Analysis of pile foundation

Simplified methods to analyse the pile foundation under lateral and vertical loads

[1]Kanakeswararao Thadapaneni,[2]Sarikonda Venkata sivaraju,[3]Ravi teja Grandhi

[1]PG Student, Lenora College of Engineering, Rampachodavaram,[2]PG Student, Kakinada institute of Engineering and technology, Ramachandrapuram,[3]PG Student, Lenora College of Engineering, Rampachodavaram

[1] Department of Civil Engineering,

[1,2,3] Andhra Pradesh, India

Abstract- Pile foundations are common foundations for bridge abutment, piers and buildings resting on soft soil strata. The pile is subjected to both vertical and horizontal loads. The objective of the current study is Lateral& Vertical loaded analysis of pile and checking the deflection in pile under loads by finite element method.

The distribution of vertical load in piles is consists of two parts. One part is due to friction, called *skin friction* or *shaft friction* and the other is due to *end bearing* at the base or tip of the pile toe.

Ultimate vertical load bearing capacity of pile analysis is done by Static Analysis based on c-ϕ values in which vesic's bearing capacity factors are used for cohesive and cohesion less soils.

The problem of a laterally loaded pile embedded in soil is closely related to the beam on an elastic foundation. A beam can be loaded at one or more points along its length (whinkler soil springs assumption). Ks values are found by most general form for either horizontal or lateral modulus of subgrade reaction, in which Hansen and Vesic's bearing capacity factors are used.

Checking of deflection in pile is done by staad software (finite element method) using the parameters of modulus of subgrade reaction "Ks".

Horizontal load carrying capacity calculations are done by is code method {Append. C , IS:2911(PartI/Sec2)}.

The maximum lateral load on any pile under normal condition shall not exceed the value corresponding to 5mm horizontal deflection

The lateral load capacity, depth of fixity and maximum moment in pile is calculated as per append. C of

IS :2911(part I/SEC 2)-1979. Minimum value of lateral load capacity is adopted for design.

Key words— vesic's bearing capacity, staad software (finite element method), whinkler soil springs assumption, IS :2911(part I/SEC 2)

I. INTRODUCTION

India is developing country, so many constructions are going on, and transportation system is developing to decrease the distance b/w states and countries.

Whatever the type of construction, before the construction of every civil engineering project, we have to know about the sub-surface of the soil which is available at the construction site.

The process of knowing of information about the sub-surface of the soil is called soil exploration.

The soil exploration is done by the different methods

1. Open exploration method
2. Borings method

Whatever the method we use, we may get the sample in disturbed or undisturbed manner physically.

Finally, the laboratory tests are conducted on sample, if the sample has low dense and low bearing capacity properties then there is better to provide deep foundation (pile foundation, Caissons or well foundation) for to made the structure durable.

Piles are generally two types based on the type of construction

1. Driven piles
2. Cast in situ piles

Before the establishment of pile foundation, we have to analyze the pile foundation under lateral and vertical loads.

