The QzSimple1 Material

uniaxialMaterial QzSimple1 matTag? qzType? qult? z50? <suction? c?>

The above command constructs a simple uniaxial q-z material for use with a zeroLength element. The argument matTag is used to uniquely identify this uniaxialMaterial object among uniaxialMaterial objects in the BasicBuilder object. The argument qzType currently can be:

- qzType = 1 Backbone curve approximates Reese & O'Neill's (1987) relation for drilled shafts in clay.
- qzType = 2 Backbone curve approximates Vijayvergiya's (1977) relation for piles in sand.

The argument qult is the ultimate capacity of the q-z material. Note that "q" or "q_{ult}" are stresses [force per unit area of pile tip] in common design equations, but are both loads for this uniaxialMaterial [i.e., stress times the tip area].

The argument z50 is the displacement at which 50% of qult is mobilized during monotonic loading. Note that Vijayvergiya's relation (qzType=2) refers to a "critical" displacement (z_{crit}) at which qult is fully mobilized, and that the corresponding z50 would be 0. 125z_{crit}.

The optional arguments suction and c must be given together or both omitted. The argument suction sets a nominal uplift resistance equal to suction*qult. Suction defaults to zero, and will only accept input values between 0 and 0.1. The argument c is the viscous damping term (dashpot) on the far-field (elastic) component of the displacement rate (velocity). This argument defaults to zero. Nonzero c values are used to represent radiation damping effects.

The load-displacement behavior of this material is different in compression than in tension (uplift). Since this material is used with zeroLength elements, it is important to note that the relative displacement within the zeroLength element is computed as the displacement of the jnode minus the displacement of the inode. For example, consider downward monotonic loading of a pile with the y-axis upwards. For the q-z tip element, the inode should be fixed in space and the jnode should be on the pile tip, such that the negative displacement of the pile tip produces a negative relative displacement within the q-z element, which produces compression (negative force) in the q-z material.

The equations for QzSimple1 and a few examples of its loading response are given in an attached document.

Appendix: Equations and Example Responses for the QzSimple1 Material

The equations describing QzSimple1 behavior are similar to those for p-y materials by Boulanger, R. W., Curras, C. J., Kutter, B. L., Wilson, D. W., and Abghari, A. (1999). "Seismic soil-pile-structure interaction experiments and analyses." Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 125(9): 750-759. Modifications were required for representing the different responses of a q-z material in compression versus uplift.

The nonlinear q-z behavior is conceptualized as consisting of elastic (q-z^e), plastic (q-z^p), and gap (q-z^g) components in series. Radiation damping is modeled by a dashpot on the "far-field" elastic component (q-z^e) of the displacement rate. The gap component consists of a bilinear closure spring (q^c-z^g) in parallel with a nonlinear drag spring (q^d-z^g). Note that $z = z^e + z^p + z^g$, and that $q = q^d + q^c$.

The plastic component has an initial range of rigid behavior between $-C_r q_{ult} < q < C_r q_{ult}$ with C_r = the ratio of q/q_{ult} when plastic yielding first occurs in virgin loading. The rigid range of q, which is initially $2\ C_r q_{ult}$, translates and grows with plastic yielding. The rigid range of q is constrained to a maximum size of 0.7qult. Beyond the rigid range, loading of the plastic (q-z^p) component is described by:

$$q = q_{ult} - \left(q_{ult} - q_o\right)\left[\frac{cz_{50}}{cz_{50} + \left|z^p - z_o^p\right|}\right]^n$$

where q_{ult} = the ultimate resistance of the q-z material in the current loading direction, q_o = q at the start of the current plastic loading cycle, $z_o^p = z^p$ at the start of the current plastic loading cycle, and c and n are constants that control the shape of q-z^p curve.

The closure (q^c-z^g) component is simply a bilinear elastic spring, which is relatively rigid in compression and extremely flexible in tension (uplift).

The nonlinear drag (q^d-z^g) component is used to allow the specification of some minimum "suction" on the pile tip during uplift. It is described by:

$$q^d = C_d q_{ult} - \left(C_d q_{ult} - q_o^d\right)\left[\frac{z_{50}}{z_{50} + 2\left|z^g - z_o^g\right|}\right]$$

where C_d = ratio of the maximum drag (suction) force to the ultimate resistance of the q-z material, $q_o^d = q^d$ at the start of the current loading cycle, and $z_o^g = z^g$ at the start of the current loading cycle.

