 92 |
| | Burnsville, behind Rainbow foods, CR 42 and CR 5 | Burnsville | 1 | W | | 91 |

*Number of general distress surveys performed at given wall location.

### 3.2 Visual Condition Surveys

It was initially planned that the visual condition survey be conducted in the following three stages:

1. Stage 1 (General Distress Survey)
2. Stage 2 (Detailed Distress Survey)
3. Stage 3 (Peak Winter Survey)

A detailed description of these surveys is described in sections 3.2.1 – 3.2.3. The objective of stage 1 was to determine the number of affected walls and obtain a rapid assessment of the extent of damage present. The objective of stage 2 was to perform a detailed visual distress survey on a reduced subset of walls surveyed from stage 1. Stage 2 was omitted from the study because the survey performed under stage 1 was much more detailed than originally planned. Thus, it was believed that stage 1 would sufficiently assess the extent of deterioration present and meet the previously described research objectives. Stage 3 was conducted for the purpose of determining exposure to accumulated snow and ice, as well as obtaining a qualitative assessment of the intensity of incident sunlight during the peak of winter.

### 3.2.1 Stage 1 (General Distress Survey)

The general distress survey was conducted for the purpose of determining the type, severity level and percentage of wall affected with each distress outlined in the distress identification manual as described in section 3.3 "Distress Identification Manual." The following information was collected during each survey:

- Project Identification – Location of survey wall
- Date/Time
- Weather Conditions
- Survey Team Initials
- Overall SCBRW Rating – An overall subjective SCBRW rating based on the following rating scale was determined prior to performing the general distress identification survey:
    - 0 – 1 Very Poor
    - 1 – 2 Poor
    - 2 – 3 Fair
    - 3 – 4 Good
    - 4 – 5 Very Good

  These ratings were collected to give an indication of the general overall condition of the SCBRWs surveyed.
- SCBRW Plan View Map – A sketch of the plan view of the wall to be surveyed with respect to locations of nearby roadways and any other relevant features (e.g., drainage, parking lots, tree coverage, etc.). A sketch of the north arrow with respect to the wall vertical surface is also included in this map.

- SCBRW Profile Map – A sketch of the profile of the wall to be surveyed. This sketch includes estimated wall heights at various locations along the wall.
- Distress Identification – Each wall was examined for the 19 distress types described in the *Distress Identification Manual.* The severity level of each distress type (i.e., low-, medium-, or high-severity level), along with the percentage of the SCBRW affected by each distress severity level (i.e., none, less than 1, 1-10, 10-25, 25-50, 50-75, 75-100 percent) was determined.
- Block Manufacturer – Physical inspection of individual masonry block units to identify the block manufacturer.
- Comments – Comments describing any relevant features present, noticeable distress location trends, etc.

Appendix D presents the general distress survey data collection form followed for the stage 1 surveys. Survey documentation also included photographs of the overall wall and any visible damage present. Personnel with the Office of Bridges and Structures of the Mn/DOT and the University of Minnesota have archived these photographs.

The number of surveys performed at each SCBRW location depended on the number of tiers or separate walls at the given location, and the type and severity of distresses present on each wall/tier. Only one distress condition survey was performed when each wall/tier had similar distress types and severity levels present. However, for cases where this did not hold true, separate surveys were performed on each tier/wall with differing distress type and severity levels. For example, one wall (Hennepin county, CSAH 101 and 130 ft south of 24$^{th}$ Ave.) had to be split into three surveys. At this location, two walls were constructed and three condition surveys had to be completed (one survey for the northern wall and two surveys for the southern wall). The northern portion of the southern wall had a significantly different distress condition than the southern portion (see figures 3.1 – 3.4). The average subjective ratings assessed for the northern and southern portion of this wall were 0.65 (“Very Poor”) and 3.85 (“Good”), respectively. In general, it appears that the southern portion of the wall is at the initial stages of durability problems (e.g., the presence of low-severity freeze-thaw damage, as exhibited in figure 3.4), while the northern portion has reached the later stages of durability failure (e.g., the presence of high-severity scaling as exhibited in figure 3.2).

Figure 3.1. Overall photo of northern portion of south wall (CSAH 101 and 24th Ave.).

Figure 3.2. Close-up photo of northern portion of south wall (CSAH 101 and 24th Ave.).

Figure 3.3. Overall photo of southern portion of south wall (CSAH 101 and 24th Ave.).

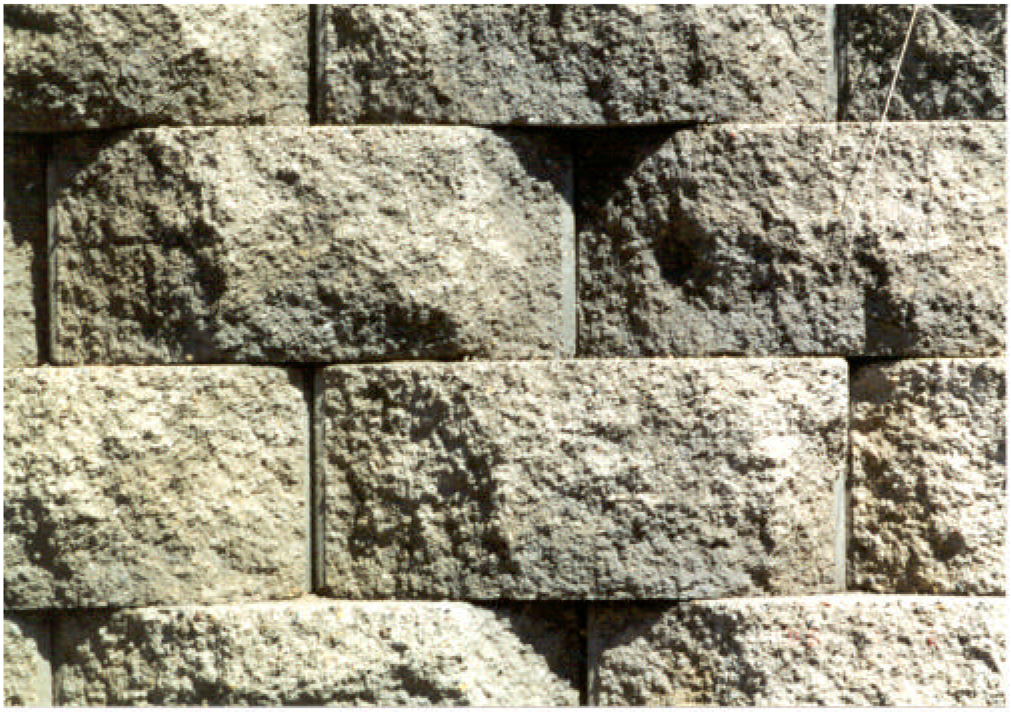


Figure 3.4. Close-up photo of southern portion of south wall (CSAH 101 and 24th Ave.).

3.2.2 Stage 2 (Detailed Distress Survey)

As mentioned previously, the detailed distress survey was excluded from the study because the stage 1 distress survey was much more detailed than was originally planned and actually represented a combining of the stage 1 and stage 2 surveys that were originally planned. The objective of this task was to conduct a detailed condition assessment of a subset of walls surveyed during stage 1. Walls exhibiting the greatest extent of damage, as well as walls that are deemed to have performed well, were to be selected to make up this subset of walls. The principal goal of this stage was to quantify more precisely the severity of damage, including the length and width of cracks, and the depth and area of the spalled or disintegrated regions. Additional photographs of localized damage would serve to document the survey.

Distress maps were to be used to show the exact location of each distress type existing on the SCBRW. The distress types, severity levels and measurement procedures used to quantify these distress types and severity levels (e.g., number of occurrences, percentage of block units, area) were to be identified by using the *Distress Identification Manual.* The preliminary data collection form for the detailed distress surveys is presented in appendix D.

3.2.3 Stage 3 (Peak Winter Survey)

The objective of the stage 3 survey was to determine whether there are any correlations between observed severity of damage and wall exposure to accumulated snow and ice and incident sunlight during the peak of winter. The following information was collected during this survey:

- Project Identification – Location of survey wall.
- Date/Time
- Weather Conditions
- Survey Team Initials
- SCBRW Plan View Map – A sketch of the plan view of the wall to be surveyed with respect to locations of nearby roadways and any other relevant features (e.g., drainage, parking lots, tree coverage, location of snow removal pile(s), location(s) of peak-day sunlight, etc.). A sketch of the north arrow with respect to the wall vertical surface is also included in this map.
- Type of Snow Removal – The type of snow removal used in the vicinity of the wall (e.g., mainline pavement or sidewalk snow removal).
- Snow Accumulation (Top Block Layer) – The type of snow accumulation on the top block layer (e.g., snow removal, falling snow).
- Snow Accumulation (Vertical Surfaces) – The type of snow accumulation on the vertical surfaces (e.g., snow removal, falling snow).
- Location of Snow Accumulation / Piles – Comments indicating the location of snow removal piles or packed snow against vertical surfaces due to snow removal.
- Fencing – Location and type of fence adjacent to wall, if any. The type and location of fencing affects the amount of snow accumulation on the top block layer.
- Peak Daytime Sunlight Exposure (Top Block Layer) – The percentage of the top block layer exposed to peak-day sunlight during the winter months (i.e., none, less than 1, 1-10, 10-25, 25-50, 50-70, 70-80, 80-90, 90-100, 100 percent). The amount of sunlight exposure affects the number of freezing and thawing cycles to which the masonry block units are subjected.
- Peak Daytime Sunlight Exposure (Vertical Surfaces) – The percentage of the vertical surface layer exposed to peak-day sunlight during the winter months (i.e., none, less than 1, 1-10, 10-25, 25-50, 50-70, 70-80, 80-90, 90-100, 100 percent). The amount of sunlight exposure

affects the number of freezing and thawing cycles to which the masonry block units are subjected.

- Snow Accumulation Containing Deicing Sand/Salt (Top Block Layer) – The percentage of wall length where snow containing deicing sand/salt accumulates on top of the wall (i.e., none, less than 1, 1-10, 10-25, 25-50, 50-70, 70-80, 80-90, 90-100, 100 percent). Additionally, the quantity of deicing sand/salt present in the snow accumulation was visually rated as low, medium and high.
- Snow Accumulation Containing Deicing Sand/Salt (Vertical Surfaces) – The percentage of wall length where snow containing deicing sand/salt accumulates along the vertical face (i.e., none, less than 1, 1-10, 10-25, 25-50, 50-70, 70-80, 80-90, 90-100, 100 percent). Additionally, the quantity of deicing sand/salt present in the snow accumulation was visually rated as low, medium and high.

Photographs taken during the snow survey served as additional documentation of the peak winter conditions. Appendix D presents the data collection form followed during this survey.

### 3.3 Distress Identification Manual

A *Distress Identification Manual* was developed to outline the survey parameters, thereby allowing uniform collection of data between each SCBRW survey. This manual outlines the listed distresses in a format similar to that developed by the Strategic Highway Research Program (SHRP) for pavements (SHRP-P-338, 1993). The following distress types were identified for inclusion into this manual:

1. Construction Defects
2. Corner Breaks
3. Cracked Block
4. Efflorescence
5. Embedded Vegetative Growth
6. Erosion
7. Fraying/Spalling (Block Edges)
8. Freeze-Thaw Damage (Top Block Layer)
9. Freeze-Thaw Damage (Vertical Surfaces)
10. Manufacturing Flaws
11. Miscellaneous Distress/Flaws
12. Open Joints
13. Popouts (Top Block Layer)
14. Position Guide Damage
15. Scaling (Top Block Layer)
16. Scaling (Vertical Surfaces)

17. Staining (External Source)
18. Staining (Internal Source)
19. Structural Distress
20. Wash-Through

The manual was divided according to the distress type. A short description was included for each distress type along with definitions of the severity levels (i.e., low, medium, and high severity) and a method for measuring of the distress type. Photographs were also included as references to illustrate the distress types described. The *Distress Identification Manual* developed for use when surveying SCBRWs is presented in appendix E.

### 3.4 Global Positioning System (GPS)

A global positioning system (GPS) receiver was used to collect the latitudinal (angular distance north or south of the equator) and longitudinal (angular distance east or west of the Prime Meridian) coordinates of each wall. These coordinates were collected in degrees, minutes and seconds by the GPS system.

SCBRW coordinates were then imported into ArcView in order to generate maps illustrating the locations of each wall surveyed. ArcView would not accept the latitude/longitude coordinates using the MnCon (Minnesota Coordinate System) program. Figure 3.5 illustrates the locations of the surveyed SCBRWs in Minnesota. Figures 3.6 and 3.7 present close-up views of the SCBRWs surveyed in Dakota and Hennepin counties of Minnesota, respectively.

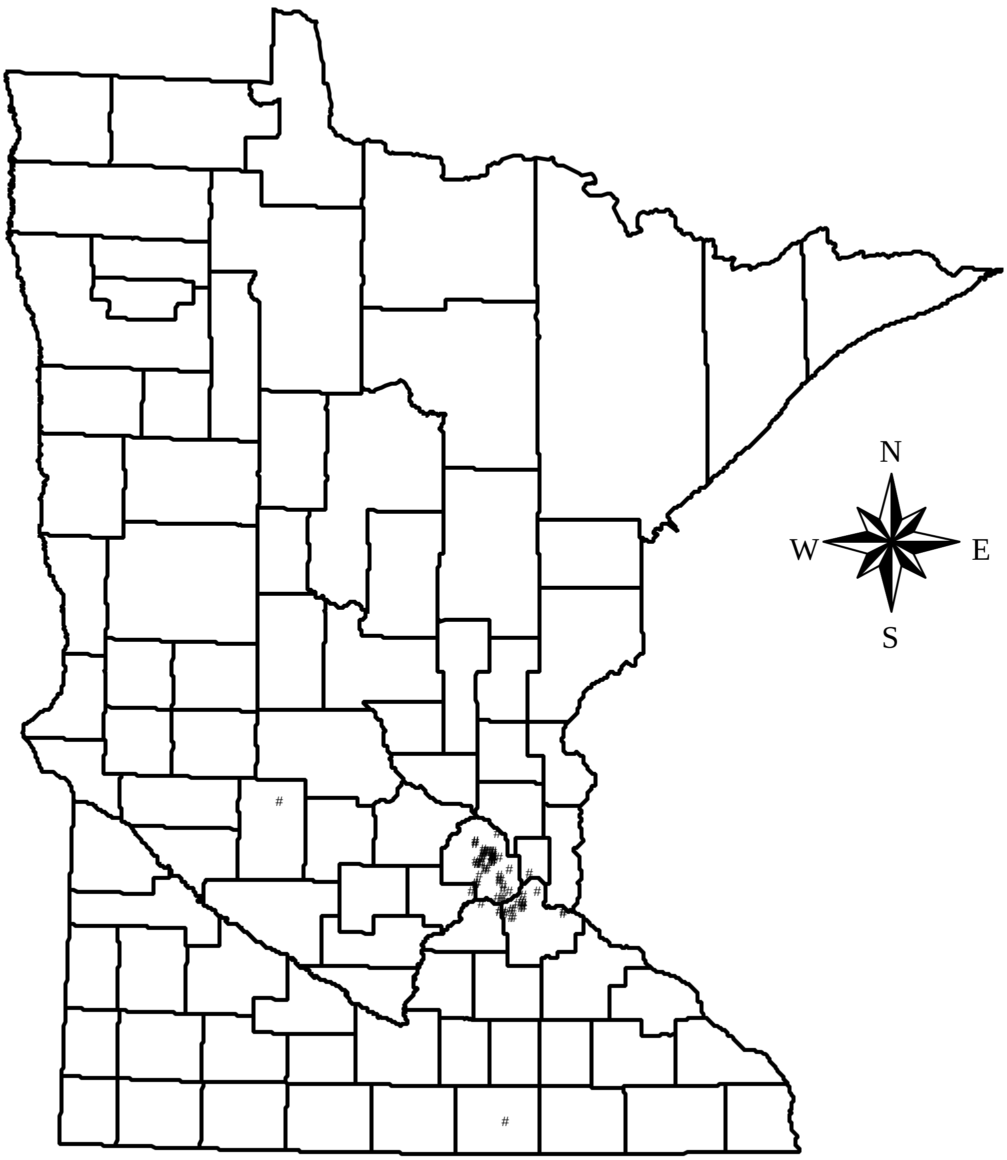



Figure 3.5.  Minnesota map showing surveyed SCBRW locations.

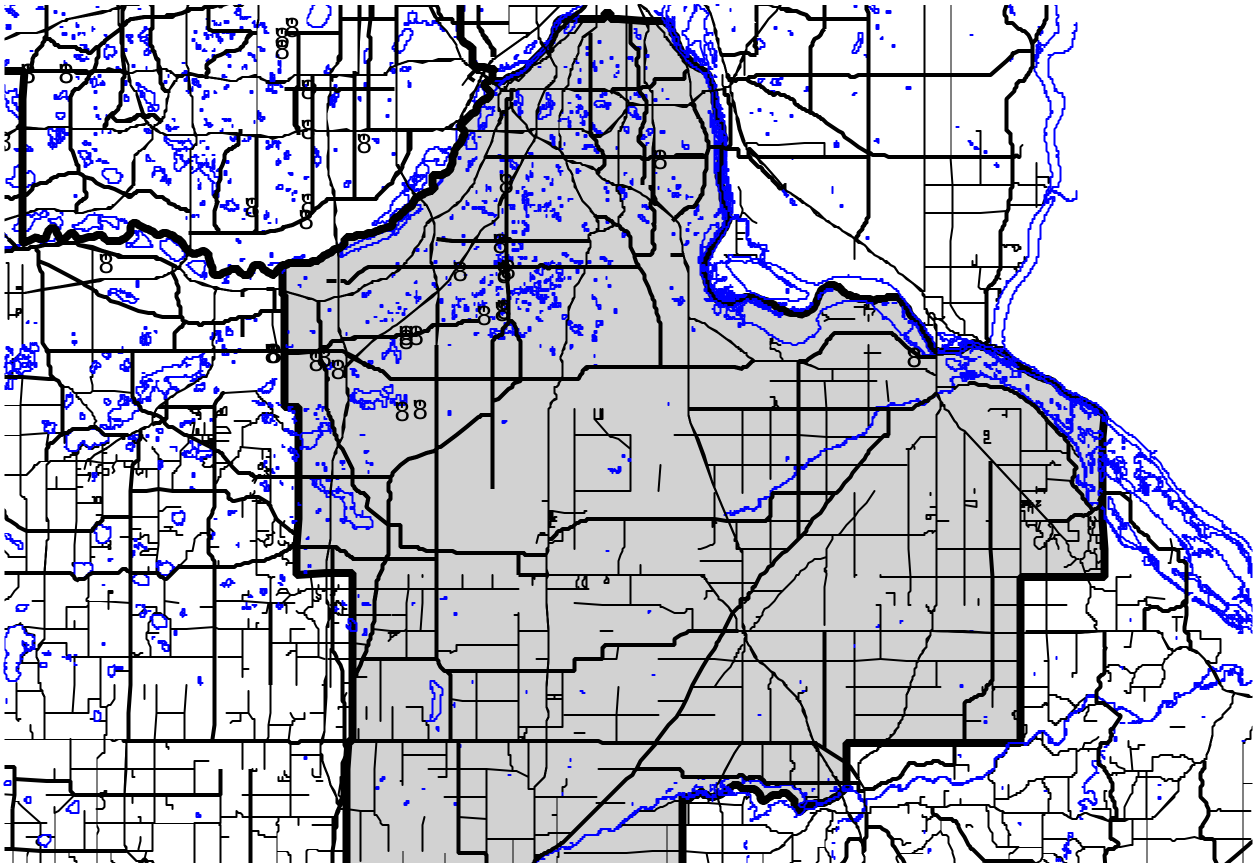


Figure 3.6. Dakota county map showing surveyed SCBRW locations (Dakota county in grey).

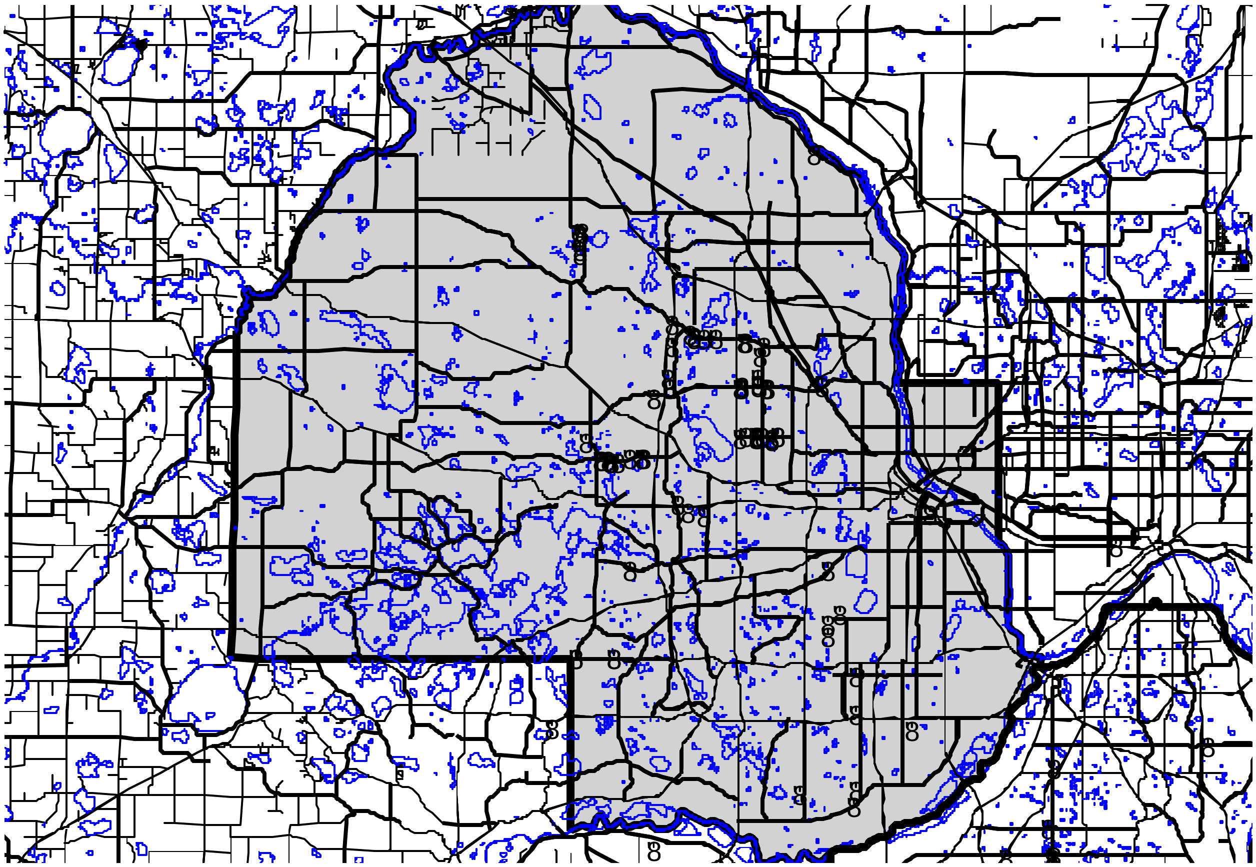


Figure 3.7. Hennepin county map showing surveyed SCBRW locations (Hennepin county in grey).

# CHAPTER 4
# RESULTS AND ANALYSIS

## 4.1 Subjective Survey Results

### 4.1.1 Subjective SCBRW Condition Ratings

As previously described, an overall subjective SCBRW condition rating was determined prior to performing the general distress identification survey. These ratings used a rating scale of 0 – 5 (i.e., 0 – 1 [very poor], 1 – 2 [poor], 3 – 4 [fair], 4 – 5 [very good]). Tables F-1, F-10, F-19 and F-28 (see appendix F) present the subjective ratings given to each SCBRW surveyed for Dakota county, Hennepin county, Mn/DOT and privately owned walls, respectively.

Figure 4.1 presents the distribution of overall subjective SCBRW ratings. These data were determined by normalizing the individual ratings assessed for each wall by the total number of walls surveyed. As illustrated in the graph, 44 percent of the walls surveyed appeared to be in "very good" condition from the survey team's point of view, while 36 percent were subjectively rated as in "good" condition. Therefore, 80 percent of the walls surveyed were in good to very good condition. The survey team subjectively rated 13, 5 and 2 percent of the total SCBRWs as "fair," "poor" and "very poor," respectively. Therefore, it was observed that the majority of the SCBRWs included in the distress condition surveys are in favorable condition.

Figure 4.2 presents the distribution of subjective ratings with respect to the age or construction date of the surveyed SCBRWs, broken down as follows:

- 1987-1989 (11-13 years old)
- 1990-1994 (6-10 years old)
- 1995-2000 (5 years old or less)

The SCBRW ratings for walls in which no construction year was available were excluded from this figure.

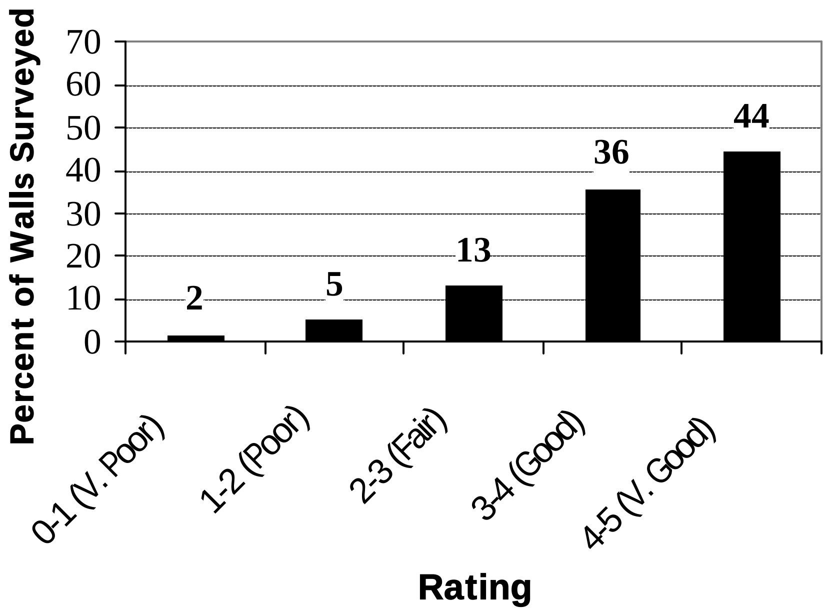



Figure 4.1. Overall subjective SCBRW ratings.

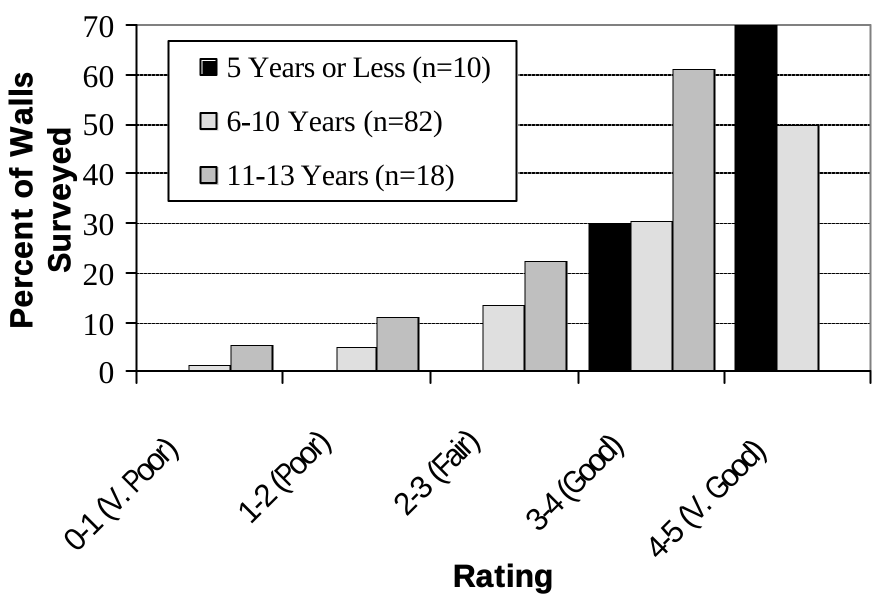



Figure 4.2. Overall subjective SCBRW ratings for various wall ages.

As illustrated in the graph, it appears that the number of SCBRWs rated “good” to “very good” decreases with age; conversely, the number of SCBRWs rated “fair” to “very poor” increases with age. The surveyed SCBRWs 5 years or less in age are all in good to very good condition

(30 percent good and 70 percent very good). After 6-10 and 11-13 years of age, the percentage of SCBRWs in very good condition decreases to 50 and 0 percent, respectively. The percentage of SCBRWs in good condition remains approximately the same (at 31 percent) after 6-10 years and was 61 percent for 11-13 year old surveyed SCBRWs. The remaining 19 percent of 6-10 year old and 39 percent of 11-13 year old SCBRWs were subjectively rated from fair to very poor.

Figures 4.3 – 4.6 graphically present the distribution of subjective ratings for Dakota county, Hennepin county, Mn/DOT and privately owned SCBRWs, respectively. It appears that 100, 92, 90 and 85 percent of the SCBRWs surveyed were in "fair" to "very good" condition for Dakota county, Hennepin county, Mn/DOT and privately owned walls, respectively. In general, the SCBRWs appear to be in favorable condition. The differences in the percentage of walls in "fair" to "very good" condition could be attributed to different construction/maintenance practices, proximity of wall to roadway, age of wall, or block types used. These effects are examined in later sections of this report.

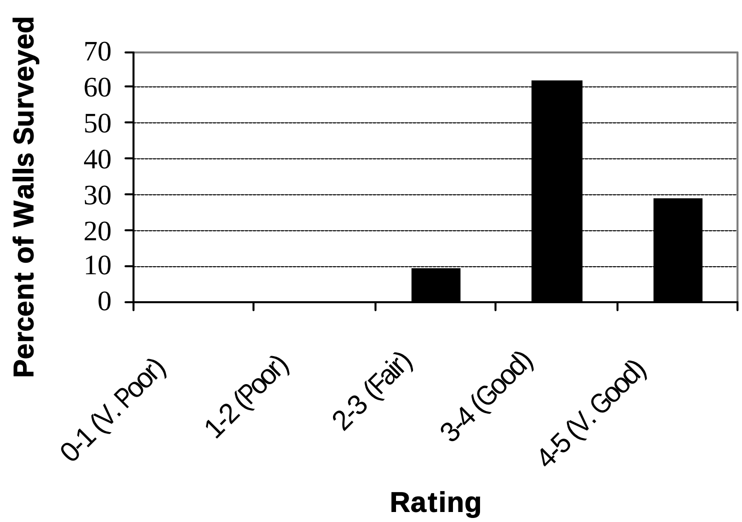



Figure 4.3. Subjective SCBRW ratings for Dakota county.

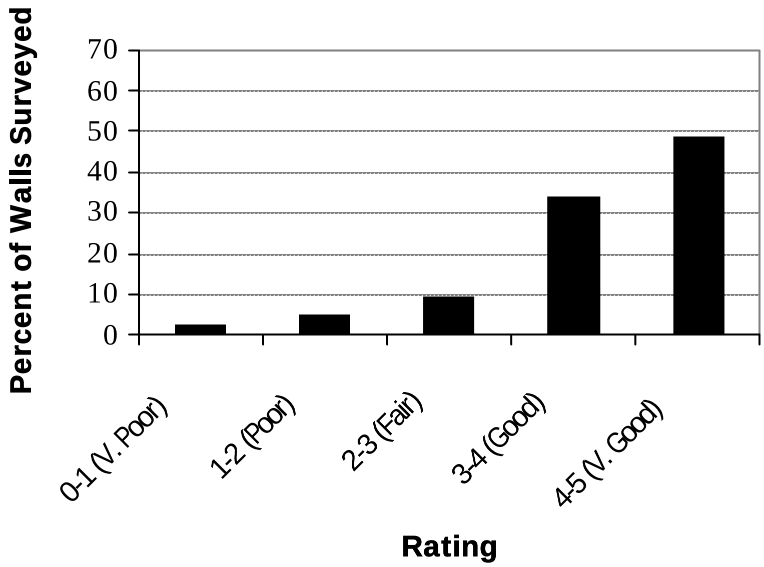



Figure 4.4. Subjective SCBRW ratings for Hennepin county.

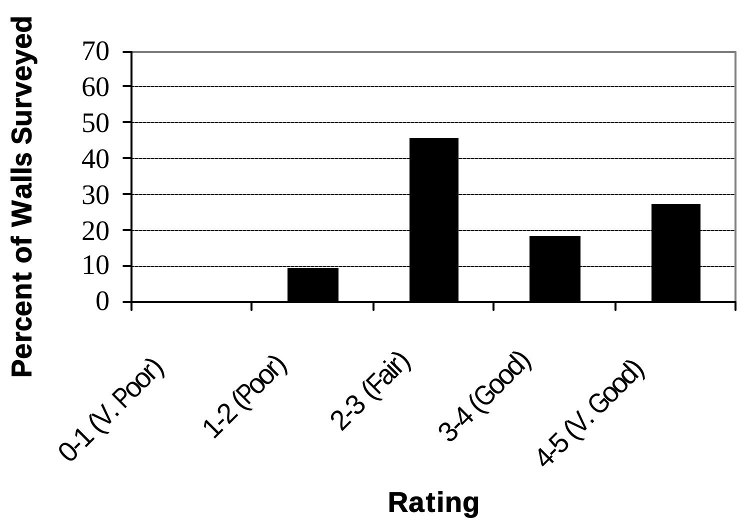



Figure 4.5. Subjective SCBRW ratings for Mn/DOT walls.

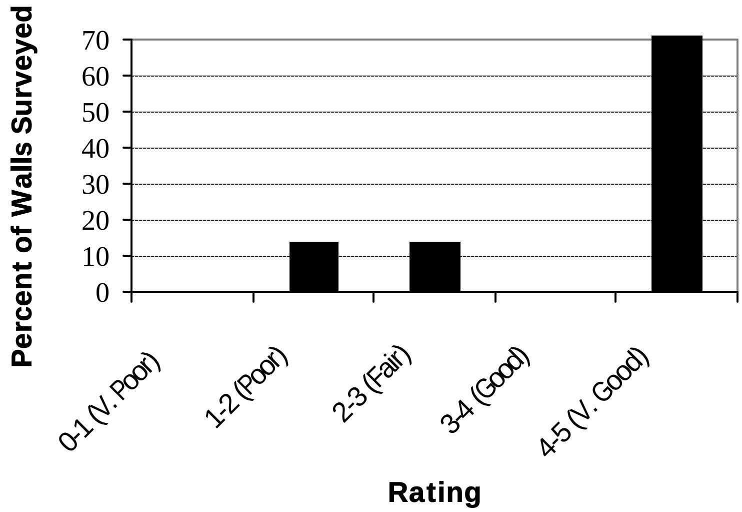



Figure 4.6. Subjective SCBRW ratings for privately owned walls.

4.1.2 Cases Representing SCBRW Ratings

The following subsections give photo illustrations of a SCBRW presenting each of these rating levels. In general, the distress types that most greatly affected the overall subjective condition ratings were durability related problems. As expected, as the percentages of high-severity freeze-thaw damage and/or scaling present increased, the overall condition rating of the SCBRW decreased.

It should be noted that in the following subsections, the sum of low-, medium- and high-severity distress level quantities may add to more than 100 percent because of measurement rules in the *Distress Identification Manual* (see appendix E).

*4.1.2.1 Very Poor*

The SCBRW located at the intersection of CSAH 9 and Oregon, in Hennepin County, Minnesota is a good illustration of a wall subjectively rated as "Very Poor". An average subjective rating of 0.85 was assessed for this SCBRW. Figures 4.7 – 4.9 illustrate photos of the typical snow coverage during the peak winter period. As illustrated, there are three types of snow removal near this wall: main-line, side-walk and parking lot snow removal. Therefore, the snow accumulation on the top block layer and vertical surfaces for this SCBRW as due to these three types of snow removal, along with "free" falling snow.  The quantity of deicing sand/salt present in the snow was visually identified as high.

Figure 4.7.  Photo of snow accumulation on SCBRW subjectively rated as "very poor".

Figure 4.8. Photo of snow accumulation on curved segment of SCBRW subjectively rated as "very poor".


Figure 4.9. Overall photo of snow accumulation on SCBRW subjectively rated as "very poor".

Figure 4.10 is a photo illustrating the overall wall condition during the general distress survey. High-severity scaling is readily apparent in this picture along the wall when looking at both the capstone, vertical surfaces and the debris (i.e., scaled material) resting on the sidewalk adjacent to the SCBRW. Figure 4.11 illustrates a close-up photo of the freeze-thaw deterioration present on the masonry block units used in this SCBRW.

As presented in tables F-15 and F-16 (see appendix F), 0, 1-10 and 75-100 percent of the SCBRW was observed with low-, medium- and high-severity scaling of the capstone and vertical surfaces, respectively. Additionally, less than 1, 75-100 and 25-50 percent of the SCBRW capstone was observed with low-, medium- and high-severity freeze-thaw damage, respectively, while 75-100, 0 and 75-100 percent of the SCBRW vertical surfaces exhibited low-, medium- and high-severity freeze-thaw damage (see table F-13 of appendix F).

Figure 4.10. Overall photo of SCBRW subjectively rated as “very poor”.

Figure 4.11. Close-up photo of high-severity scaling on SCBRW subjectively rated as "very poor".

*4.1.2.2 Poor*

The SCBRW located at the intersection of South Cross and Burnhaven, in Dakota County, Minnesota is a good example of a wall subjectively rated as "Poor". An average condition rating of 1.95 was assessed for this SCBRW. Figures 4.12 and 4.13 are photos of the typical snow coverage during the peak winter period and show that there are three types of snow removal near this wall: main-line, side-walk and parking lot snow removal. In general, it appears that the majority of the snow accumulation on the top block layer and vertical surfaces for this SCBRW was due to the parking lot snow removal located behind the SCBRW. The quantity of deicing sand/salt present in the snow was visually observed as "medium".

Figures 4.14 – 4.16 are photos showing regions of the wall exhibiting the greatest amount of distress. High-severity scaling is readily apparent in figure 4.15. This location is the same location shown in figure 4.13, where the largest amount of parking lot snow removal accumulation resided. Figure 4.16 shows both high-severity scaling and high-severity freeze-thaw damage. As discussed earlier, both of these distress types are due to poor freeze-thaw durability, but can be differentiated by the different distress type names/descriptions (i.e., high-severity scaling is the significant loss of concrete [aggregate and mortar], where high-severity freeze-thaw damage is exhibited when the affected area are exhibiting open cracks).

As presented in tables F-33 and F-34 (see appendix F), 75-100, less than 1 and 1-10 percent of the SCBRW was observed with low-, medium- and high-severity scaling of the capstone, respectively. Low-, medium- and high-severity scaling of the vertical surfaces was observed for 75-100, 1-10 and 25-50 percent of the SCBRW. Additionally, 50-75, 0 and 0 percent of the SCBRW capstone was found to exhibit low-, medium- and high-severity freeze-thaw damage, respectively; while 75-100, 10-25 and 1-10 percent of the SCBRW vertical surfaces exhibited low-, medium- and high-severity freeze-thaw damage (see table F-31 of appendix F).

Figure 4.12. Overall photo of snow accumulation on SCBRW subjectively rated as “poor”.


Figure 4.13. Close-up photo of snow accumulation from parking lot snow removal on SCBRW subjectively rated as “poor”.

Figure 4.14. General photo of SCBRW subjectively rated as “poor”.

Figure 4.15. Close-up photo of high-severity scaling on SCBRW subjectively rated as “poor”.

Figure 4.16. Close-up photo of high-severity scaling and high-severity freeze-thaw damage on SCBRW subjectively rated as “poor”.

*4.1.2.3 Fair*

The SCBRW located at the intersection of CSAH 38 and Gardenview (south wall, tier 1), in Dakota County, Minnesota is a good example of a wall subjectively rated as “Fair”. An average condition rating of 2.65 was given to this SCBRW. Figures 4.17 and 4.18 are photos of the typical snow coverage during the peak winter period, and show that there is only one type of snow removal near this wall (i.e., main-line snow removal). The quantity of deicing sand/salt present in the snow was visually identified as “high”.


Figure 4.17. Photo illustrating high quantity of deicing sand/salt in snow accumulation.

Figure 4.18. Overall photo of snow accumulation on SCBRW subjectively rated as “fair”.

Figure 4.19 is photo illustrating the general condition of the masonry block units used in this SCBRW. Figures 4.20 and 4.21 are photos illustrating regions of the wall exhibiting the greatest amount of distress. Low-severity freeze-thaw damage on the lower portions of the masonry block units and behind the position guides is readily apparent in figure 4.19. Figures 4.20 and 4.21 both show distresses due to poor freeze-thaw durability. High-severity position guide damage (high-severity freeze-thaw damage) is exhibited in figure 4.20. In addition, the sand used to spread the deicing salts can be seen behind all of the position guides. As stated earlier, the presence of the deicing chemicals increases the saturation of the block units (or the position guides for this case). Most likely, the presence of these chemicals and the ability of water to sit behind the position guides exacerbated the potential for freeze-thaw durability problems. Low-severity freeze-thaw damage can also be seen on the lower portions of the block units in this figure. High-severity scaling is readily apparent in figure 4.21. This photo illustrates the complete scaling of the position guides (the guides have completely scaled away) and severe scaling of the block unit vertical surfaces.

Figure 4.19. Photo of general condition of masonry blocks used in SCBRW subjectively rated as "fair".

Figure 4.20. Close-up photo of high-severity position guide damage (high-severity freeze-thaw damage) on SCBRW subjectively rated as "fair".

Figure 4.21. Close-up photo of high-severity scaling on SCBRW subjectively rated as “fair.”

As presented in tables F-6 and F-7 (see appendix F), 75-100, 0 and 10-25 percent of the SCBRW exhibited low-, medium- and high-severity scaling of the top block layer, respectively. Low-, medium- and high-severity scaling of the vertical surfaces was observed for 0, 0 and less than 1 percent of the SCBRW. Additionally, 25-50, 1-10 and 50-75 percent of the SCBRW capstone exhibited low-, medium- and high-severity freeze-thaw damage, respectively; while 75-100, 10-25 and 75-100 percent of the SCBRW vertical surfaces were observed with low-, medium- and high-severity freeze-thaw damage (see table F-4 of appendix F). Low-, medium- and high-severity position guide damage was observed over 10-25, 25-50 and 25-50 percent of the SCBRW.

*4.1.2.4 Good*

The SCBRW located at the intersection of CSAH 156 and 46th Ave., in Hennepin County, Minnesota is a good example of a wall subjectively rated as “Good”. An average condition rating of 3.5 was given to this SCBRW. Figures 4.22, 4.23 and 4.24 are photos of the typical snow coverage during the peak winter period, and show that there are three types of snow removal near this wall: main-line, side-walk and driveway snow removal. The quantity of deicing sand/salt present in the snow was visually observed as “medium”.

Figure 4.22. Overall photo of snow accumulation on southern SCBRW subjectively rated as “good”.

Figure 4.23. Photo of snow accumulation on portion of SCBRW located in driveway subjectively rated as “good”.

Figure 4.24. Overall photo of snow accumulation of northern SCBRWs subjectively rated as "good".

Figures 4.25 and 4.26 are photos presenting an overall view of the SCBRWs at this location. Figures 4.27 and 4.28 are photos that document the general good condition of the masonry block units used in this SCBRW. There is, however, some low-severity freeze-thaw damage present on the lower portions of the masonry block units, as shown in the figures.

As presented in tables F-15 and F-16 (see appendix F), 75-100, less than 1 and 1 percent of the SCBRW exhibitied low-, medium- and high-severity scaling, respectively, of the top block layer. Low-, medium- and high-severity scaling of the vertical surfaces was observed for 75-100, 1 and 0 percent, respectively, of the SCBRW. Additionally, 75-100, 0 and 0 percent of the SCBRW capstone exhibited low-, medium- and high-severity freeze-thaw damage, respectively, while 10-25, 0 and 0 percent of the SCBRW vertical surfaces exhibited low-, medium- and high-severity freeze-thaw damage (see table F-13 of appendix F).

Figure 4.25. Overall condition photo of SCBRWs subjectively rated as “good”.

Figure 4.26. Overall condition photo of SCBRW located in driveway subjectively rated as “good”.

Figure 4.27. Photo of general condition and low-severity freeze-thaw damage of masonry units used in SCBRW subjectively rated as “good”.

Figure 4.28. Photo of low-severity freeze-thaw damage on SCBRW subjectively rated as “good”.

#### *4.1.2.5 Very Good*

The SCBRW located at the intersection of CSAH 10 and Trenton (tiers 1 and 2), in Hennepin County, Minnesota is a good example of a wall subjectively rated as “Very Good”. An average condition rating of 4.8 was given to this SCBRW. Figure 4.29 presents a photo of the typical snow coverage during the peak winter period, and shows that there is no snow removal that affects snow accumulation on this SCBRW. Therefore, the snow accumulation on the top block layer and vertical surfaces for this SCBRW was solely due to free-falling snow. The figure does show that there is sidewalk snow removal near the SCBRW (as illustrated in the lower-right portion of the photo); however, it appears that there are no deicing chemicals in this snow to affect the saturation rate of the masonry block units.

Figure 4.29. Photo of snow accumulation of SCBRW subjectively rated as “very good”.

Figures 4.30 and 4.31 are photos illustrating an overall distress condition view of the SCBRW tiers at this location. It is apparent in the photos that the capstone on both tiers has been replaced recently. This replacement was probably necessitated by severe degradation of the original capstone units. Figure 4.32 presents a photo exhibiting the general condition of the masonry block units used in this SCBRW, and shows that these block units are in very good condition and are exhibiting only some minor external staining at the joints.

As presented in tables F-15 and F-16 (see appendix F), 75-100, 0 and 0 percent of tiers 1 and 2 exhibited low-, medium- and high-severity scaling, respectively, of the top block layer. Low-severity scaling of the vertical surfaces was observed for 1-10 and 0 percent of tiers 1 and 2, respectively. Medium- and high-severity scaling of the vertical surfaces was observed for 0 percent of tiers 1 and 2. Additionally, 0 percent of tiers 1 and 2 capstone exhibited low-, medium- and high-severity freeze-thaw damage, while 10-25, 0 and 0 percent of tier 1 vertical surfaces exhibited low-, medium- and high-severity freeze-thaw damage and 1-10, 0, and 0 percent of tier 2 vertical surfaces exhibited low-, medium- and high-severity freeze-thaw damage (see table F-13 of appendix F).

Figure 4.30. Overall condition photo of SCBRW subjectively rated as “very good”.

Figure 4.31. Overall condition photo of SCBRW subjectively rated as “very good”.

Figure 4.32. Close-up photo of general condition of masonry units used in SCBRW subjectively rated as “very good”.

4.1.3 General Comments

The following section lists key observations that were noted when performing both the general distress and peak winter surveys. Additional comments from the general distress surveys can be found in tables F-9, F-18, F-27 and F-36 (of appendix F) for Dakota county, Hennepin county, Mn/DOT and privately owned SCBRWs, respectively. Furthermore, supplementary comments from the winter snow surveys can be found in tables H-3, H-6, H-9 and H-12 for Dakota county, Hennepin county, Mn/DOT and privately owned SCBRWs, respectively.

#### *4.1.3.1 Freeze-Thaw Deterioration*

<u>Parking Lots</u>

There is a greater amount and higher severity of freeze-thaw damage observed in locations subjected to large amounts of snow accumulation containing high quantities of deicing agents. This was especially evident for walls located adjacent to parking lots where snow is often pushed into piles above the wall top block layer. In these cases, large amounts of snow were retained on the capstone units, while the remainder would fall over the wall and accumulate against the vertical surfaces of the blocks. These locations were often associated with large amounts of scaling and other freeze-thaw deterioration.

Figures 4.13 and 4.15 present photos taken at the same location and show snow accumulation due to parking lot snow removal and the resulting high-severity scaling observed on the wall. Another example of this observation is illustrated in figures 4.17 and 4.21, which present photos of snow accumulation containing a high quantity of deicing sand/salt and a close-up photo of the associated high-severity scaling (both photos were taken at the same location).

<u>Offset Distances</u>

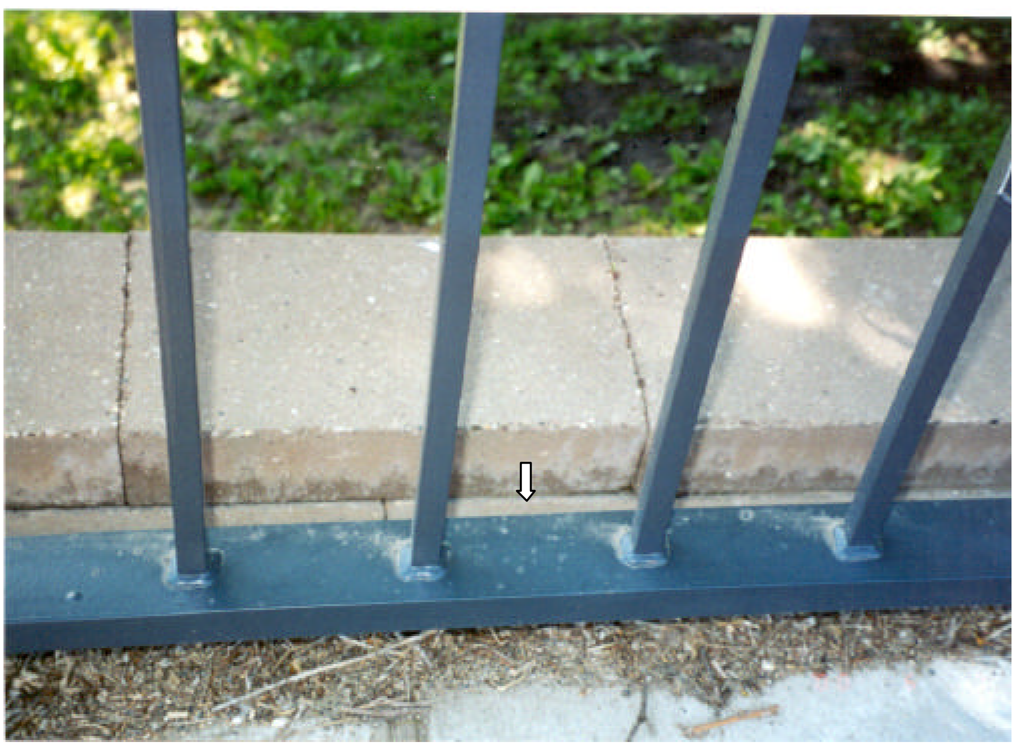
The F/C (face-to-curb) distance also appeared to have an effect on the severity or presence of freeze-thaw deterioration. In general, walls constructed at greater distances from the road had less freeze-thaw damage than those immediately adjacent to the mainline and subjected to greater amounts of snow accumulation and deicing chemicals. Figures 4.29 and 4.32 (photos of a wall rated as very good) and figures 4.17 and 4.20 (photos of a wall rated as fair) illustrate wall locations with F/C distances of 18 ft and 6 ft, respectively. Additionally, figure 4.33 presents a photo showing high-severity scaling of capstone units located at a F/C distance of 8 ft and at a region with a large amount of ground water runoff from behind the wall (the wall was subjectively rated as poor).

Figure 4.33. Photo illustrating high-severity freeze-thaw damage (top block layer) for wall with F/C distance of 8 ft.

Water Runoff

Freeze-thaw deterioration was frequently observed in locations of high moisture accumulation or water runoff. The exposed backs of a large amount of block units (a location susceptible to a immense amount of moisture) exhibited freeze-thaw deterioration in the form of cracking (see figures 4.34). Conversely, figure 4.35 demonstrates the reduced presence of freeze-thaw deterioration in locations of decreased water accumulation. The portion of the wall located at the bottom of the hill (where water accumulates) was presented in figure 4.33. As stated previously, the capstone units on this section exhibited high-severity scaling.

a. Medium-Severity Freeze-Thaw Damage (Top Block Layer).



b. Low- and Medium-Severity Freeze-Thaw Damage (Top Block Layer).

Figure 4.34. Photos (a and b) illustrating medium-severity freeze-thaw damage in a location of high water runoff.

Figure 4.35. Photo illustrating reduced freeze-thaw deterioration at a location of minimal water runoff.

In addition to the above photos, figure 4.36 does an excellent job of depicting the accelerated freeze-thaw deterioration that can occur from water runoff containing deicing chemicals. This water runoff originates from a pedestrian bridge, which is heavily salted in the winter, located above the wall. As previously stated, salt-saturated water is more readily absorbed into concrete resulting in higher levels of saturation which can accelerate freeze-thaw deterioration (the crystallization of salts in the concrete pores may also produce damaging stresses/deterioration).

a.  SCBRW located on west side of pedestrian bridge.

b.  SCBRW located on east side of pedestrian bridge.

Figure 4.36.  Photos (a and b) illustrating high-severity scaling in a location subjected to a large amount of water runoff containing deicing chemicals.

Fertilizers

In general, there was a greater amount of scaling present where large amounts of fertilizers were used. The phosphates in the fertilizers behave in a manner similar to that of deicing salts, such that freeze-thaw deterioration is accelerated due to increased water saturation in the concrete pores resulting from the water-phosphate solution. This deterioration was generally manifested in the capstone units (which are heavily exposed to the water-phosphate solution), as illustrated in figure 4.37.

#### *4.1.3.2 Efflorescence*

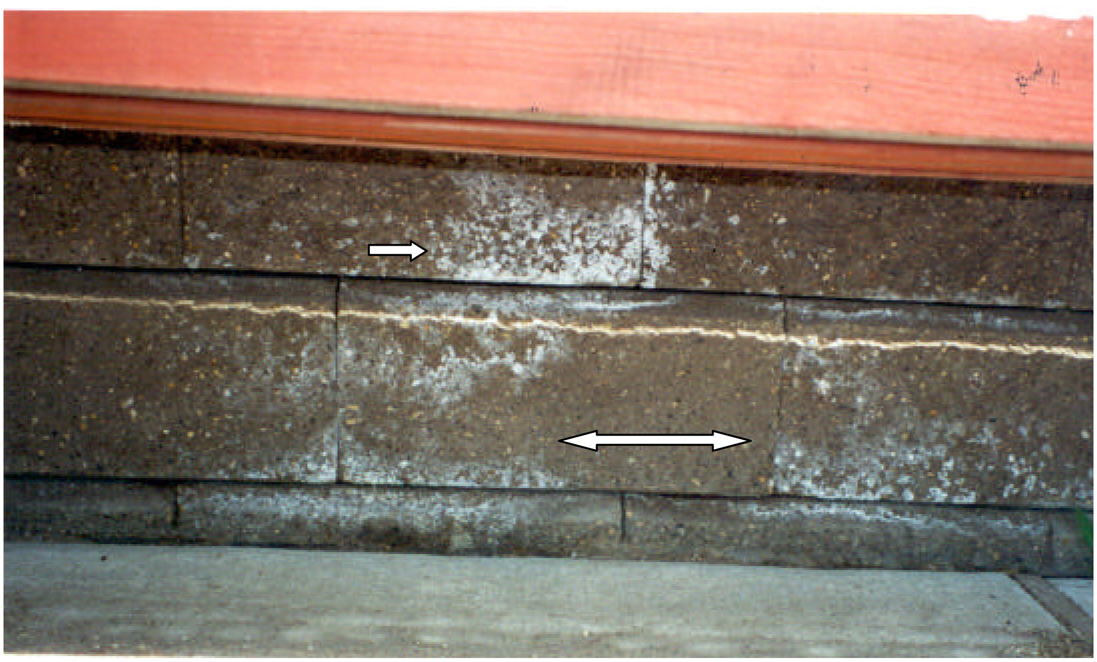
There was an increased incidence of efflorescence on block units subjected to a high quantity of water runoff (e.g., behind/below obstructions, bottom vertical surface of block unit, blocks adjacent ground water runoff). Figures 4.38a and b illustrates the presence of efflorescence on block units subjected to increased water runoff from physical obstructions. In addition, figures 4.39 and 4.40 present photos demonstrating the increased efflorescence in locations near water runoff from sloped land and adjacent to a water supply (e.g., river or drainage pipe), respectively.

a. SCBRW capstones after exposure to fertilizer.

b. SCBRW adjacent to golf course.

Figure 4.37. Freeze-thaw deterioration exacerbated by the presence of fertilizers.

a. Efflorescence behind obstruction.



b. Efflorescence below bench.

Figure 4.38. Photos (a and b) showing increased efflorescence from obstruction water runoff.

Figure 4.39. Photo demonstrating increased efflorescence in location near water runoff from sloped land.

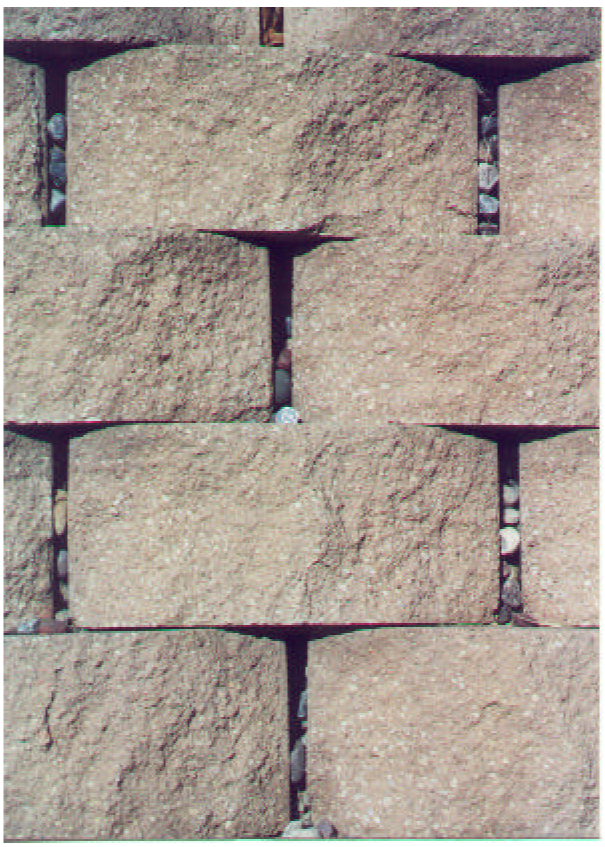
a. Efflorescence on blocks adjacent to water level of river.

b. Efflorescence around drainage pipe.

Figure 4.40. Photos (a and b) presenting increased efflorescence on blocks adjacent to a water supply.

*4.1.3.3    Open Joints*

In general, the frequency of open joints appeared to be dependent on the physical design of the masonry block units.  Rectangular shaped blocks (i.e., where the embedded portion of the block is rectangular) were apparently easier to place at the desired spacing than other block shapes.  Figure 4.41 (photos [a] and [b]) illustrates this point.



a.  embedded portion of block is angled

b.  embedded portion of block is rectangular

Figure 4.41.  Effect of block design on the presence of open joints.

*4.1.3.4 Manufacturing Flaws (Poor Consolidation)*

The observance of poor consolidation (manufacturing flaws) was highly dependent on the block manufacturer (see figure 4.42). These flaws were identified on the capstone edges (at the joints) where adequate consolidation is most difficult to achieve.

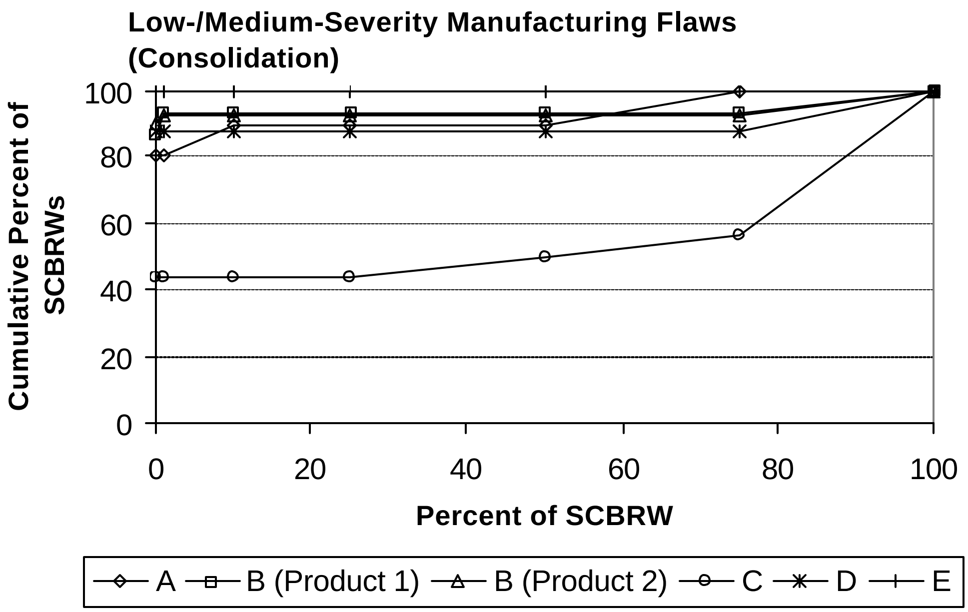



Figure 4.42. Effect of manufacturer on poor consolidation.