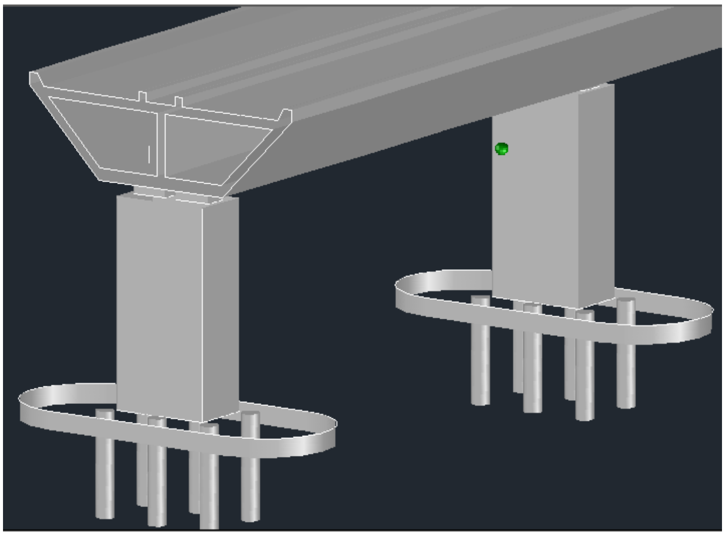


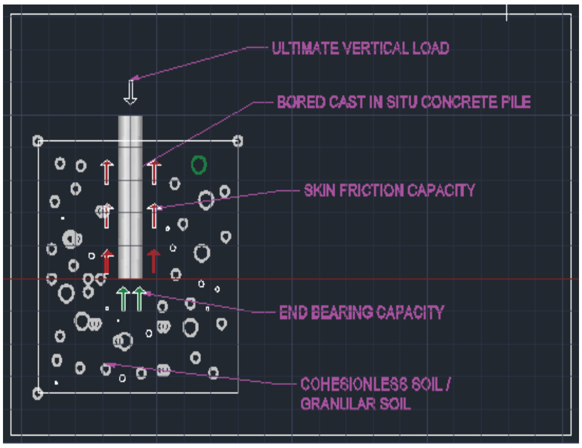
FIG: Pile foundation in Expess-way bridge

II. VERTICAL LOAD BEARING CAPACITY OF THE PILE BY STATIC ANALYSIS BASED ON THE SOIL PROPERTIES

The ultimate bearing capacity of a pile is the maximum load which it can carry without failure.
The pile transfers the load into the soil in two ways. Firstly, through the tip-in compression, termed as "*end-bearing*" or "*point-bearing*"; secondly, by shear along the surface termed as "*skin friction*".

LOAD CARRYING CAPACITY OF CAST IN-SITU PILES IN COHESIVE SOIL

The ultimate load carrying capacity (Q_u) of pile in cohesive soils is given by the formula given below, where the first term represents the *end bearing resistance* (Q_b) and the second term gives the *skin friction resistance* (Q_s).



Qu = Qb + Qf

= $q_bA_b+f_sA_S$

Where

Qu = ultimate load applied on the top of the pile

qb = ultimate unit bearing capacity of the pile at the base

Ab = bearing area of the base of the pile

As = total surface area of pile embedded below ground surface

fs - unit skin friction (ultimate)

Static Analysis based on c-ϕ values

The ultimate pile compressive capacity has been computed using the following equation as given in IS 2911 Part-I Sec 1 & 2.

Qu = Qb + Qf

Qu = $q_bA_b+f_sA_S$

$$Q_{ult} = \left[\sum_{i=1}^{n} f_s A_s L_i\right] + q_u A_p$$

$$= \left[\sum_{i=1}^{n} (\alpha c_i + p_i k \tan\delta) A_s L_i\right] + \left[c_p N_c + q_p N_q + \tfrac{1}{2}\gamma D N_\gamma\right] A_p$$

Here the cohesion terms "C values" are valuable in "cohesive soils" and the remaining terms are equals to zero

$$Q_u = [A_p N_c c_p] + \left[\sum_{i=1}^{n} \alpha_i c_i A_{si}\right]$$

Where :

Q_{ult} = ultimate pile capacity

f_s = unit skin friction

α = adhesion factor

c_i = cohesion intercept in i^{th} layer

p_i = overburden pressure at centre of ith layer

k = coefficient of lateral earth pressure

δ I = angle of friction between soil and pile (taken as equal to ϕ i) for the ith layer

A_s = surface area of pile per m length

L_i = length of pile section in i^{th} layer

c_p = cohesion intercept in bearing strata

q_u = unit end bearing

q_p = effective overburden pressure at pile toe

N_c, N_q, Nγ = bearing capacity factors, which are a function of ϕ in the bearing strata

A_p = pile cross sectional area

LOAD CARRYING CAPACITY OF CAST IN-SITU PILES IN COHESION LESS SOIL

The ultimate load carrying capacity of pile, "Q_u", consists of two parts. One part is due to friction, called *skin friction* or *shaft friction* or *side shear* denoted as "Q_s" and the other is due to *end bearing* at the base or tip of the pile toe, "Q_b".

The equation given below is used to calculate the ultimate load carrying capacity of pile.

Qu = Qb + Qf

= $q_b A_b + f_s A_S$

Where

Qu = ultimate load applied on the top of the pile

qb = ultimate unit bearing capacity of the pile at the base

Ab = bearing area of the base of the pile

As = total surface area of pile embedded below ground surface

fs - unit skin friction (ultimate)

Static Analysis based on c-ϕ values

The ultimate pile compressive capacity has been computed using the following equation as given in IS 2911 Part-I Sec1 & 2.

