

Compressibility of a 'Fat' Clay mixed with aggregates

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Abstract

'Fat' clayey soils, containing large proportion of fines (more than 50%) and mixture of aggregates are usually encountered as natural deposits in a high plasticity state. These soils may be used as row material after chemical or mechanical stabilization, in many earthworks applications. The clay content, the amount and size of aggregates, are known to affect the compressibility potential, and thus, the stiffness of the soil when subjected to vertical loads. In this investigation, a comprehensive oedometer testing program was conducted on reconstituted artificial samples, made of various mass proportions of kaolin, sand and gravel. The moisture content of the samples varied accordingly to the percentage of kaolin content in each series, but yielding samples of high plasticity, having the same Atterberg limits. The compressibility was characterized herein by the coefficient of volume compressibility (m_v). The results indicate that, for this type of soils, the compressibility is much more affected by the coarser matrix (ratio of the mass percentage of the gravel to the mass percentage of sand G/S) rather than the percentage of clay content. Based on the observations made, a chart is proposed for a quick estimation of the compressibility potential of fat clays.

Keywords: Aggregates; Compressibility; Fat clays; Kaolin; Plasticity

Introduction

Most natural soils are heterogeneous, made by a mixture of various particles components, but are usually characterized by the type of materials that is predominant. 'Fat' clayey soils containing large proportions of fines (more than 50%) and coarse aggregates, are usually encountered as natural deposits, and may be used after chemical or mechanical treatment in many earthworks applications, like for the stabilization of road shoulders, foundations for highways, unpaved roads, driveways, engineered backfill, cement-treated base, etc. Understanding the behavior of this particular type of clayey soils and quantitatively assess the effects of gradients on their mechanical behavior, remains an important issue in geotechnical engineering. Research has shown that the behaviour of soil mixtures can be significantly different from the behaviour of the individual components of the mixture, due to differences between the mechanical and chemical properties of the individual minerals, and their ensuing effects on inter-particles interactions [1]. By controlling the particle size distribution, the influence of grading on the behaviour of soils could be explored.

Nocilla [2] reported that as the clay content was reduced, the behaviour changed from a typical clay mode to a transitional form between that of clays and sands. Shiptona and Coop [3] explored the effects of mixing soils of different grain sizes, covering a wide range of grindings from clayey-silts to well-graded sands and gap-graded soils, they reported that, for such soils, it would be difficult to identify the effects of structure on the mechanics since there is no unique behaviour of the soil when reconstituted, oedometer tests performed indicated that relatively small changes to the nature or quantity of the constituent particles of a soil can change the behaviour quite dramatically. Yin and Miao [4] evaluating the impacts of soil structure on mechanical behavior for natural sedimentary clays based on oedometer tests, proposed a normalized compression line to evaluate the effects of soil structure quantitatively on the compressive behavior for natural clays mixture [5].

The work described in this paper present the results of conventional one-dimensional oedometer tests conducted on artificial (reconstituted) samples, made of fine particles (kaolin) mixed with different mass proportions coarse poorly graded aggregates (sand and gravel). Various mixing combinations were analyzed to simulate the behaviour of a large panel of fat clayey soils grading. Testing artificially reconstituted soils allows to better controlling the soil grading and

mineralogy, eliminating the complex effects that these might have on the mechanical behaviour of the soil, and it ensure the experimental repeatability.

Materials and Methods

Materials

Burland [6] stated that much modern soil mechanics has developed from the results of careful, comprehensive studies of the properties of remolded or reconstituted natural soils or artificial materials such as kaolinite or illite. Kaolin used in the present work, is made of clayey minerals dominated by the kaolinite, derived essentially from the alteration of Felds path alkaline and micas with a density of 2.62. Previous research has shown that the kaolin structure possesses great advantages in many processes due to its high chemical stability and low expansion coefficient [7,8]. The importance of kaolin is remarkable as one of the most abundant mineral in soils and sediments, its properties are such that it interacts with other soil elements and contribute to the mechanical stability of the soils [9,10]. The kaoline is also known to be the least reactive clay [11].

The sand used in this work is composed of granulated silica (of rotund shape), collected from a site near Tebessa (East of Algeria), the texture of this sand vary from coarse to very coarse and exhibit no cohesion. The grain sizes distribution of this sand is presented in Figure 1. This sand has less than 5% fine, the coefficient of uniformity $C_u = 2.5$ and the coefficient of curvature $C_c = 1.25$ and could be classified (Unified soil classification system USCS) as Sand poorly graded (SP).

The gravel used in the preparation of the samples is commercial gravel, made of crushed stones sized roughly between 5 and 8 mm. This coarse material has less than 5% fines and less than 2% of impurity content. The grains sizes distribution curve of this gravel is also shown

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in Figure 1. With values of $C_u = 1.25$ and $C_c = 1$, it could be classified (USCS) as Gravel poorly graded (GP).

