Manhattan College
Center for Geotechnology

Integrated Site Characterization and Foundation Analysis Research Project
-
Updated Site-Characterization Algorithm for Coarse-Grain Soils

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by

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former Civil Engineering Department geotechnical engineering program (CE/GE)
research report series are available in PDF format via the Internet at:

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The Manhattan College School of Engineering *Center for Geotechnology* and Its Mission

The **Manhattan College School of Engineering** ***Center for Geotechnology*** **(CGT)** is a unique organization that strives to be more than the typical academic research center or institute. It was founded in 2001 at the personal initiative of Prof. John S. Horvath, Ph.D., P.E. of the Civil Engineering Department who serves as its first Director. The CGT is the result of Prof. Horvath's evolutionary realization after almost 30 years of geotechnical engineering practice that the explosive growth in geotechnical and geoenvironmental engineering technology has made it difficult for the engineering practitioner to keep abreast of new technical developments. The traditional academic approach of simply publishing research results in narrowly disseminated technical reports and papers (a philosophy of "if you print it, they will learn") has proven to be an increasingly ineffective way of reaching practitioners and moving the state of art to the state of practice. There is an ever-growing gulf between these two states of knowledge in geotechnical engineering. The critical need for a total rethinking of how life-long continuing education is achieved not only for engineering practitioners but academicians themselves is evidenced by the appearance of "teach-the-teacher" training courses in drilled shaft foundations and geosynthetics beginning in the late 1980s. If even academicians cannot keep up with new developments by reading journal papers and conference proceedings, how can practitioners be expected to? The stagnation of geotechnology also affects current engineering students and perpetuates the cycle. The desirability of involving the practitioner in the process of formulating research programs so that they may have a more direct and immediate benefit to practice is also something that is now recognized more and more.

The CGT seeks to address the current need for effective, meaningful continuing education by recognizing that the cycle of growth for any technology has three interdependent components, what can be called the "trilogy of technology". Like a three-legged stool, each of these components must be of equal length and strength if a given technology is to succeed. Thus the CGT has adopted a holistic strategy of supporting geotechnology growth by recognizing the need to concurrently address:

- Technology advancement through research and development that involves not only the engineering practitioner but also other end users of geotechnology such as construction contractors and material manufacturers to the greatest extent practicable.

- Technology transfer (T^2) through education of engineers, contractors and manufacturers in a multi-faceted, proactive way.

- Technology documentation through standards development so that all end users (practitioners, contractors and manufacturers) of a given technology work to a common set of guidelines.

This trilogy-of-technology growth cycle is the cornerstone of all activities of the CGT. It is important to note that the interaction of these three components is never completed but assumes a constant cycle that leads to continuous growth of a technology. This concept is embodied in the CGT logo of three interconnected arrows that is displayed on all CGT documents.

The CGT receives no direct financial support on a regular basis from Manhattan College. Thus the success and growth of the CGT is totally a function of outside funding from individuals and organizations whose philanthropic philosophies are consistent with the stated goal of the CGT to treat technology growth in a more holistic fashion than is typically done in academia and considers the entire process from research to standards with end-user input at all stages. In addition, as part of its mission to promote technology transfer through education to the greatest extent practicable the CGT is willing to partner with industry and other academic institutions not only in research but also technology transfer and standards activities on any topic relevant to geotechnical or geoenvironmental engineering. The new Manhattan College School of Engineering William J. Scala Academy Room, which is located on the main floor of the Leo Engineering Building and available for CGT activities, offers modern facilities for hosting technology transfer activities. One benefit of Manhattan College's location on the northern edge of New York City adjacent to both Interstate I-87 and mass transit is that it is quite accessible (including free, off-street parking adjacent to Leo Engineering Building) from both within and outside the City. When appropriate, the CGT will bring its technology transfer activities off campus to meet the needs of a particular activity.

Regardless of financial support, the ultimate success and growth of the CGT will depend on its being responsive to the needs of the engineering practitioner. Towards this end, the CGT welcomes input from practitioners on an ongoing, continual basis. Suggestions for future research and technology transfer activities based on perceived needs in practice are always welcome. There is no topic that is too modest or simple for consideration. In fact, much of the research conducted by Prof. Horvath since he came to Manhattan College in 1987 has been based on ideas, large and small, that he developed as a result of his years in engineering practice.

