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Suction Characterization and Effect of Drying – Wetting Cycle on Desilting Material of Reservoir: A Review

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LITERATURE REVIEW

1.1.General

The literature review is covered in six sections. The first section deals with establishing drying and wetting SWCC data using different methodologies The next section presents the available research studies in suction measurement of soil. Third section deals with literature studies on volumetric shrinkage curve of soils using different methodologies. Further, the studies of Wischmeier soil erodibility factors were studied in fourth section. The fifth section focuses on Influences of multiple drying-wetting cycles on the soil-water characteristic curve (SWCC) and pore size distribution (POSD) of undisturbed granite residual soils. The last section deals with erodibility factor (i.e. K-factor) and determined by WeischmeierNomograph.

1.1.1.Soil water characteristic curve

- Water retention curve (WRC) or soil water characteristic curve representing the variation of gravimetric water content with matric suction is an important constitutive relationship for analyzing the hydro-mechanical behavior of the bentonites (Leong and Rahardjo, 2002; Mbonimpa et al., 2006; Tripathy et al., 2014). The SWCC depend on pore size distribution, compaction density, and mineralogy of the soils (Tinjum et al., 1997; Vanapalli et al., 1999; Lu and Likos, 2004; Yang et al., 2004; Thu et al., 2007; Ye et al., 2009).
- Laboratory methods such as osmotic technique (Delage et al., 1998), chilled mirror hygrometer (Leong et al., 2003), vapor equilibrium technique (Delage et al., 1998; Tang and Cui, 2005, 2007; Sun et al., 2014; Tripathy et al., 2014), axis-translation (Tripathyetal., 2014), relative humidity (RH) sensors (Agus and Schanz, 2005), tensiometer (Take and Bolton, 2003), and fixed-matrix porous ceramic discs (Tripathy et al., 2016) are widely used either to control or measure the suction in soil.
- Most of the available SWCC data on bentonites are in volume unrestrained condition where powder specimens are utilized (Tadza, 2011; Tripathy et al., 2014; Zhang et al., 2014). Only limited techniques viz., tensiometer, RH sensors, and fixed-matrix porous ceramic discs are feasible for the estimation of suction in volume restrained condition and for reading continuous data when the water content changes. However, these techniques are highly time-consuming to establish hydraulic equilibrium between soil specimen and the sensor; the continuous evaluation of transient suction data by fixed-matrix porous ceramic discs is erroneous (Tripathy et al., 2016).
- The required equilibrium time for the measurement of wetting SWCC data was, moreover, significantly higher compared to drying data (Tinjum et al., 1997; Yaldo, 1999; Fredlund, 2006; Fredlund et al., 2011; Hong et al., 2016). The measurement of SWCC data of bentonites over a wide range of suctions by single technique, further, poses several limitations (Agus and Schanz, 2005; Bulut and Leong, 2008; Nam et al., 2010; Pan et al., 2010). Therefore, limited data are available on bentonites using independent laboratory techniques for establishing SWCC over a wide range of suctions.
- The SWCC data of compacted bentonites over a wide suction range is very scarce (Ye at al., 2009, 2016), but important for accurate study

of unsaturated flow characteristics of buffer material.

- Several equations have been proposed for defining SWCC. Some of the most common models are Gardner (1958) equation, Brooks and Corey (1964) equation, van Genuchten (1980) equation, Mualem (1976) equation and Fredlund and Xing (1994) equation. The van Genuchten (vG) model is often represented in terms of different state variables such as gravimetric water content (w), degree of saturation (S_r) and volumetric water content (θ) based on the adopted measurement technique. The SWCC in terms of w is given by (Vereecken et al.,1989; Fredlund et al., 2002).

$$w = w_r + \frac{(w_s - w_r)}{(1+(\alpha\psi)^n)^m}$$

where w_s is saturated water content and $w_r$is residual water content.

- However, the entification of residual water content and air-entry value in this representation is not easible for plastic clays due to the variation in the water content from saturated to esidual state (Fredlund and Houston, 2013).
- The following representation of van Genuchten model is given by (Zhou and Yu, 2004; Hosseini et al., 2011)

$$S_r = \frac{1}{(1+(\alpha\psi)^n)^m}$$

where α, m, and n are the model parameters.

- Huang et al. (2011) represented vG (1980) model in terms of volumetric water content to fit wide range of soils.

$$\theta = \theta_r + \frac{(\theta_s - \theta_r)}{(1+(\alpha\psi)^n)^m}$$

- Where, θ is water content (cm3/cm3); θ_a is saturated water content; θ_r is residual water content; ψ is matric suction (kpa); α, n and m are empirical soil parameters. The Parameter α is related to the air entry value of the soil(kpa^{-1}), controls the slope at the Inflection point in the soil water characteristic curve and m is related to residual water content of the soil.

