Model studies of single bent pile with respect to different density i.e. loose, medium and dense of cohesion less soil

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Abstract- All engineered construction resting on the earth must be carried by some kind of interfacing element called a foundation. The foundation is the part of an engineered system that transmits to, and into, the underlying soil or rock the loads supported by the foundation and its self-weight. The resulting soil stresses except at the ground surface are in addition to those presently existing in the earth mass from its self-weight.

Piles are used to support the structures. Piles are frequently required because of the relative inability of shallow foundation to transmit inclined, horizontal, or uplift force and over-turning moments. Such situations are common in design of earth retaining structures and tall structures subjected to high wind and earthquake force.

Considering importance and necessity of pile in construction work. This thesis is based on the piles and topic name "Model studies of single bent pile with respect to different density i.e. loose, medium and dense of cohesion less soil".

The main objective of thesis is to determine reduction in load carrying capacity due to bending of single bent pile and also to determine the load carrying capacity of bent pile with respect to different density i.e. loose, medium and dense of cohesion less soil. In the present study, the carrying capacity of pile shall be ascertained under different conditions of soil and bending. The effect of degree of bending shall be studies by at different angle of bend. The study shall be made only in cohesion less soil under different degree of compaction. The study is made on one type of pile material-timber.

I. INTRODUCTION

Driving bearing piles to support the structures is one of the earliest examples of art and science of the civil engineers. Foundations may be classified based on where the load is carried by the ground:

Shallow foundations—termed bases, footings, spread footings, or mats. The ratio D/B < 1 but may be somewhat more. Deep foundations—piles, drilled piers, or drilled caissons. Lp/B > 4+ with a pile Need for a pile foundation can be justified in the following situation:

a) Upper soil strata are too compressible or generally too weak to support the heavy vertical reaction transmitted by super structure.
b) Piles are frequently required because of the relative inability of shallow foundation to transmit inclined, horizontal, or uplift force and over-turning moments. Such situations are common in design of earth retaining structures (walls and bulk-heads) and tall structures subjected to high wind and earthquake force.
c) Horizontal forces are resisted either by vertical piles in bending or by groups of vertical and battered piles.
d) Pile foundations are often required when scour around footing could cause erosion in spite of the presence of strong, incompressible strata (such as sand and gravel) at shallow depth.
e) In areas where expansive or collapsible soils extend to considerable depth below the soil surface, pile foundation may be needed to assure safety against undesirable seasonal movements of the foundations

These piles are classified on following basis:
On the basis material:

a) Timber
b) Steel
c) Plain cement concrete
d) Reinforced cement concrete
e) Pre-stressed
f) Composite

On the basis of method of construction:

a) Driven/ displacement precast piles
b) Driven/ displacement cast in situ piles
c) Bored/ replacement precast piles
d) Bored/ replacement cast in situ piles

On the basis of sectional area:

a) Circular
b) Square
c) Tubular
d) Octagonal
e) H-section

On the basis of load transfer:

a) End bearing pile
b) Friction pile
c) End bearing & frictional pile

On the basis of size of pile:

a) Micro/mini pile (<150mm)
b) Small diameter pile (150mm<diameter<600mm)
c) Large diameter pile (>600mm)

On the basis of inclination of pile:

a) Vertical piles
b) Raker/batter pile

Principal advantages and disadvantages of different pile materials:

Material	Advantages	Disadvantages
Timber	Easy to handle or cutoff, relative inexpensive material, ready available, naturally tapered, light and very durable below ground level.	Decay above water table, especially in marine environment, limited in size and bearing capacity, prone to damage by hard driving, noisy to drive.
Steel	Easy to handle, cutoff, extend. Available in any length or size, can penetrate hard strata, boulder, soft rock. Convenient to combine with steel superstructure, ability to withstand hard driving, capable for heavy loads.	Subject to corrosion, require protection in marine environment. Flexible H-piles may deviate from axis of driving. Relatively expensive material than timber and concrete. Noisy to drive
Concrete precast	Durable in almost all environment. Convenient to combine with concrete super-structure	Cumbersome to handle and drive. Difficult to cutoff or extend. Noisy to drive.
Cast in situ	Allow inspection before concreting, easy to cutoff and extend	Casting cannot be reused, thin casing may be damaged by impact or soil pressure.

II. REVIEW OF LITERATURE

Boussinesq & Westerguard (1885) developed a method based on elastic analysis for estimating soil pressures at various points in semi-infinite, isotropic, homogeneous and elastic mass of soil continuum. Here loading is vertical point load at the surface.

Mindlin (1936) produced a set of equations giving the stresses due to vertical point load applied below the surface of a semi-infinite medium. The use of this was reported by Khalifa (1940), Grilla(1914). Mindlins equation was extended by J. D. Geddas (1966) for different cases of loading.

Berezantzev, Khristoforov, V. and Glubkov, V. (1961) made theoretical and experimental investigations on the load bearing capacity of single pile and group of piles in sand. They have developed a formula for load bearing capacity and settlement of pile foundation. The settlement was observed to be proportional to square root of the size of footing. Their work on pile groups and pile test demands that the design of pile foundation with free length of piles should be based on the analysis of deformation of frames with rigidly anchored struts

Whitaker and Cooke (1966) presented a simplified method of construction load settlement curve taking account of pile soil slip along the shaft. This type of analysis revealed that for normal piles having a length to diameter ratio (L/d) greater than about 20, the load settlement curve is substantially linear until a load of about 50% to 70% of failure load is reached. The overall load settlement curve is constructed as a combination of relationship between shaft load-settlement, and base load & settlement. Shaft load- versus-settlement and base load-versus-settlement curves were constructed relying on empirical data.

Orrje, O. & Broms, B.B. (1967) studied the effects of pile driving on soil properties. They have concluded that the undrained shear strength of clay is not affected appreciably by pile driving except possibly in the case when the spacing between the individual pile is small (Less than 4 pile diameter).

Johnson (1962) made field measurements on 27m long composite piles in sand and observed that the out-of-plan position of the pile base was of the order of approximately 10% of the pile length. Like parsons & Wilsons (1954) he presented a method of safe load estimation that depended on knowledge of the deflected shape of the pile and the load distribution along the pile shaft.