Additional information about the CGT as well as access to published documents and other resources can be found on the Internet at **www.engineering.manhattan.edu/civil/CGT.html**.

Preface

This report is another in a series of contributions to the Integrated Site Characterization and Foundation Analysis Research Project. This project is one of three charter geotechnical projects currently being conducted under the auspices of the Manhattan College School of Engineering *Center for Geotechnology* (CGT). The origins and overall goals of the Integrated Site Characterization and Foundation Analysis Research Project have been discussed in detail in earlier reports (see, for example, Horvath (2002) listed in the References section on Page 8 of this report) as well as on the CGT website (see Page ii for the URL of the CGT's home page).

This particular report presents an updated version of a comprehensive site-characterization algorithm for use with coarse-grain soils. Because this report just focuses on the key elements of this update and presents some example results of its application, interested parties must first read the original reports in this series (Horvath 2000a, 2000b, 2002) to become familiar with the background of this work.

I am indebted to Prof. Paul W. Mayne, Ph.D., P.E. of the Georgia Institute of Technology for alerting me to recent developments in the field of site characterization of coarse-grain soils and providing me with key information concerning recent research that allowed development of this update. Prof. Mayne was a key contributor, along with Prof. Fred Kulhawy of Cornell University, of information (Kulhawy and Mayne 1990) used in the original site-characterization algorithm that I began to develop in the early 1990s. Prof. Mayne is also one of the leading experts in the world on the subject of site characterization so his assistance to my efforts is especially important and particularly appreciated.

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Executive Summary

This report presents an incremental upgrade to a site-characterization algorithm for coarse-grain soils that was described in detail in earlier Manhattan College reports that are referenced herein. Although the effect of this upgrade on calculated soil parameters was not studied in detail, a comparison for a site that is representative of conditions found at the John F. Kennedy International Airport in New York City suggests that using the latest empirical correlations for the stress state within a coarse-grain soil may, compared to using earlier correlations, have the greatest effect at both the lower and higher ends of the range of vertical effective overburden stresses encountered in normal geotechnical-engineering practice. However, this conclusion must be considered tentative pending further, more-detailed study.

The axial-compressive geotechnical capacities of two closed-end steel pipe piles, one with a constant diameter and the other tapered, that were also previously studied at Manhattan College have been recalculated using the results from the updated site-characterization algorithm. The calculations indicate that the effect of the changed algorithm on the correlation between calculated and measured results is mixed, with better correlation for the tapered pile and poorer correlation for the constant-diameter pile. The improvement in predictive capability for the tapered pile is consistent with results from recently-concluded research at Manhattan College that involved a significant number of different types and sizes of tapered piles. Summaries of this research will be published in early 2004. However, it appears that the overall capacity-calculation methodology requires further improvement with regard to estimating tip capacity. It appears that tip capacity is still being overestimated as was found in earlier research at Manhattan College that was reported in 2002. This tendency toward overestimation is believed to be the primary cause of the discrepancy between calculated and measured results that was found for the constant-diameter pile. Note that tip capacity has relatively much less effect on the total axial-compressive capacity of a tapered pile compared to that of a constant-diameter pile which is why the tapered-pile results were not negatively affected overall by any error in calculating tip capacity.

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INTRODUCTION

Background

The origin and overall purpose and goals of the Manhattan College School of Engineering Center for Geotechnology (CGT) Integrated Site Characterization and Foundation Analysis Research Project have been discussed in detail elsewhere (see, for example, Horvath (2002)). Consequently, they will not be repeated here.

To date, research efforts at Manhattan College to better integrate site characterization and foundation analysis have focused on coarse-grain soils. The reason is that historically, it has been practically impossible to obtain relatively-undisturbed samples of coarse-grain soil for traditional laboratory testing for routine projects. As a result, it has been difficult to implement soil-mechanics concepts such as estimating yield stress[a] and rationally estimating the Mohr-Coulomb friction angle, ϕ, into routine geotechnical engineering practice.

Advancements in in-situ testing have now made implementing such concepts into routine analytical methodologies for coarse-grain soil relatively simple and straightforward. In fact, nothing more exotic than Standard Penetration Test (SPT) N values and hand calculations are required. However, experience indicates that the advances in site characterization for coarse-grain soils have far outpaced the implementation of these advances into practice. Therefore, it was decided that research efforts for the Integrated Site Characterization and Foundation Analysis Research Project were best directed toward coarse-grain soils.

