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Paresh H. Shah[1] *and D. N. Singh,* Member ASTM International[2]

Methodology for Determination of Hygroscopic Moisture Content of Soils

ABSTRACT: Hygroscopic moisture content of the soil is usually determined by an air-drying method and has been related with the surface area and cation exchange capacity of the soil, by many researchers. However, as relative humidity influences the overall soil-water interaction, quantification of its impact on hygroscopic moisture content of the soil becomes mandatory. Incidentally, it has been noted that no standard methodology, which specifies determination of the soil hygroscopic moisture content exists in the literature. With this in view, laboratory investigations were carried out on soils, with entirely different properties, and by exposing them to different relative humidity and storage time. Based on the results, "optimal hygroscopic moisture content" of the soil has been defined and the methodology for its measurement has been proposed. Further, attempts were made to correlate hygroscopic moisture content of the soil with its surface area, cation exchange capacity, liquid limit, swelling potential, and electrical properties (conductivity and dielectric constant). Such correlations will be of the utmost help in predicting these properties of the soil by knowing its hygroscopic moisture content.

KEYWORDS: soils, hygroscopic moisture content, relative humidity, laboratory investigations, correlations

Nomenclature

ε_0 = dielectric permittivity of the vacuum
θ_{bw} = volumetric bound water
ρ_b = bulk density of the soil
ρ_d = dry density of the soil
ρ_w = density of water
ρ = electrical conductivity of the soil
σ_{dry} = electrical conductivity of the oven-dry soil
σ_{hopt} = electrical conductivity of the soil at w_{hopt}
δ = thickness of one molecular water layer
ω = the ratio of w_{h7} and w_{h1}
ΔH = change in height of the soil sample
A = area of cross section of the electrode plates
CEC = cation exchange capacity
Cp = capacitance
CH = Inorganic clays of high plasticity
CL = clay content (in %)
d = spacing between the electrode plates
FSI = free swell index (in %)
G = specific gravity of the soil
H = initial height of the soil sample
H_w = final height of the soil sample when soaked in distilled water

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[1] Research Scholar, Department of Civil Engineering, Indian Institute of Technology Bombay, Powai, Mumbai-400 076, e-mail: pareshhshah@yahoo.com
[2] Professor, Department of Civil Engineering, Indian Institute of Technology Bombay, Powai, Mumbai-400 076, e-mail: dns@civil.iitb.ac.in, (corresponding author)

H_k = final height of the soil sample when soaked in kerosene oil
k = dielectric constant of the soil
k_{dry} = dielectric constant of the oven-dry soil
k_{hopt} = dielectric constant of the soil at w_{hopt}
k_{diff} = difference between k_{hopt} and k_{dry}
l = number of molecular layers of water
LL = liquid limit
ML = Inorganic slits, and silty of clayey fine sands with low plasticity
MH = Inorganic slits of high plasticity
PI = plasticity index
R^2 = regression coefficient
R_0 = bulk resistance
R_H = relative humidity (%)
SP = swelling potential (%)
SP_{max} = maximum swelling potential (%)
SSA = specific surface area
t = storage time
w = gravimetric moisture content
w_h = hygroscopic moisture content
w_{ha} = hygroscopic moisture content of the air-dry soil
w_{h1} = hygroscopic moisture content corresponding to 1 day of storage
w_{h7} = hygroscopic moisture content corresponding to 7 days of storage
$w_{h45,1}$ = hygroscopic moisture content at R_H=45 % corresponding to 1 day of storage
$w_{h90,1}$ = hygroscopic moisture content at R_H=90 % corresponding to 1 day of storage
w_{hopt} = optimal hygroscopic moisture content
Z' = real part of the complex impedance
Z'' = imaginary part of the complex impedance

Introduction

Water in soils exists as hygroscopic water (bound water), capillary water, and free water [1]. Hygroscopic water w_h is the water adsorbed by the soil from the environment due to electromolecular surface forces, and is greatly affected by the relative humidity R_H [1]. The physical characteristics of the bound water lie between the solid and the free-liquid states, and hence its properties such as density, freezing temperature, and dielectric constant differ from the free water [2]. In addition, the thickness of the bound water varies from monomolecular layer to several molecular layers, depending upon the type of the soil and the prevailing humidity. Incidentally, the thickness of the bound water has been an uncertain parameter and different researchers have reported it to be 3.5° A [3], 5° A [4] or varying from 5 to 10° A [5], depending on the type of the soil.

Capacity of the clay to hold the bound water has been shown to be dependent on its specific surface area (SSA) and the charge density [5]. Hence, volume of the bound water adsorbed by the soil can be correlated easily with different properties [viz., liquid limit (LL), plasticity index (PI), cation exchange capacity (CEC), etc.]. In addition to this, electrical properties of soils such as conductivity σ and dielectric constant k can also be correlated with w_h. Considering the fact that for bound water, k varies with its thickness, it can be employed for determining the thickness of the bound water layer [6–8].

