Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345 (Online)
An Open Access, Online International Journal Available at www.cibtech.org/sp.ed/jls/2015/04/jls.htm
2015 Vol. 5 (S4), pp. 535-544/Boorboor and Rozbahani
Research Article

DETERMINATION OF CAPACITY LOADING OF DRIVING PILES DEPENDS ON TIME

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ABSTRACT
Loading capacity of deep foundations is usually determined through Static methods, Finite Elements Software and pile loading Test that is most useful (and most expensive) method. Usually in the designing process, at first, the loading capacity of pile is determined through the static analysis or finite element methods and the results are often regarded as the ultimate capacity of pile, while for driven piles these results will be changed because of different causes such as time after pile driving, method of pile driving, driven pile energy, number of hammer hits and type of soil in the site. This study was conducted to investigate the factors influencing on the loading capacity of driven piles from a database contains 72 different Drive-in piles come from different countries, and then the loading tests were carried out on them. Then by the use of data of Drive-in piles in database and by consideration of time factor (t), the proposed relation by this research was presented and then it was evaluated and compared to known Skov & Denver Method; as a result it was declared that there was a fine compatibility between the results. In the next step, and according to increase of the loading capacity of driving-piles, the correction coefficient β has been presented in order to estimate the loading capacity of Drive-in piles.

Keywords: *Capacity Loading*

INTRODUCTION
Determination of loading capacity of deep foundations usually needs static methods, finite element software and pile loading test that is most useful (and most expensive). Designing process includes determining pile loading capacity by using the usual static analysis or finite element methods, and the results of these relationships is often regarded as the ultimate capacity of the pile. (Of course, in some important projects after installation of pile, to ensure the loading capacity, the load test is performed), while for driven piles these results will be changed because of different causes such as time after pile driving, method of pile driving, driven pile energy, number of hammer hits and type of soil in the site. Usually these are not included in the determination of loading capacity of piles; as a result, loading capacity is anticipated very conservative. Meanwhile, most researchers only use the time parameter for Drive-in piles to present some relationships, for example among them Skove & Denver (1988), Svinkin (1996) and Matlock (1990) & Bogard can be cited.
In this study, using time as an effective parameter impacting on loading capacity of Drive-in piles in order to present the proposed relationship as well as correction factor β to determine the optimum loading capacity of pile.

Literature Review
Although a significant increase in the loading capacity of driven piles in sand deposits have been reported by many researchers, but Tavenas & Audy (1972) noted and reported about 70 percent increase of pile-capacity during 20 days for foundation piles of retaining wall on both sides of the river St. Charles and Quebec. Also, Chen *et al.*, (1999) have carried out two case-studies and seen increase of pile-capacity up to 75 and 166 percent during 7 to 33 days after installation. Two other case-studies by Fellenius *et al.*, (2002) (Abdullah and Tuncer, 1995) were carried out and shown increase of parietal capacity up to 86 and 110 percent during 1 to 27 days after installation of open-ended piles in silty sand. Mechanism of increase of capacity of piles installed in sands couldn’t be explained through amortization of additional pore water pressure due to driving process; because full pore pressure equalization within hours or a few days is expected.

Mechanisms related to setting particularly for piles driven cohesionless soils are not understood specifically. Schmetmam (1991) and Chow *et al.,* (1997) stated that long-term setting for piles driven in cohesionless soils can be attributed to both following factors (Alawneh *et al.,* 2009):

1- Stress Relaxation (creep) in an arc surrounding soil that leads to an increase in horizontal effective stress on the pile wall.
2- Soil Aging leads to an increase in stiffness and Dilatancy of soil.

Both mechanisms, immediately begins after pile set-up. However, it remains unclear which of the mechanisms under different conditions prevail and how long this process will continue.

Komurka *et al.,* (2003) divided setting mechanisms into three stages (Chen *et al.*, 1999):

a) Eliminated non-linear logarithmic ratio of excess pore water pressure (phase 1)

b) Eliminated linear logarithmic ratio of excess pore water pressure (phase 2) and

c) Independent effective stress (phase 3).

