SESAM TUTORIAL

GeniE

Soil Curves for Large Diameter Monopile

Valid from program version 8.4

Sesam Tutorial

GeniE – Soil Curves for Large Diameter Monopile

Date: October 2022

Valid from GeniE version 8.4

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1 INTRODUCTION

SPLICE is a software by DNV for analysis of pile-soil interaction of piled foundations.
In Splice V8.0 user-defined soil reaction springs has been implemented.
These springs are suitable for monopile analysis and are based on the findings and recommendations resulting from a PISA joint industry research project. In the PISA research project, it was found that four soil reaction springs are necessary to capture the behaviour large diameter monopiles. These are:

- A distributed lateral load $\boldsymbol{p}$ as a function of the lateral displacement $\boldsymbol{v}$ – PY curve
- A distributed moment $\boldsymbol{m}$ as a function of the pile cross-section rotation $\boldsymbol{\phi}$ – DM curve
- A base horizontal force $\boldsymbol{H_B}$ as a function of the base lateral displacement $\boldsymbol{v_B}$ – BS curve
- A base moment $\boldsymbol{M_B}$ as a function of the base cross-section rotation $\boldsymbol{\phi_B}$ – BM curve

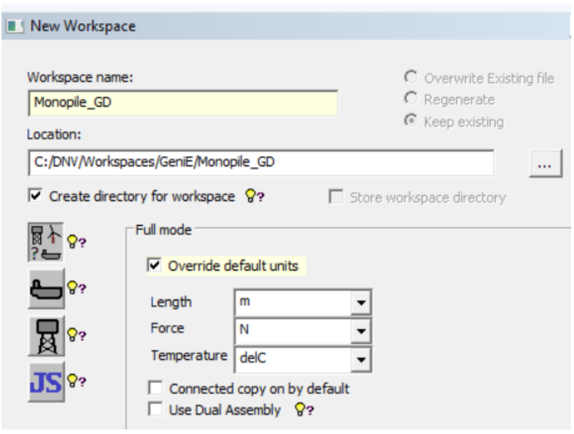
From GeniE V8.4, in addition to the conventional T-Z, Q-Z and P-Y curves, it is also supported to define three manual soil curves for large diameter pile analysis from the GUI, that is the DM, BS and BM curves.

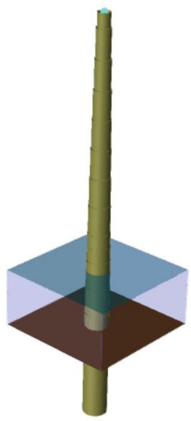
This workshop will focus on:

- How to activate soil curves for large diameter monopile in the GeniE GUI.
- How to give in data for these curves.
- How to check the input and output files.
- Possible warning/error messages

2 TUTORIAL - SOIL CURVES FOR LARGE DIAMETER MONOPILE

Create a new GeniE workspace, set the default units to N and m. Import the gnx file ***Monopile_Start.gnx***. This is a monopile model, no soil related data has been defined. In this workshop we will generate T-Z and Q-Z curves with the API2014 code. P-Y, DM, BS and BM curves will be specified manually.



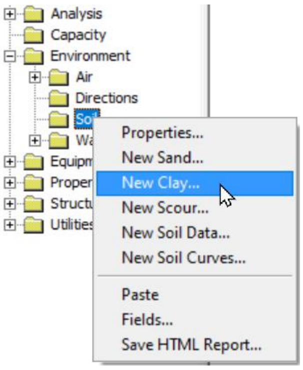


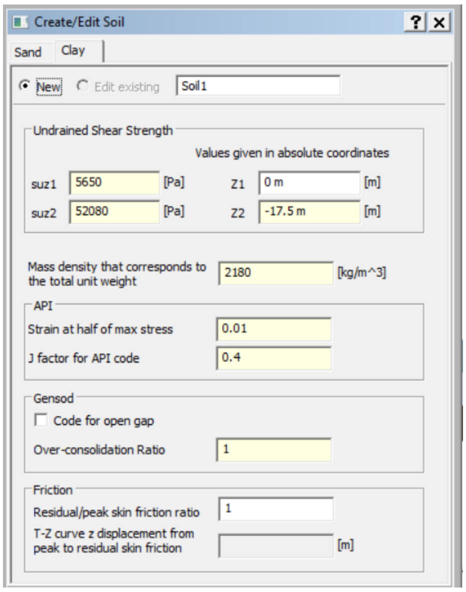
2.1 Enter Soil Type and Soil Data

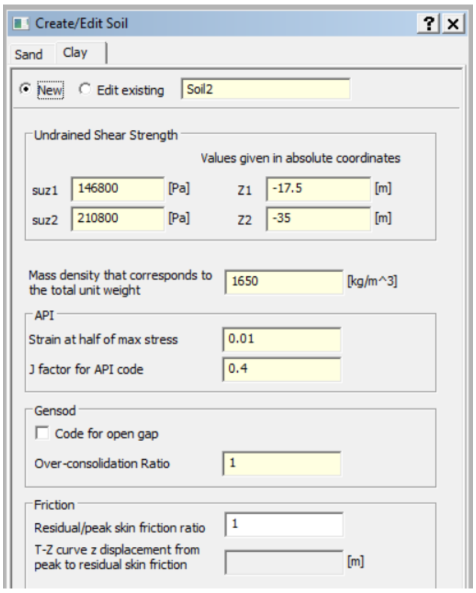
The soil basic property is listed in the following table.

