Mn/DOT's Non-Destructive Testing Program
A committee consisting of Minnesota Department of Transportation (Mn/DOT) Bridge, Pavement, and Geotechnical personnel was formed to examine the present and propose a future comprehensive Non-Destructive Testing (NDT) Program. The overall intent of their study was to define the scope of Mn/DOT's NDT program focusing on the Offices of Construction and Materials Engineering, Minnesota Road Research, and Bridge, with the intent of providing basis for future investment and use of NDT methods.

Several NDT devices are currently being used by the Department. They have a great potential for saving the Department time and money, and will enable the employees to perform their jobs better and more efficiently. Other NDT devices are still being investigated for their potential benefits to the Department, and have not been fully evaluated.

Though these devices may ultimately save time and money and improve performance, many are labor intensive. Staff approval must be obtained before making large financial or personnel commitments. It is recommended that each of the three areas have someone in charge of the evaluation of all new equipment and methods.
Mn/DOT's Non-Destructive Testing Program

Final Report

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Executive Summary

The overall intent of this study was to define the scope of the Minnesota Department of Transportation (Mn/DOT) Non-Destructive Testing (NDT) program focusing on the Offices of Construction and Materials Engineering, Minnesota Road Research, and Bridge, with the intent of providing basis for future investment and use of NDT methods.

The following NDT devices are currently being used by the Department. They have a great potential for saving the Department time and money, and will enable the employees to perform their jobs better and more efficiently. These devices and methods include the following:

A) Bridge
   i) Scour Tracker
   ii) Sonar Scour Monitor
   iii) Infrared Thermography
   iv) Radiography
   v) Dye Penetrant
   vi) Ultrasonic
   vii) Visual-Tactile Heuristics
   viii) Magnetic Particle
   ix) Coating Inspection

B) Pavements
   i) Field Nuclear Density Measurement
   ii) Laboratory Nuclear Asphalt Content Gauge
   iii) Dynamic Cone Penetrometer
   iv) South Dakota Profiler
   v) GM Profilometer
   vi) PaveTech
   vii) Friction Trailer
   viii) Falling Weight Deflectometer (FWD)

Several NDT devices are still being investigated for their potential benefits to the Department, and have not been fully evaluated. These include:

A) Bridge
   i) Geophysical Scour Monitor
   ii) Acoustic Emission
   iii) Pile Driving Analyzer

B) Pavements
   i) Ground Penetrating Radar
   ii) Numerous SHRP Equipment

C) Geotechnical
   i) Ground Penetrating Radar
   ii) Earth Resistivity
   iii) Seismic

Though these devices may ultimately save time and money and improve our performance, many are labor intensive. Staff approval must be obtained before making large financial or personnel commitments. It is recommended that each of the three areas have someone in charge of the evaluation of all new equipment.

If the Department continues to use nuclear testing gauges, it needs to continue to: provide training for personnel, collect and hand out nuclear exposure badges, perform maintenance activities, assure proper transport of gages, and require that no one be allowed to use these devices unless
they are trained and are wearing a nuclear exposure badge.

For other NDT equipment, there needs to be someone designated to be responsible for tracking and maintaining the devices.
**Introduction**

A committee consisting of Mn/DOT Bridge, Pavement, and Geotechnical personnel was formed to examine the present and propose a future comprehensive Non-Destructive Testing (NDT) Program. The findings of this report are divided into sections from these functional groups. At the end of each section are NDT Management Tables which summarize some of the conclusions from these groups.

The five objectives of the study were:

1. Determine the present available equipment and their capabilities, and the extent of the present program.
2. Identify present and emerging technologies and equipment, and describe their potential benefits and limitations.
3. Identify all personnel who are actively involved with NDT within Mn/DOT and the private sector.
4. Define the scope of anticipated NDT through 1998 (5 year plan) to include and justify the following needs:
   a) Equipment
   b) Staffing
   c) Maintenance
   d) Location & Responsibilities
   e) Training
5. Identify existing and future policies.
Group 1 - Bridge

I) Bridge Scour Monitors

Background

The collapse of the New York State Thruway bridge over Schoharie Creek in 1987 claimed ten lives, while floods in the Virginia region destroyed 73 bridges in 1985. Recognizing the need to protect the traveling public from bridge failures, as well as the need to protect infrastructure investments, the Federal Highway Administration (FHWA) issued a Technical Advisory which recommends all bridges over water be evaluated for scour.

Bridge scour occurs during periods of high flow. The scour is the result of the force of the water removing bed materials from under the bridge. To contain costs, bridges are usually designed to the minimum size that provides a hydraulically adequate waterway opening. The result is the flow through the bridge in a very large flood is constricted, which causes an increased velocity and ultimately increased bed material transportation capacity resulting in contraction scour. Placement of abutments and piers in the flow result in additional scour, by creating localized turbulence that acts to remove bed material around the foundations. Foundations in sandy soils are particularly susceptible to scour, but given time even rock can become eroded resulting in undermined bridge foundations.

Currently, Mn/DOT bridges are designed to be stable for calculated maximum scour conditions. Unfortunately, many older bridges are susceptible to scour. More than 700 Mn/DOT bridges have been identified as scour susceptible and are in need of a scour evaluation. The evaluation is expected to identify a large number of bridges as scour critical, which will require the installation of countermeasures or monitoring during and after floods.

In some circumstances monitoring will be the preferred activity, rather than constructing countermeasures. The potentially high cost of countermeasures in some cases may encourage the implementation of a cheaper monitoring program. Monitoring is also needed during the time it takes to program, design and construct countermeasures. Monitoring provides field documentation that can be used to calibrate scour equation results. Some countermeasures are not considered permanent solutions, and will need regular inspection and monitoring.

Mn/DOT has a monitoring contract for 18 bridges with the United States Geological Survey (USGS), while other bridges are monitored by district personnel. Monitoring a bridge during a flood has logistical and technical problems. Timing bridge monitoring activities to be able to detect scour in time for preventative action is difficult. Visual inspection will rarely identify a problem before serious damage occurs, because sediment laden, turbulent water is almost impossible to see through. The first visual signs could be rotating of a pier, structural cracking, or shifting or loss of fill behind the abutment. Bridges determined to be scour critical and in need of monitoring should have measurements of bed elevations taken around the piers and abutments.
during large floods. During a flood, fast and turbulent waters may prevent safe access of the site by boat, and not all bridges can be adequately checked from the bridge deck.

A) Scour Tracker

Introduction

The Scour Tracker is a fixed scour instrument consisting of a magnetic collar which slides down a vertical rod. As scour occurs at a pier, the magnetic collar falls into the hole and then stays at the lowest elevation even if the scour hole refills. The location of the magnetic collar is found by inserting a tracker probe on a graduated cable down the vertical rod.

The Scour Tracker is fairly inexpensive to produce, relatively simple to install, and will require little training to maintain and use. There are no electronics left at the site; the inspectors carry the tracker probe with them from site to site.

This equipment is best suited for small to mid-size bridges on sand bed streams. Large bridges may require prohibitively long lengths of vertical tubing where the tracker probe may hang up. Further testing is necessary, to determine if the Scour Tracker will operate adequately in cohesive soils.

This proposal should not be considered as the total solution for fixed monitoring devices. These devices are in the evaluation phase, until floods occur at the device sites. Normally floods do not hit a whole state at one time, so placing more monitoring devices throughout the whole state increases the chances that at least some of them will be tested.

Present Equipment

The Scour Tracker was developed by Resource Consultant & Engineers (RCE) of Fort Collins, Colorado as part of a National Cooperative Highway Research Program (NCHRP) project. The goal was to develop a low cost, easy to install and use system that measures scour at bridge piers. The system is still in the testing stage, with only one field installation. Several states, including Minnesota are funding further testing of the device in field applications during 1993.

Funding was allocated for installation of the Scour Tracker at two Mn/DOT bridge sites in early 1993.

Operating Season

Devices are permanently attached to the bridge site. A regular monitoring schedule of once per month is recommended initially, with additional monitoring planned in the advent of high flow conditions. After the initial monitoring period, the frequency of scour depth checks could be reduced. Devices may be inoperable during winter months.
Personnel Actively Involved and Time Commitment

The Scour Tracker was developed with the idea that it could be installed by Mn/DOT's regular maintenance employees. The device is designed and fabricated by the developer for each bridge site. Mn/DOT personnel should be able to install the device in 8-16 hours depending on the complexities of the bridge site.

Monitoring consists of lowering a tracker probe down a vertical pipe and noting at what depth the probe detects the device. The depth should be compared to previous depths to determine if any scour has occurred at the site. Any changes in the scour depth should be reported to the appropriate bridge inspection staff. This activity does not require skilled labor. Monitoring a bridge using the Scour Tracker should take as little or less staff time than current monitoring techniques.

Periodic replacement of the tubing may be necessary, if portions are damaged by exposure to ice and debris.

Present Program and Policies

All Mn/DOT bridges over water are currently being reviewed for scour susceptibility. Over the next five years scour critical bridges will be identified as needing monitoring or countermeasures. Current monitoring methods: visual, graduated pole, graduated weight or small sonar device are inadequate for some bridge sites and may not insure the safety of our bridges, Mn/DOT personnel, or the public. Funding has not been identified to meet future increases in bridge monitoring needs.

Scour equations and procedures tend to provide a conservative maximum scour estimate. Many factors which may limit scour are not quantifiable. Installation of a low cost fixed scour monitoring device, or use of geophysical methods to determine maximum historical scour could provide data to calibrate scour predictions. Data could also be used for long-term planning for the state scour program.

Customers

1. Districts
2. Office of Bridges and Structures
3. Counties
Anticipated 5-Year Program Needs

<table>
<thead>
<tr>
<th>Equipment 8 Bridges/Year at Maintenance costs Salaries &amp; Overhead</th>
<th>$5000/Bridge $1600/Year $1440/Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average total cost per bridge Total cost over 5 years</td>
<td>$5,380</td>
</tr>
<tr>
<td></td>
<td>$215,200</td>
</tr>
</tbody>
</table>

1 Costs based on assuming 6 hr/bridge labor during first year and 1.5 hr/bridge thereafter. Salary and overhead rate $20/hr.

Recommendations

1. Equipment needs: The equipment can be designed and fabricated by the patent holder and developer, Resource Consultant & Engineers (RCE) of Fort Collins. However, as a participating state in the NCHRP project, we may be allowed access to the specifications for internal design and fabrication.

Costs are based on design and fabrication of the prototype device. If this technology becomes popular and mass production occurs, one would anticipate that cost would decrease. We recommend forty Scour Tracker installations located at eight bridges per year.

2. Personnel needs: Equipment used by existing personnel. Equipment aids personnel in doing their work more efficiently and effectively.

3. Training: Minimal training.

4. Equipment locations: Equipment located at bridge sites. The operation of equipment would be the responsibility of each district.


6. Resultant cost savings from recommendations: When used as an alternative to countermeasure installations, the Scour Tracker could save between $5,000-$200,000 in costs per bridge.

7. Possible ramifications of not funding:
   a. Mn/DOT would be unable to effectively monitor some bridges at risk of failure due to scour.
   b. There would be reduced safety of Mn/DOT personnel while monitoring during flood events.
c. Costs would increased for protecting bridges with structural countermeasures, when monitoring would have been sufficient.

d. Reduced data on actual maximum scour which is occurring at Mn/DOT bridges over water.

e. Missed opportunity to be involved as a progressive agency willing to provide funding for new technologies.

B) Sonar Scour Monitor

Introduction

The final report on NCHRP project "Instrumentation For Measuring Scour at Bridge Piers and Abutments" has been distributed. Scour monitoring devices were evaluated in the laboratory and limited field settings. Several devices were evaluated including a sonar setup, which consists of a transducer and receiver, data logger, bridge mounting, and a power supply.

Equipment can be mounted permanently on a bridge to measure scour. Some devices will measure only the maximum scour which has occurred, while others provide a record of bed elevation fluctuations.

The fixed sonar monitoring device option may perform better for large bridges. They can measure fluctuations in bed over time, not just maximum measured scour. They could also be utilized to provide automated warnings during periods of flooding.

Present Equipment

None

Operating Season

Equipment permanently mounted on bridge year round. Installations can be set up for remote data transfer or for periodic manual download.

Personnel Actively Involved and Time Commitment

Existing sites installed in other states as part of the NCHRP study with similar equipment required 20 days/year for maintenance and data retrieval.

Present Program and Policies

All Mn/DOT bridges over water are currently being reviewed for scour susceptibility. Over the
next 5 years scour critical bridges will be identified as needing monitoring or countermeasures. Current monitoring methods: visual, graduated pole, graduated weight, or small portable sonar devices. They may be inadequate for some bridge sites and may not insure the safety of our bridges, Mn/DOT personnel, or the public. Funding has not been identified to meet future increases in bridge monitoring needs.