1.1.2.Suction characteristics

- Soil suction has proven to be a difficult and important variable to measure (Delage et al. 2008; Fredlund et al. 2012). Many indirect methods available for suction measurement, but filter paper technique is the mostly used to estimate soil suction because it is simple and reliable (Fawcett and Collis-George 1967; Al-Khafaf and Hanks 1974; Hamblin 1981; Daniel et al. 1981; Ching and Fredlund 1984; Chandler and Gutierrez 1986).
- The principle of this method of suction using the filter paper technique is that the pore water within a soil sample flows to an initially dry filter paper until (i.e., the filter paper and the soil) hydraulic equilibrium is reached. After that suction is measured by calibration curve which is already established earlier.
- Based on a review data available in the literature, Leong et al. (2002) showed that the performance of Whatman Grade 42 filter paper (hereafter referred to as Whatman No. 42 filter paper) was more consistent than that of Schleicher &Schuell No. 589 filter paper. Several studies in the literature established and evaluated calibration curves for soil suction estimation using Whatman No. 42 filter paper (Fawcett and Collis-George 1967; Hamblin 1981; Chandler and Gutierrez 1986; Greacen et al. 1987; Chandler et al. 1992; Houston et al. 1994; Deka, R.N, Wairiu, M., Mtakwa, P.W., Mullins, C.E.., Veenendaal, E.M., Townend 1995; Leong et al. 2002; Power et al. 2008).
- Mostly all the calibration curves that have been proposed for the Whatman No. 42 filter paper are bilinear in logarithm of suction vs. filter paper water content space (Fawcett and Collis-George 1967; Chandler and Gutierrez 1986; Greacen et al. 1987; Chandler et al. 1992; Houston et al. 1994; Deka et al. 1995; Leong et al. 2002; Power et al. 2008). The break present in the line (slope discontinuity) takes place for filter paper water contents ranging from 38 to 47%. Each of the two segments can be expressed as: $\log S = a\,(wc_{fp}) + b$

Here, S denotes suction in kPa, a is the slope of the line, wc_{fp} is the gravimetric filter paper water content in percentage, and b is the y intercept.

- To understand bilinear shape of curve, consider water absorption characteristics of filter paper (Greacen et al. 1987).
- Table 1 summarizes the equations for the Whatman No. 42 filter paper calibration curves available in the literature. The equations in Table 1 have been proposed based on filter paper. water content and suction measurements are done using different tests (Fawcett and Collis-George 1967; Hamblin 1981; Greacen

et al. 1987; Deka, R.N., Wairiu, M., Mtakwa, P.W., Mullins, C.E., Veenendaal, E.M., Townend 1995).

