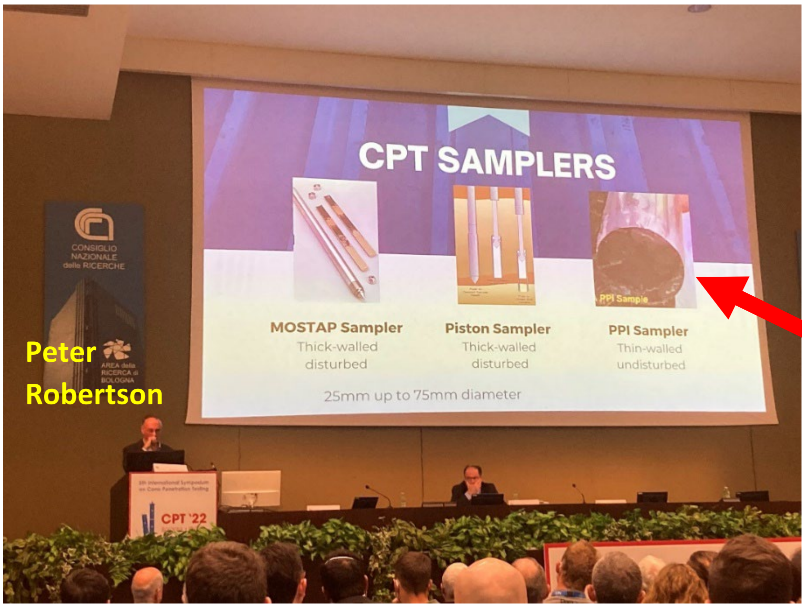
CPT'22 Conference Bologna

IGS Newsletter

The Photos Below Tell The Story

Allan presented a well-received paper on our paradigm-shifting 3MPa CPT. A copy is attached.

He also participated in a focus discussion on CPT uncertainty, led by Roi Soage Santos and chaired by Tom Lunne.



Peter Robertson gave a keynote address in which he held up IGS's PPI Sampler as "the way forward" (our words), designating it as "undisturbed" compared to others.

click the link below for all the CPT'22 papers – free of cost.

https://www.taylorfrancis.com/books/oa-edit/10.1201/9781003308829/cone-penetration-testing-2022-guido-gottardi-laura-tonni?context=ubx&refId=e4d9815c-7d77-4ef3-88fb-3682e4f2bf61

www.insitu.com.au

Mark Chapman
mark@insitu.com.au
0437-824-776

Michael (Mick) O'Rourke
mick@insitu.com.au
0407-467-025

Wyn Binmore
wyn@insitu.com.au
0417-423-769

Alex Waurich
alex@insitu.com.au
0408-185-469

Allan McConnell (founder)
allan@insitu.com.au
0417-748-669

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Cone Penetration Testing 2022 – Gottardi & Tonni (eds)

An innovative new 3MPa CPT – to detect and measure very small f_s values

A.J. McConnell
Founder of Insitu Geotech Services Pty Ltd (IGS)

E.J.C. Wassenaar
Regional Manager Asia-Pacific at Geomil Equipment B.V.

ABSTRACT: CPT testing of extremely soft soils and tailings materials requires the ability to detect and measure very low q_c values and extremely low f_s values. The former of these can and has been solved by use of low capacity cones with high quality well-calibrated load cells. The latter, detection and measurement of extremely low f_s values is an industry-wide problem, often treated as an "elephant in the room". This paper describes development of an innovative new CPT cone that the authors believe has largely solved this problem.

1 INTRODUCTION

Insitu Geotech Services (IGS) undertakes much CPT testing in soils and sediments that can be described in everyday terms as "extremely soft", or even as "ooze"; for clients who are seeking data that permits them to make confident designs.

As a consequence they are almost every day working in an arena where one would aspire to better than Application Class 1 testing quality, if being described according to ISO 22476-1-2012.

To achieve the highest quality that they can in testing these conditions and in satisfying clients they:

– Use known good quality CPT cones. In soft soils these have been previously usually of 25MPa or 10MPa tip capacity.
– Maintain/manage all CPTs meticulously.
– Undertake in-house calibration-checking-recalibration under a very stringent program, as described below.

