Pile Driving Prediction, 4th Stress-Wave Conference
The Hague, The Netherlands, September 22, 1992

#97A

CLASS A PILE DRIVEABILITY PREDICTION OF FOUR CONCRETE PILES

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INTRODUCTION

A pile driving prediction contest will be held as part of the 4th International Conference on the Application of Stress Wave Theory on Piles, The Hague, The Netherlands, September 21-24, 1992. Four 20 m long, 250 mm square prestressed precast concrete piles will be installed on September 22, 1992 at the Technical University of Delft. The test piles will be driven with four different pile driving hammers and rigs, and will be dynamically monitored during driving.

Participants have been invited to make predictions, before the piles are driven, of pile driving blow counts and stresses. A report prepared by Fugro-McClelland Engineers B.V. titled "Factual Data for Pile Driving Prediction" dated March 11, 1992 was provided to the participants. The report contains information on the test site, soil data, pile and hammer information, as well as requirements for presentation of prediction results.

In response to the above invitation, this paper presents a pile driveability prediction for the four concrete piles to be driven with the four specified hammers operating at known efficiencies. The prediction is based on analyses conducted using the GRLWEAP program (Goble Rausche Likins and Associates, Inc., 1992). The hammer, pile and soil data used in the analysis are described herein.

APPROACH

The GRLWEAP program is based on the Smith (1960) lumped mass concept for pile driving analysis using the one-dimensional wave equation. The program models the three components of the pile driving problem: driving system, pile and soil. The driving system consisting of the hammer, helmet and cushions, and the pile are represented by a series of masses, springs and dashpots. The soil is represented by a series of elastic-plastic springs and linear dashpots. The dynamic analysis is started by giving the ram elements a velocity equal to the hammer impact velocity, and the subsequent motions of the mass elements are computed. The permanent set of the soil springs is obtained in the analysis and its inverse gives the blow count of the pile for the given hammer-pile-soil input parameters. The program also computes the axial stresses in the pile corresponding to the computed blow count and the energy transferred into the pile, ENTHRU.

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The driveability, or blow count versus depth, option in GRLWEAP was used. In addition to driving system and pile data, this option requires input of the static soil resistance distribution (shaft and toe resistances), quake and damping values for the soil layers of interest. The analysis yields the blow count, stresses and ENTHRU versus pile penetration.

DRIVING SYSTEM DATA

The four different hammers that will be used to drive the concrete piles are:

1. Delmag D-25 single-acting diesel hammer
2. Menck MHF-3.3 hydraulic hammer
3. ICE D-640 double-acting diesel hammer
4. IHC SC-40 hydraulic hammer

The hammer data as contained in the HAMMER.ALT file, part of the GRLWEAP package, were used in the analysis. Table 1 summarizes the hammer rated energies and the hammer efficiency values used for the calculation of the impact velocity in GRLWEAP.

Table 1 Pertinent Hammer Information

Hammer Type	Max. Rated Energy (kJ)	Ram Weight (kN)	Hammer Efficiency
Delmag D-25	79	24.52	0.72
Menck MHF-3.3	30	31.38	0.90
ICE D-640	55	26.77	0.80
IHC SC-40	38	25.01	0.95

The striker plate, hammer cushion, helmet and pile cushion were specified for the prediction. The given dimensions, material types and weights were used to calculate the appropriate stiffnesses and weights for the springs and masses in the driving system model. Cushion material properties were not provided but were estimated for the analysis. An elastic modulus of 2070 MPa was assumed for the hardwood hammer cushion and a value of 345 MPa for the softwood pile cushion.

PILE DATA

The 20 m long 250 mm square prestressed precast concrete pile has a cross-sectional area of 0.0625 m^2 and a given Young's modulus of 40,000 MPa. The pile will be prestressed to 4.8 MPa with five 9.3 mm diameter reinforcing strands. A unit weight of 23.6 kN/m^3 was assumed for the concrete. Nominal damping values as recommended in GRLWEAP were used for the dashpots to simulate energy losses in the structural pile material.

SOIL DATA

The test piles will be driven through a sequence of loose silty sands and soft clays into a medium dense to dense sand stratum. Soil data consisting of cone penetration test (CPT) and standard penetration test (SPT) results, drill hole log and laboratory index test results were provided for the prediction. The available test data indicate relatively uniform deposits at the four test pile locations which can be characterized as shown in Table 2.

