# Modeling of Contentious Helix  Screw Piles

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# Introduction

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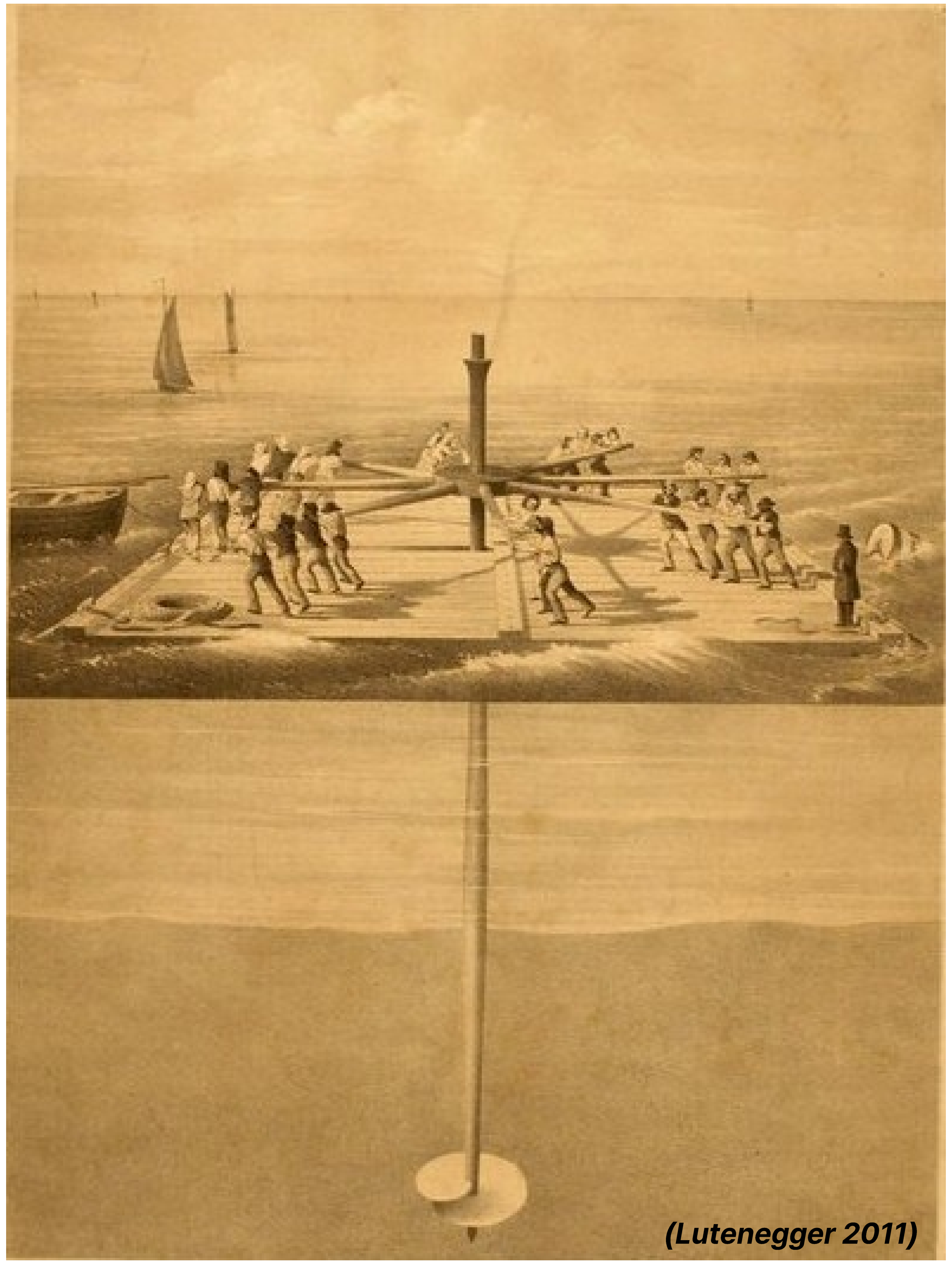
# Rise of Interest of Helical Piles

Large torque pile machines (400+ kN·m capacity) started to appear in the early 2000s.

Becoming common in the 2010s as helical piles were adopted for as alternative to driven or bored piles.




Installation of a **helical** pile (1800s)

Installation of a helical pile today

# Advantages of Helical Piles

- Quick to install
- Torque is a strong verification of capacity
- Low noise and minimal vibrations
- Low environmental impact
- Eliminate concrete curing and formwork
- No drill spoil

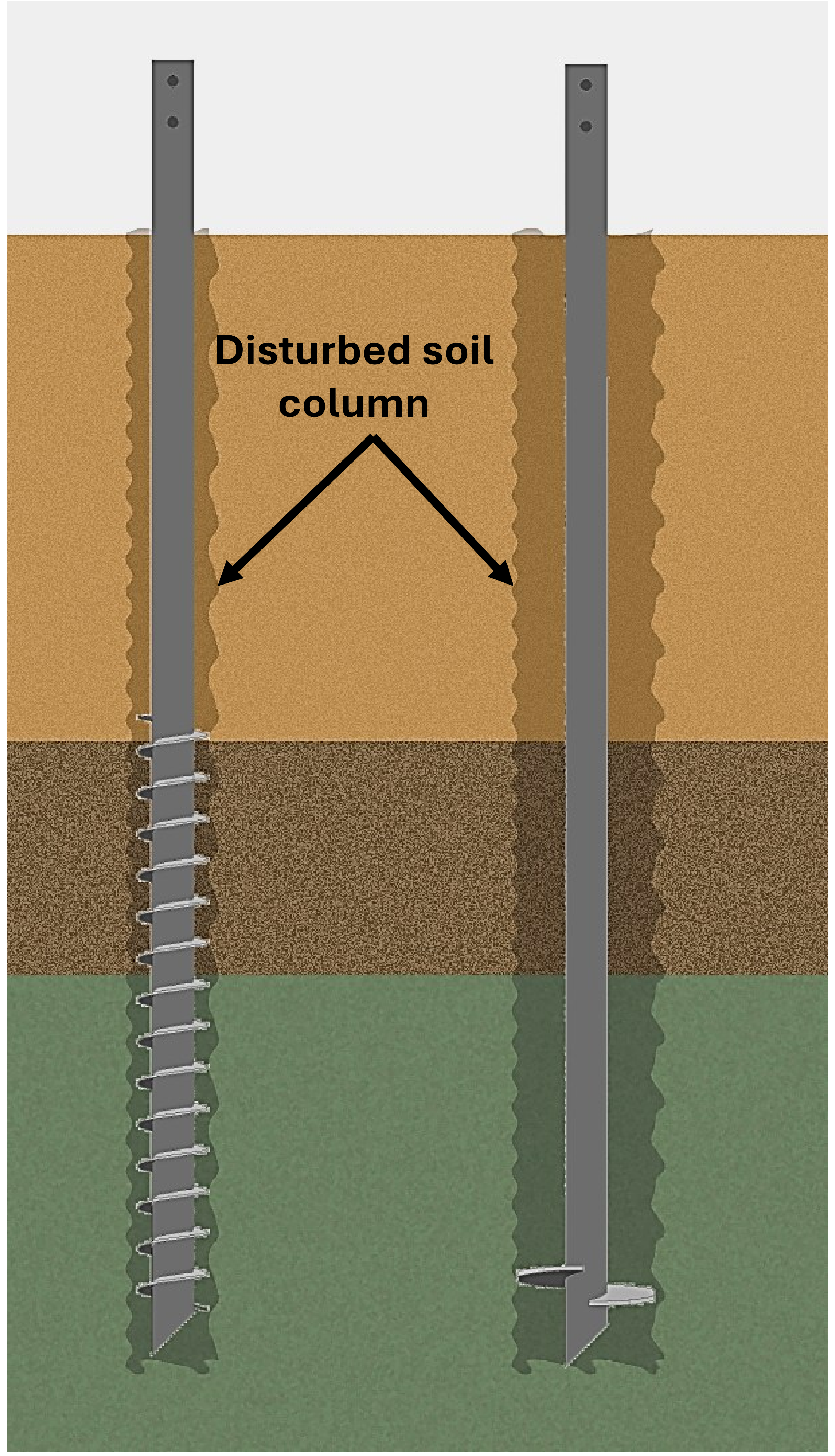
## Continuous helix screw piles

Compared to helical piles, screw piles are quicker to install and cause less soil disturbance around the pile.

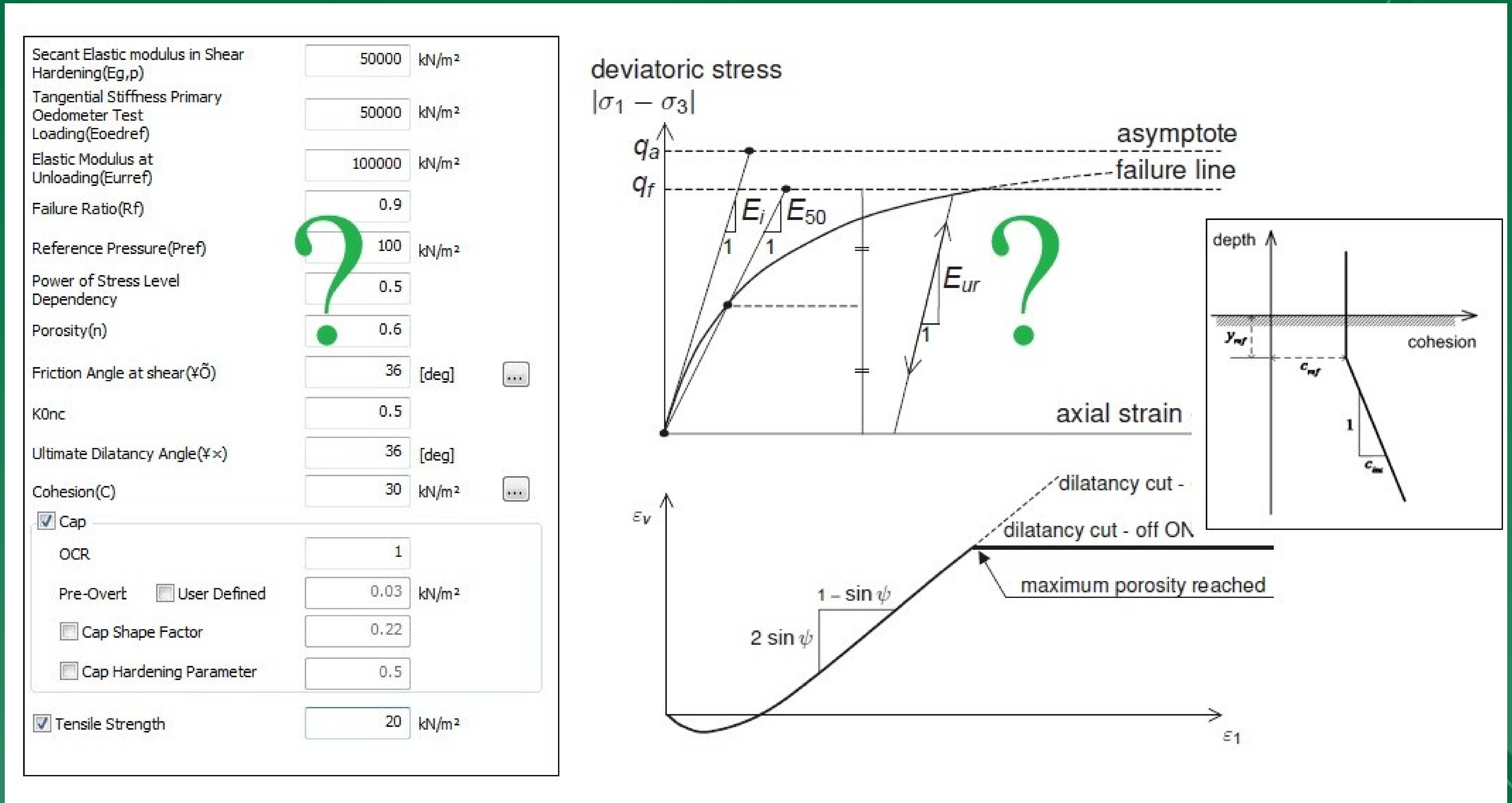
Are better than helical piles in tension performance when installed in strong soil.

More efficient in strong soils compared to helical piles.

Not recommended in soft soil.




# Workflow for proper numerical modeling

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# Workflow for Proper Numerical Modeling

Numerical modeling of piles requires a comprehensive field investigation to characterize soil properties and assess pile performance through load testing.

Prior to conducting simulations, reliable experimental data must be obtained for input into the software.

The quality and completeness of these data are reflected on the accuracy of the model. Higher-quality inputs leading to a more representative simulation of actual pile behavior.

