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Discussion of Transitional Behavior in Decomposed Granite-Kaolin Gap-graded Soils

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Abstract

In this research work, a series of one-dimensional compression tests (oedometer tests) was conducted to investigate the compression behavior of reconstituted gap-graded soils composed of kaolin and completely decomposed granite. Sieving analysis was performed to investigating the effect of the particle breakage on the transitional behavior. Stress paths are plotted in terms of void ratio against the vertical stress in semi-log graphs to examine the convergence of the compression behavior of the soils. The correlations of the initial void ratios at which the samples were prepared, the particle size of the coarse fractions as well as the percentages of clays in the mixtures with the relative breakage of the coarse particles are discussed.

Keywords

Gap-graded soils, oedometer tests, compression, particle breakage, transitional behavior, void ratio.

1. Background

A wide range of soils have been proved, by more recent research works, to be of transitional behavior in compression and shearing, including well graded clayey silts [1], well-graded sands[2] and gap-graded soils [3][4]. In the transitional behavior, non-convergence and no unique NCL can be seen in the compression curves and no unique CSL can be found in shearing. A schematic diagram, plotted by Nocilla et al. [5], is shown in Fig.1.

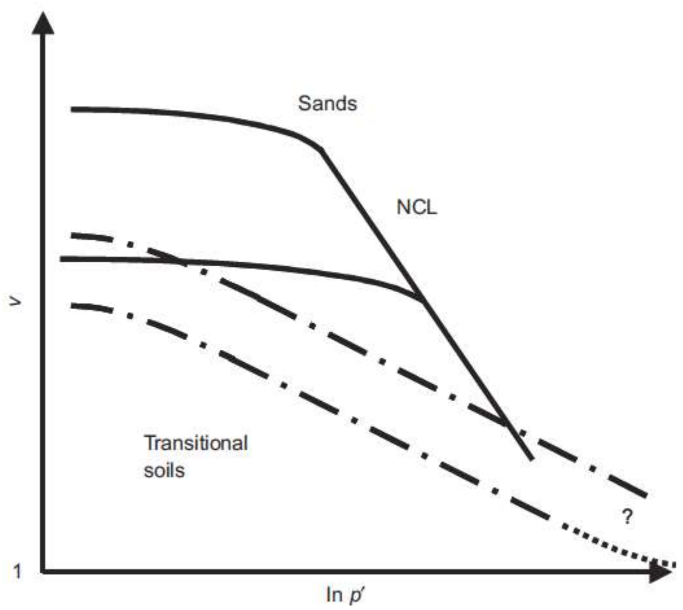

Fig. 1 Schematic diagram of the compression of sands and 'transitional' soils (Nocilla et al., 2006).

The mechanism of transitional soil behavior has not been studied thoroughly so that research in this mode of behavior may contribute significantly in the future to the design of excavation supports, foundations and other structures in geotechnical engineering. Oedometer tests and triaxial tests are the most frequently used methods to identify if there is any transitional behavior appearing in soils. In the research work presented in this dissertation, a series of oedometer tests was performed in which the specimens investigated are mixtures composed of coarse-grained fractions of completely decomposed granite with kaolin, due to the paucity of data in literature for this type of gap-graded mixtures. Previous works [3][4]have shown that the preparation method of specimens has a very small effect on the results. For this reason, all the specimens of this research work were created by one method which is the preparation as slurries (i.e., mixtures of soil with water so that the water content is higher than the liquid limit). This method is convenient to change the initial void ratio by using different initial water contents to see whether the compression curves were convergent or not, while adopting only one method to construct the samples would have no significant effect on the final conclusions and interpretations..

Compression of granular soils is normally accompanied by particle breakage, thus the research on the relationship between the breakage amount and the transitional behavior of the gap-graded soil mixtures is significant. The amount of breakage is commonly quantified by 'relative breakage' which was proposed by Hardin[6]. Relative breakage is dependent on some factors such as maximum vertical stress, size of coarse particles and the percentage of fine particles. After the oedometer tests, all the consolidated samples were put into sieves to obtain the evolving grading distributions and evaluate the relative breakage values. Some regular patterns were found by further analysis.

2. Materials Tested, Laboratory Equipment and Experimental Procedure

2.1. Introduction

This chapter is exclusively concerned with the materials tested, laboratory equipments used and the experimental methodologies and procedures. All the samples which composed of the mixtures of commercial kaolin and completely decomposed granites with two gradings were examined in one-dimensional compression (oedometer) tests. As there were two types of oedometer apparatuses in the Soil Mechanics and Geotechnical Laboratory of City University of Hong Kong, some differences between the experimental procedures of those two types oedometers are introduced. For oedometer tests the initial void ratio of each sample is important, so that the method of the calculation of initial void ratio are presented in the last sub-graph of this chapter.

2.2. Material Tested

All the soils tested in this research work are reconstituted samples of which the grading distribution and mineralogy of the soils can be controlled conveniently. Martins et al.[3] and Shipton and Coop[4]showed that preparation methods affect the results little in normal compression tests, so all the reconstituted samples were created as slurries. The initial void ratios of the samples can be adjusted by using different initial water content. In this research work, sand/clay mixtures were prepared in the laboratory and tested in conventional oedometer tests. The granular soil used as coarse-grained portion of the mixtures was completely decomposed granite while a commercial kaolin was used as clay portion of the mixtures. In order to make the research systematic, the percentage of kaolin, by dry weight, varied from 5% to 95%. Along with experiments conducted in this research work, additional data from oedometer tests performed in the Soil Mechanics and Geotechnical Laboratory of City

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University of Hong Kong were used for the analysis and interpretation of the experimental data, including mixtures with variable clay content as well as pure sand and pure kaolin.

2.2.1. Completely Decomposed Granite

The completely decomposed granite used in this research work is a standard soil tested in the Soil Mechanics and Geotechnical Laboratory of City University of Hong Kong of which the specific gravity equal to 2.63. The parent material before sieving into specific fractions is well-graded and the particular size of particles will be selected by sieving to create the artificial samples,. In this project, two kind of particle sizes i.e. 2.36-5.00 mm (CDG-1) and 0.3-1.18mm (CDG-2) were used. The photos and the grading curves of the decomposed granite are shown in Fig.2 to Fig. 5.

Fig. 2 Decomposed granite of 2.36-5.00 mm fraction

Fig. 3 Decomposed granite of 0.60-1.18mm fraction.

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Fig. 4 Decomposed granite of 0.3-0.6mm grading.

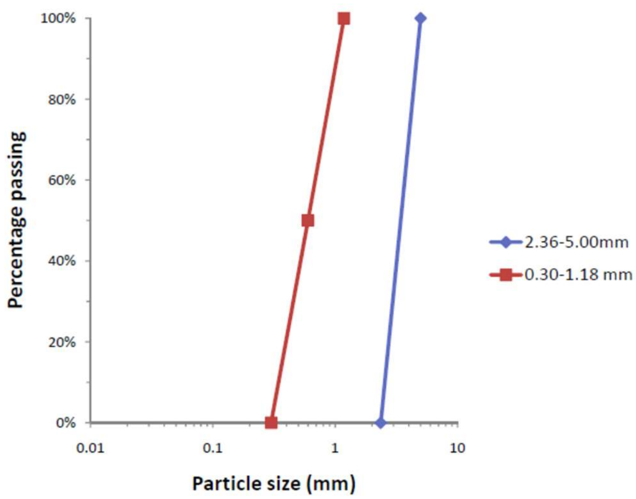

Fig. 5 Grading curves of decomposed granite tested.

2.2.2. Kaolin

The clayey soil used in this project is kaolin (Figure6) and the specific gravity is equal to 2.61. According to Atterberg limits tests performed on this material, the liquid limit (LL) is equal to 63%, the plastic limit (PL) is equal to 43% and the plasticity index (PI) is equal to 20%.

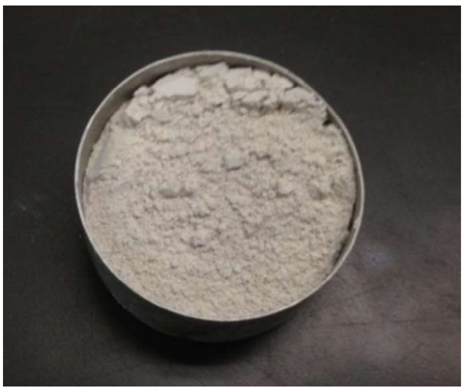

Fig. 6 Kaolin used in this research.