The IGS calibration program is run in-house because, as you can see from the explanation below, it would be unworkable to contract it out:

a) Every cone is calibrated before every job, then recalibrated after the job, each time using the cone's actual dimensions, not nominal values. If the job runs more than one week, then the cones are changed over with freshly calibrated cones on an approximate 7-day service cycle. All of this is carefully recorded and a calibration-drift-performance type of history is developed for each cone.
b) Recalibration data is then always compared to the data from the previous calibration, to cross-check for any significant change.
c) And, they take before-vs-after zero-load-drift comparisons, as part of each test's management.

It's rigorous, it works, and it's business as usual, built into the company culture and cost structures.

Following the above approach IGS has been successful in regard to the ability to defensibly and repeatably measure very low q_c values, and to be as good as reasonably achievable at measuring f_s values.

2 LIMITATION RE MEASURING VERY SMALL SLEEVE FRICTIONS

In regard to f_s though, they have run up against the "industry normal" limitation in measuring very small sleeve frictions; a limitation that is associated with the design of normal Compression Cones.

To help discussion of this, refer to Figure 1 below.

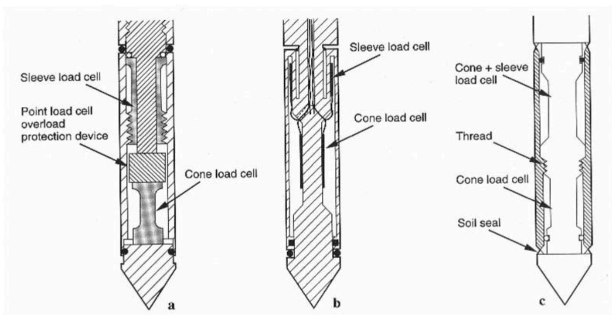

Figure 1. Design of Cone Penetrometers (Lunne et al 1997).

In this paper type (a) is designated as a Compression Cone and type (c) as a Subtraction Cone.

For this discussion, the relevant difference between a Compression Cone and a Subtraction Cone is that:

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– A Compression Cone has separate load cells for the tip and the sleeve. Hence these load cells can be sized for the purpose; typically a larger cell for the tip and a smaller load cell for the sleeve.
– A Subtraction Cone has two load cells that must both be of the larger variety. Typically they would be identical or nearly identical. One of these, that just behind the tip, measures the tip load only and the other, above the screwed on connection to the sleeve, measures the combined tip-plus-sleeve load.
– Software subtracts one value from the other to determine the sleeve friction load. Hence a relatively big number is subtracted from another relatively big number to get a smaller number. If calibration of either or both load cells is not precise, or they drift differently during a test or after calibration, one can reasonably expect significant errors in the sleeve values determined this way.

Compression Cones (these authors perceive) were developed in the first instance ostensibly to improve a CPT's ability to measure sleeve friction.

3 THE CURRENT PARADIGM

So this is the current industry-wide paradigm:

– If you want to most accurately measure sleeve friction, you must use a Compression Cone.

In support of this statement that this is the current paradigm, refer (Robertson et al 2015), as follows:

For accurate sleeve resistance measurements in soft sediments, it is recommended that cones have separate (compression) load cells.

And in support of something that follows in this paper, quoting from the same document as above, the following paragraph, referring now to Compression Cones:

f_s measurements, in general, will be less accurate than tip resistance, q_c, in most soft fine-grained soils.

The problem is that, in extremely soft or ooze-like soils, this "in general expected lower accuracy" in f_s typically ends up meaning no f_s measurement at all, or something too low to be credible.

4 EXPLANATION – WHY VERY SMALL SLEEVE FRICTIONS ARE ELUSIVE

4.1 *A simple explanation – referring to Figure 1*

– In a Compression Cone, the sleeve has to move slightly to permit it to apply load to the friction sleeve load cell.
– Dirt seals behind the friction sleeve resist this slight movement and use up some of the force applied by soil friction to the friction sleeve.
– Hence a noticeable error occurs if this applied force is very low (as it will be in extremely soft materials).

If one is testing stronger materials then it's not a significant issue at all, but if one is testing extremely soft material it becomes a problem.

Until recently this limitation was typically handled as an "elephant in the room", not talked about much, but rather agonisingly hanging around in the shadows in the background of CPT testing.

But it's become a pretty big deal for organisations like IGS that nowadays do much testing in extremely soft or ooze-like soils; and for their clients.