Purpose and Scope of Study

The original algorithm for a comprehensive site characterization of coarse-grain soils based on cone penetrometer (CPT) tip resistance, q_c, data or, if necessary, SPT N values that was developed at Manhattan College had its origins in the early 1990s. This algorithm reached its ultimate state of refinement in 2000 and its use was first illustrated using the classical problem of bearing capacity of a spread footing (Horvath 2000a, 2000b). The next problem considered was that of driven piles and results of that work were published in 2002 (Horvath 2002).

One of the primary recommendations made in Horvath (2002) was as follows:

> *"Site characterization is clearly the key component of the proposed analytical methodology. Therefore the various correlations and algorithms used and presented herein should be updated on an ongoing basis to take advantage of the latest developments in this regard. The emerging picture of the key, underappreciated role played by site characterization in foundation design also indicates that future research and development as well as technology transfer funding should be devoted to this topic which is clearly the crucial, fundamental heart of deep foundation capacity calculation."*

Following up on this advice, communications with Prof. Paul W. Mayne, Ph.D., P.E. of the Georgia Institute of Technology earlier in 2003 indicated that further research and reinterpretation of CPT data during the 1990s had resulted in updated empirical correlations between CPT q_c data and fundamental soil stress-state parameters (P. W. Mayne, personal communication, 2003). Therefore, it was decided to update the site-characterization algorithm presented in Horvath (2000a, 2002) to reflect these changed correlations. It was also decided that it would be useful and informative to assess the impact of these changes, at least on a limited scale for one set of conditions. The driven-pile study reported in Horvath (2002) was chosen for this. The purpose of this report, then, is to both describe the changes

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[a] Also referred to using a variety of alternative terms such as *maximum past effective stress*, *preconsolidation pressure*, etc.

in the site-characterization algorithm for coarse-grain soil and illustrate their impact both on calculated soil properties as well as axial-compressive pile capacities.

CHANGES TO SITE-CHARACTERIZATION ALGORITHM

The CPT remains the exploration tool of choice for most conditions involving coarse-grain soil although the SPT is still a viable alternative. The results from evaluating hundreds of sets of data involving q_c and the horizontal effective overburden stress, $\bar{\sigma}_{h_o}$, under calibration-chamber conditions produced the following updated empirical relationship (P. W. Mayne, personal communication, 2003):

$$\bar{\sigma}_{h_o} = 0.30 \cdot q_c^{0.22} \cdot \bar{\sigma}_{v_o}^{0.69} \cdot OCR^{0.27} \qquad \textbf{(1)}$$

where $\bar{\sigma}_{v_o}$ is the vertical effective overburden stress and *OCR* is the overconsolidation ratio, both at the depth of the particular piece of q_c data. Because Equation 1 involves more than one unknown ($\bar{\sigma}_{h_o}$, *OCR* and possibly $\bar{\sigma}_{v_o}$ if calculating soil unit weight is included as part of the site-characterization algorithm as discussed in Horvath (2002)), the updated site-calculation algorithm utilizing Equation 1 still requires an iterative solution as previously (Horvath 2000a, 2002).

EFFECT ON CALCULATED RESULTS

Introduction

A detailed investigation of the impact of the updated site-characterization algorithm for a range of soils and conditions is beyond the scope of this report. However, it was judged to be both of interest and desirable to perform at least some assessment of the impact. To achieve this, the site at the John F. Kennedy International Airport (JFKIA) in New York City that was discussed in detail in Horvath (2002) was reinvestigated. All assumptions made in the original study and discussed in detail in Horvath (2002) were retained. The only change was to implement Equation 1 in the site-characterization algorithm that was programmed into the computer program *HINT*.

In addition, the axial-compressive geotechnical capacities of the two closed-end steel pipe piles, one each without and with taper, that were studied in detail in Horvath (2002) were also recalculated using the results from the updated site-characterization assessment. Figure 1, which appeared originally in Horvath (2002), is reproduced here to provide background information about the overall site stratigraphy. Again, all assumptions made in the original study and discussed in detail in Horvath (2002) were retained.

Site Characterization

Figures 2 through 4, inclusive, show selected results from the site-characterization process. The results from both the original and updated analyses are shown to facilitate comparison. With regard to Figure 3, note that the results from the updated analysis within the vadose zone of the Holocene sand fill stratum are not shown as they fall off scale.