Period of elimination of pore water during the initial phase (non-linear) is not constant relative to intervals for some phases. Period of nonlinear elimination depends on soil and pile. For example, if the soil has lower permeability, the greater volume of soil can be displaced through pile; thereby non-linear elimination will be prolonged.

A similar situation also occurred in lower permeable piles. In phase 2, speed of elimination can be constant with time. Displaced soil, will tolerate increase of horizontal and vertical effective stresses, which lead to consolidation and increase of shear strength.

Elimination of excess pore water pressure in clean sands may have occurred rapidly and continue for several hours.

On the other hand, more time is needed to fully elimination in cohesionless soil. Linear logarithmic elimination in clay soil could be continued during several weeks, months or even years (Fellenius and Altaee, 2002).

Geotechnical capacity of piles is usually estimated by static relationships and then is confirmed through pile loading test.

Pile loading test is often done immediately after its set-up, and most of capacity obtained by loading test shall be considered as a long-term capacity.

However, during pile driving, the soil around the wall and into the top of pile may have high corrosion.

Studies have shown that the methods with higher corrosion of surrounding soil leave a negative influence on loading capacity (Fellenius and Altaee, 2002). Increase in pore water pressure could be an auxiliary force which is the result of pile driving process.

Depending on permeability of underlying soil, period of elimination of excess pore water pressure will change. At the time of pile loading test if there is excess pore water pressure, pile loading capacity should be considered negligible. If strength of soil around the piles due to reconsolidation is increased, pile loading capacity will be increased. For soils with low permeability, such as silt and clay, this is a normal phenomenon.

For grained-soils with high permeability, fully amortization of excess pore water pressure usually takes a few hours to several days.

Although some results have shown that even through fully amortization of pore water pressure, there is a tendency to increase the pile loading capacity. Awareness of the pile capacity after a prolonged period of time is very important for suitable designing, construction and cost-estimation of pile foundations particularly after the initial driving.

A brief description of factors effect on loading capacity of Drive-in piles has been rendered as follow, and effect of these factors on loading capacity has been explained. Effect of some factors on loading capacity such as setting and soil plug has been expressed by 2nd chapter.

Here, potential problems of piles construction has been found and suitable constructing processes will be determined. It is necessary to say that fields of problems couldn't be expressed in detail in form of a thesis because of large extent of problems.

Factors Affecting on Loading Capacity of Driving-Piles

1. Lack of adjusting of weight of hammer ratio to height of fall.
2. Lack of adjusting of driving force based on type of soil and pile.
3. Operator's skill for piling process.
4. Soil aging.
5. Stress Relaxation
6. Length of pile.
7. Diameter of pile.
8. Problems before pile set-up such as problems of carrying and preserving of piles.
9. Cracks in pile body.
10. Excess driving and damage tip of pile.
11. Appearance of problems on the ground because of inaccuracies of geotechnical studies.
12. Effect of soil plug on the loading capacity.
13. Flat or conical tip of piles. (end bearing pile could be driven easier than plane piles).
14. The points in which pile become longer, if not controlled properly or connections are not organized properly then a reduction in the capacity will take place.
15. Amortization of pore water pressure
16. Permeability and soil particle size
17. Pile spacing
18. Pile Driving order
19. Displacement of surrounding soil because of piles set-up adjacent to each other: resulting in damage to piles which have been recently installed or concreted.

MATERIALS AND METHODS

Methodology

The study gathered practical cases and used multiple and geotechnical data, and compared static relationships such as a uniting method, α and β, loading capacity of piles in database and the results of static and dynamic loading tests.

Then, by consideration of time factor (t) a relation for driving-piles was proposed and has been compared with Skove & Denver relation that is for estimating the setting; thus its accuracy has been evaluated and finally correction coefficients of this study for driving-piles will be suggested.

According to efficiency of loaded tests and progress of analytical and experimental relations and use of them in designing process and reduction of costs; a database has been collected by gathering of different operational cases in this study.

In this database, 71 cases of driving-piles have been collected on which the static and dynamic loading tests have been done in the past decades and recent years in various countries.

