Runway Crack Repair Research Project
(Silver Bay Municipal Airport)
A research project at Silver Bay Municipal Airport evaluated six different repair methods alternated along the 3,200-foot bituminous runway. In 1986, the runway developed significant transverse cracks and needed repair to maintain aircraft operations. The Minnesota Department of Transportation (Mn/DOT) and Ralph Burke Associates (RBA) identified 17 cracks for repair and analysis. Over the past seven years, Mn/DOT, RBA, and others monitored the repair behavior of the methods.

The 17 patches experienced variable behavior since the first inspection in 1987. Although most repairs experienced differential heaving, one type of repair moved with the surrounding pavement. The method used similar base material and a T-shaped cross section to distribute any movement over a larger area. The T-section, the repair that performed consistently well, was chosen to replace three of the badly faulted patches.

These second-generation repairs were completed in October 1994 and monitored over the next 15 months. The results further confirmed the consistently good performance of the T-section repair, making it the clear recommendation over the other designs evaluated in this project.
RUNWAY CRACK REPAIR RESEARCH PROJECT (SILVER BAY MUNICIPAL AIRPORT)

Final Report

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Executive Summary

In 1986 the runway at the Silver Bay Municipal Airport had developed significant transverse cracks, and needed repair to maintain aircraft operations. The runway structure consisted of bituminous surfacing over Class 5 base and clay subgrade.

The Minnesota Department of Transportation (Mn/DOT) and RBA identified seventeen cracks and six different repair methods to be used for analysis. Transverse joints were saw cut 40 feet from most of the repairs to encourage controlled movement. Construction was completed in September 1986, and annual observations were conducted by Mn/DOT and consultant staff during the next seven years to monitor repair performance.

During the first winter following construction, differential heaving was observed at most of the patch repairs. This faulting led to snowplow scuffing and gouging. Despite vertical movement and snowplow impacts, all patch repairs held together well. Within the first year, saw cut sealant failed at most locations, causing some transverse edges to crack and break. Wet weather during installation was the primary factor in sealant failure. The severe faulting was the result of disturbing the in-place subgrade and base with compaction, and disrupting the base uniformity by using other materials that were different from the original construction. Although most repairs experienced differential heaving, one type of repair moved with surrounding pavement. This repair (Appendix A, Figure 3, Type 2 design) used similar base material and a T-shaped cross section to distribute any differential movement over a larger area.

The original purpose of the research project was to determine whether and how the six different repair methods would solve the severe cracking problem. Although none of the original cracks redeveloped, the differential heaving created a new concern. The repair that consistently performed well, the T-section, was recently chosen to replace three of the badly-faulted patches. These second-generation repairs were done in October 1994, and monitored over the next 15 months. The result has further confirmed the consistently-good performance of the T-section repair, and further demonstrates its effectiveness in locations with faulting problems.
Introduction

The 3,200-foot bituminous runway at the Silver Bay Municipal Airport was experiencing severe transverse cracking prior to June 1986. (See Appendix E, photograph 1.) In an effort to repair these cracks, and also determine what repair methods might be effective at this and other airports with bituminous surfacing over gravel base and clay subgrade, RBA was selected to design a crack repair research project. Seventeen major cracks were identified on Silver Bay’s Runway 7-25. The completed research project design was submitted June 4, 1986, and featured six different repair methods that were alternated along the runway. The goal of the research project was to evaluate whether and how the six methods would solve the severe cracking problem. Great Lakes Contracting completed the runway crack repairs September 10, 1986, under the inspection of STS. Repair behavior was evaluated over the first two winters by RBA and STS, and in subsequent years by Mn/DOT Materials and Mn/DOT Aeronautics staff. Sections below discuss observations from the staff field reviews, conclusions drawn from the reviews and other project-history information, and recommendations for solving the new problems at the airport.
Discussion

The Silver Bay Municipal Airport was originally constructed in 1964 as a landing strip facility having a turf runway 3,000 feet long by 150 feet wide. In 1968 it was lengthened and paved, with the new paved runway being 3,200 feet in length and 75 feet in width. As is typical with most runway construction, the narrower pavement section (75 feet wide) is constructed in the center of the wider landing strip section (150 feet wide). This creates some drainage problems, particularly for sites with clay soils as is the case with the Silver Bay Airport site. In order to provide drainage of the aggregate base, a series of transverse granular drains (french drains) were constructed from the edge of the pavement section, across the additional 37.5 feet of landing strip, and daylighted into the in-slope.

During patch construction, considerable subsurface moisture was encountered within the pavement structure itself. (See Appendix E, photographs 2 and 3.) The french drains constructed in 1968 were no longer functioning properly, and subsurface drainage was deemed to be inadequate. However, other than the severity of the transverse cracks, no moisture-related pavement problems such as structural failures or differential frost action were observed, nor had any such problems previously been observed or documented. The conclusion was that there was uniformity of materials and moisture content throughout the pavement structure, and loadings on the pavement were light enough so as not to cause structural damage even with high subsurface moisture conditions.