Scour equations and procedures tend to provide a conservative maximum scour estimate. Many factors which may limit scour are not quantifiable. Installation of a fixed scour monitoring device could provide data to calibrate scour predictions. Data could also be used for long term planning for the state scour program.

Customers

1. Office of Bridges and Structures
2. Districts

Anticipated 5-Year Program Needs

In the next five years we would plan for fixed installations on up to two bridges.

- Equipment two bridges/5 years = $20,000/bridge.
- Maintenance cost = $500/yr/bridge
- Salary & overhead\(^2\) = $1,920/yr/bridge

Total Cost over five years = $64,200

\(^2\) Assume 4 weeks/year at $20/hour, starting annual cost in the third year.

Recommendations

1. Equipment needs: Two bridge installations.


3. Training: Some instruction necessary on equipment operation. Many bridge inspectors have already received training on the Bridge Inventory System, and these skills are similar to those needed to download data.

4. Equipment locations: The equipment is mounted directly on a bridge. Coordinating maintenance and operation of equipment would be the responsibility of district personnel.

5. Maintenance: Large scale repair would be done in the factory. District MIS personnel may be needed to help with data downloading and data manipulation. Additional maintenance may be
needed by district personnel. Mn/DOT electronic support staff (OEC) could be available as a resource.

6. Resultant cost savings from recommendations: Countermeasure installation costs between $10,000-$200,000 per bridge. Fixed monitoring devices are an alternative to structural countermeasure installations.

7. Possible ramifications of not funding:

   a. Mn/DOT would be unable to effectively monitor some bridges at risk of failure due to scour.

   b. There would be reduced safety of Mn/DOT personnel while monitoring during floods.

   c. There would be increased costs for protecting bridges with structural countermeasures when monitoring would have been sufficient.

   d. Mn/DOT would have reduced data on actual maximum scour occurring at bridges over water.

   e. Mn/DOT would missed an opportunity to be involved as a progressive agency willing to provide funding for new technologies.

C) Geophysical Scour Monitor

Introduction

The FHWA has mandated the evaluation of scour at all bridge foundations over waterways. Part of the evaluation involves looking at historical scour at the bridge site. Pier scour occurs during periods of high flow, and often scour holes will fill in as the flood recedes. This makes it difficult to determine the extent of the scour unless one monitors during the peak flood. Ground penetrating radar, a tuned transducer, or a color fathometer may be utilized to estimate historical scour occurrences after a flood occurs.

The scour susceptibility of bridges with spread footings on rock is difficult to quantify. Given enough time even rock will erode. However, there is little information available for evaluating the scour resistance of different rock types. Ground penetrating radar could be an effective tool for monitoring changes in bedrock elevations at bridge footings. Geotechnical methods are of value in cases, where the site can not be probed with a rod. Having an effective monitoring tool could potentially save funds by reducing the need for expensive scour countermeasure installations.
Another use for ground penetrating radar may be in determining the historical depth of pier scour in an alluvial stream. By detecting the different patterns of the soil around the pier, one may be able to determine how deep scour has occurred by analyzing the various materials which have been deposited, however this method will not work for all channel bottom types.

For bridges with unknown foundations, geophysical devices may be used to determine the pile lengths. A FHWA task force on unknown foundations has been set up to evaluate techniques to deal with these bridges. In the next few years, results from this study should be available.

Voids can develop around culverts, when deteriorated joints result in soil being washed away from the culvert. A large void could ultimately result in the failure of the roadway. Ground penetrating radar may be used to inspect subsurface interfaces, potentially detecting voids that may develop around culverts.

Three geophysical tools which may be of value to measure scour after in filling occurs include ground penetrating radar, a tuned transducer, and a color fathometer.

One of the primary methods is ground penetrating radar. "Ground penetrating radar (GPR) can be used to obtain continuous high resolution subsurface profiles on land or in relatively shallow water (less than 25 feet). This device transmits short, 80 to 800 MHz, electromagnetic pulses into the subsurface and measures the two-way travel time for the signal to return to the receiver. When the electromagnetic energy reaches an interface between two materials with differing physical properties, a portion of the energy is reflected back to the surface, some of it is attenuated, and a portion is transmitted to deeper layers. The penetration depth of GPR is dependent upon the electrical properties of the material through which the signal is transmitted and the frequency of the signal transmitted."

Ground penetrating radar systems include a transmitter, receiver, high density tape recorder, and player file storage of records and antenna.

Present Equipment

No geophysical Mn/DOT equipment is currently being applied to detect scour at bridges.

Operating Season

Depending on bridge geometry, site conditions, and the purpose of the investigation, geophysical equipment may be used year round. Equipment can be positioned from the bridge deck, boat, or ice tow.

Personnel Actively Involved and Time Commitment

Geophysical work provided by specialized consultants. Existing personnel would be responsible
for setting up and monitoring consultant contracts.

Present Program and Policies

All Mn/DOT bridges over water are currently being reviewed for scour susceptibility. Over the next 5 years, scour critical bridges will be identified as needing monitoring or countermeasures. Current monitoring methods: visual, graduated pole, graduated weight, or small sonar devices are inadequate for some bridge sites and may not insure the safety of our bridges, Mn/DOT personnel, or the public. Funding has not been identified to meet future increases in bridge monitoring needs.

Scour equations and procedures tend to provide a conservative maximum scour estimate. Many factors which may limit scour are not quantifiable. Installation of a low cost fixed scour monitoring device or use of geophysical methods to determine maximum historical scour could provide data to calibrate scour predictions. Data could also be used for long term planning for the state scour program.

Customers

1. Office of Bridges and Structures
2. Districts

Anticipated 5-Year Program Needs

We are recommending setting up consultant contracts to provide geophysical scour monitoring services. We do not have the in-house expertise to operate and interpret the results from geophysical equipment such as ground penetrating radar.

The consultant should have experience using this technology for the evaluation of bridge scour. The use of consultants to provide geotechnical services allows us the flexibility of choosing the best tool for each project and to access new equipment as it is refined for better scour detecting capabilities.

A $300,000 consultant contract should be set up. Twenty bridges would be investigated at an average cost of $15,000/bridge.

Recommendations

1. Equipment needs: None
2. Personnel needs: None
3. Training: None
4. Equipment locations: None

5. Maintenance: None

6. Resultant cost savings from recommendations: An alternative method of detecting scour is to take borings. Borings in these situations can be very expensive and do not always provide conclusive evidence of scour. The ability to detect historical scour and to periodically monitor scour at some sites may illuminate the need for countermeasure installations which cost between $10,000-$200,000 per bridge.

7. Possible ramifications of not funding:

   a. Lack of information on historical scour could result in the need for costly borings which do not always provide necessary information.

   b. There would be increased costs for protecting bridges with structural countermeasures, when a method of detecting maximum scour could have been adequate.

   c. Mn/DOT would have reduced data on actual maximum scour occurring at bridges over water.

   d. Mn/DOT would have missed an opportunity to be involved as a progressive agency willing to provide funding for new technologies.

References


II. Infrared Thermography (IRT)

Introduction

1. Present Program: Mn/DOT presently uses limited infrared imaging equipment to check temperatures related to welding and painting.

2. Purpose of Equipment: To detect heat (temperatures) and heat variations.

3. What Equipment does: Measures the thermally generated electromagnetic radiation from surfaces in order to detect and record temperature variations.

4. What data is collected: Thermally generated radiation.
5. How is data used: The data may be used in research and quality assurance.

6. Location of equipment: Certain testing agencies and schools have IRT equipment. Mn/DOT Structural Metals Inspection Unit has an infrared hand held temperature scanner.

7. Relevant past history: The Structural Metals Inspection Unit used IRT equipment to ensure that proper temperatures are obtained for welding and painting.

Present Equipment

1. Number: Mn/DOT Structural Metals Inspection Unit has one hand held temperature scanner.


3. Value/replacement cost: $1,300

4. Limitation/capability: It has a limited temperature range and large, uncertain target area.

5. Maintenance: The IRT needs calibration.

Operating Season

1. Time of year operated: It can be operated year round.

Seasonal effects: Limited temperature range

Personnel Actively Using Equipment and Time Commitment

1. Structural Metals personnel
   a. Supervisor: Structural Metals Engineer.

2. District personnel

Bridge inspection and maintenance

3. Other

Contractors, Fabricators and test agencies

Little time commitment is needed. It is a part of normal quality assurance. Some additional time is required for use in research.
Present Program and Policies

1. Mn/DOT inspection personnel conduct quality assurance by monitoring temperatures.

2. Fabrication shops may borrow the equipment with Mn/DOT supervision.

Customers

1. Mn/DOT maintenance and inspection
2. FHWA, AWS, & AASHTO
3. Cities, counties, & municipalities
4. Other state's DOT's
5. Structural metal contractors and fabricators
6. Other state agencies

Anticipated 5-Year Program Needs

1. Estimated Testing: There will be an increase in testing and research

2. Equipment Needs: Wider range temperature scanners with more accurate target area will be needed.  
\[ 2 \times \$2,500 = \$5,000 \]  
Calibrations = \$1,000

3. Personnel Needs: None additional

4. Training Needs: None additional

5. Location and responsibility for testing: Structural Metals Unit and District field personnel.

6. If funds are not available, research will be delayed and inspection will be less efficient.

III. Radiography (RT)

Introduction

1. Present Program: Mn/DOT presently requires the use of RT to conduct NDT for structural metals fabrication and welder qualification.

2. Purpose of Equipment: To conduct research and NDT of structural metals and welds.


4. What data is collected: The relative size, shape, location, and extent of discontinuities can be
determined.

5. How is data used: The data may be used in research, quality control, and quality assurance.

6. Location of equipment: Certain testing agencies, fabricators, and schools have RT equipment. Mn/DOT Structural Metals Inspection Unit has RT interpretation equipment.

7. Relevant past history: Based on research of welder qualification radiographs, the AWS welder qualification tests were modified to require the use of radiography. Critical welds are radiographed in the shop and numerous defects have been repaired.

Present Equipment

1. Number: Mn/DOT Structural Metals Inspection Unit has a radiographic film densitometer, and one stationary and one portable RT film illuminator.

2. Status: The densitometer and portable film illuminator were purchased in 1992; the stationary film illuminator is in good condition.

3. Value/replacement cost: Densitometer = $750, Film illuminators = $800 each.

4. Limitation/capability: Present film illuminators must be operated in a darkened environment.

5. Maintenance: The densitometer needs calibration and the illuminator needs bulb replacement.

Operating Season

1. Time of year operated: Year round

Seasonal effects: Need darkened area to view film.

Personnel Actively Involved and Time Commitment

1. Structural Metals personnel (Part of Job Responsibility)
   a. Supervisor: Structural Metals Engineer.

2. Other

Fabricators, schools and test agencies.
Present Program and Policies

1. Mn/DOT inspection requires RT for welder certification and for certain critical welds. Structural Metals personnel conduct RT evaluation with limited training and no ASNT certification.

2. RT operation and interpretation by personnel other than Mn/DOT, requires certified personnel.

Customers

1. Mn/DOT maintenance and inspection
2. FHWA, AWS, & AASHTO
3. Cities, counties, & municipalities
4. Other state's DOT's
5. Structural metal fabricators
6. Other state agencies

Anticipated 5-Year Program Needs

1. Estimated Testing: There will be an increase of testing and research due to additional weld processes being used and concerns of weld quality.

2. Equipment Needs: Use of schools or fabricator equipment for consulting and research = $10,000.


4. Training Needs: Inspectors need additional training = $1,000/yr.

5. Location and responsibility for testing: Structural Metals provides quality assurance through RT evaluation. Fabricators, schools or test agencies conduct RT.

6. If funds are not available, research will be delayed and inspection will be less efficient.

IV. Dye Penetrant (PT)

Introduction

1. Present Program: Mn/DOT presently uses PT to conduct non-destructive testing (NDT) in the field.

2. Purpose of Equipment: To conduct research and non-destructive testing (NDT) in the field.
3. What Equipment does: A penetrating liquid applied to surfaces will penetrate and then escape from surface discontinuities.

4. What data is collected: The surface size, shape, location, and extent of discontinuities can be determined.

5. How is data used: The data may be used in research, quality control, or to make repairs.

6. Location of equipment: Certain testing agencies, fabricators, and schools have PT equipment. Mn/DOT Structural Metals Inspection Unit and District inspection units have PT equipment.

