BEHAVIOUR OF VARIOUS TYPES OF PILES IN A STIFF CLAY

COMPORTEMENT DE DIFFERENTS TYPES DE PIEUX DANS UNE ARGILE RAIDE

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SYNOPSIS The paper describes a pile loading and extracting test programme which was carried out to investigate the degree of mobilization of the undrained shear strength as adhesion along various types of piles driven into stiff clay. Timber, concrete and steel tube piles were tested. An attempt was also made to determine the influence of the taper of timber and concrete piles as well as of the protruding end plate of steel tube piles. The change with time of the degree of mobilization of adhesion along the shaft of a number of piles was also investigated. The findings are discussed and certain conclusions drawn. It is believed that these conclusions are generally valid in cases with comparable subsoil conditions and where the same pile types, pile lengths and pile driving procedure would be used.

INTRODUCTION

When called upon to make the prediction on the bearing capacity of piles driven into stiff clays, foundation engineers face one of the toughest tasks of their professional activity.

Most of the available evidence and records seem to indicate that there is an upper limit of adhesion mobilized along the pile shaft. This adhesion appears to be independent of and always smaller than the undrained shear strength of stiff to very stiff clays, Meyerhof (1951), Meyerhof and Murdock (1953), Woodward, Lundgren and Britano (1961), Tomlinson (1957), Peck (1958). There is, however, also some evidence that in the case of timber piles the adhesion is almost equal to the undrained shear strength of the clay as reported by Lo and Stermac (1964).

Dimensional and physical details of piles have no doubt an important bearing on the measured capacities. The time factor has also been shown to play a significant role. Yet many more well documented case histories are needed to enable an accurate and reliable evaluation of the contribution of each of these factors towards the ultimate bearing capacity of piles.

TESTING PROGRAMME

The opportunity to carry out a reasonably extensive pile load and extraction testing programme presented itself during 1964 and 1965 in connection with the extension of Hwy. 400 within the limits of Metropolitan Toronto.

A testing programme was originally (1964) conceived with the following purposes:

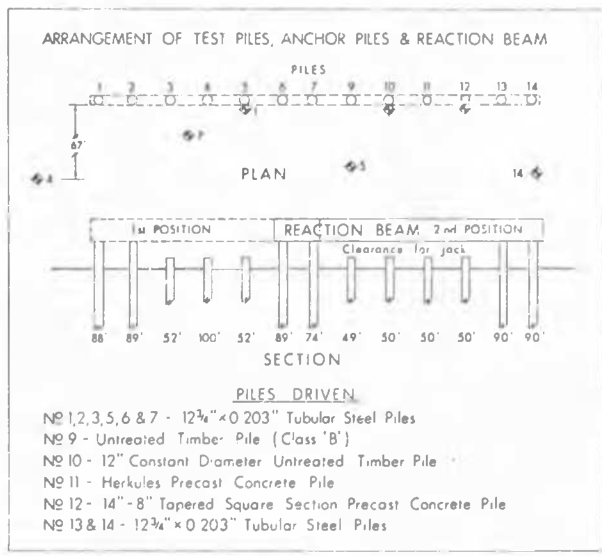

Fig. 1 - Testing Arrangement

(a) To measure and compare the adhesion along the pile shaft of steel tube and timber piles, and

(b) To investigate the effects of the standard protruding plate on steel tube piles.

In 1965 this programme was extended to:

(1) Include concrete piles in the comparison mentioned under (a) - 1964.

(2) To investigate the effect of the taper of timber and concrete piles, and

(3) To investigate the possible change of adhesion along the pile shaft with time.

The testing arrangement is shown in Fig. 1. The reaction beam system was used, the beam being shifted from one set of piles to the other.

SUBSOIL CONDITIONS

The site was the intersection of Hwy. 400 and Jane Street where an extensive subsoil investigation was carried out.

The borehole log representing the typical subsoil conditions is shown on Fig. 2.