Figure 4.42 presents the cumulative percent of *all* SCBRWs versus the percent of given SCBRW (i.e., percent of wall area) observed with low-/medium-severity manufacturing flaws (poor consolidation). Figures of this type are powerful tools for analyzing performance trends, but are not intuitive or easily interpreted at first. Since this report contains several figures like this one, the following few paragraphs present example interpretations.

Each data point represents the percentage of walls surveyed (y-axis value) that exhibited the given distress (e.g., poor consolidation) over less than a given percentage of the area of the wall (x-axis value). The points on the y-axis represent the percentages of walls that exhibited no distress. For example, in figure 4.4.2, about 45 percent of the walls containing block produced by manufacturer C exhibited no consolidation problems. Obviously, <u>the higher the y-axis intercept, the better.</u>

Continuing to the right along any given data trend line gives an indication of the incremental change in the percentage of walls exhibiting a given distress (change in y-axis value) as the threshold for distress coverage increases (change in x-axis value). When the line is relatively flat, this means that very few walls exhibit distress coverage at the corresponding levels indicated on the x-axis. For example, for manufacturer C in figure 4.42, the data trend line is relatively flat between 0 and 25 percent coverage, implying that when consolidation problems were observed, they were over much larger coverage areas (i.e., greater than 25 percent). At 50 percent or less coverage, the cumulative wall percentage for manufacturer C increases to about 50 percent, suggesting that 5 percent of the walls containing manufacturer C blocks (the difference in y-axis values) exhibited poor consolidation over 25 to 50 percent of the wall (the difference in x-axis values). At 75 percent or less coverage, the cumulative wall percentage for manufacturer C increases to about 58 percent, suggesting that 8 percent of the walls containing manufacturer C blocks (the difference in y-axis values) exhibited poor consolidation over 50 to 75 percent of the wall (the difference in x-axis values). Finally, at 100 percent or less coverage, the cumulative wall percentage for manufacturer C increases to about 100 percent, suggesting that 42 percent of the walls containing manufacturer C blocks (the difference in y-axis values) exhibited poor consolidation over 75 to 100 percent of the wall (the difference in x-axis values).

These numbers could easily be tabulated to present the same information, but the purpose of a graph is to convey an interpretation of the general trends very quickly. For the style of graphs used in this report, the best performance is indicated by trend lines that have the highest areas underneath, i.e., those that begin as high as possible on the y-axis and rise to 100 percent as quickly as possible. Starting high on the y-axis would indicate that high percentages of the walls surveyed exhibited none of the distress type in question, and rising quickly to 100 percent would indicate that any observed distress was not widespread in coverage. In figure 4.42, for example, the best performance with respect to consolidation is attributed to walls containing block produced by manufacturers A and B (product 1), while the worst performance is attributed to walls containing block produced by manufacturer C.

*4.1.3.5 Maintenance*

Capstone Replacement

Capstone units were replaced on a number of walls in Hennepin county, thereby, preventing an accurate distress survey and condition rating of the original capstone block units.

Home Owners

It is difficult to know the exact maintenance on block units adjacent to private property owned by homeowners. For instance, one case was encountered where the homeowner had been sealing and had replaced a large number of the capstone and top two course layers on the county wall without their knowledge. The owner had complained that a large amount of road spray hit this wall, thus accelerating the deterioration of those blocks (the F/C distance of this wall is 11 ft).

This individual had proceeded with these tasks without informing the county, hence no record of this maintenance was recorded and an accurate distress survey and condition rating of the original block units could not be performed (the survey and rating does not reflect the deteriorated condition of all the original block units).

## 4.2 General Distress Survey Results

The data collected from the general distress survey, as described in section 3.2.1 for Dakota county, Hennepin county, Mn/DOT and privately owned SCBRWs, are listed in tables F-1 through F-9, F-10 through F-18, F-19 through F-27 and F-28 through F-36, respectively (see appendix F). These tables indicate the percentage of each SCBRW surveyed exhibiting the indicated distress type at low, medium, and high severity levels. General comments collected from the survey for each wall are also presented in these tables. In order to determine the extent of SCBRW deterioration and the severity of damage in these walls, the data (percent of SCBRW assessed with distress for each severity level and distress type) were analyzed to reflect a percent of SCBRWs surveyed (normalized for total number of walls). The normalized data for Dakota county, Hennepin county, Mn/DOT and privately owned SCBRWs are presented in tables F-37, F-38, F-39, and F-40, respectively. Table F-41 lists the normalized data for the SCBRWs grouped as a whole (normalized for the total number of walls surveyed [i.e., total number of walls = Hennepin county + Dakota county + Mn/DOT + privately owned SCBRWs]).

#### 4.2.1 Normalized Distress Survey Results

As stated previously, the data collected were adjusted to reflect a percent of SCBRWs. Figures F-1 through F-20 in Appendix F present bar graphs of the percent of SCBRWs surveyed versus the percent of SCBRW observed with a given distress type. These graphs were generated for each distress type, along with separate bars distinguishing each severity level (i.e., low-, medium- and high-severity level) for those distress types rated at these levels.

The following discussion uses a frequency of occurrence of 60 percent as the guideline for distinguishing whether each distress type is significantly widespread and, therefore, of concern.

It appears that the following distress types (in decreasing order of occurrence) were present in less than 60 percent of the SCBRWs:

- Efflorescence (58 percent)
- Wash-Through (58 percent)
- Open Joints (57 percent)
- Internal Staining (49 percent)
- Construction Defects (45 percent)
- Miscellaneous Distress/Flaws (44 percent)
- External Staining (37 percent)
- Structural Distress (30 percent)
- Erosion (23 percent)
- Popouts (Top Block Layer) (23 percent)
- Cracked Block (17 percent)
- Manufacturing Flaws (Poor Consolidation – Capstone) (17 percent)
- Corner Breaks (14 percent)

The percentage in parentheses behind each distress type listed reflects the percentage of all SCBRWs exhibiting the distress. Comments for specific distress types listed above, where appropriate and necessary, are given below.

*Efflorescence (58 percent)*

As described in the *Distress Identification Manual* (see appendix E), efflorescence is the precipitation of white crusts of calcium carbonate on SCBRW units caused by the interaction of leached calcium hydroxide with carbon dioxide present in air. In general, the presence of efflorescence often occurred when the masonry block units were highly susceptible to freeze-thaw deterioration. Efflorescence was often observed in areas exhibiting low-severity freeze-thaw discoloration. After repeated cycles of freezing and thawing, the bright white color indicating efflorescence often turned to a dull white color in the discolored area.

*Open Joints (57 percent)*

The presence of open joints may be due to poor block placement during initial construction (construction flaw) or due to a structural problem occurring after construction (structural distress). The latter category includes displacement of the wall due to lateral movement of the retained soil. However, since general distress surveys were not performed immediately after wall construction, it is uncertain whether any open joints present during the current distress surveys were due to construction or structural problems. Therefore, any open joints encountered during the distress survey were simply noted and included under a separate category named "open joints."

*Construction Defects (45 percent)*

In general, the majority of construction defects noted were poor placement of masonry block units ("twisted blocks"). Other defects noted were masonry block units placed upside down, exposed geotextile fabric, poor placement of top block layer (capstone overhanging underlying block units) and no backfill on embedded portion of top block masonry units.

*Erosion (23 percent)*

Erosion is defined in the *Distress Identification Manual* as the uniform loss of SCBRW surface mortar due to the action of water or wind-blown abrasives. This distress may be easily confused with surface scaling because the latter distress is generally more severe in areas of water flow and saturation. Therefore, it is uncertain whether some of the distress counted as erosion was actually due to freeze-thaw deterioration (scaling) and not due to weathering (erosion). In order to be able to accurately differentiate between these two distress types, the masonry block units would need to be subjected to laboratory-based freeze-thaw testing and/or microscopic examination, which is outside the scope of this project.

*Manufacturing Flaws (Poor Consolidation – Capstone) (17 percent)*

Manufacturing flaws are characterized by the evidence of systematic or frequent damage to block units that appears to be due to a design or manufacturing problem. When performing the "general" distress condition survey, which quantifies the presence of each distress type by the percent of masonry block units affected, low- and medium-severity manufacturing flaws could not be separated into two separate categories as discussed in the *Distress Identification Manual.* The descriptions differentiating low and medium severity levels are based on whether the flaw is minor or significant (i.e., the number of occurrences). Therefore, these two severity levels were combined into one category (low/medium severity) for the general distress condition surveys that were performed.

Poor (unclean) face breaks, cleaved faces and poor consolidation were the most commonly observed manufacturing flaws. Poor consolidation was only visible at the joints (block edges) of the capstone units and therefore, the data collected for this flaw were separated from the remaining ("other") manufacturing flaws.

The following distress types (in order of decreasing occurrence) were observed in a significant number of walls (60 percent or more of the SCBRWs surveyed):

- Freeze-Thaw Damage (Vertical Surfaces) (84 percent)
- Fraying/Spalling (83 percent)
- Scaling (Top Block Layer) (83 percent)
- Freeze-Thaw Damage (Top Block Layer) (79 percent)
- Position Guide Damage (78 percent)
- Embedded Vegetation Growth (73 percent)
- Scaling (Vertical Surfaces) (73 percent)

- Manufacturing Flaws (Other) (61 percent)

As stated previously, the percentage in parentheses behind each distress type listed reflects the percentage of all SCBRWs exhibiting the distress. Comments for specific distress types listed above, where appropriate or necessary, are given below.

*Fraying/Spalling (83 percent)*

Low-, medium- and high-severity fraying/spalling was observed in 83, 63 and 31 percent of the SCBRWs surveyed, respectively. The percent of SCBRW coverage by each severity level is presented in figure 4.43.

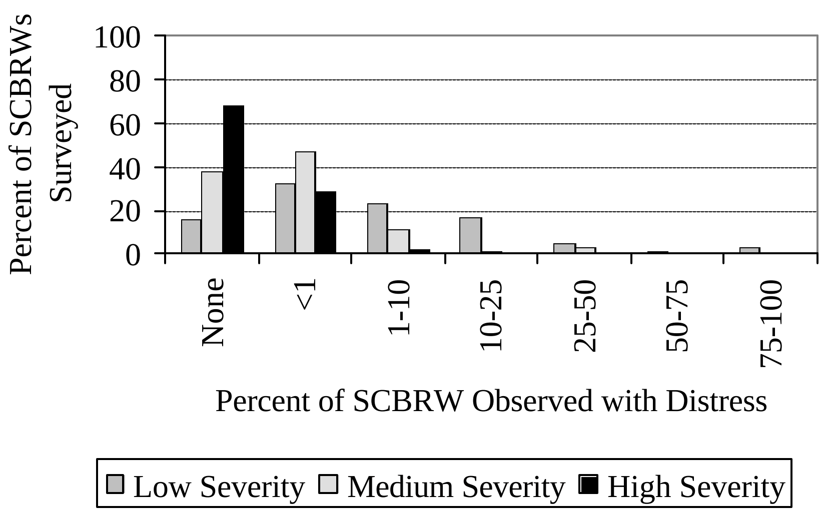



Figure 4.43. Percentage of SCBRWs surveyed with low-, medium- and high-severity fraying/spalling.

It is uncertain whether the observed fraying/spalling was due to improper handling or placement of block units, since a survey was not conducted immediately after wall construction. However, it can be assumed that any damage present not produced during handling/placement may have resulted from the restraint of thermal expansion (caused by tight block placement or infiltration of incompressibles into block joints), the placement of blocks on uneven surfaces or the movements of the wall (or portions of the wall) following placement. In general, one would expect that if the fraying/spalling was caused by the restraint of thermal expansion/contraction, the frequency of fraying/spalling would be greatest when there are no open joints. This case is not supported by figures 4.44 – 4.46. Figures 4.44, 4.45 and 4.46 graph the cumulative percent of SCBRWs with open joints versus the percent of wall observed with low-, medium- and high-severity fraying/spalling, respectively. As illustrated, the greatest amount of low- and medium-severity fraying/spalling was observed for walls exhibiting 75 to 100 percent open joints. The amount of high-severity fraying/spalling was approximately equivalent regardless of the number of open joints present. There appear to be no direct trends between these two factors and there were no observances of uneven surfaces; this suggests the breaks were due to improper handling/placement of block units.

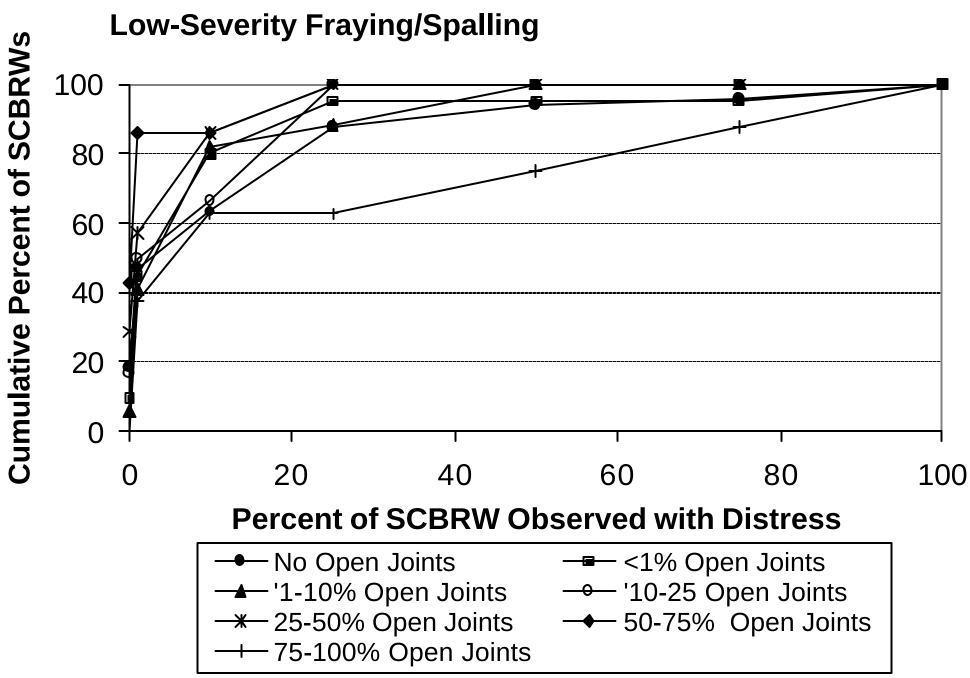



Figure 4.44. Cumulative percent of SCBRWs with open joints versus percent of SCBRW observed with low-severity fraying/spalling.

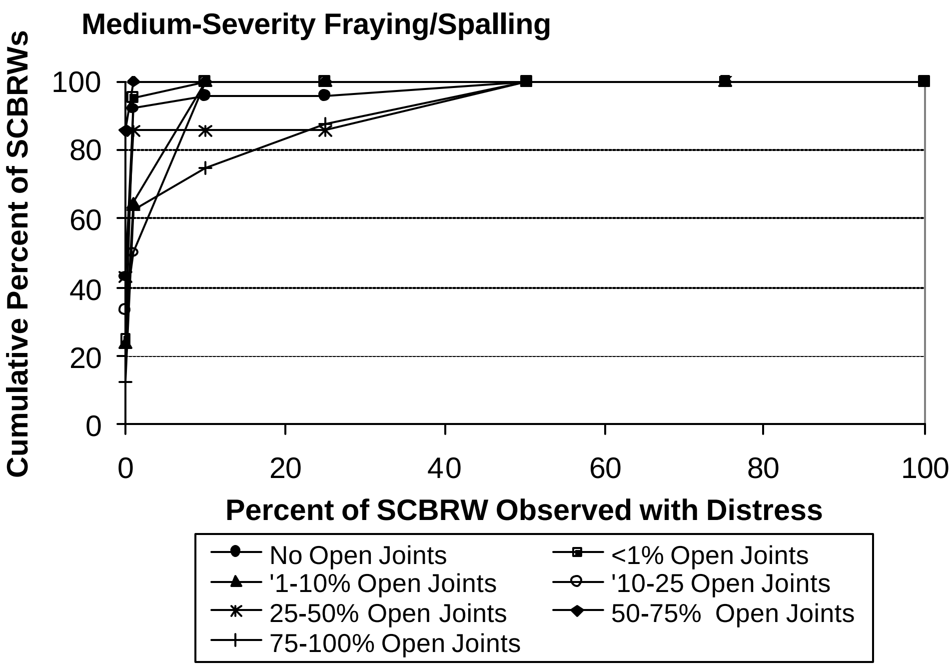



Figure 4.45. Cumulative percent of SCBRWs with open joints versus percent of SCBRW observed with medium-severity fraying/spalling.

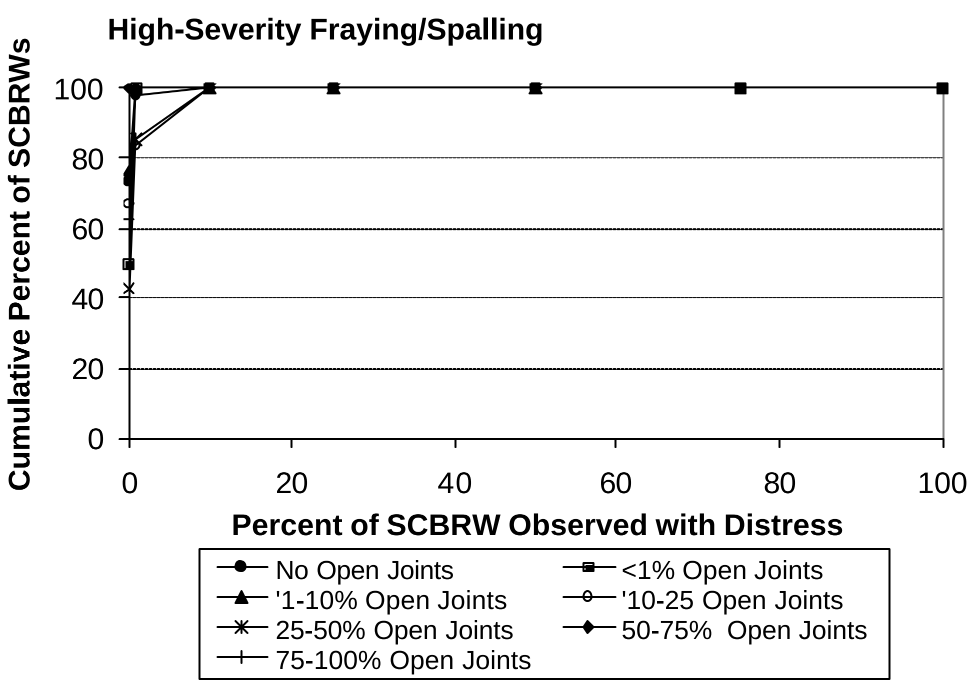



Figure 4.46. Cumulative percent of SCBRWs with open joints versus percent of SCBRW observed with high-severity fraying/spalling.

*Scaling (Top Block Layer) (83 percent)*

Low-, medium- and high-severity scaling (top block layer) was observed in 83, 59 and 43 percent of the SCBRWs surveyed, respectively. The percent SCBRW coverage by each severity level is presented in figure 4.47.

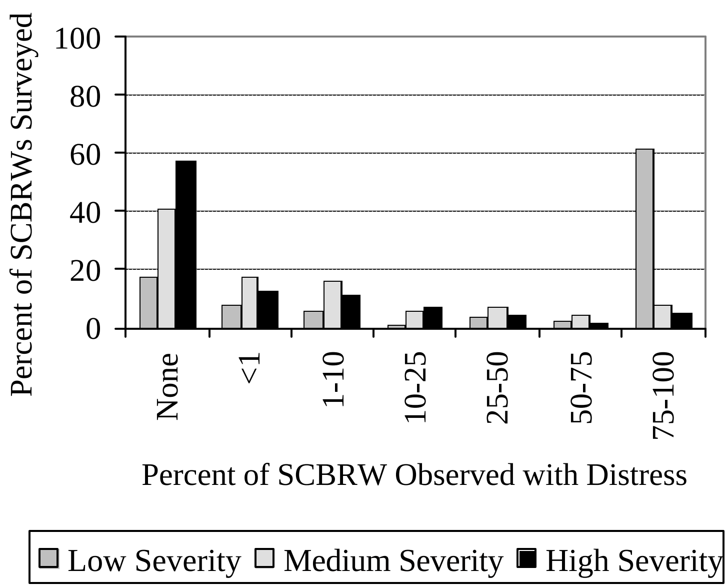



Figure 4.47. Percentage of SCBRWs surveyed with low-, medium- and high-severity scaling (top block layer).

Scaling is a special case of freeze-thaw damage to SCBRWs. As discussed previously, freeze-thaw damage is the progressive deterioration of critically saturated concrete in the presence of freezing and thawing temperatures. The expansion of water during freezing can produce internal damage to the concrete block matrix if the pore structure does not allow rapid expulsion of water or if the concrete is not air-entrained. Scaling presents itself as the loss of surface aggregate and mortar material. The presence of scaling was strongly associated with specific block manufacturers, thereby indicating that durability problems are largely due to inappropriate mix designs and/or the use of nondurable aggregate.

*Freeze-Thaw Damage (Top Block Layer) (79 percent)*

Low-, medium- and high-severity freeze-thaw damage (top block layer) was observed in 79, 21 and 24 percent of the SCBRWs surveyed, respectively. The percent SCBRW coverage by each severity level is presented in figure 4.48.

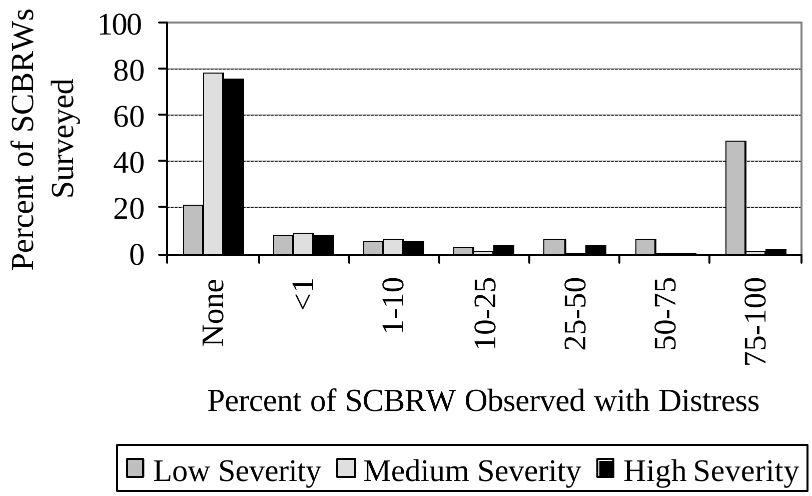



Figure 4.48. Percentage of SCBRWs surveyed with low-, medium- and high-severity freeze-thaw damage (top block layer).

Freeze-thaw damage is the progressive internal deterioration of critically saturated concrete in the presence of freezing and thawing temperatures. The expansion of water during freezing can produce internal damage of the concrete block matrix if the pore structure does not allow rapid expulsion of water or if the concrete is not air-entrained. The percentage of SCBRWs observed with freeze-thaw damage is of concern since the resulting distress will appear as a general deterioration or crumbling of the concrete in the affected areas. In general, it appears that the onset of freeze-thaw deterioration begins with the appearance of local discoloration but no significant loss of material. This discoloration was often visible along the lower extremities of the block face, extending toward the joints on each side of the block unit where water is most readily available. Early age staining was also present on some block units on the top surface. This staining was predominant along the front facial edge of the block, extending approximately

1 to 2 inches inwards across the top surface of the block unit. Here again, is a location where there is high water saturation due to runoff.

Eventually, after repeated cycles of freezing and thawing, the nondurable block units begin to deteriorate, exhibiting tight cracks (vertical delamination along the back of the block unit, horizontal delamination along the bottom facial portion of the top block unit or spider web cracking), which eventually begin to deteriorate and open. Areas exhibiting a loss of mortar and aggregate material are also evidence of freeze-thaw damaged areas. However, this type of deterioration was counted as “scaling”, as discussed in the *Distress Identification Manual*.

Photos illustrating typical freeze-thaw-damaged block units are presented in the *Distress Identification Manual.*

*Position Guide Damage (78 percent)*

Low-, medium- and high-severity position guide damage was observed in 71, 78 and 67 percent, of the SCBRWs surveyed that contained positioning guides. The percent of SCBRW coverage by each severity level is presented in figure 4.49.

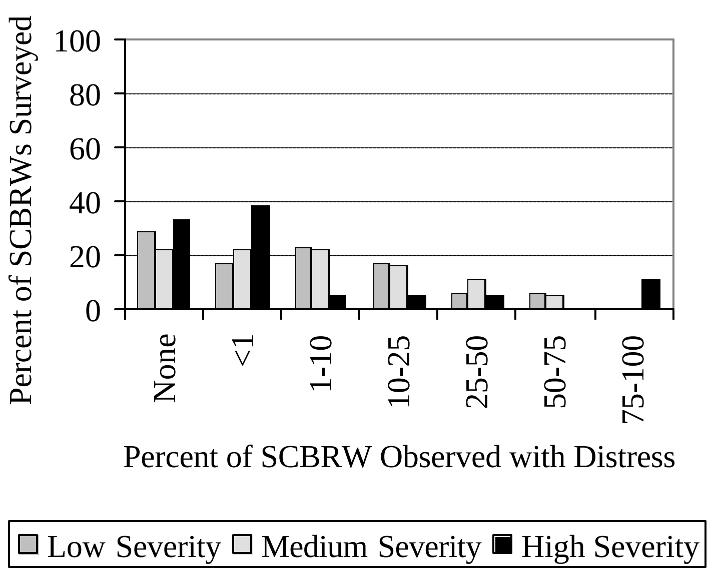



Figure 4.49. Percentage of SCBRWs surveyed with low-, medium- and high-severity position guide damage.

The position guide damage assessed for this category involves only the block types with the position guide ("lip") near the front edge of the top block surface. This guide is susceptible to manufacturing flaws, construction related damage and to freeze-thaw damage (because water and deicing chemicals can easily accumulate behind the guide). The position guide damage distress type was included in the *Distress Identification Manual*, even though the distresses that occur on these guides are also counted under other distress categories (i.e., manufacturing flaws, construction-related damage and freeze-thaw damage), to give a better indication of the source of the other types of distress. The majority of position guide damage appeared to be caused by erosion and freeze-thaw damage due to the large amount of water runoff across the guides (causing erosion) and accumulation of water and deicing chemicals behind the position guides (enhancing freeze-thaw damage, as described previously in the "freeze-thaw damage (vertical surfaces)" section. There were only a few walls with position guides damaged due to fraying/spalling or cracking due to a structural flaw (less than one percent of the SCBRW surveyed had these two distress types).

*Embedded Vegetation Growth (EVG) (73 percent)*

Low-, medium- and high-severity EVG was observed in 73, 9 and 4 percent of the SCBRWs surveyed, respectively. The percent SCBRW coverage by each severity level is presented in figure 4.50. The presence of EVG is a major concern because masonry block units may crack when the thickness and intrusion of EVG roots increase with age.

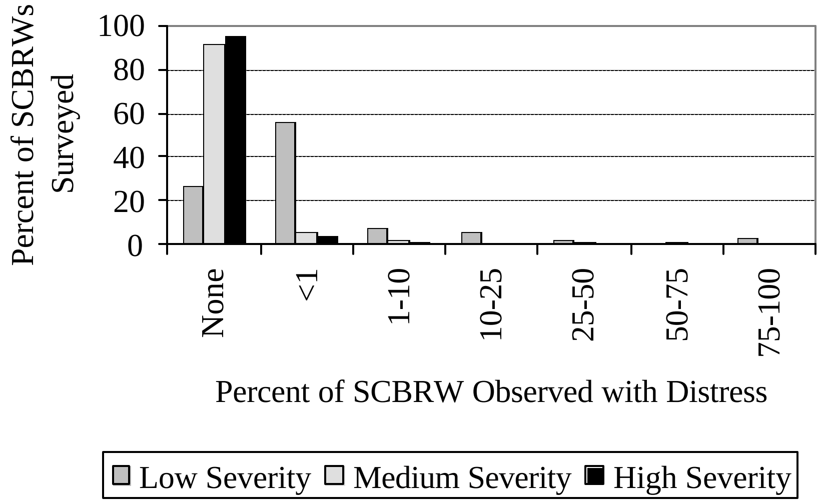



Figure 4.50. Percentage of SCBRWs surveyed with low-, medium- and high-severity embedded vegetation growth.

*Scaling (Vertical Surfaces) (73 percent)*

Low-, medium- and high-severity scaling (vertical surfaces) were observed in 73, 58 and 31 percent of the SCBRWs surveyed, respectively. The percent SCBRW coverage by each severity level is presented in figure 4.51.

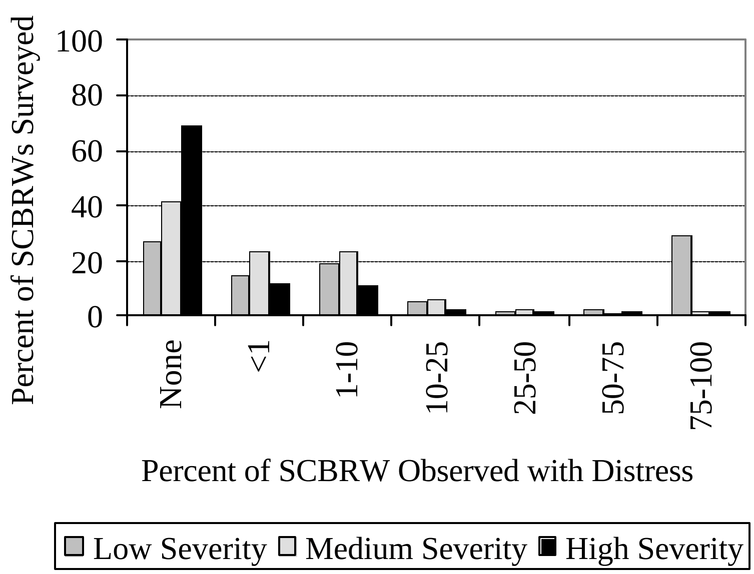



Figure 4.51. Percentage of SCBRWs surveyed with low-, medium- and high-severity scaling (vertical surfaces).

The description of this distress type is the same as that described above for scaling (top block surfaces). Again, the presence of vertical surface scaling was strongly associated with a given block manufacturer, thereby indicating that durability problems are largely due to improper mix designs. Figures 4.52 and 4.53 illustrate the association of durability problems with mix design. Sections of durable and non-durable masonry block units are visible in this wall, indicating variations of mixes from batch to batch affecting the block performance.

Figure 4.52. Example of apparent variations in mix design affecting block performance (CSAH 6 and 481 ft East of Dunkirk (north side)).

Figure 4.53. Durable and non-durable layers (CSAH 6 and 481 ft East of Dunkirk (north side)).

*Manufacturing Flaws (Other) (61 percent)*

Low/medium- and high-severity manufacturing flaws (other) were observed in 61 and 3 percent of the SCBRWs surveyed, respectively. The percent of SCBRW coverage by each severity level is presented in figure 4.54.

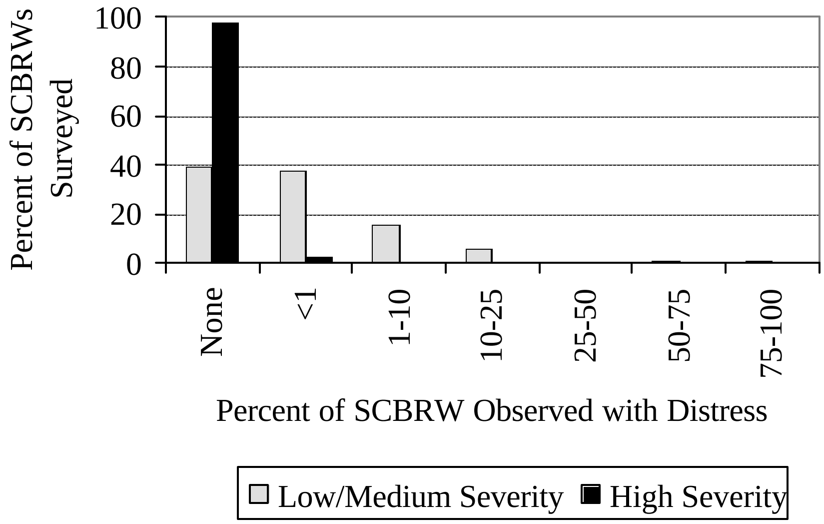



Figure 4.54. Percentage of SCBRWs surveyed with low-/medium- and high-severity manufacturing flaws (other).

As previously stated, poor (unclean) face breaks and cleaved faces were categorized separately (as "other") from poor consolidation manufacturing flaws, since the latter flaw was visible only on the capstone units.

#### 4.2.2 Effect of Different Owner/Agency

Figure 4.56 presents a bar graph illustrating the number (frequency) of surveyed walls owned by each owner/agency (i.e. Dakota county, Hennepin county, Mn/DOT or privately owned SCBRWs). Statistical analysis was performed at a 95 percent confidence level to determine the effect of different agencies on the distress types observed. The following distress types were found to be at least somewhat dependent upon the agency:

- Open Joints
- Low-Severity Cracked Block
- Low-, Medium- and High-Severity Embedded Vegetative Growth
- High-Severity External Staining
- Internal Staining
- Medium-Severity Structural Distress

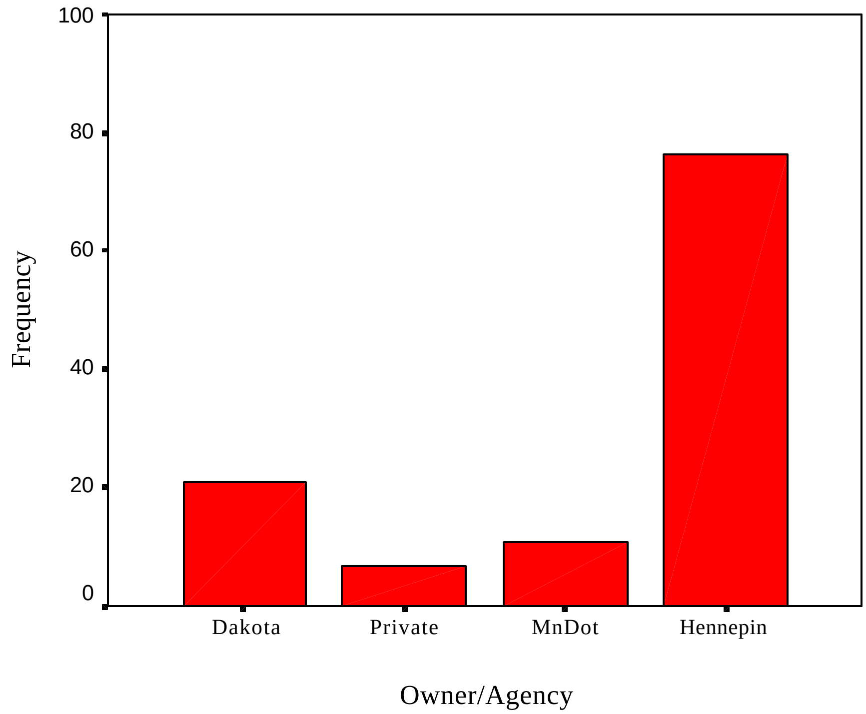
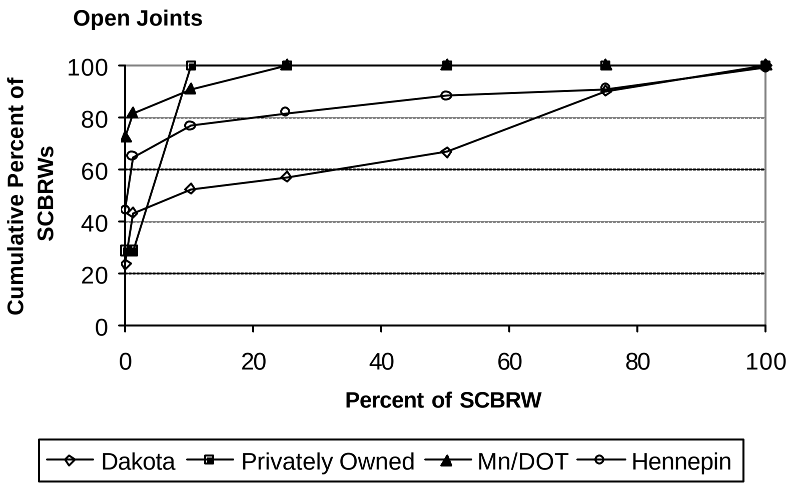


Figure 4.56. Number of surveyed SCBRWs owned by each agency.

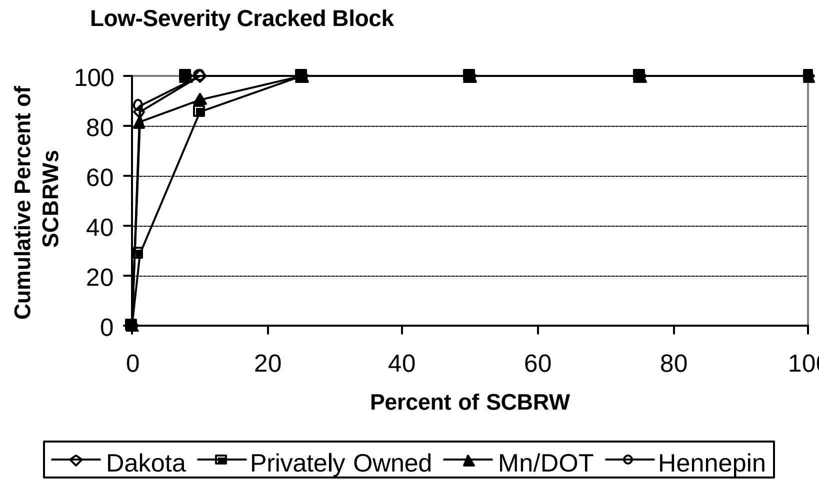
Figure 4.57 presents graphs (a) – (h) illustrating the cumulative percent of SCBRWs from each agency with respect to the observance of the above listed distress types.

In general, it appears that Dakota county walls exhibited the greatest frequency of open joints, while Hennepin county walls displayed the second largest number of walls with this distress (see figure 4.57 [a]). Privately owned walls showed evidence of the largest number of walls with open joint coverage of 10 percent or less. Additionally, privately owned walls demonstrated the greatest number of occurrences of low-severity cracked block, low-severity embedded vegetation and medium-severity structural distress (see figures 4.57 [b, c and h], respectively).

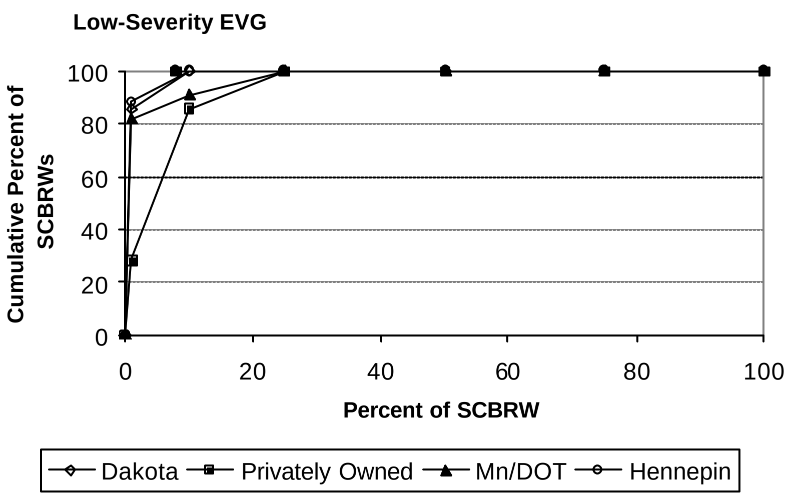
As illustrated in figures 4.57 (e) and (f), the observance of high-severity EVG and internal staining was negligible.



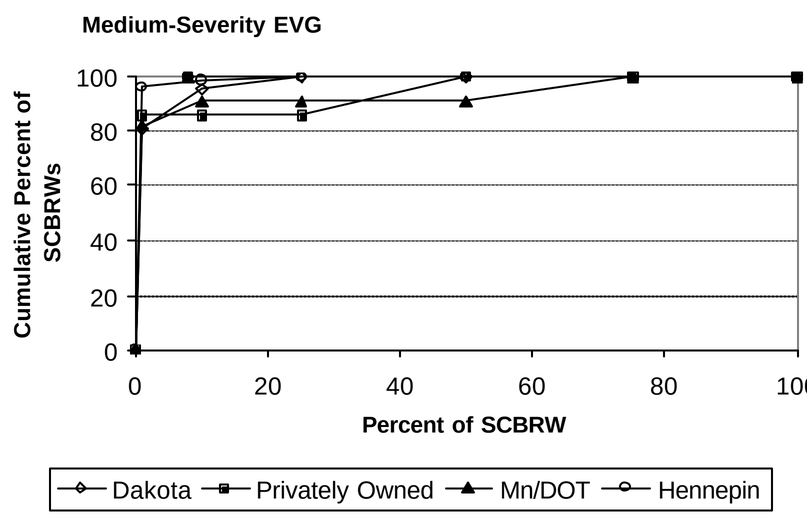

a. Open Joints




b. Low-Severity Cracked Block

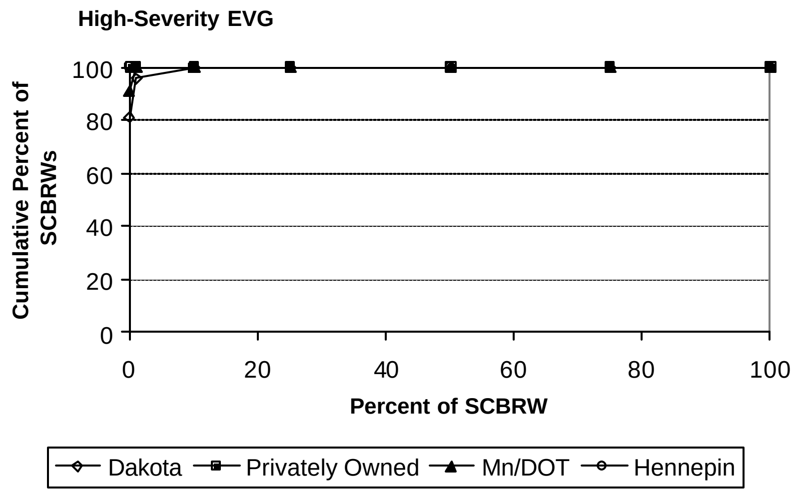



c. Low-Severity Embedded Vegetative Growth

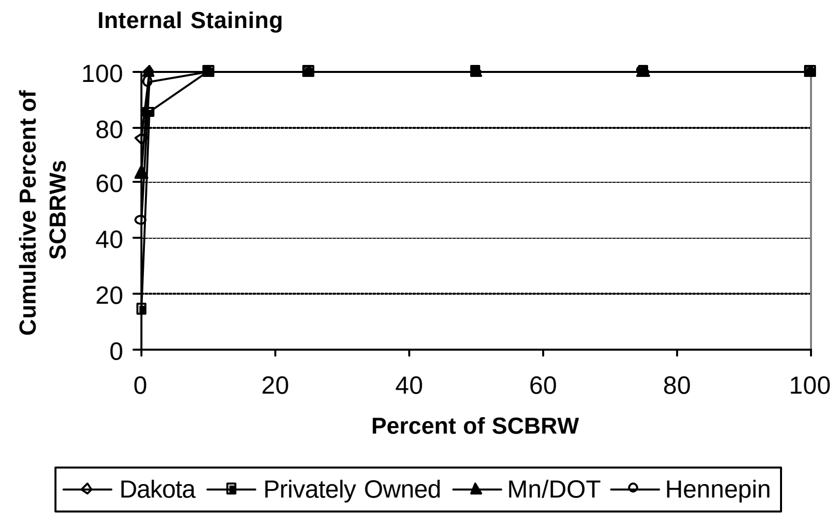



d. Medium-Severity Embedded Vegetative Growths

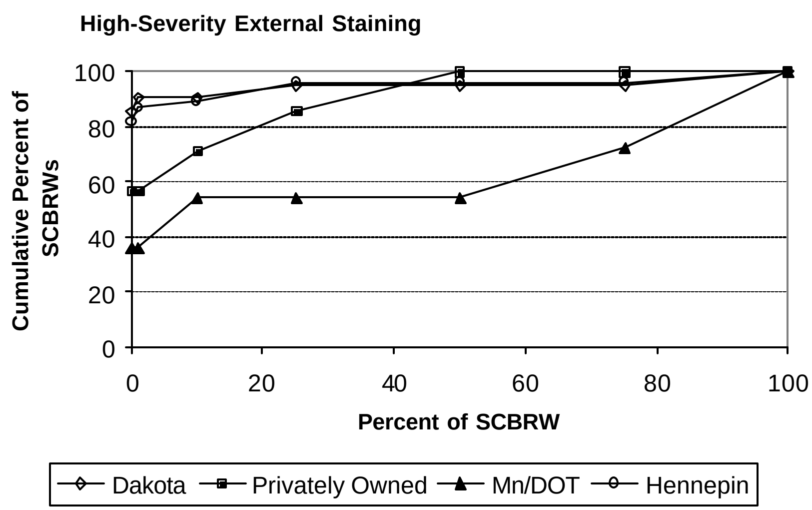
Figure 4.57. Cumulative percent of SCBRWs from each agency versus dependent distress types (graphs [a] – [h]).



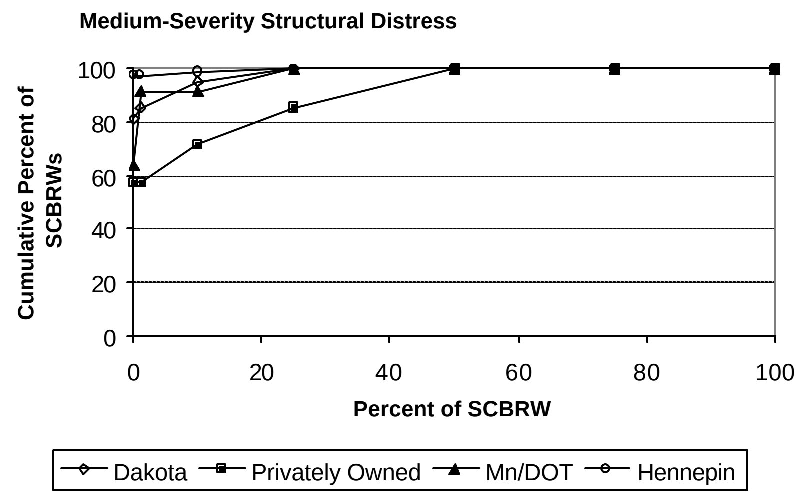

e. High-Severity Embedded Vegetative Growth




f. Internal Staining




g. High-Severity External Staining




h. Medium-Severity Structural Distress

Figure 4.57. Cumulative percent of SCBRWs from each agency versus dependent distress types (graphs [a] – [h]) (continued).

Mn/DOT walls demonstrated the greatest number of SCBRWs with medium-severity embedded vegetation (see figure 4.57 [d]) and high-severity external staining while privately owned walls displayed the second largest amount of this latter distress (see figure 4.57 [g]).

### 4.2.3 Effect of Construction Year

Figure 4.58 presents a bar graph illustrating the number (frequency) of surveyed walls versus the construction year. As illustrated in this bar graph, few walls constructed in 1987, 1988, 1990, 1993 and 1996 – 1998 were surveyed. This limited representation of specific construction years could skew the analysis of age-based trends observed.

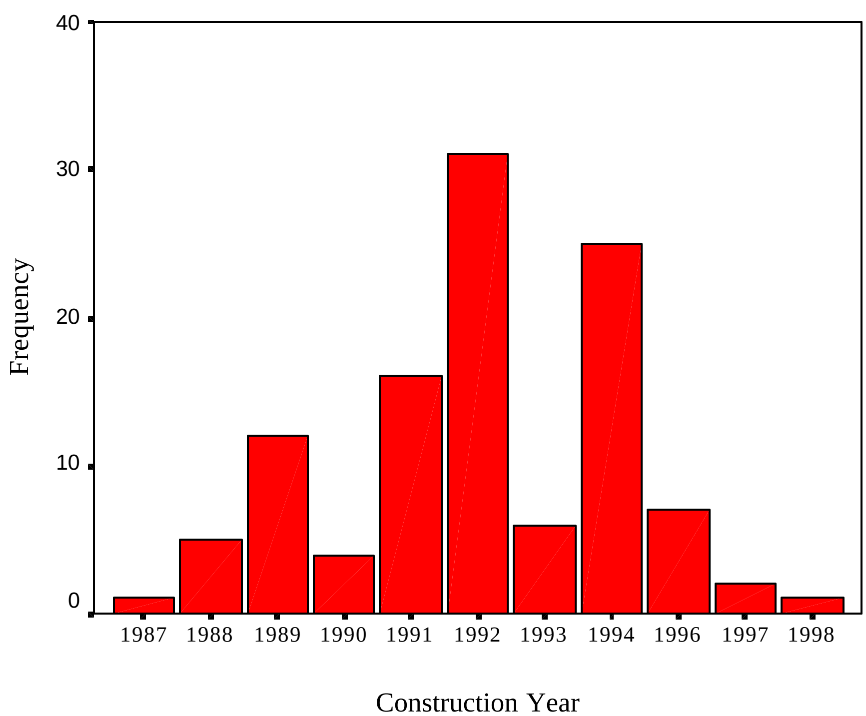


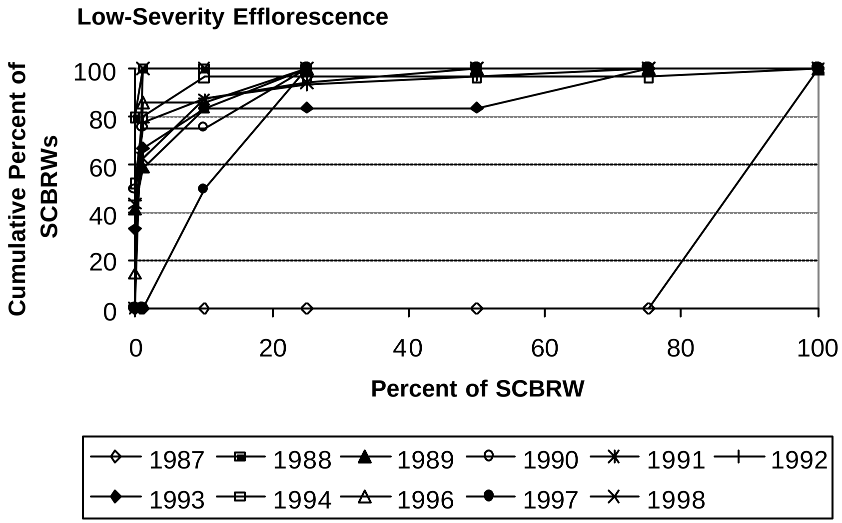

Figure 4.58. Number of surveyed walls versus construction year.

Statistical analyses were performed at a 95 percent confidence level on data describing each distress type with respect to the construction year or age of the wall. The following distress types were found to be at least somewhat dependent upon the construction year or age of the wall:

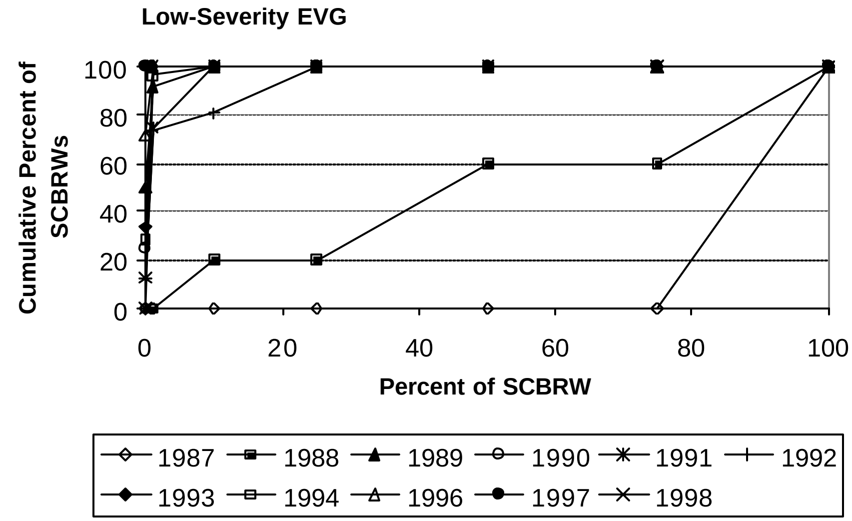
- Low-Severity Efflorescence
- Low-, Medium- and High-Severity Embedded Vegetative Growth
- Medium-Severity Erosion
- Low-Severity Freeze-Thaw Damage (Top Block Layer)
- Low-Severity Freeze-Thaw Damage (Vertical Surfaces)
- Low-/Medium-Severity Manufacturing Flaws (Other)
- Low-, Medium- and High-Severity Scaling (Top Block Layer)
- Low- and High-Severity Scaling (Vertical Surfaces)
- Internal Staining
- Medium-Severity Wash-Through

Figure 4.59 presents graphs (a) – (o) illustrating the cumulative percent of SCBRWs from each given construction year with respect the observance of the above listed distress types.

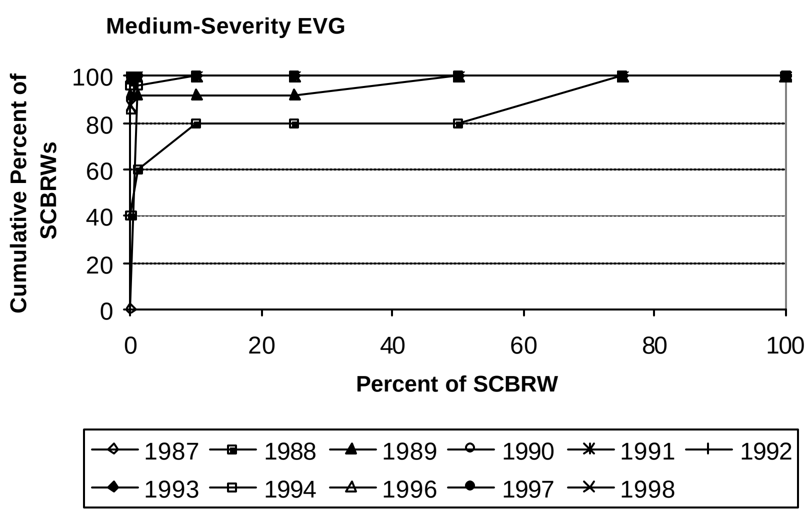
In general, the observation of freeze-thaw deterioration (i.e., freeze-thaw damage and scaling) has been a problem for walls constructed over a number of years (see figures 4.59 [f-g and j-m]); while the incidence of occurrence of the other distress types does not appear to be a problem over all the construction years presented. At this point, it would be logical to look at changes in mix designs, strength specifications and other quality control requirements that might have taken place over the years to pinpoint the cause(s) of the varying amount of freeze-thaw durability problems over the years. However, adequate records describing these parameters were not kept for the blocks used to construct the walls surveyed in this study. Therefore, laboratory testing on blocks taken from these walls would need to be done in order to determine the source of durability problems.



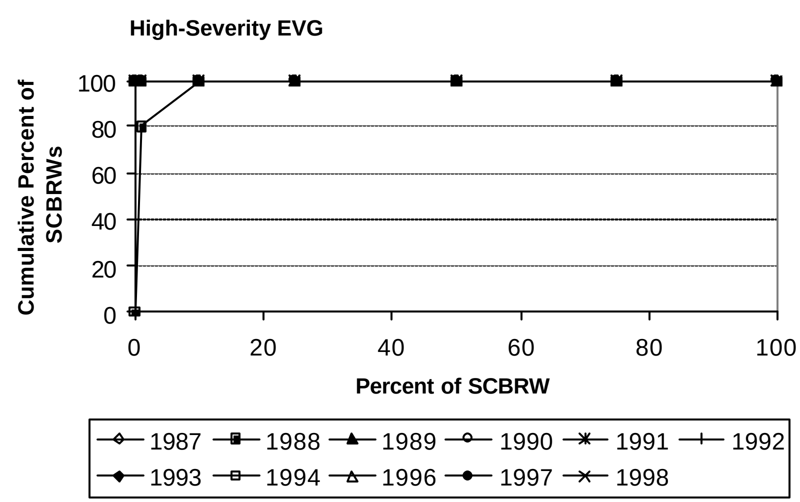

a. Low-Severity Efflorescence




b. Low-Severity EGV

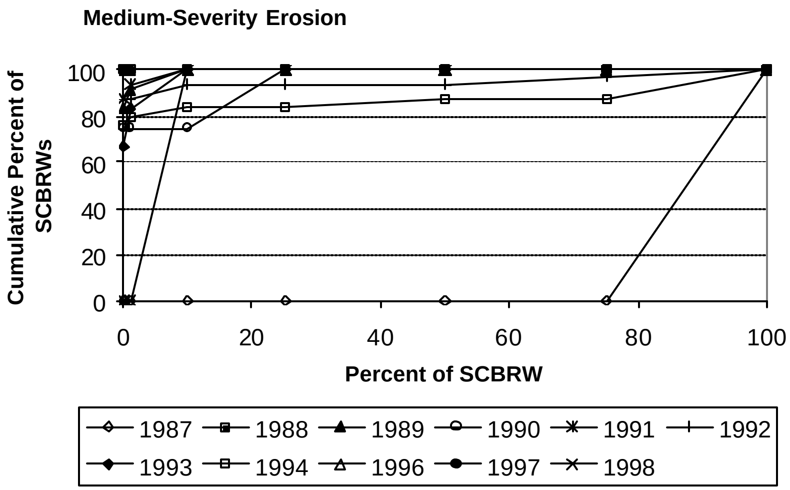



c. Medium-Severity EVG

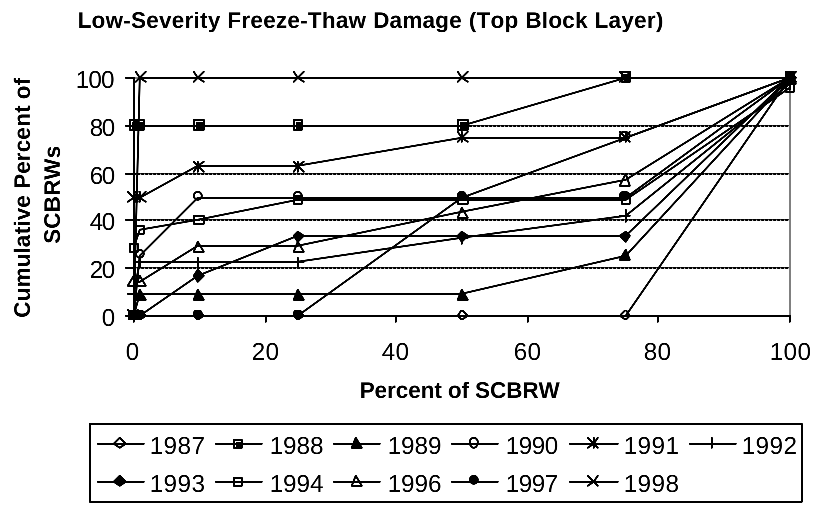



d. High-Severity EVG

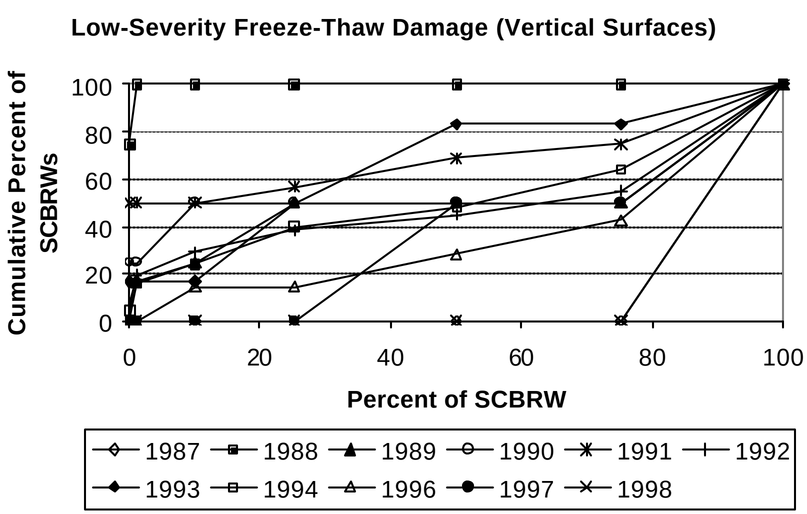
Figure 4.59. Cumulative percent of SCBRWs constructed in given year versus dependent distress types (graphs [a] – [o]).