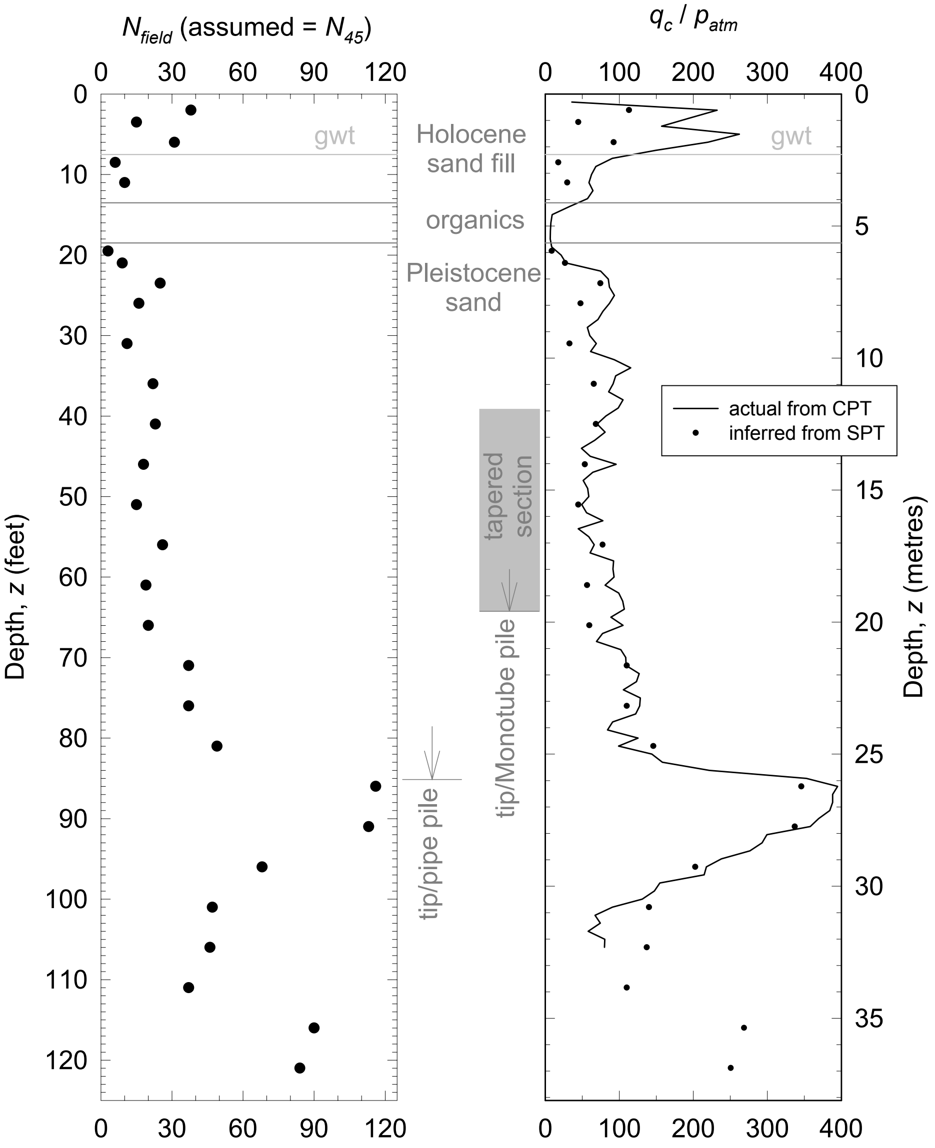

Figure 1. Overall Site Stratigraphy and In-Situ Test Data