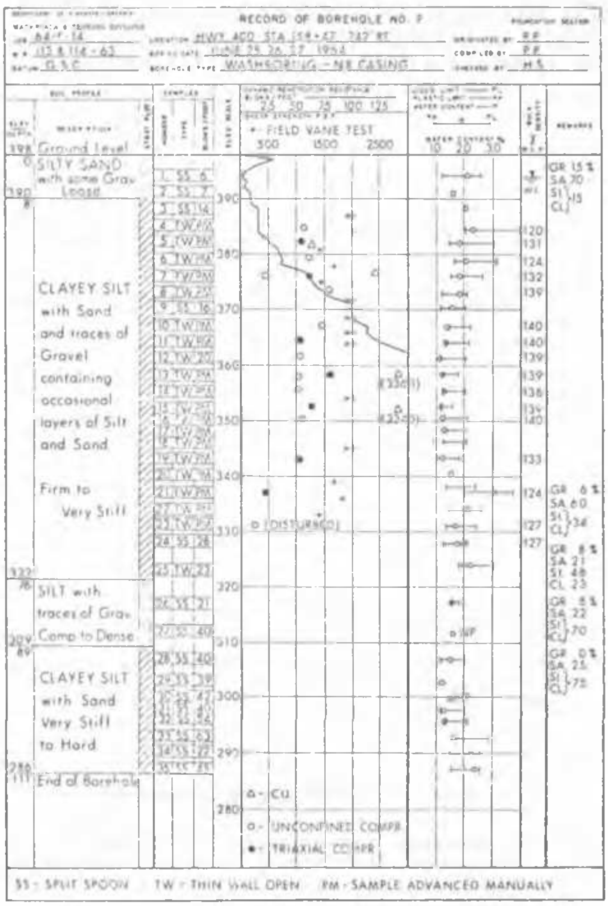

Fig. 2 - Typical Borehole Log

The upper 8 ft. is silty sand with gravel and occasional clay seams. The "N" values of this layer are 6 - 7 blows/ft. Underlying this layer down to approx. 76 ft. is a deposit of clayey silt with sand and traces of gravel, containing occasional seams of silt and sand. More plastic in its upper 10 - 15 ft. it becomes less plastic with depth to about 60 ft. below ground level from where it again becomes slightly more plastic. The liquid limit of the mid portion of this layer, some 35 ft. is slightly in excess of 20% with seams of material with a lower liquid limit. The natural moisture content within this particular zone is at the plastic limit.

The liquidity index of the somewhat more plastic upper and lower zones is around 0.5.

Field vane tests of the upper and lower zones of this layer are between 1,500 and 2,000 psf, while in the mid portion they are in excess of 2,000 psf. Unconfined compression tests as well as unconsolidated undrained triaxial tests produced values of the undrained shear strength between 1,000 and 1,500 psf. Two consolidated undrained shear strength measurements gave values of 3,360 and 3,400 psf.

The sensitivity of the silty clay varied between 1.5 to 3.0.

A careful inspection of the samples and results of the unconfined compression and unconsolidated undrained triaxial tests disclosed that the samples were somewhat disturbed. The presence of silt and sand seams has had an influence on the results.

It is believed that the average undrained shear strength of the clay layer is about 2,000 psf.

Underlying this deposit is a 13 ft. thick layer of compact to dense silt with traces of gravel. Two "N" values of 21 and 40 blows/ft. were recorded.

Below this layer a 23 ft. thick deposit of very stiff to hard clayey silt with sand and gravel was found. "N" values of 22 to 63, most of them in excess of 40, were recorded.

TESTING RESULTS

In May 1964, three piles were driven and tested. These were:

Pile No. 3 - Concrete filled steel tube 12 3/4" x 0.202" with end plate 13 1/2" dia.; length in ground 50.2 ft. (tube filled after driving).

Pile No. 5 - Concrete filled steel tube 12 3/4" x 0.202" with end plate 12 3/4" dia.; length in ground 50.1 ft. (tube filled after driving).

Pile No. 9 - Untreated timber pile, butt 15" tip 8"; length in ground 47.5 ft.

In Fig. 3 the dates of various tests and the time intervals between them are given. Due to the lack of time, only the 1964 series of piles (Piles No. 3, 5 and 9) could have been retested in 1965 - i.e., more than a year after they were driven.

