Chapter 3-Methodology

3.1 Scope of the work-Capacity Estimation of Drilled Shaft Bearing on Rock

The research work involved the use of high strain dynamic stress wave measurements for capacity estimation of drilled shaft bearing on rock. The work completed during the research period, was subdivided in to four main parts. (1) Before installation of the piles complete ground investigation was carried out at each location and test piles were installed. (2) Then ultimate capacity estimation for from dynamic static methods was done and in (3) third part the strength gain with time for driven piles was investigated as a part of research work. (4) In final stage, dynamic measurements and static pile load test data were used to estimate the dynamic soil parameters such as soil Damping factor, Quakes and to investigate the load settlement behavior of the bored piles. Wave equation analyses programs such as WEAP, CAPWAP and PITPLOT were used for data analyses.

This chapter contains the relevant details of the experimental and analytical methods carried out in this study. The methods adapted to measure stress wave measurements and data analyses are discussed. The details of the pile testing system dynamic and static are also shown.

3.2 Ground Investigation

Complete site investigation is carried out for each locations and the following test were done to determine nature of soils. All these tests were done according to ASTM specifications. Standard Penetration test (SPT), Unconfined Compressive Strength Test, Unconsolidated Undrain Tri-axial Test, Consolidated Drain tri-axial test, In-situ moisture content and & In-situ Dry density test, Sieve analysis test, Atterberg Limits Determination Tests, Specific Gravity of Soil Determination test. The above test results are used to soil classifications and to determine static soil parameters. In some cases CPT test were performed to determine values for damping factor.

3.3 Pile Installation

450mm to 1000mm diameter rock socket end bearing bored piles were installed by rotary drilling method and percussion method. In each case the boreholes were stabilized with Bentonite slurry. A steel casing about 3m from ground level was driven first before starting soil boring at each locations and soil boring was continued up to weathered rock. the spacing of the piles was 4m center to center. The piles were embedded in to the sound rock about 300mm or a depth equal the pile diameter of the corresponding pile. A circular reinforcement cage with main toe steel and stirrup mild steel was inserted in to the borehole. Grade 25 to 35 concrete was placed in the cleaned borehole with a tremie pipe.

The precast driven RC piles were installed one by a vibratory hammer and drop hammer. The other 10 piles were driven using a K-25 diesel hammer with a spacing of three meters to hard weather rock.

3.4 Pile Preparation

The original piles were cut off about 1m from their existing concrete level and was extended about two times pile diameter with grade 40 concrete in same section and with same reinforcement minimum seven days after installation. A steel casing is used as formwork for extending the pile. The pile top surface was prepared smoothly and horizontally.

3.5 Stress Wave Measurement

The stress wave measurements are pile accelerations and strain with respect to time under a heavy impact on pile top. These two quantities are measured with accelerometers and strain transducers attached about 1.5 times pile diameter below from pile top level. The two sensors are attached directly onto the pile diametrically on opposite sides to account for the effect of eccentric hammer blows with 6mm bolts. The boltholes on each strain sensor were 76mm apart. The measured strain is converted to force using cross sectional area and elastic module of the piles and acceleration is integrated into velocity. PDI piezoresistive accelerometers which are mounted on a rigid aluminum block and are terminated in a short cable with a quick disconnecting plug was bolted to the pile surface with cable oriented axially with pile in the down position 60mm apart from strain transducer.

All sensors were connected by quick connectors plugs to a short connection cable, which accept up to four individual sensors; the connection cable itself connects to a single main cable. The main cable was then connected to Pile Driving Analyzer (PAL Model)

16mm thick three plywood sheets were used at pile top as pile cushion material and a steel block 7.5 ton weight. was dropped by using a crawler crane. A stricker plate between pile cushion material and hammer was inserted to minimize bending effects. Then dynamic measurements were collected under each hammer blow. Minimum five records were collected for one pile.