7. Relevant past history: In March 1993, the Structural Metals Inspection Unit used PT to locate a crack in a overhead sign weld.

Present Equipment

1. Number: Mn/DOT Structural Metals Inspection Unit has several spray cans of dye penetrant liquids.

2. Status: OK

3. Value/replacement cost: $200

4. Limitation/capability: Need clean surface, only surface defects detected.

5. Maintenance: None

Operating Season

1. Time of year operated: Year round

Seasonal effects: Should have clean dry area

Personnel Actively Involved and Time Commitment

1. Structural Metals personnel
   
   a. Supervisor: Structural Metals Engineer.
   

2. District personnel

Bridge inspection
3. Other

Contractors and test agencies

Present Program and Policies

1. Mn/DOT inspection personnel conduct PT with minimal training and no ASNT certification.
2. PT by other than Mn/DOT requires certified personnel

Customers

1. Mn/DOT maintenance and inspection
2. FHWA, AWS, & AASHTO
3. Cities, counties, & municipalities
4. Other state’s DOT’s
5. Structural metal fabricators
6. Other state agencies

Anticipated 5-Year Program Needs

1. Estimated Testing: Increase of testing and research
2. Equipment Needs: Replacement = $100/yr
3. Personnel Needs: None
4. Training Needs: None
5. Location and responsibility for testing: Structural Metals and field, Bridge Office
6. If funds are not available, research will be delayed and inspection will be less efficient

V. Ultrasonic (UT)

Introduction

1. Present Program: Mn/DOT presently requires the use of non-destructive testing (NDT) for structural metals fabrication and this is often done with UT.
2. Purpose of Equipment: To conduct research and non-destructive testing (NDT) of structural metals and welds.
3. What Equipment does: Introduces sound waves through a transducer to a sample and receives sound waves from a sample and displays the information.

4. What data is collected: The relative size, shape, location, and extent of certain discontinuities can be determined.

5. How is data used: The data may be used in research, quality control, and quality assurance.

6. Location of equipment: Certain testing agencies, fabricators, and schools have UT equipment. Mn/DOT Structural Metals Inspection Unit has UT equipment.

7. Relevant past history: In 1992, the Structural Metals Unit provided on-site UT inspection of bridge pins to help determine which ones should be replaced. In addition, on-site UT evaluation was made on defects in the Lafayette Bridge. Critical welds which are impractical to be radiographed are UT tested in the Fabrication shop and numerous defects have been repaired.

Present Equipment

1. Number: Mn/DOT Structural Metals Inspection Unit has three UT test Units, one UT thickness gage and twelve UT transducers.

2. Status: All UT equipment is in good condition.

3. Value/replacement cost: Three test units = $7000 each, Thickness gage = $800, Transducers = $35 each.

4. Limitation/capability: Test units are large, fragile, and do not provide a permanent record of results. Transducers do not meet all needs for access.

5. Maintenance: Calibration of test units = $200/yr

Operating Season

Time of year operated: Year round

Seasonal effects: Need clean, moderately warm surface.

Personnel Actively Involved and Time Commitment

1. Structural Metals personnel

   a. Supervisor: Structural Metals Engineer.
   b. Operator: Structural Metals Inspector is responsible for quality assurance and
monitoring of UT. Occasionally, Inspector will operate UT equipment for in-situ NDT.

2. Other

Fabricators, schools, and test agencies

Present Program and Policies

1. Mn/DOT inspection requires UT for certain welds. Structural Metals personnel conduct UT evaluation and quality assurance with limited training and no ASNT certification. Also, UT is conducted by Structural Metals Inspectors who have no ASNT certification.

2. UT operation and interpretation by other than Mn/DOT requires certified personnel.

Customers

1. Mn/DOT maintenance and inspection
2. FHWA, AWS, & AASHTO
3. Cities, counties, municipalities
4. Other state’s DOT’s
5. Structural metal fabricators
6. Other state agencies

Anticipated 5-Year Program Needs

1. Estimated Testing: Increase of testing and research due to new advances in UT technology and concerns of weld quality. Work being done by Colorado DOT indicates that UT techniques may be available to analyze fillet welds. Use of these techniques would greatly increase the application of UT to both fabrication and inspection. More in-situ testing is expected due to replacement and repair of old bridges.

2. Equipment Needs: Need UT equipment that will give permanent record of data = $8,000. Use of schools or Fabricator equipment for consulting and research of fillet weld testing with UT = $10,000

3. Personnel Needs: Consultant work = $5,000

4. Training Needs: Inspectors need additional training and possible certification = $2,000/yr

5. Location and responsibility for testing: Structural Metals provides quality assurance through UT evaluation, and also conducts UT in field. Fabricators, schools, or test agencies conduct UT for structural metals inspection.
6. If funds are not available, research will be delayed and inspection will be less efficient.

**VI. Acoustic Emission (AE)**

**Introduction**

1. Present Program: Mn/DOT does not presently use AE for non-destructive testing (NDT).

2. Purpose of Equipment: To conduct research and non-destructive testing (NDT) of structural metals and welds.

3. What Equipment does: Receives and analyzes sound waves produced by events such as cracking.

4. What data is collected: The relative size and location of certain discontinuities can be determined.

5. How is data used: The data may be used in research, quality control and quality assurance, and for periodic inspection of components in service.

6. Location of equipment: Certain specialized testing agencies and Schools have AE equipment.

7. Relevant past history: In 1992, $38,000 was spent to inspect high mast light towers. In addition, inspection was virtually manual and safety risks were involved. AE may be a viable alternative to this and other type of inspections. The Physical Research Section reports that Honeywell is interested in working in this area.

**Present Equipment**

Number: Mn/DOT currently has no AE equipment and would probably use consultants to do initial work and then reevaluate our needs.

**Operating Season**

Time of year operated: Year round

**Personnel Actively Involved and Time Commitment**

1. Structural Metals personnel

Supervisor: Structural Metals Engineer and Bridge Office would set up needs for consultant work and evaluate the operation.
2. Other

Schools and test agencies

Present Program and Policies

Mn/DOT inspection for in service components is mostly visual.

Customers

1. Mn/DOT maintenance and inspection
2. FHWA, AWS, & AASHTO
3. Cities, counties, & municipalities
4. Other state's DOT's
5. Structural metal fabricators
6. Other state agencies

Anticipated 5-Year Program Needs

1. Estimated Testing: Increase of testing and research due to new advances in AE technology and concerns of cost, safety, and structural integrity. More in-situ testing is expected due to replacement and repair of old bridges and structures.

2. Equipment Needs: Use of test agency equipment consulting and research = $50,000

3. Personnel Needs: Consultant work = $3,000/yr, inspection and engineering part of regular activity.

4. Training Needs: Inspectors and engineers need additional training = $5,000

5. Location and responsibility for testing: Initially test agencies.

6. If funds are not available, research will be delayed and inspection may be more costly, unsafe and less efficient.

VII. Visual-Tactile Henristics

A) In-Service Bridge Inspection

Introduction

Visual Inspection is a non-destructive test that provides a means for detecting and analyzing
surface flaws in bridge components, such as corrosion, contamination, surface finish, and surface discontinuities. National interest in bridge inspection intensified when the 2235 foot silver bridge in West Virginia collapsed in 1967 killing 46 people. Recognizing the need to provide safety to the public and protection of the public investment, the National Bridge Inspection Standards (NBIS) was developed in 1971. The NBIS set national policy regarding frequency of bridge inspection, qualifications of bridge inspectors, a format for bridge inspection reports, and procedures for bridge inspection and ratings.

Inspection of existing bridges in Minnesota is required by state law (statute 8810.9400) every year, and more frequently if needed. This regular interval of inspection requires proper evaluation of the findings and proper repair of any deficiencies that occur. As the age of the bridge increases so does the importance of the inspection. Attention to small problems must be addressed and should not be allowed to deteriorate into major problems. Detailed records must be kept to maintain a permanent record of these problems.

Inspection of overhead signs and light poles is not addressed in the state statutes, however our districts are still responsible for the maintenance and inspection of them. The frequency of inspection on these structures may vary within each district. In 1990 the state of Michigan had two cantilever sign structures collapse due to fatigue cracks in the anchor rods.

Maintaining public safety and confidence can be a challenge. The general public travels our highways and bridges without hesitation. When a failure happens that confidence is violated and the public becomes concerned. This is why thorough annual inspections identifying conditions and defects of our structures is required.

Present Equipment

The bridge inspector must have the proper equipment in order to do a thorough job of inspection. Safety equipment such as hard hats, safety goggles, safety belts, and lanyards are all part of an inspectors attire. Snoopers, bucket trucks, and ladders are all used when a particular inspection job requires it. Presently, Mn/DOT owns two snoopers trucks that are valued at approximately $250,000 a piece.

Operating Season

Our districts inspect their bridges throughout the year, but the majority of inspections are done in the summer months.

Personnel Actively Involved and Time Commitment

Presently, there are 2 full time bridge office employees working in the bridge inspection unit, one principal engineer and one senior engineer.
Each district has set up the inspection program differently with any number of employees inspecting bridges and culverts within their jurisdiction. Some districts put together the inspection team primarily with maintenance personnel, while other districts use construction personnel. A minimum requirement for each district would be to have one full time level II bridge inspector.

Present Program and Policies

All bridges and culverts in Minnesota with a length (measured along the centerline of the roadway) of 10 feet or more must be inspected annually. Each district has the responsibility to carry out the inspection of the bridges and culverts within their jurisdiction. Additional responsibilities for the district inspection team may include inspecting noise and retaining walls, overhead sign structures, and light poles.

Customers

1. Office of Bridges and Structures
2. Districts
3. Counties
4. Cities

Anticipated 5-year Program Needs

<table>
<thead>
<tr>
<th>Salaries &amp; Overhead¹</th>
<th>$50,000/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cost over 5 years</td>
<td>$250,000</td>
</tr>
</tbody>
</table>

¹ Costs based on one additional full time employee at a salary and overhead rate of $24/hr.

Recommendations

1. Equipment Needs: There are minimal equipment needs with no plans to add additional snoopers.

2. Personnel Needs: There is a need for existing personnel plus one additional employee for the Bridge Office. This employee would be hired to start an inspection program for overhead sign structures and light poles, and would provide assistance to the districts on fracture critical bridge inspection.

3. Training: No additional training funds would be needed. Existing training costs are $10,000 for a one week course on "Engineering Concepts for Bridge Inspectors", and $20,000 for a two week course on "Safety Inspection of In-Service Bridges". Both courses are sponsored by the Federal Highway Administration, which subsidizes half of the training costs.

4. Equipment Locations: Snooper trucks are located at the Oakdale (Metro East) office.
5. Maintenance: The maintenance cost on the two snooper trucks are approximately $6,000 per year.

6. Resultant cost savings from recommendations: Hiring a consultant for inspection of structures for the districts is an alternative. A consultant fee would be considerably more than $50,000 a year.

7. Possible ramifications of not funding:
   a. Reduced inspection of fracture critical bridges could result in the partial or full collapse of a bridge.
   b. Unable to effectively monitor overhead signs and light poles resulting in reduced public safety and confidence.

B) Bridge Fabrication Inspection

Introduction

1. Present Program: Mn/DOT presently uses visual heuristic testing for inspecting bridge fabrication, construction, and maintenance.

2. Purpose of Program: To provide quality assurance and visual, dimensional acceptance and condition of Mn/DOT bridges and structures.

3. What Program does: Visual inspection is used to check material identification, inspect testing and operating procedures, make measurements (gages, rulers, tapes, etc.), check appearance (coatings, welds, etc.), and look for cracks and imperfections.

4. What data is collected: Material heat and piece mark numbers, weld procedure amperage, voltage, travel speed etc., size, shape, location and extent of discontinuities, irregularities, and dimensional inaccuracies.

5. How is data used: The data may be used in research and development, quality assurance, or to make repairs.

6. Location of equipment: Mn/DOT Structural Metals Inspection Unit, construction and maintenance inspectors, certain testing agencies, fabricators, and schools have equipment to aid in visual heuristic testing.

7. Relevant past history: The Structural Metals Inspection Unit is constantly providing visual inspection of certifications, procedures, and operations related to bridge and structure fabrication.
Present Equipment

1. Number: Mn/DOT Structural Metals Inspection Unit has two amperage meters, one portable hardness tester, two hand held magnifiers, two portable thermometer kits, one camcorder, VCR and TV, two cameras, one spotting telescope, one Skidmore-Wilhelm bolt tester, and miscellaneous visual standards and dimension gages.