PILE Nº	TYPE	DRIVEN	ΔT DAYS	1st LOAD TEST	ΔT DAYS	EXTR'N TEST	ΔT DAYS	2nd LOAD TEST	ΔT DAYS	EXTR'N TEST	ΔT DAYS	3rd LOAD TEST	ΔT DAYS	EXTR'N TEST
3	Steel Tube Protruding Plate 12¾" × 0.202"	May 12 1964	19	June 1 1964	4	June 5 1964	433	Aug 13 1965	5	Aug 19 1965				
5	Steel Tube Non Protruding Pl 12¾" × 0.202"	May 12 1964	16	May 29 1964	5	June [illegible] 1964	42	July 17 1964			393	Aug [illegible] 1965	5	Aug 20 1965
9	Tapered Timber 15" - 8	June 22 1964	15	July 9 1964			409	Aug [illegible] 1965	5	Aug 30 1965				
10	Straight Timber 12¼"	Aug [illegible] 1965	18	Aug 25 1965	5	Aug 31 1965								
11	Herkules Concrete 12" Hexagonal	Aug 6 1965	19	Aug 26 1965	5	Sept 1 1965								
12	Tapered Conc 14" - 8" Square	Aug 6 1965	20	Aug 27 1965	5	Sept 2 1965								

Fig. 3 - Driving and Testing Dates

In order to get some idea about the percentage of the ultimate bearing capacity of piles due to end-bearing, extraction tests were carried out.

The driving records for the 1964 pile series (No. 3, 5 and 9) are shown in Fig. 4.

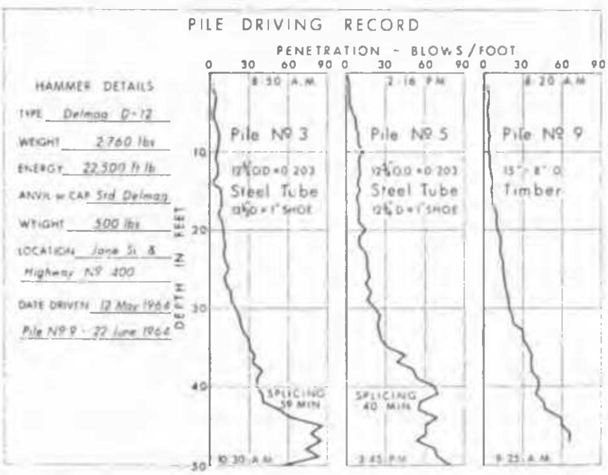

Fig. 4 - Driving Records, Pile No.3, 5 and 9

Approximately two weeks after driving, the piles were tested for the first time. The loading and extraction procedures required each load increment to be maintained for two hours or until such time as the rate of settlement fell below 0.01 inches per hour, whichever was the shorter period.

In Fig. 5 the loading and extraction test results for Pile No.3 (steel tube with protruding end plate) are shown. It is evident that there is very little difference between the loading and extraction test results, the time interval between them being 4 days.

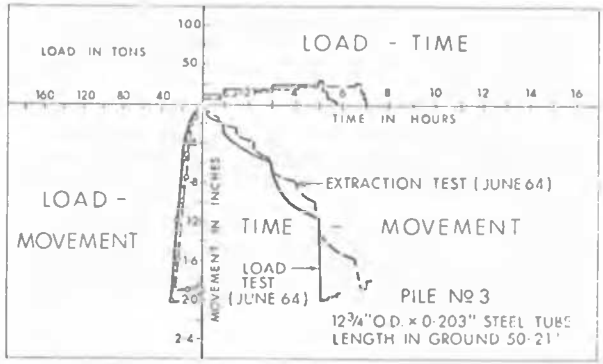

Fig. 5 - Test Results Pile No. 3 - 1964

Pile No. 5 (steel tube with non-protruding end plate) was tested twice in 1964 with a time lag of 42 days. The results of these two tests as well as the extraction test, carried out 5 days after the first loading test, are shown in Fig. 6. During the time interval of 42 days the bearing capacity of the pile did not increase noticeably, but the strain at failure decreased significantly.