Many researchers have related the volume fraction of tightly bound water θ_{bw}, which encompasses the mineral surface, with SSA of soils using the following expression [9,10]:

$$\theta_{bw} = l \cdot \delta \cdot \rho_b \cdot \mathrm{SSA} \tag{1}$$

where

$$\rho_b = \rho_d \cdot (1 + w) \tag{2}$$

and l is the number of molecular water layers of tightly bound water and its lower limit is 1 (i.e., a monomolecular layer), δ is the thickness of one molecular water layer (=2.8° A), ρ_b and ρ_d are the bulk

TABLE 1—*Properties of the soils used in the study.*

Soil	G	CL (%)	LL (%)	PI (%)	Classification[a]	SSA (m^2/g)	CEC (meq/100 g)	Mineral
ST	2.8	18	44	15	ML	25.86	5.69	Albite, anorthite, montmorillonite
BC	2.65	53	73	42	CH	37.8	8.75	Quartz, mullite
WC	2.63	54	54	26	CH	15.95	4.98	Kaolinite, illite
MC	2.78	32	61	24	MH	27.74	4.04	Quartz, illite, anorthite
BT	2.82	85	227	162	CH	43.53	8.93	Montmorillonite, illite
MT	2.81	90	411	340	CH	54.81	13.95	Montmorillonite, kaolinite

[a]USCS [20]

and dry densities of the soil, respectively, and w is the gravimetric moisture content.

In addition to this, the moisture content at wilting point (corresponding to 1500 kPa suction) has also been used to define the bound water [11]. However, this concept yields much higher values of θ_{bw} as compared to the values computed from Eq. 1 [9]. Hence, the moisture content corresponding to the matric suction of 3100 kPa has been recommended as the hygroscopic moisture content w_h by some researchers [12].

However, it has been noted that there is no standard testing methodology that can be employed for determining w_h of the soil, and that too by taking into account the influence of R_H on it. With this in view, laboratory investigations were carried out to determine w_h of soils, with entirely different properties, by exposing them to different R_H in a humidity chamber. Based on the results obtained, recommendations for determining w_h of the soil have been made in this paper. In addition to this, one-dimensional swelling potential (SP) tests [13] were conducted on these soils and attempts were made to correlate w_h of the soil with its SSA, CEC, LL, SP, σ, and k. Utility of such correlations in predicting engineering properties of the soil by knowing its w_h has also been demonstrated.

Experimental Investigations

Soil Properties

Three locally available soils; silty soil (ST), black cotton soil (BC), marine clay (MC) and commercially available white clay (WC), bentonite (BT), and montmorillonite (MT) were used in this study. Specific gravity G, particle size characteristics, LL, PI, and SSA of these soils were obtained by following the guidelines provided by the ASTM [14–18]; mineralogical composition of these soils was obtained by using the x-ray diffraction technique [19]. CEC of these soils was measured by following the guidelines presented in IS 2720, Part XXIV [20]. The results along with the classification of the soils [21] are listed in Table 1.

Determination of Hygroscopic Moisture Content

A sufficient amount of these soils was oven dried and with the help of a wooden rammer, the clumps were broken up. Fifty grams of each of these soils was passed through a 980 μm sieve and spread uniformly in a tray. Later, the tray with the soil was placed in a humidity chamber, which maintains a specified R_H. The moisture content of the sample was determined, following the methodology presented by ASTM [22], after different times t (=1, 3, 5, and 7 days) of storage, at different levels of R_H (=45, 52, 58, 78, and 90) and at a constant temperature of $22\pm0.5°C$.

Determination of Swelling Characteristics

Free swell index (FSI) [23] of these soils was determined using the methodology mentioned in the following. Ten grams of an air-dry soil sample, passing through a 425 μm sieve, was filled in two 100 ml

TABLE 2—*Details of the samples used for swelling potential tests.*

Soil	ρ_d (g/cc)	w (%)
ST	1.30	4.2
BC	1.34	8.96
WC	0.78	1.5
MC	1.36	5.67
BT	1.02	10.05
MT	1.14	10.60

graduated cylinders. Later, these cylinders were filled with distilled water and kerosene, respectively, and the free swelling of the soil was observed for a period of 7 days. The FSI of the soil was computed using the following expression:

$$\mathrm{FSI} = \frac{H_w - H_k}{H_k} \times 100 \tag{3}$$

where H_w and H_k are heights of the soil sample in distilled water and kerosene, respectively, at the end of 7 days.

In addition to this, tests were conducted on these soils (refer Table 2 for details of the samples) to determine their swelling potential SP using an oedometer [13]. The air-dry soil was packed in the oedometer ring, which is 25 mm in height and 75 mm in internal diameter, to a certain dry-density ρ_d and a small pressure (=0.7 kPa) was applied to it. Later, the sample (of height H) was inundated with distilled water and its swelling (i.e., the change in height ΔH) was recorded over a period of time untill three consecutive dial gage readings were found to be the same. Using Eq. 4, the swelling potential SP of the soil was computed.

$$SP = \frac{\Delta H}{H} \times 100 \tag{4}$$

Measurement of Electrical Properties

Electrical properties (σ and k) of these soils were determined on their oven-dry samples and the samples stored in the humidity chamber for certain duration. A rectangular Perspex box (150 mm × 150 mm × 30 mm along with two stainless steel electrodes of 150 mm × 150 mm × 2 mm size), as depicted in Fig. 1, was used for measuring the impedance of the sample with the help of a *LCR* meter (Agilent 4284A), which works in the frequency range of 20 Hz to 1 MHz [24]. Compaction of the sample was achieved in three equal layers with the help of a wooden rammer, which weighs 250 g, by imparting 25 blows to each layer. Details of the samples used for impedance measurement are presented in Table 3. To eliminate electrical interferences caused due to the length of the leads, a built-in algorithm in the *LCR* meter was used and the correction factors recommended by ASTM [25] were employed. Also, to avoid unwanted impedances, in series and parallel due to the cell and leads, open and short circuit corrections were applied before conducting experiments [24].

