Correlation of static and dynamic pile tests on large diameter drilled shafts

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1. INTRODUCTION

The West Gate Freeway in Melbourne, Australia is being built by the Road Construction Authority (RCA) of Victoria to the south of the city's central business district. The freeway is founded on large diameter cast-in-situ piles.

When doubts developed during the construction regarding the strength and serviceability of these piles, a test program was developed which included in a first phase program static and dynamic correlation tests.

A total of twelve shafts were included in the dynamic test program of which nine were socketed into mudstone and the remaining three into basalt. Because of their special geometry and/or unusual construction method, the basalt piles have been excluded from the discussions in this paper. Six of the nine mudstone socketed piles were statically tested.

The results from both static and dynamic tests are described in this paper. Correlations between skin friction and end bearing prediction and load-set curves are discussed. It should be added that the dynamic test results were obtained by consultants having no knowledge of the static test results which had been obtained both prior to and after the dynamic tests by RCA. Problem statement, discussions of the soil at the site, descriptions of the pile design and general test details are given in Reference (1).

2. MEASUREMENTS AND ANALYTICAL METHODS

Testing was performed by dropping a 200 kN steel ram onto the pile tops with fall heights varying between 1.6 m and 2.5 m. Each test pile was subjected to eight hammer blows. Strain and acceleration were measured near the pile top and using a Pile Driving Analyzer (PDA). Several results were computed and adjustments to the ram drop height were made depending on (a) shaft stresses, (b) Case Method bearing capacity and (c) permanent set under a blow.

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The data was also recorded on magnetic tape and analyzed by the CAPWAP (2) method within one week of the actual field test. CAPWAP uses one of the two measured quantities as an input into a wave equation type analysis and computes the complementary quantity for comparison with measurements. Disagreements between measured and computed quantities are investigated and changes to the initially assumed soil resistance parameters are made. The analysis is then repeated. The final soil resistance parameters are obtained from CAPWAP when no more significant improvement between computed and measured curves is achieved. With these soil parameters, a static analysis is then performed for a prediction of the static pile top load vs displacement behavior.

3. RESULTS

The report on measurements and analyses was submitted by the consultant to the RCA within one week of the completion of the field work. It included plots of the recorded data (see Ref. 1) and two CAPWAP results for each of the 12 test piles. The two CAPWAP records were chosen from early and late hammer blows for an evaluation of any changes in rock strength due to the dynamic loading.

For each blow, maximum transferred energies, transfer efficiencies, maximum forces, pile set, CAPWAP capacities and other dynamic results were included in the report. A summary is given in Table 1. The final results included also pile stresses, Case Method bearing capacity and Case Method damping factors. In addition, the skin friction predicted by CAPWAP was plotted as a function of depth.

Table 1: Summary of Results

Pile No.	Pile Dia. (m)	Pile Length (m)	Total Pile Set (mm)	Max. Dyn. Force (MN)	Max. Trans. Energy (kNm)	Max** Trans. Eff. (%)	CAPWAP Capacity (MN)
302/1	1.5	40.0	2.2	43	225	45	20.0
302/2	1.5	44.0	3.9	51	230	46	27.0
303/1	1.5	44.0	4.8	51	276	59	21.0
403/2	1.5	64.0	8.1	49	250	50	32.0
204/2	1.3	48.0	12.4	45	258	52	18.0
503/2E	1.3	39.0	5.0	39	239	55	19.0
503/2W	1.3	35.0	14.2	37	227	51	15.5
2121/2	1.1	38.0	0.4	24	157*	53	18.0
3385/1	1.1	41.0	15.1	25	150*	52	14.0

* 1.6 m fall height, 2.5 m otherwise

** Maximum efficiencies may have occurred at blow with fall heights less than maximum.

As far as Case Method is concerned, surprisingly variable Case Method damping factors were required for an agreement between Case Method and CAPWAP capacities. It was therefore concluded that Case Method results would be unreliable for capacity predictions.

4. CORRELATION

After receiving the consultant's report, the RCA performed the correlation work. First, the total capacity value, second, the skin friciton distribution and finally, the load-settlement behavior were compared. Respective plots are shown in Figures 1, 2 and 3.

The ultimate load predicted by the dynamic test was compared indirectly with an ultimate load inferred from the static load tests. Since ultimate capacity values were usually not reached, the static test ultimate load was predicted by Chin's method. In this method, the rate of settlement with respect to load is plotted against settlement. This construction is based on the assumption that the load-settlement curve approaches the ultimate load hyperbolically. The inverse of the gradient of the line provides an estimate of the ultimate load. It should be noted that the ultimate static load estimated using this method would itself be an underestimate of the true ultimate capacity as the base capacity of these piles increases with settlements of up to 30% of the pile diameter. The static ultimate loads which could be derived in this way are compared with the static ultimate loads predicted by the dynamic tests in Figure 1. In all cases, the dynamic tests underestimated the ultimate capacity inferred from the static tests by the extrapolation procedure.

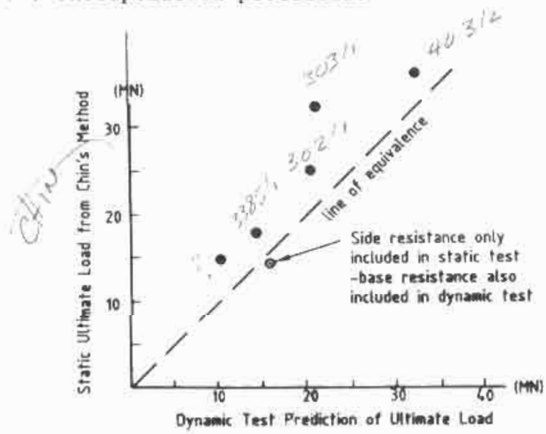

Figure 1: Comparison of Ultimate Loads
Predicted by Static and Dynamic Tests

The side resistance predictions of Figure 2 provided by the static and dynamic test are remarkably similar. For the two piles included in this figure, strain readings in the pile were obtained during the static test using strain gages. The base resistance obtained from the dynamic test is higher than predicted by the static test because of the large temporary compression of the rock during the dynamic test. It is noteworthy that theoretical resistance distributions above socket level showed no obvious correlation with either the static or the dynamic test results.

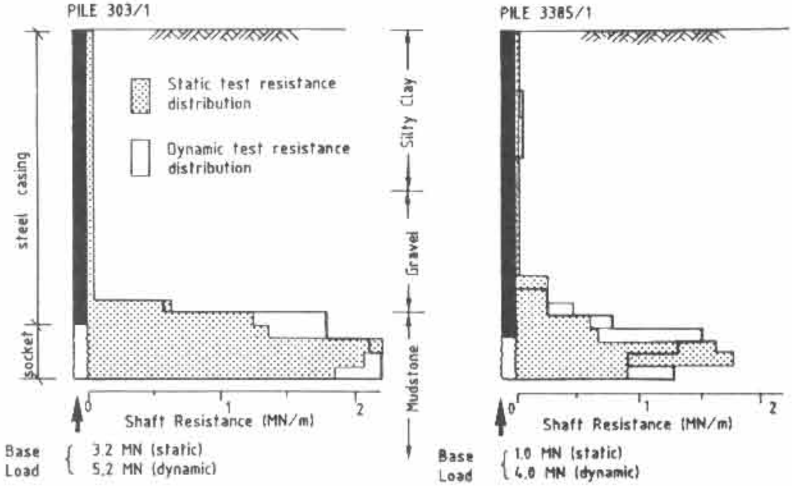

Figure 2: Resistance Distribution Predicted by Dynamic and Static Tests

During subsequent blows on the piles, base capacity was generally observed to increase in a manner consistent with the progressive decrease in permanent sets achieved. Several piles believed to contain significant inclusions of soft base debris realized large increases in base capacity after the base was driven to firm contact with the rock. The build-up of base capacity resulted in a permanent improvement in pile stiffness as confirmed by means of additional tests performed several months after the correlation test series.

The mechanism of load transfer described by Williams (3) suggests that side resistance should increase with settlements of up to 0.5 percent of the pile diameter. However, in almost all tests, the side shaft resistance was observed to decrease with successive blows. This reduction was believed to be due to a progressive rise in pore water pressure in the rock mass and clay-filled joints. Two of the piles were retested after a period of six months and the results indicated that the socket shaft resistance had been restored, presumably due to dissipation of pore pressure.

The CAPWAP analysis produces a prediction of static load vs settlement in the pile based on the predicted resistance distribution. These predictions were superimposed on the static load test results in Figure 3. It should be noted that approximately 50% of the head settlement represents elastic compression of the shaft.

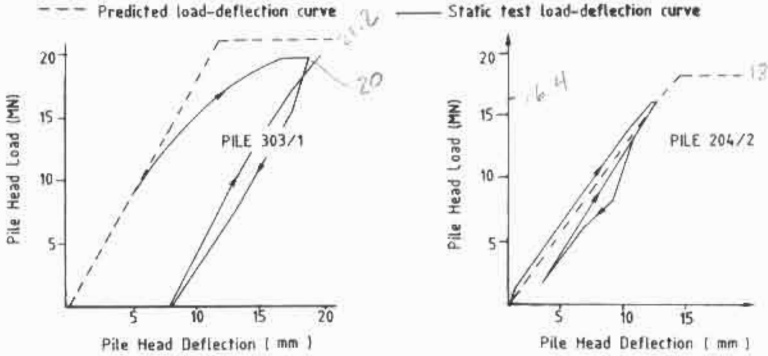

Figure 3: Load-Deflection Curves from Static and Dynamic Tests

Pile 303/1 was statically load tested prior to dynamic testing and it can be seen that the static response of the reloaded pile had very similar stiffness to that predicted in the dynamic test. Pile 204/1 was statically load tested only after dynamic testing was performed and displayed a comparable load-settement behavior on initial loading. Thus, as in static load cycles, the dynamic tests reduced permanent pile sets up to the applied cyclic load level.

5. CONCLUSIONS

The tests performed at the West Gate Freeway site in Melbourne proved that dynamic tests can provide an economical, fast and - within reasonable limits - accurate alternative to static testing. A definition of ultimate capacity is difficult for piles with large diameters. Complete activation of soil/rock resistance is uneconomical both in the static and in the dynamic case. However, it is remarkable that the dynamic activation of static resistance forces was possible to levels exceeding 30 MN for the 1.5 m piles. On the other hand, for reasons of economy, static testing had to resort to extrapolations to determine an ultimate capacity value in most cases.

Further conclusions are:

a) It was found that the skin friction magnitude and distribution can be accurately predicted by dynamic methods. Since the skin friction was relatively high, a meaningful relationship between load and immediate settlement could be determined from dynamic tests.

b) A correlation between statically and dynamically determined end bearing forces is difficult on large diameter piles since these values depend to a large degree on pile toe displacement. Dynamically determined end bearing forces showed clearly the effect of the "dynamic compaction" caused by the tests.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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