Design and performance of dynamic tests of 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 structure will be founded on large diameter cast in-situ piles. During construction of the piles, it was considered necessary to carry out proof loading tests on 17 percent of the piles to confirm that the construction method had resulted in the required capacity and static load testing of a total of 70 shafts was considered. Because of the necessary time and expense of such tests, a dynamic pile test program was also considered.

In a first test phase, correlation between static and dynamic load tests was attempted since dynamic tests on large diameter shafts drilled into rock had not yet been performed. Furthermore, since not much experience existed with a reliable dynamic test set-up for high loads, special analyses and designs were made. The test set-up included a 200 kN ram with a 2.5 m free fall which performed extremely well. This paper describes the tests only. A presentation of the results and correlation is given in Reference 1.

2. PROBLEM STATEMENT

2.1 Geology

The freeway traverses an area of unconsolidated delta deposits of Quaternary Age, typically 30 to 40 m thick, ranging from very soft silty clays near the surface to very dense sands and gravels at depth. Underlying these deposits is the Melbourne district basement rock, commonly called Melbourne mudstone, consisting of interbedded siltstones and sandstones of Silurian Age varying from slightly to extremely weathered.

2.2 Structural Details

The freeway project includes 3.6 km of elevated segmental box girder structure supported on 420 bored, cast-in-place piles of 1.1,

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1.3 and 1.5 m diameter socketed into either the mudstone or Tertiary Age basalt rock which overlies the mudstone in some areas. The mudstone-founded piles were constructed by either vibration, oscillation or percussion of a steel casing through the overburden to refusal in the rock followed by excavation of a socket of between 2 and 25 m length into the rock using a drilling bucket.

The piles were designed using a settlement-based method (2,3) which employed empirically determined load-settlement relationships for both base and shaft resistance. Individual piles were designed for a settlement of 1% of diameter at ultimate load with shaft resistance providing most of the load capacity at this settlement.

The sockets of about 70 piles were drilled and concreted under a full head of bentonite slurry according to the specifications for cast-in-place piles published by the Federation of Piling Specialists (4). However, during socket inspection, the presence of a bentonite filter-cake on the walls was observed. The existence of this layer in previously cast piles in thicknesses of up to 100 mm was later confirmed by interface coring. In view of the dependence of the design on intimate contact between the pile shaft and the socket wall to provide shaft resistance, it was considered necessary to load test all piles constructed by this method.

2.3 Static Tests

Two static load testing methods were considered. The first used rock anchors in mudstone to provide a jacking reaction and the second used kentledge. Loads of up to 20 MN were required. It was estimated that static testing would take three years to complete at a cost in excess of A$1,350,000. (A$1.00 = US$0.90)

For evaluation purposes six piles socketed into mudstone were tested statically. These piles were instrumented with strain gages and/or plate jacks at the bottom to determine resistance distribution and end bearing. Furthermore, static testing was also carried out on two piles which were socketed into basalt and which had been constructed with a non uniform cross section that allowed for a complete elimination of skin friction effects. The cross section of these piles was not standard.

2.4 Dynamic Tests

Because of the great expense of time and money for static tests, the possibility of dynamic testing of the piles was investigated. Tests of this type had not previously been performed on large diameter, cast-in-place piles socketed into weak rock. It was, therefore, decided to initially test twelve piles including the six that were previously statically load tested to assess the feasibility of this method. The firm of Goble & Associates, Inc. was engaged to perform the tests and to evaluate the bearing capacity of the piles by dynamic methods. Without prior knowledge of static test results, they had to submit their report to RCA.

3. DYNAMIC TEST SET-UP

Dynamic tests must be designed such that the necessary energies are available in the pile to activate the soil resistance forces to a level that is at least twice the working load. In addition, the necessary impact forces have to be at least as high as the proof test load and they must be applied without causing damage either in compression near the pile top nor in tension somewhere along the pile.

These considerations require the determination of the

(a) ram weight
(b) ram fall height
(c) cushion type and thickness
(d) load distribution at and above the pile top

A realistic design is possible if a wave equation analysis is performed. Such analyses were independently run in preparation of the test by both the consultants and the geotechnical staff of RCA using WEAP (5) and Bowles (6) programs, respectively.

Based on these initial studies, the RCA decided to build a 200 kN ram weight capable of freely falling up to 2.5 m. The wave equation predictions showed that a 42 m pile could then be tested to a 30 MN capacity with stresses below 24 MPa if a 200 mm plywood cushion was used.

Further details of the design of the test set-up are shown in Figure (1). Note that a leader was included to reduce the danger of eccentric impacts. An additional safety measure against eccentric loading was a reduced cushion area of 900 mm diameter for blow centering and a felt layer under a load distributing steel plate of 100 mm thickness.