**Site investigation**

Boreholes, SPT, soil properties characterization in the lab

↓

**Instrumented piles field testing**

Strain gauges data, load-displacement curve

↓

**Model building**

Pile Geometry, soil layers, constitutive model, soil parameter correlations from the literature

↓

**Model Calibration**

Using existing filed results to fine-tune the model parameters

↓

**Model Validation**

The calibrated model represents other type of piles or other conditions

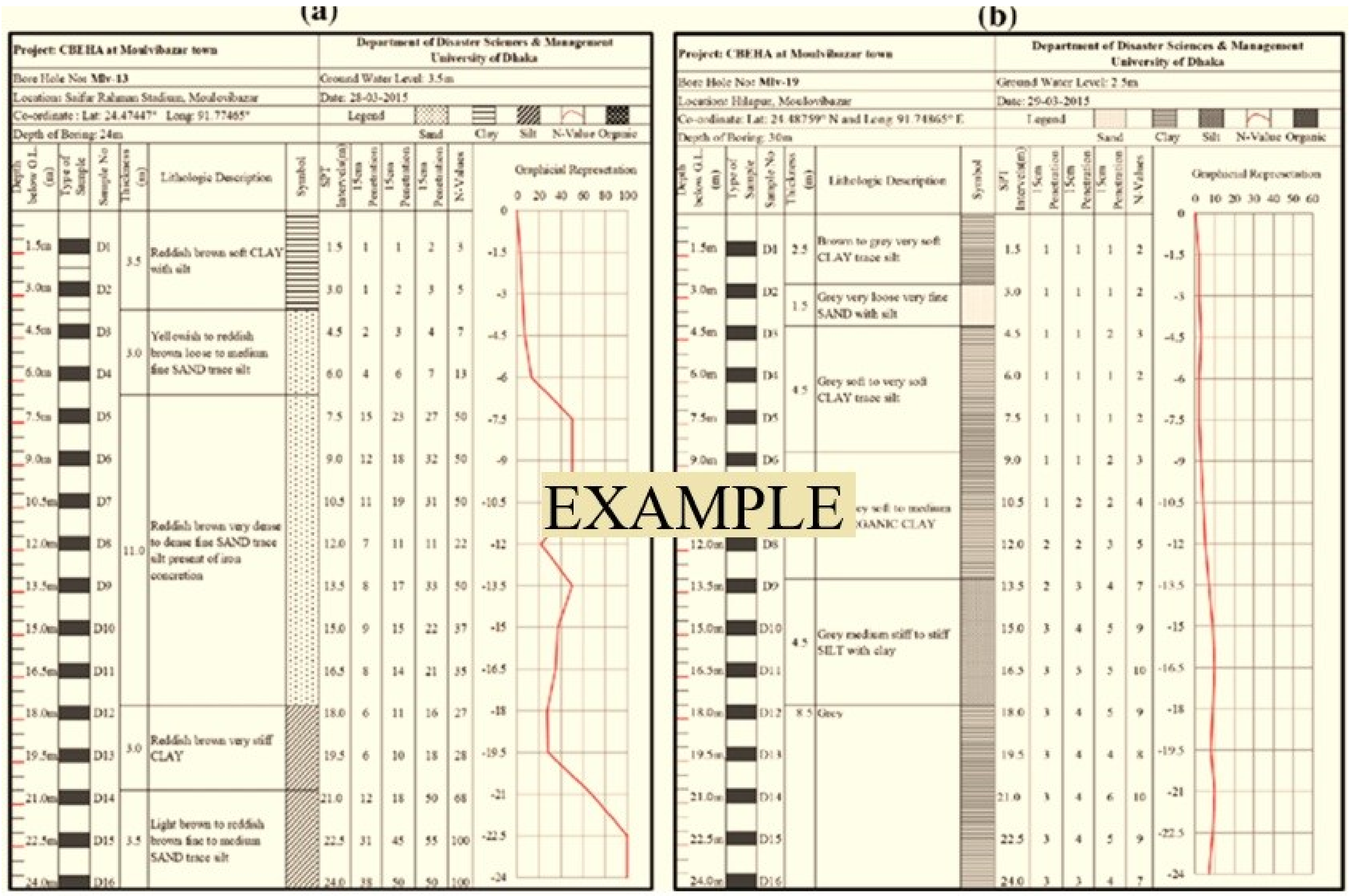
↓

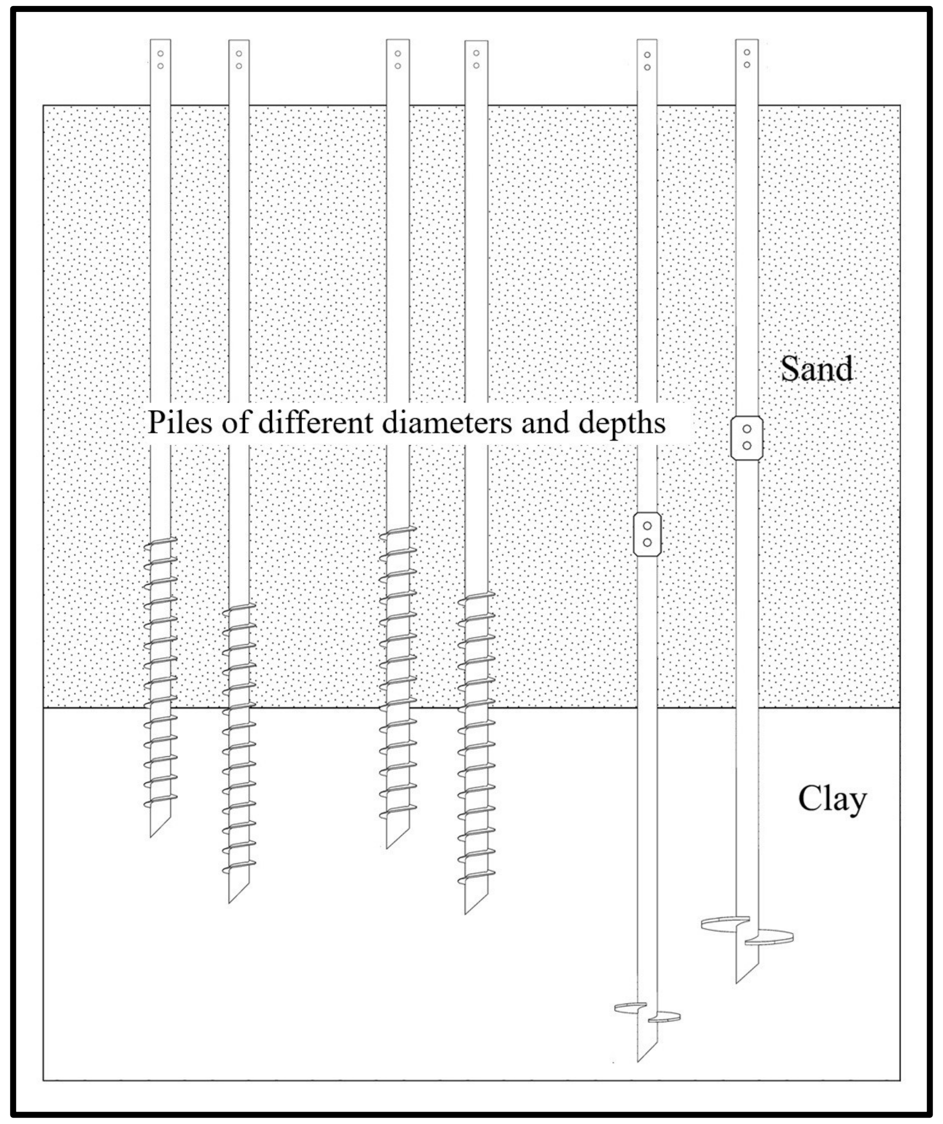
**Parametric Study**

StGudy the effect of different conditions that were not tested in the field

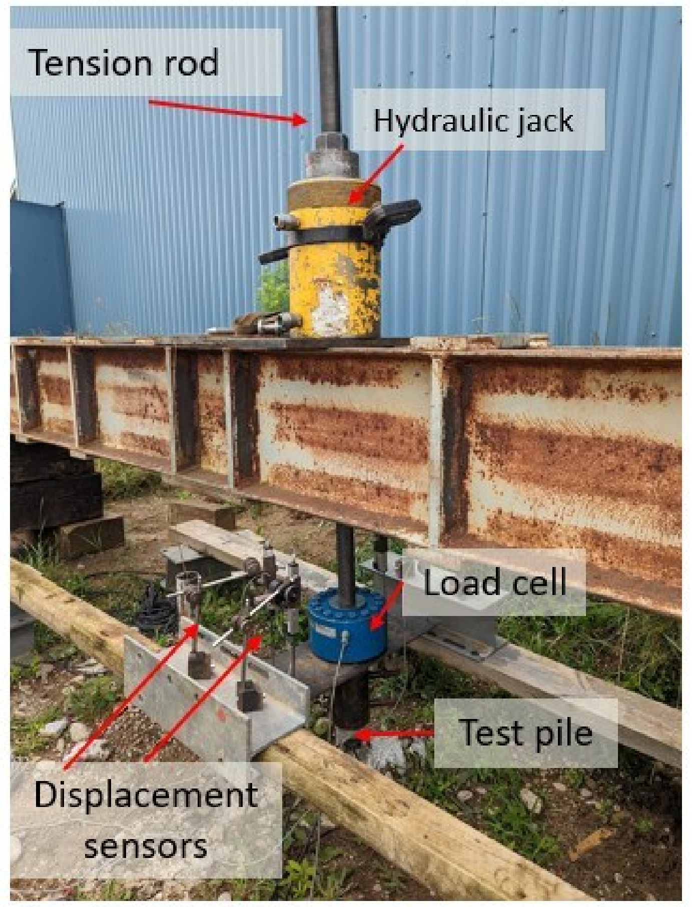
# Gathering data for the model

- Site investigation
- Load testing
- Various pile conditions
- Instrumented load tests
- Load-displacement curves
- Pile Load distribution curves