4.2 *References to this problem by others*

This issue was discussed at CPT'14 in a paper (Santos et al 2014) where the authors ascribed the problem to the friction in sleeve seals and presented an example sleeve calibration showing the difference in load cell readings compared to applied load (Figure 2a) without friction sleeve seals, and (Figure 2b) with seals.

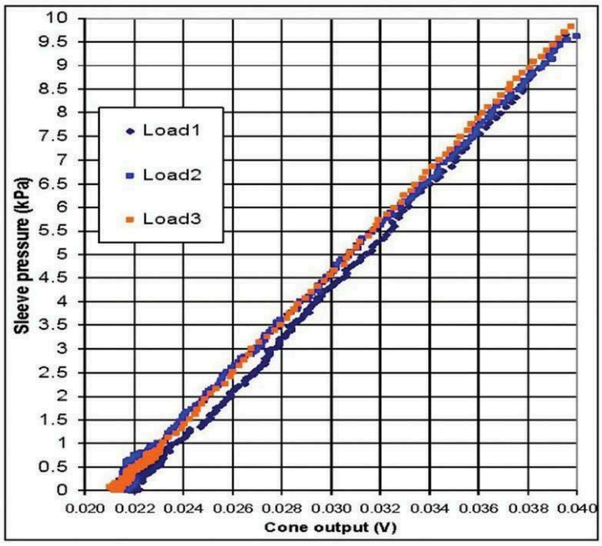

Figure 2(a). Sleeve calibration with no seals (Santos et al 2014).

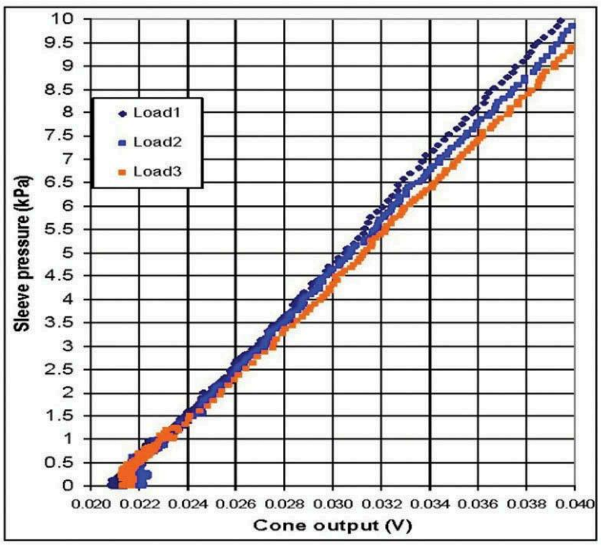

Figure 2(b). Sleeve calibration with seals (Santos et al 2014).

Those authors discussed an innovative spring-loaded (preloaded) sleeve seal design to attempt to solve the problem. This has/had been taken up by A.P. van den Berg for their cone design.

The issue was again mentioned in a paper at the 2021 Mine Waste and Tailings Conference, (Entezari et al 2021). In that paper, the authors were discussing limitations in the use of CPT data to determine the fines content of extremely soft oil sands tailings.

In that paper, for the analysis they were undertaking, many data points were "*screened out in order to remove data where the soil-sleeve friction was less than internal o-ring (sic) friction"*.

This meant discarding a good deal of their data.

5 IGS WANTED A SOLUTION – NOT AN EXCUSE OR ANOTHER COMPROMISE

IGS wanted a solution, so talked at length to their supplier/partner Geomil as to what this might entail. They then jointly conceived and funded an atypical design as a trial.

The conversation and thinking went as follows:

a) As described in Section 4, Compression Cones have friction sleeves that must move a small amount to be able to register an f_s reading.
b) The sleeves of Subtraction Cones do not have to move more than a miniscule amount to register friction load. But they have the historically-deemed problem of having to subtract one big number from another big number to get a small one, as discussed in Section 3.
c) As one solution, would it be possible to develop a Subtraction Cone with unusually high quality and sensitive load cells, and to calibrate these very rigorously to help overcome the problem in subtracting a big number from a big number?
d) And would it be possible to design for much lower cone capacity overall, hence making the two big numbers smaller, further reducing the problem?
e) And would it be possible to make the load cells more responsive than normal, by adopting different construction materials for the elastic bases on which the cells' strain gauges would be fixed?

