HAWC2 Soil model

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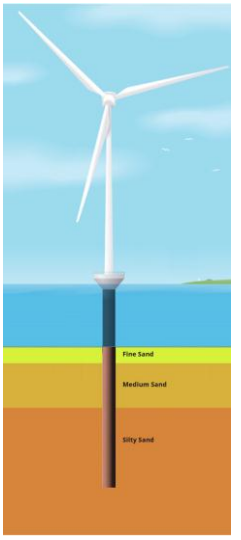
Why use a soil model?

- The foundation of the structure transfers the forces from the structure to the surrounding soil.
- A clear understanding of the load-transfer mechanisms, leads to increased confidence in the overall design.
- Critical that the foundation can sustain all loads that may be applied, particularly during extreme environmental conditions.



Pile Foundations Models

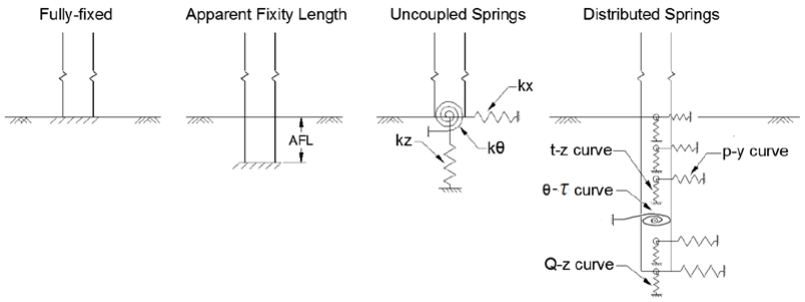
CERTAINCY & COST

- **Fully coupled finite element model simulation**
  - Most comprehensive modeling technique, includes many additional non linear effects
  - Includes interactions between soil layers (vertical) and between adjacent piles (horizontal)
  - Very time consuming and expensive, requires extensive soil lab testing
- **Sequential analysis with finite element simulations**
  - Combines the capabilities of the multiple non-linear spring model with finite element simulations
  - Allows for dynamic FE simulations of the foundation without the need for a fully coupled model
- **Multiple non-linear spring representation (p-y curves)**
  - Foundation with modeled springs distributed along length of pile
  - Dependant on accurate soil profile and characteristic parameters
- **Single non-linear spring representation**
  - Entire foundation modeled with single springs at mudline for each DOF
  - Does not account for pile flexibility or soil profile non-homogeneity
- **Model with an equivalent fixity depth (Apparent Fixity Length)**
  - Very simple and fast in computations, more representative than fixed condition
  - Does not capture any soil-structure interaction
- **Assume fixed boundary conditions**
  - Extremely simple, fast computations
  - Gross misrepresentation of stiffness of the foundation

SIMPLICITY & SPEED

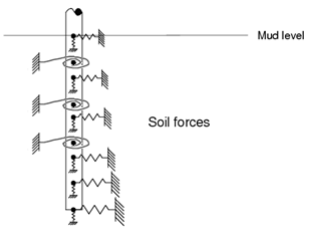
Foundation Models

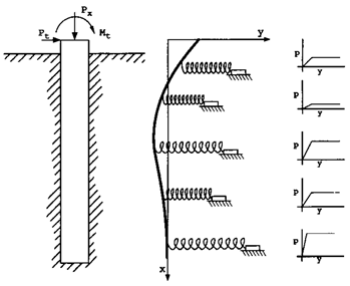
- – Fixed boundary conditions
- – Apparent Fixity Length (AFL)
- – Uncoupled Springs
- – Distributed non-linear spring model using force-displacement (p-y) curves



Distributed spring model using force-displacement curves (P-Y)

- Soil layers is modeled using different spring caracteristics for the different soil layers.



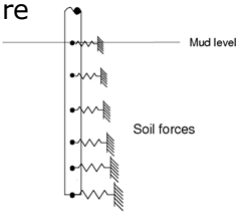


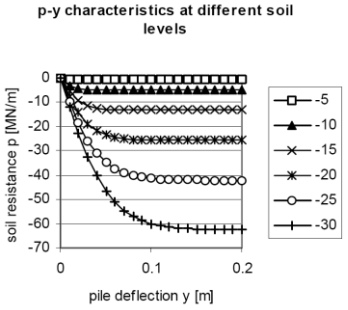
Soil spring forces – pile in sand

Lateral soil pressure

$$p(y) = A P_u \tanh\left(y k \frac{X}{A P_u} \right)$$

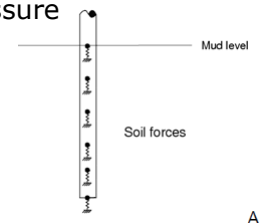
$$P_u = \min \begin{cases} (C_1 X + C_2 D)\gamma' X \\ C_3 D \gamma' X \end{cases}$$





Vertical soil pressure

$$t(z) = \frac{2G_0}{D \ln(Z_{IF})} z$$



γ'	[N/m^3]	Submerged unit weight of soil
$C_{1\text{-}3}$	[-]	Coefficients as function of friction angle
D	[m^2]	Cross sectional diameter
G_0	[Pa]	Initial shear modulus of the soil
K	[Pa/m]	Initial modulus of subgrade reaction
A	–	Loading condition factor
P_u	[N/m]	Ultimate lateral soil strength
Y	[m]	Lateral deflection
X	[m]	Height above mud level
Z_{IF}	[-]	Radius of influenced soil zone divided by pile radius