Soil Layers	Soil Type	suztop	suzbot	total density	ε50	J factor
m	-	kPa	kPa	tonne/m^3	-	
0 ~ -17.5	clay	5.65	52.08	2.18	0.01	0.4
-17.5~ - 35	clay	146.8	210.8	1.65	0.01	0.4

Under *Environment/Soil* folder, right click to select *New Clay* to define the soil1 and soil2 as below

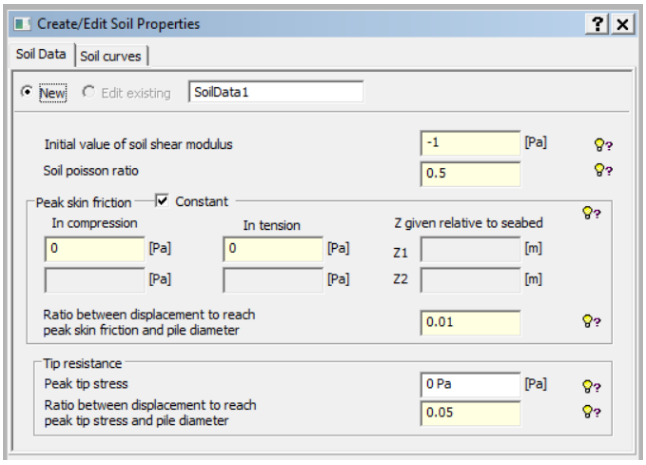






Then from the *Soil* folder, right click to select *New Soil Data* to define soil data. Enter both the peak skin friction and peak tip stress as zero.

Then as we later in this tutorial will define T-Z, Q-Z curve type as API2014, the peak skin friction and peak tip resistance will be calculated by Gensod module per API code based on the soil basic property defined in the above figures.



2.2 Enter Soil Curves

In this model, the pile length is 35 m, while the soil layers will be divided into 40 layers. All the soil curves can be found in the file *SoilCurveInput.xlsx*.

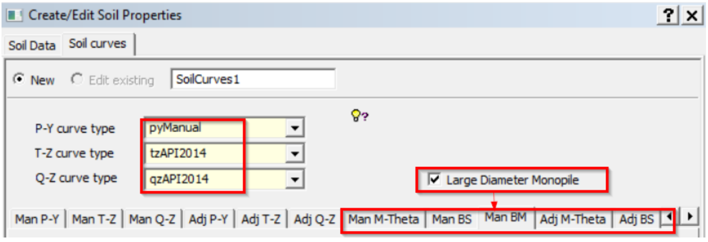
Below it is shown how to enter the data for the first soil layer and the last soil layer as an example. The curves and the unit for each parameter is listed in the below tables.

CurveNumber	type	p1	p2	p3	p4	p5	p6	p7	p8	p9	p10
1	P	0.00E+00	1.43E+04	1.81E+04	2.13E+04	2.37E+04	2.53E+04	2.62E+04	2.67E+04	2.69E+04	2.70E+04
	Y	0.00E+00	3.90E-02	7.79E-02	1.56E-01	3.12E-01	6.23E-01	1.25E+00	2.49E+00	4.99E+00	9.97E+00
1	DM	0.00E+00	2.52E+05	2.62E+05							
	Theta	0.00E+00	1.07E-01	8.59E-01							
40	P	0.00E+00	3.68E+05	5.45E+05	7.60E+05	1.00E+06	1.24E+06	1.45E+06	1.60E+06	1.69E+06	1.72E+06
	Y	0.00E+00	4.60E-03	9.20E-03	1.84E-02	3.68E-02	7.36E-02	1.47E-01	2.94E-01	5.89E-01	1.18E+00
40	BS	0.00E+00	4.59E+06	5.87E+06	7.03E+06	7.93E+06	8.53E+06	8.90E+06	9.09E+06	9.19E+06	9.21E+06
	Y	0.00E+00	4.47E-03	8.94E-03	1.79E-02	3.58E-02	7.15E-02	1.43E-01	2.86E-01	5.72E-01	1.14E+00
40	BM	0.00E+00	1.31E+07	2.07E+07	3.02E+07	4.03E+07	4.95E+07	5.65E+07	6.11E+07	6.36E+07	6.43E+07
	Theta	0.00E+00	2.15E-02	4.30E-02	8.59E-02	1.72E-01	3.44E-01	6.88E-01	1.38E+00	2.75E+00	5.50E+00

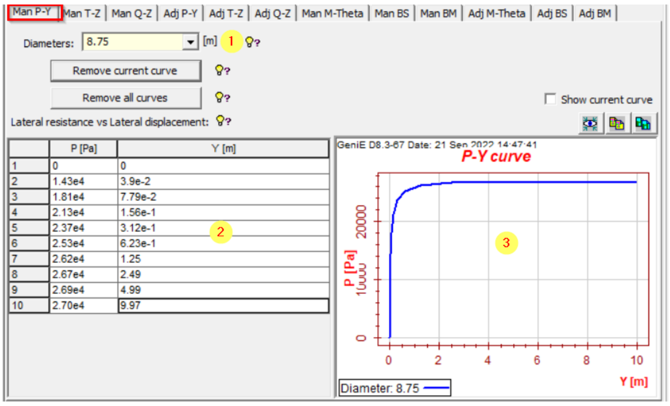
Type	Unit
P	Pa
Y	m
DM	N
Theta	deg
BS	N
Y	m
BM	N*m
Theta	deg

Under *Environment/Soil* folder, right click to select *New Soil Curves* to open the soil properties window.

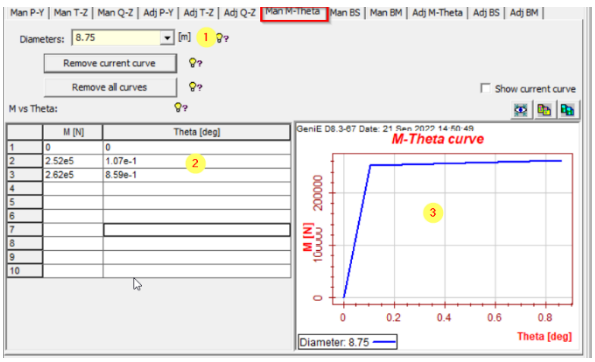
- Select API2014 as the T-Z and Q-Z curve type and select pyManual as P-Y curve type.
  Then check the option *Large Diameter Monopile* to activate the tabs for Man M-Theta, Man BS, Man BM and the correspondingly Adj- tabs.



