Republic of Iraq
Ministry of Higher Education and Scientific Research
University of Baghdad
College of Engineering
Civil Engineering Department

Treatment of Expansive Soil Using Helical Piles with Additives

A THESIS
SUBMITTED TO THE COLLEGE OF ENGINEERING OF THE UNIVERSITY OF BAGHDAD IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTORATE OF
PHEOLOSOPHY IN CIVIL ENGINEERING
GEOTECHNICAL ENGINEERING

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Objective of the Research

Due to limited knowledge currently available in the literature about using helical piles in expansive soils, the present study is an attempt to understand and demonstrate the behavior and influence of adding different types of additives during installation of helical piles in expansive soils in reducing the heave and resisting pullout force. In this research, the following aspects are covered:

1. Investigate the relative movements of the helical piles to the top surface of the bed of the soil.

2. The behavior of helical piles under pullout force.

3. The behavior of groups of helical piles embedded in high expansive soil. The effect of pile spacing, helix diameter, number of helix and pile length on the upward movement are investigated.

4. Studying the behavior of expansive soil treated with different types of additives during helical piles driving.

5. A finite element analysis is carried out to simulate the swelling process and suitability of helical piles in expansive soil in full scale problems by using Program Plaxis 3D (2013). The Plaxis computer program is used as a finite element tool and the soil is represented by hardening soil model.

Originality of Study

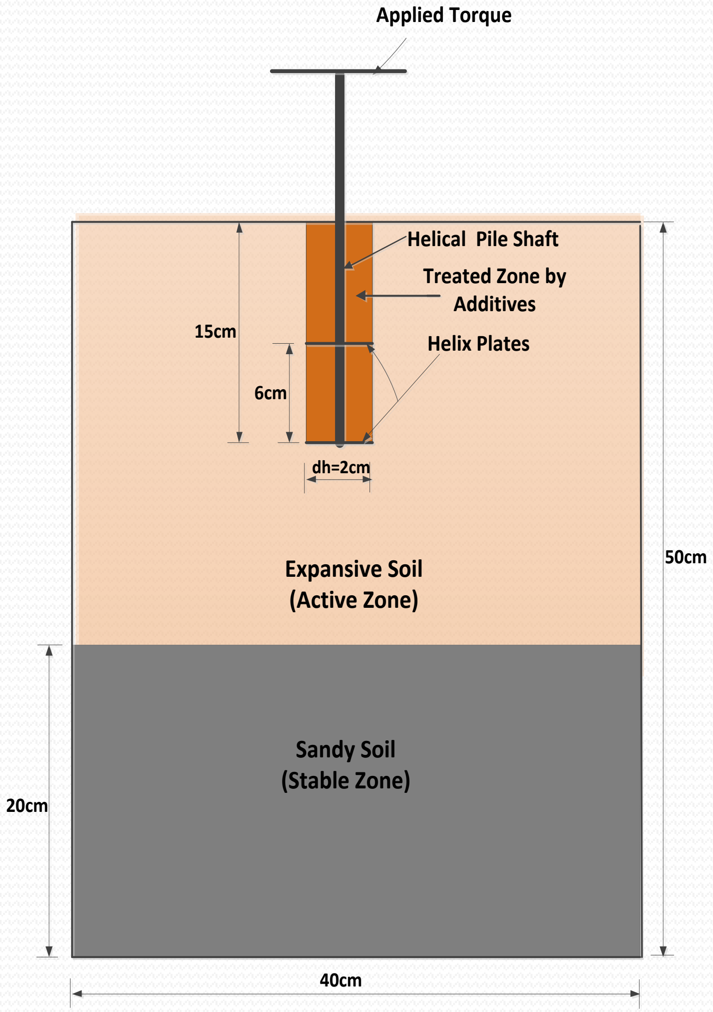
In general, there are two methods of treatment expansive soil:

1-Chemical Treatment

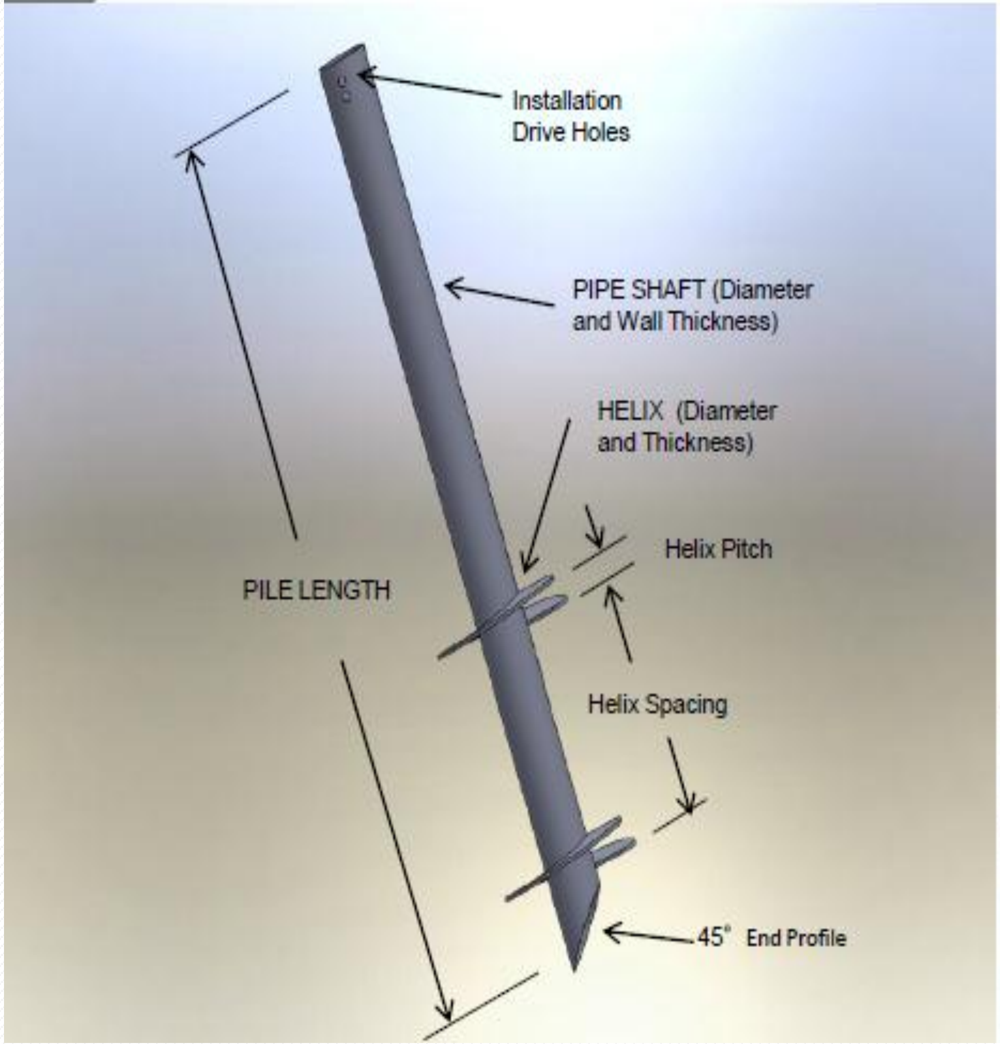
2-Mechanical Treatment

In this study, new treatment is introduced that combined between chemical and mechanical treatment as shown in figures below:

Addition of Additive During Installation of Helical Piles in Expansive Soil.



SCREW PILE: structural elements that consist of one or more helical shaped circular plate(s) affixed to a steel central shaft.



Individual Helix Bearing Method

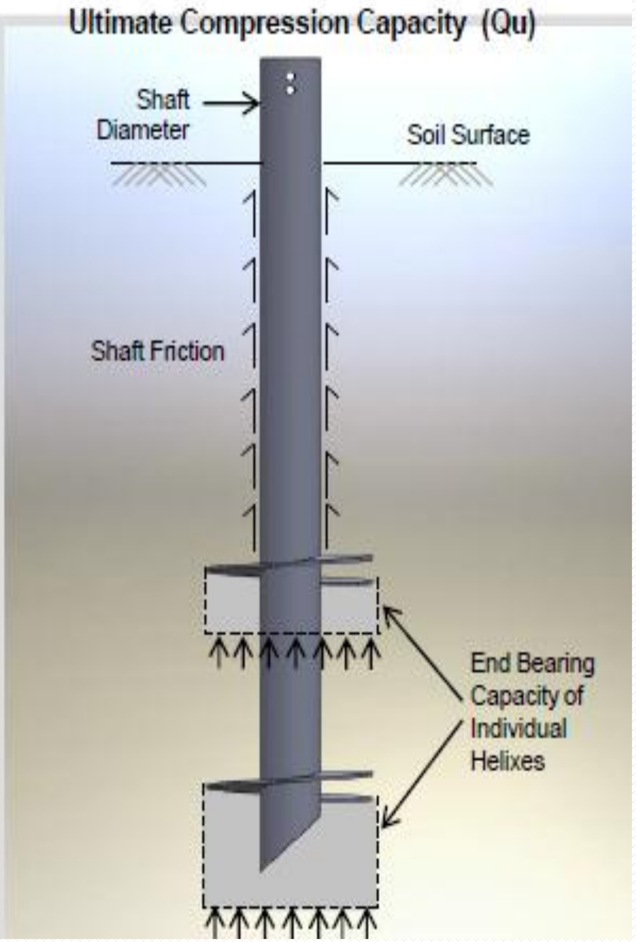
$$Q_t = Q_{shaft} + \sum Q_{i(bearing)}$$

where

Q_t = ultimate uplift capacity

Q_{shaft} = adhesion developed along the steel shaft

$\Sigma Q_{i(bearing)}$ =sum of the bearing capacity of each individual helix



Compressive Capacity using Cylindrical Shear Method

$$Q_C = Q_{shaft} + Q_{helix} + Q_{bearing}$$

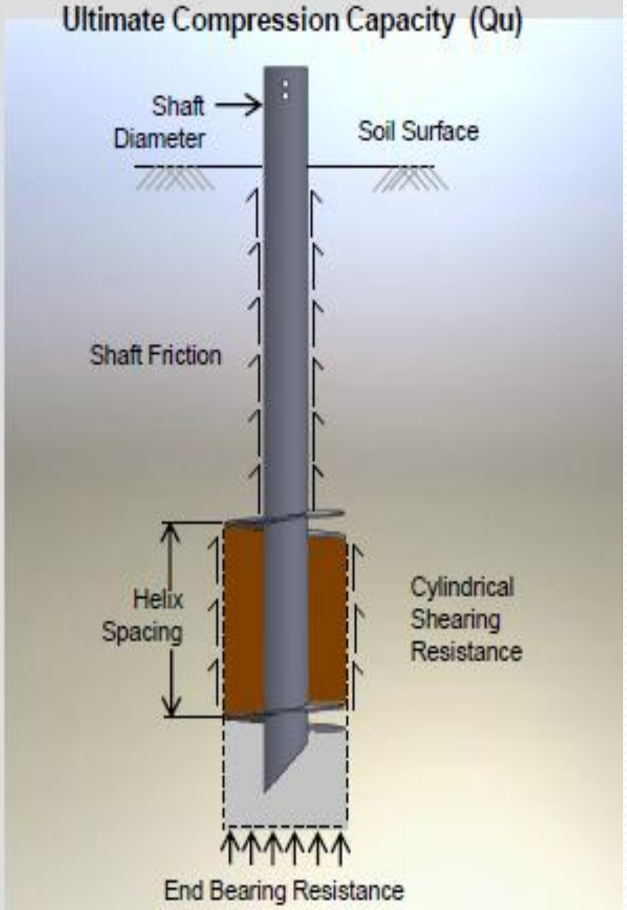
where

Q_C = ultimate compressive capacity

Q_{shaft} = adhesion developed along the steel shaft

Q_{helix} = shearing resistance mobilized along the cylindrical failure surface

$Q_{bearing}$ = bearing capacity of the bottom helix



Torque Method

$$Q_t = K_t T$$

where

K_t = empirical factor

T = average installation torque

K_t = 33 m^{-1} for all square shafts and round shaft anchors less than 89 mm in diameter

K_t = 23 m^{-1} for 89 mm round shaft anchors

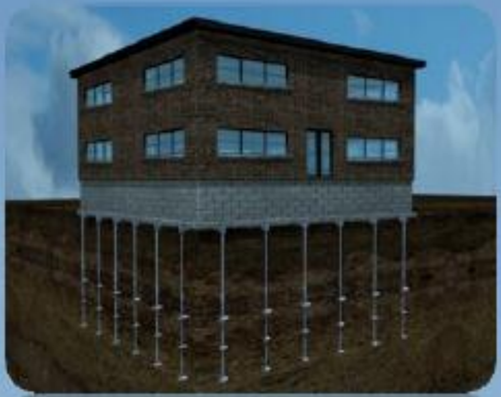
K_t = 9.8 m^{-1} for anchors with 219 mm diameter shafts

Advantages of Screw Piles

- No tailings, rebar, anchor bolts or bore lining required
- No concrete curing time required
- Do not have to dewater casing
- Can be installed in all weather conditions
- Single stage installation
- Reclaimed with minimal ground disturbance
- No additional wall thickness required to facilitate installation
- Usually requires shallower embedment depths
- Reduced material cost and faster install times

Helical Foundation Systems:

Typical Applications



New Construction Helical Piles

Helical pile installation within auditorium of community theatre

Helical Tiebacks

Retaining wall - before

Helical tiebacks on retaining wall

Helical Tiebacks

Retaining wall – after

Industrial Housing and Work Camps

- Typically install 8-10/hr.
- 114mm -178mm dia. pipe and usually 6-7m long.
- Project sizes range from a few 100 piles to >1000 piles.

Commercial - Steel Buildings

Pile Groups on Tower Structures

Summary

1. Little studies or research works was found to study the effect of adding different types of additives during installation of helical piles in expansive soils.
2. A number of studies actually dealt with using helical piles in the expansive unsaturated soil, but limited studies dealt with such soil and simulate its behavior close to the field conditions. Therefore, it is necessary to model the performance of helical piles in such soils and evaluate its behavior.
3. Also, numerical implementation of helical pile in expansive soil is scarce in the literature.

Testing Program

- Measuring water content, suction and swelling of expansive soil during period of saturation.
- Measuring uplift movement and pullout force for ordinary and helical pile with single and double helix plates extended to loose and dense sandy soil through expansive soil.
- Measuring uplift movement and pullout force for ordinary and helical pile with single and double helix plates extended to expansive soil.
- Measuring uplift movement for group of helical piles [2x2] with single and double helix plates extended to expansive soil for three spacing (3dh, 4dh, 5dh).
- Measuring uplift movement and pullout force for helical pile with double helix plates extended to expansive soil after addition of additives and mixed additives during installation of helical piles .

Summary of Physical Properties of Expansive Soil Used

Test Name	Standard	Soil Property	Value
Specific Gravity	(ASTM D-854)	Specific Gravity (Gs)	2.78
Atterbeg Limits	(ASTM D-4318)	Liquid limit(L.L),%	102
		Plastic Limit(P.L),%	43
		Plasticity Index(P.I),%	59
Grain size analysis	(ASTM D-422)	Clay, %	53
		Silt,%	27
		Sand,%	20
		Gravel,%	٠
		Unified Soil Classification System(USCS)	CH
Standard Compaction Test and (3/4) Energy of Standard Test	(ASTM D-1557)	Maximum Dry Unit Weight,(kN/m^3)	13.4, 13.1
		Optimum Moisture Content(O.M.C),%	18, 19
		Initial void ratio(e0)	1.08
Linear Shrinkage	(ASTM D-4318)	Linear Shrinkage,%	22
Activity		Activity	1.11

Summary of Mechanical Properties of Expansive Soil Used.

Test Name	Standard	Soil property	Value
Unconfined Compression	(ASTM D-2216)	Unconfined Compressive Strength(qu),kPa	312
Unconsolidated Undrained Triaxial (UU)	(ASTM D-2850)	Undrianed Cohesion (cu), kPa	160
		Undrained Angle of Internal Friction (φu)	17
Direct Shear at (0.02 mm/min) strain rate	(ASTM D-3084)	Drained Cohesion (c'), kPa	2
		Drained Angle of Internal Friction (φ´°)	21
One-Dimensional Swell or Consolidation	(ASTM D-3084) Method (A)	Compression Index (Cc)	0.068
		Swelling Index (Cs)	0.017
		Free Swelling, (%)	26.5
		Swelling Pressure, (kPa)	260

Types of Additives with their Percentages.