The seventeen patches along Runway 7-25 have experienced variable behavior since the first inspection in 1987. Inspection summaries and repair cross sections are included in Appendix A.

General observations of the project results are as follows:

- The Type 2 T-section repair design (Appendix A, Figure 3) has been the only consistently-good, crack repair method. Despite sealant failures and resulting edge cracking at all three Type 2 locations, the patches themselves have been behaving much like the surrounding pavement. (See photograph 4.)
Most of the transverse saw cuts, spaced 40 feet from patch centers, appear to be providing the intended horizontal movement relief. These joints have become full-depth cracks, opening typically a half-inch or more. This action has led to sealant deterioration and/or separation, exposed backer rods and granular base materials, and standing water in some joints. Significant deterioration with secondary cracking and edge breaking has recently occurred at some of the saw cut locations.

For most of the patches, at least one of the two edges between the patch and original pavement has separated and taken up some of the seasonal horizontal movement. These working joints have never been routed and sealed. As a result, secondary cracking and edge breaking has occurred.

The ride along the runway was reported to be very rough during the winter following construction, compared to near-perfect results immediately after repair completion. Widespread differential heaving had occurred at most patch locations. During the winter months, the original runway pavement was heaving uniformly throughout its full length. Most patches, however, were not experiencing the frost action, thus creating differential heaving and significant faulting at the interface between the original pavement and most of the patches. (See photographs 5 and 6.)

Patch integrity continues to be at or near 100% for all repairs, despite the coarse, open-graded finish appearance and considerable gouging of the original pavement at faulted locations by snowplow activity. (See photograph 7.)

On August 3, 1994, patch numbers 4, 7, and 8 were raised well above the adjacent pavement. Some, of this summertime “reverse” faulting can be attributed to the severe gouging of the original pavement that heaved during the winter, was damaged by snowplows that caught the faulted edge at these patch locations, and then settled during spring thawing with the gouged pavement dropping below the patch elevation. During take-off or landing, these patches produced the worst bumps for aircraft in all seasons.
relative to the other patches along the runway. Saw cuts were not constructed at 40-foot spacing from patches 7 and 8. The repair type used for patch 8 worked reasonably well at a different location that did include saw cuts 40 feet from the patch center. The designs used for patches 4 and 7 had variable results at other locations.

- Saw cut and sealed joints were placed at the center of some patch repairs to influence and control future transverse cracking. However, the original cracks still have not reflected through the patches. The saw cuts at the center of patches did not appear to be working joints. Contraction and expansion have occurred either at the saw cut joints 40 feet away, at the joints between patches and original pavement (where no sealant was originally provided), or at new transverse cracks.

- The sealant material has deteriorated or separated at most saw cut joints (as described above) and at other cracks and joints. The seal construction may have been negatively influenced by foggy and drizzly conditions during placement. Some sawn sealant reservoirs were sawn with a V-shape, not rectangular as designed. Sealant failure has led to secondary cracking, with some of the saw cut joints now experiencing noticeable edge breaking.

- At least five new significant transverse cracks have formed since patch construction in 1986. Unlike the 1990 observation, when they were just beginning to form, some of these new cracks are now relieving movement between adjacent 40-foot saw cut joints. These new transverse cracks have never been routed and sealed, and are now experiencing noticeable secondary cracking and edge breaking.

Appendices B, C, and D contain copies of correspondence from RBA and STS that offer additional early observations of the repairs. Appendix E contains photographs of conditions before this project began, during construction, and after project completion.
SC = saw cuts spaced 40 feet from patch centers
0 = number within circle indicated repair type
numbers below runway sketches identify patches

Figure 1. Silver Bay Airport Layout
Conclusions

The original purpose of the research project was to determine whether and how the six different repair methods would solve the severe cracking problem. This goal was partially achieved in that the cracks have not redeveloped in their original locations. In fact, joints saw cut into the patch centers were completely ineffective. Instead, the previously-working transverse cracks were shifted to the 40-foot saw cut joints or to the edges between constructed patches and original pavement. These edges should have been either better tack-coated to provide bonding between surfaces, or else routed and properly sealed to prevent water infiltration and damage.

Saw cut joints spaced 40 feet from patch centers have become working, full-depth cracks. Due to the significant movement they relieve, either the frequency of saw cuts should be increased or else the construction, sealant materials, and maintenance of fewer joints must be improved. Since 1987 the joint seals have consistently failed, thus exposing the base structure to water and erosion problems. The middle one-third of the runway did not receive 40-foot saw cuts. As a result, five new significant transverse cracks have developed between repair patches.