Of course this would all comprise a significant paradigm shift, compared to the existing one. Reiterating here: *If you want to most accurately measure sleeve friction, you must use a Compression Cone.*

Some heart was taking in the knowledge that Fugro's very sensitive Fibre Optic Cone, announced at the prototype stage via a paper (Looijen et al 2018) at CPT'18 in Delft, also designed for testing soft materials, is a Subtraction Cone with unusually sensitive load cells; in principle the same idea.

So IGS and Geomil talked more and eventually Geomil made a first small run of special cones to the agreed design. In accord with (c) and (d) above, they opted for a cone size of $15cm^2$ and tip capacity of only 3MPa; this being adequate for the testing of extremely soft materials that were/are the target.

And, in accordance with (e) above they opted for a special alloy base for the load cells, giving a physical strain gauge response approximately 300% greater than it would be for a conventional steel base.

Of course, also in accordance with (c) above, IGS has adopted the same calibration regime discussed in Section 1, with the enhancement of using dead weights for the application of load to the tip and sleeve for (at the moment) the bottom approximate 6% of loading; ie up to ~0.17MPa on the tip and ~11.5kPa on the sleeve. Planning is that in the future IGS will go full-range with the dead weights. At present they are using a very sensitive calibrated load cell of just 5kN capacity for the remainder of the range.

6 HIGH HOPES AND EXPECTATIONS

Because of high hopes for these cones, IGS has set a policy in place that, to the extent possible, they will calibrate these cones to achieve the accuracy outcomes proposed by the new draft international standard ISO/DIS 22476-1 criteria for Class 1+ cones.

To date that objective is looking good. A full IGS calibration for one of these cones is shown on the last page of this paper.

In other words, these cones, under these rigorous calibration processes, are pretty remarkable by current measures.

Of course calibration is just one aspect of a CPT. How have these cones behaved in the field?

7 FIELD TRIALS

IGS has had several 3MPa cones in operation now for a few months, in one place testing very soft natural soils and in other places testing ooze-like tailings sediments. The results are satisfying, demonstrating:

a) Ability to repeatably detect, measure and record very low q_c values – say 10kPa and even below.
b) Ability to repeatably detect, measure and record very low f_s values that make sense when compared to the q_c values being measured – say 1kPa and even below.

Figure 3 below, shows the improved response to sleeve friction compared to what was previously possible.

Laboratory tests on samples taken from this coal tailings dam site showed the materials tested (in the test plot "troughs") to have:

– 37% fine sand, 51% silt size, 12% clay size.
– Liquid Limit 34%, Plasticity Index 9%, Moisture Content 40.5% (ie in liquid phase).
– Soil Particle Density ("SG") $1.52t/m^3$.

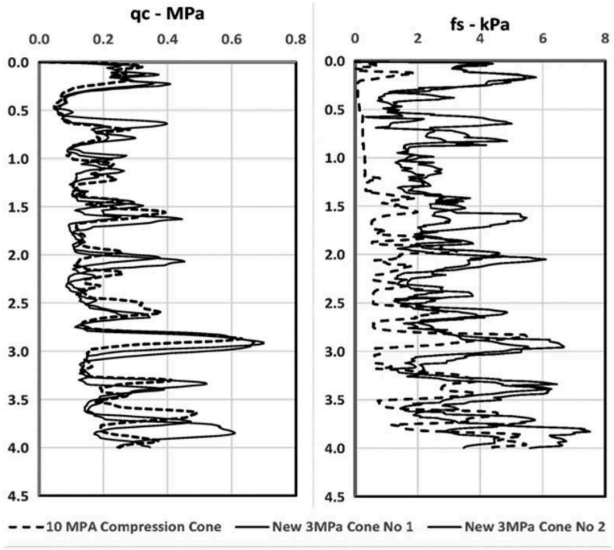

Figure 3. Q_c and f_s plots – new 3MPa cone vs 10MPa Compression Cone – tests by IGS – plotted to 4.0m depth for relevance.

All the tests undertaken with these new cones show the ability to measure very low q_c and a much improved response in regard to sleeve friction.