No.	Additives Name	Percentages%
1	Silica Fumes	0.5,1.5,3
2	Fumed Silica	0.5,1.5,3
3	Hydrated Lime	2,4,6
4	Cement(SRC Type)	1,3,5
5	Cement Dust	1,3,5
6	Coal Fly Ash	0.5,1.5,3
7	Crushed Brick	2,3.5 ,5
8	Crushed Ceramic	2,3.5 ,5
9	Clinker	2,4,6
10	Hydrated lime:Slica Fumes (1:1)	2,4,6
	Hydrated lime:Slica Fumes (1:3)	2,4,6
	Hydrated lime:Slica Fumes (3:1)	2,4,6
11	Silica Fumes: Coal Fly Ash(1:1)	0.5,1.5,3
	Silica Fumes: Coal Fly Ash(1:3)	0.5,1.5,3
	Silica Fumes: Coal Fly Ash(3:1)	0.5,1.5,3
12	Hydrated lime: Cement (1:1)	2,4,6
	Hydrated lime: Cement (1:3)	2,4,6

Helical Pile Models

Uplift Movement Test

Pullout Load Test

Results of Experimental Work

Swelling Stages of Soil Surface and Helical Pile

Time=0 day, Ss=0 , Sp=0

Time=1day, Ss=10mm , Sp=1.1mm

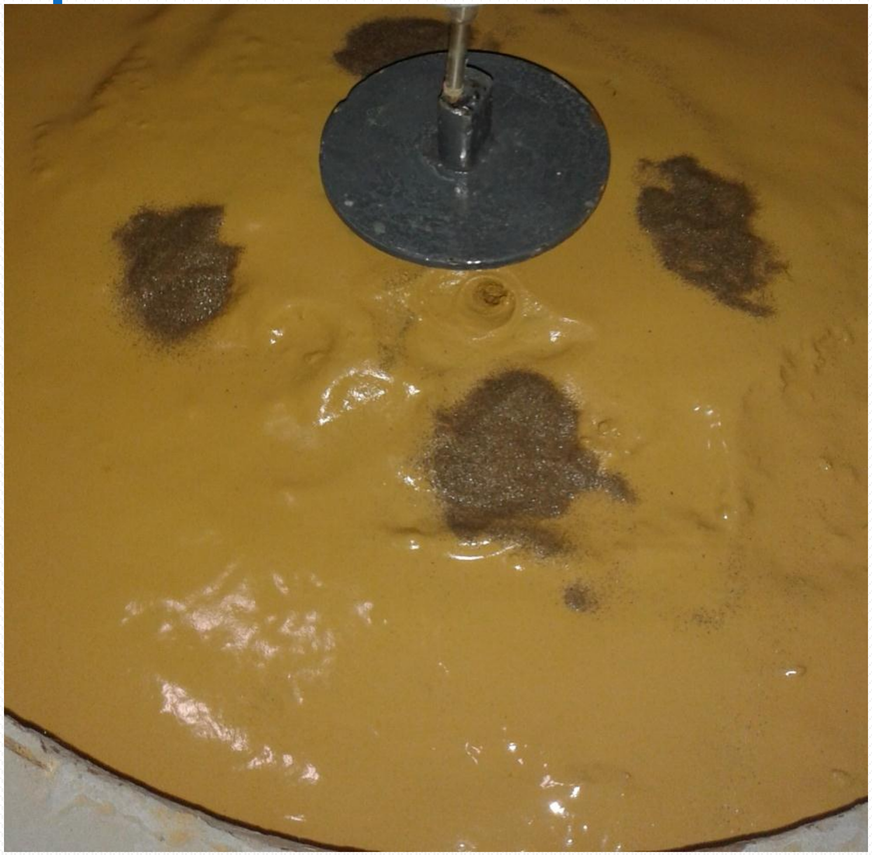
Swelling Stages of Soil Surface and Helical Pile

Time=7days, Ss=53.5mm, Sp=4.56mm

Time=13days, Ss=79mm, Sp=13.35mm

Swelling Stages of Soil Surface and Helical Pile

Time=16days, Ss=84mm, Sp=19.1mm

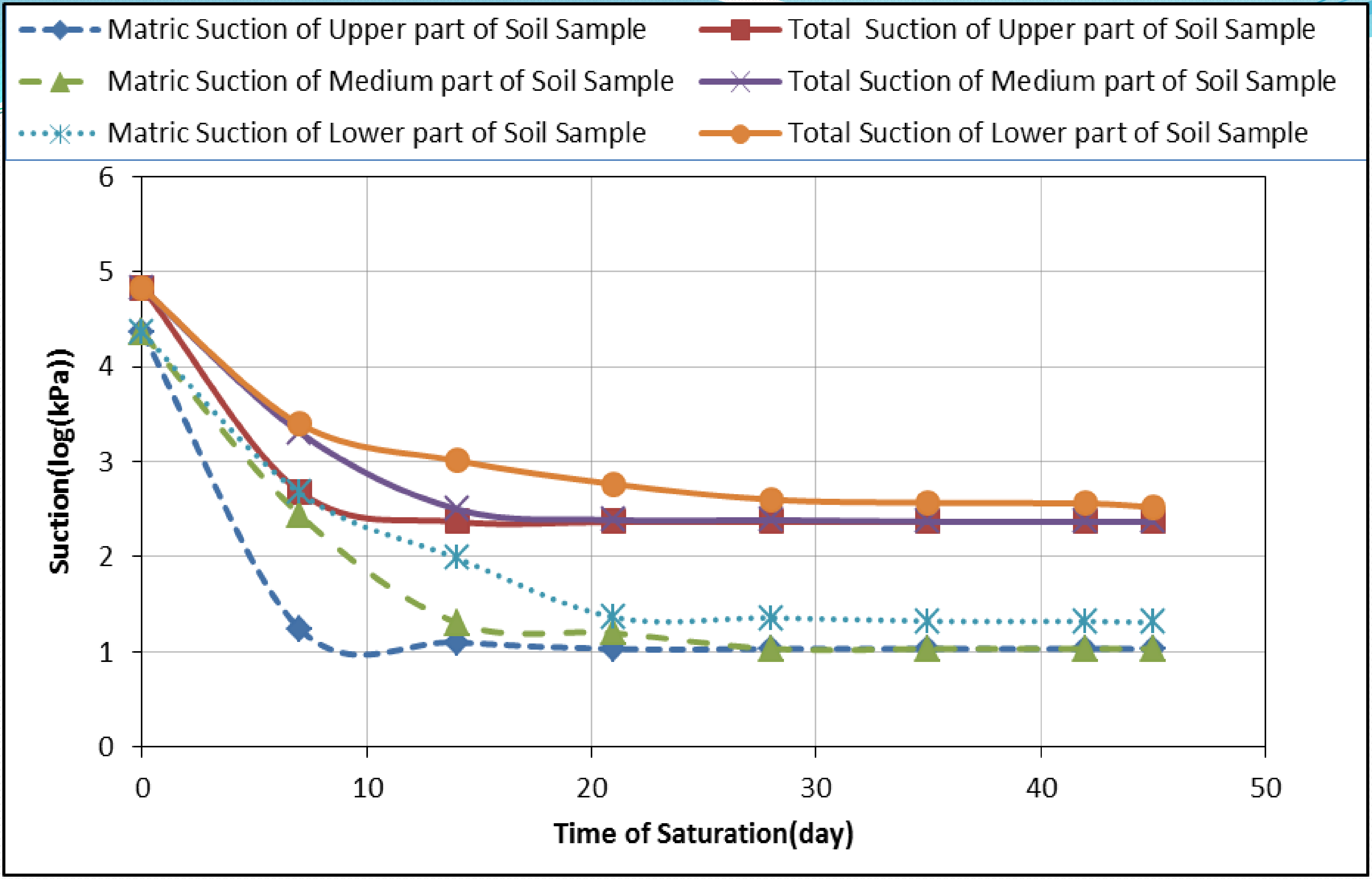


Time=34days, Ss=85.5mm, Sp=39.54mm

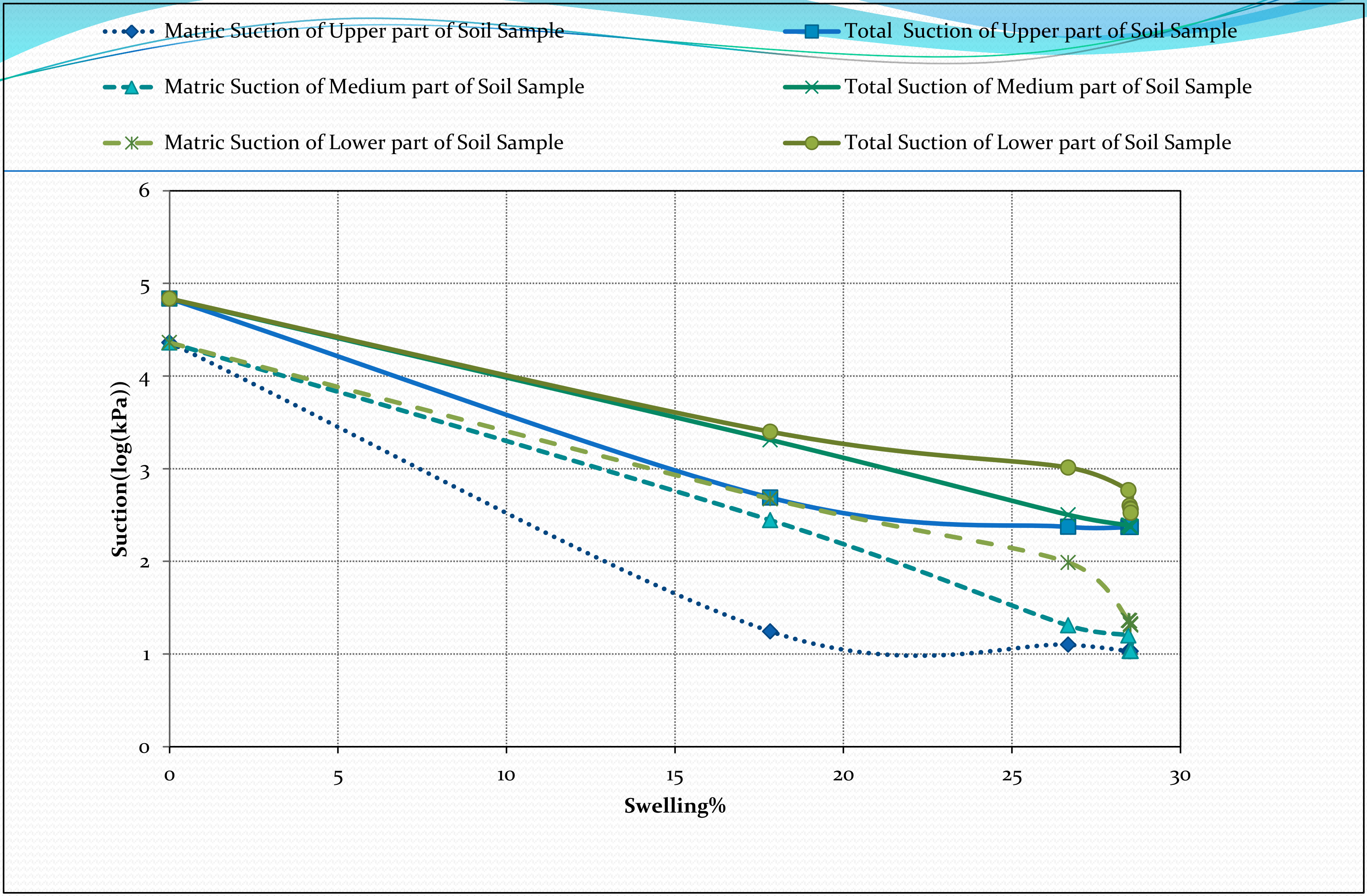
Swelling Stages of Soil Surface and Helical Pile

Before Beginning of Saturation

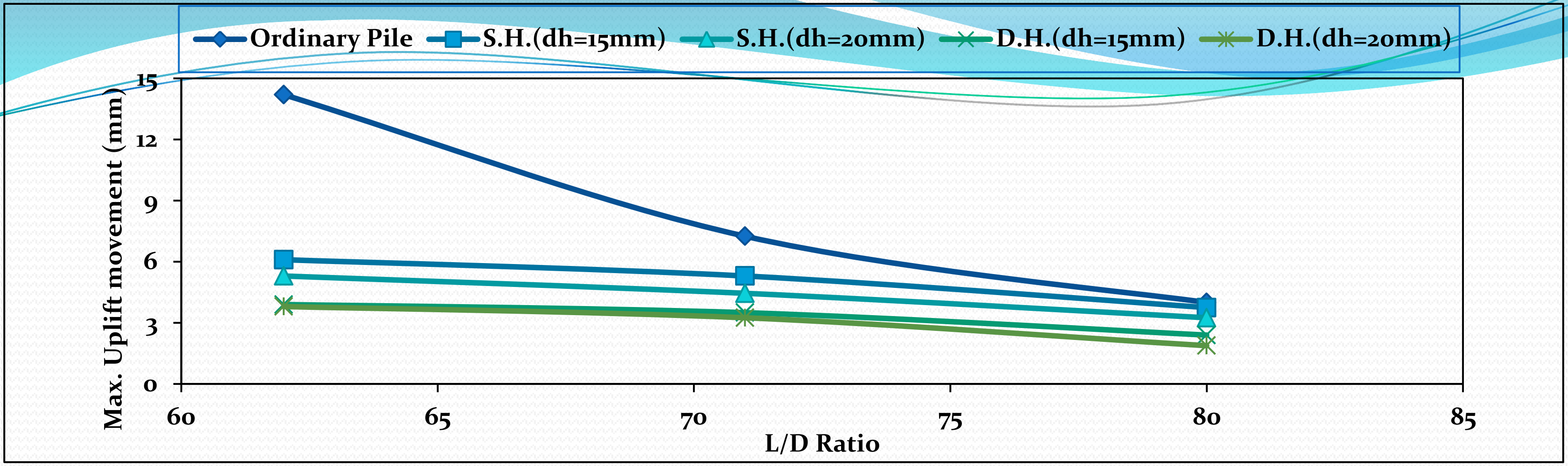
Time=45days, Ss=85.6mm, Sp=47mm



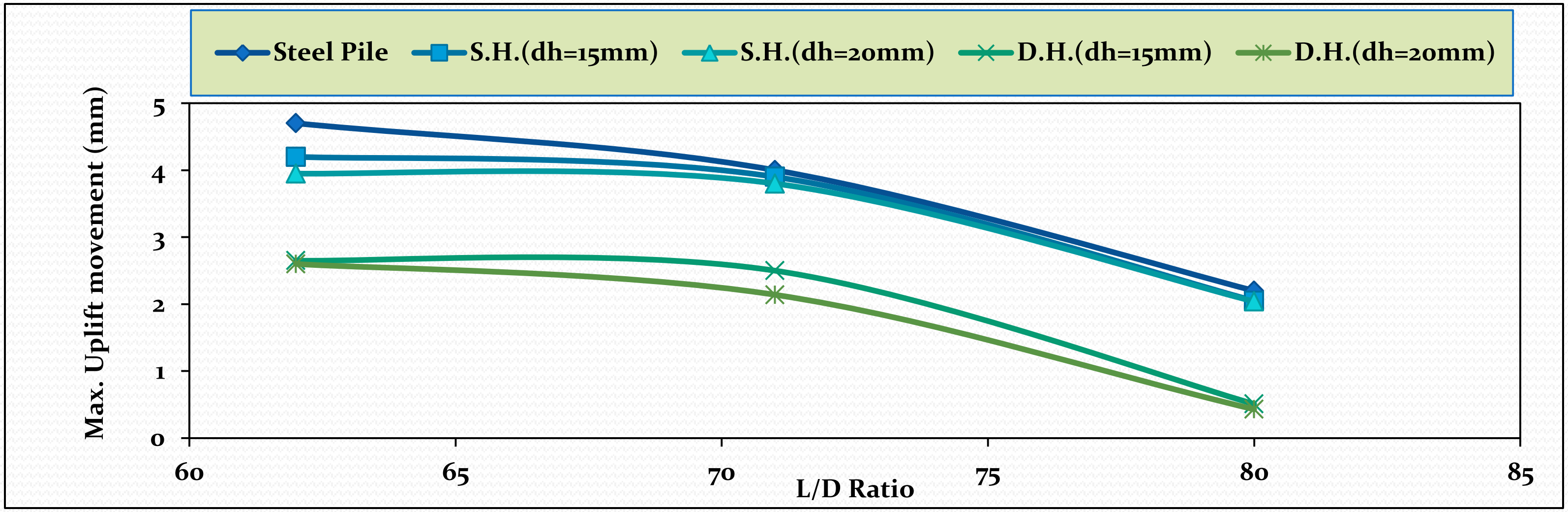
Relationship between Time of Saturation and Suction of Prepared Expansive Soil.