STS stated in their October 1, 1986, report, that:

Sincere efforts were made by Great Lakes Contracting throughout the course of crack repair construction to meet the compaction requirements of this project. The pumping clays made this difficult in many situations. The STS field engineer on site would test compaction... Generally, the contractor would continue compacting materials placed until the required compaction was achieved, or pumping was observed and test results showed no improvement from compaction efforts... our field engineer is of the opinion that compaction of the materials placed in these repair sections is as good as it could be, given the condition of the clays encountered. (See Appendix B for additional information.)

Crack repairs should not have included compacting of the subgrade clay layer. This is true not only because of the construction problems discussed above, but also because of the differential heaving that resulted from altered base and subgrade conditions. In fact one might argue that the original
granular base should also have remained intact, except for minor shaping and compacting following removal of cracked bituminous pavement.

Vertical faulting has become an unforeseen side effect at many of the crack repairs. The differential heaving has generally decreased since initial observations, possibly a result of more uniform subsurface moisture conditions throughout the original and patch base materials as suggested by RBA. (See page C-2.) However, movement has continued, especially at patches 4, 7, and 8 where the repair base materials (bituminous, taconite tailings, fine-filter aggregate) behave differently than the Class 5 under the original pavement. Appendices B, C and D contain additional conclusions by project consultants. Future use of the Type 2 design could perhaps be modified to use granular material that is tapered from a narrow base to the ends of the T-section. This cross section would be similar to standard Mn/DOT methods for culvert treatment and frost heave correction.

Some sealant has been pulled up by snowplow activity, possibly indicating that the sealant was not properly leveled below the bituminous surface during placement. Mn/DOT sealant specifications have improved since project completion in 1986. Current material and application techniques may have resulted in fewer sealant failures.

Some patches had become year-around problems. For example, patches 4, 7, and 8 were raised well above the original pavement during August 1994, and at least partially high in July 1993. Yet during the winter inspections, these patches were typically lower than the surrounding runway. These patches used base materials totally different from the Class 5 material under the original pavement. Patch 4 used bituminous (Type 3 design). Patch 7 used fine-filter aggregate wrapped in non-woven fabric (Type 5 design). Patch 8 used taconite tailings wrapped in non-woven fabric (Type 4 design).

These patches did not frost heave with the adjacent pavement, thus creating the faulting that led to severe gouging of the original pavement from snowplowing activities. As the pavement settled during spring thaw, the gouges dropped below the patches creating summertime faulting in the opposite direction of wintertime faulting. The difference in movement between crack repairs and the original pavement reinforces the need for uniformity of construction material and uniformity of compaction throughout the pavement area.
Recommendations

The Type 2 repair design has been the best performer since 1986, typically matching the level of surrounding pavement in summer and winter. The Type 2 repair is the clear recommendation over the other designs evaluated in this project.

In the summer of 1994 a determination was made that the severely-faulted patches (numbers 4, 7, and 8) should be reconstructed, using the Type 2 design as the replacement patch repair. This would provide an opportunity to obtain additional research data on the best performing patch repair. The Type 2 design incorporates the use of materials similar to the original pavement structure. Furthermore, since significant differential heaving had taken place at locations 4, 7, and 8, the additional transition provided by the wider T-shaped, Type 2 design seemed worthy of additional analysis for combating this problem.

In October 1994, the faulted patches at locations 4, 7, and 8 were replaced with the Type 2 patch repair design. Sawed joints at the 40-foot spacing from the patch centers had already been done in the original 1986 contract work at these locations. The patch design was modified slightly to eliminate sawed joints at the center of the patches. Also, one vertical interface between the patch and the original bituminous pavement was tacked, and the opposite interface left untacked to allow for horizontal separation.

A final inspection was conducted on January 8, 1996, to document the performance of the three Type 2 replacement patches. No observable faulting or heaving had occurred. No reflective cracking in or near the patches had occurred. No separation at the tacked interface between the replacement patch and the original pavement was noted. Relief separation at the untacked interface was negligible.

There is some doubt whether grid reinforcement has been helpful to the pavement structure. The Type 2 is the only design that used the reinforcing grid. The replacement Type 2 patch repairs also included the grid. No performance comparisons as to the grid’s overall influence in the success of
the Type 2 design were determined in this research effort. However, since the Type 2 patch is wider than any of the other patch types, it may be safe to assume that the reinforcing grid would assure that any seasonal movement would be transferred to the edges of the patch.