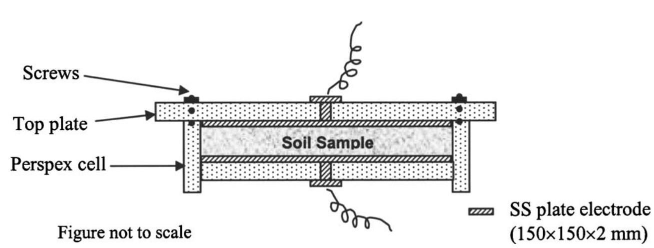

FIG. 1—*Test setup used for measuring electrical properties of the soil sample.*

TABLE 3—*Details of the samples used for electrical property measurements.*

Soil	ρ_d (g/cc)	
	Oven-dry soil	Soil at w_{hopt}
ST	1.44	1.20
BC	1.38	1.15
WC	0.67	0.51
MC	1.22	1.21
BT	0.81	0.81
MT	1.07	0.82

Results and Discussion

The variation of w_h with respect to the storage time t and R_H is depicted in Fig. 2. It can be observed from the trends depicted in the figure that, in general, w_h increases very rapidly, initially, with increase in t or R_H. These trends also reveal that w_h for a soil is not unique and is dependent on R_H and t. Hence, mention of w_h without referring to these parameters, as done by previous researchers, would be improper. Due to the lack of such studies in the literature, the obtained trends could not be compared and validated. However, w_h for bentonite corresponding to $R_H=50\ \%$, which is available in the literature [26], was used for validating the results obtained for soil BT. Though, the corresponding t has not been mentioned, the reported value of w_h (=4.9 %) is found to be quite close to the measured w_h for this soil (=4.42 %) corresponding to $R_H=52\ \%$ and $t=7$ days. This shows that the methodology developed and reported in this study yields appropriate results. It can also be noted from the trends depicted in Fig. 2 that the adsorption of moisture on the soil attains a constant value, corresponding to a very small t at $R_H=90\ \%$. Therefore, w_h corresponding to $R_H=90\ \%$ can be considered as the optimal hygroscopic moisture content w_{hopt}.

Though Eq. 1 has been used by the previous researchers [9,10] to correlate w_h and SSA, authors are of the opinion that it requires to be represented as Eq. 5. This is mainly due to the fact that Eq. 1 has been derived based on the assumption that $\rho_b \approx \rho_d$, which is not absolutely correct and is valid only for $w \cong 0$ [refer to Eq. 2].

$$w_h = l \cdot \delta \cdot \rho_w \cdot (\text{SSA}) \tag{5}$$

where ρ_w is the density of water.

By substituting the value of SSA in Eq. 5, for the soils considered in the present study, parameter l was obtained and the same is listed in Table 4. It can be noted from the data presented in the table that l depends on R_H and varies from 2 to 10. This is contrary to the assumed value of l, equal to unity, by many researchers [9,10] and which may be valid for w_h measurements corresponding to $R_H < 45\ \%$. However, due to the limitations of the humidity chamber, w_h corresponding to $R_H < 45\ \%$ could not be measured.

Further, a factor $\omega(=w_{h7}/w_{h1})$, which corresponds to the ratio of w_h measured on the 7th and 1st day of storage, at a certain R_H, has been computed as listed in Table 4. This factor is indicative of the susceptibility of a soil to gain maximum increase in the hygroscopic moisture due to its interaction with the environment. This factor when plotted against R_H, as depicted in Fig. 3, exhibits a decrease in scatter with increase in R_H, in general. The scatter of the data is found to be maximum and minimum for $R_H=58$ and 90 %, respectively. From the data presented in Table 4, an average value of 1.06 can be assigned to ω corresponding to $R_H=90\ \%$. Hence, when based only on the 1st day storage of the soil sample at $R_H=90\ \%$, its optimal hygroscopic moisture content w_{hopt}, which is equal to $w_{h90,7}$, can be computed.

$$w_{hopt} = 1.06 \cdot w_{h90,1} \tag{6}$$

where $w_{h90,1}$ corresponds to the w_h at $R_H=90\ \%$ and for 1 day of sample storage.

Hence, the methodology developed and discussed above can be employed for determining hygroscopic moisture content of the soil, which would also incorporate the effect of humidity and time of interaction of the soil with the environment.