Hanna (1963) reported the results of three tests on long H section steel piles driven through firm clays to bed rock at 44m depth. A Wilson slope indicator was used to determine the plan position of these piles with depth. In contrast to the pile bending observation of others these piles had two bends and the field observations are reproduced. The top part of this diagram gives the measured components of pile deflections for two of the piles; in the lower part of the figure the plan positions of three piles with depth are shown. In addition to these observations extensive load testing was carried out to arrive at permissible load. Attempts were also made to control pile

III. EXPERIMENTAL INVESTIGATION

General:

To proof the validity of the theoretical analysis an attempt has to be made to analysis the settlement behavior of initially bent piles and pile group in the laboratory under vertical load embedded in sand. An extensive experimental project has to be under taken to evaluate the extent of pile-soil-pile interaction. Emphasis on model test has to be found worth in enhancing an easy and rapid comparison of many combinations of variables. Therefore the principles of dimensional analysis is one of the most systematic approach to interpret ate the results to prototype.
In the present investigation, locally available Swarnrekha River sand will be used as soil medium and placement of soil has been made by rainfall method. The soil media will be chosen as loose, medium dense and dense by varying the height of fall of sand while filling the test tank. The behaviors of single wooden bent pile as well as bent piles in a group will be study in the laboratory. The group of piles may be extended to two, three, four and five pile groups respectively. Keeping in view the practical limitations viz. space, size of test tank, time allotted and other constraints, the pile bent will restricted to 0^{0}, 6^{0}, 15^{0}, and 30^{0} and space-diameter ration will be chosen for 2, 4, 6 and 8. The tests shall conduct under loose, moderately dense and dense

state of soil medium. The entire tests will subject to vertical compressive load.

The following experimental program has to be made for undertaking this project. The entire program has to be divided qualitatively and quantitatively into the following major groups.

Single piles						
Angle	**L/d Ratio**			**Soil Medium**		
0^0	**10**	**20**	**40**	**Loose**	**Medium dense**	**Dense**
6^0	**10**	**20**	**40**	**Loose**	**Medium dense**	**Dense**
15^0	**10**	**20**	**40**	**Loose**	**Medium dense**	**Dense**
30^0	**10**	**20**	**40**	**Loose**	**Medium dense**	**Dense**

Where Soil Medium: - Loose, Dense, Medium dense

Material Sand:- Sand has to be chosen as soil medium for the tests because it is easy to handle and is free from time effects. Dry sand transported from Local River has to be used. Various physical properties of sand has to be found by laboratory method.

Experimental set up:- Experimental set up mainly consists of test tank, loading frame with loading arrangement, pile, pile group and pile caps for testing purpose and measuring devices.

Model piles:- 5 Nos Straight piles L/d = 10
5 Nos 6^0 Inclined piles L/d = 10
5 Nos 15^0 Inclined piles L/d = 10
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5 Nos 30^0 Inclined piles L/d = 10
5 Nos Straight piles L/d = 20
5 Nos 6^0 Inclined piles L/d = 20
5 Nos 15^0 Inclined piles L/d = 20
5 Nos 30^0 Inclined piles L/d = 20
5 Nos Straight piles L/d = 40
5 Nos 6^0 Inclined piles L/d = 40
5 Nos 15^0 Inclined piles L/d = 40
5 Nos 30^0 Inclined piles L/d = 40

Hence 5 Nos cylindrical wooden piles of 0^0 inclination, 5 Nos cylindrical wooden piles of 6^0 inclination, 5 Nos cylindrical wooden piles of 15^0 inclination and 5 Nos cylindrical wooden piles of 30^0 inclination of length 300, 600, 1200 mm in length and 30 mm dia in section shall be made. Young's Modulus of elasticity of pile material has to be found.

Pile caps:- Wooden pile caps have to be fabricated according to different group of pile spacing. Keeping in mind the practical limitations of size of the tank, capacity of loading mechanism, volume of sand to be handled following groups are decided for testing programme.
Single pile: - Angle 0^0, 6^0, 15^0, & 30^0
Where d = diameter of the pile

Test Tank: - A wooden tank of size 100 X 100 X 150 cm will be made with 6mm ply board and sufficiently stiffened with 2cm thick wooden plank and 7.5cm x 7.5cm asserted length of wooden runner to serine as a container of sand. The size of tank will be chosen on the basis of following assumptions.

(I) The intensity of stress at the base of tank due to the load on the pile should be small fraction of applied load (5%)

(II) The dispersion planes of stress distribution should not interfere with the walls of the tank.

As the above conditions are satisfied, the sand contained in the tank can be treated as a semi-infinite cohesion less sand media.

Loading arrangements: - The loading arrangement is shown in figure. The loading frame will composed of two vertical channels anchored at bottom. Two channels of the same section will be bolted at tip of the frame to mount screw jack with proving-ring. Load will be applied through a screw jack operated by a gear system. Load will measured by a proving-ring. A Proving ring of required capacity will be used. The proving-rings having calibration 1 div = 1.447 kg will be used to apply load on single pile, group of 2 piles group, 3 piles group, 4 piles group and 5 piles group of straight in nature and inclined in nature of 6^0, 15^0, & 30^0 .

Measuring Devices: - Load has to be measured by proving-ring and two numbers dial gauges of least count 0.01 mm will be used to measure the settlement of piles.

Placement of sand:- As it is already been stated earlier that locally available river sand will be used as the soil medium and to maintain the same, placement density for each test while pouring the dry sand through hopper by rain fall method, the height of fall of sand is kept almost constant and the quantity of sand taken every time into hopper was also kept more or less constant to confirm the equal placement density of different layer of deposits, a penetrometer has been used to get the same penetration at each layer.

In the experimental work, three, type of sand deposits i.e. loose deposits, medium dense deposits and dense deposits shall be maintained. The corresponding relative densities shall be determined. The details of soil properties shall be presented. The angles of shear resistance from direct shear tests shall be determined for loose, medium dense and dense sand.

IV. EXPERIMENTAL PROCEDURE

Vertical Load Test

Due to specific time limit and depending on the availability of the instruments in the laboratory the experimental investigation has been restricted to vertical pile load test only. However a good number of tests have been carried-out on a single bent pile and bent pile groups.

Single Pile Load Test: - At first a sand layer of 200mm will be provided at the bottom of the tank by pouring sand from constant height. Then the pile with pile cap will be placed in a vertical position by little penetration into the sand to ensure proper seating of the pile and will be held in position till the tank is filled up. The tank will be filled up to the required level by pouring sand from some constant height. Single pile will be tested for three depths of embedment i.e. 275 mm. (L/d = 10), 575 mm. (L/d = 20), 1175 mm. (L/d = 40) for straight pile and different angle inclined piles i.e. (6^0,15^0, 30^0). The dial gauges of least count 0.01 mm will be placed in two opposite sides of the pile on the pile cap for measuring the settlement at different loading increments. Load will then apply with the help of screw jack and was measured with proving ring having calibration 1 div. = 1.447 kg till the failure takes place. Failure of pile will assumed when the proving ring dial gauge shows no further resistance for increasingly applied displacements for the test. The tests have to be done for different density of sand such as loose, medium dense and dense on straight and inclined piles of angle of bent 6^0,15^0, & 30^0 by varying the height of fall of sand.

Load versus settlement curve have to be shown by graphical representation. The ultimate load capacities will be obtained from the load displacement curve.

V. PRENSENTATION OF RESULTS & DISCUSSIONS

6.1 GENERAL: - In the present investigation locally available cohesion less soil has been used as soil medium and placement of soil has been made by rainfall method. Throughout the investigation identical method for placement of soil was used for different densities. For a particular density viz. loose or medium or dense. The variation being marginal for each cases for that particular density. Relevant soil properties required for the theoretical analysis and to represent the particular soil, details of test results are presented appendix –A. As the nature of problem is three dimensional, tri-axial test was performed to get the value of angle of shearing resistance (Φ).