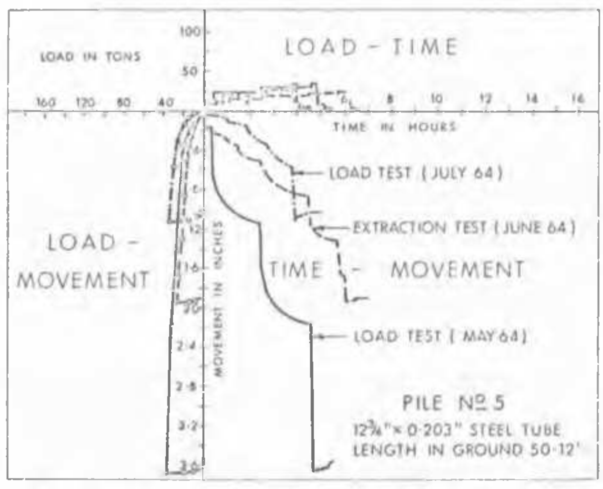

Fig. 6 - Test Results Pile No. 5 - 1964

Pile No. 9 (untreated timber 15" butt 8" tip) was tested once in 1964 and the result is shown in Fig. 7.

The test results of the described pile series seem to indicate the following:

(1) When bearing capacities of piles, tested approx. two weeks after driving, are compared, the capacity of a timber pile is about three times as high as that of 12 3/4" O.D. concrete filled steel tube pile of comparable length.

(2) A relatively short waiting period (42 days) has not contributed to the increase of the bearing capacity of the steel tube pile, but has resulted in a significant decrease of the deformation at failure.

(3) The contribution of end-bearing to the ultimate bearing capacity of steel tube piles was negligible, as expected.

(4) The protruding plate does not seem to have influence on the ultimate bearing capacity of the steel tube piles when tested within the above-described period of time.

All three piles (No. 3, 5 and 9) were retested next year - i.e., 1965.

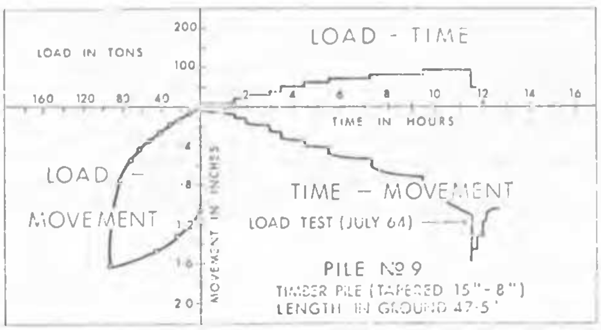

Fig. 7 - Test Results Pile No. 9 - 1964

Test results for Pile No. 3 (1965) are shown in Fig. 8. It is obvious that the bearing capacity of the pile has greatly increased. There is again very little difference between failure load at loading and extracting, indicating that the main increase is due to the increase in adhesion along the pile shaft. The measured rebound seems to have remained of the same order.

In Fig. 9 results of the 1965 retesting of Pile No. 5 are shown. This is the steel tube pile with the non-protruding end plate. Although the bearing capacity of this pile in 1964 tests was about the same as for Pile No. 3 (with the protruding plate), the 1965 test shows a greater bearing capacity. In addition to a significant increase of the ultimate bearing capacity, the failure deformation has markedly decreased.

The difference between the loading and extraction test seems to indicate a more significant contribution of end-bearing.

Pile No. 9 (tapered timber pile) was also retested in 1965 and the results are given in Fig. 10. An increase in the bearing capacity is noticeable, but the percentage is not as high as with the steel tube piles.

The significant difference between loading and extraction failure forces could possibly be attributed to the pile's tapered shape.

