Date of Report: March 10, 1996 Reporting Period: 10/1/95-2/29/96

LCMR Research Work Program 1993 - Summary

I. Project Title: **M12 Mitigating Concrete Aggregate Problems in Minnesota**

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A. Legal Citation: ML 1993, Chapter 172, Section 14, Subd. 9(a)

Total Biennial LCMR Budget:	$ 179,000.00
Balance (estimated as of 2/29/96):	$ 0,000.00

Appropriation Language as drafted 7/27/92:
This appropriation is from the future resources fund to the commissioner of transportation for a contract with the University of Minnesota to study means of mitigating concrete aggregate problems in southern Minnesota.

The project is extended to December 31, 1995; on that date the appropriations cancel and no further payment is authorized, Minnesota Laws 1995, Chap. 220, Sec. 19, Subd. 19.

B. LMIC Compatible Data Language: Not applicable.

C. Status of Match Requirement:

Match required:	$ 0
Funds Raised to Date:	$ 0

II. Project Summary: A study will be conducted to explore means of mitigating concrete aggregate problems in southern Minnesota. It is believed that certain aggregate sources in southern Minnesota are responsible for the premature failure of large parts of Interstate 90. The freeze-thaw behavior associated with the aggregate has been suspected. The intent of this proposal is to pinpoint the problem sources and develop methods to mitigate the problem. This will be accomplished by running an intensive test series on concrete specimens typical of the sections experiencing problems. Methods will then be developed to improve the concrete performance using existing aggregate sources. The proposed research will result in improved concrete pavement performance throughout Minnesota, especially in southern Minnesota, while allowing the continued use of local Minnesota aggregate resources. Possible economic benefits include the reduction of Minnesota pavement life-cycle costs and the improved marketability of Minnesota aggregate resources that were previously considered marginal performers.

Mr. Graham R. Ford, Engineering Geologist, and Mr. Mark Bintzler, Concrete Engineer, of the Minnesota Department of Transportation were closely consulted during the preparation of this proposal. A preliminary literature review was conducted in conjunction with this proposal. A brief literature summary and listing of references appear in Section XII of this proposal. It should be emphasized that this research program will encompass more than merely testing materials. It includes the identification and classification of aggregates, correlating laboratory results to field performance, developing criteria to identify D-cracking susceptible aggregates, and developing beneficiation techniques for marginal aggregates.

The experiment designs are not clearly defined in this proposal; to do so at this stage would be premature. This is due to the uncertainty of current tests methods being able to predict whether an aggregate is susceptible to D-cracking. Current test methods have been shown to be excessively conservative by eliminating some potentially sound sources. Pore structure is the most important characteristic influencing the D-cracking susceptibility of coarse aggregate. Furthermore, the characteristics of the pore structure that control most pore-related properties are porosity and pore-size distribution. Yet, the current methods used to determine these quantities give only a partial measure in terms of inter-connected voids, or else these properties are measured indirectly. The proposed research is set up to evaluate each of the standard experimental methods, but uncertainty exists in determining how accurate the results will be for a particular aggregate. This will be evaluated by examining actual field performance.

III. Statement of Objectives:

A. Compile Existing Knowledge

B. Identify Sources of Problems and Develop Methods to Mitigate Problems

C. Outreach and Technology Transfer

IV. Research Objectives:

A. *Title of Objective:* **Compile Existing Knowledge**

A.1. *Activity:* **Literature Search**

A.1.a. *Context within project:* This phase of the project identifies the existing state of knowledge associated with this problem area. This will provide a starting point for the research team to examine the problems, test methods, and solutions.

A.1.b. *Methods:* Interviews with experts will be used to identify the sources of problems. Although experts within Mn/DOT's Materials and Research Laboratory have been consulted, the interviews would expand to include Mn/DOT District Materials Engineers, concrete suppliers, and aggregate producers. Pertinent literature will be identified through computerized databases such as the Transportation Research Information Service and the National Technical Information Service. The literature will be reviewed to summarize the causes and cures of aggregate durability and aggregate-paste reactions. This will result in an updated annotated bibliography concerning aggregate durability which will be an expansion of the recently completed SHRP C-203 bibliography on the same topic. The literature review in the project would expand on that done for this proposal (Section XII). It will allow the investigators to screen out certain tests and beneficiation techniques which have not worked well in the past. An interim report will be produced summarizing problems, topics requiring additional research and possible solutions or avenues for future research. At this point, a draft work plan would be submitted for Task B.