Considering the main objective of present investigation i.e. to know the behavior of bent piles and pile groups under vertical load, a series of single pile test and tests on group of two piles, three piles, four piles and five piles have been carried out. Due to practical limitations of the size of the tank, capacity of the loading arrangement and volume of sand to be handled, spacing of pile has been restricted to 2d, 4d, 6d& 8d. The details of tests procedure and setup have already been discussed in unit-V of this thesis.

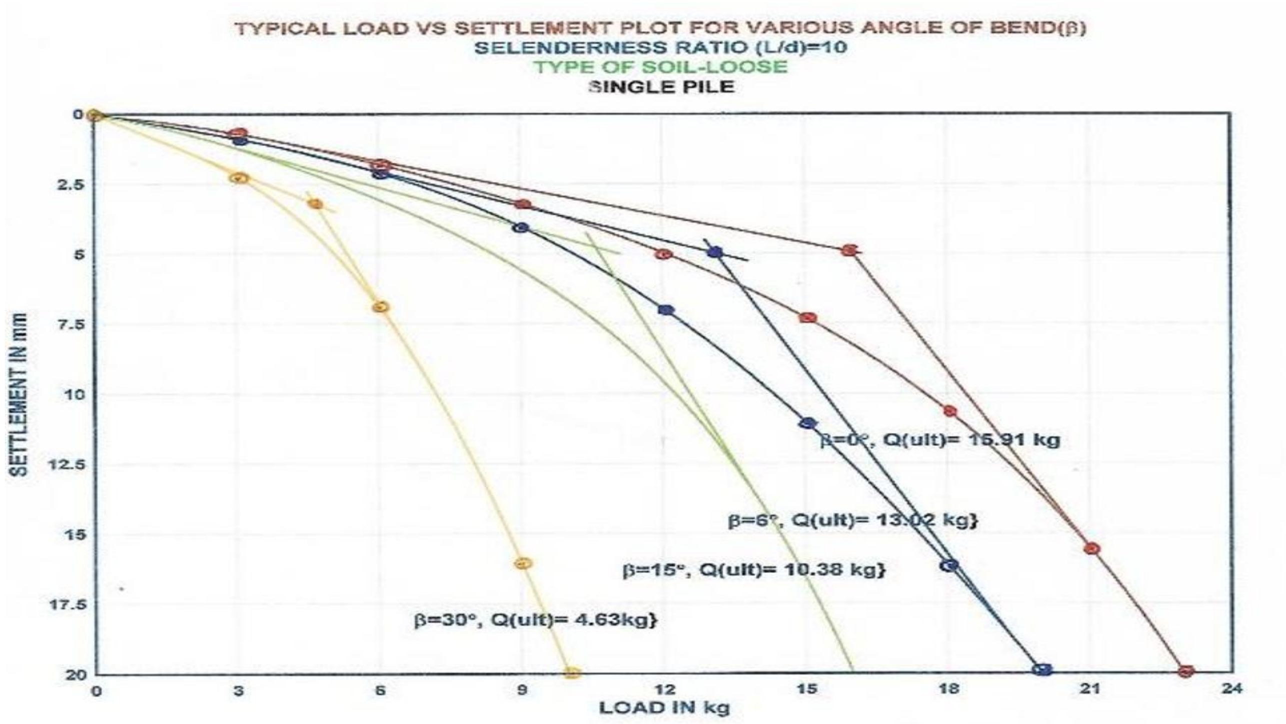
6.2 SINGLE PILE TEST AND LOAD SETTLEMENT BEHAVIOUR

The load settlement behavior for single vertical straight pile and bent piles of different angle of bent embedded in locally available cohesion-less soil have been carried out in the laboratory and test results have been presented on table no:-6.1 to 6.3 and fig no:-6.1 to 6.3.

It is observed from the figure that all cases the safe load carrying capacity is decreasing with respect to increase in angle of bent (β). The numerical value of safe load (Q) is dependent on soil density and slenderness ratio(L/d) of pile.

TYPICAL LOAD Vs SETTLEMENT PLOT FOR VARIOUS ANGLE OF BEND
TYPE OF SOIL: - LOOSE
SLENDERENESS RATIO (L/d) = 10, ONE PILE

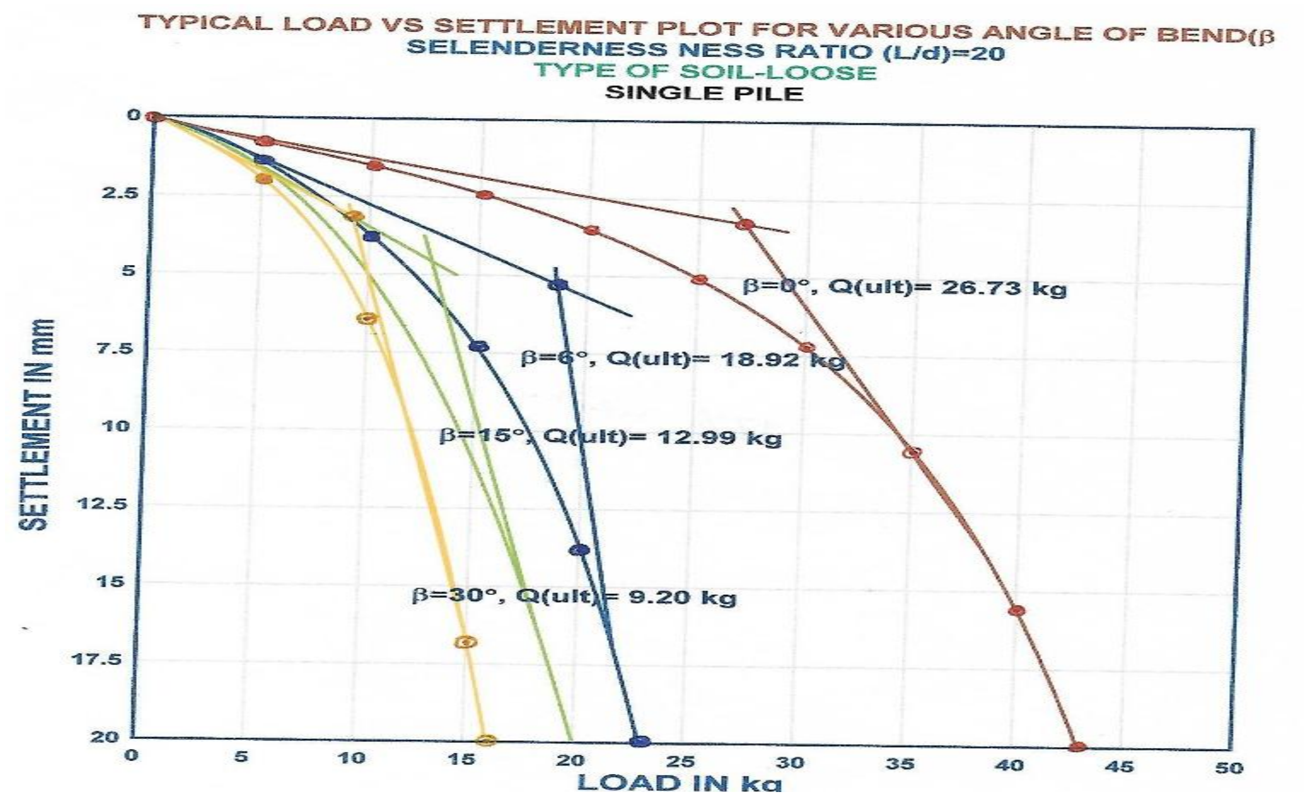
$\beta=0^0$		$\beta=6^0$		$\beta=15^0$		$\beta=30^0$	
LOAD	SETTLE	LOAD	SETTLE	LOAD	SETTLE	LOAD	SETTLE
0	0	0	0	0	0	0	0
1	0.33	1	0.33	1	0.5	1	0.67
2	0.51	2	0.51	2	0.67	2	1.42
3	0.68	3	0.83	3	1.17	3	2.17
4	0.91	4	1.25	4	1.84	4	3.34
5	1.33	5	1.66	5	2.34	5	3.68
10	3.84	10	3.84	10	6.68	8	20
15	7.18	15	11	15	16.54	**Q(ULT)=4.63kg**	
20	13.69	19	20	16	20		
23	20	**Q(ULT)=113.02kg**		**Q(ULT)=10.38kg**			
Q(ULT)=15.91kg							