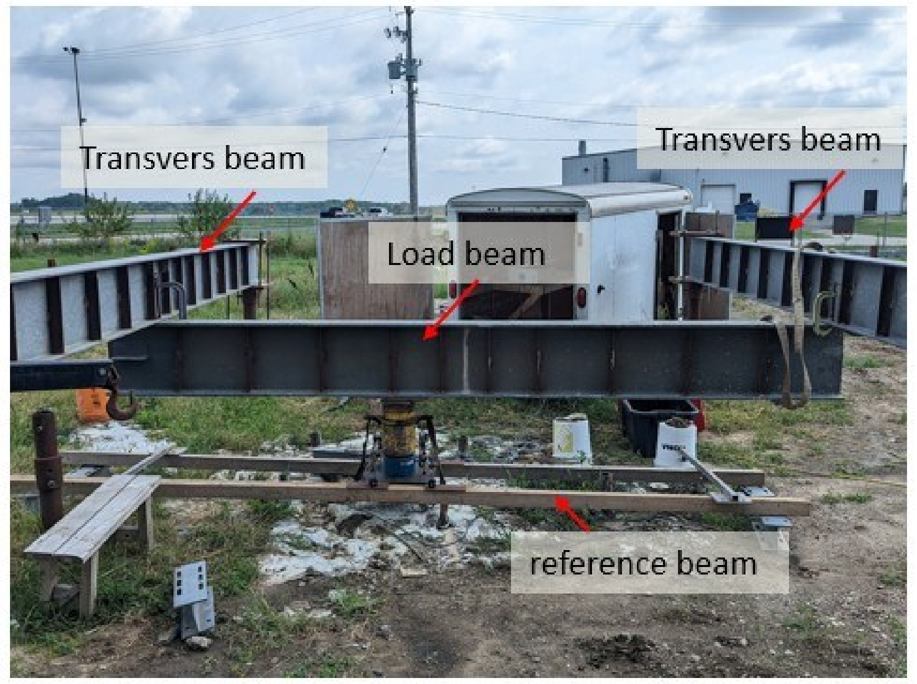


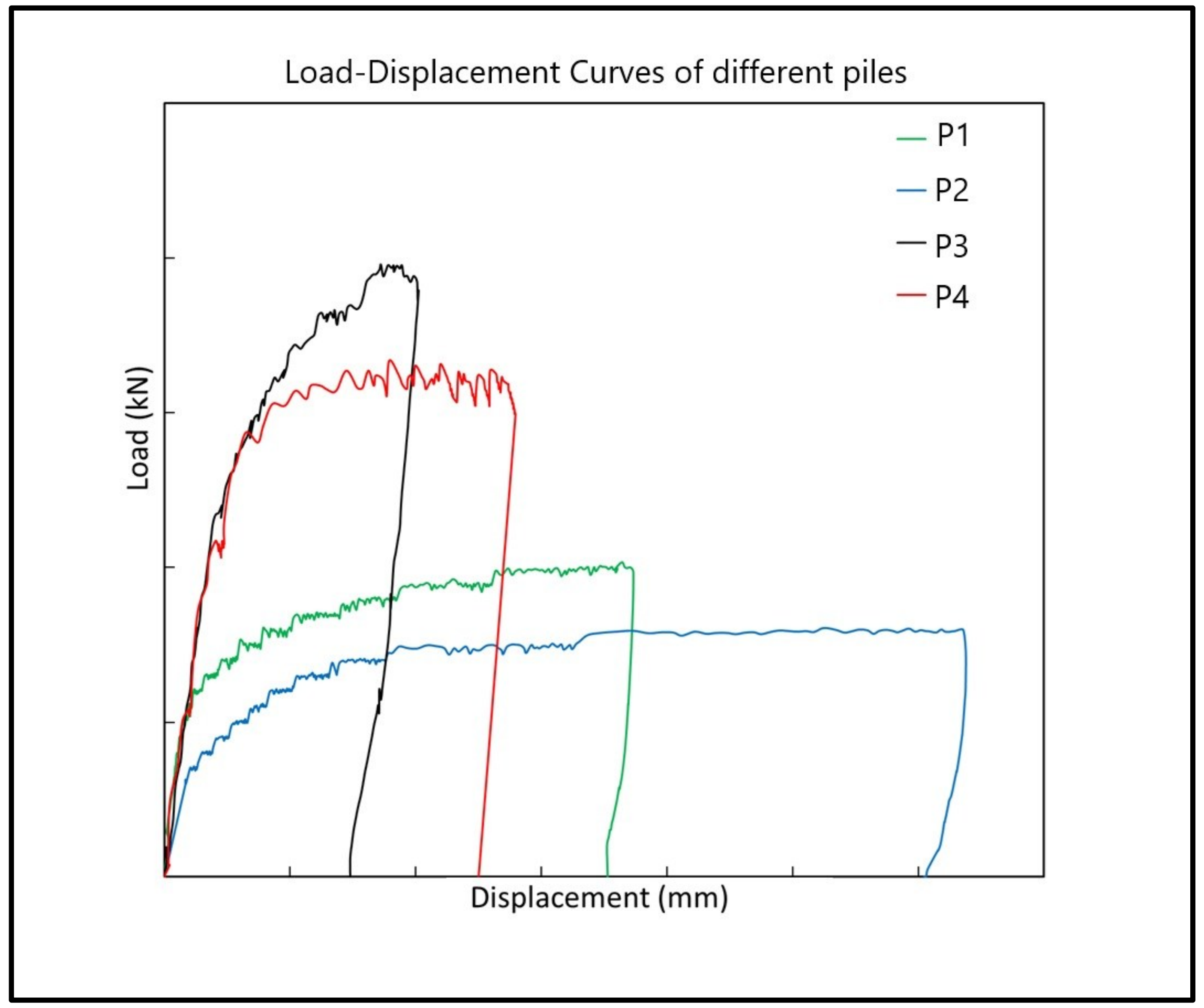

## Uplift and Compression test setup

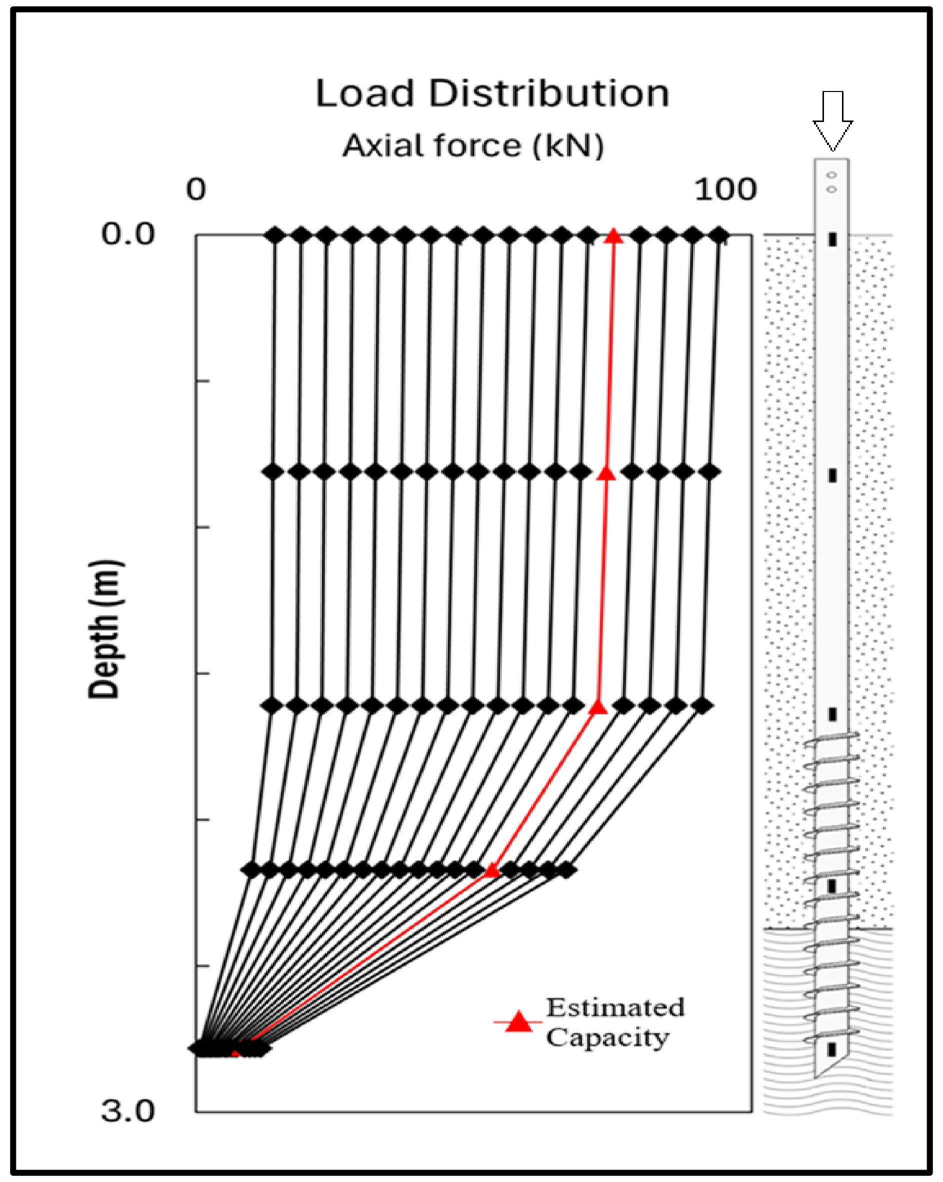



Uplift test setup




Compression test setup



# Hardening Soil Model AKA Modified Mohr-Coulomb Parameters

The Hardening Soil model is more suitable for detailed design and performance predictions, particularly where accurate settlement and load–displacement behavior are important (e.g., piles, retaining walls, tunnels).

In pile analysis (including helical piles), the HS model provides a closer match to field test results because it accounts for nonlinear stiffness and stress-dependent behavior, whereas the Mohr-Coulomb model often underestimates settlements and misrepresents load transfer mechanisms.

Following is the summary of parameters for the Modified Mohr-Coulomb model.

| Parameter | Description | Reference value (kN, m) |
|---|---|---|
| Soil stiffness and failure | | |
| E50ref | Secant stiffness in standard drained triaxial test | Ei x (2 – Rf) / 2<br>(Ei = Initial stiffness) |
| Eoedref | Tangent stiffness for primary oedometer loading | E50ref |
| Eurref | Unload / reloading stiffness | 3 x E50ref |
| m | Power for stress-level dependency of stiffness | 0.5 ≤ m ≤ 1 (**0.5** for hard soil,<br>1 for soft soil) |
| C ($C_{inc}$) | Effective cohesion (Increment of cohesion) | Failure parameter as in MC model |
| φ | Effective friction angle | Failure parameter as in MC model |
| ψ | Ultimate dilatancy angle | 0 ≤ ψ ≤ φ |
| Advanced parameters (Recommend to use Reference value) | | |
| Rf | Failure Ratio (qf / qa) | 0.9 (< 1) |
| Pref | Reference pressure | 100 |
| KNC | Ko for normal consolidation | 1-sinφ (< 1) |
| Tensile strength | Cut off value for tensile hydrostatic pressure | - |
| Dilatancy cut-off | | |
| Porosity | Initial void ratio | - |
| Porosity(Max) | Maximum void ratio | Porosity < Porosity(Max) |
| Cap yield surface | | |
| OCR / Pc | Over Consolidation Ratio / Pre-overburden pressure | When entering both parameters, Pc has the priority of usage |
| α | Cap Shape Factor (scale factor of preconsolidation stress) | from KNC (Auto) |
| β | Cap Hardening Parameter | from Eoedref (Auto) |

Different correlations to estimate different parameters of HS model

secant stiffness $E_{50}$, unloading-reloading stiffness $E_{ur}$ and oedometric stiffness $E_{oed}$ (all at reference stress level $p^{ref}$):

- $E_{50}^{ref} = 60{,}000 \cdot D_r$ by Lengkeek (2003)
- $E_{ur}^{ref} = 180{,}000 \cdot D_r$ by Brinkgreve et al. (2010)
- $E_{oed}^{ref} = E_{50}^{ref}$ by Schanz & Vermeer (1998)
- $E_{oed}^{ref} = 3 \cdot \sqrt{p_a/\sigma'_{v0}}$ by Vermeer (2000)

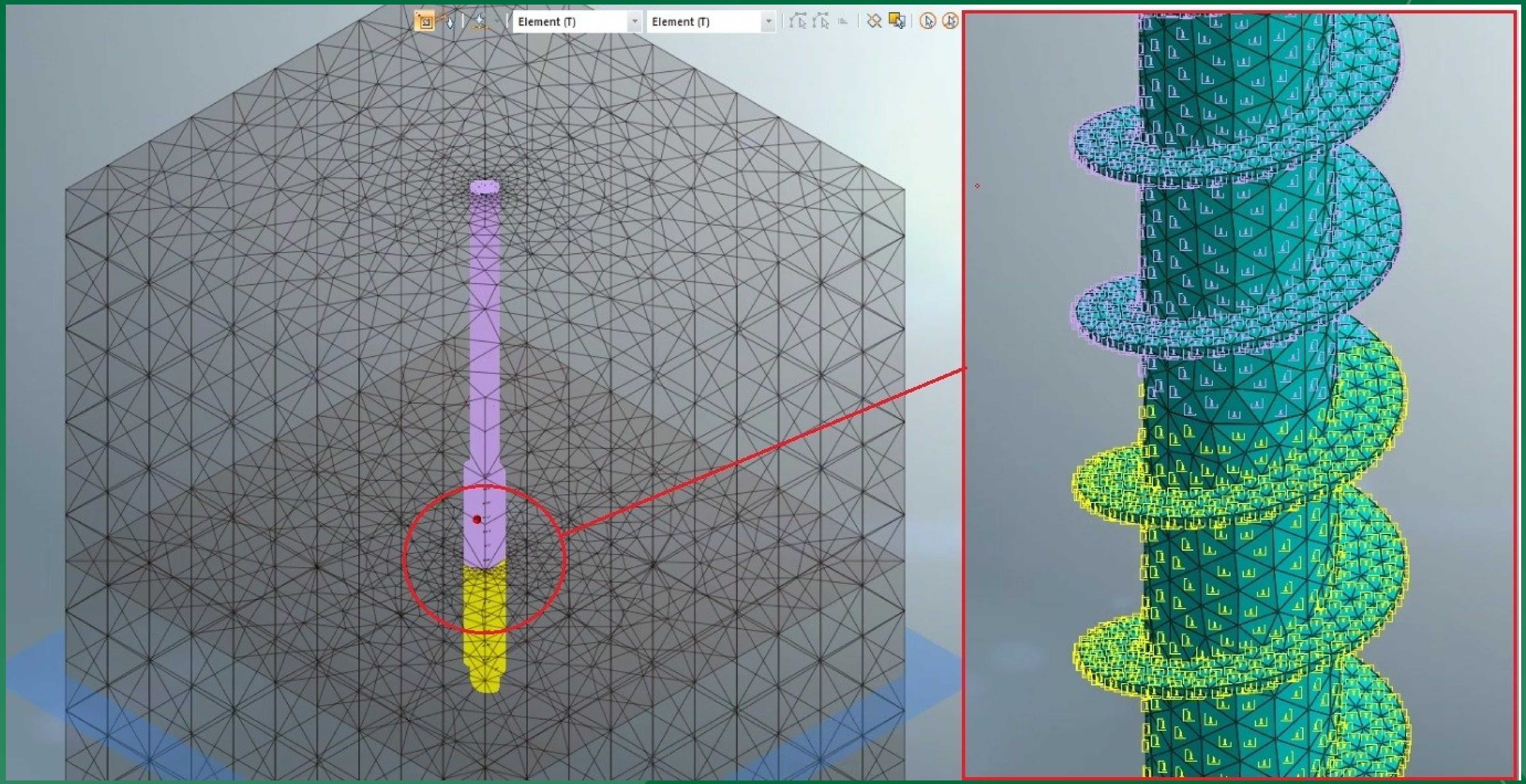
$E_s = 15N_{60} \times 100\ kPa$ *kulhawy and Mayne* 1990 for sand
$E_s = 1000 \times N_{60}$ For Clay

Table 2. Correlations of hardening soil model parameters.

| Soil description | $E_{50}^{ref}$ (kN/m²) | $E_{ur}^{ref}$ (kN/m²) | m (–) |
|---|---|---|---|
| Made ground | 5000–7000 | 5 $E_{50}^{ref}$ | 0.5 |
| Soft and medium clay | 250 $S_u$ | 8 to 10 $E_{50}^{ref}$ | 1.0 |
| Stiff clay | 700 $N_{60}$ | 10 $E_{50}^{ref}$ | 0.85 |
| Clayey sand & silty/sandy clay | 900 $N_{60}$ | 3 $E_{50}^{ref}$ | 0.85 |
| Medium to dense sand | 750 N | 3 $E_{50}^{ref}$ | 0.8 |
| Dense to very dense sand | 1000 N | 3 $E_{50}^{ref}$ | 0.5 |
| Hard clay | 1100 $N_{60}$ | 10 $E_{50}^{ref}$ | 0.8 |
| Dark grey clay | 2500 $N_{60}$ | 10 $E_{50}^{ref}$ | 0.8 |

$S_u = 5.35N_{60}$ Sirvikaya and Togrol 2006

# Model Geometry and Mesh



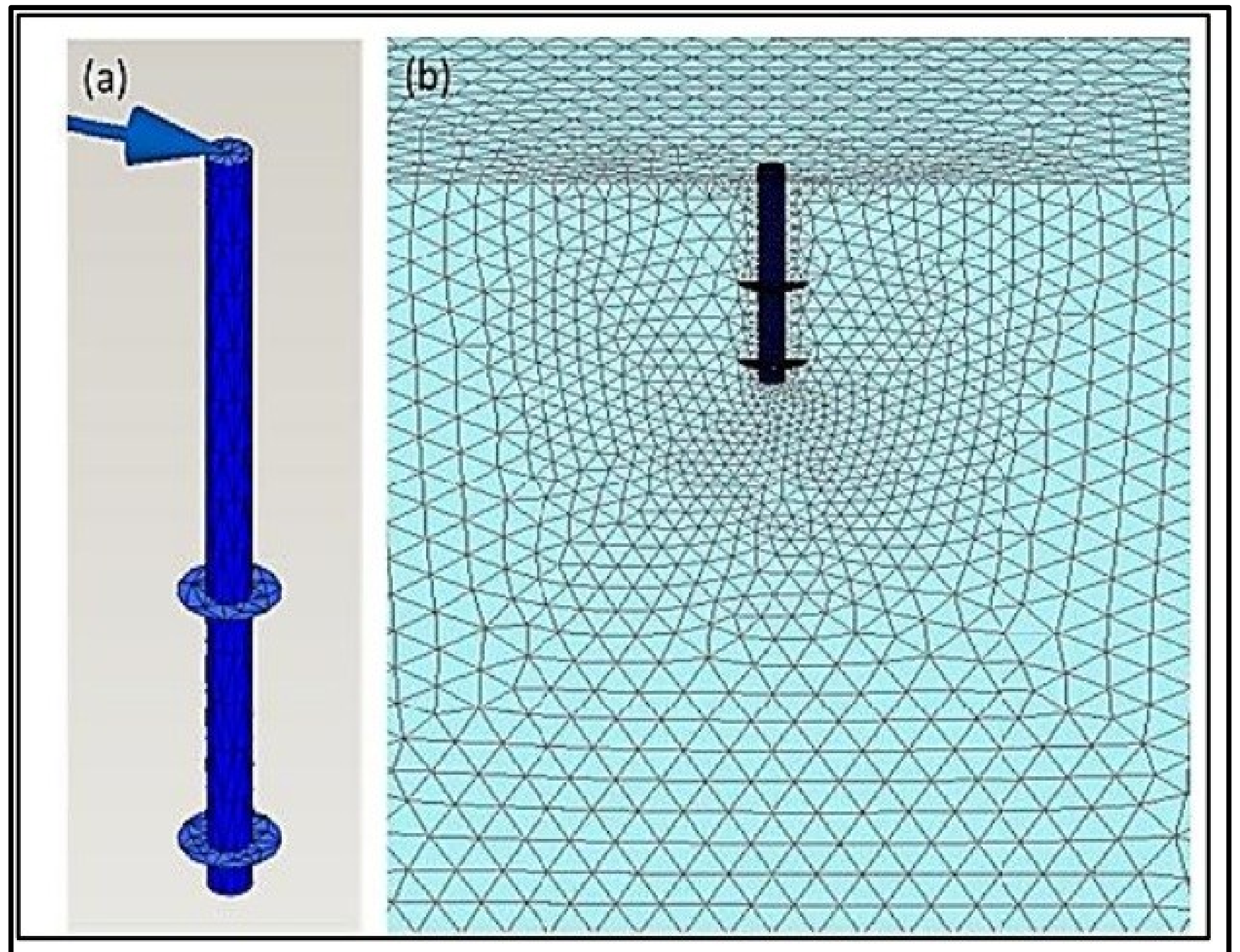
# Helix Models in the Literature

Most of the finite element modeling of helical piles in the literature models the helix as a circular disc for simplification.