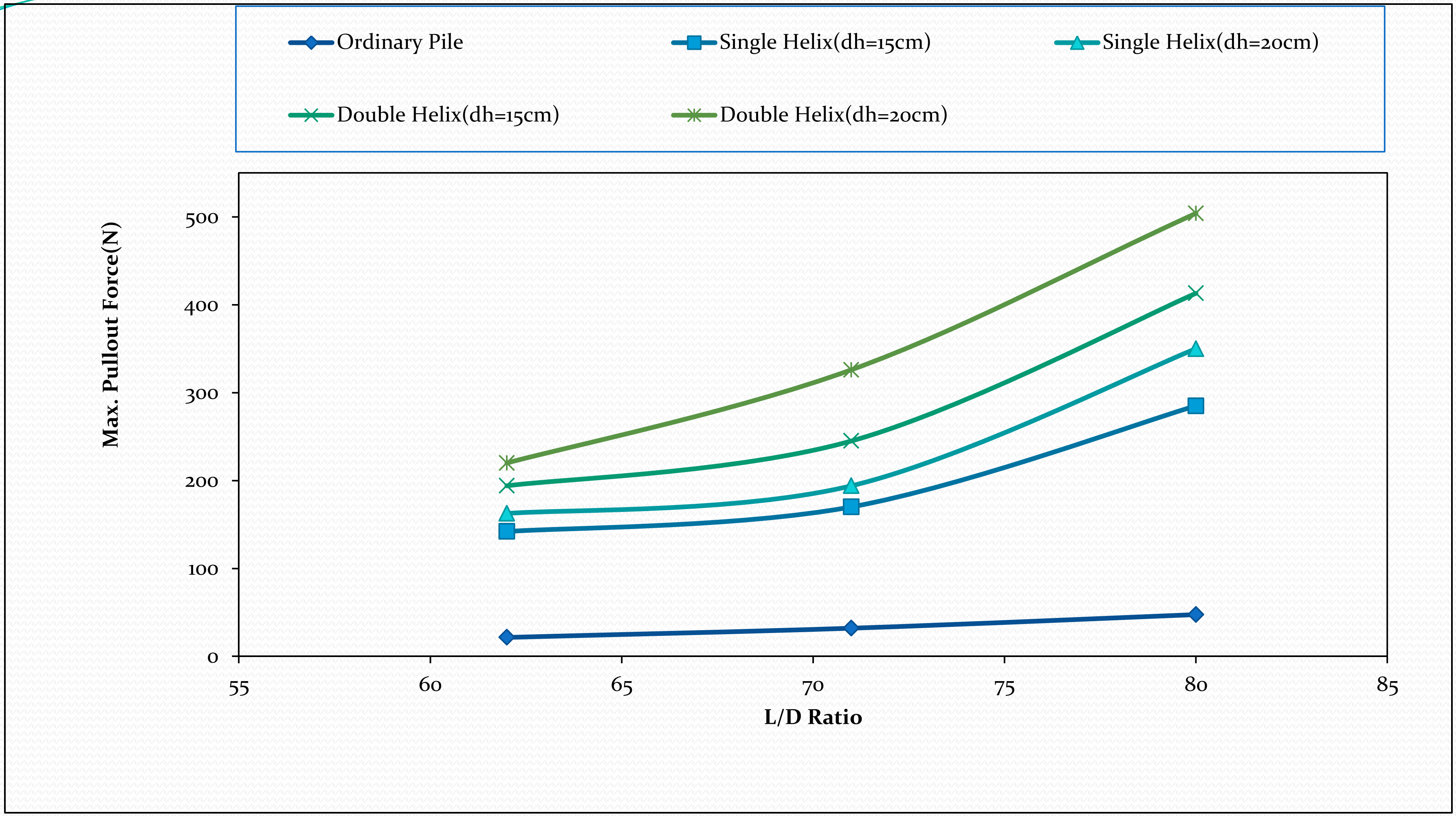
Relationship between Swelling and Suction of Prepared Expansive Soil.



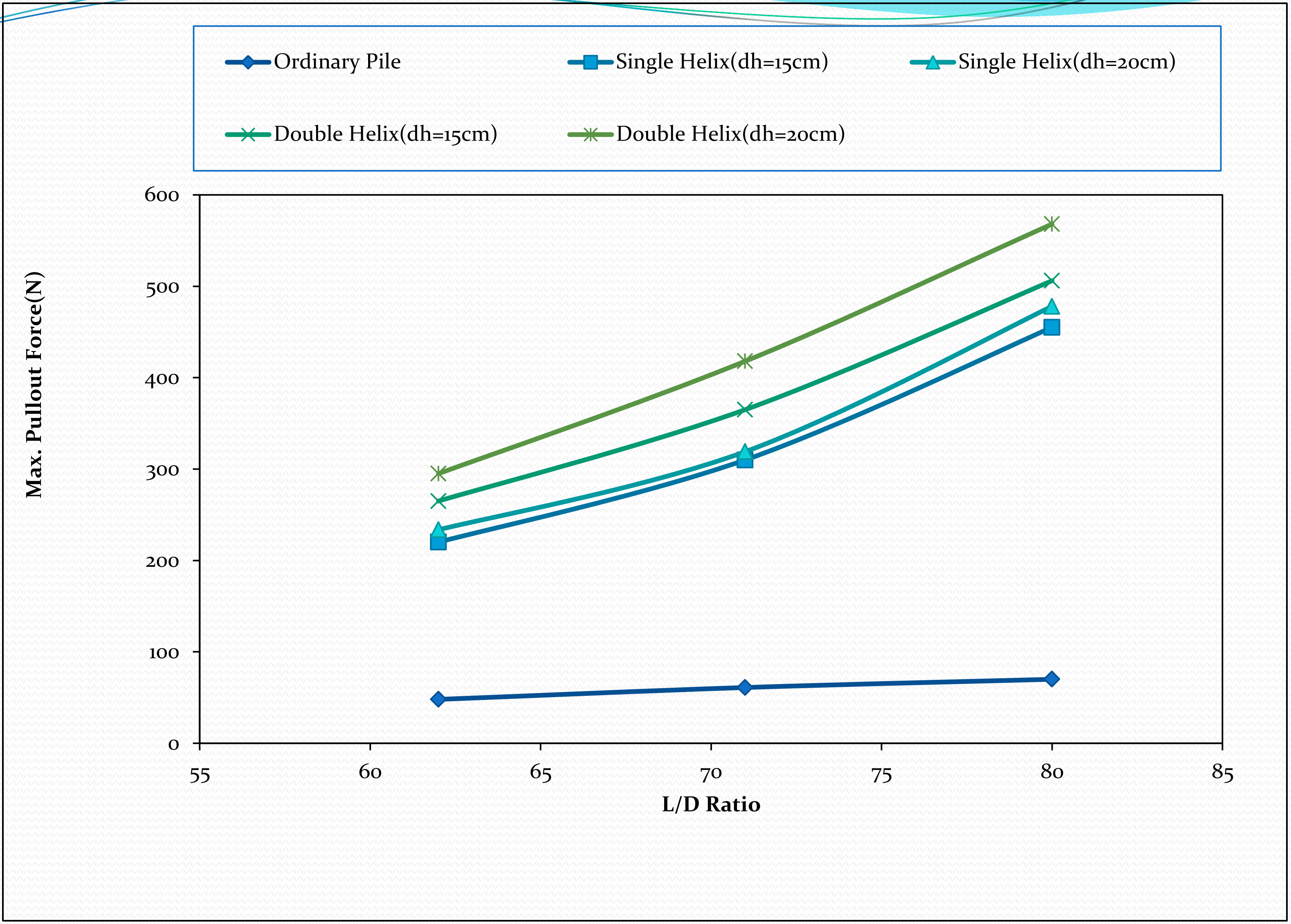
Variation of Maximum Uplift Movement of Helical Pile with L/D Ratio for Different Lengths and Helix Diameters (Dr=40%).



Variation of Maximum Uplift Movement of Helical Pile with/D Ratio for Different Lengths and Helix Diameters (Dr=80%).

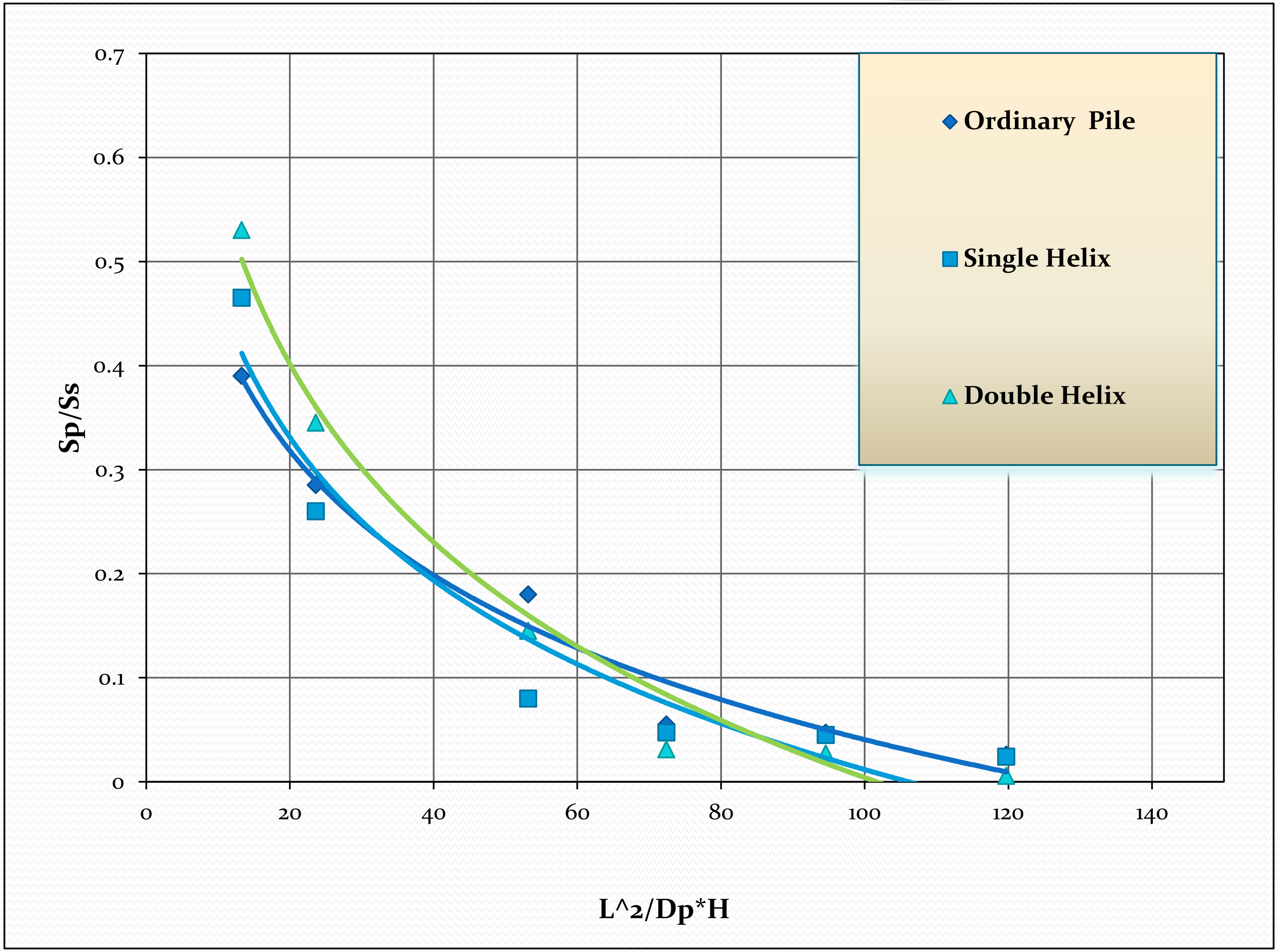


Variation of Maximum Uplift Movement of Helical Pile with L/D Ratio for Different Lengths and Helix Diameters (Dr=40%).

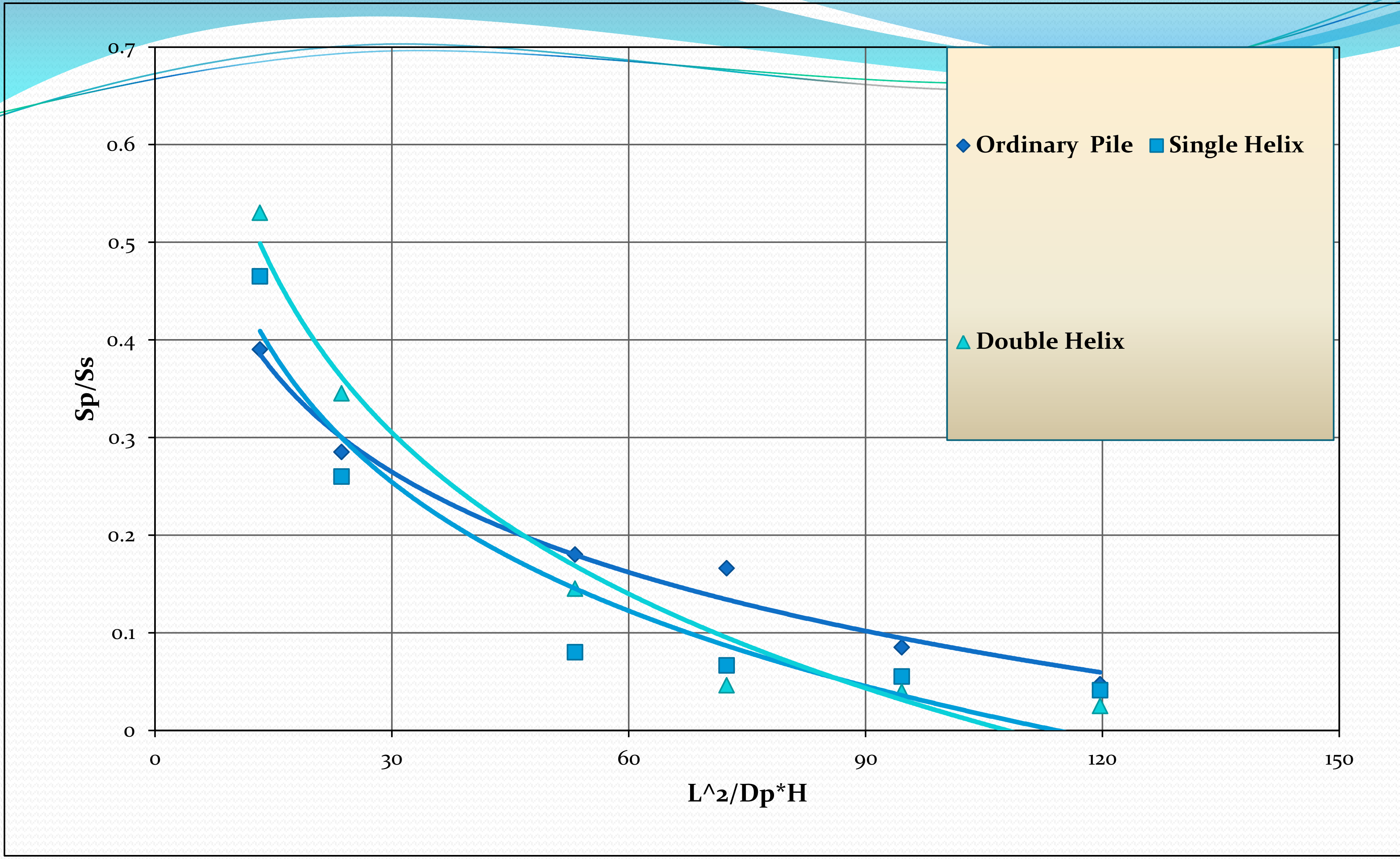


Variation of Maximum Uplift Movement of Helical Pile with/D Ratio for Different Lengths and Helix Diameters (Dr=80%).

Design Charts

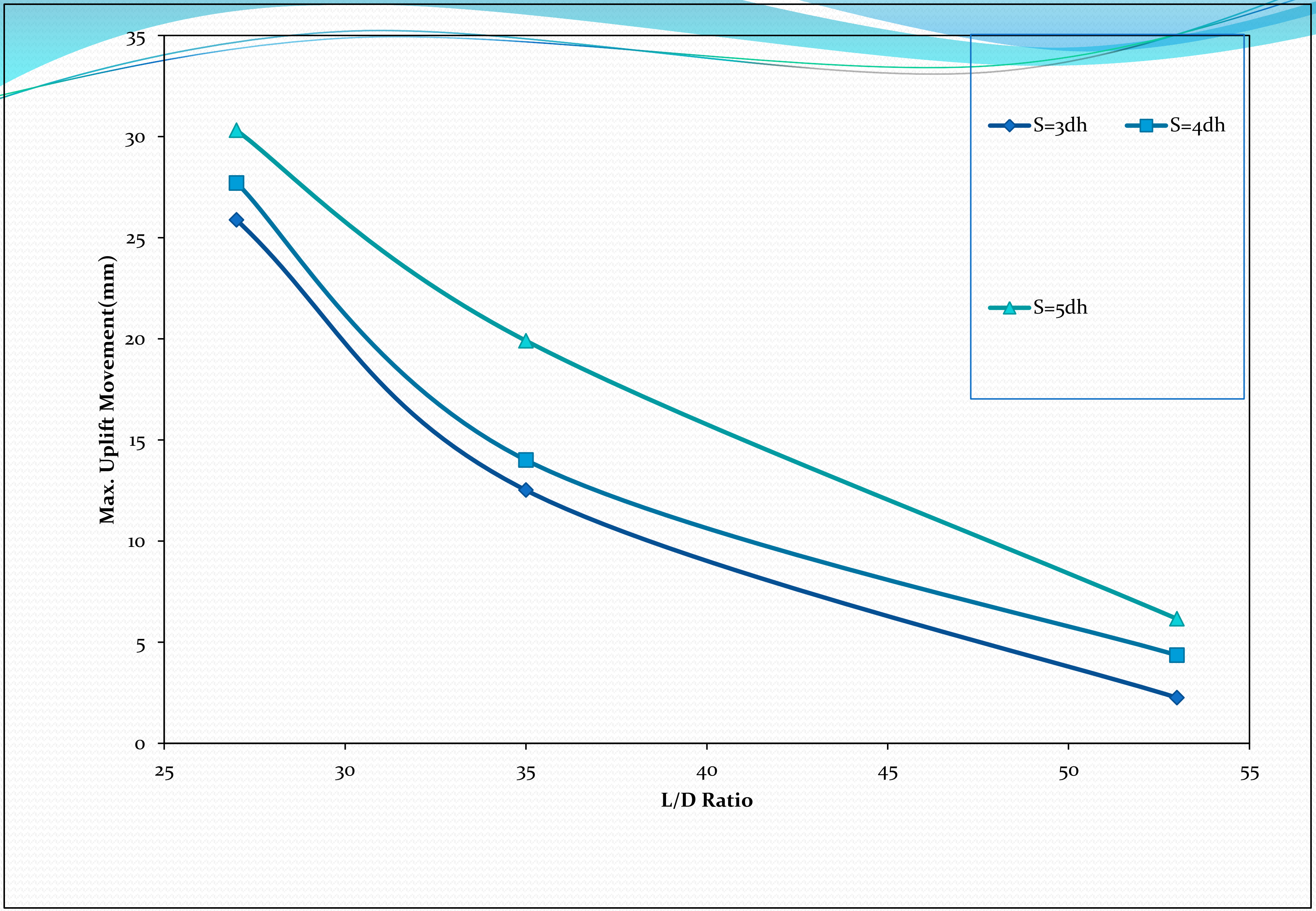


Proposed Relationship for Determining Ordinary and Helical Pile with Single and Double Helix Dimension in Expansive Soil Overlying Dense Sandy Soil.