TYPICAL LOAD Vs SETTLEMENT PLOT FOR VARIOUS ANGLE OF BEND
TYPE OF SOIL: - LOOSE
SLENDERENESS RATIO (L/d) = 20, ONE PILE

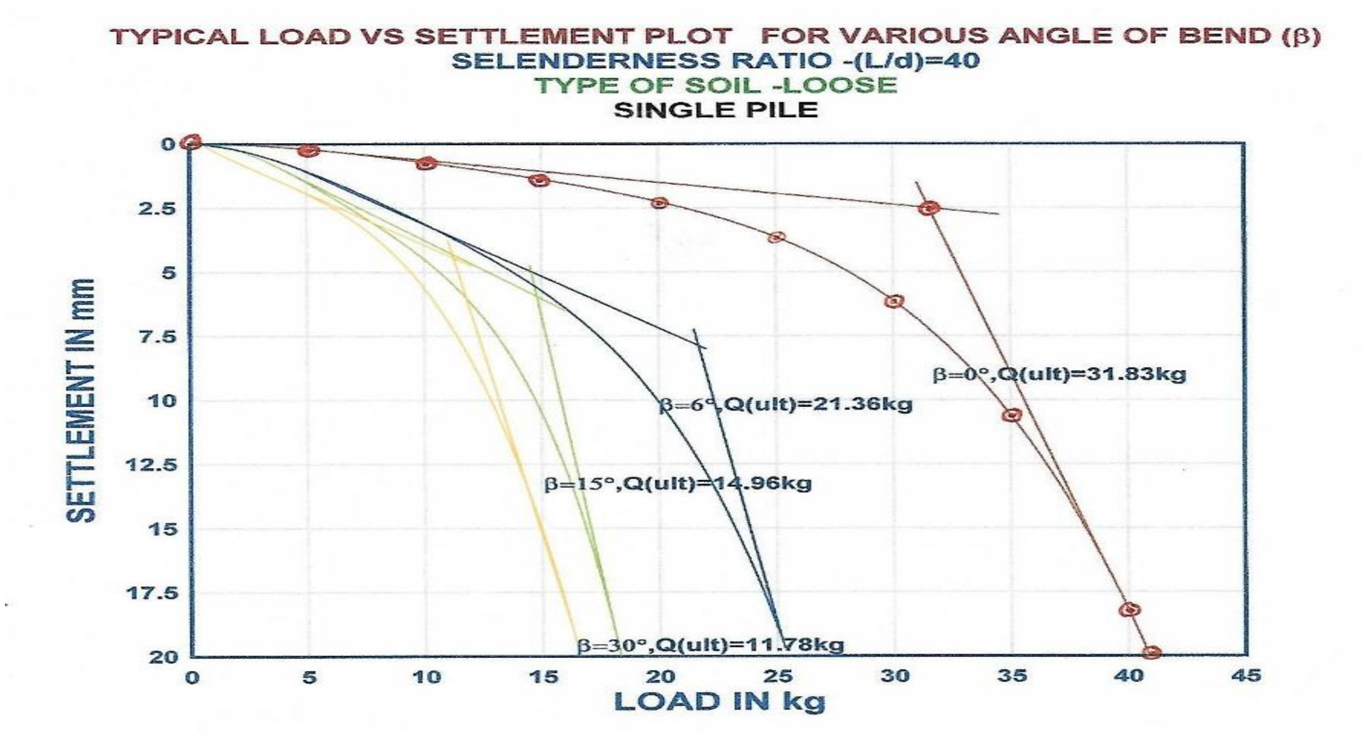
$\beta=0^0$		$\beta=6^0$		$\beta=15^0$		$\beta=30^0$	
LOAD	SETTLE	LOAD	SETTLE	LOAD	SETTLE	LOAD	SETTLE
0	0	0	0	0	0	0	0
10	1.5	1	0.33	1	0.33	1	0.5
20	3.25	2	0.51	2	0.51	2	0.66
30	7.75	3	0.68	3	0.83	3	1.25
40	13.25	4	0.91	4	1.25	4	2.25
43	20	5	1.33	5	1.66	5	3.5
Q(ULT)=26.73kg		10	3.84	10	4.84	10	4.5
		15	7.18	15	11	15	16.53
		20	13.69	20	20	16	20