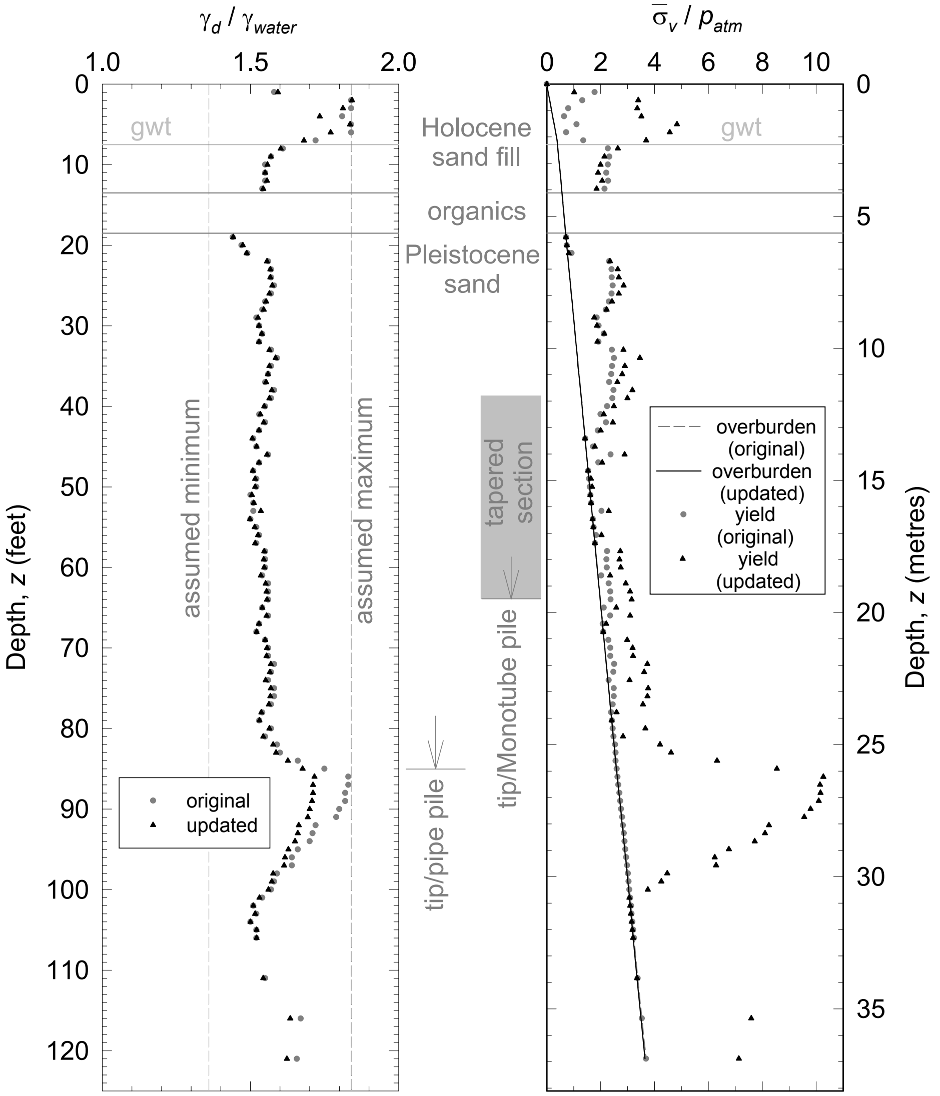

Figure 2. Site-Characterization Results:
γ_d and Vertical Effective Stresses v. Depth