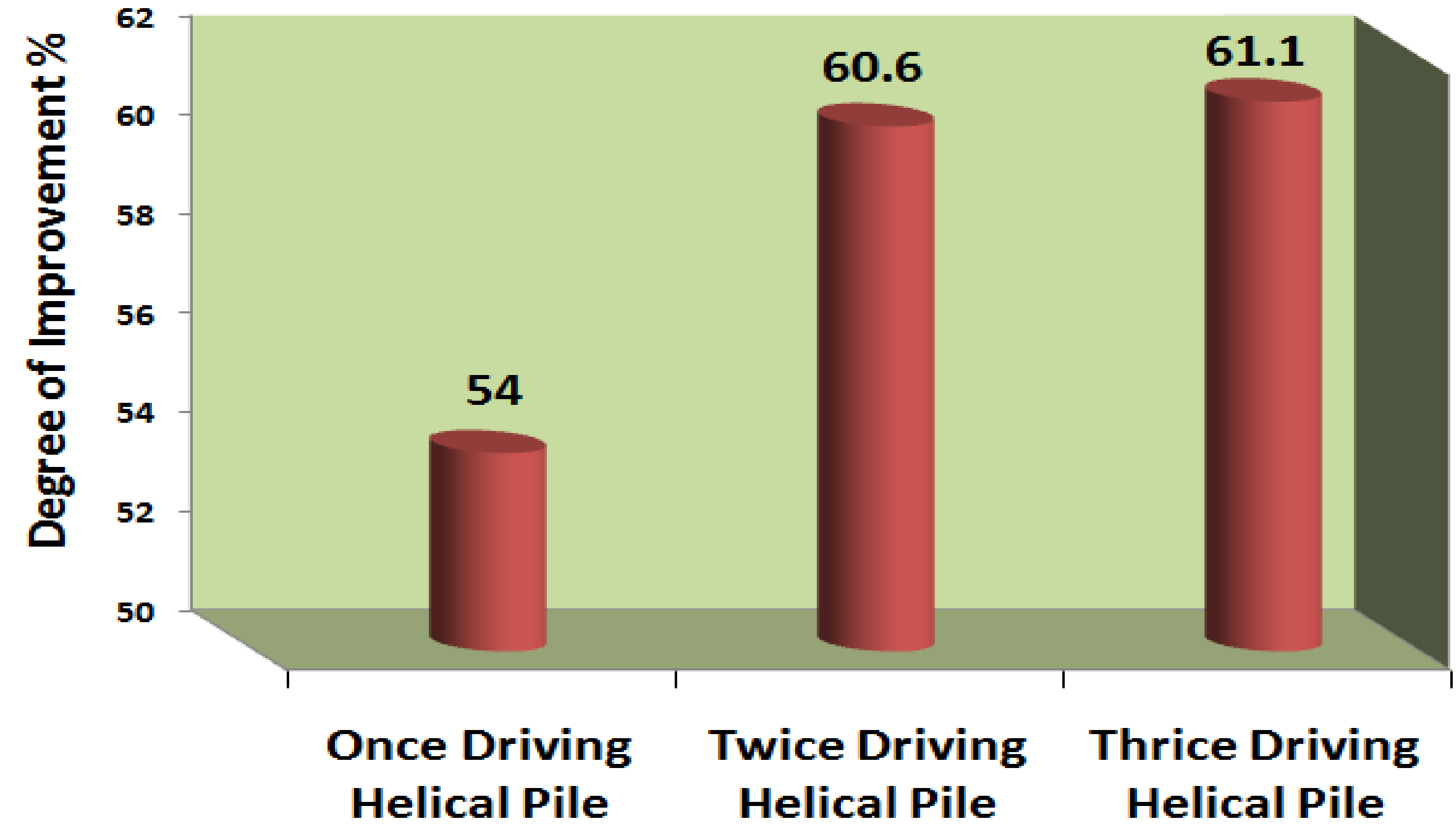
Proposed Relationship for Determining Ordinary and Helical Pile with Single and Double Helix Dimension in Expansive Soil Overlying loose Sandy Soil.

Type of Mode of Failure

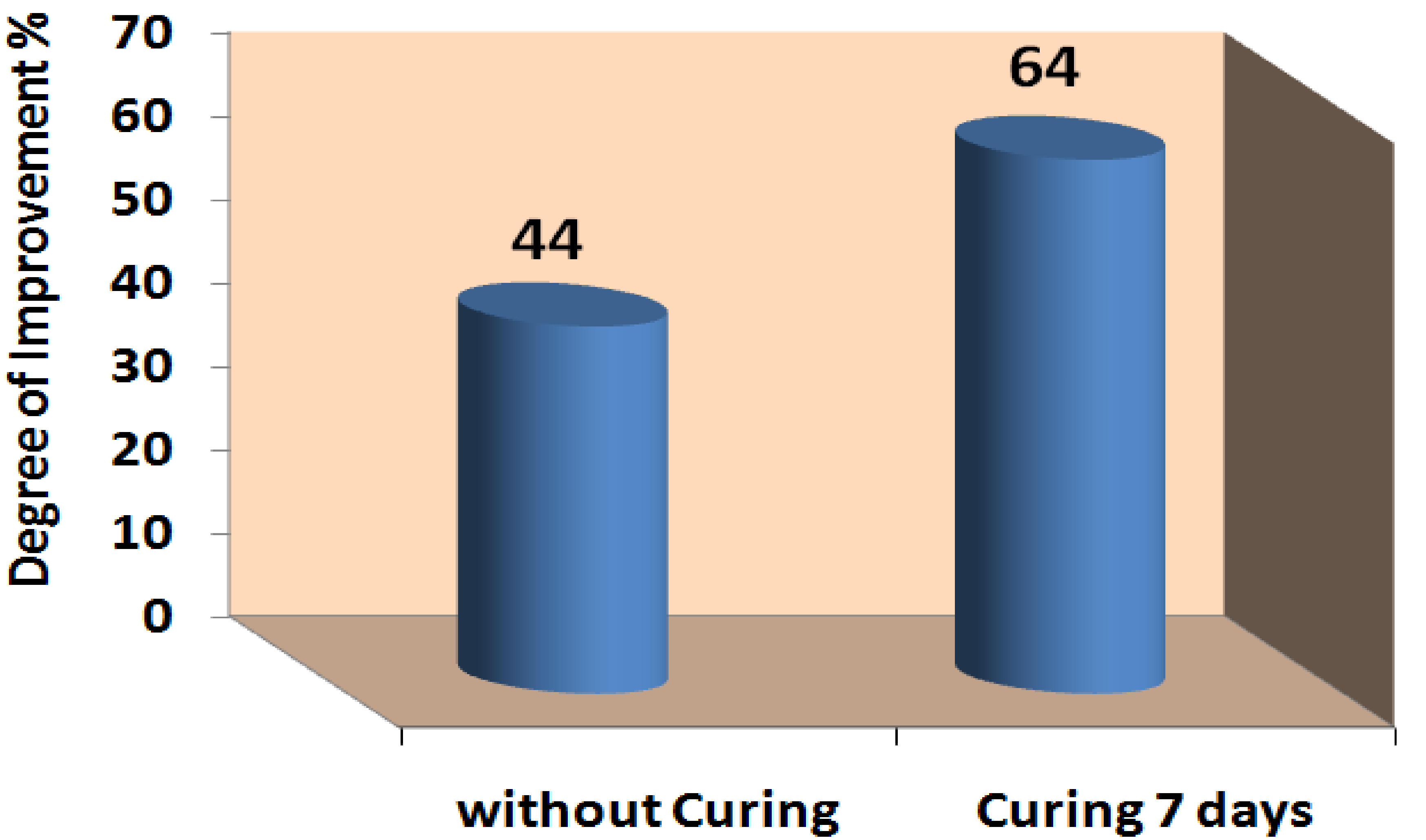


Relationship between L/D Ratio and Maximum Uplift Movement for Helical Piles Group with Single Helix (dh=15mm).

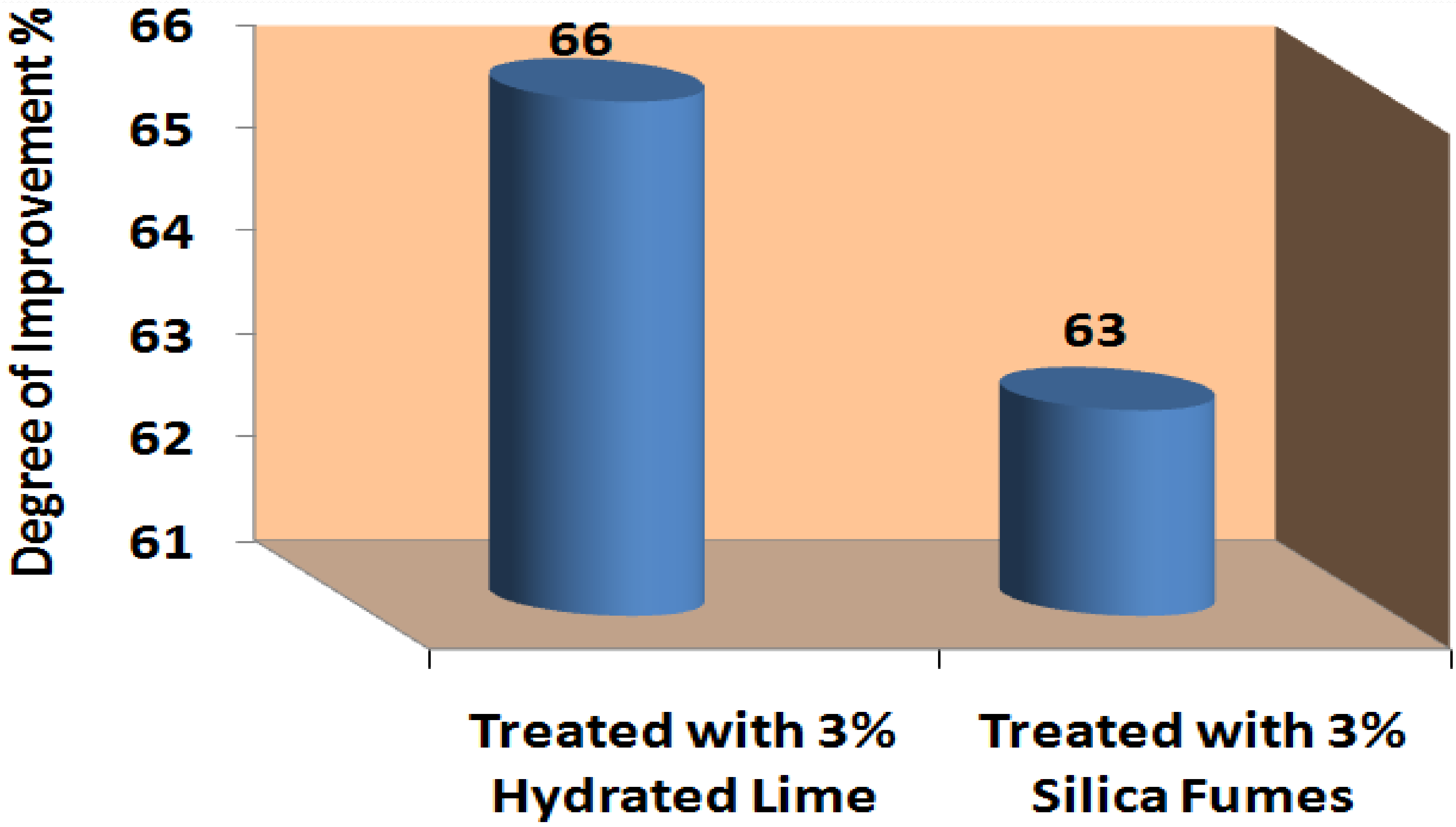
Effect of Number of Driving of Helical Piles on Uplift Movement when Adding 3% Silica Fumes.



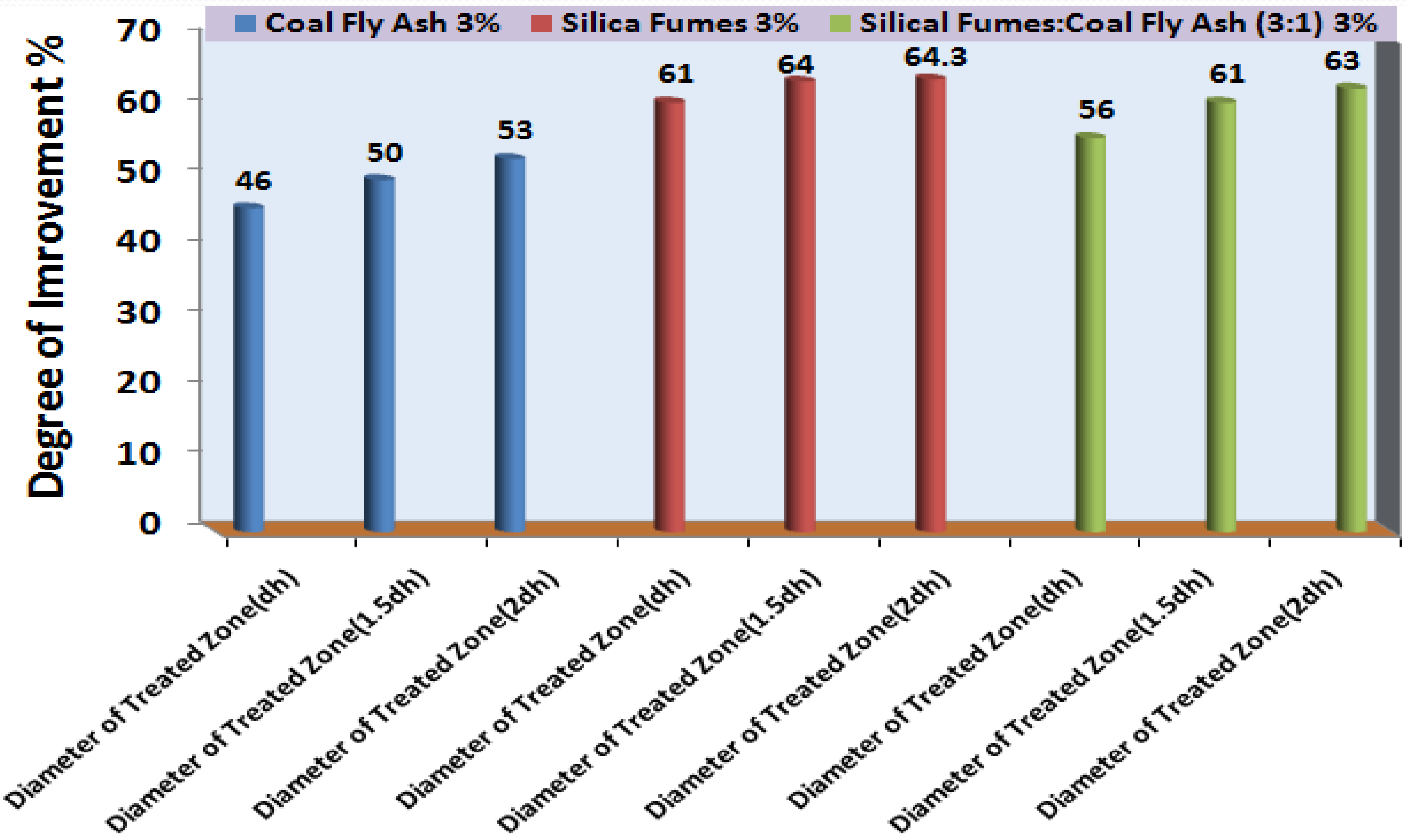
Effect of Period of Curing for 6% Hydrated Lime on Uplift Movement of Helical Pile.