Determination of Soil Properties Using Its Hygroscopic Moisture Content

Results of the studies reported in the literature [9,27,28] were used for developing relationships between the hygroscopic moisture content of the air-dried soils w_{ha}, SSA, and CEC, as depicted in Fig. 4 and Table 5. The value of the coefficient of linear regression (depicted in bold letters) for these relationships is also

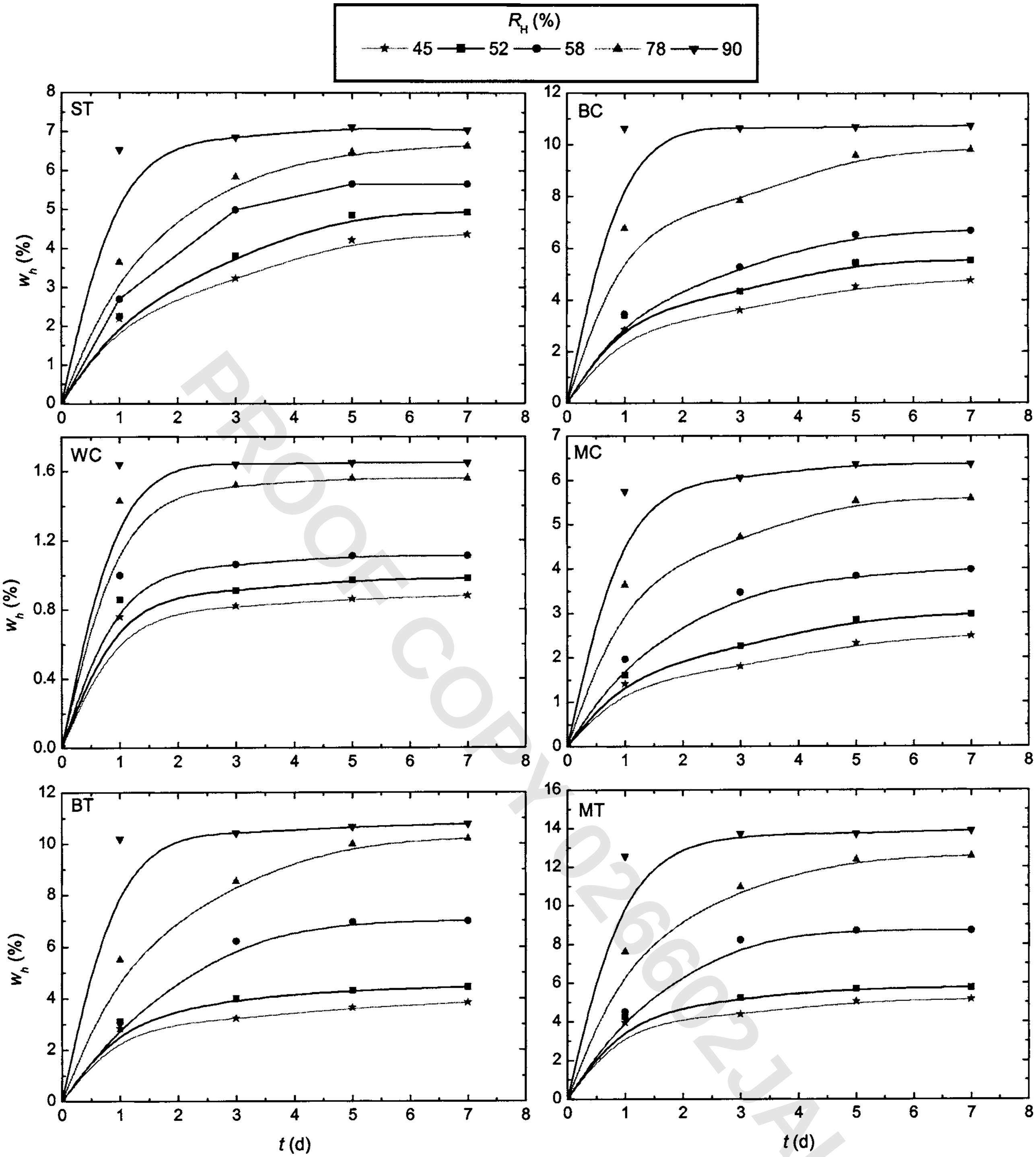

FIG. 2—*The variation of hygroscopic moisture content of the soils with storage time and relative humidity.*

presented in Table 5. These trends are similar to those reported in the literature [29]. In order to generalize these relationships, which are bound to be location specific and dependent on the methodology adopted by the respective researchers, the combined data (cd) was also used to develop these relationships, as listed in Table 5.

However, in the authors' opinions, as w_{ha} used by these researchers [9,27,28] has not been referred to a specific R_H, the developed relationships are bound to yield entirely different results. In order to prove this, w_{h1} for these six soils was plotted against R_H, as depicted in Fig. 5. From the trends depicted in the figure, it can be noted that for $R_H \leqslant 45$ %, w_{h1} remains practically constant ($=w_{h45,1}$) and hence it can be correlated with w_{ha}. With this in view, the variation of SSA and CEC was plotted with $=w_{h45,1}$ as depicted in Fig. 6 and these trends can be expressed as