		23	20	**Q(ULT)=12.99kg**		**Q(ULT)=9.20kg**	
		Q(ULT)=18.92kg					



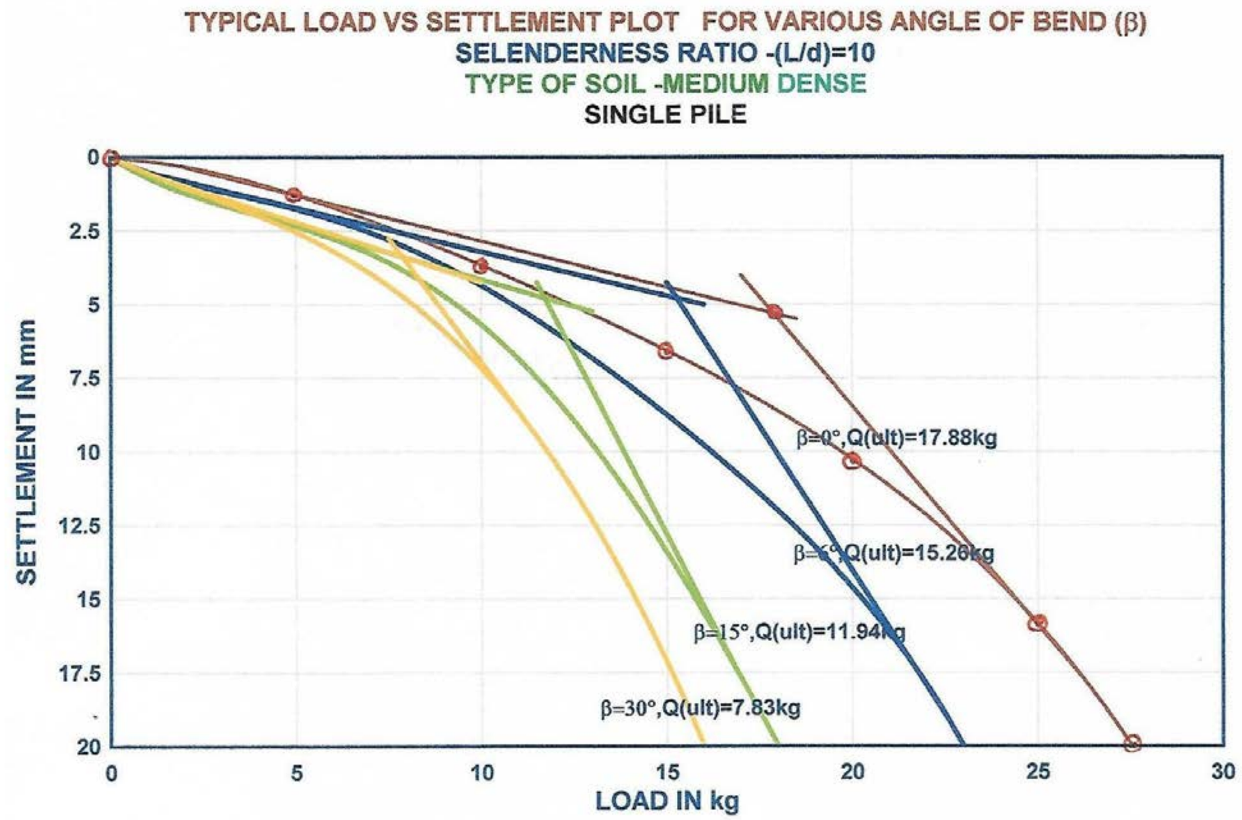
TYPICAL LOAD Vs SETTLEMENT PLOT FOR VARIOUS ANGLE OF BEND
TYPE OF SOIL: - LOOSE
SLENDERENESS RATIO (L/d) = 40, ONE PILE

$\beta=0^0$		$\beta=6^0$		$\beta=15^0$		$\beta=30^0$	
LOAD	SETTLE	LOAD	SETTLE	LOAD	SETTLE	LOAD	SETTLE
0	0	0	0	0	0	0	0
5	0.25	5	1.17	5	1.5	5	1.75
10	0.69	10	2.93	10	4.50	10	5.75
15	1.34	15	5.85	15	10.5	15	11.75
20	2.34	20	8.35	18.33	20	16	20
25	3.75	25	18.5	**Q(ULT)=14.96kg**		**Q(ULT)=11.78kg**	
30	6.01	25.33	20				
35	10.52	**Q(ULT)=21.36kg**					
40	18.54						
41	20						
Q(ULT)=31.83kg							



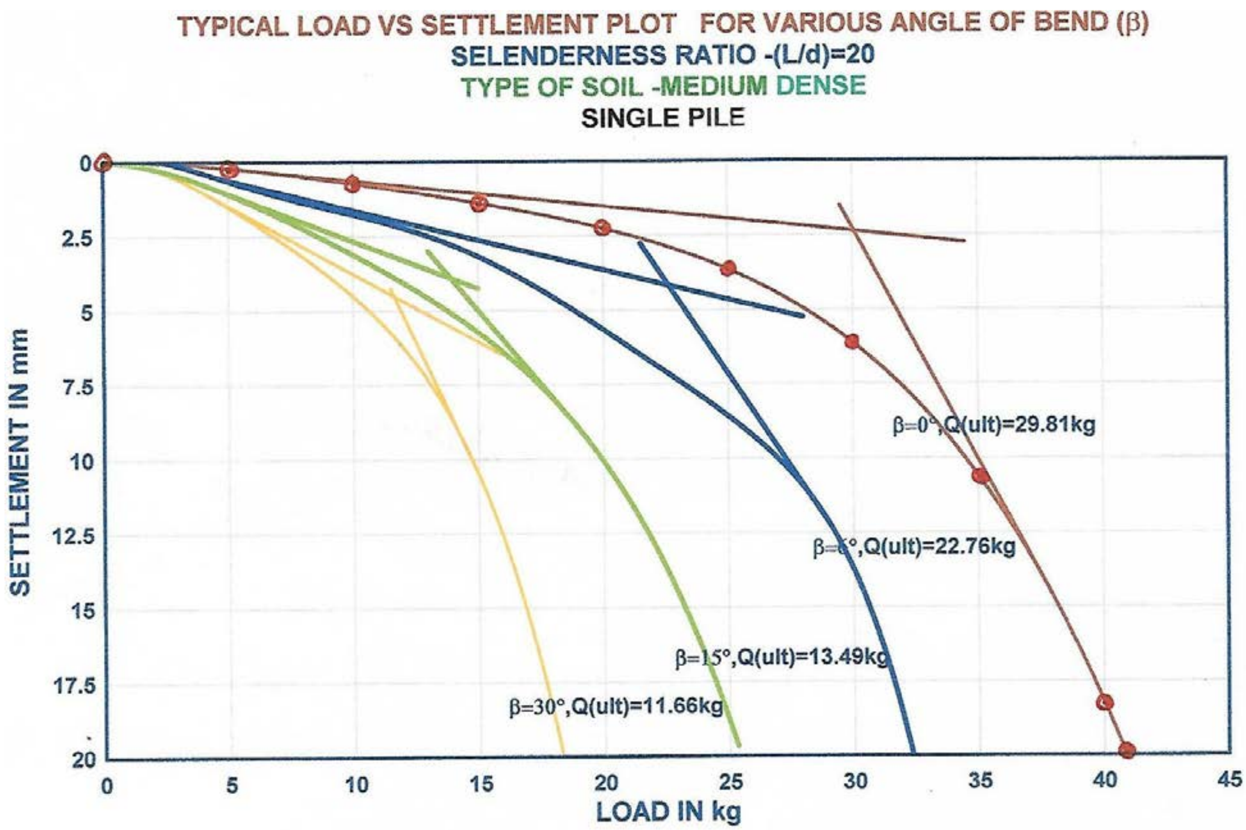
TYPICAL LOAD Vs SETTLEMENT PLOT FOR VARIOUS ANGLE OF BEND
TYPE OF SOIL: - MEDIUM DENSE
SLENDERENESS RATIO (L/d) = 10, ONE PILE

