



# Advancing Silo Foundations The Role of High-Resolution Geotechnical Characterization in Optimized Design

According to **Sorabh Gupta, Director at Cengrs Geotechnica**, advanced geotechnical testing, particularly CPTu integrated with SPT data, transforms foundation engineering by replacing assumptions with evidence, cutting unnecessary conservatism, and ensuring cost-efficiency. Better data is the foundation of smarter, safer, and more economical design.

India's modernization of agricultural storage systems has spurred the construction of grain silos across the country. These large cylindrical structures, often built in clusters, require equally robust foundations designed to perform under high loads with minimal settlement. The challenge lies in achieving both structural safety and economic efficiency, as excessive conservatism in design can lead to costly and unnecessary ground improvement.

Traditionally, ground improvement techniques (such as vibro-stone columns) or deep foundations—have been used to counter uncertainties in soil behavior under loads. However, the advent of advanced in-situ ground characterization tools has redefined standards for reliability and efficiency in subsurface investigation.

In particular, Cone Penetration Testing with pore pressure measurement (CPTu), supported by Standard Penetration Test (SPT) energy measurements, has proven to be a major advancement, offering continuous, high-resolution data for more accurate design decisions. These methods enable optimized foundation design, reducing dependence on costly interventions while ensuring structural safety.

This article presents two case studies from northern India where advanced geotechnical investigation techniques eliminated the need for ground improvement and demonstrated significant economic and time benefits. The conclusion is clear: "data quality is the key driver of efficient foundation design."

## The Value of Advanced Testing

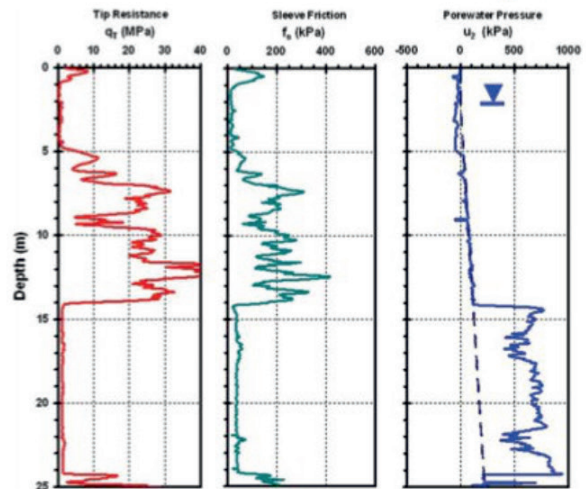
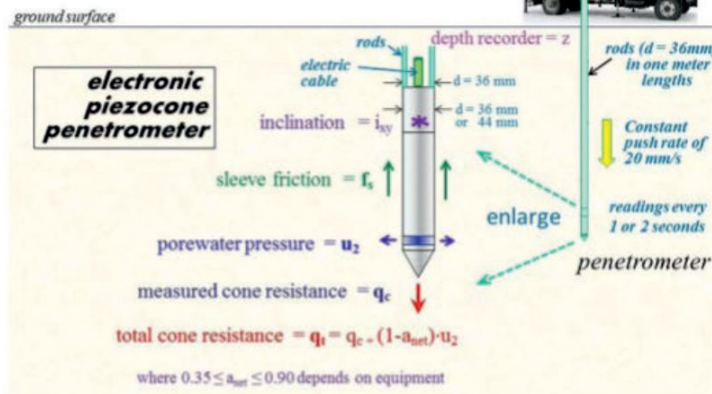
The saying "a foundation is only as strong as the soil beneath it" highlights the importance of comprehensive geotechnical investigation. Conventional boreholes, SPTs, and laboratory testing provide useful but discrete datasets that may lead to conservative interpretations, underestimating soil strength and increasing foundation costs.