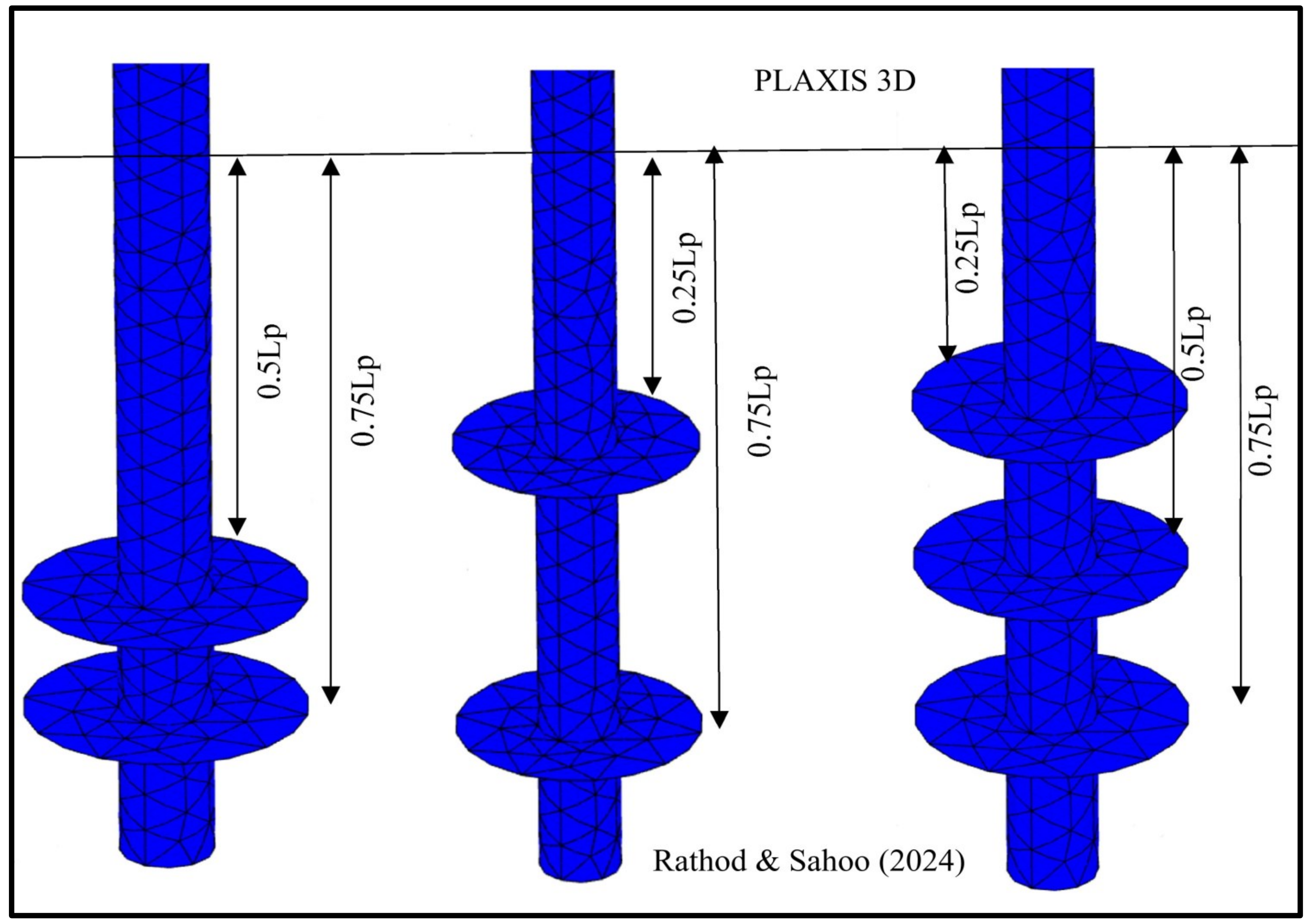
While this simplification is acceptable in practice, yet the reason behind this simplification is the complexity of modeling the helix in FEM software.

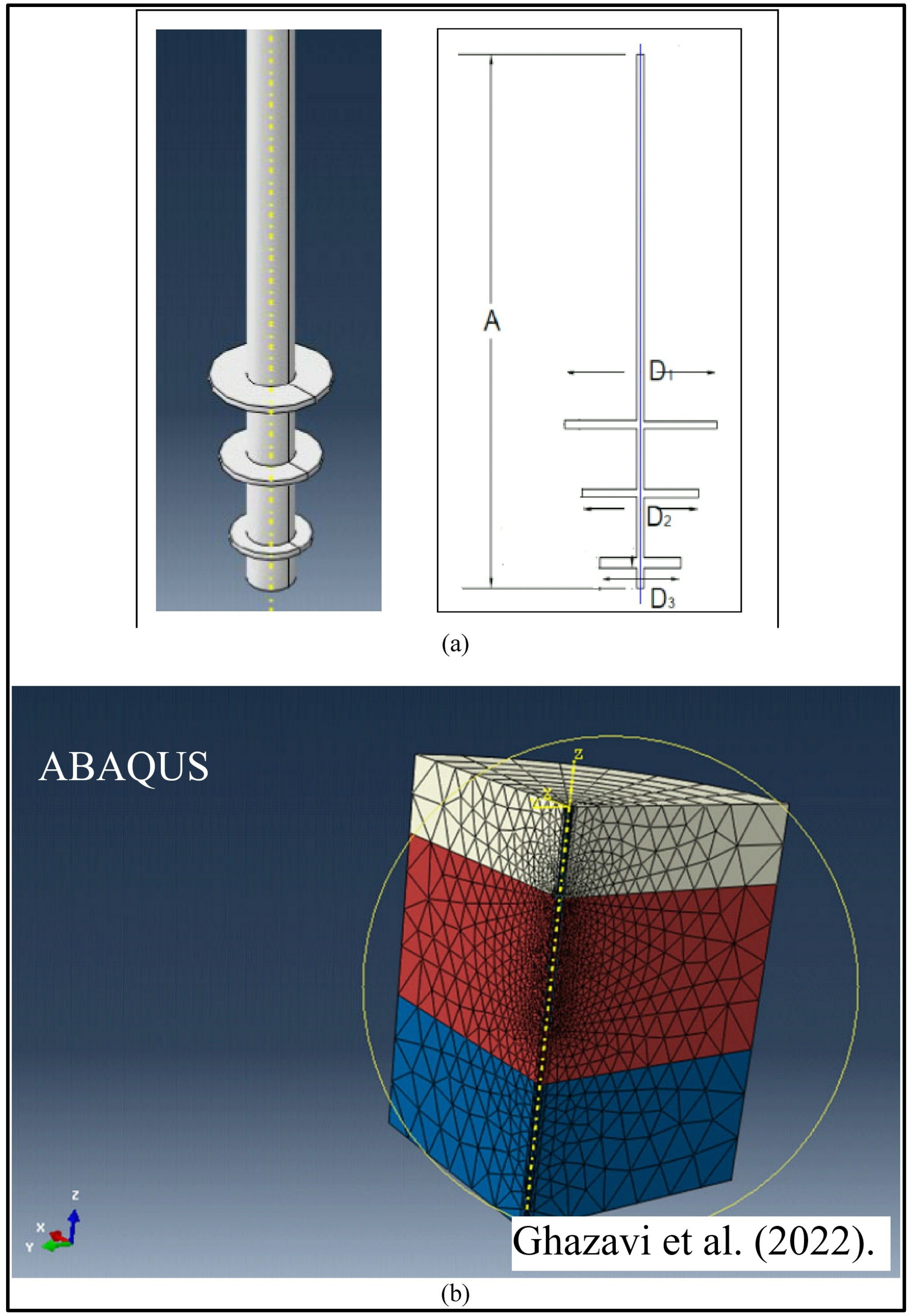
The helical pitch which is sometime equal to the shaft diameter is ignored in this simplification.

In smaller inter-helix spacing, this could be oversimplification of the model as it ignores much of the interaction between the helices.



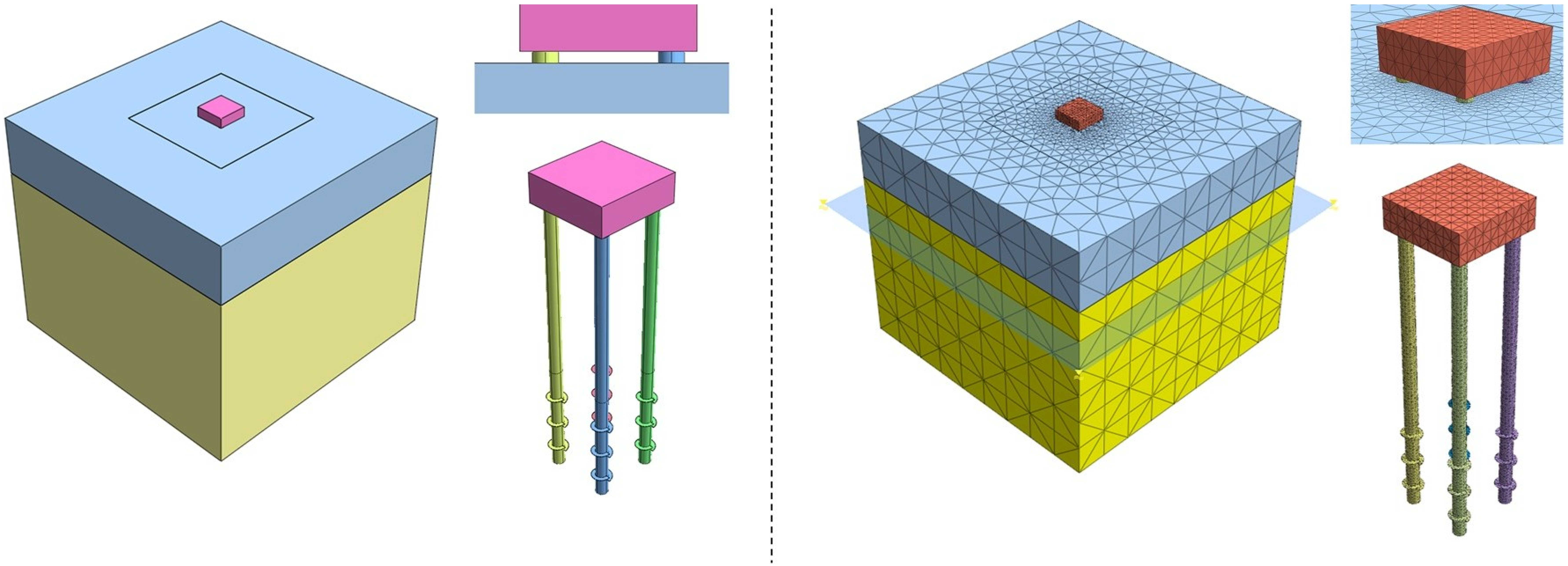
PLAXIS 3D Analysis of helical pile, Elhami, & Abu-keifa (2016)



# Helix Geometry in GTS NX

Alwalan & Alnuaim (2021)
https://doi.org/10.1007/s13369-021-06422-9

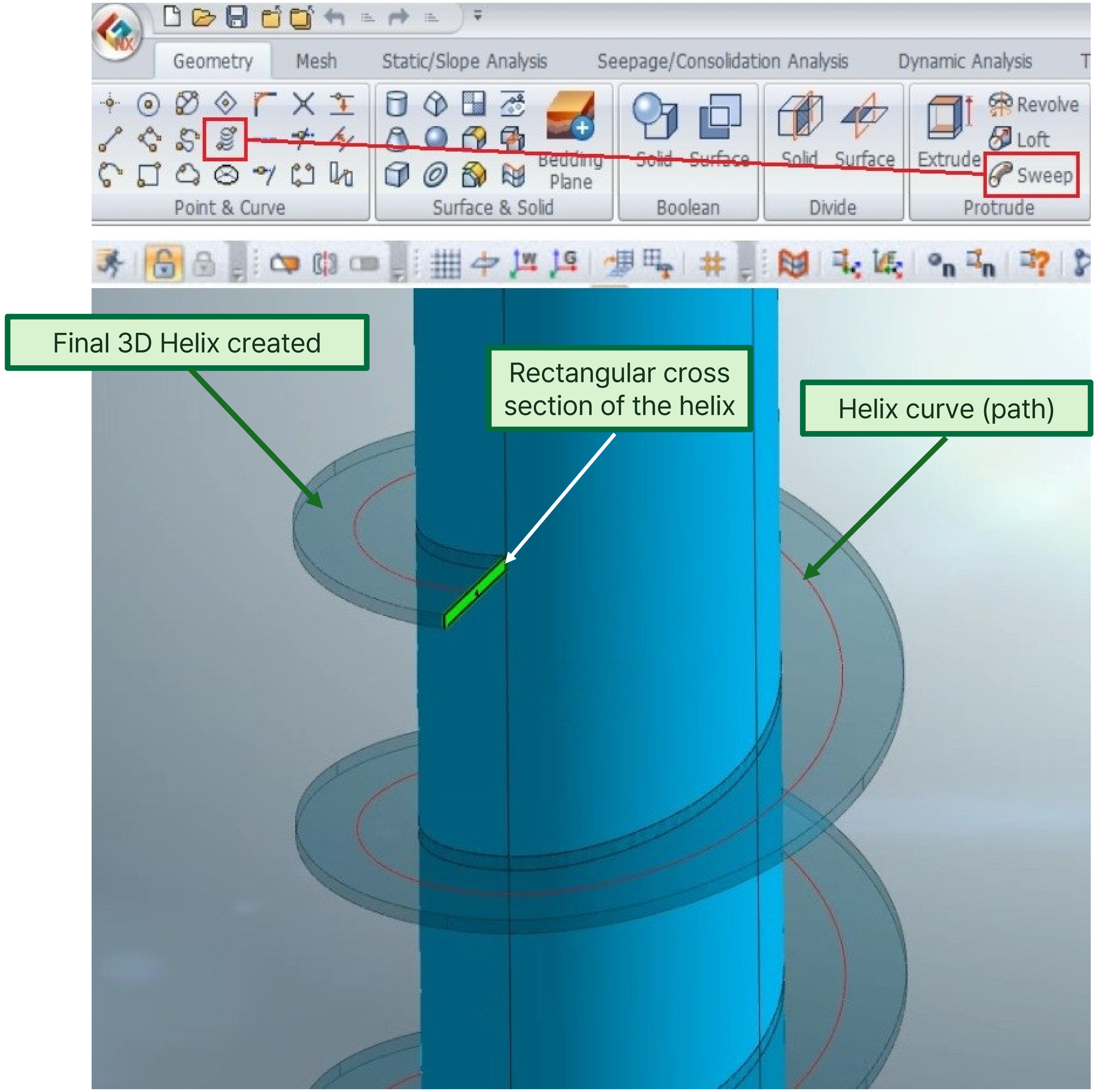


# Helix Geometry in GTS NX

Construction of helix in GTS NX is straight forward approach with the built-in Helix curve creator.

The helix curve is used as the sweep path for the helix cross section which is model by drawing a rectangular surface with the desired cross-section dimension.

The sweep command is sued then create a helical solid shape where the rectangle cross section follows the helical curve path created earlier.