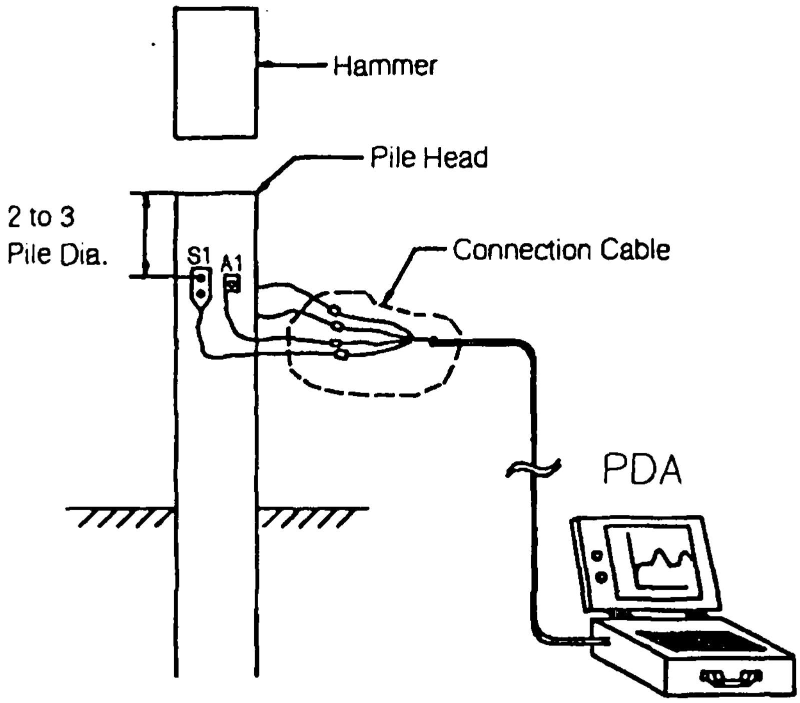

Figure 3.1 Instrumented pile

3.6 Measuring pile top settlement under static load

Since, it needed to compare static load settlement curve predicted by dynamic measurements, four maintain pile load test according to ASTM standard were carried out. A static dead load on the pile top was applied by a hydraulic jack in 25% load increments. The pile is loaded two times and unloaded. Pile top settlement at each load increment level was measured with thee or four dial gauges attached to the pile top.

3.7 Capacity variation monitoring of a driven pile

A pre-cast concrete RC pile was driven by a vibratory hammer up to 6m and one meter from drop hammer and six high strain dynamic pile load tests were carried on the same pile for a period of 185 days to check the setup effect or capacity variation with time. (See appendix E)The dynamic data are analyzed with CAPWAP and corresponding capacity at each time is predicted.

3.8 Data Analyses

Several results can be predicted from a single data set when applying different analysis methods. Mainly Automatic, Best Match, Residual Stress Analyses, Multiple Blow Analysis (MBA) and three author defined CAPWAP analysis method are used with various damping options. Finally the solutions for dynamic soil parameters for the each analysis are estimated.

3.9 The CAPWAP Procedure

As discussed in literature, the shaft resistance is lumped into Ns shaft resistance forces plus one toe resistance. With 3 unknowns of the basic Smith model for each soil

segment (resistance, quake and damping), the number of unknown becomes 3(Ns+1). However, in most instances, it may be assumed that quakes and Smith shaft damping values have equal magnitudes. Thus, there are Ns+1 unknown Rui, values, plus 2 unknowns each for damping and quakes. The extension of the CAPWAP soil model add (practically as trimming parameters for signal matching) two unknowns for the unloading quakes (shaft and toe), one for the shaft resistance unloading level, two for reloading levels, and three for a toe damping option (Smith or viscous damping), toe gap and plug. Four parameters are available for radiation damping and one for the residual stress analysis option. Thus, the total number of unknowns is Ns+18.
The distribution of ultimate shaft resistance forces can be directly determined from the record portion between the time of impact and the time of first wave return. Quakes can be calculated from the time rate of resistance increase (often clearly apparent at time 2L/ C after impact, i.e., when the toe reflected wave returns to the pile top after having traveled along a pile length L). Damping factored by the duration of resistance activation. The remaining quantities have to be determined from match trimming or experience.

An automatic matching option performs CAPWAP in the same way in which a user would go about this task. First, the early record portion is matched using shaft resistance distribution. Next, the match at the time of first wave return is improved with toe resistance values. Thirdly, the match of the time period immediately following the first wave returns is adjusted by assigning the proper total ultimate capacity. Finally, using quakes and unloading values, the remaining record portion is matched. Further improvements may be achieved by varying damping values and other quantities of the extended CAPWAP soil model.