Qu = Qb + Qf

Qu = $q_b A_b + f_s A_S$

$$Q_{ult} = \left[\sum_{i=1}^{n} f_s A_s L_i\right] + q_u A_p$$

$$= \left[\sum_{i=1}^{n} (\alpha c_i + p_i k \tan\delta) A_s L_i\right] + \left[c_p N_c + q_p N_q + \tfrac{1}{2}\gamma D N_\gamma\right] A_p$$

Here the cohesion terms "C values" are not voluble C=0 in "cohesion less soils" and the remaining terms are valuable.

$$Q_u = A_p\left(\frac{1}{2} D\gamma N_\gamma + P_D N_q\right) + \sum_{i=1}^{n} k_i P_{Di} \tan\delta A_{si}$$

Where,

A_p = cross-sectional area of pile base, m^2

D = diameter of pile shaft, m

γ = effective unit weight of the soil at pile tip, kN/m^3

N_γ= bearing capacity factor

N_q = bearing capacity factor
Φ = Angle of internal friction at pile tip
P_D = Effective overburden pressure at pile tip, in kN/m^2
K_i = Coefficient of earth pressure applicable for the ith layer
P_{Di} = Effective overburden pressure for the ith layer, in kN/m^2
δ_i = Angle of wall friction between pile and soil for the ith layer
A_{si} = Surface area of pile shaft in the ith layer, in m^2

The bearing capacity factors depends on "Φ" value.
According to Vesic's bearing capacity theory, the bearing capacity factors are

$$Nq = \tan^2\left(45 + \frac{\phi}{2}\right)e^{\pi.\tan\phi}$$

$$Nc = (Nq - 1)\cot\phi$$

$$N\gamma = 2(Nq + 1)\tan\phi$$

Ø	Nc	Nq	Nγ		Ø	Nc	Nq	Nγ
0	5.14	1.00	0.00		25	20.72	10.66	10.88
1	5.63	1.09	0.07		26	22.25	11.85	12.54
2	5.63	1.20	0.15		27	23.94	13.20	14.47
3	5.99	1.31	0.34		28	25.80	14.72	16.72
4	6.19	1.43	0.34		29	27.86	16.44	19.34
5	6.49	1.57	0.45		30	30.14	18.40	22.40
6	6.81	1.72	0.57		31	32.67	20.63	25.90
7	7.16	1.88	0.71		32	35.49	23.18	30.22
8	7.53	2.06	0.86		33	38.64	26.09	35.19
9	7.92	2.25	1.03		35	46.12	29.44	41.06
10	8.35	2.47	1.22		35	46.12	33.30	48.03
11	8.80	2.71	1.44		36	50.59	37.75	56.31
12	9.28	2.97	1.69		37	55.63	42.92	66.19
13	9.81	3.26	1.97		38	61.35	48.93	78.03
14	10.37	3.59	2.29		39	67.87	55.96	92.26
15	10.98	3.94	2.65		40	75.31	64.20	109.41
16	11.63	4.34	3.06		41	83.86	73.90	130.22
17	12.34	4.77	3.53		42	93.71	85.38	155.55
18	13.10	5.26	4.07		43	105.11	99.02	186.54
19	13.93	5.80	4.68		44	118.37	115.31	234.64
20	14.83	6.40	5.39		45	133.88	134.88	271.76
21	15.82	7.07	6.20		46	152.10	158.51	330.35
22	16.88	7.82	7.13		47	173.64	187.21	403.67
23	18.06	8.66	8.20		48	199.26	222.31	496.01
24	19.32	9.60	9.44		49	229.93	265.51	613.16
					50	266.89	319.07	762.89

III. EFFECTIVE OVERBURDEN PRESSURE

The effective overburden pressure at a given depth is the vertical stress at that depth due to the weight of the overlying soils.

