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GCD – Ground Conductivity Designation

A testing method to quantify ground's hydraulic conductivity and solidification quality

Bineshian, H
Aberfoyle Park, SA 5159, Australia
DrBineshian@outlook.com

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Abstract

This paper aims to introduce GCD as a testing manual for measuring ground's hydraulic conductivity and solidification quality. It was first developed in 2013, further examined in 2015, and cited by author in tunnelling papers in 2017. It is further verified till now in several projects. GCD is originally developed based on Lugeon concept. Its empirical equation contains three parameters, which are easily derivable by proposed test procedure in this paper. Water intake rate, peak head before the first drop in pressure, and length of drilled hole are the input parameters for calculation. Proposed method quantifies the hydraulic conductivity of ground prior to grouting or injection and after solidification. GCD procedure is conducted in a single stage water injection procedure using a simple grouting pump through a naked hole that drilled at any direction, orientation, diameter, or length. Output includes a quantitative measure as well as a qualitative description that obtained by application of GCD test as a time- and cost-efficient procedure in assessment of ground's hydraulic conductivity.

Keywords: consolidation, GCD, grouting, hydraulic conductivity, injection, solidification

Nomenclature

GCD	Ground Conductivity Designation (dimensionless)
I-System	Index of Ground–Structure or (I); a classification and characterization system, which is applicable for ground irrespective of type including rock and soil (Bineshian, 2019, 2020)
L_i	Length of water injected portion (packed length) of drilled hole (m) or length of casing hole (m) or length of installed perforated SDA (m) in the GCD test procedure
NX	Hole with 54.7 mm diameter
P_m	Peak head (MPa) during injection period of T_i in GCD test procedure; it is the measured water pressure before the first drop in peak is observed.
PU-2C	Polyurethane with two components
Q_w	Water intake rate (lit/min) in GCD test procedure
SDA	Self-Drilling Anchor
T_i	Injection period (minutes) taken for injection of V_w quantity of water in GCD test procedure; it is the period of time from initial raise in pressure till the first drop in peak is observed.
V_w	Injected quantity of water (lit) during injection period of T_i in GCD test procedure; it is measured from the time that pressure is started to raise till the first drop in peak pressure is observed.

1. Introduction

Field measurements of hydraulic conductivity and/or permeability of ground including rock or soil in geotechnical and geomechanical investigations is crucial for the design and planning of civil, mining, and oil and gas projects in design or construction phase. Lugeon and Lefranc tests are common tests used by engineers and geologists for measurement of permeability of ground.

Lugeon test or packer test or water test is the most common in-situ test used to estimate hydraulic conductivity of rock mass. The test, which derives its name from Maurice Lugeon (1933), is a constant head type test that takes place in an isolated portion of a borehole in which, water at constant pressure is injected into the rock mass through a slotted pipe bounded by pneumatic packers (Quiñones-Rozo, 2010).

Lefranc (1936, 1937) proposed constant-head and variable-head tests in casing borehole for the first time. These field test methods are known as Lefranc test, which is used for measurement of hydraulic conductivity and assessment of groutability of ground as well as measuring coefficient of anisotropy of aquifer (Cassan, 1980, 2000, 2005, Bell, 2006).

Though, Lugeon and Lefranc are common water tests in geomechanical and geotechnical investigations for measurement of hydraulic conductivity of ground – as an input for design and planning of the projects – their application in construction phase of projects is usually skipped or avoided due to several stages involved with these test methods. Author developed a test method that is called Ground Conductivity Designation in a short form as GCD to simplify and to ease the application of test method in practice for regular use in measurement of hydraulic conductivity prior and after grouting or injection works.

GCD is developed by author in 2013 based on Lugeon concept and over 18 years of practical verification in tunnelling and dam projects. It is further examined in 2015 in USBRL Projects and the results were cited by the author for the first time in a paper in 2017 (Bineshian, 2017). Later on, by further application as well as verification of GCD as a quick examination technique in practice, it is cited in further publications and design reports in 2019 (Bineshian et al. 2019, Bineshian, 2019, Choudhary et al. 2019). GCD also been used in I-System as an option in calculation of Hydro Index (Bineshian, 2019, 2020).

