THE QUEST FOR QUALITY IN DEEP FOUNDATIONS (Continued)

John. A. (Jack) Hayes[1], P.Eng., D.I.C., Member ADSC

[1]President, LOADTEST Inc., Gainesville, Florida, hayes@loadtest.com

OVERVIEW

In Part 1 of this three-part series we explored the proposition that the natural desire to improve the way we design and build deep foundations provides a fundamental motive for achieving excellence and high quality. Unfortunately, perceived high cost and the lack of rewards or incentives to make the effort that quality work demands, often leads us to complacency and mediocrity. This complacency can result in substantial reductions in bored pile capacity that dwarfs the potential improvements available from high quality engineering design and construction.

In Part 2 we examined some case histories that illustrate how seemingly minor factors in design or construction technique can cause capacity reductions of 80% or more. Faced with the daunting risks and uncertainties associated with deep foundations many engineers fall back on code-value engineering and from there to unnecessarily expensive foundations. A review of the impact of shaft diameter on measured side shear resistances led to cautionary advice about how too much reliance on intuition can affect the quality of our analytical work.

In Part 3 we describe several options that the engineer and the contractor have for improving and maintaining quality. Perhaps not surprisingly these higher quality options lead to lower costs. We can accomplish this by: better assessments of the high cost of risk and uncertainty, changing the low-bid approach to awarding foundation contracts, by including a special bid item to encompass all of the QA/QC work on a project and generally by making a greater effort to focus on the value that high quality brings to any deep foundation project.

PURSUING THE VALUE IN QUALITY

With respect to deep foundations how should we define value and how should we tie it to quality? Usually we think of anything with a high monetary value as “valuable” and we generally associate high quality with high value. Almost by definition we consider anything cheap as not valuable. Only rarely do we perceive cheaper as a better value and certainly the cheapest usually does not qualify as the “Best Buy.” Do we want the cheapest foundation or the most effective (valuable) foundation? What kind of message do we send when we award foundation drilling contracts to the lowest (cheapest) bidder? Surely we should always have the goal of getting the best quality, or the least risk, for our money. The low bid process does not convey that message.

A Possible Guideline to Value and Quality

Consider the development guideline promoted by NASA..... "Faster, better, cheaper". This mantra gave incentive to improve quality and reduce costs (mainly because of the "faster' part of it – i.e. time means money). On construction projects such a guideline tends to "morph" into faster, better, cheaper (with less emphasis on *better* and more on the faster, cheaper part). This inevitably leads to - cheaper regardless of how fast. For our industry we should say - "First better, then faster, then lower cost". Reduced cost has more value than cheaper and correlates much better to improved reliability and reduced risk.

Looking for Value (The really exciting stuff!)

Our experience suggests that 95% of bored pile foundations, because of overly-conservative designs, (meaning more expensive than necessary) provide a potential source of hidden value. We have already discussed at length how uncertainty about strength parameters, variable conditions, construction methods and lack of quality control lead to understandable conservativism and mediocrity in design. We know that more effective deep foundation designs would result if we could somehow reduce the uncertainty and mitigate the related risks. We know that testing programs and QA/QC processes can provide more certainty and fewer risks. But how do we justify the expense? "There's the rub."

A proper risk assessment, including an estimate of the costs associated with it, would go a long way to giving the geotechnical engineer the financial clout to institute a valuable testing program. It seems to me that making use of the Load Resistance Factored Design (LRFD) approach to deep foundation design makes it easy to put a dollar amount against the mitigating of risk and uncertainty.

By way of example (or thought experiment) let us make a few assumptions about a generic drilled shaft foundation design.

- Assume that the engineer carries out a routine geotechnical investigation.
- The MC^3 engineer estimates ultimate capacity of the shaft using code values.
- Based on a resistance factor of 0.4 (maximum allowed under these conditions) and the structural loads, the engineer calculates a foundation cost of $20 million.
- Assume a new resistance factor of 0.5 on the basis of a load testing program that tests 2% of the shafts and calculate a new foundation cost of $18 million. If the test program will cost less than $2 million, get it approved to reduce the total project cost.
- But let's do something even more exciting. Let's have the engineer assume an even higher resistance factor of 0.8 and calculate a foundation cost of say $12 million. The engineer has just calculated a risk and uncertainty cost of at least $8 million. This amount becomes the carrot for convincing the owner to accept only the best geotechnical engineering investigation and design, hiring the best contractor using the best QA/QC techniques including an extensive load testing program. Even if this QA/QC program cost $5 million, the owner has acquired a high quality, risk-mitigated foundation for $17 million which cuts $3 million from the one first envisioned by the MC^3 engineer.

