

Evaluation of compression index of remoulded clays by means of Atterberg limits

C.I. Giasi · C. Cherubini · F. Paccapelo

Abstract The literature contains numerous equations linking a soil's characteristics of compressibility to its index properties, such as liquid limit and plasticity index. As these equations are often used to obtain preliminary evaluations of the compression index C_c , it is important to know the reliability of these equations. The paper analyses some of the equations more frequently used to calculate C_c from laboratory index properties, using a methodology based on two specific indices: ranking distance and ranking index. Forty-six samples formed the data set, mainly of Blue Clays and Varicoloured Clays outcropping in the southern part of the Bradanic Foredeep. It was concluded that the most reliable equation correlates C_c with the shrinkage index.

Résumé La bibliographie contient de nombreuses équations reliant les caractéristiques de compressibilité des sols à leurs paramètres d'identification géotechnique, tels que la limite de liquidité et l'indice de plasticité. Comme ces équations sont souvent utilisées pour obtenir des évaluations préliminaires de l'indice de compression C_c , il est important de connaître leur fiabilité. L'article considère quelques unes des équations le plus souvent utilisées pour calculer C_c à partir d'essais d'identification géotechnique de laboratoire, mettant en œuvre un traitement statistique des données de mesures basé sur l'utilisation de deux indices statistiques particuliers. Quarante six échantillons constituent la base de données. Ils sont issus principalement des Argiles Bleues et des Argiles Versicolores en affleurement

dans le bassin d'avant-fosse de Bradano. Il apparaît que l'équation la plus fiable met en relation C_c avec l'indice de retrait.

Keywords Clays · Compressibility · Correlations · Atterberg limits · Ranking distance · Ranking index

Mots clés Argiles · Compressibilité · Limites d'Atterberg · Indices statistiques

Introduction

It is very important in geotechnics to know the compressibility properties of a soil. Considering that oedometric tests, often used for this purpose, are expensive and require a lot of time, numerous attempts have been made to correlate compressibility with some simple index properties. The multitude of equations present in the literature indicates that none of them can be assumed to have general validity, but that each of them can be valid within defined ranges. As it is not always easy to identify the best correlation to use, in this paper an attempt has been made to provide evaluation criteria on which to assess the reliability of some of the available correlations. It is known that the compressibility characteristics of a soil can be correlated to different characteristic properties, such as the liquid limit, the plasticity index, the natural water content, the void index, etc. The use of one property rather than another is linked to the kind of soil being considered and to the conditions in which it is analysed. For example, the Atterberg limits can be used to evaluate the compression index of remoulded soils samples. As in this study only analyses of remoulded samples have been undertaken, the compressibility characteristics have been evaluated by means of equations based on the liquid limit (LL), shrinkage index (SI) and plasticity index (PI).

Compression index equations

Table 1 contains some of the equations available in the literature, with their relative ranges of application. As can

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Table 1

Some of the correlations available for determining the value of C_c . Some of the papers cited, if not reported in the References, are taken from Balasubramaniam and Brenner 1981