Table 2 Generalized Soil Profile and Average CPT Tip Resistance

Depth (m)	Soil Type	CPT Tip Resistance Average Qc (bar)
0 to 2.5	silty clay	10
2.5 to 5.0	silty sand	20
5.0 to 9.5	clay	5
9.5 to 13.0	silty sand	40
13.0 to 15.5	clay-silt	10
15.5 to 20.0	sand	150

Note: 1 bar = 100 kPa = 0.1 MPa

The static, long-term shaft and toe resistances (or ultimate capacities) of the soil layers were estimated from the CPT data using the LCPC method (Bustamante and Gianeselli, 1982). Figure 1 shows the calculated ultimate static shaft and toe resistance profiles. For driveability prediction, it is the static resistances during driving that are required in the analysis. To account for soil strength decrease along the pile shaft due to pile driving, the static ultimate or long-term shaft resistance values in Figure 1 were multiplied by the following factors in the analysis: 0.2 for clay, 0.4 for silty sand, and 0.6 for sand. These factors are based on the authors' experience. The pile toe resistances were not reduced.

Conventional Smith-type damping and quake parameters as recommended in GRLWEAP were used in the analysis.

PREDICTIONS

The participants were requested to provide, for each hammer and for transferred energy levels of 5, 12.5 and 20 kJ:

1. Blow count profiles for each 0.25 m of pile penetration.
2. Maximum compressive stresses at 0.5 m below the pile head at three specified pile penetration intervals.

3. Maximum tensile stresses at 9.0 m below the pile head at two specified pile penetration intervals.

The driveability predictions are presented in Plates 1 to 4 for the four specified hammers. Note that no predicted quantities are shown for the two diesel hammers for a transferred energy of 5 kJ, since the analyses indicated that the diesel hammers could not operate at this low energy level. Instead, predicted quantities for a transferred energy of 30 kJ are given for these two hammers.

REFERENCES

Bustamante, M. and Gianeselli, L. (1982). "Pile Bearing Capacity Prediction by Means of Static Penetrometer CPT", Proc. ESOPT II, Amsterdam, Vol. 2, 493-500.

Goble Rausche Likins and Associates, Inc. (1992). "GRLWEAP - Wave Equation Analysis of Pile Driving", March 1992 version.

Smith, E.A.L. (1960). "Pile Driving Analysis by the Wave Equation", J. Soil Mech. and Found. Div., ASCE, Vol. 86.