Horizontal movement throughout the runway has occurred at one or both edges of all patches and at the 40-foot saw cut joints, but not at the center-patch saw cuts as originally anticipated. Center-patch saw cuts should not be used with the Type 2 design. The modified Type 2 replacement patches encouraged movement at one edge of the patch by leaving that edge untacked while tack coating the other edge. Timely routing and sealing of the untacked edge, as well as the working edge of the other patches, are recommended. Saw cut joints spaced 40 feet from repairs should be installed in areas where they were not included in the previous contract, especially between (and including) cracks 6 and 12 (note that repair number 9 already has sawn joints). Additional joints will provide more opportunities for movement and reduce the overall strain on sealant material. Sealant application should be restricted to appropriate weather conditions.
Appendix A

Inspection Summaries
Type 1 Repair

Notes:
1. Saw cut 2' each side of crack, excavate 4" bit. surface and 9" class 5 base, and compact subgrade to 98% max.
2. Replace base with class 5, compacted to 100%
3. Replace 4"-5" bit. surface (MN DOT 2351)
4. Saw cut rout and seal to d=D/3 in surface course at crack line
5. Saw cut rout and seal to d=D/3 in surface 40' each side of crack

Figure 2. Type 1 Repair Cross Section

Patch 1:
- 91% - 93% bituminous compaction (97% required)
- 94% - 95% aggregate base compaction (100% required)
- 92% - 97% subgrade compaction (98% desirable)

4/24/87 low; scuffing on original pavement
3/23/89 level
3/20/90 good; 40-foot saw cut joints open 1/2 inch
3/20/91 low and open on both sides
12/17/92 raveled; SE side of repair failing
7/23/93 level
8/03/94 low 1/2 - 3/4 inch; edges breaking off
Patch 9:

98% aggregate base compaction (100% required)

- 4/24/87  low; scuffing on original
- 3/20/90  good; 40-foot saw cut joints open 1/2 inch
- 3/20/91  very good; level
- 12/17/92 good; W edge has secondary cracking
- 7/23/93  very good; seals failing
- 8/03/94  slightly low

Patch 17:

clay pumping during bituminous compaction

95% aggregate base compaction (100% required)

- 4/24/87  slightly low; W edge open
- 3/20/90  OK; edges open up to 1 inch
- 3/20/91  level; 40-foot saw cuts working
- 12/17/92 W side low; W 40-foot saw cut breaking off
- 7/23/93  level; no scuffing; good seals
- 8/03/94  low 1/2 inch; edges breaking off
Type 2 Repair

Notes:
1. Saw cut 2' each side of crack, excavate 4" bit. surface and 9" class 5 base, and compact subgrade to 98% max.
2. Saw cut and remove bit. surface 6' each side of crack ("T" Section)
3. Replace base with class 5, compacted to 100%
4. Place tensile grid over base ("T" Section)
5. Replace 4"-5" bit. surface (MnDOT 2351)
6. Saw cut rout and seal to d=D/3 in surface course at crack line
7. Saw cut rout and seal to d=D/3 in surface 40' each side of crack

Figure 3. Type 2 Repair Cross Section

Patch 5:
- 95% - 98% aggregate base compaction (100% required)
- 95% subgrade compaction (98% desirable)
- 4/24/87 slightly high; E edge separation
- 3/23/89 level
- 3/20/90 good; 40-foot saw cuts open 1 inch
- 3/20/91 level; E edge seal failed
- 12/17/92 very good; S end slightly high; seal failures
- 7/23/93 level; more seal failures
- 8/03/94 slightly high; SE edge sealed but breaking off

A-3
Patch 11: 97% aggregate base compaction (100% required)

4/24/87  slightly low
3/20/90  good W; E slightly high; minor edge cracks
3/20/91  OK
12/17/92  E side is high; cracking on original
7/23/93  very good; E edge open and starting to fault
8/03/94  good; E edge broken off

Patch 15: clay pumping during bituminous compaction

97% aggregate base compaction (100% required)

4/24/87  no scuffing
3/20/90  good; 40-foot joints working, open 1/2 inch
3/20/91  very good; SW edge seal failure
12/17/92  good; slightly high in center; crack in patch
7/23/93  very good; level
8/03/94  good; W edge is breaking off
Type 3 Repair

Notes:
1. Saw cut 2' each side of crack, excavate 4" bit. surface and 9" class 5 base, and compact subgrade to 98% max.
2. Replace base with prime coat and full depth asphalt (MnDOT 2331)
3. Replace 4"-5" bit. surface (MnDOT 2351)
4. Saw cut, rout and seal to d=4" at crack line
5. Saw cut, rout and seal to d=D/3 in surface 40' each side of crack

Figure 4. Type 3 Repair Cross Section

Patch 4: 90% - 91% bituminous compaction (97% required)
91% - 98% bituminous base compaction (100% required)
92% - 97% subgrade compaction (98% desirable)

4/24/87 low; considerable faulting; raveling
3/23/89 low
3/20/90 low; 40-foot saw cuts open 1/2 inch
3/20/91 good; E saw cut open 3/4 inch, failed seal
12/17/92 low N half; more seal failures
7/23/93 low N half; high S half; E saw cut open
8/03/94 high 1/2 inch

A-5
Patch 10:

94% aggregate base compaction (100% required)