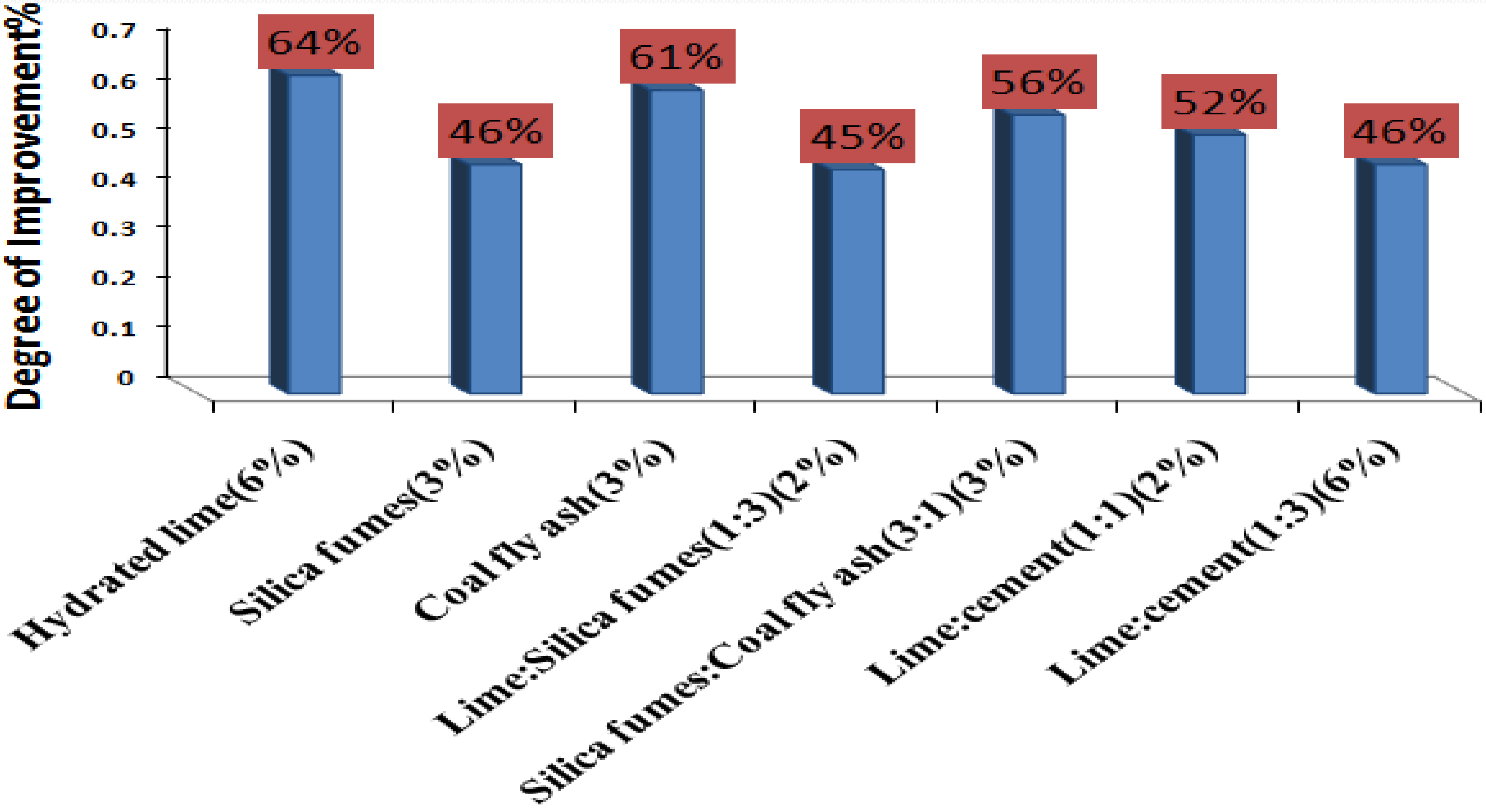
Effect of Adding Two Additives on Uplift Movement of Helical Piles Group [2x2].



Effect of Increased Diameter of Treated Zone around Helical Pile on Uplift Movement for Three Additives.



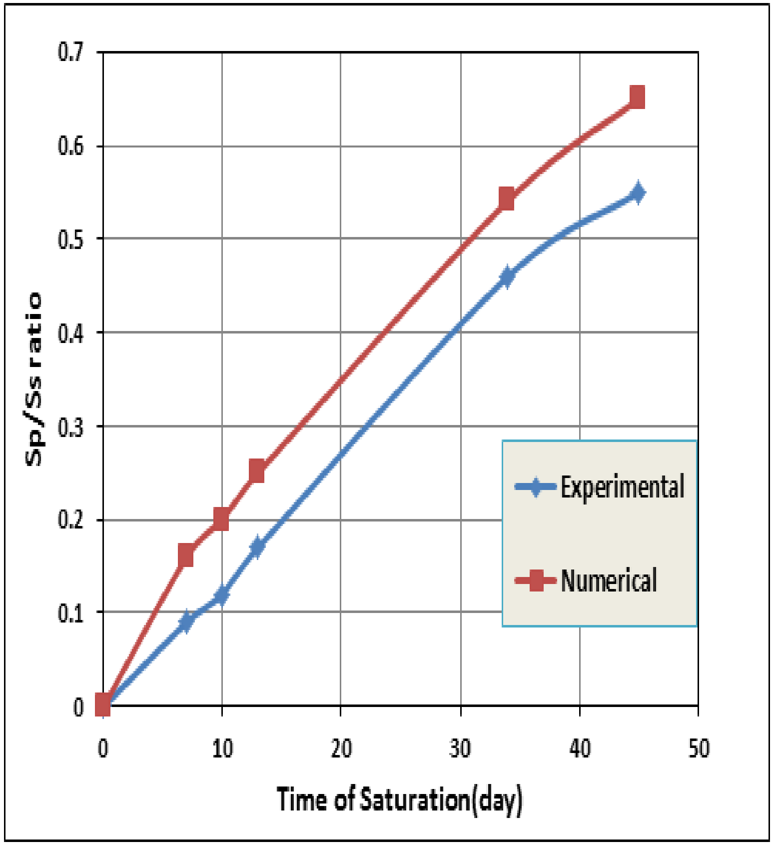
Additives and Mixed Additives That Gave Good Degree of Improvement in Reducing Uplift Movement of Helical Piles in Expansive Soil.



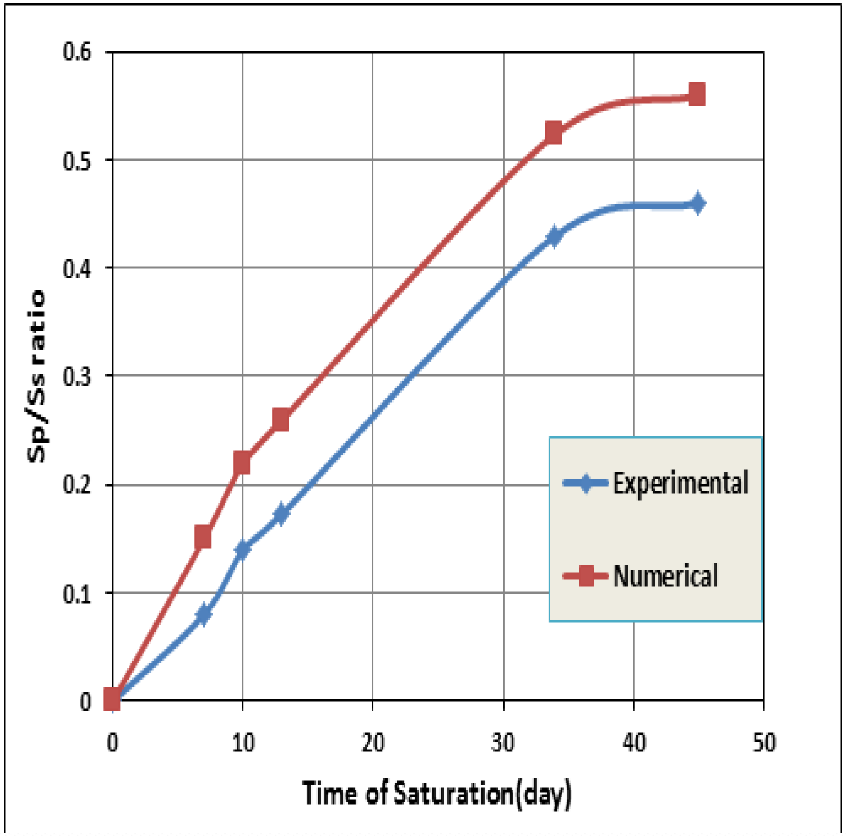
Finite Element Results

Verification of Experimental Results with Numerical.

Single Helical Pile

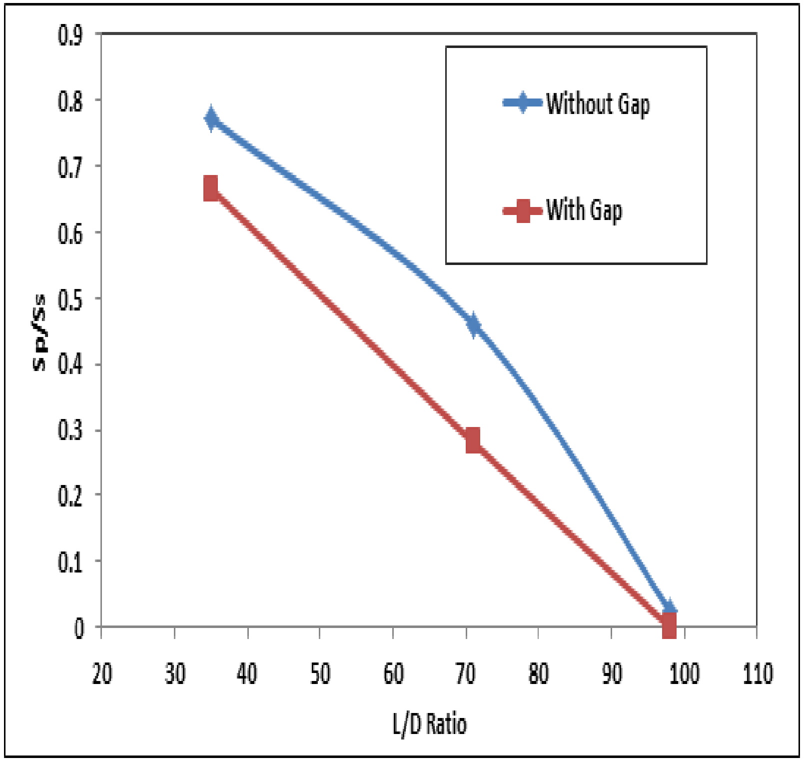


Group of Helical Piles [2x2]

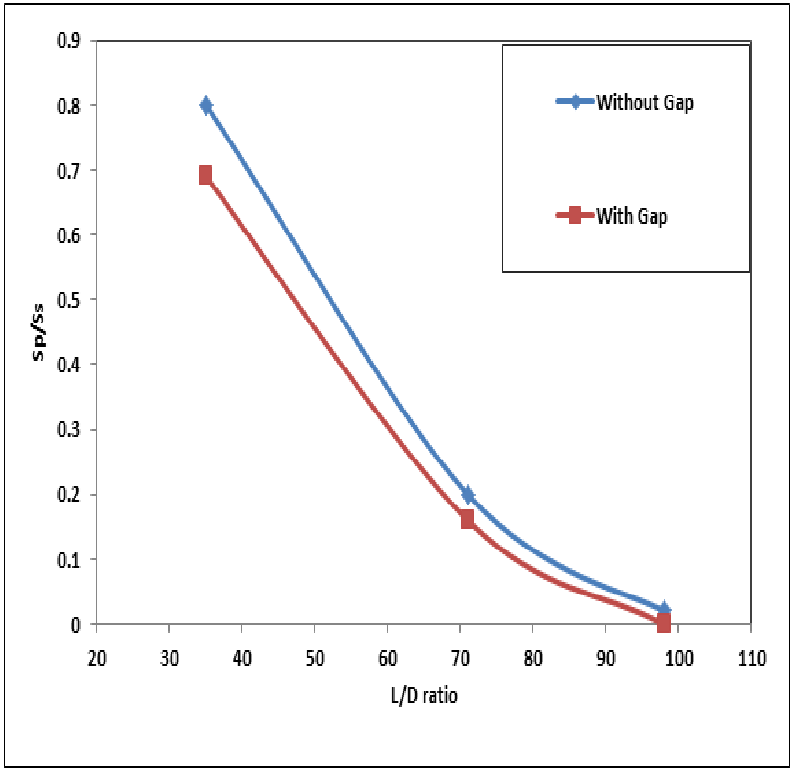


Variation of L/D Ratio with Sp/Ss Ratio for Single and [2x2] Group of Helical Piles Touched and Untouched with Surface of Expansive Layer.

Single

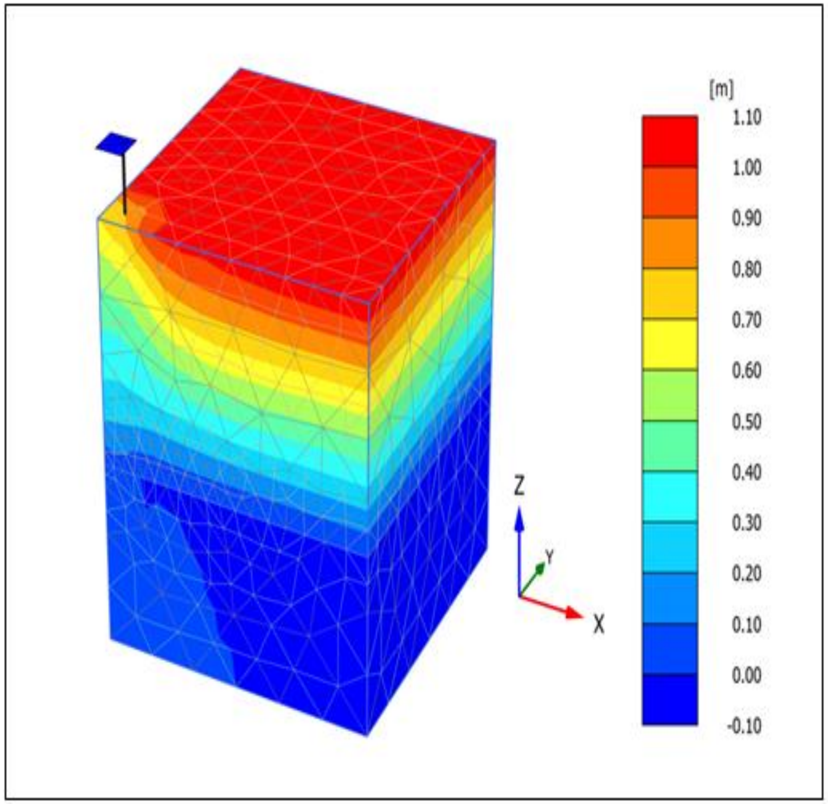


Group [2x2]

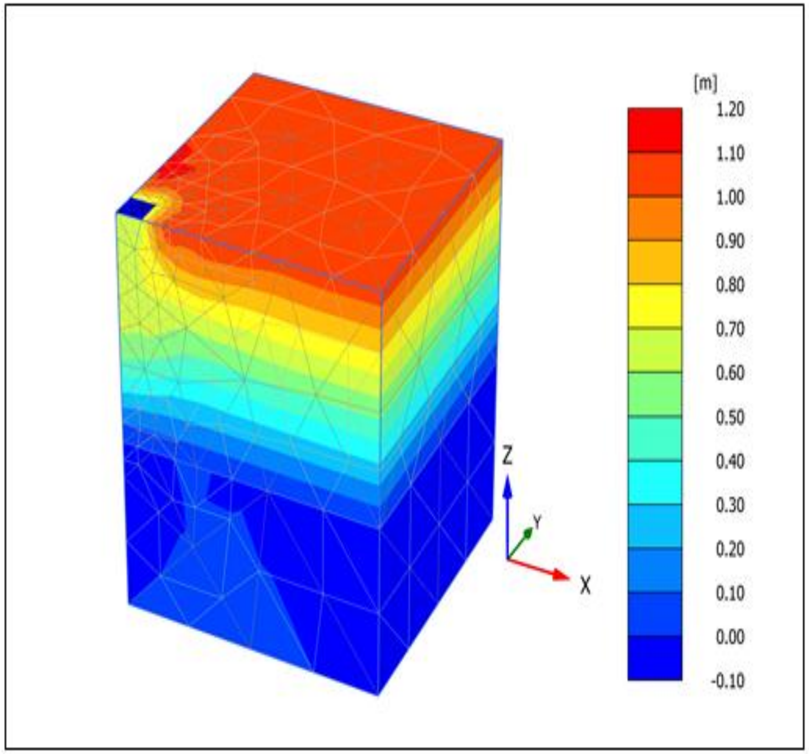


Shading Diagram of Vertical Displacement Distribution Resulting from Swelling of Expansive Layer for Group of Helical Piles.