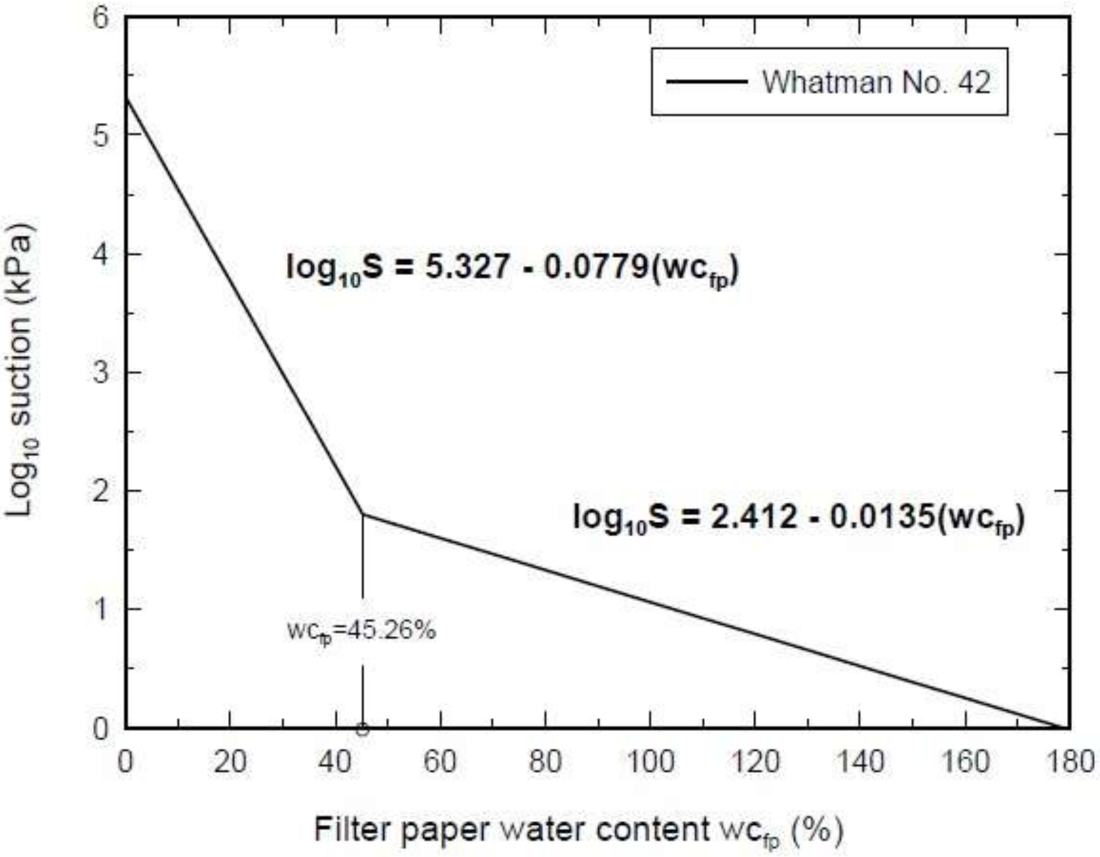

Figure 1: Calibration curve for Whatman No. 42 paper based on the wetting testing procedure (modified after ASTM D5298-10).

1.1.3.Volumetric Shrinkage Characteristics

The hydro- mechanical behavior of the expansive soils is required to be estimated in terms of degree of saturation versus suction as the balance equations are based on either volumetric water content or degree of saturation (Lu and Likos, 2006; Lu et al., 2010; Jacinto et al., 2012; Baille et al., 2014).

The estimation of Sr from the SWCC requires the estimation of volumetric shrinkage behavior of soils which is a relationship between the specimen volume and the corresponding water content, represented by volumetric shrinkage curve (VSC) (Fredlund, 2002; Fredlund and Houston, 2013; Wijaya et al., 2015).

Determination of volumetric shrinkage behaviour is important for the analysis of flow, compressibility, and shear strength behavior of unsaturated bentonite clays. The study of volumetric shrinkage behavior is also important in the design of impoundments for mine tailings (Saleh-Mbemba, 2010) and to address the problem of subsidence caused due to volumetric shrinkage (Nelson and Miller, 1992; Tariq and Durnford, 1993a).

Further, the shrinkage behavior is important in GCLs and clay liners due to waste generated heat as the generated heat causes loss of moisture from the bentonite (Doll, 1997; Cripps and Parmar, 2001; Tay et al., 2001; Southen and Rowe, 2005; Azad et al., 2012). A precise estimation of VSC data is, therefore, important for accurate determination of the unsaturated soil characteristics (Wijaya et al., 2015).

Laboratory determination of gravimetric water content of a soil specimen is straightforward and the water content is estimated using well-established techniques such as oven drying method (ASTM D2216-10, 2010). However, an accurate measurement of volume of the specimen at different saturated states of the soil specimen is challenging.

The soil bulk volume is measured in the laboratory using standard methods such as mercury displacement (IS: 2720 Part 6 1972; BS 1377: Part2 1990; ASTM D427-04, 1998) or wax method (ASTM D7263, 2009). Pertaining to serious health hazards with the mercury to the skin and prolonged inhalation of mercury vapors, mercury displacement technique is withdrawn from the standards in some countries (ASTM C493-98, 2002). The wax method is, therefore, widely used in engineering practice as an alternative technique to measure the bulk volume of the soil specimen (Lauritzen and Stewart, 1941; Braudeau et al., 1999).

Alternative techniques are surfaced to minimize possible errors in wax method due to the requirement of volume measurement on duplicate soil specimens. Non-wetting fluids such as Kerdane oils are used to estimate the volume of the specimen from weights taken after the inhibition and apparent weight while immersed in non-wetting fluid (Fleureau et al., 1993). Encasement techniques using water-repellent solutions such as MEK Saran (Nelson and Miller, 1992; Crescimanno and Provenzano, 1999), waterproof polyvinyl acetate (PVAc) based adhesives (Krosley et al., 2003), automotive varnish (de Almeida et al., 2009) are widely used to estimate the volume of the specimen for establishing the VSC for different clay soils (Baille et al., 2014; Tripathy et al., 2014).

Direct measurement techniques are used for measuring the specimen volume with the help of a caliper (Peron et al., 2009) or analyzing the images (Puppala et al., 2004; Tang et al., 2011; Stewart et al., 2012) for low-plastic tailings (Saleh-Mbemba et al., 2016) and clays soils (Por et al., 2015). Balloon method (Tariq and Durnford, 1993a) is used in few studies (Cornelis et al., 2006a, 2006b) for quasi-continuous measurement of both soil volume and water content on the same specimen. Comparative studies (Cornelis et al., 2006; Tripathy et al., 2014) for establishing shrinkage data on VSC by different volume measurement techniques are scarce. Moreover, the available studies only focus on the difference in the estimated model parameters from different volume measurement techniques (Cornelis et al., 2006).

