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CPT – AN OLD AND PROVEN SOIL INVESTIGATION METHOD WITH A BRIGHT AND EXCITING FUTURE

While the official reason for this special issue of *Geotechniek* is the CPT'22 conference, another equally good reason for this issue could have been that Cone Penetration Testing (CPT) turns 90 this year. After all it was in 1932 that Pieter Barentsen, an engineer with the Rijkswaterstaat, the Directorate-general for Public Works and Water Management in The Netherlands, performed the first tests with the Dutch Cone Penetrometer. And what started out as a simple solid mechanical cone that was pushed by hand into the soil has developed into a sophisticated soil investigation method, where a digital instrument with multiple sensors is pushed down using a hydraulic pusher in a climate-controlled workspace on wheels or tracks.

For a method that is 90 years old, and for decades the standard soil investigation method in The Netherlands, it may be surprising to realize that in many parts of the world CPT is still seen as a relatively new and unfamiliar soil investigation method. As a result it is not always applied where it could provide very useful data, and that makes a recent description of this method by the US Federal Highway Administration very appropriate: a proven, effective, and underutilized technology. The basic principle of CPT is that a cone with standardized dimensions is pushed into the ground

at a continuous rate of 20 mm/s (0.8 in/s). As this process is completely standardized, the measurements obtained can be correlated to the soil behavior, which allows for the characterization of the soil without taking any samples. While the basic version of CPT, the so-called mechanical CPT, generates only readings of the tip resistance and the sleeve friction (that are read at the surface using manometers), the more advanced, and much more commonly used, electric CPTu also collects pore pressure readings and the inclination of the cone. These readings are then transmitted electronically to the surface, where they can be converted in real-time into a soil behavior characterization.

The most common use of CPT data is for geotechnical design and engineering applications: foundation design, quality control for ground improvement work or monitoring of the condition of a levee or a dike, to name just a few examples. Over the years CPT results have proven to be effective input for these applications, but as geotechnical engineering advanced the potential need to enhance CPT has become apparent. A good example to illustrate this is pile driving. CPT as we know it allows for very accurate simulations of pile driving with an impact hammer. But with the use of large diameter (say 3 m or more) open ended pipe

piles as the foundation for offshore wind turbines, the use of vibratory hammers rather than impact hammers to drive the piles into the ground has become more widespread. These vibratory hammers operate at a frequency of approximately 20 Hz and CPT data obtained with the addition of vibratory movement may well provide more accurate input for simulations of pile driving with a vibratory hammer.

While the use of CPT data obtained with vibratory movement will require some additional research before it can be standard practice, there are other applications where this kind of CPT can be implemented immediately. First, by applying these vibrations the friction along the CPT rods will be largely eliminated, and therefore most (if not all) the force generated by the pusher will be transferred to the cone. This could allow the cone to be pushed deeper into the soil and potentially even much deeper. If for example during standard CPT operations refusal occurs when the cone encounters a relatively thin stiff layer, which is on top of softer soil layers, the vibratory mode may allow the cone to pass this stiff layer, after which standard CPT can be continued in the layers underneath.

The second potential application is dealing with soft rock types, such as sandstone and limestone. While it may be impossible to push a cone through layers of this kind of rock, the pulsating action may allow the cone to work itself through these soft rock layers. In case there are soil layers underneath that rock, it may then be possible to continue with standard CPT. Currently it is unclear to what extent this is possible, but for all these reasons Eijkelpark view the addition of vibratory movement as an exciting “new” application of CPT that we have named “SonicCPT”.

The word new is put between quotation marks because the addition of vibratory movement to the cone when performing CPT is really nothing new. Almost 40 years ago the Japanese researchers Sasaki and Koga reported on their work to develop and use of what they termed a vibratory cone (or vibrocone) for liquefaction analysis. They compared the tip resistance with and without



Figure 1 – A ballasted track unit being moved to perform CPT efficiently and comfortably from a climate-controlled work space.

SUMMARY

While the official reason for this special issue of *Geotechniek* is the CPT'22 conference, another equally good reason for this issue could have been that Cone Penetration Testing turns 90 this year. Over the years this soil investigation technique, which started out as a simple solid mechanical cone that was pushed by hand into the soil, has developed into a sophisticated

testing method, where a digital instrument with multiple sensors is pushed down using a hydraulic pusher. But as pointed out in this article, the developments continue and that is why CPT is an old and proven soil investigation method with a bright and exciting future.



Figure 2 –
Pieter
Barentsen
out in the
field performing
CPT in the
early days of
the method

vibration (generally at 200 Hz) and they found that when the soil is loose, the penetration resistance will be substantially lower in the vibratory mode due to the additional excess pore pressure generated. On the other hand, in stiff soils the vibration will not create any additional excess pore pressure and therefore the penetration resistance will be similar in either mode.

The concept of liquefaction also highlights another exciting aspect of CPT, which centers around “the friends of the cone”. When pushing the cone into the ground it is hardly any extra effort to add a module with additional sensors on the back of the cone. While the potential of soil liquefaction can already be assessed using only the data obtained with a standard CPT cone, shear wave velocity data derived from data obtained with a seismic sensor at regular intervals during a CPT sounding provides additional insight into this potential. And that is really what these modules, these friends of the cone, generate: additional information to supplement the data collected with the cone itself.