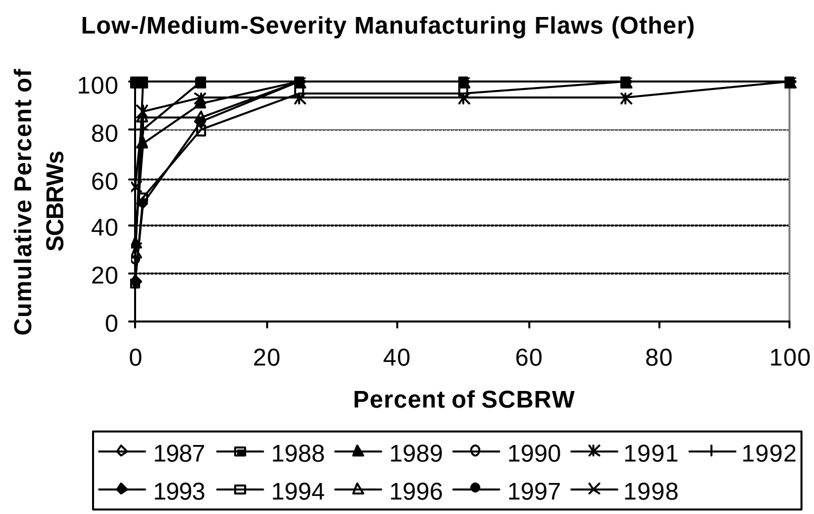

e. Medium-Severity Erosion




f. Low-Severity Freeze-Thaw Damage (Top Block Layer)

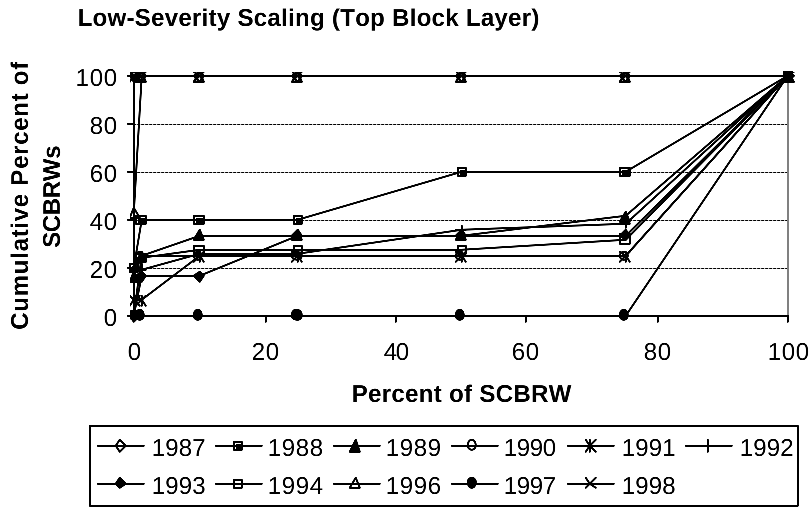



g. Low-Severity Freeze-Thaw Damage (Vertical Surfaces)

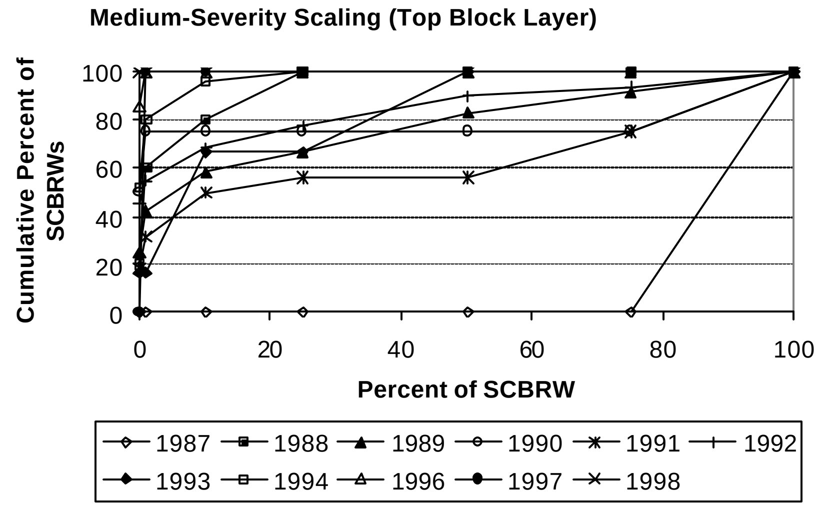



h. Low-/Medium-Severity Manufacturing Flaws (Other)

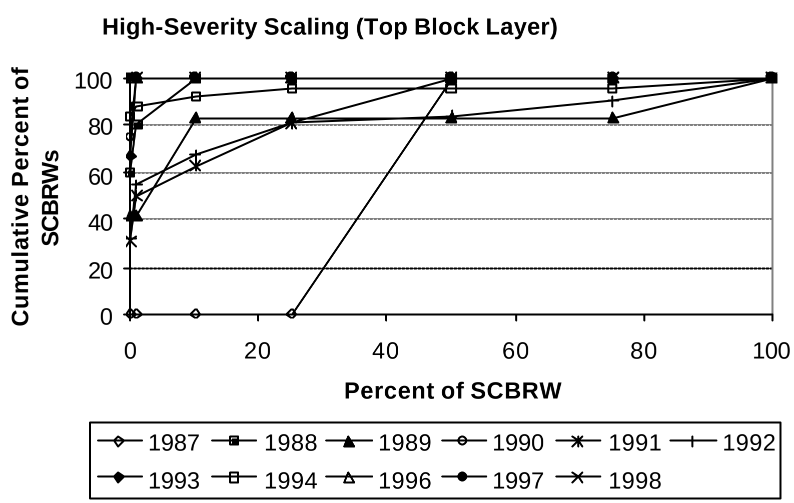
Figure 4.59. Cumulative percent of SCBRWs constructed in given year versus dependent distress types (graphs [a] – [o]) (continued).



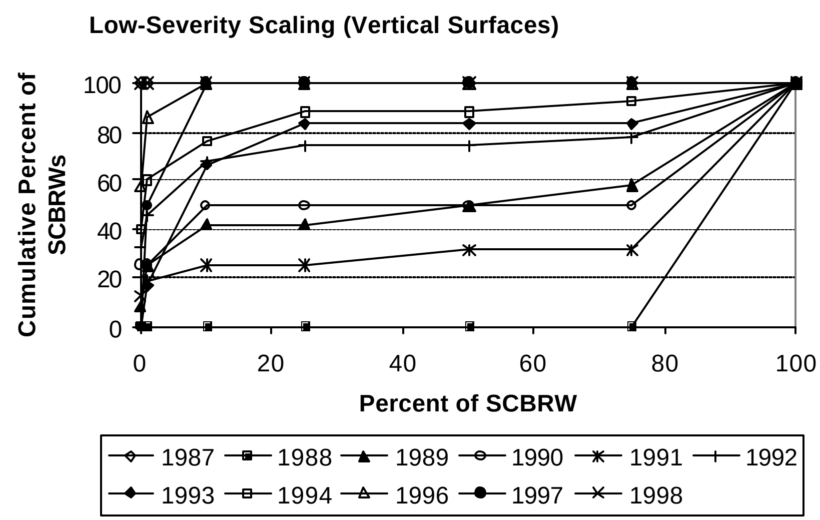

i. Low-Severity Scaling (Top Block Layer)




j. Medium-Severity Scaling (Top Block Layer)

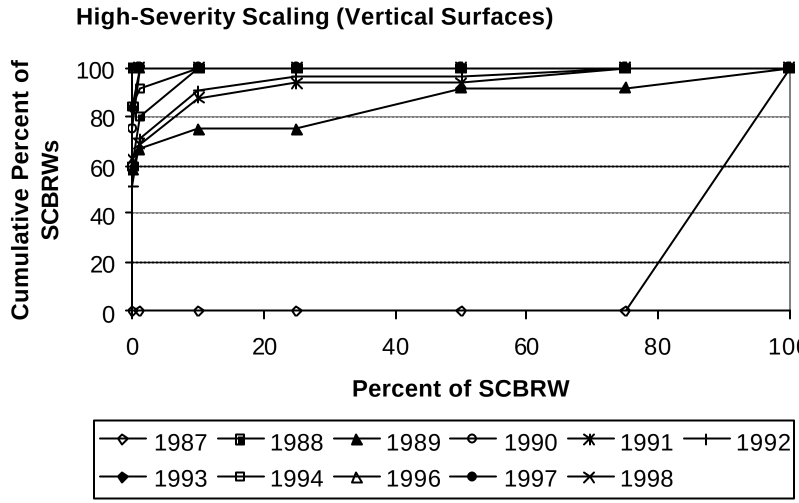



k. High-Severity Scaling (Top Block Layer)

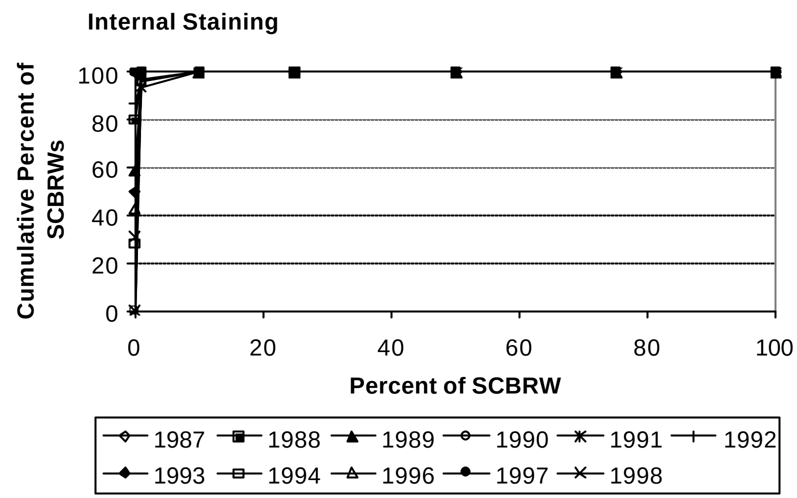



l. Low-Severity Scaling (Vertical Surfaces)

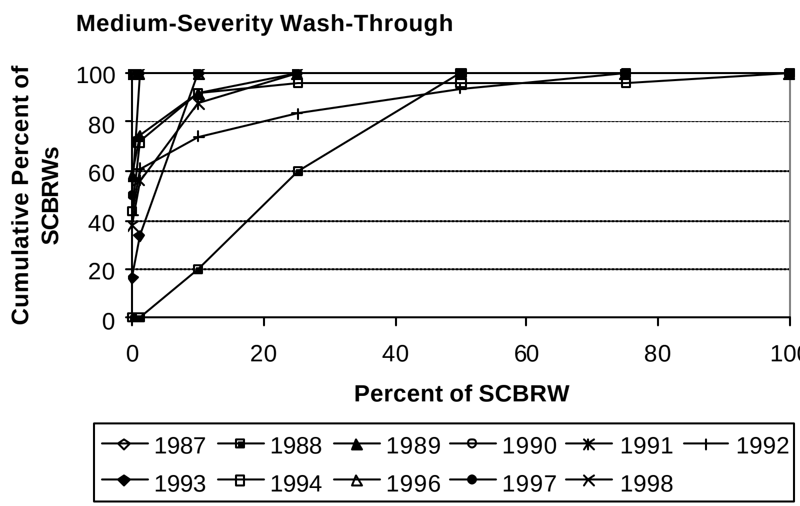
Figure 4.59. Cumulative percent of SCBRWs constructed in given year versus dependent distress types (graphs [a] – [o]) (continued).




m. High-Severity Scaling (Vertical Surfaces)




n. Internal Staining

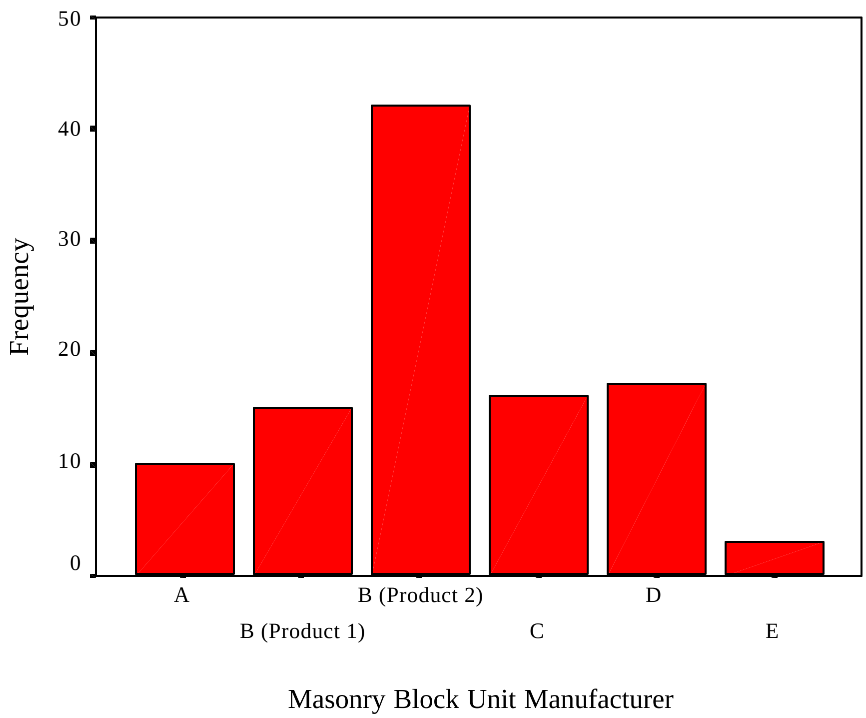



o. Medium-Severity Wash-Through

Figure 4.59. Cumulative percent of SCBRWs constructed in given year versus dependent distress types (graphs [a] – [o]) (continued).

4.2.4 Effect of Masonry Block Unit Manufacturer

Figure 4.60 presents a bar graph illustrating the number (frequency) of surveyed walls versus the masonry block unit manufacturer. As illustrated in this bar graph, the greatest number of walls surveyed (42 walls [41 percent of the SCBRWs surveyed]) were constructed with blocks produced by manufacturer B (product 2). Block manufacturers A, B (product 1), C and D were used for the construction of 10, 15, 16 and 17 of the SCBRWs surveyed (approximately 10-17 percent of the SCBRWs surveyed), respectively. Only three of the surveyed walls were constructed with manufacturer E products.




*The manufacturer was unknown for 12 (10 percent) of the SCBRWs surveyed.

Figure 4.60. Number of surveyed walls versus the masonry block unit manufacturer.

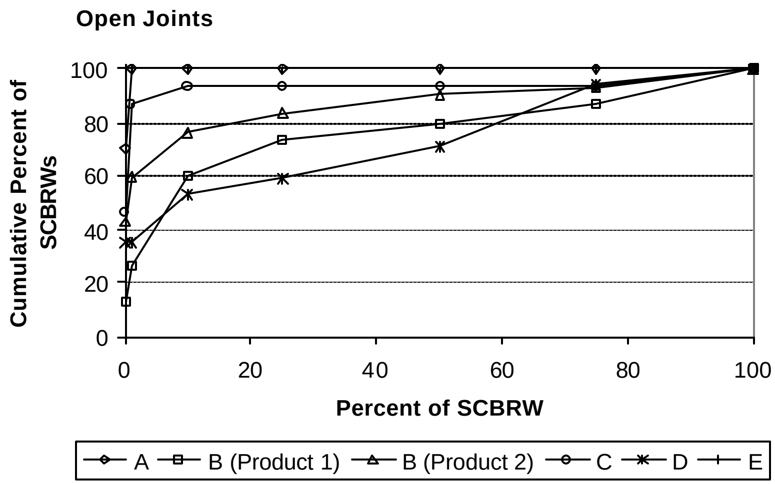
Statistical analyses were performed at a 95 percent confidence level on data collected from the survey describing each distress type with respect to the masonry block manufacturer (i.e., manufacturer “A, B, C, D, or E”). The following distress types were found dependent on the block manufacturer:

- Open Joints
- Low-/Medium-Severity Construction Flaws
- Low- and Medium-Severity Efflorescence
- Low- and High-Severity Embedded Vegetative Growth
- Low-Severity Erosion
- Low- and High-Severity Fraying/Spalling
- Low- and Medium-Severity Freeze-Thaw Damage (Top Block Layer)
- Low-, Medium- and High-Severity Freeze-Thaw Damage (Vertical Surfaces)
- Low-/Medium-Severity Manufacturing Flaws (Other)
- Low-/Medium-Severity Manufacturing Flaws (Poor Consolidation)
- Popouts (Top Block Layer)
- Low-, Medium- and High-Severity Scaling (Top Block Layer)
- Low-, Medium, and High-Severity Scaling (Vertical Surfaces)
- Low- and High-Severity External Staining
- Low-Severity Structural Distress
- Low-, Medium- and High-Severity Wash-Through

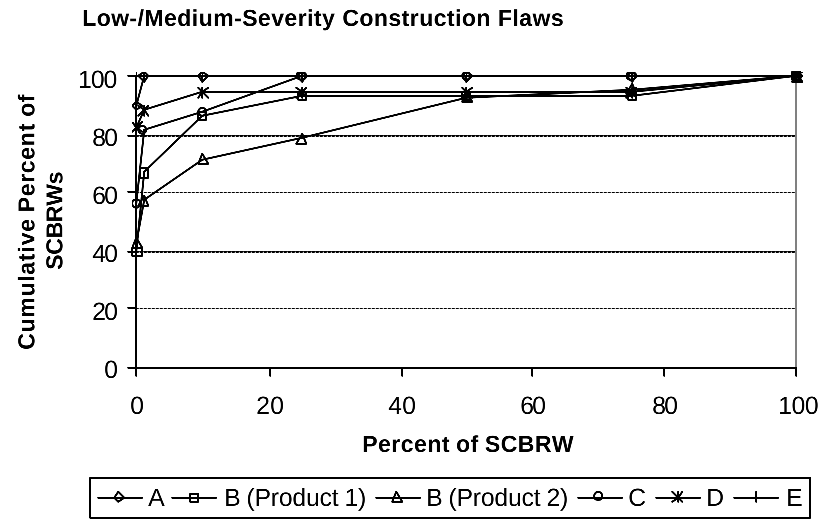
Figure 4.61 presents graphs (a) – (ab) illustrating the cumulative percent of SCBRWs constructed by each manufacturer with respect to the observance of the above listed distress types.

In general, figure 4.61 illustrates obvious differences in the susceptibility of the different products to specific types of distress. A large number of the SCBRWs exhibited a fair amount of distress coverage for most of the distress types examined, regardless of the manufacturer. However, the percent coverage by each manufacturer was minimal for high-severity EVG, high-severity fraying/spalling and low-severity structural distress (see figure 4.61 [graphs (f, i and y)]).

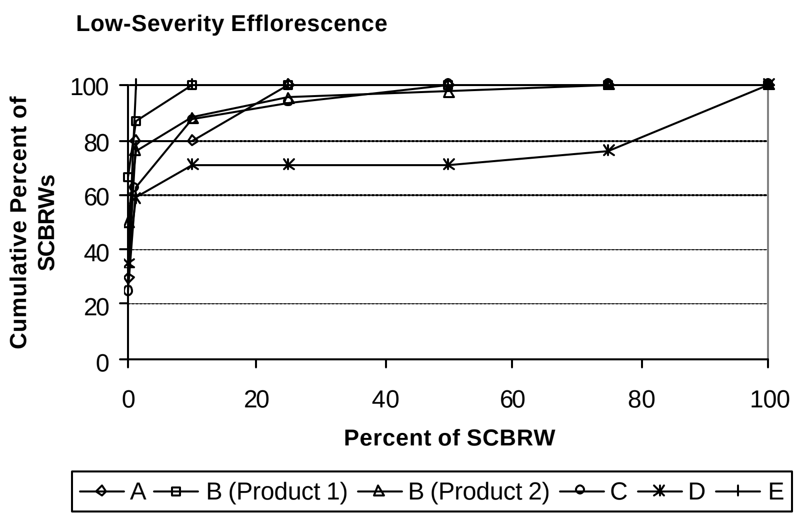
Of the 29 figures, figure 4.61 (graphs [j-m] and [q-v]) stand out the most, illustrate that a large portion of the walls exhibited some severity level of freeze-thaw damage, regardless of the block manufacturer. Additionally, the percentage of walls observed with low- and high-severity external staining (figure 4.61 [graphs (w and x)]) show a large portion of this distress type present for most of the manufacturers.



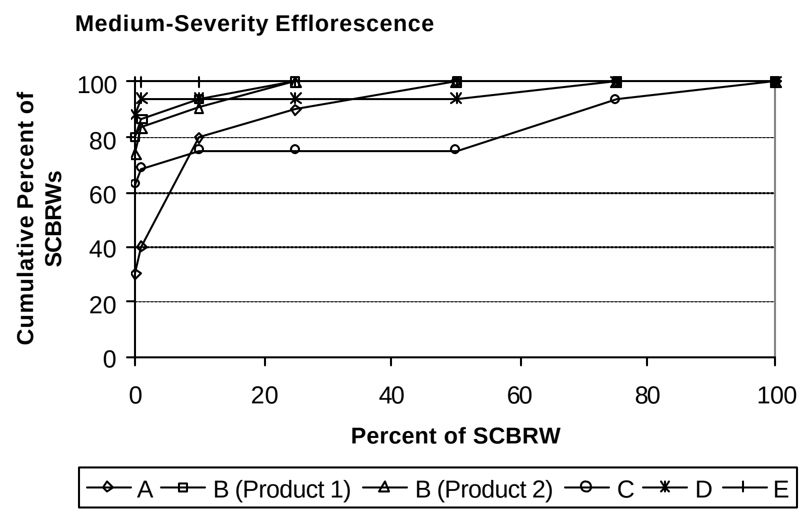

a. Open Joints




b. Low-/Medium-Severity Construction Flaws

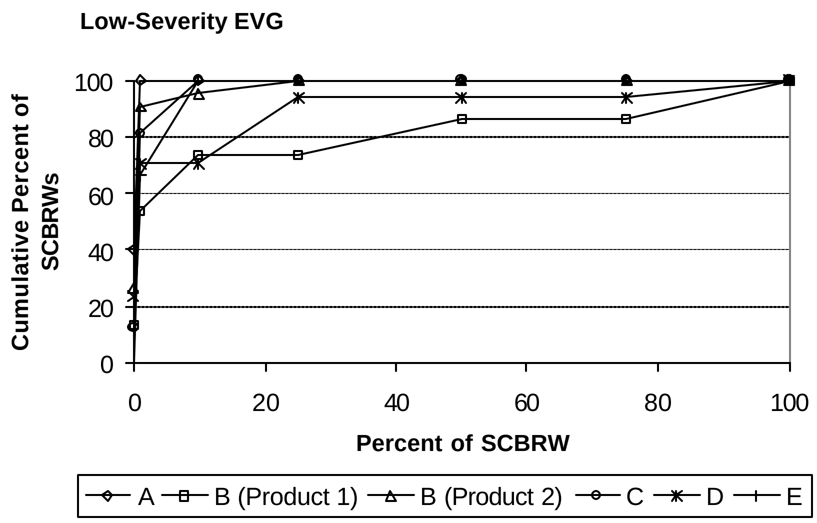



c. Low-Severity Efflorescence

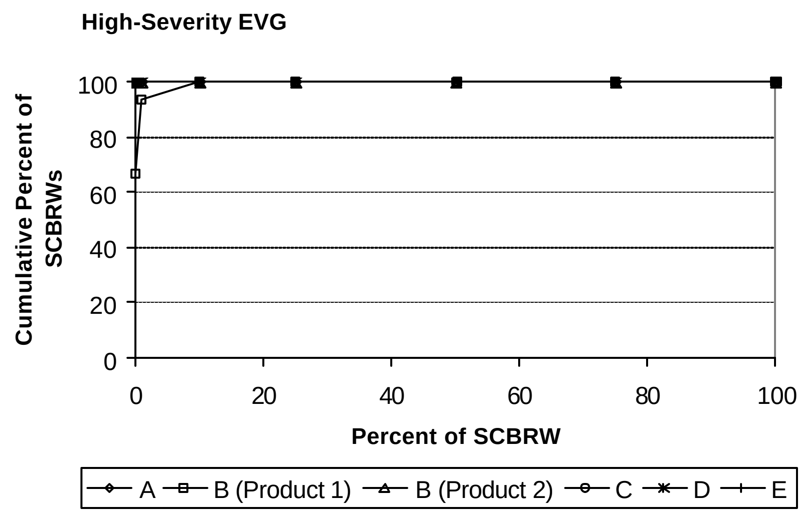



d. Medium-Severity Efflorescence

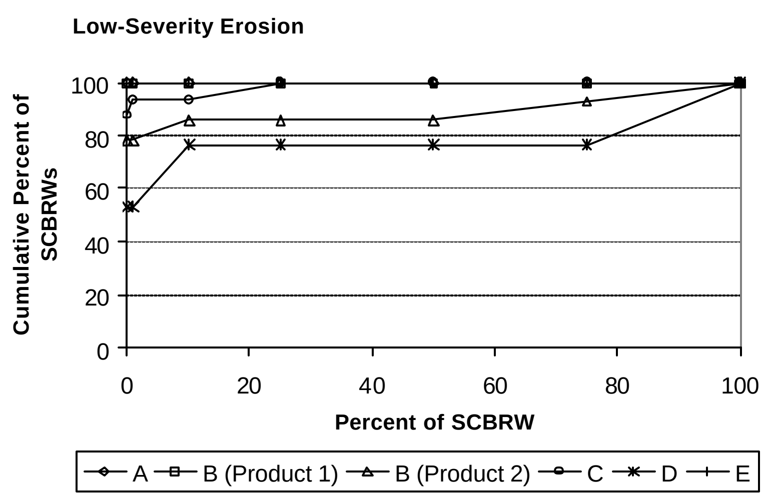
Figure 4.61. Cumulative percent of SCBRWs constructed with each manufacturer block unit versus dependent distress types (graphs [a] – [ab]).



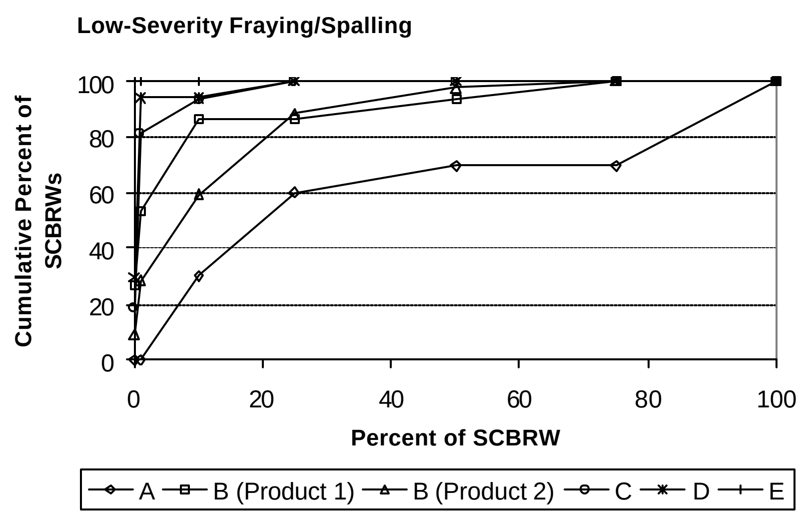

e. Low-Severity EVG




f. High-Severity EVG

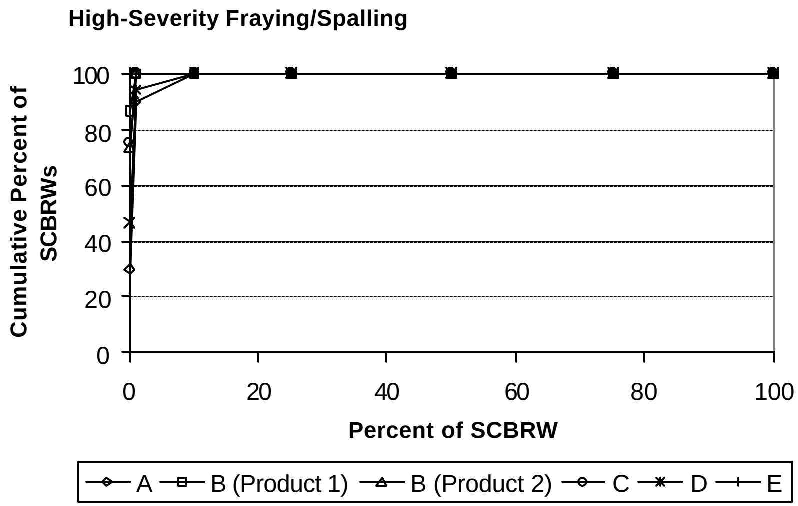



g. Low-Severity Erosion

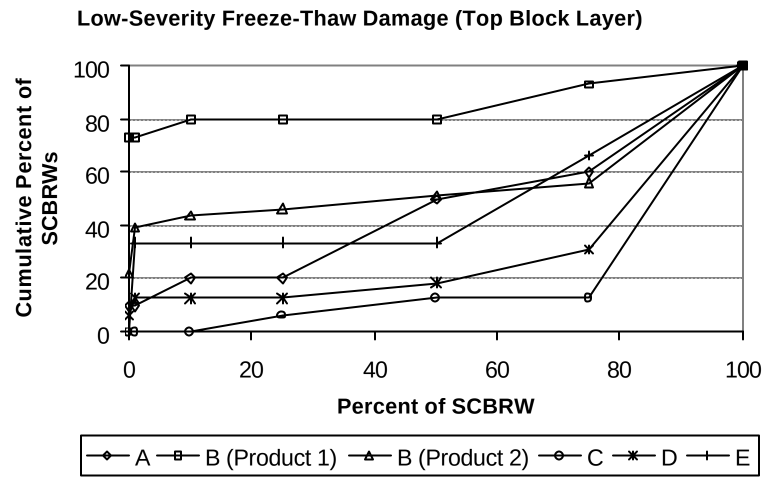



h. Low-Severity Fraying/Spalling

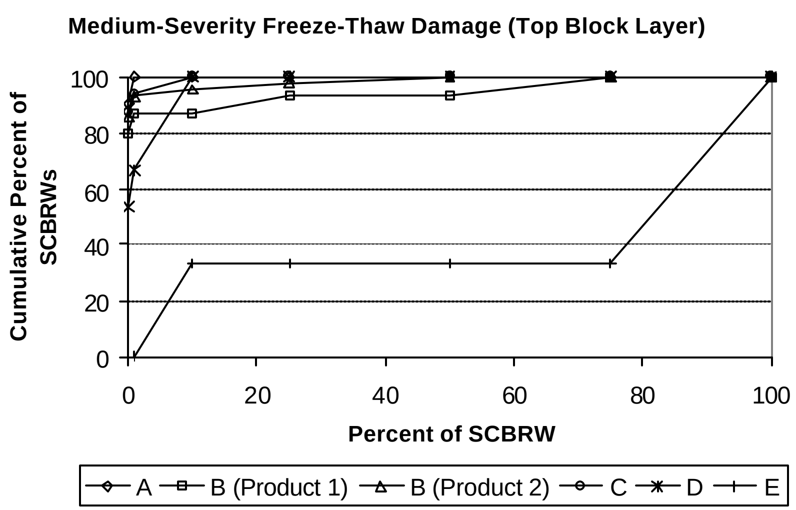
Figure 4.61. Cumulative percent of SCBRWs constructed with each manufacturer block unit versus dependent distress types (graphs [a] – [ab]) (continued).



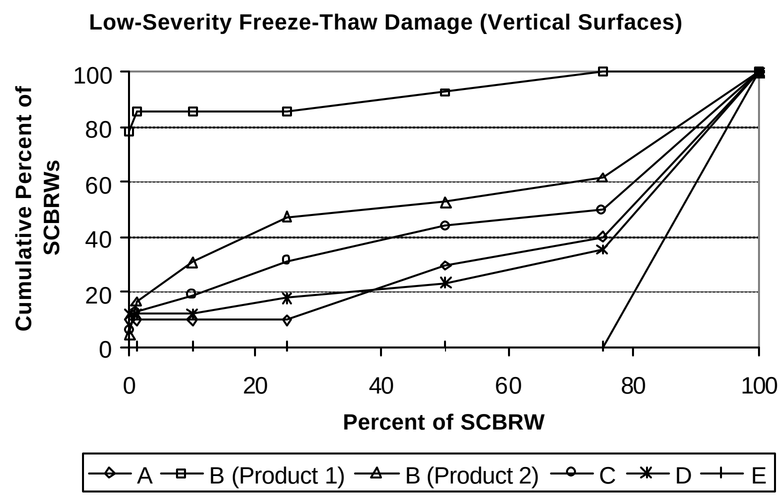

i. High-Severity Fraying/Spalling




j. Low-Severity Freeze-Thaw Damage (Top Block Layer)

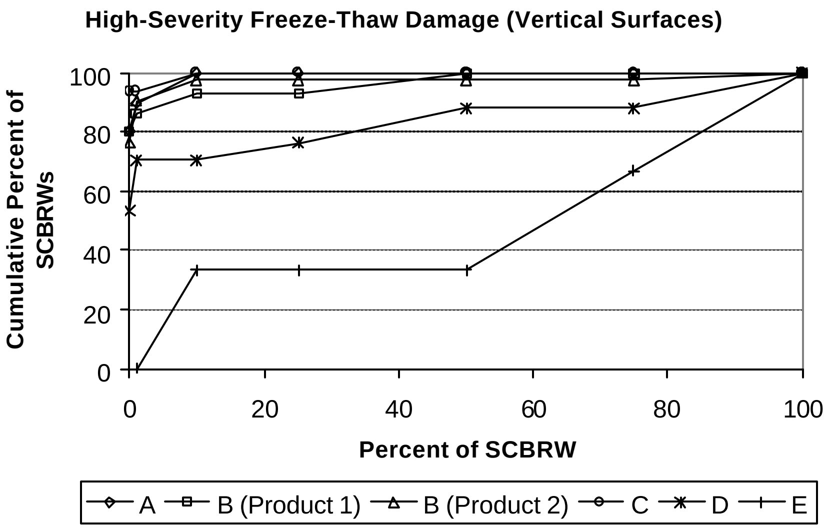



k. Medium-Severity Freeze-Thaw Damage (Top Block Layer)

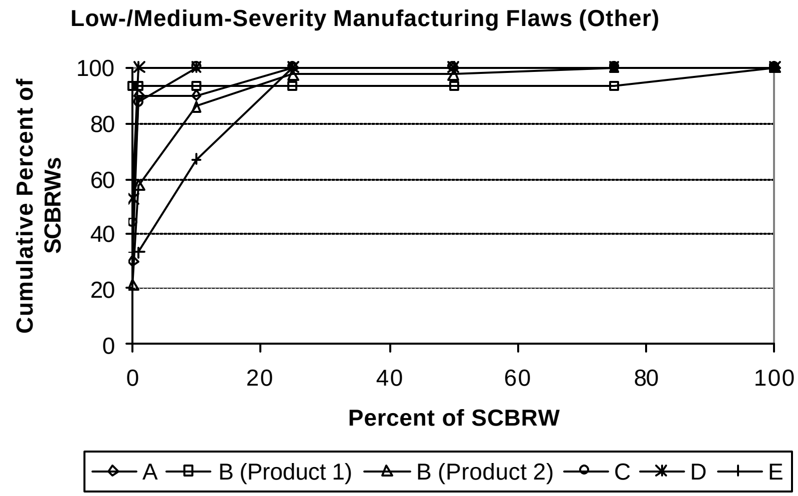



l. Low-Severity Freeze-Thaw Damage (Vertical Surfaces)

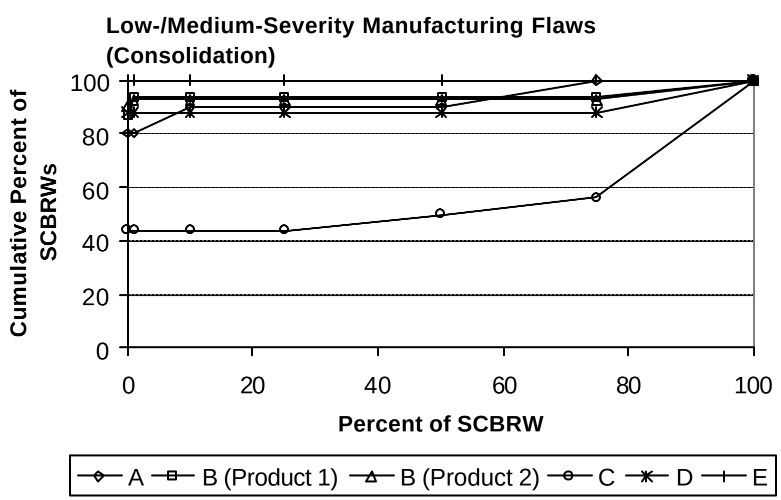
Figure 4.61. Cumulative percent of SCBRWs constructed with each manufacturer block unit versus dependent distress types (graphs [a] – [ab]) (continued).



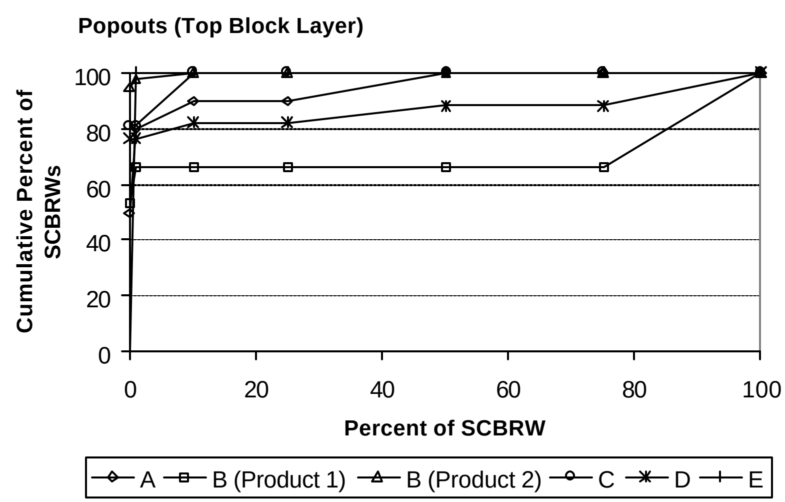

m. High-Severity Freeze-Thaw Damage (Vertical Surfaces)




n. Low-/Medium-Severity Manufacturing Flaws (Other)

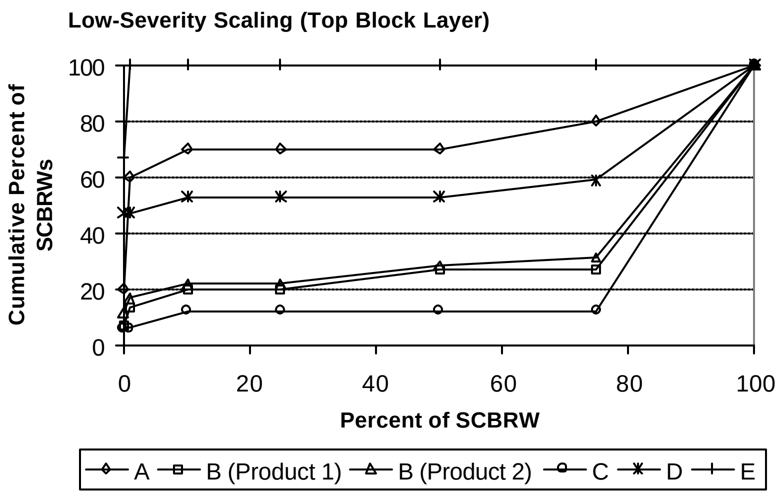



o. Low-/Medium-Severity Manufacturing Flaws (Consolidation)

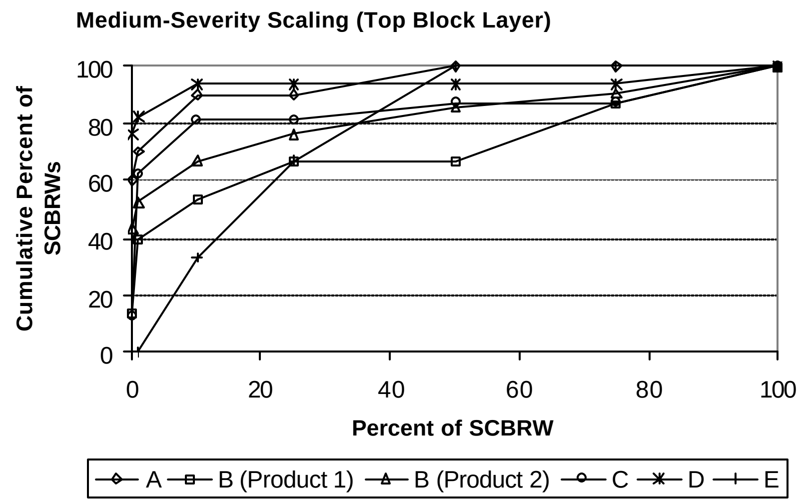



p. Popouts (Top Block Layer)

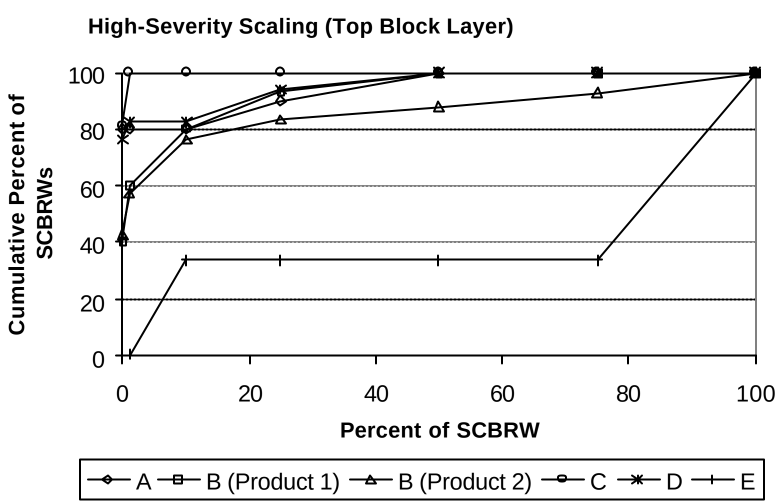
Figure 4.61. Cumulative percent of SCBRWs constructed with each manufacturer block unit versus dependent distress types (graphs [a] – [ab]) (continued).



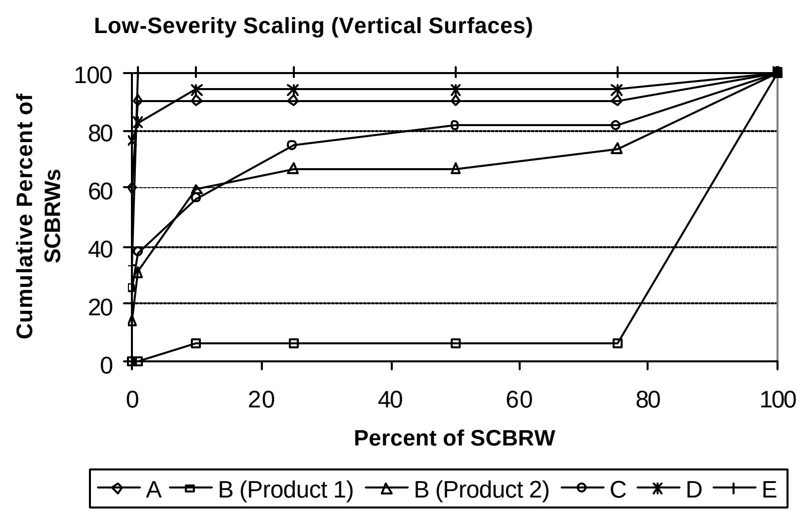

q. Low-Severity Scaling (Top Block Layer)




r. Medium-Severity Scaling (Top Block Layer)

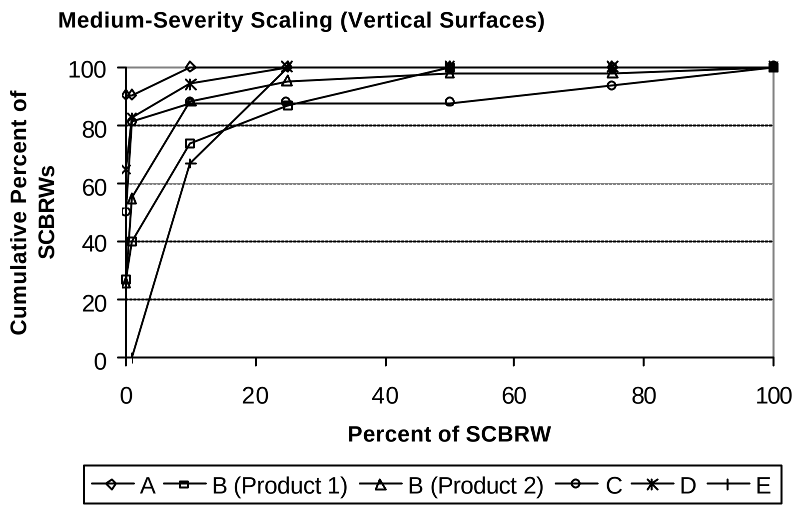



s. High-Severity Scaling (Top Block Layer)

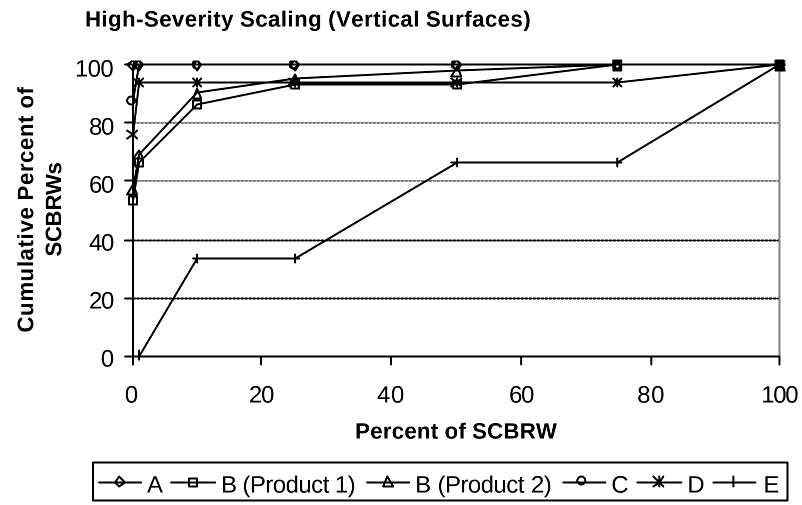



t. Low-Severity Scaling (Vertical Surfaces)

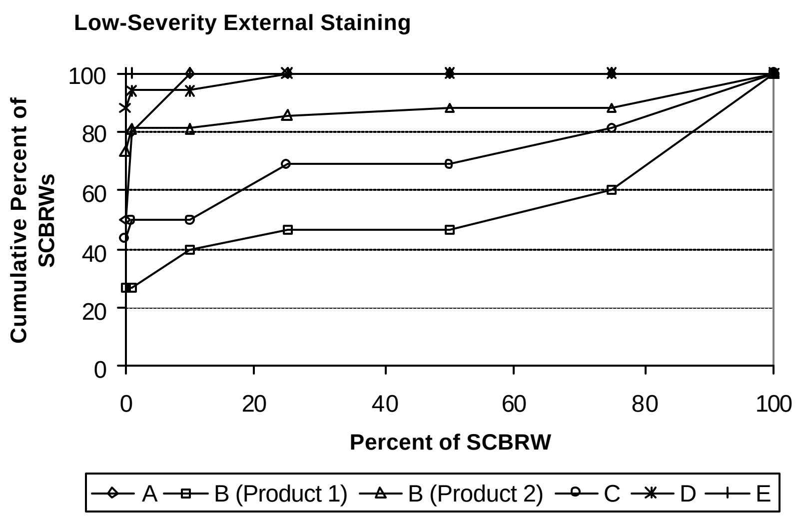
Figure 4.61. Cumulative percent of SCBRWs constructed with each manufacturer block unit versus dependent distress types (graphs [a] – [ab]) (continued).



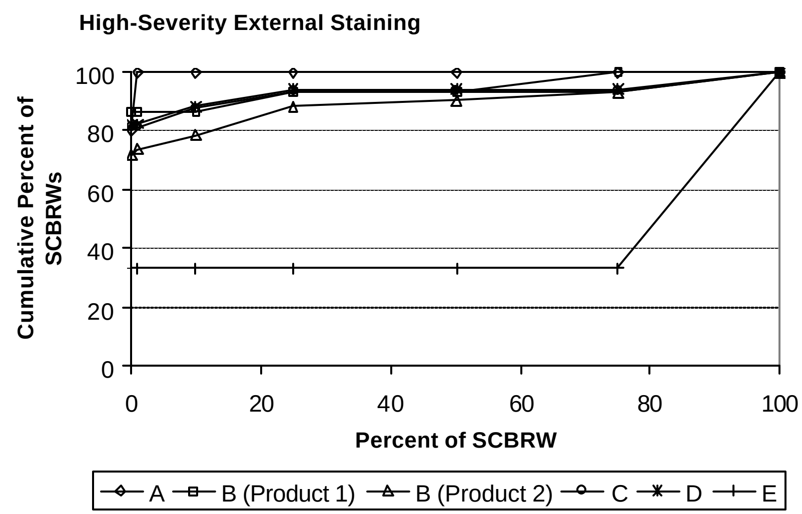

u. Medium-Severity Scaling (Vertical Surfaces)




v. High-Severity Scaling (Vertical Surfaces)

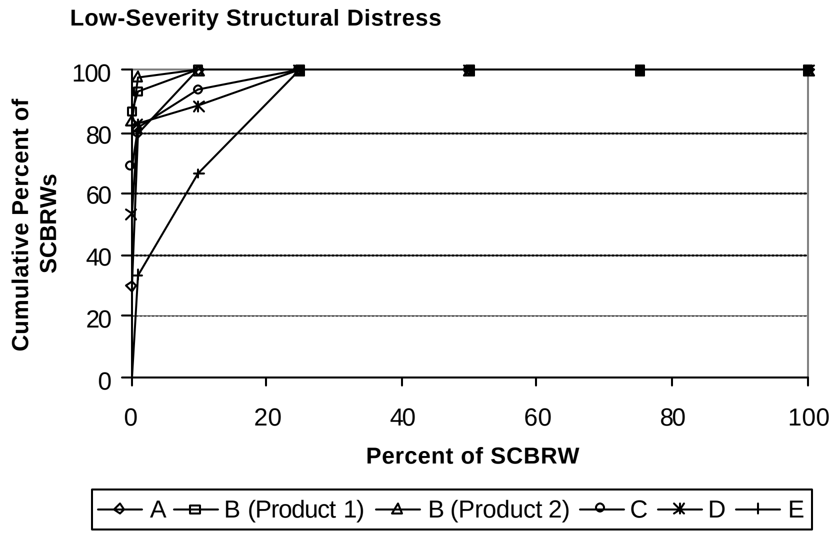



w. Low-Severity External Staining

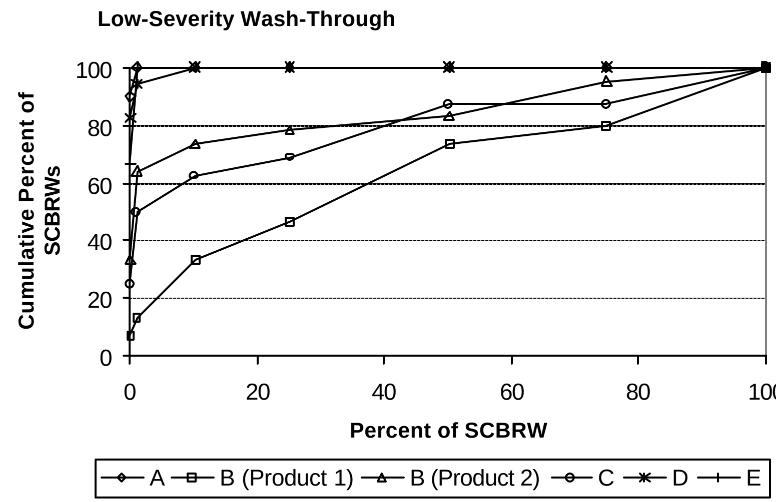



x. High-Severity External Staining

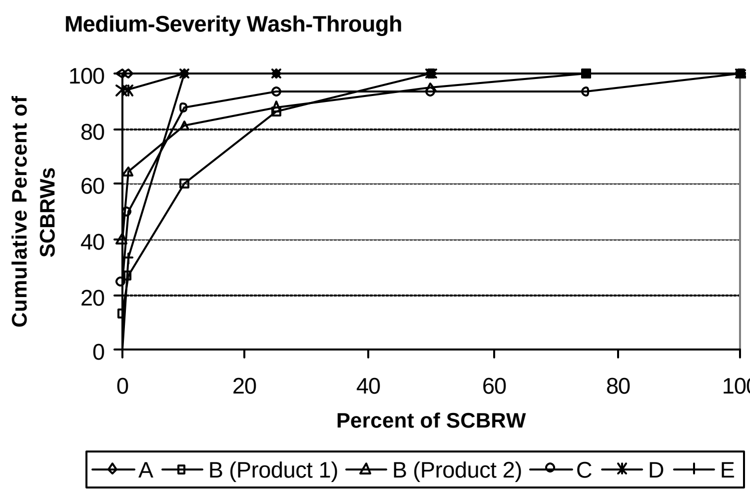
Figure 4.61. Cumulative percent of SCBRWs constructed with each manufacturer block unit versus dependent distress types (graphs [a] – [ab]) (continued).



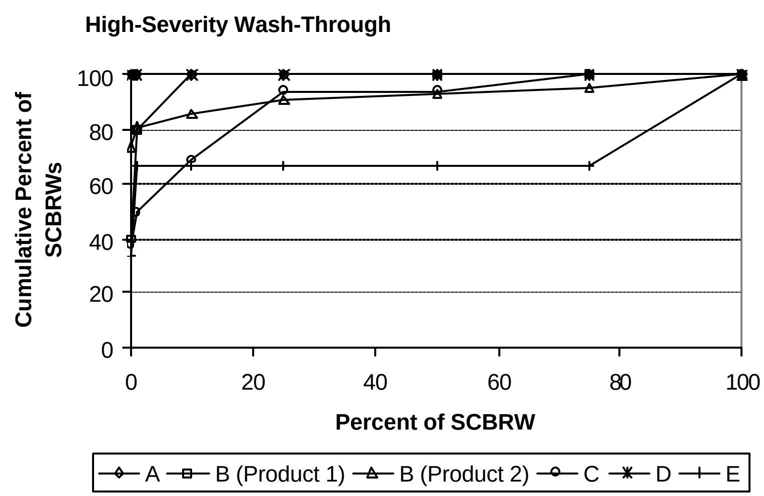

y. Low-Severity Structural Distress




z. Low-Severity Wash-Through




aa. Medium-Severity Wash-Through




ab. High-Severity Wash-Through

Figure 4.61. Cumulative percent of SCBRWs constructed with each manufacturer block unit versus dependent distress types (graphs [a] – [ab]) (continued).

## 4.3 Peak Winter Survey Results

The data collected from the peak winter survey, as described in section 3.2.3 for Dakota county, Hennepin county, Mn/DOT and privately owned SCBRWs, are listed in tables G-1 through G-3, G-4 through G-6, G-7 through G-9 and G-10 through G-12, respectively (see appendix G). In order to determine the overall peak winter survey conditions, the data were analyzed and presented to reflect percentages of SCBRWs surveyed (normalized for total number of walls). The normalized data for Dakota county, Hennepin county, Mn/DOT and privately owned SCBRWs are presented in figures H-1, H-2, H-3 and H-4, respectively. Figure H-5 lists the normalized data for the SCBRWs grouped as a whole (normalized for the total number of walls surveyed [i.e., total number of walls = Hennepin county + Dakota county + Mn/DOT + privately owned SCBRWs]).

The peak winter condition survey could not be performed on all SCBRWs included in the general distress condition surveys due to the short and mild 1998 – 2000 winters during which snowfall accumulations were well below normal. The peak winter condition survey was not performed on the following 8 SCBRWs:

- CSAH 42 and Grove Street, East and West Side of Road (Dakota County)
- I35W/I94, NW of Ramp (Mn/DOT)
- I94 and Western Ave (Mn/DOT)
- TH9 and New London, Minnesota, North and South Side of Road (Mn/DOT)
- I90 Hayward Rest Area, Northern and Southern Wall, (Mn/DOT)

### 4.3.1 Peak Daytime Winter Sunlight Exposure

Peak daytime winter sunlight exposure for the top block layer and vertical surfaces was present on 99 and 73 percent of SCBRWs surveyed, respectively. Vertical surface sunlight exposure was partially to completely indirect for 48 percent of the SCBRWs surveyed with vertical surface sunlight exposure. The percent of SCBRWs surveyed versus the percent of SCBRW area exposed to peak daytime winter sunlight exposure is presented in figure 4.62. The amount of winter sunlight exposure is of concern, since it affects the number of freezing and thawing cycles to which the block units are subjected during peak winter conditions.

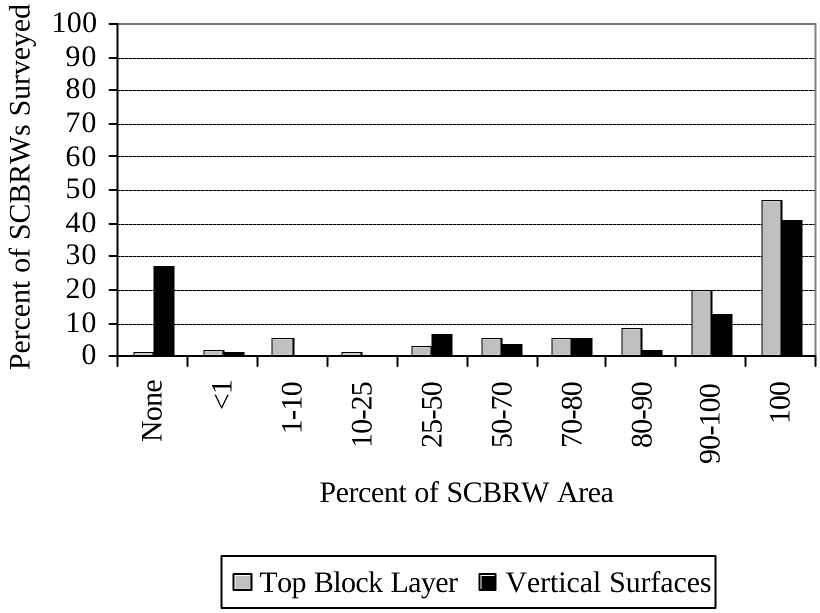



Figure 4.62. Percentage of SCBRWs observed with peak daytime winter sunlight exposure.

### 4.3.2 Snow Accumulation Containing Deicing Sand/Salt

Snow accumulation containing deicing sand/salt was observed on the top block layer and vertical surfaces of 86 and 73 percent of SCBRWs surveyed, respectively. The percent of SCBRWs surveyed versus the percent of SCBRW length exposed to snow accumulation containing deicing sand/salt is presented in figure 4.63. The exposure of the masonry block units to deicing salts can accelerate freeze-thaw damage (salt-saturated water is more readily absorbed into concrete, resulting in higher levels of saturation). In addition, the crystallization of salt in the concrete pores as the water evaporates may also produce damage stresses and deterioration.

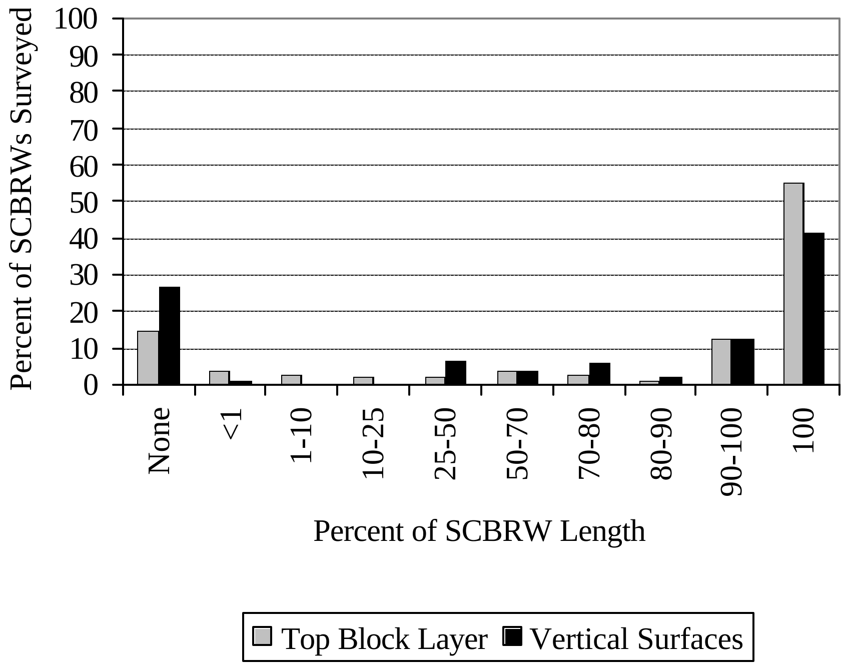



Figure 4.63. Percentage of SCBRWs observed with snow accumulation containing deicing sand/salt.

