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Estimating uncertainties for the driving torque in continuous flight Auger machine during space sampling drilling operation

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Abstract. Auger drilling operation is considered as one of the ideal ways for space sampling as it depends on a dry drilling method. This study represents a measurement uncertainty model for the driving torque in Continuous Flight Auger machine during soil drilling operation. The measuring system is established to provide a simple way for driving torque measurement that involves the usage of a combination of different sensors. A simple data acquisition software is resolved using Labview® software package. This program enables displaying and recording the directly measured data mainly from transducers. Type-A and type-B uncertainties are estimated in detail for measuring results. The two different types are combined to evaluate the deviation of readings resulted from several sources. The overall system accuracy for the drilling torque is derived from estimating uncertainties of the measured torque. An error bar is provided for each reading to indicate the possible deviation with 95 % level of confidence. Uncertainty detailed calculation for the driving torque in Continuous Flight Auger machine during drilling operation is computed as a function of the directly measured values.

1. Introduction

Auger drilling is widely used in pile foundation engineering, geological sampling for sand soil, and even regarded as one of the best drilling approaches for space sampling because of its continuity of transportation of soil as well as the high efficiency of construction etc [3]. Continuous Flight Auger machines are widely used in construction industry for piling operations as shown in figure 1 (a). Piles are formed by screwing a continuously flight auger into the ground to required depth. Then concrete is pumped through the hollow auger stem to fill the drilled bore simultaneously the auger moves out of the hole [4]. CFA piling is a widely employed piling method offering both technical and commercial advantages, when used appropriately, in the right ground conditions and project circumstances. This method has the advantages that there is never an open or unsupported pile bore, as with some other bored piling methods [5]. Higher production rates, adjustable auger height, adjustable auger diameter, suitable for many types of soil such as; clay, sand, silt and moderate rocks [6].

The drilling tool comprises a hollow stemmed tube with a boring head or teeth at its tip. Over the entire length of the tube is a continuous helix of “flights”. The horizontal distance between the edges of the flights define the diameter of the pile and the vertical distance between the flights is the pitch as shown in figure 1 (b).



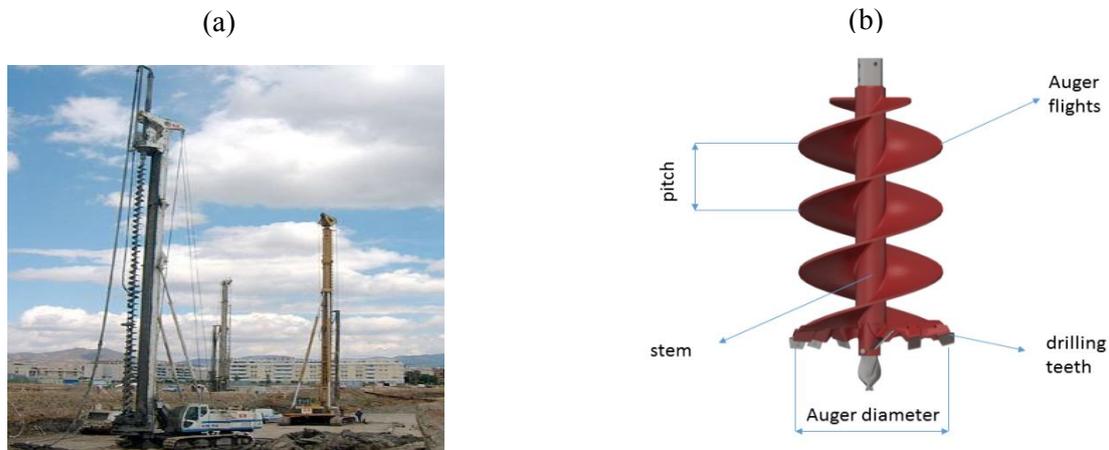


Figure 1. Label (a). Soilmec® Hydraulic CFA machine [2] (b). Soilmec® CFA Rig [2] .