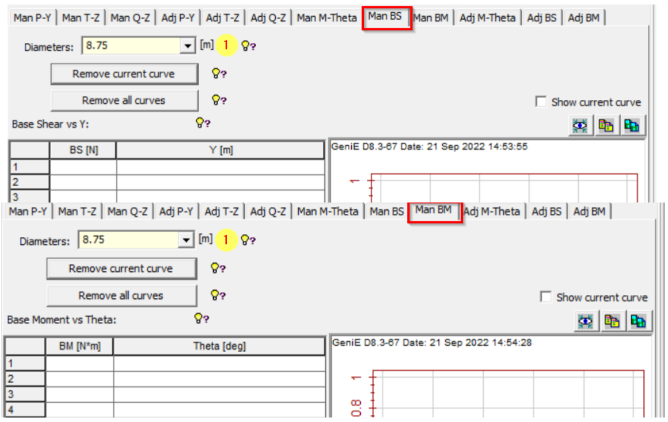
- Under Man P-Y tab, enter 8.75m as the pile diameter, and enter the P and Y values shown to the right.



- Then switch to the Man M-Theta tab, enter 8.75m as the pile diameter, and enter M and Theta values as shown to the right.



- Since this soil layer doesn't contain the pile tip, BS and BM curves are not needed. But we still need to switch to Man BS and Man BM tab to enter the pile diameter.



- Then click *OK* to finish the definition of this soil curve. The command lines will be generated like below

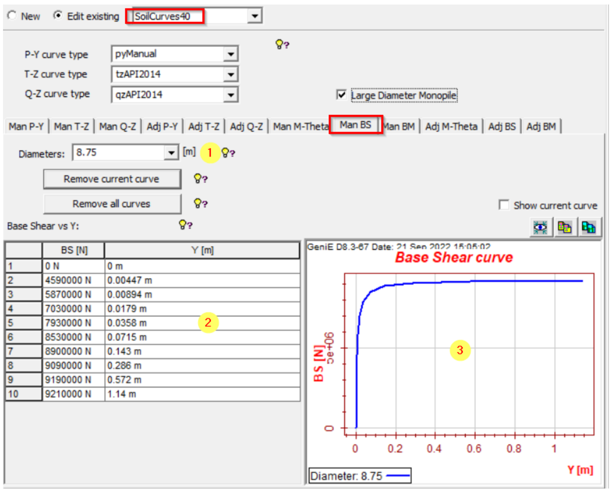
  SoilCurves1 = SoilCurves(pyManual,tzAPI2014,qzAPI2014);

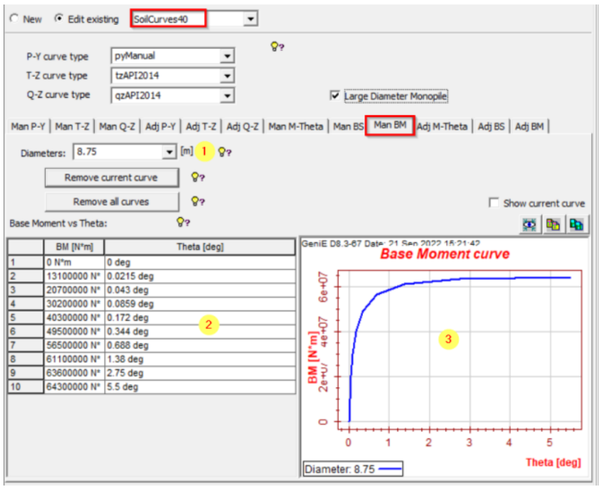
  SoilCurves1.addManualPY(8.75,Array(0,3.9e-2,7.79e-2,1.56e-1,3.12e-1,6.23e-1,1.25,2.49,4.99,9.97),Array(0,1.43e4,1.81e4,2.13e4,2.37e4,2.53e4,2.62e4,2.67e4,2.69e4,2.7e4));

  SoilCurves1.largeDiameterMonopile = true;

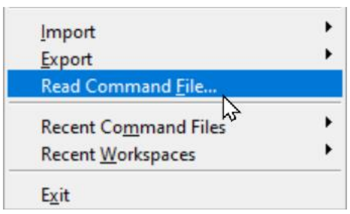
  SoilCurves1.addManualMomTheta(8.75,Array(0,1.07e-1,8.59e-1),Array(0,2.52e5,2.62e5));

- In the same way, we can define the last soil layer which contains the pile tip. For this soil layer, except M-Theta curve, BS and BM curve need to be defined as well.





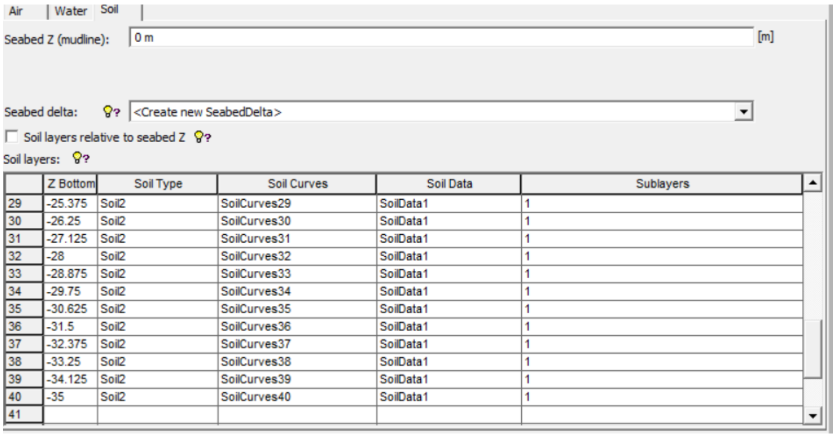
- All the soil curves can be found out from *SoilCurves_all.js*. You can click *File/Read Command File* to read all the soil curves directly.