A.1.c. *Materials:* In order to complete this portion of the work, the researchers will use library facilities available at the University of Minnesota and the Minnesota Department of Transportation. Additionally, personal and telephone interviews and mail surveys will be conducted with local, national, and international experts with experience in these problem areas (e.g. IA, IL, KS, etc.).

A.1.d. *Budget:* $20,000
Estimated Balance: $ 0
Financial Cutoff Date: 6/30/95

A.1.e. *Timeline:*

	7/93	1/94	6/94	1/95	6/95	1/96	6/96
Summary of Lit. Review and Interviews.	xxxxxxxxx						

A.2. *Status:* Literature searches have been completed. The following resources were accessed: Transportation Research Information Service (TRIS), National Technical Information Service (NTIS), University Microfilms International (UMI, a dissertation microfilm service), internal Mn/DOT documents (obtained through Glenn Engstrom, the Mn/DOT project contact), contacts within the silane industry and Universities and State DOTs that have been performing research with that industry (Louisiana, Oklahoma, Wyoming), and other sources. The results of these searches have been combined with selected publications identified during the course of the SHRP C-203 project ("Resistance of Concrete to Freezing and Thawing") to produce an annotated bibliography of publications relevant to the study of aggregate frost resistance. The final version of this bibliography includes more than 200 citations. A review of the publications cited in the bibliography was performed and an interim report was produced to summarize the state of knowledge concerning aggregate frost resistance problems, topics requiring additional research, and possible avenues of future research.

The literature review described above was used as the basis for developing a research work plan for this project. This work plan was presented at a project advisory panel meeting on May 10, 1994. The work plan was approved (with minor modifications) at a project advisory panel meeting on May 26, 1994.

Problems: None at this time.

B. *Title of Objective:* **Identify Sources of Problems and Develop Methods to Mitigate Problems**

B.1. *Activity:* **Identify Sources of Problems**

B.1.a. *Context within project:* Researchers will conduct a field survey of good performing pavements as well as those experiencing durability problems and will perform durability tests on aggregates and concrete samples typical of those used in pavements of southern Minnesota to pinpoint causes of premature pavement deterioration. Both quick and long-term aggregate and concrete durability tests will be conducted and correlated with field performance. The results of this study will provide additional insight into the materials, design, and field site conditions that have the greatest impact on concrete durability problems in Minnesota. This will further define the areas of research that should be undertaken to produce useful results. In addition, this work will provide Mn/DOT with information on the reliability of a variety of "quick-screening" tests that are intended to identify aggregates that are nondurable.

B.1.b. *Methods:*

Task 1 - Field surveys will be conducted over pavements that have exhibited good, fair, and poor durability performance. These pavements will be selected with the assistance of Mn/DOT personnel to represent a range of the important factors identified in previous project activities. The Mn/DOT Pavement Management System will be used to help identify appropriate pavement sections for inclusion in the study as well as to identify the aggregate sources and test records, and construction records for the projects. Pavement cores will be obtained for testing and pore structure analysis; aggregate samples will be obtained for extensive laboratory testing from several ledges at each of the aggregate source quarries. It is estimated that between 25 and 50 aggregate samples from various sources and ledges will be selected for testing. The results of the laboratory testing will be correlated with the observed field performance data to confirm theories concerning aggregate durability in Minnesota. An experimental design for this portion of the project will be determined at the end of this task. Once the scope and magnitude of aggregate problems have been defined, an appropriate test matrix can be developed.