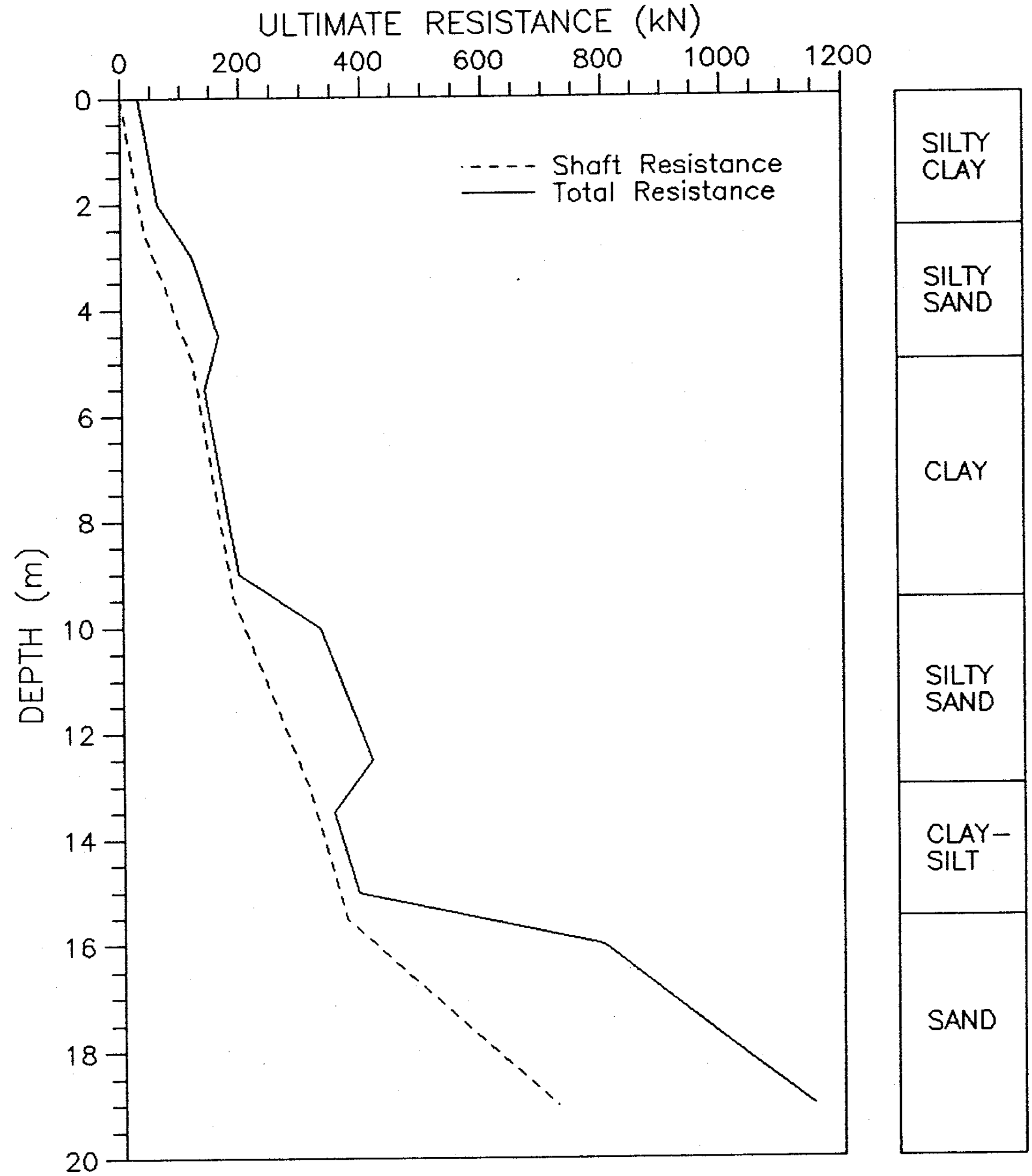