Equation	Applicability	Reference
$C_c=0.007(LL-10)^a$	Remoulded clays	Skempton (1944)
$C_c=0.0046(LL-9)^a$	Brazilian clays	Cozzolino (1961)
$C_c=0.009(LL-10)^a$	Normally consolidated clays	Terzaghi and Peck (1967)
$C_c=0.006(LL-9)^a$	All clays with liquid limits less than 100%	Azzouz et al. (1976)
$C_c=0.009(LL-8)$	Osaka Bay clay	Tsuchida (1991)
$C_c=0.009LL$	Tokio Bay clay	Tsuchida (1991)
$C_c=0.008(LL-12)^a$	All clays	Sridharan and Nagaraj (2000)
$C_c=0.014(PI+3.6)^a$	All clays	Sridharan and Nagaraj (2000)
$C_c=0.007(SI+18)^a$	All clays	Sridharan and Nagaraj (2000)
$C_c=0.01w_n$	All clays	Koppula (1981)
$C_c=0.01(w_n-7.549)$	All clays	Herrero (1983)
$C_c=0.0115w_n$	Organic silt and clays	Bowles (1989)
$C_c=1.15(e-e_0)$	All clays	Nishida (1956)
$C_c=0.29(e_0-0.27)$	Inorganic soils	Hough (1957)
$C_c=0.35(e_0-0.5)$	Organic soils	Hough (1957)
$C_c=0.246+0.43(e_0-0.25)$	Motley clays from Sao Paulo, Brazil	Cozzolino (1961)
$C_c=1.21+1.055(e_0+1.87)$	Lowland of Santos, Brazil	Cozzolino (1961)
$C_c=0.75(e_0-0.5)$	Soils with low plasticity	Sowers (1970)
$C_c=0.208e_0+0.0083$	Chicago clays	Bowles (1989)
$C_c=0.156e_0+0.0107$	All clays	Bowles (1989)
$C_c=0.329[0.027(w-PL)+0.0133PI(1.192+ACT^{-1})]$	All remoulded, normally consolidated clays	Carrier (1985)
$C_c=0.2237e_L$	All remoulded, normally consolidated clays	Nagaraj and Srinivasa Murthy (1983)
$C_c=0.2343e_L$	All remoulded, normally consolidated clays	Nagaraj and Srinivasa Murthy (1986)
$C_c=0.274e_L$	Clay-sand mixes	Nagaraj et al. (1995)
$C_c=0.037(e_0+0.003LL-0.34)$	Clays from Greece and some parts of the USA	Nagaraj et al. (1976)
$C_c=0.048(e_0+0.001w_n-0.25)$	Clays from Greece and some parts of the USA	Azzouz et al. (1976)
$C_c=0.37(e_0+0.003LL+0.0004w_n-0.34)$	Clays from Greece and some parts of the USA	Azzouz et al. (1976)
$C_c=0.015(LL-19)$	Japanese marine clays	Ogawa and Ogawa (1978)
$C_c=0.014(LL-20)$	Ishikan clay	JSSMFE (1966)
$C_c=0.013LL$	Ariake clay	JSSMFE (1966)
$C_c=0.063(LL-10)$	Egyptian clay	Abdrabbo and Mahamoud (1990)
$C_c=0.048(LL-10)$	Brazilian clays	Bowles (1979)

^aThese equations are analysed in this paper

be seen, in most cases these are linear correlations based on the value of a single index property. Some of the most commonly used correlations are those based on liquid limit, as this index property can be easily determined and the degree of compressibility of clay soils is connected to the size of the surface of the particles that make them up and therefore to their mineralogy. The liquid limit can be considered to be a measure of the quantity of water attracted by these particles for a given value of undrained shear strength (Al-Khafaji and Andersland 1992), thus making it possible to correlate this parameter with the compressibility. However, it is important to emphasise that the liquid limit and all the Atterberg limits must be considered representative of the behaviour of a remoulded soil (Skempton 1944) or of a normally consolidated one (Terzaghi and Peck 1967). In other words, using the liquid limit it is possible to take into account parameters such as the nature and the mineralogical composition of the soil, but not the influence of factors such as the stress state. Tsuchida (1999) notes that when consolidating a sample with a pressure much larger than the pre-consolidation yield stress, the consolidation curve converges towards the so-called ultimate standard compression (USC) curve independent of the initial conditions of the sample. Under these conditions Tsuchida identifies a good correlation between the liquid limit and compressibility.

However, a number of authors have emphasised the fact that equations based on the value of the liquid limit are not always reliable (Cherubini 1991; Al-Khafaji and Andersland 1992; Sridharan and Nagaraj 2000). In particular, Sridharan and Nagaraj (2000) demonstrate that soils having the same liquid limit but different plastic and shrinkage limits have a different compressibility. This can be explained by the fact that the liquid limit cannot be fully representative of plasticity characteristics, which are very important to determine the compressibility of soil. From this these authors have developed equations based on the shrinkage and plasticity indices. In particular the shrinkage index, defined as the difference between the shrinkage limit and the liquid limit ($SI=SL-LL$), thus containing the extreme values of Atterberg limits of a particular soil, seems to be the index that is best correlated with the compression index C_c .

