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Anisotropy of consolidation parameters in artifically sedimented clays

B. R. Rankine
BEng (Civil)(Hons)
PhD Student, James Cook University, Australia

N. Sivakugan
PhD, Member ASCE, RPEQ Aust.
Senior Lecturer, James Cook University, Australia

T. Messer
BEng (Civil)(Hons)
Undergraduate Student, James Cook University, Australia

Summary: The stability of an earth structure on soft clay foundations is influenced by the stress-strain behaviour, drainage conditions and the associated failure mechanisms of the clay. The rapid increase of pore water pressure during construction, and the subsequent slow rate of pore pressure dissipation are often the main factors that dictate soft clay failure. Subsequently, ground improvement methods such as the use of prefabricated vertical drains (PVD) are becoming more popular for stabilisation of these soils. Calculations of soil behaviour commonly utilize the assumption of soil as an isotropic material regardless of the widely documented reality that soft clays exhibit significant anisotropy.

The consolidation and permeability characteristics of two artificial clays were investigated within this study through a series of oedometer tests. These tests were conducted on both horizontally and vertically cut specimens, and values for anisotropy detailed. Such results will be helpful in approximating the anisotropy present in natural soils of similar plasticity.

INTRODUCTION

The directional variation of properties displayed by cohesive soils is referred to as 'anisotropy' and is commonly documented as a ratio of a parameter in its horizontal and vertical directions'. It is widely documented in literature that clays not only exhibit this phenomenon significantly in their strength properties, but also in their compressibility and permeability parameters.

The consolidation parameters quantified in this paper are coefficient of consolidation (c), coefficient of volume compressibility (m), and permeability (k)[2]. The relationship between each parameter in terms of effective stress, σ' and anisotropy (horizontal / vertical) are defined for both clays below.

Coefficient of consolidation, c, is typically determined using time-settlement data obtained through standard oedometer testing, and applying a curve fitting method (normally either Casagrande or Taylor) for each load increment. Using Terzaghi's one-dimensional consolidation theory, c may be defined by equation (1):

$$c = \frac{T_{50} H_{dr}}{t_{50}} \qquad \ldots (1)$$

Here H_{dr} is the shortest drainage path length, T_{50} is the time factor at 50% consolidation (= 0.197), and t_{50} is the time taken to reach 50% consolidation.

Coefficient of volume compressibility, m, is commonly defined using:

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[1] *Anisotropy is defined in this paper as the ratio of the horizontal vertical values for the parameter under consideration The symbol for this ratio is R with subscripts describing the sample to which the ratio belongs*

[2] *Where parameters are referring to a specific sample, a subscript 'v' or 'h' will be used to denote the sample orientation to which the parameter refers i e vertical or horizontal respectively*

$$m = \frac{\Delta H}{\Delta p \times H} \qquad \ldots (2)$$

Where ΔH is the total height deformation between the beginning and end of consolidation for a load increment, H is the initial height of the sample, and Δp is the incremental pressure. .

Once incremental values for c and m are established, permeability is determined using equation 3, which expresses permeability as it relates to Terzaghi's consolidation theory:

$$c = \frac{k}{\gamma_w \times m} \qquad \ldots (3).$$

LABORATORY TESTING

Description of Soils

Soil	Liquid Limit, LL	Plastic Limit, PL	Plasticity Index, PI	Specific Gravity, Gs
Grundite	51	29	22	2.75
Kaolinite	63	36	27	2.65

Specimen Preparation

Each specimen was initially prepared by mixing the soil under consideration (i.e. grundite or kaolinite) with water to form a slurry. The water contents of these slurries ranged between approximately 1.5 and 3.6 times the liquid limit, and are detailed below in Table 2. This range of water contents was adopted to establish the effect of water contents both less than and greater than the 2.5LL considered by (Krizek and Sheeran (1970) to produce high quality artificial samples

Samples were k_0-consolidated[3] and then specimens cut from the consolidated block at two separate orientations to study the anisotropic variation of parameters in both the vertical and horizontal directions. This method is commonly employed by various other researchers for shear anisotropic studies, and was considered suitable for this study (Krishnamurthy et al., 1980, Sivakugan et al.,1993).

