AN EXAMPLE
USING A VARIETY OF
CAPACITY DETERMINATION METHODS

by

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Introduction

GRL had an opportunity to review data collected on a project where restrike tests were conducted on 18 piles as a check on pile bearing capacity. The tests indicated some variability as did the installation criteria. Capacities calculated by CAPWAP were lower than expected and for that reason the data and analysis review was made.

Test Details

The piles consisted of 700 mm dia. spiral welded pipes with 14 mm wall thickness. They were typically 45 m long and extended through silt, sand into a silty, sandy gravel layer. Pile embedment was typically 35 m.

A Model PAK Pile Driving Analyzer conditioned and processed signals from 4 strain transducers and 2 accelerometers. Two strain transducers would not have provided sufficiently accurate strain/force records.

The piles were restruck with a 6 ton drop hammer. Typically, increasing drop heights were utilized starting at 2 m and reaching 4.5 m. The piles had been installed with an open ended diesel hammer of 4.5 ton ram weight; it proofed too small for generating enough energy and pile set during the restrike tests. Pile sets were measured for each blow by means of a transit.

Plugging of this 700 mm diameter pile was considered essential for full end bearing development and for that reason short internal 1/4 pipe panels were welded inside the pile toe. It was hoped that the four smaller chambers formed in this manner would facilitate plugging at least when applying static loads. Furthermore, plug measurements were made which shoed that the internal soil plug did move partially with the pile (approximately 30%).

Data Quality

It is not easy to obtain high quality data on spiral welded pipe because of the imperfections of the pipe such as stress concentrations due to local bending near welds. After a few initial tests the test engineers very quickly realized that the only remedy would be the use of four strain transducers. A greater than 2 diameter distance from the pile top would also be beneficial, however, that was not possible to move the gages further down on this job because of the nearness to the water surface. Only two accelerometers were used which is satisfactory as far as the data quality of velocity is concerned.

Even when strain was measured with four transducers, high bending components still appeared to produce non-proportionality. Thus, for CAPWAP analysis, calibration adjustments had to be made between 0 and -10% on strain while acceleration calibration adjustments were limited to at most +3% because of the lesser sensitivity of motion measurements to the imperfections of impact and pipe type.

On some records a final force shift was noted. That means that a least one strain transducer slipped. While it is sometimes possible to avoid the analysis of such records by choosing another one, when a series of blows is to be analyzed (see below), that option does not exist. For that reason, force shifts (FA) in the CAPWAP data adjustment section were applied with magnitudes less than 10% of maximum force. Fortunately, this measure had to be taken only in a few cases. Note that such a force shift does not alter the dynamic content of the record since CAPWAP subtracts a constant force value, present in the beginning of the record, from the force record prior to analysis. The offset is, however, added to the final result. This is reasonable considering the effect that the transducer slippage had on the records.

Initial results

The first analyses followed the usual approach: an early high energy blow with good data quality was selected and the standard analysis was then performed. No radiation damping was applied because damping factors were within limits, and sets per blow were considered adequate for capacity mobilization.

It was quickly noticed however that the later blows exhibited lower friction values than later ones. Thus, for a few piles early and late records were analyzed, a characteristic friction was calculated and applied to all piles using the resistance distribution calculated by CAPWAP. This same approach is often used when the restrike cannot activate the full end bearing because of high friction. However, the end bearing has been recognized in the end of driving records. Successful application of this superposition method requires that the end bearing does not relax and that shaft resistance and end bearing can be accurately differentiated. To be conservative it is then important that not too much end bearing is calculated (by inadvertently including in it shaft resistance values) in the end of drive analysis.

Reanalysis

The characteristic friction approach is an unusual interpretation method for dynamic pile testing records and an zlternate method of assessing the total pile capacity was sought. Thus, in order to assess the "lost" friction, the following additional analyses were made.

Multiple Blow Analysis (MBA) of the data of two piles
Single blow analysis of all blows of the same two piles
Analysis of both an early blow and a high energy later blow of all other piles
TIPWHIP (Finite Element) static analysis for one representative pile

Unit resistance values obtained from MBA are shown in Figure 1 for one pile analyzed. MBA analyzes a continuous series of blows, all with the same damping values, quakes, end bearing and the same resistance distribution along the shaft, except that shaft resistance values decrease as the pile penetrates into the ground (CAPWAP Manual, 1996). The decrease of the shaft resistance values is accomplished by factoring. Obviously, the shaft resistance in the uppermost segments decreased to a much greater degree than those at deeper segments. MBA may be somewhat non-conservative, because resistance quickly lost in the upper segments may also be lost quickly during static load applications. The MBA analysis, however, suggested that indeed the resistance decreased during the restrike test while the end bearing has been present but not mobilized during the earlier blows. Local experience suggested that relaxation would not occur in the silty sandy gravels into which the piles were driven.