The piles include 31 pre-stressed concrete piles, 26 opened-end steel tubular piles, 10 closed-end steel tubular piles, two single-wall piles, one prefabricated circular pile, one thin wall tubular pipe, and one thick wall tubular pile. This information formed the basis of the studies in this chapter.

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Table 1: Data base of study

Reference	No.	Pile type	length)m(	diameter)mm(	Calculated capacity Total capacity	Tip capacity	Parietal capacity	Time (day)	1. Tested capacity Tip capacity	Parietal capacity	Total capacity
Chen *et al.*, 1999 (Fellenius *et al.*, 1992)	1	**Prefabricated reinforced concrete circular pile**	36	350	1154	1349	2503	30	-	-	3030
Fellenius *et al.*, 2002 (Fellenius *et al.*, 1989)	2	Steel tubular pile	16/5	320	614	572	1186	27	600	1200	1800
	3		16/5	457	1220	806	2026	27	900	1500	2400
Jardine *et al.*, 2007 (Fellenius *et al.*, 1989)	2. 4	**Steel tubular pile**	26	457	570	585	1155	17	579	2055	2634
Svinkin 2002 (Fleming *et al.*, 2009)	5	**Pre-stressed concrete**	24/5	610*610	468	1097	1565	18	-	-	1672
	6		34/2	270	401	891	1292	18	-	-	1730
	7		34/2	270	401	891	1292	25	-	-	2025
	8		35/7	270	429	1052	1481	20	-	-	2445
	9		36/6	270	446	1154	1600	21	-	-	2455
	10		36/6	270	446	1154	1600	14	-	-	1710
	11		34/4	300	523	1132	1655	26	-	-	1940
Fellenius *et al.*, 1992 (Jardine *et al.*, 2007)	12	**Closed-end steel tubular**	35/1	270	418	986	1404	20	300	2100	2400
	13		36/6	300	550	1282	1833	17	6	2179	2185
	14		34/1	300	493	978	1471	13	-	-	2060
	15		33/5	300	479	910	1389	26	780	1610	2390
	16		35/5	300	525	1144	1669	11	-	-	1710
	17		33/5	300	393	910	1303	22	-	-	2070
	18		36/6	300	446	1154	1600	18	-	-	2000
	19		37/5	270	463	1260	1723	25	-	-	1890
Fellenius *et al.*, 1989 (Ng *et al.*, 2010)	20	Steel tubular piles	36/9	324	1005	1535	2540	5	1303	2268	3572
	21		33/9	324	920	1253	2174	7	779	2027	2806
	22		46/8	244	729	1983	2713	6	786	2868	3654
	23		42	244	652	1556	2209	9	855	2593	3448
	24		31/8	244	488	807	1295	12	1262	1738	3000
	25		42/6	244	662	1607	2268	1	634	2537	3172

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Study of Effect of Aging on Loading Capacity of Driving-Piles

As shown in Figure 1, time is limited to 30 days, because the loading test for installed piles in sand shouldn't be done less than 7 days (Svinkin, 2002), as well as Seed & Reese, Vesic, (1980) Thorburn & Rigden (1977), have reported maximum increase in pile loading capacity during the first 30 days (Svinkin, 2002). This is given in regulations of PN-83/B-02482 and Table 1. Given that most researchers have proposed the interval time between 7 to 30 days to recover the driving-pile loading capacity, as a result the correction coefficient β for achieved capacities in this area will be provided.