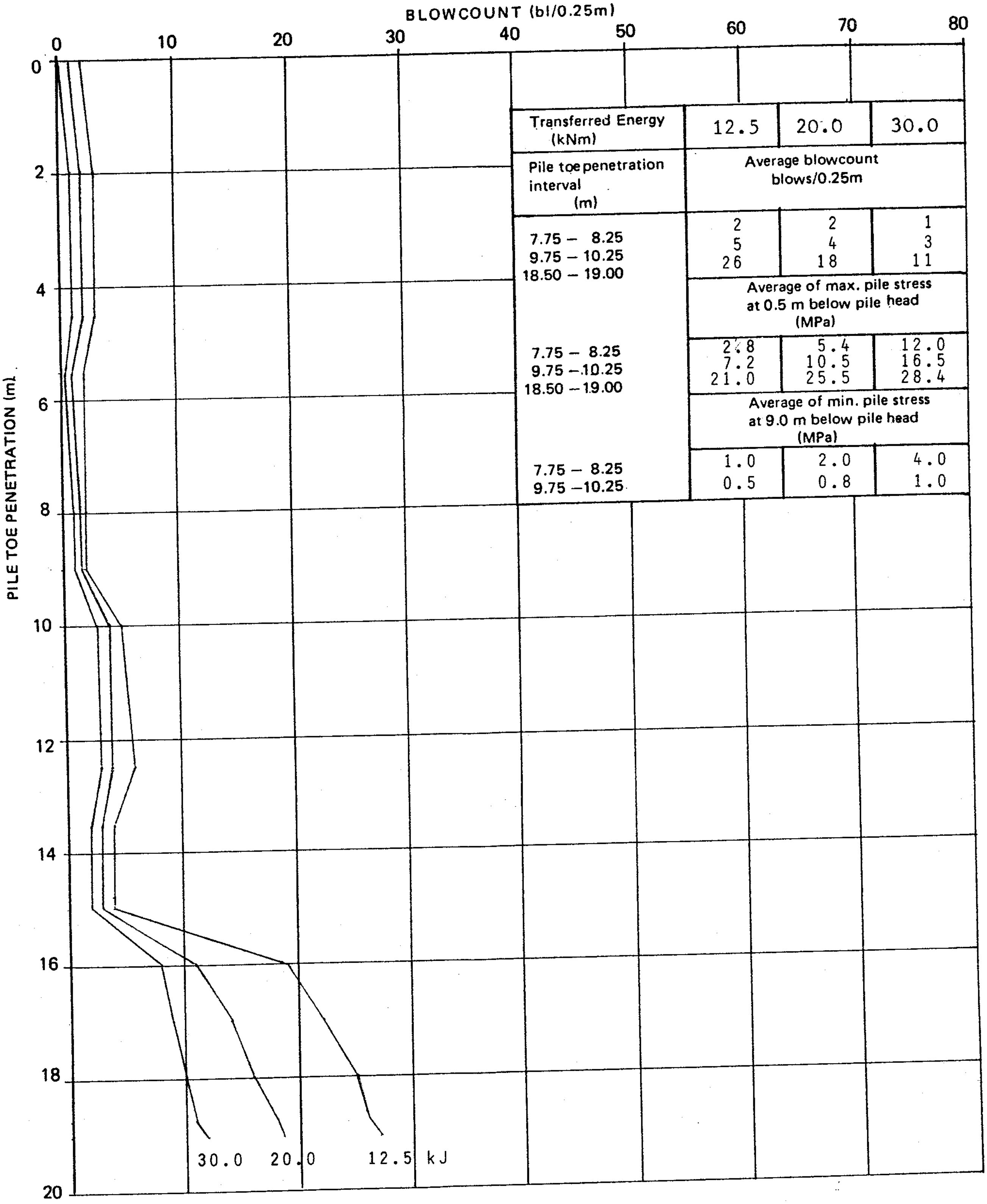