Task 2 - Tests will be conducted to determine the aggregate properties. These tests may be conducted in conjunction with researchers at Mn/DOT. Many of these tests are considered quick-screening methods for evaluating D-cracking susceptibility; however, a wide scatter in results has been observed by various researchers and state transportation agencies around the country. These tests will be correlated with observed field performance and environmental simulation tests in Task 3 to evaluate the effectiveness of the quick-screen techniques relative to the observed performance of Minnesota aggregates. This task, in addition to aggregates already classified by Mn/DOT, will provide information regarding the properties of aggregates in Minnesota.

Tests considered include:

Specific Gravity and Absorption.
A sample of aggregate is weighed in an oven-dry condition, in water, and in a saturated-surface dry condition. The specific gravity and absorption are determined from these weights. This is one of the most common methods of screening aggregates, but the results are not always meaningful.

Absorption-Adsorption.
A sample of aggregate is weighed and sawed into thin slices. Alternate slices are measured for absorption and adsorption.

Iowa Pore Test.
A modified air pressure meter is used to estimate the amount of water required to fill aggregate macro- and micropores.

Washington Hydraulic Fracture.
Aggregates are submerged in water and subjected to sustained high pressures. Rapid release of pressure simulates internal pressures generated during freezing which can fracture aggregate susceptible to D-cracking. The test results are expressed in terms of the hydraulic fracture index.

Petrographic Analysis.
Visual inspection of aggregate in terms of lithology and individual particle properties.

Acid Insoluble Residue.
Determination of percent weight of noncarbonate silt and clay size particles remaining after whole sample is dissolved in hydrochloric acid.

X-ray Diffraction.
Determine mineral and elemental compositions by bombarding the sample with x-rays.

Determination of Freezable Water.
In this test, the equilibrium moisture content of the aggregates is measured at various relative humidities. The freezable moisture is estimated as the difference between the moisture content at 85 and 100 percent relative humidity.

Selection of specific tests for inclusion in the research program will be based upon the literature review and discussions with the Minnesota Department of Transportation.

Task 3 - Conduct environmental simulation studies on concrete beam and aggregate specimens. Data from the individual aggregate property tests will be correlated with the field performance and environmental simulation studies conducted in this phase of the investigation. "Quick-screen" environmental simulation tests will be correlated with the observed field performance and longer-term simulation studies such as the Rapid Freeze-Thaw Test (ASTM C 666). This test will probably be used as a standard in ascertaining the performance of aggregates.

Tests considered include:

Rapid Freeze-Thaw Test (ASTM C 666).
Beam specimens are cycled between temperatures of 0 and 40°F in 2 to 5 hours. Periodically, relative dynamic modulus of elasticity and length changes are monitored to determine the rate of deterioration. Tests are run for 300 cycles or until the modulus is reduced to 60% of the initial modulus. There are currently four methods for performing this test, two of which are being considered by the Strategic Highway Research Program. The most rigorous of these methods is one in which the concrete is saturated and frozen, and then thawed in water. Samples surviving 300 freeze-thaw cycles with at least 60% of their initial modulus will be considered satisfactory performers. The aggregates in those specimens failing this criterion will be considered candidates for beneficiation.

VPI Single-Cycle Slow-Freeze Test.
Concrete beams are placed in a freezer. Strain measurements are made at 5 to 15 minute intervals over a four-hour period.

Sodium or Magnesium Sulfate Tests.
Ice growth in the pores of coarse aggregate is simulated by the growth of salt crystals. Results are expressed in terms of the weight loss of the coarse aggregate attributed to the deterioration due to crystal formation.

Unconfined Aggregate Particle Freeze Thaw.
Coarse aggregate is subjected to freeze-thaw conditioning in water. The results are again expressed in terms of the coarse aggregate

weight loss.

Task 4 - Conduct a statistical analysis relating the performance of the aggregates observed in the variety of tests to field observations. This statistical analysis should provide a basis for assessing the effectiveness of "quick-screening" methods to gauge aggregate durability. This will be one way that the properties of Minnesota aggregates will be identified and classified.

A summary report will be prepared documenting the field study as well as the accuracy and comparison of the "quick-screen" and environmental simulation tests.