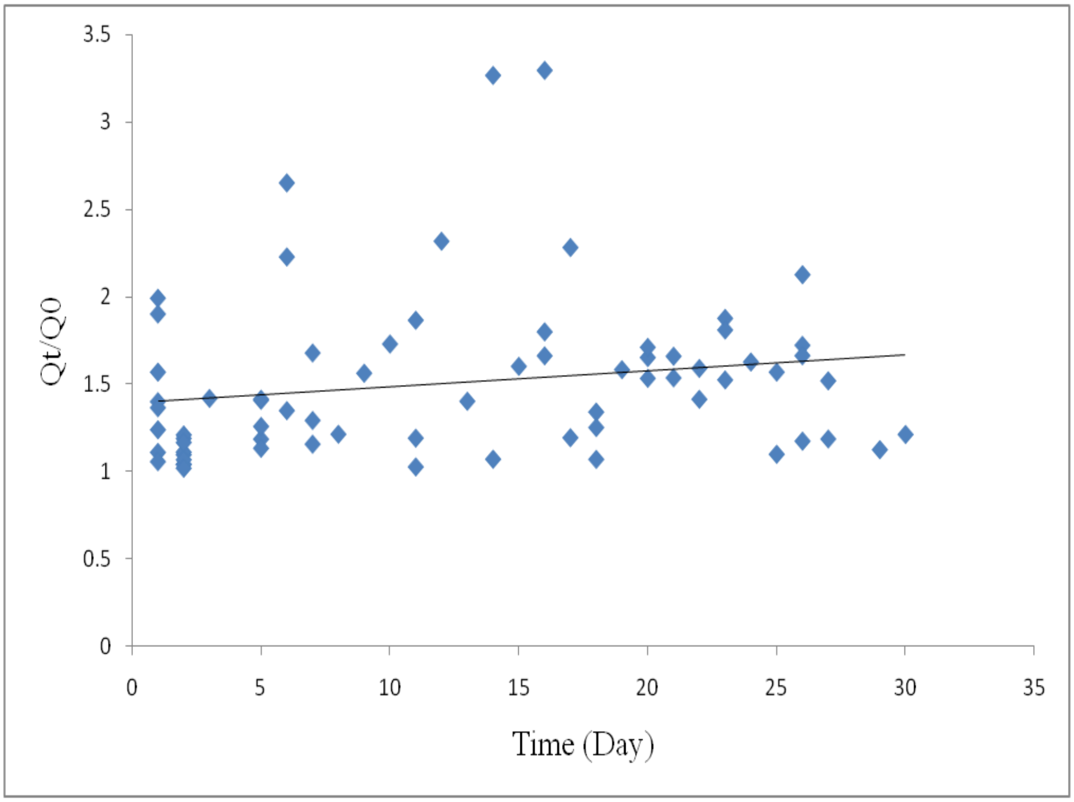

Figure 1: Qt/Q0 toward Time

Figure 2 clearly shows that the pile loading capacity increased with time. Increase value of the pile loading capacity, as shown in 4.4, was significant for some cases and may be more than 300% of initial pile capacity, after end of the initial driving. This suggests that the impact of set-up should be considered in designing process carefully. If the impact of set-up is considered, a reduction in depth and diameter of pile, and a reduction in size of piling equipment will be obtained which leads to cost savings in deep foundations.

Table 2: Interval time between pile set-up and static loading tests (Svinkin, 2002)

Piling method	**Soil type** **Cohesionless**	**Cohesion**	
Driven-in	7 days	20 days	30 days
Bored	30 days	30 days	30 days

During the studies about data in database it can be seen that 85 % of cases showed increase of parietal capacity during time of 1 to 30 days, from 1.44 to 4.25 times of the initial capacity.

However, 55% of cases showed reduction of loading between 1.14 to 91 times of the initial capacity and remaining 45% of cases showed increase of capacity between 1.01 to 2.6 times the initial capacities.