Soil spring example

begin soil;

begin soil_element;

mbdy_name pile_substructure;

datafile ./data/soil.dat;

soilsections uniform 30; Distribution of soil calculation points from mbdy node 1 to n

damping_k_factor 0.01 ; Rayleigh damping based on soil stiffness matrix

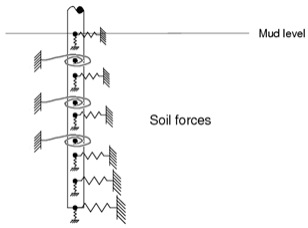
set 1; lateral (p-y –curve)

set 2; axial (t-z, Q-z curve)

set 3; rotation_z (θ-τ curve)

end soil_element;

end soil;



Soil spring data file

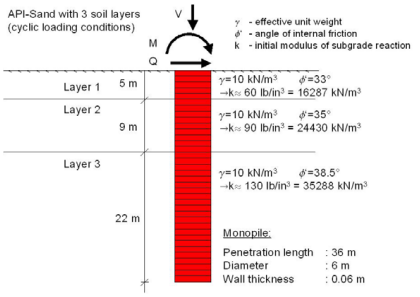
```
This is a nonlinear soil spring demonstration file
#1
lateral                (axial/lateral)
5 4                     nrow ndefl
        0.0     0.1     0.2     1.0   x1 x2 x3 .....   [m]
0.0     0       15      20      500   Z_G  P_1 P_2 P_3 .... F_ndefl [kN/m]
10.0    0       15      20      500
20.0    0       15      20      500
30.0    0       15      20      500
40.0    0       15      20      500
#2
axial                  (axial/lateral)
5 4                     nrow ndefl
        0.0     0.1     0.2     1.0   x1 x2 x3 .....   [m]
0.0     0       150     200     5000  Z_G  P_1 P_2 P_3 .... F_ndefl [kN/m]
10.0    0       150     200     5000
20.0    0       150     200     5000
30.0    0       150     200     5000
40.0    0       150     200     5000
#3
rotation_z             (axial/lateral/rotation_z)
5 4                     nrow ndefl
        0.0     0.1     0.2     1.0   x1 x2 x3 .....   [rad]
0.0     0       150     200     5000  Z_G M_1 M_2 M_3 .... M_ndefl [kNm/m]
10.0    0       150     200     5000
20.0    0       150     200     5000
30.0    0       150     200     5000
40.0    0       150     200     5000
```

Example from 0C3

- Values specified and P-y calculated
- A – Loading condition factor is 0.9 (for cyclic loading)
- Curves are linearized (1 point)

$$p(y) = A P_u \tanh\left(y k \frac{X}{A P_u} \right)$$

$$P_u = \min \begin{cases} (C_1 X + C_2 D)\gamma' X \\ C_3 D \gamma' X \end{cases}$$

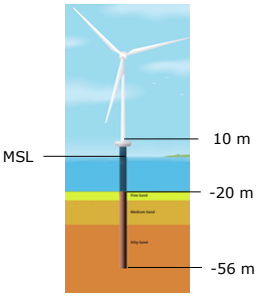


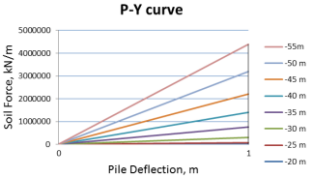
	Layer 1	Layer 2	Layer 3
Soil type	API sand	API sand	API sand
Loading type	cyclic	cyclic	cyclic
Layer top [m]	0	5	14
Layer bottom [m]	5	14	∞
Effective unit weight γ [kN/m^3]	10	10	10
Internal friction angle ϕ [°]	33	35	38.5
p-y modulus k [kN/m^3]	16287	24430	35288
Coefficient C_1 [-]	2.49133	2.97045	4.04577
Coefficient C_2 [-]	3.09732	3.41918	4.06556
Coefficient C_3 [-]	41.72551	53.79345	85.05375

Input for the htc-file

.htc input file

```
begin soil;
  begin soil_element;
    body_name pile_substructure;
    datafile ./data/soil.dat;
    soilsections uniform 30; damping_k_factor 0.01 ;
    set 1;  lateral
  end soil_element;
end;
```



soil.dat

```
#1
lateral                                   (axial/lateral)
37 2                                      nrow ndefl
     0.0        1.0        x_1 x_2 x_3 .....x_ndefl  [m]
20   0.0        1.16E+03   Z_G F_1 F_2 F_3 .... F_ndefl [kN/m]
21   0.0        9.00E+03
22   0.0        2.09E+04
23   0.0        3.56E+04
24   0.0        5.22E+04
25   0.0        8.02E+04
26   0.0        1.14E+05
27   0.0        1.43E+05
28   0.0        1.72E+05
29   0.0        2.00E+05
30   0.0        2.28E+05
31   0.0        2.54E+05
32   0.0        2.80E+05
33   0.0        3.05E+05
34   0.0        3.85E+05
35   0.0        4.60E+05
36   0.0        4.95E+05
............
56   0.0        5.95E+05
```