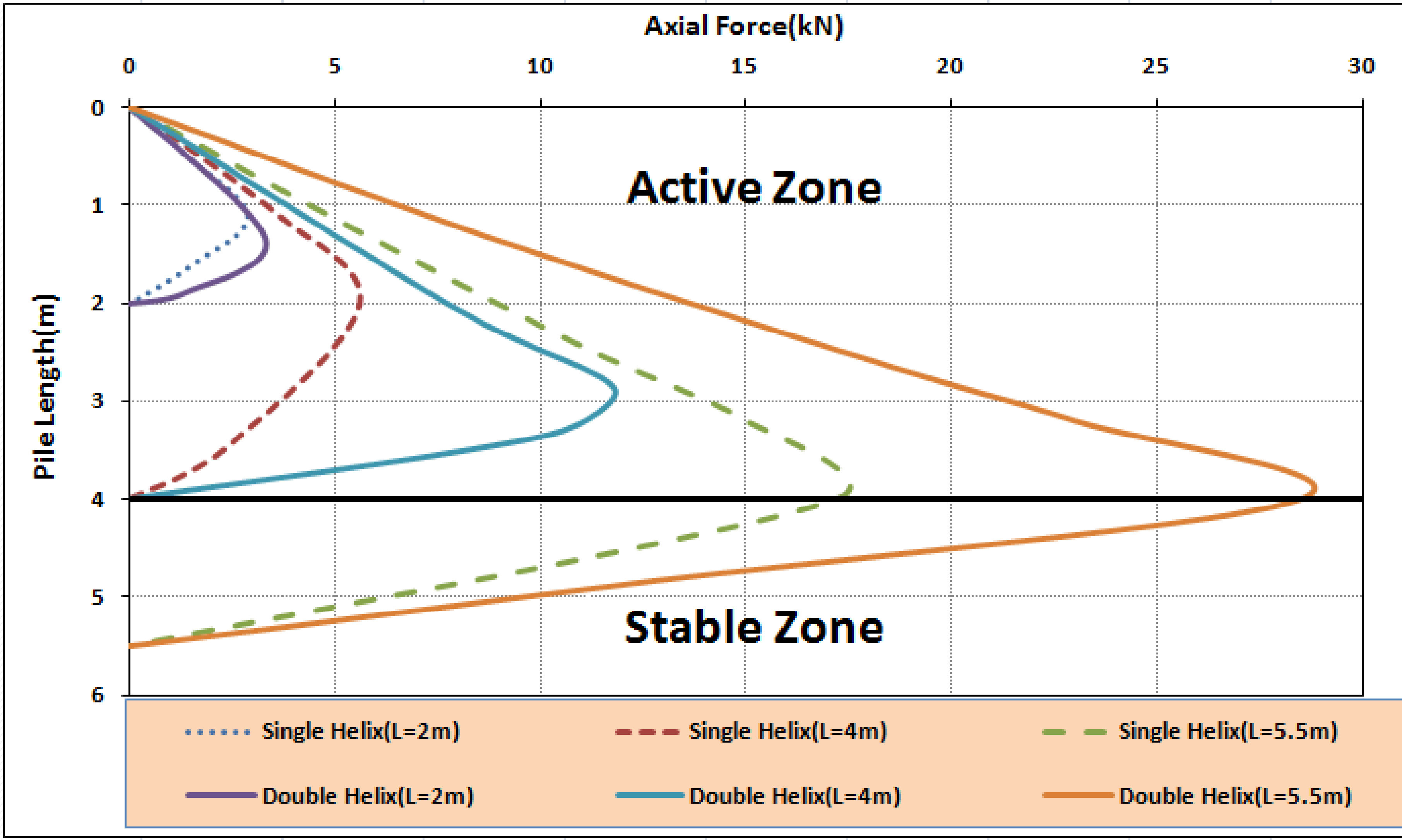
With Gap (Untouched)

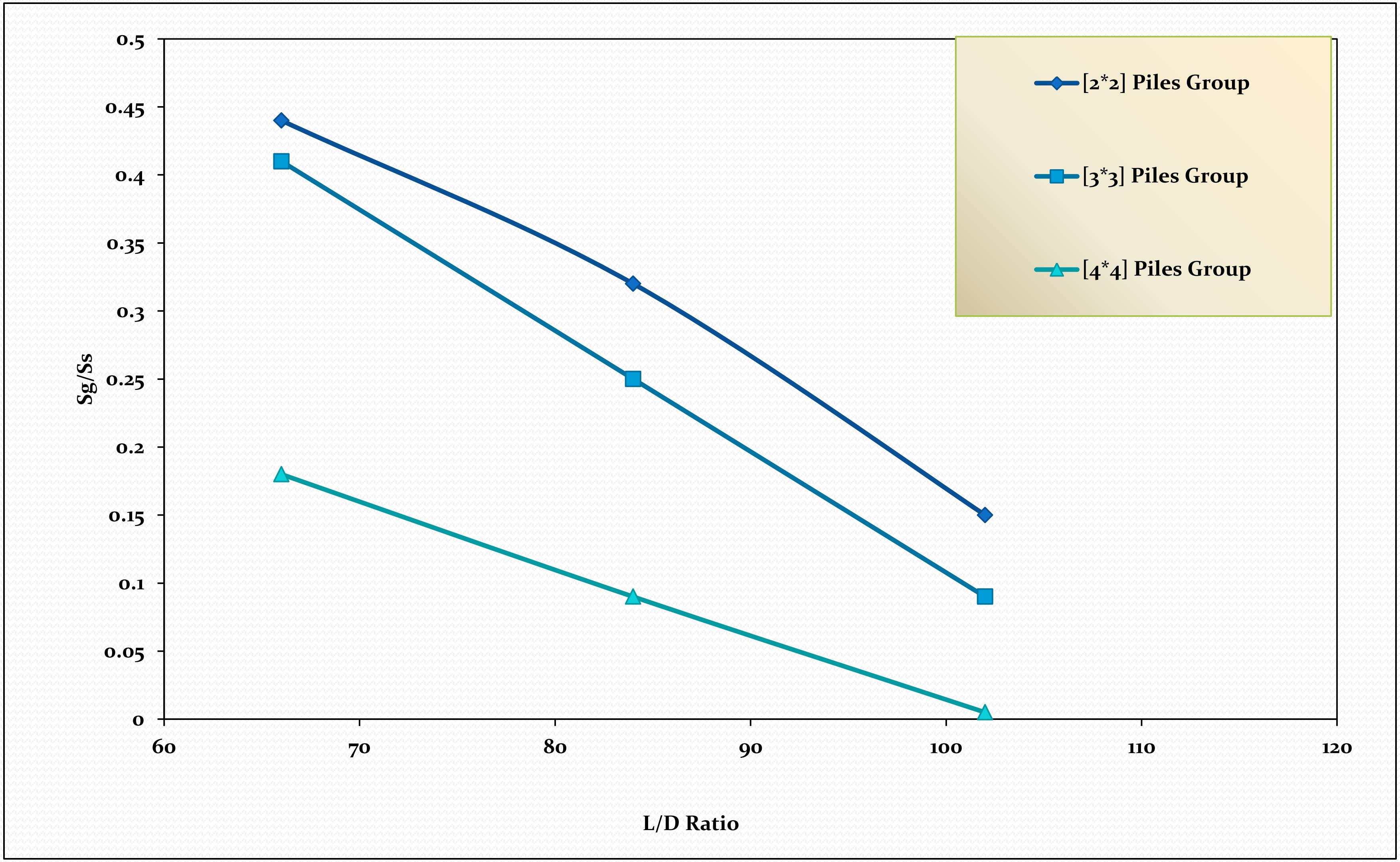


Without Gap (Touched)



Variation of the Axial Forces along the Single Helical Pile Shaft.

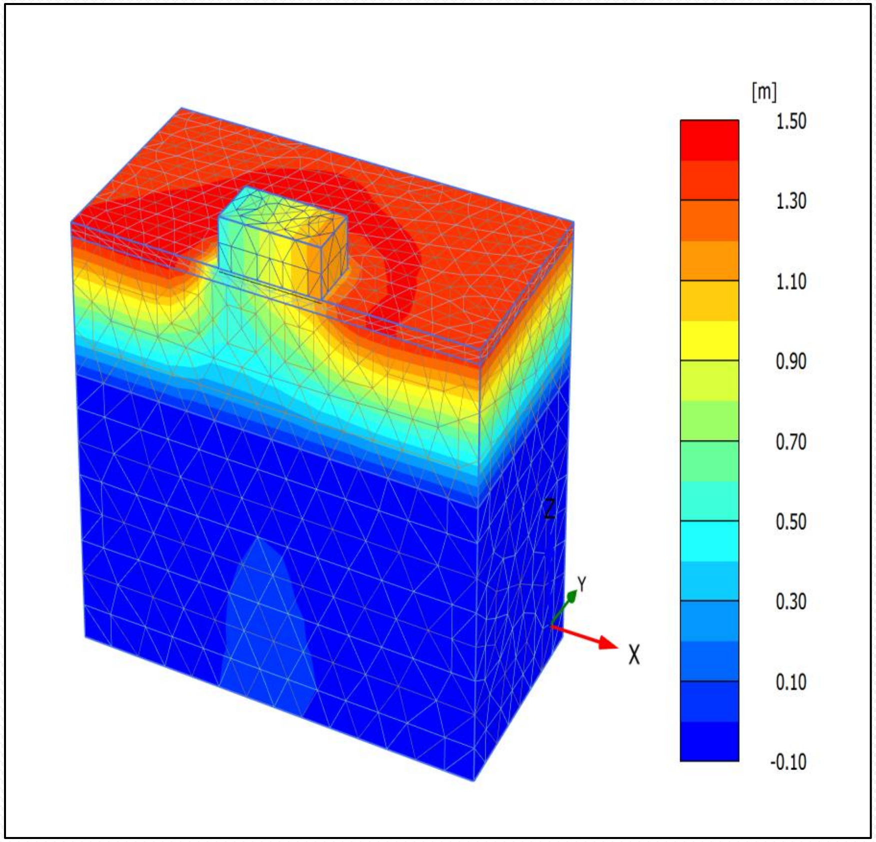




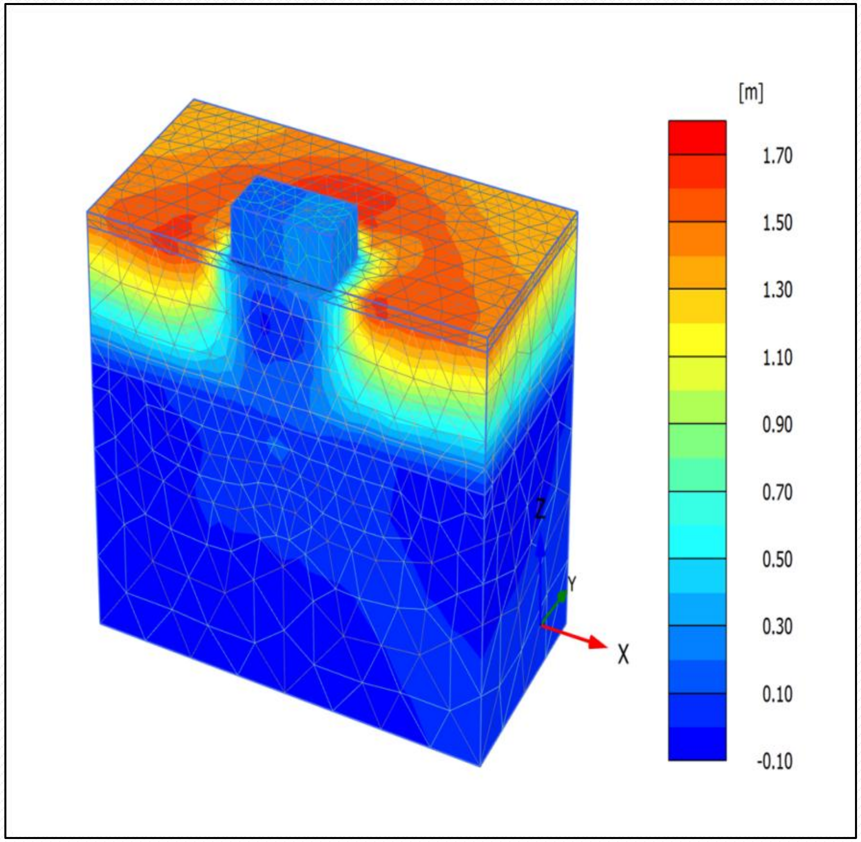
Relationship between the Maximum Uplift Movements (Sp/Ss) and (L/D) Ratio for Different Helical Piles Group Under Tower Foundation.

Vertical Displacement Distribution under Foundation of Tower for without and with Using Group of Helical Piles.

Unpiled Case

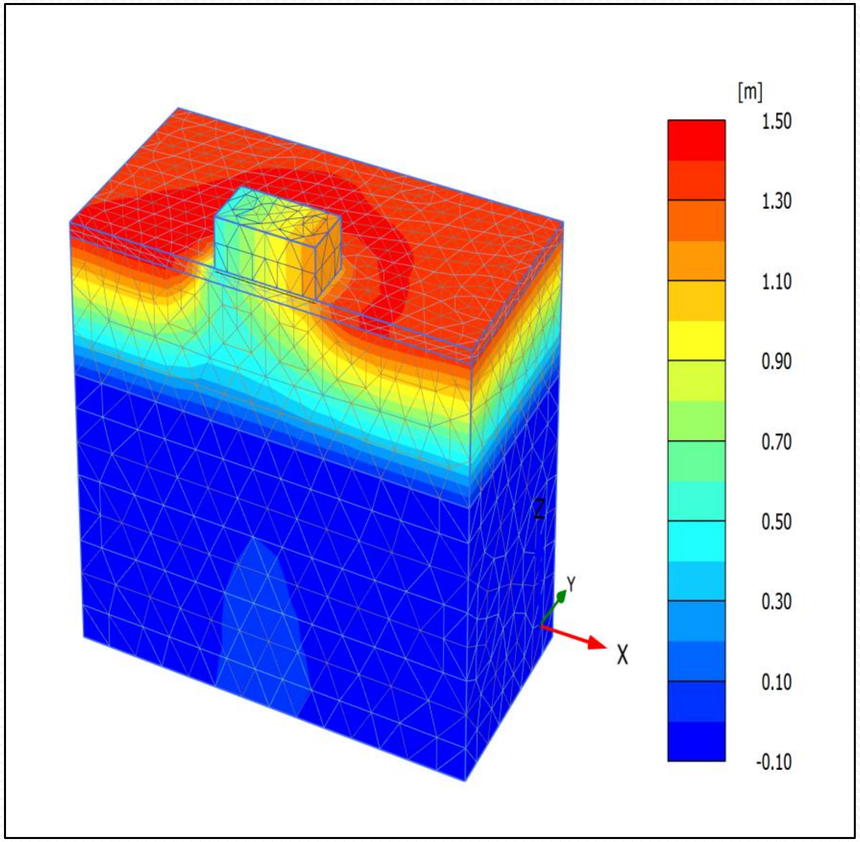


[4x4] Group with L/D Ratio=66

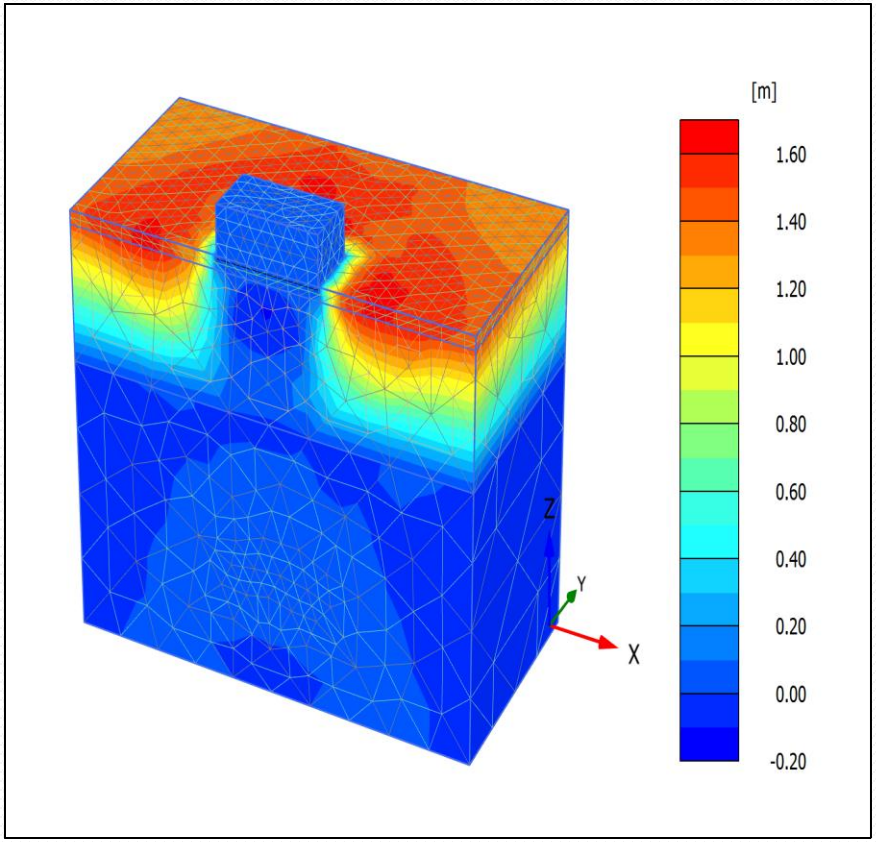


Vertical Displacement Distribution under Foundation of Tower for without and with Using Group of Helical Piles.