Samples preparation

In order to simulate the behaviour of a large panel of 'fat' clayey soils gradations, four series of samples were prepared, corresponding to different proportions of kaolin content (50, 60, 70 and 80%). For each series, samples were made of different mass proportions of sand and gravel. The ratio G/S stand for the percentage of gravel used over the percentage of sand. Table 1 summarizes the combinations considered for the production of the 10 different samples investigated. The moisture content of the samples varied accordingly to the percentage of kaolin content in each series, but yielding samples of high plasticity, having the same Atterberg limits: $LL = 63.3\%$, $LP = 27.75\%$ and a plasticity index $IP = 35.55\%$.

The samples are prepared by a mechanical mixer at the desired

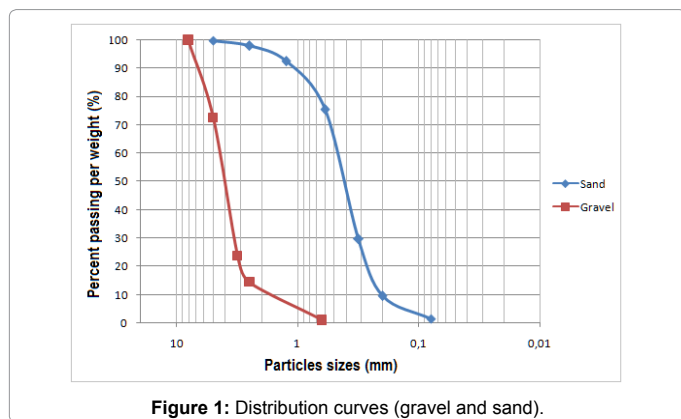


Figure 1: Distribution curves (gravel and sand).

Kaolin content (%)	Sand (%)	Gravel (%)	G/S	W (%)	(USCS) Classification
50	10	40	4	17.77	Gravelly CH
	20	30	1.5		Gravelly CH with sand
	30	20	0.66		Sandy CH with gravel
	40	10	0.25		Sandy CH
60	10	30	3	21.33	Gravelly CH
	20	20	1		CH with sand and gravel
	30	10	0.33		Sandy CH
70	10	20	2	24.88	CH with gravel
	20	10	0.5		CH with sand
80	10	10	1	28.44	CH with sand and gravel

Table 1: Samples gradations and classification.

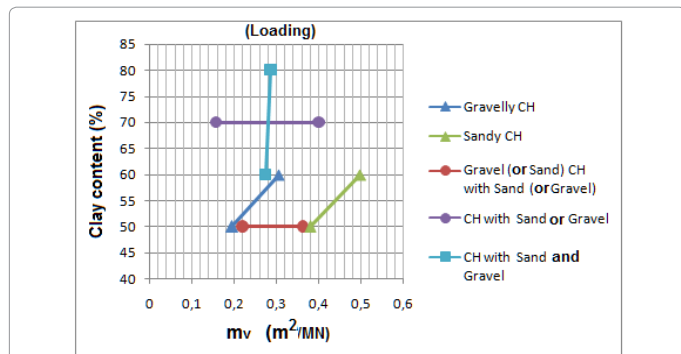


Figure 2: Variation of the average coefficient of compressibility m_v (loading stage).

Soil Groups	Clay content (%)	G/S	Average m_v Loading (m^2/MN)	Average m_v Unloading (m^2/MN)
Gravelly CH	50	4	0.1951	0.4906
	60	3	0.3042	0.7539
Gravelly (or Sandy) CH with Sand (or Gravel)	50	1.5	0.2196	0.6109
	50	0.66	0.3621	0.6921
Sandy CH	50	0.25	0.3787	0.6742
	60	0.33	0.4978	0.8062
CH with Sand (or Gravel)	70	2	0.1569	0.7250
	70	0.5	0.4007	0.7593
CH with Sand and Gravel	60	1	0.2737	0.6210
	80	1	0.2869	0.8015

Table 2: Classification of the samples into groups.

moisture content and then remolded manually in a compaction apparatus under the same weight applied to each layer. The molding procedure of the samples was the same and carried out under the same manual weight applied. Extreme care has been taken to obtain samples of high quality, to avoid as much possible, mechanical disturbances during extrusion from the mould, trimming, and mounting of the specimens into the oedometer cell.