An accurate measurement can be defined as the value that is close to the true value, which is unknown. The importance of measuring Uncertainty is to show the measurement range. Measurements, it is required that measurement uncertainty be known and consistent with required measurement efficiency of any screening, or measuring device. True measurement result is expected to be included in a range that can be specified according to a level of confidence, Uncertainty is the value provided with a measured value that indicates that range [7].

Presenting experimental results without calculating its uncertainties is not acceptable in several fields. J.Moffat [8], presented a common description of error sources and uncertainty in experimental measurements by using a numerical technique for estimating uncertainty for computerized data.

It is important to include Uncertainty analysis reports for measurement quality assurance. The analysis report is advisable to be comprehensive enough to describe a functional guide for measurements reading [9]. Workouts for calculating measurement uncertainty were recommended by Suzanne Castrup [10] in 2004.

2. Measuring system description

The designed system in figure 2 is used to investigate and measure the drilling torque required cutting and drilling in loose sand for 0.5m depth. This continuous flight auger system consists of an auger, which is driven by an AC motor; the AC motor is equipped with a worm type gearbox. An AC inverter controls the AC motor speed. The AC motor is fitted to a carriage moving vertically along four linear guide motion system. A linear actuator causes the penetration action, which is responsible for the vertical feed. The feeding rate is about 5mm per second. A torque transducer device is connected between the output shaft from the gearbox and the auger. Steel structure frame is designed to carry all components of the proposed measuring system, the frame is bolted to the soil bin main frame, soil bin is a box which containing soil sample to be drilled.

The AC inverter model AS 2 - 115 is used to control the speed of the three-phase AC motor. It is also responsible for reversing the direction of rotation from clockwise to anti clockwise and vice versa. A data acquisition system was built to enable reading the drilling torque it consists of T4A torque transducer uses a 4-wire connection technique inserted between the driving shaft and the auger .the output signal from T4A is sent to NI 9219 compact DAQ then to PC via a USB port.

Labview® software package was used to establish a simple program to enable recording and displaying the received data in excel sheet to be easily processed. Figure.3 shows how data is processed.

After getting displacement sensor calibration curve, sensor transfer function is deduced. The drilling torque curve was drawn between the drilling torque and the drilled depth at constant drilling speed.