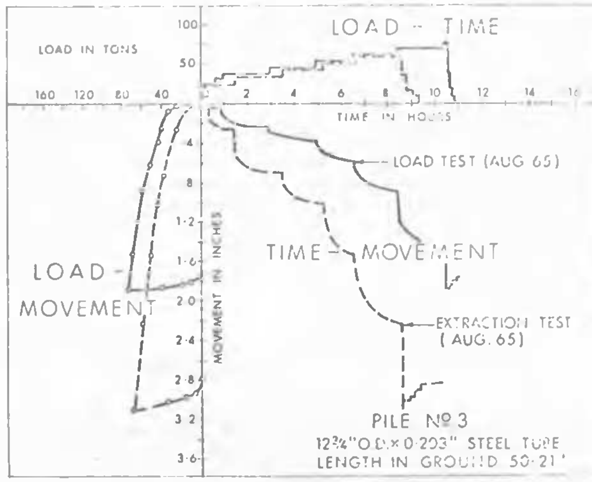

Fig. 8 - Test Results Pile No. 3 - 1965

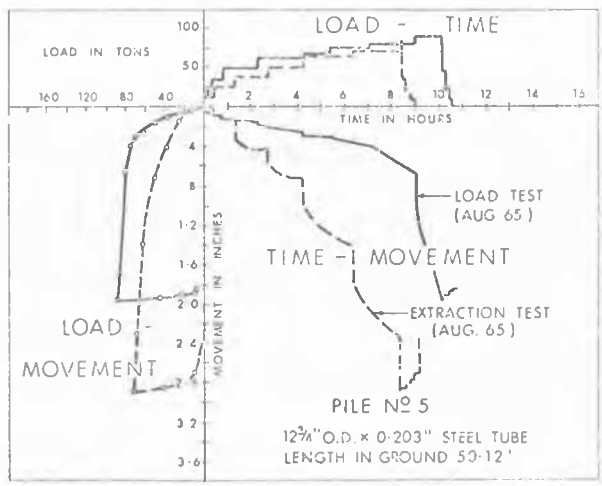

Fig. 9 - Test Results Pile No. 5 - 1965

In 1965 another three piles were driven and tested. These were:

Pile No. 10 - Constant diameter timber pile, $12\frac{1}{4}$" dia.; length in ground 43.5 ft.

Pile No. 11 - Constant cross-section (12") hexagonal precast concrete "Herkules" type pile; length in ground 48.5 ft.

Pile No. 12 - Square cross section tapered precast concrete pile 3" tip, 14" butt; length in ground 46.25 ft.

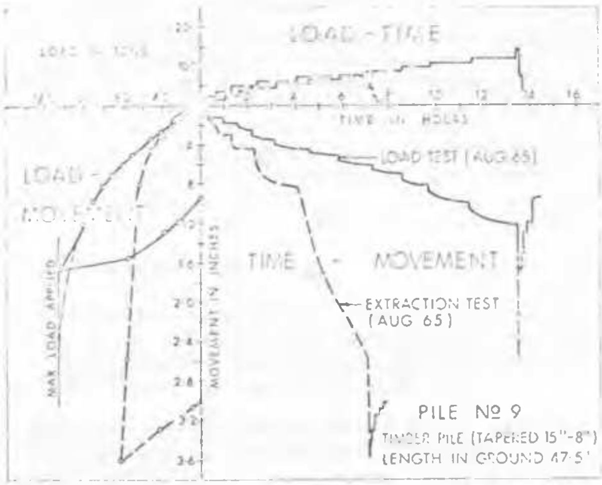

Fig. 10 - Test Results Pile No. 9 - 1965

The pile driving records for these piles are shown in Fig. 11. It should be noted that these piles were driven with a drop hammer.

The above-mentioned piles were tested approximately 19 days after driving.

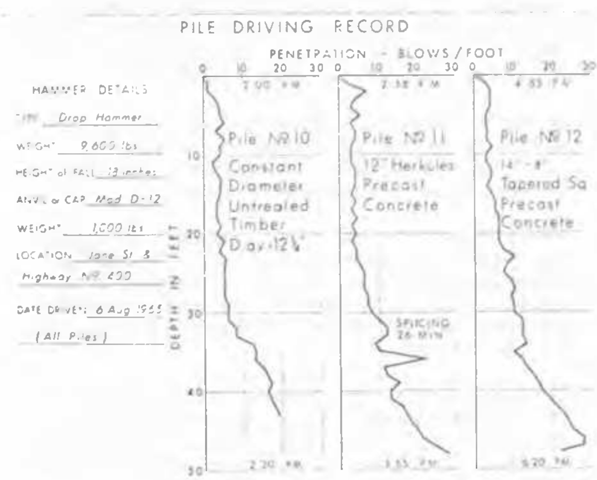

Fig. 11 - Driving Records Piles No. 10, 11 and 12

The test results of Pile No. 10 (const. dia. timber) are given in Fig. 12. The ultimate bearing capacity is high although the deformation at failure is also considerable. As expected, the rebound is significant. The large difference between the loading and extraction test results was quite unexpected and no explanation for this is suggested.

