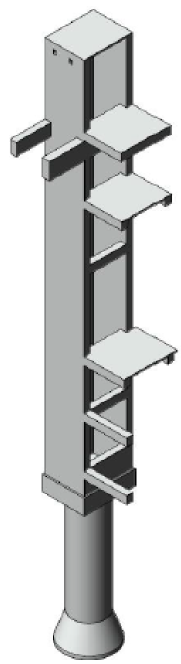
# Response of a laterally-loaded pile foundation.

The following example discusses the design of a laterally-loaded pile foundation. The fundamental problem is that of finding the required length of a 2.20m diameter pile under an externally applied lateral load and bending moment. The mechanical properties of the soil deposit are given in table 01. The analysis is conducted for the maximum lateral load and bending moment under service conditions.

Units for this example are **[tonf-m]**.

**Input and output files for this problem are available in the examples folder of this REPO (notebooks\Examples).**



The main problem parameters are described next.

# Mechanical properties.

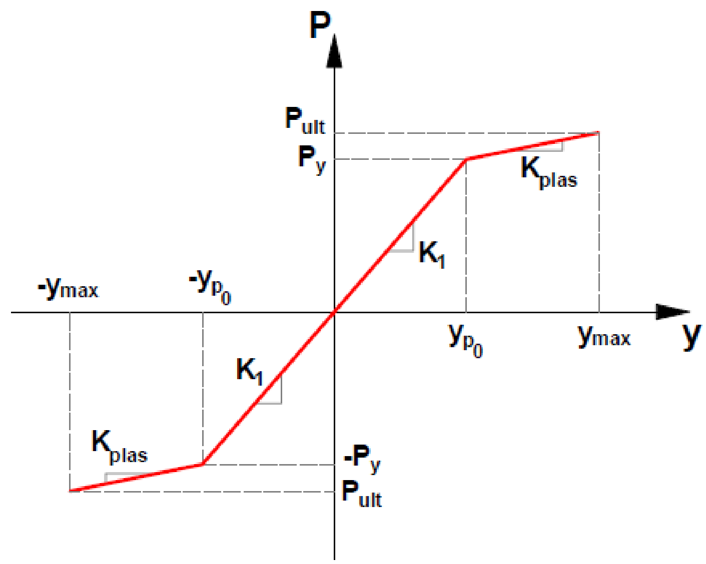
The following set of parameters defines the soil deposit at the site:

- $Y$ : Depth.
- $K_h$ : Lateral soil stiffness at a depth $Y$.
- $\sigma_{ult}$ : Maximum stress in the soil at a depth $Y$.

| Depth | Kh | $\sigma_{ult}$ |
|---|---|---|
| 0.0 m | 917 tonf/m³ | 21.6 tonf/m² |
| 5.5 m | 4280 tonf/m³ | 21.6 tonf/m² |
| 7.5 m | 9070 tonf/m³ | 54.0 tonf/m² |
| 12.5 m | 24470 tonf/m³ | 90.0 tonf/m² |