$\beta=0^0$		$\beta=6^0$		$\beta=15^0$		$\beta=30^0$	
LOAD	SETTLE	LOAD	SETTLE	LOAD	SETTLE	LOAD	SETTLE
0	0	0	0	0	0	0	0
5	1.67	5	1.75	5	2.34	5	2.84
10	3.26	10	3.84	10	6.68	10	7.18
15	6.85	15	7.18	15	16.54	15	17.16
20	10.35	20	13.69	18	20	16	20
25	15.70	23	20	**Q(ULT)=11.94kg**		**Q(ULT)=7.83kg**	
27.5	20	**Q(ULT)=15.26kg**					
Q(ULT)=17.88kg							



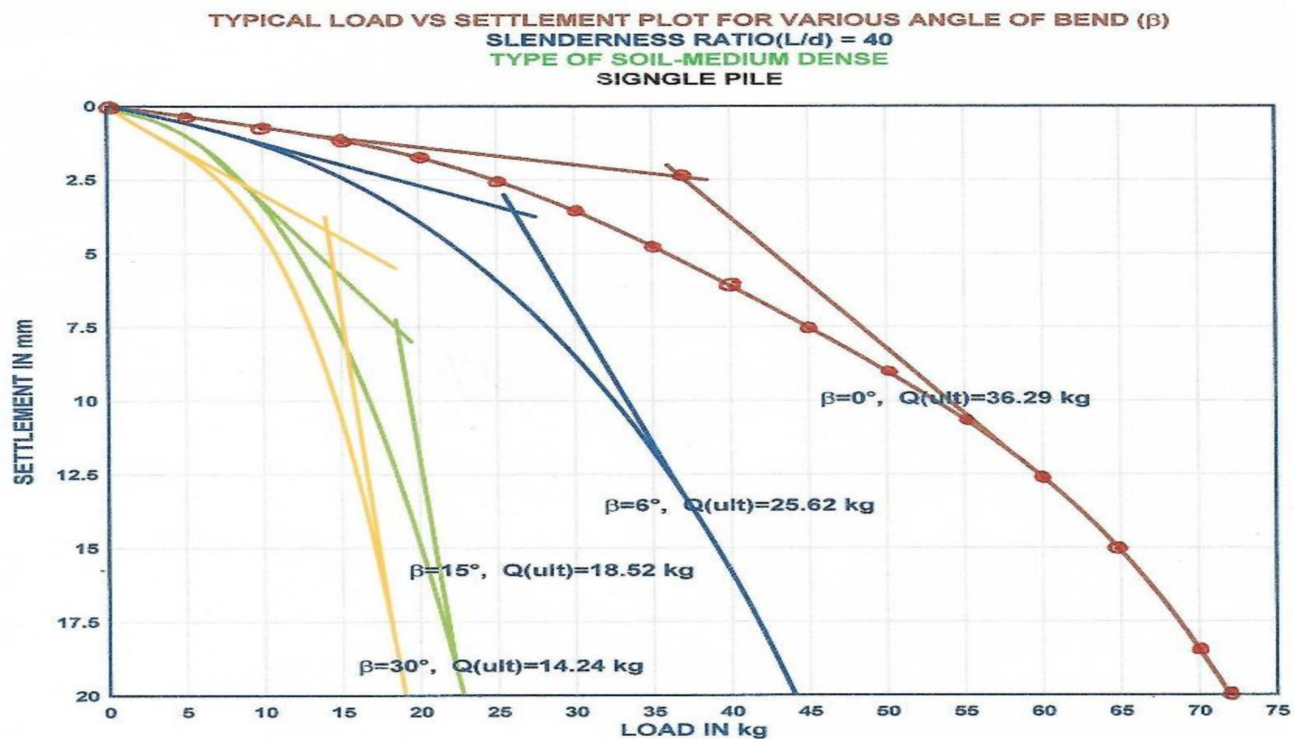
TYPICAL LOAD Vs SETTLEMENT PLOT FOR VARIOUS ANGLE OF BEND
TYPE OF SOIL: - MEDIUM DENSE
SLENDERENESS RATIO (L/d) = 20, ONE PILE

β=0^0		β=6^0		β=15^0		β=30^0	
LOAD	SETTLE	LOAD	SETTLE	LOAD	SETTLE	LOAD	SETTLE
0	0	0	0	0	0	0	0
5	0.25	5	0.66	5	1.17	5	1.50
10	0.67	10	1.67	10	2.92	10	3.76
15	1.34	15	3.20	15	5.85	15	8.35
20	2.34	20	5.51	20	10.02	18.33	20
25	3.76	25	8.68	25	16.78	**Q(ULT)=7.83kg**	
30	6.01	30	13.69	25.33	20		
35	10.52	32.33	20	**Q(ULT)=13.49kg**			
40	18.54	**Q(ULT)=22.76kg**					
41	20						
Q(ULT)=29.81kg							



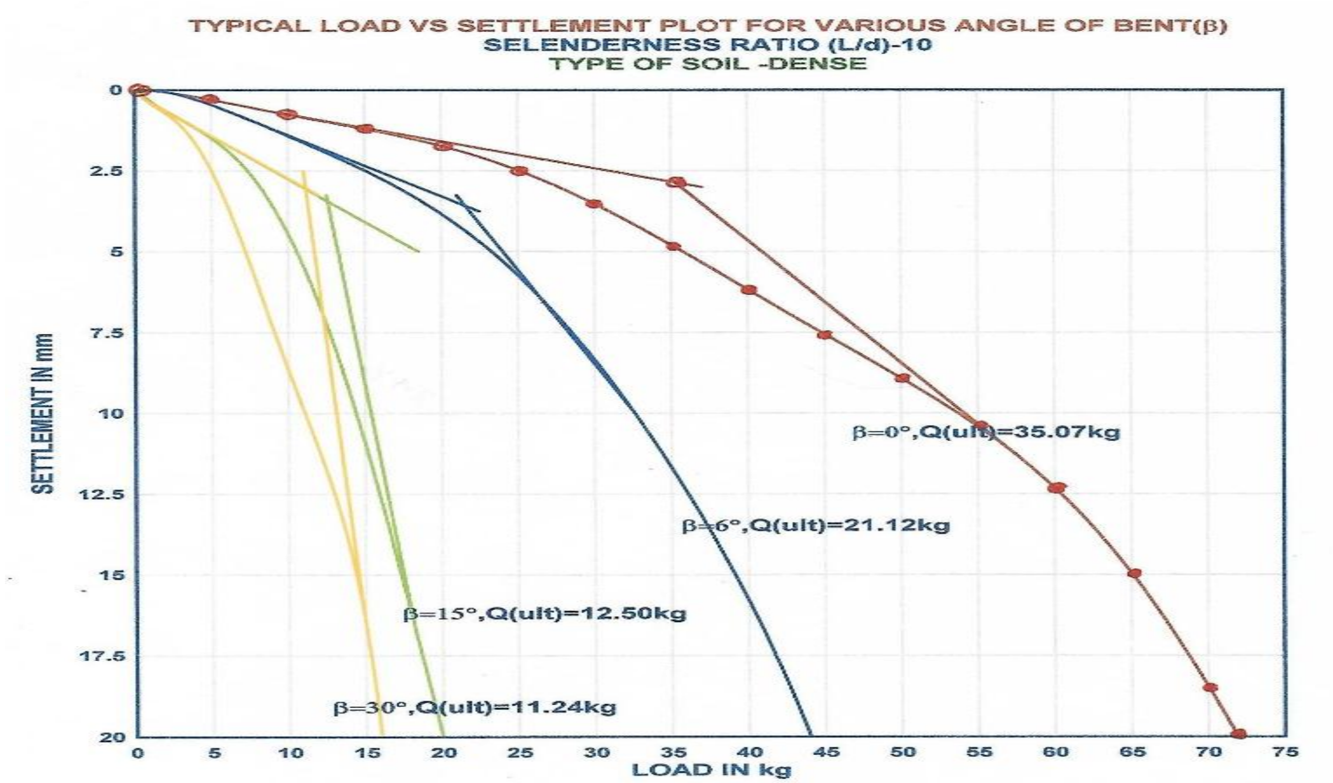
TYPICAL LOAD Vs SETTLEMENT PLOT FOR VARIOUS ANGLE OF BEND
TYPE OF SOIL: - MEDIUM DENSE
SLENDERENESS RATIO (L/d) = 40, ONE PILE