IV. FACTOR OF SAFETY

In almost all cases where piles are acting as structural foundations, the allowable load is governed solely from considerations of tolerable settlement at the working load.
The working load for all pile types in all types of soil may be taken as equal to the sum of the base resistance and shaft friction divided by a suitable factor of safety. A safety factor of 2.5 is normally used.
Therefore we may write

A minimum factor of safety of 2.5 is used to arrive at the safe pile load capacity (Q_{safe}) from ultimate load capacity (Q_u).

$$\mathbf{Q_{safe} = Q_u/2.5}$$

$$Q_a = \frac{Q_b + Q_f}{2.5}$$

V. EXAMPLE PROBLEM

CALCULATIONS FOR VERTICAL LOAD CARRYING CAPACITY OF PILE BASED ON SOIL PROPETIES

INTRODUCTION:-
Bore hole no 2, Bore hole depth 18.75, Designed By IRC

DESIGN DATA
Type of pile = Bored cast-in-situ pile
Diameter of pile = 1.20 m
Length of pile (from pile cap bottom) = 18.8 m
Founding level = -18.8 m
Pile cap bottom level = -1.80 m
Pile cap thickness = 1.80 m
Ap = X-sectional area of pile = p*dia*dia/4 =1.131 m^2

SOIL PROPERTIES
Angle of internal friction at tip = ø = 32.0 deg
N_γ = Bearing capacity factor (for Ø = 32.0 deg)
(as per IS:6403-1981) = 32.652
N_q = Bearing capacity factor (for Ø = 32.0 deg) =34.360
Cohesion at pile tip = Cp = 0.96 t/m^2
Density of soil = kn/m^3 =1.689 t/m^3
Bearing capacity factor = Nc = 37 = 165.686
Effective unit weight of soil at pile tip = γ_{sub} = 0.689 t/m^3

VI. VERTICAL LOAD CARRYING CAPACITY CALCULATIONS

VII. (BY STATIC FORMULA, APPENDIX B, IS:2911(PARTI/SEC2)

a) End Bearing

The ultimate bearing capacity in end bearing (Qp) for piles in C-Ø Soil is given by

$$\mathbf{Q_P = A_p * [(N_C * C_P) + (1/2 * D * g * N_g + P_D * N_q)]}$$

As per IS : 2911 –(1/2), for calculating effective overburden pressure. Depth corresponding to 15 times diameter of pile shall be considered.

Layer >>	Upto	1	2	3	4	5	6	7	8	9	10	11	Total
P_D at -18.8	-0.8	0.96	0.95	1.01	1.02	1.02	1.02	5.76	5.03	0.00	0.00	0.00	= 16.76 t/m^2
Depth of layer from bottom		1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	3.00	3.00	0.75	

=1.131*[(36.532*0.95)+(0.5*1.20*0.689*327+17.205*24.4)] = 39.3+489.3 =528.5 t

b) Side friction

The ultimate bearing capacity inside friction (Qa) for piles in C-Ø Soil given by

$$\mathbf{Q_S = \Sigma^n_{i=1} [a * C_i * A_s + K * P_{Di} * \tan \square * A_{si}]}$$

Soil properties as per Bore Hole No.1 (Depth below 2.0m G.L)
Coefficient of Earth Pressure = K = 1.0

S.No	ϕ	γ_d	Depth from GL	Depth of Pile	G	e	γ_{sat}	γ_{sub}	P_{D1}	P_{D2}	P_{Davg}	A_{si}	C	α	αCA_{si}	Load - t
1	31	1.69	1.50	0.75	1.69	0.000	1.690	0.690	0.000	0.518	0.259	2.827	0.00	0.5	0.000	0.440
2	31	1.68	4.50	3.00	1.68	0.000	1.680	0.680	1.035	3.075	2.055	11.310	0.00	0.5	0.000	13.965
3	32	1.68	7.50	3.00	1.68	0.000	1.680	0.680	3.075	5.115	4.095	11.310	0.00	0.5	0.000	28.940
4	31.5	1.67	9.00	1.50	1.67	0.000	1.670	0.670	5.115	6.120	5.618	5.655	0.00	0.5	0.000	19.466
5	32	1.64	10.50	1.50	1.64	0.000	1.640	0.640	6.120	7.080	6.600	5.655	0.00	0.5	0.000	23.321
6	31.5	1.68	12.00	1.50	1.68	0.000	1.680	0.680	7.080	8.100	7.590	5.655	0.74	0.5	2.101	26.302
7	32	1.68	13.50	1.50	1.68	0.000	1.680	0.680	8.100	9.120	8.610	5.655	0.00	0.5	0.000	30.424
8	31.5	1.68	15.00	1.50	1.68	0.000	1.680	0.680	9.120	10.140	9.630	5.655	0.00	0.5	0.000	33.371
9	32	1.67	16.50	1.50	1.67	0.000	1.670	0.670	10.140	11.145	10.643	5.655	0.00	0.5	0.000	37.606
10	30.5	1.63	18.00	1.50	1.63	0.000	1.630	0.630	11.145	12.090	11.618	5.655	0.00	0.5	0.000	38.698
11	31	1.64	19.50	1.50	1.64	0.000	1.640	0.640	11.145	12.105	11.625	5.655	0.00	0.5	0.000	39.499