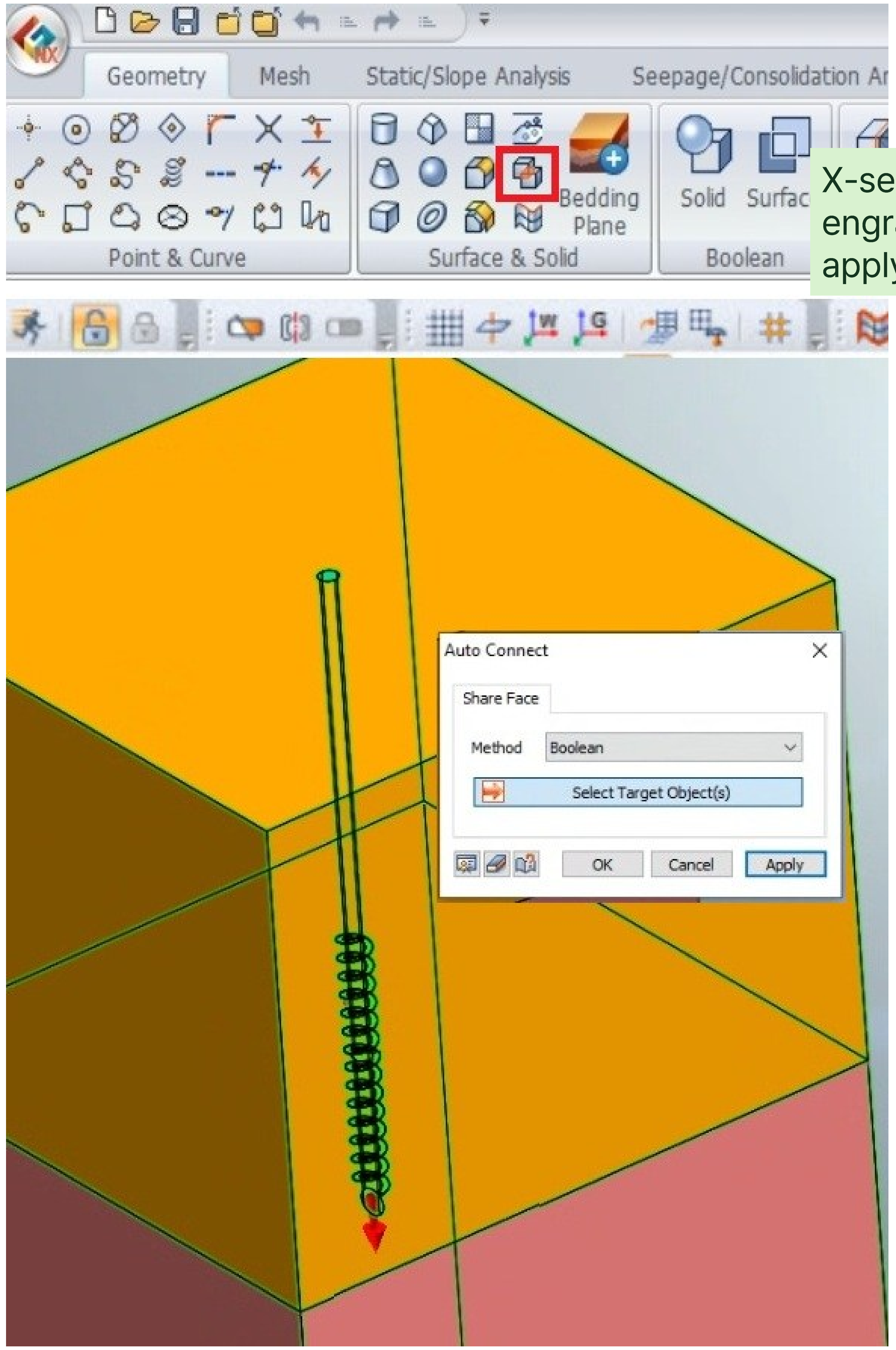


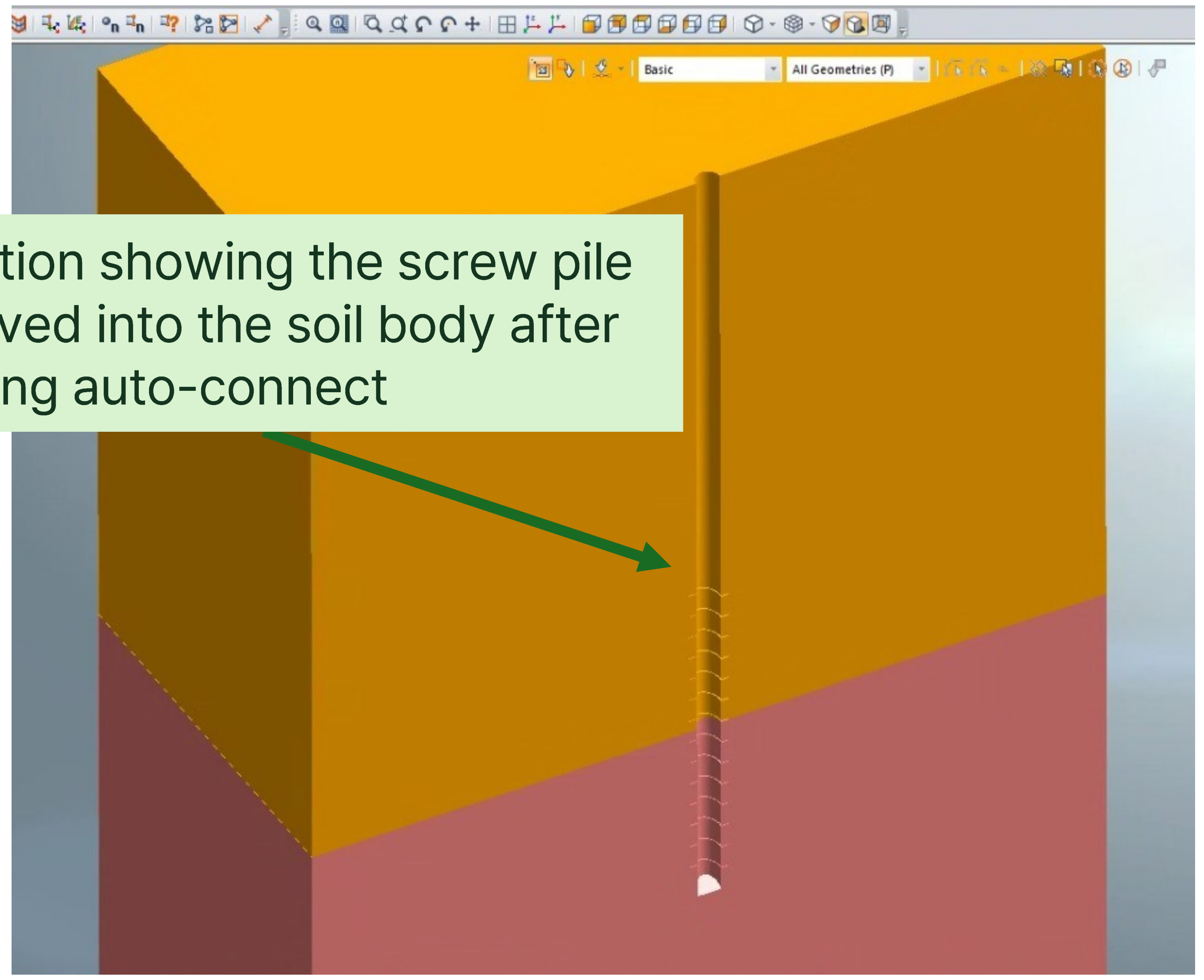
# Auto connect faces

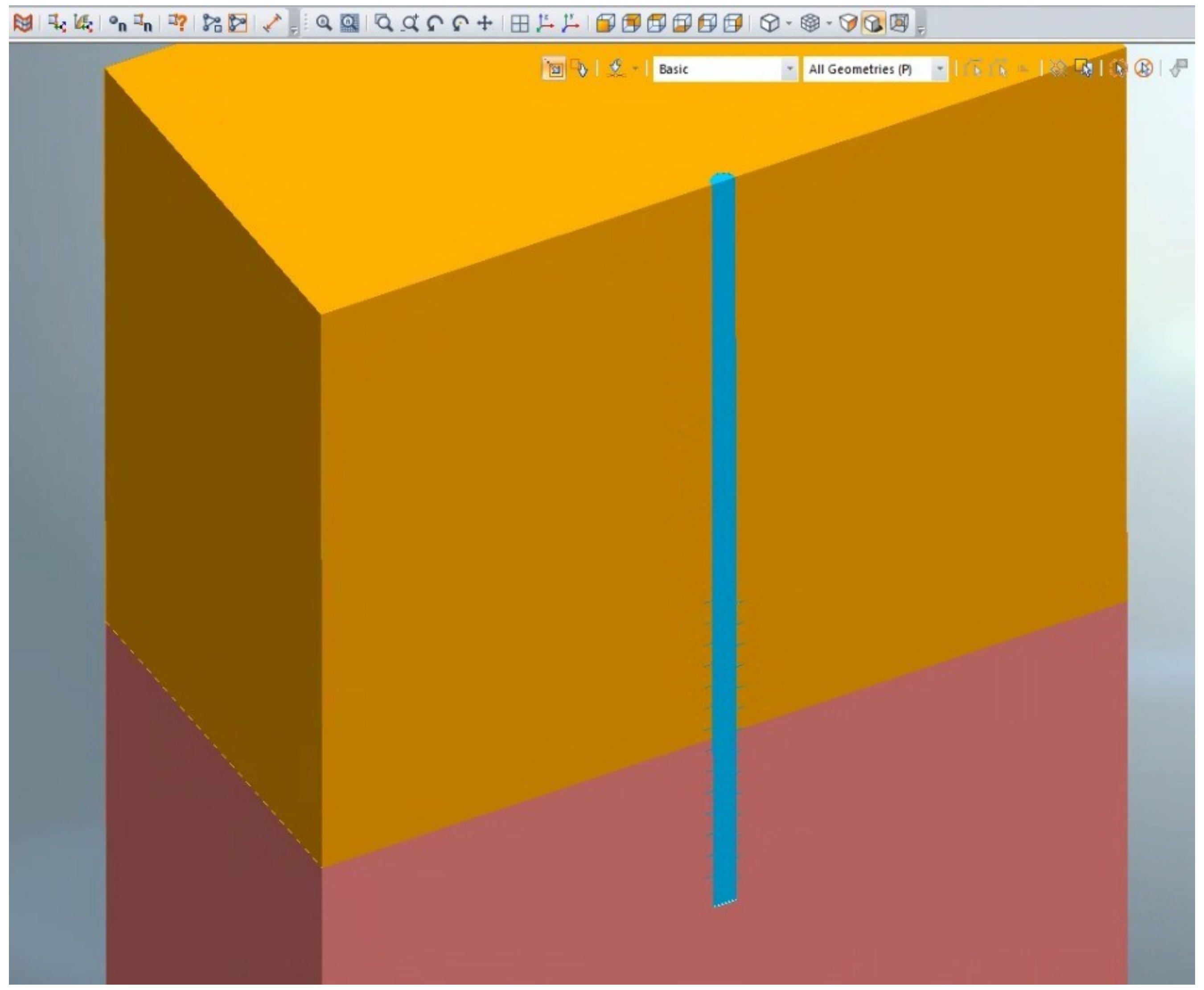
In FEM, all faces should be connected, and no free face should be allowed to occur, otherwise the mesh wont built properly.

Using the Auto Connect feature in GTS NX, you can connect the faces of all  geometry in few clicks.

The software will recognize the adjacent face and engrave the embedded geometry in  inclosing solids.



# Control the size of the mesh

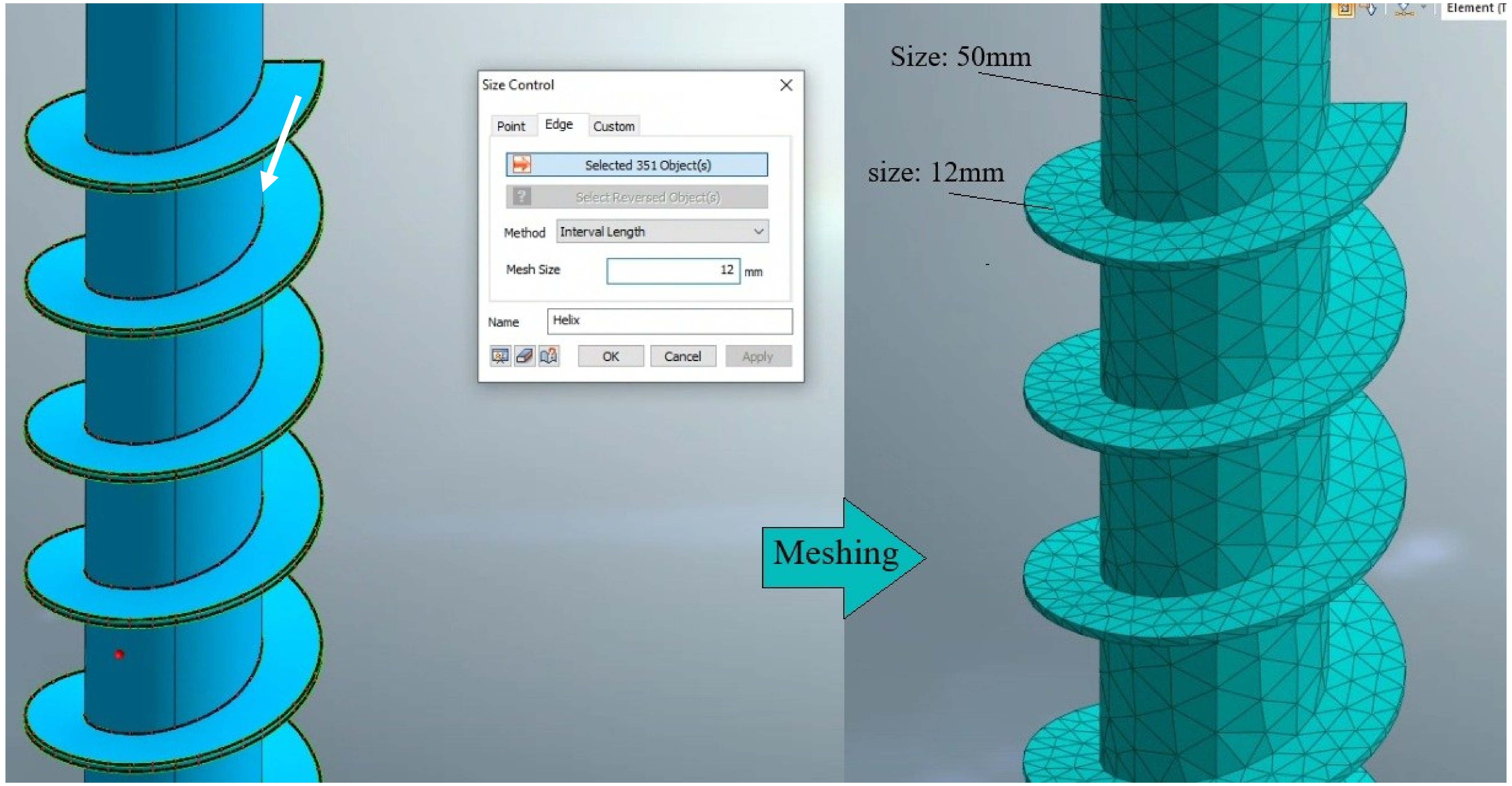
After Auto-connecting faces, the geometry is ready for meshing. The mesh will take the size of any adjacent mesh based on connected faces.