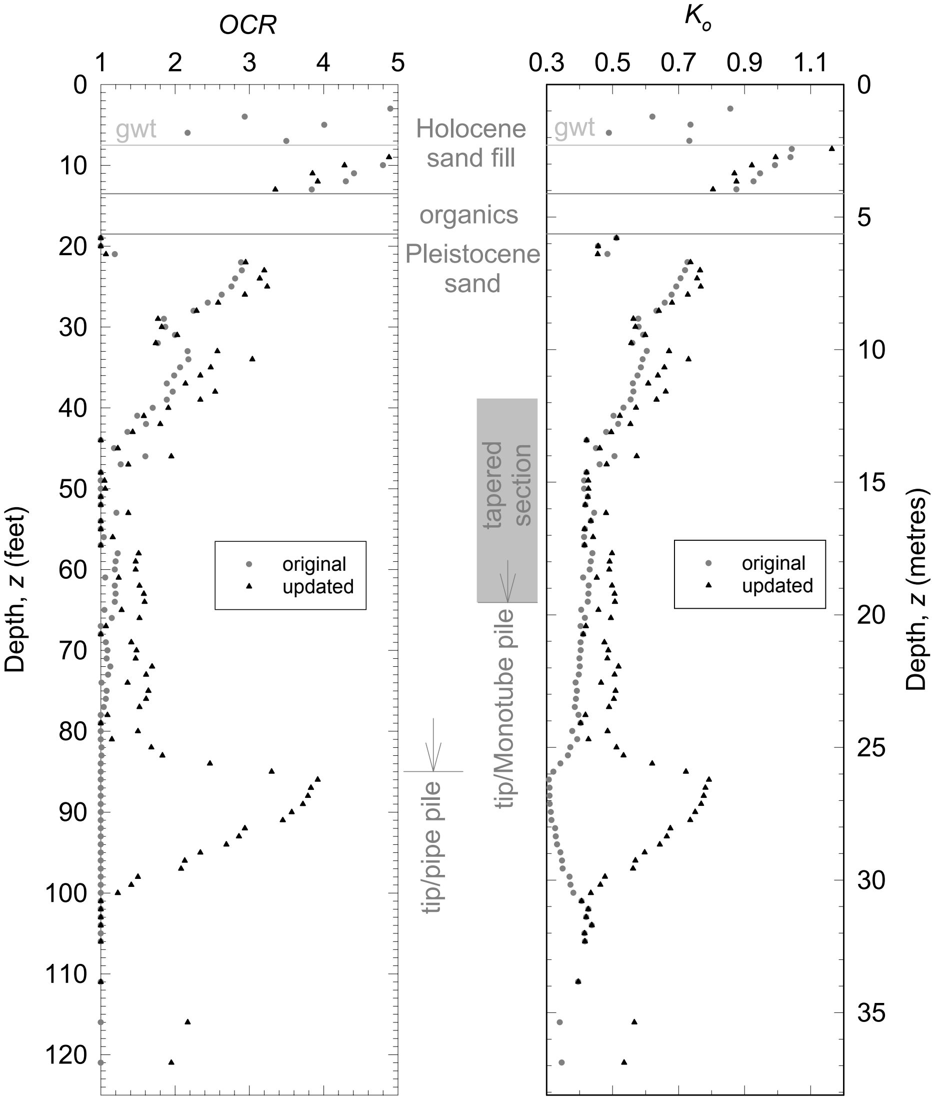

Figure 3. Site-Characterization Results: *OCR* and K_o v. Depth

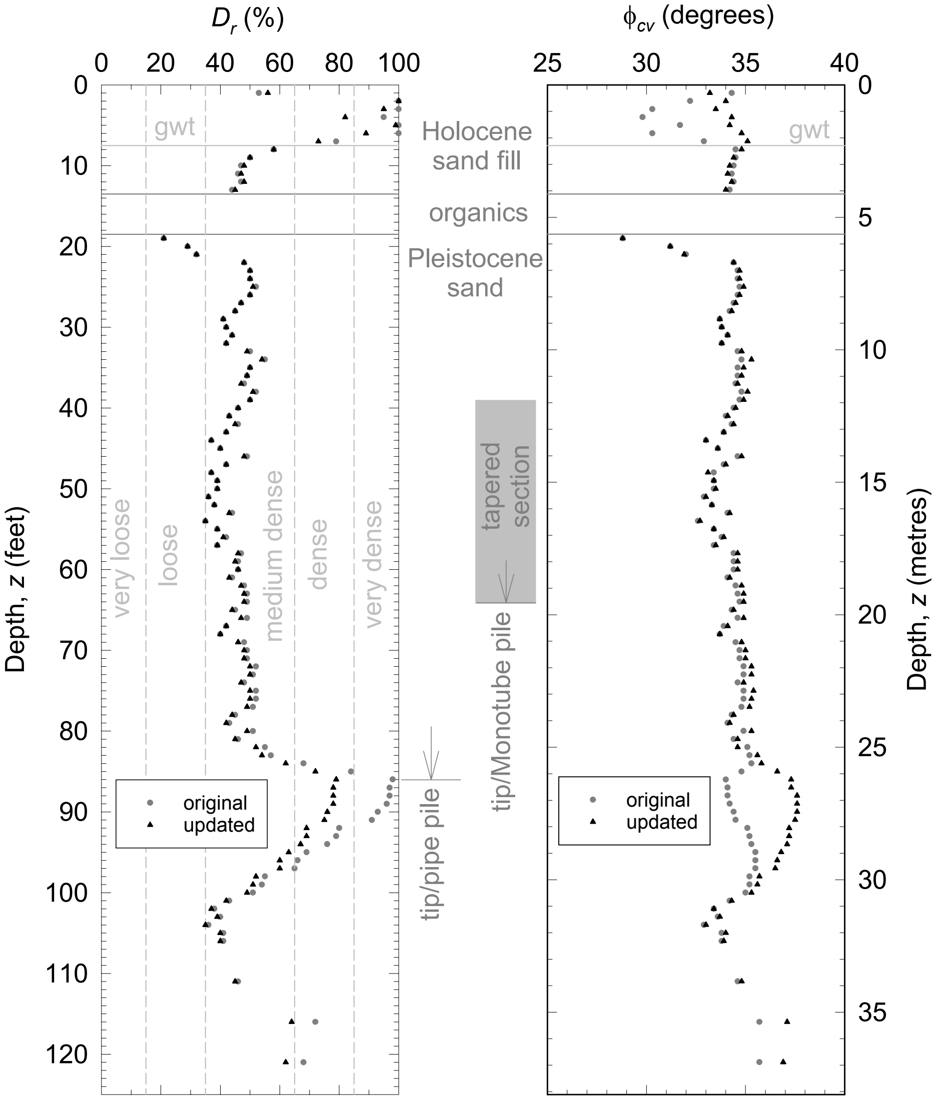

Figure 4. Site-Characterization Results: D_r and ϕ_{cv} v. Depth

It can be seen from figures 2 through 4 that there is, in general, only a modest difference in calculated results between the two algorithms with the important exceptions of within the aforementioned vadose zone and the deep dense zone within the Pleistocene sand stratum that lies between the depths of approximately 80 to 100 feet (25 to 30 metres). Here there are significant differences between the two analyses for each of the six soil parameters shown in these figures. This suggests that the differences between the original and updated algorithms may be greatest where the vertical effective overburden stresses are at the low and high ends of the range of stresses normally considered in geotechnical engineering practice.

Pile Capacities

The results for the constant-diameter pipe pile are summarized in Table 1a and those for the tapered (*Monotube*-brand) pipe pile in Table 1b. Also shown are the geotechnical "failure" loads interpreted from the static pile load tests. Note that the cautions discussed in Horvath (2002) concerning sources of error and subjectivity in pile load tests are still applicable here.

Table 1a. Comparison between Calculated and Measured Pile Capacities for Constant-Diameter Pipe Pile

Algorithm	**Net total resistance, Q_c, in kips (kN) [see notes below]**	
	calculated	**measured maximum**
original	549 - 576 (2440 - 2560)	450 (2000)
updated	649 - 683 (2890 - 3040)	

Table Notes:

1. Calculated net resistances are less the effective pile weight which was calculated based on the assumption that the pile was filled with portland-cement concrete after driving but before load testing.
2. Range in calculated resistances is without and with side-shear resistance in the Holocene sand-fill and organics strata.

Table 1b. Comparison between Calculated and Measured Pile Capacities for Tapered (*Monotube*-brand) Pipe Pile