The same two piles that had been analyzed by MBA also were analyzed one blow at a time.

Radiation damping was chosen considering that the sets per blow were rather low during the early blows when most shaft resistance was present and also considering the silt content of the soils along the pile. Alhough these individual blow analyses resulted in more conservative capacities than MBA (one example is shown in Figure 2) they did indicate the higher resistance in the upper segments for earlier blows. Since local experience suggested that relaxation would not occur in the silty sandy gravels into which the piles were driven, it was decided to analyze for each pile tested both one early and one high energy blow and to combine resistance forces as follows:

> Friction values from the early blow and all segments except those representing the bottom 6 m with friction values over the bottom 6 m plus end bearing for the high energy blows.

This superposition scheme prevented that an inaccurately calculated end bearing and shaft resistance components would affect the combined results. Two such results are shown in Figures 3 and 4.

In summary, the following average capacities were calculated:

> Standard, single high energy blow analyzed without radiation damping:
> Standard, single high energy blow analyzed with radiation damping:
> Combined resistance values, early and late, with radiation damping:

These results are depicted in Figure 5 which shows that there is, on the average, only an 8 % capacity increasing due to radiation damping. The increase due to capacity combination was an additional 9%.

Finally, a TIPWHIP analysis was performed to investigate whether it would be likely that the pipe plugs in the static loading situation. The calculated load-set curve is shown in Figure 6. Indeed, according to this analysis, plugging was forecast and a significant increase of end bearing with larger deflections. It should be mentioned that the TIPWHIP soil parameters were chosen such that Davisson would match the average CAPWAP result. Large deflections (say greater than 25mm) cannot be generated in a dynamic test and are therefore not predicted by CAPWAP.

Safety Factor Considerations

CAPWAP tends to be conservative, in general and in particular for open ended pipe piles driven into a granular material. The GRL data base contains a few of these cases. Figure 7 shows their correlation. It is believed that CAPWAP predicts low because it usually is based on a non-plugging analysis while statically most pipe piles plug.

Several codes allow for a reduction in safety factor with increasing number of tests (Swedish Highway code, EC 7, DIN 1054). This philosophy is based on the idea that statistically, increasing the knowledge about the quality of the foundation should and could be rewarded with a reduction in safety factor. Indeed, if all piles were tested and their tests would show sufficient strength and small settlements, then there would be no need to cover uncertainties about bearing capacity and the safety would only have to cover uncertainties about load.

In the present case a total of 430 piles were to be driven and 18 were tested. The end of driving results suggested a 15% variability. Allowing a 1/2% probability of failure then a safety factor that would be satisfactory for 1 pile tested, could be reduced by 10% if 18 piles were tested. This concept is only acceptable where the failure of a single pile would could be compensated for by neighboring piles.

Conclusions

General conclusions and conclusions based on the present case study may be summarized as follows:

> It is recommended that four strain readings are taken whenever large diameter piles, spiral welded pipes or cast in place shafts are tested. It may even be beneficial to test H-piles with four transducers.
>
> Capacity combination using early and late restrike blows may by acceptable and reasonable, as long as there is no relaxation and as long as early restrike blows cannot activate the full capacity because of lack of energy.
>
> Combination of resistance values has to be done with caution such that there is no accidental confusion of end bearing and shaft resistance near the toe.
>
> Radiation damping solutions are reasonable even if sets per blow are not very small since the capacity increasing effect of the radiation damping model vanishes as sets increase.
>
> TIPWHIP can help in assessing additional gains of capacity with higher sets.