4/24/87  low, but not as bad as Patch 4
3/20/90  low; E edge breaking off; 1-inch cracks 50 feet E and W
3/20/91  good; slightly low; raveling; seal OK
12/17/92 good; low 1 inch; seal OK
7/23/93  low 1/2 inch; plow damage to both sides of original
8/03/94  high on southerly 1/2 of W side

Patch 16:

clay pumping during bituminous compaction

4/24/87  scuffing; excessive on S side, minor on N side
3/20/90  good; edge joint open, up to 1 inch
3/20/91  very good; level; sealed edges
12/17/92 low E side; W saw cut open 3 inches, edges cracking
7/23/93  level; extensive scuffing on patch; good seals
8/03/94  slightly high
Type 4 Repair

Notes:
1. Saw cut 2’ each side of crack, excavate 4” bit. surface and 9” class S base, and compact subgrade to 98% max.
2. Wrap non-woven fabric (MnDOT 3733 Type I mod EOS 70-100)
3. Replace base with taconite tailings compacted (MnDOT Type B—TT)
4. Replace 4”-5” bit. surface (MnDOT 2351)
5. Saw cut rout and seal to d=D/3 in surface course at crack line
6. Saw cut rout and seal to d=D/3 in surface 40’ each side of crack

Figure 5. Type 4 Repair Cross Section

Patch 3: 92% - 96% bituminous compaction (97% required)

4/24/87 low; raveling; plow scuffing
3/23/89 level
3/20/90 good; minor secondary cracks; saw cuts open
3/20/91 level; saw cuts working
12/17/92 S side high; original pavement to W breaking off
7/23/93 level; original pavement edge W cracking, 1 inch low
8/03/94 slightly high; some edges breaking off

A-7
Patch 8:

4/24/87 low; scuffing on original mat
3/20/90 low
3/20/91 low; W edge cupping
12/17/92 low 1-1/2 inch; plow damage; cupping on W side
7/23/93 level; edges low
8/03/94 high; W edge breaking off

Patch 14: clay pumping during aggregate base compaction
96% aggregate base compaction (100% required)

4/24/87 moderate scuffing on original pavement
3/20/90 cracking, settling E edge; saw cuts open 1/2 inch
3/20/91 good; raveling; E edge movement, seal failure
12/17/92 low 1/2 inch, cracking; saw cuts seal failures
7/23/93 level, but plow damage was bad
8/03/94 slightly high; W edge breaking off
Type 5 Repair

Notes:
1. Saw cut 2' each side of crack, excavate 4" bit. surface and 9" class 5 base, and compact subgrade to 98% max.
2. Wrap non-woven fabric around base (MnDOT 3733 Type 1, mod EOS 70-100)
3. Replace base with fine filter aggregate compacted (MnDOT 3149.25)
4. Replace 4"-5" bit. surface (MnDOT 2351)
5. Saw cut rout and seal to d=D/3 in surface course at crack line
6. Saw cut rout and seal to d=D/3 in surface 40' each side of crack

Figure 6. Type 5 Repair Cross Section

Patch 2:
92% - 95% bituminous compaction (97% required)
91% - 94% subgrade compaction (98% desirable)

4/24/87 low; raveling from plow action
3/23/89 low
3/20/90 good; 40-foot saw cuts open about 1/2 inch
3/20/91 high, plow now scuffing patch; joints working
12/17/92 W edges breaking off; E edge seal failure
7/23/93 level; W side and original pavement low 1-1/2 inches
8/03/94 edges breaking off; E saw cut seal failed

A-9
Patch 7: 86%-95% subgrade compaction (98% desirable)

4/24/87 excessive scuffing on original pavement; no saw cuts
3/23/89 low
3/20/90 very low; significant faulting; E edge cupping;
3/20/91 E edge open 5 inches, plow catching edge; seals OK
12/17/92 low 2 inches; faulting of original pavement on E side
7/23/93 plow damage to W side original binder course
8/03/94 high; E edge breaking in; major scuffing

Patch 13: 91% subgrade compaction (98% desirable)

4/24/87 moderate scuffing on original
3/20/90 W edge cracking & settling; 40-foot joints open
3/20/91 level; E edge cracking; saw cuts working
12/17/92 low; cracking in original pave E; seal failure
7/23/93 level; E saw cut open 1 inch; edges breaking off
8/03/94 E and SW edges broken off
Type 6 Repair

Notes:
1. Saw cut 2' each side of crack, excavate 4" bit. surface and 9" class 5 base, and compact subgrade to 98% max.
2. Replace base with class 5, compacted to 100%
3. Replace 4"-5" bit. surface (MnDOT 2351)

Figure 7. Type 6 Repair Cross Section

Patch 6: 90% - 91% aggregate base compaction (100% required)
94% subgrade compaction (98% desirable)