The significance of these model parameters on the estimated Sr is not known. While a saturated soil specimen left for thermodynamic equilibrium with the surrounding environment in the laboratory, the specimen attains a thermodynamic potential of the environment by reducing its water content.

The loss of moisture from the expansive clay specimen during the drying process causes rearrangement of particles and aggregates; results in decrease of its bulk volume. The change in the magnitude of the volume of the specimen with reduction in the water content is described by VSC. The VSC data is expressed in terms of specific volume versus water content (w), void ratio (e) versus water content (w), or void ratio versus moisture ratio (Groenevelt and Grant, 2002; Saleh-Mbemba et al., 2016). A typical illustration of volumetric shrinkage curve was shown in Fig. 2.1. Volumetric shrinkage curve consists of four distinguished phases such as structural, normal, residual, and zero shrinkage phases (Bensallam et al., 2012). The structural shrinkage signifies that the reduction in volume of the soil is smaller than the amount of extracted water from the soil.

The reduction in volume in this phase is governed by the free water extracted from the soil. However, this phase is absent in clayey soils (Chertkov, 2003). The rate of volume reduction and the amount of water extracted is same during normal shrinkage phase (McGarry and Malafant, 1987; Tariq and Durnford, 1993a). Normal shrinkage phase plays a major role in the

VSC as it represents about 30 - 80% of the total water loss and a decrease of about 64 - 94% of the total volume in many soils (Peng and Horn, 2005). Tripathy et al. (2002) also reported that more than 80% of volume change occurs in this zone. The volume of the soil specimen is not influenced by change in water content in zero shrinkage phase.

The air-entry water content is the point on the volumetric shrinkage curve where the rate of volume reduction deviates from the normal shrinkage trend and the shrinkage limit is the water content at which the volume of the specimen remains constant (Wijaya et al., 2015).

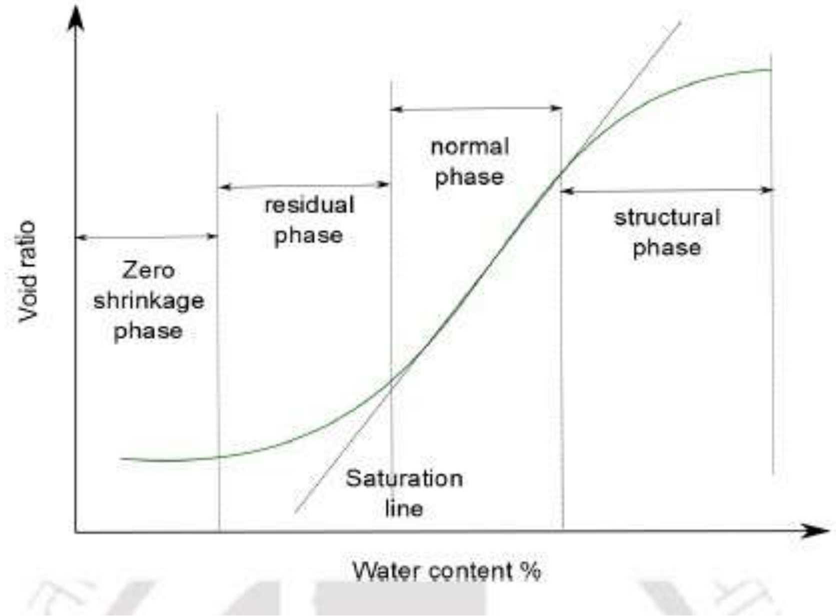

Figure 2: Volumetric Shrinkage Curve (after Bensallam et al., 2012)

The VSC data is described by several theoretical models (Kim et al., 1992; Tariq and Durnford, 1993b; Braudeau et al., 1999; Fredlund et al., 2002; Chertkov, 2003; Cornelis et al., 2006). The number of fitting parameters varies from two to seven in these models. Some models require air-entry value (AEV) and minimum void ratio as the input parameters.

Kim et al. (1992) presented a theoretical model in terms of void ratio as $e = e \times \text{expr}(-\beta w) + m_2 w$

where β is the slope parameter which depends on AEV, m2 is slope of the saturation line of VSC, w is the water content. The zero and residual zones are expressed by the inverse exponential function, in this model, that gradually advances to a certain denominator value with decrease in water content or moisture ratio. The mechanical changes to the soil specimens due to several drying-wetting cycles were directly corroborated with the model parameters of Kim et al. (1992).

