

MnROAD and the Adoption of New Products in Pavements

MnROAD Lessons Learned – December 2006

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1 Abstract

Throughout its decade of operation, MnROAD has become a major resource in the pavement community for test track expertise, pavement data, and pavement research. However, one overlooked benefit of MnROAD's first phase of operation is the effort of MnROAD engineers to introduce, develop, and encourage the use of new technologies and techniques for pavement engineers. While the list of new products tested and/or developed at MnROAD is extensive, this brief will focus on three products and the influence of those products outside of MnROAD: the Dynamic Cone Penetrometer, used to estimate the strength of subgrades; Ground Penetrating Radar, used in pavements to assess, among other things, layer thicknesses and subsurface conditions; and Continuous Compaction Control, which involves continuously measuring soil compaction and adjusting the needed force to compact the soil. These three highlights emphasize the ability of MnROAD to:

1. serve as a test facility for pavement and pavement foundation experiments,
2. develop new technologies and procedures for pavement engineering,
3. contribute in a significant manner to pavement engineering both at a local and national level.

It is hoped that this brief exposes the reader not only to a few past accomplishments of MnROAD in new technologies but will give a better idea of the promise and ability of MnROAD in the development and adoption of these technologies.

2 Background

This brief will explore three examples of MnROAD's involvement in the development of significant tools in pavement engineering. Before detailing MnROAD's involvement in these tools, a general introduction to each tool is provided.

2.1 Dynamic Cone Penetrometer

The dynamic cone penetrometer (DCP) is a tool that has been used in various forms for centuries to test soils, beginning in 17th century Germany. The DCP as used by MnDOT is a variation of a version that has existed since the late 1950s. Since that time, pavement engineers have used the DCP as a quick, portable means of estimating the soil shear strength or modulus of elasticity of a given subgrade. To conduct a DCP test, a drop hammer of a specific weight is dropped onto an anvil with a pointed tip. The penetration of the tip is recorded as an indexed value (usually in terms of mm/blow), and the engineer can correlate this index to a specific soil property for a given soil/base type. While values determined using DCP are not as accurate as those of other more complicated tests, engineers have used the DCP for some time due to its portability and ease of use in assessing in situ foundation characteristics, including uniformity of compaction.

As will be seen, MnROAD has contributed to developments in the DCP and its adoption in the field.

2.2 Ground Penetrating Radar

Ground penetrating radar (GPR) is a non-destructive test used to assess the subsurface properties of a pavement in the field. GPR consists of a transmitter to create a pulse of electromagnetic energy into the ground; an antenna to detect the reflected pulses; and a data collection system to monitor the arrival times and amplitudes of the reflected pulses. GPR can assist engineers in determining a variety of material properties of the pavement (including density and moisture content) and in identifying inconsistencies in the pavement, such as cracks, air voids, or areas of noticeable stripping. The ability of GPR to detect these properties and do so non-destructively makes it an excellent candidate to monitor and assess the condition of a given pavement. The only limitations of GPR hinge on the material being analyzed: GPR is best suited for asphalt concrete pavements and dry Portland cement concrete pavements. GPR is not suited for wet layers or layers containing a high amount of clay or materials that absorb the pulse signals (e.g. taconite).

2.3 Continuous Compaction Control and Lightweight Deflectometer

Continuous compaction control, or “intelligent compaction” (IC), is a means of quality control in the construction of pavements. During IC, the stiffnesses of the materials under compaction are continuously monitored, and the stiffness data is linked to the machine controls, which then adjust the compaction accordingly. This continuous loop of stiffness measurement informing compaction avoids over- or under-compaction and is thus an efficient system for achieving appropriate compaction. In fact, IC has been found to reduce labor and overall costs by as much as 30% (Briaud and Seo). While many European nations have been using IC for over a decade, most North American pavement engineers consider IC an emerging technology. As such, many North American pavement experts are recently “discovering” IC for pavement construction.