The flexibility of the above equations can be used to approximate different q-z backbone relations. Reese and O'Neill's (1987) recommended backbone for drilled shafts in clay is closely approximated using c = 0.35, n = 1.2, and C_r = 0.2. Vijayvergiya's (1977) recommended backbone for piles in sand is closely approximated using c = 12.3, n = 5.5, and C_r = 0.3. QzSimple1 is currently implemented to allow use of these two default sets of values. Values of q_{ult}, z_{50}, and suction (i.e., C_d) must then be specified to define the q-z material behavior.

Viscous damping on the far-field (elastic) component of the q-z material is included for approximating radiation damping. For implementation in OpenSees the viscous damper is placed across the entire material, but the viscous force is calculated as proportional to the component of velocity (or displacement) that developed in the far-field elastic component of the material. For example, this correctly causes the damper force to become zero during load increments across a fully formed gap in uplift. In addition, the total force across the q-z material is restricted to q_{ult} in magnitude so that the viscous damper cannot cause the total force to exceed the near-field soil capacity. Users should also be familiar with numerical oscillations that can develop in viscous damper forces under transient loading with certain solution algorithms and damping ratios. In general, an HHT algorithm is preferred over a Newmark algorithm for reducing such oscillations in materials like QzSimple1.

Examples of the monotonic backbones and cyclic loading response of QzSimple1 are given in the following plots.

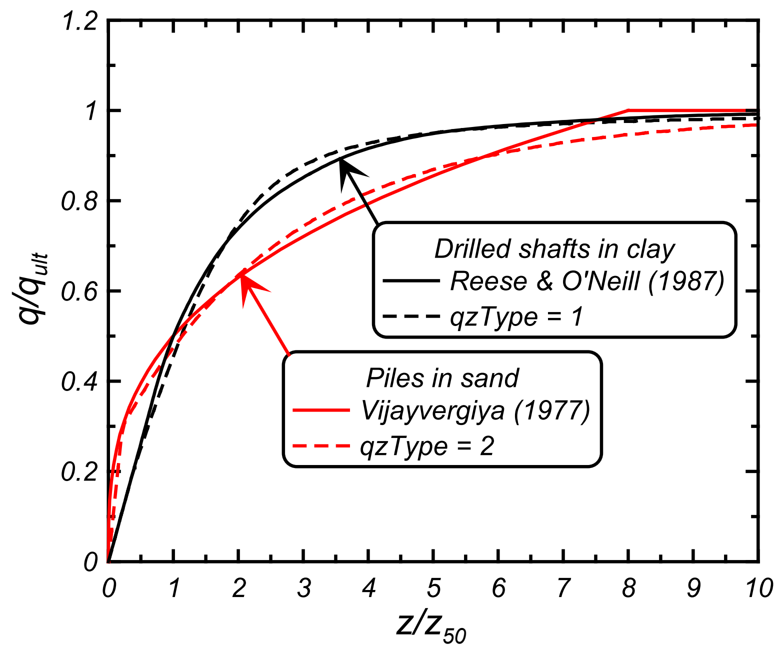

FIG. Comparison of Monotonic Backbones for qzTypes 1 and 2 versus the Relations by Reese & O'Neill (1987) and Viyavergiya (1977).

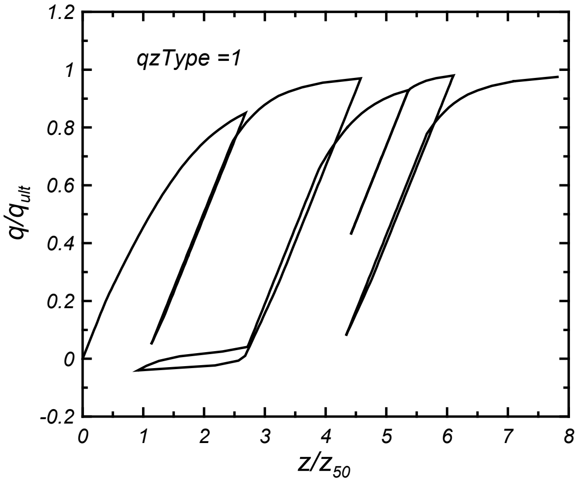

FIG. Cyclic loading responses for qzType = 1 (left) and 2 (right), with suction = 0.05, for identical q/q_{ult} loading time histories.