2. Status: Most equipment is relatively new and in good working condition.

3. Value/replacement cost: Amperage meters = $600, portable hardness tester = $800, magnifiers = $300, thermometer kits = $1,600, camcorder = $1000, VCR = $400, TV = $300, cameras = $3,000, spotting telescope = $1.300, Skidmore-Wilhelm bolt tester = $500, and miscellaneous visual standards and dimension gages = $500.

4. Limitation/capability: Amperage meters need attachments to measure voltage = $300, camera needs lens for darker environments = $300, surface roughness measurements should be automated = $2,000, miscellaneous equipment needs periodic replacement = $200/yr.

5. Maintenance: Calibrations, adjustments, etc. = $200/yr

Operating Season

1. Time of year operated: Year round

Seasonal effects: varies

Personnel Actively Involved and Time Commitment

1. Structural Metals personnel
   a. Supervisor: Structural Metals Engineer.

2. District personnel

Bridge inspection

3. Other

Contractors and test agencies

Present Program and Policies

1. Mn/DOT inspection personnel conduct visual inspection with limited training and only some
AWS certification.

2. Visual inspection by other than Mn/DOT requires certified personnel

Customers

1. Mn/DOT maintenance and inspection
2. FHWA, AWS, & AASHTO
3. Cities, counties, & municipalities
4. Other state’s DOT’s
5. Structural metal fabricators
6. Other state agencies

Anticipated 5-Year Program Needs

1. Estimated Testing: Increase of testing and research
2. Equipment Needs: = $3,600
3. Training Needs: Inspectors need trained and certified = $15,000
4. Location and responsibility for testing: Structural Metals and field, Bridge Office
5. If funds are not available, research will be delayed and inspection will be less efficient

VIII. Electro Corrosion

Introduction

Electro Corrosion will be handled primarily as a research tool for the Office of Minnesota Road Research. Funding requests will be made on an as needed basis. The primary use of this equipment has been for research, inspection, and monitoring of corrosion of reinforcing steel in bridge decks.

IX. Pile Driving Monitoring

Introduction

Mn/DOT presently uses traditional pile testing methods to determine bearing capacities for piles. In the Standard Specifications for Construction a dynamic energy formula is used to calculate the bearing capacities for driven piles. This formula has been used by Mn/DOT for many years. Some of the inherent problems with using this dynamic energy formula are listed below.

- It poorly represents the driving system and system energy losses.
- It assumes a rigid pile thus neglecting pile stiffness.
- It assumes that soil resistance is constant.
Static load testing is another method used to verify a pile's integrity and bearing capacity, but this method can be very expensive and time consuming for the contractor. These two factors limit the number of tests being performed at the site, thus they inaccurately predict the soil conditions.

Another method for predicting bearing capacities of piles would be to use a Pile Driving Analyzer. Developed by Pile Dynamics, Inc., it has the potential to revolutionize the way in which we monitor pile driving on Minnesota's bridges. This method has been used quite extensively in the state of Ohio for analyzing bridge piles. Some of the advantages are given below.

- It analyzes hammer performance. It tells the operator if the hammer is operating properly and if the right hammer size is being used.
- It may prevent unnecessary over driving.
- It will indicate when a pile has become damaged or broken.
- It can calculate the compressive and tensile stresses in the pile while it's being driven.

A negative aspect of the Pile Driving Analyzer is that it requires an skilled person with prior pile driving experience to be able to interpret the results of the analyzer. The piece of equipment is expensive and would not be able to be passed around to different districts.

Present Equipment

Mn/DOT recently purchased a Pile Driving Analyzer along with GRLWEAP and CAPWAP software. These programs perform wave equation analyses that could be used as a substitute for Mn/DOT's dynamic formula. This equipment is located in the Geotechnical Engineering Section.

Operating Season

The Pile Driving Analyzer is a portable microcomputer that can be used anytime during pile driving operations.

Personnel Actively Involved and Time Commitment

The Geotechnical Engineering Section is presently operating the Pile Driving Analyzer.

Present Program and Policies

In 1964 the FHWA provided Case Institute of Technology (now Case Western Reserve University) with a grant to develop a reliable pile driving monitoring system for piles under dynamic loading. Dr. George G. Goble led a research team to develop this monitoring system, out of which a company was formed called Pile Dynamics, Inc. (PDI). PDI now manufactures testing equipment that provides solutions to foundation design and construction. PDI manufactures the Pile Driving Analyzer along with various software and hardware products to better monitor pile driving.
PDI has a sister firm, Golbe Rausche Likins and Associates, Inc. that offers field testing services, dynamic testing analysis using CAPWAP and GRLWEAP, training for PDI equipment, and seminars across the country for dynamic testing and wave equation analysis.

Four metropolitan consulting firms have purchased a Pile Driving Analyzer and are capable of performing an analysis for Mn/DOT. Consultants have performed this type of analysis on certain large bridge projects within Minnesota. The Pile Driving Analyzer is presently being used to evaluate bearing capacities on the Bloomington Ferry Bridge in Hennepin and Scott counties.

Customers

1. Office of Bridges and Structures
2. Districts
3. Counties
4. Cities

Anticipated 5-year Program Needs

Mn/DOT will perform testing on one or two selected projects a year. Additional Pile Driving Analyzers should not be purchased, until such time that Mn/DOT has been able to assess the usefulness of the equipment and is able to determine personnel requirements to perform the testing.

Recommendations

1. Equipment needs: None at this time
2. Personnel needs: None at this time
3. Training: Include with instrument purchase
4. Equipment Locations: Geotechnical Engineering Section
5. Maintenance: To be determined
6. Resultant cost savings from recommendations: To be determined
7. Possible ramifications of not funding: Pile foundation construction will be less optimum. This has an initial economic impact and possible future additional maintenance and repair consequences.
X. Magnetic Particle (MT)

Introduction

1. Present Program: Mn/DOT presently uses MT to conduct non-destructive testing (NDT) in the field.

2. Purpose of Equipment: To conduct research and non-destructive testing (NDT) in the field.

3. What Equipment does: By spreading fine ferromagnetic particles over a magnetized area, surface and subsurface discontinuities in ferromagnetic materials can be located.

4. What data is collected: The size, shape, location, and extent of discontinuities can be determined.

5. How is data used: The data may be used in research, quality control, or to make repairs.

6. Location of equipment: Certain testing agencies, fabricators, and schools have MT equipment. The Mn/DOT Structural Metals Inspection Unit has MT equipment.

7. Relevant past history: In January 1993, the Structural Metals Inspection Unit used MT to ensure that a crack in a fracture critical member of Bridge # 9320 was completely removed.

Present Equipment

1. Number: The Mn/DOT Structural Metals Inspection Unit has magnetic particles and one fixed and one adjustable leg yoke for creating a magnetized area.

2. Status: The fixed leg yoke is old and has been replaced with a new adjustable model.


4. Limitation/capability: The fixed leg is heavy and has limited access, whereas the adjustable model is more versatile.

5. Maintenance: None

Operating Season

1. Time of year operated: Year round

Seasonal effects: must have dry area
Personnel Actively Involved and Time Commitment

1. Structural Metals personnel
   a. Supervisor: Structural Metals Engineer.

2. District personnel
   Bridge inspectors

3. Other
   Contractors and test agencies

Present Program and Policies

1. Mn/DOT inspection personnel conduct MT with minimal training and with no ASNT certification.

2. MT by other than Mn/DOT requires certified personnel

Customers

1. Mn/DOT maintenance and inspection
2. FHWA, AWS, & AASHTO
3. Cities, counties, & municipalities
4. Other state's DOT's
5. Structural metal fabricators
6. Other state agencies

Anticipated 5-Year Program Needs

1. Estimated Testing: Increase of testing and research

2. Equipment Needs: Prod type MT and accessories = $2,000

3. Personnel Needs: half time technician for field inspection = $15,000/yr
4. Training Needs: Inspectors need trained and certification = $2,000

5. Location and responsibility for testing: Structural Metals and field, Bridge Office

6. If funds are not available, research will be delayed and inspection will be less efficient
XI. Coating Inspection

Introduction

1. Present Program: Mn/DOT presently uses coating inspection equipment to conduct non-destructive testing (NDT) in the shop and field.

2. Purpose of Equipment: To assure that coatings are applied as specified.

3. What Equipment does: Measures and detects weather conditions, surface preparation, and thickness and adhesion of coating.

4. What data is collected: Temperature, dew point, cleanliness, surface profile, thickness, adhesion.

5. How is data used: The data may be used in research and quality assurance.

6. Location of equipment: Certain testing agencies, fabricators, and schools have coating inspection equipment. Mn/DOT Structural Metals Inspection Unit and District inspection units have coating inspection equipment.

7. Relevant past history: Structural Metals Inspection Unit continuously uses coating inspection equipment to assure quality coatings.

Present Equipment

1. Number: Mn/DOT Structural Metals Inspection Unit has 4 sling psychrometers = $260, 2 UV lamps = $600, 4 surface profile test kits = $800, 2 surface profile comparators = $500, 11 paint thickness gages = $7,000, & 2 adhesion testers = 1,200.

2. Status: Some paint thickness gages unreliable

3. Value/replacement cost: $10,500

4. Limitation/capability: Coating thickness at edges hard to measure, some paint gages slow or hard to read, and the psychrometer is outdated.

5. Maintenance: Limited

Operating Season

1. Time of year operated: Year round
Seasonal effects: Minimal

**Personnel Actively Involved and Time Commitment**

1. Structural Metals personnel
   a. Supervisor: Structural Metals Engineer.

2. District personnel
   Bridge inspection

3. Other
   Contractors & manufacturers

**Present Program and Policies**

Mn/DOT and Fabricator inspection personnel conduct coating inspection with minimal training.

**Customers**

1. Mn/DOT maintenance and inspection
2. FHWA, AWS, & AASHTO
3. Cities, counties, & municipalities
4. Other state's DOT's
5. Structural metal fabricators
6. Other state agencies
7. Coating manufacturers

**Anticipated 5-Year Program Needs**

1. Estimated Testing: Increase of testing and research

2. Equipment Needs:
   
   Replacement = $1000/yr
   Additional = $5000

3. Personnel Needs: None

5. Location and responsibility for testing: Structural Metals and field, Bridge Office

6. If funds are not available, research will be delayed, inspection will be less efficient and coatings will be of a lesser quality.
# GROUP 1 (Bridge) NDT MANAGEMENT PLAN

## PRESENT LEVEL OF SERVICE

<table>
<thead>
<tr>
<th>Program/Technology</th>
<th>Equipment Replacement Cost</th>
<th>Operation</th>
<th>Maintenance &amp; Calibration</th>
<th>Upgrade (Software, Etc.)</th>
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# GROUP 1 (Bridge) NDT MANAGEMENT PLAN

## RECOMMENDED ADDITIONS

<table>
<thead>
<tr>
<th>Program/Technology</th>
<th>Estimated Testing (1)</th>
<th>Equipment</th>
<th>Personnel</th>
<th>Total Estimated Annual Cost</th>
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<td>Vis.-Tact.-Hear.</td>
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<td>Electro Corrosion</td>
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</tr>
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*CONSULTANT CONTRACT*
# GROUP 1 (Bridge) NDT MANAGEMENT PLAN

## FIVE YEAR SUMMARY-PROJECTED COSTS (PRESENT LEVEL OF SERVICE)

<table>
<thead>
<tr>
<th>Program/Technology</th>
<th>Equipment</th>
<th>Personnel</th>
<th>5-Year Total</th>
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<tbody>
<tr>
<td></td>
<td>Equipment Needs</td>
<td>Total Cost (Operations)</td>
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<td></td>
<td>Number</td>
<td>Cost</td>
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<tr>
<td>Tactile-</td>
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# GROUP 1 (Bridge) NDT MANAGEMENT PLAN

## FIVE YEAR SUMMARY-PROJECTED COSTS (RECOMMENDED LEVEL OF SERVICE)

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<tr>
<th>Program/Technology</th>
<th>Equipment Needs</th>
<th>Equipment</th>
<th>Personnel</th>
<th>5-Year Total</th>
</tr>
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<tr>
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<td>Number</td>
<td>Cost</td>
<td>Total Cost (Operations)</td>
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<td>Electro Corrosion</td>
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*CONSULTANT CONTRACT EACH YEAR*
Group 2 - Pavements

1. Field Nuclear Density Measurement

Introduction

Mn/DOT uses the Seaman C-200 Nuclear Density Testing device to non-destructively measure the in place field density of bituminous pavement and the in place field density of granular base materials at the time of construction. The Seaman testing device is capable of making rapid non-destructive determinations of aggregate shouldering and base material densities in the range of 120 to 135 pounds per cubic foot (PCF).