4/24/87  good; a little scuffing on the original mat
3/23/89  level
3/20/90  low, with cupping along E edge
3/20/91  slightly high; E edge open 2 inches; sealant failure
12/17/92  high; E side of orig. pave cracking
7/23/93  level; original pave on E side is low 1 inch
8/03/94  high on E side; E edge breaking in
Patch 12: 96% aggregate base compaction (100% required)
89% subgrade compaction (98% desirable)

4/24/87  very minor scuffing on original mat
3/20/90  good; new 1-1/4 inches crack with cracking to W
3/20/91  low; E seal failure; crack to W moving
12/17/92 good; some seal failure
7/23/93  level; very little plow damage; good
8/03/94  slightly low; E edge open
Appendix B

STS Project Report
Mr. J. David Scherling  
Ralph Burke Associates, Inc.  
1550 Northwest Highway  
Suite 400  
Park Ridge, IL  60062  

Re: Silver Bay Municipal Airport,  
Runway Crack Repair Evaluation  

Dear Mr. Scherling:

On Friday, November 19, 1987, Mr. Scherling of RBA, Inc. and Mr. Gale of STS Consultants visited the airport in order to observe the cracks that were repaired in September, 1986 as part of a project in conjunction with the Minnesota Department of Transportation.

Introduction

During the month of September, 1986, transverse cracks within the airport runway pavement were repaired using six different procedures. These procedures were as follows:

- Detail 1 - Control with control joint cuts. Reconstruct crack area with new class 5 aggregate base and bituminous wear, providing saw cut at crack and 40 feet each side of crack.

- Detail 2 - T-section. Reconstruct crack area employing full removal and replacement of class 5 aggregate base beneath crack with transition zone where class 5 aggregate base is not removed. Tensile reinforcement grid placed, and then an additional 2 inches of class 5 with bituminous wear surfacing placed. Saw cut provided at crack and 40 feet each side of crack.

- Detail 3 - Full depth bituminous. Reconstruct crack area with full depth bituminous to clay subgrade soil and provide saw cut at crack and 40 feet each side of crack.

- Detail 4 - Taconite tailings. Reconstruct crack area with taconite tailings wrapped in a geotextile. Saw cut provided at crack and 40 feet each side of crack.
Detail 5 - Fine filter aggregate. Reconstruct crack area with fine filter aggregate wrapped with non-woven geotextile. Saw cut provided at crack and 40 feet each side of crack.

Detail 6 - Control - no control joint cuts. Reconstruct crack area with new class 5 aggregate base and bituminous wear.

Documentation of the crack reconstruction work is as included in the STS report dated October 1, 1986.

Discussion

The intention of the crack repair project was to alleviate the cracking that had been occurring at approximate 200 foot spacings across the runway. One of the original thoughts regarding the cause of the cracking was that it was thermally induced. After the initial crack formed, water running through the crack had been retained within the class 5 aggregate base causing deterioration of the crack. Based on previous testing performed, we have identified the class 5 to have between 7.7 and 11.1 percent by dry weight passing the U.S. No. 200 sieve (STS report dated November 20, 1985). Though class 5 material similar to that identified beneath the pavement at Silver Bay has been used beneath thousands of miles of pavements in Minnesota, studies show that this material is frost susceptible. The degree of heave of the aggregate base was suspected to be fairly minimal since no evidence of heave problems was presented by the local authorities. Further discussion of heave is included in the November 20, 1985 STS report.

All the repair details effectively and successfully repaired the cracking that had taken place. However, a secondary problem developed. Heave of the existing pavement and aggregate base, outside of the crack repair area, occurred over the winter of 1986-87. It appears that the repaired areas do not heave and the previously existing class 5 and runway surface does heave, thus causing the pavement to lift up at the saw cut locations. As the snow plow clears snow from the runway, the blade catches on the heaved surface and tears it away. During our site visit, the scraped off sections of bituminous surface could be identified and were used to detect which areas had heaved and which had not.

Fine Filter Aggregate and Taconite Tailings - It seems that the section which included fine filter aggregate and taconite tailings wrapped with the non-woven geotextile, and provided the most fully drained conditions, created the greatest case for differential movement. In other words the pavement outside the crack area heaved and that area repaired did not heave.
Full-depth Bituminous - The full depth bituminous repair section did heave a slightly lesser amount than the free draining aggregate base repair cases, thus indicating that either trapped moisture between the bituminous and the clay, or the clay itself was a factor in the heave. During the repair construction process, the lowest density was achieved for the bituminous within the full depth bituminous detail, because of the nature of the clay which pumped slightly at the time of compaction.

Control Section - The control section, which consisted of replaced class 5 material, showed signs of differential movement in some locations, and in others did not show signs of differential movement. The class 5 used was determined to have a percent passing the U.S. No. 200 sieve of 7% to 10% which is within the same range as the material used beneath the present pavement. The fine filter aggregate and the taconite tailings had 2.6 and 3.5 percent passing the U.S. No. 200 sieve, respectively.

