GRL Dynamic Measurements and Analyses
engineers, inc.

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June 23, 2020

Sherri Meiklejohn, General Manager/Owner
Authentic Drilling, Inc.
33555 County Road 37
Kiowa, Colorado 80117

Re: Energy Measurement for Dynamic Penetrometers
Standard Penetration Tests
Kiowa, Colorado GRL Job No. 202001-1

Dear Mrs. Sherri Meiklejohn:

This report transmits our findings from energy measurements and related data analysis conducted by GRL Engineers, Inc. (GRL) for your four drill rigs, with measurements collected in Kiowa, Colorado. Four automatic hammers and penetrometer systems were monitored during Standard Penetration Tests. Dynamic testing summarized herein was conducted on January 2, 2020.

A Pile Driving Analyzer® Model 8G recorded, processed and displayed the dynamic data to meet the objectives of the hammer system calibration. Discussions on the test methods, limitations and implementation are provided in Appendix A. The energy measurement results are summarized in Tables 1A through 1D, with the average and standard deviation provided in Appendix B, and representative plots of force and normalized velocity provided in Appendix C.

EQUIPMENT

Hammer and Penetrometer System

Energy measurements were recorded during standard penetration tests conducted for four automatic hammers and the following drill rig type(s) and serial number(s).

Drill Rig	Serial Number	Drill Rod Size
CME 550X	404583	AWJ
CME 55	406085	AWJ
Acker RENEGADE	191980417	AWJ
CME 550X	409193	AWJ

Measurements were recorded for one boring location for each of the four drill rigs. Authentic Drilling, Inc. (Authentic) advanced the penetrometer to a minimum depth of an approximate 19.0 feet prior to energy measurements. The instrumented subassembly was connected to the top of the drill rod string and measurements recorded at intervals for up to five depths of data.

Measurements were recorded for every blow required to advance the sampler 18 inches. Results are provided for the final 12 inches or less of the sampler advancement alone (i.e., excluding the initial 6 inches of advancement). ASTM Standard D4633 recommends that tests for energy evaluation be limited to Standard Penetration Test (SPT) N-values between 10 and 50. Energy measurements of all samples are included in the averages reported herein.

The following drill rod dimensions, of rod size AWJ, were employed during testing.

Drill Rod Area sq. inch				Outside Diameter Inch				Inside Diameter inch			
1.20				1.75				1.23			
Depth of Penetrometer feet				Drill Rod Section Lengths feet				Transducer to Penetrometer Lengths feet			
A	B	C	D	A	B	C	D	A	B	C	D
19.5	19.0	20.0	19.5	20	20	22	20	23.9	23.9	25.9	23.9
24.5	24.0	25.0	24.5	25	25	27	25	28.9	28.9	30.9	28.9
29.5	29.0	30.0	29.5	30	30	32	30	33.9	33.9	35.9	33.9
34.5	34.0	35.0	34.5	35	35	37	35	38.9	38.9	40.9	38.9
39.5	39.0	40.0	39.5	40	40	42	40	43.9	43.9	45.9	43.9

* A (CME 550X Serial Number 404583); B (CME 55 Serial Number 406085);
C (Acker RENEGADE Serial N. 191980417); D (CME 550X Serial Number 409193).

Instrumentation

A Pile Driving Analyzer® was employed for recording, processing, and displaying the dynamic data. An instrumented subassembly, inserted at the top of the drill rod string below the hammer and anvil system and above the drill rods, recorded the force and acceleration data. The subassembly was instrumented with two foil strain gages in a full bridge circuit and two piezoresistive accelerometers attached on diametrically opposite sides of the subassembly. Data sampling frequency was 50.0 kHz.

The 8G utilizes a digital system, and with the employed sampling frequency of 50.0 kHz, the signal conditioning conforms to ASTM D4633. Results for the maximum hammer operating rate, rod top force and velocity, and transferred energy are provided in Appendix B and summarized in Tables 1A through 1D. Discussions on the test method and its limitations can be found in Appendix A.