Best practice is to start meshing from inward-out, i.e. meshing form the center of the pile towards the furthest boundary of model and start with the smallest mesh size first.

The helix thickness could be smaller than the pile wall thickness, hence requiring smaller element size. This is achieved using the size control feature where you control the different mesh sizes of the pile components.

Select the edge of the mesh geometry and apply the desired size control

The software will enforce the size and connect it with  the any adjacent face if it was connected using auto-connect.



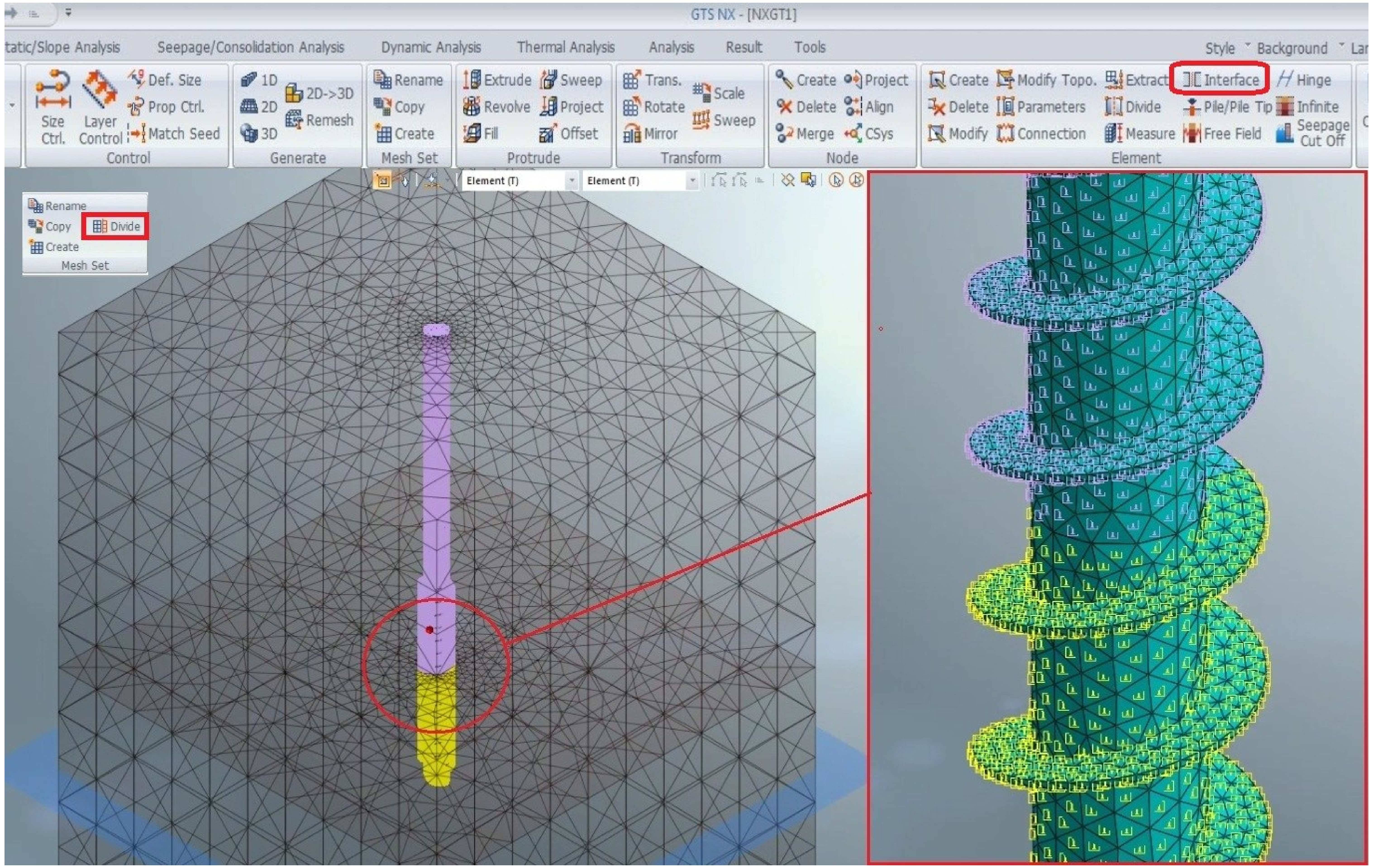

**Helix has smaller mesh size than the pile shaft, although they are in the same mesh set.**

# Create soil-pile plane interface

One of the most critical steps in modeling pile as 3D volume is the interface. It tells the software how the pile-soil elements slips relative to each other mimicking the behavior in the field.

It is important to be aware of different soils in the model and create separate interface mesh for each soil as they behave differently. Once created, use the divide mesh set feature to divide the interface mesh to match the desired soil layer and assign different properties to each set.

It is also important to create a rigid-link mesh along with the interface if you are performing staged analysis (which is the case almost always)

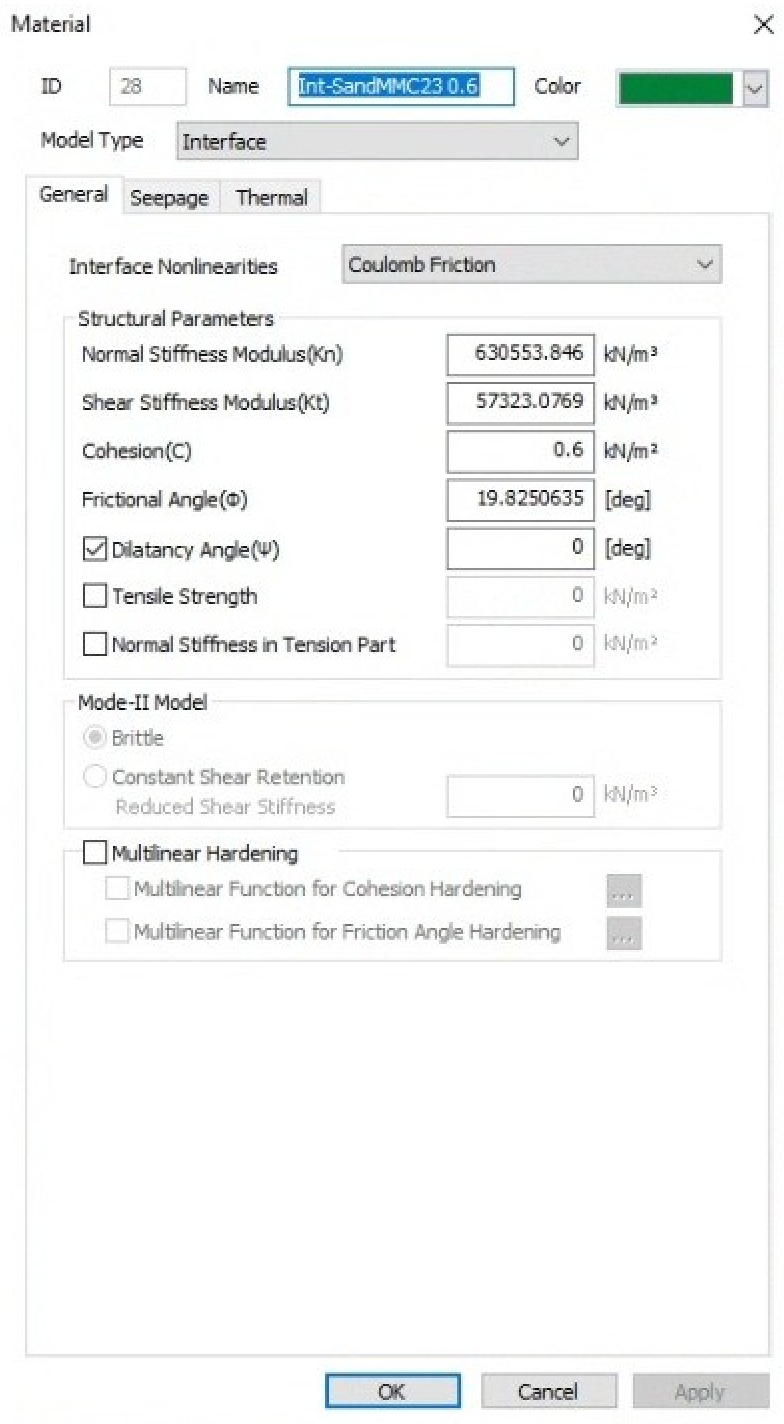


# Interface material

GTS NX interface wizard can calculate the interface property for you. I personally recommend using the interface equations to calculate the properties instead of relying on the wizard.

Because if you change the adjacent soil material, the wizard won't automatically update the interface, and you have to either delete and construct the interface from scratch or adjust the properties using the equation.

Another reason is that if you have multiple soil layer you need interface material for each layer, and the wizard can't do that as of today.




**Tip**

The interface material can be defined using the following equation. Using the stiffness of adjacent elements and nonlinear parameters, the virtual thickness (tv) and strength reduction factor (R) is applied. R x ( Fn + Ft x tan(phi) - C) = 0 → R x ( Kn x un + Kt x ut x tan(phi) - C) = 0
The Wizard can be used to simplify this process.

$$K_n = E_{oed,i} / t_v$$
$$K_t = G_i/t_v$$
$$C_i = R \times C_{soil}$$
$$phi_i = \tan^{-1} (R \times \tan (phi_{soil}))$$

Here, $E_{oed,i} = 2 \times G_i \times (1-\nu_i)/(1-2 \times \nu_i)$

($\nu_i$ =Interface Poisson's ratio=0.45, the interface is used to simulate the non-compressive frictional behavior and automatically calculates using 0.45 to prevent numerical errors.)

$t_v$ = Virtual thickness(Generally has a value between 0.01~0.1, the higher the stiffness difference between ground and structure, the smaller the value)

$G_i = R \times G_{soil}$ ($G_{soil} = E/(2(1+ \nu_{soil}))$), R = Strength Reduction Factor

The general Strength reduction factor for structural members and neighboring ground properties are as follows.

- Sand/Steel : R ≈ 0.6~0.7
- Clay/Steel : R ≈ 0.5
- Sand/Concrete : R ≈ 0.8~1.0
- Clay/Concrete : R ≈ 0.7~1.0