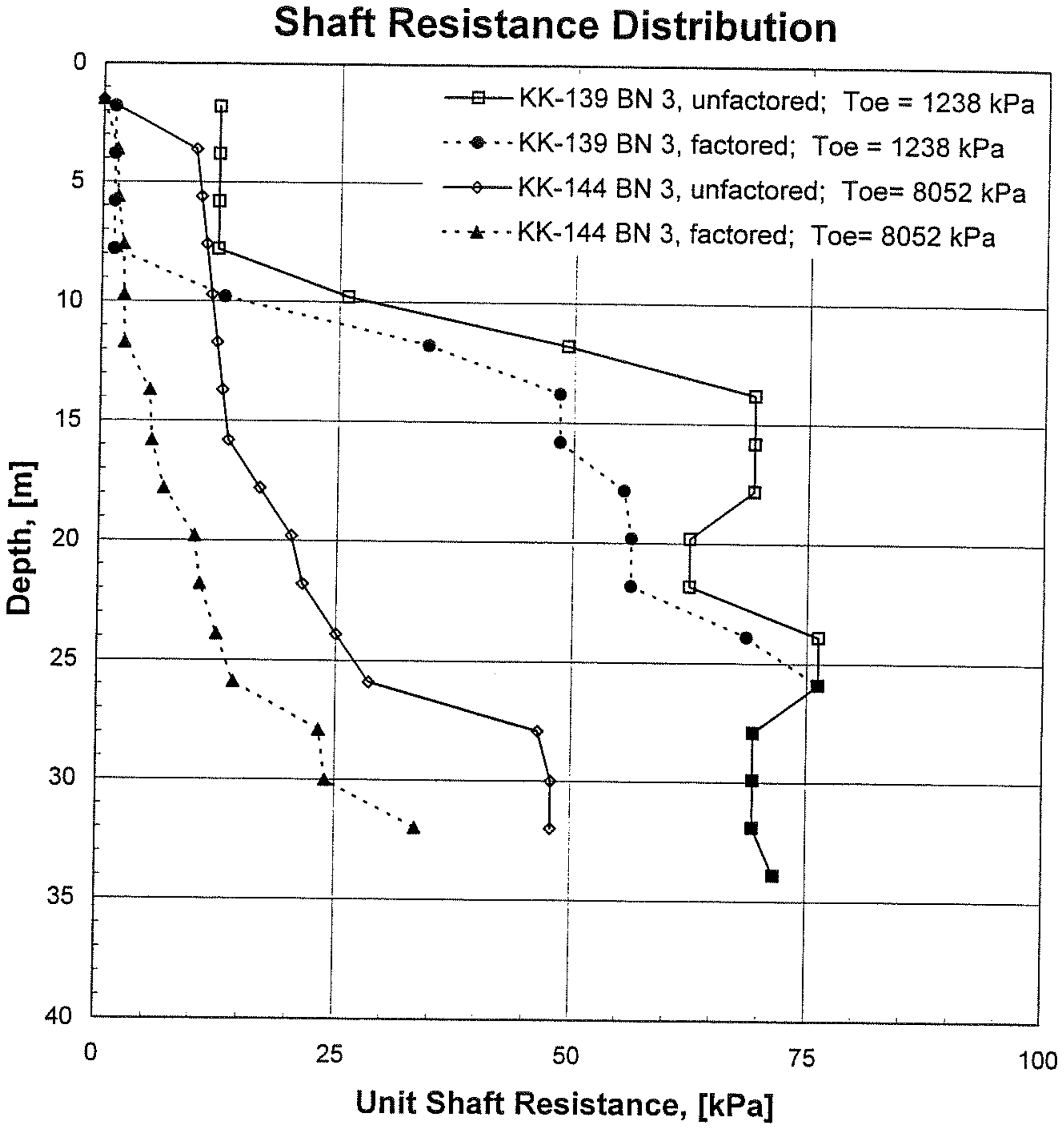


Figure 1: Results from MBA

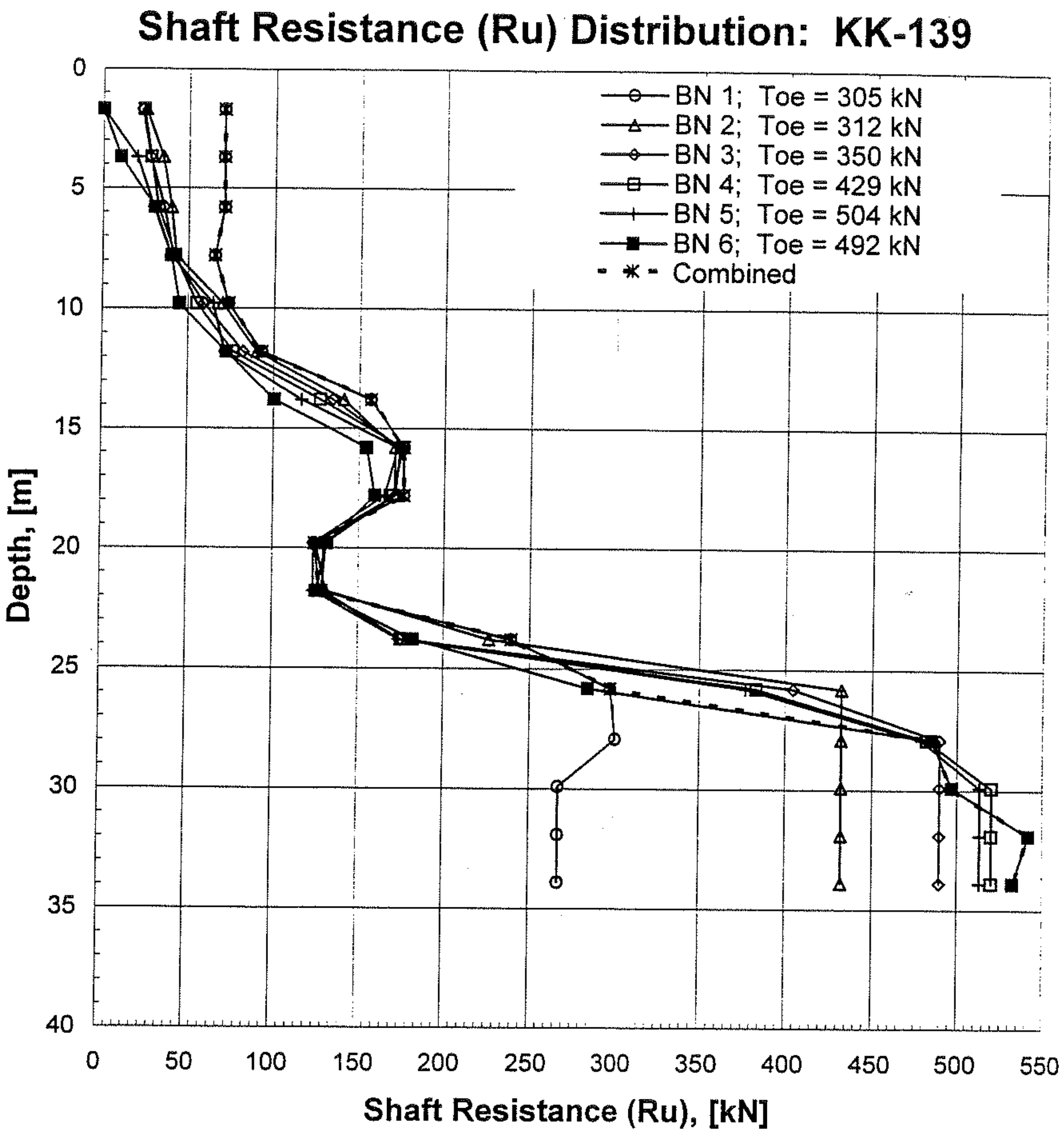