Typically compaction results are a requirement of the contract and part of bituminous quality management. Compaction and density is a strong indicator of the percentage of voids in a bituminous pavement which has been correlated to the quality and life of a bituminous pavement product.

In nuclear density testing, the material being tested is exposed to a known amount of gamma radiation from a radioactive source. A Geiger-Mueller detector tube measures how much radiation is reflected, or scattered back from the material to the meter. This radiation ionizes the gasses in the detector tube, thus creating an electrical pulse. The meter then counts these pulses. Since dense materials absorb more radiation than the same material with a lower density, a high meter count implies the test material is of relatively low density, while a low meter count implies the test material has a relatively high density.

Nuclear moisture measurements as part of a density test are based on the neutron moderation principle. The radioactive source in the meter emits high speed neutrons that travel at the speed of light. The neutrons have the same atomic weight as a hydrogen atom. When the high speed neutrons encounter hydrogen atoms in the test material, the resulting collision reduces the speed of the neutron. The neutrons are now called slow-speed, or thermal neutrons, and travel at 1/1,000,000 the speed of a high speed neutron. The moisture detector in the meter is sensitive only to slow speed neutrons. The greater the moisture count, the greater the amount of moisture in the sample being tested.

The device generally samples material to an approximate depth of 2 inches, but can be adjusted to take measurements of thinner layers. It is assumed that density measurements of bituminous and aggregates, and measurements of granular base moisture are representative of the material conditions throughout the entire lift thickness.

Subgrade and grading soils are not tested with the nuclear device. Nuclear testing can produce adequate results on mechanically placed homogeneous isotropic graded soils. Isotropic soils must display the same properties in all directions, horizontal and vertical. Variability of soils and the presence of trace elements that may exist in variable quantities within the matrix of grading
materials, cause the testing device to produce questionable results.

Present Equipment

Mn/DOT owns and operates 11 Seaman C-200 Nuclear Testing Gauges. Nine Gauges are maintained and stored in each District and Metro site. Two Gauges are maintained and stored in Mn/DOT's Materials Lab. Use and licensing is presently being administered by the Bituminous Unit. The amount of use each nuclear test gauge receives is highly variable between the districts and presently there is no formal process of tracking the amount of use each receives. The process of tracking the location of each nuclear gauge as they are checked out consists of writing a District Number along with the serial number of the gauge to be taken on a piece of paper. This list of District names is kept in the storage room. Many districts include nuclear testing within the project contract and monitor the contractor's employees as they run the tests.

Each Seaman Nuclear Testing Gauge has an approximate replacement value of $9,000. When a nuclear gauge is to be either replaced or disposed of, the nuclear source within the gauge becomes a liability to the Department, and the costs associated with its disposal are incurred by the Department.

Operating Season

This equipment is typically operated at the time of construction paving. It is believed that the operational range of the nuclear testing apparatus is a function of the range of operation for the battery. The nuclear density testing devices have been successfully operated April through November.

Personnel Actively Involved and Time Commitment

Nuclear density testing is a project level test. Use of nuclear testing gauges is limited by the number of gauges and the number of trained personnel. Use of the nuclear device becomes highly advantageous on projects requiring a large number of repetitive density tests.

Operators are required to wear badges that monitor exposure to radioactivity at all times while handling and operating nuclear testing gauges. These badges are sent to an independent testing company, which then reports back the level of radiation an employee had been exposed to while handling and operating the nuclear gauge on a monthly basis.

Trained users of the Seaman Nuclear Density Gauge include members of the Bituminous Engineering and the Grading & Base Units in the Central Lab. Trained Mn/DOT District personnel vary, but may include the Materials Engineer, Soils Engineer, other materials office personnel and members of the construction offices. The Materials Engineer in each district is generally, but not always responsible for equipment care and training of personnel in their district.
Other users include county and other municipal agencies, along with private enterprises including contractors and consultants.

Training for the operation and care of the Seaman gauge is provided to all parties who are potential users on Mn/DOT projects. In the past, training was coordinated by Mn/DOT's Bituminous Engineering Unit and presented every three years. Recently, it was decided to transfer training responsibilities to the Technician Certification Coordinator and offer training classes on a yearly basis.

Tim Andersen, Mankato District Soils Engineer distributed a questionnaire to all Mn/DOT Districts concerning use and availability of the Seaman C-200 Nuclear Density Testing Gauge. Response was not received from all of the contacted District Offices. The following is a list of returned responses:

Duluth        Thief River Falls      Detroit Lakes      Morris
Mankato       Windom                 Metro West          Marshall
Bemidji       Brainerd              Willmar

Consensus of the returned questionnaires is that most district offices have adequate access to nuclear density testing gauges, but there are a few districts which do not use the equipment. Most of the respondents indicated they could use more of the gauges but a few qualified the desire to have more gauges with the desire to use more contractor testing.

Many respondents to the questionnaire expressed concern regarding insufficient nuclear gauge training. However, since that survey was conducted 50 people were train, and Mn/DOT is planning to train 65 more people, which include 15 Safety Officers. This may be one of the reasons why some of the respondents indicated that the equipment was not being used to determine aggregate base densities, but said it could be a future potential application. Training classes presented on a yearly basis has helped resolve these concerns.

Present Program and Policies

In the past, use and licensing of the gauges was administered through the Mn/DOT Materials Testing Unit, these duties were then transferred to the Mn/DOT Bituminous Engineering Unit.

Training is presently required for inspectors who perform nuclear testing and also inspectors who monitor contractor testing using nuclear gauges. Also, any person who operates a gauge must wear a radiation exposure badge and needs to be trained.

In the past, the nuclear testing gauges have been sent to the manufacturer on a yearly basis for cleaning, calibration, and leak testing. However, it has been found to be more cost effective to perform the cleaning and leak testing in-house. It has also been determined that yearly calibration of the nuclear testing gauge is unnecessary and will instead be recalibrated every five years at a
cost of $200 per gauge. Presently, all gauges are in good operating condition.

No records have been kept to determine time expenditures or costs associated with the in-house maintenance.

Customers

1. Mn/DOT Districts
2. Other state agencies
3. Counties
4. Consultants
5. Contractors

Anticipated 5-Year Program Needs

The need for additional equipment in the future is unlikely. The future policy of the Bituminous Engineering Unit will be to require the Contractor to furnish and operate the nuclear testing gauge. This will allow the Grading and Base Unit exclusive use of 11 nuclear gauges.

Training will continue to be an important issue. Classes are now offered on a yearly basis and geared to provide information to individuals on safety, correct handling, and proper testing procedures.

Recommendations

1. Purchase no additional equipment at the present time.

2. Continue the yearly training program. Scheduling of classes should be done through the Technician Certification Coordinator.

3. Each Office should have a license for their gauge(s).

4. Allow only those people who have had training to operate the gauges.

5. Designate a single person in each District to be responsible for checking out gauges, maintaining necessary records, maintaining gauges, and ensuring that operators are trained in the use, operation, and handling of the device.

6. Badges will be administered by the Physical Research Section for the lab. In the Districts, badges are administered by the District Materials Engineer.
II. Laboratory Nuclear Asphalt Content Gauge

Introduction

Nuclear asphalt content gauges provide a quick and accurate method to determine asphalt content without the use of solvents.

The nuclear asphalt content gauge directs a beam of neutrons through a bituminous mixture. As these neutrons strike hydrogen atoms, they lose energy and are thermalized. A counter measures the number of thermalized neutrons, which is directly related to the amount of hydrogen in the sample.

The primary limitation of the nuclear asphalt content gauge is that it has to be recalibrated for each new lot of aggregate, or if there is a greater than 20% change in the aggregate source, aggregate content, or recycled asphalt pavement content. This recalibration requirement is a major drawback for this device.

A second limitation to the nuclear asphalt gauge is that it is still necessary to extract the asphalt from the samples in order to obtain a product suitable for performing a mechanical sieve analysis. Current specifications require that a sieve analysis be performed to determine aggregate conformance with specifications.

Results obtained from side-by-side analysis of the solvent extraction method and the nuclear asphalt content gauge are consistent with each other. The nuclear gauge shows percent asphalt content generally 0.3% higher than solvent extraction methods. Current specifications allow a 0.8% difference between contractor and state tests.

Present Equipment

The Department owns nine Troxler Model 3242 nuclear asphalt content gauges. At the present time, two gauges are located at the Materials and Research Lab and one in each District lab.

The nuclear source life of each gauge is estimated at more than 2 years, and the electronics life is estimated at ten years. Each gauge has an approximate value of $9,000. When a nuclear gauge is to be either replaced or disposed of, the nuclear source within the gauge may become a liability to the Department, and the costs associated with its disposal are incurred by the Department.

Operating Season

The nuclear asphalt content gauges are used primarily during the construction season. Because the gauges are operated indoors, they could be used for research applications in the winter.
Personnel Actively Involved and Time Commitment

Trained users of the nuclear asphalt content gauge include members of the Bituminous Engineering Unit and District Materials Laboratories. Some contractor personnel also use the gauges.

No state or federal licenses are required to store or operate the gauges. However, state personnel wear radiation exposure badges which must be sent to an independent testing company every quarter for an analysis and report.

Present Programs and Policies

Currently, no formal testing program has been established for the nuclear asphalt content gauges, and the use of all gauges is considered experimental. The present program plan compares extracted asphalt contents with nuclear asphalt content determinations.

No state or federal licenses are required to store or operate the gauges. However, state personnel are required to wear radiation exposure badges when operating the gauges.

Maintenance consists of a leak test which must be performed every six months. This is performed by the Bituminous Office or the Districts where appropriate.

Customers

1. Mn/DOT Districts
2. Other state agencies
3. Counties
4. Consultants
5. Contractors

Anticipated Five-Year Program Needs

No additional equipment should be needed in the next five years. In addition, asphalt content determined with the nuclear gauge should be more cost effective and less labor intensive than solvent extraction methods. Nuclear testing has the potential to offer savings in time, personnel, and chemical disposal costs. However, new technology on the market may lead us to change our course.

Recommendations

1. Continue research using nuclear asphalt content gauges as an alternate method for determining asphalt cement content. Future specifications may not require extracted gradation.

2. Require state gauge operators to attend a training class.
III. Neutron Probe

Introduction

Neutron probes are used to determine the total moisture content in granular base and cohesive subgrade materials. The instrument measures total water content regardless of physical state (solid or liquid). When used in conjunction with other soil moisture measurements the data collected can be used to determine frost characteristics in frozen soils.

The probe contains a radioactive source (usually americium-241/beryllium) and a tube filled with a boron tri-fluoride gas. The fast neutrons emitted by the radioactive source are slowed by collisions with hydrogen atoms in the soil surrounding the source. These thermalized neutrons pass into the gas filled tube, collide with a boron tri-fluoride molecule and release an alpha particle. The alpha particle is attracted to a negative high-voltage electrode in the detector, and the resulting electrical pulse is counted by a logging instrument. The number of thermalized neutrons counted is then related to the number of water molecules in the soil.

The neutron probe assembly consists of an access tube and a probe. The access tube is approximately 8 feet in length and is driven through a 6 inch diameter hole cored through the pavement after road construction is complete. A rubber stopper is placed on top of the access tube and a surface box assembly is grouted into place. During the evaluation, the moisture probe device is lowered into the tube assembly and measurements are taken at prescribed depths.

Present Equipment

One Troxler 4302 Depth Moisture Gauge, Troxler Electronic Laboratories Inc.

Operating Season

Operating season is year round, except during extremely cold weather, when the readout device cannot be used because of the liquid crystal display.

Personnel Activity and Time

Currently, the gauge is being used exclusively on the Mn/ROAD research project. Operation of the gauge is limited to three designated operators.

Present Program and Policies

All users must be trained in use of nuclear materials, safety procedures, and legal transportation of nuclear materials. All operators are required to wear a monitoring badge to measure exposure levels. A radiation safety officer (RSO) is responsible for collecting radiation monitoring badges.
Customers
Currently, the only customers are within Mn/DOT, particularly the Mn/ROAD project.

Anticipated Five Year Program

Physical Research will most likely phase out this instrument in the next two years. The expense of the license from the Nuclear Regulatory Commission is a deterrent to continuing the use of this instrument.

Recommendations

No recommendations as the instrument will most likely be phased out in the next two years.

IV. Dynamic Cone Penetrometer (DCP)

Introduction

The objective of the DCP is to measure the in situ strengths of subgrade and base materials in an inexpensive and timely manner. While the DCP is not a true nondestructive testing device by definition, the lower shaft of the device leaves only a 5/8" (16 mm) hole in the material it penetrates.