GCD is further used in practice till date of publication of this paper in design and practice in USBRL Projects in the state of J & K, India including tunnels T05, T13, T14, and T41 to T47 as well as Pernem Tunnel in the state of Goa, India.

This paper aims to introduce the GCD and makes it available to engineers and geologists – who work in the field of geology, geomechanics, and geotechnics in tunnelling, dam works, etc., – as a quick procedure (for the first time as an individual paper and as a testing method manual) in examination of hydraulic conductivity of ground in practice or in design. This paper does not aim to compare the GCD with other common water test methods that are applicable for the same; however, it can be subject to a further research and development for researchers who are interested in this field.

2. GCD; Definition

GCD is a test method based on a simple single stage water injection procedure for examination of the ground's hydraulic conductivity (Bineshian, 2017). It is essentially based on water-intake measurement that is pumped thorough a drilled hole (NX preferred) at any direction or angle before and after grouting or injection (Bineshian, 2017, 2019, 2020). GCD test is an easy and quick single stage procedure that provides an appropriate economic estimate for hydraulic conductivity to assess permeability of ground prior to any grouting/injection works as well as post-examination of solidification quality. The output of GCD guides engineers and/or geologists to have a pre- and/or post-grouting/injection assessment on ground quality in terms of:

- permeability,
- solidification,
- consolidation,
- water ingress reduction, and/or
- sealing quality.

Eq 1 represents dimensionless empirical form of GCD. Eq 2 represents water intake rate in lit/min, which is used in Eq 1. Figure 1 demonstrates schematics for the GCD test setup. Table 1 provides the proposed classification for ground hydraulic conductivity as well as ground solidification quality.

$$\mathrm{GCD} = \mathrm{Q_w}/(\mathrm{P_m} + \mathrm{L_i}) \tag{1}$$

$$\mathrm{Q_w} = \frac{V_w}{T_i} \tag{2}$$

Where;

GCD Ground Conductivity Designation (dimensionless)
Q_w Water intake rate (lit/min); to be calculated using Eq 2.
V_w Injected quantity of water (lit) during injection period of T_i; it is measured from the time that pressure is started to raise till the first drop in peak pressure is observed.
T_i Injection period of time (min) taken to inject V_w quantity of water; it is the period of time from initial raise in pressure till the first drop in peak is observed.
P_m Peak head (MPa) during injection period of T_i; it is the measured water pressure before the first drop in peak is observed.
L_i Length of water injected portion (packed length) of hole or perforated SDA in m

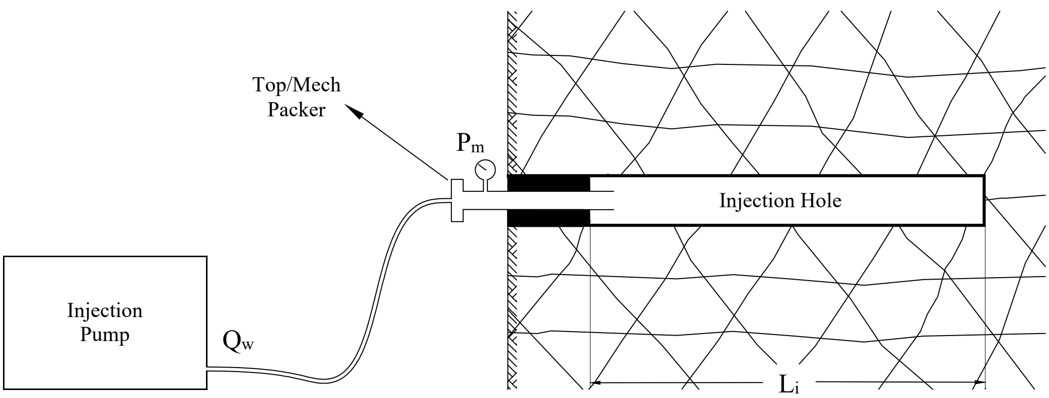

Figure 1. GCD setup (Bineshian, 2017, 2019)