2.3 Define Soil Layers

After all the soil curves, soil data and soil types have been defined, right click *Location1* to specify each soil layer. All the soil layers can be found out the *SoilCurveInput.xlsx* Location worksheet. You can enter these values cell by cell, or you can just copy from the sheet and paste into GeniE. The latter way will be selected in this workshop.

- 40 soil layers are needed in this model, but there are only 10 rows in the location table, add more rows by positioning yourself in the last row and press the down arrow on the keyboard to make at least 40 rows in this table.
- Copy data from excel and then press Ctrl+V to paste them.

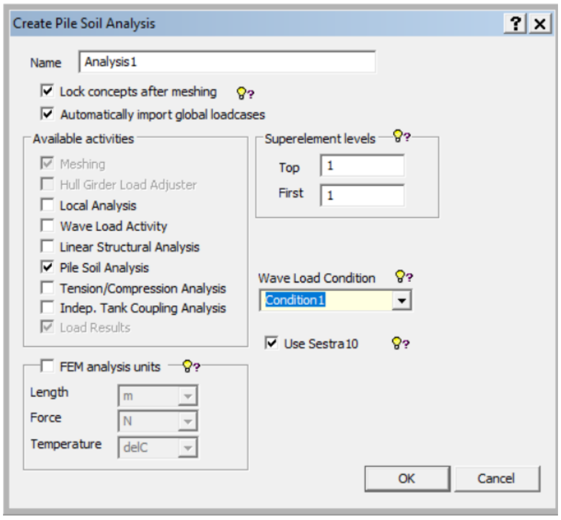


- If you have scour that needs to be included, you can define and assign *New Scour*. In this workshop, it will be omitted.

2.4 Run the Analysis and Check the Results Files

After all the soil curves have been specified and assigned to the soil layers, run the analysis.

- Under *Analysis/Activities*, right click *New Analysis.* Check *Pile Soil Analysis* and select Condition1 as wave load condition



- Open Activity Monitor (Alt+M) and click Start to run the analysis.

2.4.1 GENSOD.INP

In the gensod.inp file, some new command lines and sections have been added to support this feature.

- Control Section
  - NUMDM – the number of distributed moment curves
  - NUMBS – the number of base shear moment curves
  - NUMBM – the number of base moment curves
  - These soil curves are all optional, so 0 means the related soil curves have not been specified.
- Manual Data Section and Data Modification Section

Please note that in Genie GUI, the rotation is specified in unit degrees, while in Gensod it is written in unit radian.

2.4.2 GENSOD.LIS

In the gensod.lis file, the new soil curves will be printed in the table “COMPLETE M-THETA / BS-Y / BM-THETA RESULTS”.

All the input values will be interpolated by the program by the mobilization factor which has been hard coded in the program with the below array

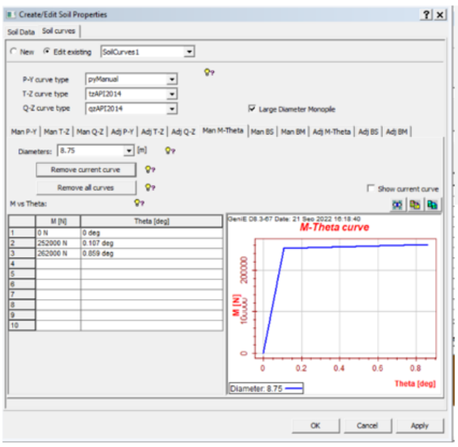
p_m/p_m_max = [0, 0.01, 0.02, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.99,1]

In the program the peak force and moments and the corresponding lateral displacement and rotation will be searched out first. Then the forces or moment will be derived based on the below formula before the interpolation of the displacement and the rotation from the curves.

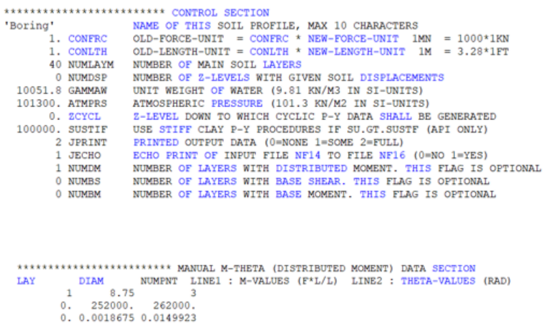
p_m_gensod = p_max * p_m / p_m_max

y_r_gensod = interpolate (p_m_gensod, p_m, y_r)

The below figure indicates the workflow from GeniE GUI input to Gensod output.