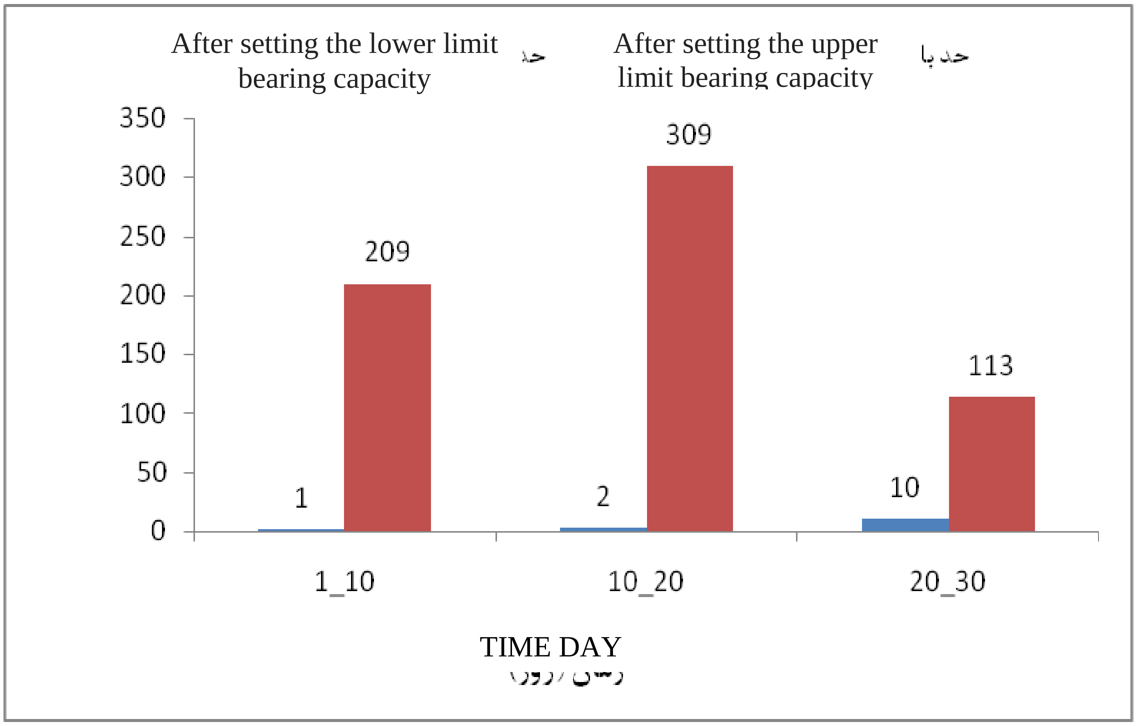

Figure 2: Percentage of increase of loading capacity over time

Review of static relations by limit method can be concluded that the coefficient β and Nt are used to determine loading capacity of Drive-in Piles. Since Nt is effective in capacity of tip, and because capacity of tip of Drive-in piles not only changed over time, but decreased in most cases, it can be concluded that total capacity can be increased if parietal capacity is increased and coefficient β is changed. Due to constant parameters in the formula of pile loading capacity such as pile dimensions, soil layers a logical and justified conclusion could be achieved. In continue coefficient β before and after setting will be discussed.

Correction Coefficient B for Canadian Foundation Regulations – Drive-In Piles

To obtain a pile loading capacity, at first coefficient β was obtained from Table 2 and then loading capacity was obtained as shown in the table below. Because most studied soils are fine-grained sands with low-mean density, so reconsolidation of soil around the pile after driving and pile set-up reconsolidation will be taken place, that it leads to increase soil strength; so for this reason pile loading capacity will be increased.

According to studies of capacity and static test during time spending and based on a statistical study, as shown in Figure 3, of 71 case studies, 31 cases were tested in an interval of 1 to 10 days after piling, 19 cases were tested in an interval of 10 to 20 days after piling and 22 cases were tested in an interval of 20 to 30 days after piling.

Table 3: Nt and β for piles in various soils based on uniting method

Soil type	**Angle φ**	**Bored-piles**		**Drive-in piles**	
		β	**N_t**	**β**	**N_t**
Clay	25-30	0.25-0.32	3-10	0.25-0.32	3-10
Silt	28-34	0.2-0.3	10-30	0.3-0.5	20-40
Soft sand	29-31	0.2-0.4	20-30	0.3-0.8	30-80
Mean sand	32-42	0.3-0.5	30-60	0.6-1	50-120
Condensed sand	39-41	0.4-0.6	50-100	0.8-1.2	100-120
Gravel	35-45	0.4-0.7	80-150	0.8-1.5	150-300

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In addition, Figure 4 also shows that during the first 10 days, only 7 tested piles showed higher than 50% increase in loading capacity, and other 24 piles showed lower than 50%. During 10-20 resting days, increase of loading capacity has been got higher. Finally, during 20-30 days, increase of loading capacity were continued and among 22 studied samples, 19 samples showed higher than 50% and only 3 samples showed lower than 50% increase of loading.