Fredlund et al. (2002) proposed a three-parameter model which is given by:

$$e(w) = a_{sh}\left[\frac{w^{c_{sh}}}{{b_{sh}}^{c_{sh}}} + 1\right]^{\left(\frac{1}{c_{sh}}\right)}$$

And

$$\frac{a_{sh}}{b_{sh}} = \frac{G_s}{S_r} = constant$$

where G_s is the specific gravity of soil and S_r is degree of saturation. Parameter s_{ha} is related to the minimum void ratio (e_{min}) and s_{hb} parameter is the slope of the line of tangency. The curvature of the VSC at desaturation region is controlled by the s_{hc} parameter. The Fredlund et al. (2002) model is used for the prediction of field settlement which involves the use of limiting lower void ratio after drying, e_{bs} (Bardanis and Kavvadas, 2006). It has application to study the unsaturated soil behavior as far as the evolution of limiting lower void ratio with initial void ratio and physical properties of soils is concerned. Further, the model is used to study the drying behavior of oil sand tailings (Vardon et al., 2014); volume change behavior of environmentally stabilized soils (Gould et al., 2011).

1.1.4.SOIL ERODIBILITY FACTOR

There are mainly two factors in erosion process: Rain energy that expressed by erosivity and Soil factors are expressed in erodibility (Hudson, 1971).

The effect of drying-wetting cycle's repetition on undisturbed soil from Manting Basin Mojokerto had been studied. The drying-wetting cycle's processes were repeated 6 times. The properties of the soil specimens were investigated at 1, 2, 4 and 6 cycle. During the drying process, the soil specimens were naturally and gradually air dried; while in the wetting process, the soil specimens were gradually wetted up to their fully saturated condition. The soil properties such as: water content (wc), degree of saturation (Sr), void ratio (e), suction and dry unit weight were measured at every desired conditions.

The specimen is undisturbed silty loam was tested by drying and wetting repetition. Where drying process is done by reducing the water content of the specimen to be 25%, 50%, 75%, and 100% of the initial (natural) water content (W_i) in field. While the wetting process is done by adding water to the specimen to be; w_i + 25% (w_{sat}-w_i), w_i + 50% (w_{sat}-w_i), w_i + 75% (w_{sat}-w_i) and w_i + 100 % (w_{sat}-w_i), where w_i is the initial water content and w_{sat} is saturated water content. Suction measurement done by filter paper method (Fredlund and Rahardjo, 1993).

Shear strength of soil measured by direct shear laboratory test and physical properties of soil testerd by gravimetric-volumetric test in the soil mechanic laboratory (Das B.M., 1993). Figure 2 shows the relationship of water content, suction, dry density, degree of saturation, and soil erodibility of Nomogram Method Wischmeier et al. (1971). Soil parameters variation is due to hydraulic conductivity in this case (Asmaranto et al., 2010). On dry soil, hydraulic conductivity values obtained are different than the saturated condition. Erodibility changes have been rarely observed and its value was constant throughout the year despite the condition of the soil in the tropics change due to the changing seasons. In the USLE formula (A = RKLSCP) determination is less precise parameter K will cause the value of soil loss (A) is also not match the reality on the ground. So the initial water content before the rain would cause the value of the erodibility changed to saturated conditions. The water content changing has been affected to the soil erodibility due to soil permeability changing. Meanwhile, in the silty loam result shows that the decreasing of water content will increase the erodibility. It though be due to the decreasing of soil permeability caused by the increasing of nomogram erodibility.

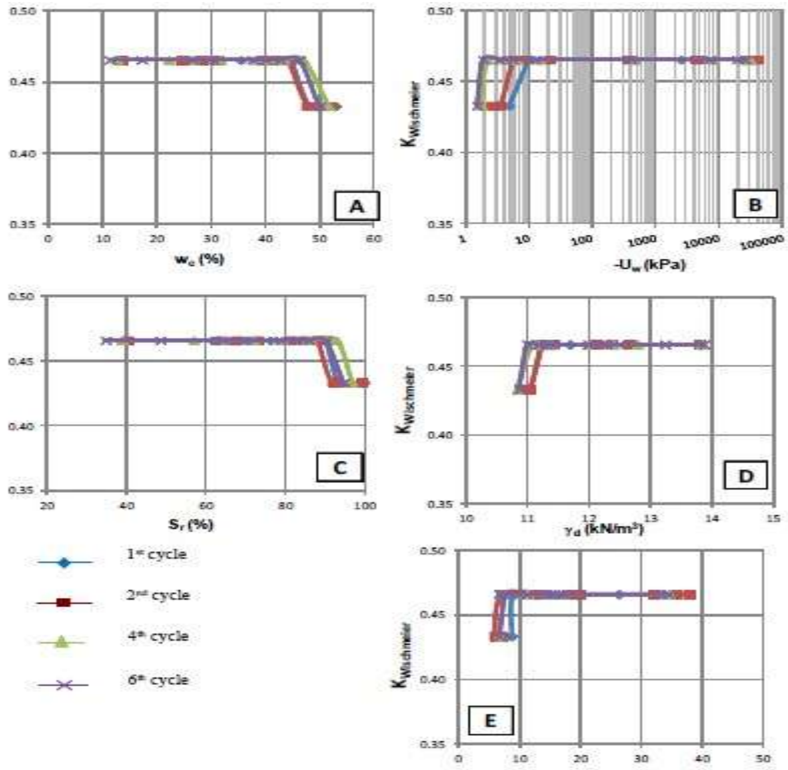

Figure 3:**The correlation of water content (wc), suction (-Uw), dry density (γd), degree of saturation (Sr) and soil erodibility of Nomogram Method (KWischmeier)**