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2.2.3. Mixtures

Table 1. Information of the mixtures used in this research work

Test No.	Test Code	Soil	Initial water content	Comment
1	I-1	5% kaolin 95% CDG-1	15.50%	
2	I-2	5% kaolin 95% CDG-1	14.40%	
3	I-3	5% kaolin 95% CDG-1	17.30%	
4	I-4	35%kaolin 65% CDG-1	52.30%	
5	I-5	35%kaolin 65% CDG-1	36.90%	
6	I-6	35%kaolin 65% CDG-1	41.60%	
7	I-7	65% kaolin 35% CDG-1	57.70%	
8	I-8	65% kaolin 35% CDG-1	62.60%	
9	I-9	65% kaolin 35% CDG-1	66.40%	
10	I-10	65% kaolin 35% CDG-1	72.00%	
11	I-11	75% kaolin 25% CDG-1	87.70%	
12	I-13	75% kaolin 25% CDG-1	80.60%	
13	I-14	75% kaolin 25% CDG-1	53.70%	
14	I-15	85% kaolin 15% CDG-1	66.00%	
15	I-16	85% kaolin 15% CDG-1	58.70%	
16	I-17	85% kaolin 15% CDG-1	78.80%	
17	I-18	85% kaolin 15% CDG-1	90.20%	
18	I-19	95% kaolin 5% CDG-1	71.60%	
19	I-20	95% kaolin 5% CDG-1	81.50%	
20	I-21	95% kaolin 5% CDG-1	84.30%	
21	I-22	95% kaolin 5% CDG-1	90.40%	
22	II-1	100% CDG-2	17.70%	
23	II-2	100% CDG-2	19.60%	
24	II-3	25% kaolin 75% CDG-2	52.20%	
25	II-4	25% kaolin 75% CDG-2	55.80%	
26	II-5	25% kaolin 75% CDG-2	60.10%	
27	II-6	50% kaolin 50% CDG-2	70.90%	
28	II-7	50% kaolin 50% CDG-2	40.70%	
29	II-8	50% kaolin 50% CDG-2	50.50%	
30	II-9	50% kaolin 50% CDG-2	55.70%	
31	II-10	75% kaolin 25% CDG-2	70.60%	
32	II-11	75% kaolin 25% CDG-2	58.80%	
33	II-12	75% kaolin 25% CDG-2	75.90%	
34	E-4	25% kaolin 75% CDG-1	22.80%	From Chan, 2012
35	E-5	25% kaolin 75% CDG-1	26.60%	From Chan, 2012
36	E-6	25% kaolin 75% CDG-1	21.40%	From Chan, 2012
37	E-7	25% kaolin 75% CDG-1	23.70%	From Chan, 2012
38	E-12	50% kaolin 50% CDG-1	44.20%	From Chan, 2012
39	E-18	50% kaolin 50% CDG-1	42.20%	From Chan, 2012
40	E-19	50% kaolin 50% CDG-1	55.00%	From Chan, 2012
41	E-20	50% kaolin 50% CDG-1	56.30%	From Chan, 2012
42	R-4	100% kaolin	58.40%	From Chau, 2012
43	R-5	100% kaolin	72.20%	From Chau, 2012
44	R-7	100% kaolin	60.80%	From Chau, 2012
45	R-9	100% kaolin	100.00%	From Chau, 2012
46	R-11	100% kaolin	85.90%	From Chau, 2012

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In this research work, thirty-three oedometer tests were conducted and additional data of seventeen tests from final year project reports of two undergraduate student were used. All the samples were mixtures composed of kaolin with completely decomposed granite by different proportions. There were two gradings of the decomposed granite i.e. 2.36-5.00mm (CDG-1) and 0.30-1.18mm (CDG-2). The information of the mixtures including the mixtures from other reports are summarized in Table1.

2.3. Equipments

Fig.7 shows the typical section sketch of the oedometer cell. As introduced by Atkinson and Bransby[7] the sample is a circular plate of soil contained within a metal containing ring effectively prevents radial strain so that the state of strain in the sample is one-dimensional. there are two filter papers between the sample and the top cap and bottom base. As the containing ring is impermeable, thus pore water flows are one-dimensional as well. Water pressure in the drainage discs must remain zero whereas pore pressures of the sample may be varied. During a oedometer test the vertical stress can be changed in a stress-controlled manner by the weights on a hanger supported by the top cap. The magnitude of the vertical stress is calculated from the area of the top surface of the sample and the current vertical load times the length of the lever arm. The axial strain is measured through the settlement of the top cap by recording the reading number of a dial gauge.

Two types of oedometers were used in this research work; one was the front loading oedometer and the other one was the Bishop type oedometer. As shown in Fig.8, the main difference between these two types of oedometers is the design of the lever arm. For the front loading oedometer, the lever arm is in the front while the Bishop type oedometer is opposite. There were two kinds of oedometer cells used in the tests. The first one, as shown in Fig.9, is special designed for the conventional oedometer to prevent the slurry from overflowing out by setting up rubber gaskets on the base, the ring and the top cap. The second type is shown in Fig.10 and it is applied to the Bishop type oedometer. For both of the two types of cells, the oedometer rings are bottomless, thus the drainage rate is faster and the consolidation period can be shorter.

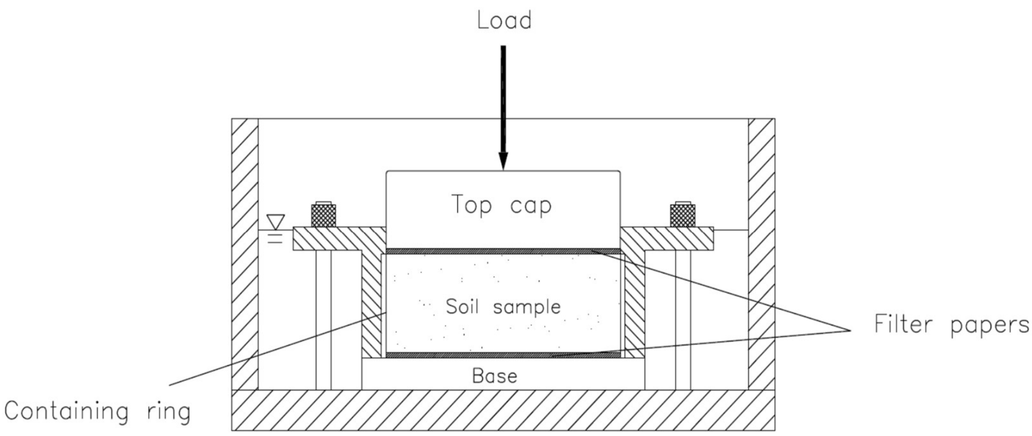

Fig. 7 Typical section sketch of the oedometer cell.

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(a)

(b)

Fig. 8 Two different types of oedometers: (a) Front loading oedometers; (b) Bishop type oedometers.

Fig. 9 Special designed oedometer cell (the diameter of the ring is 50.80mm).

Fig. 10 Oedometer cell for Bishop type oedometer (the diameter of the ring is 50mm).

2.4. Oedometer Tests

2.4.1. Sample Preparation

About 100g of dry mixture composed of sand and clay with a certain required proportion was prepared for one sample. In order to create the slurry samples, distilled water was added to the dry mixture of which the amount was dependent on the required initial water content and different initial void ratios can be created by adopting different initial water contents. All the slurries must be mixed evenly to make sure that the samples are uniform.

2.4.2. Test Procedure

After the sample preparation, the height, diameter and mass of the oedometer ring, as well as the mass of the top cap were measured. Two filter papers were cut to fit the size of the oedometer ring. A type of oedometer cell and top cap designed by Dr. Kostas Senetakis and Prof. Matthew Coop in order to test slurries of fine-grained materials with high accuracy were used for most of the slurry samples.

