State Transportation Innovation Council

Final Report on Michigan Department of Transportation's Improving Geotechnical Site Characterization with Cone Penetration Testing

Submitted by: Richard Endres, Ryan Snook, and Erron Peuse
Michigan Department of Transportation
Bureau of Bridges and Structures
Geotechnical Services Section

DESCRIPTION OF THE PROJECT

The Michigan Department of Transportation (MDOT) participated in the Federal Highway Administration's (FHWA) Every Day Counts – 5 (EDC-5) Advanced Geotechnical Methods in Exploration (A-GaME). A-GaME is a set of underutilized subsurface exploration tools for enhanced, effective site characterization. These A-GaME tools assist with assessing risk and variability in site characterization, optimizing subsurface exploration programs, and maximize return on investment in project delivery. There are a variety of featured exploration methods in A-GaME including cone penetration testing (CPT), electrical methods, seismic methods, monitoring while drilling, and downhole televiewers. MDOT has chosen to pursue CPT for EDC-5 as it was suspected to have the biggest impact on MDOT's typical work.

CPT involves pushing an instrumented cone into the ground at a rate of 2 cm/sec and collecting data every 2 cm. The cone has sensors that record the tip resistance, sleeve friction, and pore water pressure, which can be used to establish important soil parameters for design and construction. With the high rate of data collection, CPT creates a nearly continuous profile of the subsurface.

MDOT's goal for participating in A-GaME was to improve our site characterizations by exploring one of the underutilized methods, specifically CPT. By improving site characterization, MDOT intends to reduce risk to a project by reducing uncertainties in the subsurface conditions and thus improve quality and confidence in the geotechnical characterization. This will accelerate project delivery by reducing construction delays from inadequate knowledge of subsurface conditions. MDOT's goals for A-GaME were to acquire CPT equipment, train staff, use CPT on 5-10 projects, present findings, and update guidance documents.

Prior to A-GaME, MDOT had some exposure to CPT. In the mid-1990s, CPT was used on the expansion of the Blue Water International Bridge Plaza (completed by a consultant), and CPT was demonstrated at a Midwest Geotechnical Conference that MDOT hosted. In 2006, MDOT completed an internal demonstration project by

pushing an electric cone but used a retrofitted auger drill rig to complete the soundings. The process with the retrofitted drill rig was slow and cumbersome because issues with the mechanical and data collection systems were significant. As a result, subsequent use of CPT on internal MDOT projects was not pursued. Historically, there has been little CPT use in Michigan, and no commercial CPT contractors were available in the state. However, through webinars and discussions with other states that use CPT, we did see the benefits CPT can offer and wanted to evaluate it as a tool to improve the quality of geotechnical investigations in Michigan. The need to procure specialized CPT equipment was weighed with respect to the potential benefits.

MDOT made the decision to purchase CPT equipment as a complement to our traditional drilling and perform the work in-house. MDOT purchased the S4 system from Vertek, which is a self-anchoring CPT system with 20 tons of push force and attaches to a commercial skid steer. MDOT has equipped the S4 with 15 cm^2 seismic piezocones, which provide tip resistance, sleeve friction, and pore pressure readings. The cones can also be used to determine shear wave velocity and complete pore pressure dissipation tests. The S4 was selected based on several factors including:

- portability of the equipment for use in uneven terrain/softer soils
- CPT system, cones, data acquisition system, and accessories from the same manufacturer
- technical support for the equipment and software from the same United States manufacturer
- initial investment required to get CPT up and running
- equipment and software options, etc.

In addition to the CPT system, MDOT also purchased a skid steer, truck, and trailer to create a complete package. Having the CPT in-house allows us to be agile with when and where we complete CPT soundings and allows MDOT field and office personnel the opportunity to get hands-on with the CPT instead of just receiving the data. CPT and auger boring rigs can be mobilized at the same time to minimize traffic control and mobilization efforts. We can be agile with adjusting the number and type of soundings if conditions warrant while we are still on site.

OVERALL BUDGET

As previously noted, MDOT had very little experience with CPT and did not possess modern CPT equipment to make the exploration process efficient. To procure the CPT system and associated equipment, a total of $271,861.58 was needed; the breakdown is shown below in Table 1.