8 CPT-BASED SOIL BEHAVIOUR TYPE (SBT)

Data from the tests shown in Section 7 have been processed using the computer software CPeT-IT v.3.0 – CPT Interpretation Software (Ioannides 2007) to plot CPT-based Soil Behaviour Type using the classification system proposed by Robertson (2016). Plots are shown below as Figures 4(a) and (4(b).

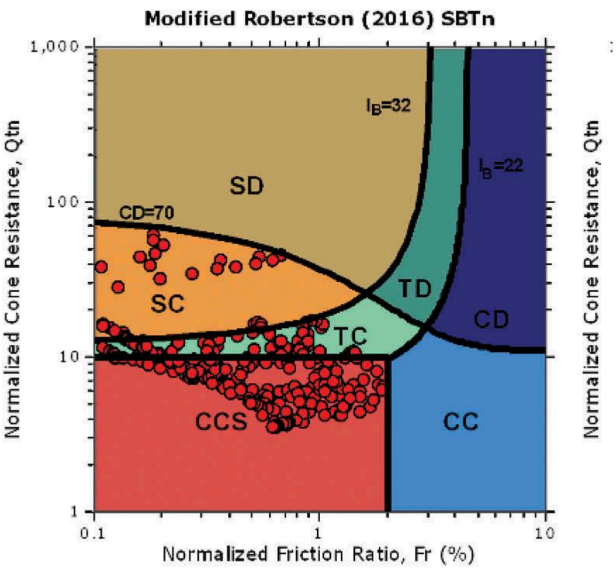

Figure 4(a). SBT to 3.2m from 10MPa Compression Cone.

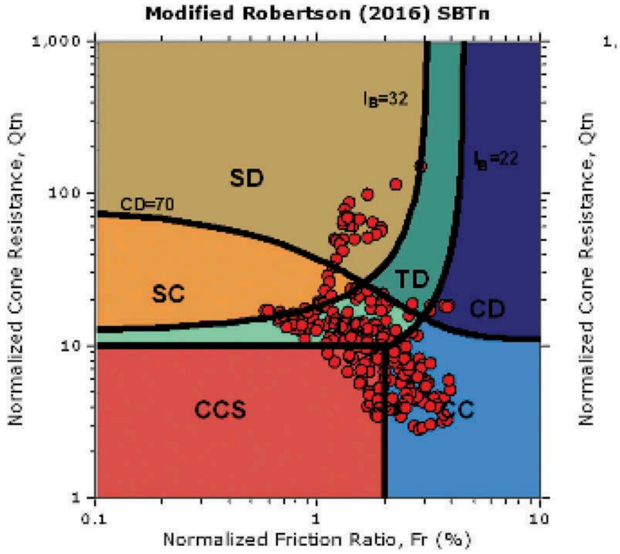

Figure 4(b). SBT to 3.2m from the new 3MPa Cone.

CCS: Clay-like – Contractive – Sensitive
CC: Clay-like – Contractive
CD: Clay-like – Dilative
TC: Transitional – Contractive
TD: Transitional – Dilative
SC: Sand-like – Contractive
SD: Sand-like - Dilative

The data from the new 3MPa cones interpret SBT that is significantly different to that from the 10MPa Compression Cone.

9 FIELD TRIALS - ZERO-LOAD-OFFSETS

The CPT industry/profession is passionate on the issue of comparing "before-vs-after" zero-load-offset values as a method of determining/monitoring:

– the quality and actual condition of a cone itself, and
– the quality of a test that has been undertaken.

IGS's cone history recording system will one day allow a report on the reliability of this dependence on zero-load-offsets; a quantified study to support the passion (or otherwise).

In the meantime however it is acknowledged that this is an accepted field indicator of the quality of a test undertaken, so monitoring and recording these zero-load-offsets is part of IGS's every-test practice.

The new draft ISO/DIS 22476-1 relies heavily on this parameter in determining test quality, called "Test Category", with different Categories/qualities numbered A to D in the draft; A being the highest quality.

Under the draft standard, one decides the Test Category by:

a) the Class of cone used and
b) the drift/difference in the before-vs-after zero-load-offset values.

In the draft standard, a before-vs-after drift/difference of less than 15kPa for the tip, combined with less than 2kPa drift/difference for the sleeve, categorises the test as Class A, the highest test quality classification.