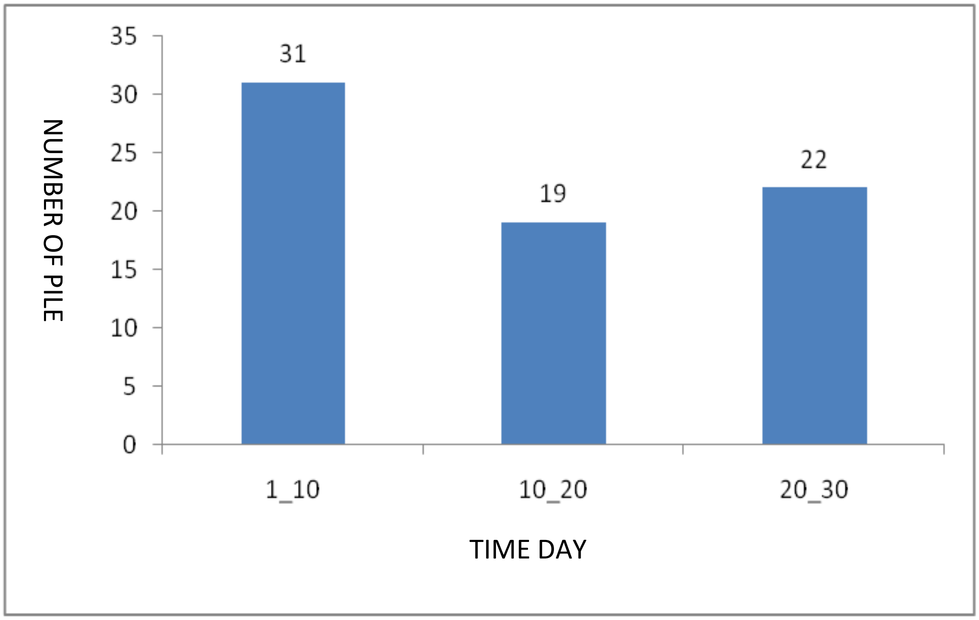

Figure 3: Number of tested piles during 30 days

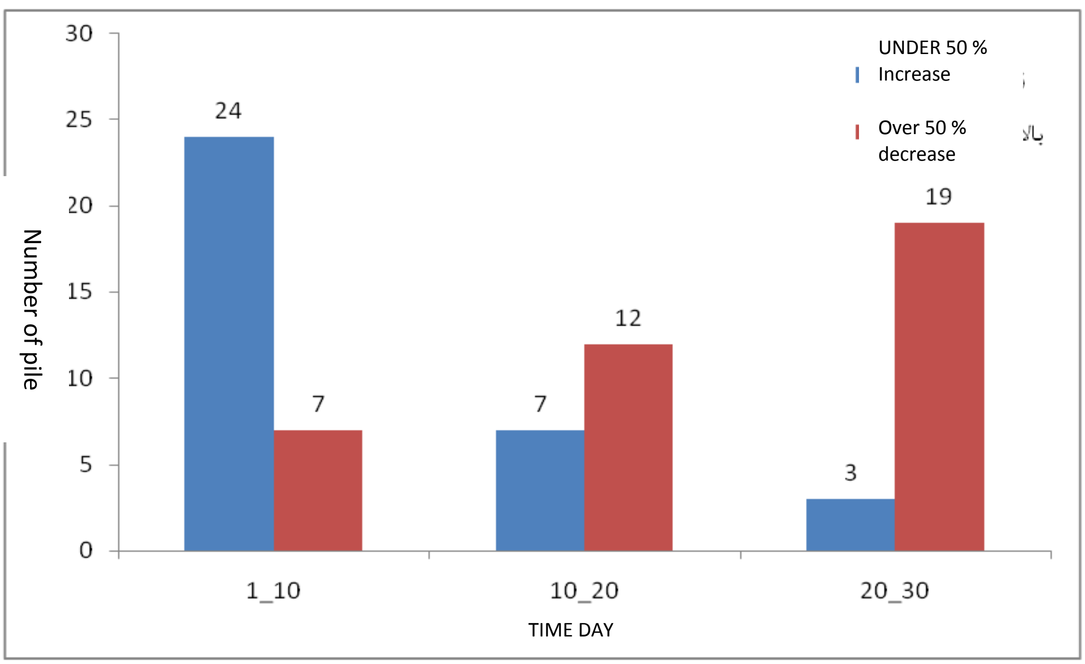

Figure 4: Number of piles that are below 50% or above 50 % loading during 30 days

Finally, Figure 5 also plotted. By looking at Figure 5, it can be concluded that the majority of the increase in pile loading capacity in the range of 1% to 80 % is compared to the initial loading. According to Database (Table 3) and Figure 4, it is observed that most piles were processed by loading tests within 1 to

10 days showed increase in loading up to 20 %; since this time is not sufficient to show the loading with passing of time, it is abandoned.