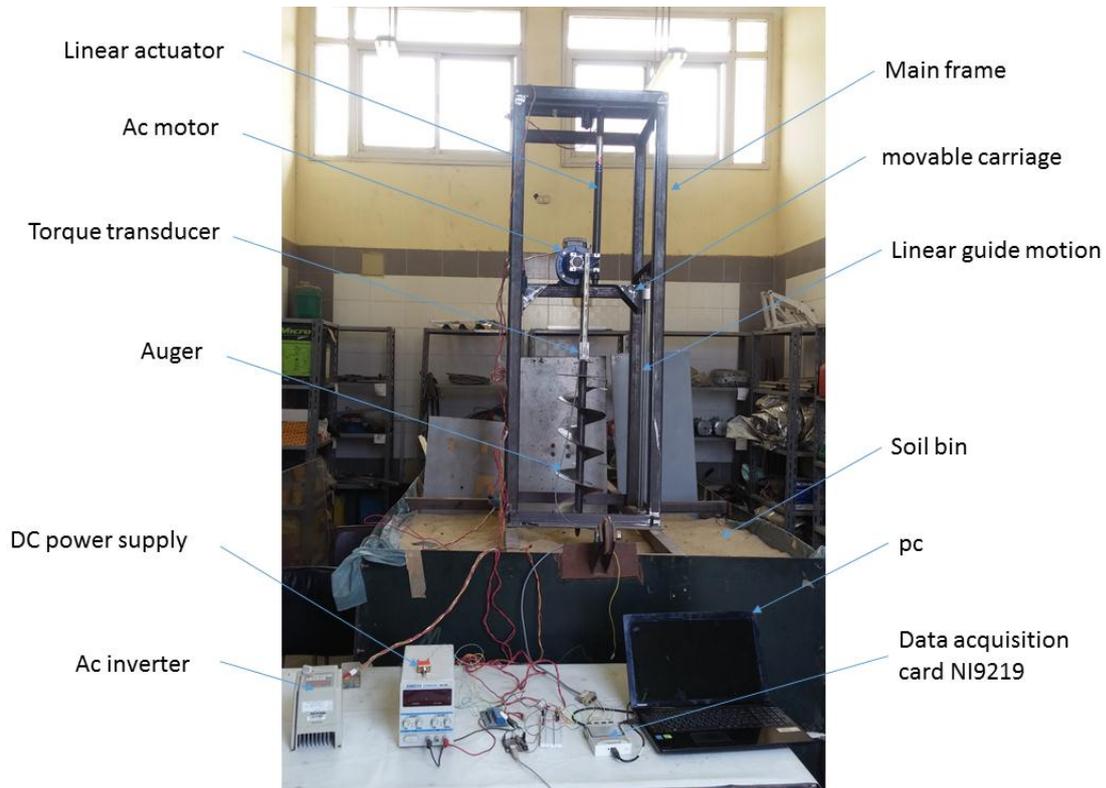


Figure 2. General layout of the drilling test rig.

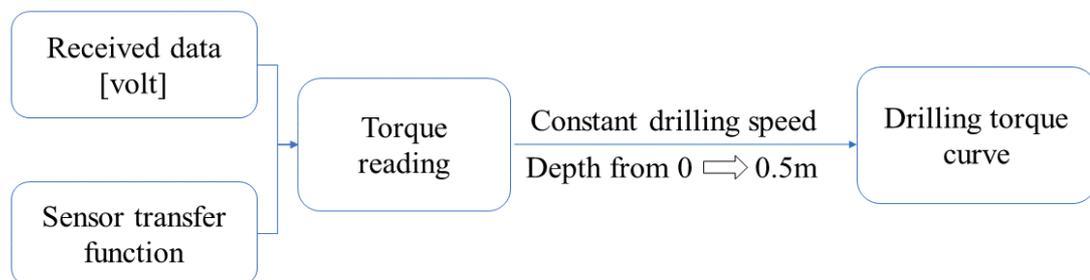


Figure 3. Data processing flow chart

Loose sand is used as cutting medium, Sieve analysis test is performed to obtain the tested soil parameters as shown in figure 4 and table 1.

Table 1. Properties of tested sand

Property	Value
Water content, W_c (%)	1.0
Specific gravity, G_s	2.62
Dray density, γ_d (kN/m^3)	18
Cohesion, C (kN/m^2)	0
Angle of shearing resistance, ϕ°	32
Effective diameter, D_{10} (mm)	0.2
D_{30} (mm)	0.4
D_{60} (mm)	0.5
Grading coefficient, C_c	1.6
Uniformity coefficient, U_c	2.50
Unified soil classification	Sp

