This Design Guide has been developed to provide geotechnical and structural engineers with alternative procedures for estimating geotechnical axial capacity of drilled shafts in shale.

The Department has experienced many projects in the past where conventional sampling and testing methods for shale has resulted in the material being poorly characterized with weak compressive strengths. In addition, estimating the nominal side and tip resistance of drilled shafts in shale using conventional formulas for rock or intermediate geomaterials has also often resulted in conservative capacities. Poor characterization and estimation of geotechnical resistance often translates into drilled shafts that have an excessively large diameter and/or embedment into the shale resulting in increased foundation costs. As such, the Department has conducted a research project with the University of Illinois at Urbana-Champaign (UIUC) to evaluate sampling and testing procedures for shales in Illinois as well as methods for estimating side and tip resistance of drilled shafts. Alternative procedures for field testing and estimating the side and tip resistance of drilled shafts in weak shales having an unconfined compressive strength ranging from 10 to 100 ksf are presented in research report FHWA-ICT-13-017, "Improvement for Determining the Axial Capacity of Drilled Shafts in Shale in Illinois". The research results for estimating the side and tip resistance of drilled shafts in weak shales are summarized below.

Geotechnical Axial Resistance of Drilled Shafts in Shale:

The factored resistance of drilled shafts in shale, R_R, should be determined considering the combined side and tip resistances using the following formulas:

$R_R = \phi R_n = \phi_{qs} R_s + \phi_{qp} R_p$

R_s = nominal shaft side resistance

$= q_s A_s$

R_p = nominal shaft tip resistance

$= q_p A_p$

ϕ_{qs} = geotechnical resistance factor for side resistance

= 0.5 for Strength Limit State

= 1.0 for Service and Extreme Limit State

ϕ_{qp} = geotechnical resistance factor for tip resistance

= 0.5 for Strength Limit State

= 1.0 for Service and Extreme Limit State

A_s = area of shaft side surface (ft^2)

q_s = unit side resistance (ksf)

= $0.31\ q_u \leq 30$

A_p = area of shaft tip (ft^2)

q_p = unit tip resistance (ksf)

= $3.0\ q_u\ d_c$

d_c = Skempton's depth correction factor

= 1.0 + 0.2(k)

k $= \frac{L}{D}$ for $\frac{L}{D} \leq 1$

$= \tan^{-1}\left(\frac{L}{D}\right)$ for $\frac{L}{D} > 1$ (radians)

L = embedment depth in shale (in.)

D = shaft diameter (in.)

q_u = unconfined compressive strength of shale (ksf)

It is recommended that the q_u value used to calculate tip resistance reflect the weighted average within a depth of 2 shaft diameters below the tip elevation. Also, it is permissible to assume that the full length of drilled shaft embedded in shale contributes to the development of side resistance.

Settlement Analysis:

The Service Limit State "settlement", or axial displacement of the drilled shaft that occurs as the side and tip resistance is mobilized, should be determined. The estimated displacement should be reported along with the geotechnical axial resistance so that the structural designer can select a drilled shaft depth that provides sufficient factored axial capacity and results in a tolerable service settlement for the structure being designed. The following relationships should be used in evaluating the axial load-deformation response for side and tip resistance.

q-z = unit tip resistance load-displacement response (k/in.)

$$= \frac{q_u\ d_c\ D\ \pi}{\left(\frac{\delta}{D} + \frac{1.5}{100}\right)}$$

δ = tip movement (in.)

t-z = unit side resistance load-displacement response (k/in.)

$= \dfrac{R_S}{0.007\ D}$ for $\Delta \leq 0.007\ D$

$= 0$ for $\Delta > 0.007\ D$

Δ = settlement for a given layer (in.)

Variables not described above are defined in the previous section for estimating the factored geotechnical axial resistance of the drilled shaft. Please note that the t-z relationship is bilinear in that the stiffness and side resistance plateau at a settlement value of approximately 0.7% of the shaft diameter.

An Excel spreadsheet has been developed as a companion tool to the Design Guide to assist designers with use of this alternative design procedure for drilled shafts in shale. This spreadsheet is available at: *Drilled Shaft Axial Capacity in Shale < 100 KSF*