In order to make the measurement of the initial height of the samples accurate, a dummy sample was used. The dummy sample was a cylindrical metal disc which can fit into the containing ring. The height of the dummy sample was measured first and then the dummy sample was put into the containing ring with the two filter papers. After the top cap was put onto the dummy sample, the dial gauge reading was recorded. Then the dummy sample was taken out in order to prepare the samples. A moist filter paper was put on the base of the oedometer ring and the sample was placed inside the oedometer containing ring carefully to prevent trapped air which may affect the accuracy of the initial void ratio calculation. Slurry was added into the ring until the top surface was close to the top level of the ring and make the top surface of the sample was smooth by spatulas. In mixtures with very low clay content the initial water content was relatively low because of the "granular" nature of these samples and thus in these cases the reconstituted specimens were not slurries in reality. These samples were mostly tested in the Bishop type oedometer. During the preparation, this kind of samples were compacted lightly by a light weight hammer in order to make denser samples and the amount of distilled water mixed with the dry soil was reduced in order to compact the samples efficiently. A moist filter paper was put on the top of the sample making sure that no air was trapped between the filter paper and the sample.

For the conventional oedometer, the initial reading of the dial gauge was very important because the initial reading should be recorded before setting up the lever arm and the frame. Although overall vetical stress applied by the top cap to the sample is very low, of 1-2 kPa approximately, this stress is sufficient to consolidate the sample resulting in a small change of the specimen initial height. If the initial reading of the dial gauge is measured when the top cap was placed on the top surface of the sample, the record may not be accurate due to the start of the consolidation. So the top surface of the sample should be smooth enough assuming that the level of the sample is even to the top surface of the ring between the sample and the ring. After the top cap was placed onto the top of the sample, the initial reading should be recorded about half an hour later when the initial consolidation stopped and then set up the lever arm and the frame, another initial reading was recorded. With these two initial dial gauge record and the dial gauge reading of the dummy sample, the dial gauge record of initial sample can be back calculated. The procedure for the Bishop type oedometer was much simpler because of the different configuration. With the reading of the dummy sample and the assumption of the initial height of the sample, the initial gauge reading of the sample could be back calculated easily.

2.5. Sieving Analysis

By using a caliper, the final height of the sample was determined after the completion of the unloading stage. Then the samples were put into an oven at about 100°C for drying. After 3 or 4 days, the oven-dried specimens could be weighed to determine the final water content. Then the samples were washed with distilled water in a 0.063 mm sieve to eliminate the fine particles. After the samples were dried again, standard sieving analysis tests were conducted. Fig.11 shows a typical series of sieves used in this research work.

Fig. 11 A typical series of sieves used in this research.

2.6. Calculation of Initial Void Ratio

Shipton and Coop (2012) suggested four equations to calculate the initial void ratio (equations 1 to 4)[4]. These four equations used were chosen to be as independent of each other as possible. They were based on the initial water content, wi, the initial dry unit weight, γdi, the initial bulk unit weight, γi, and the final water content, wf.

$$e_{i1} = \frac{w_i \times G_s}{S_r} \tag{1}$$

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$$e_{i2} = \frac{\gamma_w \times G_s}{\gamma_{di}} - 1 \tag{2}$$

$$e_{i3} = \frac{G_s - S_r}{\gamma_i / \gamma_w - S_r} - 1 \tag{3}$$

$$e_{i4} = \frac{w_f \times G_s + 1}{1 - \varepsilon_v} - 1 \tag{4}$$

where
w_i = Initial water content
w_f = Final water content
γ_w = Unit weight of water
γ_i = Initial bulk unit weight
γ_{di} =Initial dry unit weight
ε_v = Volumetric strain
G_s = Specific gravity
S_r = Degree of saturation

In order to identify whether the compression behavior is convergent or not, the accuracy of the calculation of the initial void ratio, ei, is of major importance, ensuring that the locations of the compression paths in e:logσ'v space are accurate (as shown in Fig.12). This will determine whether it can be conclusively determined that the compression curves from different initial void ratios are convergent towards a unique NCL or not.

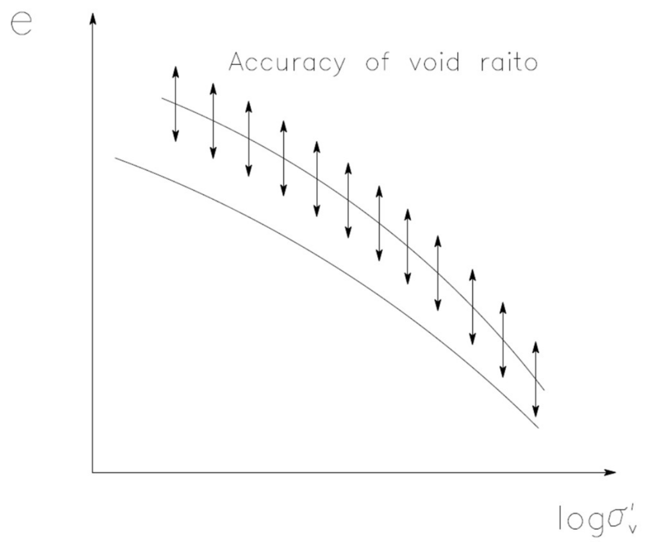

Fig. 12 Effect of the calculation accuracy on void ratio in e:logσ'v space.

3. Results and Discussion

In this chapter the experimental data and analysis-interpretations of the oedometer test results and the sieving analysis tests are thoroughly presented and discussed. As mentioned in the previous chapter, in this report a total number of fifty oedometer experiments are included. Thirty-three tests were performed during this project and seventeen tests were performed by Mr. Chan (Chan, 2012)[8], Mr. Chau[9] (Chau, 2012) during their final year projects of City University of Hong Kong.

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At first, some experiments on representative sample are presented in order to show the step-by-step analysis and determination of the average void ratio - vertical stress curve for each sample based on different methods for calculating the initial void ratio. Then, a thorough presentation of the experimental data in terms of accuracy of experiments, relative breakage, and the effects of clay content and preparation method (or initial water content and void ratio) are presented and discussed. Particular emphasis is given on whether there is observed a unique normal compression line for mixtures with variable clay content and on the possible correlation between relative breakage and transitional behavior in gap graded soils.

3.1. Example of Void Ratio - Vertical Stress Determination

As mentioned before, the initial void ratio of the sample for each test were calculated by four independent methods. Fig.13shows an example of the oedometer compression curves of different initial void ratios which is from test I-1. There is a large difference between e3 and the other three, thus the data of e3 will be rejected and then a average value of remaining values of initial void ratio will be taken to get the resulting curve for analysis. After getting the average results of all the tests, the compression curves for a certain type of mixture will be plotted together in e:logσ'v space to determine whether the soil is transitional or not.

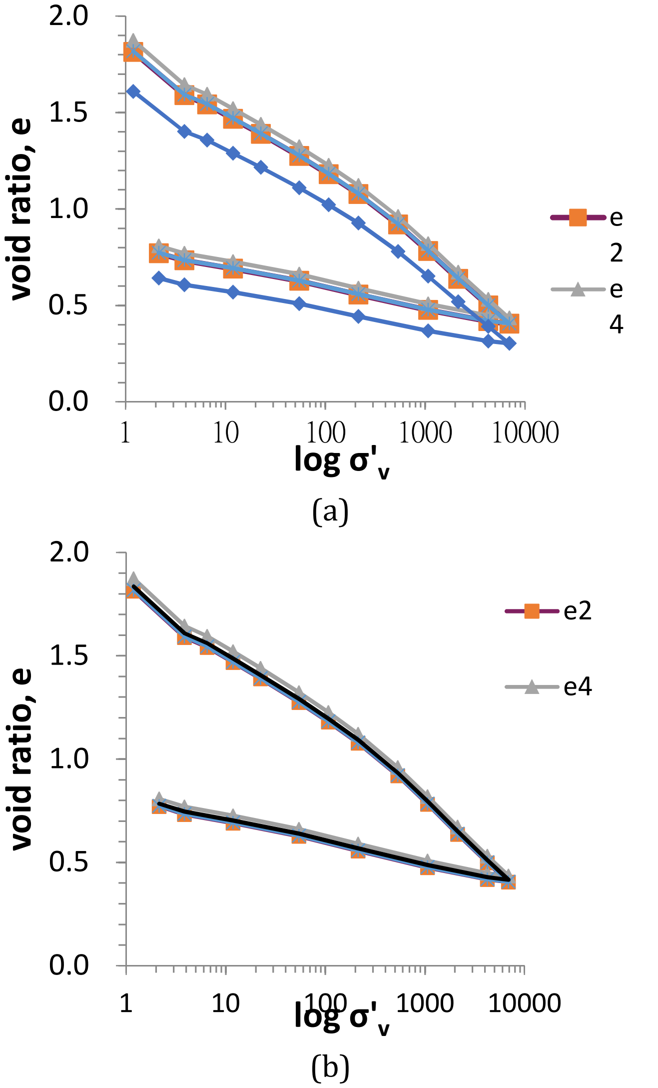

Fig. 13 An example of void ratio - vertical stress determination from test I-1: (a) compression curves of different initial void ratios calculated by four different methods; (b) average of the remaining three curves.