Since at least increase of loading capacity was 20% of initial capacity and the maximum increase of loading capacity is 80% of initial capacity; so correction coefficient β will be proposed 20% to 80% of initial loading capacity in regards to resting time for piles.

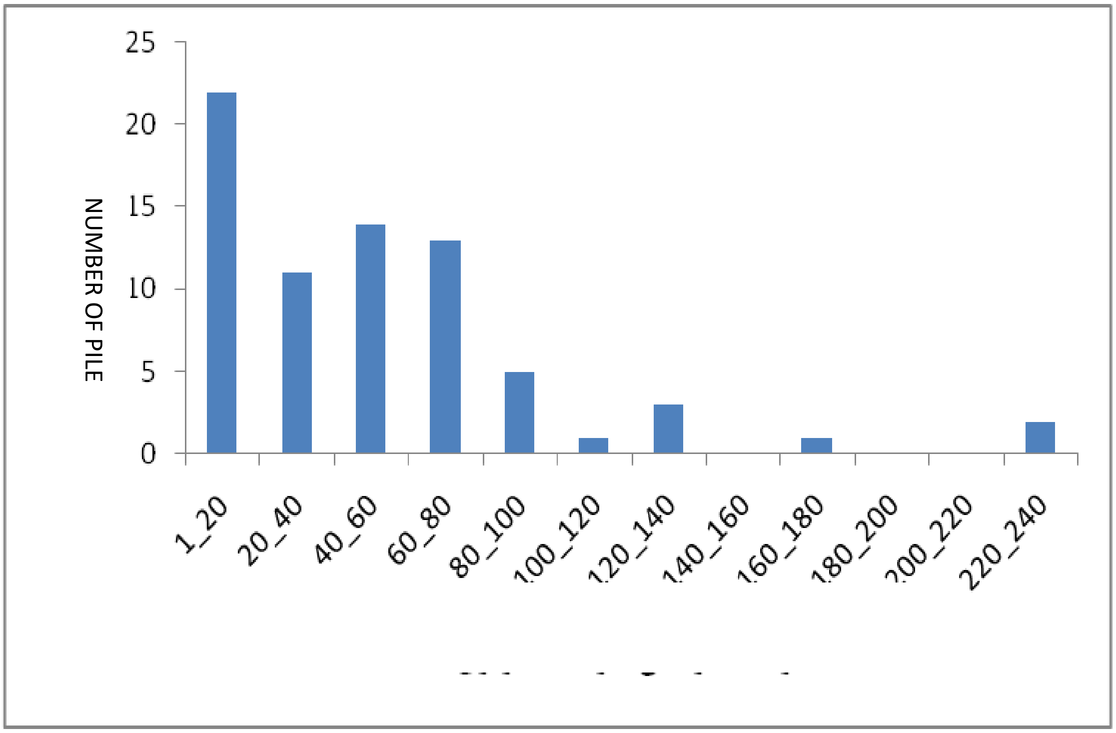

Figure 5: Percentage of increase in pile loading capacity

Parietal capacity can be obtained by the use of correction coefficient β.
r_s =(1.20 to 1.80) β(1-4)
in which
$\sigma'_{z=Df:}$ Effective stress at level of bottom of pile
And β is obtained by Table 2 for Drive-in piles.