3 MnROAD Experiences with New Products

Beginning with its fourteen original research objectives, MnROAD engineers have set out to explore new methods of testing on pavement systems both to assess the pavements at MnROAD and to contribute to the development of these methods in the larger community (at the local, state, and federal levels). Thanks to MnROAD’s accessibility and its engineers’ willingness to experiment with non-standard materials, testing devices, procedures, and pavement designs, MnROAD has served as a capable facility for the staging and examination of a variety of experiments (some of which are not pavement related). MnROAD’s experiences with three products and MnROAD’s contribution to the development of those products are detailed in this section.

3.1 MnROAD Experiences with the Dynamic Cone Penetrometer

MnROAD personnel have applied the DCP to test sections since the initial stages of MnROAD beginning in June 1991. During the construction phase, MnROAD engineers conducted over 700 DCP tests at the MnROAD facility. Since that time, MnROAD has used the DCP regularly to evaluate newly constructed and rehabilitated pavements. While MnROAD has experienced a

significant number of highlights, one of the brightest of MnROAD's accomplishments has been its long and productive relationship with DCP.

Outside of MnDOT Report 1993-05, *In Situ Foundation Characterization Using the Dynamic Cone Penetrometer*, most of the early work at MnROAD using the DCP was not focused on the DCP apparatus or procedure itself: the DCP was being used mainly to characterize the subgrade soil/granular base types and compare these results with those of falling weight deflectometer (FWD) tests (MnDOT 1994-19, MnDOT 1996-19). However, as MnROAD engineers became more familiar with the DCP, they began to modify the DCP apparatus and consider applications for the DCP on Minnesota pavement systems.

Given the large amount of use the DCP devices at MnROAD have tolerated, MnROAD engineers have suggested and made a series of physical modifications to the device itself, modifications that have now become standard on the DCP as used by MnDOT. One improvement was to improve the connection between the upper and lower rods of the device to facilitate quicker and easier assembly. MnROAD engineers also added a hand guard on the anvil to prevent accidents from misplaced hammer blows. The durability of the DCP device was also improved by reinforcing the welds at the junctions in the assembly.

Furthermore, MnROAD's DCP testing and the frequency of its testing gave it an insight into the labor intensive and repetitive procedures needed to conduct the test properly. To avoid inaccurate results due to operator fatigue, MnDOT proposed the development of an automated DCP (ADCP) based on MnROAD's experience with the DCP. Though other DOTs proposed an ADCP, few succeeded in seeing the proposal result in a functioning design. However, through the Breakthrough Innovation Program MnDOT awarded a contract to design and construct an ADCP to a firm in March 1992, and by 1993 MnDOT had a working concept to evaluate for use in the field. Pioneering projects such as this have made today's generation of ADCP a reality.

In the early testing of its subgrade soils and granular bases, a number of engineers and researchers constructed a comparison of DCP estimations of stiffness with those of FWD and lab testing. Some work determined the appropriateness of correlating the DCP's penetration index (DPI) with the soil modulus of elasticity. An early example of this research is MnDOT Report 1994-19, *Characterization of the Subgrade Soils at the Minnesota Road Research Project*. Later research, MnDOT Report 1996-19, investigated the correlation between the DPI and resilient modulus values.

Much like the modifications made to the apparatus, investigations into the DPI were a product of MnROAD's ongoing effort to characterize the pavement test sections for the sake of other research. Hence, work such as that in MnDOT 1994-19 led to later research from MnROAD that focused on the DCP alone, work such as "Comparison of the Dynamic Cone Penetrometer with Other Tests During Subgrade and Granular Base Characterization in Minnesota" (Siekmeier, et. al. 1999). In this paper, from the analysis of data collected at MnROAD and other locations in Minnesota, the authors found a correlation between the strength as measured by the DCP and the modulus of elasticity as measured by a portable FWD.

In addition, MnROAD's continued work in refining the application of the DCP in the field prompted MnDOT to investigate and eventually adopt the use of the DCP to evaluate the uniformity of compaction of pavement edge drain trenches and granular base layers. In MnDOT Report 1997-19, *Application of Dynamic Cone Penetrometer to Minnesota Department of Transportation Pavement Assessment Procedures*, the author deals mainly with specifying the limits on the DPI values for a given material to be used in the sublayers of the pavement system. However, though the report concerns the limits of DPI values for different types of materials, a by-product of this work in DPI limits that the report acknowledges is the development of MnDOT specifications from MnROAD's experiences in DCP between 1991 and 1996, which will be discussed in a later section.