B.1.c. *Materials:* Cores will be taken from existing pavements representing a range from excellent to poor performance. Aggregate sources found in southern Minnesota which have been used in concrete pavement will be sampled in order to study the raw materials. Concrete samples will be obtained from deteriorated areas of the pavement to more accurately determine the extent of the durability problems. Cores and beams will also be cut from areas of the pavements that are relatively sound but incorporate aggregates with known durability problems. This will allow the testing of these materials via the methods described earlier so that the accuracy of the various test procedures can be determined. In addition, these samples will be useful in Task B.2 for testing methods of aggregate beneficiation. Equipment such as a freeze-thaw chamber, Washington Hydraulic Fracture apparatus, and petrographic analysis equipment will be required to complete the testing.

B.1.d.		
	Budget:	$110,000
	Estimated Balance:	$ 0
	Financial Cutoff Date:	6/30/95

B.1.e. *Timeline:*

	7/93 1/94 6/94 1/95 6/95 1/96 6/96
Identify Sources of Problems.	xxxxxxxxxxxxxxxxxxxxxxxxxxxx
Task 1	xxxxx
Task 2	xxxxxxxxxxxxxxxx
Task 3	xxxxxxxxxxxxxxxx
Task 4	xxxxxxxxxxxxxxxx

B.2. *Activity:* **Develop Methods to Mitigate Problems**

B.2.a. *Context within project:* In this part of the project, the researchers will explore ways of treating the aggregates or mixtures to minimize the concrete expansion, thus minimizing the cracking and progressive pavement deterioration. Based on the research in Task B.1, aggregate candidates for beneficiation will be identified by the researchers in conjunction with individuals from Mn/DOT. A total of at least five different aggregates will be included in the beneficiation study. The aggregates will be subjected to a variety of beneficiation techniques; the results of these treatments will be evaluated through the use of environmental simulation tests and "quick-screening" tests that were determined to be most useful during previous project tasks. The results of these tests will be analyzed with respect to the results of the same tests performed on the original unbeneficiated materials to identify treatments that produce significant improvements in durability. A brief literature review on beneficiation of concrete aggregates was attached in Section XII of the original proposal (and is not repeated in this or other quarterly reports).

B.2.b. *Methods:*

Task 1 - Choose at least five aggregates from Task B.1 to be subjected to beneficiation techniques.

Task 2 - Subject each of the aggregates chosen to a variety of beneficiation techniques.

Possible methods of beneficiation to be considered include:

Reduction in Maximum Size of Coarse Aggregate.
Determine if a reduction in size will produce a durable coarse aggregate. Investigate the effect of the crusher type used. This is the most common method of beneficiation, although evidence indicates that it has not completely solved the problem in Minnesota. Furthermore, some states have reported rapid deterioration of transverse cracks on some concrete pavements that were constructed using small coarse aggregates.

Heavy-Media Separation.
Separate aggregates on the basis of specific gravity. Some investigators have suggested that this process has not been very successful in discriminating between good and bad aggregates.

Blending.
Upgrade aggregate by blending with more durable aggregate. This is a conventional technique in which aggregates from different sources are combined to improve the durability of the concrete. There have been mixed results using this technique.

Concrete Mix Proportioning.
Investigate variation in cement content and composition (proportions of cement, silica fume, fly ash, ground slag,...). This approach appears to be among the most promising. Numerous state departments of transportation have reported good success by adding silica fume or more cement to the concrete mixtures.

Coatings or Impregnations.
Coat surface of aggregate with thin film or impregnate with polymer or linseed oil. This approach is considered experimental, but one which may have potential. One concern is that the coating will interfere with the bonding between aggregates and the cement paste.

Heat-Treat Aggregates.
It is possible to develop a ceramic surface by heating aggregates from 450 to 800 degrees Centigrade using another technique considered to be experimental. Sintering the exterior of the aggregate may close the surface pores making it less permeable to water.

Task 3 - Evaluate beneficiation methods using at least the Rapid Freeze-Thaw Test (ASTM C 666) and other tests (identified under Activity B.1, Tasks 2 and 3) that are believed to correlate well with field performance.