Fig.1 Ultimate static resistance distribution for 250 mm square prestressed precast concrete pile at Delft pile test site



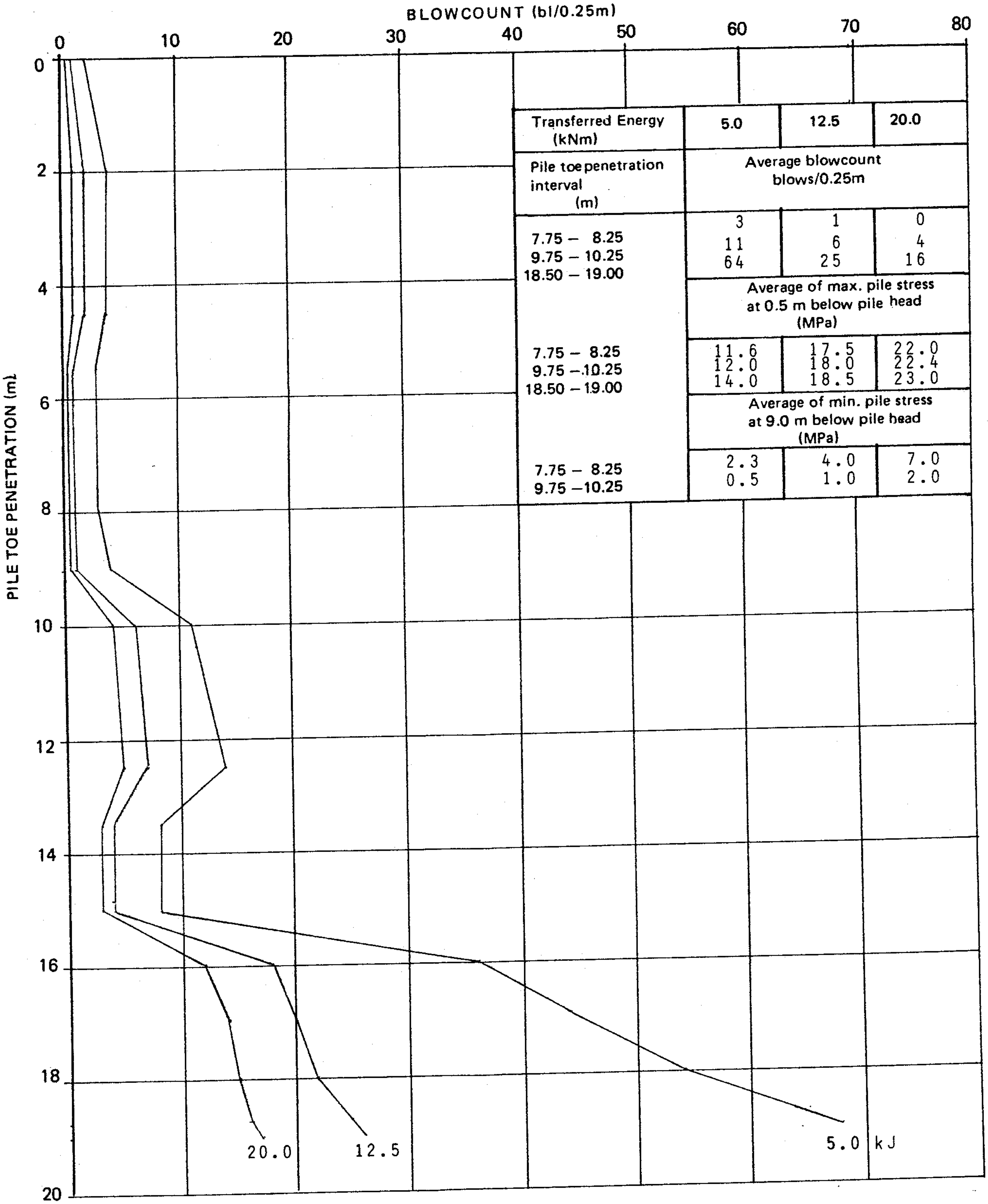
Transferred Energy (kNm)	12.5	20.0	30.0
Pile toe penetration interval (m)	Average blowcount blows/0.25m		
7.75 – 8.25	2	2	1
9.75 – 10.25	5	4	3
18.50 – 19.00	26	18	11
	Average of max. pile stress at 0.5 m below pile head (MPa)		
7.75 – 8.25	2.8	5.4	12.0
9.75 – 10.25	7.2	10.5	16.5
18.50 – 19.00	21.0	25.5	28.4
	Average of min. pile stress at 9.0 m below pile head (MPa)		
7.75 – 8.25	1.0	2.0	4.0
9.75 – 10.25	0.5	0.8	1.0