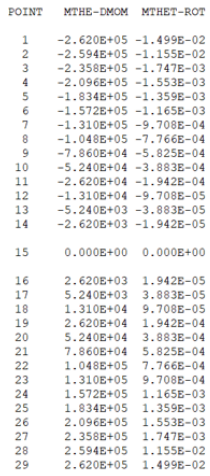


GeniE GUI input



```
************************* CONTROL SECTION
'Boring'            NAME OF THIS SOIL PROFILE, MAX 10 CHARACTERS
      1. CONFRC     OLD-FORCE-UNIT  = CONFRC * NEW-FORCE-UNIT  1MN  = 1000*1KN
      1. CONLTH     OLD-LENGTH-UNIT = CONLTH * NEW-LENGTH-UNIT  1M  = 3.28*1FT
      40 NUMLAYM    NUMBER OF MAIN SOIL LAYERS
       0 NUMDSP     NUMBER OF Z-LEVELS WITH GIVEN SOIL DISPLACEMENTS
  10051.8 GAMMAW    UNIT WEIGHT OF WATER (9.81 KN/M3 IN SI-UNITS)
  101300. ATMPRS    ATMOSPHERIC PRESSURE (101.3 KN/M2 IN SI-UNITS)
       0. ZCYCL     Z-LEVEL DOWN TO WHICH CYCLIC P-Y DATA SHALL BE GENERATED
  100000. SUSTIF    USE STIFF CLAY P-Y PROCEDURES IF SU.GT.SUSTF (API ONLY)
       2 JPRINT     PRINTED OUTPUT DATA (0=NONE 1=SOME 2=FULL)
       1 JECHO      ECHO PRINT OF INPUT FILE NF14 TO FILE NF16 (0=NO 1=YES)
       1 NUMDM      NUMBER OF LAYERS WITH DISTRIBUTED MOMENT. THIS FLAG IS OPTIONAL
       0 NUMBS      NUMBER OF LAYERS WITH BASE SHEAR. THIS FLAG IS OPTIONAL
       0 NUMBM      NUMBER OF LAYERS WITH BASE MOMENT. THIS FLAG IS OPTIONAL


  ************************* MANUAL M-THETA (DISTRIBUTED MOMENT) DATA SECTION
  LAY      DIAM      NUMPNT  LINE1 : M-VALUES (F*L/L)  LINE2 : THETA-VALUES (RAD)
        1      8.75         3
       0.   252000.   262000.
       0. 0.0018675 0.0149923
```

Gensod input



POINT	MTHE-DMOM	MTHET-ROT
1	-2.620E+05	-1.499E-02
2	-2.594E+05	-1.155E-02
3	-2.358E+05	-1.747E-03
4	-2.096E+05	-1.553E-03
5	-1.834E+05	-1.359E-03
6	-1.572E+05	-1.165E-03
7	-1.310E+05	-9.708E-04
8	-1.048E+05	-7.766E-04
9	-7.860E+04	-5.825E-04
10	-5.240E+04	-3.883E-04
11	-2.620E+04	-1.942E-04
12	-1.310E+04	-9.708E-05
13	-5.240E+03	-3.883E-05
14	-2.620E+03	-1.942E-05
15	0.000E+00	0.000E+00
16	2.620E+03	1.942E-05
17	5.240E+03	3.883E-05
18	1.310E+04	9.708E-05
19	2.620E+04	1.942E-04
20	5.240E+04	3.883E-04
21	7.860E+04	5.825E-04
22	1.048E+05	7.766E-04
23	1.310E+05	9.708E-04
24	1.572E+05	1.165E-03
25	1.834E+05	1.359E-03
26	2.096E+05	1.553E-03
27	2.358E+05	1.747E-03
28	2.594E+05	1.155E-02
29	2.620E+05	1.499E-02

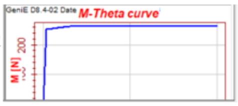
Gensod output

Please also note that currently this interpolation by mobilisation factor is only applicable for the new soil curves, which means that for the old T-Z, Q-Z and P-Y curves there is no such interpolation process.

2.4.3 GENSOD.MLG

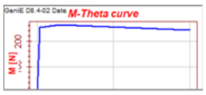
In the *Gensod.mlg* file, if a duplicate point or descending point is found from the soil curve, then the below warning message will be printed out. The values in the red font are the peak values used in the interpolation process.

1 8.75 4
0.00E+00 2.52E+02 **2.62E+02** 2.62E+02
0.00E+00 1.87E-03 **1.50E-02** 1.0E-01



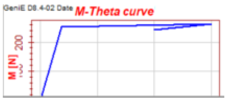
**** WARNING: **Duplicate point** found for M data in M-THETA curve, layer: 1 diameter: 8.75.

1 8.75 4
0.00E+00 2.52E+02 **2.62E+02** 2.40E+02
0.00E+00 1.87E-03 **1.50E-02** 1.0E-01



**** WARNING: **Descending point** found for M data in M-THETA curve, layer: 1 diameter: 8.75.

1 8.75 4
0.00E+00 2.52E+02 **2.62E+02** 2.40E+02
0.00E+00 **1.87E-03** 1.50E-02 1.00E-02



**** WARNING: **Descending point** found for M data in M-THETA curve, layer: 1 diameter: 8.75.

2.4.4 GENSOD.SIF

Since Splice7.6-00, Splice has been extended to transfer Gensod results data through the SIF format instead of the binary file SOIL.10.

The cards RVSOILBS, RVSOILBM and RVSOILDM have been implemented in Gensod.SIF to represent these new soil curves.

2.4.5 SPLICE.LIS

Splice will generate the results based on the defined soil curves. For these 3 soil curves, Splice handle them as described below:

- Base shear and base moment curve – depend on the pile tip boundary condition
    - NITP=0 Free Pile tip (default setting) – the base shear and base moment curve will be handled in a similar way as Splice handles Q-Z springs, i.e. axial, lateral and rotational springs at the pile tip will be derived from the soil curves.
    - Other boundary condition - base shear and base moment springs at the pile tip will be ignored.
- Distributed moment curve – the distributed moment springs are handled using the same theory as described in Section 6.3 lateral pile solution in the Splice engineering document.