Figure2: Results from Individual Analysis

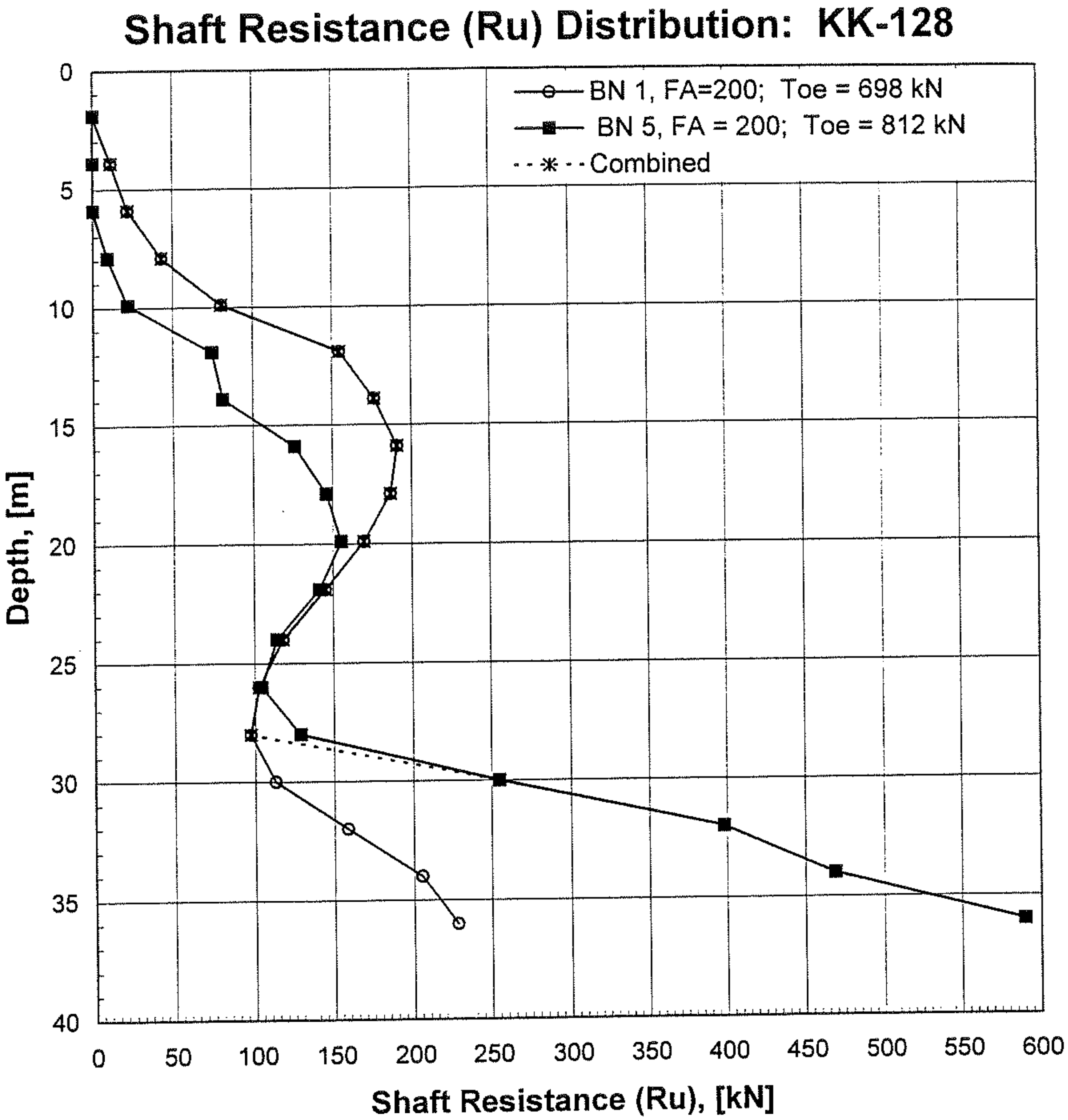


Figure 3: Results from Individual Analysis