T-section - The best repair scheme was the T-section. It is envisioned that this section, which did not include the removal of the class 5 material and showed only minimal signs of differential movement at the cracks performed the best. It is concluded that throughout this section the entire pavement did heave over the winter but did not move differentially thus not creating a problem for the plows.

Based on our observations, it appears that the tensile reinforcement grid that was placed a few inches below the bottom of the bituminous base had no affect with regard to cracks opening up at this time. None of the sections had any cracks that did open up. The stress-strain properties of Tensar SS-2 would govern the grid influence on cracking.

Recommendations

We recommend that further study of the aggregate base be made over the winter of 1987-88. As was discussed at Silver Bay, additional heave measurements should be taken during the worst part of the winter. We suggest that 3 or 4 inch diameter cores of the pavement be taken at a few of the repair areas in order to investigate frost formation within heaved portions of the aggregate base. We feel that the best time to do this would be when the frost heave is the greatest, probably sometime in February. The study could be correlated with other studies that have been done on moderately clean aggregate base materials that do heave.
If you have any questions or comments regarding our observations or recommendations, please do not hesitate to contact us.

Respectfully,

STS CONSULTANTS, LTD.

Stephan M. Gale, P.E.
Principal Engineer

SMG/dn
Appendix C

RBA Project Follow-up Report
December 23, 1987

Mr. David Nybakken  
Minnesota Department of Transportation  
Division of Aeronautics  
Transportation Building, #417  
St. Paul, Minnesota  55155

Re: Silver Bay Municipal Airport  
Crack Repair Project  
Follow-up Report

Dear Mr. Nybakken:

Enclosed are the following as a follow-up report on the above referenced project:

- STS Crack Repair Evaluation of December 1, 1987
- Salo survey study composite
- RBA photo report of November 19, 1987

Performance of Crack Repairs

As you noted in your comments upon visiting the project, it may be too early for an exhaustive conclusion evaluating the various methods of crack repair, the prime objective of the project. As of this time, all methods appear to have satisfactorily repaired the cracks and reduced the crack return potential. No conclusion can be drawn at this time as to the relative performance of one method versus the others.

Secondary Problem

As Steve Gale of STS notes in his evaluation, a secondary problem has surfaced; that is, the differential heaving between the patched areas and the remainder of the runway pavement.
The February 18, 1987 readings (Salo Survey Summary) confirm that the differential heave consistently affects all methods. The following table summarizes the maximum differentials noted:

<table>
<thead>
<tr>
<th>Method</th>
<th>MnDOT Class 5 Base</th>
<th>Full Depth Asphalt</th>
<th>Taconite Tailings</th>
<th>Fine Filter Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repair No.</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>Elev.</td>
<td>.05</td>
<td>.03</td>
<td>.06</td>
<td>.06</td>
</tr>
<tr>
<td>Diff.</td>
<td>.06</td>
<td>.04</td>
<td>.04</td>
<td>.05</td>
</tr>
<tr>
<td>Ave.</td>
<td>.05</td>
<td>.04</td>
<td>.06</td>
<td>.05</td>
</tr>
</tbody>
</table>

The photo report confirms your observation that the "T" section method performed the best, in that the heave differential was distributed across the arms-of the "T". This is probably due to the arms of the "T" being constructed on the existing Class 5 base. The fabric under the pavement may have had a positive influence, however.

It is interesting to note that we, the engineers and the contractor, made a special effort not to disturb the subgrade so that we would have a uniform subgrade and eliminate differential heaving. Since this extra care was taken, we can say, with a great deal of certainty, that the differential heave is caused by frost action in the Class 5 material. Minnesota may want to reevaluate that specification to reduce the frost susceptible material in the allowable gradation.

It is possible that now that the pavement has endured a full summer wet season, that it may perform more uniformly during this winter than it did last winter. That is, maybe the moisture that is constantly in the fines in the Class 5 under the asphalt had not had a chance to "stabilize" in the material under the patch pavement. We have instructed Salo to take at least one more measurement during the month of February, when the elevation differential should be maximum to confirm or rebut this possibility.
Recommendation

We concur with the STS recommendation that cores be taken in the winter to analyze the frost in the Class 5.

We also suggest that stress meters be installed on the fabric to determine if the tensile reinforcing grid is actively participating in the success of the "T" section by noting if the stresses have reached working levels.

It is recommended that if the maximum differentials between the runway and the patch pavement are as great this winter, all other patch areas be constructed as "T" sections for safety of aircraft traffic.