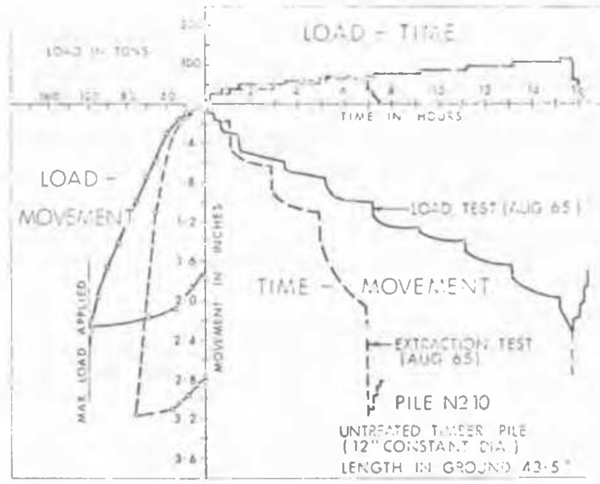

Fig. 12 - Test Results Pile No. 10 - 1965

The constant dia. hexagonal precast concrete pile "Herkules" type (Pile No. 11) was tested next and the results are shown in Fig. 13. Although the ultimate bearing capacity was considerable, the deformation at failure was very large. The rebound was small. There is quite a marked difference between loading and extracting forces.

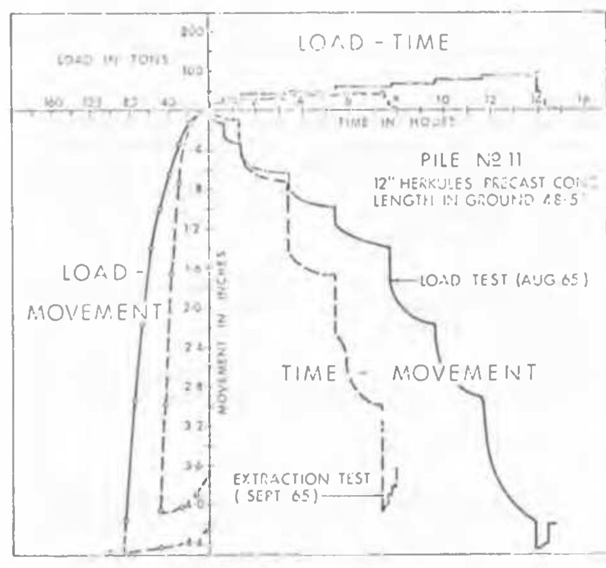

Fig. 13 - Test Results Pile No. 11 - 1965

The test results for Pile No. 12 (tapered concrete) are shown in Fig. 14. At a quite small deformation a relatively high bearing capacity was recorded. The marked difference between the loading and extraction tests appears to be due to the pile's taper.