TABLE 4—*Hygroscopic moisture content of the soils used in the study.*

		t (days)								
		1		3		5		7		
Soil	R_H (%)	w_h (%)	l	w_h (%)	l	w_h (%)	l	w_h (%)	l	ω
ST	45	2.18	3.0	3.22	4.5	4.21	5.8	4.36	6.0	2.00
	52	2.26	3.1	3.81	5.2	4.86	6.7	4.93	6.8	2.18
	58	2.69	3.7	4.99	6.9	5.65	7.8	5.66	7.8	2.10
	78	3.65	5.0	5.84	8.1	6.48	8.9	6.64	9.2	1.82
	90	6.54	9.0	6.86	9.5	7.12	9.8	7.05	9.8	1.08
BC	45	2.84	2.7	3.61	3.4	4.52	4.2	4.76	4.5	1.68
	52	3.4	3.2	4.34	4.1	5.45	5.1	5.54	5.2	1.63
	58	3.45	3.3	5.27	5	6.54	6.2	6.68	6.3	1.94
	78	6.77	6.4	7.85	7.4	9.61	9.1	9.83	9.3	1.45
	90	10.63	10.0	10.65	10.1	10.7	10.1	10.77	10.2	1.01
WC	45	0.76	1.7	0.82	1.8	0.86	1.9	0.88	2.0	1.16
	52	0.86	1.9	0.91	2	0.97	2.1	0.98	2.2	1.14
	58	1	2.2	1.06	2.4	1.11	2.5	1.11	2.5	1.11
	78	1.43	3.1	1.52	3.4	1.56	3.5	1.56	3.5	1.05
	90	1.64	3.6	1.64	3.6	1.65	3.7	1.65	3.7	1.00
MC	45	1.4	1.8	1.80	2.3	2.32	3.0	2.48	3.2	1.77
	52	1.61	2.1	2.26	2.9	2.85	3.7	2.98	3.8	1.85
	58	1.96	2.5	3.47	4.5	3.83	4.9	3.97	5.1	2.03
	78	3.63	4.7	4.72	6.1	5.53	7.1	5.58	7.2	1.54
	90	5.75	7.4	6.06	7.8	6.37	8.2	6.37	8.2	1.11
BT	45	2.83	2.3	3.22	2.7	3.63	3.0	3.81	3.1	1.35
	52	3.11	2.5	3.99	3.3	4.3	3.5	4.42	3.6	1.42
	58	3.07	2.5	6.21	5.1	6.95	5.7	6.98	5.7	2.27
	78	5.49	4.5	8.54	7	9.98	8.2	10.19	8.4	1.86
	90	10.19	8.4	10.42	8.5	10.65	8.7	10.76	8.9	1.06
MT	45	3.94	2.6	4.38	2.9	5.04	3.3	5.16	3.4	1.31
	52	4.25	2.8	5.24	3.5	5.71	3.8	5.76	3.8	1.36
	58	4.52	3	8.22	5.4	8.71	5.7	8.71	5.7	1.93
	78	7.61	5	10.96	7.1	12.38	8.1	12.55	8.2	1.65
	90	12.55	8.2	13.72	8.9	13.72	8.9	13.89	9.1	1.11

$$\text{SSA} = 14.24 \cdot w_{h45,1} \quad (7)$$

$$\text{CEC} = 3.26 \cdot w_{h45,1} \quad (8)$$

These relationships when compared vis-à-vis the relationships obtained by using the combined data, as listed in Table 5, reveal the following:

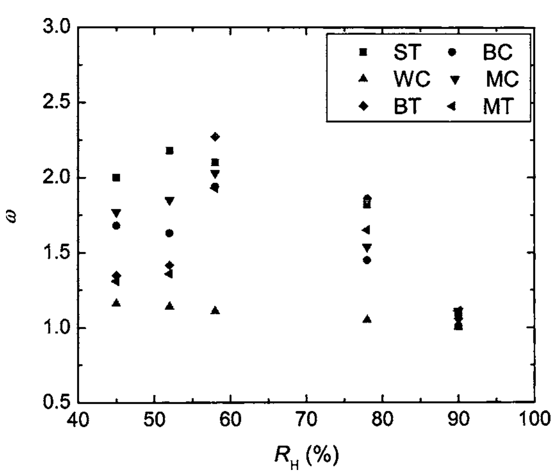

FIG. 3—*Variation of* ω *with* R_H *for the soils used in the study.*

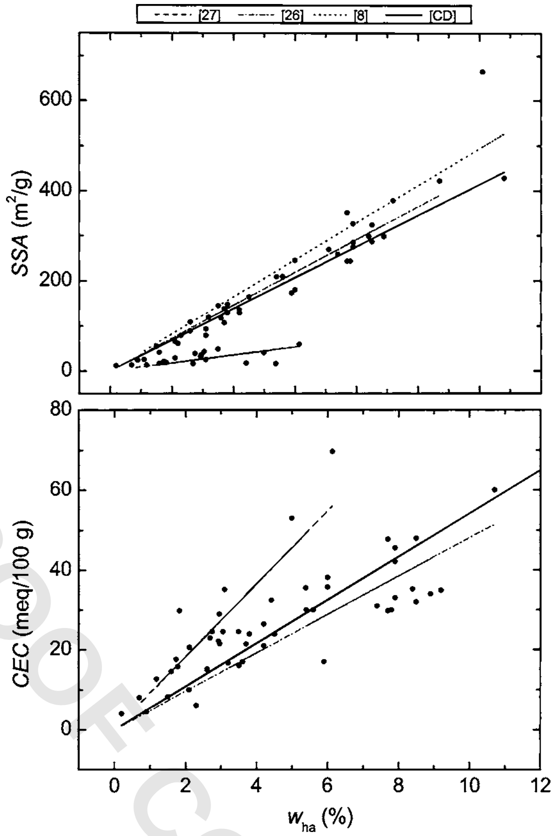

FIG. 4—*Trends depicting the variation of SSA and CEC with air-dry moisture content.*