3.2 MnROAD Experiences with Ground Penetrating Radar

Though ground penetrating radar (GPR) has existed as a viable technology since the late 1970s, the pavement community did not completely embrace GPR in assessing pavements until the early 1990s. While many of these assessments were conducted on in-field pavements, very few were constructed on pavement systems whose design and components were documented to the extent of those at MnROAD. Hence, very soon after opening to traffic, GPR studies were conducted at MnROAD.

In the earliest work beginning in 1994, GPR was used to evaluate the thicknesses of the test sections and compare these values against known design thicknesses in Maser's *Ground Penetrating Radar Survey of Pavement Thickness on MnROAD Sections* (MnDOT 1995-06). This early report is evidence of MnROAD as the first full-scale test track to support and use GPR testing. This early test acted as a pilot quality control for MnROAD (to confirm that sections were constructed to design) and simultaneously as a way for the researcher to compare the GPR's assessment against actual thicknesses (determined through coring).

MnDOT Report 1995-06 correlated the measured thicknesses with the design thicknesses to determine the accuracy of the GPR assessments. For asphalt pavements, the comparison between measured thicknesses and thicknesses from cores yielded a strong correlation ($R = 0.98$). For concrete pavements, the correlation was less convincing ($R = 0.76$). The recommendation from this report was that GPR could be used confidently to assess the thicknesses of asphalt pavement systems and could be used confidently in conjunction with limited coring to assess concrete pavement thicknesses. Another result of this report is that suspicions about certain sections not having been built to the specified design were confirmed by the GPR.

In the last five years, MnDOT has purchased and maintains state-of-the-art GPR equipment, including two data collection units and five antennas, capable of underground profiling from 2" to 50'. MnROAD is used to calibrate these antennas on a frequent (semi-annual) basis. Metal calibration plates have been placed at precise locations and depths within several test sections (Cells 31, 33, 34, and 54). GPR air-coupled antennas are calibrated to within 1/2" for asphalt thickness and to within 1" for base thickness. However, calibration with concrete thicknesses is not possible (Cell 54) because of the high taconite content. Currently, GPR calibration

specifications are being developed (and possibly proposed as an ASTM standard) that incorporate this calibration information.

3.3 MnROAD Experiences with Continuous Compaction Control

The two products discussed thus far each have been ongoing areas of concern at MnROAD for a decade or more. To illustrate that MnROAD's contribution to developing new products in pavements is not finished, this brief presents MnROAD's involvement in an exciting new tool in pavement construction quality control, continuous compaction control (more commonly known as "intelligent compaction" or IC).

Through demonstrations at MnROAD and the involvement of MnROAD engineers in a statewide IC Task Force, many factors related to the use of IC in unbound material compaction have been uncovered through MnROAD. During the demonstrations, MnROAD engineers confirmed the steps involved in the IC process and the tools used to complete each step. The compactor was found to be easy to operate and capable of measuring the stiffness and adjusting the compactive force. Engineers also confirmed the data transfer from compactor to server. Overall, MnROAD engineers found that intelligent compactors do an excellent job of ensuring uniformity in compaction and acquiring the soil modulus for the next generation of mechanistic-empirical pavement design (MnDOT 2005-07).

Furthermore, MnROAD engineers have developed a series of steps needed to test for compaction in a given project in supplanting sand cone testing with IC. Whereas the current tests for compaction assign an R-value that is primarily an index parameter, the IC measurement provides a modulus of elasticity that is more useful to engineers as an input for mechanistic-empirical pavement design. While the modulus is also dependent on density, moisture, soil stress, age, and other factors, the introduction of technologies such as the lightweight deflectometer (LWD) and GeoGauge have improved the ability to characterize the soil or aggregate layers in ways not available through those associated with the R-value.

MnROAD experiences with IC have led to MnDOT's implementation of IC for truck highway project construction and the drafting of pilot specifications for this use. In both instances, MnROAD engineers have played a role, either as a member of the statewide IC task force or in authoring or overseeing the specifications. These IC experiences will be further detailed in the following section.