In other hand, nomogram erodibility value on specific soil was not fixed variable, but it could be varied variable which affected by initial water content changing before rainfall. The saturated soil condition could be affected the erodibility value decrease rapidly. Although erosion process occurred on the saturated condition, but the initial water content is contributed to increase the erosion at the beginning of rainfall occurrence. The effect of suction changing to the erodibility was resulted some conditions. The suction is affecting to the erodibility especially on the initial soil condition (unsaturated condition). The initial soil condition is potentially transported by splash erosion at the beginning of rainfall event. Nomogram erodibility value was constantly at K=0.468 between 15% to 45% of water content. Furthermore, the erodibility value was decreasing to K=0.435 in which the water content was above 45%. This phenomenon is though being due to the saturated soil condition and capillarity pressure become smaller which are cause the pore water work on the rain kinetic energy.

1.1.5. Influences of multiple drying-wetting cycles on the soil-water characteristic curve (SWCC) and pore size distribution (POSD)

Residual soils are the weathering product of their parent materials with same properties as parent soil. Their engineering properties and behaviours vary from place to place and according to climate depending upon the rock of origin and the local climate during their formation (Fookes 1990).

A number of investigations have been done to understand the effects of drying-wetting cycles on physical and mechanical properties of soil. It is observed that soil fabric, particle cementation, water content and void ratio are altered significantly due to weathering effect (Cuisinier and Masrouri 2005; Rao and Revanasiddappa 2006; Tripathy et al. 2009; Tovar and Colmenares 2011; Sun and Huang 2015). Due to these effects formation of cracks as well as the development of fissures in soils, which significantly increase soil compressibility and hydraulic conductivity and decrease the overall structural strength and stability of structure (Morris et al. 1992; Albrecht and Benson 2001; Pires et al. 2008; Li et al. 2009; Sayem et al. 2016).Bodner et al. (2013) demonstrated that the pore size distribution (POSD) is closely related to cyclic dryingwetting, while overseason dynamics are mainly influenced by soil mechanical disturbance and crop rotation.

Matric suction is important factor and one of the two stresses state variables controlling the behaviour of an unsaturated soil, which plays an important role in unsaturated soil mechanics and widely used to predict the hydraulic conductivity, soil water storage and shear strength of unsaturated soils (Fredlund and Rahardjo, 1993). And the shape of the SWCC is dependent upon the POSD (pore size distribution) of the soil which is associated with the porosity, void ratio and controls the physical, mechanical and hydraulic behaviors of soils i.e. permeability, storage capacity, shear strength. Some researchers attempted to obtain the SWCC through the POSD and capillary model (Prapaharan et al. 1985; Olson 1985; Kong and Tan 2000; Aung, et al. 2011; Beckett and Augarde 2013; Zeng, et al. 2013).Several methods are there to obtain the POSD from porous materials such as the Mercury Intrusion Porosimetry (MIP), Water Vapour or Nitrogen Adsorption method, X-ray Computer Tomography (CT), Scanning Electron Microscopy (SEM) etc. Here the potentiality of NMR relaxometry to assess the POSD of porous media in a fast and non-destructive way (Kleinberg 1994; Strange et al. 1993; Hinedi et al. 1997; Milia et al. 1998; Dunn et al. 2002; Ramia et al. 2010).
The variations of POSD also analyzed using the NMR T2 technique and it will be useful to understand the possible micro-structural variations of granite residual soil subject to a periodic drying and wetting cycle.

1.1.5.1.Theoretical background of NMR T2

The NMR signal is an exponential decay, characterized by initial signal amplitude and distribution of relaxation times (T2) known as spin-spin relaxation or transverse relaxation. The NMR signals are generated from liquids when the sample is placed in a magnetic field and then excited with a brief pulse of radio frequency (RF) energy. The signal amplitude is an indication of total fluid present or related to characteristic pore abundance while the relaxation time (T2) is a measure of the rate at which the precession of hydrogen nuclei in the formation pore fluid gradually decay in the presence of an inhomogeneous magnetic field, which give information on the POSDs.