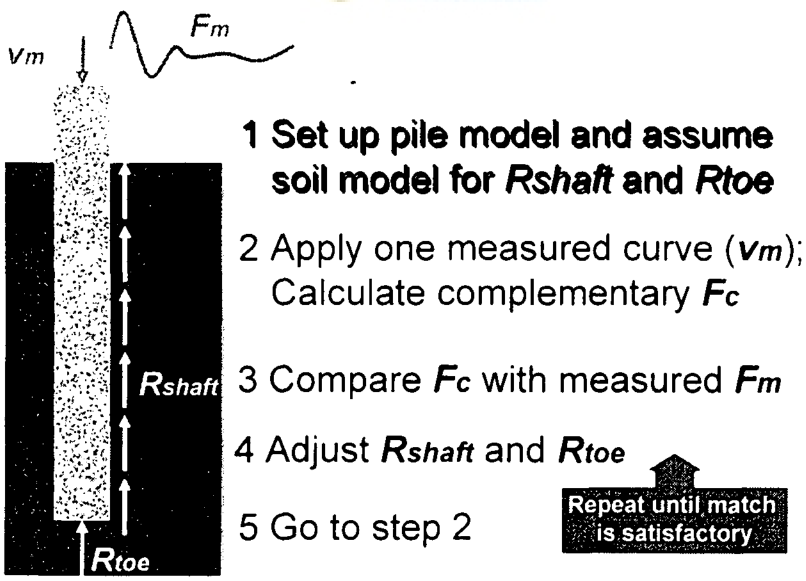

Figure 3.2 CAPWAP Data Analyses Procedure

3.9.1 The Residual Stress Analysis (RSA)

Residual stress analysis are probably the only realistic means of calculating blow count for complex situations such as long, flexible pile with quakes of very different magnitudes. RSA actually calculate the blow count that happens after an initial blow, which is the only blow that the normal wave equation analysis considers. For an initial blow the pile and soil are at a zero stress state and the hammer energy has to completely compress both media. In the presence of an appreciable shaft resistance, the pile will not completely spring back. Thus, energy stored in pile and soil and under the next blow, the pile will behave stiffer and it will be easier for the hammer to drive to drive the pile. For pile of moderate length the residual stresses remaining in the pile (and therefore the compression of the pile) after the hammer blow, which means that the residual stress analysis has converged, and the blow count can be calculated as the final set of any pile segment. For very long piles this convergence will not happen quickly and it may be erratic. For example certain patterns of higher and lower final file set may evolve. In these cases the pattern of final pile sets may be used to predict the eventual steady state blow count.

RSA blow counts are always lower and pile stresses are higher than those from standard analysis. Thus, even though the RSA concept is superior to simple Smith approach it should be realized that non conservative result may be obtained if RSA were used together with established recommendation of quakes and damping values. Correlation of static with dynamic RSA result have only been established for Monotube piles, appropriately pile type which is made of thin walled, high strength steel and is tapered and fluted. Because of its relative flexibility and high frictional resistance, Monotube piles store substantial amounts of energy.

RSA must converge a final stress or deformation pattern between conservative blows before the calculated blow count can be accepted. The user is therefore urged to check the numerical output file for any massage concerning convergence. If convergence is not achieved, the number of trail analyses may be increased from the default of 10, the analysis time may be extended so that the less dynamic energy remains in the pile at the end of the individual analyses. Also it is recommended that the Smith-Viscous damping option be chosen.

In the past, CAPWAP engineers sometimes felt that the calculated resistance distributions may have been distorted because residual stresses were not considered. The reason is that at the end of a blow some of the upper soil resistance forces are directed downwards (negative), while portions of the lower friction and the end bearing are still directed upwards. During the next blow, activation of the upper resistance forces requires deformations which first bring the negative friction forces to zero before positive resistance is generated. At and near the pile toe, resistance which has been partially preloaded by the previous blow takes less deformation to activate full ultimate resistance of the lower soil strata. Since the conventional CAPWAP analysis assumes resistances and displacements initially to be zero, it tends to under predict the lower shaft and end bearing resistances and overpredict resistance in the upper strata. By performing residual stress analysis in CAPWAP, the correct resistance distribution can be better estimated, although the predicted total capacity is generally unchanged. The following steps are undertaken during a single trial analysis.