Table 1: CPT Equipment Cost Breakdown

Equipment	Cost
Vertek S4 Seismic CPT System	$129,937.80
Bobcat T770 Skid Steer	$60,370.78
Ford F-550	$67,615.00
Felling Trailer	$13,938.00
Total	**$271,861.58**

Funding for the procurement of the CPT and associated equipment was made through a combination of State Transportation Innovation Council (STIC) incentive program funds and fleet funding through MDOT. The awarded STIC funds totaled $70,000 and the remainder was paid for with State of Michigan funds through MDOT's fleet services.

It should be noted that the Geotechnical Services Section did not have the ancillary equipment needed to support the S4 CPT system (skid steer truck and trailer), but if an agency had the necessary ancillary equipment, then the cost of getting into CPT would be less than half of MDOT's costs.

HOW MDOT'S WORK MEETS THE PROGRAM CRITERIA

MDOT procured the CPT system and associated equipment in late 2019 to early 2020 and began using it on projects in April 2020. The photos on this report's title page show our CPT system attached to the skid steer and an up-close view of the cone.

MDOT completed CPT soundings at locations adjacent to recently completed soil penetration testing (SPT) soil borings or on projects where we were scheduled to complete SPT soil borings. These side-by-side comparisons are important for geotechnical staff to become acquainted with data that the CPT provides versus the data and soil samples we are currently using for design and construction. At the time of this report, MDOT has completed over 90 CPT soundings at 18 project locations around the state. These projects cover not only a wide geographical range of Michigan but also the geologic conditions. We have pushed CPT in a variety of subsurface conditions consisting of sands, silts, clays, and organic soils.

MDOT has taken the CPT results, along with the side-by-side borings and soil laboratory test results and begun comparing them to gain a better understanding of what CPT data represents and how CPT data compares to information gathered from SPT borings. Beyond comparing soil properties, we have also noticed that CPT provides a more detailed stratigraphy. This increased detail is immediately evident as material boundaries and changes in the density or consistency can be seen. This includes interbedded thin soil layers, which can easily be missed in SPT borings.

RESULTS OF THE PROJECT

As previously noted, MDOT has successfully procured the CPT equipment and used it on 18 sites across Michigan. We have completed CPT sounding at these sites and are comparing them with our SPT borings and laboratory testing. This gives us the opportunity to build familiarity with CPT by comparing it with our exploration and testing methods we are accustomed to.

One of the first things that stands out is the more detailed stratigraphy that CPT provides. With traditional SPT borings we typically drive one 18-inch sample every 5 feet while CPT is taking readings of tip resistance, sleeve friction, and pore pressure every 2 cm. The increased data density enhances the stratigraphy and is beneficial on all MDOT projects, and we have found it especially valuable in two of our common geologic conditions.

First, Michigan has a variety of organic and soft soils throughout the state from the formation of swamps after the last glaciers retreated. When roads were built through the swamps, the organic and soft soils may have been covered or removed to various degrees of effectiveness. We have used CPT in these organic soil conditions for culvert replacement projects and the investigation of an area with ongoing roadway settlement. The detailed stratigraphy enabled MDOT to better delineate the organic and soft soils but also identify areas where partial replacement of the organic soils with granular soils had occurred. The improved stratigraphy and understanding of the subsurface conditions allowed MDOT to make better decisions and recommendations for culvert and roadway projects. Figure 1 shows a typical CPT sounding log that encountered organic soils from about 9 to 30 feet below ground surface. Notice that CPT picked up on 2 sand layers within the larger organic layer.