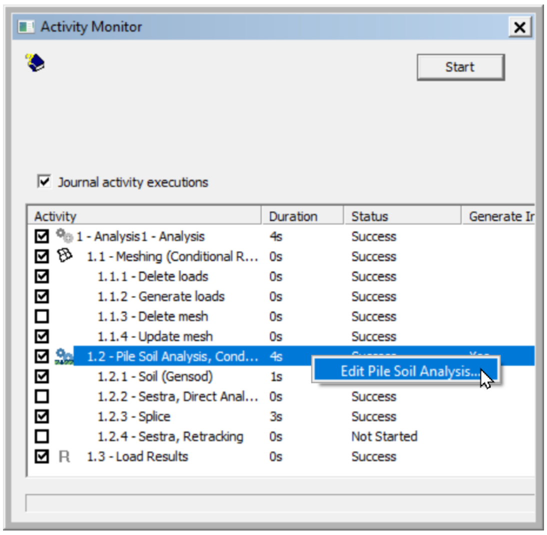
In this workshop, we have only one load case that needs to be solved. Check the trace iterations in this load case by opening the *Splice.lis* file. It can be seen that there are still 30 nodes outside criterion when the max iterations have been reached (20 by default).

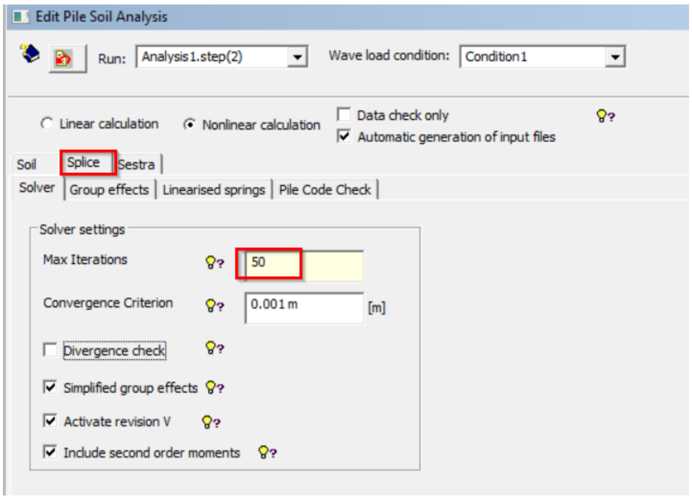
TRACE OF COMPUTED INCREMENTAL GLOBAL DISPLACEMENTS AND FORCES AT PILE HEAD 1

IT	DSPX	DSPY	DSPZ	ROTXX	ROTYY	ROTZZ	FRCX	FRCY	FRCZ	MOMXX	MMOMYY	MOMZZ	ICONV
1	6.73E-02	0.00E+00	2.35E-03	0.00E+00	-5.19E-03	0.00E+00	1.10E+07	0.00E+00	7.64E-08	0.00E+00	-9.62E+08	0.00E+00	42
2	1.13E-01	0.00E+00	2.35E-03	0.00E+00	-7.13E-03	0.00E+00	1.10E+07	0.00E+00	7.64E-08	0.00E+00	-9.62E+08	0.00E+00	40
3	1.56E-01	0.00E+00	2.35E-03	0.00E+00	-8.74E-03	0.00E+00	1.10E+07	0.00E+00	7.64E-08	0.00E+00	-9.62E+08	0.00E+00	40
4	1.98E-01	0.00E+00	2.35E-03	0.00E+00	-1.03E-02	0.00E+00	1.10E+07	0.00E+00	7.64E-08	0.00E+00	-9.62E+08	0.00E+00	40
5	2.38E-01	0.00E+00	2.35E-03	0.00E+00	-1.18E-02	0.00E+00	1.10E+07	0.00E+00	7.64E-08	0.00E+00	-9.62E+08	0.00E+00	40
6	2.75E-01	0.00E+00	2.35E-03	0.00E+00	-1.32E-02	0.00E+00	1.10E+07	0.00E+00	7.64E-08	0.00E+00	-9.62E+08	0.00E+00	40
7	3.09E-01	0.00E+00	2.35E-03	0.00E+00	-1.44E-02	0.00E+00	1.10E+07	0.00E+00	7.64E-08	0.00E+00	-9.62E+08	0.00E+00	40
8	3.39E-01	0.00E+00	2.35E-03	0.00E+00	-1.56E-02	0.00E+00	1.10E+07	0.00E+00	7.64E-08	0.00E+00	-9.62E+08	0.00E+00	40
9	3.65E-01	0.00E+00	2.35E-03	0.00E+00	-1.65E-02	0.00E+00	1.10E+07	0.00E+00	7.64E-08	0.00E+00	-9.62E+08	0.00E+00	40
10	3.88E-01	0.00E+00	2.35E-03	0.00E+00	-1.74E-02	0.00E+00	1.10E+07	0.00E+00	7.64E-08	0.00E+00	-9.62E+08	0.00E+00	40
11	4.08E-01	0.00E+00	2.35E-03	0.00E+00	-1.81E-02	0.00E+00	1.10E+07	0.00E+00	7.64E-08	0.00E+00	-9.62E+08	0.00E+00	38
12	4.26E-01	0.00E+00	2.35E-03	0.00E+00	-1.88E-02	0.00E+00	1.10E+07	0.00E+00	7.64E-08	0.00E+00	-9.62E+08	0.00E+00	38
13	4.41E-01	0.00E+00	2.35E-03	0.00E+00	-1.93E-02	0.00E+00	1.10E+07	0.00E+00	7.64E-08	0.00E+00	-9.62E+08	0.00E+00	38
14	4.54E-01	0.00E+00	2.35E-03	0.00E+00	-1.98E-02	0.00E+00	1.10E+07	0.00E+00	7.64E-08	0.00E+00	-9.62E+08	0.00E+00	38
15	4.65E-01	0.00E+00	2.35E-03	0.00E+00	-2.03E-02	0.00E+00	1.10E+07	0.00E+00	7.64E-08	0.00E+00	-9.62E+08	0.00E+00	36
16	4.75E-01	0.00E+00	2.35E-03	0.00E+00	-2.06E-02	0.00E+00	1.10E+07	0.00E+00	7.64E-08	0.00E+00	-9.62E+08	0.00E+00	36
17	4.83E-01	0.00E+00	2.35E-03	0.00E+00	-2.09E-02	0.00E+00	1.10E+07	0.00E+00	7.64E-08	0.00E+00	-9.62E+08	0.00E+00	34
18	4.90E-01	0.00E+00	2.35E-03	0.00E+00	-2.12E-02	0.00E+00	1.10E+07	0.00E+00	7.64E-08	0.00E+00	-9.62E+08	0.00E+00	34
19	4.96E-01	0.00E+00	2.35E-03	0.00E+00	-2.14E-02	0.00E+00	1.10E+07	0.00E+00	7.64E-08	0.00E+00	-9.62E+08	0.00E+00	32
20	5.01E-01	0.00E+00	2.35E-03	0.00E+00	-2.16E-02	0.00E+00	1.10E+07	0.00E+00	7.64E-08	0.00E+00	-9.62E+08	0.00E+00	30