Testing and results

Oedometer test

Standard oedometer tests were carried out for each series to investigate the compressibility of the considered samples. The one-dimensional coefficient of compressibility m_v was explored, defined as the ratio of volumetric strain over the changes in effective stress: $(\Delta \epsilon_v / \Delta \sigma_v)$, $\Delta \epsilon_{volumetric} = \Delta \epsilon_{vertical}$ (du to the boundary conditions of the oedometer). Since the compression and swelling of soils are non-linear m_v is not constant but depends on the current stress and it is not constant (Atkinson 2007). To better evaluate the general trend of the compressibility, the different samples considered were gathered into 5 groups, according to their USCS classification as illustrated in Table 2, where the averages values of m_v corresponding to each samples are also shown.

Figure 2 shows the variation of the average coefficient of compressibility m_v , for the loading stage, plotted against the percentages of clay content for each group of samples (Table 2). From this figure it is evident that for the Gravelly CH and the Sandy CH the compressibility coefficient increases with the percentage of clay content. For samples belonging to the following classes: Gravelly CH with sand, Sandy CH with gravel, CH with sand and CH with gravel, the compressibility seems to increase without increasing the percentage of clay content. For samples of CH with Sand and Gravel, the compressibility coefficient seems to be not affected by the percentage of clay content, as the compressibility remains almost constant with the increase of the clay content of the soil [12].

Figure 3 shows the variation of average coefficient of compressibility m_v , for the swelling (unloading) stage, plotted against the percentages of clay content for each group of samples. From this figure it could be stated that: for the Gravelly CH and the Sandy CH the compressibility coefficient increases with the percentage of clay content. For the samples of : Gravelly CH with sand, Sandy CH with gravel, CH with sand and CH with gravel, the compressibility seems slightly to increase without increasing the percentage of clay content. For samples of CH with Sand and Gravel, the compressibility coefficients increase with the percentage of clay content.

The compressibility of clayey soils could be categorized following the qualitative description of the values of the average loading coefficient of compressibility m_v shown in Table 3, proposed by Ghosh [13]. Table 4 presents the description of the different samples tested with the related qualitative description of their related compressibility.

Figure 4 shows the variation of the coefficient of compressibility plotted against the ratio G/S , from this figure it could be argued that, for fat clay with a proportion of G/S inferior to 1, the soil exhibit a high

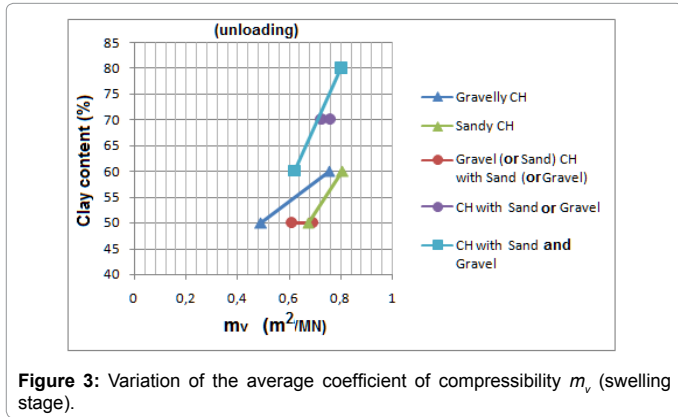


Figure 3: Variation of the average coefficient of compressibility m_v (swelling stage).

m_v (m ² /MN)	Qualitative description	Abbreviation	Typical soils
0.05-0.1	Low compressibility	LC	Boulder, clay and very stiff clay
0.1-0.3	Medium compressibility	MC	Normally consolidated clay
0.3-1.5	High compressibility	HC	Quick clay
Above 1.5	Very high compressibility	VHC	Very organic alluvial clays and peats

Table 3: Qualitative description of m_v for different type of clayey soils [13].

Soil Groups	Clay Content (%)	G/S	m_v (m ² /MN)	Compressibility
Gravelly CH	50	4	0.1951	MC
	60	3	0.3042	MC
Gravelly CH with Sand	50	1.5	0.21966	MC
Sandy CH with Gravel	50	0.66	0.3621	HC
Sandy CH	50	0.25	0.3787	HC
	60	0.33	0.4978	HC
CH with Gravel	70	2	0.1569	MC
CH with Sand	70	0.5	0.4007	HC
CH with Sand and Gravel	60	1	0.2737	MC
	80	1	0.2869	MC

Table 4: Compressibility description of the different samples.