LOCATION : 04

PILE DRIVING PREDICTION
DELMAG D-25 HAMMER

STRESS-WAVE

Plate 1



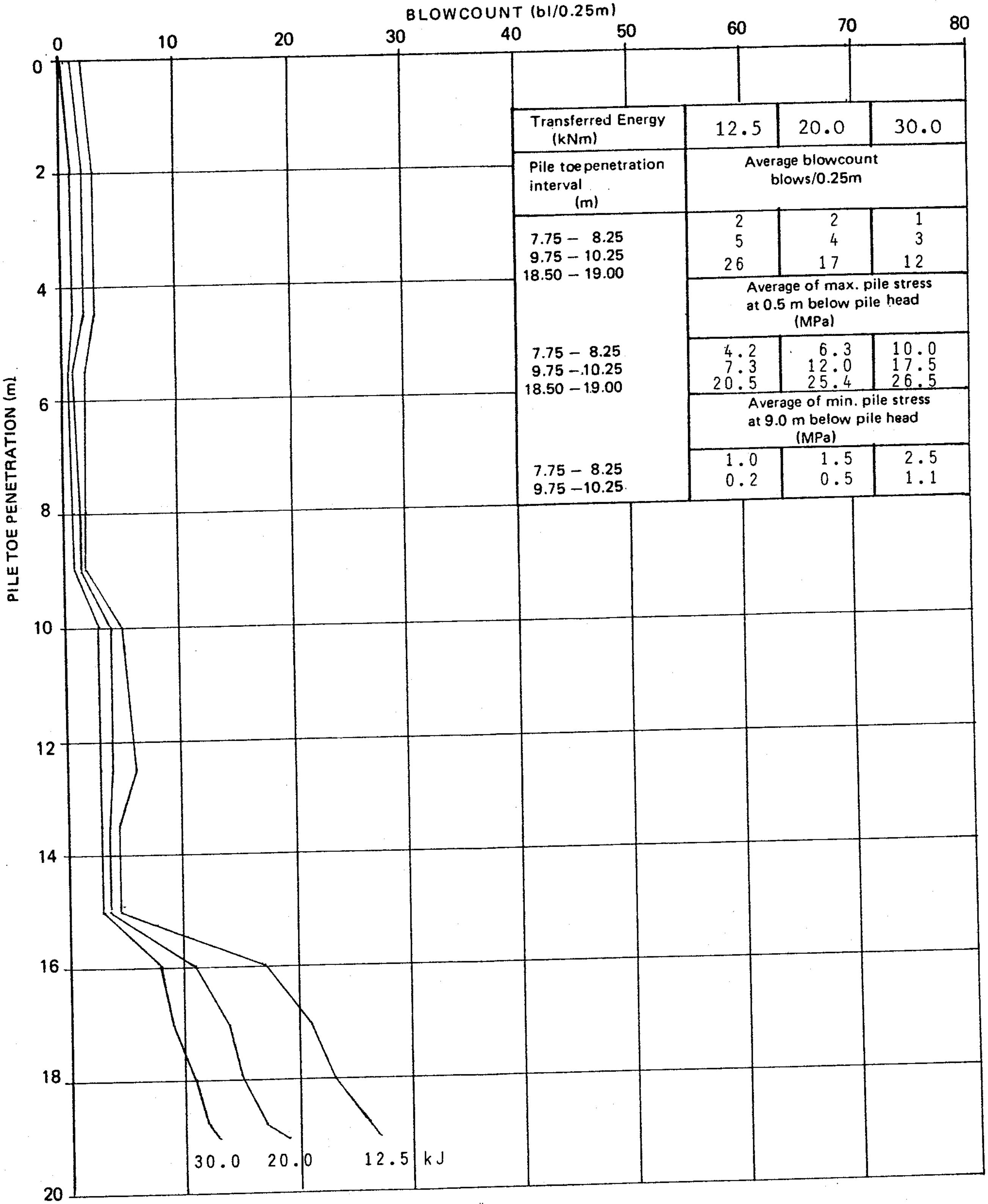
Transferred Energy (kNm)	5.0	12.5	20.0
Pile toe penetration interval (m)	Average blowcount blows/0.25m		
7.75 – 8.25	3	1	0
9.75 – 10.25	11	6	4
18.50 – 19.00	64	25	16
	Average of max. pile stress at 0.5 m below pile head (MPa)		
7.75 – 8.25	11.6	17.5	22.0
9.75 – 10.25	12.0	18.0	22.4
18.50 – 19.00	14.0	18.5	23.0
	Average of min. pile stress at 9.0 m below pile head (MPa)		
7.75 – 8.25	2.3	4.0	7.0
9.75 – 10.25	0.5	1.0	2.0

LOCATION : 05

PILE DRIVING PREDICTION

MENCK MHF 3-3 HAMMER

STRESS-WAVE



Transferred Energy (kNm)	12.5	20.0	30.0
Pile toe penetration interval (m)	Average blowcount blows/0.25m		
7.75 – 8.25	2	2	1
9.75 – 10.25	5	4	3
18.50 – 19.00	26	17	12
	Average of max. pile stress at 0.5 m below pile head (MPa)		
7.75 – 8.25	4.2	6.3	10.0
9.75 – 10.25	7.3	12.0	17.5
18.50 – 19.00	20.5	25.4	26.5
	Average of min. pile stress at 9.0 m below pile head (MPa)		
7.75 – 8.25	1.0	1.5	2.5
9.75 – 10.25	0.2	0.5	1.1