Unpiled Case

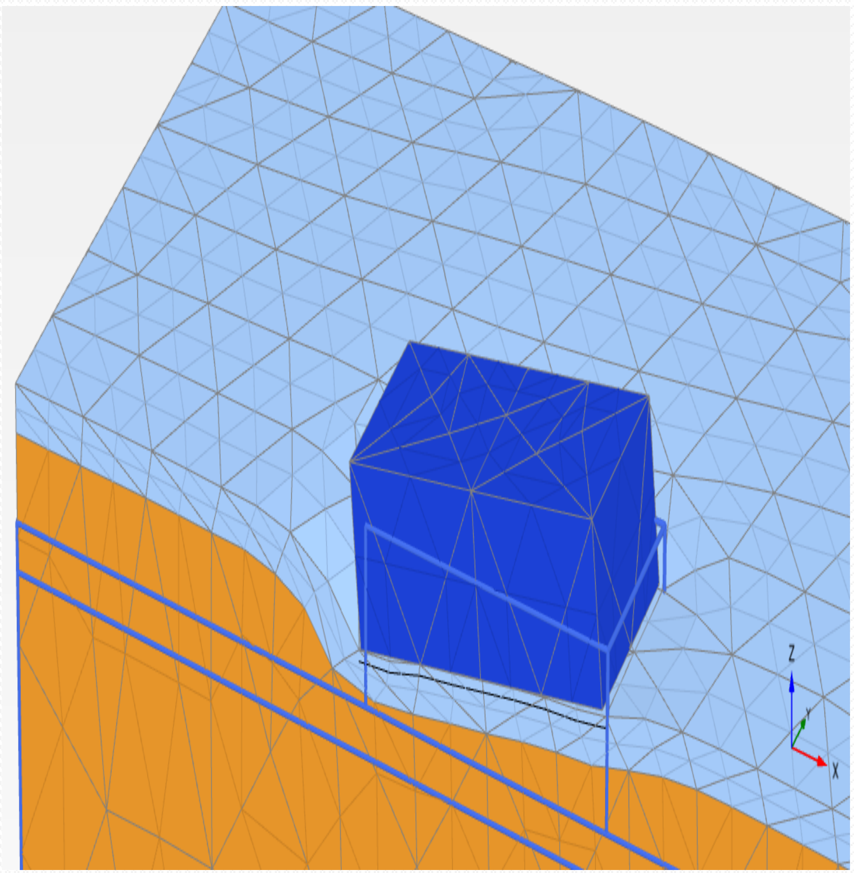


[4x4] Group with L/D Ratio=102

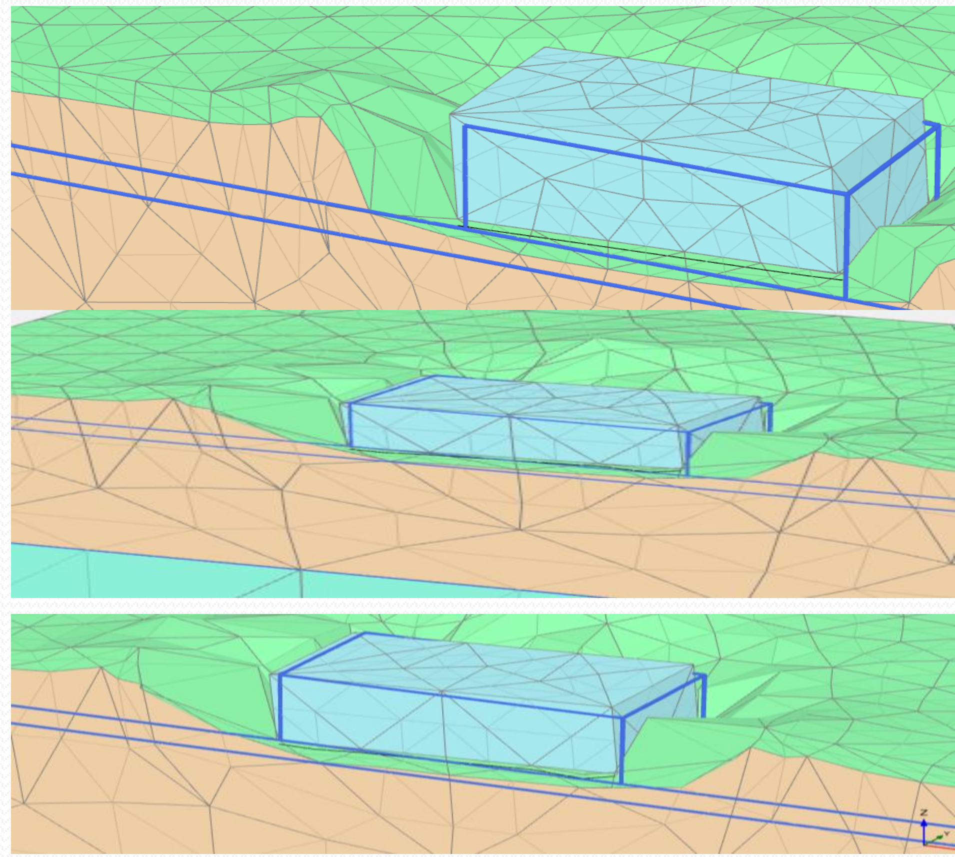


Deformed Shape of Tower Foundation with and without Using Group of Helical Piles [2x2]

Without Using Helical Piles

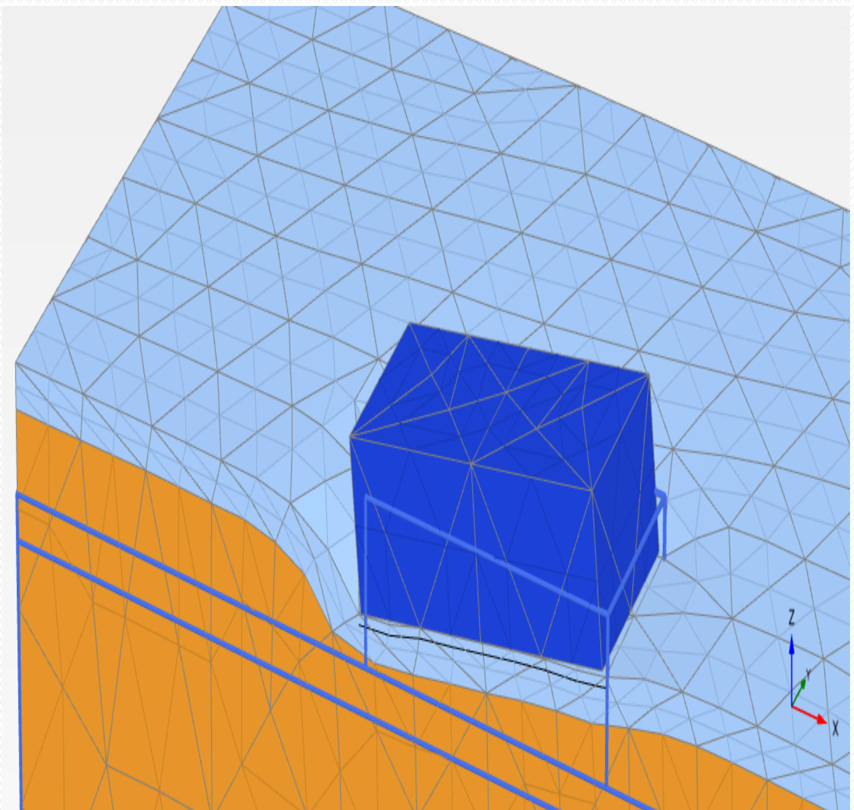


Using Group [2x2] Helical Piles, L/D=66, 84, 102

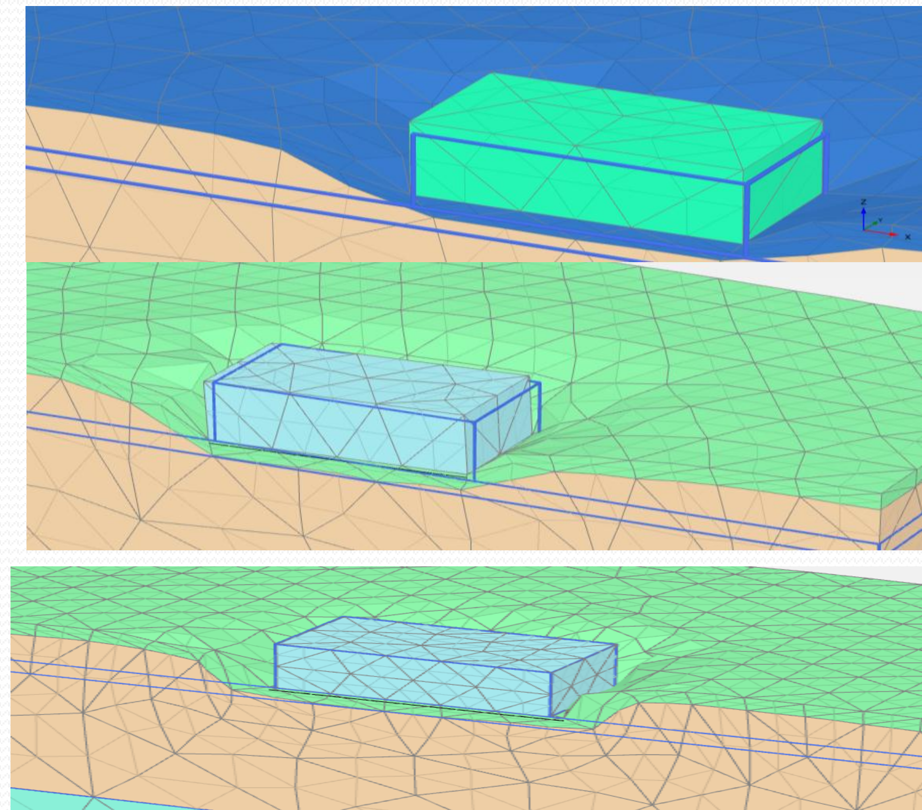


Deformed Shape of Tower Foundation with and without Using Group of Helical Piles [4x4]

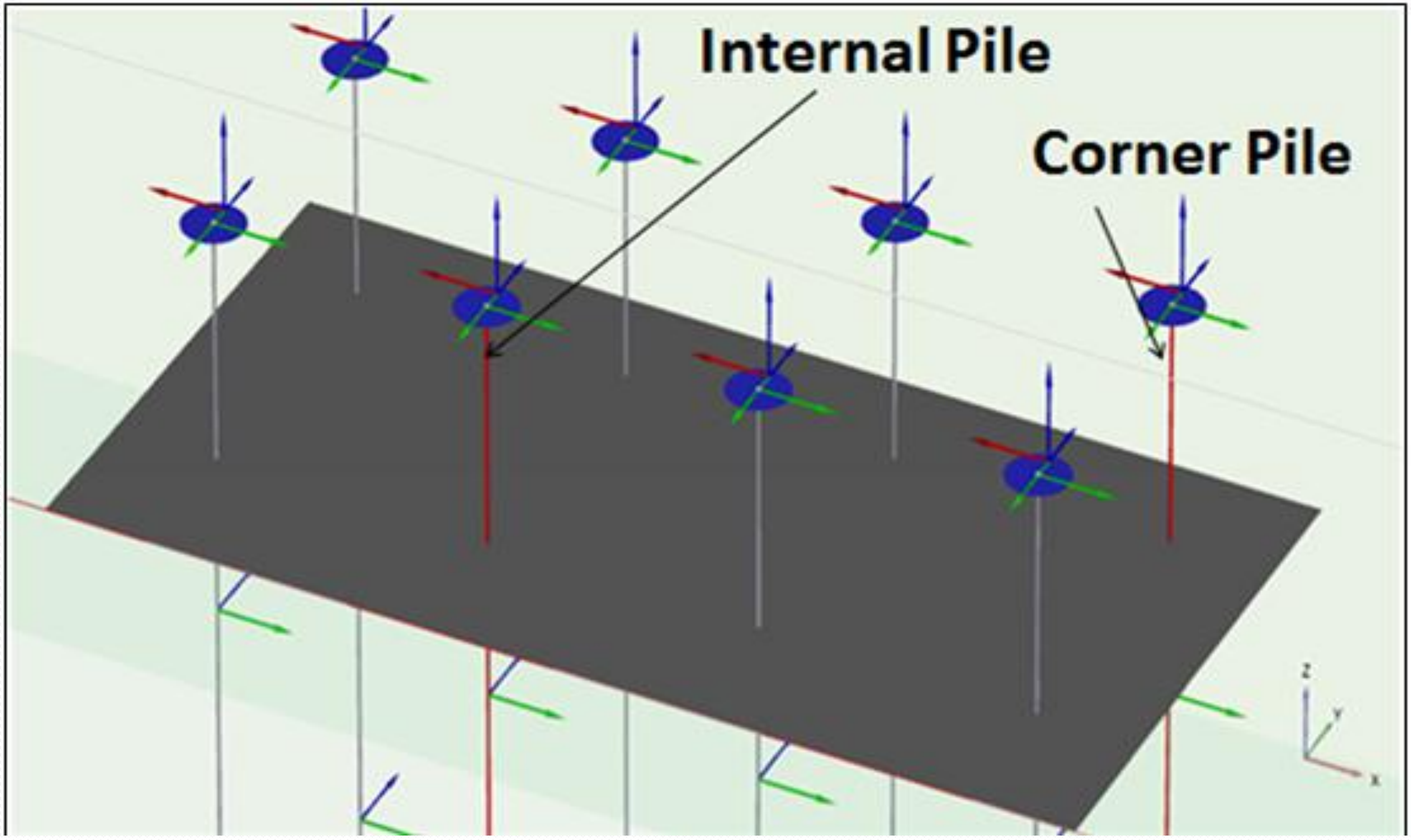
Without Using Helical Piles



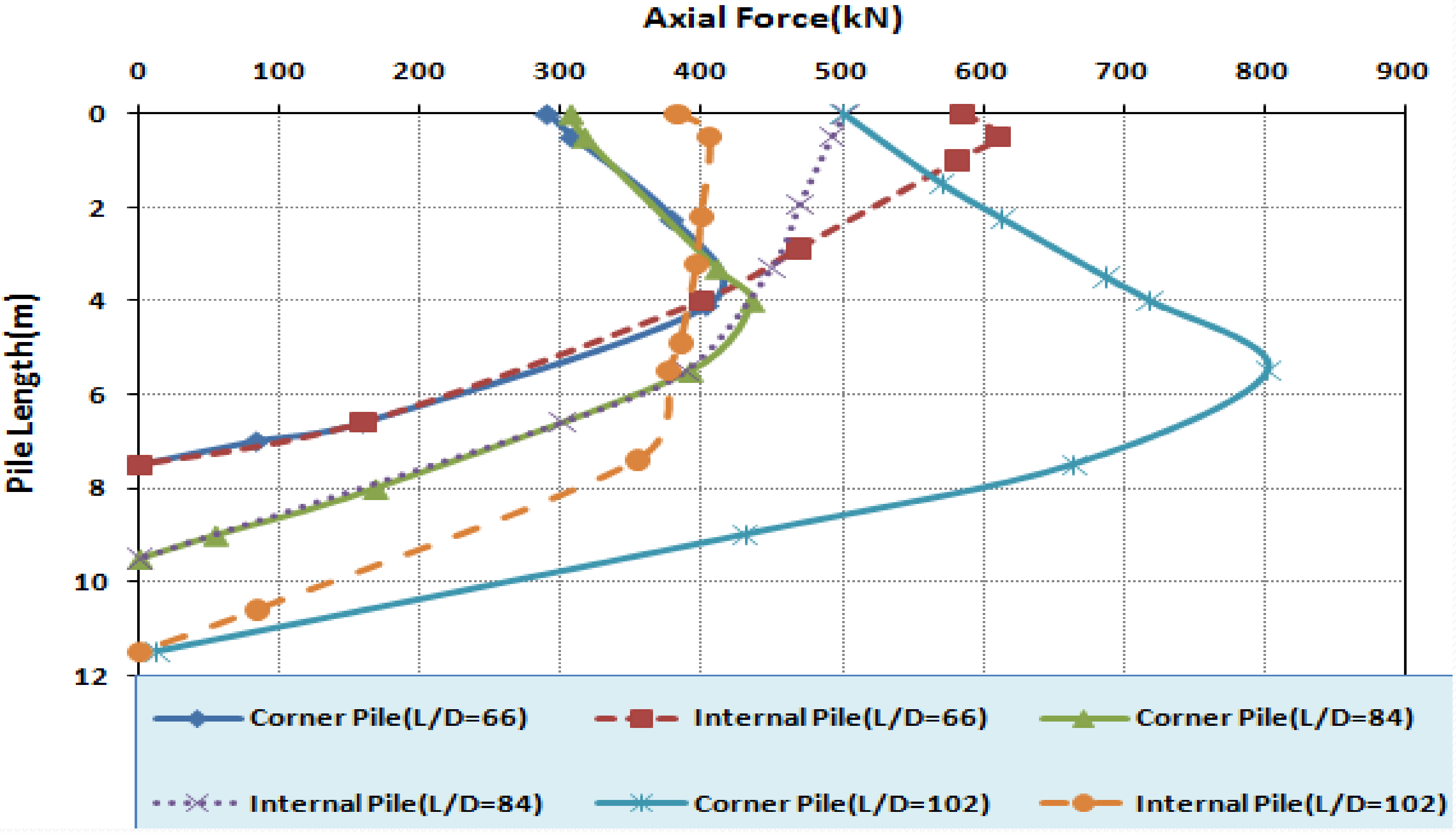
Using Group [4x4] Helical Piles, L/D=66, 84, 102