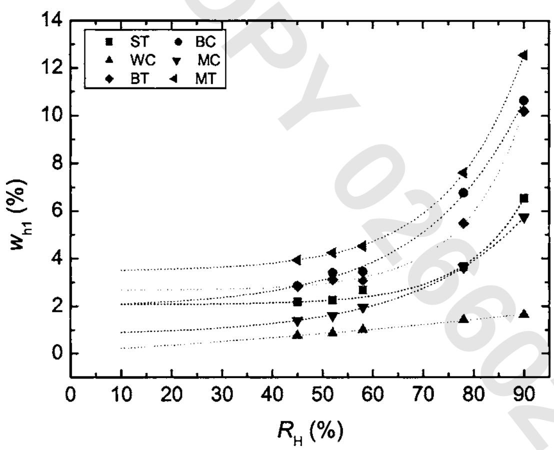

FIG. 5—*Variation of* w_{h1} *with* R_H *for the soils used in the study.*

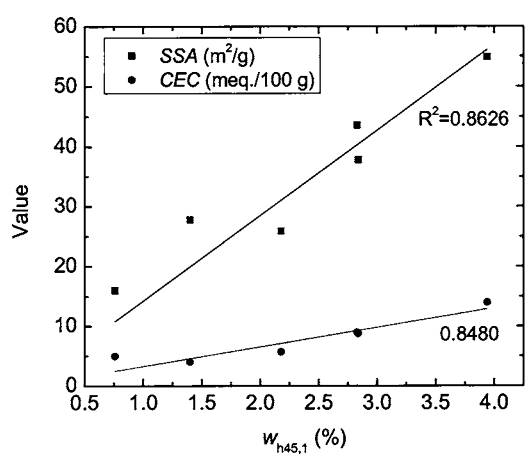

FIG. 6—*Variation of the SSA and CEC with* $w_{h45,1}$ *for the soils used in the study.*

TABLE 5—*Relationships of SSA and CEC with w_{ha} from data reported in literature.*

Researchers	SSA	CEC
Banin and Amiel [27]	$36.44 \cdot w_{ha}$ **0.9441**	$4.81 \cdot w_{ha}$ **0.8034**
Hedley et al. [28]	$8.89 \cdot w_{ha}$ **0.1215**	$9.31 \cdot w_{ha}$ **0.7757**
Dirksen and Dasberg [9]	$41.18 \cdot w_{ha}$ **0.8812**	—
Combined data (CD)	$34.5 \cdot w_{ha}$ **0.8001**	$5.42 \cdot w_{ha}$ **0.4575**

$$w_{ha} \approx (0.4 \text{ to } 0.6) \cdot w_{h45,1} \tag{9}$$

It must be appreciated that w_{hopt}, which can be obtained from the methodology mentioned above and Eq. 6, can be used for estimating different soil properties such as SSA, CEC, LL etc. With this in view, data of the six soils used in this study were plotted against w_{hopt}, as depicted in Fig. 7, and the following

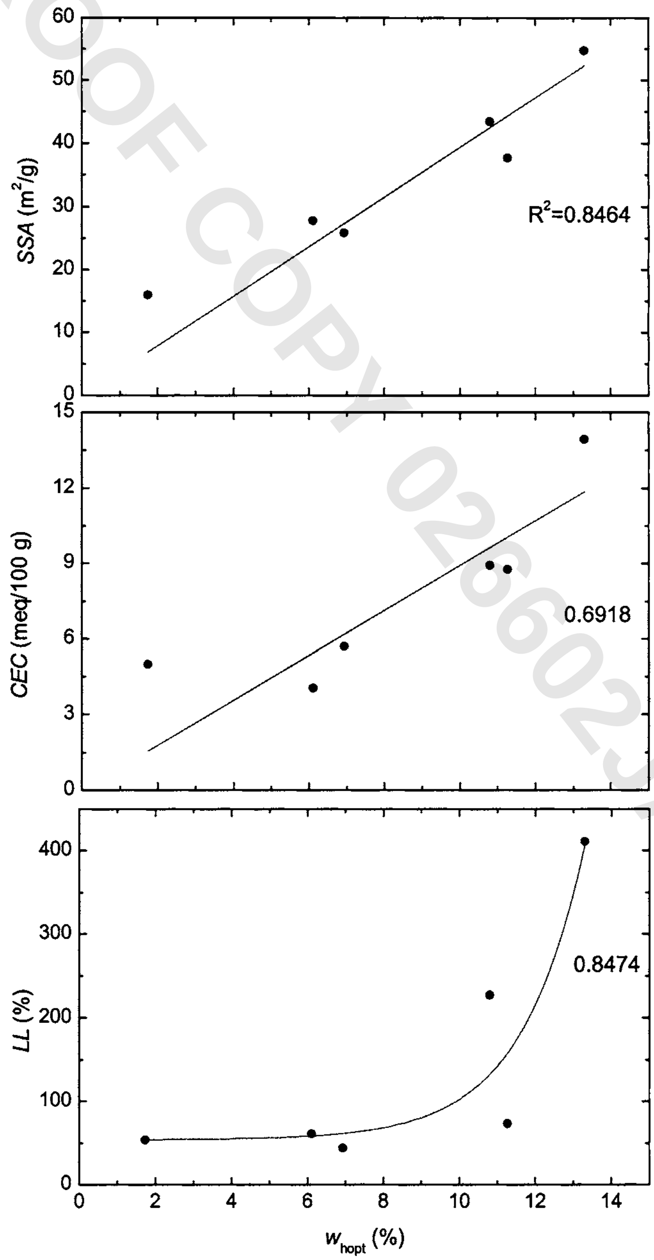

FIG. 7—*Variation of the SSA, CEC, and LL with w_{hopt} for the soils used in the study.*