Those who have been paying attention will note that these numbers probably represent the "tip of the foundation cost iceberg". A good engineer will move to the next phase based on real ultimate resistance values instead of code values. He or she will discover many situations where testing every bored pile will result in high quality, lower cost, non-redundant, deep foundations with virtually no risk of poor performance.

The graph in Figure 1 illustrates how much cost, related to risk and uncertainty, can actually exist in conventional deep foundation designs. The upper left blue diamond represents a design based on minimal geotechnical investigative work, standard design techniques and code values. (An all-too-common situation with MC^3 engineers) Following the red circles we find an improved design with some quality control, better investigation design and test procedures allowing an LRFD resistance factor of 0.6 shown by the red square. These improvements in the process reduced costs in this example by 20%. Now let's hire a really good design engineer and a contractor that does high quality work, introduce a high level of quality control and testing making it possible to use An LRFD resistance factor of 0.8. This results in a cost reduction of 40%. At this point it starts to get very interesting not only for the owner, but also for the engineer, the contractor and the QC people. This means that on a $100,000,000 foundation project we might have a budget of $15,000,000 to spend on eliminating risk through superior design, construction and quality control while saving the owner $25,000,000. The purple circle on the lower right represents the ultimate elimination of risk achieved with high levels of quality workmanship and quality assurance (proof) testing of every foundation element. At that point less expensive non-redundant foundations make sense.