The final report will summarize the results of the mitigation studies.

B.2.c. *Materials:* The same materials and equipment identified in Section B.1.c. are to be used with the addition of coating materials to be considered for beneficiation. Additionally, tests such as compressive strength and flexure tests may be specified in order to investigate the effects of treatment processes on the strength of concrete mixtures.

B.2.d. *Budget:* $ 40,000
Estimated Balance: ($6,385)
Financial Cutoff Date: ~~6/30/95~~ 12/31/95

B.2.e. *Timeline:*

	7/93	1/94	6/94	1/95	6/95	1/96	6/96
Develop Methods to Mitigate Problems.				xxxxxxxxxxxxxxxxxxx			
Task 1				x			
Task 2				xxxxxxxxxxxxxxxxxx			
Task 3				xxxxxxxxxxxxxxxxxx			

B.3. *Status:* The approved work plan included a list of 24 different pavement sections (representing approximately 19 different Minnesota aggregate sources and a range of freeze-thaw durability) that were considered for inclusion in the project field and laboratory studies. This list was developed with the input of Mn/DOT personnel (obtained at several meetings with members of the project advisory panel) and the review of volumes of pavement design, materials and performance data provided by Mn/DOTs pavement management group. Preliminary verification of project limits, overall project condition, etc. was made by the project team through reviews of the Mn/DOT video log records and PaveTech video tapes (filmed in 1993 and 1994), as described in a previous semi-annual progress report.

This information was used to plan and prepare for the field condition surveys that were conducted in July and August of 1994. Locations for core retrieval were also marked during these surveys, and coring was completed by Mn/DOT personnel (also during July and August). Up to 15 cores of varying sizes were obtained from each field site (depending upon the condition of the site and the geometry of the pavement). These cores were used for some of the lab testing described below. They were also subjected to petrographic analyses to assist in identifying the location of aggregate sources that produce aggregates with properties comparable to those used in the construction of the concrete pavements examined during the field condition surveys. A detailed photo log and written distress and drainage survey were also performed at each site.

The cores obtained from the field were prepared for the various tests to which they were subjected. This preparation included trimming of all specimens, capping of specimens that were tested in compression, cutting and polishing specimens that were subjected to microscopic examination and linear traverse measurements, etc. In addition, test logs and specimen tracking forms were developed to ensure that each specimen was subjected to all proposed tests in the proper order and that all data are recorded and stored in an organized fashion. Testing of the cores was begun in the 6th quarter and completed in the 8th quarter (except for freeze-thaw durability testing of cores retrieved form the mid-panel regions of each section; these tests were delayed until the freeze-thaw testing of the laboratory specimens was complete.) All testing was performed in accordance with applicable ASTM specifications.

A total of more than 40,000 lbs of aggregate samples was retrieved from the selected sources during August and September of 1994 (2,000 to 6,000 lbs of material from each selected source) for use in performing the lab testing and mitigation studies described previously. Each source sample was sieved (25 to 50 lbs at a time) in order to separate the sample into component particle size fractions. These fractions were then recombined to produce identically-graded samples for all samples being subjected to each specific test.

All testing of the sieved and recombined aggregate samples was also begun in the 6th quarter and completed during the 8th quarter, including replicate tests, were appropriate. These tests included the following: acid insoluble residue test; Iowa Pore Index test; absorption-adsorption tests; specific gravity and absorption capacity tests; Washington Hydraulic Fracture test (WHFT);

In addition, thermogravimetric analyses (TGA), X-ray diffraction (XRD) and X-ray fluourescence (XRF) tests were performed at Iowa State University on all aggregate sources.

Each aggregate sample was used to prepare concrete specimens for performing freeze-thaw testing in accordance with ASTM C666 (procedure B, proposed procedure C and Iowa salt treatment methods) and for the VPI Single Cycle Slow Freeze Test. This was done during the 7th quarter and testing was performed on all specemens during the 7th and 8th quarters.