TABLE 6—*Swelling properties of the soils used in the study.*

Soil	FSI (%)	SP_{max} (%)
ST	23	12
BC	67	47
WC	[a]	[a]
MC	33	37
BT	133	75
MT	218	134

[a]Insignificant.

relationships are being proposed. The coefficient of regression (R^2) for these trends is also depicted in the figure

$$SSA = 3.92 \cdot w_{hopt} \tag{10}$$

$$CEC = 0.89 \cdot w_{hopt} \tag{11}$$

$$LL = 53.67 + 0.117 \cdot \exp(w_{hopt}/1.66) \tag{12}$$

On comparing Equations 6–8, 10, and 11 and the equations for the combined data, as presented in Table 5, the following equivalent relationship can be derived

$$w_{hopt}:w_{h90,1}:w_{h45,1}:w_{ha} \equiv 1:0.94:0.27:0.13 \tag{13}$$

Equation 13 can be applied for relating the hygroscopic moisture contents at different environmental conditions (viz., $w_{h45,1}$ and w_{ha}) to w_{hopt}, which has been shown to be the maximum possible hygroscopic moisture content for a soil. Equation 13 is found to be valid for experimentally obtained values of $w_{h90,1}$ and $w_{h45,1}$, for the soils considered in this study.

Table 6 presents the maximum value of the swelling potential SP_{max} and FSI for the six soils considered in this study. For the sake of completeness, the variation of SP with time t is depicted in Fig. 8.

Further, the variation of SP_{max} and FSI with w_{hopt} was developed for the soils used in the present study, as depicted in Fig. 9, and the trends can be represented by the following expressions:

$$SP_{max} = 7.74 + 1.09 \cdot \exp(w_{hopt}/2.81) \tag{14}$$

$$FSI = 2.62 + 2.5 \cdot \exp(w_{hopt}/3.0) \tag{15}$$

Hence, Eqs. 14 and 15 can be used for determining swelling properties of the soil if its w_{hopt} is known.

From the measured impedance values, the Nyquist impedance plots for these soils were developed, following the guidelines presented in the literature [24]. For the sake of brevity, the Nyquist plot for the

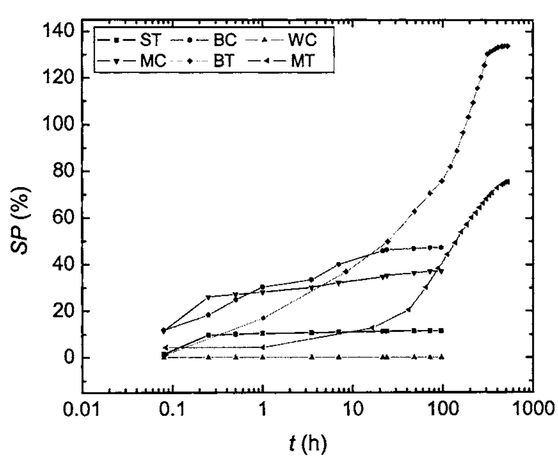

FIG. 8—*Swelling characteristics of the soils used in the study.*

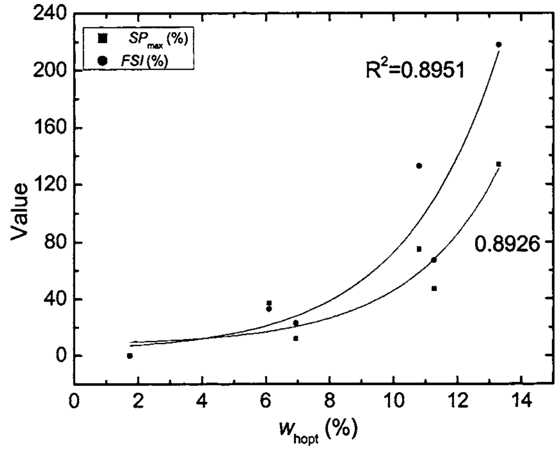

FIG. 9—*Variation of the swelling characteristics of the soils used in the study with* w_{hopt}.

soil MC is being depicted in Fig. 10, only. σ of the soil was obtained using Eq. 16 from the corresponding values of the bulk resistance R_0. It must be noted that R_0 is equal to the real part Z', of the complex impedance corresponding to the minimum value of imaginary part Z''.

$$\sigma = d/(R_0 \,.\, A) \tag{16}$$

where A corresponds to the area of cross section of electrodes and d is their spacing.

The electrical conductivities of the oven-dried soil and the soil at w_{hopt}, represented as σ_{dry} and σ_{hopt}, respectively, are listed in Table 7. In addition to this, k for the soils, used in the present study, corresponding to 1 MHz was obtained using the following expression:

$$k = \frac{C_p}{\varepsilon_0} \cdot \frac{d}{A} \tag{17}$$

where C_p is the capacitance in F, ε_0 is the dielectric permittivity of the vacuum (=8.85×10^{-12} F/m).