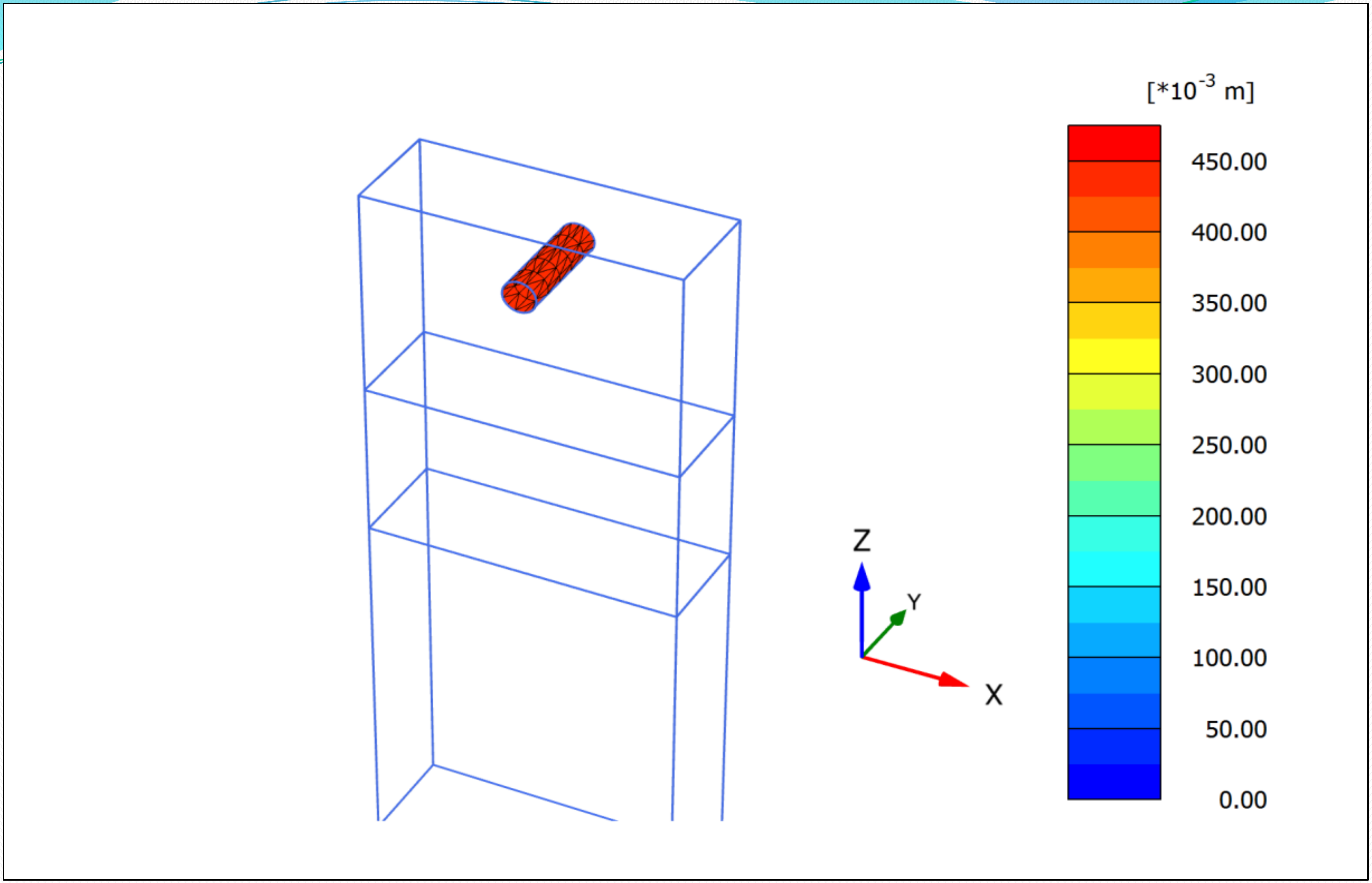


Location of Corner and Internal Helical Piles in a Group of [4x4].

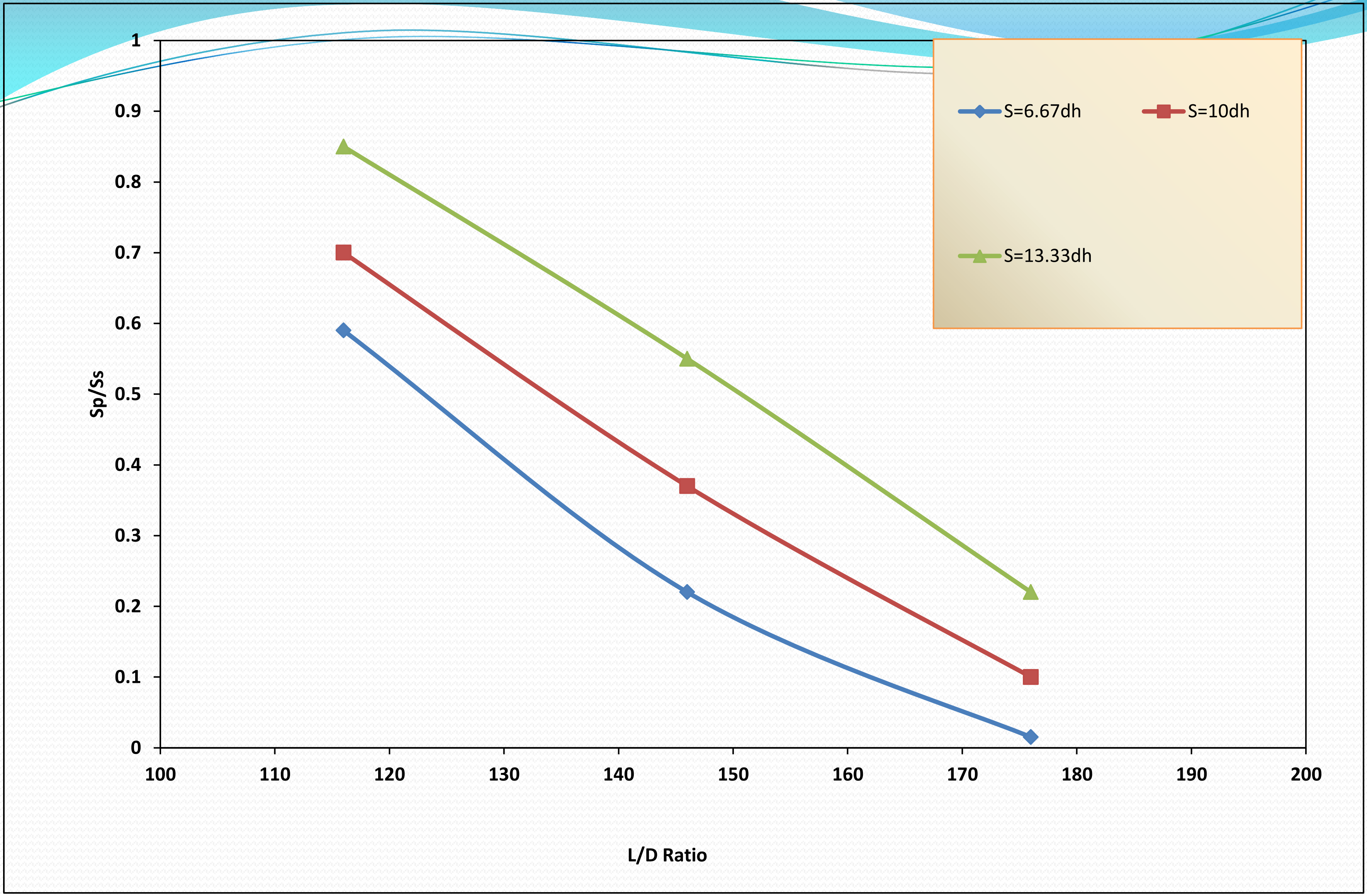


Variation of the Axial Forces along the Helical Pile Shaft for Corner and Internal Helical Piles under Foundation of Tower.





Shading Diagram of the Total Displacement Distribution of Pipeline Resulting from the Heave of Expansive Soil in (m) for the Unpiled Case.

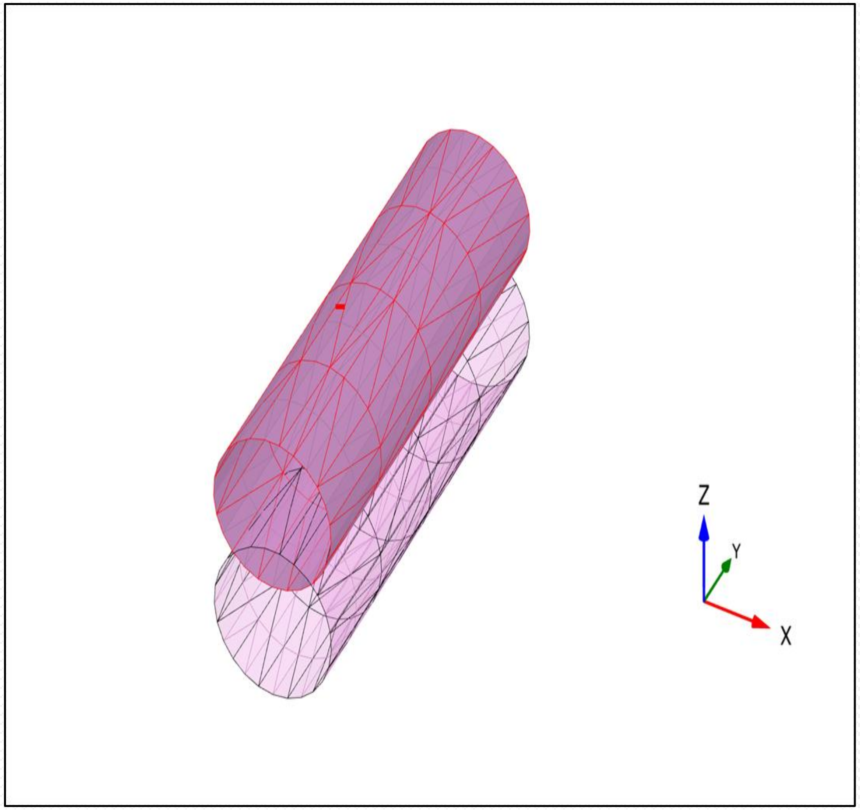


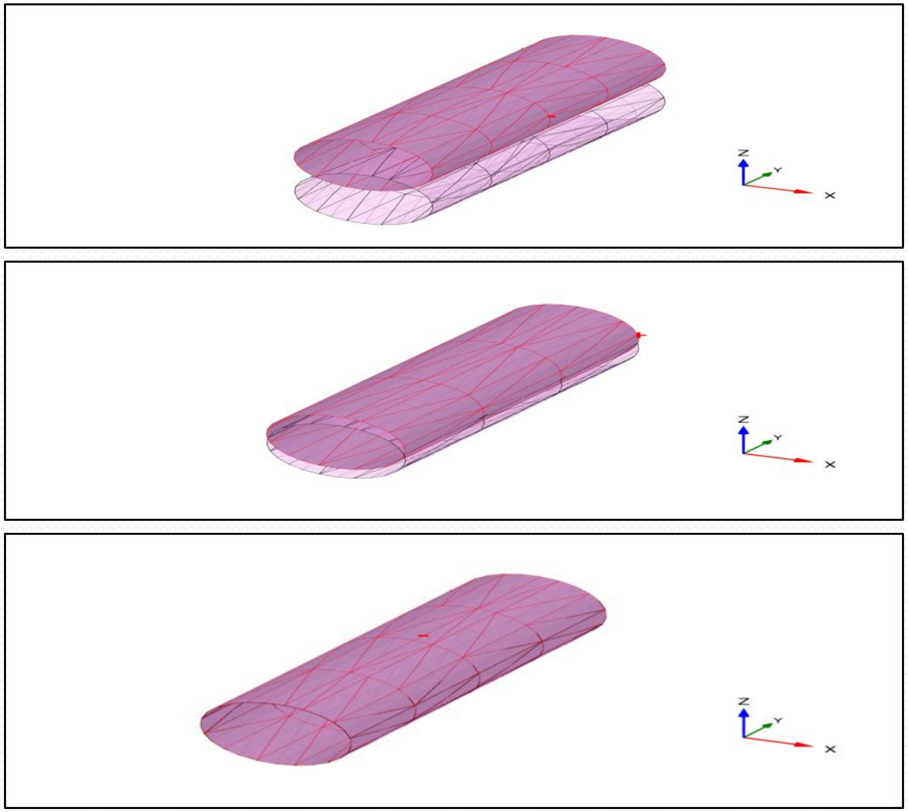
Relationship between the Maximum Uplift Movements (Sp/Ss) and (L/D) Ratio for Different Helical Piles Spicing under Pipeline.

Deformed Shape of Pipeline after Swelling Expansive Layer for without and with Using Helical Piles.

Unpiled Case

L/D Ratios= 116, 146, 176
L/H Ratios= 0.67, 1.33, 2





Conclusions and Recommendations

1- Conclusions from the Experimental Work:

1. The reduction in upward movement of piles for piles embedded to sandy soil(stable layer) through expansive soil when L/D ratio changes from 62 to 80 are as follows:

	loose state	dense state
Ordinary pile	72%	53%
Single helix	39%	50%
Double helix	45%	43%

2. To reach zero uplift movement state, pile should be embedded in sandy soil(stable zone) below expansive layer as follows:

	loose state	dense state
Ordinary pile	1.08H	0.60H
Single helix	0.51H	0.46H
Double helix	0.47H	0.42H

3. Helical piles with single and double helix plates have ability to resist uplift movement (6-73)% and (3-81)% more than ordinary piles when piles embedded to loose and dense sandy soil through expansive soil respectively.

4. The increase in pullout capacity of piles extended to sandy soil(stable zone) through expansive soil when L/D ratio changes from 62 to 80 are as follows:

	loose state	dense state
Ordinary pile	121%	46%
Single helix	108%	106%
Double helix	121%	92%

5. Helical piles with single and double helix plates have pullout capacity (5-11) and (5-8) times more than ordinary piles when piles extended to loose and dense sandy soil through expansive layer respectively.

6. The amount of upward movement of model of four helical piles grouped embedded in expansive soil increases with the increase of pile spacing, helix diameter and number of helix for shallower depths, but decreases with increasing the lengths of the helical piles.

7. The maximum upward movement of helical piles group is less than that of single helical pile. As helical piles spacing increased, the maximum upward movement is approximated to that of single piles.

8. Silica fumes with 3% , coal fly ash 3% and hydrated lime 6% gave good degree of improvement exceed 46% in reducing uplift movement of helical piles when added during pile driving in expansive soil.

9. Mixed of silica fumes: coal fly ash (3:1) with 3%, hydrated lime: cement (1:1) with 2% gave good degree of improvement exceed 50% in reducing uplift movement of helical piles when added during pile driving in expansive soil.

2- Conclusions from Finite Element Analysis:

1. Helical piles with two helix plates gave reduction in uplift movement 15% more than those of single helix plate when L/D changes from 35 to 71.

2. Helical pile cap with a gap from soil surface has (11-18) % lower than uplift movement that of without gap.

3. For the helical piles group, the ratio (Sp/Ss) decreases with increasing (L/D) ratio, increasing spacing between helical piles group. When spacing reached (5dh) group tends to be as a single helical pile behavior.

4. Helical piles group cap with a gap from soil surface has uplift movement (4-11) % lower than that of without gap.

5. To reach zero uplift movement of tower foundation constructed on expansive soil need L/D ratio 118, 113 and 102 for helical piles group of [2x2], [3x3] and [4x4] respectively with single and double helix plates in the upper and lower part of helical

6. To reach zero uplift movement of tower founded on expansive layer, L/H ratio should be penetrated (1.52, 1.37, 1.20) for helical piles group of [2x2], [3x3] and [4x4] respectively with single and double helix plates in the upper and lower part of helical pile.

7. The reduction in uplift movement of pipeline founded on expansive layer, when L/D (116, 146, 176) is (39%, 77%, 99%) for spacing of 6.67dh and (28%, 62%, 90%) for spacing 10dh and (12%, 43%, 77%) for spacing 13.33dh.

8. Uplift movement of pipeline founded on expansive layer decreases to zero values when L/H ratio should be (2, 3.4, and 3.7) in stable zone for spacing 6.67dh, 10dh and 13.33dh respectively.

Recommendations for Future Works:

1. Conducting a large-scale field works to study the behavior and performance of single and group of helical piles in expansive soil.

2. Further studies on other parameters such as helix gap, spacing between helix, different helix diameter used in helical pile, corrosion, etc. on efficiency of helical piles in expansive soil.

3. A comprehensive study is required on loaded helical piles embedded in expansive soil overlaying a non-swelling soil.

4. Further studies on adding additives during installation of helical piles in expansive soil in field to do design charts.

5. Studying the lateral soil pressure exerted on a helical pile embedded in expansive soil under saturation-desaturation cycles.

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Mitigation of Expansive Soil Problems by Using Helical Piles with Additives

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Abstract

In this study, nine essential additives in addition to three mixed additives with different ratios have been chosen and implemented during the installation of helical pile. The choice took into consideration that some of the additives were cheap and available in the local market; others were waste materials such as ceramic, brick fragments and coal fly ash. Some relatively expensive additives such as silica fumes were also added because it reduces the swelling soil. Three different ratios of each additive were considered according to their types. The ratios are between 0.5 and 6%. The helical piles with double helix (dh=20 mm) were embedded in expansive soil with length 15 cm (L/D=27). From this study, it is found that the 3% silica fumes, 3% coal fly ash, and 6% hydrated lime exhibits good significant improvement which exceeds 50% in reducing uplift movement of helical piles when added during the driven process in expansive soil. Also, 3% mixture of silica fumes to coal fly ash (3:1), 2% of

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MEASUREMENTS OF SUCTION AND WATER CONTENT DURING SATURATION OF COMPACTED EXPANSIVE SOIL

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ABSTRACT: The change of climate gives fluctuation of water content in its result rain, evaporation, rising water ground level and evapotranspiration. The expansive soil will volume change and suction. This behavior can damage on construction structures especially, roads and light building. The phenomenon is very interesting to be researched, how far the

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م/ قبول نشر

تحية طيبة ...

نود أعلامكم أن هيئة تحرير المجلة تدارست البحث المقدم من قبلكم والموسوم:

Helical Piles Embedded in Expansive Soil Overlaying Sandy Soil

وبعد الأطلاع على تقييمات الخبراء فقد قررت هيئة تحرير مجلة الخوارزمي الهندسية قبول بحثكم
نشر في مجلتنا في الأعداد اللاحقة .

مع التقدير

أ.م.د. علاء كريم محمد
رئيس التحرير
١٩/٤/٢٠١٦

Thank you