The DCP is a quick and simple testing device which gives a continuous record of material shear strength with depth. The device consists of two 16 mm shafts connected in the middle, with the upper shaft serving as a guide for a 8 kg drop hammer, and the lower shaft containing a cone tip and scaled marks used for penetration measurement. A DCP requires two operators, one to lift and release the drop hammer, and the other to record the penetration following each drop. The current DCP design can penetrate approximately 40" into a material.

Test data is analyzed by plotting depth of penetration versus penetration index (mm/blow or in/blow). Material layers with a low penetration index have a higher relative shear strength. The most widely accepted strength correlation to the penetration index is the California Bearing Ratio (CBR). Since Mn/DOT design does not incorporate CBR strength, research is underway for DCP correlation to other strength parameters such as Proctor density or undrained shear strength.

The present program of DCP research began in 1991. To date there has been an extensive subgrade and base testing program conducted on the Mn/ROAD project, as well as several pilot projects used to develop information on how the DCP reacts to different soil types. Rudy Ford, formerly of the Mn/DOT Geology Unit, conducted research and formulated new specifications, currently in use, using the DCP to monitor edge drain trench compaction. In addition, the University of Minnesota recently began using the DCP in one of their compaction studies.
Present Equipment

Mn/DOT currently has 19 (manually operated) DCP's and one ADCP (automated DCP). Location of the devices are as follows:

- Physical Research: 2 DCP's and one ADCP
- Grading and Base Unit: 1 DCP
- Districts 1,3,4,6,8, & Metro: 2 DCP’s each
- District 7: 3 DCP’s
- District 2: 1 DCP

The remaining life of the DCP is unknown, however because they are well constructed and there is a low cost for their replacement components, a life expectancy of over 10 years is expected. The estimated value/replacement cost of a DCP test kit is approximately $1000, which includes the testing device, a case, an easy to read scale device, and a jack (for lifting the DCP after each test). Maintenance on the DCP is very low, consisting of replacement or reconditioning of cone tips, and the repair of welded connections as they break due to fatigue.

One prototype automated DCP was purchased by Mn/DOT in 1993. This device is continuing to be evaluated for both its comparison to the manual DCP results and its durability as a testing machine. Early experience has shown it to match DCP results very closely. However, mechanical bugs continue to be found and corrected. To date, over 250 ADCP tests have been conducted.

Operating Season

The DCP is used during the construction season for both research and project testing. Possible extension of its use may include determination of frost depth or use in preliminary surveys for project design.

Personnel Actively Involved and Time Commitment

Currently there is a supervisor (principle engineer) and operator/researcher (graduate engineer II) involved in DCP research and development. Time commitment from these individuals is approximately 5% and 25% respectively.

Customers

The customers presently being served by DCP data are:

- Mn/DOT Offices: Physical Research (Mn/ROAD)
- Foundations
- Pavement Engineering
District Soils and Materials
Construction

Potential Customers: Other State Agencies
SHRP
Universities
Contractor/Construction companies

Anticipated 5-Year Program Needs

The amount of testing is expected to increase, as DCP data could become part of standard in-situ data gathering in the districts. The DCP could also become another method of testing subgrade and base compaction during construction. The DCP may also be used as a form of "test rolling" for projects that currently do not justify mobilization of the high cost test rolling equipment.

The personnel needs will be incorporated into the present conditions, with the exception of the centrally located ADCP. If the workload for the ADCP increases significantly, a trained operator would be needed. This person might spend up to 40% of their time running and maintaining the ADCP machine. The benefits of the ADCP is that it requires only one operator, the testing procedure is much less labor intensive, and consistent test results are easy to obtain.

Recommendations

Establish a user/implementation group after completion of two years of use by the districts. This group's function will be to insure that proper information gets tied into design procedures and construction testing.

V) South Dakota Profiler

Program/Technology/Equipment

Introduction

Mn/DOT has been collecting pavement condition rating information since 1967. This information consists of two parts, (1) a subjective observation, by a pair of technicians in each district, of the surface distresses visible in a sampling of each mile, and (2) an assessment of the pavements "rideability" as measured with various electro-mechanical devices, and it is then correlated back to a panel of raters to get a "Present Serviceability Rating" (PSR).

From 1967 to 1983 ride was measured in each district with car mounted PCA Road meters, an electro-mechanical device more mechanical than electrical. They required a lot of maintenance, were difficult to calibrate and were slow and laborious to operate. Beginning in 1983, trailer
mounted Mays Meters were used to measure rideability. These devices were more sophisticated electronically, less prone to mechanical problems, eliminated many of the variables associated with being car mounted, and were much faster and more efficient to operate. However, they did still require the same annual correlation against a panel of raters.

In 1989, Mn/DOT put into service a "South Dakota Profiler" built in house for a cost of approximately $24,000, which included a van. The profiler replaced the nine Mays ride meters, and is operated centrally out of the Pavement Management Unit in the Office of Construction and Material Engineering. This device again represents an advancement in electronic sophistication. Equipped with three ultrasonic sensors and an accelerometer, the profiler establishes a spacial plane from which a pavement roughness profile is measured. An algorithm for the AASHTO Quarter Car is bumped against this profile to create an International Roughness Index (IRI) value in meters/kilometers or inches/mile. IRI is the index accepted by all technical and scientific organizations throughout the world.

In addition to IRI, the profiler is able to measure, at highway speeds, the height of the crown between right and left wheel paths thus approximating the average rut depth every two feet along the pavement. This improves the previous procedure of having raters estimate the depth and length of rut based on visual observation from a van moving slowly along the shoulder.

The roughness and rut data generated by the profiler is factored and weighted into the Pavement Management System for network reporting, program selection, and optimization. It is also used on a project level by district maintenance, materials, and preliminary design engineers.

The Department currently has one S.D. Profiler and it is housed at the Office of Construction and Material Engineering. It is operated by the Pavement Management Unit of that office.

Present Equipment

The current Profiler is mounted in a van with approximately 130,000 miles on it. The van, at this time, is in good mechanical condition. Electronics could be switched to a new vehicle without much complication by ESS personnel. Mn/DOT’s Profiler is based on Digital computer technology which is not being supported any longer. In the future, we will have to go to PC based system at a cost of $50,000 - $65,000.

Maintenance has been minimal, 6-10 man days/year done by ESS personnel.

Upgrades have been provided by South Dakota Dot at no cost. However, they are in the process of switching to a commercial PC based version of their profiler, and at that time will no longer support the original Digital version.

Commercial PC based South Dakota type profilers are available starting at $50,000 depending on the attributes desired.
Operating Season

The profiler can be operated in almost any reasonable weather condition, except during heavy rain or blowing snow. Extreme cross winds are also undesirable. The equipment has been used during windchills as low as -35.

Network testing is historically done beginning in April-May. Project level testing is performed year round.

Personnel Actively Involved and Time Commitment

Sr. Engineering Specialist: Planning, development, administration, data processing, and analysis - 9 work-weeks.

Student Worker: Primary operator - 18 man-weeks; data processing and reporting - 9 work-weeks.

Sr. Technician: Provided by districts as guide and driver for network and HPMS surveys - 17 work-weeks.

Sr. Electronic Technician - Maintenance - 1.5 work-weeks.

Present Program and Policies (include data utilization)

1. Network Level: Each year at least 50% (about 900 miles) of the roadways in each district are surveyed. This is accomplished with an operator from the pavement management office and a driver-guide from the district materials office. An exception to this is in the Metro Division where the respective Materials Offices borrow the Profiler and complete the survey with their own personnel.

The roughness and rutting data acquired from the survey, along with the distress data provided by the districts, are processed by Pavement Management staff for inclusion in the Pavement Management System.

A survey of all districts indicated that they anticipated no change in the usage levels for the S.D. Profiler other than a possible increase generated by its use for new pavement construction acceptance.

2. Project Level: The Profiler is used for project level analysis on a request basis. It has been used to determine if:

1) the incidence of rutting is greater in recent years than in prior years,

2) to evaluate the effect of frost heaves on ride,
3) to monitor the progression of rutting over time on a specific segment of roadway,
4) to determine any difference over time, in performance between research sections of varying mix designs,
5) to assess the change in ride quality and rutting on roads used for hauling and detours,
6) to locate and quantify the grinding necessary on the Rochester Airport's primary, runaway.

Currently, we are in the process of evaluating the feasibility of using the Profiler for concrete acceptance testing when the GM Profilometer is not available. There is also a study in progress to evaluate the possibility of using the Profiler to enforce a bituminous acceptance specification for ride quality.

Customers

1. Mn/DOT - District and C.O. Materials, Maintenance, and Preliminary Design Offices; Pavement Management; Pavement Design; Concrete and Bituminous Units; Physical Research; Mn/Road; Programming; and Aeronautics.
2. FHWA & SHRP
3. Counties
4. Consultants

Anticipated 5-year Program Needs

1. Beginning in 1993 the Network Level needs for ride and rutting data will be met using the PaveTech vehicle. The Profiler will be used as a back-up for the Network and for Project Level work where only ride and/or rutting data is required. The Profiler may also be used for concrete ride quality acceptance.

2. In order to meet the needs as stated above for the next five years we will need one Profiler. However, the current Profiler van currently has over 130,000 miles on it and would as a minimum have to be replaced at a cost of about $15,000 plus the cost of retro-fitting the electronics which are obsolete. More practically, a new commercial version of the Profiler should be purchased for approximately $50,000 within the five year period.

In the event that management decides that the Profiler will be used to measure new bituminous construction for ride acceptance, as a result of the current study mentioned above, then a need for at least three Profilers operated regionally (i.e. Duluth, Rochester and Metro) are envisioned.

3. In the past, the Profiler has been operated out of the Pavement Management Unit by a student
worker. Almost all of the network testing was done during the summer months when he was available full-time and when the districts have had time to complete their distress surveys and determine where the Profiler should be used.

With the acquisition of the PaveTech device we can now do the distress and ride/rutting surveys at the same time with one pass. We can test virtually year around as long as the roads are clear. However, we only have a student worker full-time during the summer; to take advantage of the PaveTech we need a full-time operator position. The PaveTech is an expensive complex piece of equipment not suitable for the casual operator. Pavement Management needs a technician as the primary operator of the PaveTech and the Profiler.

4. Emerging technology and equipment: In 1983 we purchased Mays Meters thinking they would last 5 years, in 1988 we replaced them with the S.D. Profiler, in 1993 we began using the PaveTech. In the next five years, the next big break through would be computer analysis of video imagery which would save at least 7 labor months each year and reduce subjectivity greatly.

5. Training for operation of the Profiler has been provided for two Metro Division operators as well as for the student worker in the Pavement Management Unit. It is provided by the Pavement Management Unit and can be accomplished in one day.

Recommendations:

1. Equipment needs: one replacement commercial version of the Profiler in the near future at a cost of $50,000, or possibly three such units at a cost of $150,000. (See previous discussion)

2. Personnel needs: one full-time position as primary operator of the PaveTech and the Profiler to enable us to operate the equipment year around and at times optimum for the districts. Cost $31,000.

3. Equipment location: current equipment housed at the Construction and Materials Engineering Lab, additional units would be located in the districts.

4. Maintenance: with the presence of many expensive, hi-tech electronic testing devices in the Lab there is a need for a Sr. Electronic Technician to provide preventative maintenance and repair to this equipment. This would minimize downtime. Much of our test equipment operates on the road and is already restricted by the shortened testing seasons in Minnesota. We are currently dependent on others for repair and thus subject to their work loads etc. Preventive maintenance, if done at all, is done by someone untrained in electronics and/or not overly familiar with the equipment. Cost $38,000.

5. Possible ramifications of not funding: failure to fund a position for a full-time operator of the Profiler and the PaveTech could leave an expensive piece of equipment idle much of the year when it could be used for special projects or to do the network survey in a district at a time most
convenient for them. The PaveTech equipment is expected to generate a work-hour savings of over $100,000 a year for the Operations Division.

VI) California Profilograph

Introduction

The California Profilograph is currently used by the Mn/DOT Concrete Engineering Unit as a method of measuring the roughness of new concrete pavements, and as an acceptance test on concrete texture planing projects. The machine, which resembles a truss on wheels, is pushed at a walking pace by the operator and a trace of vertical displacement of the pavement is then drawn on a roll of paper.

There has been no direct correlation drawn between the roughness measured by the profilograph and ride quality of a pavement. On new pavement the trace is used only to delineate areas which have "bumps" over 0.3 inches which require grinding by the Contractor as stated in Mn/DOT Specification 2301 because of the significant impact these defects cause in ride quality. It is known that surface defects of smaller dimension also detract from the ride of a pavement, but their effects can be better quantified with the GM profilometer.