Table 1. Ground Conductivity Designation

Ground Hydraulic Conductivity	GCD	Ground Solidification Quality
VH - Very High	> 100	VP - Very Poor
H - High	100 - 51	P - Poor
M^+ - Medium	50 - 16	F - Fair
M^- - Moderate	15 - 6	G - Good
L - Low	5 - 1	VG - Very Good
VL - Very Low	< 1	E - Excellent

A proper conduction of GCD test method includes procedures as follows:

1. Selection of location in which ground conductivity to be measured.

2. Drilling a single naked hole in any direction or orientation in the chosen location including horizontal, vertical, or inclined at face, wall/s, crown, or invert. Figure 2 demonstrates examples of location, position, orientation, and/or direction of injection hole for GCD test. Drilling can be conducted using a rotary-percussion or rotary drilling system; however, rotary drilling system is preferred.

3. Stabilisation of drilled hole using casing; however, naked hole for GCD test is preferred. If hole is not sustained, casing can be applied or SDA system of drilling can be used; therefore, in this case, test will be conducted in a casing hole or through SDA.

4. Flushing the naked hole using clear water to remove fine debris and cuttings. If casing hole or SDA is used, the same flushing procedure to be applied in casing hole or through SDA.

5. Packing the collar of the naked drilled hole using a top/mechanical packer (Figure 3). Packing must be conducted in a proper way that the collar is completely sealed and no leakage of water is observed. If casing or SDA is used, a proper packing inside casing or on the outlet of SDA is necessary to be conducted. The space between casing and ground and/or between the SDA and ground should be completely sealed at collar only using cement mortar or PU-2C or any method/material that may be applicable. It is important to note that only a short portion at collar of the hole to be sealed.

6. Setting up a suitable water pump and connections for injection of water to the hole (Figure 1). The water pump should have the capacity in providing enough pressure. Water pump should be equipped with pressure gauge. Use of grouting pump unit in GCD test procedure is highly recommended.

7. Injection of water to the hole and measuring the V_w in T_i period of time.

8. Calculation of Q_w and consequently calculation of GCD.

9. Finding the right range of GCD in Table 1 based on the calculated value.

10. Classification of Ground Hydraulic Conductivity and Ground Solidification Quality using Table 1 for further judgment and use in design and/or practice.

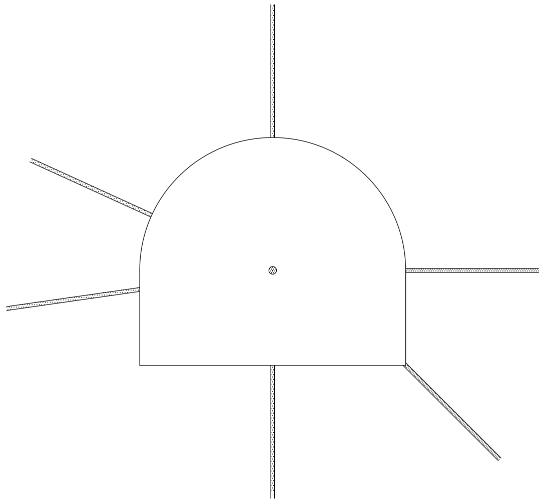

Figure 2. Examples of drilling hole for GCD test in different location, direction, or orientation

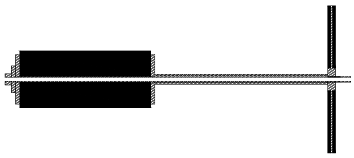

Figure 3. Top-mechanical packer

GCD ranges from below 1 to above 100 (see Table 1) that classifies ground's hydraulic conductivity into 6 categories; very low (VL), low (L), moderate (M^-), medium (M^+), high (H), and very high (VH). GCD also classifies ground's solidification quality into 6 categories as excellent (E), very good (VG), good (G), fair (F), poor (P), and very poor (VP).