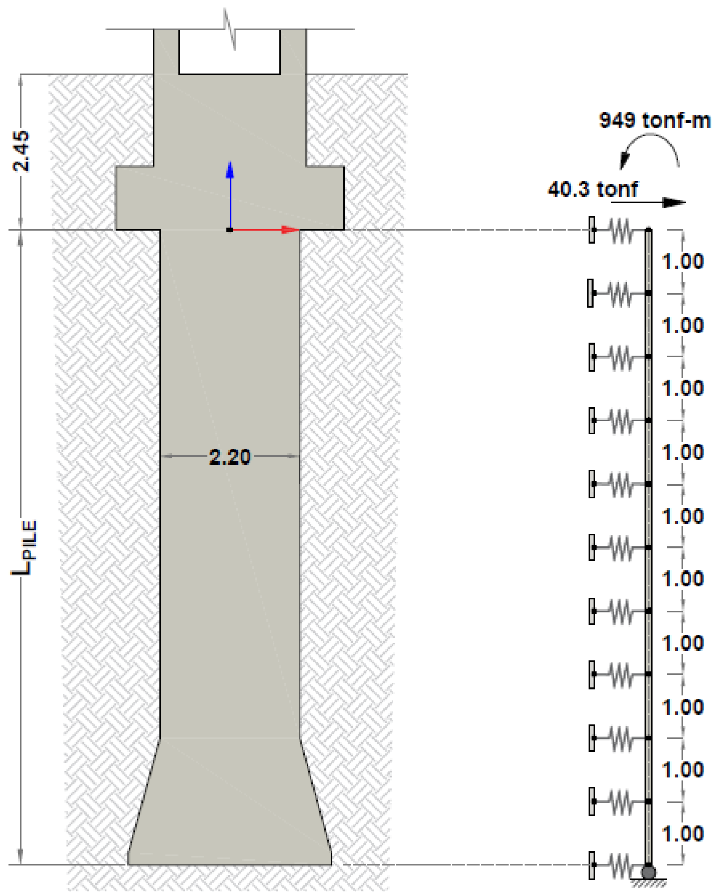
*Table 01. Soil properties*

- Soil stiffness is represented by a bilinear $P$-$Y$ curve according to the variation with depth of $K_h$.



# Structural idealization for the pile

## Concrete drilled shaft




- Element type: 2
- Pile cross sectional diameter: *2.20 m*
- Material profile for the pile is concrete with an elastic modulus of *2527000 tonf/m²* and unit weight of *2.4 tonf/m³*

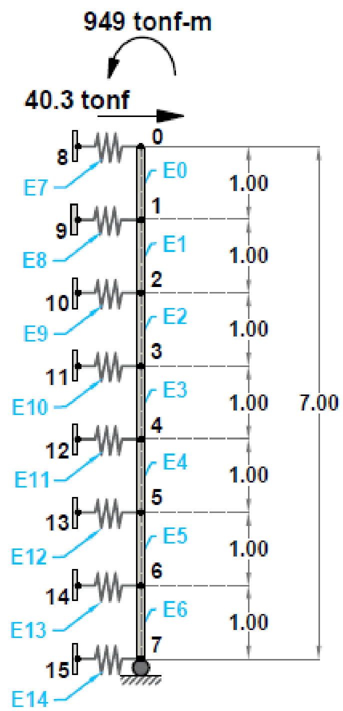
## Soil springs

- Element type: 9
- Material profile for the springs according to the variation with depth of $K_h$:

| Depth | $K_1$ | $Yp_0$ | $K_{plas}$ | $P_{ult}$ |
|---|---|---|---|---|
| 0.0 m | 2018 tonf/m | 0.024 m | 0 tonf/m | 95 tonf |
| 1.0 m | 3363 tonf/m | 0.014 m | 0 tonf/m | 95 tonf |
| 2.0 m | 4708 tonf/m | 0.010 m | 0 tonf/m | 95 tonf |
| 3.0 m | 6053 tonf/m | 0.008 m | 0 tonf/m | 95 tonf |
| 4.0 m | 7398 tonf/m | 0.006 m | 0 tonf/m | 95 tonf |
| 5.0 m | 8743 tonf/m | 0.005 m | 0 tonf/m | 95 tonf |

The pile response was computed for a pile length of `7.0m` .

Identifiers for nodal points, elements and other problem dimensions are shown below:




The springs located at the `0.0m` and `7.0m` level employ `50%` of the total stiffness as per table 02.