$\beta=0^0$		$\beta=6^0$		$\beta=15^0$		$\beta=30^0$	
LOAD	SETTLE	LOAD	SETTLE	LOAD	SETTLE	LOAD	SETTLE
0	0	0	0	0	0	0	0
5	0.33	5	0.50	5	1.33	5	1.50
10	0.50	10	1.34	10	3.84	10	4.50
15	1.17	15	2.51	15	7.18	15	10.5
20	1.67	20	3.84	20	13.69	18.33	20
25	2.59	25	5.85	23	20	**Q(ULT)=14.24kg**	
30	3.50	30	8.52	**Q(ULT)=18.52kg**			
35	4.84	35	11.86				
40	6.01	40	15.70				
45	7.52	44	20				
50	9.02	**Q(ULT)=25.62kg**					
55	10.69						
60	12.02						
65	15.03						
70	18.54						
72	20						
Q(ULT)=36.29kg							



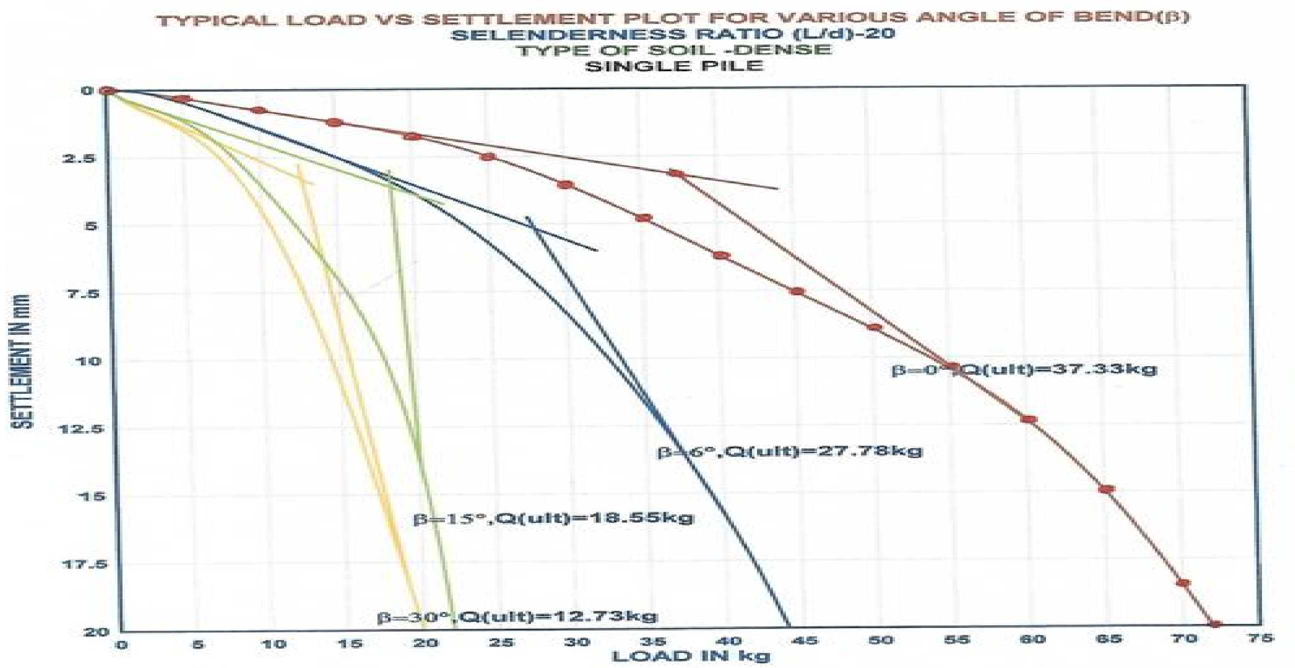
TYPICAL LOAD Vs SETTLEMENT PLOT FOR VARIOUS ANGLE OF BEND
TYPE OF SOIL: - DENSE
SLENDERENESS RATIO (L/d) = 10, ONE PILE

$\beta=0^0$		$\beta=6^0$		$\beta=15^0$		$\beta=30^0$	
LOAD	SETTLE	LOAD	SETTLE	LOAD	SETTLE	LOAD	SETTLE
0	0	0	0	0	0	0	0
5	0.33	5	0.50	1	.33	1	0.5
10	0.50	10	1.34	2	0.51	2	0.67
15	1.17	15	2.51	3	0.83	3	1.17
20	1.67	20	3.84	4	1.25	4	1.84
25	2.59	25	5.85	5	1.66	5	2.34
30	3.50	30	8.52	10	4.84	10	6.68
35	4.84	35	11.86	15	11	15	16.54
40	6.01	40	15.70	20	20	16	20
45	7.52	44	20	**Q(ULT)=12.50kg**		**Q(ULT)=11.26kg**	
50	9.02	**Q(ULT)=21.12kg**					
55	10.69						
60	12.02						
65	15.03						
70	18.54						
72	20						
Q(ULT)=35.01kg							