Algorithm	**Net total resistance, Q_c, in kips (kN) [see notes below]**	
	calculated	**measured maximum**
original	422 - 452 (1880 - 2010)	500 (2200)
updated	433 - 472 (1930 - 2100)	

Table Notes:

1. Calculated net resistances are less the effective pile weight which was calculated based on the assumption that the pile was filled with portland-cement concrete after driving but before load testing.
2. Range in calculated resistances is without and with side-shear resistance in the Holocene sand-fill and organics strata.

As can be seen from Table 1a, using the results from the updated site-characterization algorithm worsened the agreement between calculated and measured capacities for the constant-diameter pipe pile. It is believed that the overall capacity-calculation methodology presented in Horvath (2002) is still overestimating the tip capacity, even when using the results from the updated site-characterization algorithm. The effect of this is most noticeable when a constant-diameter pile with a closed end is involved as in this case. This is because it is well known that for constant-diameter, closed-end "friction" piles in coarse-grain soil the tip capacity usually contributes a significantly (and surprisingly) large percentage of the total capacity (this is typically not the case for tapered piles). Thus a significant error in estimating tip capacity will have a significant influence on calculated total capacities for a constant-diameter pile in coarse-grain soil. Clearly, resolving this issue is a high priority for future study.

On the other hand, the agreement between calculated and measured capacities was improved for the tapered pile as a result of using output from the updated site-characterization algorithm. This outcome is consistent with what was found as part of a recently-concluded study encompassing a larger variety and number of tapered piles (Horvath and Trochalides 2004, Horvath et al. 2004).

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