Relationship of This Study

By analyzing of Database and by considering of time (t) and based on anticipated capacity (Q0) with Excel software a relation has been derived that is given in Table 4. It was compared with Skove & Denver relation in Table 4-5.

Table 4: Relationship of the study

$Q_t/Q_0 = 0.009t + 1.280$ $Q_t = (0.009t + 1.280)\, Q_0$	Relation (1) based on time (t)

In which
Q_0: Loading capacity is calculated using the static relationships
Q_t: Loading capacity measured using static and dynamic tests
t: time basis after initial piling per day
Statistical analysis of the collected database show that time interval between piles set-up and loading apply is the most important factor influencing on loading capacity. Hence, the decision to postpone piling is difficult until obtaining the results of static loading test.

Following table shows loading capacity with available data in the literature have been calculated by static relationships. Then tested loading capacity was achieved through related papers. It can be seen that in most cases tested loading capacity is greater than the calculated capacity due to setting phenomenon. The next step is to predict more accurately the capacity setting, with statistical analysis and taking into account the time parameter, Equation 1. was obtained from Figure1. By comparing the results obtained by the proposed equation, the results of loading tests and the results of the well-known Skove & Denver relation can be seen that there is a proper adapt between both relations and loading tests. Also Table 5 shows different rates of loading capacity and the static test.

Table 5: Calculation of loading capacity based on different relations (validation of the proposed relation)

Loading capacity based on Skove&Denver	Loading capacity based on formula	Calculated capacity	Tested capacity
2117	2302	1669	1710
3299	3619	2713	3654
2405	2923	2268	3172
1151	1311	851	956
681	747	560	1247
3961	4465	2949	4900
1246	1390	935	1691
922	1068	822/7	900

According to studies about Drive-in piles; in this study it was observed that the largest number of Drive-in piles include diameters ranging from 200 to 400 mm and showed that in conventional construction processes the piles with above diameter are used mostly. Most Drive-in piles have 15 to 40 m length (10 to 15 m and 30 to 40 m). Drive-in piles mainly have higher parietal capacity, so they have low diameter and high length, and high limits for length and diameter are also quite reasonable and justified.

CONCLUSION

Loading capacity of Drive-in piles has been increased along time passing. In some cases, increase of loading capacity has been significant and may be become more than 300% of initial capacity after initial piling. This suggests that the impact of set-up should be carefully considered in the design. If you consider the impact of set-up, depth and diameter of pile, and also size of piling equipment will be reduced, which leads to cost savings in deep foundations. It was concluded that most setting capacity will be achieved during the first 30 days, after which, with the passage of time, the loading capacity will be increased slowly.

The study found that if rest-time increases then pile loading capacity will increase. The studied piles showed that during the first 10 days, only 7 of tested piles had more than 50 % increase in loading capacity; and 24 of piles showed lower than 50% increase. Increase of loading capacity was continued during 10-20 resting-days, because among 19 cases, 12 of them showed more than 50% increase and 7 cases showed lower than 50%. Finally increase of loading capacity has been continued during 20-30 days, so it was observed that among 22 studied cases, 19 of them showed more than 50% increase in loading capacity and only 3 cases showed lower than 505.

According to studies about data in database, it has been observed that 85% of cases showed increase of parietal capacity between 1.44 to 4.25 times of initial capacity during 1 to 30 days. However, 55% of cases showed decrease of loading between 1.14 to 91 times of initial capacity and 45% of remaining showed increase of capacity between 1.01 to 2.6 times of the initial capacity. Therefore it can be concluded that increase in ultimate pile loading capacity is due to increase of parietal loading capacity.

5. Most predicted capacities by this study, has been obtained by (CFEM) method. The results showed that predicted capacities are close to the measured capacities. Suggested that methods noted by regulations

and handbooks are used to estimate loading capacities; because these methods present more desirable results as what mentioned by this study.

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