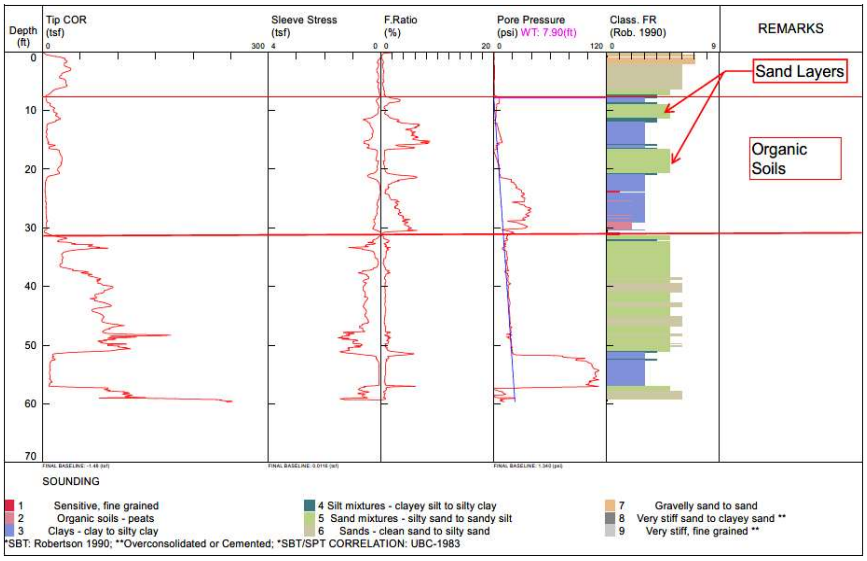

Figure 1: Typical CPT Data

The second geologic condition where MDOT has seen benefit is in our lacustrine clay deposits, which are associated with glacial activity that formed the Great Lakes. In Michigan's lacustrine clay deposits, there is typically a stiffer desiccated crust that overlies a significant deposit of softer clays to depths of 80-100 feet below ground surface. From the CPT data, delineating the thickness of this curst was easily identifiable versus our traditional SPT borings. This additional confidence in the understanding of the subsurface conditions will allow for an increase in the use of shallow foundations bearing in the stiffer desiccated crust versus constructing more costly deep foundations. MDOT's overall program will see savings as more projects are able to utilize shallow foundations due to CPT.

As previously noted, MDOT took CPT soundings side-by-side with SPT borings to become familiar with how CPT data looks for a variety of Michigan's soils. We have plotted CPT results on Soil Behavior Type (SBT) charts to get more familiar with differences and similarities between soil classification and SBT. In general, the CPT data for our sands tends to plot in the sand and sandy mixture areas (zones 5 and 6) with the looser sands plotting in the sandy mixture zone. On sites consisting of predominantly clay soils, most of the CPT data plots in the silt mix or clay areas (zones 3 and 4) on the SBT chart. However, many of the organic soils we encountered plot in the clay area (zone 3) and the boundary of organic silts and clay areas (zones 2 and 3).

In Figure 2, the red ovals are highlighting some of the CPT data from organic soil layers that did not plot in the sensitive or organic soil regions of the SBT plot (zones 1 and 2). Why data from these organic soil layers do not plot in zones 1 and 2 is something that we will need to be further investigated as we continue to work with the CPT data.