Another parameter generally used to define the compressibility of a soil is the initial void index (e_0). The value of this index is that it takes into account the structure that the soil has assumed during the course of its geological history. For this reason the value of e_0 can be very useful in defining the behaviour of undisturbed samples, for which the compressibility characteristics depend not only on the intrinsic properties of the soil but also on their initial conditions. It is clear, therefore, that in order to define

completely and exhaustively the behaviour of an undisturbed sample it is necessary to include equations based on more than one parameter, in order to take into account both the initial state and the type of soil analysed.

Equations that use multiple regressions provide a more accurate estimate of the compression index, in particular those based on values of e_0 and LL. It is important to remember that in this kind of regression, in order not to lose the physical significance of the mathematical operation, the variables considered must be absolutely independent of each other (Li and White 1993; Cherubini and Giasi 2000). Therefore the equations that, for example, contain both e_0 and w_n (which for saturated soils are correlated through the equation $e_0 = w_n \times G$) are not significant.

In this paper some of the equations reported in Table 1 are analysed and reference is made to those developed by Skempton (1944), Terzaghi and Peck (1967) and Sridharan and Nagaraj (2000). The equations of Cozzolino (1961), Azzouz et al. (1976) and Carrier (1985) are reviewed and reported in the text of Balasubramaniam and Brenner (1981), while the equations of JSSMFE (1966), Ogawa and Ogawa (1978), Bowles (1979) and Abdrabbo and Mahmoud (1990) are reported in Tsuchida et al. (2000).

Particular attention has been paid to the equations of Sridharan and Nagaraj (2000) as they have been developed from a given set of data but making reference to various characteristic properties of the soil. For this reason it is considered that these equations indicate the parameter that is best correlated with the compressibility. It is obvious, however, that it is necessary to compare the results obtained using other equations.

Data used in the equations

Given the aim of the present paper, data to analyse were chosen in order to include samples with a wide range of index properties (Table 2). The data relative to the first ten soils have been taken from Sridharan and Nagaraj (2000). These are characterised by a liquid limit that varies within a fairly restricted range (40–70%) and by a shrinkage index between 10 and 60%. In addition, the data for the Italian Blue Clays and Varicoloured Clays were considered (Belviso et al. 1977a, 1977b, 1977c, 1977d; Cherubini et al. 1980)—a total of 36 samples (Table 2). These data were chosen because the Blue Clays and Varicoloured Clays had been the subject of in-depth studies which involved a detailed characterisation, and in particular because the Varicoloured Clays show considerable mineralogical variability.

The samples in Table 2 are therefore characterised by a wide range of index properties: liquid limits between 40 and 120%, plasticity indices between 10 and 85% and shrinkage indices between 10 and 110%. Plotting all the samples on the Casagrande chart (Fig. 1), it can be observed that the studied clays cover all the fields with the exception of inorganic silts and low-compressibility clays. A confirmation of the wide variability of the data analysed

can be seen from the histograms in Figs. 2, 3 and 4 which include all 46 samples. As regards the methodology used to obtain the index properties and the compression index of the Blue and Varicoloured Clays, it should be emphasised that the laboratory tests were carried out following ASTM standards (American Society for Testing and Materials 1979).

Varicoloured Clays

The Varicoloured Clays belong to the complex that Ogniben (1969, 1985) refers to as “Sicilide” due to the well-exposed sequence in Sicily. The Sicilide units consist of grey clay successions with green and red intercalations (Cocco 1973; Cocco and Pescatore 1975) which contain different lithological elements (marly limestones, siliciferic limestones, sandstones, etc.) and are always found to be tectonised where they occur in outcrops in Campania, Molise, Basilicata, along the Ionic belt of Calabria and south-east Puglia. They are commonly affected by landsliding, even on very gentle slopes.