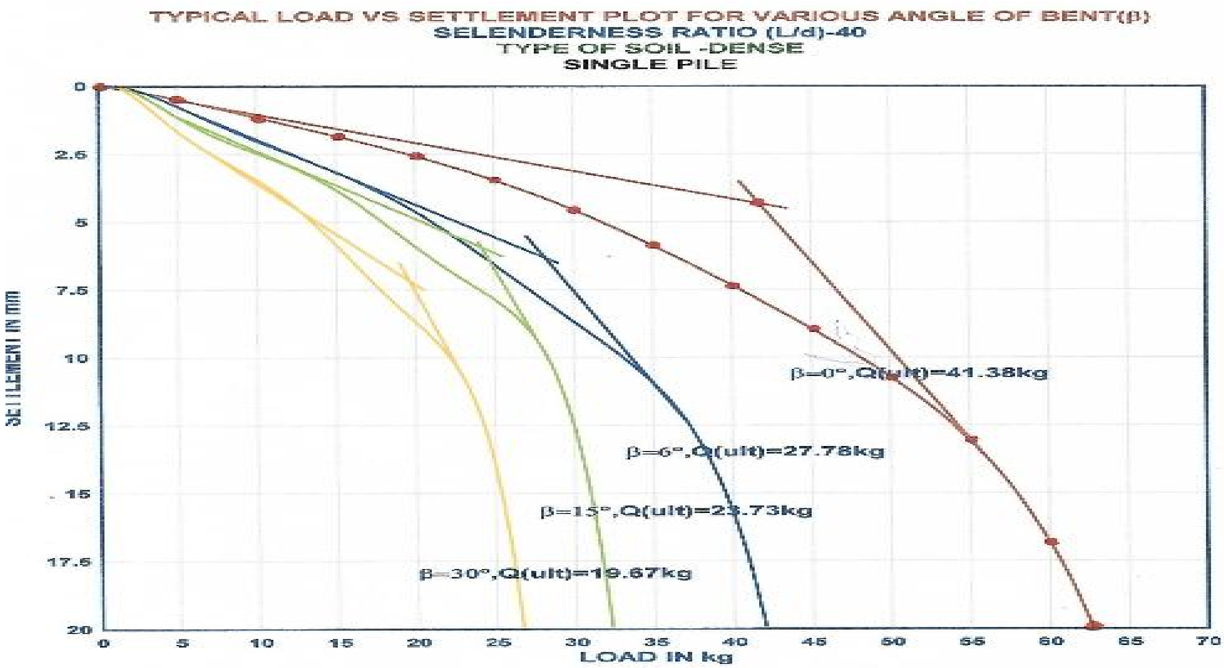
TYPICAL LOAD Vs SETTLEMENT PLOT FOR VARIOUS ANGLE OF BEND
TYPE OF SOIL: - DENSE
SLENDERENESS RATIO (L/d) = 20, ONE PILE

$\beta=0^0$		$\beta=6^0$		$\beta=15^0$		$\beta=30^0$	
LOAD	SETTLE	LOAD	SETTLE	LOAD	SETTLE	LOAD	SETTLE
0	0	0	0	0	0	0	0
5	0.33	5	0.50	1	0.33	1	.33
10	0.50	10	1.34	2	0.51	2	0.51
15	1.17	15	2.51	3	0.68	3	0.83
20	1.67	20	3.84	4	0.91	4	1.25
25	2.59	25	5.85	5	1.33	5	1.66
30	3.50	30	8.52	10	3.84	10	4.84
35	4.84	35	11.86	15	7.18	15	11
40	6.01	40	15.70	20	13.69	20	20
45	7.52	44	20	23	**20**	**Q(ULT)=12.73kg**	
50	9.02	**Q(ULT)=23.73kg**		**Q(ULT)=18.55kg**			
55	10.69						
60	12.02						
65	15.03						
70	18.54						
72	20						
Q(ULT)=37.33kg							



TYPICAL LOAD Vs SETTLEMENT PLOT FOR VARIOUS ANGLE OF BEND
TYPE OF SOIL: - DENSE
SLENDERENESS RATIO (L/d) = 40, ONE PILE

$\beta=0^0$		$\beta=6^0$		$\beta=15^0$		$\beta=30^0$	
LOAD	SETTLE	LOAD	SETTLE	LOAD	SETTLE	LOAD	SETTLE
0	0	0	0	0	0	0	0
5	0.50	5	0.84	5	1.17	5	1.67
10	1.17	10	1.84	10	2.39	10	3.44
15	1.84	15	3.26	15	3.94	15	5.85
20	2.42	20	4.68	20	5.76	20	8.68
25	3.50	25	6.51	25	7.95	25	14.03
30	4.68	30	8.52	30	11.36	26.66	20
35	5.85	35	11.19	32.3	20	**Q(ULT)=19.67kg**	
40	7.27	40	15.53	**Q(ULT)=23.73kg**			
45	8.77	42	20				
50	10.86	**Q(ULT)=27.78kg**					
55	13.19						
60	16.54						
62.65	20						
Q(ULT)=41.38kg							



VI. CONCLUSIONS

It is noted that the behavior of various bent pile tests with respect to load carrying capacity is imaging good and this confirms that contrary to general belief the bent piles have relatively good load carrying capacity. In all cases there is load reduction in capacity with respect to the straight vertical piles.

It was observed that the variation in load reductions are less with respect to variation in angle of bent i.e. 0^0 to 15^0 but the load reduction is large when angle of bent is greater than 15^0 (i.e. 30^0) . Thus, as the bend increases, the load carrying capacity decreases.

The ultimate load carrying capacity is lesser cohesion-less soil for the same type of pile (i.e. same L/d ratio & same angle of bent) than dense soil. But the percentage reduction in load carrying capacity of pile is lesser in loose soil as compared to dense soil. In case of loose soil percentage reduction in load bearing capacity is 33% to 37% and in case of dense soil percentage reduction in load bearing capacity is 38% to 45%.
A bent pile having sharp bent gives more reduction in capacity as compared to piles having long sweep. On the other hand it can be stated that a sharp bend or knuckle is more detrimental than a long sweep.

The load carrying capacity of initially bent piles has great influence of on slenderness ratio. From fig no-4.16 to 4.30, it is noted that the increase in L/d ratio increases the ultimate load carrying capacity. The percentage reduction in ultimate load carrying capacity is lesser for higher slenderness ratio.

From table 4.16 to 4.22 it is observed that the variation of theoretical results and experimental results are marginal. In single pile theoretical load carrying capacity of pile is higher than that of experimental values. The increases of values are within the range of 2.5% to 18% in all cases. In group of piles the trends are observed of similar nature, for two pile group the variation are within the range of 2.75% to 12.5%, for group of three piles 0.80% to 7.50% , for group of four piles 1% to 4% and for group of five piles 0.45% to 4%. These variations incorporate all variables e.g. slenderness ratio (L/d), angle of bent (β) and change of degree of compaction of soil.

The objective of this detail experimental study on initially bent model piles made of wood is to know the behaviour of pile capacity under vertical load. The behaviour of such piles for a range of loading and pile conditions has been presented. This has enabled areas of importance to be identified that will provide a basis for further laboratory, field and analytical study. It is clear that much in foundation or much investigation still has to be done before a full understanding of the behavior of the bent piles can be achieved.

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