### 4.3.3 Type of Snow Removal

The percent of SCBRWs surveyed versus the type of snow removal near the wall is presented in figure 4.64. Mainline, sidewalk, parking lot and driveway snow removal was present at 85, 78, 16 and 25 percent of the SCBRWs surveyed, respectively. The type of snow removal adjacent to a SCBRW affects the amount of snow accumulation and type of snow (i.e., concentration of deicing salts) to which the SCBRW is exposed.

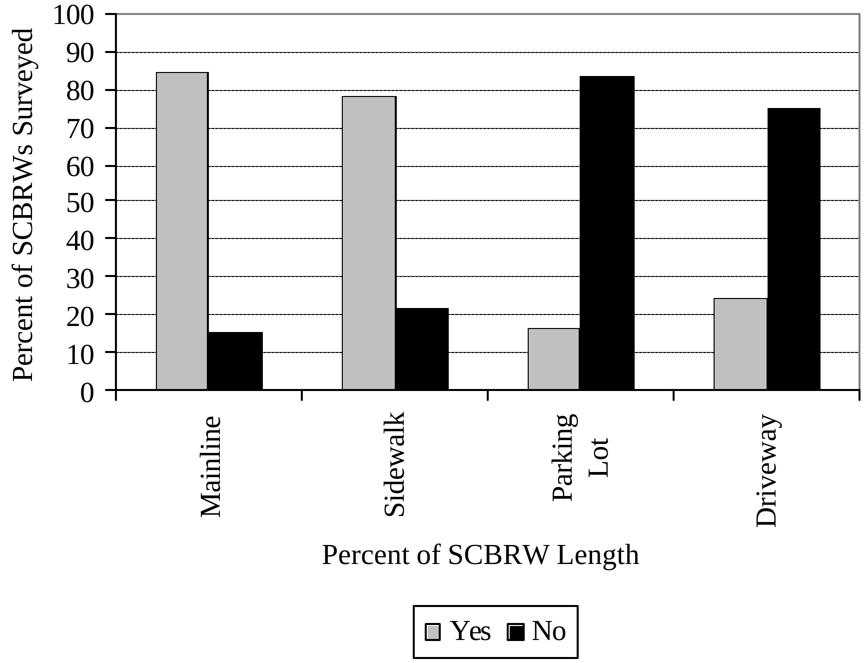



Figure 4.64. Type of snow removal used around SCBRW.

4.3.4 Snow Removal Accumulations

The percentage of SCBRWs surveyed and exposed to snow removal accumulations is presented in figure 4.65. Snow removal accumulations were present on the top block layer and vertical surfaces of 77 and 84 percent of the SCBRWs surveyed, respectively. This type of snow often contains deicing chemicals, which can accelerate freeze-thaw damage as discussed earlier.

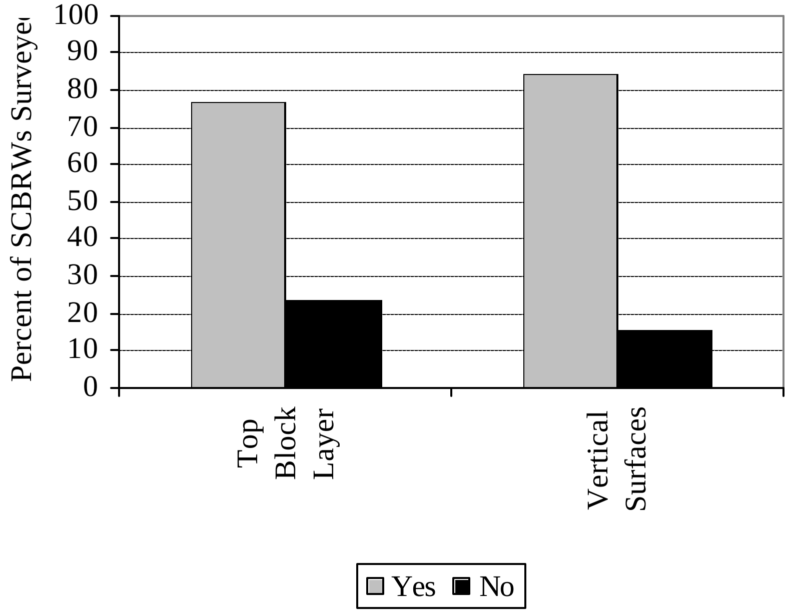



Figure 4.65. Percentage of SCBRWs observed with snow removal accumulations.

Figure 4.66 presents a photo illustrating how the offset distance of SCBRW vertical surfaces and the type of snow removal near the wall affects the amount of snow and quantity of deicing sand/salt in the snow accumulation on or adjacent to the SCBRW. For the case illustrated in this photo, mainline snow removal is the only type of snow removal present. Snow accumulation containing a high quantity of deicing sand/salt snow is located approximately 4 to 5 ft away from the vertical surfaces. Therefore, the vertical surfaces are exposed to only a minimal amount of snow accumulation with deicing chemicals. The snow accumulation on 25-50 percent of the top block layer is due to the snow removal from the residential roadway behind the SCBRW. As illustrated in the photo, the guardrail present behind the top block layer allows a larger amount of snow to accumulate on the capstone.

Figure 4.66. Photo illustrating the effect of the type of snow removal and offset distance on snow accumulation and quantity of deicing chemicals (SE Quadrant of Pilot Knob and Cliff Road).

### 4.3.5 Fence (or Other Obstruction) Behind SCBRW

Fifty percent of the SCBRWs surveyed have a fence constructed behind the top block layer. The type and location of fencing often affects the amount of snow accumulation on the top block layer, which in turn, affects the degree of saturation to which the masonry block units are exposed. Figures 4.66 – 4.67 illustrate the increased snow accumulation due to fencing (or a guardrail, as illustrated in figure 4.66) constructed immediately behind the SCBRW. In addition, the effect of the type of snow removal on snow accumulation can be seen in figure 4.67. For this case, there was both mainline and sidewalk snow removal near the wall. The snow on the sidewalk was removed using a plow, which resulted in the packing of snow against the vertical surfaces, as illustrated in the photo for the bottom 3 ft of the SCBRW.

Figure 4.67. Photo illustrating the effect of fencing on snow accumulation (CSAH 101 and 87th Place [west SCBRW]).

4.3.6 Visual Rating of Quantity of Deicing Sand/Salt in Snow Accumulation

As previously described in section 3.2.3 “Stage 3 (Peak Winter Survey), the quantity of deicing sand/salt in the snow accumulation on the top block layer and adjacent to the vertical surfaces was visually rated as low, medium or high. Figures 4.68, 4.69 and 4.70 present photos illustrating typical concentrations classified as low, medium and high, respectively. It appears that 18, 12 and 70 percent of the SCBRWs are exposed to snow accumulation containing low, medium and high concentrations of deicing agent, respectively, on the top block layer; 9, 14 and 77 percent of the SCBRWs surveyed are exposed to low, medium and high concentrations, respectively, of deicing agent on the vertical surfaces (see figure 4.71).

Figure 4.68. Photo illustrating low quantity of deicing sand/salt in snow accumulation (CSAH 101 and 82nd Ave. N).

Figure 4.69. Photo illustrating medium quantity of deicing sand/salt in snow accumulation (CSAH 10 and Jonquil).

Figure 4.70. Photo illustrating high quantity of deicing sand/salt in snow accumulation (CSAH 38 and Gardenview).

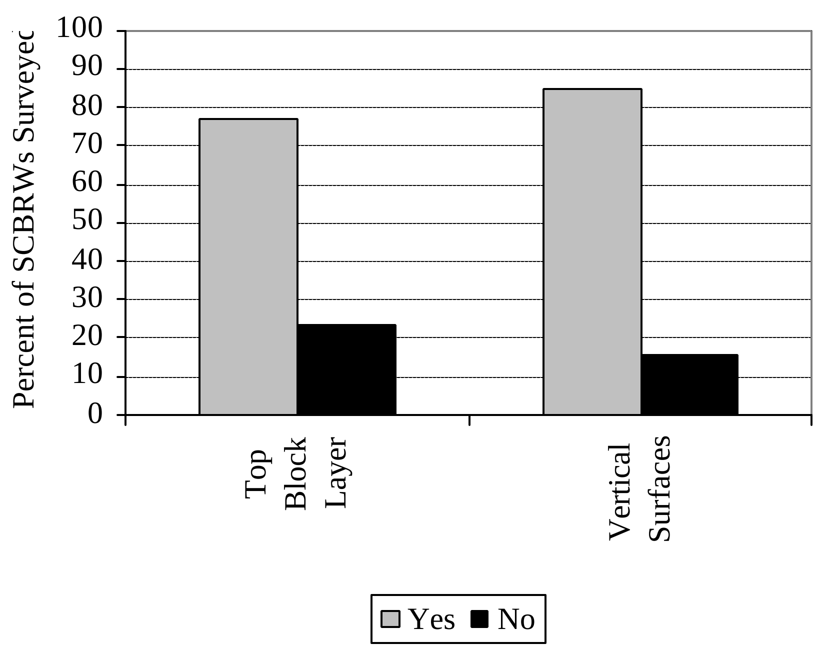



Figure 4.71. Visual rating of quantity of deicing sand/salt contained in snow accumulation on SCBRWs surveyed.

## 4.4 Effect of External Factors on Durability Damage

### 4.4.1 Description of Analyses

As used for the previous statistical dependence analyses, the GLM (General Linear Model) multivariate procedure was used to look at the analysis of variance for multiple dependent variables (e.g., low-severity scaling) by one or more factor (fixed) variables (e.g., offset distance, wall vertical surface direction, etc.). Through this procedure, the null hypothesis concerning the effects of factor variables on the means of various groupings (effects of individual factors) was tested along with the interactions between factors (SPSS, 1999).

The analysis of variance was performed on the following fixed and dependent variables that were expected to affect the frost resistance of the block units:

*Fixed Variables*

- F/C Offset Distance:

  Freeze-thaw related deterioration is expected to increase with decreased F/C distance, due to the potentially larger amount of snow accumulation and exposure to deicing chemicals.
- Peak Daytime Winter Sunlight Exposure:

  Freeze-thaw related deterioration is anticipated to increase with increased sunlight exposure, due to the potential for increased numbers of freeze-thaw cycles with increased sunlight exposure.
- Vertical Surface Facing Direction (i.e., north, south, east, west):

  Freeze-thaw related deterioration is anticipated to increase with increased sunlight exposure, due to the potential for increased numbers of freeze-thaw cycles. For instance, it is most likely that walls facing the south would be observed with larger amounts of freeze-thaw deterioration than those facing the north.
- Snow Removal Accumulation (Yes or No):

  Freeze-thaw related deterioration is expected to increase with increased snow accumulation, due to the increased availability of moisture.

- Visual Rating of the Quantity of Deicing Sand/Salt Contained in Snow Accumulation (Low, Medium, High):

  Freeze-thaw related deterioration is anticipated to increase with increased quantity of deicing chemicals, due to the increased saturation rate of the concrete pores caused by the deicing chemicals and the stresses caused by the crystallization of salts in the pores.
- Snow Accumulations Containing Deicing Sand/Salt:

  Freeze-thaw related deterioration is anticipated to increase with increased quantity of deicing chemicals, due to the increased saturation rate of the concrete pores caused by the deicing chemicals and the stresses caused by the crystallization of salts.
- Fencing (or Other Obstruction) behind SCBRW (Yes or No):

  Freeze-thaw related deterioration would most likely increase with the presence of fencing (or other obstruction) behind the SCBRW, due to the potential for increased snow accumulation on the top block layer.

*Dependent Variables*

- Low-, Medium- and High-Severity Freeze-Thaw Damage (Top Block Layer)
- Low-, Medium- and High-Severity Freeze-Thaw Damage (Vertical Surfaces)
- Low-, Medium- and High-Severity Scaling (Top Block Layer)
- Low-, Medium- and High-Severity Scaling (Vertical Surfaces)
- Low-, Medium- and High-Severity Position Guide Damage
- Low-, Medium- and High-Severity External Staining

In addition to the above main effect terms, the following two-way interactions were investigated:

- F/C Offset Distance * Vertical Surface Direction
- F/C Offset Distance * Snow Removal Accumulation
- F/C Offset Distance * Visual Rating of Quantity of Deicing Sand/Salt Contained in Snow Accumulation
- F/C Offset Distance * Snow Containing Deicing Sand/Salt
- F/C Offset Distance * Peak Daytime Winter Sunlight Exposure

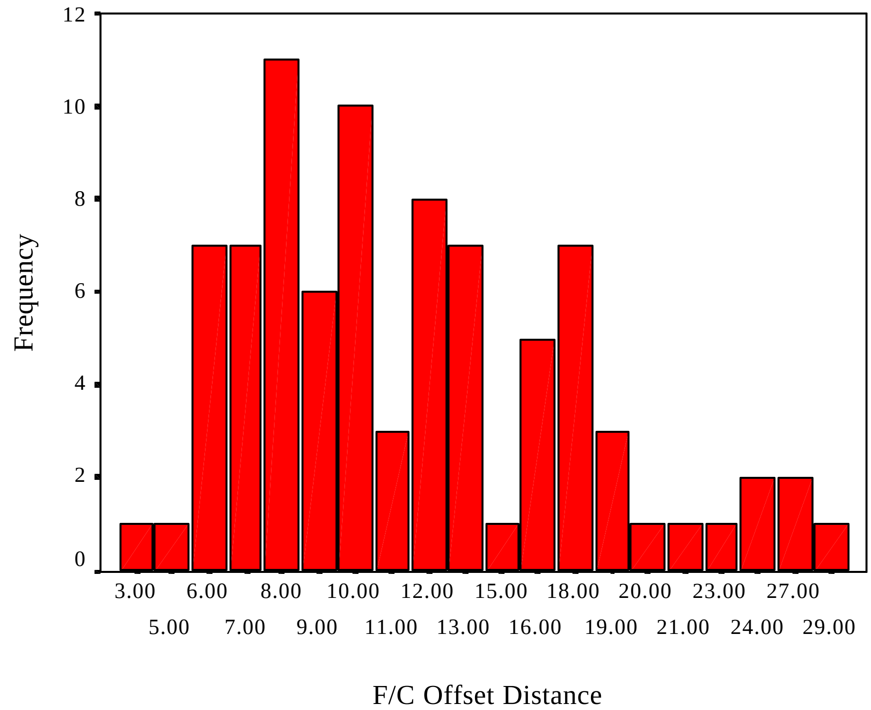
- F/C Offset Distance * Fencing (or Other Obstruction) behind SCBRW
- Visual Rating of Quantity of Deicing Sand/Salt Contained in Snow Accumulation * Vertical Surface Direction
- Visual Rating of Quantity of Deicing Sand/Salt Contained in Snow Accumulation * Peak Daytime Winter Sunlight Exposure

Some two-way interactions were not investigated due to redundancies in the effects measured or observed for given factors. For instance, the effects of snow containing deicing sand/salt is reflected in the visual rating of the quantity of deicing sand/salt contained in the snow accumulation on or immediately adjacent to the SCBRW. Therefore, this two-way interaction effect was not investigated.

Three-way or larger interactions between factors could not be investigated due to the limited degrees of freedom in the analysis. In addition, two-way interactions between factors could not be performed when looking at position guide damage (for walls with guides on the front face of the block units) due to the small sample of walls containing these guides and, therefore, the insufficient number of degrees of freedom.

### 4.4.2 Analyses of Variance

Figures 4.72 and 4.73 present bar graphs illustrating the number (frequency) of surveyed walls versus the offset distance and vertical surface direction, respectively. (The percentage of SCBRWs with respect to the other fixed variables has already been presented in section 4.2 "Peak Winter Survey Results".) As illustrated in figure 4.72, there are a minimal number of walls surveyed at F/C offset distances of 3, 5, 11, 15 and 19 – 29 ft. This limited representation of these distances could bias the outcome of trends observed.




*The F/C offset distance was unknown for 30 (26 percent) of the SCBRWs surveyed.

Figure 4.72. Number of surveyed walls versus the F/C Offset Distance.

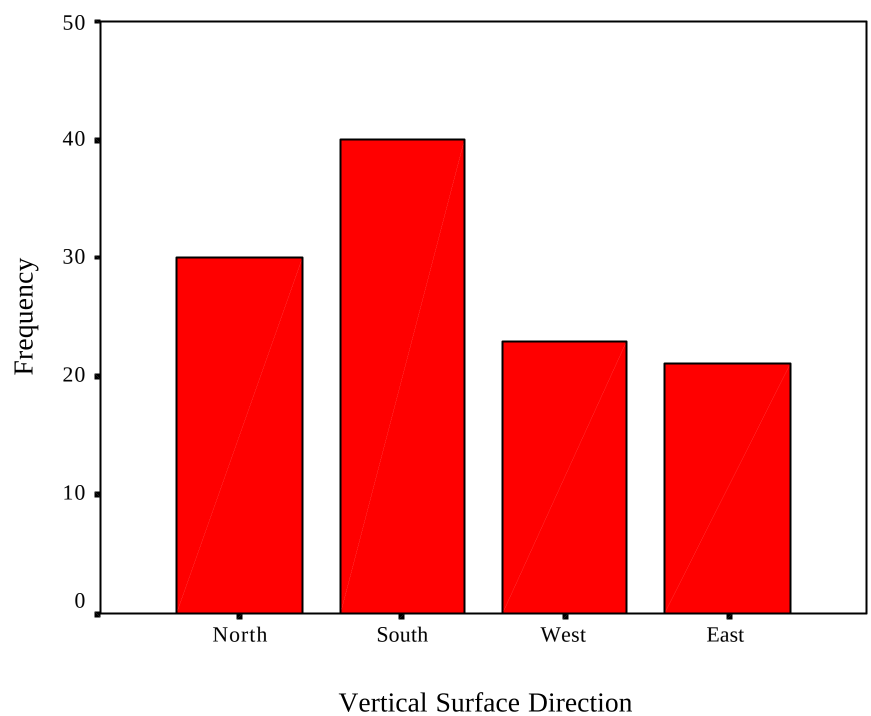



Figure 4.73. Number of surveyed walls versus the vertical surface direction.

Statistical analyses were performed at a 95 percent confidence level on the data collected for the above dependent and fixed variables. The following distress types were found dependent on the specified main effect or interaction terms.

Main Effect: F/C Offset Distance

- Low-Severity Scaling (Top Block Layer)
- Low-Severity Freeze-Thaw Damage (Top Block Layer)

Main Effect: Vertical Surface Direction

- Low-Severity Freeze-Thaw Damage (Top Block Layer)
- Low-Severity Freeze-Thaw Damage (Vertical Surfaces)

Main Effect: Snow Accumulation Containing Deicing Sand/Salt

- Low-Severity External Staining

Two-Way Interaction: F/C Offset Distance * Vertical Surface Direction

- Low-Severity External Staining

Two-Way Interaction: F/C Offset Distance * Snow Removal Accumulation

- Low-Severity External Staining

Two-Way Interaction: F/C Offset Distance * Visual Rating of Quantity of Deicing Sand/Salt Contained in Snow Accumulation

- Low-Severity External Staining

Two-Way Interaction: F/C Offset Distance * Snow Containing Deicing Sand/Salt

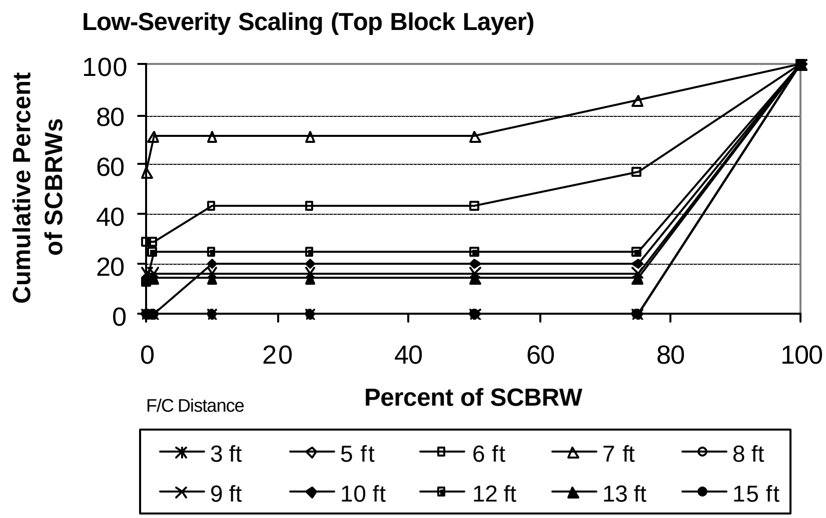
- Medium-Severity Scaling (Vertical Surfaces)
- Low-Severity External Staining

Two-Way Interaction: F/C Offset Distance * Peak Daytime Winter Sunlight Exposure

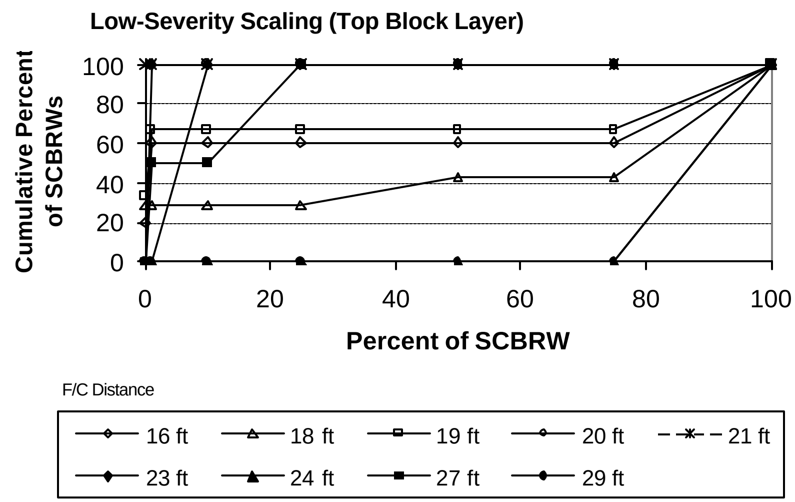
- High-Severity Scaling (Vertical Surfaces)

Figure 4.74 presents graphs (a) – (ae) illustrating the cumulative percentage of SCBRWs observed with the specified main effect or interaction terms with respect to the identification of the above listed distress types. In general, these graphs suggest a very general trend of increasing durability distress (i.e., freeze-thaw damage, scaling and position guide damage) with decreasing F/C distances and increasing incidence of deicing sand/salt exposure. Most other effects and trends are fairly weak or unclear.

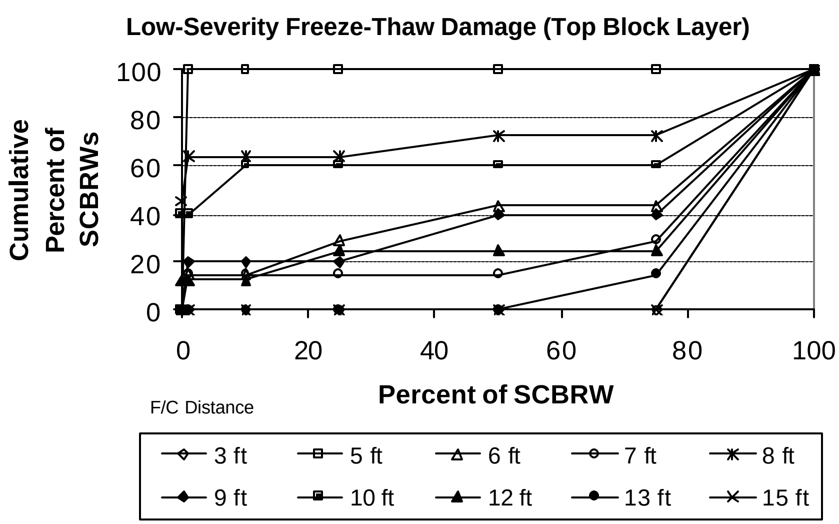
It should be noted that the incidence and severity of durability-related distresses was highly dependent upon manufacturer type (as discussed previously). A well-designed experiment (as opposed to a survey of available walls) may have found stronger effects for the other factors considered in this analysis.



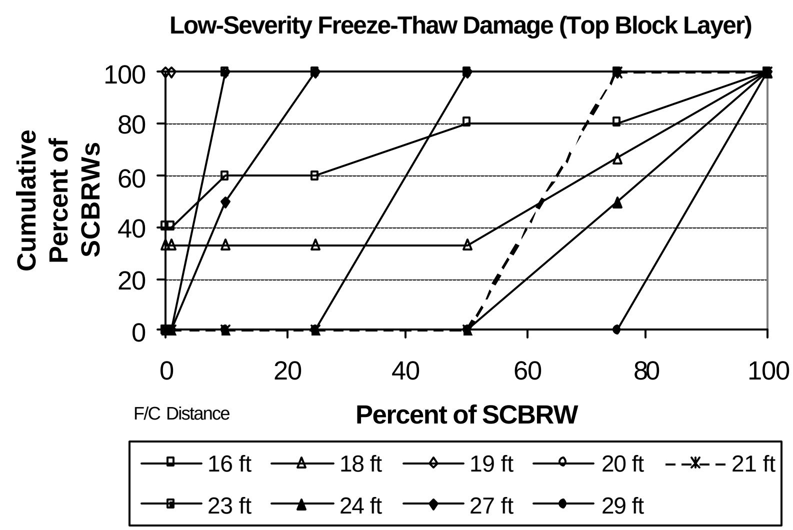

a. Effect of offset distance on low-severity freeze-thaw damage (3-15 ft).




b. Effect of offset distance on low-severity freeze-thaw damage (16-29 ft).

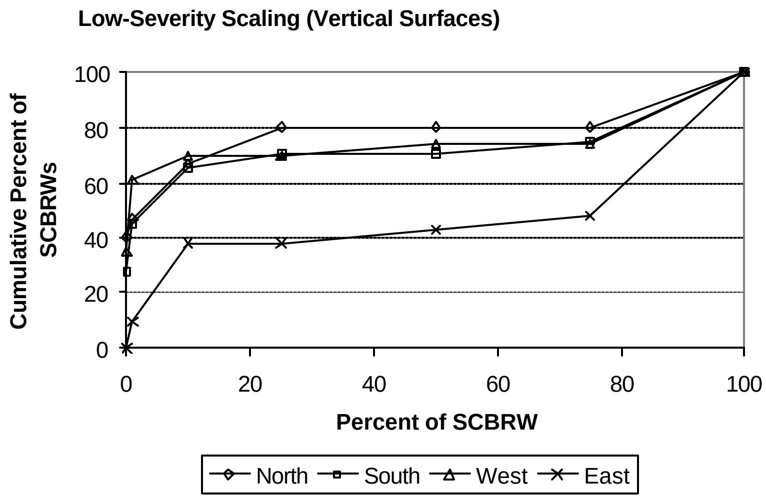



c. Effect of offset distance on low-severity freeze-thaw damage (3-15 ft).

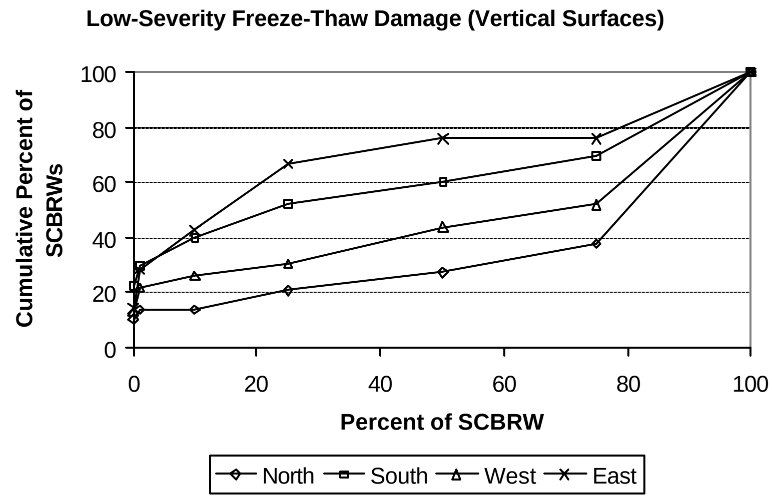



d. Effect of offset distance on low-severity freeze-thaw damage (16-29 ft).

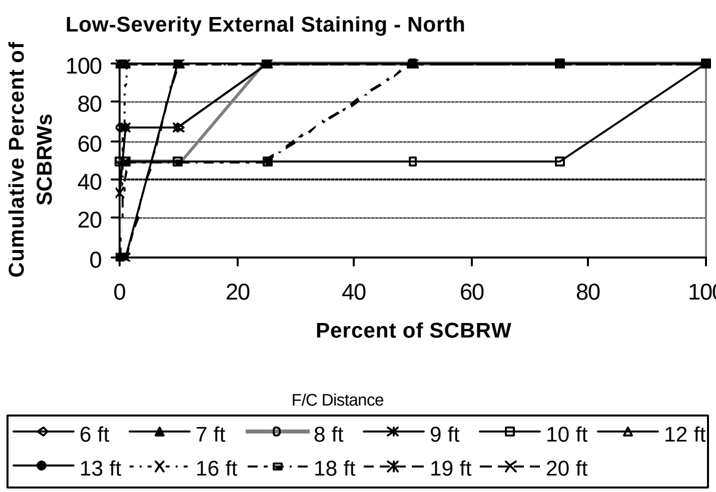
Figure 4.74. Cumulative percent of SCBRWs observed with specified main effect or interaction term versus dependent distress types (graphs [a] – [ae]).



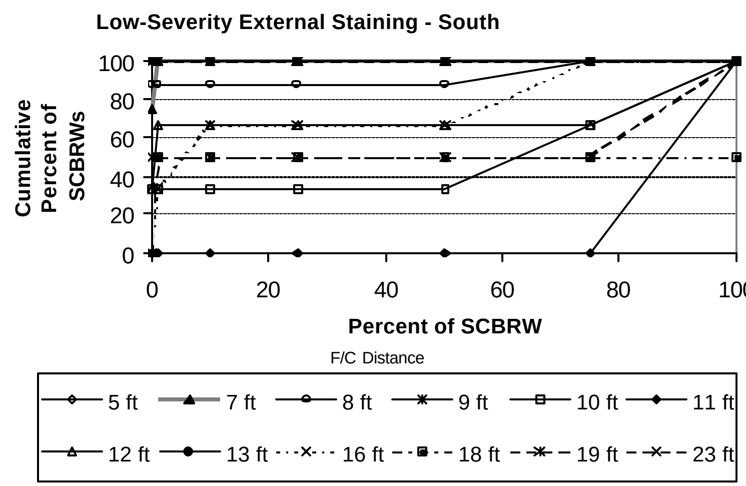

e. Effect of vertical surface direction on low-severity scaling.




f. Effect of vertical surface direction on low-severity freeze thaw damage.

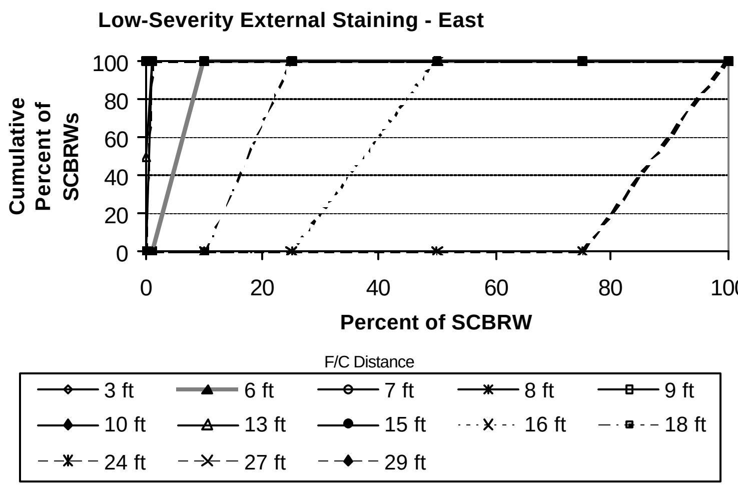



g. Interaction plot: vertical surface direction (north)*F/C distance.

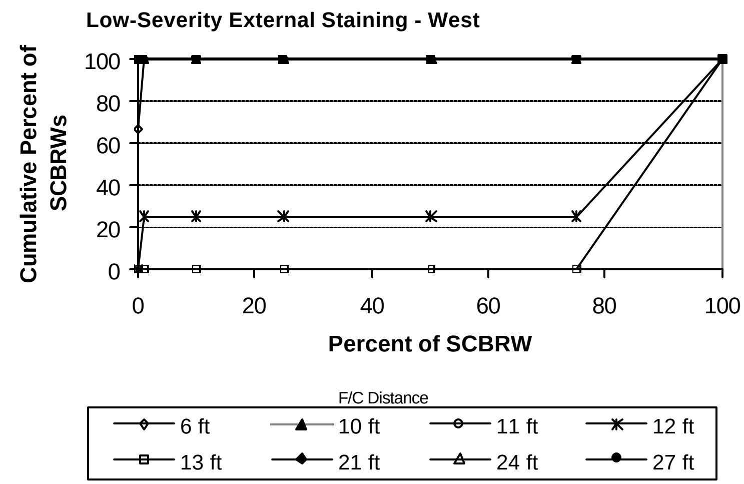



h. Interaction plot: vertical surface direction (south)*F/C distance.

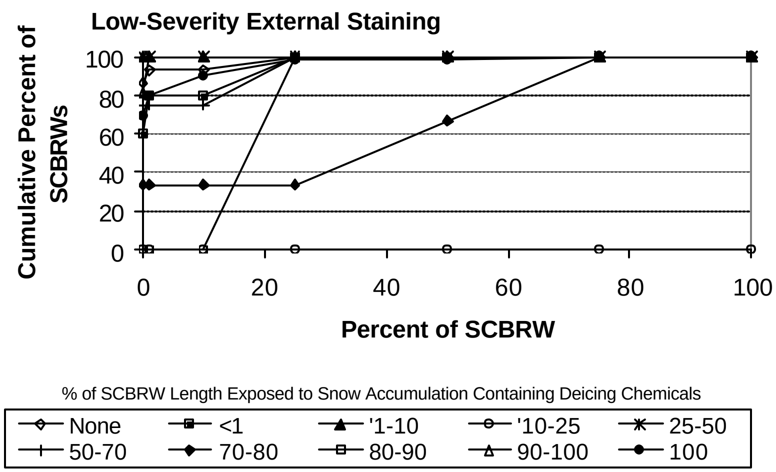
Figure 4.74. Cumulative percent of SCBRWs observed with specified main effect or interaction term versus dependent distress types (graphs [a] – [ae]) (continued).



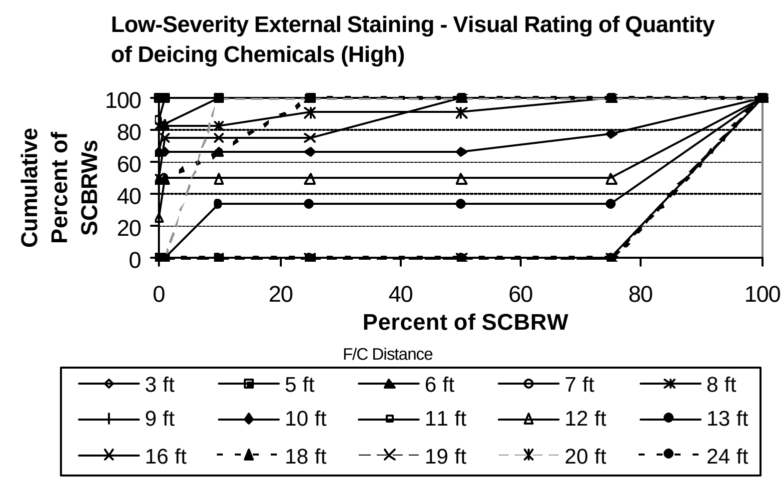

i. Interaction plot: vertical surface direction (east)*F/C distance.




j. Interaction plot: vertical surface direction (west)*F/C distance.

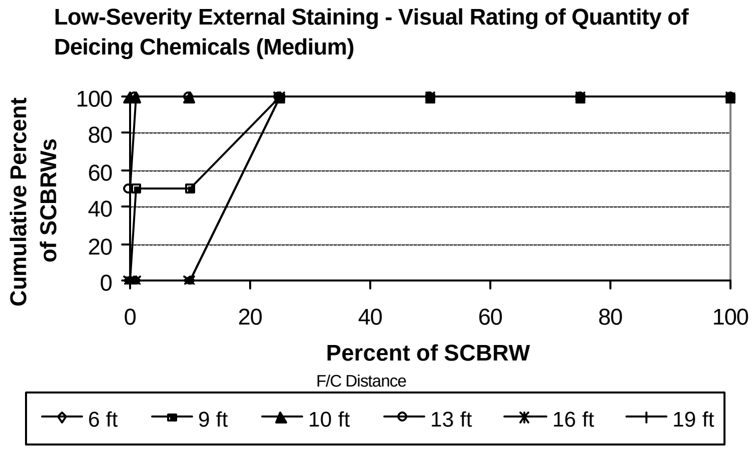



k. Effect of exposure to snow accumulation containing deicing chemicals on low-severity external staining.

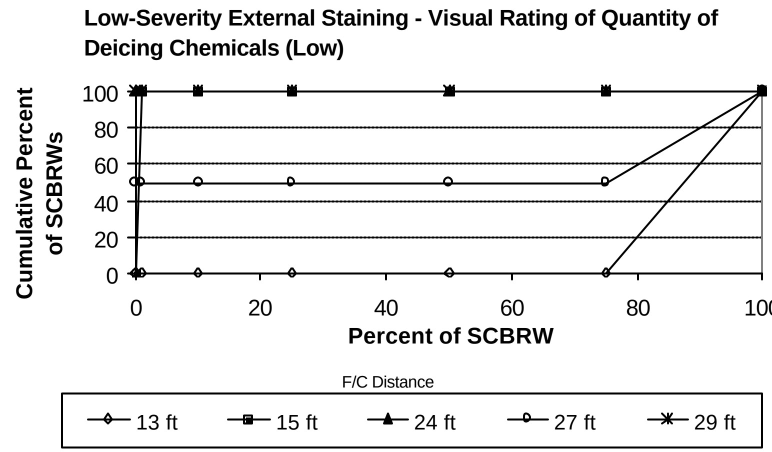



l. Interaction plot: F/C offset distance*visual rating of quantity of deicing sand/salt contained in snow accumulation (high).

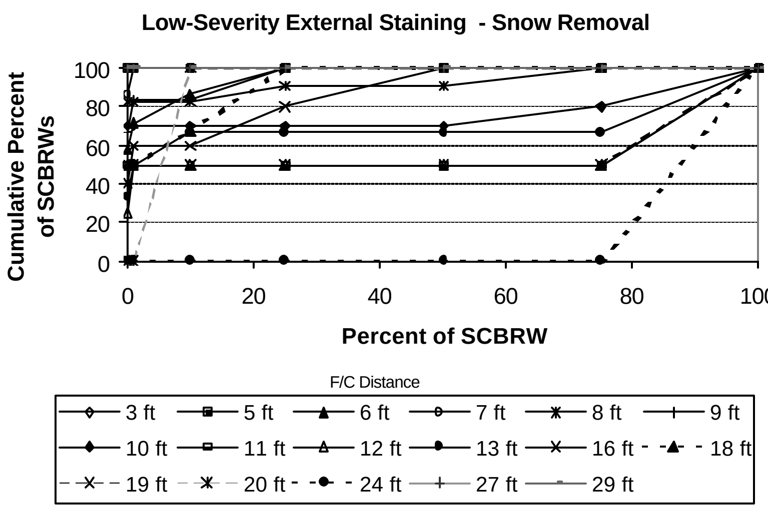
Figure 4.74. Cumulative percent of SCBRWs observed with specified main effect or interaction term versus dependent distress types (graphs [a] – [ae]) (continued).



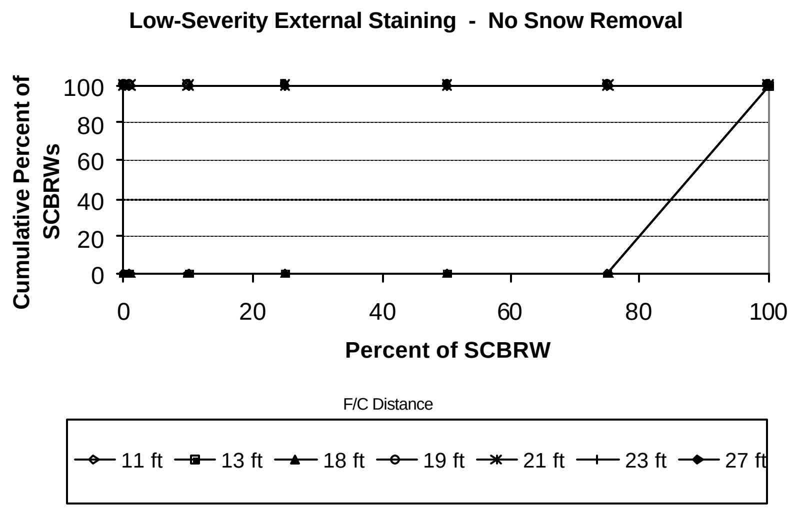

m. Interaction plot: F/C offset distance*visual rating of quantity of deicing sand/salt contained in snow accumulation (medium).




n. Interaction plot: F/C offset distance*visual rating of quantity of deicing sand/salt contained in snow accumulation (low).

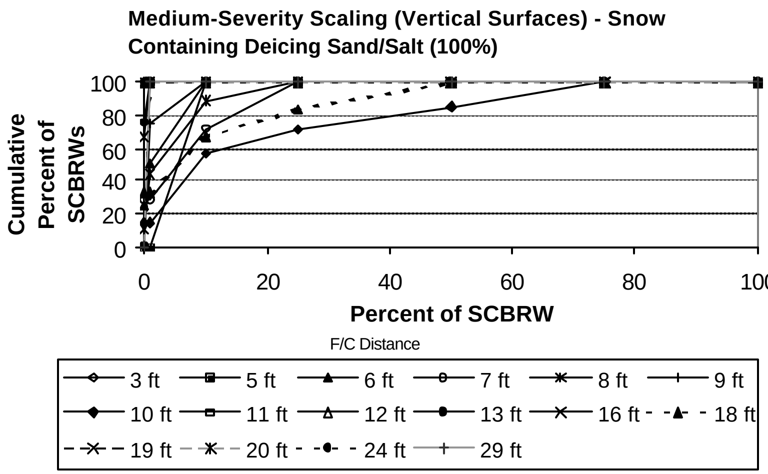



o. Interaction plot: F/C offset distance*snow removal accumulation.

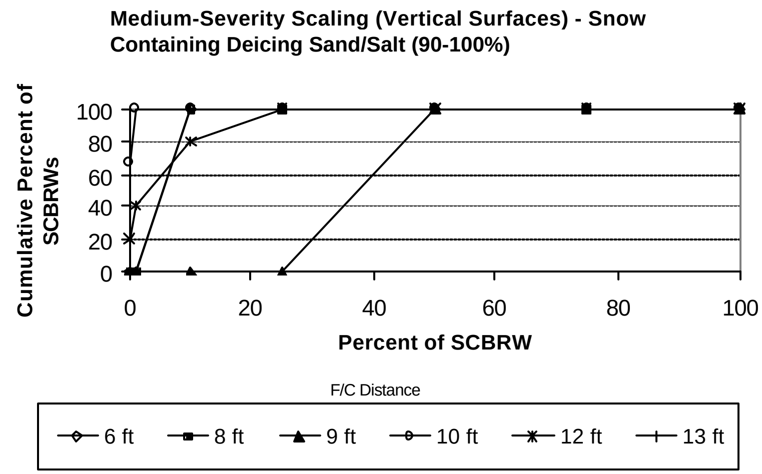



p. Interaction plot: F/C offset distance*no snow removal accumulation.

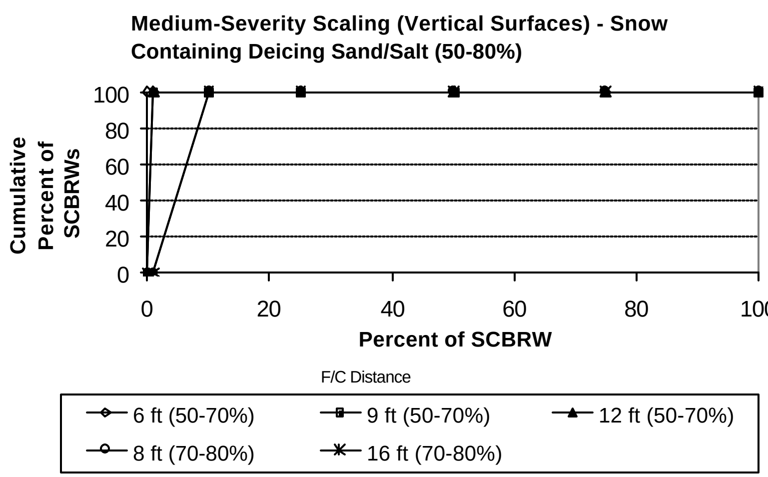
Figure 4.74. Cumulative percent of SCBRWs observed with specified main effect or interaction term versus dependent distress types (graphs [a] – [ae]) (continued).



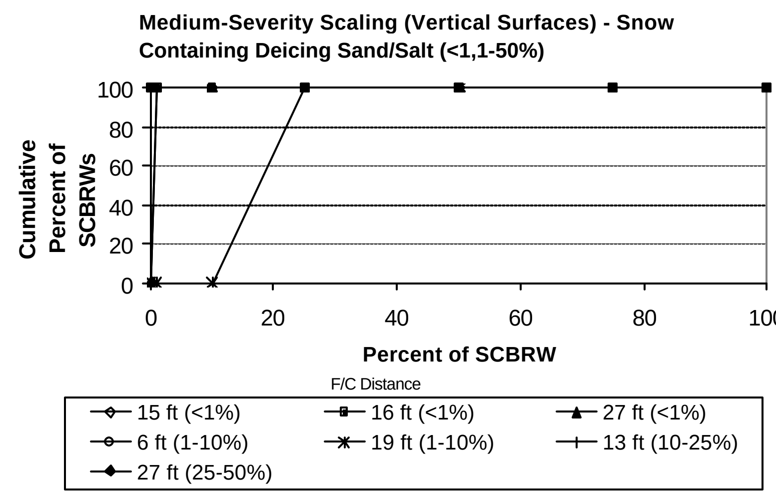

q. Interaction plot: F/C offset distance*snow containing deicing sand/salt (100%).




r. Interaction plot: F/C offset distance*snow containing deicing sand/salt (90-100%).

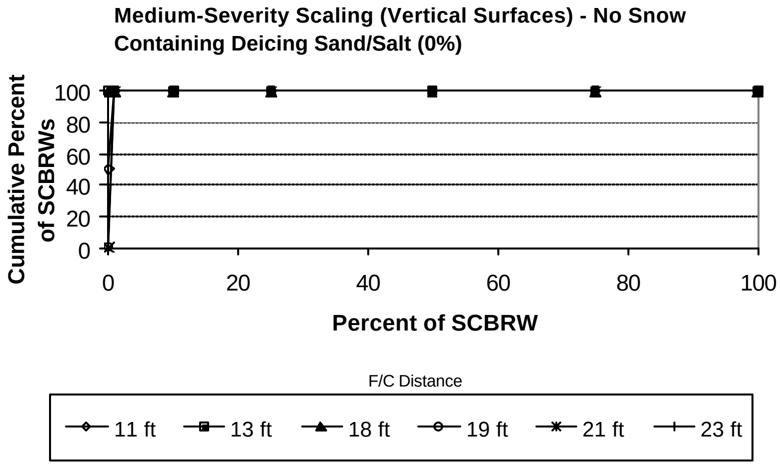



s. Interaction plot: F/C offset distance*snow containing deicing sand/salt (50-70,70-80%).

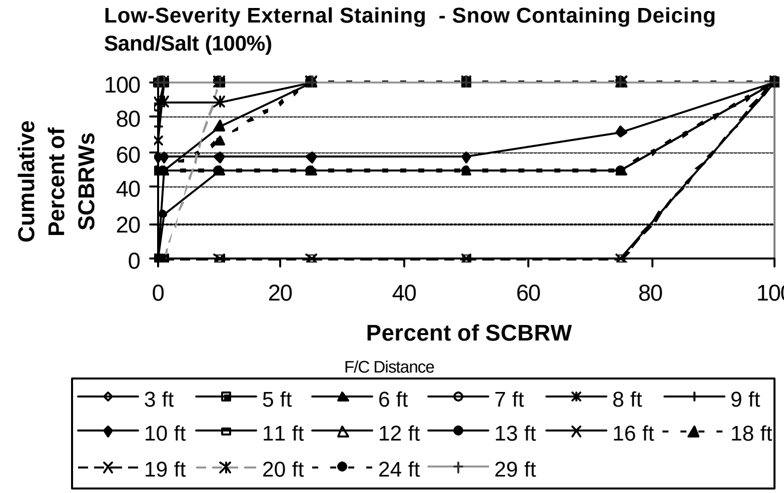



t. Interaction plot: F/C offset distance*snow containing deicing sand/salt (<1, 1-10, 10-25, 25-50%).

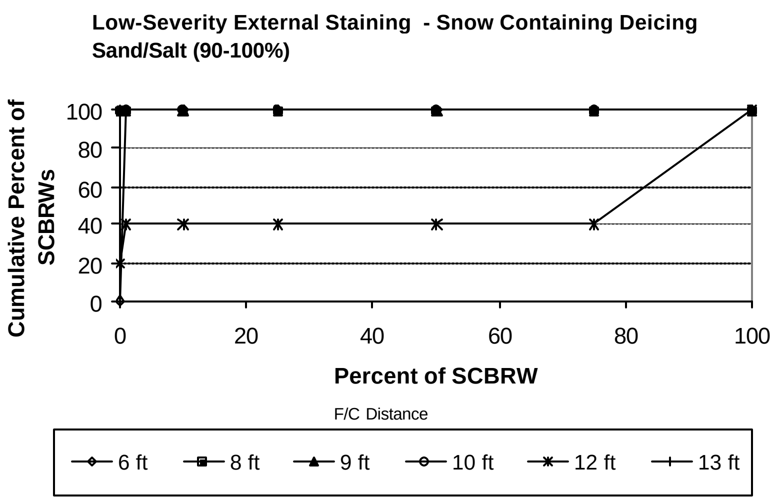
Figure 4.74. Cumulative percent of SCBRWs observed with specified main effect or interaction term versus dependent distress types (graphs [a] – [ae]) (continued).



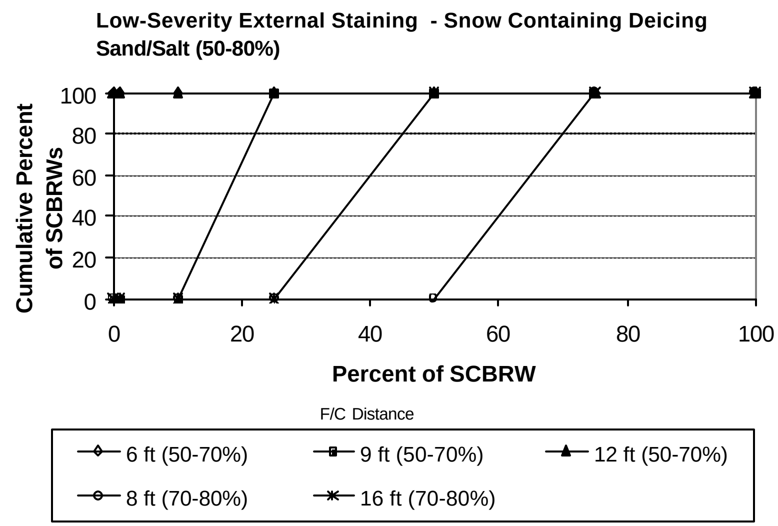

u. Interaction plot: F/C offset distance*snow containing deicing sand/salt (0%).




v. Interaction plot: F/C offset distance*snow containing deicing sand/salt (100%).

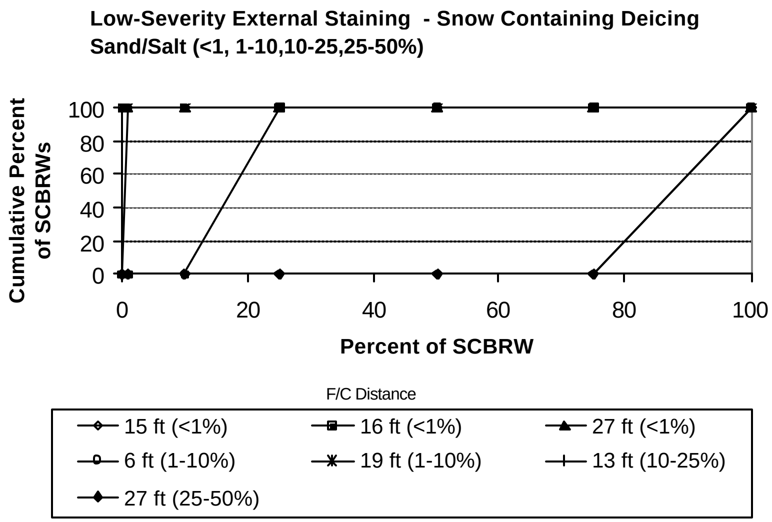



w. Interaction plot: F/C offset distance*snow containing deicing sand/salt (90-100%).

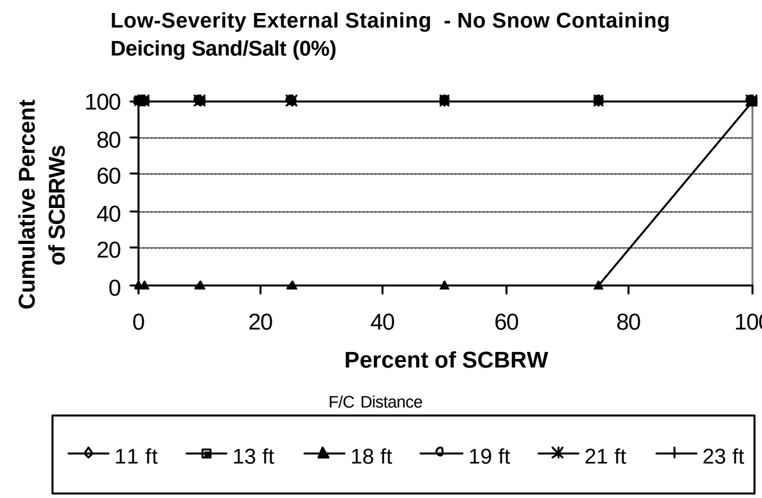



x. Interaction plot: F/C offset distance*snow containing deicing sand/salt (50-70, 70-80%).

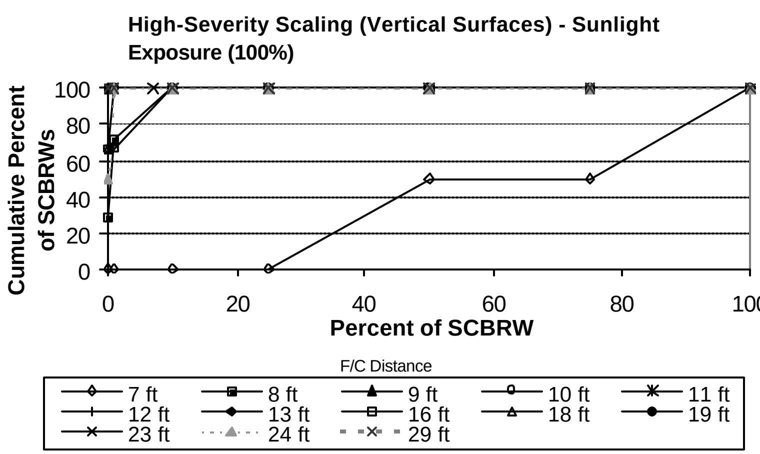
Figure 4.74. Cumulative percent of SCBRWs observed with specified main effect or interaction term versus dependent distress types (graphs [a] – [ae]) (continued).



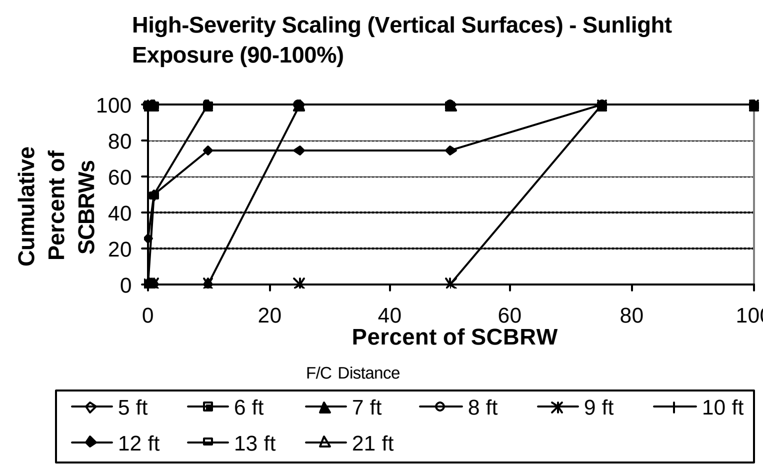

y. Interaction plot: F/C offset distance*snow containing deicing sand/salt (<1, 1-10, 10-25, 25-50%).




z. Interaction plot: F/C offset distance*snow containing deicing sand/salt (0%)

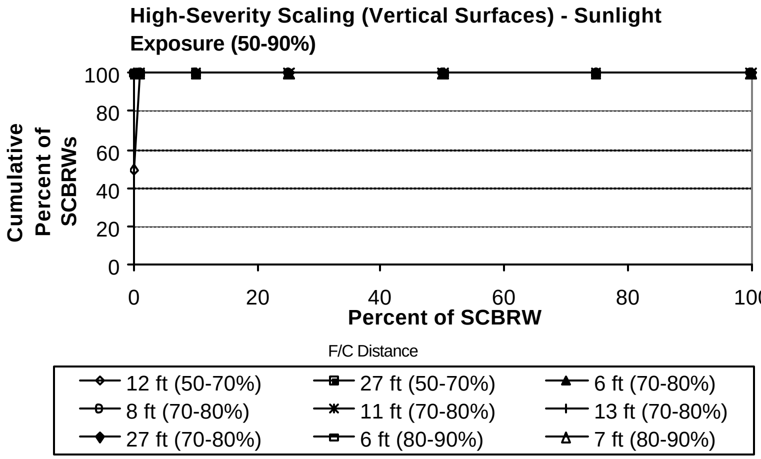



aa. Interaction plot: F/C offset distance*peak daytime winter sunlight exposure (100%).

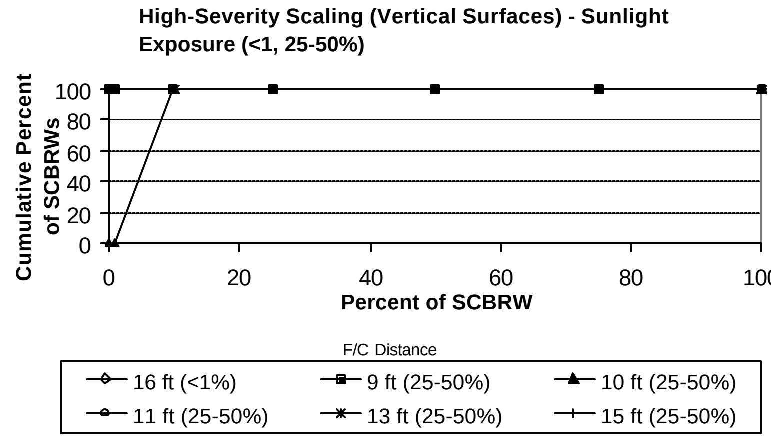



ab. Interaction plot: F/C offset distance*peak daytime winter sunlight exposure (90-100%).

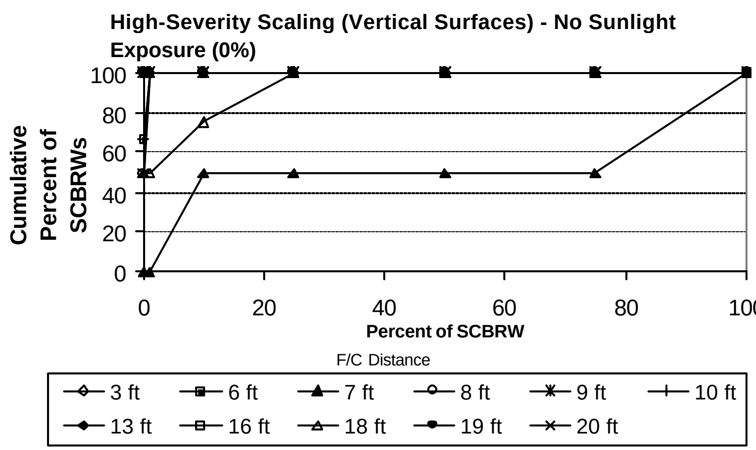
Figure 4.74. Cumulative percent of SCBRWs observed with specified main effect or interaction term versus dependent distress types (graphs [a] – [ae]) (continued).




ac. Interaction plot: F/C offset distance*peak daytime winter sunlight exposure (50-70, 70-80, 80-90%).




ad. Interaction plot: F/C offset distance*peak daytime winter sunlight exposure (<1, 25-50%).




ae. Interaction plot: F/C offset distance*peak daytime winter sunlight exposure (0%).