All piles were cast nearly flush with grade. For attachment of strain transducers and accelerometers, a minimum distance of one diameter below the pile top was required. Excavation to that depth was often not possible because of ground water. Thus, it was decided to extend the 12 mm casing by welding an additional section of casing onto the pile and pouring concrete after extending reinforcement into the added pile top portion.

Two strain transducers and two accelerometers were then attached to the piles in windows (approximately 200 x 200 mm) cut into the casing on opposite pile sides (see Figure 2). In this way, axial forces and accelerations were measured.

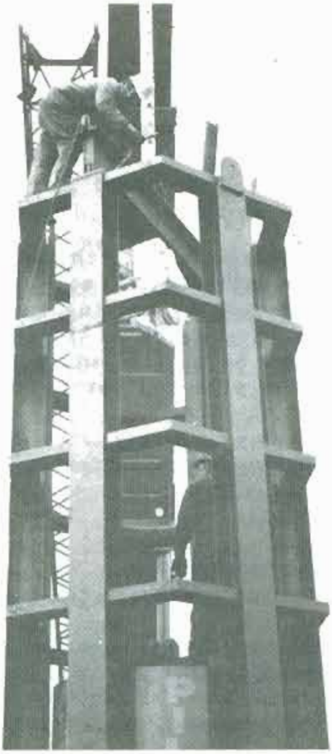

Figure 1: Field testing apparatus showing ram, free release device bar with pin holes for different fall heights and leader.

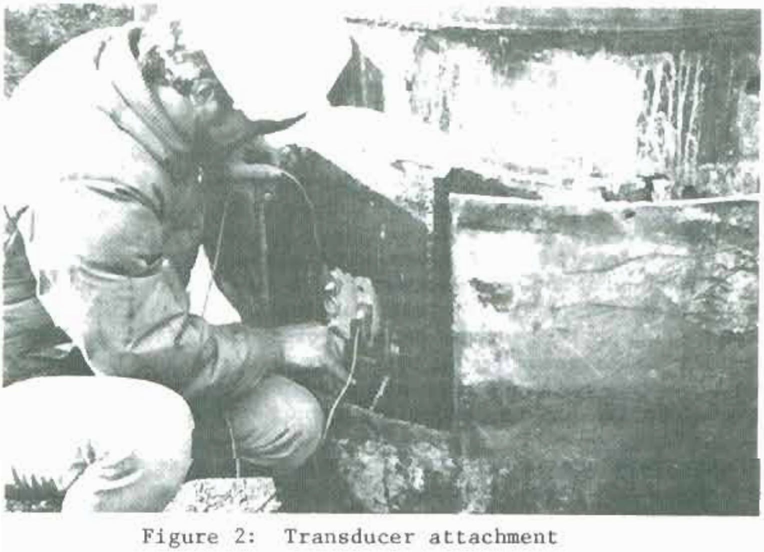

Figure 2: Transducer attachment

Measurements of excellent quality were obtained. Pile tops showed no distress even under 2.5 m free fall blows. The activated resistance forces were, in some instances, well above 30 MN and, depending on the strength of the piles tested, permanent sets under single blows reached 2.2 mm. The monitored records did not indicate any sign of structural distress in the piles.

4. MEASUREMENTS

Testing was performed by dropping the 200 kN steel ram onto the pile tops from heights of between 1.6 and 2.5 m. After each blow, a trip mechanism attached to a steel bar was lowered by a mobile crane to engage the hammer. The ram was then raised and locked at the selected height by insertion of a pin through one of several holes in the steel bar. Release of the hammer was activated by pulling a rope which opened the jaws of the trip mechanism. During the first test series, three piles were tested per day. This rate was increased to six piles per day during testing of the remaining piles in February, 1983.

Each test pile was subjected to eight hammer blows. Strain and acceleration were measured near the pile top according to the Case Method (7) using a Pile Driving Analyzer. This unit immediately integrated the acceleration to velocity and converted the strain to force. Digital printouts, calibration traces and automatic circuit checking provided for an immediate confirmation of data validity. Furthermore, the maxima of compressive and tensile stresses (at locations other than the pile top) were computed in real time and adjustments to the ram drop height were made depending on the stress level, activated bearing capacity and permanent set under a blow.

It was important that no damage was caused in the piles due to the dynamic loads. Thus, after each blow was applied, the force-velocity records were investigated on an oscilloscope for a relative tension wave effect at the pile top. Such waves would be reflected from a reduction in cross-sectional area or stiffness. Figure 3 very faintly indicates such reflections from the bottom of the reinforcement. However, no other damage indicators were apparent in the records.