MAX ITERATIONS REACHED   30 NODES OUTSIDE CRITERION

To resolve this, reopen the Activity Monitor. Open the Edit Pile Soil Analysis window, and then increase the max. iterations to 50.





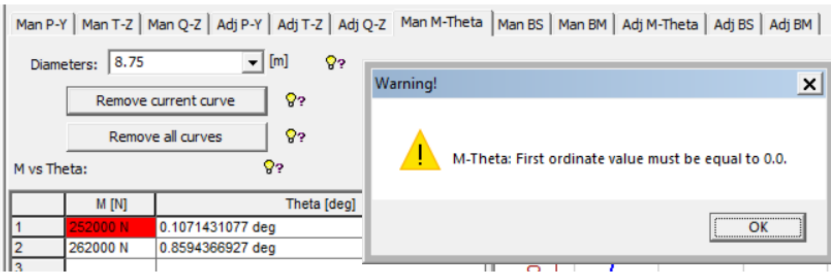
Run the analysis again. Then it can be seen that the convergence criterium is satisfied after 31 iterations. The pile head resulting displacement and forces can be checked in the below figure.

```
CONV CRIT SATISFIED AFTER    31 ITERATIONS

PILE HEAD GLOBAL RESULTING DISPLACEMENTS
****************************************

PILE  CON     X        Y        Z        X-DSP       Y-DSP       Z-DSP       XX-ROT      YY-ROT      ZZ-ROT

  1    0     0.00     0.00     0.09    5.2626E-01  0.0000E+00  2.3524E-03  0.0000E+00 -2.2518E-02  0.0000E+00

PILE HEAD GLOBAL RESULTING FORCES
*********************************

PILE  CON     X        Y        Z        X-FRC       Y-FRC       Z-FRC       XX-MOM      YY-MOM      ZZ-MOM

  1    0     0.00     0.00     0.09    1.1000E+07  0.0000E+00  7.6368E-08  0.0000E+00 -9.6250E+08  0.0000E+00

                                     SUM OF FORCES AND MOMENTS WITH RESPECT TO ORIGIN. DUMMY PILES NOT INCLUDED

                                       1.1000E+07  0.0000E+00  7.6368E-08  0.0000E+00 -9.6154E+08  0.0000E+00
```

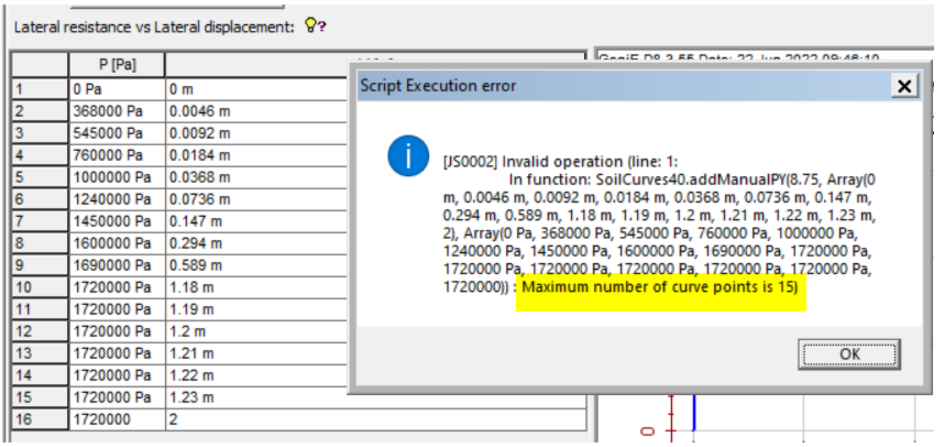
3 ERRORS AND WARNINGS

In this section, the limitations when entering the soil curves and the possible errors and warnings will be described.

- The limitation when entering all the soil curves:
    - For symmetric curve, the first point must be zero point, the below error window will pop-out if not.

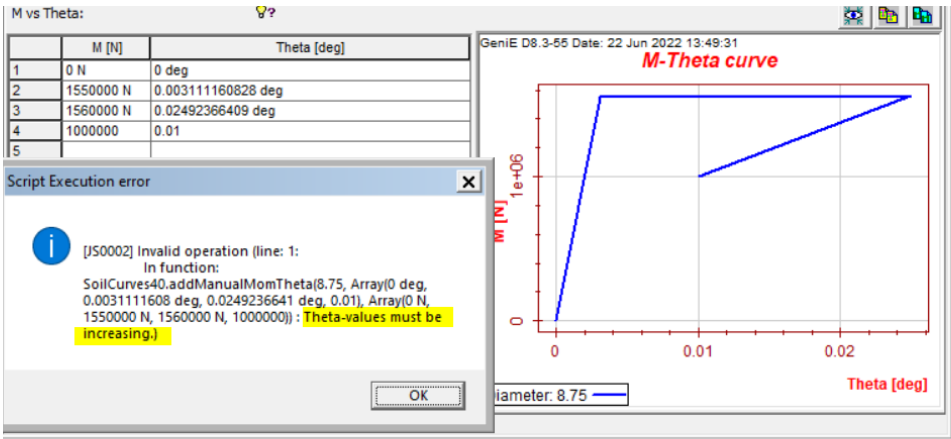


    - The maximum number of points is 15, but only 10 rows in the soil curve table, add more rows by positioning yourself in the last row and pressing the down arrow on the keyboard. If more than 15 points are input, the below error window will pop-out.