Figure 4.74. Cumulative percent of SCBRWs observed with specified main effect or interaction term versus dependent distress types (graphs [a] – [ae]) (continued).

## 4.5 Overall Conclusions

The preceding analyses suggest that, while external factors, such as offset distances, vertical surface directions, peak-winter conditions, etc., affect the incidence of SCBRW durability problems, the most direct sources of SCBRW durability problems are manufacturer mix designs and materials.

Freeze-thaw durability of concrete is controlled by (Mehta and Monteiro, 1993):

- the location of escape boundaries (distance over which water has to travel for pressure relief),
- the poor structure of the system (size, number and continuity of pores),
- the degree of saturation (amount of freezable water present),
- the rate of cooling, and
- the tensile strength of the material that must be exceeded to cause rupture.

Provision of escape boundaries in the cement paste matrix and modification of its pore structure are two parameters that are relatively easy to control. The former can be controlled by means of air entrainment in concrete, and the latter by the use of proper mix proportions (water-cement ratio) and curing (Mehta and Monteiro, 1993). In addition, compressive strengths exceeding 4000 psi (which were not required for SCBRWs constructed during the 1980's to mid-1990's) are generally considered necessary for durable concrete.

It is recommended that the manufacturers investigate the durability of the dry-cast mixtures used in their masonry block units and make any necessary mix design and material modifications.

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Findings

- The survey team found that 93 percent of the SCBRWs surveyed were in fair, good or very good condition. Seven percent were in poor or very poor condition.
- It appears that 100, 92, 90 and 85 percent of the SCBRWs surveyed were in “fair” to “very good” condition for Dakota county, Hennepin county, Mn/DOT and privately owned walls, respectively.
- The general condition of SCBRWs generally decreases with age.
- The following distress types were observed on the SCBRWs (percentage of all wall affected in parentheses):
    - Freeze-Thaw Damage (Vertical Surfaces) (84 percent)
    - Fraying/Spalling (83 percent)
    - Scaling (Top Block Layer) (83 percent)
    - Freeze-Thaw Damage (Top Block Layer) (79 percent)
    - Position Guide Damage (78 percent)
    - Embedded Vegetation Growth (73 percent)
    - Scaling (Vertical Surfaces) (73 percent)
    - Manufacturing Flaws (Other) (61 percent)
    - Efflorescence (58 percent)
    - Wash-Through (58 percent)
    - Open Joints (57 percent)
    - Internal Staining (49 percent)
    - Construction Defects (45 percent)
    - Miscellaneous Distress/Flaws (44 percent)
    - External Staining (37 percent)
    - Structural Distress (30 percent)
    - Erosion (23 percent)
    - Popouts (Top Block Layer) (23 percent)
    - Cracked Block (17 percent)

    - Manufacturing Flaws (Poor Consolidation – Capstone) (17 percent)
    - Corner Breaks (14 percent)
- The presence of freeze-thaw damage and/or scaling was most highly associated with decreases in the overall wall condition rating.
- The majority of construction defects noted were poor placement of masonry block units ("twisted blocks").
- The presence of efflorescence often occurred when the masonry block units were highly susceptible to freeze-thaw deterioration. Efflorescence was often observed in areas exhibiting low-severity freeze-thaw discoloration. After repeated cycles of freezing and thawing, the bright white color indicating efflorescence often turned to a dull white color in the discolored area.
- It is uncertain whether the open joints present during the current distress surveys were due to construction or structural problems, since general distress surveys were not performed immediately after wall construction.
- There appears to be no direct correlation between the presence of fraying/spalling and closed, tight joints (as determined through the open joint data) and there were no observances of uneven surfaces.
- It appears that the onset of freeze-thaw deterioration begins with the appearance of local discoloration visible along the lower extremities of the face of the blocks extending toward the joints on each side of the block unit where saturating conditions are the greatest. This discoloration is exacerbated behind position guides near the front edge of the top block surface where water and deicing chemicals accumulate. Later stages of freeze-thaw damage exhibit cracking patterns that begin tight and later open and deteriorate through scaling.
- The presence of scaling is strongly associated with specific block manufacturers.
- The following distress types were found dependent upon the construction year or age of the wall:
    - Efflorescence
    - Embedded Vegetative Growth
    - Erosion
    - Freeze-Thaw Damage (Top Block Layer and Vertical Surfaces)
    - Manufacturing Flaws

    - Scaling (Top Block Layer and Vertical Surfaces)
    - Internal Staining
    - Wash-Through
- The following distress types were found to be at least partly dependent on the block manufacturer:
    - Open Joints
    - Construction Flaws
    - Efflorescence
    - Embedded Vegetative Growth
    - Erosion
    - Fraying/Spalling
    - Freeze-Thaw Damage (Top Block Layer and Vertical Surfaces)
    - Manufacturing Flaws
    - Popouts (Top Block Layer)
    - Scaling (Top Block Layer and Vertical Surfaces)
    - External Staining
    - Structural Distress
    - Wash-Through

## 5.2 Conclusions

- There appears to be no direct correlation between the presence of fraying/spalling and closed, tight joints (as determined through the open joint data) and there were no observances of uneven surfaces suggesting the breaks were due to improper handling/placement of block units.
- The majority of position guide damage was caused by erosion and freeze-thaw damage due to the large amount of water runoff across the guides (causing erosion) and accumulation of water and deicing chemicals behind the position guides (enhancing durability problems).
- After looking at the various factors (e.g., offset distances, vertical surface directions, peak-winter conditions, etc.), it appears that poor durability problems where they exist, are directly related to the lack of durability of the wall units, thereby, indicating that these problems are largely due to improper mix designs and/or the use of nondurable aggregate.

## 5.3 Recommendations

- It is recommended that the manufacturers investigate and improve the durability of the materials and mixtures used in their masonry block units.
- Production quality control improvements should be considered to reduce the production and distribution of non-durable masonry units. Block units should be tested to determine the source of durability problems (i.e., aggregate-related versus paste/mortar-related).
- The design of masonry unit features (e.g., block shape, the presence of thin sections [i.e., positioning guide lips], split versus formed faces, etc.) should consider potential effects on durability (through trapping of moisture and chemicals) and susceptibility to manufacturing and/or construction defects.
- SCBRW field installations should be instrumented to more accurately assess field exposure conditions and, thereby, develop realistic acceptance/rejection tests that are appropriate for predicting field performance potential.

# CHAPTER 6

# REFERENCES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# APPENDIX A

# DESIGN DATA COLLECTION FORMS

# DESIGN DATA

**A** Project Section Identification/Location Information

Project ID......................................................______________________________________________

Construction Contract ID..............................______________________________________________

State..............................................................______________________________________________

County..........................................................______________________________________________

Adjacent Roadway.......................................______________________________________________

Location Relative to Roadway......................______________________________________________

Location Along Roadway.............................______________________________________________

Direction Wall Faces....................................______________________________________________

Direction of Survey......................................______________________________________________

# DESIGN DATA (CONTINUED)

**B** Environmental Data

| Month | Avg. Monthly Temp., (°C) | Avg. Max. Daily Temp., (°C ) | Avg. Min. Daily Temp., (°C ) | Avg. Monthly Precip., CMS of Water |
|---|---|---|---|---|
| January | | | | |
| February | | | | |
| March | | | | |
| April | | | | |
| May | | | | |
| June | | | | |
| July | | | | |
| August | | | | |
| September | | | | |
| October | | | | |
| November | | | | |
| December | | | | |

Latitude (degrees) ......................................... ____________________

Freezing Index............................................... ____________________

Elevation....................................................... ____________________

# DESIGN DATA (CONTINUED)

**C** SCBRW Design/Construction Data

Length of Wall ............................................. ______________________________

Nominal or Average Height of Wall............. ______________________________

Batter Angle .................................................. ______________________________

Base Leveling Pad........................................................ Material ______________

Thickness ______________

Wall Depth Below Grade .............................. ______________________________

Unit/Drainage Material ................................................ Type ______________

Width ______________

Used to fill cavities? Yes / No

Use of Geogrid or Structural Tie-Backs Behind Wall .. .................... ........... Yes / No

Vertical Spacing ______________

Horizontal Spacing ______________

Backfill Material Type.................................. ______________________________

Completion Date .......................................... ______________________________

# DESIGN DATA (CONTINUED)

**D** Concrete Block Data

Manufacturer.................................................______________________________

Block Model.................................................______________________________

Manufacturer's Lot Number(s) ......................______________________________

Coarse Aggregate Type/Source .....................______________________________

Fine Aggregate Type/Source .........................______________________________

Target Mix Design.......................................................Coarse Aggregate ____________

Fine Aggregate ____________

Water ____________

Cement ____________

Fly Ash ____________

Other Admixtures:

| Type(s) | Dosage(s) |
|---|---|
| | |
| | |
| | |

Block Casting/Formation Technique .............______________________________

______________________________

## DESIGN DATA (CONTINUED)

Manufacturer Test Results:

| Strength Test | | Durability Test | |
|---|---|---|---|
| Test Type | Result(s) | Test Type | Result(s) |
| | | | |
| | | | |
| | | | |
| | | | |

**E** Maintenance Records

| Type of Work | Date of Work | Location Along or Within Wall | Work Quantity | Reason for Work |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
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# APPENDIX B
# DESIGN DATA

Table B-1. Dakota county SCBRW design data.

| Route No. | Location | Constr. Contract ID | Wall Length (ft) | Nominal / Avg. Wall Height (ft) | Batter Angle | Base Leveling Pad: Material | Base Leveling Pad: Thickness | Wall Depth Below Grade | Unit/Drainage Mat'l: Type | Unit/Drainage Mat'l: Width | Used to fill Cavities (Yes/No)? | Use of Geogrid or Structural Tie-Backs (Yes/No)? | Backfill Mat'l Type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 26 | Bovey Ave. | SP 19-626-11, CP 26-20E | 200 | 6 | 1"/6" | Cl. 5 aggregate | 6" | 12" | coarse filter aggregate | 12" | Yes | Yes (continuous horizontal spacing/ variable vertical spacing) | native soils (compactible) |
| 31 | Delores Lane (SW Quad Pilot Knob & Cliff Rd) | SP 19-631-17, CP 31-21 | 200 | 7 | 0.75"/ foot | Cl. 5 aggregate | 6" | 8" | granular | same as backfill | Yes | Yes (continuous horizontal spacing/ variable vertical spacing) | granular (<20% passing 200) |
| 31 | Apple Valley, on Pilot Knob at Cliff Rd. (SE Quad) | | | | | | | | | | | | |
| 31 | Diffley Road (SW Quad, frontage Road, house #1440) | SP 19-631-17, CP 31-21 | 40 | 2 | 0.5"/8" | Cl. 5 aggregate | 6" | 4" | granular | | Yes | No | granular |
| 32 | Fairway Hills Drive | SP 19-632-11, CP 31-21 | 800 | 7 | 0.75"/ foot | Cl. 5 aggregate | 6" | 8" | granular | same as backfill | Yes | Yes (continuous horizontal spacing/ variable vertical spacing) | granular (<20% passing 200) |
| 38 | Gardenview Ave, North Side | SP 19-638-03, CP 38-08 | 800' tier 1, 200' tier 2 | 10' tier 1, 6' tier 2 | 7.13° | Cl. 5 aggregate | 6" | 16" | ¾" minus | 12" | Yes | Yes (continuous horizontal spacing/vertical spacing: mostly 2') | granular |
| 38 | Gardenview Ave, South Side | SP 19-638-03, CP 38-08 | 190' tier 1, 150' tier 2 | 6' tier 1, 5' tier 2 | 7.13° | Cl. 5 aggregate | 6" | 16" | ¾" minus | 12" | Yes | Yes (continuous horizontal spacing/vertical spacing: mostly 2') | granular |

Table B-1. Dakota county SCBRW design data (continued).

| Route No. | Location | Constr. Contract ID | Wall Length (ft) | Nominal / Avg. Wall Height (ft) | Batter Angle | Base Leveling Pad | | Wall Depth Below Grade | Unit/Drainage Mat'l | | | Use of Geogrid or Structural Tie-Backs (Yes/No)? | Backfill Mat'l Type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Material | Thickness | | Type | Width | Used to fill Cavities (Yes/No)? | | |
| 38 | Havelock Trail | SP 19-638-03, CP 38-08 | 850 tier 1, 600 tier 2, 200 tier 3 | 6' tier 1, 4' tier 2, 3' tier 3 | 7.13° | Cl. 5 aggregate | 6" | 16" | ¾" minus | 12" | Yes | Yes (continuous horizontal spacing/vertical spacing 2' (majority) | granular |
| 38 | Diamond Path | SP 186-114-01, CP 38-09 | 500 | 11 | 3.57° | Cl. 5 aggregate | 6" | 8" | select granular | | Yes | Yes (continuous horizontal spacing/vertical spacing: 2-4 courses) | Select granular |
| 38 | Apple Valley, on McAndrews at Pilot Knob (NE Quad) | | | | | | | | | | | | |
| 38 | Apple Valley, on McAndrews at Pilot Knob (SE Quad) | | | | | | | | | | | | |
| 42 | East Side, Grove Street (Hastings) | SP 19-642-33, SP 130-020-03, CP 42-45 | 100 | 2.5 | 7.13° | Cl. 5 aggregate base | 6" | 8" | coarse filter aggregate | 12" | Yes | No | select granular |
| 42 | West Side, Grove Street (Hastings) | SP 19-642-33, SP 130-020-03, CP 42-45 | 100 | 2.5 | 7.13° | Cl. 5 aggregate base | 6" | 8" | coarse filter aggregate | 12" | Yes | No | select granular |
| 42 | Burnsville, Glendale Rd W ~~to Vernon Ave~~ (NW Quad) | | | | | | | | | | | | |

Table B-1. Dakota county SCBRW design data (continued).

| Route No. | Location | Constr. Contract ID | Wall Length (ft) | Nominal / Avg. Wall Height (ft) | Batter Angle | Base Leveling Pad: Material | Base Leveling Pad: Thickness | Wall Depth Below Grade | Unit/Drainage Mat'l: Type | Unit/Drainage Mat'l: Width | Used to fill Cavities (Yes/No)? | Use of Geogrid or Structural Tie-Backs (Yes/No)? | Backfill Mat'l Type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 42 | Burnsville, Glendale Rd W ~~to Vernon Ave~~ (SW Quad) | | | | | | | | | | | | |
| 46 | Church, Highview Ave. | SP 188-122-01, CP 46-04 | | | 3.57° (1/2" per course) | Cl. 5 aggregate | 6" | 12" | coarse filter aggregate | 12" | Yes | Yes (continuous horizontal spacing/vertical spacing 2' (majority) | native soils - granular |
| 46 | Grove Trail | SP 188-122-01, CP 46-04 | | | 3.57° (1/2" per course) | Cl. 5 aggregate | 6" | 12" | coarse aggregate filter | 12" | Yes | Yes (continuous horizontal spacing/vertical spacing 2' (majority) | native soils - granular |

Table B-2. Hennepin county SCBRW design data.

| | | | | | | Base Leveling Pad | | | Unit/Drainage Mat'l | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Route No. | Location | Constr. Contract ID | Wall Length (ft) | Nominal / Avg. Wall Height (ft) | Batter Angle | Material | Thickness | Wall Depth Below Grade | Type | Width | Used to fill Cavities (Yes/No)? | Use of Geogrid or Structural Tie-Backs (Yes/No)? | Backfill Mat'l Type |
| **HENNEPIN COUNTY** | | | | | | | | | | | | | |
| 1 | 702' E of Sheridan Ave S | | | | | | | | | | | | |
| 5 | 343' E of Jidana Lane | | | | | | | | | | | | |
| 6 | 825' E of CSAH 101 | 8642 | 68 | 2 | ¼" per course | compacted granular | 6" Min. | 8":6' | compacted granular | 12" Min. | | No | select grading mat'l |
| 6 | 25' E of Garland Ln (W) | 8642 | 190 | 5.5 | ¼" per course | compacted granular | 6" Min. | 8":6' | compacted granular | 12" Min. | | No | select grading mat'l |
| 6 | 481 E of Dunkirk Ln (north side) | 8642 | 350 | 4 | ¼" per course | compacted granular | 6" Min. | 8":6' | compacted granular | 12" Min. | | No | select grading mat'l |
| 6 | 481 E of Dunkirk Ln (south side) | 8642 | 170 | 4 | ¼" per course | compacted granular | 6" Min. | 8":6' | compacted granular | 12" Min. | | No | select grading mat'l |
| 6 | 52' E of Dunkirk Ln | 8642 | 90 | 2 | ¼" per course | compacted granular | 6" Min. | 8":6' | compacted granular | 12" Min. | | No | select grading mat'l |
| 6 | 149' E of Yuma Ln | 8642 | 270 | 5 | ¼" per course | compacted granular | 6" Min. | 8":6' | compacted granular | 12" Min. | | No | select grading mat'l |
| 6 | 530 E of Shenandoah Ln | | | | | | | | | | | | |
| 6 | 1103' E of Niagara Ln | | | | | | | | | | | | |
| 6 | 50' E of Juneau | | | | | | | | | | | | |
| 9 | SW Quad. Annapolis Ln | | | | | | | | | | | | |
| 9 | SE Quad. Annapolis Ln | 8424 | 150 | 4 | Min. ¾":12" (7.1°) | aggregate bedding | 2' Min. | 1' Min. | ¾" clear drainage rock | 2' Min. | No | Yes (geogrid, 2' vertical spacing) | reinforced granular Mn/DOT 3149.2B |
| 9 | SE Quad Gettysburg | | | | | | | | | | | | |
| 9 | 47' E of Flag Ave N | | | | | | | | | | | | |
| 9 | 430' E of Ensign Ave | | | | | | | | | | | | |
| 9 | 40' E of Quebec Ave N | | | | | | | | | | | | |
| 9 | 50' E of Quebec Ave N | | | | | | | | | | | | |
| 9 | SW Quad. Oregon | | | | | | | | | | | | |
| 9 | 278' E of Lake Rd | | | | | | | | | | | | |

Table B-2.  Hennepin county SCBRW design data (continued).

| | | | | | | Base Leveling Pad | | | Unit/Drainage Mat'l | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Route No. | Location | Constr. Contract ID | Wall Length (ft) | Nominal / Avg. Wall Height (ft) | Batter Angle | Material | Thickness | Wall Depth Below Grade | Type | Width | Used to fill Cavities (Yes/No)? | Use of Geogrid or Structural Tie-Backs (Yes/No)? | Backfill Mat'l Type |
| 10 | 275' E of I 494 On-Ramp | 7408 | 270 | 3.5 | ¼" per course (7.1°) | compacted granular | 6" Min. | 8":6' | granular | 12" | Yes | Yes | common excavation |
| 10 | 85' E of Jonquil Ln N | 7408 | 270 | 4 | ¼" per course (7.1°) | compacted granular | 6" Min. | 8":6' | granular | 12" | Yes | Yes | common excavation |
| 10 | 300' E of CSAH 61 (NE Quad) | | 38 | 2.6 | | | | | | | | | |
| 10 | 435' E of CSAH 61 (SE Quad) | 7408 | 250 | 5 | ¼" per course (7.1°) | compacted granular | 6" Min. | 8":6' | granular | 12" | Yes | Yes | common excavation |
| 10 | 656' E of Deerwood Ln N (SE Quad) | 7408 | 110 | 3 | ¼" per course (7.1°) | compacted granular | 6" Min. | 8":6' | granular | 12" | Yes | | common excavation |
| 10 | 890' E of Deerwood (NE Quad) | | | | | | | | | | | | |
| 10 | 500' E of Trenton | | | | | | | | | | | | |
| 10 | 170' E of Decatur Ave N | | | | | | | | | | | | |
| 10 | SE Quad Boone Ave | 9014 | 250 | 2 | | | | | | | | Yes | aggregate bedding |
| 10 | 31' E of Sumter Ave N | | | | | | | | | | | | |
| 12 | 747' N of Noble Ave N | | | | | | | | | | | | |
| 17 | 135' N of W Fuller St | | | | | | | | | | | | |
| 17 | 423' N of W 52nd St | | | | | | | | | | | | |
| 17 | 200' N of W 49th St | | | | | | | | | | | | |
| 17 | 862' N of W 37th St | | | | | | | | | | | | |
| 32 | 555' N of Maple Ave S | | | | | | | | | | | | |
| 32 | 86' N of W 78th St | | | | | | | | | | | | |
| 34 | 881' N of 102nd St | | | | | | | | | | | | |
| 35 | 495' N of E 83rd St | | | | | | | | | | | | |
| 53 | At Queen NE Quadrant | | | | | | | | | | | | |

Table B-2. Hennepin county SCBRW design data (continued).

| | | | | | | Base Leveling Pad | | | Unit/Drainage Mat'l | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Route No. | Location | Constr. Contract ID | Wall Length (ft) | Nominal / Avg. Wall Height (ft) | Batter Angle | Material | Thickness | Wall Depth Below Grade | Type | Width | Used to fill Cavities (Yes/No)? | Use of Geogrid or Structural Tie-Backs (Yes/No)? | Backfill Mat'l Type |
| 61 | 300' N of W. Med. Lake Dr. | | | | | | | | | | | | |
| 61 | 138' N of 42nd Pl N | | | | | | | | | | | | |
| 61 | At 46th Ave N | 011 | 490 | 2.5 | | Compacted coarse filter aggregate Mn/DOT 3149.2H | 6" Min. | 1 course/6" vertical wall height | Compacted coarse filter aggregate Mn/DOT 3149.2H | 12" Min. | | Yes | Suitable grading mat'l |
| 61 | 200' N of 54th Ave N | | | | | | | | | | | | |
| 61 | 25' N of 66th Ave N | | | | | | | | | | | | |
| 62 | 200' E of CSAH 101 (SE Quad) | 7419 | 210 | 5 | Min. ¾":12" (7.1°) | aggregate bedding | 2'6" | 1' Min. | granular (meeting a specified gradation) | 2' Min. | Yes | Yes (geogrid) | granular Mn/DOT 3149.2D |
| 62 | 200' E of CSAH 101 (NE Quad) | 7419 | 320 | 3.5 | Min. ¾":12" (7.1°) | aggregate bedding | 2'6" | 1' Min. | granular (meeting a specified gradation) | 2' Min. | Yes | Yes | granular Mn/DOT 3149.2D |
| 62 | At Ellerdale Lane (North Side) | 7419 | 900 | 6 | Min. ¾":12" (7.1°) | aggregate bedding | 2'6" | 1' Min. | granular (meeting a specified gradation) | 2' Min. | Yes | Yes (geogrid) | granular Mn/DOT 3149.2D |
| 62 | E of Ellerdale Lane (South Side) | 7419 | 160 | 5 | Min. ¾":12" (7.1°) | aggregate bedding | 2'6" | 1' Min. | granular (meeting a specified gradation) | 2' Min. | Yes | Yes (geogrid) | granular Mn/DOT 3149.2D |
| 70 | At Flag AveN | 8726 | 90 | 1.5 | ½" per course | aggregate bedding | 6" Min. | one course | aggregate bedding | 12" Min. | Yes | No | compacted granular |
| 70 | 130' E of Decatur Ave N. | 8726 | | | | | | | | | | | |
| 70 | 57' E of Xylon Ave N | 8726 | 70 | 4 | ½" per course | aggregate bedding | 6" Min. | one course | aggregate bedding | 12" Min. | Yes | | compacted granular |
| 70 | 100' E of Virginia Ave | 8726 | 40 | 1.5 | ½" per course | aggregate bedding | 6" Min. | one course | aggregate bedding | 12" Min. | Yes | No | compacted granular |
| 70 | At NW Quad. Winnetka Ave N | 8726 | 120 | 1.5 | ½" per course | aggregate bedding | 6" Min. | one course | aggregate bedding | 12" Min. | Yes | No | compacted granular |

Table B-2. Hennepin county SCBRW design data (continued).

| Route No. | Location | Constr. Contract ID | Wall Length (ft) | Nominal / Avg. Wall Height (ft) | Batter Angle | Base Leveling Pad: Material | Base Leveling Pad: Thickness | Wall Depth Below Grade | Unit/Drainage Mat'l: Type | Unit/Drainage Mat'l: Width | Used to fill Cavities (Yes/No)? | Use of Geogrid or Structural Tie-Backs (Yes/No)? | Backfill Mat'l Type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 70 | At Rhode Island Ave N | 8726 | 100 | 1.5 | ½" per course | aggregate bedding | 6" Min. | one course | aggregate bedding | 12" Min. | Yes | No | compacted granular |
| 70 | 248' E of Nevada Ave | 8726 | 210 | 3.5 | ½" per course | aggregate bedding | 6" Min. | one course | aggregate bedding | 12" Min. | Yes | No | compacted granular |
| 70 | 29' E of Louisiana Ave N | 8726 | 160 | 3 | ½" per course | aggregate bedding | 6" Min. | one course | aggregate bedding | 12" Min. | Yes | No | compacted granular |
| 70 | 100' E of Jersey | 8726 | 45 | 1.5 | ½" per course | aggregate bedding | 6" Min. | one course | aggregate bedding | 12" Min. | Yes | No | compacted granular |
| 70 | 20' E of Idaho Ave N | 8726 | 52 | 1 | ½" per course | aggregate bedding | 6" Min. | one course | aggregate bedding | 12" Min. | Yes | No | compacted granular |
| 73 | At Oak Knoll Terrace N | | | | | | | | | | | | |
| 101 | 130' S of 24th Ave N | | | | | | | | | | | | |
| 101 | 90' N of 82nd Ave N | | | | | | | | | | | | |
| 101 | 90' N of 82nd Pl N | | | | | | | | | | | | |
| 101 | SE Quad. Weaver Lake Dr | 9422 | 125 | 1.5 | | compacted cl. 5 or crushed rock | 0-6" | 0 | 3/8" crushed rock | 1' behind first row | Yes | No | compacted fill (3/8" crushed rock) |
| 101 | 100' S of 87th Pl N (west side) | 9422 | 510 | 5 | | compacted cl. 5 or crushed rock | 0-6" | 0 | 3/8" crushed rock | 1' behind first row | Yes | Yes (2' vertical spacing/horizontal spacing varies) | compacted fill (3/8" crushed rock) |
| 101 | 100' S of 87th Pl N (east side) | 9422 | 210 | 5 | | Compacted cl. 5 or crushed rock | 0-6" | 0 | 3/8" crushed rock | 1' behind first row | Yes | No | compacted fill (3/8" crushed rock) |
| 156 | SW Quad. CSAH 70 | 8726 | 200 | 1.5 | ½" per course | aggregate bedding | 6" Min. | one course | aggregate bedding | 12" Min. | Yes | No | compacted granular |
| 156 | 706' N of CSAH 9 | | | | | | | | | | | | |
| 156 | 894' N of CSAH 9 (44th Ave.) | | | | | | | | | | | | |
| 156 | 35' N of 46th Ave N | | | | | | | | | | | | |

# APPENDIX C
# STANDARD SPECIFICATIONS FOR
# MODULAR BLOCK RETAINING WALLS

***<u>Specification taken from SAP No. 27-662-57 – August 5, 1996</u>***

S-31 Modular Block Retaining Walls (0411.603)

S-31.1 Description

This work shall consist of furnishing and installing modular concrete block retaining walls in accordance with the applicable specifications of Mn/DOT 2411, and the following:

The walls shall be constructed in the locations and to the configurations and the dimensions shown in the plans. The Engineer shall have the right to alter the alignment and location to improve constructability and aesthetics.

The approved wall system shall be constructed in accordance with manufacturer's recommendations and certified designs, if required, upon approval of the design methodology by the Engineer.

S-31.2 Design

A. On walls, or segments thereof, with an exposed height of 2 feet or less the Contractor will be required to submit shop drawings and the block manufacturer's suggested installation procedure showing materials and construction methods to the County's Project Engineer for approval prior to beginning any retaining wall work.

B. On walls, or segments thereof, with exposed heights greater than 2 feet and less than 6.5 feet the contractor shall have the wall system designed and detail drawings prepared by a Professional Engineer experienced in retaining wall design who is registered in the State of Minnesota. The design computations and the plans showing geogrid placement, drainage components and other pertinent design data shall be certified by the Contractor's design engineer and shall be submitted to the County's Project Engineer, for the project's permanent records, prior to beginning any retaining wall work. The block manufacturer's suggested installation procedure shall also be submitted.

   If the wall is supporting a live load, building or other structure, or an unusually high dead load, the design requirements included in the following subsection C shall apply.

C. On walls, or segments thereof, with exposed heights of 6.5 feet or greater the wall system design shall conform to the following specifications and typical section requirements:

   1. The wall shall be designed and the detailed drawings prepared by a Professional Engineer experienced in retaining wall design who is registered in the State of Minnesota. The design computations and the plans shall be certified by the Contractor'' design engineer and shall be submitted to the County'' Project

Engineer, for the project's permanent record, prior to beginning any retaining wall work. The design shall be per AASHTO and the Mn/DOT Roadway Design Manual except as noted.

2. The detailed drawings shall contain all the necessary information for the construction of the wall. Included shall be a typical section detailing excavation limits, geotextile locations, block embedments, leveling pad dimensions, backfill, etc. Include as many sections and other views necessary for the construction and inspection of the wall. The information on embedment, geotextile locations, and geotextile lengths as they relate to wall heights may be shown in tabular form. Also included shall be the pertinent information on the individual blocks and the geotextile material.
3. All plan sheets shall clearly identify the name of the responsible engineering firm and the name of the person certifying the plan. Each sheet shall be certified.

D. If a fence is required along the top of the wall, the wall shall be designed to include the additional loading and provide for the post installation.

E. When the longitudinal slope of the footing is greater than 10:1, the footing may be stepped.

F. The Contractor's wall designer shall become aware of the existing locations of all utilities affected by the proposed wall construction as well as the locations where they are to be relocated and also any new utilities that may be installed in the vicinity of the proposed wall construction.

All new and/or relocated utilities shall be installed outside the construction limits of the proposed retaining walls whenever possible. If this is not possible, the wall designer shall identify all utilities, in their proposed locations, which are to be installed within the construction limits of the wall. It shall be the wall designer's responsibility to coordinate all designs with the affected utility owners and to provide ample room for their installation, to the satisfaction of the County's Project Engineer.

Any utilities needing to be located within the construction limits of the wall shall be installed as the wall is being constructed.

S-31.3 Materials

The modular block retaining wall shall be constructed of mortarless masonry units complying with ASTM C14075 Sampling and Testing Concrete Masonry Units, and either ASTM C9085 For Hollow Load Bearing Masonry Units or ASTM C14585 Solid Load Bearing Concrete Masonry Units as applicable. Concrete wall units shall have a minimum 28-day compressive strength of 3900 psi and a maximum water absorption rate of 6.0%. Units shall be capable of attaining concave and convex alignment curves as shown on the plans. Units shall be interlocked by positive, mechanical means that provides a minimum set back of ¾ in per foot and a maximum setback of 2 ½ inches per foot. Individual wall units shall be earth tone in color with a rockface texture.

A Certificate of Compliance in accordance with 1603.3 shall be provided for all masonry units to be incorporated into the project. Acceptance of all masonry units will be in accordance with 1603.4.

If not specified in the submitted designs, the wall footing material shall be either unreinforced concrete or aggregate bedding meeting the requirements of 3149.2G. The material for filling voids in and between all units as well as the granular backfill shall meet the wall designer's specifications. In the event the wall designer does not specify backfill material either 3149.2H (Course Filter Aggregate) or 3149.2G (Aggregate Bedding) may be used.

In the event backfill material containing more than 10 percent passing the No. 4 sieve is used, whether specified by the wall designer or not, a geotextile filter fabric meeting the requirements of 3733, Type I shall be installed along the back of the wall units to eliminate material sifting through the joints.

S-31.4 Construction Requirements:

Modular block retaining wall shall be constructed in accordance with the designs and specifications prepared and submitted by the Contractor's wall designer and the following:

A. Excavation

Over excavation and additional compacted backfill shall not be paid for unless directed by the Engineer. The Contractor shall not disturb embankment materials beyond the lines shown on the Contractor's wall designer's plans unless so directed by the Engineer.

C. Foundation Soil Preparation

The Contractor's wall designer shall examine the foundation soils to assure that the actual foundation soil strength meets or exceeds assumed design strength for the retaining wall system to be constructed. Soils not meeting required strength shall be removed and replaced with acceptable material at the direction of the Engineer.

D. Base Footing
Footing materials shall be installed upon undisturbed in situ soils.

The base material shall be compacted to provide a level hard surface on which to place the first course of units. Compaction shall be obtained with mechanical plate compactors to 95 percent of standard proctor density.

Footing shall be prepared to insure complete contact of retaining wall unit with base. Gaps shall not be allowed.

Footing materials shall be installed in accordance with the depths and widths shown in the Contractor's submitted wall plans.

D. Unit Installation

Backfill shall be placed as per the submitted design and compacted as each course is completed. A minimum of 24 inches of granular drainage fill material shall be placed behind the block units unless otherwise specified. Geotextile filter fabric, if required, shall be placed between the block and the backfill prior to backfilling.

The top row of block shall be produced under the exact same method as the rest of the block in the wall and shall have a solid concrete top (no voids).

E. Geogrid Reinforcement

Geogrid reinforcement shall be furnished and installed in accordance with the design submitted by the Contractor. All costs associated with furnishing and installing the geogrid reinforcement, including excavation and backfill, shall be considered incidental to the Contract.

F. Drainage Systems

Drainage systems for the retaining wall, if required by the Contractor's design, shall be furnished and installed according to the submitted design. It shall be the Contractor's responsibility to ensure that any drainage system installed behind any walls is properly discharged into the storm sewer system in the vicinity or through wee holes through the face of the wall. All costs associated with wall drainage and discharge shall be incidental to the modular block retaining wall.

***Specification taken from SAP No. 27-662-55 (CP 7419) – June 23, 1994***

S-34 (0411.603) Modular Block Retaining Walls

S-34.1 Scope

A. This specification covers hollow or solid concrete modular block retaining wall units, wall caps, and coarse drainage fill used to form modular block walls. This work shall consist of furnishing: design calculations conforming to the plan specified parameters, wall construction details, materials and construction of interlocking modular block retaining walls in accordance with the requirements of this Special Provision and applicable portion of the Standard Specifications.

B. The concrete modular block walls shall be designed and constructed in accordance with the cross-sections, grades, and dimensions shown on the contract drawings, and as herein specified and as directed by the Engineer.

D. The concrete modular block retaining walls are indicated in the contract drawings in plan view and/or in the sections.

S-34.2 Applicable Publications

A. AASHTO-AGC-ARTBA Joint Committee: Subcommittee Task Force 27, Guidelines for the design of Mechanically Stabilized Earth Walls.

B. AASHTO Standard Specifications for Highway Bridges, Fifteenth Edition, dated 1992.

C. American Society of Testing and Materials (ASTM):

| | |
|---|---|
| C 33-90 | Concrete Aggregates. |
| C 90-75 | Freeze/Thaw Protection. |
| D 666-91 | Test Method for Resistance of Concrete to Rapid Freeze-Thaw. |
| C 140-75 (1988) | Concrete Masonry Units. |
| C 90-90 | Hollow Load Bearing Masonry Units. |
| C 150-89 | Portland Cement. |
| C 595-89 | Blended Hydraulic Cements |
| C 618-89a | Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete. |
| C 920-87 | Elastomeric Joint Sealants. |

S-34.4 Materials

A. Concrete Modular Blocks: Materials shall conform to the following applicable specifications:
1. Portland Cement. ASTM Specification C 150.

2. Bended Cements. ASTM Specification C 595.
3. Pozzolans. ASTM Specification C 618.
4. Aggregates: ASTM Specification C 33.
   Other constituents: Air-entraining agents, coloring pigments, integral water repellents, silica, and other constituents shall be previously established as suitable for use in concrete segmental retaining wall units and shall conform to applicable ASTM Standards or, shall be shown by test to not be detrimental to the durability of the concrete segmental retaining wall units or any material customarily used in masonry construction.

   Concrete modular blocks shall be precast units of uniform dimensions, and color.

B. Geogrid: The geogrid material shall be a high density polyethylene (HDPE) polypropylene or polyester grid, specifically fabricated for use as a soil reinforcement. The geogrid must consist of a regular network of tensile elements that have sufficient pullout resistance to perform the prime function of reinforcement. The geogrid elements shall be integrally connected at crossover points such that they will not separate during handling, construction activities, or throughout the service life of the structure.

   The allowable long-term tension "Ta" shall be the lesser of, Ta1 (Eq 3) and Tas (Eq. 4) as defined by Task Force 27, AASHTO-AGC-ARTB guidelines using the following values:

   1. T1 – is the limit state reinforcement tensile load based on 10,000-hour creep tests. T1 shall be the highest tension level at which the cumulative creep strain-rate continues to decrease with the log of time within the total strain and time requirements for a given design. The Serviceability state shall be based on creep limited strength at 5 percent reduced by Factors of Safety for construction damage and durability.
   2. FD – is the durability safety factor, based on results of durability studies that define the appropriate factor of safety to be applied to the limit state reinforcement tensile load. If data does not exist, a minimum factor of safety of 2.0 shall be used. If data does exist, the minimum safety factor shall be 1.1.
   3. FC – is the construction induced damage safety factor based on full-scale field damage trials that define the appropriate safety factor to be applied to the limit state reinforcement tensile load. Site damage trials shall be conducted using representative soils and construction procedures. That is test results shall be based on granular material no less coarse than the wall module fill and wall backfill specified in Subsections 4.3 and 4.4. If data does not exist, a site damage safety factor of 3.0 shall be used. Where the specific backfill has not been tested but data exists conforming to the guidelines set forth in the Geosynthetic Research Institute's (GRI) publication GG4, a minimum factor of safety of 1.15 shall be used.
   4. FS – is the overall factor of safety which shall be 1.5.

The geogrid connection to modular concrete facing units shall be capable of carrying 100 percent of the maximum design tensile load of the geogrid at no more than 0.75 inch total deformation, at all levels. The maximum design tensile load of the geogrid shall be less than or equal to 50 percent of the as-tested ultimate strength of the connection between the geogrid and the concrete modular block.

C. Concrete Modular Block Drainage Fill: Granular fill placed in hollow cells and extending a minimum of 2 ft behind the back the back face shall be free-draining granular material. Gradation of material shall be limited to that having a maximum of 5 percent passing the 200 sieve, less than 50 percent passing the 40 sieve and 100 percent passing the 3/8-inch screen.

   In the event backfill material containing more than 10 percent passing the No. 4 sieve is used, whether specified by the manufacturer or not, a geotextile filter fabric meeting the requirements of 3733. Type I placed along the back of the wall units to eliminate material sifting through the joints will be required.

D. Reinforced Backfill: The reinforced zone shall be backfilled with Granular Backfill as determined by Mn/DOT Specification 3149.2D.
E. Aggregate Base material for all wall footings shall be in accordance with Mn/DOT Specification 3149.2 G Stabilizing Bedding.
F. Masonry Adhesive: The type of masonry adhesive utilized to bond the upper two course of modular block units to each other, and to bond the wall caps, as shown on the drawings shall be in accordance with ASTM C 920.

S-34.5 Physical Requirements

Same description as described in S-31.3. However, the following additional information was included in this section:

‘The units shall be capable of attaining concave and convex curves with 1/8 inch minimum gap in joints as shown on the drawings.’

S-34.6 Permissible Variations in Dimensions

Overall Dimensions: Modular block’s (width, height, length as defined by the manufacturer) shall not vary more than 1/8 inch from specified dimensions.

S-34.7 Delivery, Storage and Handling

A. Modular Block Units and Wall Caps: The units shall be checked upon delivery to assure proper units have been received. The Contractor shall protect the materials from damage and shall prevent excessive mud, wet cement and like materials which may affix themselves, from coming in contact with the Concrete blocks. Damage blocks shall not be incorporated in the retaining wall.

B. Geogrid: During all periods of shipment and storage, the geogrid shall be protected from prolonged periods of direct sunlight. The Contractor shall inspect the geogrid upon delivery to assure that the proper material has been delivered to the site in a dry and undamaged condition and stored out of contact with the ground. Rolled geogrid material shall be laid flat or stood on end when stored. The Contractor shall prevent mud, wet cement, epoxy and like material from coming n contact with the geogrids. The geogrid rolls shall not be dropped or dragged.

S-34.8 Retaining Wall Installation

A. Excavation: Excavation shall conform to the dimensions and elevation as shown on the contract drawings or as directed by Engineer. Shoring, including sheet piling, shall be provided as necessary to protect workers, banks, structures and utilities. The Contractor shall be responsible for design and maintenance of all temporary shoring or sheeting. Over-excavated areas shall be filled with approved compacted backfill material.

B. Subgrade Preparation: Foundation soil shall be examined by the Engineer to insure that the actual foundation soil meets or exceeds assumed design strength. Soil not meeting the required strength shall be removed and replaced with acceptable material.

C. Aggregate Base: Base materials shall be installed on undisturbed native soils or suitable replacement fills compacted to 95 percent of Standard Proctor. Base materials shall be compacted to 95 percent of Standard Proctor to provide a level hard surface on which to place first course of concrete modular blocks. Compaction shall be accomplished by pneumatic-tired rollers, steel-wheeled rollers, or other approved equipment well suited to the soil being compacted.

The aggregate base shall be constructed to insure complete contact of the first course of concrete modular blocks with the aggregate base. No gaps shall be allowed between the first course of concrete modular blocks and the aggregate base. The first course of modular concrete blocks shall be checked for level and alignment by the Engineer prior to installation of subsequent courses of concrete modular blocks.

D. Concrete Modular Block Installation: The installation of the modular block shall be in accordance with manufacture’s published installation instructions, drawings and the requirement herein. A field representative from the manufacture shall be available for a minimum of 1 day at the beginning of installation of the block and on an as needed basis thereafter at no cost to the owner.

First course of concrete modular blocks shall be placed on the prepared aggregate base a minimum of 1 ft below finished grade at the exposed face of wall. Insure that concrete modular blocks are in full contact with aggregate base.

Modular concrete blocks shall be place side by side for full length of wall alignment. The Contractor shall follow the manufacture's published installation instructions when making curves.

At the end of each course where the wall changes elevation, wall units shall be turned into the backfill. A minimum of 3 units shall be installed below grade on wall returns. Manufactured corner unit shall be used to insure that exposed face showing is textured.

S-34.9 Geogrid Installation

A. The installation of geogrids shall be in accordance with manufacturer's published installation instructions, drawings and the requirements herein. A field representative from the manufacture shall be available for a minimum of 1 day at the beginning of installation of the block and on as needed basis thereafter at no cost to the owner.

B. The geogrid shall be laid to the proper elevation and orientation as shown on the drawings or as directed by the Engineer. The geogrid shall be secured between the concrete modular block units and embedded between adjacent blocks a minimum of 10 inches. Primary reinforcing layers shall be placed such that the reinforcing strength is perpendicular to the wall face. The geogrid shall be pulled taut and anchored prior to backfill placement on the geogrid.

C. Mechanical splices of the geogrid in the primary strength direction shall be allowed only if preapproved by the engineer and shall develop 100 percent of the specified geogrid strength. Overlaps in the primary strength direction shall not be allowed.

D. Placement of geogrid around curves will require diagonal overlapping to ensure that excessive buckling of grid material does not occur. A minimum vertical spacing of 3 inches is required between geogrid layers in these areas.

E. Geotextile filter fabric shall be placed between the block and the backfill prior to backfilling.

S-34.11 Drainage systems for the retaining wall, if required, shall be furnished and installed according to specifications. It shall be the Contractor's responsibility to ensure that any drainage system installed behind any walls is properly discharged. All costs associated with wall drainage and discharge shall be incidental to the modular block retaining wall.

S-34.12 Sampling and Testing

A. Modular concrete blocks shall be tested for compressive strength and absorption in accordance with Method C 140. Compressive strength test specimens shall conform to the saw-cut coupon provisions of section 5.2.4 of C 140 with the following exception: Coupon shall have a minimum thickness of 1.5 inches.

B. The expense of inspection and testing shall be incidental to the price bid for Concrete Block Retaining Walls.

S-34.13 Quality Control

A. The Contractor shall establish and maintain quality control for work under this section to assure compliance with contract requirements and maintain records of its quality control for all construction operations including but not limited to the following:

1. Sample Block
    a. Dimensions
    b. Weight
    c. Face appearance
2. Foundation Preparation
3. Alignment Tolerances
    a. Horizontal
    b. Vertical
    c. Plumbness
    d. Gaps between wall units
4. In place finish, appearance and defects.
5. Test results and certificates.
6. Installation.
7. Backfill.

A copy of the records of inspections and tests, as well as the records of corrective action taken, shall be furnished to the Engineer.

***<u>Technical Memorandum No. 98-21-MRR-08</u>***

**Part A**

Segmental Masonry Retaining Wall Units

<u>1.1 Scope</u>

This specification covers segmental masonry units for use in the construction of mortarless retaining walls.

<u>1.2 Requirements</u>

Each manufacturing facility shall provide the State Materials Engineer with a copy of their quality control plan and procedures, including testing rates and material sources. Each manufacturing facility shall also supply test reports and documentation to verify compliance with this specification.

The units shall conform to ASTM C 1372, except that:

(a) the minimum compressive strength requirements shall be 38 MPa (5500 psi) for any individual unit, and 40 MPa (5800 psi) for the average of three units.

(b) The maximum 24 hour water absorption shall not exceed 5 percent.

(c) Cap blocks must meet the requirements of (a) and (b) and have a top surface sloped at 1 mm fall per 10 mm run front to back or crowned at the center.

<u>1.3 Sampling and Testing</u>

Shall conform to ASTM C 140, except that:

Section 6.2.4 shall be deleted and replaced with: "The specimens shall be coupons cut from a face shell of each unit and sawn to remove any face shell projections. The coupon size shall have a height to thickness ratio of 2 to 1 before capping and a length to thickness ratio of 4 to 1. The coupon shall be cut from the unit such that the coupon height dimension is in the same direction as the unit height dimension. Compressive testing of full size unit swill not be permitted. The compressive strength of the coupon shall be assumed to represent the net area compressive strength of the whole unit."

Two of the eight blocks sampled per 10,000 units must be cap units.

Segmental Masonry Wall Surface Sealing

Segmental masonry retaining wall surface sealing shall consist of preparation, furnishing, and applying the surface sealer to the top, exposed front face, and back side of the upper three courses of all walls.

Surface sealers shall meet the requirements on file in the Mn/DOT Concrete Unit (779-5572).

Due to the hazardous ingredients contained in sealer formulations extreme care must be exercised in their handling and use, and the manufacturer's recommendations shall be closely followed.

Construction Requirements

1. The Contractor shall comply with the manufacture's written instructions for preparing, handling and applying the surface sealer.
2. The surface to be treated shall receive a light waterblast to the extent that the surface is clean and free of oils.
3. Before the surface sealer is applied, the surface to be sealed shall be dry and free of all dust, debris, and frost.
4. Surface sealers shall be applied at the heavies application rate specified by the manufacturer.

All materials and work performed as specified above will be incidental to construction of the wall.

**Part B**

Units shall meet all the requirements listed in Part A with the following addition:

"Section 1.2 Requirements – Dry Cast Units, Segmental Masonry Retaining Wall Units" shall be modified to include the following:

(d) Freeze-thaw durability testing will be required in accordance with ASTM C 1262. Specimens shall be tested in a 3 percent saline solution. Specimens shall conform with either of the following: 1) the weight loss of each of five test specimens at the conclusion of 40 cycles shall not exceed 1 percent of its initial weights; or 2) the weight loss of four out of five test specimens at the conclusion of 50 cycles shall not exceed 1.5 percent of its initial weight. Testing shall be continued until one of the following occurs: 1)the weight loss of each of five test specimens exceeds 2 percent of its initial weight; or 2) the weight loss of one of the five test specimens exceeds 2.5 percent of its initial weight; or 3) the specimens have been tested for at least 100 cycles. Complete test reports, including the cycle number at which failure occurred shall be submitted to the State Materials Engineer.

# APPENDIX D
# SURVEY DATA COLLECTION FORMS

# FIELD DATA DISTRESS SUMMARY SHEET

(General Distress Survey)

| | |
|---|---|
| Survey Team Initials: | Project ID: |
| Date/Time: | |
| Weather Conditions: | Field Data Sheet _____ of _____ |

Instructions: Provide an overall subjective SCBRW rating based on the following rating scale:

```
0 – 1 Very Poor   3 – 4 Good
1 – 2 Poor        4 – 5 Very Good
2 – 3 Fair
```

| Survey Team Initial | Subjective SCBRW Rating |
|---|---|
| | |
| | |

Instructions: Provide scales and north arrow. Sketch plan view of wall and locations of nearby roadways on the SCBRW plan view wall provided. Sketch wall profile, distress locations and severities, along with any other relevant features (e.g., drainage), on the blank SCBRW profile wall provided.

**SCBRW Plan View**

**North**

**SCBRW Profile**

Height

**North**

Station

# FIELD DATA DISTRESS SUMMARY SHEET (CONTINUED)

(General Distress Survey)

| | |
|---|---|
| Survey Team Initials: | Project ID: |
| Date/Time: | |
| Weather Conditions: | Field Data Sheet _____ of _____ |

| Distress Type | Severity Level | Quantity (% of SCBRW) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | None | <1 | 1-10 | 10-25 | 25-50 | 50-75 | 75-100 |
| 1 – Construction Defects<br>*Description:*_________________<br>____________________________ | Low | | | | | | | |
| | Medium | | | | | | | |
| | High | | | | | | | |
| 2 – Corner Breaks | Low | | | | | | | |
| | Medium | | | | | | | |
| | High | | | | | | | |
| 3 – Cracked Block | Low | | | | | | | |
| | Medium | | | | | | | |
| | High | | | | | | | |
| 4 – Efflorescence | Low | | | | | | | |
| | Medium | | | | | | | |
| | High | | | | | | | |
| 5 – Embedded Vegetative Growth | Low | | | | | | | |
| | Medium | | | | | | | |
| | High | | | | | | | |
| 6 – Erosion | Low | | | | | | | |
| | Medium | | | | | | | |
| | High | | | | | | | |
| 7 – Fraying/Spalling | Low | | | | | | | |
| | Medium | | | | | | | |
| | High | | | | | | | |
| 8 – Freeze-Thaw Damage (Top Block Layer) | Low | | | | | | | |
| | Medium | | | | | | | |
| | High | | | | | | | |
| 9 – Freeze-Thaw Damage (Vertical Surfaces) | Low | | | | | | | |
| | Medium | | | | | | | |
| | High | | | | | | | |
| 10 – Manufacturing Flaws<br>*Description:*_________________<br>____________________________ | Low | | | | | | | |
| | Medium | | | | | | | |
| | High | | | | | | | |

# FIELD DATA DISTRESS SUMMARY SHEET (CONTINUED)

(General Distress Survey)

| | |
|---|---|
| Survey Team Initials: | Project ID: |
| Date/Time: | |
| Weather Conditions: | Field Data Sheet _____ of _____ |

| Distress Type | Severity Level | Quantity (% of SCBRW) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | None | <1 | 1-10 | 10-25 | 25-50 | 50-75 | 75-100 |
| 11 – Misc. Distress/Flaws *Description:*_________________ ____________________________ | None | | | | | | | |
| 12 – Popouts (Top Block Layer) | None | | | | | | | |
| 13 – Position Guide Damage | Low | | | | | | | |
| | Medium | | | | | | | |
| | High | | | | | | | |
| 14 – Scaling (Top Block Layer) | Low | | | | | | | |
| | Medium | | | | | | | |
| | High | | | | | | | |
| 15 – Scaling (Vertical Surfaces) | Low | | | | | | | |
| | Medium | | | | | | | |
| | High | | | | | | | |
| 16 – Staining (External Source) | Low | | | | | | | |
| | Medium | | | | | | | |
| | High | | | | | | | |
| 17 – Staining (Internal Source) | None | | | | | | | |
| 18 – Structural Distress *Description:*_________________ ____________________________ | Low | | | | | | | |
| | Medium | | | | | | | |
| | High | | | | | | | |
| 19 – Wash-Through | Low | | | | | | | |
| | Medium | | | | | | | |
| | High | | | | | | | |

BLOCK MANUFACTURER: ___________________________

COMMENTS:

______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

# FIELD DATA DISTRESS SUMMARY SHEET

(Detailed Distress Survey)

| | |
|---|---|
| Survey Team Initials: | Project ID: |
| Date/Time: | |
| Weather Conditions: | Field Data Sheet _____ of _____ |

Instructions: Provide scales and north arrow. Sketch distress locations and severities, along with any other relevant features, on blank wall provided.

Height **North**

Station

Distresses:

| | | | |
|---|---|---|---|
| 1-Construction Defects | 6-Fraying/Spalling | 11-Scaling (Capstone) | 16-Wash-Through |
| 2-Corner Breaks | 7-Freeze-Thaw Damage | 12-Scaling (Face) | 17-Other |
| 3-Efflorescence | 8-Manufacturing Flaws | 13-Staining (External) | |
| 4-Embbeded Vegetation | 9-Popouts | 14-Staining (Internal) | |
| 5-Erosion | 10-Pos. Guide Damage | 15-Structural Distress | |

Instructions: Record each incidence and severity of distress on a separate line. Project totals are tallied on a separate sheet.

| Distress | Severity | Quantity | Units | Comments |
|---|---|---|---|---|
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General Comments:

# FIELD DATA DISTRESS SUMMARY SHEET (CONTINUED)

(Detailed Distress Survey)

| | |
|---|---|
| Survey Team Initials: | Project ID: |
| Date/Time: | |
| Weather Conditions: | Field Data Sheet _____ of _____ |

Distresses:
1-Construction Defects
2-Corner Breaks
3-Efflorescence
4-Embbeded Vegetation
5-Erosion
6-Fraying/Spalling
7-Freeze-Thaw Damage
8-Manufacturing Flaws
9-Popouts
10-Pos. Guide Damage
11-Scaling (Capstone)
12-Scaling (Face)
13-Staining (External)
14-Staining (Internal)
15-Structural Distress
16-Wash-Through
17-Other

Instructions: Record each incidence and severity of distress on a separate line. Project totals are tallied on a separate sheet.

| Distress | Severity | Quantity | Units | Comments |
|---|---|---|---|---|
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General Comments:

**QUALITATIVE ASSESSMENT OF PEAK WINTER CONDITIONS**

| | |
|---|---|
| Survey Team Initials: | Project ID: |
| Date/Time: | Hennepin / Dakota / Mn/DOT |
| Weather Conditions: Sunny / Cloudy / Raining / Snowing / Snow Cover | |

Field Data Sheet ___ of ___

Instructions: Provide scales and north arrow. Sketch plan view of wall and locations of nearby roadways on allotted space below. Provide direction of surrounding drainage, location(s) of snow removal pile(s) if any, locations of peak-day sunlight, locations of objects that shade wall capstone/top course.

**SCBRW Plan View**

**North**

| | YES | NO |
|---|---|---|
| 1. Type of Snow Removal | | |
| 1a. Main-Line Snow Removal | | |
| 1b. Side-Walk Snow Removal | | |
| 1c. Other: | | |
| 2. Snow Accumulation (Top Block Layer) *due to*: | | |
| 2a. Snow Removal | | |
| 2b. Falling Snow | | |
| 3. Snow Accumulation (Vertical Surface Layers) *due to*: | | |
| 3a. Snow Removal | | |
| 3b. Falling Snow | | |
| 4. Location of Snow Accumulation / Pile(s): | | |
| 5. Other External Sources of Moisture: | | |
| 6. Fence located adjacent to wall (behind top block layer)<br>Type of fence: | | |

| Peak-Day Sunlight Exposure | Percent of Wall Area | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | None | <1 | 1-10 | 10-25 | 25-50 | 50-70 | 70-80 | 80-90 | 90-100 | 100 |
| 7. Top Block Layer | | | | | | | | | | |
| 8. Vertical Surface Layers | | | | | | | | | | |

| Sand/Salt Snow Accumulation | Percent of Wall Length | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | None | <1 | 1-10 | 10-25 | 25-50 | 50-70 | 70-80 | 80-90 | 90-100 | 100 |
| 9. Top Block Layer Concentration = Low / Med / High | | | | | | | | | | |
| 10. Vertical Surface Layers Concentration = Low / Med / High | | | | | | | | | | |

# APPENDIX E
# DISTRESS IDENTIFICATION MANUAL

# Table of Contents

## Introduction

This manual is intended for use as a standard guide for the identification and measurement of distress and damage associated with segmental concrete block retaining walls (SCBRW). Each distress type is described, along with a general description of the associated distress mechanism or cause. Levels of distress severity are defined and typical photographs are provided for many distresses to assist the user in consistently identifying each distress in the field. Suggested units of measurement are also provided.

The distress definitions described are based on the results of preliminary field surveys of SCBRWs in the Minneapolis/St. Paul metropolitan area that were conducted in early 1999, along with the input and comments of Mn/DOT and industry personnel that were present at those surveys. Most of the photographs presented were also obtained on these surveys. In addition, this guide is patterned after the U.S. Air Force distress identification manual for airfields[*], which has served as the basis for currently accepted highway distress identification manuals as well.

Recommended field survey and evaluation procedures for SCBRW are described in a separate document.

[*] Shahin, M.Y., Darter, M.I. and Kohn, S. D. "Development of a Pavement Maintenance Management System. Volume V, Proposed Revisionof Chapter 3, AFR 93-5." Report No. CEE-DO-TR-77-44. U.S. Air Force, U. S. Army Construction Engineering Research Laboratory, Champaign, Illinois, 1977.

**1** 

## Construction Defects (General)

Description:
Construction flaws are often characterized by damage to block units that appears to be due to poor construction techniques or errors. Examples might include evidence of cracked units (possibly caused by mishandling during placement), open joints in locations other than a bend, or evidence of improper design/construction, such as improper block alignment (either vertical or horizontal).

Severity Levels:

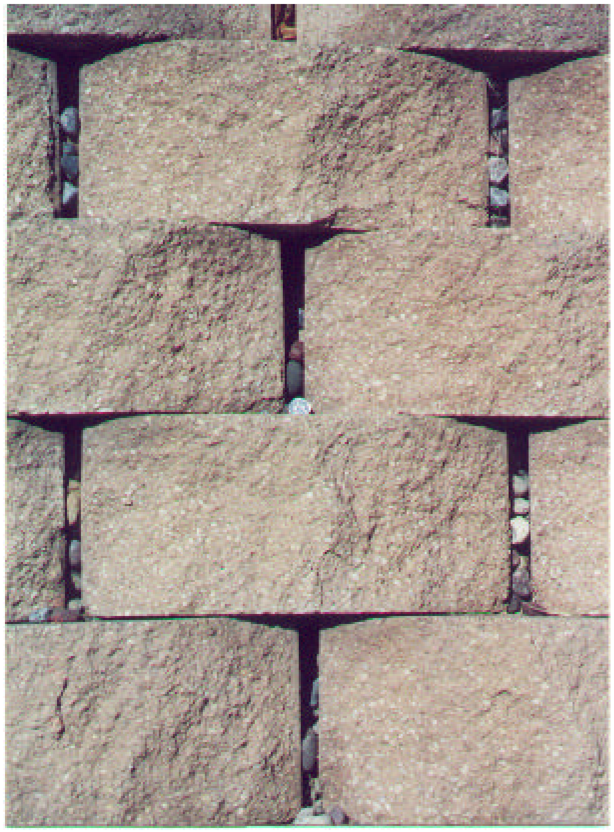
*Low:* Damage is infrequent and cosmetic in nature (e.g., occasional chipping of block edges or corners.

*Medium:* Damage is primarily cosmetic, but extensive; or individual units are seriously damaged, but the structural integrity of the retaining wall is not compromised.

*High:* Damage or condition is both severe and extensive; the structural integrity of the wall may be compromised.

Measurement:
The extent of construction flaws should be measured in terms of the estimated affected area for each incidence and severity level present. For example, if a particular wall contains 3 separate areas of construction flaw-related distress, then the area and severity level of each area should be estimated and recorded separately. In addition, if a single area contains more than one level of distress, the estimated area of each distress level should be recorded separately.

Medium-Severity Construction Flaw (Twisted Blocks)


Medium-Severity Construction Flaw (Open Joints)

## 2 Corner Breaks

Description:
One or more block corners are broken through or off (the fractured corner may be present or missing). The plane of fracture is approximately 45 degrees from vertical, and the size of the fracture exceeds 2 inches along all three major axes. Smaller breaks should be considered to be fraying or edge spalls.