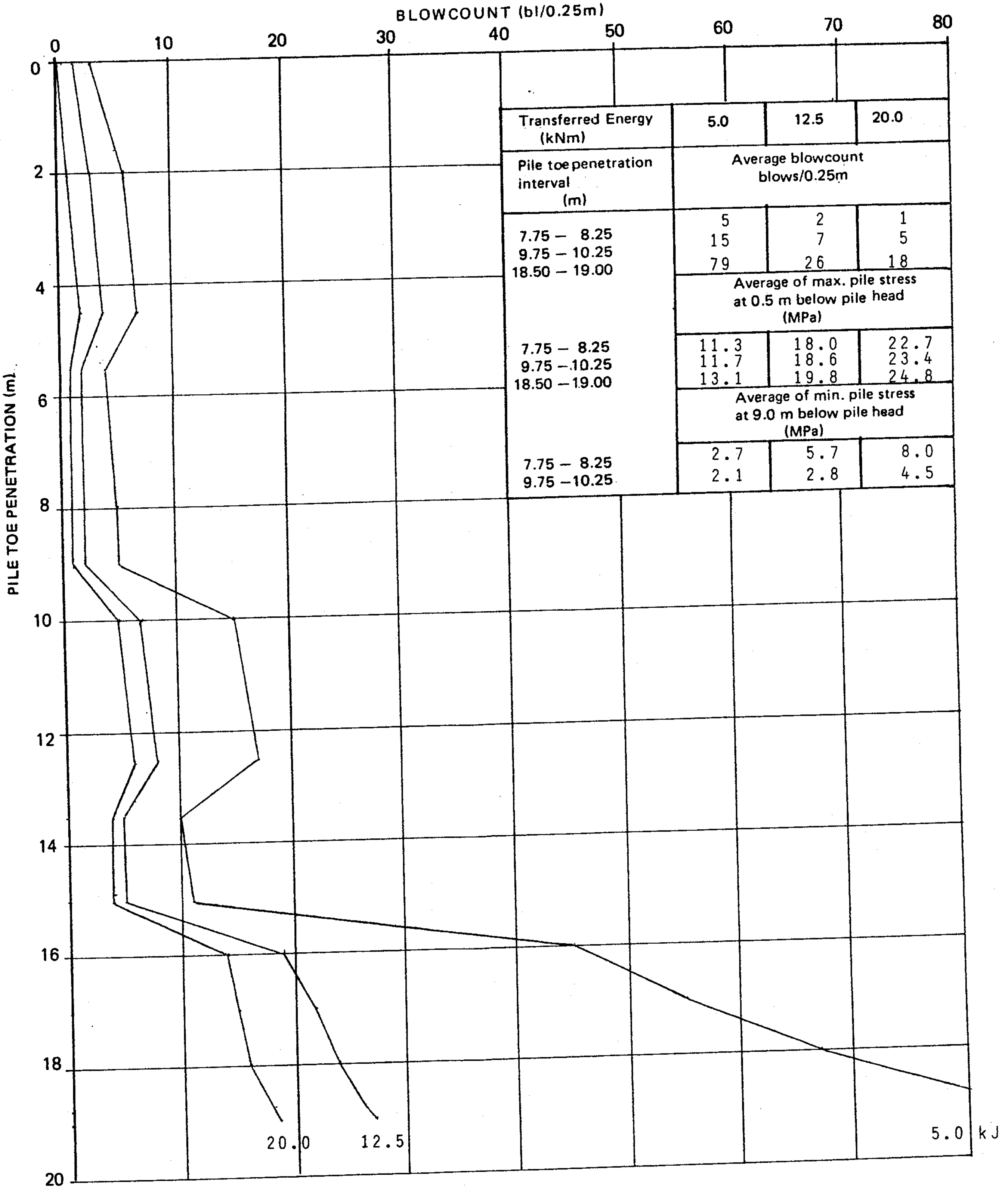
LOCATION : 06

PILE DRIVING PREDICTION

ICE D-640 HAMMER

STRESS-WAVE

Plate 3



Transferred Energy (kNm)	5.0	12.5	20.0
Pile toe penetration interval (m)	Average blowcount blows/0.25m		
7.75 – 8.25	5	2	1
9.75 – 10.25	15	7	5
18.50 – 19.00	79	26	18
	Average of max. pile stress at 0.5 m below pile head (MPa)		
7.75 – 8.25	11.3	18.0	22.7
9.75 – 10.25	11.7	18.6	23.4
18.50 – 19.00	13.1	19.8	24.8
	Average of min. pile stress at 9.0 m below pile head (MPa)		
7.75 – 8.25	2.7	5.7	8.0
9.75 – 10.25	2.1	2.8	4.5

LOCATION : 07

PILE DRIVING PREDICTION
IHC SC-40 HAMMER

Plate 4

STRESS-WAVE