CPTu addresses this limitation. With decades of international application and growing adoption in India, CPTu delivers continuous depth profiles of soil response by measuring tip resistance, sleeve friction, and pore water pressure. This allows engineers to infer density, shear strength, stiffness, and hydrogeological properties with precision. When combined with SPT energy normalization, which corrects for hammer efficiency,

# Piezocone (CPTu)



## CONE PENETRATION TEST (CPT) ASTM D 5778



- IS 1892 - 2021: Code of Practice for Subsurface Investigations for foundations (Clause 6.9)
- IS 4968 - : Part 4 - Method of subsurface sounding for soils - Electric Cone and Piezocone Penetration test (draft code under review at BIS, expected to be finalized this year)
- ASTM D5778-20: Standard Test Method for Electronic Cone and Piezocone Penetration Testing of Soils
- ISO 22476-1: Geotechnical investigation and testing - Field testing (Part 1: Electrical cone and piezocone penetration test)

engineers obtain reliable, field-calibrated soil parameters. Together, these techniques elevate subsurface characterization from approximate to precise.

### Case Study 1: Eliminating Stone Columns

In the Ganga-Yamuna Doab region, two silos with 32 m diameter rafts were planned. Borehole investigations suggested a safe bearing capacity of about 110 kPa, insufficient for the design loads, and recommended installing approximately 1,100 vibro-stone columns per silo at a cost of INR 7 crore.

To verify, four CPTu soundings and SPT energy transfer measurements were conducted. The results revealed significantly higher soil capacity, nearly doubling the safe bearing pressure derived from boreholes alone. Settlement predictions confirmed that performance was within acceptable limits.

This allowed the silos to be founded directly on natural soil, eliminating the need for stone columns. An additional INR 5 lakh investment in advanced testing avoided INR 7 crore in ground improvement, yielding a 14,000% return on investment and saving 4–6 months of project time.

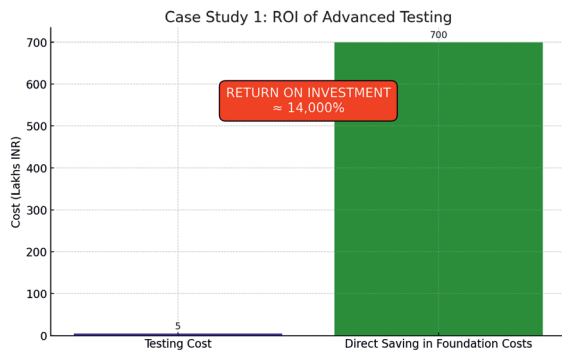


Figure 1: Cost impact — ₹5 lakh spent on advanced testing produced a direct saving of ₹7 crore in foundation costs (=14,000% ROI).

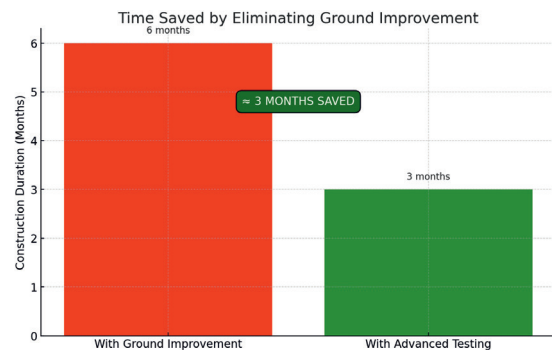


Figure 2: Stone column installation would have extended construction by several months. Eliminating ground improvement saved 2-3 months.

## Case Study 2: Controlling Settlement with Better Data

In Hardoi, Uttar Pradesh, six silos of 32 m diameter were planned on alluvial soils. Initial borehole and laboratory data predicted settlements of 190 mm, exceeding IS code limits, leading to a recommendation for stone columns.

A supplementary investigation with CPTu and SPT energy corrections provided more accurate data. Settlement was recalculated at 70–124 mm, well within the 125 mm limit prescribed by IS 1904:2021. The silos were safely constructed on natural soil without ground improvement.