In the case of concrete texture planing, the contractor is again required to provide the Project Engineer a trace which is used to determine whether an acceptable level of smoothness (10 inches per mile or less) has been achieved by the contractor.

Contractors are required by Specification 2301, and the Texture Planing Special Provisions, to provide their own equipment to measure the roughness of new concrete pavements and turn the reduced trace over to the Project Engineer for evaluation.

The Department's profilograph is used primarily as a teaching tool, as a specification enforcement aid, and as a research tool by the Concrete Engineering Unit when determining specification limits. The Mn/DOT unit has only been used once on new paving projects to confirm the readings taken by a contractor profilograph.

Present Equipment

Presently, the Department has one California Profilograph. The equipment is virtually maintenance free due to the lack of any sophisticated computing devices or mechanized mode of locomotion. The profilograph was purchased used from Allstate Paving in 1990 for approximately $7,000. Replacement cost is approximately $30,000.

The only anticipated equipment upgrade may be the addition of a computerized trace at some future date, if Mn/DOT incorporates the Profilograph into the ride bonus specification or if it is
added to the bituminous pavement specification. This cannot be definitely known at this time, however due to a possible upcoming change in the specification which will take a committee approval.

Operating Season

The profilograph can be operated year-round. The only physical constraints are the cleanliness of the pavement. Dirt, rocks and other material on the roadway may influence the readings.

Recommendations

This piece of equipment does not actually fall under the same category as the other NDT equipment from the standpoint that there is no actual testing program now, nor is there any anticipated in the future. Due to the use of the GM Profilometer for ride bonus computation and the fact that the contractor is responsible for supplying a profilograph trace to the Project Engineer there are no increases predicted in testing.

The only possible exception to this would be if a ride specification was added to bridge decks or bituminous pavement. In this case, some additional research by Mn/DOT would be required to determine an acceptable level of roughness before a specification was written. There would be no associated equipment costs to implement this specification change, due to the fact that contractors would still be required to provide the profilograph trace, much the same as they do for concrete pavement texture planing.

Therefore it is recommended that there be no changes made to the location, responsibility or testing program for the California Profilograph until such time as any future specification changes are implemented.

VII) GM Profilometer

Introduction

The GM Profilometer is used to determine the ride quality of new concrete pavements as stated under Mn/DOT Specification 2301. Simply stated, the machine is used to determine whether a pavement ride is good, average, or poor and assigns a roughness number to the ride which is used to determine whether a bonus or penalty will be assessed to the contractor.

The Department bought the GM High Speed Profilometer in 1982 as a replacement to the BPR Roughometer, which was used for several years to measure pavement roughness.

The equipment is located in the Non-Destructive Testing Unit of the Construction and Materials Engineering Laboratory.
Present Equipment

Currently, the Department owns one GM Profilometer which is used to test all new concrete pavements statewide. The machine is 10 years old and has an onboard Digital computer of 1979 vintage, which is both obsolete and virtually unserviceable and irreplaceable. The computer significantly delays the retrieval and analysis of data. A computer upgrade would cost approximately $80,000; a new machine would be approximately $300,000. A study is being proposed which would evaluate the South Dakota Profiler as an alternate method of obtaining the same information.

Operating Season

The Profilometer is operated year round, although primarily in the late summer and fall as new concrete pavements are completed. The equipment can be operated any part of the year, and at any temperature as long as the pavement is clean and dry.

Present Program and Policies

The Profilometer is currently used to enforce Specification 2301.3P1c, Riding Quality. There is no network level testing performed, only project level. The Construction and Materials Engineering staff needed to operate the equipment includes one Senior Highway Technician and one Tenured Laborer at approximately one-third time and a small amount of time from the Concrete Engineering Unit to determine which roadways need testing. The only district personnel needed are construction personnel to notify Materials when the pavement is ready to be tested and to handle any special traffic control problems which may be encountered.

Customers

Customers are primarily Mn/DOT Construction and the Concrete Engineering Unit. Occasionally, a county or city may include the ride specification in concrete paving if the speed limit of the roadway is above 42 MPH.

Anticipated 5-Year Program Needs

It is anticipated that the testing program will remain unchanged, unless the bituminous industry adopts a similar ride quality specification, in which case the anticipated testing would triple and the personnel to operate the equipment would need to devote full time to the testing program.

It seems highly likely that the present equipment will need to be replaced, either by a new GM Profilometer or a South Dakota Profiler. As was stated earlier, a study has been proposed which would evaluate the Profiler as a suitable low cost alternative since a South Dakota Profiler costs approximately $60,000. Since Specification 2301 does require the pavement to be evaluated for ride, some provision for replacing the Profilometer should be made.
Location of the equipment could either remain where it currently located, or be moved to the Pavement Engineering Section, depending upon the need for bituminous testing. If it becomes routine for bituminous to be tested for ride, then it would seem logical to have the equipment reside with Pavements so that there would be less steps in the process of getting a pavement tested, and the personnel would be doing the testing and analysis full-time.

Recommendations

Determine whether the bituminous industry will be going to a performance based specification for ride quality, and if so when. Should this occur, then provide for the transfer of the equipment and personnel to the Pavement Engineering Unit to expedite the testing and analysis of data.

In either event, budget for a minimum of $60,000 for a new South Dakota Profiler to replace the GM Profilometer. If the funds are not provided to replace the Profilometer, and it breaks down, Mn/DOT could be liable for as much as $700,000 in ride bonus payments to Contractors working under ride Specification provisions.

VIII) Survey on the Use of the FWD, Skid Tester, and South Dakota Profiler

USE OF THE FWD:

DISTRICT 1 (Todd Campbell) - The Materials section schedules and coordinates the work of the FWD. FWD testing is requested for any highways that are programmed, or that are preliminarily programmed, and that have not been tested in the last 5 to 6 years. The District uses TONN (computer program) to aid in designing overlays. Future needs will depend on programming and introduction of a detour policy.

DISTRICT 2 (Graig Gilbertson) - The Materials section schedules and coordinates the work of the FWD, however, SHRP has used Mn/DOT’s FWD to test some sections in the District. FWD testing is requested for any highways that are programmed, or that are preliminarily programmed. The District uses TONN to aid in designing overlays. The District also requests testing for determining spring recovery. All new bituminous pavements and overlays are tested. The District has an on-going program to maintain an up-to-date inventory of their highway system. Future needs will increase, due to the use of mechanistic design programs.

DISTRICT 3 (Kelvin Howieson and Bob Mathews) - The Materials section schedules and coordinates the work of the FWD. FWD testing is requested for any highways that are programmed or that are preliminarily programmed. The District uses TONN to aid in designing overlays. The District also requests testing for determining spring recovery. All new bituminous pavements and overlays are tested. The District does not have an on-going program of FWD testing. The District uses the FWD in evaluating detours and haul roads and has participated in research projects where the FWD is used. Future needs may increase if an on-going program of
testing is initiated.

**METRO DIVISION - GOLDEN VALLEY (Mike Robinson)** - The Materials section schedules and coordinates the work of the FWD. FWD testing is requested for special situations only. The Division does not have an on-going program of FWD testing. Future use will increase.

**METRO DIVISION - OAKDALE (Dan Hayne)** - The Materials section schedules and coordinates the work of the FWD. FWD testing is requested for any highways that are programmed or that are preliminarily programmed. The Division uses TONN to aid in designing overlays. The Division also uses FWD testing for special situations with Maintenance and Construction. The Division would like to utilize FWD testing for determining spring recovery, but has been unable to obtain the required testing from the NDT section. All new bituminous pavements and overlays are tested. The Division has an on-going program to maintain an up-to-date inventory of their highway system. Future needs will increase due to the use of mechanistic design programs and introduction of a haul road testing policy.

**DISTRICT 4 (Tom Swenson)** - The Materials section schedules and coordinates the work of the FWD. FWD is requested for every previous year's overlays. It is also requested on low rating strength roadways for overlay thicknesses. The District uses TONN to aid in designing overlays. They usually have 6 to 10 requests per year. The District once used the FWD for county detour routes. Now the counties are paid by vehicles. The District also tried FWD on haul roads, but it showed no damage.

**DISTRICT 6 (Ruth Betcher)** - The Materials section schedules and coordinates the work of the FWD. FWD is requested for highways that are programmed or they are trying to get programmed. The District uses TONN to aid in designing overlays. The District also requests testing for determining Spring recovery. Future needs will increase due to the use of the mechanistic design and developing an on-going program to maintain an up-to-date inventory of their highway system.

**DISTRICT 7 (Tim Anderson)** - The Materials section schedules and coordinates the work of the FWD. FWD is requested for highways that are programmed or that are preliminarily programmed. The District uses TONN to aid in designing overlays. FWD is also run on the shoulders of concrete roadways. Future needs will increase, because the District wants to check more shoulders. They would also like to use the FWD on roadways before reconstruction to locate pockets of poor soils for sites of further soils investigation. They have done county roads, but like the detour policy better.

**DISTRICT 8 (Art Bolland)** - The Materials section schedules and coordinates the work of the FWD. FWD is requested for highways that are programmed or they are trying to get programmed. The District uses TONN to aid in designing overlays. Future needs will increase due to the use of the mechanistic design and developing an on-going program to maintain an up-to-date inventory of their highway system.
USE OF THE SKID TESTER:

DISTRICT 1 (Todd Campbell) - The Materials section is nominally responsible for requesting skid testing, however in reality, traffic will make the requests through the Materials section when special situations arise. Testing use will not change unless the friction characteristics of the pavement surface is utilized in maintenance and replacement planning. This issue is addressed in the Department’s Maintenance Business Plan.

DISTRICT 2 (Graig Gilbertson) - The Materials section is responsible for requesting skid testing. Testing has been done in connection with a research project comparing skid numbers on 2341 vs. 2361. Also, testing is done for programming purposes. Testing use will probably not change in the future.

DISTRICT 3 (Kelvin Howieson and Bob Mathews) - The Materials section is responsible for requesting skid testing. The Maintenance and Traffic sections also make requests through Materials when special situations arise. Testing is requested for programming purposes, on all new bituminous pavements and on the previous years overlays. Testing use will probably not change in the future.

METRO DIVISION - GOLDEN VALLEY (Mike Robinson) - The Materials section is responsible for requesting skid testing. The Maintenance and Traffic sections also make requests through Materials when special situations arise. Testing is requested for programming purposes, on all new bituminous pavements, and on the previous year’s overlays. The Division has an on-going program to maintain an up-to-date inventory of their highway system. Testing use will probably not change in the future.

METRO DIVISION - OAKDALE (Dan Hayne) - The Materials section is responsible for requesting skid testing. Until recently, the traffic section was the responsible unit. The Maintenance and Traffic sections also make requests through Materials when special situations arise. The District intends to introduce the same testing criteria/schedule as Metro Division - Golden Valley in order to have uniformity within the Division.

DISTRICT 4 (Tom Swenson) - The Materials section is responsible for requesting the skid tester. Usually the Materials section picks up on the skid areas. The District averages two requests per year. The District noted prompt testing with the trailer, but the results need to come back more quickly. Lately, skid is not a major problem in the District. Testing use will probably not change in the future.

DISTRICT 6 (Ruth Becker) - The Materials section is responsible for requesting the skid tester. The Maintenance and Traffic sections also make requests through the Materials section when special situations arise. Testing use will probably not change in the future.
DISTRICT 7 (Tim Anderson) - The Materials section is responsible for requesting the skid tester. The Maintenance and Traffic sections also make requests through the Materials section when special situations arise. Testing use will probably not change in the future.

DISTRICT 8 (Art Bolland) - The Materials section is responsible for requesting the skid tester. The Maintenance and Traffic sections also make requests through the Materials section when special situations arise. Testing use will probably not change in the future.

USE OF THE SOUTH DAKOTAProfiler:

DISTRICT 1 (Todd Campbell) - The Materials section is responsible for requesting testing by the South Dakota Profiler. The Profiler is used for determining the ride for the PQI (Condition Rating) yearly, and for special situations such as where rutting may occur. No change in the Profiler’s usage is anticipated.

DISTRICT 2 (Graig Gilberston) - The Materials section is responsible for requesting testing by the South Dakota Profiler. The Profiler is used for determining the ride for the PQI (Condition Rating) yearly, and for special situations such as where rutting may occur. The District has used the Profiler test results as an indicator of poor soil strength in narrow embankments. No change in the Profiler’s usage is anticipated.

DISTRICT 3 (Kelvin Howieson and Bob Mathews) - The Materials section is responsible for requesting testing by the South Dakota Profiler. The Profiler is used for determining the ride for the PQI (Condition Rating) yearly, and for special situations such as where rutting may occur. The District uses the Profiler to record the condition of detours and haul roads. No change in the Profiler’s usage is anticipated.