Figure 1: Energy Measurements with Instrumented Subassembly

MEASUREMENTS AND CALCULATIONS

The primary objective of testing was the measurement of the energy transmitted from the hammer impact through the anvil into the instrumented subassembly and drill rods. Strain transducers and accelerometers were employed for the calculation of the transferred energy using force, F(t) and velocity v(t), records as follows:

$$EMX = \int_{b}^{a} F(t)v(t)dt$$

where time "b" is to the beginning of the energy transfer and time "a" is to the time at which the energy transfer reaches a maximum. Force is calculated as the product of the measured strain, elastic modulus and cross-sectional area, and measured acceleration is integrated to velocity.

Integrated over the complete impact event and calculated from measured force and velocity, the energy transferred to the top of the drill rod was calculated as a function of time. The maximum transferred energy (i.e., EMX or also referred to as EFV) is used as an indicator of the energy content of the event. The described method is the only theoretically correct method of measuring energy transfer and automatically corrects for rod non-uniformities such as connector masses or loose joints. The EF2 method results included in Appendix B are inherently incorrect and included in the appendices for reference alone.

TEST RESULTS

Result Discussion

Dynamic data was evaluated for the hammer operating rate, rod top force and velocity, and transferred energy. Appendix B provides the evaluated quantities for blows making up the SPT N-value, with their averages and standard deviation, plotted and printed as a function of depth for the monitored sequences of the standard penetration tests. Measurements collected for all samples are presented herein.

The plots in Appendix B include:

- FMX – the maximum measured rod top force
- VMX – the maximum measured rod top velocity
- BPM – the hammer operating rate, provided in blows per minute
- BLC – the equivalent N-value or count of impacts per each 12 inches set
- EFV – the maximum calculated energy (EMX) transferred to the rod top
- EF2 – the maximum of the integral of the square of force, a theoretically incorrect energy transfer calculation

Corresponding tables also include:

- CSX – the maximum measured rod top compressive stress, averaged over the cross-sectional area
- ETR – ratio of transferred energy (EFV) to the maximum theoretical potential energy

The maximum theoretical potential energy is the product of the standard 140-lb hammer impact mass dropped the standard 30 inches.

A representative plot of force and normalized velocity versus time for a typical blow from each data set is provided in Appendix C to demonstrate the data quality.

Summary of Results

I. Four automatic hammers were monitored during standard penetration tests conducted on January 2, 2020. The average energy transfer ratios calculated with the EFV method for the monitored sequences are tabulated below together with the corresponding, average hammer operating rate(s).

Drill Rig / Serial Number	Energy Transfer Ratio percent	Operating Rate bpm
CME 550X / 404583	95	48
CME 55 / 406085	98	53
Acker RENEGADE / 191980417	101	57
CME 550X / 409193	96	54

It was observed for select impacts that the energy transfer ratio exceeded 100 percent. This generally occurs when the actual drop height is higher than the standard 30 inches.

II. The uncorrected N-values encountered during the dynamically monitored sequences ranged from 39 blows to refusal conditions (i.e., at the deepest penetration depth in most boreholes).

III. To convert the uncorrected N-values for the employed hammer and penetrometer system and operators, the Schmertman correction for adjustment to 60 percent transfer efficiency is

$$N_{60} = \left(\frac{e_m}{60}\right) N_m$$

where N_{60} is the corrected hammer N-value, e_m is the percent energy transfer efficiency (i.e., e_m = 100*ETR) and N_m is the measured SPT N-value. N_{60} values for all measurements and monitored depths are presented in Tables 1A through 1D. The measured overall energy transfer ratio(s), tabulated above, produces the respective N_{60} equivalent of roughly 1.6Nm, 1.6Nm, 1.7Nm and 1.6Nm. Further corrections due to overburden stresses in the soil have not been considered but may be made prior to the use of N-values for design purposes.

We appreciate the opportunity to be of assistance to you on this project. Please contact our offices if you have any questions regarding the contents of this report, or if we may be of further service.

Respectfully,
GRL ENGINEERS, INC.

06/23/2020

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Exp: 10/31/2021

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