GTS NX User's Manual

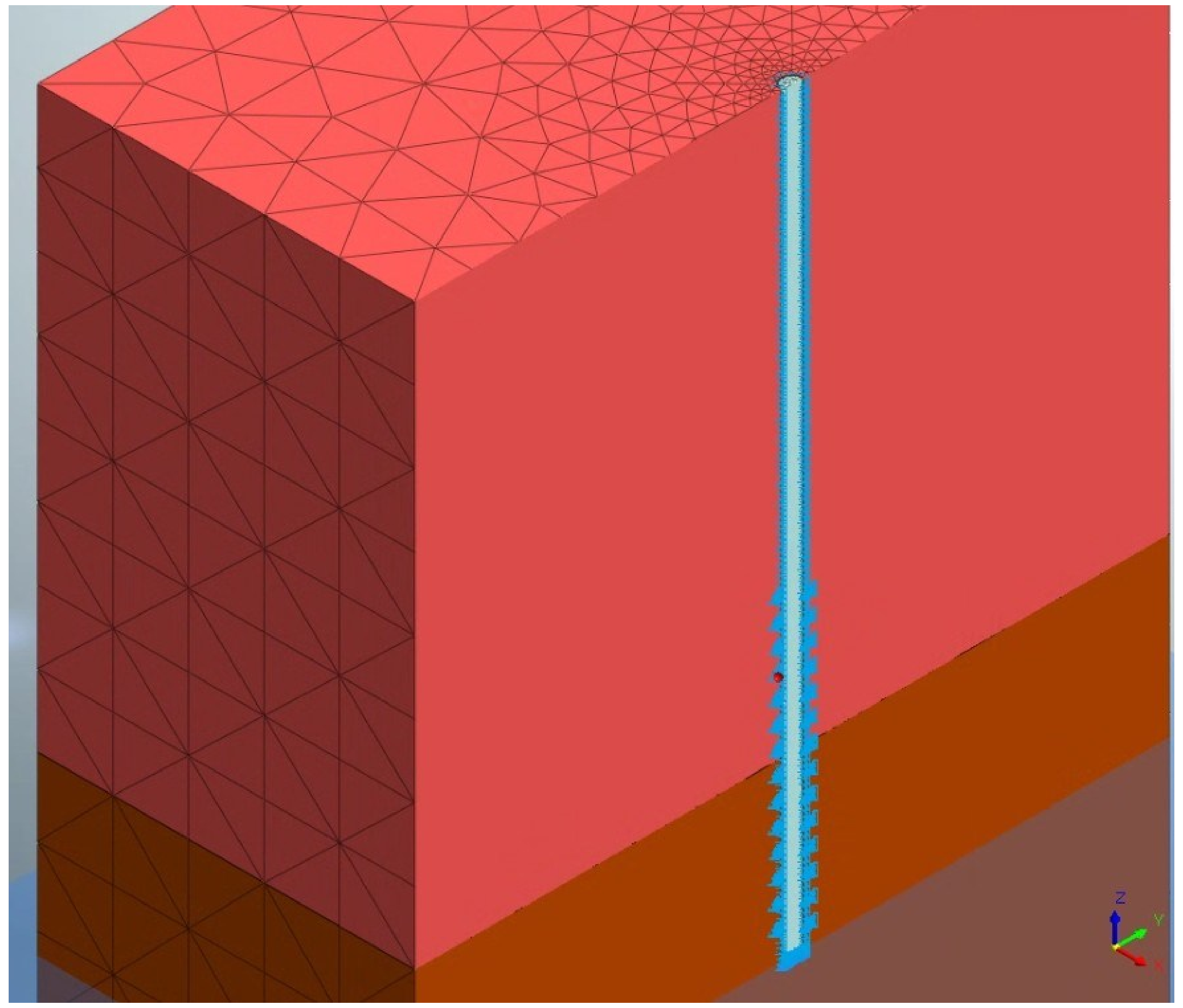
# Analysis and Results

## Staged Analysis

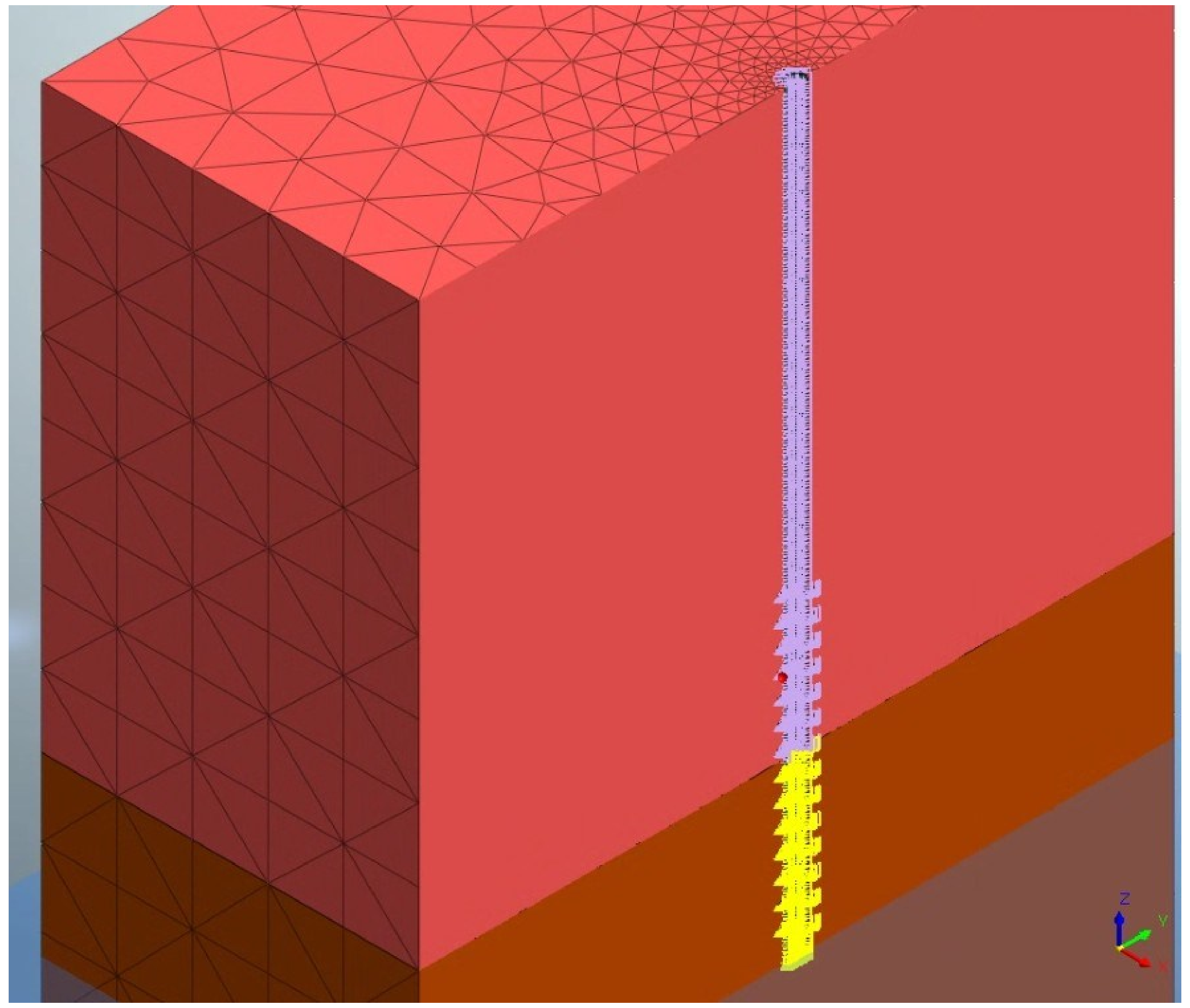
It is crucial to analyze the pile-soil interaction problem using stage analysis. The reason is to estimate the in-situ stresses of the soil prior to pile installation. These stresses are used to estimate the stiffens parameters of the hardening soil model and interface friction parameters during loading stage. The different stages are:

1. Initial stage: the pile is given soil properties making the whole model run as soil only.
2. Change property stage: changing the pile property to pile material and removing the inner soil mesh, deactivating the rigid link mesh and activating the interface.
3. Loading stage: Applying the load