A corner break may be caused by poor construction practices, such as the mishandling of blocks, the placement of block on an uneven surfaces, or entrapment of incompressible materials between courses (resulting in high point bearing stresses). Frequent corner breaks may be an indication of a manufacturing defect.

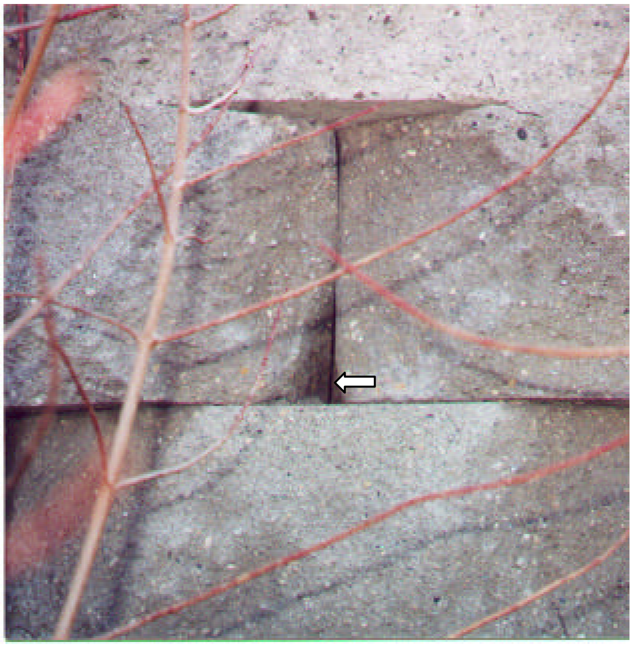
Severity Levels:

*Low:* The break measures *less than 4 inches* along all major axes (breaks measuring less than 2 inches along all major axes are considered fraying or edge spalls).

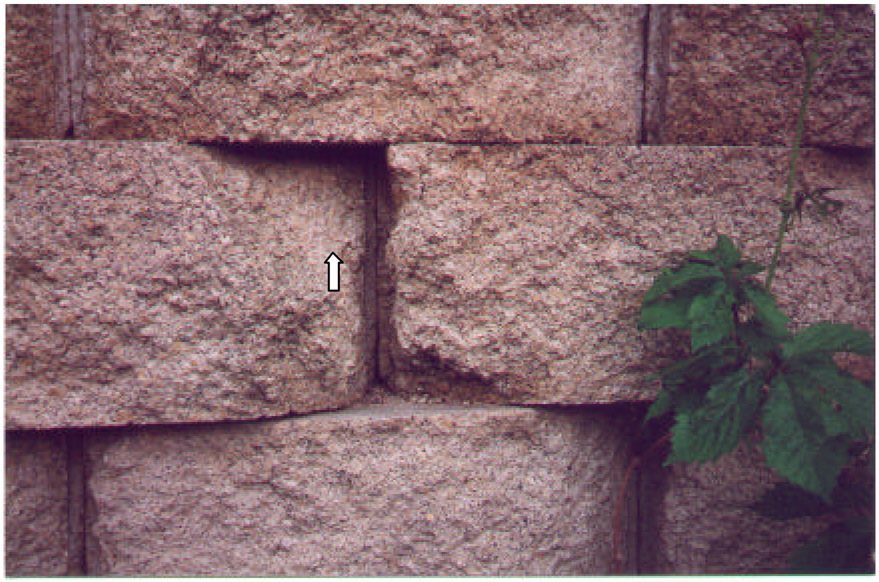
*Medium:* The break measures *4 to 6 inches* along one or more axes.

*High:* The break measures *more than 6 inches* along one or more axes.

Measurement:
Corner breaks are counted individually and tallied according to severity level.



Low-Severity Corner Break



Medium-Severity Corner Break

**3** 

## Cracked Block

Description:

Cracked block units are often characterized by random cracks to block units. The direct cause of the crack development is uncertain. Examples might include a diagonal or straight crack propagation across the capstone, vertical crack propagation along a block unit face (e.g., the crack is located directly below the joint formed by two adjoining blocks in the layer above), etc.

Severity Levels:

*Low:* A few individual block units are cracked at *random* locations; affected areas are exhibiting *tight cracks with no apparent spalling*.

*Medium:* A few individual block units are cracked at *random* locations; affected areas are exhibiting *tight cracks with apparent spalling*.

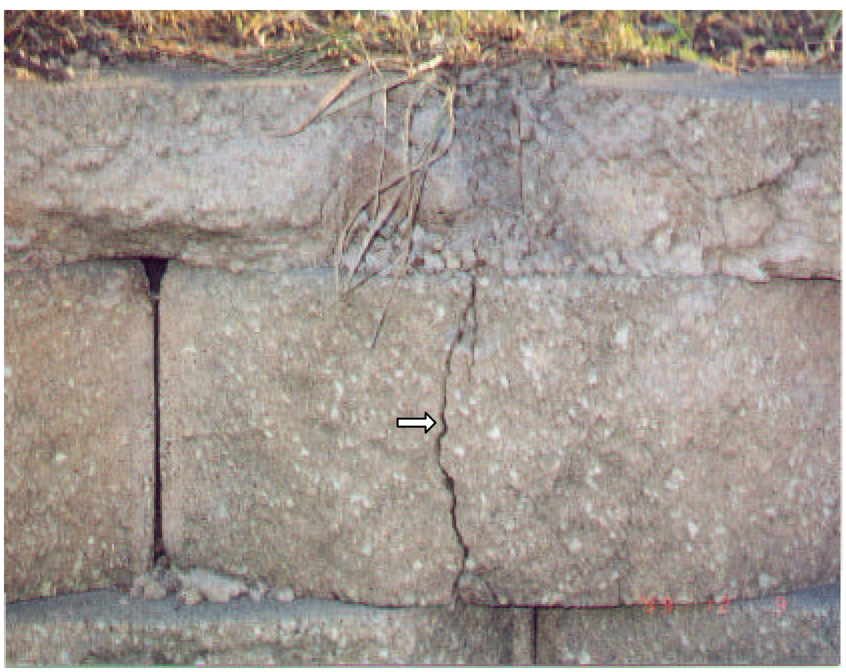
*High:* Deterioration is extreme and affected areas are exhibiting *open cracks with severe spalling*.

Measurement:

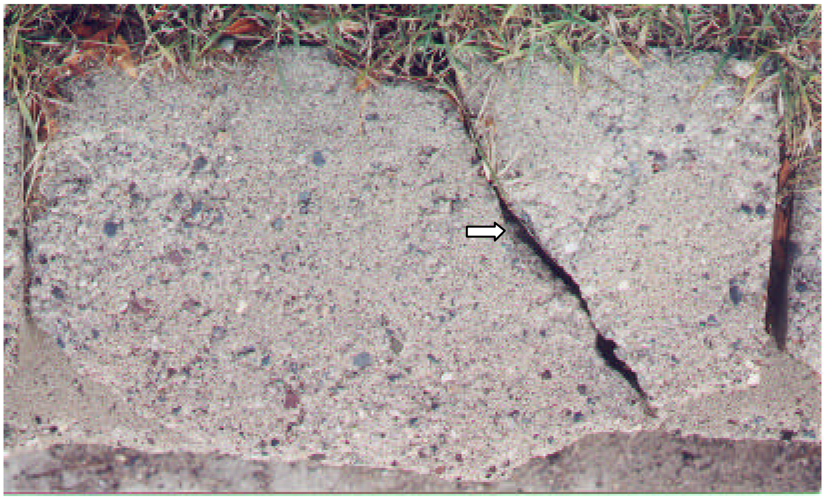
Cracked block units are counted individually and tallied according to severity level.

Low-Severity Cracked Block

Medium-Severity Cracked Block



High-Severity Cracked Block



High-Severity Cracked Block

**4**

## Efflorescence

Description:

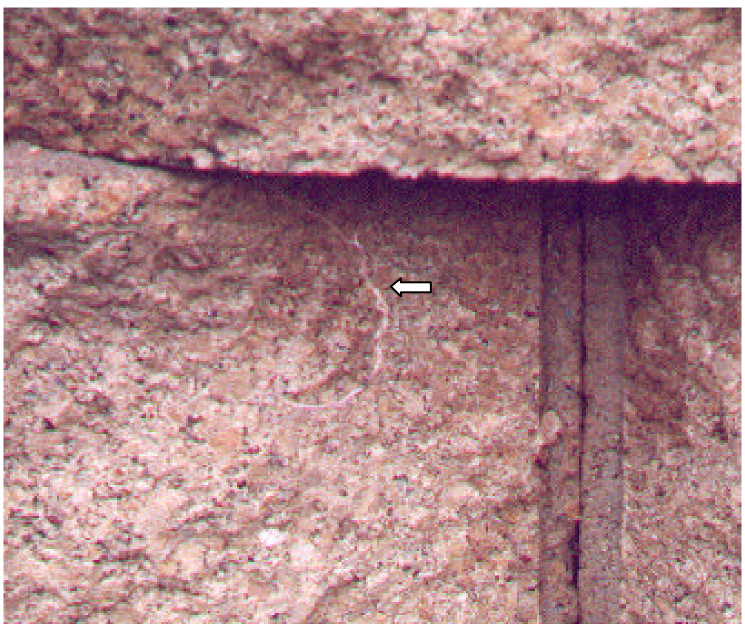
Efflorescence is the precipitation of white crusts of calcium carbonate on SCBRW units caused by the interaction of leached calcium hydroxide with carbon dioxide present in air.

Efflorescence is primarily an aesthetic problem, but can serve as evidence of increased block porosity and weakness in extreme cases.

Severity Levels:

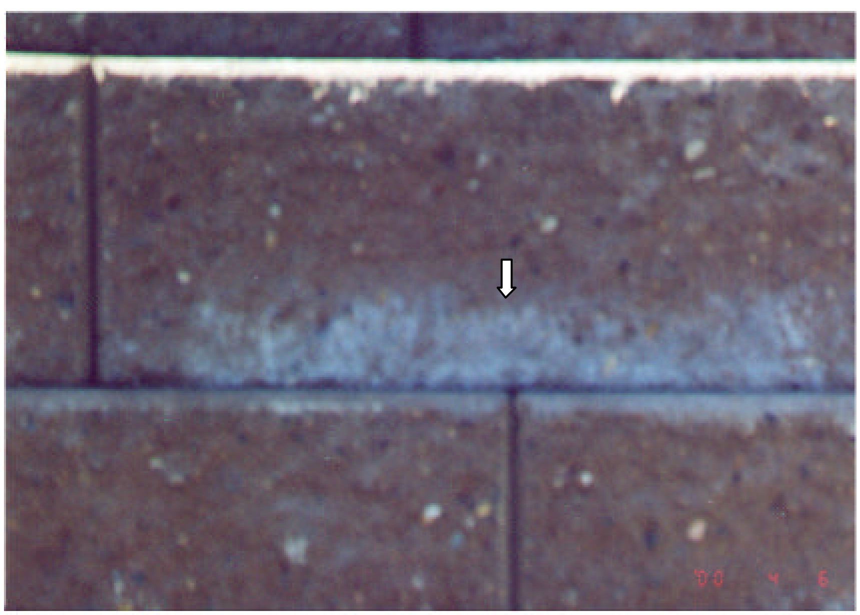
| | |
|---|---|
| *Low:* | Presence of minor or thin mineral deposits, with little effect on SCBRW appearance. |
| *Medium:* | Mineral deposits are readily apparent near block joints or cracks, detracting from SCBRW appearance. |
| *High:* | Mineral deposits are highly visible and extensive. SCBRW appearance is seriously affected. |

Measurement:
The extent of efflorescence should be measured in terms of the estimated affected area for each incidence and severity level present. For example, if a particular wall contains 3 separate areas of efflorescence, then the area and severity level of each area should be estimated and recorded separately. In addition, if a single area contains more than one level of distress, the estimated area of each distress level should be recorded separately.

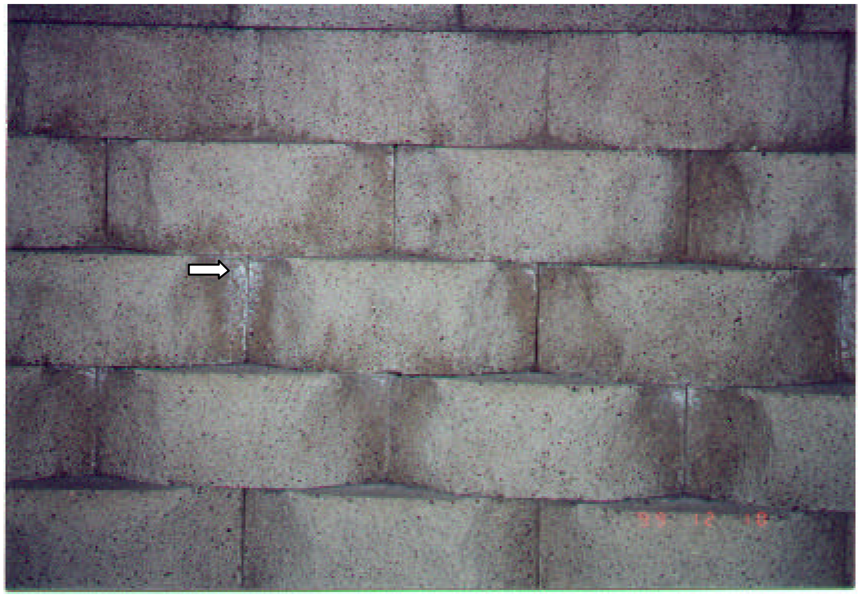


Low-Severity Efflorescence along Crack

Low-Severity Efflorescence



Medium-Severity Efflorescence



Medium-Severity Efflorescence

High-Severity Efflorescence

## 5 Embedded Vegetative Growth

Description:
Embedded vegetative growth (EVG) is the presence of plant foliage growing from between block units or in wash-through deposits. The penetration of plant roots into the SCBRW from EVG may cause block units to crack either through root growth into pores and small flaws or by extensive plant growth between block units.

Exposed fine tree and plant roots that have grown through the wall from behind are not considered EVG. Plants that are present as architectural enhancements are also not considered EVG.

Severity Levels:

*Low:* Occasional small plants are observed growing on the SCBRW face. Most growth is confined to wash-through deposits. Diameter of plant-growth root measures *less than ¼ inch*.

*Medium:* Plant growth is common, but not dense, on the SCBRW face. The presence of large plants indicates root growth into the wall through gaps between the block units. Little, if any, damage is observed. Seasonal coverage by vines is generally considered medium-severity distress. Diameter of plant-growth root measures *¼ inch to 1 inch*.

*High:* Foliage is dense, with large plants and extensive root systems. Some apparent plant-related damage may be evident. Diameter of plant-growth root measures *more than 1 in*.

Measurement:
The extent of embedded vegetative growth should be measured in terms of the estimated affected area for each incidence and severity level present. For example, if a particular wall contains 3 separate areas of EVG, then the area and severity level of each area should be estimated and recorded separately. In addition, if a single area contains more than one level of distress, the estimated area of each distress level should be recorded separately.

Low-Severity Embedded Vegetative Growth

Medium-Severity Embedded Vegetative Growth


Medium-Severity Embedded Vegetative Growth


High-Severity Embedded Vegetative Growth

High-Severity Embedded Vegetative Growth

## 6 Erosion

Description:
Erosion is the loss of SCBRW surface material due to the action of water or wind-blown abrasives (e.g., sand and salt). This distress may be easily confused with surface scaling and freeze-thaw damage because the latter distresses are generally more severe in areas of water flow and saturation. Erosion is typically evidenced by relatively uniform loss of surface mortar along the paths of water flow; scaling and freeze-thaw damage often involve loss of embedded aggregate and damage to greater depths, particularly near the bottom of the block where critical levels of saturation may exist more frequently.

Severity Levels:

*Low:* Loss of mortar is minor, characterized by slight roughening of surface texture and slight evidence of aggregate exposure in areas of greatest flow.

*Medium:* Loss of mortar is easily seen, significant aggregate exposure is apparent.

*High:* Heavy loss of mortar, some evidence of aggregate loss as well. May be difficult to distinguish from scaling or freeze-thaw damage except that loss of material does not increase significantly in areas where water may accumulate.

Measurement:
The extent of erosion should be measured in terms of the estimated affected area for each incidence and severity level present. For example, if a particular wall contains 3 separate areas of erosion, then the area and severity level of each area should be estimated and recorded separately. In addition, if a single area contains more than one level of distress, the estimated area of each distress level should be recorded separately.

Low-Severity Erosion

Medium-Severity Erosion

**7**

## Fraying/Spalling (Block Edges)

Description:
Fraying or spalling is the presence of minor chipping along block edges and corners, usually extending 2 inches or less into the block face. Occasional fraying or spalling may be caused by improper handling or placement of block units. Some spalling may also result from the restraint of thermal expansion (caused by tight block placement or infiltration of incompressibles into block joints) or placement of blocks on uneven surfaces. The presence of more frequent distress may be evidence of a systematic problem in block manufacturing and should be noted as such (see Manufacturing Flaws (General)).

Deterioration of small thin vertical sections formed along the top edge of the block as placement guides should not be considered spalling if the deterioration appears to be the result of freeze-thaw or moisture-related distress.

Severity Levels:

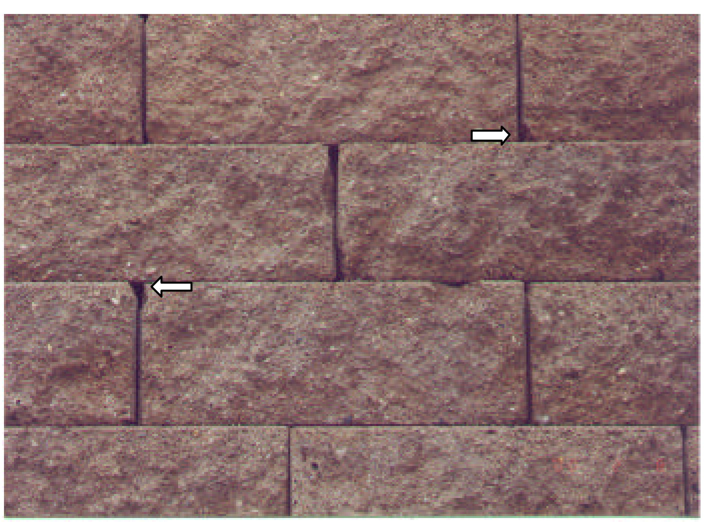
*Low:* Spalls extending ¼ inch or less into the block face are present.

*Medium:* Spalling or fraying are present. Spalls extending between ¼ and 1 inch into the block face are present.

*High:* Spalls are either *extensive* (present over 25 percent or more of the block edges) or severe (extending between 1 and 2 inches into the block face).

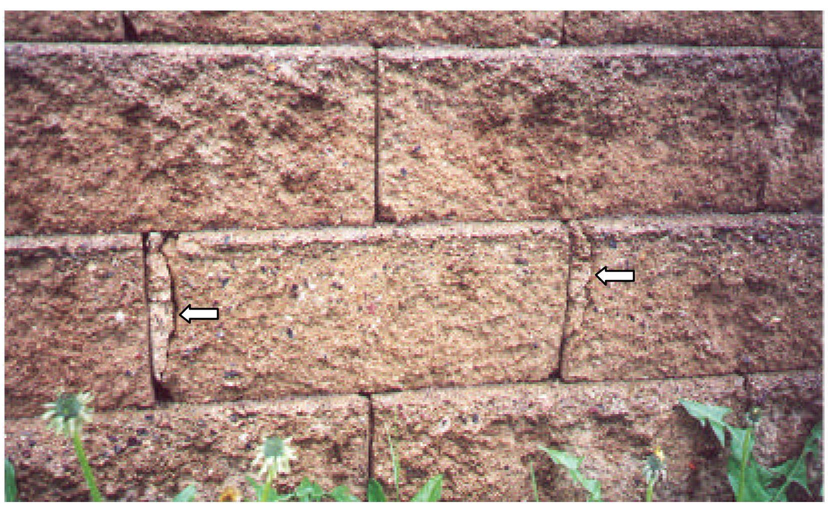
The severity level of blocks exhibiting spalling/fraying is determined according to the highest level of distress present. For example, if a block contains only two spalls, but one is a large spall, the severity is considered high for the entire block.

Measurement:
Blocks exhibiting edge fraying or spalling are counted individually and tallied according to severity level.



Low-Severity Spalling


Medium-Severity Spalling


High-Severity Edge Spalling

## 8 Freeze-Thaw Damage (Top Block Layer)

Description:
Freeze-thaw damage is the *progressive* internal deterioration of critically saturated concrete in the presence of freezing and thawing temperatures. The expansion of water during freezing can produce internal damage to the concrete block matrix if the pore structure does not allow rapid expulsion of water or if the concrete in not air-entrained. The resulting distress will appear as a general deterioration or crumbling of the concrete in the affected areas.

Freeze-thaw damage will be most severe in areas that are frequently saturated when exposed to freezing conditions. For example, areas of walls that are exposed to surface runoff are more likely to experience saturating conditions than other wall areas. In addition, walls that are placed in close proximity to highway pavements may be exposed to frequent spray from passing vehicles during wet weather; freeze-thaw damage may increase as the distance to the roadway decreases (both horizontally and vertically).

The presence of deicing salts may accelerate freeze-thaw damage because salt-saturated water is more readily absorbed into concrete, resulting in higher levels of saturation. In addition, the crystallization of salt in the concrete pores as the water evaporates may also produce damaging stresses and deterioration.

*Exceptions:*
Snow melt and rainfall may result in the ponding of water on the capstones that are often placed at the top of SCBRW. These frequent periods of saturation often produce higher rates of freeze-thaw deterioration (typically surface scaling) than are observed on other portions of the SCBRW. This type of freeze-thaw damage is referred to as "Scaling (Capstone Surface)" and is recorded separately.

Extensive scaling of the vertical surface of the wall (away from block joints and corners) may be the result of frequent periods of saturation due to surface water run-off. This type of freeze-thaw damage is referred to as "Scaling (Vertical Surface)" and is recorded separately.

Certain types of individual aggregate particles (e.g., cherts and shales) may expand significantly during freezing and, if located near the surface of the block, can cause concrete in the immediate vicinity to flake off or chip away. This freeze-thaw related damage is called a popout, and is recorded as a separate type of distress (see Popouts).

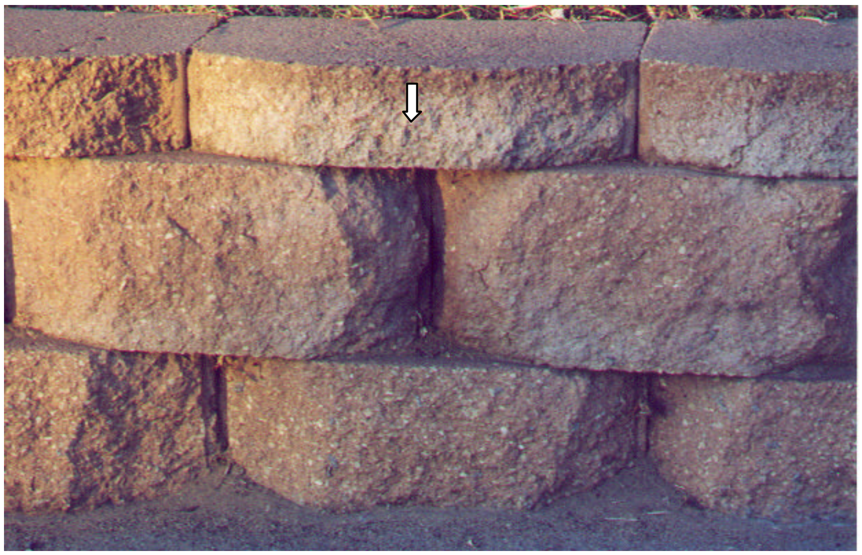
Severity Levels:

*Low:* Deterioration is localized and minor, exhibiting some *local discoloration* but no significant loss of material.

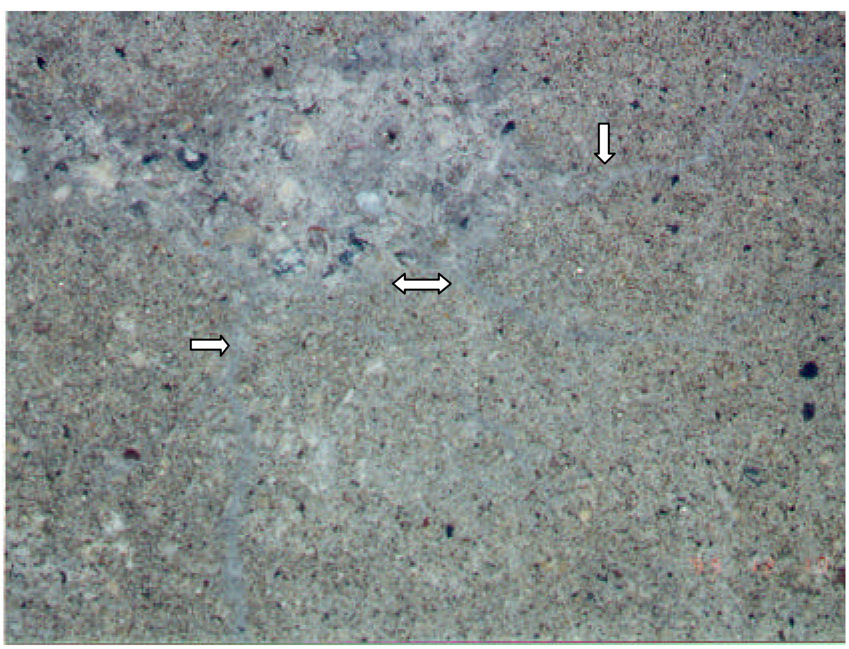
*Medium:* Deterioration is present in most areas that might be saturated during freezing and thawing. Discoloration is easily observed and affected areas are exhibiting *tight cracks*.

*High:* Deterioration is extreme and affected areas are exhibiting *open cracks*.

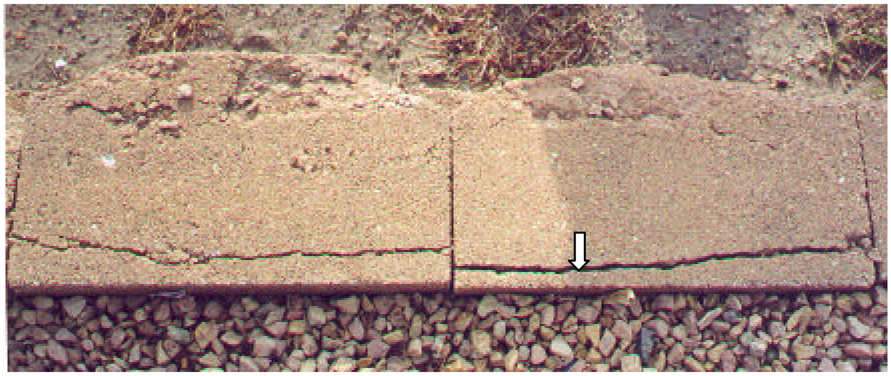
Measurement:
The extent of freeze-thaw damage should be measured in terms of the estimated affected area for each incidence and severity level present. For example, if a particular wall contains 3 separate areas of freeze-thaw damage, then the area and severity level of each area should be estimated and recorded separately. In addition, if a single area contains more than one level of distress, the estimated area of each distress level should be recorded separately.



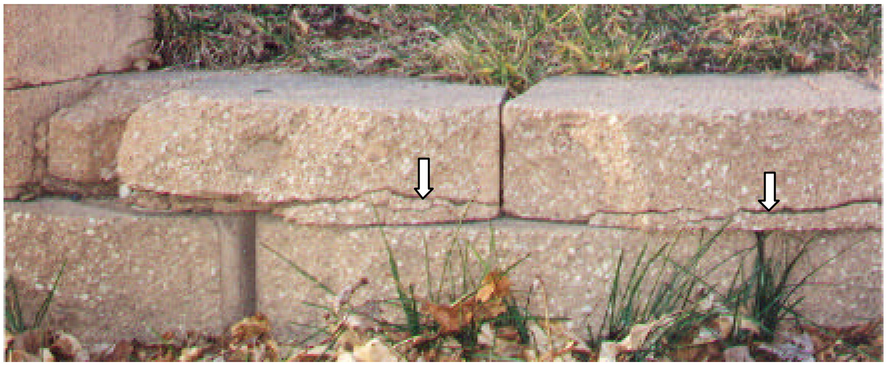
Low-Severity Capstone Freeze-Thaw Damage



Medium-Severity Capstone Freeze-Thaw Damage (Spider-Web Crack)



High-Severity Capstone Freeze-Thaw Damage (Delamination)



High Severity Capstone Freeze-Thaw Damage (Delamination)

## 9 Freeze-Thaw Damage (Vertical Surfaces)

Description:
Freeze-thaw damage is the *progressive* internal deterioration of critically saturated concrete in the presence of freezing and thawing temperatures. The expansion of water during freezing can produce internal damage to the concrete block matrix if the pore structure does not allow rapid expulsion of water or if the concrete in not air-entrained. The resulting distress will appear as a general deterioration or crumbling of the concrete in the affected areas.

Freeze-thaw damage will be most severe in areas that are frequently saturated when exposed to freezing conditions. For example, areas of walls that are exposed to surface runoff are more likely to experience saturating conditions than other wall areas. In addition, walls that are placed in close proximity to highway pavements may be exposed to frequent spray from passing vehicles during wet weather; freeze-thaw damage may increase as the distance to the roadway decreases (both horizontally and vertically).

The presence of deicing salts may accelerate freeze-thaw damage because salt-saturated water is more readily absorbed into concrete, resulting in higher levels of saturation. In addition, the crystallization of salt in the concrete pores as the water evaporates may also produce damaging stresses and deterioration.

*Exceptions:*
Snow melt and rainfall may result in the ponding of water on the capstones that are often placed at the top of SCBRW. These frequent periods of saturation often produce higher rates of freeze-thaw deterioration (typically surface scaling) than are observed on other portions of the SCBRW. This type of freeze-thaw damage is referred to as "Scaling (Capstone Surface)" and is recorded separately.

Extensive scaling of the vertical surface of the wall (away from block joints and corners) may be the result of frequent periods of saturation due to surface water run-off. This type of freeze-thaw damage is referred to as "Scaling (Vertical Surface)" and is recorded separately.

Certain types of individual aggregate particles (e.g., cherts and shales) may expand significantly during freezing and, if located near the surface of the block, can cause concrete in the immediate vicinity to flake off or chip away. This freeze-thaw related damage is called a popout, and is recorded as a separate type of distress (see Popouts).

Severity Levels:

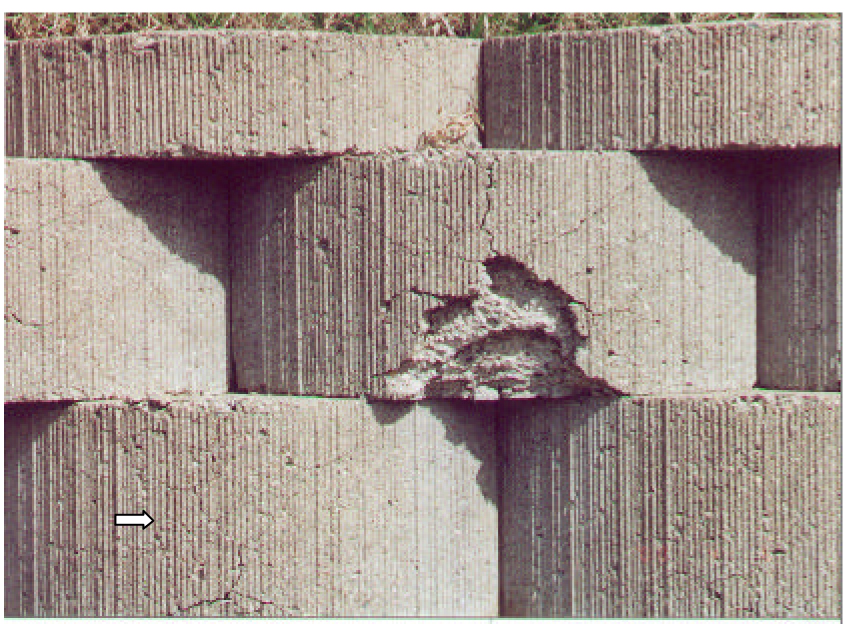
*Low:* Deterioration is localized and minor, exhibiting some *local discoloration* but no significant loss of material.

*Medium:* Deterioration is present in most areas that might be saturated during freezing and thawing. Discoloration is easily observed and affected areas are exhibiting *tight cracks*.

*High:* Deterioration is extreme and affected areas are exhibiting *open cracks*.

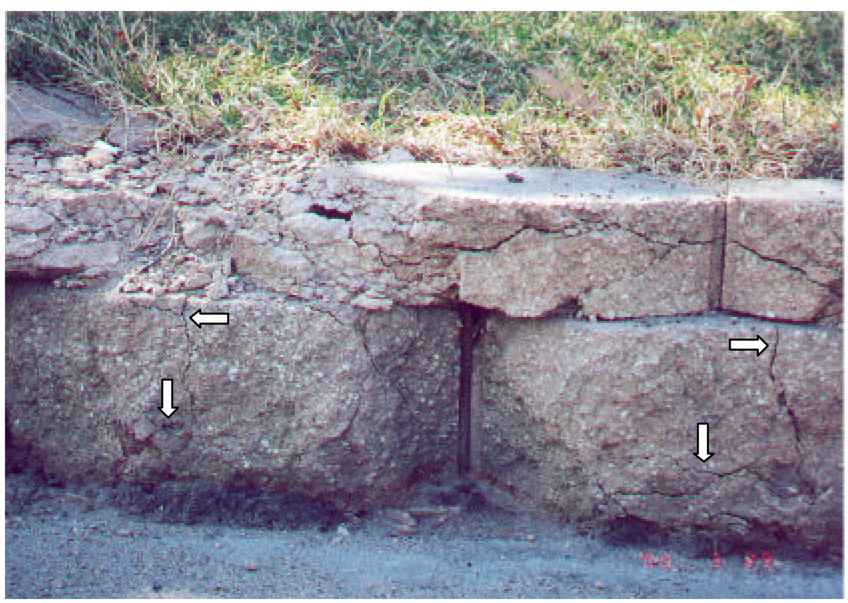
Measurement:
The extent of freeze-thaw damage should be measured in terms of the estimated affected area for each incidence and severity level present. For example, if a particular wall contains 3 separate areas of freeze-thaw damage, then the area and severity level of each area should be estimated and recorded separately. In addition, if a single area contains more than one level of distress, the estimated area of each distress level should be recorded separately.

Low-Severity Vertical Surface Freeze-Thaw Damage



Medium-Severity Vertical Surface Freeze-Thaw Damage

High-Severity Vertical Surface Freeze-Thaw Damage



High-Severity Vertical Surface Freeze-Thaw Damage

**10** 

## Manufacturing Flaws (General)

<u>Description</u>:
Manufacturing flaws are characterized by the evidence of systematic or frequent damage to block units that appears to be due to a design or manufacturing problem. Examples might include flaws in surface texture, original coloration or architectural enhancements (e.g., decorative features and coatings).

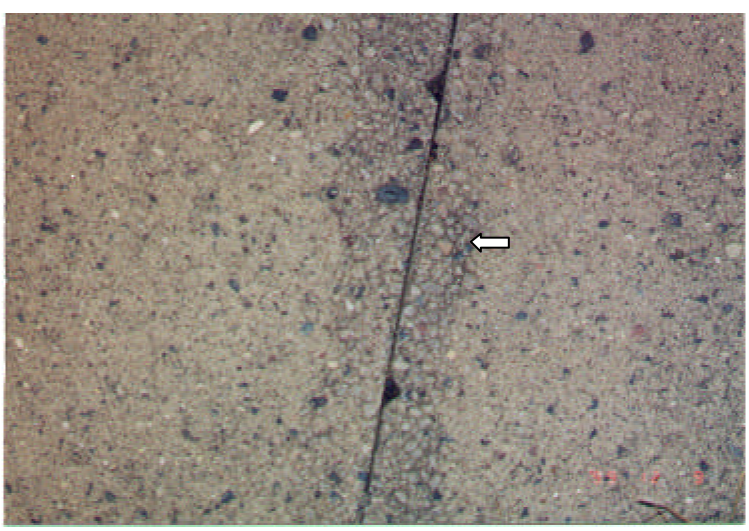
<u>Severity Levels</u>:
Severity levels for manufacturing flaws are somewhat subjective and are based on the apparent impact of the flaw on block function or appearance. When more than one manufacturing flaw is observed in a given block, the more severe flaw controls the severity level rating.

*Low:* The flaw is minor, infrequent and cosmetic in nature. Examples might include minor variation in color or surface texture, evidence of minor mold flaws, etc.

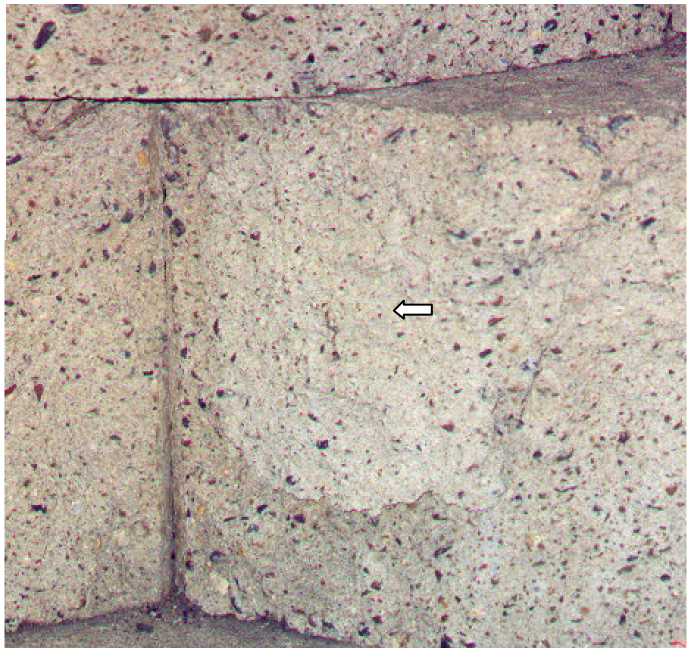
*Medium:* The flaw is significant, but is primarily cosmetic in nature. These flaws may be similar to, but more apparent and extensive than, those noted for low severity.

*High:* This category includes cosmetic flaws that are highly significant and obvious. Also included are flaws that compromise block structure, such as frequent cracks and corner breaks that appear to be a result of a manufacturing problem rather than handling or exposure problems.

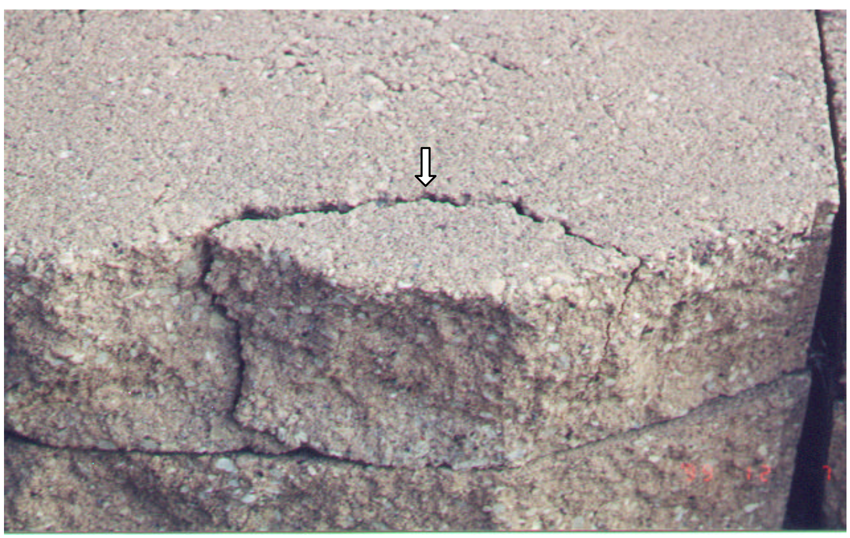
<u>Measurement</u>:
An estimate shall be made of the total percentage of block units that exhibit manufacturing flaws (e.g., none, less than 1 percent, 1 to 5 percent, 5 to 25 percent, more than 25 percent). Separate estimates shall be made of the distribution of severity within the flawed blocks (e.g., 75 percent low, 20 percent medium and 5 percent high, for a total of 100 percent).



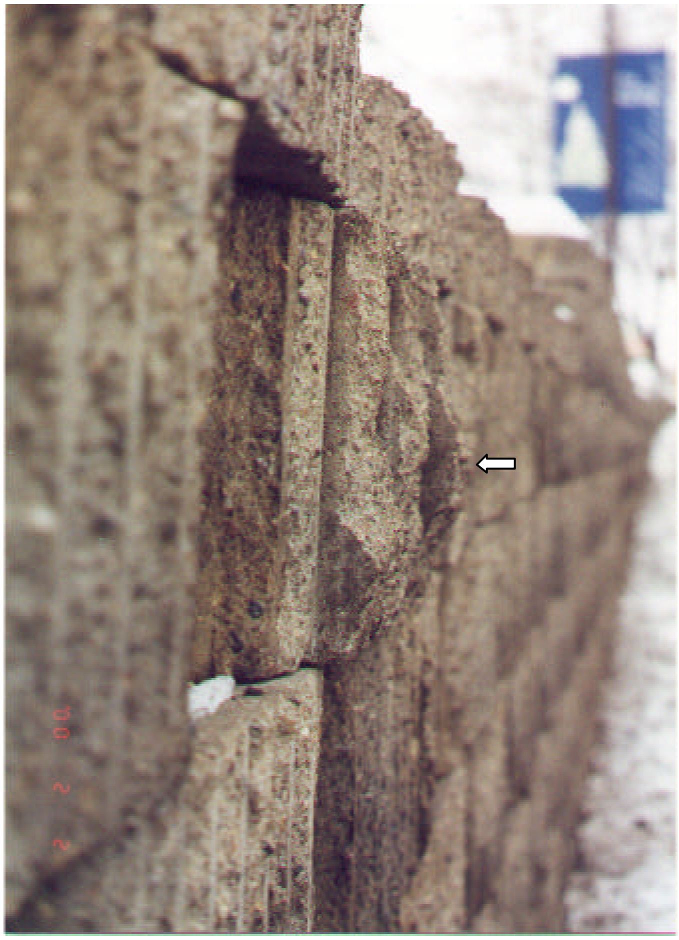
Poor Consolidation of Capstone Block Edges



Cleaved Face



Poor Face Break



Unclean Face Break

## 11 Miscellaneous Distresses/Flaws

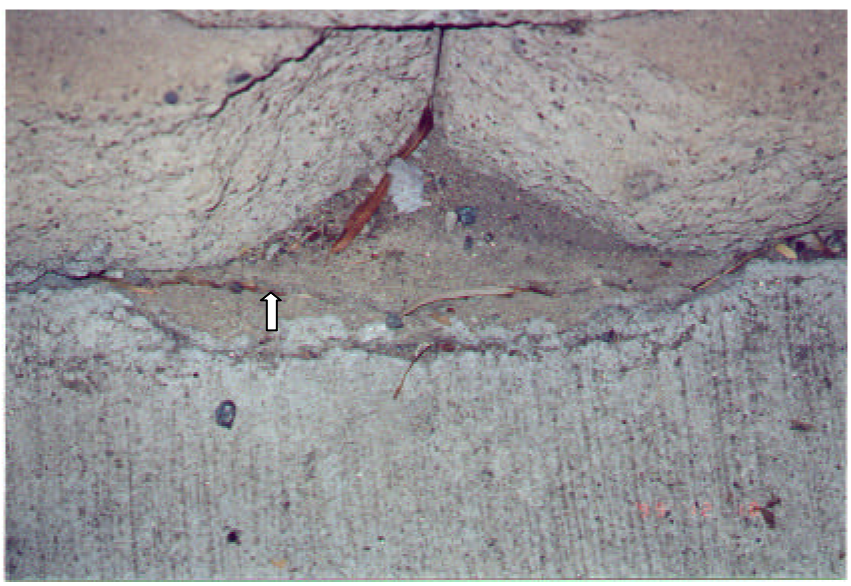
Description:
This category encompasses miscellaneous distresses/flaws that do not affect the structural integrity of the wall. The distresses/flaws are infrequent in nature and have not already been defined under another distress category.

Severity Levels:
Severity levels are not defined for miscellaneous distresses/flaws. They are either present or they are not present.

Measurement:
Miscellaneous distresses/flaws are counted individually and tallied.

Scrapes in Vertical Surface Block

Bottom Block Popped out of Ground.



Reflective Crack across Recessed Bottom Block


Missing Backfill behind Top Block Layer

## 12 Open Joints

Description:
The presence of open joints may be due to poor block placement during initial construction (1 – Construction Defects [General]) or due to a structural problem occurring after construction (19 – Structural Distress). This latter category includes displacement of the wall due to lateral movement of the backfill. However, since some surveys are not performed immediately after wall construction, it is uncertain whether any open joints present are due to construction or structural problems. Therefore, any open joints encountered, during a distress survey that is not performed immediately after construction, are simply noted and included under this separate category named “open joints”.

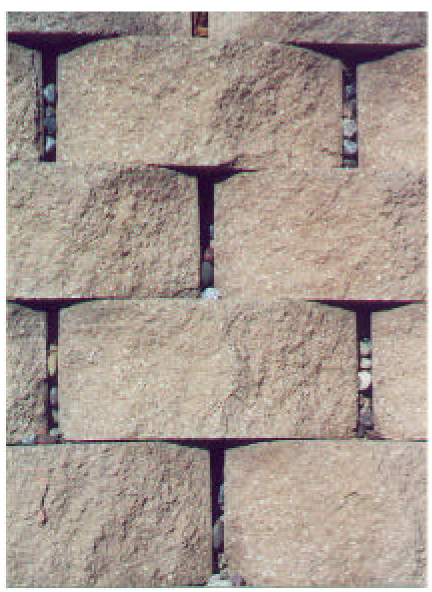
Severity Levels:

*Low:* Damage is infrequent and cosmetic in nature.

*Medium:* Damage is primarily cosmetic, but extensive; or individual units are seriously damaged, but the structural integrity of the retaining wall is not compromised.

*High:* Damage or condition is both severe and extensive; the structural integrity of the wall may be compromised.

Measurement:
The extent of open joints should be measured in terms of the estimated affected area for each incidence and severity level present. For example, if a particular wall contains 3 separate areas of open joints, then the area and severity level of each area should be estimated and recorded separately. In addition, if a single area contains more than one level of distress, the estimated area of each distress level should be recorded separately.



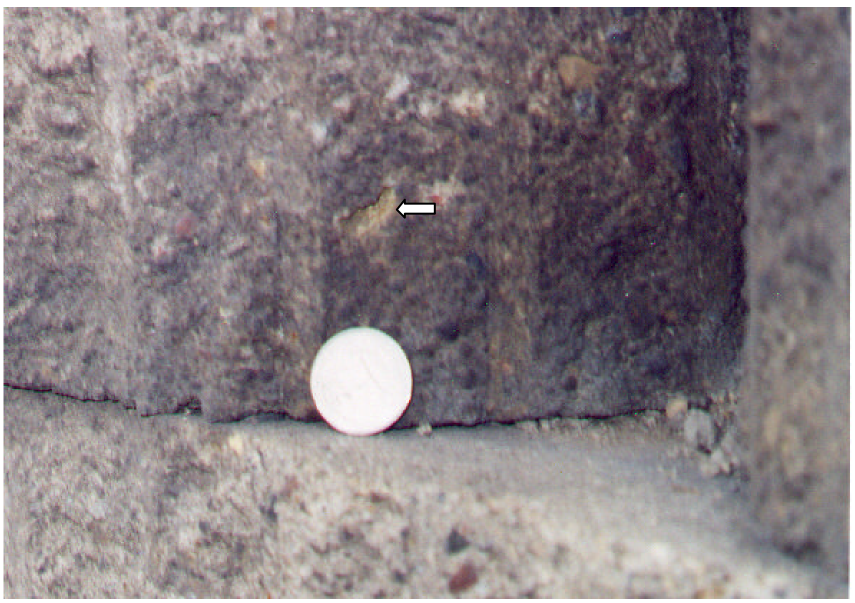
Medium-Severity Open Joints

## 13 Popouts

Description:
Certain types of individual aggregate particles (e.g., cherts and shales) may expand significantly if critically saturated during freezing and, if located near the surface of the block, can cause concrete in the immediate vicinity to flake off or chip away. This freeze-thaw related damage is called a popout.

Severity Levels:
Severity levels are not defined for popouts. They are either present or they are not present.

Measurement:
The measurement of popouts should be performed as an estimate of size of the affected area and the average number of popouts per block within the affected area. For example, the affected area might be reported to measure 10 ft by 20 ft (200 sq. ft.) and exhibit an average of 3 popouts per block unit within that area. Multiple affected areas can be reported for a single wall.



Popout Present in Top Course Block

## 14 Positioning Guide Damage

Description:
Some block designs feature a small vertical concrete "lip" near the front edge of the top block surface. This "lip" provides guidance in the positioning of each block unit to ensure a uniform rate of step back (vertical slope) as the wall is constructed.

This concrete positioning guide is susceptible to manufacturing flaws, construction-related damage (due to careless handling and placement of blocks) and to freeze-thaw damage (because water can easily accumulate behind the guide). Damage from any of these sources generally characterized by the formation of a crack along the base of the concrete "lip," followed by eventual loss of all or a portion of the guide. Freeze-thaw damage may cause the lip to disintegrate as well.

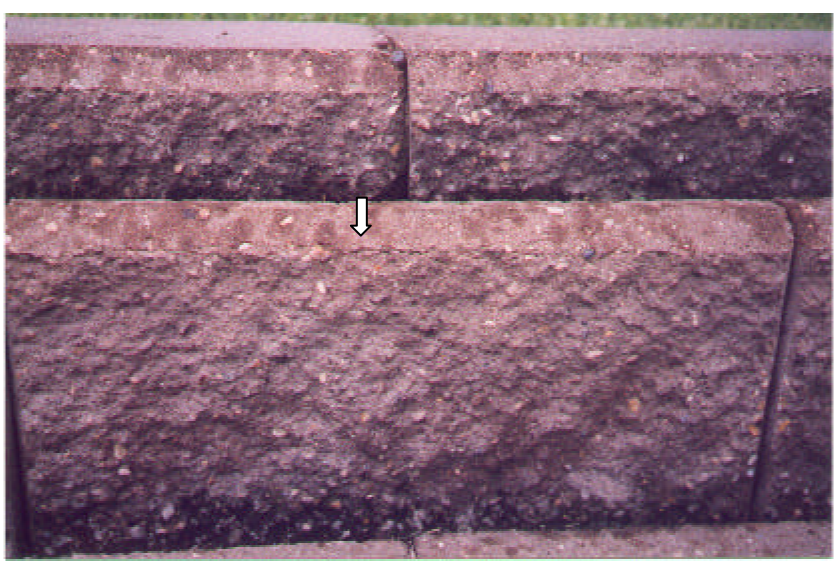
Severity Levels:

*Low:* A crack exists at the base of the positioning guide, but the guide itself is largely intact and shows no evidence of freeze-thaw deterioration or spalling.

*Medium:* Cracking may be present at the base of the positioning guide and portions of the guide are missing from some blocks, but the damage is not extensive.

*High:* Damage is extensive, with frequent missing portions and/or freeze-thaw deterioration.

Measurement:
The measurement of positioning guide damage should be performed as an estimate of percentage of blocks exhibiting each severity level (e.g., 75 percent none, 15 percent low, 9 percent medium and 1 percent high, for a total of 100 percent).



Low-Severity Block Position Guide Damage


High-Severity Block Position Guide Damage


High-Severity Block Position Guide Damage


High-Severity Block Position Guide Damage

## 15 Scaling (Top Block Layer)

Description:
Capstone surface scaling is a special case of freeze-thaw damage to SCBRW.

Freeze-thaw damage is the *progressive* deterioration of critically saturated concrete in the presence of freezing and thawing temperatures. The expansion of water during freezing can produce internal damage to the concrete block matrix if the pore structure does not allow rapid expulsion of water or if the concrete in not air-entrained. The resulting distress will appear as a general deterioration or crumbling of the concrete in the affected areas.

Freeze-thaw damage is most severe in areas that are frequently saturated when exposed to freezing conditions. Snow melt and rainfall may result in the ponding of water on the capstones that are often placed at the top of SCBRW. These frequent periods of saturation often produce higher rates of freeze-thaw deterioration (typically surface scaling) than are observed on other portions of the SCBRW. In addition, the presence of deicing salts may accelerate freeze-thaw damage because salt-saturated water is more readily absorbed into concrete, resulting in higher levels of saturation. In addition, the crystallization of salt in the concrete pores as the water evaporates may also produce damaging stresses and deterioration.

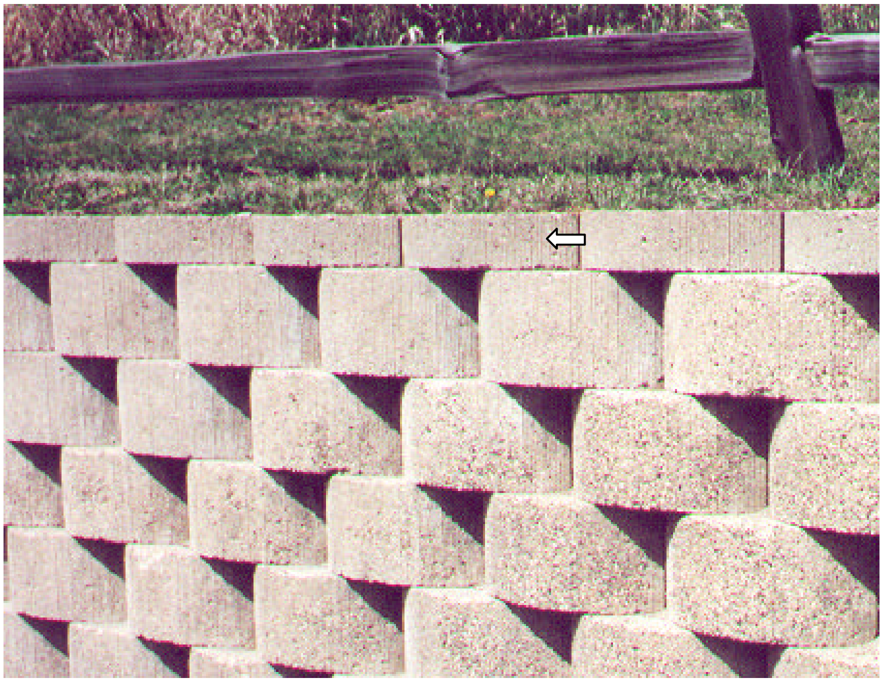
Severity Levels:

*Low:* Scaling is light with little debris or loose concrete in evidence.

*Medium:* Scaling is significant, often present to a depth *up to ¼ inch or more*. Loose materials may still be present.

*High:* Severe deterioration is present. Scaling is widespread and present to depths *exceeding ¼ inch*. Much loose concrete debris is present on the surface and possibly at the base of the wall.

Measurement:
The extent of capstone surface scaling should be measured in terms of the estimated percentage of capstone blocks that are affected (e.g., 20 percent) and the distribution of block percentages within each severity category (e.g., 50 percent low, 30 percent medium and 20 percent high, totaling 100 percent).



Low-Severity Top Block Layer Scaling

Low-Severity Top Block Layer Scaling

Medium-Severity Top Block Layer Scaling

High-Severity Capstone Surface Scaling

## 16 Scaling (Vertical Surfaces)

Description:
Vertical face scaling is generally evidence of a special case of freeze-thaw damage to SCBRW, although it may indicate a manufacturing defect as well.

Freeze-thaw damage is the *progressive* deterioration of critically saturated concrete in the presence of freezing and thawing temperatures. The expansion of water during freezing can produce internal damage to the concrete block matrix if the pore structure does not allow rapid expulsion of water or if the concrete in not air-entrained. The resulting distress will appear as a general deterioration or crumbling of the concrete in the affected areas.

Freeze-thaw damage is most severe in areas that are frequently saturated when exposed to freezing conditions. Extensive scaling of the vertical surface of the wall (away from block joints and corners) may be the result of frequent periods of saturation due to surface water run-off or close proximity to roadway spray. In addition, the presence of deicing salts may accelerate freeze-thaw damage because salt-saturated water is more readily absorbed into concrete, resulting in higher levels of saturation. The crystallization of salt in the concrete pores as salt-saturated water evaporates may also produce damaging stresses and deterioration.

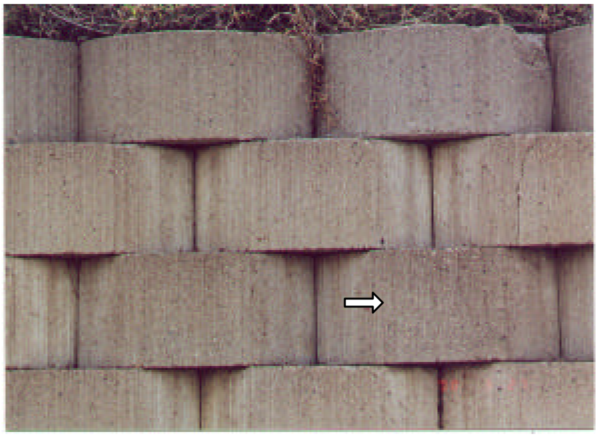
Severity Levels:

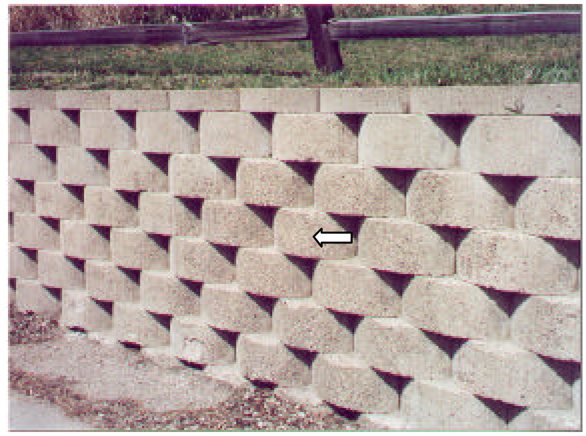
*Low:* Scaling is light with little debris or loose concrete in evidence.

*Medium:* Scaling is significant, often present to a depth up to *¼ inch or more*. Loose material may still be present.

*High:* Severe deterioration is present. Scaling is widespread and present to depths *exceeding ¼ inch*. Much loose concrete debris is present beneath the scaled area and possibly at the base of the wall.

Measurement:
The extent of vertical face scaling should be measured in terms of the estimated affected area for each incidence and severity level present (e.g., an affected area might measure 10 ft by 20 ft or 200 sq. ft. and exhibit medium-severity scaling). If a particular wall contains separate areas of vertical face scaling, then the area and severity level of each area should be estimated and recorded separately. In addition, if a single area contains more than one level of distress, the estimated area of each distress level should be recorded separately.





Low-Severity Vertical Surface Scaling

Medium-Severity Vertical Surface Scaling

High-Severity Vertical Surface Scaling

## 17 Staining (External Source)

Description:
Staining (external source) is the discoloration of SCBRW units caused by exposure to staining elements. These staining elements might include surface runoff containing dark clays or organic materials, road spray containing deicing chemicals, and other sources. The appearance of staining may also be caused by the growth of moss, moulds and other cultures. Staining may be either localized (as is typically the case with stains due to localized runoff) or fairly uniform (as may be the case with staining due to exposure and growths).

In most cases, staining is a cosmetic problem. However, some staining elements (e.g., road spray containing deicing chemicals) can also cause or exacerbate freeze-thaw damage, scaling, etc.

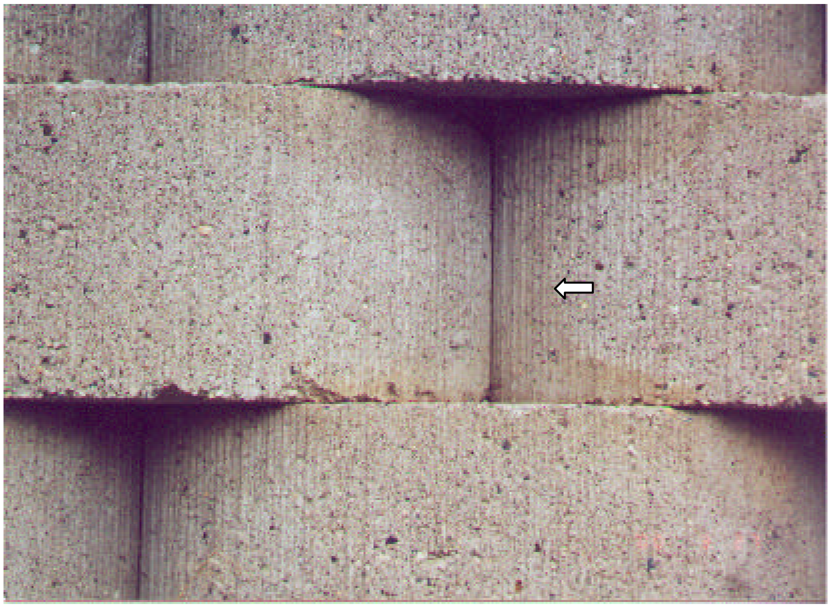
Severity Levels:
Assessing the severity level of staining is based on the degree of staining present (not the extent) and is highly subjective.