The total ultimate bearing capacity of pile (Qu)

$\mathbf{Q_U} = \mathbf{Q_P} + \mathbf{Q_S}$

$= 528.5 + 294.208 = 822.7$ t

Therefore

Ultimate bearing capacity of pile = 822.7 ton

Net bearing capacity as per static formula

Qnet = Qu / FOS = 329.1 ton, say 329.0 ton

Density of concrete = 2.4 t/m^3

Self weight of pile (Buoyant) = 1.131*18.8*(2.4-1.0) = 29.7 t

Net bearing capacity of pile = 329.0-29.7 = 299.3 t , say 299.0 ton

Net vertical load carrying capacity of pile (excluding self weight) = 299.0 ton

VIII. LATERALLY LOADED ANALYSIS OF PILE FOUNDATION BASED ON SOIL PROPERTIES

The problem of a laterally loaded pile embedded in soil is closely related to the beam on an elastic foundation. A beam can be loaded at one or more points along its length, whereas in the case of piles the external loads and moments are applied at or above the ground surface only. Most of the theoretical solutions for laterally loaded piles involve the concept of modulus of subgrade reaction or otherwise termed as soil modulus which is based on Winkler's assumption that a soil medium may be approximated by a series of closely spaced independent elastic springs.

A series of nonlinear springs represents the force deformation characteristics of the soil. The springs attached to the blocks of different sizes indicate reaction increasing with deflection and then reaching a yield point, or a limiting value that depends on depth; the taper on the springs indicates a nonlinear variation of load with deflection. The gap between the pile and the springs indicates the molding away of the soil by repeated loadings and the increasing stiffness of the soil is shown by shortening of the springs as the depth below the surface increases

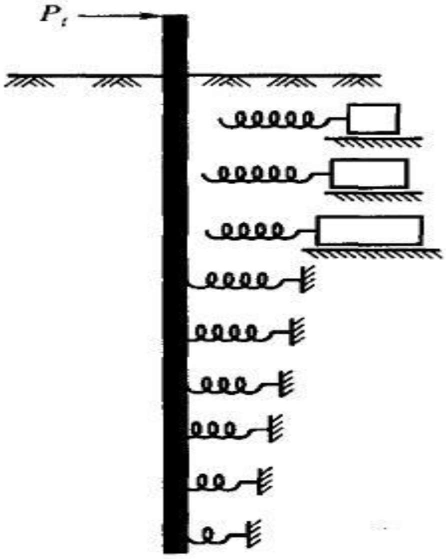


Fig: The concept of laterally loaded pile-soil system

IX. CHECKING OF DEFLECTION IN PILE BY STAAD SOFTWARE USING THE PARAMETERS OF MODULUS OF SUBGRADE REACTION

First we have to find out the modulus of subgrade reaction at each layer of soil along the length of the pile, then apply those "Ks" values to the pile in "STAAD PRO" software, in analysis we can get the deflection.

X. MODULUS OF SUBGRADE REACTION

The modulus of subgrade reaction is a conceptual relationship between soil pressure and deflection that is widely used in the structural analysis of foundation members.

It is used for continuous footings, mats and various types of piles.

Based on plate load test,

Ks = q/δ

Where q = soil pressure, δ = deflection

A number of persons do not like to use the concept of modulus of sungrade reaction; rather, they prefer to use Es (and μ) in some kind of finite element analysis.

A major problem is to estimate the numerical value of "Ks". One of the early contributions was that of "Terzaghi" (1955), who proposed that "Ks" for full-sized footings could be obtained from plate load tests using the fallowing equations.

For footings on clay Ks = (K1*B1)/B

For footings on sand (and including size effects)

$$Ks = K1((B+B1)/2B))^2$$

In these two equations use B1= side dimension of the square base used in the load test to produce K1.