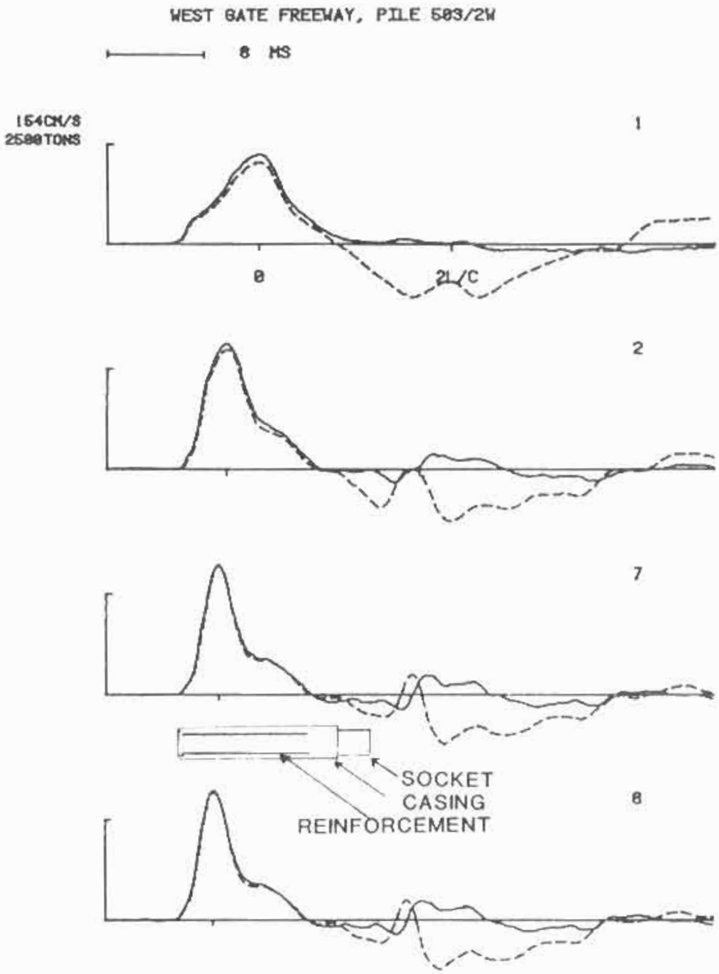

Figure 3: Sample records of pile top force and velocity. Note the wave effects from the bottom of the reinforcement.

When the records of the first pile tested indicated low stresses and no pile damage, the cushion thickness was decreased to three sheets of 19 mm plywood sandwiched between three sheets of 12 mm steel plates, all of 900 mm diameter.

The data was recorded on 4-channel FM magnetic tape for further analyses. A photograph of the complete field measurement system including Pile Driving Analyzer, oscilloscope and recorder is shown in Figure 4.

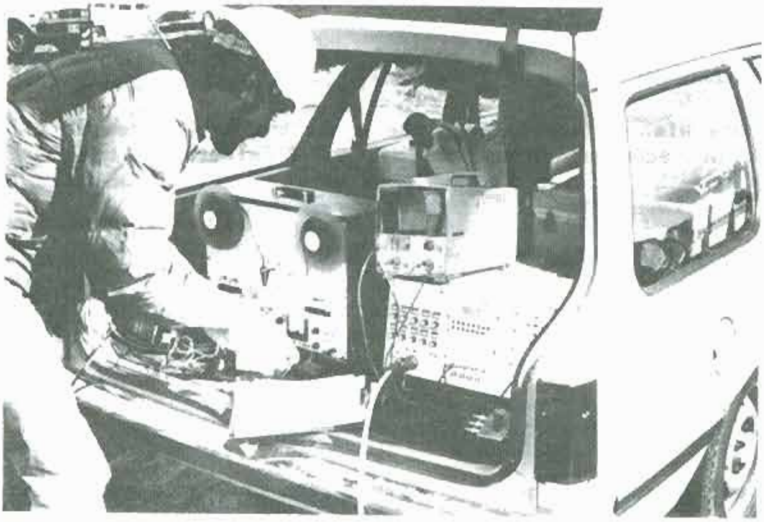

Figure 4: Photograph of the car-mounted field measurement equipment

5. CONCLUSIONS

The tests performed at the West Gate Freeway site in Melbourne proved that dynamic testing provides an economical, fast and - within reasonable limits - accurate alternative to static testing. It was concluded that the careful planning and design of both the testing procedure and test equipment prevent disappointments as far as pile structural failures or lack of pile penetration are concerned.

The tests provided a few other interesting results that may be summarized as follows:

a) Even though the ram fell freely, only up to 68% of its energy was transferred into the piles. Some of the energy may have been taken up by the leader. The number of cushion sheets had a marked effect on energy transfer. Also, the transfer efficiency strongly increased from early to late blows due to cushion hardening. Figure 3 demonstrates the change of records from the first to the last blows.

b) With a cased smooth pile top and centered, cushioned impact, pile stresses may reach or exceed 32.5 MPa without causing pile top damage.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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