Seven specimens (5 vertical, 2 horizontal) were prepared for testing on each clay. The properties of each are presented in Table 2.

Experimental Program

Oedometer tests were conducted on all prepared samples to measure void ratio, and determine the coefficient of consolidation, coefficient of volume compressibility, and permeability in both the vertical and horizontal directions. A standard oedometer set-up of a fixed ring (63.5mm dia., 25.4mm height) subjected to double drainage was used. While working each of the prepared samples into the oedometer rings, care was taken to ensure minimal disturbance to the samples.

[3] K_0 consolidation of the samples was undertaken under additional loading. The loads applied to each of these samples ranged between 50 and 75 kPa.

Table 2. Chai cteristics of Artificial

Sample[4]	LI	w./LL	C.	C..
GV_1	2.09	1.47	0.343	0.075
GV_2	2.12	1.48	0.347	0.061
GV_3	3.69	2.16	0.393	0.077
GV_4	4.38	2.55	0.382	0.075
GV_5	7.18	3.67	0.397	0.073
GH_1	2.09	1.47	0.343	0.075
GH_2	2.12	1.48	0.347	0.061
KV_1	2.35	1.58	0.304	0.061
KV_2	2.53	1.66	0.186	0.032
KV_3	3.46	2.05	0.347	0.059
KV_4	3.74	2.17	0.342	0.053
KV_5	3.96	2.27	0.351	0.053
KH_1	2.35	1.58	0.304	0.061
KH2	2.53	1.66	0.186	0.032

CONSOLIDATION PARAMETER RESULTS AND ANALYSIS

Figures 1 – 6 represent the data obtained from consolidation tests on grundite and kaolinite clays as plots of anisotropic ratio values against effective stress, σ'. Conventionally, these ratios are determined by cutting both horizontal and vertical samples from the same consolidated block. However, due to limited data available with respect to the horizontal direction, an average of the horizontal results' for each clay was established, and individual vertical results divided by this value to find the anisotropic ratio in question.

Water content of the samples, as stated previously, ranged from approximately 1.5 to 3.6 times the liquid limit of the individual clay. This choice of water contents was adopted to establish the effect of water contents outside the water content of 2.5 recommended by Ktizek and Sheeran (1970). The results obtained within this study suggest that water contents above this value affect the values of anisotropy achieved, however, values lower than this value do not greatly affect the anisotropic value obtained.

The degree of permeability anisotropy, shown in Figures 1 and 2, was found to generally factor between approximately 0.2 and 1.8, and 0.5 and 1.6 for gmndite and kaolinite respectively. These results agree with experimental and theoretical results by Witt and Brauns (1983) that stated that the permeability anisotropy cannot exceed 2.5 for sedimentary soil. However, it is suggested that this factor for permeability anisotropy may be refined for clays and that it rarely exceeds a factor of 1.8.

When looking at the compressibility of clays, it is generally preferred to look at the anisotropy of C, and C, as they are less dependent of stress. By comparing the C, and C, values in Table 2, it can be seen that the compressibility of the clays in the vertical and horizontal direction was exactly the same (GV-1 vs. GH-1, GV-2 vs. GH-2, KV-1 vs. KH-1 and KV-2 vs. KH-2). This leads to the conclusion that the only anisotropic property observable is permeability. This hypothesis is further supported through the relatively constant anisotropic ratios observable in Figures 3 - 6.

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[4] Samples are symbolised by G or K initially to indicate clay type, 'V' or 'H' to indicate sample orientation, and then the sample number.

[5] The average of the horizontal results was simply calculated by summing the horizontal values, and then dividing by the number of values added. While it is noted by the authors that this is not the best procedure to use for horizontal averaging, the limited data obtained with respect to horizontal properties precluded the use of any other method.