1 In the initial analysis all pile and soil variable are initialized to zero.
2 In all subsequent RSA, all variable except the pile segment displacements and the soil resistance forces are initialized to zero.

3 After each analysis (initial and RAS) CAPWAP perform a static analysis (velocities and therefore damping resistance forces are zero) which produces an equilibrium set of soil resistance forces and the resulting residual pile segment displacements.

4 CAPWAP calculate the blow count from the final file top set occurring during the last analysis. Before each additional RSA analysis, displacements of all pile segments are reduced by the final set of the pile top segment.

5 CAPWAP displays the pile top sets. It the percentage change of pile compression between the two last analyses is high, the convergence has not been achieved and it may be necessary to perform additional consecutive analyses.

6 No residual forces exist when negative shaft resistance is prevented by UN = 0 (the shaft resistance unloading level). Therefore the UN value must be greater than zero.

7 RSA assumes that repetitive blows produces identical force and velocity records and activate identical soil resistance forces. This situation typically occurs during driving. During the early restriking when both impact energies and activated shaft resistance values change, Multiple Blow Analysis would be the more appropriate analysis method.

8 Wave equation analysis program attempt to achieve convergence of RSA by repeating analyses until pile compression values agree. However, CAPWAP only suggests that users investigate convergence and increase the number of analyses until pile compression values of successive analyses agree.

9 Convergence may exist among alternative blows (say blow 1,3,5) even if consecutive blows have different pile compressions. This may be the case when very long piles are analyzed.

3.9.2 The Multiple Blow Analysis (MBA)

If, in early restriking, the records of force and velocity vary greatly from blow to blow and that at the same time residual forces build up in the pile while shaft resistance (that had increased due to soil setup during the waiting period) decreases. CAPWAP can analyze up to ten different (usually consecutive) records with identical quakes and damping values and with the same static resistance distribution. Furthermore to simulate the loss of shaft resistance from blow to blow, MBA offers the multiplication of the shaft resistance forces with a resistance reduction factor.

The process starts with the first record assuming a zero stress state. After the first records is analyzed, a static analysis determines the static equilibrium condition of the residual stresses. The dynamic and then static analysis of the second record and then all remaining records follow a similar manner.

For each record analyzed, measured and computed pile top quantities are compared to calculate a match quality number. In addition, a realistic comparison of measured and computed pile top penetration can be made.

It is assumed that long term capacity, R_{uk}, is present at pile segment i in the beginning of the MBA. A capacity reduction factor f_{rk}, $(0 < f_{rk} < 1)$ is defined as an indicator of the lowest degree to which the capacity R_{uk} can degrade. The degraded ultimate shaft resistance, R_{duk}, of soil segment k is calculated from the long term capacity R_{uk} as follows.

$$R_{duk} = R_{uk} \text{ for } U_i \le q_k \qquad 3.1$$

$$R_{duk} = f_{tk} R_{uk} \text{ for } q_k \le U_i \le kq_k \qquad 3.2$$

$$R_{duk} = f_{rk} R_{uk} \text{ for } kq_k < U_i \qquad 3.3$$

the temporary capacity reduction factor $f_{tk}(f_{tk} \le f_{tk} \le 1)$, is computed from the accumulated pile set U_{ia}, decreasing linearly from 1.0 to f_{rk}. The full reduction occurs after the cumulated pile set has reached and exceeded the reduction displacement kq (k is an input for MBA)

obviously the assumption that the capacity degrades fully within several quake displacements is rather arbitrary. In fact full degradation may actually not be reached during a few hammer blows analyzed.

3.9.3 Static Analysis

After the CAPWAP procedure has yielded a set of shaft and toe resistance parameters, a static analysis can be performed based on *Rui* and *qi*. Typically, the analysis is performed with the dynamic toe displacement vs. time from the best match CAPWAP analysis imposed as a boundary condition at the pile toe. The equilibrium pile top force and displacement are then easily computed; mass and viscous effects are ignored. As a result, a simulated pile top force vs. pile top displacement relationship is obtained which may be compared with standard load test results.