4 MnROAD Contributions in Pavements for New Products

For the three products discussed in this brief, MnROAD's contributions to pavements have been quite significant, especially in the state of Minnesota. MnROAD's entire efforts with DCP as detailed above have influenced MnDOT and its assessment of subgrades and pavement systems in the field. The most basic of MnROAD's lasting effects on DCP use in Minnesota is the amount of MnDOT engineers who have benefited from the DCP modifications and procedural expertise developed by MnROAD engineers. Furthermore, MnROAD's work with DCP prompted MnDOT to incorporate DCP testing in two specifications for pavement assessments: 1) quality control for the backfill compaction of pavement edge drain trenches (MnDOT Spec SP5-

128) and 2) quality control of granular base layer compaction (MnDOT Spec 2211.3.C4). Furthermore, thanks to the research on DCP done at MnROAD, MnDOT has had the confidence to use DCP testing for a variety of nonspecified work that includes an assessment of base and subgrade conditions under full-depth bituminous cracks and the foundation strength of footing pads for a building.

Pavements in Minnesota have also benefited from the improvements in GPR that have taken place thanks to MnROAD. Since the first use of GPR at MnROAD, MnDOT has expanded both its GPR equipment and user expertise. More importantly, MnDOT has expanded the number of fields in which GPR is a useful non-destructive method of assessing a given situation. In addition to its applications in pavements, MnDOT now uses GPR to profile subsurface conditions, to locate underground utilities, and to assess the condition of bridges. More information on MnDOT's use of GPR can be found in "Current State of the Art and Practice of Using GPR for Minnesota Roadway Applications" from the Minnesota Local Road Research Board.

The demonstrations of IC equipment at MnROAD were a noticeable component of the MnDOT's scrutiny of current MnDOT compaction acceptance criteria and the quality control and quality assurance procedures for soil and aggregate bases. The use of IC by MnDOT could potentially lead to better record keeping and reporting of project activities and increased compaction uniformity and complete documentation of every lift. In addition, the use of IC through this pilot specification could potentially lead to reduced costs and labor during the compaction process. The potential benefits of the use of IC led to the development in January 2006 of an IC Pilot Specification. This specification details the use of IC in meeting MnDOT compaction requirements and will lead to more uniformly compacted lifts in the pavement systems and more QC/QA data describing the lifts in the pavement system.

Furthermore, MnROAD experience has been involved during work plan development for IC in NCHRP 21-09, a federally funded project to determine the reliability of IC equipment and develop construction specifications for projects involving IC. MnDOT is also lending its MnROAD-derived experience to an FHWA-led IC Pooled Fund study. Thanks to MnROAD experience and initiatives, Minnesota has a docket of projects and demonstrations scheduled that involve IC, and this experience will likely play a large role in the development of IC in the United States.

5 Conclusion and Recommendations

MnROAD's long involvement with these products is an excellent example of the benefits of research and data collection. Had there been no desire for completeness in research to characterize the test sections at MnROAD, the later DCP developments in specifications would not have occurred.

This example further illustrates the need for MnROAD to promote its ongoing research and data more aggressively. Much of this research has the potential to influence pavements in the way that the DCP work has, but MnROAD's inability to devote resources to promoting research only makes MnROAD research, data, and expertise easy for outside agencies, corporations, and

institutions to overlook. MnROAD's experience in these new products suggests that the MnROAD facility and its pool of experienced researchers is a valuable—but still after 10 years a relatively untapped—resource to the pavement community.

The DCP example is especially notable in that it represents the potential benefits of regular, thorough data collection, analysis, and reflection. At each stop in MnROAD's history with the DCP, whether it be the initial collection of subgrade data from the original test cell construction or the comparison of a the DCP characterization of a soil with that of an FWD profile-based characterization, the overall research presents solutions and alternatives for existing problems and raises challenges for future research. This process, drawn over five or more years, is capable of providing MnDOT (and other organizations) with a wealth of pavement expertise. In the case of DCP, MnDOT was able to use this DCP expertise as the foundation for the adoption of DCP on a large scale in the state of Minnesota. Furthermore, as evidenced by ongoing and future work, a similar experience is playing out with GPR and IC both on the state and national levels.

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