*Low:* Staining is barely noticeable.

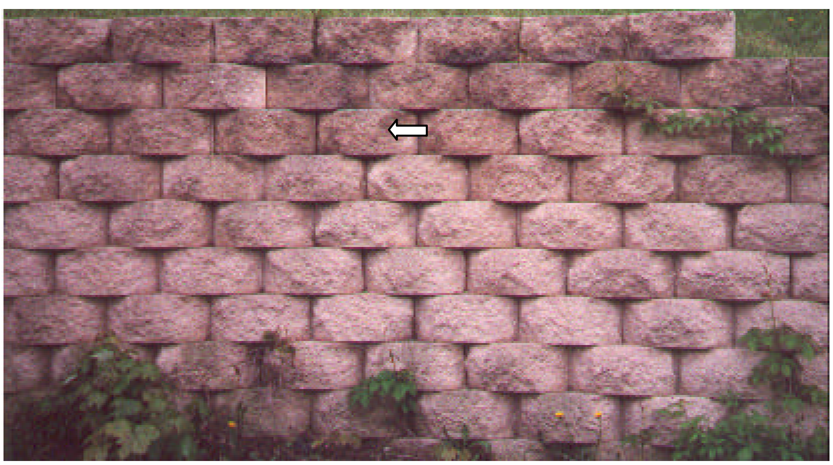
*Medium:* Staining is clearly visible and presents a moderate loss of architectural beauty.

*High:* Staining is *extremely unsightly*, presenting sharp contrasts with unstained areas or a significant uniform change from the originally intended color.

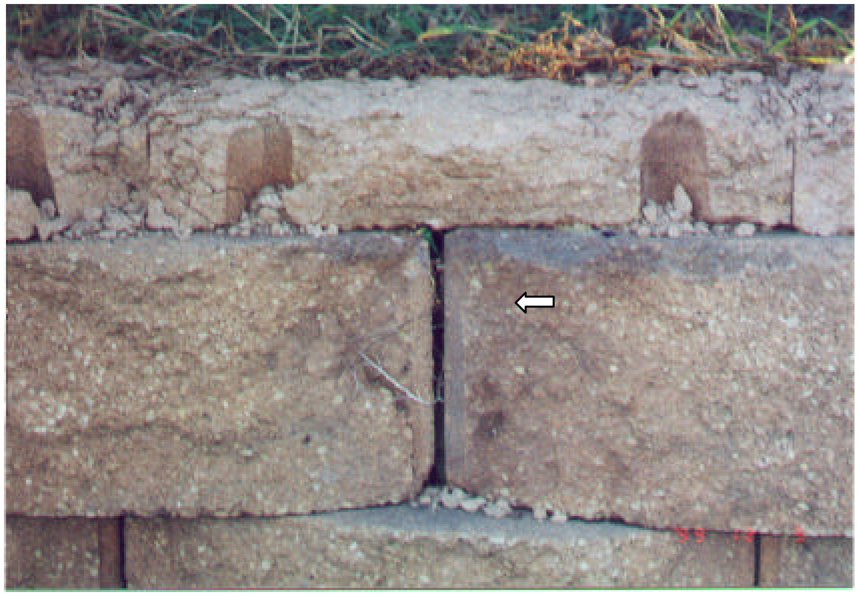
Measurement:
The extent of staining should be measured in terms of the estimated affected area for each incidence and severity level present (e.g., an affected area might measure 10 ft by 20 ft or 200 sq. ft. and exhibit medium-severity scaling). If a particular wall contains separate areas of staining, then the area and severity level of each area should be estimated and recorded separately. In addition, if a single area contains more than one level of distress, the estimated area of each distress level should be recorded separately.



Low-Severity Staining (External Source)



Medium-Severity Staining (External Source)



Medium-Severity Staining (External Source)

High-Severity Staining (External Source)

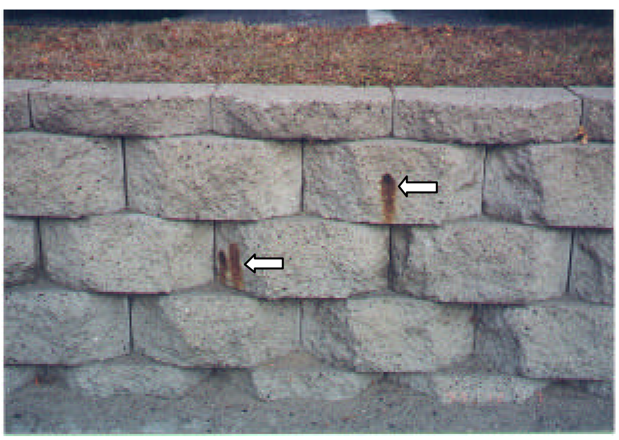
## 18 Staining (Internal Source)

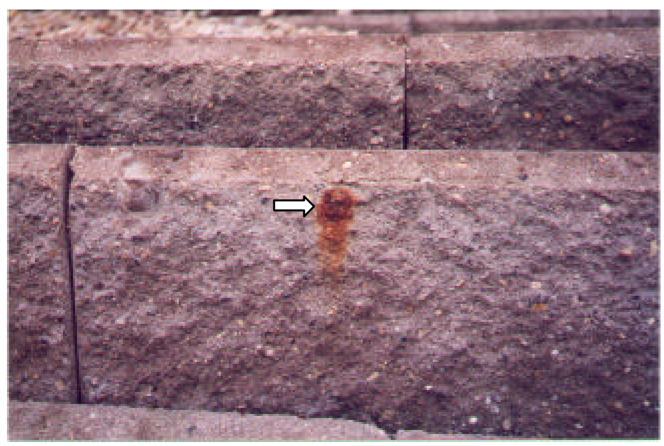
Description:
Staining (internal source) is the localized discoloration of SCBRW units caused by oxidation and leaching of an internal block component, typically an aggregate particle or metallic inclusion. The result is the typically the appearance of a rust-colored stain that runs down the block face from the source.

In most cases, staining is a cosmetic problem. However, the formation of oxidation compounds is often accompanied by tremendous expansion, which could produce some localized distress (e.g., cracking or spalling of the block face).

Severity Levels:
No severity levels are defined for staining due to internal sources.

Measurement:
An estimate shall be made of the total percentage of block units that exhibit staining due to internal sources (e.g., none, less than 1 percent, 1 to 5 percent, 5 to 25 percent, more than 25 percent).





Staining (Internal Source)

## 19 Structural Distress

Description:
Any evidence of structural failure of the *overall* SCBRW is considered structural distress. Examples of structural distress include: shifting of individual blocks since placement; evidence of wall movement or "bowing" since placement; and impending structural failure.

Causes of structural distress include the construction of SCBRW that exceed the engineering limitations of the block units (e.g., walls too tall, construction on poor foundation materials, poor consolidation of backfill materials, etc.).

Severity Levels:

*Low:* Small movement of wall is apparent without significant loss of retained material.

*Medium:* Significant movement of wall has occurred; or block units in localized area are exhibiting separation.

*High:* Structural failure of wall has occurred or is imminent.

Measurement:
The extent of structural distress should be measured in terms of the estimated area affected in each instance and highest severity level present within the area (e.g., an affected area might measure 10 ft by 20 ft or 200 sq. ft. and exhibit medium-severity structural distress).

If a particular wall contains multiple incidences of structural distress, then the area and severity level of each area should be estimated and recorded separately.

Low-Severity Structural Distress

Medium-Severity Structural Distress

High-Severity Structural Distress

High-Severity Structural Distress

## 20 Wash-Through

Description:
Wash-through is the erosion of retained material through the SCBRW. Evidence of wash-through is the observance of deposits of retained material on the flat surfaces of the exposed side of the wall.

Minor amounts of wash-through are primarily detrimental only in a cosmetic sense, although they may serve as a foothold for vegetative growth. Excessive amounts of wash-through indicate severe erosion of backfill material, which may suggest a functional problem with either the design or construction of the wall. In addition, settlement of the soil or paved surface may be observed behind the top of the wall.

External source staining may also be associated with some wash-through, depending upon the nature of the retained material.

Severity Levels:

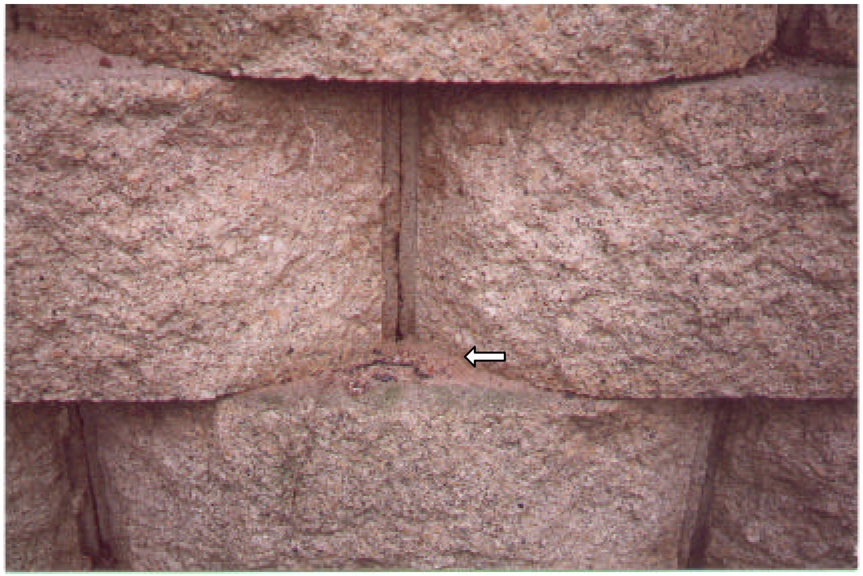
*Low:* Very small amounts of soil can be observed on the flat surfaces of the exposed side of the wall. The deposits are not sufficient to support significant plant growth. Little, if any, deposit has accumulated at the base of the wall.

*Medium:* Moderate amounts of soil can be observed on the flat surfaces of the exposed side of the wall. The deposits may support significant plant growth. Little, if any, deposit has accumulated at the base of the wall. Some staining may accompany the wash-through.

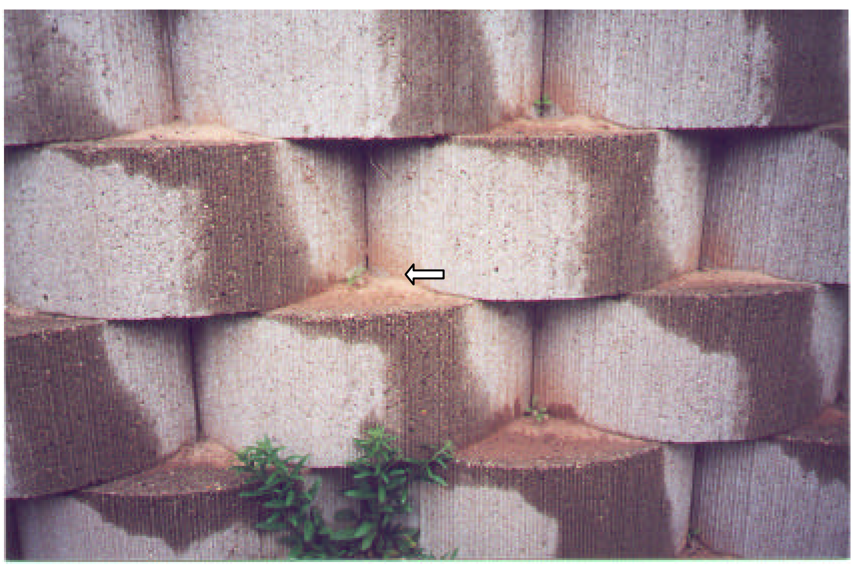
*High:* Large amounts of soil have accumulated on the flat surfaces of the exposed side of the wall. The deposits are sufficient to support significant plant growth. Overflow from the wash-through deposits may have accumulated at the base of the wall. Some staining may accompany the wash-through.

Measurement:
The extent of wash-through should be measured in terms of the estimated area affected in each instance and highest severity level present within the area (e.g., an affected area might measure 10 ft by 20 ft or 200 sq. ft. and exhibit medium-severity wash-through).

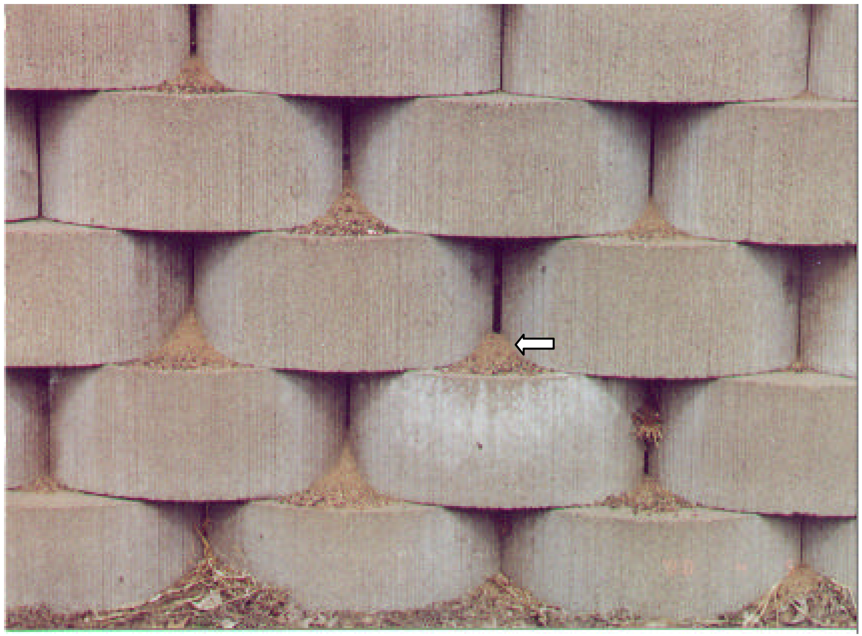
If a particular wall contains multiple incidences of wash-through, then the area and severity level of each incidence should be estimated and recorded separately.



Low-Severity Wash-Through



Medium-Severity Wash-Through


High-Severity Wash-Through

# APPENDIX F
# DISTRESS SURVEY CONDITION DATA

Table F-39. Mn/DOT SCBRW normalized distress condition data.

| | | Percentage of SCBRWs (Number of SCBRWs Per Total Number Surveyed) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Percentage of SCBRW | | | | | | |
| **Distress Type** | **Severity Level** | **None** | **<1** | **1-10** | **10-25** | **25-50** | **50-75** | **75-100** |
| 1 – Construction Defects | Low/Medium | 55 | 36 | 9 | 0 | 0 | 0 | 0 |
| | High | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 – Corner Breaks | Low | 91 | 9 | 0 | 0 | 0 | 0 | 0 |
| | Medium | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| | High | 91 | 9 | 0 | 0 | 0 | 0 | 0 |
| 3 – Cracked Block | Low | 82 | 9 | 9 | 0 | 0 | 0 | 0 |
| | Medium | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| | High | 82 | 18 | 0 | 0 | 0 | 0 | 0 |
| 4 – Efflorescence | Low | 45 | 18 | 18 | 0 | 0 | 9 | 9 |
| | Medium | 73 | 18 | 9 | 0 | 0 | 0 | 0 |
| | High | 91 | 0 | 9 | 0 | 0 | 0 | 0 |
| 5 – Embedded Vegetative Growth | Low | 36 | 36 | 27 | 0 | 0 | 0 | 0 |
| | Medium | 82 | 9 | 0 | 0 | 0 | 9 | 0 |
| | High | 91 | 9 | 0 | 0 | 0 | 0 | 0 |
| 6 – Erosion | Low | 82 | 0 | 18 | 0 | 0 | 0 | 0 |
| | Medium | 91 | 0 | 9 | 0 | 0 | 0 | 0 |
| | High | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 – Fraying/Spalling | Low | 9 | 36 | 27 | 18 | 9 | 0 | 0 |
| | Medium | 27 | 64 | 9 | 0 | 0 | 0 | 0 |
| | High | 64 | 36 | 0 | 0 | 0 | 0 | 0 |
| 8 – Freeze-Thaw Damage (Top Block Layer) | Low | 9 | 9 | 9 | 0 | 0 | 0 | 73 |
| | Medium | 91 | 9 | 0 | 0 | 0 | 0 | 0 |
| | High | 91 | 0 | 9 | 0 | 0 | 0 | 0 |
| 9 – Freeze-Thaw Damage (Vertical Surfaces) | Low | 9 | 0 | 18 | 0 | 9 | 0 | 64 |
| | Medium | 64 | 36 | 0 | 0 | 0 | 0 | 0 |
| | High | 73 | 9 | 18 | 0 | 0 | 0 | 0 |
| 10 – Manufacturing Flaws (Poor Consolidation - | Low/Medium | 91 | 0 | 0 | 0 | 0 | 0 | 9 |
| | High | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 – Manufacturing Flaws (Other) | Low/Medium | 36 | 64 | 0 | 0 | 0 | 0 | 0 |
| | High | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 – Misc. Distress/Flaws | None | 45 | 55 | 0 | 0 | 0 | 0 | 0 |
| 12 – Open Joints | None | 73 | 9 | 9 | 9 | 0 | 0 | 0 |
| 13 – Popouts | None | 64 | 0 | 9 | 0 | 0 | 0 | 27 |
| 14 – Position Guide Damage | Low | 0 | 0 | 100 | 0 | 0 | 0 | 0 |
| | Medium | 0 | 100 | 0 | 0 | 0 | 0 | 0 |
| | High | 50 | 50 | 0 | 0 | 0 | 0 | 0 |
| 15 – Scaling (Top Block Layer) | Low | 18 | 9 | 9 | 0 | 18 | 0 | 45 |
| | Medium | 55 | 9 | 18 | 0 | 0 | 0 | 18 |
| | High | 64 | 18 | 18 | 0 | 0 | 0 | 0 |
| 16 – Scaling (Vertical Surfaces) | Low | 27 | 0 | 9 | 0 | 0 | 0 | 64 |
| | Medium | 36 | 45 | 0 | 0 | 0 | 0 | 18 |
| | High | 73 | 9 | 18 | 0 | 0 | 0 | 0 |

Table F-39. Mn/DOT SCBRW normalized distress condition data (continued).

| | | Percentage of SCBRWs (Number of SCBRWs Per Total Number Surveyed) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Percentage of SCBRW | | | | | | |
| Distress Type | Severity Level | None | <1 | 1-10 | 10-25 | 25-50 | 50-75 | 75-100 |
| 17 – Staining (External Source) | Low | 73 | 0 | 9 | 0 | 0 | 9 | 9 |
| | Medium | 82 | 0 | 9 | 9 | 0 | 0 | 0 |
| | High | 36 | 0 | 18 | 0 | 0 | 18 | 27 |
| 18 – Staining (Internal Source) | None | 64 | 36 | 0 | 0 | 0 | 0 | 0 |
| 19 – Structural Distress | Low | 64 | 18 | 18 | 0 | 0 | 0 | 0 |
| | Medium | 64 | 27 | 0 | 9 | 0 | 0 | 0 |
| | High | 91 | 0 | 0 | 0 | 0 | 9 | 0 |
| 20 – Wash-Through | Low | 64 | 18 | 9 | 0 | 9 | 0 | 0 |
| | Medium | 73 | 9 | 9 | 0 | 9 | 0 | 0 |
| | High | 91 | 9 | 0 | 0 | 0 | 0 | 0 |

Table F-38. Hennepin county SCBRW normalized distress condition data.

| Distress Type | Severity Level | Percentage of SCBRWs (Number of SCBRWs Per Total Number Surveyed) Percentage of SCBRW None | <1 | 1-10 | 10-25 | 25-50 | 50-75 | 75-100 |
|---|---|---|---|---|---|---|---|---|
| 1 – Construction Defects | Low/Medium | 54 | 17 | 11 | 5 | 7 | 1 | 5 |
| | High | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 – Corner Breaks | Low | 86 | 13 | 1 | 0 | 0 | 0 | 0 |
| | Medium | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| | High | 96 | 4 | 0 | 0 | 0 | 0 | 0 |
| 3 – Cracked Block | Low | 88 | 12 | 0 | 0 | 0 | 0 | 0 |
| | Medium | 84 | 16 | 0 | 0 | 0 | 0 | 0 |
| | High | 91 | 9 | 0 | 0 | 0 | 0 | 0 |
| 4 – Efflorescence | Low | 41 | 33 | 16 | 7 | 1 | 1 | 1 |
| | Medium | 71 | 7 | 8 | 8 | 3 | 4 | 0 |
| | High | 87 | 4 | 4 | 3 | 1 | 0 | 1 |
| 5 – Embedded Vegetative Growth | Low | 30 | 58 | 8 | 3 | 0 | 0 | 1 |
| | Medium | 96 | 3 | 1 | 0 | 0 | 0 | 0 |
| | High | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 – Erosion | Low | 79 | 4 | 5 | 5 | 0 | 1 | 5 |
| | Medium | 82 | 5 | 4 | 1 | 1 | 1 | 5 |
| | High | 93 | 1 | 0 | 0 | 1 | 0 | 4 |
| 7 – Fraying/Spalling | Low | 16 | 28 | 29 | 21 | 4 | 1 | 1 |
| | Medium | 39 | 50 | 7 | 1 | 3 | 0 | 0 |
| | High | 74 | 25 | 1 | 0 | 0 | 0 | 0 |
| 8 – Freeze-Thaw Damage (Top Block Layer) | Low | 24 | 9 | 7 | 4 | 4 | 5 | 47 |
| | Medium | 78 | 9 | 5 | 3 | 1 | 1 | 3 |
| | High | 76 | 8 | 5 | 3 | 5 | 0 | 3 |
| 9 – Freeze-Thaw Damage (Vertical Surfaces) | Low | 16 | 12 | 8 | 16 | 7 | 11 | 32 |
| | Medium | 84 | 7 | 1 | 1 | 5 | 1 | 0 |
| | High | 82 | 8 | 5 | 0 | 1 | 1 | 3 |
| 10 – Manufacturing Flaws (Poor Consolidation - Capstone) | Low/Medium | 87 | 3 | 0 | 0 | 0 | 0 | 11 |
| | High | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 – Manufacturing Flaws (Other) | Low/Medium | 36 | 32 | 21 | 9 | 0 | 1 | 1 |
| | High | 96 | 4 | 0 | 0 | 0 | 0 | 0 |
| 11 – Misc. Distress/Flaws | None | 57 | 34 | 9 | 0 | 0 | 0 | 0 |
| 12 – Open Joints | None | 45 | 20 | 12 | 5 | 7 | 3 | 8 |
| 13 – Popouts | None | 75 | 11 | 7 | 0 | 1 | 0 | 7 |
| 14 – Position Guide Damage | Low | 0 | 50 | 50 | 0 | 0 | 0 | 0 |
| | Medium | 0 | 0 | 50 | 50 | 0 | 0 | 0 |
| | High | 0 | 50 | 0 | 0 | 0 | 0 | 50 |
| 15 – Scaling (Top Block Layer) | Low | 16 | 9 | 5 | 1 | 0 | 3 | 66 |
| | Medium | 37 | 17 | 14 | 7 | 11 | 7 | 8 |
| | High | 55 | 13 | 12 | 7 | 4 | 1 | 8 |
| 16 – Scaling (Vertical Surfaces) | Low | 22 | 18 | 24 | 5 | 3 | 3 | 25 |
| | Medium | 34 | 28 | 26 | 8 | 3 | 1 | 0 |
| | High | 67 | 12 | 12 | 3 | 1 | 3 | 3 |

Table F-38. Hennepin county SCBRW normalized distress condition data (continued).

| | | Percentage of SCBRWs (Number of SCBRWs Per Total Number Surveyed) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Percentage of SCBRW | | | | | | |
| **Distress Type** | **Severity Level** | **None** | **<1** | **1-10** | **10-25** | **25-50** | **50-75** | **75-100** |
| 17 – Staining (External Source) | Low | 58 | 11 | 3 | 7 | 1 | 3 | 18 |
| | Medium | 78 | 1 | 8 | 0 | 4 | 1 | 8 |
| | High | 82 | 5 | 3 | 7 | 0 | 0 | 4 |
| 18 – Staining (Internal Source) | None | 46 | 50 | 4 | 0 | 0 | 0 | 0 |
| 19 – Structural Distress | Low | 71 | 18 | 8 | 3 | 0 | 0 | 0 |
| | Medium | 97 | 0 | 1 | 1 | 0 | 0 | 0 |
| | High | 96 | 0 | 4 | 0 | 0 | 0 | 0 |
| 20 – Wash-Through | Low | 30 | 24 | 13 | 8 | 11 | 7 | 8 |
| | Medium | 39 | 21 | 24 | 8 | 4 | 3 | 1 |
| | High | 63 | 12 | 9 | 8 | 1 | 3 | 4 |

Table F-41. Overall SCBRW normalized distress condition data.

| Distress Type | Severity Level | Percentage of SCBRWs (Number of SCBRWs Per Total Number Surveyed) Percentage of SCBRW None | <1 | 1-10 | 10-25 | 25-50 | 50-75 | 75-100 |
|---|---|---|---|---|---|---|---|---|
| 1 – Construction Defects | Low/Medium | 55 | 18 | 10 | 6 | 5 | 1 | 4 |
| | High | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 – Corner Breaks | Low | 86 | 13 | 1 | 0 | 0 | 0 | 0 |
| | Medium | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| | High | 96 | 4 | 0 | 0 | 0 | 0 | 0 |
| 3 – Cracked Block | Low | 83 | 15 | 2 | 0 | 0 | 0 | 0 |
| | Medium | 86 | 14 | 0 | 0 | 0 | 0 | 0 |
| | High | 89 | 11 | 0 | 0 | 0 | 0 | 0 |
| 4 – Efflorescence | Low | 42 | 30 | 14 | 7 | 2 | 3 | 3 |
| | Medium | 70 | 9 | 8 | 7 | 2 | 3 | 1 |
| | High | 89 | 4 | 3 | 2 | 1 | 0 | 1 |
| 5 – Embedded Vegetative Growth | Low | 27 | 56 | 8 | 5 | 2 | 0 | 3 |
| | Medium | 91 | 5 | 2 | 0 | 1 | 1 | 0 |
| | High | 96 | 3 | 1 | 0 | 0 | 0 | 0 |
| 6 – Erosion | Low | 77 | 3 | 7 | 3 | 0 | 3 | 7 |
| | Medium | 83 | 4 | 6 | 1 | 1 | 1 | 4 |
| | High | 95 | 2 | 0 | 0 | 1 | 0 | 3 |
| 7 – Fraying/Spalling | Low | 17 | 32 | 23 | 17 | 5 | 2 | 3 |
| | Medium | 37 | 47 | 11 | 1 | 3 | 0 | 0 |
| | High | 69 | 29 | 3 | 0 | 0 | 0 | 0 |
| 8 – Freeze-Thaw Damage (Top Block Layer) | Low | 21 | 8 | 5 | 3 | 6 | 7 | 50 |
| | Medium | 79 | 9 | 7 | 2 | 1 | 1 | 2 |
| | High | 76 | 9 | 5 | 3 | 3 | 1 | 3 |
| 9 – Freeze-Thaw Damage (Vertical Surfaces) | Low | 16 | 9 | 7 | 11 | 9 | 8 | 40 |
| | Medium | 78 | 9 | 2 | 6 | 4 | 1 | 0 |
| | High | 76 | 10 | 7 | 1 | 3 | 1 | 3 |
| 10 – Manufacturing Flaws (Poor Consolidation - | Low/Medium | 87 | 2 | 1 | 0 | 0 | 1 | 10 |
| | High | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 – Manufacturing Flaws (Other) | Low/Medium | 39 | 37 | 17 | 6 | 0 | 1 | 1 |
| | High | 97 | 3 | 0 | 0 | 0 | 0 | 0 |
| 11 – Misc. Distress/Flaws | None | 56 | 37 | 7 | 1 | 0 | 0 | 0 |
| 12 – Open Joints | None | 43 | 18 | 15 | 5 | 6 | 6 | 7 |
| 13 – Popouts | None | 77 | 9 | 5 | 0 | 2 | 0 | 8 |
| 14 – Position Guide Damage | Low | 29 | 18 | 24 | 18 | 6 | 6 | 0 |
| | Medium | 22 | 22 | 22 | 17 | 11 | 6 | 0 |
| | High | 33 | 39 | 6 | 6 | 6 | 0 | 11 |
| 15 – Scaling (Top Block Layer) | Low | 17 | 8 | 6 | 1 | 3 | 3 | 62 |
| | Medium | 41 | 17 | 17 | 6 | 7 | 4 | 8 |
| | High | 57 | 13 | 11 | 7 | 4 | 2 | 5 |
| 16 – Scaling (Vertical Surfaces) | Low | 27 | 15 | 19 | 5 | 2 | 3 | 30 |
| | Medium | 42 | 23 | 23 | 6 | 3 | 1 | 2 |
| | High | 69 | 12 | 11 | 3 | 2 | 2 | 2 |

Table F-41. Overall SCBRW normalized distress condition data (continued).

| | | Percentage of SCBRWs (Number of SCBRWs Per Total Number Surveyed) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Percentage of SCBRW | | | | | | |
| **Distress Type** | **Severity Level** | **None** | **<1** | **1-10** | **10-25** | **25-50** | **50-75** | **75-100** |
| 17 – Staining (External Source) | Low | 63 | 8 | 4 | 7 | 1 | 3 | 14 |
| | Medium | 76 | 1 | 8 | 3 | 4 | 2 | 7 |
| | High | 77 | 4 | 4 | 6 | 1 | 2 | 6 |
| 18 – Staining (Internal Source) | None | 51 | 45 | 3 | 0 | 0 | 0 | 0 |
| 19 – Structural Distress | Low | 70 | 18 | 9 | 3 | 0 | 0 | 0 |
| | Medium | 89 | 3 | 3 | 3 | 0 | 1 | 0 |
| | High | 97 | 0 | 3 | 0 | 0 | 1 | 0 |
| 20 – Wash-Through | Low | 42 | 20 | 12 | 5 | 9 | 5 | 7 |
| | Medium | 49 | 17 | 19 | 8 | 4 | 2 | 1 |
| | High | 70 | 11 | 8 | 5 | 1 | 2 | 3 |

Table F-37. Dakota county SCBRW normalized distress condition data.

| Distress Type | Severity Level | Percentage of SCBRWs (Number of SCBRWs Per Total Number Surveyed) Percentage of SCBRW: None | <1 | 1-10 | 10-25 | 25-50 | 50-75 | 75-100 |
|---|---|---|---|---|---|---|---|---|
| 1 – Construction Defects | Low/Medium | 57 | 19 | 10 | 10 | 0 | 0 | 5 |
| | High | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 – Corner Breaks | Low | 90 | 10 | 0 | 0 | 0 | 0 | 0 |
| | Medium | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| | High | 95 | 5 | 0 | 0 | 0 | 0 | 0 |
| 3 – Cracked Block | Low | 86 | 14 | 0 | 0 | 0 | 0 | 0 |
| | Medium | 81 | 19 | 0 | 0 | 0 | 0 | 0 |
| | High | 81 | 19 | 0 | 0 | 0 | 0 | 0 |
| 4 – Efflorescence | Low | 57 | 14 | 5 | 10 | 5 | 5 | 5 |
| | Medium | 71 | 5 | 5 | 10 | 0 | 5 | 5 |
| | High | 95 | 5 | 0 | 0 | 0 | 0 | 0 |
| 5 – Embedded Vegetative Growth | Low | 10 | 52 | 0 | 19 | 10 | 0 | 10 |
| | Medium | 81 | 14 | 5 | 0 | 0 | 0 | 0 |
| | High | 81 | 14 | 5 | 0 | 0 | 0 | 0 |
| 6 – Erosion | Low | 71 | 0 | 10 | 0 | 0 | 10 | 10 |
| | Medium | 90 | 0 | 5 | 0 | 0 | 0 | 5 |
| | High | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 – Fraying/Spalling | Low | 24 | 43 | 5 | 5 | 5 | 5 | 14 |
| | Medium | 43 | 33 | 14 | 0 | 10 | 0 | 0 |
| | High | 57 | 33 | 10 | 0 | 0 | 0 | 0 |
| 8 – Freeze-Thaw Damage (Top Block Layer) | Low | 20 | 0 | 0 | 0 | 20 | 15 | 45 |
| | Medium | 70 | 10 | 20 | 0 | 0 | 0 | 0 |
| | High | 57 | 19 | 5 | 10 | 0 | 5 | 5 |
| 9 – Freeze-Thaw Damage (Vertical Surfaces) | Low | 15 | 5 | 0 | 5 | 15 | 5 | 55 |
| | Medium | 62 | 5 | 5 | 24 | 5 | 0 | 0 |
| | High | 57 | 14 | 5 | 5 | 10 | 0 | 10 |
| 10 – Manufacturing Flaws (Poor Consolidation - | Low/Medium | 90 | 0 | 5 | 0 | 0 | 5 | 0 |
| | High | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 – Manufacturing Flaws (Other) | Low/Medium | 48 | 43 | 10 | 0 | 0 | 0 | 0 |
| | High | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 – Misc. Distress/Flaws | None | 62 | 33 | 0 | 5 | 0 | 0 | 0 |
| 12 – Open Joints | None | 24 | 19 | 10 | 5 | 10 | 24 | 10 |
| 13 – Popouts | None | 81 | 10 | 0 | 0 | 5 | 0 | 5 |
| 14 – Position Guide Damage | Low | 30 | 10 | 10 | 30 | 10 | 10 | 0 |
| | Medium | 18 | 9 | 27 | 18 | 18 | 9 | 0 |
| | High | 36 | 27 | 9 | 9 | 9 | 0 | 9 |
| 15 – Scaling (Top Block Layer) | Low | 19 | 5 | 10 | 0 | 10 | 5 | 52 |
| | Medium | 43 | 24 | 24 | 10 | 0 | 0 | 0 |
| | High | 62 | 10 | 5 | 14 | 5 | 5 | 0 |
| 16 – Scaling (Vertical Surfaces) | Low | 43 | 10 | 14 | 10 | 0 | 0 | 24 |
| | Medium | 67 | 5 | 19 | 5 | 5 | 0 | 0 |
| | High | 71 | 19 | 5 | 5 | 0 | 0 | 0 |

Table F-37. Dakota county SCBRW normalized distress condition data (continued).

| | | Percentage of SCBRWs (Number of SCBRWs Per Total Number Surveyed) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Percentage of SCBRW | | | | | | |
| **Distress Type** | **Severity Level** | **None** | **<1** | **1-10** | **10-25** | **25-50** | **50-75** | **75-100** |
| 17 – Staining (External Source) | Low | 62 | 5 | 10 | 14 | 0 | 5 | 5 |
| | Medium | 62 | 0 | 10 | 10 | 10 | 5 | 5 |
| | High | 86 | 5 | 0 | 5 | 0 | 0 | 5 |
| 18 – Staining (Internal Source) | None | 76 | 24 | 0 | 0 | 0 | 0 | 0 |
| 19 – Structural Distress | Low | 76 | 14 | 5 | 5 | 0 | 0 | 0 |
| | Medium | 81 | 5 | 10 | 5 | 0 | 0 | 0 |
| | High | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 – Wash-Through | Low | 67 | 14 | 5 | 0 | 5 | 5 | 5 |
| | Medium | 62 | 14 | 10 | 10 | 5 | 0 | 0 |
| | High | 81 | 10 | 10 | 0 | 0 | 0 | 0 |

Table F-40. Privately owned SCBRW normalized distress condition data.

| | | Percentage of SCBRWs (Number of SCBRWs Per Total Number Surveyed) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Percentage of SCBRW | | | | | | |
| Distress Type | Severity Level | None | <1 | 1-10 | 10-25 | 25-50 | 50-75 | 75-100 |
| 1 – Construction Defects | Low/Medium | 57 | 0 | 14 | 14 | 14 | 0 | 0 |
| | High | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 – Corner Breaks | Low | 71 | 29 | 0 | 0 | 0 | 0 | 0 |
| | Medium | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| | High | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 – Cracked Block | Low | 29 | 57 | 14 | 0 | 0 | 0 | 0 |
| | Medium | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| | High | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 – Efflorescence | Low | 0 | 57 | 14 | 14 | 0 | 0 | 14 |
| | Medium | 57 | 29 | 14 | 0 | 0 | 0 | 0 |
| | High | 86 | 14 | 0 | 0 | 0 | 0 | 0 |
| 5 – Embedded Vegetative Growth | Low | 29 | 71 | 0 | 0 | 0 | 0 | 0 |
| | Medium | 86 | 0 | 0 | 0 | 14 | 0 | 0 |
| | High | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 – Erosion | Low | 71 | 0 | 0 | 0 | 0 | 0 | 29 |
| | Medium | 57 | 14 | 29 | 0 | 0 | 0 | 0 |
| | High | 86 | 14 | 0 | 0 | 0 | 0 | 0 |
| 7 – Fraying/Spalling | Low | 14 | 43 | 14 | 14 | 14 | 0 | 0 |
| | Medium | 14 | 29 | 57 | 0 | 0 | 0 | 0 |
| | High | 57 | 43 | 0 | 0 | 0 | 0 | 0 |
| 8 – Freeze-Thaw Damage (Top Block Layer) | Low | 14 | 14 | 0 | 0 | 0 | 14 | 57 |
| | Medium | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| | High | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 – Freeze-Thaw Damage (Vertical Surfaces) | Low | 29 | 0 | 0 | 0 | 14 | 0 | 57 |
| | Medium | 86 | 0 | 0 | 14 | 0 | 0 | 0 |
| | High | 71 | 14 | 14 | 0 | 0 | 0 | 0 |
| 10 – Manufacturing Flaws (Poor Consolidation - | Low/Medium | 71 | 0 | 0 | 0 | 0 | 0 | 29 |
| | High | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 – Manufacturing Flaws (Other) | Low/Medium | 57 | 29 | 14 | 0 | 0 | 0 | 0 |
| | High | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 – Misc. Distress/Flaws | None | 43 | 43 | 14 | 0 | 0 | 0 | 0 |
| 12 – Open Joints | None | 29 | 0 | 71 | 0 | 0 | 0 | 0 |
| 13 – Popouts | None | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 – Position Guide Damage | Low | 67 | 33 | 0 | 0 | 0 | 0 | 0 |
| | Medium | 67 | 33 | 0 | 0 | 0 | 0 | 0 |
| | High | 33 | 67 | 0 | 0 | 0 | 0 | 0 |
| 15 – Scaling (Top Block Layer) | Low | 29 | 0 | 0 | 0 | 0 | 0 | 71 |
| | Medium | 57 | 14 | 14 | 0 | 0 | 0 | 14 |
| | High | 57 | 14 | 14 | 0 | 14 | 0 | 0 |
| 16 – Scaling (Vertical Surfaces) | Low | 29 | 14 | 0 | 0 | 0 | 14 | 43 |
| | Medium | 57 | 0 | 43 | 0 | 0 | 0 | 0 |
| | High | 71 | 0 | 14 | 0 | 14 | 0 | 0 |

Table F-40. Privately owned SCBRW normalized distress condition data (continued).

| | | Percentage of SCBRWs (Number of SCBRWs Per Total Number Surveyed) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Percentage of SCBRW | | | | | | |
| Distress Type | Severity Level | None | <1 | 1-10 | 10-25 | 25-50 | 50-75 | 75-100 |
| 17 – Staining (External Source) | Low | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Medium | 86 | 0 | 0 | 0 | 0 | 0 | 14 |
| | High | 57 | 0 | 14 | 14 | 14 | 0 | 0 |
| 18 – Staining (Internal Source) | None | 14 | 71 | 14 | 0 | 0 | 0 | 0 |
| 19 – Structural Distress | Low | 43 | 29 | 14 | 14 | 0 | 0 | 0 |
| | Medium | 57 | 0 | 14 | 14 | 0 | 14 | 0 |
| | High | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 – Wash-Through | Low | 57 | 0 | 29 | 0 | 0 | 0 | 14 |
| | Medium | 71 | 0 | 14 | 14 | 0 | 0 | 0 |
| | High | 86 | 14 | 0 | 0 | 0 | 0 | 0 |

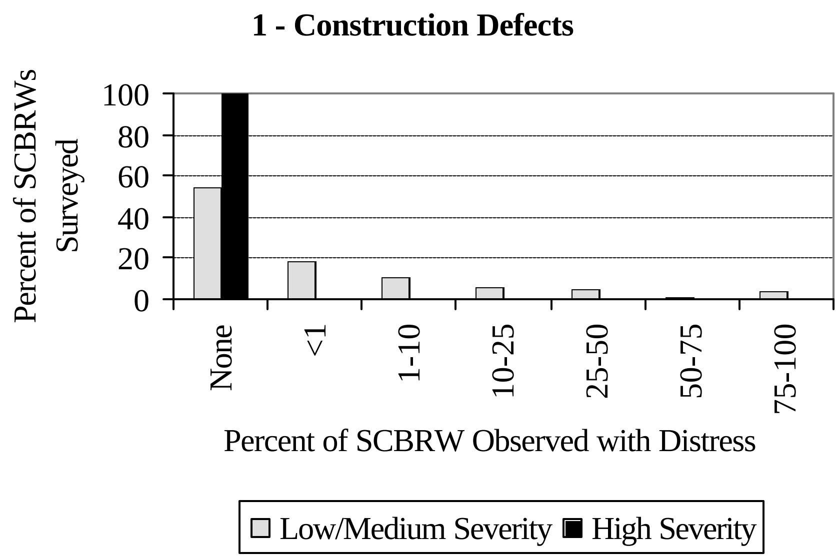



Figure F-1. Percentage of SCBRWs surveyed with low-, medium- and high-severity construction defects.

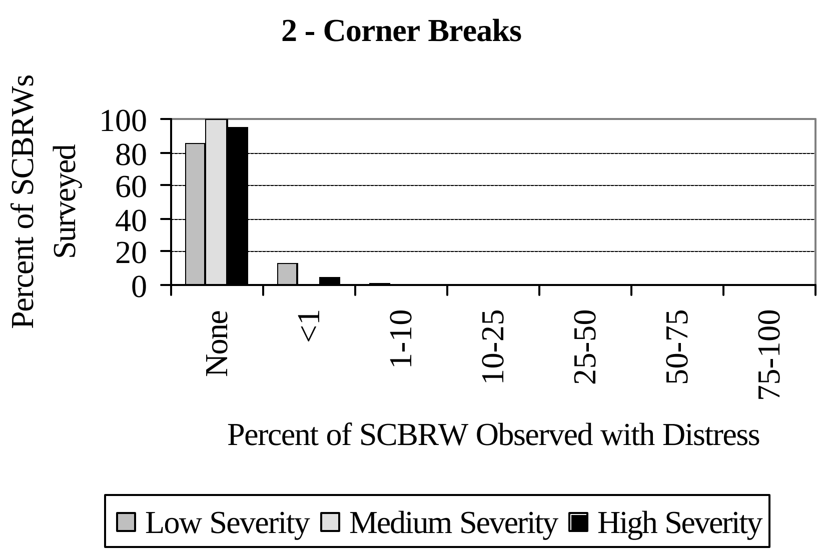



Figure F-2. Percentage of SCBRWs surveyed with low-, medium- and high-severity corner breaks.

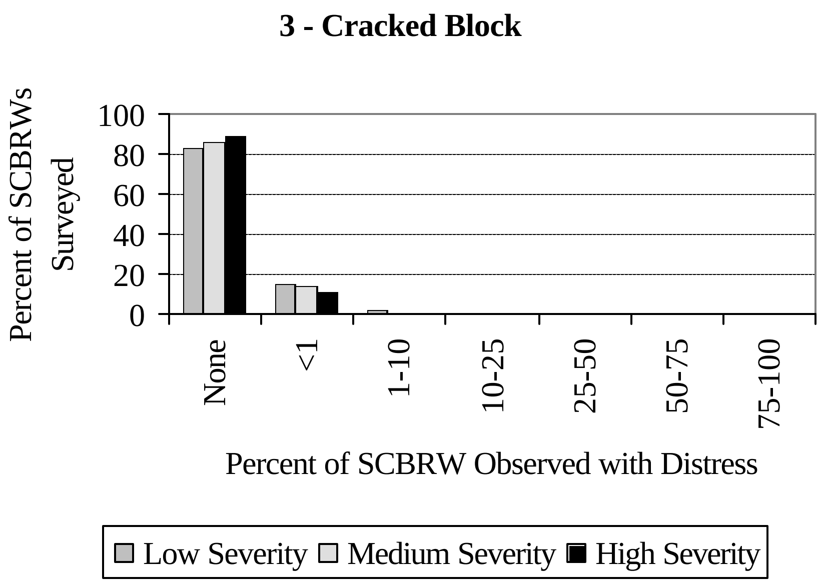



Figure F-3. Percentage of SCBRWs surveyed with low-, medium- and high-severity cracked block.

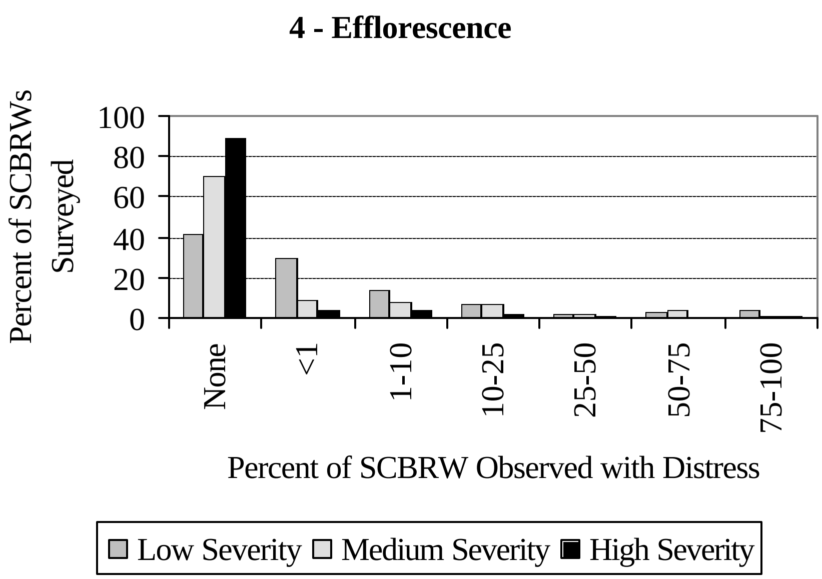



Figure F-4. Percentage of SCBRWs surveyed with low-, medium- and high-severity efflorescence.

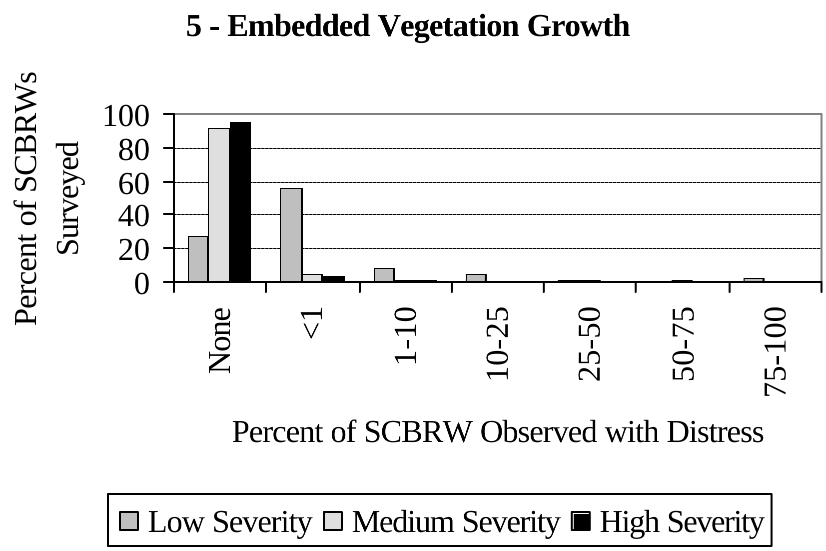



Figure F-5. Percentage of SCBRWs surveyed with low-, medium- and high-severity embedded vegetation growth.

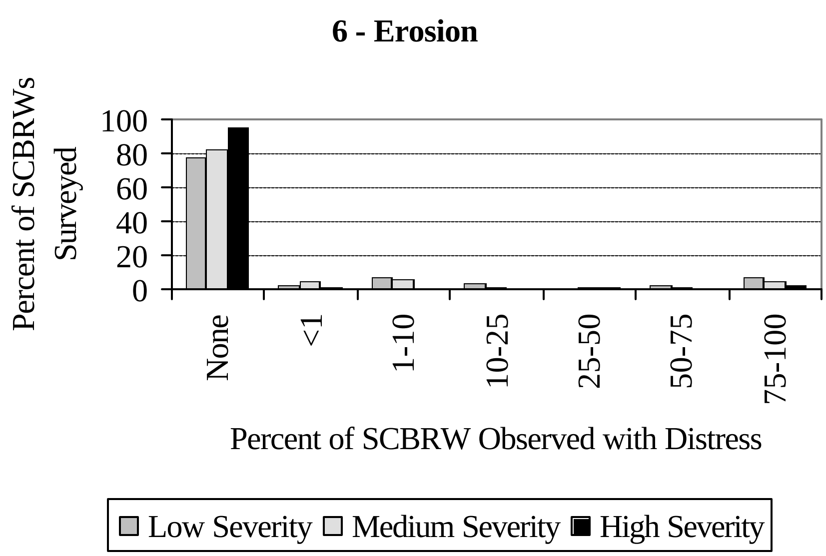



Figure F-6. Percentage of SCBRWs surveyed with low-, medium- and high-severity erosion.

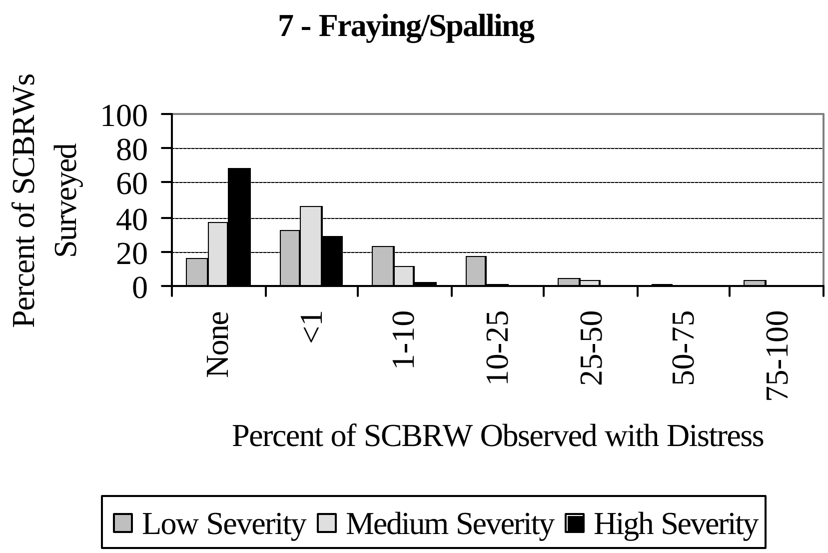



Figure F-7. Percentage of SCBRWs surveyed with low-, medium- and high-severity fraying/spalling.

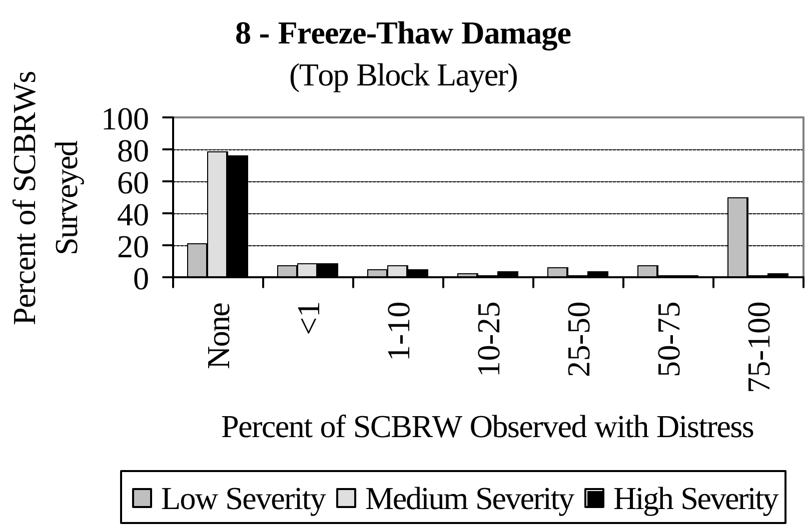



Figure F-8. Percentage of SCBRWs surveyed with low-, medium- and high-severity freeze-thaw damage (top block layer).

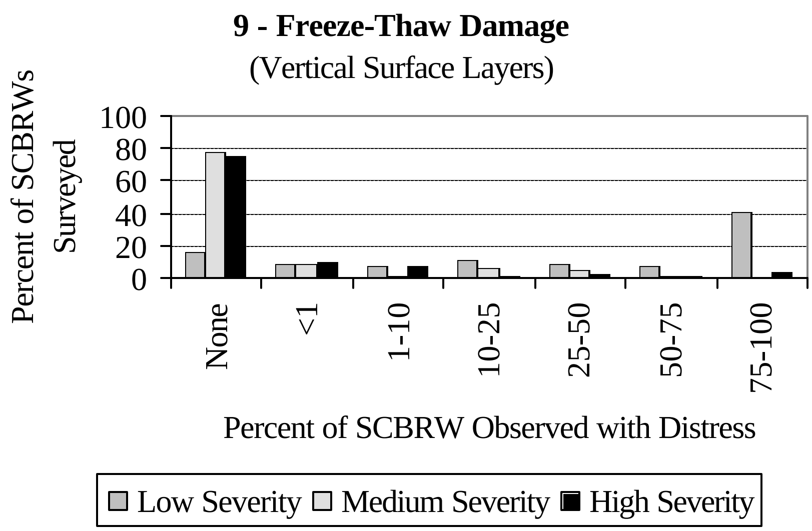



Figure F-9. Percentage of SCBRWs surveyed with low-, medium- and high-severity freeze-thaw damage (vertical surfaces).

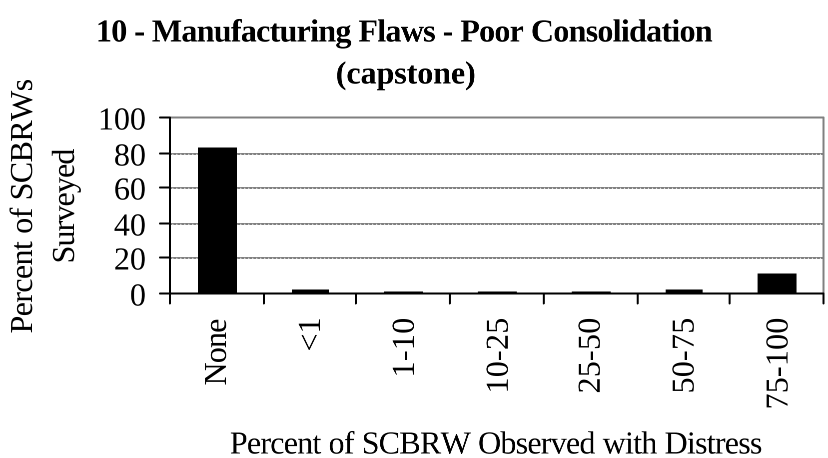



Figure F-10. Percentage of SCBRWs surveyed with low-, medium- and high-severity manufacturing flaws (poor consolidation – capstone).

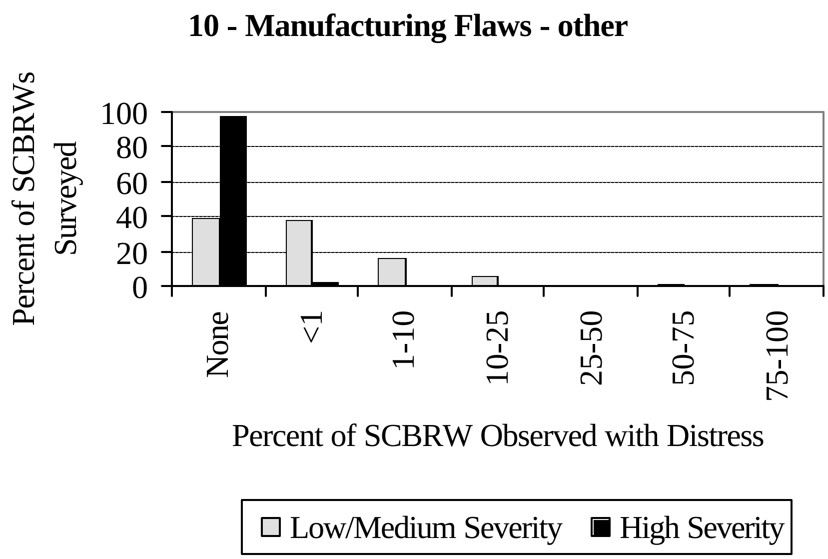



Figure F-11. Percentage of SCBRWs surveyed with low-, medium- and high-severity manufacturing flaws (other).

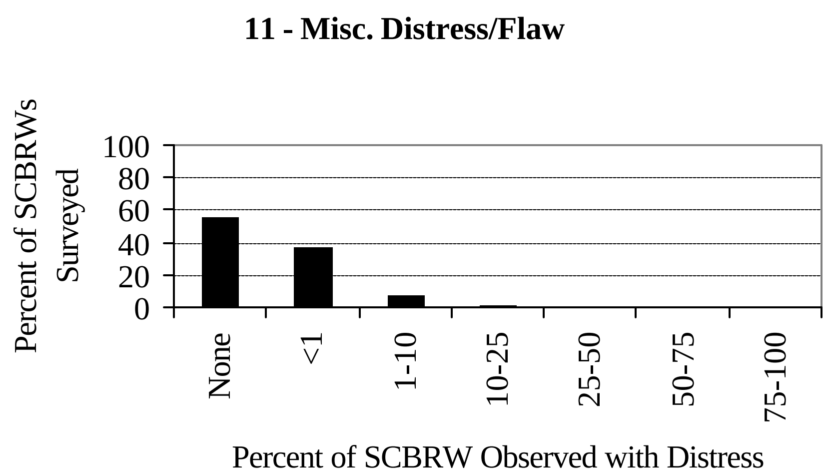



Figure F-12. Percentage of SCBRWs surveyed with miscellaneous distress/flaws.

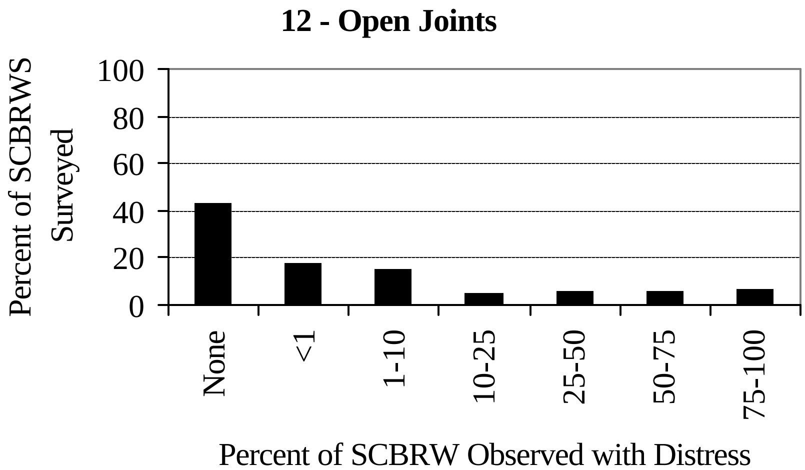



Figure F-13. Percentage of SCBRWs surveyed with open joints.

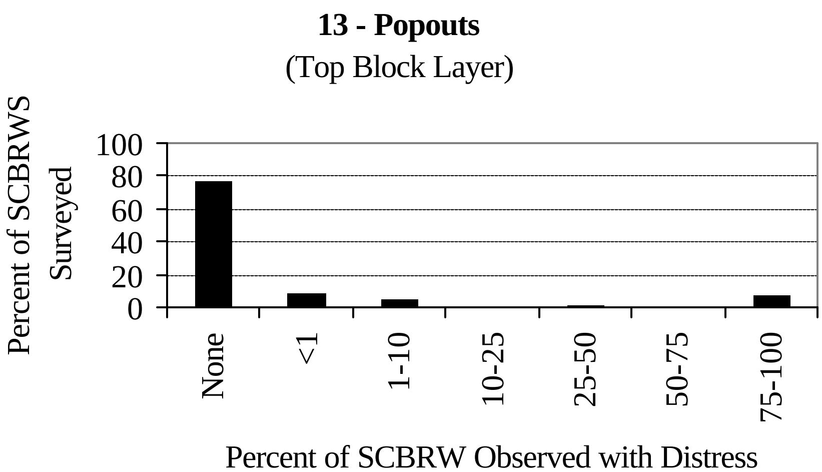



Figure F-14. Percentage of SCBRWs surveyed with popouts (top block layer).