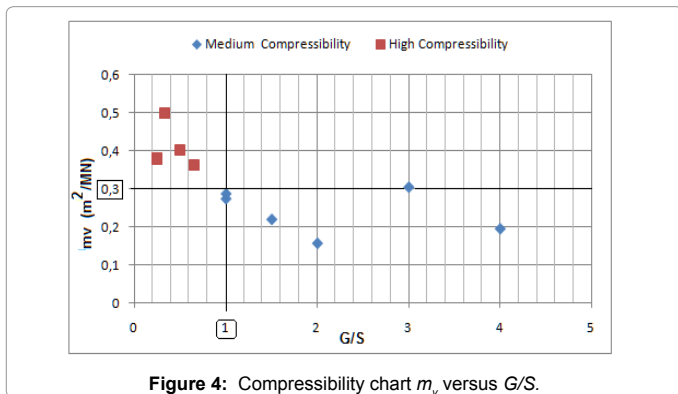


Figure 4: Compressibility chart m_v versus G/S .

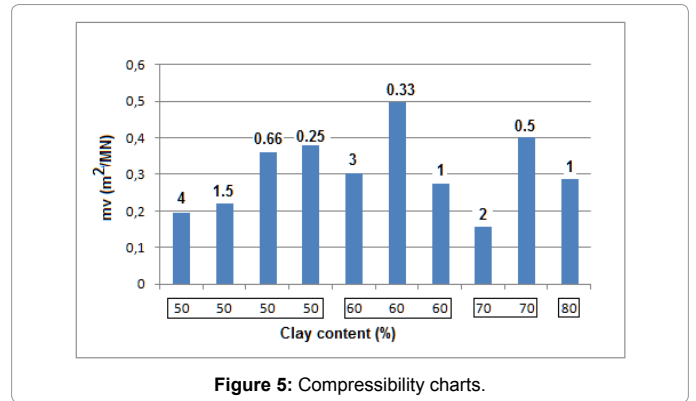


Figure 5: Compressibility charts.

compressibility, however, for fat soil with G/S superior to 1 the soil exhibits a medium compressibility.

In Figure 5 the computed average values of the coefficient of volume compressibility m_v are plotted against the corresponding sample percentage of clay content, the ratio of aggregate G/S is also indicated above the corresponding sample. From this figure it could be argued that, for high plasticity fat clays, the value of the coefficient of volume compressibility m_v is much more affected by the aggregate ratio G/S rather than the percentage of clay content. For the combination of the samples considered in the present investigation, the maximum value of the coefficient of volume compressibility m_v is obtained for the sample with 60% clay content and a ratio $G/S = 0,33$ (30% sand and 10% gravel), classified previously as Sandy CH (Table 1). The minimum value of the coefficient of volume compressibility m_v is obtained for the sample with 70% clay content and a ratio $G/S = 2$ (10% sand and 20% gravel), classified as CH with Gravel (Table 1). This indicates that for the case of fat clays (more than 50% clay content) the compression behaviour is controlled by the nature of the grain matrix composition rather than the percentage of clay content. Similar observation was reported by Lupogo [14], where a transitional level of fine content was defined (30%) above which the author reported that the compression behaviour of the soil is controlled by the grain matrix regardless the fines types.

This observation could be of relevance since the consolidation coefficient $C_v = (k / (m_v \cdot \gamma_w))$ is usually computed on the basis of the coefficient of volume compressibility m_v , the prediction of the compressibility of the high plasticity fat clay allows to better estimate its settlement and consolidation potential.

Conclusions

A comprehensive oedometer testing program was performed on reconstituted artificial samples, made of various mass proportions of kaolin, sand and gravel, to investigate the compressibility potential of 'fat' clays. The compressibility was characterized in this analysis by the coefficient of volume compressibility (m_v). In order to simulate the behaviour of a large panel of 'fat' clayey soils gradations, four series of samples were tested, corresponding to different proportions of kaolin content (50, 60, 70 and 80%), For each series, samples were made of different mass proportions of sand and gravel, consequently numerous ratios G/S were considered. The moisture content of the samples varied accordingly to the percentage of kaolin content in each series, but yielding samples of high plasticity, having the same Atterberg limits. The results indicates that, for this type of soils the compressibility is much more affected by the coarser matrix (ratio G/S) rather than the percentage of clay content, for the samples considered it was found that:

1. The highest compressibility (the lowest stiffness) was encountered with sample classified (USCS) as Sandy clays of high plasticity (Sandy CH), made of 60% of kaolin and having a ratio of $G/S=0.33$.

2. The lowest compressibility (highest stiffness) was obtained with sample of CH with gravel, having 70% clay content and a ratio $G/S = 2$. For fat clay with a proportion of G/S inferior to 1, the soil exhibit a high compressibility (low stiffness), however, for fat soil with G/S superior to 1 the soil exhibits a medium compressibility (medium stiffness).

Based on the observations made, a chart is proposed for a quick estimation of the compressibility potential of fat clays. Those observations could be of relevance since the consolidation coefficient C_v is usually computed on the basis of the coefficient of volume compressibility m_v , the prediction of the compressibility of the high plasticity fat clay allows to better estimate its settlement and consolidation potential.

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