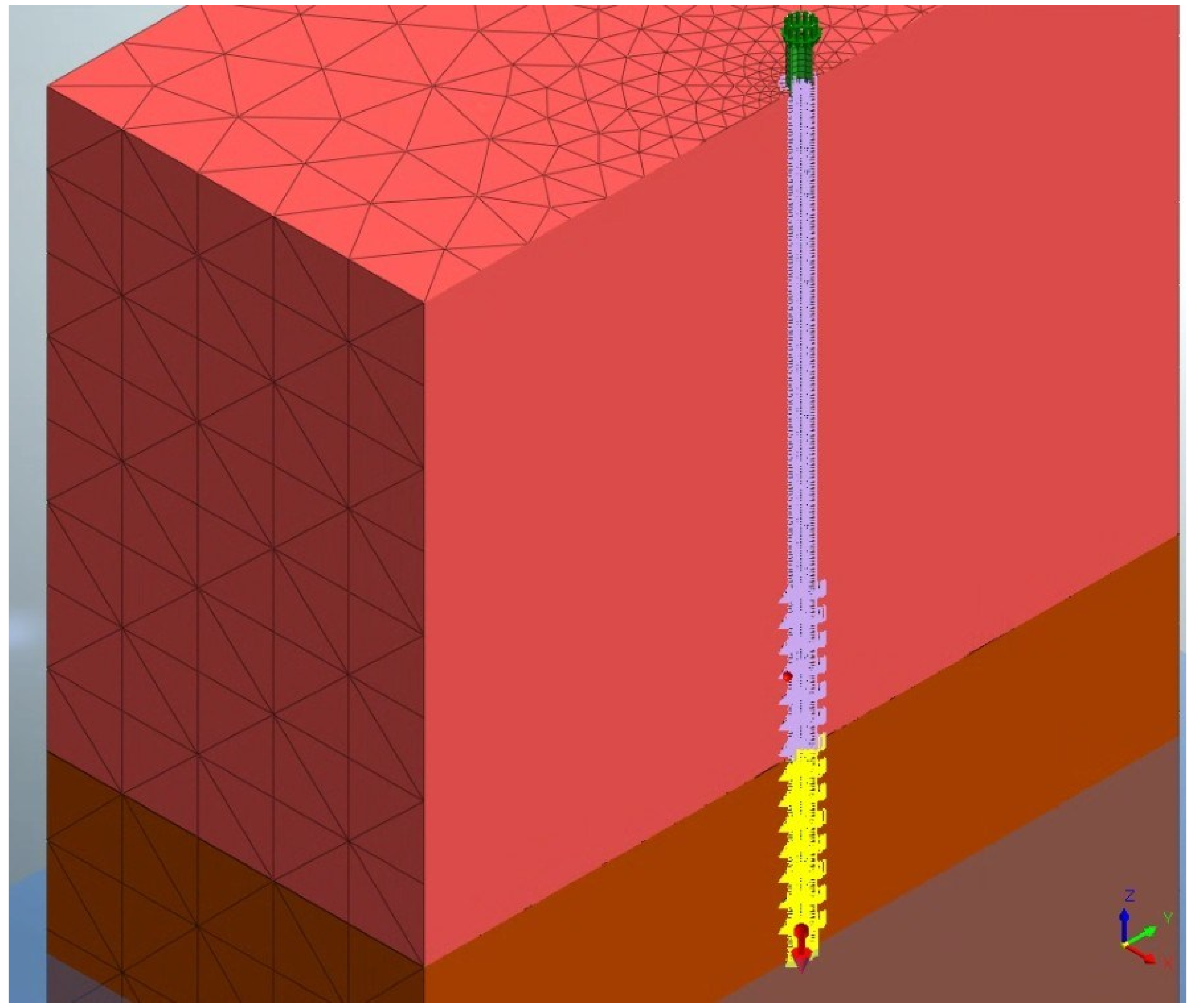
Initial stage with rigid link activated



Change property stage
with rigid link deactivated, and interface activated

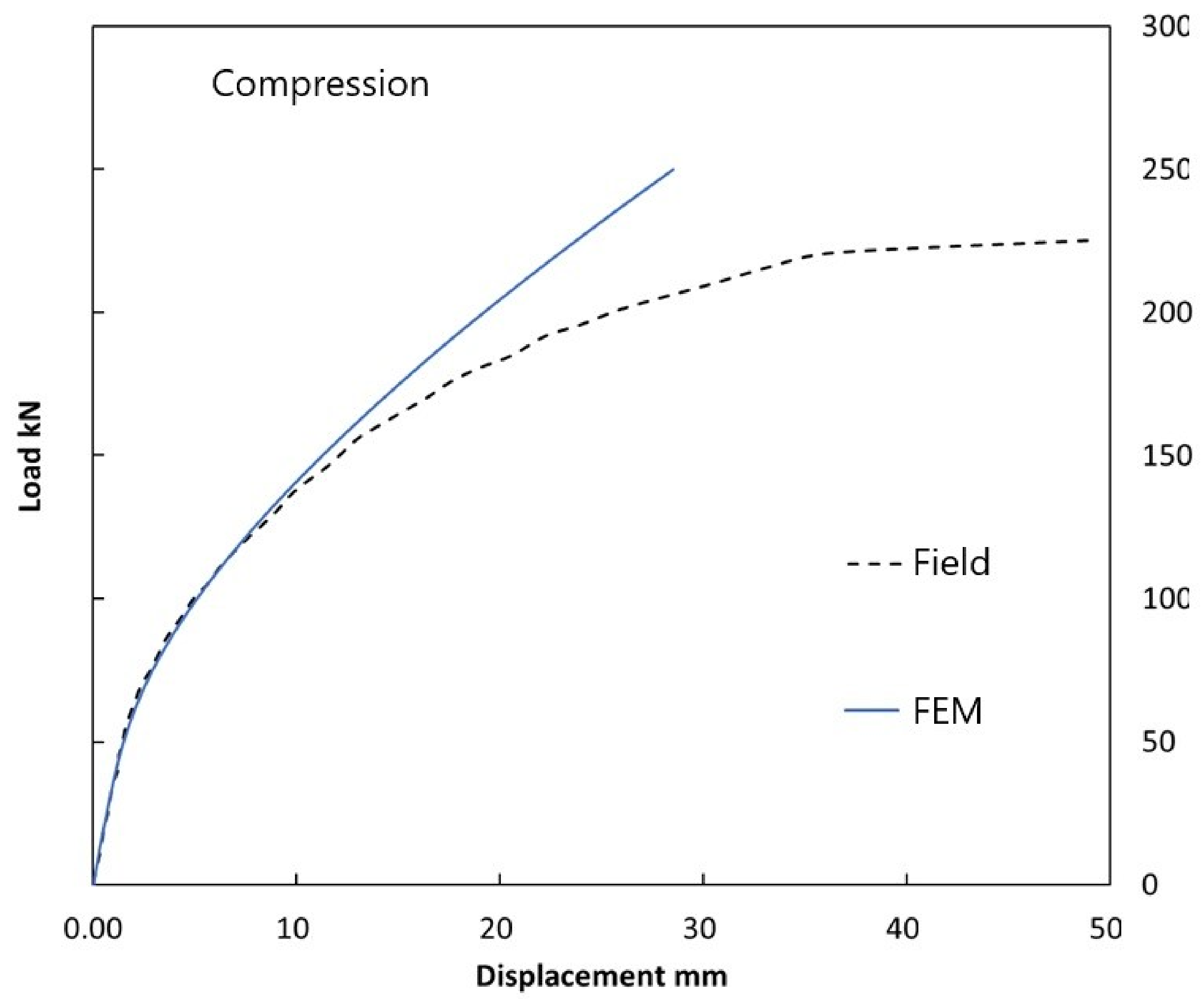


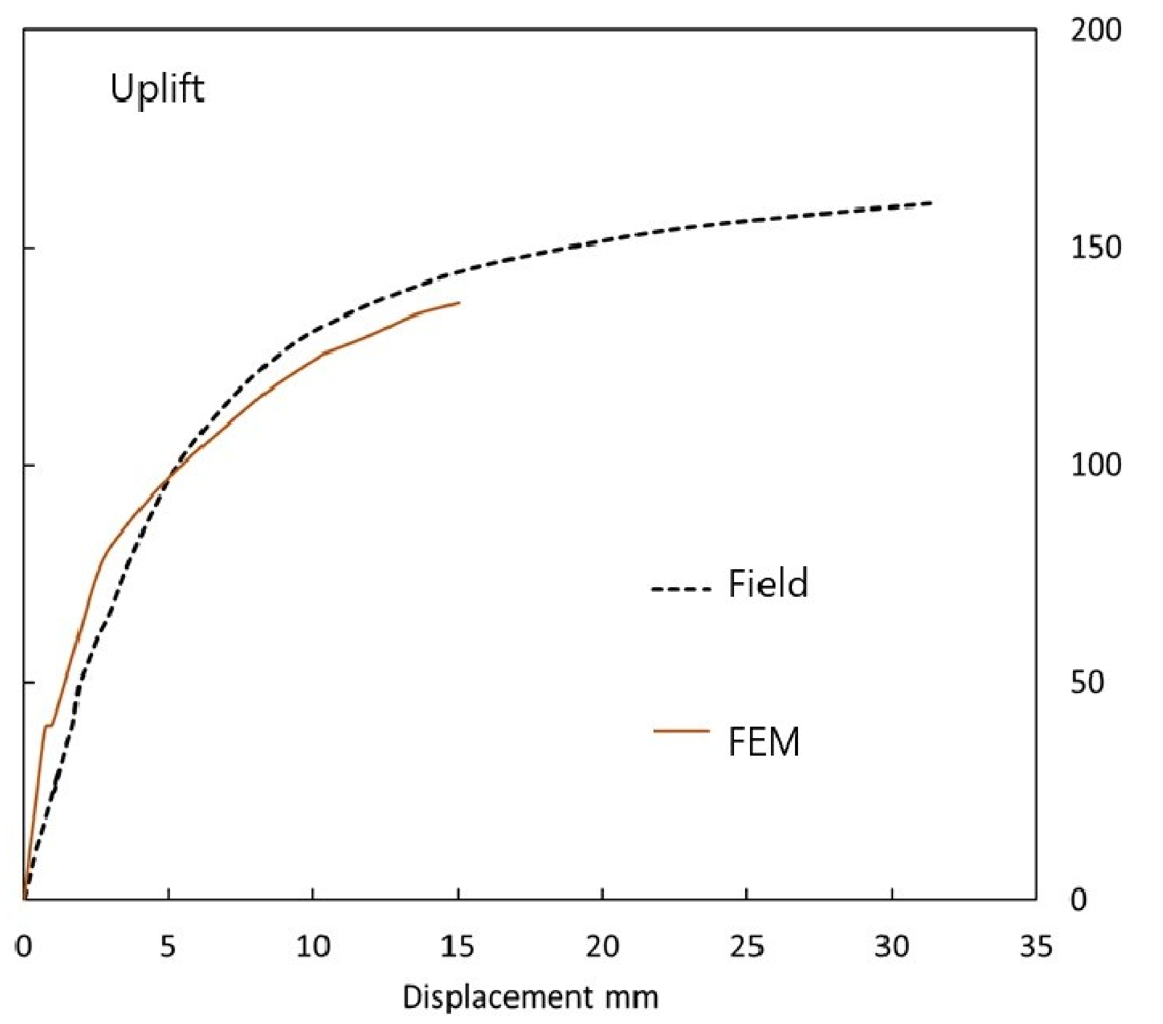
Loading stage

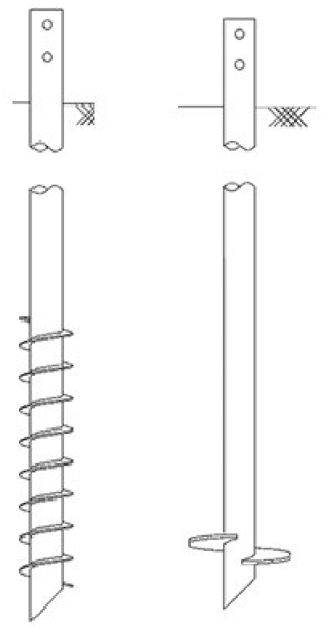


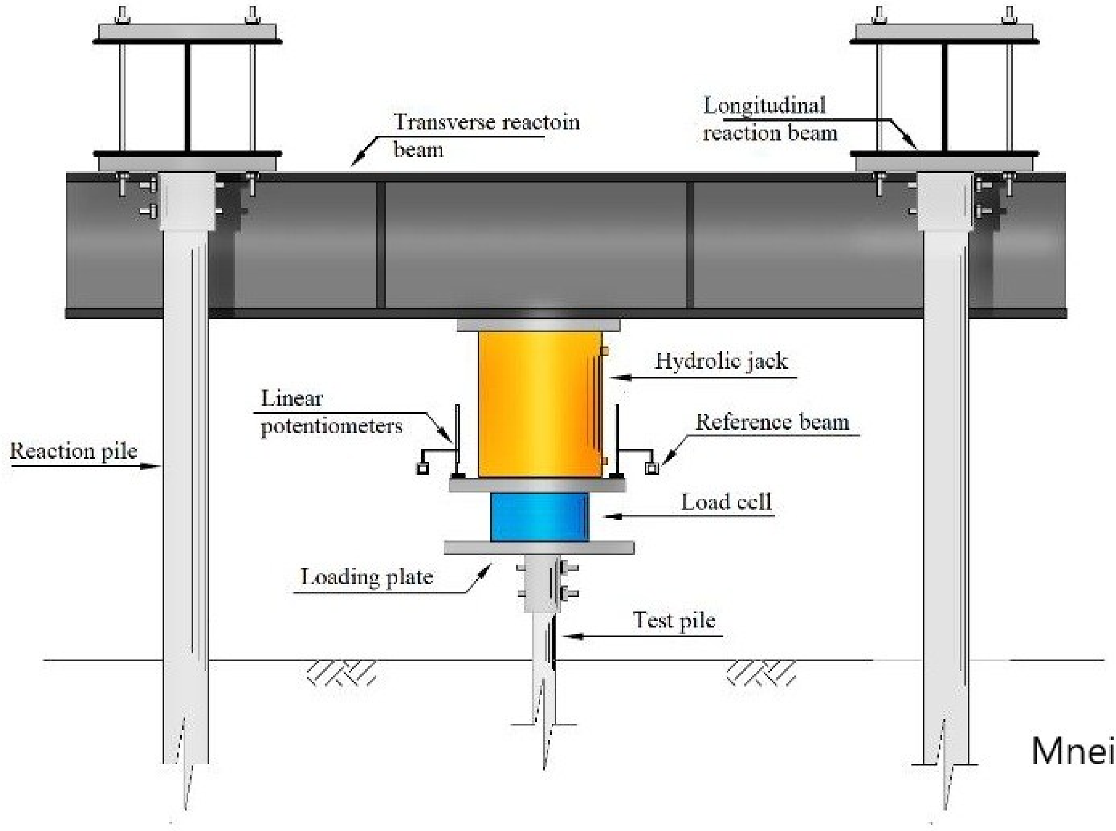
# Calibration & Validation

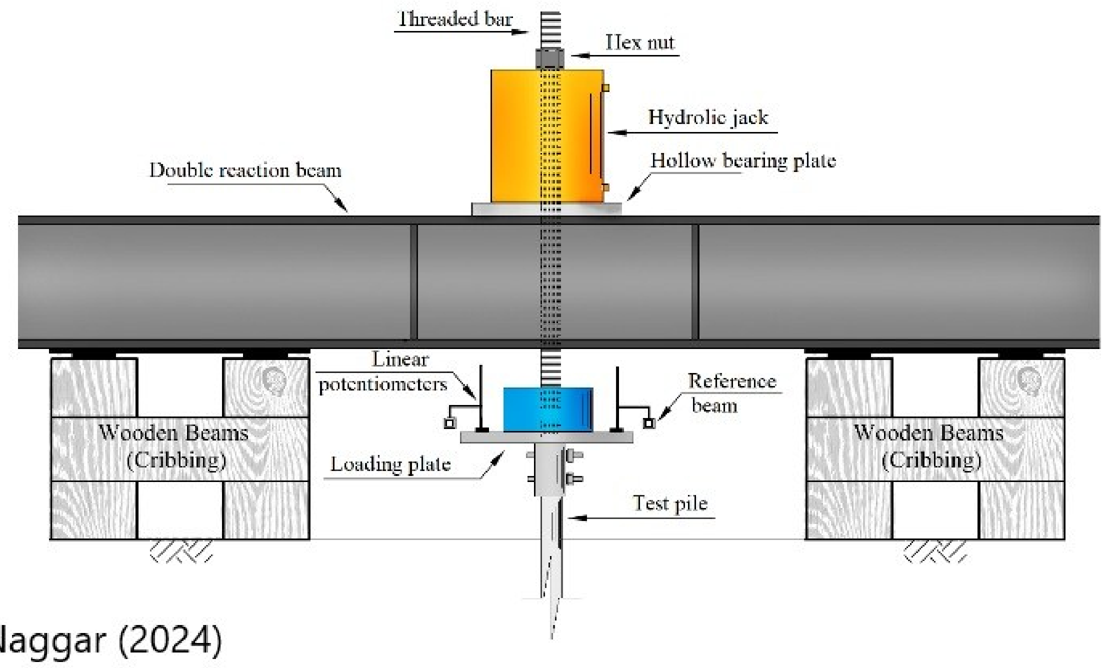
The soil and interface parameters are then calibrated against the load displacement curve from the filed. The calibration was done using helical  pile test and it was validated for screw piles at different depths.





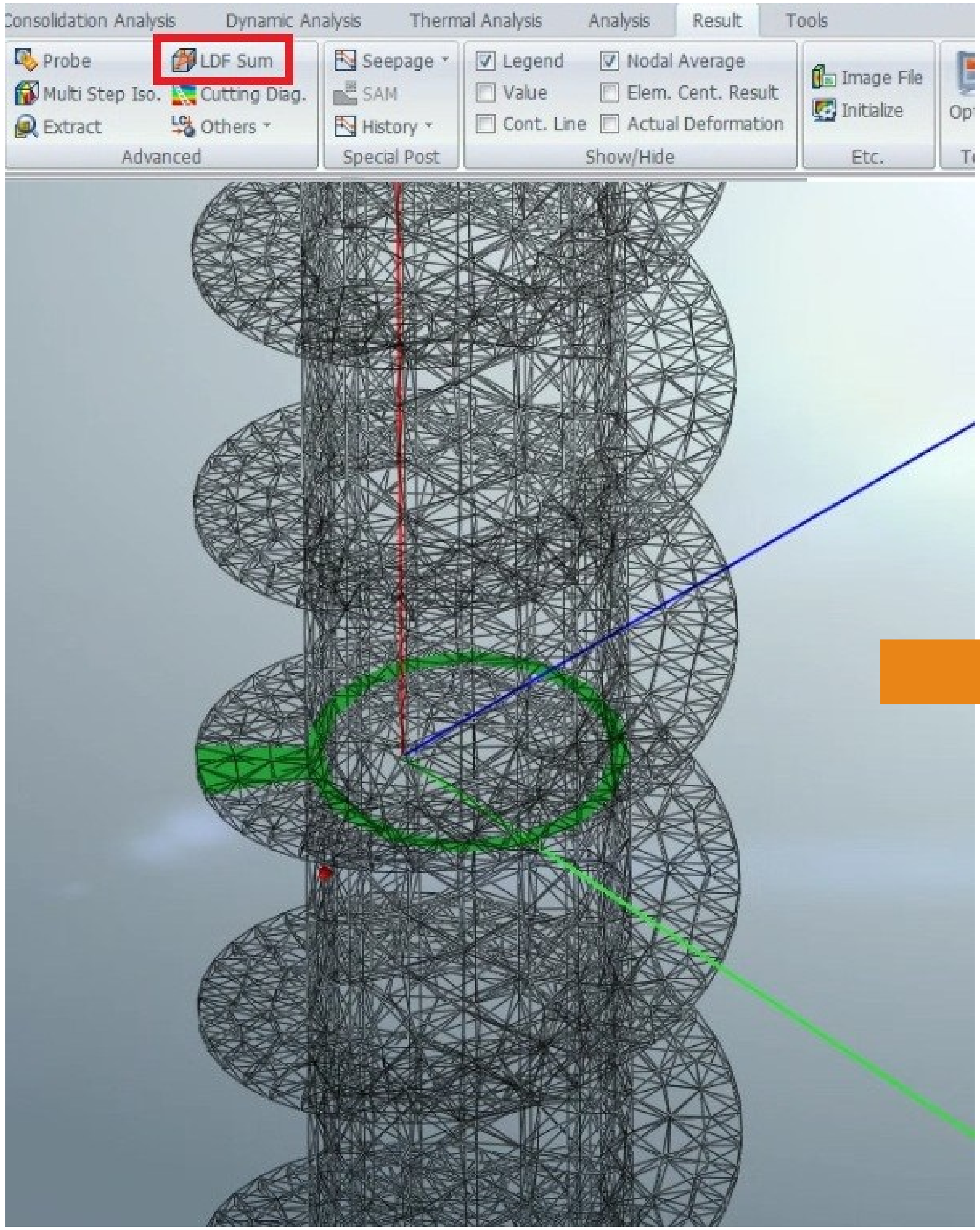

Mneina and El Naggar (2024)

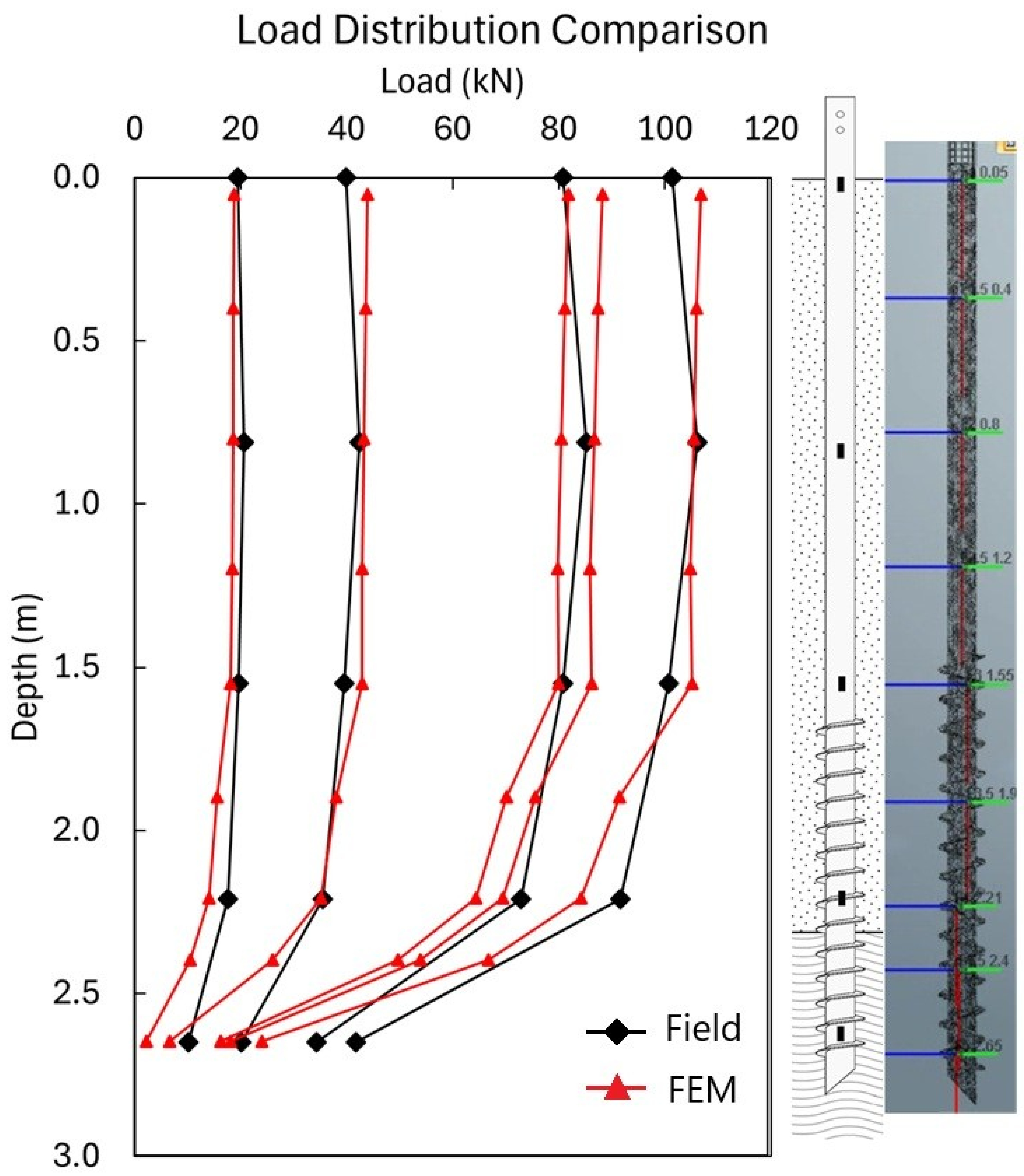
# LDF Sum feature

Using LDF sum feature, the internal axial forces were accurately calculated at given cross-section of the pile.

The advantages of modeling a 3D helix is manifested here as it shows that part of the helix (about 12%) is contributing to the axial internal force in the cross-section.

This representation would not have been calculated assuming a circular disc instead.




The results form the field were compared with the model results. The figure shows a close representation of the field behavior.

# Thank you for your attention


Photo: GeoMontreal Conference 2024, Montreal, Canada

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# Live Q&A