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3.2. Summary of Test Results

Details of the oedometer tests performed on two different soil mixtures are summarized in Table2 and Table3. In order to make this research work systematic and complete, some data which did not be published, from the final year project reports of Chan [8]and Chau[9] , were combined and summarized in Table 4.The initial void ratios of the samples e1, e2, e3 and e4 were calculated by four different methods, there were certain differences between the results of these four methods. So some data were rejected and changed into bold italics due to large error.

As shown in Table2, twenty-one tests were carried out on mixtures of completely decomposed granite and kaolin. The grading of the decomposed granite tested was 2.36-5.00 mm (CDG-1) and six kinds of clay content, i.e. 5%, 35%, 65%, 75%, 85% and 95% were used. The soils tested in the tests summarized in Table 4.2 were also mixtures of decomposed granite but the grading was 0.30-1.18 mm (CDG-2). In this group of test, only three kinds of clay content (25%, 50% and 75%) were applied.

Table 2. Summary of oedometer test results for mixtures of kaolin and decomposed granite (fraction 2.36-5.00mm, CDG-1).

Test code	Soil	Initial void ratio, e					Max. stress (MPa)	Estimated accuracy	Relative breakage
		e1	e2	e3	e4	Average			
I-1	5% kaolin 95% CDG-1	1.434	1.452	1.424	***1.387***	1.437	7	±0.015	25.88%
I-2	5% kaolin 95% CDG-1	1.615	1.614	1.550	***1.428***	1.593	7	±0.046	24.88%
I-3	5% kaolin 95% CDG-1	1.207	1.224	1.174	***1.094***	1.202	7	±0.027	25.06%
I-4	35% kaolin 65% CDG-1	1.368	1.351	***1.277***	1.363	1.361	7	±0.010	19.06%
I-5	35%kaolin 65% CDG-1	***0.967***	0.880	0.842	0.853	0.859	7	±0.022	16.41%
I-6	35%kaolin 65% CDG-1	1.089	1.035	***0.952***	1.032	1.052	7	±0.010	17.07%
I-7	65% kaolin 35% CDG-1	1.377	1.362	1.339	***1.432***	1.360	7	±0.020	12.65%
I-8	65% kaolin 35% CDG-1	1.739	1.738	1.712	1.728	1.729	7	±0.017	10.65%
I-9	65% kaolin 35% CDG-1	1.740	1.774	1.736	1.723	1.743	7	±0.021	12.48%
I-10	65% kaolin 35% CDG-1	1.965	1.984	***1.946***	1.999	1.982	7	±0.018	15.90%
I-11	75% kaolin 25% CDG-1	2.359	2.378	2.352	2.353	2.360	7	±0.017	14.77%
I-12	75% kaolin 25% CDG-1	2.108	2.067	***1.763***	2.086	2.087	7	±0.021	13.12%
I-13	75% kaolin 25% CDG-1	1.429	1.453	***1.405***	1.457	1.447	7	±0.017	10.83%
I-14	85% kaolin 15% CDG-1	1.609	1.575	1.525	***1.809***	1.569	7	±0.040	8.90%
I-15	85% kaolin 15% CDG-1	1.739	1.748	***1.621***	1.759	1.749	7	±0.010	7.88%
I-16	85% kaolin 15% CDG-1	2.089	2.095	2.106	***2.002***	2.097	7	±0.009	10.88%

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Table 2. Summary of oedometer test results for samples of kaolin and decomposed granite (fraction 2.36-5.00mm, CDG-1) (continued).

Test code	Soil	Initial void ratio, e					Max. stress (MPa)	Estimated accuracy	Relative breakage (%)
		e1	e2	e3	e4	average			
I-17	85% kaolin 15% CDG-1	2.359	2.353	2.339	***2.314***	2.350	7	±0.011	14.12%
I-18	95% kaolin 5% CDG-1	1.894	1.889	***1.680***	1.951	1.911	7	±0.040	4.83%
I-19	95% kaolin 5% CDG-1	2.175	2.160	2.131	***2.288***	2.155	7	±0.025	2.45%
I-20	95% kaolin 5% CDG-1	2.249	2.218	2.158	***2.383***	2.208	7	±0.050	8.84%
I-21	95% kaolin 5% CDG-1	2.527	2.514	2.488	***2.624***	2.510	7	±0.022	10.30%

*Values shown in bold italics are rejected due to large error

Table 3. Summary of oedometer test results for samples of kaolin and decomposed granite(fraction 0.30-1.18mm, CDG-2).

Test code	Soil	Initial void ratio, e					Max. stress (MPa)	Estimated accuracy	Relative breakage (%)
		e1	e2	e3	e4	average			
II-1	100% CDG-2	1.223	1.220	1.201	***1.155***	1.215	7	±0.014	17.91%
II-2	100% CDG-2	1.514	1.513	1.510	1.503	1.510	7	±0.007	18.14%
II-3	25% kaolin 75% CDG-2	1.119	1.121	1.123	***1.087***	1.121	7	±0.002	9.72%
II-4	25% kaolin 75% CDG-2	1.325	1.276	***1.190***	1.245	1.282	7	±0.043	11.12%
II-5	25% kaolin 75% CDG-2	1.502	1.503	1.504	1.493	1.500	7	±0.007	11.25%
II-6	50% kaolin 50% CDG-2	1.377	1.370	***1.297***	1.405	1.384	7	±0.021	7.20%
II-7	50% kaolin 50% CDG-2	1.483	1.494	1.460	***1.518***	1.479	7	±0.019	7.80%
II-8	50% kaolin 50% CDG-2	1.671	1.674	1.635	***1.817***	1.660	7	±0.025	10.16%
II-9	50% kaolin 50% CDG-2	1.902	1.911	1.896	1.908	1.904	7	±0.008	11.475%
II-10	75% kaolin 25% CDG-2	1.884	1.913	***1.850***	1.936	1.911	7	±0.027	8.77%
II-11	75% kaolin 25% CDG-2	1.549	1.540	***1.461***	1.581	1.557	7	±0.025	8.02%
II-12	75% kaolin 25% CDG-2	2.113	2.093	2.112	2.134	2.113	7	±0.020	8.82%

*Values shown in bold italics are rejected due to large error

Table 4. Summary of additional oedometer test results for samples of kaolin and decomposed granite (fraction 2.36-5.00mm, CDG-1) from other research works.