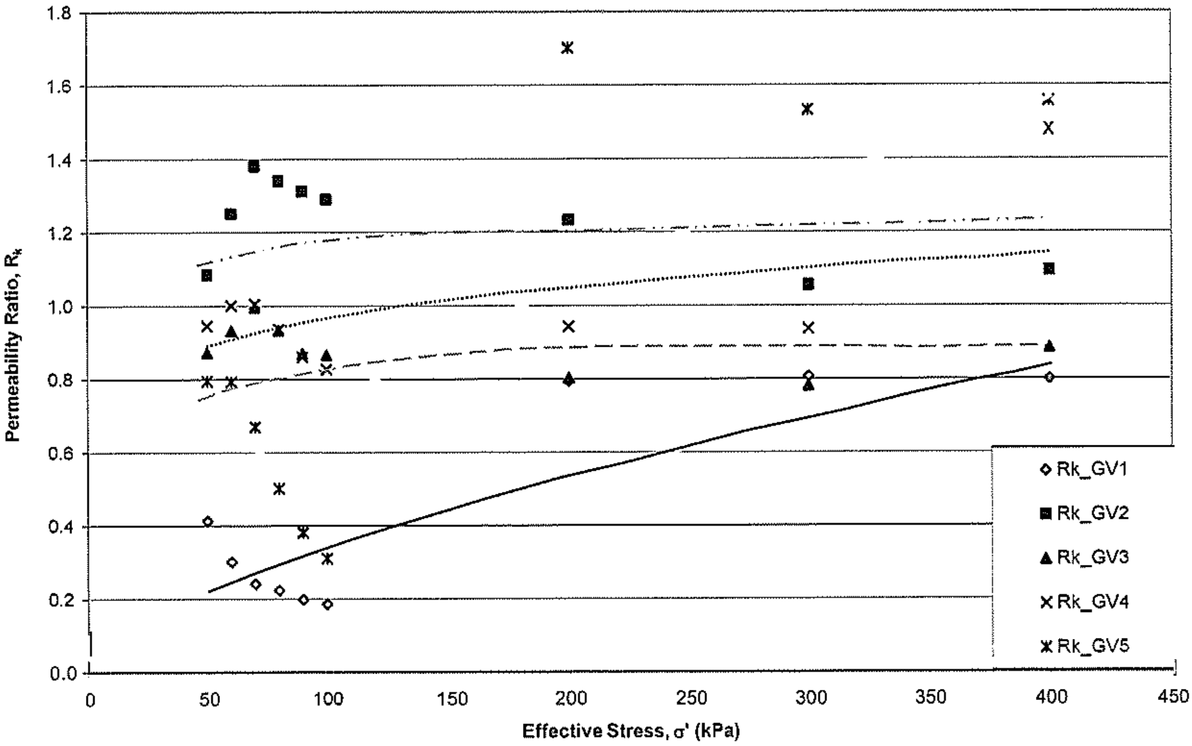

Figure 1. k_h/k_v Ratios (R_k) for Grundite Clay Specimens

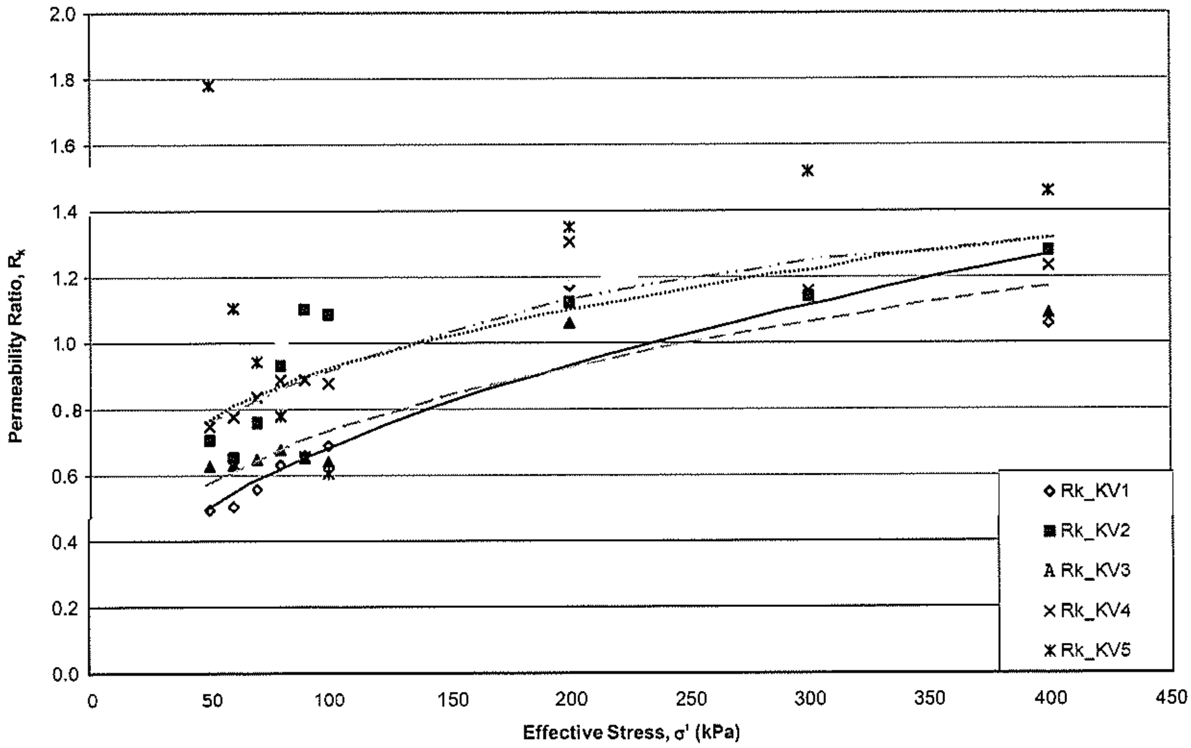

Figure 2. k_h/k_v Ratios (R_k) for Kaolinite Clay Specimens

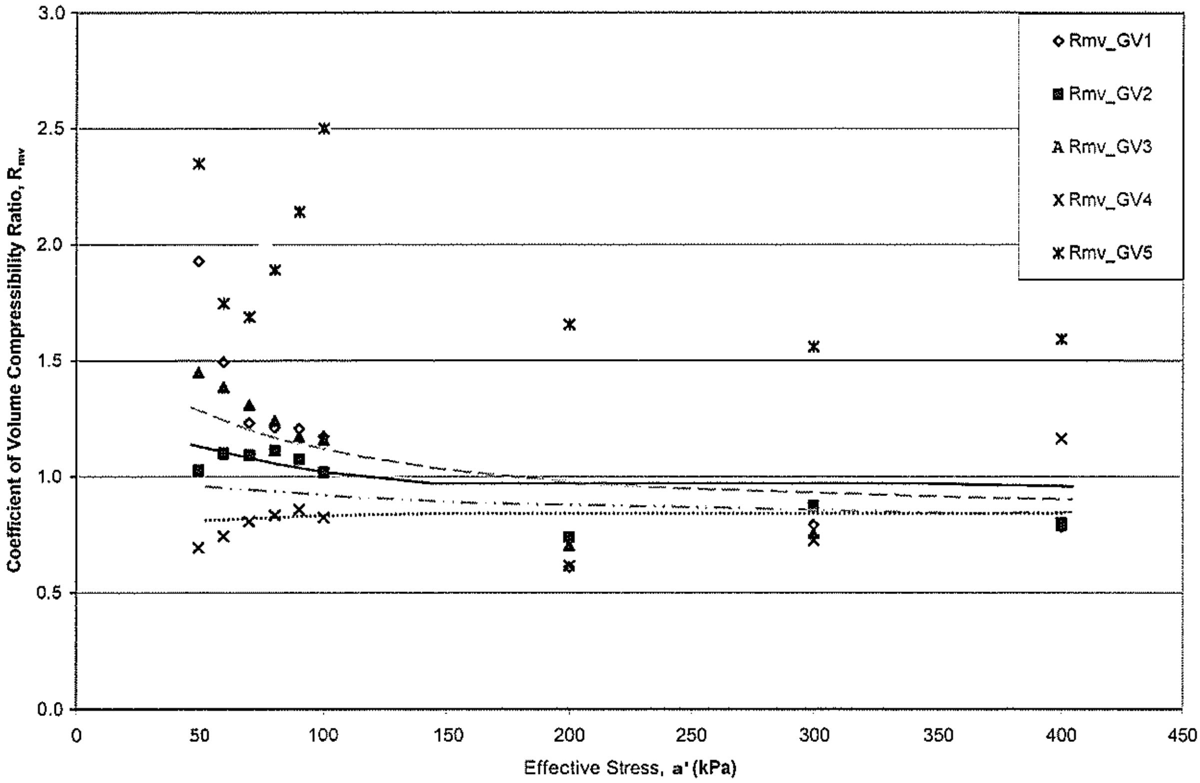

Figure 3. m_h/m_v Ratios (R_v) for Grundite Clay Specimens

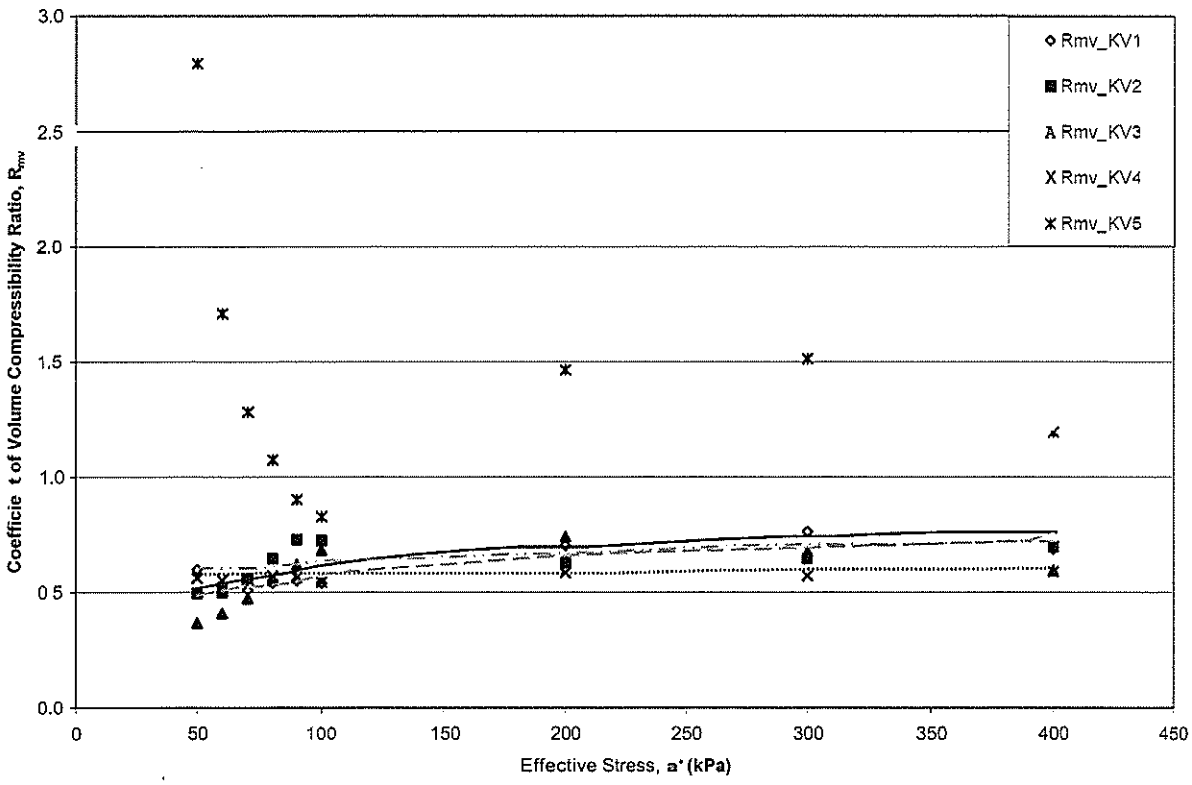

Figure 4. m_h/m_v Ratios (R_v) for Kaolinite Clay Specimens