In most cases B1 =0.3m, but whatever B1 dimension was used should be input.

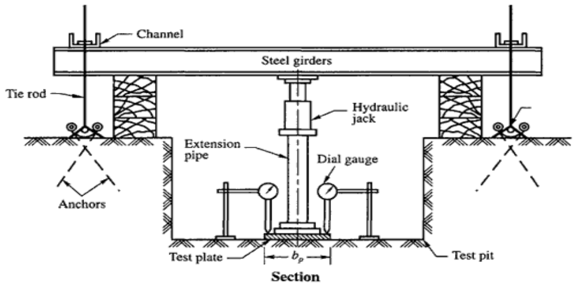


Fig. Plate load test

For rectangular footing on stiff clay (or) medium dense sand with dimensions of B*L with m= L/B.

$$Ks= K1\ (m+0.5)/1.5m$$

Where Ks = Desired value of modulus of subgrade reaction for the full size foundation.

K1 = Value obtained from plate load test using a 0.3*0.3 m or other size load plate.

Vesic (1961a,1961b) proposed that the modulus of subgrade reaction could be computed using the stress-strain modulus "Es" as

$$Ks = 0.65 \sqrt[12]{\frac{ESB4}{EfIf}} * Es/(1-\mu^2)$$

The most general form for either horizontal or lateral modulus of subgrade reaction is,

$$k_s = A_s + B_s Z^n$$

Where A s = constant for either horizontal or vertical members
Bs = coefficient based on depth variation
Z = depth of inType equation here.terest below ground
n = exponent to give ks the best fit.
We know that ultimate bearing capacity is given by,

$$q_{ult} = cN_c S_c + \gamma Z N_q S_q + 0.5\gamma B N_\gamma S_\gamma$$

Observing that,

$$A_s = C(cN_c S_c + 0.5\gamma\ BN_\gamma S_\gamma) \text{ and } B_s Z^n = C(\gamma N_q S_q) Z^n$$

In this equations the Terzahi or Hansen bearing capacity factors can be used.
The "C " factor is 40 for SI units and 12 for FPS units.
Similarly find the Ks values for each layer at every 1m interval. Apply those Ks values to the pile in STAAD, we can get the deflection of pile in analysis.

Range of modulus of subgrade reaction ks.

Soil	**Ks (kN/m3)**
Loose sand	4800-6000
Medium dense sand	9600-80000
Dense sand	64000-128000
Clayey medium dense sand	32000-80000
Slity medium dense sand	24000-48000
Clayey soil	16000-25000
qa ≤ 200 kPa	12000-24000
200 < qa ≤ 800 kPa	24000-48000
qa > 800 kPa	>48000

Calculation of Soil Spring Constant:

Input Data:
Design scour level = (+) 1.15 m
Depth of consideration = 26.00 m
Diameter of pile = 1.00 m
The horizontal modulus of subgrade reaction

$$k_s = A_s + B_s Z^n$$

$$\text{Where } A_s = CmC(cN_c + 0.5\gamma\ BN_\gamma) \text{ and } B_s Z^n = CmC(\gamma N_q) Z^n$$

Exponent n = 0.5
Size factor Cm = 1.555824
Factor depending on displacement of pile C = 40
Soil data and calculation is as under:
For layer 1,
Thickness of layer = 5m
Angle of internal friction = 0
Cohesion of soil = 150 kN/m2
Submerged unit weight of soil = 7.75 kN/m3
Bearing capacity factor, Nc = 5.14
Nq = 1, Nγ = 0
As = 1.555*40* (150*5.14 + 0.5*7.75*1*0) = 47981.6 kN/m3
Bs = 1.555*40* (7.75*1) = 482.32 kN/m3
Ks = 47981.6 + (482.32* Z^0.5) kN/m3
Similarly for other layers, 'Ks' is found out and from that, value of spring constant is also found out for every 1m interval as per equations given above. Values of spring constants throughout Similarly for other layers, 'Ks' is found out and from that, value of spring constant is also found out for every 1m interval as per equations given above. Values of spring constants throughout the entire depth are calculated using spread sheet **"**Spring Constant**"**.