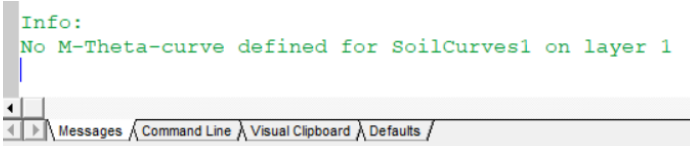


Note: Before GeniE8.4, only 12 points is allowed.

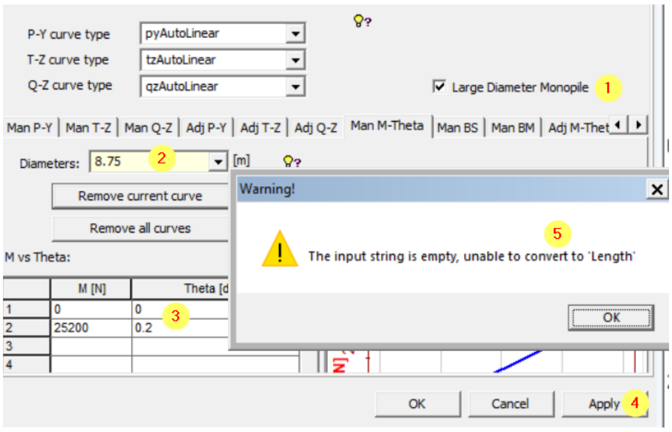
    - The soil curve must be monotonically increasingly, otherwise the below error window will pop-out.



- M-Theta curve - Under Man M-Theta tab, enter the pile diameter and specify moment as a function of rotation.
    - The M-Theta function is normally required for all soil layers. However, the curves may be omitted for testing purposes or other reasons. If M-Theta curve is lacking in one soil layer, the below information will be printed in the Message window.



- BS curve - Under Man BS tab, enter the pile diameter and specify base shear as a function of lateral displacement.
    - The BS curve is only required for the soil layer that contains the pile tip. But if you only define the M-theta curves and then click Apply, then the below window will pop-out



- Therefore, for all soil layers, we need to ensure that the pile diameter has been specified.

- BM curve – under Man BM tab, enter the pile diameter and specify base moment as a function of rotation.
    - The BM curve is only required for the soil layer that contains the pile tip. Then for the other soil layers, we only need to enter pile diameter. This is same with BS curve.

4 SOIL REACTION SPRINGS GENERATION

In this section, we will briefly discuss how to generate soil reaction springs.

The input for the non-linear, user-defined lateral and rotational springs along the pile and pile tip can be established using numerical procedures, such as the Finite Element Method (FEM). In a pseudo-static, push-over analysis, the normal and shear stresses in the pile-soil interface can be extracted for each load increment. By integration of the stresses over a pre-defined pile segment area, the resulting Man P-Y and Man M-Θ data sets can be determined. In the same way, the corresponding soil response curves at the pile tip, that means the base shear, Man BS, and base moment, Man BM, can be assessed. Alternatively, the normal and shear stresses in the pile may be used, which, however, need to be integrated over the pile cross sectional area and the pile segment height.

All general-purpose FE programs may be used, which provide plate and continuum elements for modelling of the pile and soil body. In addition, appropriate constitutive soil models should be used, which are capable to describe the non-linear stress-strain behaviour of soils subjected to general loading conditions. In future versions of SESAM there will be a dedicated FE solver available for the purpose of establishing the input to the non-linear, user-defined springs.

Where not sufficient site-specific soil data are available for performing advanced FE analyses, a rule-based approach may be adopted for estimating the input to the non-linear, user-defined springs. In frame of the so-called PISA project, a mathematical framework, including correlations for one sand type and one clay type was proposed, which can be found in [1] or [2], respectively. These can provide a first estimate, when adjusted for the considered pile geometry and soil state, i.e. density, stress, shear strength, etc. However, it is strongly recommended to verify and revise the springs established with the rule-based approach when site-specific information become available in the project, but latest in the FEED or Detailed Design.

Important to note is that the correlations suggested in [1] and [2] do not consider cyclic loading effects, which, however, is mandatory according to most relevant design standards and guidelines, including [3] and [4]. Numerous procedures for different foundation concepts have been suggested in the literature on how cyclic loading effects can be considered. These may be used accordingly when assessing the input to the non-linear, user-defined lateral and rotational springs.

5 REFERENCES

[1] Burd, H.J. et al (2020), *PISA design model for monopiles for offshore wind turbines: application to a marine sand*, Géotechnique 70, No. 11, 1048–1066, https://doi.org/10.1680/jgeot.18.P.277

[2] Bryne B.W. et al. (2020), *PISA design model for monopiles for offshore wind turbines: application to a stiff glacial clay till*, Géotechnique 70, No. 11, 1030–1047 https://doi.org/10.1680/jgeot.18.P.255

[3] DNV-ST-0126, *Support structures for wind turbines*, Edition December 2021

[4] DNV-RP-C212, *Offshore soil mechanics and geotechnical engineering*, Edition September 2019, Amended September 2021