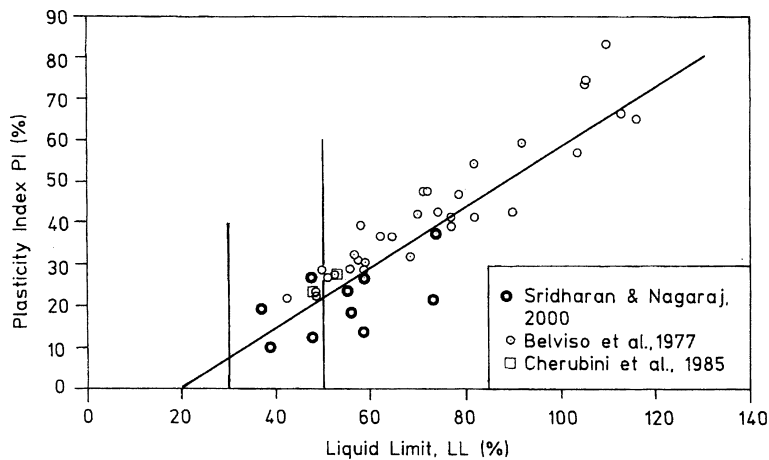
The mechanical behaviour of these clays is highly dependent on their structure. As a consequence of tectonic deformation, they typically have a fine network of discontinuities separating small fragments with a high consistency. These materials comprise aggregates of particles strongly cemented by diagenetic processes and characterised by smooth shiny surfaces. In the zone in which the tectonic deformations have been more intense, the clay material has a scaly structure and consists mainly of “splinters” varying in dimension from a millimetre to a centimetre. They are often shiny and smooth, rhombohedral in form and generally with an ordered aspect and a preferential direction. Often within the clay matrix there is an enclosed fraction consisting of stony pieces or even the disarticulated remains of thick beds or relicts of contorted stones and polygenic fragments with sharp edges (D’Argenio et al. 1973).

The Varicoloured Clays have unusual characteristics and are highly variable, making both in-situ and laboratory investigations difficult. Further details on their geomechanical behaviour can be found in the paper of Picarelli et al. (2000). With regard to their mineralogical composition, the data relative to samples taken along the external belt of the south Apennines show some variability. The overall results of the mineralogical analysis indicate the presence of typical minerals including montmorillonite, kaolinite, illite, chlorite, vermiculite, interstratified illite/smectite and to a lesser extent illite/vermiculite and illite/chlorite. Other minerals occasionally present are quartz, calcite, dolomite, feldspars, iron oxides and hydroxides. The values found for montmorillonite ranged between 0 and 90% with an average value of 25% and for kaolinite between 0 and 70% with an average of 26%. For illite there is less variability, with values of between 5 and 20% and an average value of 12%. The percentages of vermiculite, chlorite, smectite and the other materials cited above are not particularly relevant (Belviso et al. 1977a).

Table 2

Data relative to samples used in this paper. The first ten correspond to the samples analysed by Sridharan and Nagaraj (2000). Samples 11 and 12 belong to the Blue Clay formation and the remaining 34 belong to Varicoloured Clays