Test code	Soil	Initial void ratio, e	Max. stress (MPa)	Estimated accuracy	Relative breakage	Comment
E-4	25% kaolin 75% CDG-1	0.761	7	±0.032	17.10%	From Chan (2012)
E-5	25% kaolin 75% CDG-1	0.817	7	±0.021	17.90%	From Chan (2012)
E-6	25% kaolin 75% CDG-1	0.920	7	±0.033	18.00%	From Chan (2012)
E-7	25% kaolin 75% CDG-1	0.894	7	±0.014	20.20%	From Chan (2012)
E-12	50% kaolin 50% CDG-1	1.188	7	±0.027	11.0%	From Chan (2012)
E-18	50% kaolin 50% CDG-1	1.176	7	±0.001	13.0%	From Chan (2012)
E-19	50% kaolin 50% CDG-1	1.411	7	±0.032	14.5%	From Chan (2012)
E-20	50% kaolin 50% CDG-1	1.518	7	±0.016	14.6%	From Chan (2012)
R-4	100% kaolin	1.668	7	±0.044	\	From Chau (2012)
R-5	100% kaolin	2.065	7	±0.017	\	From Chau (2012)
R-7	100% kaolin	1.719	7	±0.092	\	From Chau (2012)
R-9	100% kaolin	2.770	7	±0.067	\	From Chau (2012)
R-11	100% kaolin	2.309	7	±0.053	\	From Chau (2012)

3.3. Analysis and Interpretation of Oedometer Test Results

3.3.1. Kaolin-Decomposed Granite (fraction 2.36-5.00mm) Mixtures

In this research work, five types of mixtures were created which had a coarse fraction of completely decomposed granite (fraction 2.36-5.00mm) and a fine fraction of kaolin while there were two other mixtures composed of same materials but different proportions of fine-grained soil studied by Chan (2012). The contents by dry weight of kaolin were 5% to 95% at intervals of 15% or 25% and the oedometer results of these mixtures are shown in Fig.14 to Fig.21respectively including the data from Chan (2012). For 75%, 85% and 95% clay content mixtures, the compression curves in Fig.19 to Fig.21 show clay type behaviors and convergence, indicating that the compression are not affected by the coarse fraction even the sand content is up to 25%. For percentages of clay higher or equal to 65% (Fig.17), the clay type compression behavior persists but the data are scattered and no unique normal compression line can be found. The coarse fraction is therefore starting to affect the compression behavior of the soils. However, when the sand content increases to 65%, the curves, as shown in Fig. 4.4, converge again but the type of compression behavior is similar to sandy soil though the knee points are not clear. Data for the 95% sand content mixtures are shown in Fig. 4.2, this type of soils show a typical sand behavior with distinct knee points while the compression curves converge. It seems that the behavior of the mixtures varies from clay to sand with increasing sand content. When the proportion of sand is up to 35% the mixture starts to show transitional behavior and the compression curves converge again at 65%. Additional data from Chan[8] are shown in Figs.

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4.3 and 4.5 in which the compression curves of 50% and 75% sand contents mixtures are plotted in e: logσ'$_v$ space. The data of 50% kaolin-50% sand mixtures do not converge and show transitional behavior clearly while the 75% sand content mixtures exhibit sand type behavior with a unique NCL and much more distinct knee points than those of 65% sand mixtures.

The data of reconstituted kaolin from the final year project report of Chau[9] are also included in this project for comparison and further interpretations (Figs.22).

For the clay, it was observed that a unique NCL could be identified which is an evidence of transitional behavior but further research might be needed to verify this trend.

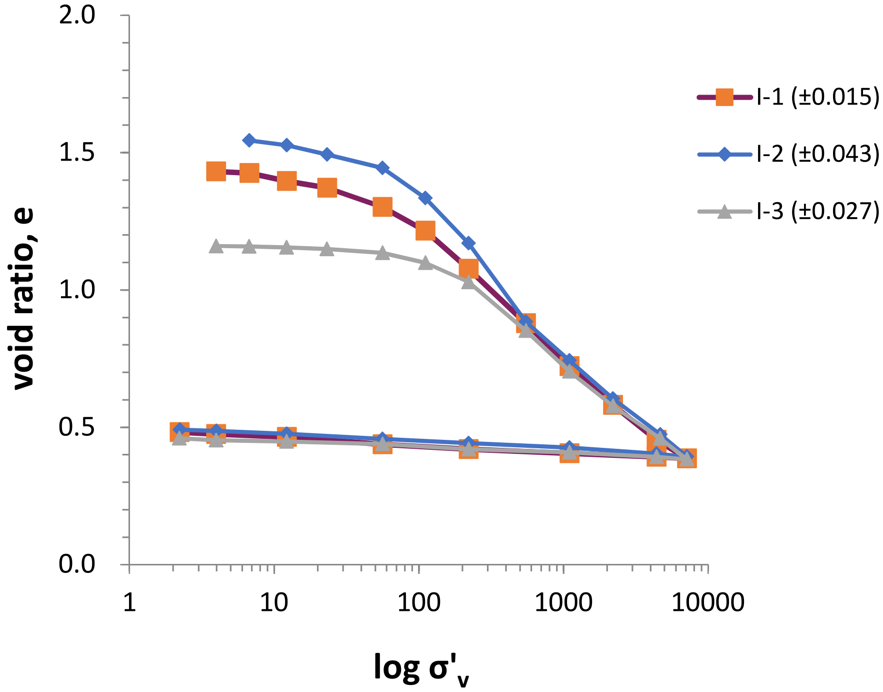

Fig. 14 Compression curves of 5% kaolin-95% decomposed granite (2.36-5.00mm) mixtures (the numbers in brackets are estimated accuracy).

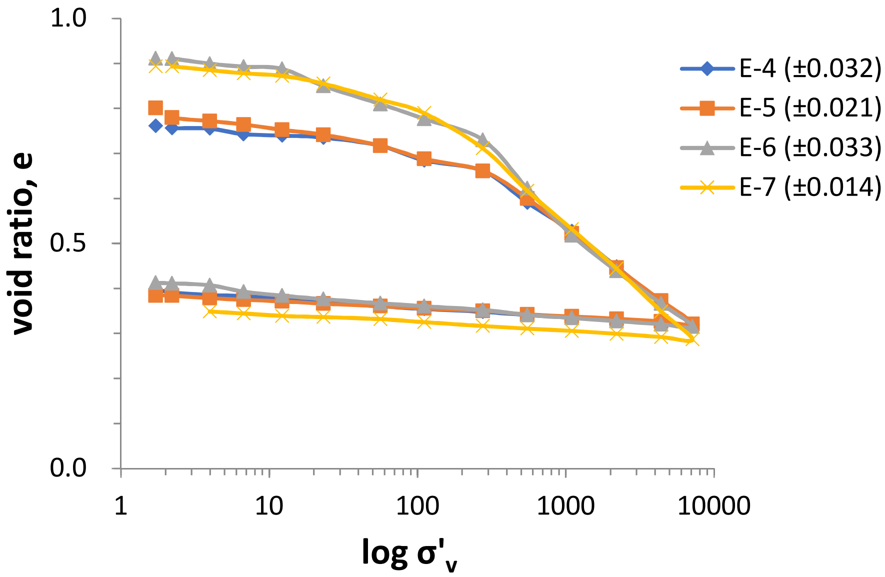

Fig. 15 Compression curves of 25% kaolin-75% decomposed granite (2.36-5.00mm) mixtures (the numbers in brackets are estimated accuracy) (Chan,2012).

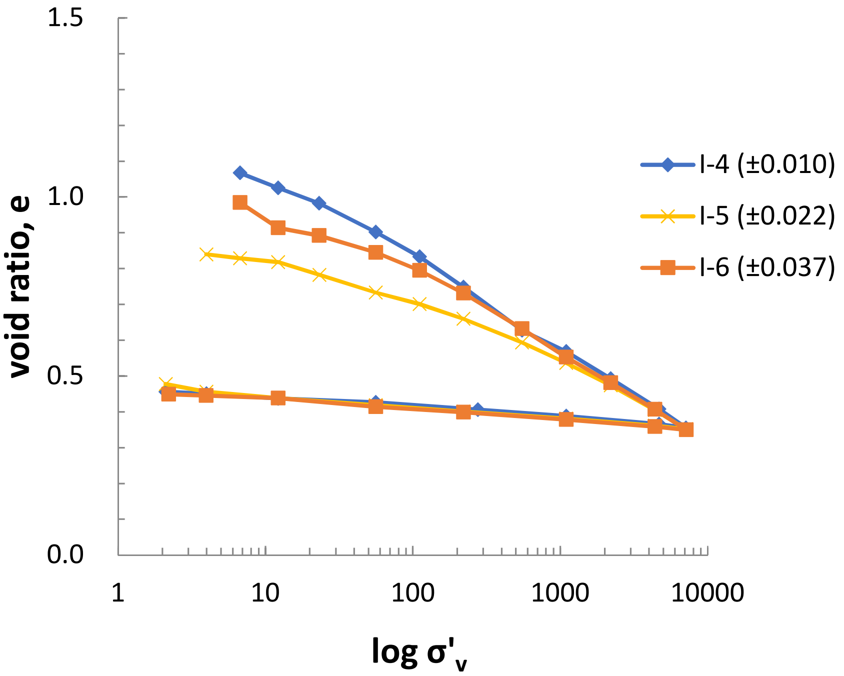

Fig. 16 Compression curves of 35% kaolin-65% decomposed granite (2.36-5.00mm) mixtures (the numbers in brackets are estimated accuracy).