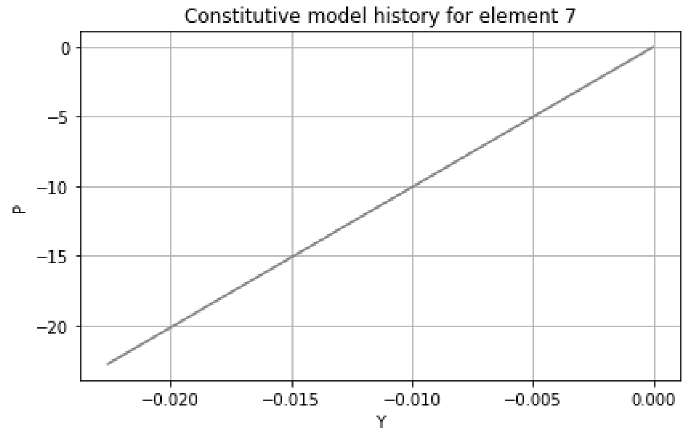
In [1]:
```
%matplotlib inline
import matplotlib.pyplot as plt
import numpy as np
import sympy as sym
from os import sys
sys.path.append("../source/")
from STRUCTURE import Struct_DYN
from postprocesor import *

# Execute analysis
displacement,folder,IBC,nodes,elements,ninc,T,MvarsGen,ILFGen = Struct_DYN("Examples/E
06/01_INPUT/")
```

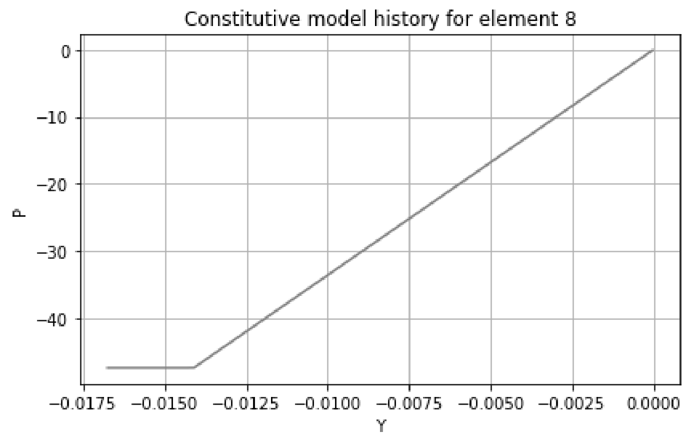
```
----------------------
Number of nodes: 16
Number of elements: 15
Number of equations: 23
Number of equations after constraints: 23
----------------------
Natural periods of the system :  Not computed,static system solution
----------------------
Time step for solution: 0.01 sec
Number of time increments: 500
----------------------
Convergency reached after  1  iterations at increment  334  ( 3.34 sec)
Convergency reached after  1  iterations at increment  462  ( 4.62 sec)
Convergency reached after  1  iterations at increment  481  ( 4.81 sec)
Duration for system solution: 0:00:00.767947
Duration for the system's solution: 0:00:00.768939
Duration for post processing: 0:00:00
----------------------
Analysis terminated successfully!
----------------------
```