The results of this test program were summarized in a report and presented to the project advisory panel on June 22, 1995. A proposed work plan for the mitigation portion of the study was also proposed and approved at the same meeting. This work plan identified 6 aggregate sources of varying source (both limestones and gravels) and durability for the mitigation portion of the study. Mitigation test work was completed during the current reporting period and included the following techniques: modified mix designs (e.g., reduced water content, increased use of pozzolanic admixtures such as Class F flyash and silica fume); aggregate pretreatment with silane or linseed oil; reduced aggregate top size; and blending of nondurable sources with durable materials. The tests that were performed to evaluate these techniques included traditional strength tests, Iowa Pore Index, Washington Hydraulic Fracture, absorption capacity, specific gravity, VPI single-cycle slow freeze test, traditional freeze-thaw (ASTM C666, procedures C and Iowa salt treatment), and traditional strength tests (compression and split tensile tests). These sources and tests were selected on the basis of the analyses performed under Task B1.

Problems: No problems are reported at this time.

C. *Title of Objective:* **Outreach and Technology Transfer.**

C.1. *Activity:* **Dissemination of Information.**

C.1.a. *Context within project:* In this phase of the project the results will be disseminated to practicing engineers, contractors, aggregate suppliers, and other interested parties.

C.1.b. *Methods:* The final report will be compiled, and presentations will be made to Mn/DOT, local and national conferences, and the results will be published. The University of Minnesota Center for Transportation Studies will facilitate dissemination of results, and CTS Advisory Councils will monitor project progress. If needed, a short course could be arranged in order to convey the information.

C.1.c. *Materials:* The preparation of audio-visual aids and course notes will be needed in this portion of the project. Additionally, the cost of copying and incidental travel will be included. The services of the Continuing Education Department at the University of Minnesota may be required.

C.1.d. *Budget:* $9,000
Estimated Balance: $6.385
Financial Cutoff Date: ~~6/30/95~~ 12/31/95

C.1.e. *Timeline:*

	7/93	1/94	6/94	1/95	6/95	1/96	6/96
Interagency Coordination.	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx						
Technology Transfer.				xxxxxxxxxxxxxxxxxxxxxx			

C.2. *Status:* On January 10, 1996, a brief presentation of the project activities was made to the Transportation Research Board Committee on Mineral Aggregates (A2J03). A technical paper summarizing project findings was submitted to this same committee and was accepted for publication in an upcoming (1996 publication) Transportation Research Record.

On February 16, 1996, a half-day technology transfer seminar was presented to personnel from Mn/DOT and LCMR summarizing the results of this research project. An executive summary of the project results was also provided to seminar attenders. The seminar was well-received and input provided to the research team is being incorporated into the final report.

The final report has been drafted and is now being editted for distribution. Delivery of the draft final report is expected on or before April 30, 1996. Mn/DOT will review the document and provide the project team with written comments by May 31, 1996, and the revised final project report will be delivered on or before June 30, 1996.

Project meetings held to date:

September 20, 1993, 1:30 p.m.	Meeting with project advisory committee
October 7, 1993, 8:30 a.m. --	Meeting with Mark Bintzler and Mark Snyder
October 27, 1993, 10 a.m. --	Meeting with Mark Bintzler, Mark Snyder and other Mn/DOT personnel
November 24, 1993, 1 p.m. --	Meeting with Mark Bintzler, Glenn Engstrom, Amir Koubaa and Mark Snyder
December 13, 1993, 7 a.m. --	Meeting with Mark Bintzler and Mark Snyder
December 16, 1993, 10 a.m.--	Meeting with project advisory committee.
April 4, 1994, 10:30 a.m. --	Meeting with project advisory committee.
May 10, 1994, 10:00 a.m. --	Meeting with project advisory committee.
May 26, 1994, 11:00 a.m. --	Meeting with project advisory committee.
July 28, 1994, 1:00 p.m. --	Meeting with project advisory committee.
January 19, 1995. 10:00 a.m. --	Meeting with project advisory committee.
June 22, 1995. 10:00 a.m. --	Meeting with project advisory committee.
February 16, 1996. 9:00 a.m.	Seminar to present project findings to Mn/DOT and LCMR personnel.

Problems: None.