According to Coates et al. (1999), for a fluid saturated porous media (e.g. soil/rock), the NMR relaxation mechanisms are given by,

$$\frac{1}{T_2} = \frac{1}{T_{2B}} + \frac{1}{T_{2S}} + \frac{1}{T_{2D}}$$

Where, T_2 is the transverse relaxation time of the pore fluid as measured by a CarrPurcell-Meiboom-Gill (CPMG) sequence; T_{2B} is the transverse bulk fluid relaxation time; T_{2S} is the transverse surface relaxation time; T_{2D} is the diffusion relaxation time and accounts for the transverse relaxation in an inhomogeneous magnetic field. It is reported that the NMR relaxation of water saturated sedimentary rock or unconsolidated sediments occurs in the fast-diffusion regime and that there is little or no pore coupling (Brownstein and Tarr 1979; Kenyon

1997; Dunn et al. 2002). T_{2B} is typically much larger than T_{2S} and the effect of T_{2D} is minor for CPMG pulse sequence (Yun et al. 2002; Lao 2010; Behroozmand et al. 2015). Furthermore, at low field NMR, both T_{2B} and T_{2D} are negligible compared to T_{2S} (Kleinberg 2006). Therefore, in the fast diffusion limit, the transverse relaxation time (T_2) depends on the transverse surface relaxation (T_{2S}) and the T_2 relaxation rate $1/T_2$ is proportional to the surface-to-volume (S/V) ratio of the pore (Brownstein and Tarr 1979, Godefroy et al. 2001; Tian et al. 2014; Behroozmand et al. 2015). Hence, the equation is,

$$\frac{1}{T_2} = \frac{1}{T_{2S}} = \rho_2 \left(\frac{S}{V}\right)_{pore}$$

Where, ρ2 is the surface relativity coefficient, which is a characteristics of magnetic interactions at the fluid-solid interface and (S/V) pore is the ratio of the pore surface area S to the pore water volume V and related to the pore diameter (D), i.e. (S/V) pore =Fs/D. The geometry factor, Fs, depends on the pore shape, which assumes a value of 2, 4 and 6 for planar, cylindrical and spherical pores, respectively. For cylindrical pores (Tian et al. 2014), the equation is,

$$\frac{1}{T_2} = \rho_2 \frac{4}{D}$$

Therefore, the distribution of relaxation time is linearly proportional to the POSD i.e. short relaxation times correspond to small pores and long relaxation times correspond to large pores. After knowing the value of surface relaxivity coefficient (ρ_2), one can estimate the POSD using Equation. It is important to note that the coefficient surface relaxivity (ρ_2) is normally assumed to be constant when interpreting NMR data. The coefficient ρ_2 is attributed to the paramagnetic impurities on the surface of the grains that interact with hydrogen nuclei and impose an additional relaxation (Korringa 1962) and the value is constant for a particular soil and depends on the specific combination of mineral grain and pore fluid (Tian et al. 2014).

1.1.5.2.Experimental method

1.1.5.2.1.Determination of SWCC and POSD

The swcc curve is obtained by pressure meter plate methods as stated in section 1.1.2 and refer figure. The POSD is analyzation is done in terms of T_2 distribution using a 23 MHz MiniMR NMR, jointly developed by the Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, and Niumag Corporation, Suzhou, Jiangsu Province, China, figure. The system consists of a sample tube, magnet unit, radio-frequency (RF) system, temperature controlling system and data acquisition-analysis system. A stable and uniform magnetic field ia generated by, the temperature of the magnet unit is set to be 32 °C, within a variation of ±0.01 °C. for T_2 relaxation time, the Carr-Purcell-Meiboom-Gill pulse sequence is employed to minimize the effect of magnetic field in homogeneities on the NMR signal. The detailed method for measuring the T_2 distribution curves is given in the literature (Tian et al. 2014).

1.1.5.2.2.Determination of Surface Relaxivity coefficient (ρ2)

NMR-permeability equation is used for surface relaxivity coefficient, known as SchlumbergerDoll Research (SDR) equation developed by Kenyon et al. (1988), is used to obtain the surface relaxivity coefficient (ρ_2) which is given by,

$$k_s = {\rho_2}^2 \Phi^4 \, T_{2LM}^2$$

According to Kleinberg et al. (2003), the constant C of SDR equation is to be proportional to the square of the surface relaxivity coefficient i.e. $C = {\rho_2}^2$, which depends on mineralogy and magnetic impurities (For details see Daigle and Dugan 2009). Therefore, the equation is as follows:
ks = *ρ*22Φ4 *T*22*LM*
Or

$$\rho_2 = \sqrt{k_2 \Phi^4 \mathrm{T}_{2LM}^2}$$

Where, $k_s$is the saturated permeability of the soils (m^2) which is measured by virgin portion of the consolidation curve (k_s=9.91×10-16 m2); Φ is the saturated porosity of the NMR samples (Φ=0.5006); T_{2LM} is the geometric mean value of the T_2 distribution (T2LM=0.86534 ms). The obtained ρ2 value is about 0.1452µm/ms.

Figure 4: bar Pressure Plate Extractor.

Figure 5: MHz MiniMR NMR.