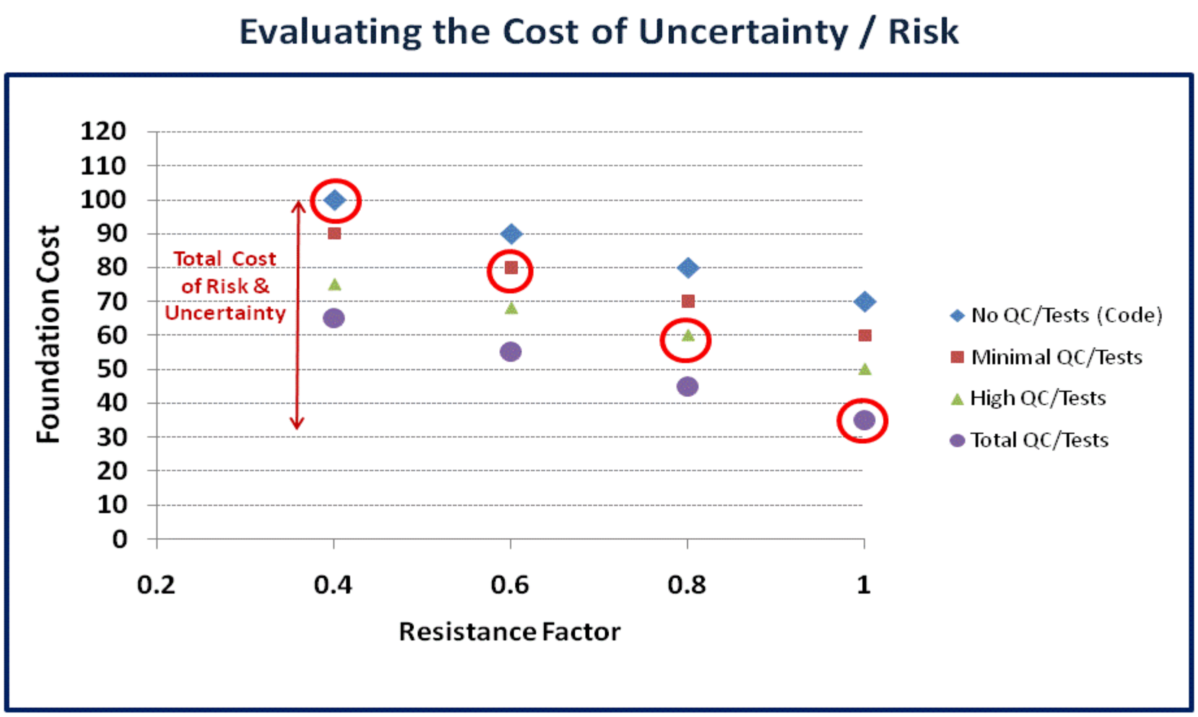

Figure 1

Undoubtedly expanding the quality control to the extent of testing every pile would sometimes reveal unexpected problems. Isolating such problems at that early stage of the project would increase construction costs. These costs, however, pale in comparison to those of remediating unrevealed problems later on.

Putting Quality into the Bidding Process

In my opinion we as engineers need to take on the task of changing, modifying or discarding the low bid process as it applies to deep foundations. We should explore, and promote the use of, the "second-low-bid" concept advocated by Walter Vickrey (1997), Nobel Prize winner in Economics. More realistic pricing for construction work would result from a process whereby all bidders know in advance that contract award always goes to the second lowest bid.

In addition we could improve construction quality, and the attitude toward it, if we provided a special QC bid item in the project specifications and used it to assess best buy. This would allow the contractor to include all the quality control work into one bid item, the price of which would get deducted from his total bid price. Table 1 illustrates how the contractor putting the most effort into quality wins the contract as the second low bidder.

Table 1 – Illustrating the Use of a Special QA/QC Bid Item

Best Value Assessment			
Contractor	**A**	**B**	**C**
Total Bid	**110**	**115**	**122**
QA/QC bid item	**5**	**12**	**18**
"Net Bid"	**105**	**103**	**104**

The QA/QC bid item would include:

- Material testing for concrete, steel (slump test etc)
- Monitoring of shaft shape and alignment (caliper)
- Slurry control (viscosity, sand content etc)
- Base cleanliness assessment (Shaft Inspection Device)
- Base cleaning, side wall roughening, reaming etc.
- Proof testing for capacity (load testing)

Payment for this bid item would require completion of all of the work described in it, to the satisfaction of the engineer-of-record.

THERE YOU HAVE IT!

High quality, a desirable goal in all foundation works, becomes especially so for deep foundation projects. Good quality requires the proper state of mind and attitude. Trying to achieve high quality by “force” through rigid specifications often leads to trouble and high cost. The best results occur when the pile constructor (manufacturer) takes responsibility for the construction quality, leaving the engineer-designer free to concentrate on the geotechnical aspects. Quality in design engineering happens when we avoid Complacency, Contentment and Code reliance. Remember $\Delta E = MC^3$.

Both design engineers and pile constructors need to pay attention to the devilish but important details that produce high quality and high capacity in bored piles. Documented examples show that improper casing techniques can cause 80 to 95% reductions in shear capacity. Similarly mismatching rebar design and concrete mix can result in measured side shear reductions of 90 to 95%. Having a great attitude about QA/QC provides a basis for eliminating such risks and uncertainties during the construction process.

Design engineers should always make sure to question their intuition about geotechnical issues, especially when it might affect the quality of their work. Available test data and project experience indicates, for example, that using smaller diameter test piles (scaled-down) to get unit shear parameters may produce unit values much higher (40% or more) than those achievable on the actual larger production pile sizes. Resisting the temptation to do things cheaply requires effort. Recognize that the sweetness of cheapness soon wears off leaving the bitterness of bad work.

Engineers should always make the effort to quantify the cost of the inherent risk and uncertainty associated with designing and constructing a deep foundation. We can use the LRFD approach to get a sense of the magnitude of such costs. The engineer then has a much better idea of how much QA/QC expense the owner should commit to the task of reducing risk and uncertainty.

Few in the deep foundation industry question the fact that the low-bid award process has a deadening impact on getting high quality results. The design geotechnical engineering profession should take the lead in changing the way we award contracts for deep foundation work. The “second-low-bid” concept advocated by Walter Vickrey, along with a special bid item for QA/QC work, deserves our attention. As John Schmertmann has often said when suggesting a new approach - - “*try it, you might like it*”.

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