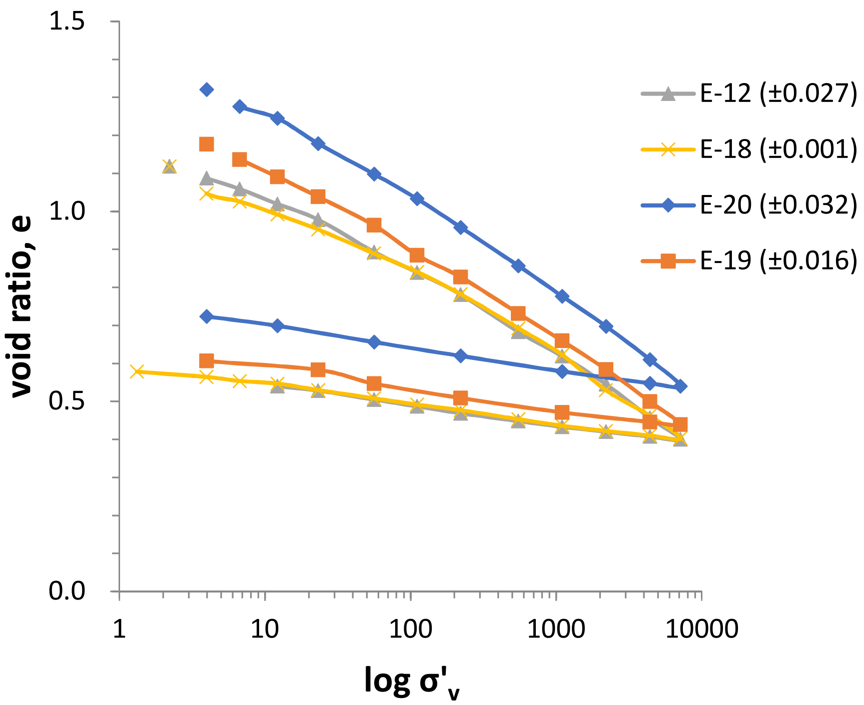

Fig. 17 Compression curves of 50% kaolin-50% decomposed granite (2.36-5.00mm) mixtures (the numbers in brackets are estimated accuracy) (Chan, 2012).

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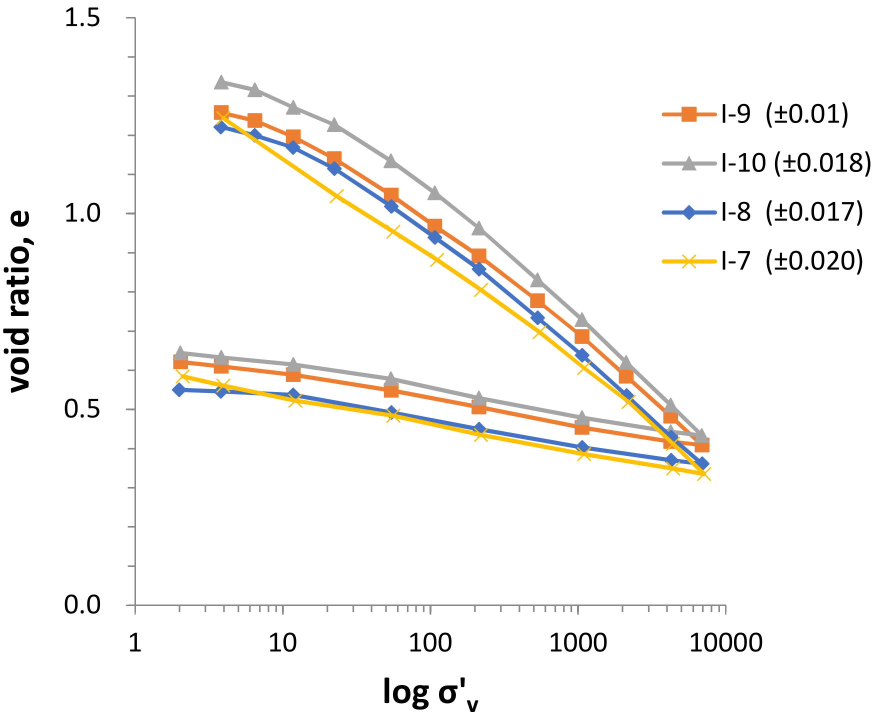

Fig. 18 Compression curves of 65% kaolin-35% decomposed granite (fraction 2.36-5.00mm) mixtures (the numbers in brackets are estimated accuracy).

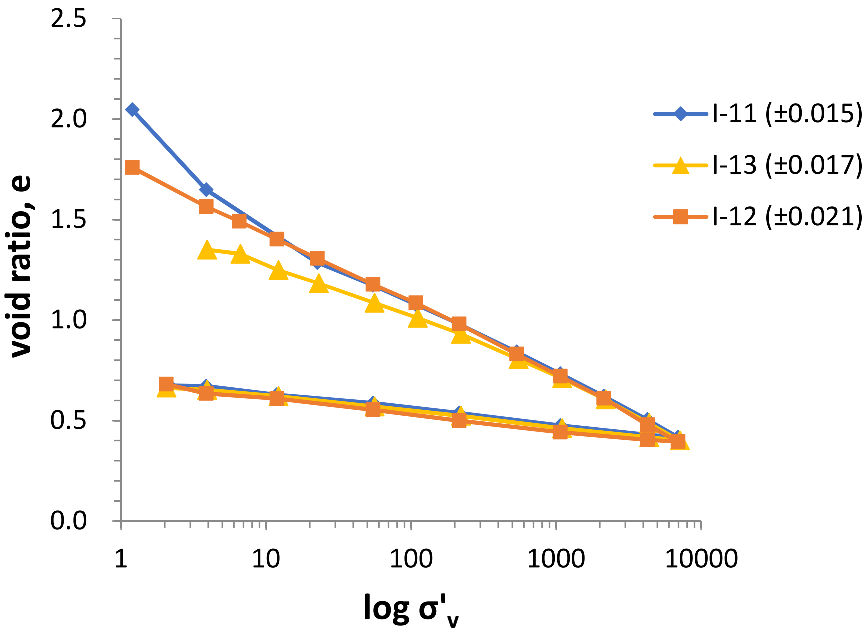

Fig. 19 Compression curves of 75% kaolin-25% decomposed granite (fraction 2.36-5.00mm) mixtures (the numbers in brackets are estimated accuracy).

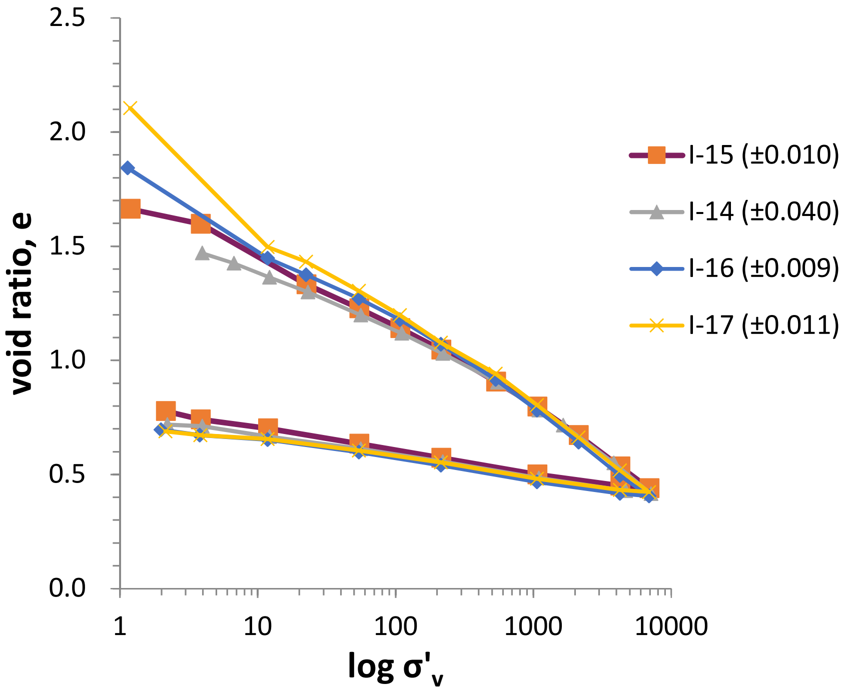

Fig. 20 Compression curves of 85% kaolin-15% decomposed granite (fraction 2.36-5.00mm) mixtures (the numbers in brackets are estimated accuracy).

