The PySimple1 Material

> uniaxialMaterial PySimple1 matTag? soilType? pult? y50? Cd? <c>

The above command constructs a simple uniaxial p-y 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 soilType currently can be:

> soilType = 1 Backbone of p-y curve approximates Matlock (1970) soft clay relation.
> soilType = 2 Backbone of p-y curve approximates API (1993) sand relation.

The argument pult is the ultimate capacity of the p-y material. Note that "p" or "p_{ult}" are distributed loads [force per length of pile] in common design equations, but are both loads for this uniaxialMaterial [i.e., distributed load times the tributary length of the pile].

The argument y50 is the displacement at which 50% of pult is mobilized during monotonic loading. The argument Cd sets the drag resistance within a fully formed gap as Cd*pult.

The optional 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 equations for PySimple1 and a few examples of its cyclic loading response are given in an attached document.

Appendix: Equations and Example Responses for the PySimple1 Material

The equations describing PySimple1 behavior are described in 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. Only minor changes have been made in its implementation for OpenSees.

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

The plastic component has an initial range of rigid behavior between $-C_r\,p_{ult} < p < C_r\,p_{ult}$ with C_r = the ratio of p/p_{ult} when plastic yielding first occurs in virgin loading. The rigid range of p, which is initially $2\,C_r\,p_{ult}$, translates with plastic yielding (kinematic hardening). The rigid range of p can be constrained to maintain a minimum size on both the positive and negative loading sides (e.g., 25% of p_{ult}), and this is accomplished by allowing the rigid range to expand or contract as necessary. Beyond the rigid range, loading of the plastic (p-y^p) component is described by:

$$p = p_{ult} - \left(p_{ult} - p_o\right)\left[\frac{cy_{50}}{cy_{50} + \left|y^p - y_o^p\right|}\right]^n$$

where p_{ult} = the ultimate resistance of the p-y material in the current loading direction, $p_o = p$ at the start of the current plastic loading cycle, $y_o^p = y^p$ at the start of the current plastic loading cycle, c = constant to control the tangent modulus at the start of plastic yielding, and n = an exponent to control sharpness of the p-y^p curve.

The closure (p^c-y^g) spring is described by:

$$p^c = 1.8 p_{ult}\left[\frac{y_{50}}{y_{50} + 50\left(y_o^+ - y^g\right)} - \frac{y_{50}}{y_{50} - 50\left(y_o^- - y^g\right)}\right]$$

where y_o^+ = memory term for the positive side of the gap, y_o^- = memory term for the negative side of the gap. The initial values of y_o^+ and y_o^- were set as $y_{50}/100$ and $-y_{50}/100$, respectively. The factor of 1.8 brings p^c up to p_{ult} during virgin loading to y_o^+ (or y_o^-). Gap enlargement follows logic similar to that of Matlock et al. (1978). The gap grows on the positive side when the plastic deformation occurs on the negative loading side. Consequently, the y_o^+ value equals the opposite value of the largest past negative value of $y^p+y^g+1.5y_{50}$, where the $1.5y_{50}$ represents some rebounding of the gap. Similarly, the y_o^- value equals the opposite value of the largest past positive value of $y^p+y^g-1.5y_{50}$. This closure spring allows for a smooth transition in the load-displacement behavior as the gap opens or closes.

The nonlinear drag (p^d-y^g) spring is described by:

$$p^d = C_d\, p_{ult} - \left(C_d\, p_{ult} - p_o^d\right)\left[\frac{y_{50}}{y_{50} + 2\left|y^g - y_o^g\right|}\right]$$

where C_d = ratio of the maximum drag force to the ultimate resistance of the p-y material, $p_o^d = p^d$ at the start of the current loading cycle, and $y_o^g = y^g$ at the start of the current loading cycle.

The flexibility of the above equations can be used to approximate different p-y backbone relations. Matlock's (1970) recommended backbone for soft clay is closely approximated using $c = 10$, $n = 5$, and $C_r = 0.35$. API's (1993) recommended backbone for drained sand is closely approximated using $c = 0.5$, $n = 2$, and $C_r = 0.2$. PySimple1 is currently implemented to allow use of these two default sets of values. Values of p_{ult}, y_{50}, and C_d must then be specified to define the p-y material behavior.

Viscous damping on the far-field (elastic) component of the p-y 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 addition, the total force across the p-y material is restricted to p_{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 PySimple1.

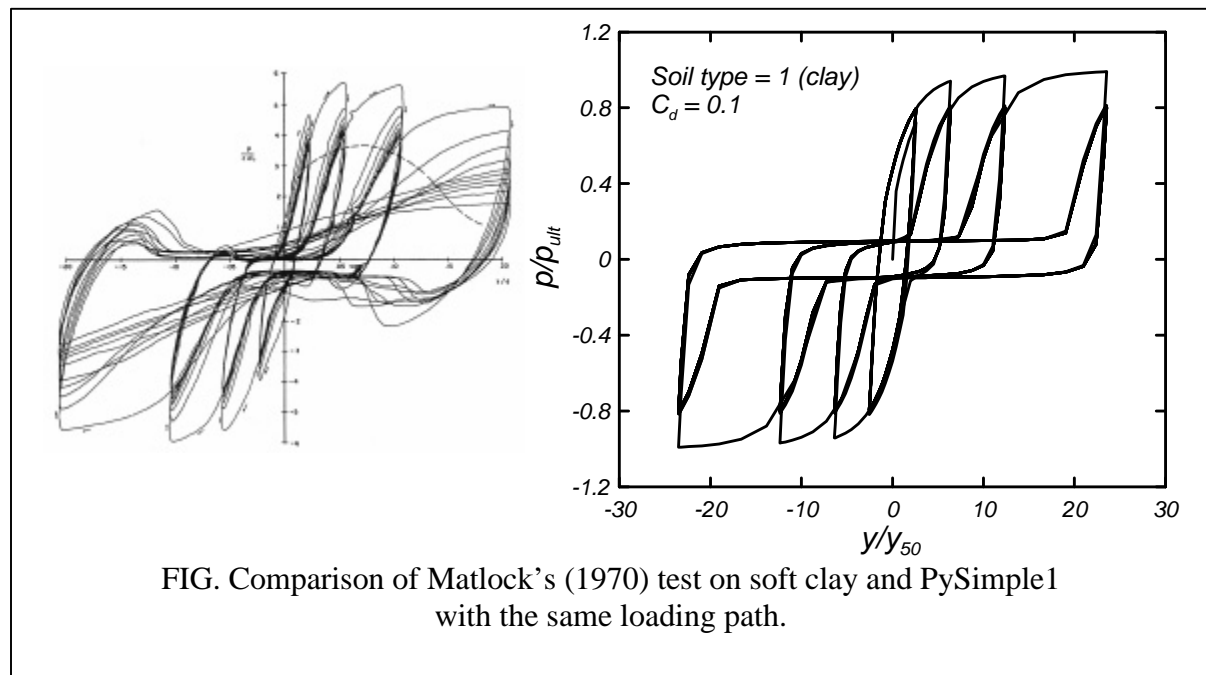Examples of the cyclic loading response of PySimple1 are given in the following plots.

FIG. Comparison of Matlock's (1970) test on soft clay and PySimple1
with the same loading path.

FIG. Four examples of cyclic loading response; three for soilType = 1 with Cd = 0.1, 1.0, and 10, and one for soilType = 2 with Cd = 0.3.