1.1.6.Erodibility Factor as per Weis chmeier Nomograph

The soil erodibility factor i.e. K-factor is a quantitative parameter of the inherent erodibility of a particular soil; it is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. Erodibility factor reflects the fact that different soils erode at different rates when the other factors that affect erosion (e.g., infiltration rate, permeability, total water capacity, dispersion, rain splash, and abrasion) are the same. Soil texture is the principal factor affecting K_{fact}, but structure, organic matter, and permeability are also important factors. The ranges soil erodibility factor varies from 0.02 to 0.69 (Goldman et al. 1986; Mitchell and Bubenzer 1980). Goldman et al. (1986) noticed that several methods can be used to estimate the K-factor. The most frequently used methods for soil erodibility are 1) SCS County Soil Survey reports compiled for many counties in the United States and 2) nomographs relating K-factors to topsoil conditions. The SCS county soil surveys contain soil maps superimposed on aerial photographs and maps provide easy location of sites and tentative determination of soil series. Recent surveys list K-factors for the soil is dependent the soil's physical and chemical properties. Among all the method of the soil erodibility factor WeischmeierNomograph is simplest and accurate method whereas direct methods are costlier and tedious. From the results it is noted that the soil erodibility factors were almost insignificantly unchanged on the dry condition up to around 90% degree of saturation but then they were decreased up to 100% degree of saturation. This is due to the permeability coefficient; permeability factor greatly increases at nearly saturated condition because of that permeability level from very slow to slow to moderate in the WeischmeierNomograph.

The K-factor can be calculated using the Universal Soil Loss Equation(USLE), frequently applied to estimate soil erosion on the basis of other factors obtained from simulated or natural rainfall experimental data (Wischmeier& Smith,1978). However, the direct estimation of K-factor is expensive and time taking (Buttafuocoetal.,2012). In this study, the K-factors of the collected top soil samples were estimated using USLE nomograph reported by Wischmeieretal. (1971), the modified by Foster, McCool, Renard, and Moldenhauer (1981) and Rosewell (1993), so as to definite the K-factor in international system of unit (SI unit) (MghMJ$_{\_1}$ mm$_{\_1}$). The K-factor can be calculated from the observed soil values (texture, organic matter (OM), structural and permeability class) in accordance with following Equation, [9]

$K(factor) = 2.77 \times 10^{-7}(12 - OM)\, M^{1.14} + 4.28 \times 10^{-3}(s - 2) + 3.29 \times 10^{-3}(p - 3)$

Where,

$M = [(10 - C)(L + A_{rmf})]$

C is % of clay (< 0.002 mm), L is % of silt (0.002–0.05 mm) and A_{rmf} is % of very fine sand (0.05–0.1 mm) (Pérez-Rodríguez, Marques&Bienes,2007), OM is the organic matter content (%), p is a code indicating the class of permeability, and s is a code for structure size, type and grade based on field observation and interpreted as described by Soil Survey Staff (1993). Then each soil texture is assigned a permeability class using (SSS, 1993) document.

1.1.6.1. Semivariograms

The K-factor is a quantitative parameter which reflect ability of soil particles to resist moving down slope and this factor reflects the that different soils erode at different rates when the other factors that affect erosion are remain same (Goldman, Jackson&Bursztynsky,1986). This variability of K-factor across the study of interest can be described through a semivariogram model, which is a plot of the structure function that describes the degree of linear association between pairs of values separated by a given distance (Nielsen &Wendroth, 2003). In addition, semivariogram is useful for interpolation of values at unmeasured points across the study watershed (Li &Heap, 2008). Values of K-factor anywhere on the landscape differ from location to location, and spatial variations are generally highly irregular and not exactly described by deterministic equations, instead geo statistical analysis is used (Nielsen&Wendroth,2003). In geo statistics, for N pairs of values of soil attribute A_i separated by a distance h, the semivariogram (a measure of the strength of statistical correlation as a function of distance) (Goovaerts,1997) is calculated using following equation,

$$\gamma = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [A_i(x_i) - A_i(x_i + h)]^2$$

The software package GS+ (Gamma Design Software) version 10 (Robertson,2008) was used to obtain the semivariogram model of K-factor, which were obtained through USLE nomograph

1.2. Conclusion

TheeffectoftemperatureontheSWCCofdesilting material isminorinthemiddle stagebutis relatively much larger in the saturated stage (Wetting stage) and the residual section. At higher water content, the influence of temperature on the SWCC of desilting material is mainly due to its effect on pore size and matric suction, whereas it depends on both the Matric suction and the pore size when the water content is lower. However, A complete prediction model of SWCC will be obtained in the temperature interval 10–40°C by the limitation on different moisture content. When the water contentislow, theeffect of temperature onunsaturatedhydraulicconductivity is not obvious, but its effect becomes more obvious with an increase in water content.

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