This decision saved over INR 2.5 crore while also eliminating delays associated with ground treatment, accelerating commissioning timelines.

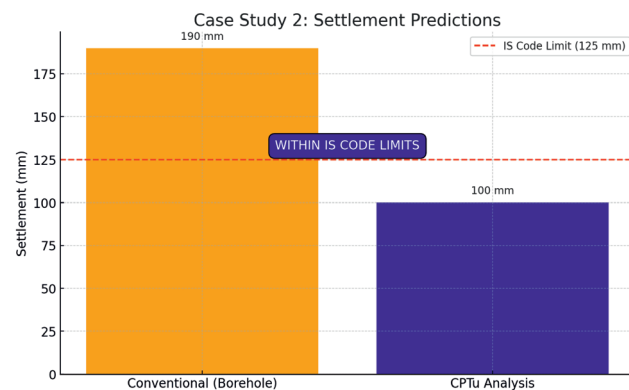


Figure 3: Borehole analysis predicted 190 mm settlement. CPTu refined this to 70–124 mm, within IS code limits.

## Why CPTu Matters

CPTu is valuable because it provides continuous, high-resolution soil profiles. Unlike borehole data that captures conditions at specific depths, CPTu identifies stratigraphic changes and soil variability that influence performance. With CPTu, engineers can:

- Identify soil layers and transitions accurately.
- Estimate shear strength and stiffness with higher confidence.
- Assess bearing capacity through direct correlations.
- Predict settlement with improved reliability.

When combined with normalized SPT data, the resulting dataset is robust and well-suited for both conventional design and advanced numerical modeling.

## Economic Benefits: Testing vs. Construction Costs

The case studies clearly show the large disparity between testing costs and construction savings:

- **Case Study 1:** ~14,000% ROI (₹5 lakh spent vs. ₹7 crore saved).
- **Case Study 2:** Direct savings exceeding ₹2.5 crore.

Equally important are the time savings. By avoiding stone column installation, project schedules were shortened by several months, a critical benefit for agricultural infrastructure.

## Broader Relevance for Infrastructure

These findings extend well beyond silos. Advanced geotechnical investigations, including CPTu, pressuremeter tests, and shear wave velocity measurements, enhance data reliability, supporting better foundation design, cost reduction, and risk mitigation across many project types:

- **Tall buildings:** Improved settlement predictions for large raft foundations.
- **Metros and bridges:** Continuous ground characterization for stations, depots, and bridges to avoid foundation-related risks.
- **Industrial plants:** Accurate static and dynamic soil parameters for heavy machinery foundations.
- **Energy facilities:** Safer and more economical foundations for power plants and related infrastructure.

In summary, adopting advanced testing enhances both economic efficiency and structural safety, delivering reliable foundations and reduced risk across infrastructure sectors.

## Toward a New Standard in Practice

- **Institutionalize CPTu:** Include advanced testing in all major geotechnical investigations.
- **Normalize SPT values:** Energy transfer measurements should be standard practice.
- **Adopt data-driven design:** Replace conservative assumptions with field evidence.
- **Educate stakeholders:** Highlight the economic and technical advantages of advanced testing.
- **Follow global trends:** Wider adoption will align Indian practice with international benchmarks.

## Conclusion

The silo projects provide strong evidence that advanced geotechnical testing is a strategic necessity rather than an optional extra. CPTu and SPT energy measurements generated robust datasets that justified eliminating ground improvement, enabled cost savings in crores, and accelerated project delivery—all while ensuring safety.

As India continues to expand its infrastructure, the lesson is clear: better investigations lead to smarter construction. The answers lie in the soil—but only if we use the right tools to uncover them!

## About the Author:

Sorabh Gupta is a specialist in Geotechnical Engineering and Director at Cengrs Geotechnica (<http://www.cengrs.com>) with an undergraduate degree from IIT Delhi and a Master's from Stanford University. He has about 20 years of professional experience in foundation engineering.