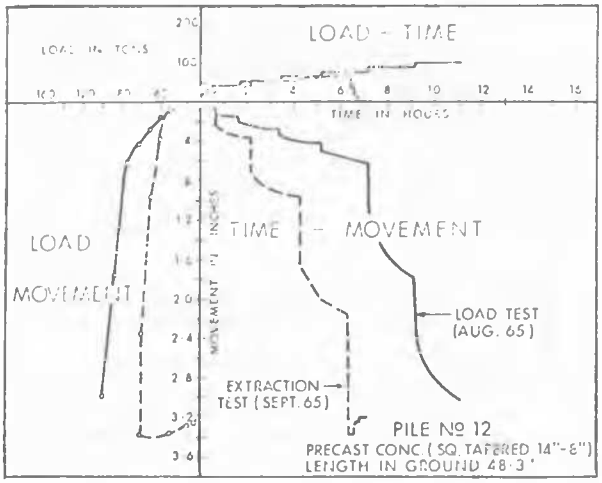

Fig. 14 - Test Results Pile No. 12 - 1965

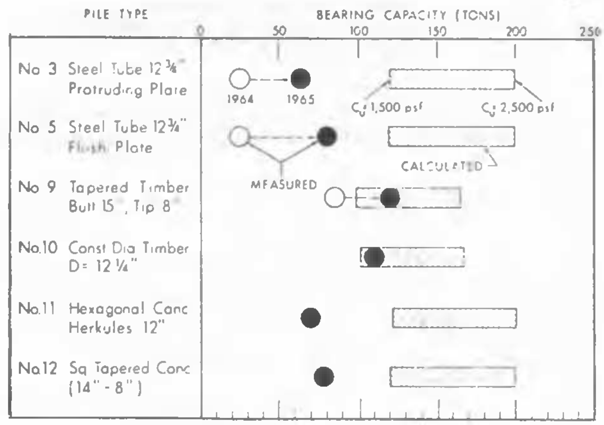

Fig. 15 - Summary of Test Results - Comparison between Theoretical and Measured Bearing Capacities

DISCUSSION AND CONCLUSIONS

There are many ways and methods for the interpretation of pile load - Chellis (1961). However, each test should be interpreted in the light of the pile's usage. In certain cases larger deformation or settlements can be tolerated than in others. It is therefore emphasized that whatever bearing capacities are shown in this paper, they are by no means presented as absolute values.

The significance of this investigation and whatever benefit that can be derived from it is based on the comparison of the behaviour of various types of piles - i.e., on relative merits of each of them, the absolute bearing capacity values being in this case, of only secondary importance.

For the computation of the theoretical ultimate bearing capacities, values of 1,500 and 2,500 psf were used.

The ultimate bearing capacity of piles was computed using the following expression:

$$Q_{ult} = C_b \, N_c \, A_b + C_a \, A_s$$

where,

C_a = Average undrained shear strength of clay for the length of pile.

C_b = Undrained shear strength of clay at and below bottom of pile.

N_c = Bearing capacity factor (9).

A_b = Area of pile base.

A_s = Effective pile shaft area.

All test results as well as theoretical minimum and maximum capacities are shown in Fig. 15. A careful review of these values seems to permit the drawing of the following conclusions:

(1) Timber piles when tested approx. 2 weeks after driving, had higher bearing capacities than concrete or steel tube piles.

(2) After one year the bearing capacities of the tested piles had increased; approximately 50% for the tapered timber pile, and between 250 and 300% for the steel tube piles. However, the final (after one year) bearing capacity of the tapered timber pile was still between 40 and 50% higher than that of the steel tube piles.

(3) Concrete piles tested two weeks after driving had smaller bearing capacities than timber piles, but considerably greater than steel tube piles.

(4) It would appear that the protruding plate on the steel tube piles has no immediate detrimental effect, but that it may have a long range one.

(5) The comparison of test results of timber and concrete taper piles with those of comparable piles, but of constant diameter, does not permit the attribution of any special or significant influence to the taper.

(6) In evaluating the degree of mobilization of the strength of the surrounding soil as adhesion, it appears mandatory that a clear distinction must be made between piles of different materials. The results of this test series seem to indicate that with timber piles possibly near full mobilization of the strength of the material as adhesion is being achieved.

(7) Irrespective of whether the piles are of steel or timber (for concrete data not available, but it is believed that the same also applies) the degree of strength mobilization as adhesion increases with time.

(8) Because it is believed that both the driving energy and equipment used exhibit an influence on the pile behaviour, a direct comparison between the performance of the piles of the two test series is not fully justified.

The preceding conclusions are not necessarily generally applicable, but it is believed that a number of findings would very well hold true in comparable soils and under similar driving conditions. It is hoped that the results of this investigation will contribute to a better understanding of the behaviour of piles in stiff clays.

ACKNOWLEDGEMENTS

This paper is presented by permission of Mr. H. W. Adcock, Assistant Deputy Minister (Engineering), Department of Highways, Ontario.

The participation of Dr. K. Y. Lo in the setting up of the testing programme is acknowledged.

The assistance of Messrs. P. Payer and H. Szymanski in the field, and of Mr. H. Reed in the preparation of the figures is gratefully acknowledged.

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