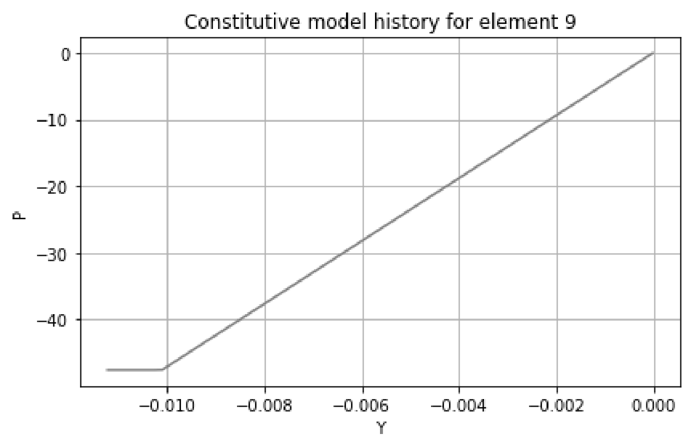
## Results

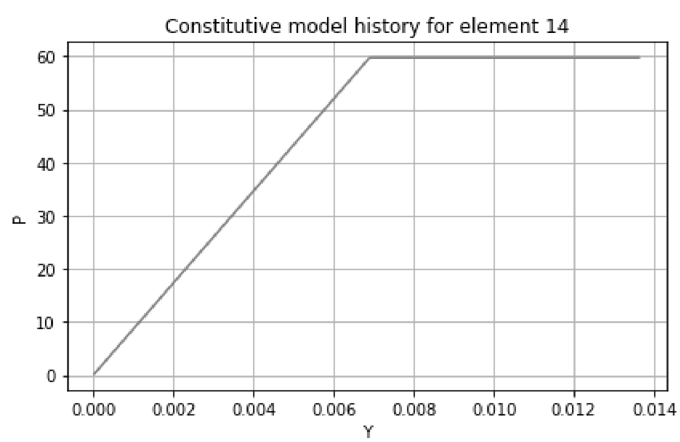
The evolution of the soil response in terms of the $P$-$Y$ curves for the springs undergoing plastic behavior is shown next. The plastified springs are identified by elements `8` , `9` and `14` .

In [2]:
```
histe = PlasModel(MvarsGen, Element = 7, xlabel = "Y", ylabel = "P")
histe = PlasModel(MvarsGen, Element = 8, xlabel = "Y", ylabel = "P")
histe = PlasModel(MvarsGen, Element = 9, xlabel = "Y", ylabel = "P")
histe = PlasModel(MvarsGen, Element = 14, xlabel = "Y", ylabel = "P")
```


Constitutive model history for element 7
P
Y
0
−5
−10
−15
−20
−0.020
−0.015
−0.010
−0.005
0.000


Constitutive model history for element 8
P
Y
0
−10
−20
−30
−40
−0.0175
−0.0150
−0.0125
−0.0100
−0.0075
−0.0050
−0.0025
0.0000


Constitutive model history for element 9
P
Y
0
−10
−20
−30
−40
−0.010
−0.008
−0.006
−0.004
−0.002
0.000

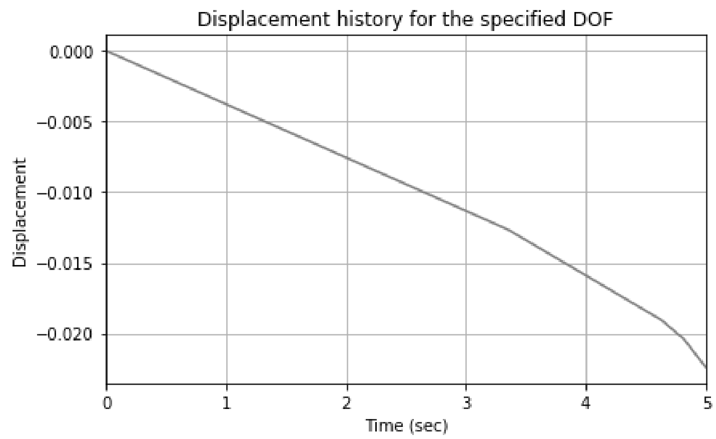

Constitutive model history for element 14
P
Y
60
50
40
30
20
10
0
0.000
0.002
0.004
0.006
0.008
0.010
0.012
0.014

As expected the spring elements with low rigidity exhibit plastic response (elements 7, 8 and 9) since these elements are associated to materials with low capacity to sustain lateral loads. Typically the soil at large depths exhibits a larger stiffness. Although element 7 did not experience inelastic response its maximum strain was close the plastic limit of the material $Y_{p_0}$.

On the other hand, element 14, corresponding to the spring associated to the soil layer with larger stiffness along the pile length undergoes plastic behavior since the found strains are larger than the plastic limit.

The predicted displacement time history along the horizontal direction for the node at the top of the pile is shown in the figure below:

In [3]:
```
fig    = NodalDispPLT(displacement[0,:], T, ninc, ylabel = "Displacement")
```




Internal forces, together with a simple displacement diagram are available in the file: *...\01_NoteBooks\Examples\Ex_05\Output.xls*

In [4]:
```
from IPython.core.display import HTML
def css_styling():
    styles = open('./nb_style.css', 'r').read()
    return HTML(styles)
css_styling()
```

Out[4]:

In [ ]: