The behaviour of a pile-raft foundation in weak rock

Le comportement d'un fondation sur pieux-radieur dans roche faible

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SUMMARY This paper describes behaviour of a pile-raft foundation for a 42-story Office Complex constructed in weak rock. Observations from geotechnical instruments installed in the foundation system are presented for the initial stages of superstructure construction. At the end of monitoring period reported here, when seventeen of the forty-two floors had been completed, it appears that the piles had taken up approximately 60% of the structural load whereas the raft supported the remaining 40%. Settlement of raft was found to be negligible.

INTRODUCTION

The paper presents results obtained from field instrumentation of a pile-raft foundation. The foundation was constructed to support a 42-storey tower block of a modern office complex constructed by the Port of Singapore Authority. 203 large diameter bored cast in place piles were installed to support the 2m thick raft. Geotechnical instruments were installed in the foundation to monitor their performance throughout the construction period. The instruments included vibrating wire strain gauges, piezometers, settlemonitors and earth pressure cells. Details of the layout of instruments are shown in Fig 1.

SUBSURFACE CONDITION

The surface condition at the site of the tower block consisted of weathered sedimentary rock. In over 20 boreholes carried out at the project site, the Rock Quality Designation (RQD) values in the highly fractured and weathered siltstone formations were observed to vary from 10% to 50%. The siltstone formations were more fractured at shallower depths than at depths 10 to 15m below the base of the raft. The pile toes therefore may be assumed to rest on more intact rock.

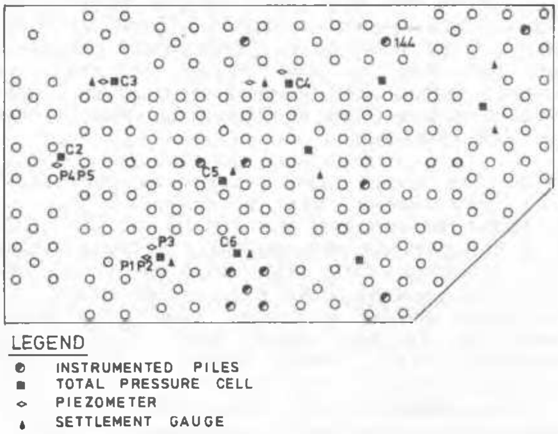

Fig. 1 Instrument layout plan

In-situ Plate loading tests carried out on a 380mm diameter plate at about the raft base level gave settlements less than 10mm at a maximum load of 4 MN/m^2.

Pressuremeter tests in boreholes within the siltstone formations could be performed only upto a maximum pressure of 2.5 MN/m^2 due to limitations in available equipment. With the exception of one test, all the other tests (Total of 12 tests in 3 boreholes) had to be terminated before reaching the plastic phase. The pressuremeter modulus computed from the available test data are therefore approximate. The computed values of pressuremeter modulus varied from about 100 MN/m^2 at about the base of the raft to about 4000 MN/m^2 at a depth of 10m below the raft.

INSTRUMENTATION OBSERVATIONS

Construction of the superstructure is still in progress at the time of writing. Instrumentation readings observed for a period of over one year from the time of foundation construction in end 1982 till Dec 1983 are presented in this paper. Only selected instrument results are reported here.

25 bored piles were instrumented with vibrating wire strain gauges along their shafts. Three of these piles were load tested to twice the working load and were observed to satisfy the load-settlement criteria assumed in the foundation design.

Fig 2 shows the load distribution and shaft resistance distribution of a typical instrumented pile (pile 144) at various stages of construction. Data obtained from pile load test during foundation construction are included for comparison.

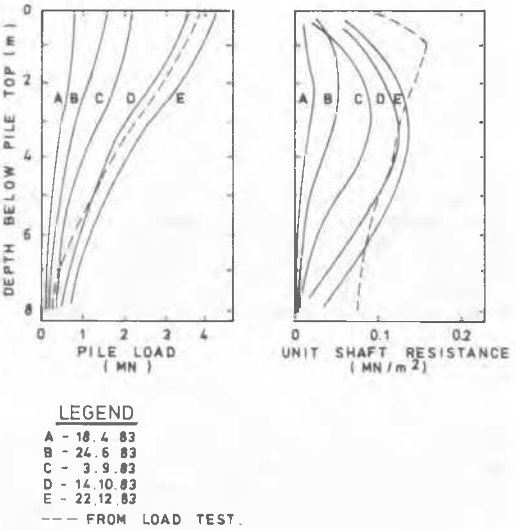

Fig. 2 Behaviour of Instrumented Pile No 144

At the raft-soil interface, 10 contact pressure cells were installed to monitor the load transferred from raft to soil. Typical raft contact pressures observed are presented in Fig 3. Irregularities in the readings between September and November 1982 are attributed to disturbances during concreting of the raft.

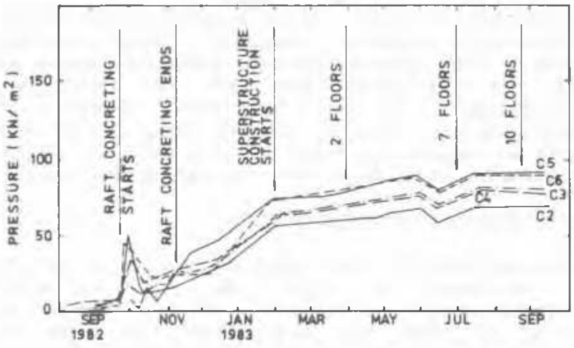

Fig. 3 Pressure Cell Measurements

Altogether nine settlemonitors were installed to monitor the settlement of the raft. Three settlemonitors were found to be malfunctioning after some time. Again large fluctuation in the settlement readings were observed during the raft concreting period after which the readings began to stabilize. It is noted that the settlements so far have been very small. The maximum settlement recorded was 3.5mm. The maximum differential settlement recorded was also 3.5mm.

Piezometers were installed at 11 locations below the raft to monitor the variation of pore water pressure behaviour during the construction period. Typical variation of pore water pressures with time at different depths is illustrated in Fig 4.

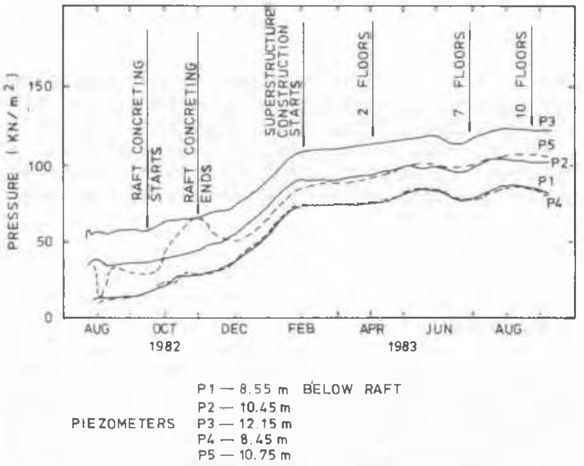

Fig. 4 Piezometer Measurements

ANALYSIS

Pile-Soil Interaction

The well established 'transfer function' approach (Vesic, 1970) was employed in the analysis of pile-soil interaction. The pile load distribution curves were generated from measured strain data using the least squares regression method suggested by O'Neill and Reese (1972). From Fig 2 it may be noted that the load transferred to the pile base was about 18% when the pile load was 4.2 MN. Load test carried out on the same pile soon after pile installation showed that only about 4% of the applied load was transferred to pile base under an applied load of 5 MN. Ladanyi (1977) suggested that such phenomena could be due to the creep of rock and concrete along the socket with time, thus increasing the pile toe loads gradually over a period of time.

Fig 2 also shows that a large proportion of shaft resistance was contributed by the siltstone around the mid-length of the pile. Again the pattern was markedly different from that observed from the earlier pile load test. In general, the pile under maintained load test showed a higher shaft resistance especially in the upper half of the pile compared with that under long term structural load. This could possibly be due to the presence of the raft inhibiting mobilization of shaft resistance near the pile top. Using three dimensional finite element analysis of vertically loaded pile groups in a homogeneous linearly elastic medium, Ottaviani (1975) has shown that the reduction in friction over the upper part of the shaft is associated with an increase in friction near the bottom of the shaft together with a substantial increase in pile toe loads.

Raft-soil Interaction
Because of the limited number of pressure cells employed in the instrumentation, certain assumptions had to be made to estimate the total load borne by the raft. It was assumed that raft pressure varied evenly and radially outwards from the point of highest pressure. Pressure contours were plotted by interpolating linearly the values of earth pressure from the known position of the earth pressure cells as shown in Fig 5. A simplification made was that the raft pressure distribution was unaffected by the presence of piles.