Sample no.	G _s	LL (%)	PI (%)	SI (%)	C _{meas}	C.F. (%)	ACT	e _L
1	2.70	37.0	19.0	22.3	0.23	26.0	1.42	1.00
2	2.65	39.0	9.5	11.6	0.20	5.0	7.80	1.03
3	2.65	48.0	12.4	9.0	0.24	9.5	5.05	1.27
4	2.70	48.0	26.7	32.9	0.40	35.0	1.37	1.30
5	2.64	55.0	23.6	21.9	0.30	32.0	1.72	1.45
6	2.61	56.4	18.3	35.4	0.37	17.5	3.22	1.47
7	2.66	58.5	26.4	45.0	0.43	35.0	1.67	1.56
8	2.65	58.7	13.5	12.3	0.25	11.5	5.10	1.56
9	2.58	73.4	21.5	34.4	0.42	27.5	2.67	1.89
10	2.70	73.5	37.9	61.6	0.62	51.5	1.43	1.98
11	2.72	53.0	27.4	38.7	0.39	43.0	0.66	1.44
12	2.70	47.8	23.2	32.3	0.36	34.0	0.68	1.29
13		105.4	73.5	94.0	0.59	46.0	1.84	
14		72.0	47.7	59.0	0.47	50.0	1.06	
15		103.7	57.3	88.0	1.01	58.0	1.09	
16		113.0	66.8	107.7	1.02	53.0	1.39	
17		116.5	65.3	105.3	0.92	59.0	1.21	
18		68.5	32.2	57.0	0.78	41.0	0.73	
19		74.4	42.7	60.4	0.65	35.0	1.42	
20		57.4	31.2	45.2	0.46	54.0	0.64	
21		56.9	31.0	41.4	0.49	34.0	1.07	
22		77.4	39.5	69.9	0.64	44.0	1.01	
23		52.5	27.0	40.0	0.43	54.0	0.55	
24		71.4	47.6	60.7	0.74	69.0	0.74	
25		62.0	36.8	51.8	0.57	50.0	0.82	
26		58.2	39.5	47.2	0.44	53.0	0.82	
27		78.8	47.0	71.0	0.67	39.0	1.38	
28		42.4	21.6	27.1	0.27	40.0	0.62	
29		64.7	37.0	53.1	0.53	48.0	0.86	
30		52.0	27.5	40.5	0.39	44.0	0.71	
31		90.0	42.5	79.0	0.84	50.0	1.01	
32		59.1	29.1	48.7	0.50	54.0	0.59	
33		77.0	41.2	67.2	0.75	58.0	0.78	
34		51.3	26.4	39.3	0.42	48.0	0.61	
35		69.9	42.1	58.6	0.59	58.0	0.79	
36		105.7	74.8	97.7	0.91	73.0	1.10	
37		55.6	28.6	46.6	0.45	50.0	0.64	
38		48.5	22.7	30.5	0.32	66.0	0.37	
39		57.0	31.9	46.5	0.43	60.0	0.58	
40		58.5	30.8	46.8	0.48	47.0	0.73	
41		109.8	83.7	99.0	1.31	73.0	1.23	
42		82.0	41.3	70.4	0.63	58.0	0.78	
43		49.7	28.5	35.2	0.35	58.0	0.54	
44		82.0	54.4	72.3	0.44	48.0	1.27	
45		57.5	31.0	47.6	0.43	42.0	0.83	
46		48.6	23.4	37.8	0.46	49.0	0.63	

**Fig. 1**
Casagrande chart

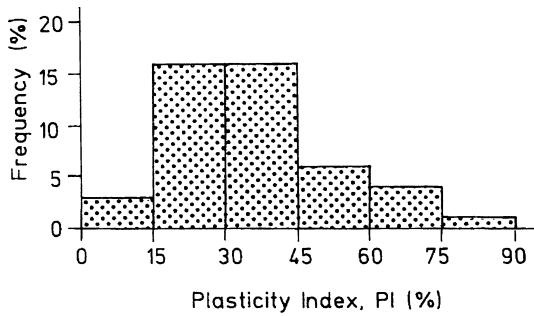


Fig. 2
Histograms of the plasticity index

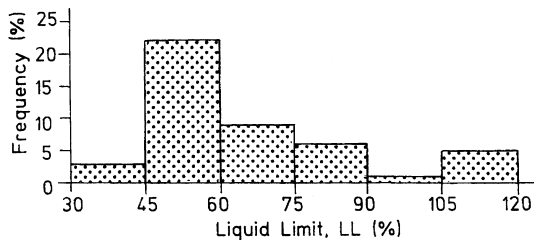


Fig. 3
Histograms of the liquid limit

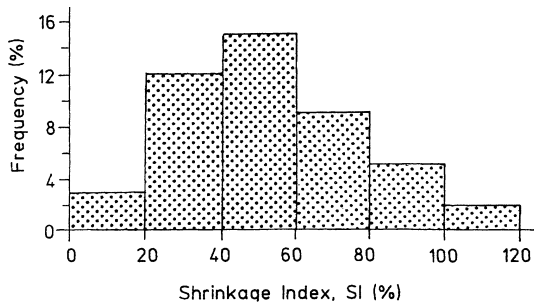


Fig. 4
Histograms of the shrinkage index

Blue Clays

The Blue Clays formation consists of silty clays and clayey silts which are blue-grey in colour but yellowish at the surface due to alteration. In general, the Blue Clays can be divided into two periods: the Inframeso-Pliocene and the second supra-Pliocene-Pleistocene (Del Prete and Valentini 1971). The clays that make up these deposits are known as the Sub-Apennine clays of the Postorogeno Complex (Ogniben 1969, 1985).