METRO DIVISION - GOLDEN VALLEY (Mike Robinson) - The Materials section is responsible for requesting testing by the South Dakota Profiler. The Profiler is used for determining the ride for the PQI (Condition Rating) yearly, and for special situations such as where rutting may occur. No change in the Profiler’s usage is anticipated.

METRO DIVISION - OAKDALE (Dan Hayne) - The Materials section is responsible for requesting testing by the South Dakota Profiler. The Profiler is used for determining the ride for the PQI (Condition Rating) yearly, and for special situations such as where rutting may occur. No change in the Profiler’s usage is anticipated.

DISTRICT 4 (Tom Swenson) - The Materials section is responsible for requesting the South Dakota Profiler. The Profiler is used for determining the ride for the PQI (Condition Rating) yearly, and for special situations such as where rutting may occur. The District would like to see the South Dakota Profiler used for concrete rating deducts. They had an instance where a new concrete roadway had a ride of 3.0 with the South Dakota Profiler.
DISTRICT 6 (Ruth Betcher) - The Materials section is responsible for requesting the South Dakota Profiler. The Profiler is used for determining the ride for the PQI (Condition Rating) yearly, and for special situations such as where rutting may occur. No change in the Profiler usage is anticipated.

DISTRICT 7 (Tim Anderson) - The Materials section is responsible for requesting the South Dakota Profiler. The Profiler is used for determining the ride for the PQI (Condition Rating) yearly, and for special situations such as where rutting may occur. Future usage will increase if the Profiler is used for bituminous roughness.

DISTRICT 8 (Art Bolland) - The Materials section is responsible for requesting the South Dakota Profiler. The Profiler is used for determining the ride for the PQI (Condition Rating) yearly, and for special situations such as where rutting may occur. No change in the Profiler usage is anticipated.
## Group 2 (Pavements) NDT MANAGEMENT PLAN

### PRESENT LEVEL OF SERVICE

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<thead>
<tr>
<th>Program/Technology</th>
<th>Equipment Replacement Cost</th>
<th>Estimated Annual Costs</th>
<th>Personnel</th>
<th>Total Estimated Annual Cost</th>
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# Group 2 (Pavements) NDT MANAGEMENT PLAN

## RECOMMENDED ADDITIONS

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<th>Program/Technology</th>
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### Group 2 (Pavements) NDT MANAGEMENT PLAN

#### FIVE YEAR SUMMARY-PROJECTED COSTS (PRESENT LEVEL OF SERVICE)

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<th>Program/Technology</th>
<th>Equipment Needs</th>
<th>Total Cost (Operations)</th>
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<td>1 1/2</td>
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<tr>
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Total: $371,500 + $678,250 + $153,500 + $567,060 + $57,000 = $1,840,370
## Group 2 (Pavements) NDT MANAGEMENT PLAN

### FIVE YEAR SUMMARY-PROJECTED COSTS (RECOMMENDED LEVEL OF SERVICE)

<table>
<thead>
<tr>
<th>Program/Technology</th>
<th>Equipment Needs</th>
<th>Total Cost (Operations)</th>
<th>Personnel</th>
<th>Total Cost</th>
<th>Total</th>
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<td>(Pavtech)</td>
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<td>(DCP)</td>
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<td>IR Thermograph</td>
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Group 3 - Geotechnical

I. Ground Penetrating Radar Geotechnical Applications

Introduction

The Foundations and Geology Units of the Geotechnical Section determine approximate soil and rock profiles and their properties based on foundation borings taken in representative locations. This information, along with laboratory testing, is used to determine the foundation recommendations for bridges, retaining walls, culverts, embankments, towers, and buildings.

The classification and properties are determined for the soil and rock encountered in the soil borings, and the anticipated conditions in between these borings are based on interpolation and past experience. Ground penetrating radar has the advantage of producing continuous information. In areas where the location of rock or transitions between soil layers are variable and must be known with a certain level of confidence, ground penetrating radar could be used to define these layers on a continuous basis between the borings. Ground penetrating radar could also be used for determining marsh depths, locating voids in rock, and locating underground tanks.

Ground penetrating radar works by transmitting short, 80 to 800 MHz, electromagnetic pulses into the subsurface. The two way travel time is measured for the signal to return to the receiver. The penetration depth of GPR is dependent on the electrical properties of the material through which the signal is transmitted and the frequency of the transmitting signal. The lower frequency signals yield better penetration but have reduced resolution, and higher frequency signals yield higher resolution but have less penetration.

Highly conductive (low resistivity) materials such as clay severely attenuate radar signals. Water also attenuates the radar signal. When readings are taken through water, such as at a river channel, water depths must be less than 25 feet to obtain usable readings.

The Wisconsin Department of Transportation has access to ground penetrating radar equipment through their State Historical Society. They have tried the equipment in several situations with mixed results. For locating rock, their experience has been poor especially when the rock is overlain by silts or clays, with somewhat better results when the overlaying soils are sands. They have also used ground penetrating radar for determining marsh depths and locating underground tanks with mixed results for both of these applications. More promising results were obtained in locating voids under pavement and in rock. They plan to pursue testing ground penetrating radar for checking the joints in concrete and other applications.

GPR and other geophysical methods require some boring information to interpret the results. GPR gives reflections/refractions off layers of dissimilar materials. The layers can be picked out with a fair degree of accuracy, but the type of material of which the layer is composed is not
generally determinable.

GPR is best used to extend subsurface boring data, or to look at changes in layers over time by comparison to a previous traverse.

Present Equipment

Mn/DOT does not have any ground penetrating radar equipment at this time.

Operating Season

According to the brochures, the equipment can operate between -10° C and 40° C.

Personnel Actively Involved and Time Commitment

No Mn/DOT personnel are involved with ground penetrating radar at this time.

Present Program and Policies

Ground penetrating radar has been used at Mn/ROAD to determine pavement thicknesses.

Customers

1. Mn/DOT (Bridge Design and Districts)
2. Other state agencies
3. Counties
4. Consultants

Anticipated 5-year Program Needs

Ground penetrating radar should be pursued as a research project and evaluated in different situations and for different applications. It could be used to supplement boring information on select projects. One or two projects a year would be estimated to benefit from the use of ground penetrating radar.

If Mn/DOT were to purchase the equipment, the Geology Unit would need to be trained in gathering and interpreting the information. Ground penetrating radar systems cost between $20,000 and $50,000 depending on the applications. A different antennae is required for different applications and depths. The estimated time for gathering data and interpreting and presenting that data in a usable format would obviously depend on the size of the projects, but for two projects a year, two weeks total time for gathering and interpreting the information would seem sufficient. This may not be sufficient usage for someone to establish and maintain proficiency in the use of the equipment and interpreting data.
Recommendations

Ground penetrating radar may be beneficial in selected applications, situations, and locations. In order to determine where ground penetrating radar would fit into foundations investigations, it needs to be tried. The trial and evaluation of the equipment would probably best be handled as a research project that would evaluate the usefulness and economics for differing site conditions and applications. When needed on a production basis, consultants could be utilized for gathering and interpreting data on several representative locations. Consultant fees for gathering the information and interpreting the results are expected to be approximately $2,500 a day. Estimating two weeks for collecting and processing data, $25,000 a year for consultant services should be budgeted.

For Mn/DOT work done by consultants using GPR should be confirmed with boring information.

II. Earth Resistivity

Introduction

This is a surface geophysical testing method that measures the resistance to current flow conducted to the ground through surface electrodes. The spacing of the electrodes controls the depth and volume of investigation. The method principally yields an average resistance for the given volume of material it measures. Because of the large volume it measures, small changes in lithology or water content are often difficult to detect. It is generally a good tool for preliminary investigation, but must be accompanied by drilling or outcrop data.

This method has been used for many years, and improvements in equipment and methods of measurement have made it more practical. It is useful in areas where subsurface drilling is not possible due to limited access, or to characterize strata between known boring locations. It is an imprecise method, and is best used to look for relative changes or anomalies in the subsurface. Interpretation is difficult, although computer programs can generate solutions to fit the data. This method should never be used without subsurface borings for calibration. The best use of this method is a preliminary source for looking at areas in which to concentrate a drilling program or to stretch drilling data over a large area.

The method requires physical placement of at least four electrodes to test a given volume of soil. After the current is passed through and the reading is taken, the electrodes are moved to a different location, or are expanded to measure increasing depths.

Present Equipment

None.
Operating Season

Would not work with frozen ground.

Personnel Actively Involved and Time Commitment

None.

Present Program and Policies

None.

Customers

1. Mn/DOT - Bridge and Districts
2. Other state agencies
3. Counties
4. Consultants

Anticipated 5-year Program Needs

This method has not been used to any large extent by Mn/DOT in recent years, however with added restrictions on auger borings, it may become a valuable tool. Personnel in the Geology Unit are trained in this method and could conduct a resistivity survey with minor training.

Recommendations

At this time it is recommended that instrumentation be rented when needed. Should the demand for this service increase, consideration should be given to purchasing equipment.

The purchase price would be approximately $11,000 including interpretation software. Rental would be approximately $500 per week, however we may still need to purchase the interpretation software.

III. Seismic

Introduction

This is a surface geophysical method that uses artificially generated waves to measure distances to and thicknesses of subsurface layers. Seismic refraction measures the time the seismic wave takes to reach one or more geophones, which measures the velocity of the material and indirectly
yields the depth of layer changes. Seismic reflection measures the elapsed time it takes for a seismic wave to reflect off a layer and return to the geophone.

These methods have been employed for quite some time, and are useful in areas where subsurface drilling is not possible due to limited access. The methods are particularly useful for the detection of shallow bedrock. One limitation of this method is that the earth layer must be successively denser (higher velocity) with depth. This method is difficult to use and interpret under conditions of highly variable topography, and where there are shallow high density layers (such as clay or till).

Present Equipment

The Geology Unit currently owns a "Bison" MD-3 engineering seismograph, which is obsolete. Members of the Geology Unit have performed seismic refraction surveys, and are familiar with the current available instrumentation.

Operating Season

Would not work with frozen ground.

Personnel Actively Involved and Time Commitment

None.

Present Program and Policies

None.

Customers

1. Mn/DOT - Bridge and Districts
2. Other state agencies
3. Counties
4. Consultants

Anticipated 5-year Program Needs

At this time the Geology Unit is prepared to conduct seismic surveys where this method is appropriate, and would need to rent the necessary equipment. Seismic analysis would be practical on projects where depth of bedrock measurements are necessary and access by drilling vehicles is limited. One application would be rock cuts where the bedrock surface dictates the shape of the cut slope, and therefore the amount of right-of-way that needs to be required. We anticipate using the seismic method possibly as much as once a year, but more likely every two years. The
factors that will determine whether or not one of the seismic methods are used on a project are:

1. How much bedrock information can be obtained through direct investigative methods (drilling or outcrop measurement).

2. Type of bedrock - can we expect it to be consistent between borings, or is more information required at smaller intervals.

3. Weather - seismic methods can not be conducted in frozen ground.

Recommendations

1. Equipment needs: Rent the equipment when needed. Rental is estimated to run $1,000 per week.

2. Personnel needs: No additional personnel are required at the anticipated level of usage. This could be handled within the Geology Unit.
# Group 3 (Geotechnical) NDT MANAGEMENT PLAN

## PRESENT LEVEL OF SERVICE

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<thead>
<tr>
<th>Program/Technology</th>
<th>Equipment Replacement Cost</th>
<th>Estimated Annual Costs</th>
<th>Personnel Estimated Annual Cost</th>
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<td>Resistivity</td>
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Group 3 (Geotechnical) NDT MANAGEMENT PLAN

FIVE YEAR SUMMARY-PROJECTED COSTS (PRESENT LEVEL OF SERVICE)

| Program/Technology | Equipment Needs | | | Personnel | | | | | Total | Total |
|-------------------|------------------|--|--|--|--|--|--|--|--|
|                   | Number | Cost | Total Cost (Operations) | Number | Salaries, Etc. | Training | Total |
| Seismic           | 0      | 0    | 0                        | 0      | 0               | 0        | 0    |
| Resistivity       | 0      | 0    | 0                        | 0      | 0               | 0        | 0    |
| Ground Penetrating Radar | 0      | 0    | 0                        | 0      | 0               | 0        | 0    |
| Totals            |        |      |                          |        |                 |          |      |
## Group 3 (Geotechnical) NDT MANAGEMENT PLAN

### FIVE YEAR SUMMARY-PROJECTED COSTS (RECOMMENDED LEVEL OF SERVICE)

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<th>Total</th>
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