For many years there was a practical limitation to the use of the modules. Their use only became possible with the introduction of the electrical cone in the early 1970s. But at that time the cone was an analog system and each sensor in the cone required a separate core in the cable to bring the sensor data to the surface. Given that there is limited space in the CPT tubes for the cable, the number of cores was limited and thus the use of the modules. Now that digital cones are common



Figure 3 – Driving and levelling the unit can be performed via a remote control system from outside the cabin, which enhances the safety of these operations.



Figure 4/5 – Controlling the CPT itself can be performed easily from inside the cabin.

practice, adding multiple modules becomes a viable option, although one with practical consequences. After all, adding a module to the back of the cone extends the length and that will make it harder to line the unit up, especially if a friction reducer is used.

As these modules become easier to use, we can envision a (not so distant) future where the modules are nothing more an empty housing with a connector. And just as various things can be connected to a computer using a USB cable, it

might be possible to plug different types of sensors into the module and switch them out depending on the need at a particular test site. This approach will provide not just additional data when performing a CPT, it will also enhance the correlations for various soil parameters. After all, just as the correlations based on CPT data (where three parameters are recorded) are better than those generated based on SPT data (where just one parameter is recorded), additional data will allow to make these correlations more sophisticated.



Figure 6 – Where a full-size crawler cannot go, the Compact Crawler can find its way.



Figure 7 – Another way to perform CPT is by using the Drill'n CPT: a fully automatic CPT pusher placed in the break-out clamps of a drill rig.

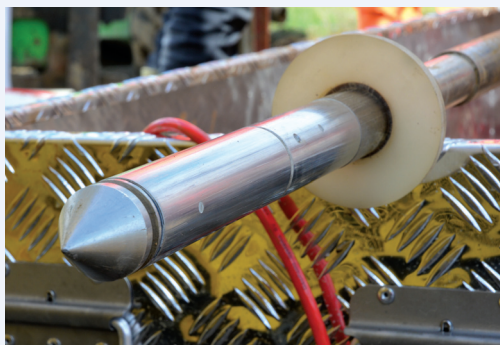


Figure 8 – A cone waiting to explore.

Figure 9 – CPT pushers are also available as stand-alone items together with hydraulic power packs driven by electric motors to eliminate exhaust gases.



The use of additional sensors will also greatly enhance other uses of CPT data. Earlier in this article the geotechnical applications were mentioned, but CPT data can also be used for hydrogeological purposes, e.g. to analyze the level and flow of groundwater or the interaction between groundwater and the surrounding soil. While the pore pressure readings in the cone provide useful data for these purposes, specific sensors in modules will allow for much more elaborate data gathering and thus greatly enhance the ability to assess hydrogeological issues.

The enhancement of the ability to assess issues will be even more obvious when it comes to geo-environmental issues, e.g., to check the length of unknown foundations or the presence of buried steel objects, and to determine the presence of contaminants in the soil. Here the cone data by themselves hardly provide useful information, but the use of modules on the back of the cone (e.g. a video

module that sends ultraviolet (UV) light into the soil and assesses the presence of contaminants through fluorescence, which is the process where certain substances reflect UV light as visual light) may provide such data. When applying a cone with a video module the cone could then obtain the data required to design the foundation, while the module checks for soil contamination.

Combining all these aspects implies that the CPT method has a bright and exciting future with all kinds of potential. But it would be wrong to focus only on the strong points and the potential of this soil investigation method, without talking about the “other side of the coin”. At a conference in London in the late 1980s Huw Williams expressed the following about foundation testing methods, which applies just as well to soil investigation methods:

Many engineers are unaware of the inherent limitations [of test methods] and cannot therefore

choose the technique best suited to their requirements. All too often the choice of method will be dictated by cost alone. All test methods, however, have limitations and it is only by being aware that the engineer can specify an appropriate test programme.

And so it is with CPT. While in most soil types CPT is an excellent choice for soil investigations, in gravelly and soft rock conditions it is much less so, and in rock or urban fill it simply doesn't work. To use the words of Mary Nodine, a geotechnical engineer in the US, “Use of CPTs on sites with shallow bedrock or urban fill may result in the following side effects: damage to probe, subcontractor frustration, schedule risk, change orders, field staff overtime, and use of the phrase “I told you so.” Right now other site investigation techniques are more appropriate for those kinds of soil conditions, but maybe research efforts will generate a soil behavior classification similar to the one every CPT practitioner is familiar with (the Robertson and Campanella Soil Behavior type Classification) for SonicCPT or maybe those research efforts will find a correlation between the data obtained with traditional CPT and those with SonicCPT. And in that case CPT can work in gravelly and soft rock conditions as well. Such a development would be similar to what was originally perceived as a major shortcoming of CPT: the fact that you could not take any samples. But once the CPT equipment manufacturers developed the samplers that shortcoming disappeared.

That is why this article calls CPT an old and proven soil investigation method with a bright and exciting future. As it turns 90 years old, there are still exciting developments in its future, and conferences such as CPT'22 will not only promote, but also speed up those new developments. ●