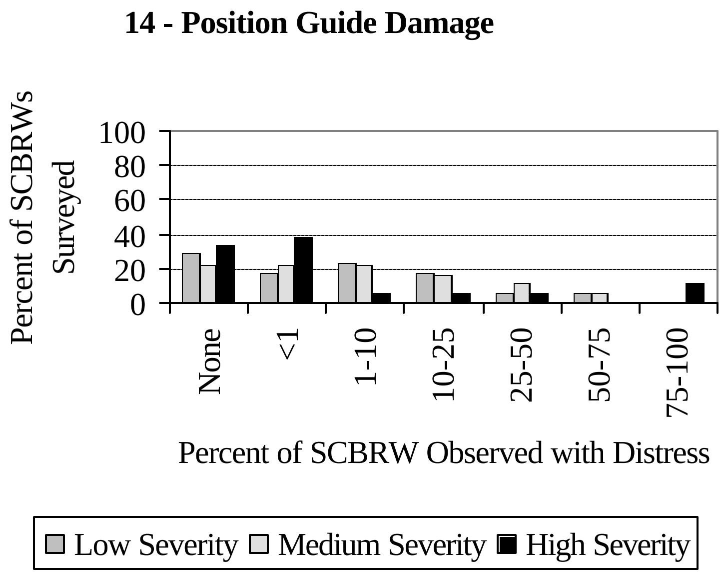



Figure F-15. Percentage of SCBRWs surveyed with low-, medium- and high-severity position guide damage.

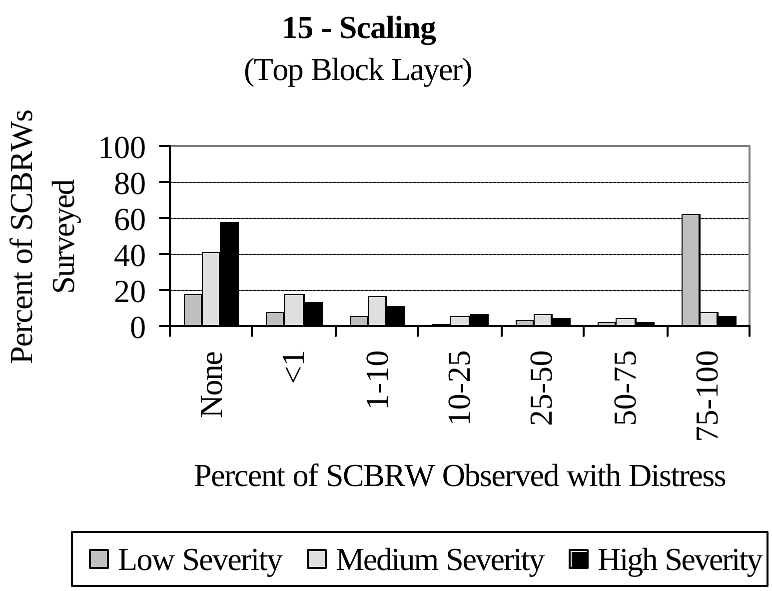



Figure F-16. Percentage of SCBRWs surveyed with low-, medium- and high-severity scaling (top block layer).

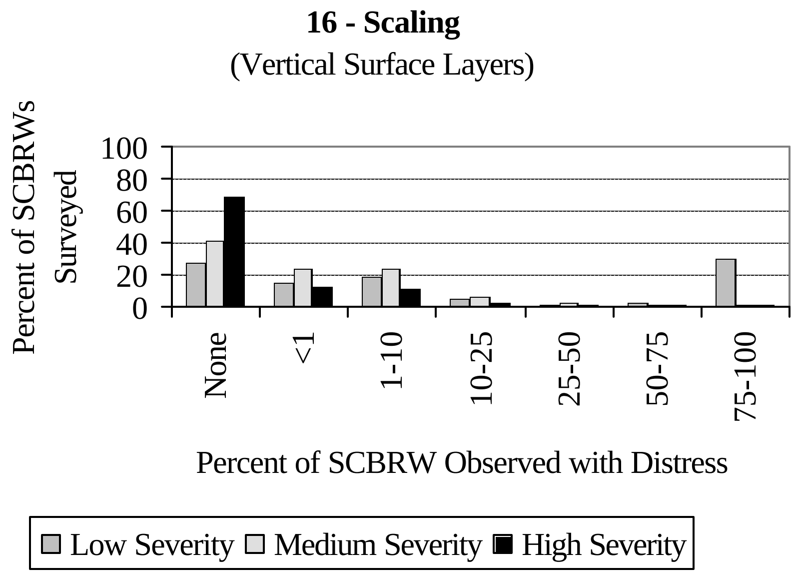



Figure F-17 Percentage of SCBRWs surveyed with low-, medium- and high-severity scaling (vertical surfaces).

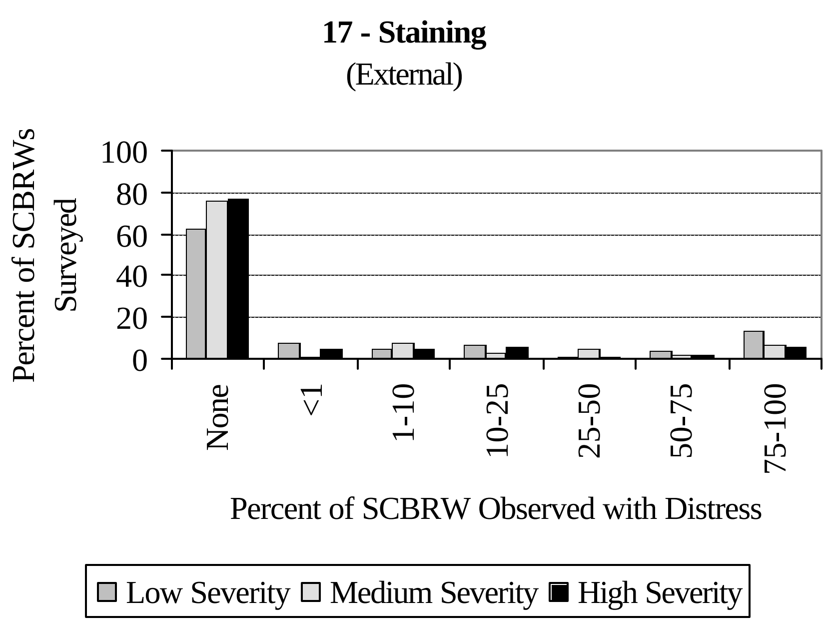



Figure F-18 Percentage of SCBRWs surveyed with low-, medium- and high-severity staining (external).

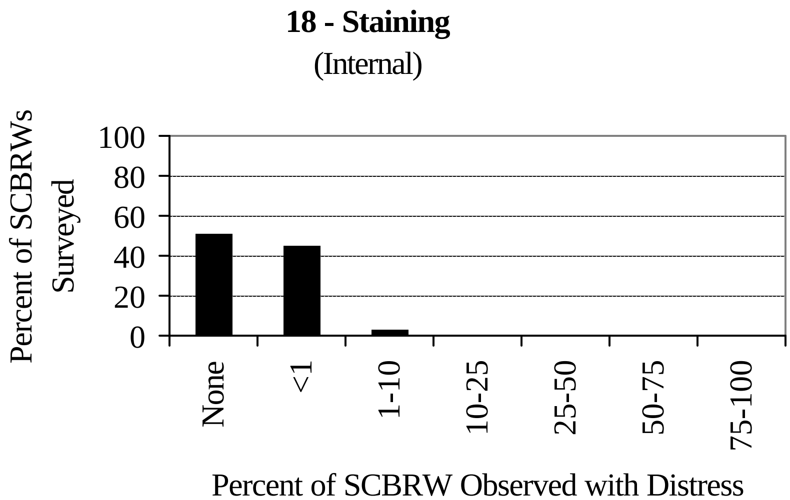



Figure F-19  Percentage of SCBRWs surveyed with low-, medium- and high-severity staining (internal).

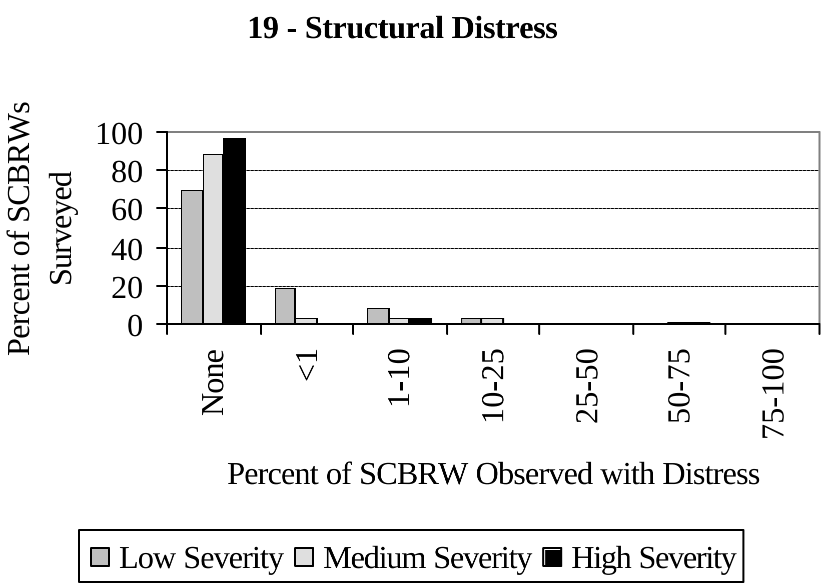



Figure F-20  Percentage of SCBRWs surveyed with low-, medium- and high-severity structural distress.

## 20 - Wash-Through

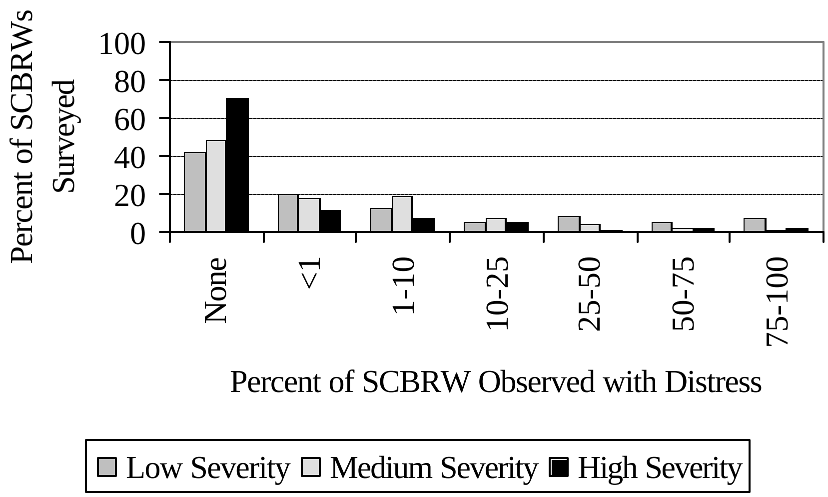



Figure F-21 Percentage of SCBRWs surveyed with low-, medium- and high-severity wash-through.

Table G-2. Hennepin county SCBRW snow survey data (peak-day sunlight exposure - concentration of deicing sand/salt snow mixture).

| | | | Percentage of SCBRW Area | | | Percentage of SCBRW Length | | Concentration of Deicing Sand/Salt Snow Mixture (*Subjective*) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Peak-Day Sunlight Exposure | | | Deicing Sand/Salt Snow Accumulation | | | |
| **CSAH** | **Location** | **Date** | **Top Block Layer** | **Vertical Surfaces** | **Indirect Sunlight (Vertical Surfaces)** | **Top Block Layer** | **Vertical Surfaces** | **Top Block Layer** | **Vertical Surfaces** |
| 1 | Sheridan | | 90-100 | 90-100 | | 90-100 | 90-100 | High | High |
| 5 | 343' E of Jidana Lane | 2/7/2000 | 1-10 | 0 | | 1 | 100 | Low | High |
| 6 | 50' E of Juneau | 2/2/2000 | 90-100 | 70-80 | 20 | 1-10 | 70-80 | High | High |
| 6 | 1103' E of Niagara Ln | 2/2/2000 | 100 | 100 | | 0 | 100 | | High |
| 6 | 530 E of Shenandoah Ln | 2/2/2000 | 100 | 100 | | 100 | 100 | Low | High |
| 6 | 149' E of Yuma Ln | 2/2/2000 | 100 | 100 | | 25-50 | 100 | High | High |
| 6 | 52' E of Dunkirk Ln | 2/2/2000 | 100 | 100 | | 0 | 100 | | High |
| 6 | 481 E of Dunkirk Ln (south side of road) | 2/2/2000 | 90-100 | 0 | | 0 | 100 | | High |
| 6 | 481 E of Dunkirk Ln (north side of road) | 2/2/2000 | 90-100 | 90-100 | | 90-100 | 90-100 | High | High |
| 6 | 25' E of Garland Ln (W) | 2/7/2000 | 100 | 100 | | 100 | 100 | High | High |
| 6 | 825' E of CSAH 101 | 2/7/2000 | 100 | 100 | | 100 | 100 | High | High |
| 9 | 50' E of Quebec Ave N (NE Quad) | 2/2/2000 | 100 | 100 | | 1-10 | 100 | High | High |
| 9 | 40' E of Quebec Ave N (SE Quad) | 2/2/2000 | 1-10 | 0 | | 90-100 | 100 | Medium | High |
| 9 | W. of Oregon (Quebec) | 2/2/2000 | 90-100 | 0 | | 100 | 100 | High | High |
| 9 | 430' E of Ensign Ave | 2/2/2000 | 90-100 | 100 | | 100 | 100 | High | High |
| 9 | 47' E of Flag Ave N | 2/2/2000 | 25-50 | 0 | | 100 | 100 | Low | Medium |
| 9 | SE Quad Gettysburg | 2/2/2000 | 80-90 | 70-80 | 70-80 | 1-10 | 1-10 | High | High |
| 9 | SW Quad. Annapolis Ln (SE Quad) | 2/2/2000 | 70-80 | 25-50 | | 1-10 | 0 | Low | |
| 9 | SW Quad. Annapolis Ln (SW Quad) | 2/2/2000 | 1 | 1 | | 10-25 | 1 | High | Medium |
| 9 | 278' E of Lake Rd | ####### | 80-90 (Filtered) | 80-90 (Filtered) | | 100 | 100 | High | High |
| 10 | 275' E of I 494 On-Ramp | 2/1/2000 | 100 | 100 | | 0 | 100 | | High |
| 10 | 85' E of Jonquil Ln N | 2/1/2000 | 1 (Filtered) | 0 | | 100 | 100 | Medium | Medium |

Table G-2. Hennepin county SCBRW snow survey data (peak-day sunlight exposure - concentration of deicing sand/salt snow mixture) (continued).

| | | | Percentage of SCBRW Area - Peak-Day Sunlight Exposure | | | Percentage of SCBRW Length - Deicing Sand/Salt Snow Accumulation | | Concentration of Deicing Sand/Salt Snow Mixture (*Subjective* ) | |
|---|---|---|---|---|---|---|---|---|---|
| **CSAH** | **Location** | **Date** | **Top Block Layer** | **Vertical Surfaces** | **Indirect Sunlight (Vertical Surfaces)** | **Top Block Layer** | **Vertical Surfaces** | **Top Block Layer** | **Vertical Surfaces** |
| 10 | 300' E of CSAH 61 (NE Quad) | 2/1/2000 | 100 | 100 | | 0 | 0 | | |
| 10 | 435' E of CSAH 61 (SE Quad) | 2/1/2000 | 1-10 | 0 | | 1 | 1-10 | Low | Medium |
| 10 | 656' E of Deerwood Ln N (SE Quad) | 2/1/2000 | 10-25 | 0 | | 100 | 100 | Low | Medium |
| 10 | 890' E of Deerwood (NE Quad) - tier 1 | 2/1/2000 | 100 | 100 | | 0 | 70-80 | | High |
| | 890' E of Deerwood (NE Quad) - tier 2 | 2/1/2000 | 100 | 100 | | 0 | 0 | | |
| 10 | 500' E of Trenton | 2/1/2000 | 100 | 100 | | 0 | 0 | | |
| 10 | 170' E of Decatur Ave N | 2/1/2000 | 90-100 | 90-100 | | 100 | 100 | High | High |
| 10 | SE Quad Boone Ave | 2/1/2000 | 80-90 | 25-50 | | 70-80 | 50-70 | Low | Medium |
| 10 | 31' E of Sumter Ave N | 2/2/2000 | 80-90 (Filtered) | 0 | | 100 | 100 | High | High |
| 12 | 747' N of Noble Ave N | 2/1/2000 | 70-80 | 70-80 | 70-80 | 0 | 0 | | |
| 17 | 135' N of W Fuller St | 2/9/2000 | 90-100 | 80-90 | 20 | 90-100 | 90-100 | High | High |
| 17 | 423' N of W 52nd St | 2/9/2000 | 90-100 | 90-100 | 90-100 | 100 | 100 | High | High |
| 17 | 200' N of W 49th St - tier 1 | 2/9/2000 | 100 | 100 | 100 | 100 | 100 | High | High |
| | 200' N of W 49th St - tier 2 | 2/9/2000 | 0 | 0 | | 90-100 | 90-100 | High | High |
| 17 | 862' N of W 37th St | 2/9/2000 | 1-10 | 25-50 | 25-50 | 1 | 1 | Low | Low |
| 32 | 555' N of Maple Ave S | 2/9/2000 | 100 | 100 | 100 | 100 | 100 | Low | Low |
| 32 | 86' N of W 78th St | 2/9/2000 | 100 | 100 | 100 | 100 | 100 | High | High |
| 34 | 881' N of 102nd St | 2/9/2000 | 100 | 100 | 100 | 100 | 100 | High | High |
| 35 | 495' N of E 83rd St | 2/9/2000 | 90-100 | 90-100 | 90-100 | 90-100 | 90-100 | High | High |
| 53 | At Queen NE Quadrant | 2/9/2000 | 100 | 100 | 1-10 | 90-100 | 100 | High | High |
| 61 | 25' N of 66th Ave N | 2/1/2000 | 25-50 | 25-50 | | 0 | 0 | | |
| 61 | 138' N of 42nd Pl N | 2/2/2000 | 100 | 100 | 100 | 100 | 100 | High | High |

Table G-2. Hennepin county SCBRW snow survey data (peak-day sunlight exposure - concentration of deicing sand/salt snow mixture) (continued).

| | | | Percentage of SCBRW Area — Peak-Day Sunlight Exposure | | | Percentage of SCBRW Length — Deicing Sand/Salt Snow Accumulation | | Concentration of Deicing Sand/Salt Snow Mixture (*Subjective*) | |
|---|---|---|---|---|---|---|---|---|---|
| **CSAH** | **Location** | **Date** | **Top Block Layer** | **Vertical Surfaces** | **Indirect Sunlight (Vertical Surfaces)** | **Top Block Layer** | **Vertical Surfaces** | **Top Block Layer** | **Vertical Surfaces** |
| 61 | At 46th Ave N | 2/2/2000 | 90-100 | 90-100 | 90-100 | 0 | 0 | | |
| 61 | 200' N of 54th Ave N | 2/2/2000 | 100 | 100 | 100 | 100 | 100 | Low | Low |
| 62 | 200' E of CSAH 101 (SE Quad) | 2/7/2000 | 50-70 | 0 | | 100 | 100 | High | High |
| 62 | 200' E of CSAH 101 (NE Quad) | 2/7/2000 | 100 | 100 | | 100 | 100 | High | High |
| 62 | At Ellerdale Lane (North side) - tier 1 | 2/7/2000 | 100 | 100 | | 0 | 100 | | High |
| | At Ellerdale Lane (North side) - tiers 2-4 | 2/7/2000 | 100 | 100 | | 0 | 0 | | |
| 62 | E of Ellerdale Lane (South side) | 2/7/2000 | 80-90 (Filtered) | 0 | | 100 | 100 | Medium | High |
| 70 | 20' E of Idaho Ave N | 2/7/2000 | 100 | 100 | | 100 | 100 | High | High |
| 70 | 100' E of Jersey | 2/7/2000 | 100 | 100 | 10 | 100 | 90-100 | High | High |
| 70 | 29' E of Louisiana Ave N | 2/7/2000 | 90-100 | 100 | | 100 | 100 | Medium | High |
| 70 | 248' E of Nevada Ave | 2/7/2000 | 100 | 100 | | 100 | 100 | High | High |
| 70 | At Rhode Island Ave N | 2/7/2000 | 100 | 90-100 | 60 | 100 | 100 | High | High |
| 70 | At NW Quad. Winnetka Ave N | 2/7/2000 | 90-100 | 90-100 | | 100 | 100 | High | High |
| 70 | 100' E of Virginia Ave | 2/7/2000 | 100 | 100 | | 100 | 100 | High | High |
| 70 | 57' E of Xylon Ave N | 2/7/2000 | 100 | 100 | | 100 | 100 | High | High |
| 70 | 130' E of Decatur Ave N. | 2/7/2000 | 1-10 | 0 | | 100 | 100 | High | High |
| 70 | At Flag AveN | 2/7/2000 | 90-100 | 25-50 | 25 | 70-80 | 90-100 | High | High |
| 73 | At Oak Knoll Terrace N | 2/7/2000 | 1-10 | 0 | | 100 | 100 | High | High |
| 101 | 100' S of 87th Pl N (E. side of road) | 2/1/2000 | 50-70 | 50-70 | 50-70 | 80-90 | 90-100 | High | High |
| 101 | 100' S of 87th Pl N (W. side of road) | 2/1/2000 | 90-100 | 90-100 | | 100 | 100 | High | High |
| 101 | SE Quad. Weaver Lake Dr | 2/1/2000 | 90-100 | 90-100 | | 100 | 100 | High | High |
| 101 | 90' N of 82nd Pl N | 2/1/2000 | 70-80 | 70-80 | | 25-50 | 25-50 | Low | Low |
| 101 | 90' N of 82nd Ave N | 2/1/2000 | 50-70 | 50-70 | | 1 | 1 | Low | Low |

Table G-2. Hennepin county SCBRW snow survey data (peak-day sunlight exposure - concentration of deicing sand/salt snow mixture) (continued).

| | | | Percentage of SCBRW Area | | | Percentage of SCBRW Length | | Concentration of Deicing Sand/Salt Snow Mixture (*Subjective*) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Peak-Day Sunlight Exposure | | | Deicing Sand/Salt Snow Accumulation | | | |
| **CSAH** | **Location** | **Date** | **Top Block Layer** | **Vertical Surfaces** | **Indirect Sunlight (Vertical Surfaces)** | **Top Block Layer** | **Vertical Surfaces** | **Top Block Layer** | **Vertical Surfaces** |
| 101 | 130' S of 24th Ave N - north wall | 2/7/2000 | 100 | 90-100 | 90-100 | 1 | 90-100 | High | High |
| | 130' S of 24th Ave N - south wall | 2/7/2000 | 90-100 | 90-100 | 70 | 1 | 90-100 | High | High |
| 156 | 208' N of Angeline Dr | 2/2/2000 | 100 | 70-80 | | 1-10 | 10-25 | Low | Low |
| 156 | 35' N of 46th Ave N | 2/1/2000 | 70-80 | 25-50 | | 10-25 | 100 | Medium | Medium |
| 156 | 894' N of CSAH 9 (44th Ave.) | 2/2/2000 | 100 | 90-100 | 90-100 | 10-25 | 100 | High | High |
| 156 | 706' N of CSAH 9 | 2/2/2000 | 100 | 100 | 100 | 50-70 | 100 | High | High |
| 156 | SW Quad. CSAH 70 | 2/7/2000 | 100 | 100 | 100 | 100 | 100 | High | High |

Table G-3. Mn/DOT SCBRW snow survey data (peak-day sunlight exposure - concentration of deicing sand/salt snow mixture).

| | | | Percentage of SCBRW Area Peak-Day Sunlight Exposure | | | Percentage of SCBRW Deicing Sand/Salt | | Concentration of Deicing Sand/Salt | |
|---|---|---|---|---|---|---|---|---|---|
| **CSAH** | **Location** | **Date** | **Top Block Layer** | **Vertical Surfaces** | **Indirect Sunlight (Vertical Surfaces)** | **Top Block Layer** | **Vertical Surfaces** | **Top Block Layer** | **Vertical Surfaces** |
| TH55/100 | SW Frontage Road (SW Ramp for hwy 100 South) | ####### | 90-100 | 0 | | 100 | 100 | Medium | Medium |
| I-394 | Ridgedale Entrance - Corner of CSAH 73 & S. Frontage Road - South Wall | ####### | 50-70 | 0 | | 0 | 0 | | |
| | Ridgedale Entrance - Corner of CSAH 73 & S. Frontage Road - North Wall | ####### | 100 | 100 | 70-80 | 70-80 | 70-80 | High | High |
| I-394 | N Frontage Road @ Veteranary Clinic | ####### | 100 | 100 | 10 | 0 | 1 | | Low |

Table G-1. Dakota county SCBRW snow survey data (peak-day sunlight exposure - concentration of deicing sand/salt snow mixture).

| | | | Percentage of SCBRW Area Peak-Day Sunlight Exposure | | | Percentage of SCBRW Deicing Sand/Salt | | Concentration of Deicing Sand/Salt | |
|---|---|---|---|---|---|---|---|---|---|
| **CSAH** | **Location** | **Date** | **Top Block Layer** | **Vertical Surfaces** | **Indirect Sunlight (Vertical Surfaces)** | **Top Block Layer** | **Vertical Surfaces** | **Top Block Layer** | **Vertical Surfaces** |
| 26 | Bovey Ave. | 2/9/2000 | 80-90 | 0 | | 100 | 100 | High | High |
| 31 | Delores Lane (SW Quad Pilot Knob & Cliff Rd) | 2/8/2000 | 100 | 100 | 100 | 100 | 100 | High | High |
| 31 | Apple Valley, on Pilot Knob at Cliff Rd. (SE Quad) | 2/8/2000 | 100 | 100 | 100 | 25-50 | 10-25 | Medium | Medium |
| 31 | Diffley Road (SW Quad, frontage Road, house #1440) | 2/9/2000 | 25-50 | 25-50 | 25-50 | 0 | 0 | | |
| 32 | Fairway Hills Drive | 2/8/2000 | 90-100 | 0 | | 100 | 100 | Low | High |
| 38 | Gardenview Ave, North Side - tier 1 | 2/8/2000 | 100 | 100 | | 90-100 | 100 | High | High |
| | Gardenview Ave, North Side - tier 2 | 2/8/2000 | 100 | 100 | | 0 | 0 | | |
| 38 | Gardenview Ave, South Side - tier 1 | 2/8/2000 | 50-70 | 0 | | 25-50 | 50-70 | High | High |
| | Gardenview Ave, South Side - tier 2 | 2/8/2000 | 50-70 | 0 | | 0 | 0 | | |
| 38 | Havelock Trail - First Tier | 2/8/2000 | 80-90 | 0 | | 100 | 100 | High | High |
| | Havelock Trail - Second Tier | 2/8/2000 | 80-90 | 0 | | 80-90 | 80-90 | | |
| | Havelock Trail - Third Tier | 2/8/2000 | 80-90 | 0 | | 0 | 0 | | |
| 38 | Diamond Path | 2/8/2000 | 90-100 | 0 | | 10-25 | 100 | High | High |
| 38 | Apple Valley, on McAndrews at Pilot Knob (SE Quad) | 2/8/2000 | 70-80 | 70-80 | 70-80 | 0 | 0 | | |
| 38 | Apple Valley, on McAndrews at Pilot Knob (NE Quad) | 2/8/2000 | 100 | 100 | 100 | 25-50 | 100 | High | High |
| 42 | Burnsville, Glendale Rd W to Vernon Ave - SW Quad Glendale & CSAH 42 | ####### | 100 | 50-70 | 50-70 | 50-70 | 50-70 | High | High |
| 42 | NW Quad. Glendale & CSAH 42 | ####### | 100 | 100 | | 1-10 | 90-100 | High | Medium |
| 46 | Church, Highview Ave. | 2/8/2000 | 100 | 0 | | 100 | 100 | Medium | High |
| 46 | Grove Trail | 2/8/2000 | 90-100 | 0 | | 90-100 | 100 | High | High |

Table G-4. Privately owned SCBRW snow survey data (peak-day sunlight exposure - concentration of deicing sand/salt snow mixture).

| | | | Percentage of SCBRW Area Peak-Day Sunlight Exposure | | | Percentage of SCBRW Deicing Sand/Salt | | Concentration of Deicing Sand/Salt | |
|---|---|---|---|---|---|---|---|---|---|
| **CSAH** | **Location** | **Date** | **Top Block Layer** | **Vertical Surfaces** | **Indirect Sunlight (Vertical Surfaces)** | **Top Block Layer** | **Vertical Surfaces** | **Top Block Layer** | **Vertical Surfaces** |
| 31 | Extended Stay Hotel, NW Quad. Pilot Knob and Yankee Doodle | ####### | 70-80 | 0 | | 90-100 | 0 | Medium | |
| 32 | RHS Building, SE Quad. 35E and Cliff Rd | 2/9/2000 | 100 | 100 | | 90-100 | 90-100 | High | High |
| | Burnsville, corner of S. Cross and Burnhaven | 2/8/2000 | 100 | 50-70 | 50-70 | 90-100 | 90-100 | Medium | Medium |
| | Burnsville, behind K-Mart between Burnhaven and Irving | 2/8/2000 | 100 | 100 | 25-50 | 0 | 50-70 | | Low |
| | Burnsville, behind Rainbow foods, CR 42 and CR 5 | 2/8/2000 | 100 | 100 | 90 | 100 | 100 | High | High |
| | Shakopee Printing, Hwy 101 S of Valley Fair Entrance (Valley Park Road & Valley Industrial Drive S.) | ####### | 100 | 0 | | 1-10 | 25-50 | High | High |
| | St. Hubert's Church, Hwy 5 and Great Plains Rd South | ####### | 100 | 100 | 100 | 1-10 | 1-10 | Low | Medium |

Table G-6. Hennepin county SCBRW snow survey data (snow removal/snow accumulation and fencing).

| | | Type of Snow Removal | | | | Snow Accumulation — Top Block Layer — Type of Snow | | Snow Accumulation — Vertical Surfaces — Type of Snow | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CSAH | Location | Main-Line Snow Removal | Side-Walk Snow Removal | Parking Lot | Driveway | Snow Removal | Falling Snow | Snow Removal | Falling Snow | Fence Behind Wall |
| 1 | Sheridan | Y | Y | N | Y | Y | Y | Y | Y | N |
| 5 | 343' E of Jidana Lane | Y | N | N | N | Y | Y | Y | Y | N |
| 6 | 50' E of Juneau | Y | N | N | Y | Y | Y | Y | Y | N |
| 6 | 1103' E of Niagara Ln | Y | N | N | N | N | Y | Y | Y | N |
| 6 | 530 E of Shenandoah Ln | Y | Y | N | N | N | Y | Y | Y | N |
| 6 | 149' E of Yuma Ln | Y | Y | N | N | Y | Y | Y | Y | N |
| 6 | 52' E of Dunkirk Ln | Y | Y | N | N | Y | Y | Y | Y | N |
| 6 | 481 E of Dunkirk Ln (south side of road) | Y | N | N | Y | N | Y | Y | Y | Y |
| 6 | 481 E of Dunkirk Ln (north side of road) | Y | Y | N | N | Y | Y | Y | Y | N |
| 6 | 25' E of Garland Ln (W) | Y | Y | N | N | Y | Y | Y | Y | N |
| 6 | 825' E of CSAH 101 | Y | Y | N | N | Y | Y | Y | Y | N |
| 9 | 50' E of Quebec Ave N (NE Quad) | Y | Y | Y | N | Y | Y | Y | Y | N |
| 9 | 40' E of Quebec Ave N (SE Quad) | Y | Y | Y | N | Y | Y | Y | Y | Y |
| 9 | W. of Oregon (Quebec) | Y | Y | Y | N | Y | Y | Y | Y | N |
| 9 | 430' E of Ensign Ave | Y | Y | N | N | Y | Y | Y | Y | N |
| 9 | 47' E of Flag Ave N | Y | Y | Y | Y | y | Y | Y | Y | N |
| 9 | SE Quad Gettysburg | Y | Y | N | N | Y | Y | Y | Y | N |
| 9 | SW Quad. Annapolis Ln (SE Quad) | Y | Y | Y | N | Y | Y | Y | Y | N |
| 9 | SW Quad. Annapolis Ln (SW Quad) | Y | Y | N | N | Y | Y | Y | Y | Y |
| 9 | 278' E of Lake Rd | Y | Y | N | Y | Y | Y | Y | Y | N |
| 10 | 275' E of I 494 On-Ramp | Y | Y | N | N | N | Y | Y | Y | Y |
| 10 | 85' E of Jonquil Ln N | Y | Y | N | N | Y | Y | Y | Y | N |
| 10 | 300' E of CSAH 61 (NE Quad) | Y | Y | N | Y | N | Y | N | Y | N |

Table G-6. Hennepin county SCBRW snow survey data (snow removal/snow accumulation and fencing) (continued).

| | | Type of Snow Removal | | | | Snow Accumulation: Top Block Layer — Type of Snow | | Snow Accumulation: Vertical Surfaces — Type of Snow | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CSAH | Location | Main-Line Snow Removal | Side-Walk Snow Removal | Parking Lot | Driveway | Snow Removal | Falling Snow | Snow Removal | Falling Snow | Fence Behind Wall |
| 10 | 435' E of CSAH 61 (SE Quad) | Y | Y | N | N | Y | Y | Y | Y | Y |
| 10 | 656' E of Deerwood Ln N (SE Quad) | Y | Y | N | Y | Y | Y | Y | Y | N |
| 10 | 890' E of Deerwood (NE Quad) - tier 1 | N | Y | N | N | N | Y | Y | Y | N |
| | 890' E of Deerwood (NE Quad) - tier 2 | N | N | N | N | N | Y | N | Y | N |
| 10 | 500' E of Trenton | N | N | N | N | N | Y | N | Y | N |
| 10 | 170' E of Decatur Ave N | Y | Y | N | N | Y | Y | Y | Y | N |
| 10 | SE Quad Boone Ave | Y | Y | N | N | N | Y | Y | Y | N |
| 10 | 31' E of Sumter Ave N | Y | Y | N | Y | Y | Y | Y | Y | N |
| 12 | 747' N of Noble Ave N | Y | N | N | N | N | Y | N | Y | N |
| 17 | 135' N of W Fuller St | Y | Y | N | N | Y | Y | Y | Y | N |
| 17 | 423' N of W 52nd St | Y | Y | N | N | Y | Y | Y | Y | N |
| 17 | 200' N of W 49th St - tier 1 | Y | Y | N | Y | Y | Y | Y | Y | N |
| | 200' N of W 49th St - tier 2 | Y | Y | N | Y | Y | Y | Y | Y | N |
| 17 | 862' N of W 37th St | Y | Y | N | N | N | Y | N | Y | N |
| 32 | 555' N of Maple Ave S | N | Y | N | N | | Y | | Y | N |
| 32 | 86' N of W 78th St | Y | Y | N | N | Y | Y | Y | Y | N |
| 34 | 881' N of 102nd St | Y | Y | N | N | Y | Y | Y | Y | N |
| 35 | 495' N of E 83rd St | Y | Y | N | Y | Y | Y | Y | Y | N |
| 53 | At Queen NE Quadrant | Y | Y | N | N | Y | Y | Y | Y | N |
| 61 | 25' N of 66th Ave N | N | Y | N | N | N | Y | Y | Y | N |
| 61 | 138' N of 42nd Pl N | Y | Y | N | N | Y | Y | Y | Y | N |
| 61 | At 46th Ave N | Y | Y | N | N | N | Y | N | Y | N |
| 61 | 200' N of 54th Ave N | Y | Y | N | N | Y | Y | Y | Y | Y |

Table G-6. Hennepin county SCBRW snow survey data (snow removal/snow accumulation and fencing) (continued).

| | | Type of Snow Removal | | | | Snow Accumulation: Top Block Layer — Type of Snow | | Snow Accumulation: Vertical Surfaces — Type of Snow | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CSAH | Location | Main-Line Snow Removal | Side-Walk Snow Removal | Parking Lot | Driveway | Snow Removal | Falling Snow | Snow Removal | Falling Snow | Fence Behind Wall |
| 62 | 200' E of CSAH 101 (SE Quad) | Y | Y | N | N | Y | Y | Y | Y | Y |
| 62 | 200' E of CSAH 101 (NE Quad) | Y | Y | N | N | Y | Y | Y | Y | N |
| 62 | At Ellerdale Lane (North side) - tier 1 | Y | Y | N | N | N | Y | Y | Y | N |
| 62 | At Ellerdale Lane (North side) - tiers 2-4 | Y | Y | N | N | N | Y | N | Y | N |
| 62 | E of Ellerdale Lane (South side) | Y | Y | N | N | Y | Y | Y | Y | N |
| 70 | 20' E of Idaho Ave N | Y | Y | N | N | Y | Y | Y | Y | N |
| 70 | 100' E of Jersey | Y | Y | N | Y | Y | Y | Y | Y | N |
| 70 | 29' E of Louisiana Ave N | Y | Y | N | N | Y | Y | Y | Y | Y |
| 70 | 248' E of Nevada Ave | Y | Y | Y | N | Y | Y | Y | Y | N |
| 70 | At Rhode Island Ave N | Y | Y | N | Y | Y | Y | Y | Y | N |
| 70 | At NW Quad. Winnetka Ave N | Y | Y | Y | Y | Y | Y | Y | Y | N |
| 70 | 100' E of Virginia Ave | Y | Y | N | N | Y | Y | Y | Y | N |
| 70 | 57' E of Xylon Ave N | Y | Y | N | N | Y | Y | Y | Y | N |
| 70 | 130' E of Decatur Ave N. | Y | Y | N | Y | Y | Y | Y | Y | N |
| 70 | At Flag AveN | Y | Y | N | Y | Y | Y | Y | Y | N |
| 73 | At Oak Knoll Terrace N | Y | N | N | N | Y | Y | Y | Y | N |
| 101 | 100' S of 87th Pl N (E. side of road) | Y | Y | N | Y | Y | Y | Y | Y | Y |
| 101 | 100' S of 87th Pl N (W. side of road) | Y | Y | N | N | Y | Y | Y | Y | Y |
| 101 | SE Quad. Weaver Lake Dr | Y | Y | N | N | Y | Y | Y | Y | Y |
| 101 | 90' N of 82nd Pl N | N | Y | N | N | N | Y | N | Y | N |
| 101 | 90' N of 82nd Ave N | N | Y | N | N | Y | Y | Y | Y | Y |
| 101 | 130' S of 24th Ave N - north wall | Y | Y | N | Y | Y | Y | Y | Y | N |
| 101 | 130' S of 24th Ave N - south wall | Y | Y | N | Y | Y | Y | Y | Y | N |
| 156 | 208' N of Angeline Dr | Y | Y | N | Y | N | Y | N | Y | N |
| 156 | 35' N of 46th Ave N | Y | Y | N | Y | Y | Y | Y | Y | N |

Table G-6. Hennepin county SCBRW snow survey data (snow removal/snow accumulation and fencing) (continued).

| | | Type of Snow Removal | | | | Snow Accumulation: Top Block Layer — Type of Snow | | Snow Accumulation: Vertical Surfaces — Type of Snow | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CSAH | Location | Main-Line Snow Removal | Side-Walk Snow Removal | Parking Lot | Driveway | Snow Removal | Falling Snow | Snow Removal | Falling Snow | Fence Behind Wall |
| 156 | 894' N of CSAH 9 (44th Ave.) | Y | Y | N | Y | Y | Y | Y | Y | N |
| 156 | 706' N of CSAH 9 | Y | Y | N | Y | Y | Y | Y | Y | N |
| 156 | SW Quad. CSAH 70 | Y | Y | N | N | Y | Y | Y | Y | Y |

Table G-7. Mn/DOT SCBRW snow survey data (snow removal/snow accumulation and fencing).

| | | Type of Snow Removal | | | | Snow Accumulation | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Top Block Layer | | Vertical Surfaces | | |
| | | | | | | Type of Snow | | | | |
| **CSAH** | **Location** | **Main-Line Snow Removal** | **Side-Walk Snow Removal** | **Parking Lot** | **Driveway** | **Snow Removal** | **Falling Snow** | **Snow Removal** | **Falling Snow** | **Fence Behind Wall** |
| TH55/100 | SW Frontage Road (SW Ramp for hwy 100 South) | Y | N | N | N | Y | Y | Y | Y | Y |
| I-394 | Ridgedale Entrance - Corner of CSAH 73 & S. Frontage Road - South Wall | Y | Y | N | N | N | Y | N | Y | N |
| | Ridgedale Entrance - Corner of CSAH 73 & S. Frontage Road - North Wall | Y | Y | N | N | Y | Y | Y | Y | Y |
| I-394 | N Frontage Road @ Veteranary Clinic | N | N | Y | Y | N | Y | N | Y | Y |

Table G-5. Dakota county SCBRW snow survey data (snow removal/snow accumulation and fencing).

| | | Type of Snow Removal | | | | Snow Accumulation: Top Block Layer — Type of Snow | | Snow Accumulation: Vertical Surfaces — Type of Snow | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CSAH | Location | Main-Line Snow Removal | Side-Walk Snow Removal | Parking Lot | Driveway | Snow Removal | Falling Snow | Snow Removal | Falling Snow | Fence Behind Wall |
| 26 | Bovey Ave. | Y | Y | N | Y | Y | Y | Y | Y | N |
| 31 | Delores Lane (SW Quad Pilot Knob & Cliff Rd) | Y | Y | N | N | Y | Y | Y | Y | Y |
| 31 | Apple Valley, on Pilot Knob at Cliff Rd. (SE Quad) | Y | N | N | N | Y | Y | Y | Y | Y |
| 31 | Diffley Road (SW Quad, frontage Road, house #1440) | N | N | N | Y | Y | Y | Y | Y | N |
| 32 | Fairway Hills Drive | Y | Y | N | N | Y | Y | Y | Y | N |
| 38 | Gardenview Ave, North Side - tier 1 | Y | Y | N | N | Y | Y | Y | Y | Y |
| | Gardenview Ave, North Side - tier 2 | N | N | N | N | N | Y | N | Y | Y |
| 38 | Gardenview Ave, South Side - tier 1 | Y | N | N | N | Y | Y | Y | Y | N |
| | Gardenview Ave, South Side - tier 2 | Y | N | N | N | N | Y | N | Y | Y |
| 38 | Havelock Trail - First Tier | Y | N | N | N | Y | Y | Y | Y | N |
| | Havelock Trail - Second Tier | Y | Y | N | N | Y | Y | Y | Y | N |
| | Havelock Trail - Third Tier | Y | Y | N | N | N | Y | N | Y | Y |
| 38 | Diamond Path | Y | Y | N | N | Y | Y | Y | Y | Y |
| 38 | Apple Valley, on McAndrews at Pilot Knob (SE Quad) | N | N | N | N | N | Y | N | Y | N |
| 38 | Apple Valley, on McAndrews at Pilot Knob (NE Quad) | Y | N | N | N | Y | Y | Y | Y | Y |
| 42 | Burnsville, Glendale Rd W to Vernon Ave - SW Quad Glendale & CSAH 42 | Y | Y | Y | N | Y | Y | Y | Y | N |
| 42 | NW Quad. Glendale & CSAH 42 | Y | Y | Y | N | Y | Y | Y | Y | N |
| 46 | Church, Highview Ave. | Y | Y | N | N | Y | Y | Y | Y | Y |
| 46 | Grove Trail | Y | Y | N | N | Y | Y | Y | Y | Y |

Table G-8. Privately owned SCBRW snow survey data (snow removal/snow accumulation and fencing).

| | | Type of Snow Removal | | | | Snow Accumulation | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Top Block Layer | | Vertical Surfaces | | |
| | | | | | | Type of Snow | | | | |
| **CSAH** | **Location** | **Main-Line Snow Removal** | **Side-Walk Snow Removal** | **Parking Lot** | **Driveway** | **Snow Removal** | **Falling Snow** | **Snow Removal** | **Falling Snow** | **Fence Behind Wall** |
| 31 | Extended Stay Hotel, NW Quad. Pilot Knob and Yankee Doodle | N | N | Y | N | Y | Y | N | Y | N |
| 32 | RHS Building, SE Quad. 35E and Cliff Rd | N | N | Y | N | Y | Y | Y | Y | N |
| | Burnsville, corner of S. Cross and Burnhaven | Y | Y | Y | N | Y | Y | Y | Y | N |
| | Burnsville, behind K-Mart between Burnhaven and Irving | N | N | Y | N | N | Y | Y | Y | N |
| | Burnsville, behind Rainbow foods, CR 42 and CR 5 | Y | Y | Y | N | Y | Y | Y | Y | N |
| | Shakopee Printing, Hwy 101 S of Valley Fair Entrance (Valley Park Road & Valley Industrial Drive S.) | N | N | Y | N | Y | Y | Y | Y | Y |
| | St. Hubert's Church, Hwy 5 and Great Plains Rd South | N | N | Y | N | Y | Y | Y | Y | Y |

Table G-10. Hennepin county SCBRW snow survey data (comments).

| CSAH | Location | Comments |
|---|---|---|
| 1 | Sheridan | large accumlation of snow by driveway entrances against wall |
| 5 | 343' E of Jidana Lane | snow adjacent to bottom 2 ft of wall |
| 6 | 50' E of Juneau | snow removal on 10% of capstone |
| 6 | 1103' E of Niagara Ln | snow adjacent to bottom 1 ft of wall |
| 6 | 530 E of Shenandoah Ln | snow buildup from road behind wall drains toward wall (high concentration of deicing sand/salt) |
| 6 | 149' E of Yuma Ln | snow adjacent to bottom 1-2 ft of wall, a large amount of deicing sand/salt snow beyond wall |
| 6 | 52' E of Dunkirk Ln | snow adacent to bottom 1 ft of wall, a large amount of deicing sand/salt snow beyond wall |
| 6 | 481 E of Dunkirk Ln (south side of road) | snow very packed against vertical surfaces, snow adjacent to bottom 2 ft of wall |
| 6 | 481 E of Dunkirk Ln (north side of road) | snow adjacent to bottom 1 ft of wall |
| 6 | 25' E of Garland Ln (W) | snow adjacent to bottom 3 in of wall |
| 6 | 825' E of CSAH 101 | snow adjacent to bottom 1-2 in of wall |
| 9 | 50' E of Quebec Ave N (NE Quad) | parking lot not cleared, building got taken down fall 1999. |
| 9 | 40' E of Quebec Ave N (SE Quad) | snow very packed against vertical surfaces, parking lot extends 50 percent of wall length, snow piles have high concentration of deicing sand/salt (however, not as much on capstone), large snow piles near capstone from parking lot (50 percent of wall), snow adjacent to bottom 2 ft of wall, snow piles prevent sun on capstone by parking lot |
| 9 | W. of Oregon (Quebec) | parking lot snow piles extend 75 percent of wall length |
| 9 | 430' E of Ensign Ave | large amount of deicing sand/salt snow beyond fence |
| 9 | 47' E of Flag Ave N | snow adjacent to bottom 1-2 ft of wall |
| 9 | SE Quad Gettysburg | snow removal on CSAH 9 capstone only, no sidewalk on Gettysburg, only falling snow on SCBRW capstone adjacent to Gettysburg, large amount of packed snow behind telephone pole and large piles on top of SCBRW capstone adjacent to CSAH 9 |
| 9 | SW Quad. Annapolis Ln (SE Quad) | none of snow piles are adjacent to wall, snow piles might get close to approximately 30 percent of the vertical surfaces if a larger quantity of snow present, snow removal present on 10 percent of the capstone |
| 9 | SW Quad. Annapolis Ln (SW Quad) | snow removal snow on vertical surfaces and capstone at corner of road only, snow removal snow against in front of solid fence - this snow drains under fence over wall |

Table G-10. Hennepin county SCBRW snow survey data (comments) (continued).

| CSAH | Location | Comments |
|---|---|---|
| 9 | 278' E of Lake Rd | large amount of snow against corner by driveway, snow adjacent to bottom 4 in of face |
| 10 | 275' E of I 494 On-Ramp | snow adjacent to wall extends ~ 1ft from bottom of wall |
| 10 | 85' E of Jonquil Ln N | snow adjacent to wall extends ~ 2ft from bottom of wall |
| 10 | 300' E of CSAH 61 (NE Quad) | little snow adjacent to wall |
| 10 | 435' E of CSAH 61 (SE Quad) | mostly falling snow, plowed snow 2-3 ft away |
| 10 | 656' E of Deerwood Ln N (SE Quad) | snow adjacent to wall extends ~ 1ft from bottom of wall |
| 10 | 890' E of Deerwood (NE Quad) - tier 1 | snow adjacent to wall extends ~ 2 in from bottom of front wall |
| | 890' E of Deerwood (NE Quad) - tier 2 | |
| 10 | 500' E of Trenton | |
| 10 | 170' E of Decatur Ave N | snow adjacent to wall extends ~ 1ft from bottom of front wall |
| 10 | SE Quad Boone Ave | snow adjacent to wall extends ~ 1ft from bottom of front wall |
| 10 | 31' E of Sumter Ave N | snow very packed against vertical surfaces, vertical snow accumulation reaches height of capstone (bottom 2 ft of wall) |
| 12 | 747' N of Noble Ave N | bottom courses covered with snow accumulation, mainline snow not adjacent to wall (2-4ft away) |
| 17 | 135' N of W Fuller St | snow packed against face, snow adjacent to bottom 1ft of wall. |
| 17 | 423' N of W 52nd St | very high concentration of deicing sand/salt, snow packed against vertical surfaces, snow adjacent to bottom 2ft of wall |
| 17 | 200' N of W 49th St - tier 1 | snow adjacent to bottom 1 ft of wall |
| | 200' N of W 49th St - tier 2 | almost completely covered with snow piles from cleaning sidewalk |
| 17 | 862' N of W 37th St | folliage in front and behind wall, snow shoveled toward road |
| 32 | 555' N of Maple Ave S | snow adjacent to bottom 1 ft of wall |
| 32 | 86' N of W 78th St | snow adjacent to bottom 1-2 ft of wall |
| 34 | 881' N of 102nd St | snow adjacent to bottom 2 ft of wall |
| 35 | 495' N of E 83rd St | snow adjacent to bottom 1 ft of wall |
| 53 | At Queen NE Quadrant | no capstone |

Table G-10. Hennepin county SCBRW snow survey data (comments) (continued).

| CSAH | Location | Comments |
|---|---|---|
| 61 | 25' N of 66th Ave N | snow adjacent to wall extends ~ 1.5ft from bottom of wall |
| 61 | 138' N of 42nd Pl N | snow removal snow sprayed on top of wall - can see some accumulated piles, snow very packed into vertical surfaces, snow adjacent to bottom 3 ft of wall |
| 61 | At 46th Ave N | snow removal accumulation ~ 9ft away from wall |
| 61 | 200' N of 54th Ave N | snow very packed against vertical surfaces, snow adjacent to 1.5-2 ft of wall |
| 62 | 200' E of CSAH 101 (SE Quad) | snow is very packd against wall (~bottom 5.5 ft of wall) |
| 62 | 200' E of CSAH 101 (NE Quad) | snow adjacent to bottom 1 ft of wall |
| 62 | At Ellerdale Lane (North side) - tier 1 | a large amount of meltwater with foam through joints, no melt water through drains |
| | At Ellerdale Lane (North side) - tiers 2-4 | |
| 62 | E of Ellerdale Lane (South side) | snow adjacent to bottom 2 ft of wall |
| 70 | 20' E of Idaho Ave N | snow adjacent to bottom 4 in of wall |
| 70 | 100' E of Jersey | less deicing sand/salt against vertical surfaces in driveway, snow adjacent to bottom 4 in of wall |
| 70 | 29' E of Louisiana Ave N | snow adjacent to bottom 4 in of wall |
| 70 | 248' E of Nevada Ave | snow accumulation on capstone from parking lot snow removal, a large amount of ice on sidewalk and adjacent to bottom 2 in of wall |
| 70 | At Rhode Island Ave N | |
| 70 | At NW Quad. Winnetka Ave N | large snow pile at west end of wall (large quantities of deicing sand/salt in snow pile) |
| 70 | 100' E of Virginia Ave | snow adjacent to bottom 1 in of wall |
| 70 | 57' E of Xylon Ave N | driveway/road located behind wall, snow accumulation due to both sidewalk and road, snow adjacent to bottom 2 ft of wall |
| 70 | 130' E of Decatur Ave N. | snow very packed against vertical surfaces, snow adjacent to bottom 2 ft of wall |
| 70 | At Flag AveN | |
| 73 | At Oak Knoll Terrace N | snow very packed against vertical surfaces |
| 101 | 100' S of 87th Pl N (E. side of road) | bottom 3 courses covered with snow |
| 101 | 100' S of 87th Pl N (W. side of road) | snow adjacent to wall extends ~ 3ft from bottom of wall |
| 101 | SE Quad. Weaver Lake Dr | snow extends adjacent to wall up ~ 34 in from bottom of wall (entire wall ht.) |
| 101 | 90' N of 82nd Pl N | smow accumulation up entire wall |

Table G-10. Hennepin county SCBRW snow survey data (comments) (continued).

| CSAH | Location | Comments |
|---|---|---|
| 101 | 90' N of 82nd Ave N | snow removal on capstone at very ends of wall, snow extends ~ 2ft from bottom of wall |
| 101 | 130' S of 24th Ave N - north wall | snow adjacent to bottom 1 ft of wall, high concentration of deicing sand/salt on capstone by driveway |
| | 130' S of 24th Ave N - south wall | very high quantity of deicing sand/salt, snow packed against vertical surfaces, snow adjacent to wall bottom 2ft of wall |
| 156 | 208' N of Angeline Dr | shoveled driveway, snow adjacent to bottom 1 ft of wall |
| 156 | 35' N of 46th Ave N | snow removal on capstone by driveway |
| 156 | 894' N of CSAH 9 (44th Ave.) | very little snow removal on capstone, snow adjacent to bottom 2 ft of wall |
| 156 | 706' N of CSAH 9 | snow adjacent to bottom 1 ft of wall |
| 156 | SW Quad. CSAH 70 | |

Table G-11. Mn/DOT SCBRW snow survey data (comments).

| CSAH | Location | Comments |
|---|---|---|
| TH55/100 | SW Frontage Road (SW Ramp for hwy 100 South) | Block median against back of wall |
| I-394 | Ridgedale Entrance - Corner of CSAH 73 & S. Frontage Road - South Wall | only falling snow, snow cleared on corner by light |
| | Ridgedale Entrance - Corner of CSAH 73 & S. Frontage Road - North Wall | no snow removal on 10 percent of wall, remaining 90 percent of wall completely barried |
| I-394 | N Frontage Road @ Veteranary Clinic | snow removal pile located at end of lot, less than 1 percent of snow pile is on the wall |

Table G-9. Dakota county SCBRW snow survey data (comments).

| CSAH | Location | Comments |
|---|---|---|
| 26 | Bovey Ave. | 3-4 ft of packed snow adjacent to wall, a large amount of snow accumulation against fence |
| 31 | Delores Lane (SW Quad Pilot Knob & Cliff Rd) | snow accumulation against fence, snow packed against vertical surfaces, snow adjacent to bottom 2 ft of wall |
| 31 | Apple Valley, on Pilot Knob at Cliff Rd. (SE Quad) | snow on capstone is due to snow removal from road behind wall (25-50 percent of wall), most of the deicing sand/salt solution from CSAH 31 is 4-5ft away from wall, guardrail behind wall |
| 31 | Diffley Road (SW Quad, frontage Road, house #1440) | snow pushed out towards frontage road |
| 32 | Fairway Hills Drive | little if any snow removal on capstone (some deicing sand/salt), snow packed against vertical surfaces, snow adjacent to bottom 2-3ft of wall |
| 38 | Gardenview Ave, North Side - tier 1 | a large amount of deicing sand/salt snow behind wall, snow adjacent to bottom 1ft of wall, a large amount of dirt/growth on capstone of entire wall |
| | Gardenview Ave, North Side - tier 2 | |
| 38 | Gardenview Ave, South Side - tier 1 | large quantity of snow against wall from snow removal (~ 2-3 ft. very packed) |
| | Gardenview Ave, South Side - tier 2 | |
| 38 | Havelock Trail - First Tier | |
| | Havelock Trail - Second Tier | |
| | Havelock Trail - Third Tier | |
| 38 | Diamond Path | snow adjacent to bottom 1.5 ft of wall |
| 38 | Apple Valley, on McAndrews at Pilot Knob (SE Quad) | |
| 38 | Apple Valley, on McAndrews at Pilot Knob (NE Quad) | very high deicing sand/salt concentration, snow packed against bottom 3ft of wall |
| 42 | Burnsville, Glendale Rd W to Vernon Ave - SW Quad Glendale & CSAH 42 | Very packed snow on face by road, 80 percent high concentration of deicing sand/salt on CSAH 42 face, tier 2 on CSAH 42 completely covered with snow |
| 42 | NW Quad. Glendale & CSAH 42 | snow on capstone due to parking lot snow removal |
| 46 | Church, Highview Ave. | snow accumumlation behind fence due to black plastic snow fence (large amount of deicing sand/salt in this snow), high concentration of deicing sand/salt 1-2 ft. behind capstone |
| 46 | Grove Trail | snow very packed against wall, a large amount of deicing sand/salt behind fence, snow adjacent to bottom 3-4ft of wall |

Table G-12. Privately owned SCBRW snow survey data (comments).

| CSAH | Location | Comments |
|---|---|---|
| 31 | Extended Stay Hotel, NW Quad. Pilot Knob and Yankee Doodle | |
| 32 | RHS Building, SE Quad. 35E and Cliff Rd | parking lot snow removal pushed up to walls, larger piles in corners |
| | Burnsville, corner of S. Cross and Burnhaven | Large snow pile accumumulation against wall vertical surfaces from cleaning parking lot, piles extend ~5ft up wall, largest pile at south end of wall, <1 percent of vertical surfaces and capstone with high concentration of deicing sand/salt |
| | Burnsville, behind K-Mart between Burnhaven and Irving | |
| | Burnsville, behind Rainbow foods, CR 42 and CR 5 | snow adjacent to bottom 1-2 ft of wall |
| | Shakopee Printing, Hwy 101 S of Valley Fair Entrance (Valley Park Road & Valley Industrial Drive S.) | parking lot in front and behind wall, the snow from the parking lot does not appear to go through the fence onto capstone, only 1-10 percent of wall has this snow removal |
| | St. Hubert's Church, Hwy 5 and Great Plains Rd South | snow removal on tier 1 and tier 3, fence behind tier 5 |

Figure G-5.  Overall SCBRW normalized peak-winter snow survey condition data.

| Peak-Day Sunlight Exposure | Percentage of SCBRWs — Percent of SCBRW Area | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | None | <1 | 1-10 | 10-25 | 25-50 | 50-70 | 70-80 | 80-90 | 90-100 | 100 |
| Top Block Layer | 1 | 2 | 6 | 1 | 3 | 6 | 6 | 9 | 20 | 47 |
| Vertical Surfaces | 27 | 1 | 0 | 0 | 7 | 4 | 6 | 2 | 13 | 41 |

| Deicing Sand/Salt Snow Accum. | Percentage of SCBRWs — Percent of SCBRW Length | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | None | <1 | 1-10 | 10-25 | 25-50 | 50-70 | 70-80 | 80-90 | 90-100 | 100 |
| Top Block Layer | 20 | 6 | 8 | 4 | 5 | 2 | 3 | 2 | 12 | 39 |
| Vertical Surfaces | 14 | 4 | 3 | 2 | 2 | 4 | 3 | 1 | 13 | 55 |

| | Percentage of SCBRWs | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Type of Snow Removal | | | | Snow Accumulation | | | | *Indirect Sunlight Exposure (Vertical Surfaces) | Fences Behind SCBRW |
| | | | | | Top Block Layer | | Vertical Surfaces | | | |
| | Main-Line Snow Removal | Side-Walk Snow Removal | Parking Lot | Driveway | Snow Removal | Falling Snow | Snow Removal | Falling Snow | | |
| Yes | 85 | 78 | 16 | 25 | 77 | 100 | 84 | 100 | 48 | 50 |
| No | 15 | 22 | 84 | 75 | 23 | 0 | 16 | 0 | 52 | 50 |

* Surveyed SCBRWs where peak-day sunlight exposure is partially to completely indirect

| Location | Percentage of SCBRWs — Concentration of Deicing Sand/Salt Snow Mixture (*subjective*) | | |
|---|---|---|---|
| | Low | Medium | High |
| Top Block Layer | 18 | 12 | 70 |
| Vertical Surfaces | 9 | 14 | 77 |