Sincerely,

RALPH BURKE ASSOCIATES
Engineers - Architects - Planners

Dave Scherling

DS/1c
8127D
Enclosure

c: Silver Bay Airport Commission
   Steve Gale, STS
Appendix D

RBA Final Project Report
April 6, 1988

Mr. David Nybakken  
Minnesota Department of Transportation  
Division of Aeronautics  
Transportation Building, #417  
St. Paul, Minnesota 55155

Re: Silver Bay Municipal Airport  
Crack Repair Project

Dear Mr. Nybakken:

Enclosed are the updated survey data sheets from Salo incorporating the work completed on March 16, 1988, on the above referenced project.

The primary purpose of the study project was to evaluate the various selected crack repair methods. Two winters have passed since construction and all of the methods appear to be serving adequately as far as horizontal movement is concerned. Table I shows the maximum opening across the patch joints by repair method. Note that the maximum opening by method averages are all the same. If the joint sealer is adequate, the repairs should be satisfactory and it is probably still too early to make a distinguishing determination.

<table>
<thead>
<tr>
<th>Method</th>
<th>MnDOT Class 5 Base</th>
<th>Full Depth Asphalt</th>
<th>Taconite Tailings</th>
<th>Fine Filter Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(6)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>Horiz.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.02</td>
<td>0.03</td>
<td>0.02</td>
<td>0.04</td>
<td>0.01</td>
</tr>
<tr>
<td>Diff.</td>
<td>0.02</td>
<td>0.06</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>0.01</td>
<td>0.05</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>Ave.</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
</tbody>
</table>

RALPH BURKE ASSOCIATES  
1550 Northwest Highway  
Suite 333  
Park Ridge, Illinois 60068-1488  
(312) 297-1172  

Ref. #85085-14
As was discussed in our follow-up report of December 23, 1987, the critical problem seems to be in the vertical movement. That is, the patch areas' vertical movement is not consistent with the vertical movement of the rest of the runway. The primary problem experienced by pilots using the runway is the difference in elevation across the repair section. Table II shows the maximum elevation differences across the section by repair method. Note that the averages have been slightly reduced from the measurements taken in February of 1987.

### TABLE II

**MAXIMUM ELEVATION DIFFERENCES BY METHOD**

<table>
<thead>
<tr>
<th>Method</th>
<th>MnDOT Class 5 Base</th>
<th>Full Depth Asphalt</th>
<th>Taconite Tailings</th>
<th>Fine Filter Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repair No.</td>
<td>(1)</td>
<td>(6)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>Elev.</td>
<td>.02</td>
<td>.05</td>
<td>.01</td>
<td>.04</td>
</tr>
<tr>
<td>Diff.</td>
<td>.06</td>
<td>.03</td>
<td>.05</td>
<td>.03</td>
</tr>
<tr>
<td>Ave.</td>
<td>.03</td>
<td>.03</td>
<td>.05</td>
<td>.05</td>
</tr>
</tbody>
</table>

It is also interesting to note the differences in elevation between the December 1987 readings and the March 1988 readings. Table III shows the range of differences between those readings by method. Note that, again, the method appears to be immaterial, but differences occur merely because a repair was made.

### TABLE III

**RANGE OF ELEVATION CHANGE**

<table>
<thead>
<tr>
<th>Method</th>
<th>MnDOT Class 5 Base</th>
<th>Full Depth Asphalt</th>
<th>Taconite Tailings</th>
<th>Fine Filter Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repair No.</td>
<td>(1)</td>
<td>(6)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>Elev.</td>
<td>.03 - .09</td>
<td>.08 - .16</td>
<td>.06 - .12</td>
<td>.07 - .16</td>
</tr>
<tr>
<td>Change</td>
<td>.09 - .15</td>
<td>.03 - .10</td>
<td>.08 - .12</td>
<td>.08 - .13</td>
</tr>
<tr>
<td>Ave.</td>
<td>.04 - .09</td>
<td>.05 - .11</td>
<td>.05 - .09</td>
<td>.08 - (-.07)</td>
</tr>
<tr>
<td>Ave.</td>
<td>.09</td>
<td>.08</td>
<td>.09</td>
<td>.10</td>
</tr>
</tbody>
</table>
Mr. David Nybakken
Minnesota Department of Transportation
April 7, 1988
Page 3

With this update we will consider our part in the project closed. We
would appreciate an update of further development. Please let us know
what happens and if we can help.

Sincerely,

RALPH BURKE ASSOCIATES
Engineers - Architects - Planners

[Signature]

Dave Scherling

DS/1c
8048

c: Silver Bay Airport Commission
   Steve Gale, STS
   John Bergren, Salo
Appendix E

Project Photographs
Photograph 1

Transverse crack prior to patch repair
Photographs 2 and 3
Subsurface moisture encountered during patch repair construction
Photograph 4
Patch repair Type 2 design after 15 months
Photographs 5 and 6
Note dip and snowplow scuffing
Photograph 7

Patch integrity good. Adjacent pavement scuffed by snowplows. Sealant failure is prevalent.