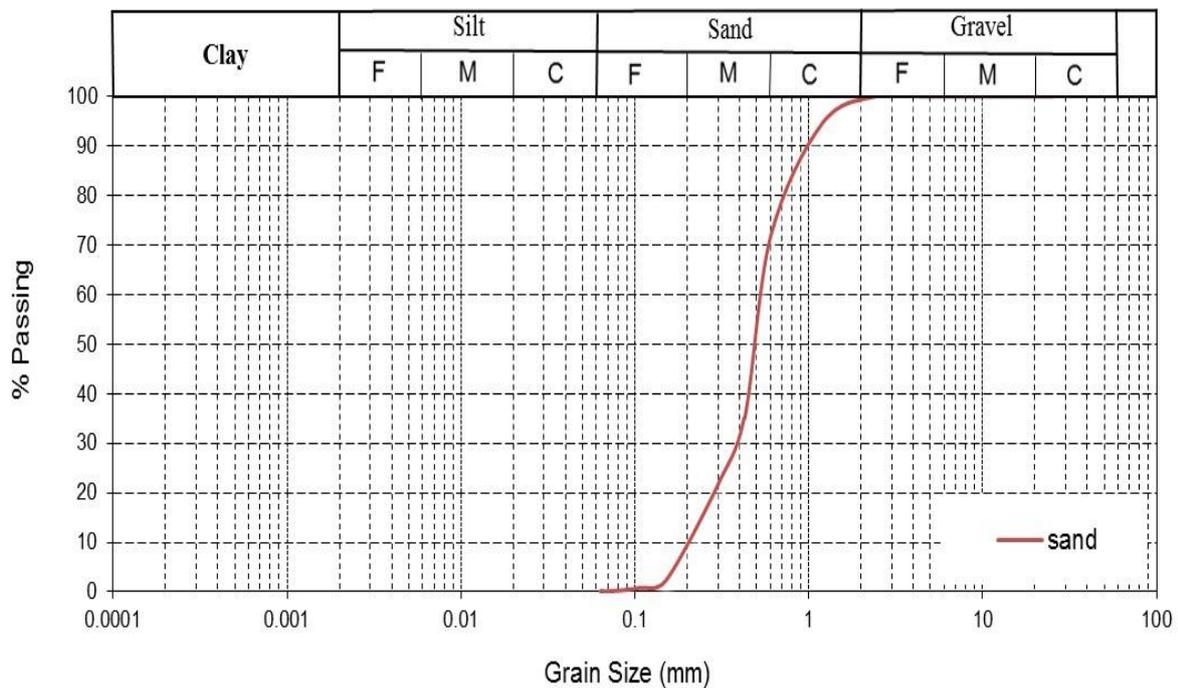


Figure 4. Grain size distribution curve.

3. Uncertainty measurement

Uncertainty can be divided to two different types [9]; Type-A and Type-B. Type-A uncertainty analysis is determined on the basis of observation and calculated statistically, from frequent measurement [11].

Type-B uncertainty analysis is obtained by uncertainties assigned to reference data taken from handbooks, manufacturer's specifications, previous measurement data, properties of relevant materials and instruments, data provided in calibration and other certificates [11].

3.1. Type-A uncertainty (UA) calculation

For Type-A uncertainty analysis, the changeability of n-readings is characterized by their standard deviation (σ) as shown in figure 5 (a).

$$\sigma = \sqrt{\frac{\sum_{i=1}^n (\text{reading}_i - \text{average})^2}{n-1}} \quad (1)$$

On measuring drilling torque, the five confirmed readings taken were 23.520455, 23.224843, 23.772157, 32.370688 and 23.4723102 with mean value of 23.4723102N.m. Therefore, standard deviation will be 0.202357553. Table 2 shows the steps for calculating the standard deviation for drilling torque at different depths. The standard deviation of 0.00258 mm is an estimate for the above drilling torque readings. The improvement of the confidence in the estimate of the average increases by taking more readings. For n readings, this fact is defined by terms of the standard uncertainty (UT) provided with the mean as shown in equation (3).

$$U_T = \frac{\sigma}{\sqrt{n}} \quad (2)$$

$$U_{A_T} = 0.090497049 \quad (3)$$

Table 2. Type-A uncertainty calculation for torque measurements

measurement	Reading(N.m)	Reading average	Reading average square
1-	23.520455	0.0481448	0.002317922
2-	23.224843	-0.2474672	0.061240015
3-	23.772157	0.2998468	0.089908103
4-	23.370688	-0.1016222	0.010327072
5-	23.473408	0.0010978	1.20516E-06
Average	23.4723102	Sum=	0.163794317
		Sum/4=	0.040948579
Standard deviation		$\sqrt{\text{Sum}/4=}$	0.202357553
Standard uncertainty		Standard deviation $/\sqrt{n}$	0.090497049

3.2. Type-B uncertainty (UB) calculation

The measurement accuracy for the instrument or the sensor used has its own effect on the reading so Type-B uncertainty calculation is required to assess uncertainties. Rectangular distribution gives the upper and lower limits as shown in figure 5 (b).