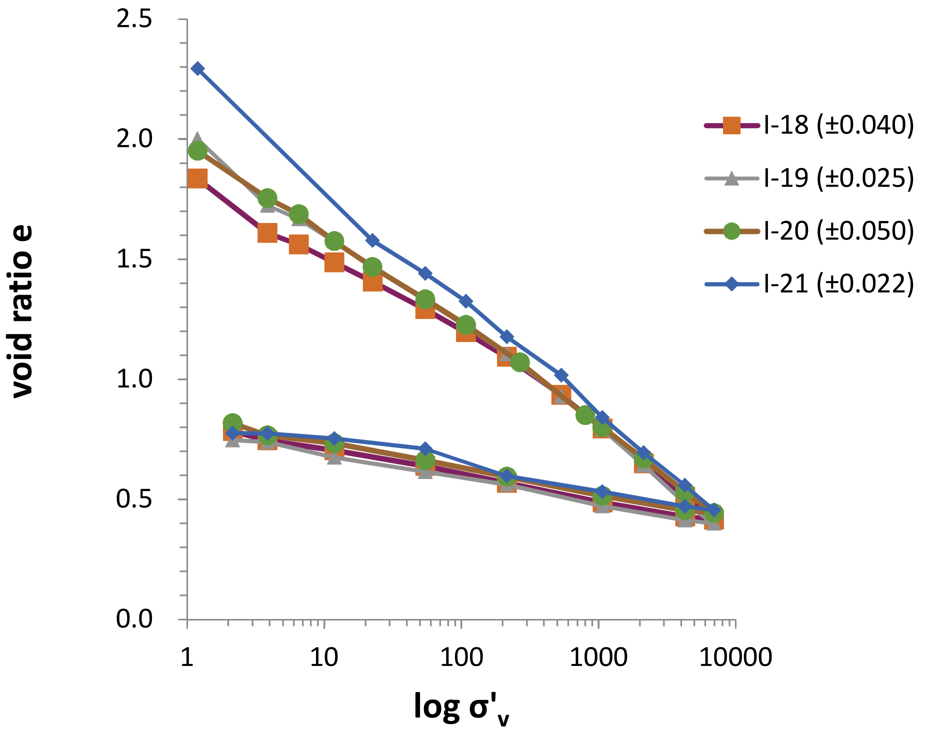

Fig. 21 Compression curves of 95% kaolin-5% decomposed granite (fraction 2.36-5.00mm) mixtures (the numbers in brackets are estimated accuracy).

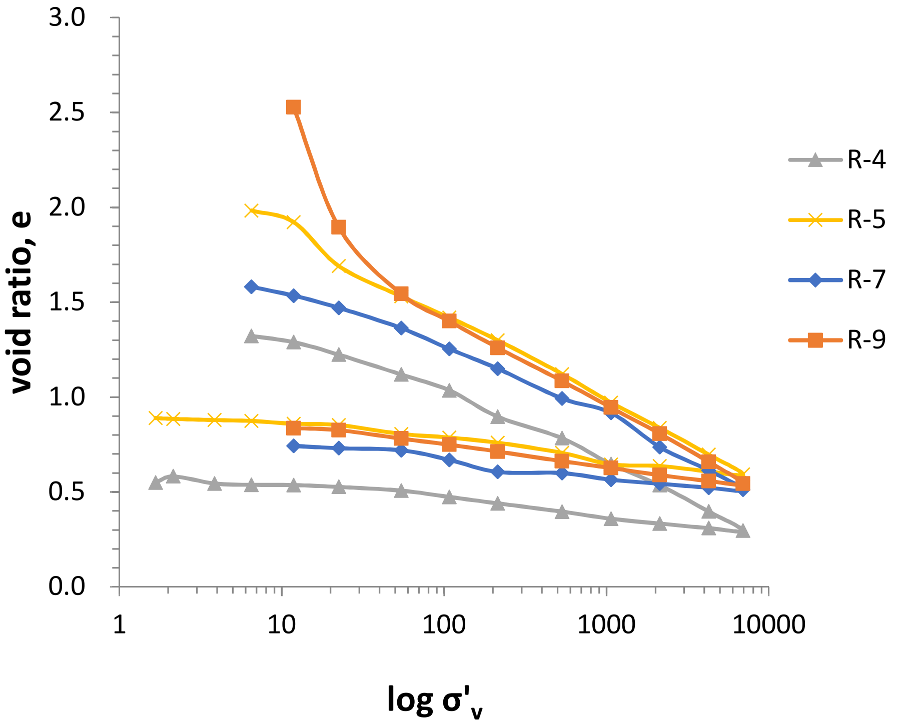

Fig. 22 Compression curves of reconstituted kaolin (the numbers in brackets are estimated accuracy) (Chau, 2012).

3.3.2. Kaolin-Decomposed Granite (0.30-1.18mm) Mixtures

Oedometer tests were also conducted on mixtures of kaolin and fraction 0.30-1.18mm from completely decomposed granite of which the grading is different. A range of proportions of kaolin were used from 25 up to 75% at intervals of 25% along with tests on pure sands. All of the specimens were created as slurries at a variety of different initial water contents except the 100% sands. The test data are shown in Figs.23 to 26.

For the pure decomposed granite (fraction 0.30-1.18mm), the data show a sand type behavior with distinct knee points and converge well (Fig.23). This kind of poorly graded sand is not transitional. However, with adding some fine fraction into this poorly graded sand, the data of the 25% clay content mixtures do not converge to a unique NCL as shown in Fig.24. The compression curves which start from different initial void ratios lie parallel to each other and no unique normal compression line can be found. Although the percentage of sand of this type of mixtures is 75%, the behavior of this mixture is not similar to that of sandy soil which has apparent knee points. For the sandy soils, the knee or steepening of the compression paths are thought to be the onset of large amounts of particle breakage[10], so that the compression behavior may not be affected by particle breakage significantly. At 50% and 75% clay contents (Figs.25 and 26), the compression curves converge which are straighter than the curves of 25% clay content mixtures. It means the behavior of compression are starting to be dominated by the fine fraction.

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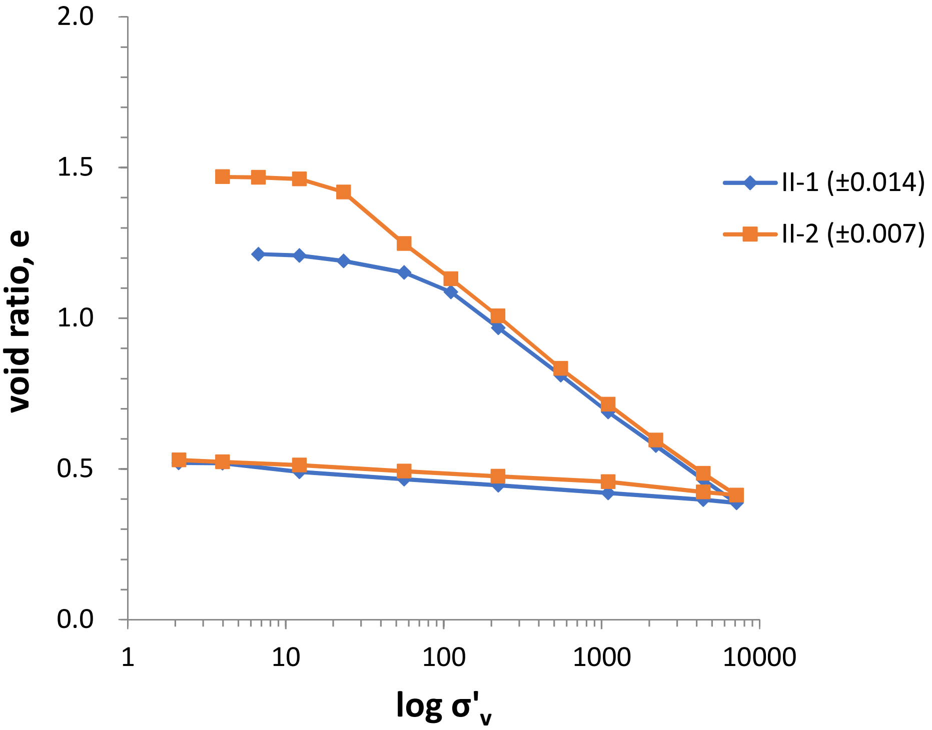

Fig. 23 Compression curves of pure decomposed granite (fraction 0.30-1.18mm) mixtures (the numbers in brackets are estimated accuracy).