Conduction of GCD test does not contain complicated procedure; however, there are some important notes that needs to be considered in measurements as follows:

- It is recommended to repeat the test for 3 times and then making an average of values to obtain a better precision and accuracy in GCD estimation.

- If during the water injection, pressure is not obtained, or it is lesser than 0.20 MPa, then the ground hydraulic conductivity would be considered as VH, which means that quality of grouting or injection executed at the location of the hole is classified as VP (see Table 1). In this case the section should be further grouted/injected by a proper consolidation material/s and/or with a better configuration to improve the ground solidification quality and to obtain the targeted GCD value that designated in particular design.

- If the pressure is rapidly raised and exceeded 1 MPa, then the ground hydraulic conductivity would be considered as VL, which means that quality of grouting or injection executed at the location of the hole is classified as E (see Table 1).

- If in any case the GCD measurement is not used then observational ground water condition is considered as a criterion for scoring the hydraulic conductivity of ground. Wetness diagram (Figure 4) is proposed in I-System

(Bineshian, 2019) for the cases, which GCD is not used. The same can be used as a rough estimation of ground hydraulic conductivity prior to execution of ground improvement procedure or it can be used as a rough judgment criterion in evaluation of quality of solidification after ground improvement using grouting/injection. Wetness diagram presented in Figure 4 is based on observational identification, which provides a descriptional estimation that classifies the ground wetness into 11 ranges; however, quantification of hydraulic conductivity of ground using GCD is preferred.

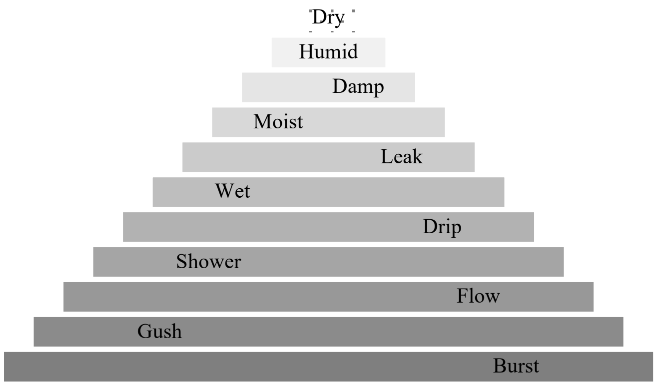

Figure 4. Wetness diagram (Bineshian, 2019, 2020)

3. Equipment

General requirement including equipment or material for conduction of GCD test is listed as follows:

- Rotary or rotary-percussion drilling unit
- Top-mechanical packer
- Water pump equipped with water pressure gauges
- Clear water

In the event that hole is not sustained due to drilling in an incompetent ground, casing hole or SDA to be used. In this case, proper casing or SDA with suitable method for sealing of the collar of the hole is required (see Section 2).

4. Conclusions

Ground Conductivity Designation (GCD) is a testing method for measurement and classification of hydraulic conductivity of ground as well as assessment of solidification quality after ground improvement procedure. It includes an empirical equation developed for calculation of conductivity designation. GCD is a function of water intake rate, peak head during injection, and length of injected portion of hole in a simple water injection procedure.

GCD testing method's output provides a classification for hydraulic conductivity-related properties of ground for use in geomechanical and geotechnical investigations in design and/or construction phase for surface, semi-surface, and/or underground structures in rock and/or soil medium.

5. Further Research Recommendations

Author proposed the ranges provided in Table 1 for GCD-based classification of ground conductivity and solidification quality; however, further research may improve the GCD ranges, which is defined for each class in Table 1 based on the needs and requirements in engineering works in ground including pre-excavation freezing for solidification in tunnel faces, pre- and post-excavation grouting/injection for solidification and consolidation in tunnelling, jet grouting, etc.

6. Acknowledgement

Verification of GCD in practice have been done since 2015 in USBRL Projects. I would like to thank Northern Railway (NR) and Konkan Railway Corporation Limited (KRCL) for making the verification possible.

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