According to sensor certificate Type-B uncertainty can be calculate by dividing half of the range by square root of three.

$$U_{B_T} = \frac{\text{half the range}}{\sqrt{3}} = 0.1154 \quad (4)$$

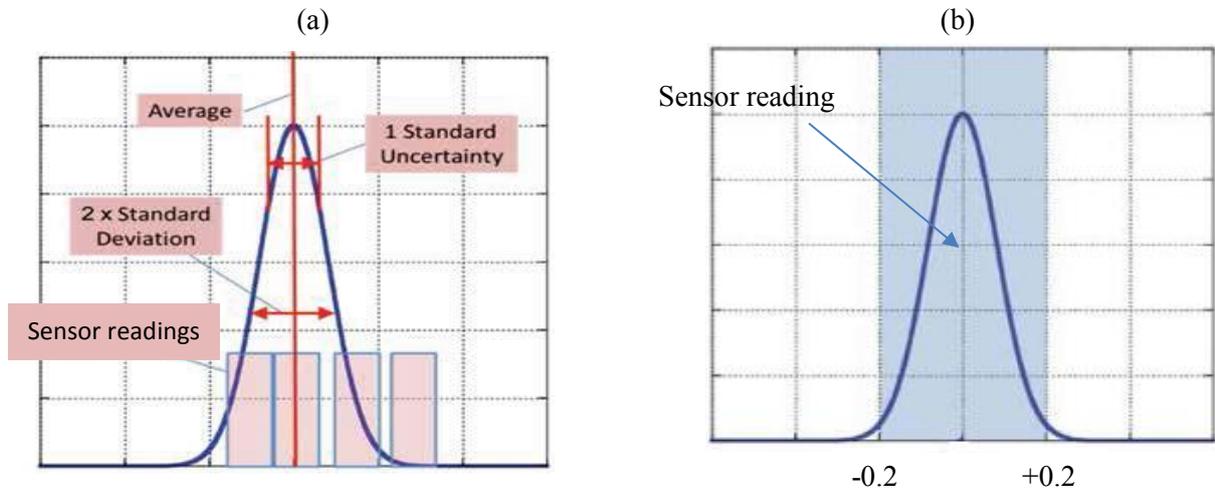


Figure 5. Label (a). Type-A uncertainty [1] (b). Type B uncertainty.

3.3. Combined uncertainty calculations

After calculating individual standard uncertainties of Type-A and Type-B, the overall uncertainty can be calculated by combining type-A and type-B standard uncertainties. That is achieved by getting the root sum of its squares. The result is called the 'combined standard uncertainty'.

$$U_T = \sqrt{U_{A_T}^2 + U_{B_T}^2} = 0.14665 \tag{5}$$

Table 3. Combined uncertainty of drilling torque calculation

Source of uncertainty	Value[N.m]	Probability Distribution	Factor	Standard Uncertainty
variability	0.090497049	Normal	1	0.090497049
calibration	±0.2	Rectangular	$1/\sqrt{3}$	0.1154
Standard Uncertainty = $\sqrt{U_{A_T}^2 + U_{B_T}^2}$				0.14665

The changeability of the data (Type-A) and the sensor calibration certificate (Type-B) are the two terms that may cause a deviation of reading. Therefore, the two components are integrated as shown in table 3.

The torque and its standard uncertainty are estimated finally by combining the standard uncertainties resembled the major factors, which may lead the sensors to read incorrectly.

4. Expanded Uncertainty For Higher Level Of Confidence

To increase the level of confidence range within which the correct estimated value is expected, the standard uncertainty should be multiplied by the coverage factor to give an expanded uncertainty as shown in table 4.

$$\text{Expanded uncertainty } U = \text{coverage factor } k \times \text{combined standard uncertainty} \tag{6}$$

Table 4. Expanded uncertainty for different levels of confidence

Standard uncertainty	Coverage factor	Expanded uncertainty	Probability that true value lies in range
0.14665	1	0.14665	68%
	2	0.2933	95%
	3	0.43995	99.8%

Figures 6 and 7 show the drilling torque diagram with and without an error bar based on a standard uncertainty multiplied by coverage factor $K = 2$, providing a level of confidence of approximately 95%.