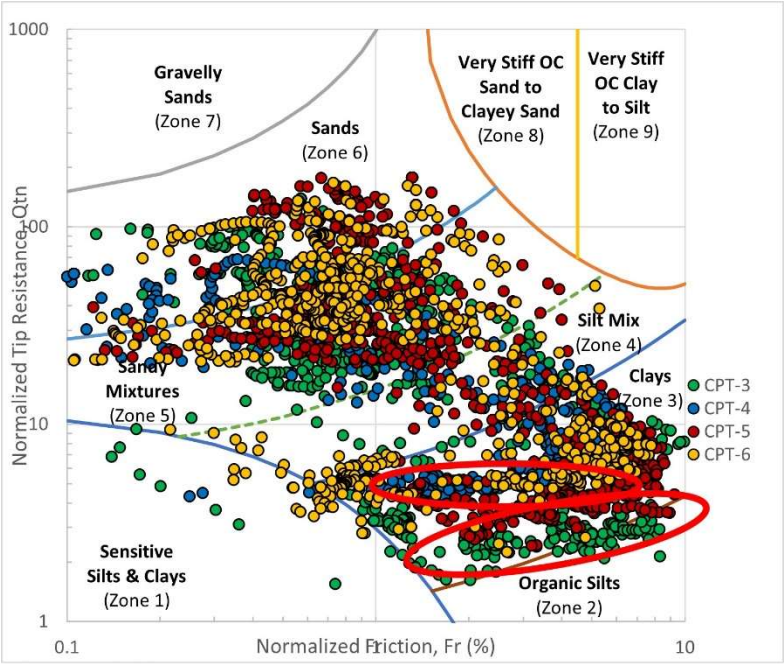

Figure 2: SBT Chart from CPT Data

MDOT has begun to compare CPT correlations to soil properties and has started looking at undrained shear strength since this is an important parameter in geotechnical engineering. In general, we have found that one of CPT correlations to undrained shear strength is reasonably close to the results from our laboratory tests. Figure 3 presents the estimated shear strength based on tip resistance from four CPT soundings plotted with the shear strength from laboratory unconfined compression tests (red and blue squares and triangles). The correlation of the estimated shear strength from the CPT data matches well with laboratory data. As Figure 3 shows, the nearly continuous CPT data provides a substantially more detailed profile of the shear strength at a particular site versus a few discreet laboratory test results. This increased understanding of the subsurface conditions reduces uncertainties and risk to the project.

CHALLENGES, LESSONS LEARNED, AND FUTURE WORK

While CPT is not yet institutionalized at MDOT, we do see potential in its use and are continuing to work through how we incorporate CPT into our exploration, design, and construction phases of our projects.

We are still learning more about performing CPT and becoming increasing familiar with its data, but have not yet had any significant challenges with the implementation of CPT. We have had issues using the CPT in areas where heavy gravel, cobbles, or boulders are present near the surface. These conditions present difficulties anchoring the S4 and pushing the cone past these obstructions.

Additionally, MDOT needs to establish how the CPT data will be presented in our deliverables for use in design and construction. We need to identify what specifically should be included in the contract documents versus provided for reference information. With support from FHWA through the A-GaME initiative and by learning from other agencies' CPT implementation, we do not anticipate challenges with CPT that cannot be overcome.

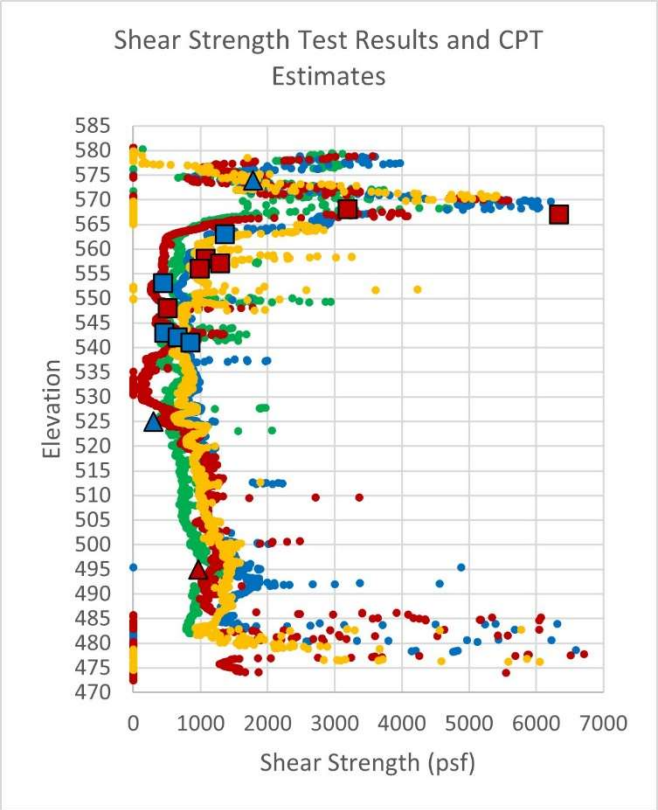

Figure 3: Shear Strength Comparison of Laboratory Tests and CPT Estimates

MDOT is continuing to use and learn more about CPT and how to utilize it to its fullest potential for our projects. We have been impressed with the improved stratigraphy, faster exploration rates (2 to 4 times that of SPT borings), and the resulting nearly continuous soil profile. We see CPT continuing to become more fully integrated into our subsurface investigations. MDOT's future work with CPT includes a research project to further develop the correlations of our CPT data and SPT soil borings/laboratory test results and evaluating direct design methods for use. We will also be hosting a training with a variety of industry partners to share our experience with CPT and where MDOT is headed with the use of CPT.