This typically involves measuring the after-test-offsets once the cone has been cleaned and reassembled after testing. It cannot be a value extracted from the completed test's data file, as this immediately-after value is likely to be influenced by dirt in seals and gaps after cone extraction.

Figures 5(a) and 5(b) below show sets of before-vs-after drift/difference data from the first three IGS jobs, using two of these new 3MPa cones.

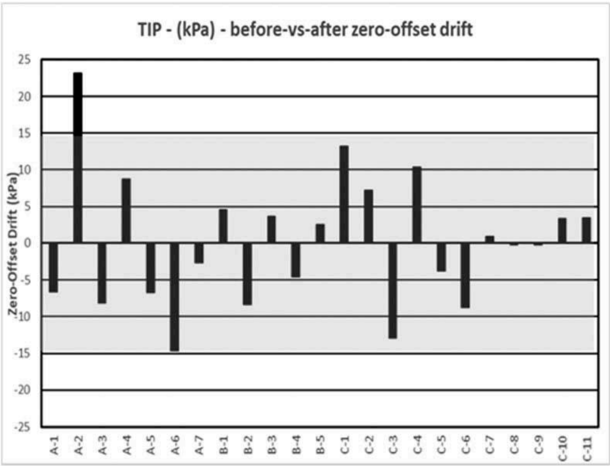

Figure 5(a). Before-vs-After Tip Zero-Load-Offsets -23 tests by IGS (grey shaded band is +/- 15kPa).

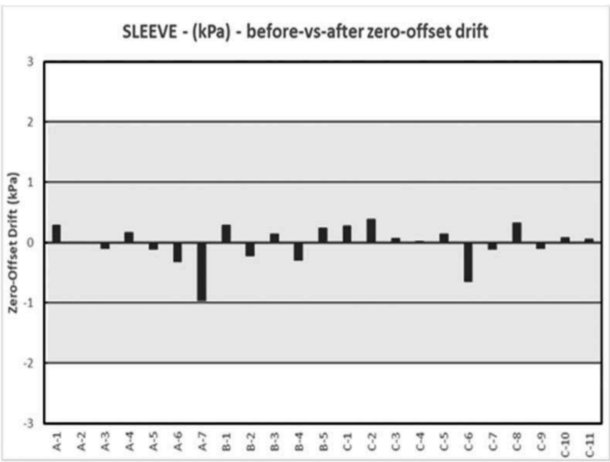

Figure 5(b). Before-vs-After Sleeve Zero-Load-Offsets -23 tests by IGS (grey shaded band is +/- 2kPa).

The data shows that, except for one test, all of these tests undertaken using the 3MPa cones have experienced drift/difference of less than the designated 15kPa for the tip, and all achieved better than 2kPa for the sleeve.

The single test that fell outside 15kPa for the tip was the second test ever made using one of these cones and the before-vs-after monitoring process in that instance had not been undertaken cautiously – transient temperature shift was a possible cause of that aberration – remember that these are all very small numbers.

By the time of the CPT'22 Conference IGS's database will be more comprehensive.

10 TRANSIENT TEMPERATURE EFFECTS

Transient temperature effect is a matter that IGS takes seriously in all of their testing. Their default testing procedures do what is reasonably possible to minimise these effects during all stages of a test.

The new 3MPa cones are each fitted with a temperature sensor and IGS is currently developing a plot format for these cones that will include temperature along with the usual parameters of q_c, f_s and u.

The work has not yet been done; however we anticipate that these new cones may stabilise more quickly than conventional cones due to the use of the special alloy instead of steel in the load cell bases.

By the time of the CPT'22 Conference we authors expect to be able to report on this aspect of these new 3MPa cones.

11 SUMMARY AND CONCLUSIONS

Measurement of extremely low sleeve friction (f_s) values during CPT testing is an industry-wide problem, often treated as an "elephant in the room".

This paper describes the development of an innovative new CPT cone that the authors believe has largely solved this problem.

The solution has involved shifting of the paradigm, that "*if you want to most accurately measure sleeve friction, you must use a Compression Cone"*. This solution involved the use of a Subtraction Cone design.

The solution also involved development of more-responsive-than-conventional load cells using a special alloy for the load cell base, rather than steel.

So far the new CPT, calibrated and managed as described in this paper, is meeting or exceeding the authors' expectations.

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