V. Evaluation: The purpose of Objective A is to compile the existing knowledge related to the durability of concrete pavements. A summary of information found in the literature and through interviews will be presented along with the first interim report. The product may be evaluated considering the breadth of sources and relation of the information with respect to the project.

Activity B.1 is divided into four tasks. The first task will be accomplished by conducting a field survey of concrete pavements and sampling aggregates from various sources. Task 2 will consist of conducting various tests to ascertain the properties of the aggregates. The behavior of the aggregates with respect to environmental conditions will be studied in Task 3. Finally, a statistical analysis will be performed in order to correlate the aggregate behavior to pavement performance. The success of this activity may be gauged by 1) the accomplishment of the tasks and 2) the ability of laboratory tests to distinguish between good and bad aggregates.

Activity B.2 has three tasks: 1) selecting aggregates, 2) subjecting these to beneficiation techniques, and 3) evaluating the effects of beneficiation techniques. The evaluation of this portion of the work may be accomplished by considering the relative success of one or more of the beneficiation techniques in improving the concrete durability.

The success of objective C (Outreach and Technology Transfer) may be evaluated by the number of presentations, articles, and short courses that result from this project. Also, the amount of implementation by Mn/DOT and other agencies will be a measure of success.

VI. Context within field: Durability cracking is the predominant problem with concrete pavements in Minnesota according to the Minnesota Department of Transportation. If the problem can be eliminated or slowed, significant savings of state funds may be realized through increased pavement life. Although extremely good and bad aggregates can be discerned using current testing techniques, they are often not able to distinguish the behavior of marginal aggregates. Different testing techniques may prove to be better indicators of performance. If better means of beneficiating aggregates to improve concrete durability are discovered, then much of the uncertainty about southern Minnesota aggregate sources can be removed.

VII. Benefits: It is believed that certain aggregate sources in southern Minnesota are responsible for the premature failure of large parts of Interstate 90. The cause of the problem seems to be the freeze-thaw behavior of the aggregates in the region. If these sources are excluded from the production of exposed concrete structures, then construction could be more costly. This proposal serves two purposes: (1) maintain the construction cost of pavements in southern Minnesota by improving the pavement performance using existing aggregate sources, and (2) reduce the long-term costs of the pavements by increasing the service life.

VIII. Dissemination: The final report will be compiled, and presentations will be made to Mn/DOT, local conferences (University of Minnesota Center for Transportation Studies Annual Conference and Concrete Conference), national conferences such as ACI and TRB. Results will be submitted for publication to the ACI Materials Journal and Transportation Research Record.

IX. Time: The proposed project may exceed the two-year time limit by as much as one year due to the long-term nature of the testing involved in Sections B.1. and B.2.

X. Cooperation: The Department of Natural Resources will administer the research and monitor the progress through a contract with the University of Minnesota. The Minnesota Department of Transportation will assist university researchers in locating the needed pavement sections, providing construction and performance records, sampling the materials, and performing some of the tests. Researchers at the University of Minnesota will produce the literature review, design the experiments, work in cooperation with Mn/DOT in reviewing records and sampling materials, perform testing, and analyze the results. The dissemination of information will be the joint work of the researchers and the Center for Transportation Studies. The interim and final reports will be generated at the University of Minnesota. The major cooperators are listed below:

Ronald Visness, Mineral Development Manager
Department of Natural Resources
Richard Sullivan, Director
Materials and Research
Minnesota Department of Transportation

Richard Braun, Director
Center for Transportation Studies
University of Minnesota
Mark B. Snyder, Assistant Professor
Catherine French and Joseph Labuz, Associate Professors
Civil and Mineral Engineering Department
University of Minnesota

XI. Reporting Requirements:
Semiannual status reports will be submitted not later than Jan. 1, 1994, July 1, 1994, Jan. 1, 1995, Jul. 1, 1995, Jan. 1, 1996 and a final status report by June 30, 1996.

XII. Brief Literature Review

The literature review provided in the original proposal and repeated in several quarterly and semi-annual reports since the execution of this contract is not repeated here.