The Upper Pleistocene deposits are found widely in the Bradanic Foredeep where they are often covered by sandy conglomerate. The morphologies of the areas where the clays outcrop are very different. The Inframeso-Pliocenic clay hills have a gentle relief and the characteristic badlands found frequently on slopes of supra-Pliocene-Pleistocene age are rarely noted. This is due to the fact that the extensive fissuring present in the upper clays in the

southern area is less developed in the lower clays. It is also noted that the clays of the lower cycle are much less vulnerable to landslide phenomena, with the movements recorded being generally near the surface (translation slides). However, numerous intense morpho-evolutionary processes affect the upper cycle clays, both on slopes where regressive sequences are found outcropping at the summit and on slopes completely constituted of clay overlain by marine terrace deposits.

The mineralogical composition of the grey Blue Clays is characterised by the presence of quartz and feldspars together with other formless pale-yellow and grey aggregates, accompanied by inorganic and organic calcite of detrital origin with subordinate quartz and feldspars. The mineralogical data of the upper cycle clays are variable. The overall content of phyllosilicates varies from 29 to 71%, with average values around 53%. The quartz content varies from 11 to 36%, with an average value of 18%. Among the clay minerals, illite is prevalent, with values varying from 25 to 72% and an average value of 54%. The montmorillonite content varies from 8 to 56%, with an average of 36%, while the kaolinite content varies from 5 to 20%, with an average of 9%. The chlorite values are frequently negligible.

From the geotechnical point of view the clays of the upper cycle can be classified as silty clays of medium to high plasticity, overconsolidated and often fissured (Valentini et al. 1979; Cherubini et al. 1980).

Validation methods for the equations examined

The evaluation of the compression index, as with other geotechnical parameters, is affected by a series of uncertainties which can be grouped as follows:

1. Uncertainties connected with the variability of the properties of a soil, including both the natural variability of the properties considered and measurement errors.
2. Uncertainties due to the limited number of samples examined.
3. Uncertainties connected with the calculation methods used.

Whilst the first source of uncertainty can be reduced by carrying out tests correctly and the second by sufficient sampling, the third involves an indirect evaluation of C_c . This can be checked by an adequate comparison of calculated and measured values using the ratio:

$$K = \frac{C_{c,calc}}{C_{c,meas}}$$

Using a statistically significant number of samples, this ratio assumes, for each calculation method considered, the characteristics of a random variable extracted from a population of possible values of K . In order to compare different calculation methods it is necessary to statistically analyse the values of K obtained for each method and thus identify and calculate statistical parameters which can

provide an evaluation of the capability of the method analysed to “fit” the experimental results.

The accuracy of a calculation method can be associated with a central value of the set of data available (for example the mean or trimean), while the precision can be obtained by evaluating a dispersion index (standard deviation or interquartile range). It is also possible to express an overall judgement on the quality of a calculation method using two indices that take into consideration the mean value and the standard deviation of all the K data.

The first, known as the ranking index, is formulated as follows (Briaud and Tucker 1988):

$$RI = \mu \left| \ln \left(\frac{c_{c_{calc}}}{c_{c_{meas}}} \right) \right| + s \left| \ln \left(\frac{c_{c_{calc}}}{c_{c_{meas}}} \right) \right|$$

The second, known as the ranking distance, assumes the following form (Cherubini and Orr 2000):

$$RD = \sqrt{\left[1 - \mu \left(\frac{c_{c_{calc}}}{c_{c_{meas}}} \right) \right]^2 + s^2 \left(\frac{c_{c_{calc}}}{c_{c_{meas}}} \right)^2}$$

where μ and s represent the mean and standard deviation of the series of analysed data respectively.

Considering a graph with mean (μ) values on the x axis and standard deviation (s) on the y axis, RD expresses the distance of the point representing a particular calculation method from the point expressing the optimum situation ($\mu=1$ and $s=0$). For this reason the value of RD is kept constant along the semi-circumference, having its centre at the optimum point. The value of RI, having a logarithmic form, assumes a significance slightly different from that of RD.