Following this, k_{dry} and k_{hopt} for the oven-dry soil and soil at w_{hopt}, respectively, were computed and their values are presented in Table 7. Values of k_{dry} are found to vary from 3.17 to 6.7, which is consistent with the results reported in the literature [30]. In order to demonstrate the dependence of electrical properties of the soil on its hygroscopic moisture content, $\sigma_{hopt}/\sigma_{dry}$ and k_{diff} (=k_{hopt}-k_{dry}) were plotted against w_{hopt}, as depicted in Fig. 11. The trends depicted in the figure can be represented as

$$\sigma_{hopt}/\sigma_{dry} = 9543 \cdot \exp(w_{hopt}/9.4) - 10310 \tag{17a}$$

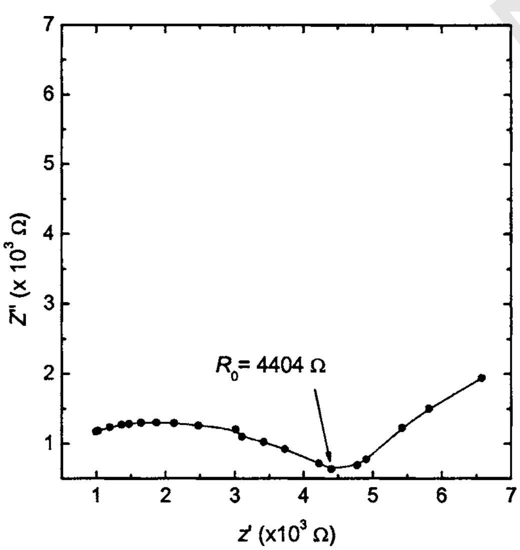

FIG. 10—*Nyquist impedance plot for the Soil MC.*

TABLE 7—*Electrical properties of the soils used in the study.*

	Oven-dry soil		Soil at w_{hopt}			
Soil	σ_{dry} ($\times 10^{-7}$ S/m)	k_{dry}	σ_{hopt} ($\times 10^{-4}$ S/m)	k_{hopt}	$\sigma_{hopt}/\sigma_{dry}$ ($\times 10^4$)	k_{diff}
ST	0.33	4.03	1.52	19.24	0.46	15.21
BC	0.31	4.61	7.18	19.57	2.32	14.96
WC	0.90	3.17	0.03	5.64	0.003	2.47
MC	0.54	4.09	6.67	14.21	1.24	10.12
BT	1.57	6.2	31.0	20.6	1.98	14.4
MT	2.45	6.7	69.0	28.8	2.82	22.1

$$k_{diff} = 1.55 \cdot w_{hopt} \tag{18}$$

Equations 17 and 18 reveal that as w_{hopt} increases, $\sigma_{hopt}/\sigma_{dry}$ and k_{diff} increase. These parameters when correlated with the activity of the soil (=PI/CL) can be used for quantifying the susceptibility of the soil to interact with the environment. However, extensive investigations must be conducted on soils of different composition and properties, following the proposed methodology for this purpose.

Concluding Remarks

Based on the study, it can be concluded that the hygroscopic moisture content w_h of the soil strongly depends on the time of storage under a specific relative humidity R_H. Hence, the methodology presented in this paper must be used for determining w_h of the soil. The importance of defining the optimal hygroscopic moisture content w_{hopt} of the soil has been highlighted in this study, which also presents an easy way of determining it. It is recommended that w_{hopt} should be obtained based on the one day storage of the soil sample at $R_H = 90\,\%$. Further, it has been demonstrated that by knowing w_{hopt} of a soil, its basic characteristics (viz., specific surface area, cation exchange capacity, swelling characteristics, liquid limit, and electrical properties) can be estimated, quite easily. However, due to the lack of data reported in the literature, and due to improper reporting of the hygroscopic moisture content by the previous researchers, the efficiency of the proposed relationships could not be checked.

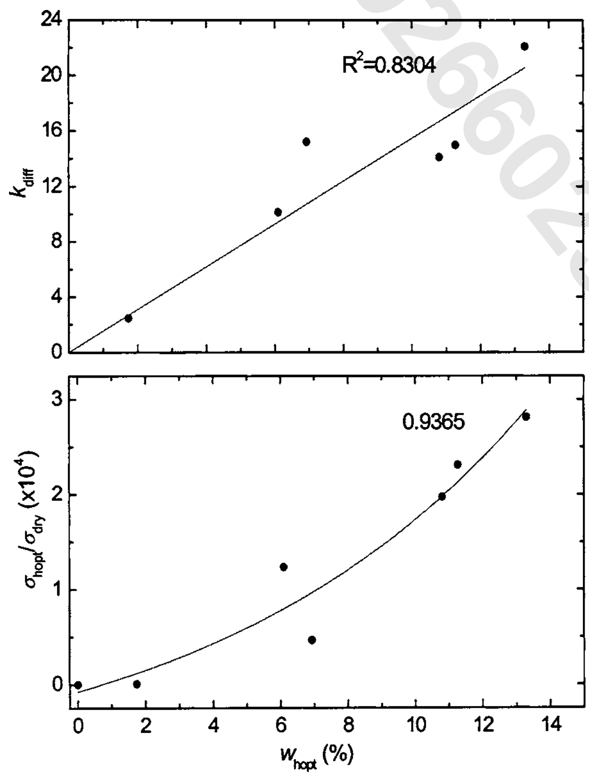

FIG. 11—*Variation of the electrical properties of the soils with w_{hopt}.*

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