Calculated values are shown below in Table 9 and Table 10

Table 9

Layer Thk.(m)	C (kN/m2)	Φ (Deg)	Γsub (kN/m3)	Nc	Nq	Nγ	As (kN/m2)	Bs (kN/m3)
5	150	0	7.75	5.14	1	0	47981.6	482.31
1.53	150	0	7.75	5.14	1	0	47981.6	482.31
5	80	0	7.75	5.14	1	0	25590.2	482.31
4	80	0	7.75	5.14	1	0	25590.2	482.31
5	160	0	7.75	5.14	1	0	51180.4	482.31
2.5	160	0	7.75	5.14	1	0	51180.4	482.31
3	0	35	7.75	46.12	33.3	48.03	11582.6	16061

Table 10

Depth (m)	**As (kN/m2)**	**Bs (kN/m3)**	**Ks (kN/m3)**	**K (kN/m)**
0	47981.61	482.3054	47981.61	24082.96
1	47981.61	482.3054	48463.91	48440.37
2	47981.61	482.3054	48663.69	48659.82
3	47981.61	482.3054	48816.98	48814.98
4	47981.61	482.3054	48946.22	48944.94
5	47981.61	482.3054	49060.07	49059.16
6	47981.61	482.3054	49163.01	47296.37
7	25590.19	482.3054	26866.25	28731.66
8	25590.19	482.3054	26954.36	26953.91
9	25590.19	482.3054	27037.11	27036.73
10	25590.19	482.3054	27115.37	27115.05
11	25590.19	482.3054	27189.82	27189.54
12	25590.19	482.3054	27260.94	27260.7
13	25590.19	482.3054	27329.17	27328.95
14	25590.19	482.3054	27394.81	27394.62
15	25590.19	482.3054	27458.15	29590.49
16	51180.38	482.3054	53109.6	50976.93
17	51180.38	482.3054	53168.98	53168.83
18	51180.38	482.3054	53226.63	53226.5
19	51180.38	482.3054	53282.7	53282.58
20	51180.38	482.3054	53337.32	53337.2
21	51180.38	482.3054	53390.58	53390.48
22	51180.38	482.3054	53442.59	53442.5
23	51180.38	482.3054	53493.44	56553.41
24	11582.56	16060.77	90263.94	87334.94
25	11582.56	16060.77	91886.41	91883.73
26	11582.56	16060.77	93476.74	46474.65

Apply these Ks values to the each individual pile at every layer of the soil in STAAD then get the deflection of the pile result in analysis

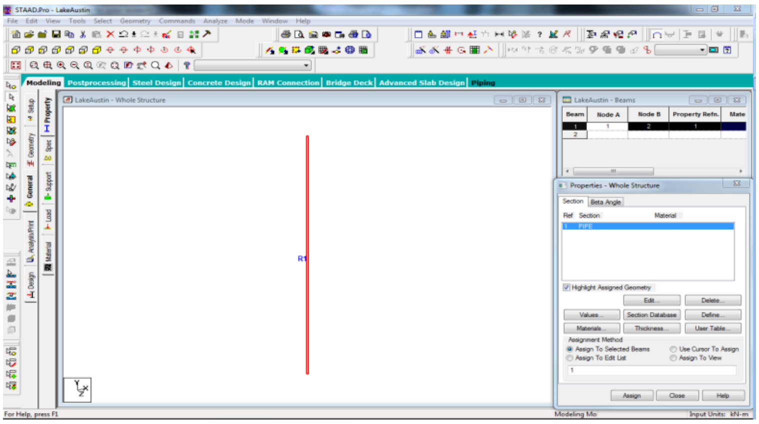


Fig: The Structure Model of Group of piles after being assigned with Elastic Soil springs

XI. HORIZONTAL LOAD CARRYING CAPACITY CALCULATIONS (IS CODE METHOD) {Append. C , IS:2911(PartI/Sec2)}

The maximum lateral load on any pile under normal condition shall not exceed the value corresponding to 5mm horizontal deflection (produced at cut-off level)

The lateral load capacity, depth of fixity and maximum moment in pile is calculated as per append. C of IS :2911(part I/SEC 2)-1979. Minimum value of lateral load capacity is adopted for Design.

Depth of Fixity

Depth of Fixity for pile (L_F) is given by plots in Fig. 2 (Append.C) of IS:2911 between L_F/R or L_F/T.