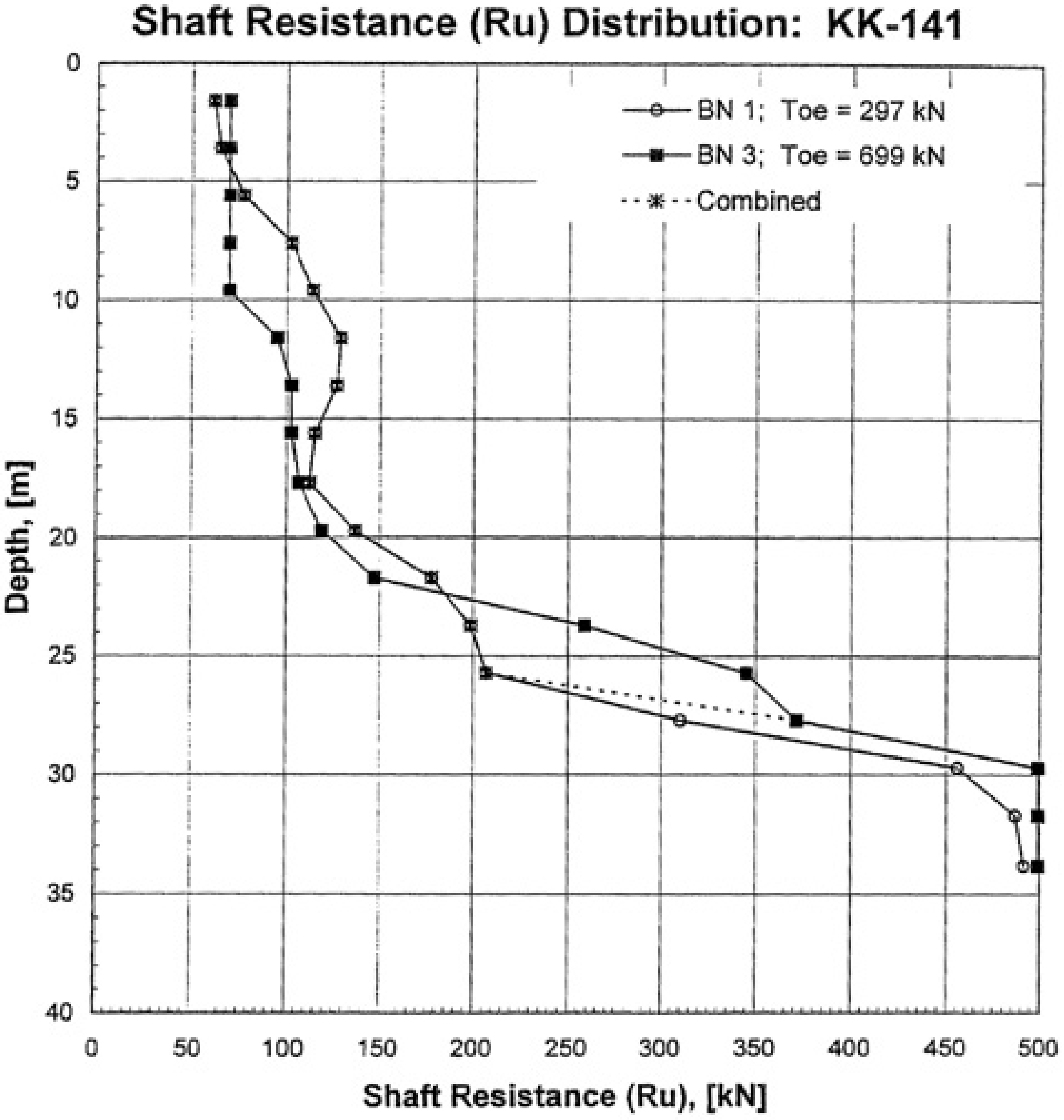


Figure 4 : Results from Individual Analysis

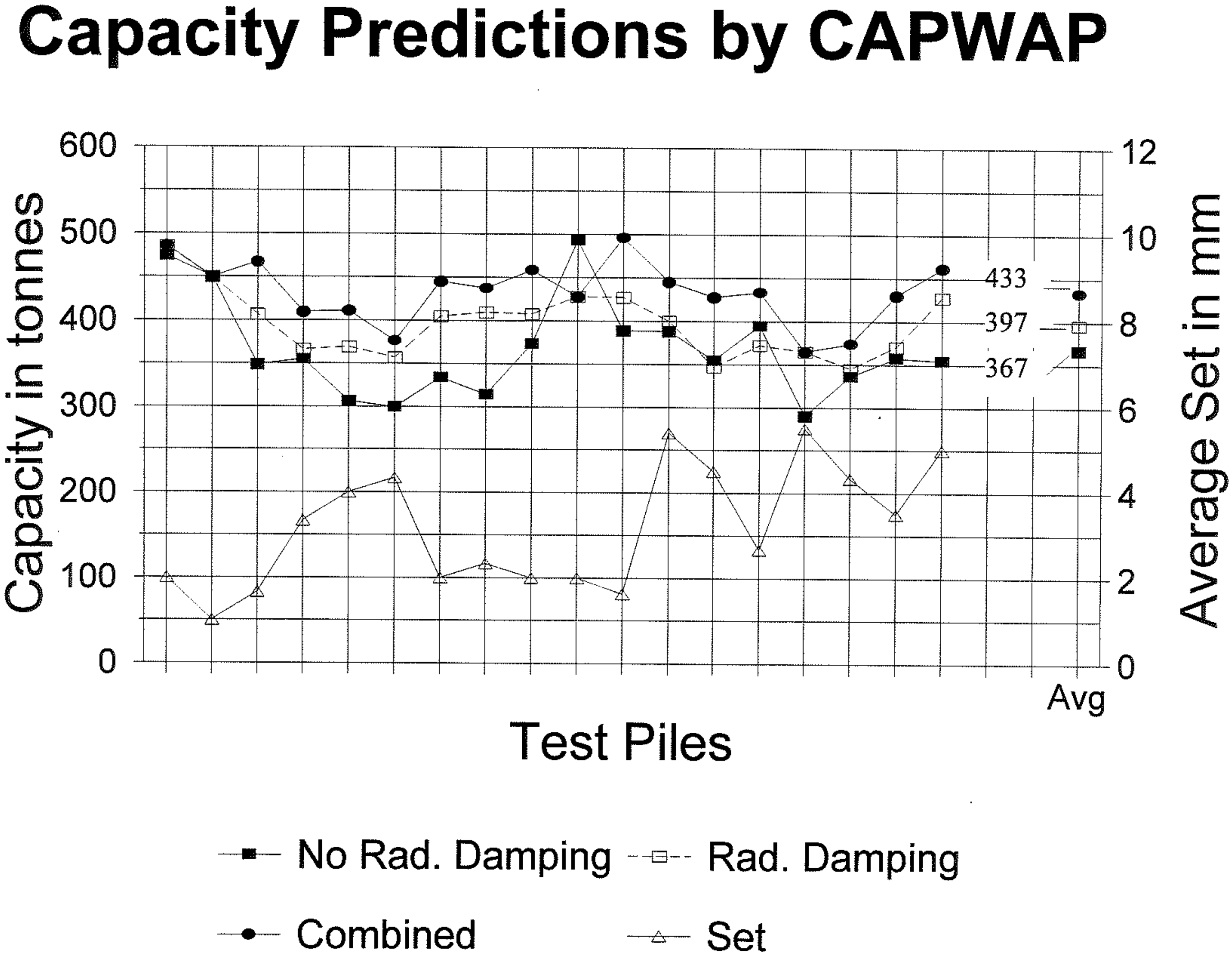