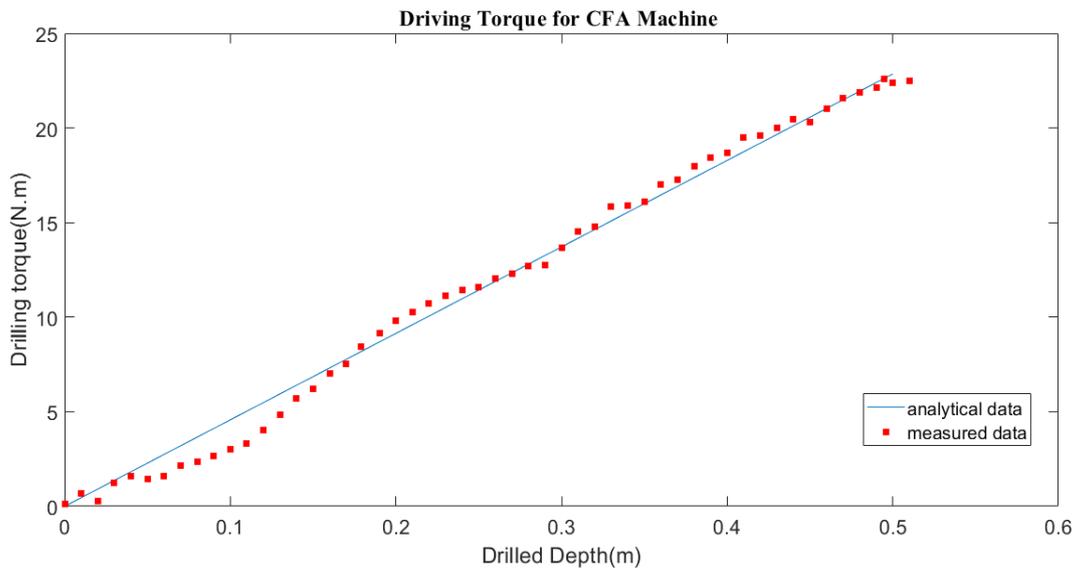


Figure 6. Driving torque for CFA machine.

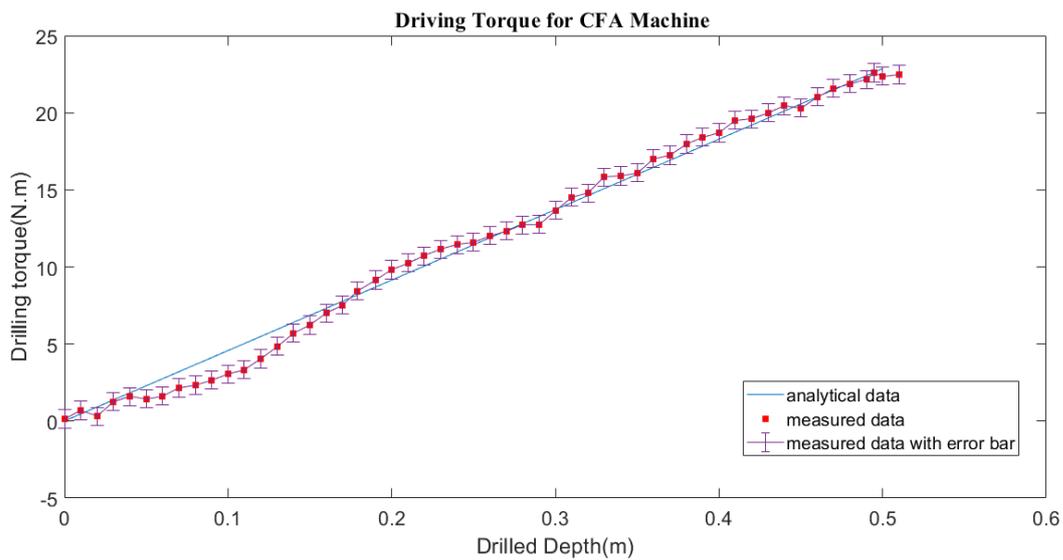


Figure 7. Driving torque for CFA machine with error bar.

5. Conclusion

The uncertainty detailed calculations for any measuring system provide the correct estimated value range with a specified level of confidence, and increase measurement reliability. Uncertainty detailed calculation for drilling torque measuring system is computed as a function of the measured values. A test rig representing continuous flight auger machine was established as a measuring system. Type-A, Type-B, combined uncertainties were calculated. Error bars are provided for each reading to show its uncertainty with 95 % level of confidence.

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