In their recent paper, Cherubini and Orr (2000) show how RD and RI provide a different evaluation of the capability of a given equation to fit a measured value. By carrying out some simple simulations it is possible to note that RD gives a better result than RI for methods, where the precision and accuracy are similar, while for those that are either very accurate or very precise, RI gives the best result. So although the RD index appears to be the most rational way to compare the calculation methods, in view of the different significance that the two parameters assume, it can be useful to compare the results obtained using both.

Results

As stated above, this paper develops a comparison between the different equations used for the calculation of the compression index C_c , with the aim of quantifying the uncertainty connected with the calculation methods used in the evaluation of this parameter and identifying, if possible, the parameter that best correlates with the compression index of a soil.

The procedure followed for the comparison of the different calculation methods considered is based on the concepts and parameters reported above. The values of the ratio $K = \frac{c_{c_{calc}}}{c_{c_{meas}}}$ have been calculated for each of the 46 data (Table 2) and the eight methods considered. The values of K are treated statistically in order to evaluate the accuracy and precision of the calculation methods analysed. In particular, the accuracy is evaluated by making reference to the mean value of K , while the precision is evaluated using the standard deviation. The values of the mean and standard deviation, together with those relative to the RI (ranking index) and RD (ranking distance) and to the percentage of K values less than 1, are reported in Table 3 and Figs. 5 and 6.

It can be seen from Table 3 that the equations of Skempton (1944), Cozzolino (1961), Azzouz et al. (1976) and Sridharan and Nagaraj (2000) significantly underestimate the value of the compression index, as they indicate in excess of 80% of the K values to be less than 1 and mean values of K between 0.52 and 0.86. It is important to note that all these equations are based on the values of the liquid limits of the soils. Using the equations of Carrier (1985) and Sridharan and Nagaraj (2000) based on the plasticity index, the percentages of K less than 1 fall to 15 and 45% respectively, showing a notable overestimate on the part of the Carrier equation, which also gives a mean value of K close to 1.3. The equation of Terzaghi and Peck (1967) based on the liquid limit and that of Sridharan and Nagaraj (2000) based on the shrinkage index indicate 65% of the K values to be equal to or less than 1 with mean values very close to 1. From these mean values it is possible to conclude that the most accurate equations are the latter, together with that of Sridharan and Nagaraj (2000) based on the plasticity index. The best result is obtained using the equation of Terzaghi and Peck (1967) which gives a mean value equal to 1.007.

Table 3

Results of the statistical analysis

Authors	Percentage of $K < 1$		RD		RI		
Sridharan and Nagaraj (2000) (SI)	65.22	0.954	0.153	0.160	0.237	0.126	0.110
Terzaghi and Peck (1967) (LL)	65.22	1.007	0.221	0.222	0.282	0.151	0.131
Sridharan and Nagaraj (2000) (LL)	82.61	0.860	0.188	0.235	0.350	0.236	0.114
Sridharan and Nagaraj (2000) (PI)	43.48	1.068	0.237	0.247	0.291	0.141	0.150
Skempton (1944) (LL)	84.78	0.783	0.172	0.277	0.442	0.300	0.142
Azzouz et al. (1976) (LL)	95.65	0.685	0.151	0.350	0.593	0.408	0.185
Carrier (1985) (PI, ACT)	15.22	1.290	0.334	0.443	0.471	0.290	0.181
Cozzolino (1961) (LL)	82.61	0.525	0.116	0.489	0.867	0.665	0.202