Figure 5: Summary of Capacity Predictions

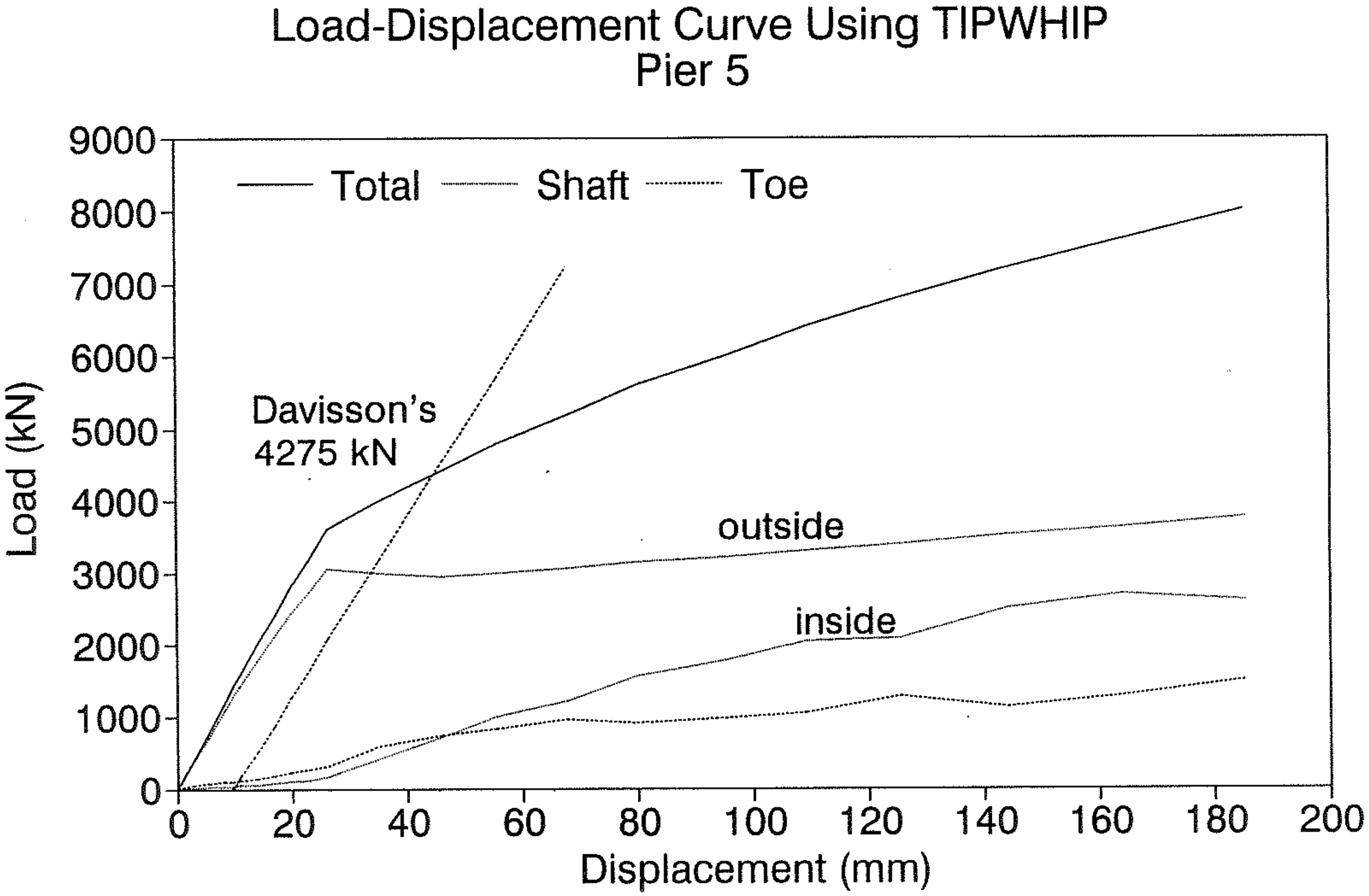
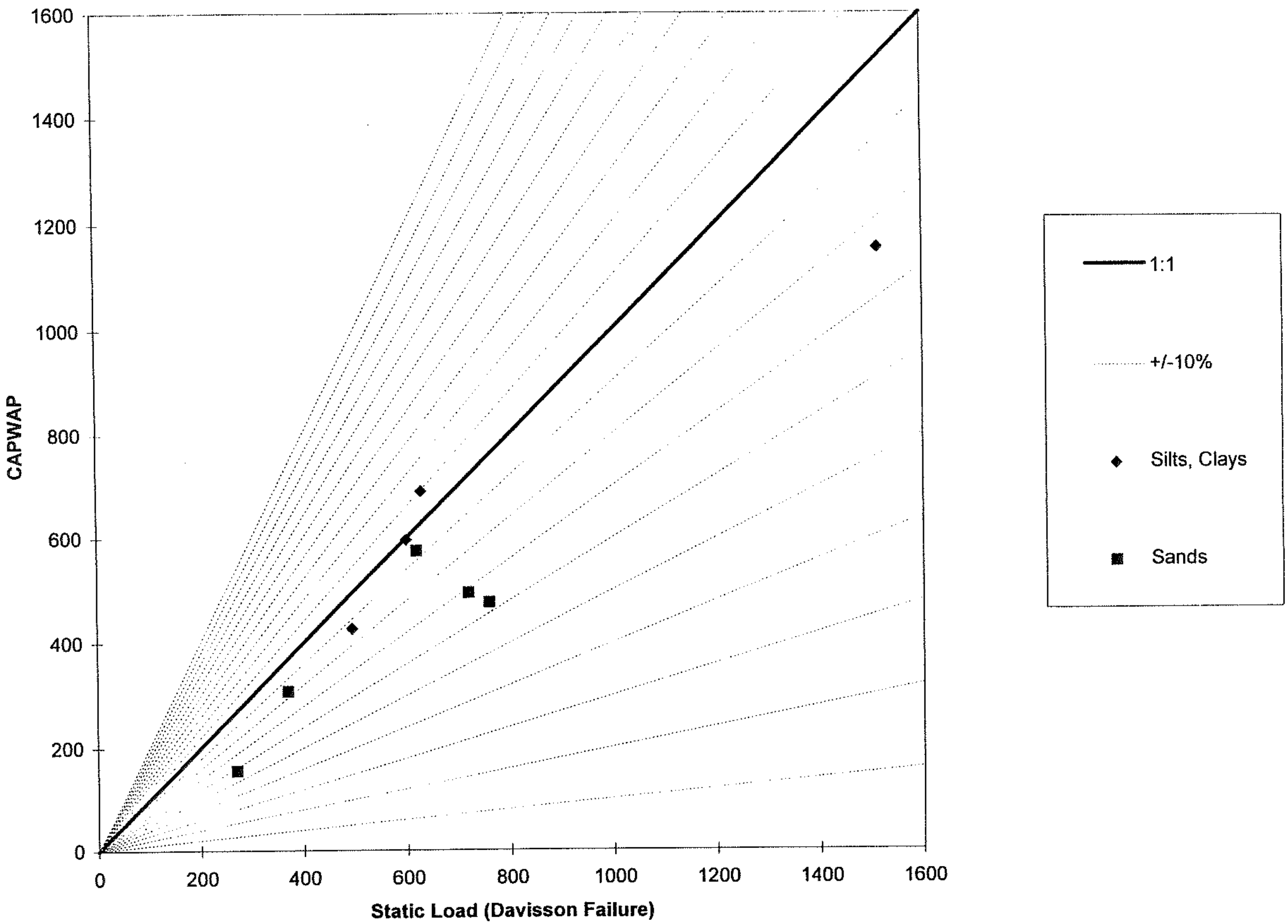


Figure 6: Results from TIPWHIP Finite Element Analysis



Open Ended Pipes: BOR Correlation
(By End Bearing Soil Type)

Figure 7 : CAPWAP (Normal Soil Model) *vs* Static Load Test Result

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