As expected, the raft pressure was highest at the centre of the raft during the period of observation. Area occupied by the pile was not considered in the computation of raft loads. Fig 6 shows the increase in pile and raft load during the period of observation reported herein. It is assumed that the piles only began to take up load in February 1983 when the construction of superstructure started. It is apparent that most of the building load was taken up by the raft during the initial period of construction. The total raft load was computed to be about 140MN in February 1983. Later on it increased to about 190MN in September 1983. The raft seems to have ceased to take up any additional load since then. Although only a relatively small amount of building load was taken up by the piles during the initial construction stage, it appears that the piles started to support more and more load at later stages of construction. At the end of the period of observation, it was noted that about 60% of the building load was carried by the piles and the balance load by the raft. The observation appears to be similar to that reported by Hooper (1979). It is felt that it is still too early to confirm that the foundation will continue to behave the same way.

Pore-water pressure
A rapid increase in pore-water pressure was observed (Fig 4) from Nov 1982 to Jan-Feb 1983 after which the rate of increase was slower with minor fluctuations. The initial rapid increase was perhaps due to the rise in the ground water level which had been lowered during the foundation construction.

CONCLUSIONS

Foundation instrumentation observations of a pile-raft system during the initial construction period of the superstructure has been described. Analysis of instrument observations during this period show the following:

1. The load transfer characterisitics of piles under long term structural load differed from those observed under

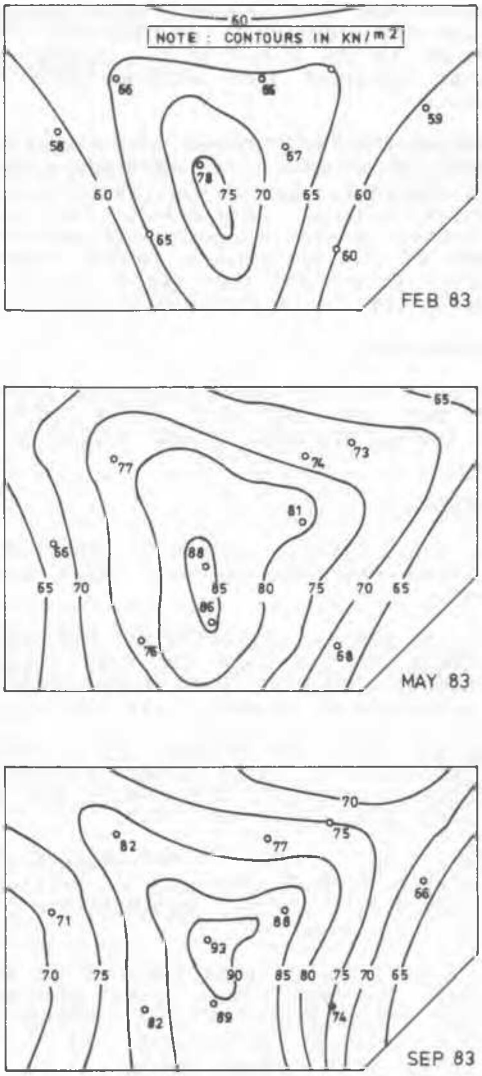

Fig 5 Raft Contact Pressures

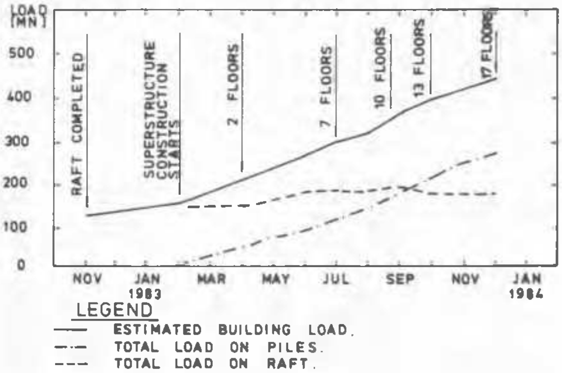

Fig 6 Estimated and Observed Loads

maintained load tests. Pile toe load observed during construction were found to be significantly higher than that obtained from earlier pile load tests.

2. During the early stages of construction, most of the structural load was taken up by the raft. As the construction of the superstructure progressed, the piles started to take up more load and at the end of the monitoring period reported here, it appears that the piles carried about 60% of the structural load.

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