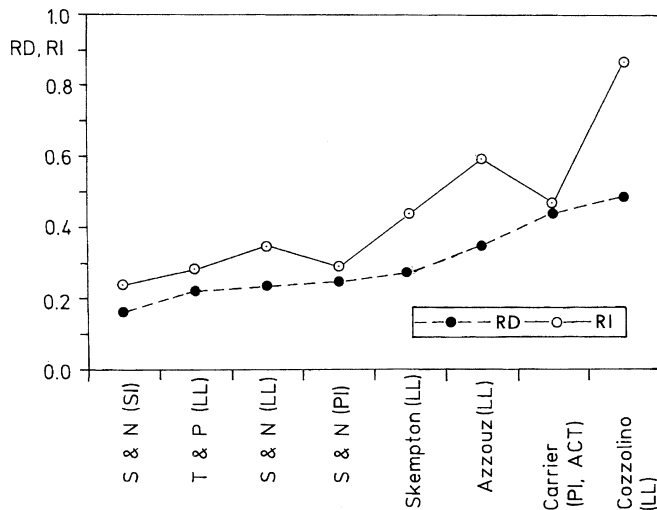


Fig. 5

Values of RD and RI calculated for the different measurement methods considered. References cited in the figure are Sridharan and Nagaraj (2000) (S & N); Terzaghi and Peck (1967) (T & P); Skempton (1944); Azzouz et al. (1976); Carrier (1985); and Cozzolino (1961)

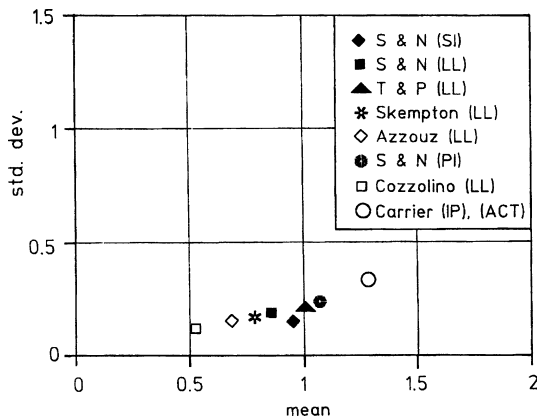


Fig. 6

Correlation of means and standard deviations. For detail of references cited, see Fig. 5

As regards the precision, the equation of Cozzolino (1961) offers the best result (0.116), even if it has limited accuracy. The worst result is given by the equation of Carrier ($s=0.337$), while all the other equations are characterised by a standard deviation value between 0.151 and 0.237. Considering the value of RD, the equation of Sridharan and Nagaraj based on the shrinkage index offers the best result (0.160), immediately followed by Terzaghi and Peck's which gives a value of 0.222. These two equations also give the best results for RI, due to the fact that they are both characterised by good accuracy. In fact, comparing the values of RD and RI (Fig. 5) for all the equations considered, it can be seen that a divergence between the two indices is only apparent for those equations with limited accuracy. This is due to the fact that RI, for reasons to be found in its mathematical form, attributes a greater weight to accuracy. As previously stated, RD seems to be

the most rational way to compare different calculation methods, but nevertheless comparing the two indices is useful when assessing the reliability of such equations to evaluate C_c . In the present case, the comparison between the two indices (Fig. 6) shows a notable divergence between the values of RI and RD for the equations of Skempton (1944), Cozzolino (1961) and Azzouz et al. (1976), highlighting the accuracy problems associated with these equations.

Conclusions

The presence in the literature of numerous equations linking the compression index of remoulded clays to index characteristics such as the liquid limit, plasticity index, etc. sometimes makes the choice of the most reliable equation very difficult. Based on a set of 46 samples with widely varying characteristics, mainly related to clays outcropping in the south of Italy, some equations that correlate C_c with easily determined index parameters have been analysed. The equation of Sridharan and Nagaraj (2000), which introduces the shrinkage index, proved to be the most efficient, followed by the classic Terzaghi and Peck (1967) equation which uses the liquid limit as the basic parameter. Clearly, this study cannot be considered exhaustive, being significant only for the data analysed and in particular for the numerous Varicoloured Clays samples. However, it is considered that the methodology proposed represents a good way of validating correlations between two different geotechnical characteristics.

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Appendix

List of symbols

μ :	mean
s :	standard deviation
RI:	ranking index
RD:	ranking distance
C_c :	compression index
$C_{c,calc}$:	calculated value of compression index
$C_{c,meas}$:	measured value of compression index
G:	specific gravity
w_n :	natural water content
e_0 :	initial void index
e_L :	void index corresponding to liquid limit
LL:	liquid limit
PI:	plasticity index
SI:	shrinkage index
PL:	plastic limit
ACT:	activity
C.F.:	clay fraction

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