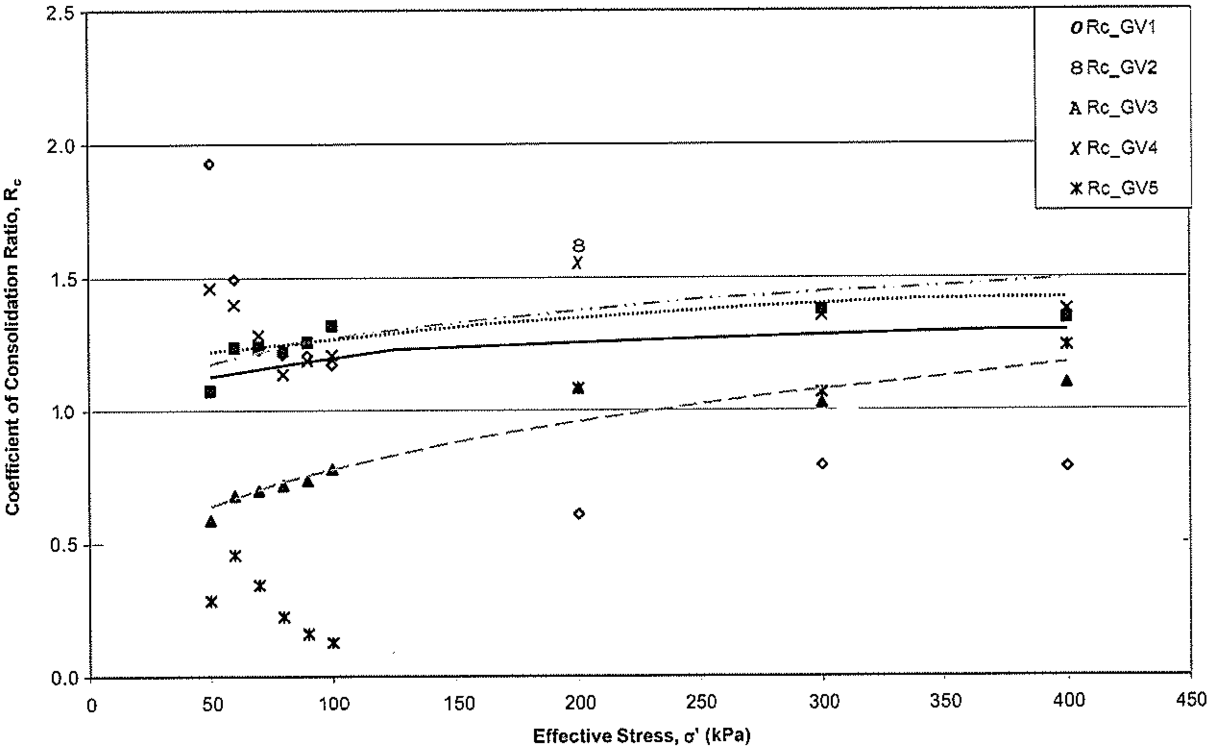

Figure 5. c_h/c_v Ratios (R_c) for Grundite Clay Specimens

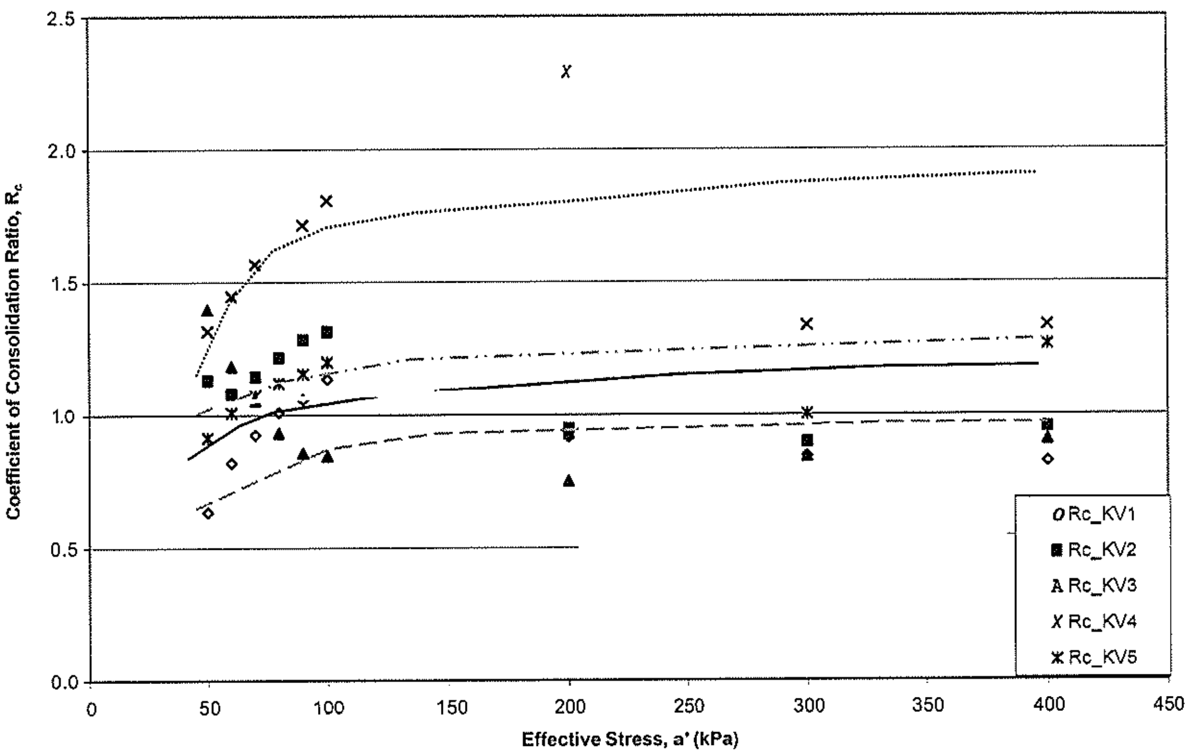

Figure 6. c_h/c_v Ratios (R_c) for Kaolinite Clay Specimens

CONCLUSIONS

A series of oedometer tests were conducted upon two different artificial clays to study the stress dependence of anisotropy with respect to consolidation and permeability characteristics. Tests were undertaken on both horizontally and vertically cut specimens, and values for anisotropy determined.

The results herein suggest that the only observable anisotropic property of clay is permeability. This conclusion is supported by examining the results detailed in Table 2 with regards to C_c and C_v. These results, along with the relatively constant anisotropic values observable in Figures 3 – 6, clearly show that the compressibility of clays are comparable, if not identical, in both the horizontal and vertical directions, and that any variation between the two is not significant.

Additionally, the anisotropic ratios of permeability, coefficient of volume compressibility and coefficient of consolidation can be less than 1, especially in the case of artificially sedimented clays.

It may also be concluded fiom the studies shown above, that water contents above the value of 2.5 times the liquid limit (Krizek and Sheeran, 1970) increase the anisotropic results obtained quite significantly, whereas, water contents lower than this value, do not have a notable affect on the anisotropic results obtained.

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