Where

L_F = Depth of Fixity

L_1 = Height above ground level of lateral forces

R = $(EI/K_1)^{1/4}$

Grade of Concrete M 35

Dia of Pile = 1.0 m

E = Young's Modulus of the Pile Material (i.e. M35 grade concrete) = 2.96E+06 t/m^2

I = pi * (dia)^4 / 64 = 0.0491 m^4

K_2 = Constant (Soil modulus or soil stiffness) = 488.0 t/m^2

Therefore

R = $(E * I / K2)^{1/4}$ = 4.15

L_1= (for Fixed Head Piles) = 0.0 m

for Fixed Head Piles in Preloaded Clays, from Fig.2 of Append.C

L_F/R = Depth of Fixity = 1.93

Therefore

L_F = 1.93 * R = 1.93 * 4.15 = 8.017 m

Pile Head Deflection (Y) is given by, $Y = Q (L_1 + L_F)^3 / 12EI$ or $Q = 12EI * Y / (L_1 + L_F)^3$
Where, Q = Lateral Load Capacity and Y = 5 mm = 0.005 m (Maximum Deflection, as per Design criteria)
Therefore
$Q = 12EI * Y / (L_1 + L_F)^3$
=12 * 2,960,000 * 0.049 * 0.005 / (0.0 + 8.02)*3 = 16.92 ton
i.e. Lateral Load Carrying Capacity of Pile under Normal Condition = Q_{lat} = 16.92 ton
Therefore
$Q_{SEISMIC}$ = 1.25 * 16.9 = 21.1 ton
Thus, Lateral Load Carrying Capacity of Pile
Under Normal Condition =16.92 ton
Under Seismic Condition = 21.10 ton

Maximum Moment in Pile

Fixed End Moment in Pile is given by $M_F = Q (L_1 + L_F) / 2$
and Actual Maximum Moment in Pile is given by
M = m* (M_F) or $M = m * Q (L_1 + L_F) / 2$
Where
m = Reduction Factor
for $L_1/T = 0.00$
m = 0.7
Therefore
M = Maximum Moment in Pile
$= m * Q (L_1 + L_F) / 2 = 0.7 * Q * (0.0 + 8.02) / 2 = 2.81*Q$
Therefore
Maximum Moment in Pile = **2.81 * Q tm (ton-moment)**
where Q is Lateral load in tons

SUMMARY OF DESIGN FORCES
Vertical load carrying capacity of pile
Under normal condition = 299.0 ton
Under seismic condition = 374.0 ton

Lateral load carrying capacity of pile
Under normal condition = 16.9 ton
Under seismic condition = 21.1 ton

Maximum moment in pile = 2.81*Q tm (ton-moment)

REFERENCES

[1] Bowles, J.E. (1996). *Foundation Analysis and Design,* McGraw-Hill, NewYork.
[2] Chellis, R.D. (1961). *Pile Foundations,* McGraw Hill, New York.
[3] Desai, C.S. (1974). "Numerical Design-Analysis for Piles in Sands," *J. Geotech.Eng. Div.,* ASCE,Vol. 100, No. GT6.
[4] Meyerhof, G.G (1951). "The Ultimate Bearing Capacity of Foundation" *Geotechnique,* Vol.2, No.4.
[5] V.N.S Murthy, and K.S.Subbarao (1995). "Prediction of Nonlinear Behaviour of Laterally Loaded Long Piles," *Foundation Engineer,* Vol. 1, No. 2, New Delhi.
[6] Matlock, H. (1970). "Correlations for Design of Laterally Loaded Piles in Soft Clay," *Proc. 2nd Offshore Tech. Conf.,* Houston, Vol. 1.
[7] Matlock, H, and Reese, L.C. (1960). "Generalized Solutions for Laterally Loaded Piles," *JSMFD,* ASCE, Vol. 86, N. SMS, Part 1.
[8] Matlock, H., and Reese, L.C. (1961). "Foundation Analysis of Offshore Supported Structures, "*Proc. 5th Int. Conf. SM and FE,* Vol. 2.
[9] Reese, L.C. (1975). "Laterally Loaded Piles," *Proc. of the Seminar Series,* Design, Construction and Performance of Deep Foundations: Geotech. Group and Continuing Education Committee, San Francisco Section, ASCE, Berkeley.