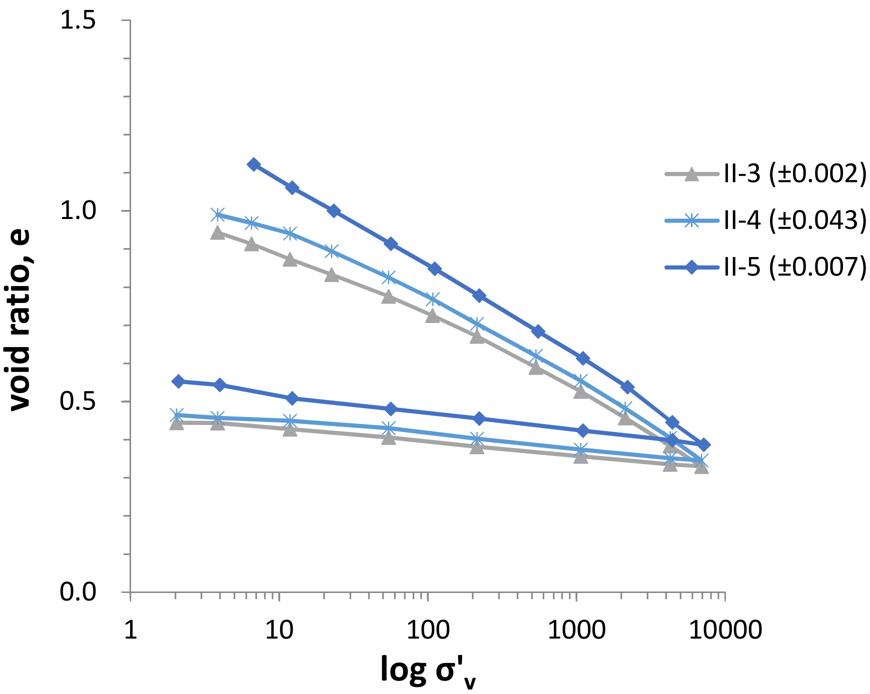

Fig. 24 Compression curves of 25% kaolin-75% decomposed granite (fraction 0.30-1.18mm) mixtures (the numbers in brackets are estimated accuracy).

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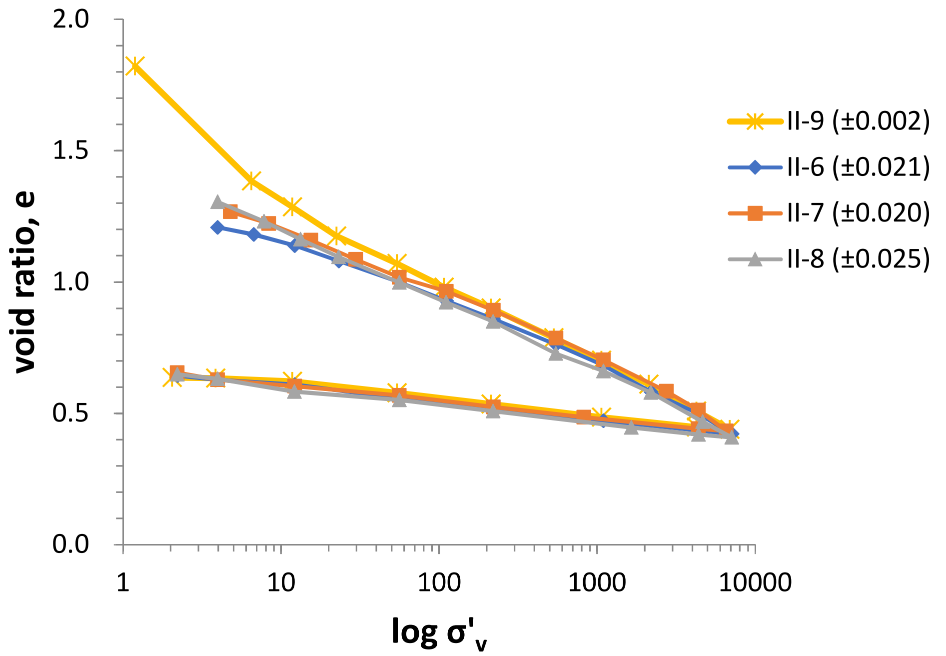

Fig. 25 Compression curves of 50% kaolin-50% decomposed granite (fraction 0.30-1.18mm) mixtures (the numbers in brackets are estimated accuracy).

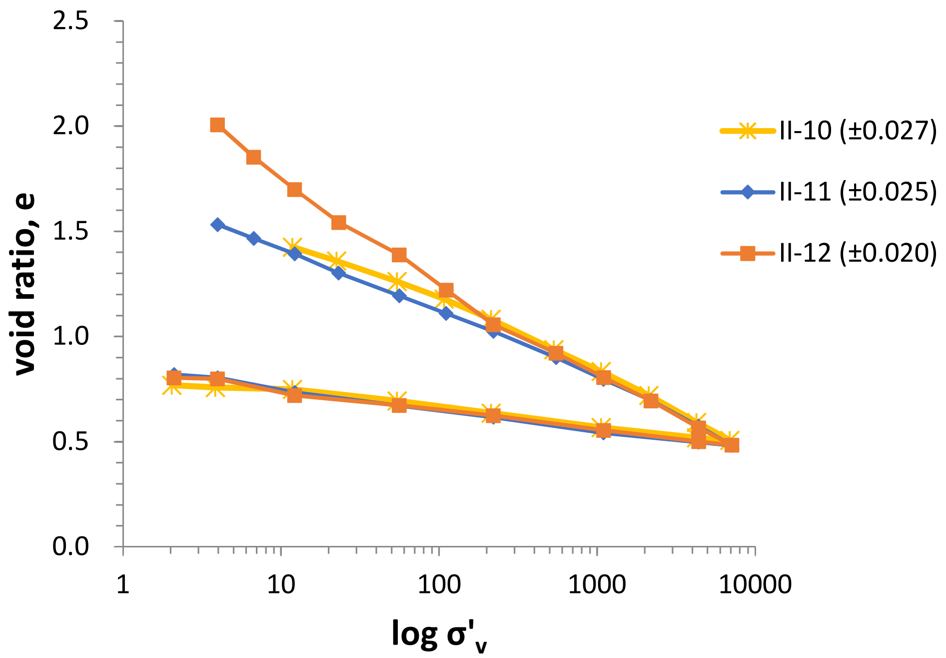

Fig. 26 Compression curves of 75% kaolin-25% decomposed granite (fraction 0.30-1.18mm) mixtures (the numbers in brackets are estimated accuracy).

3.3.3. Transitional Behavior Evaluation

All the discussions above are qualitative analyses which cannot evaluate the extent of the convergent or transitional behavior of the soils. In order to do some quantitative analyses of the soil behavior a method promoted by Ponzoni (2012) were applied. Ponzoni plotted the specific volumes at 20kPa against the specific volumes at 6000kPa for a given type of soils[11]. For a transitional soil, the points will pass a straight line with a slope equal to one. If the curves of the soils are fully convergent, the slope must be equal to zero. The slope therefore becomes the measurement of the extent of the transitional behavior. In this research work void ratios were used instead of specific volumes and the lower stress 20kPa was altered to 10kPa.

The plots of kaolin and completely decomposed granite (fraction 2.36-5.00mm) mixtures are shown in Figs.27 to 34. For the 5%, 25%, and 35% clay content mixtures, the slopes M are almost equal to zero (shown in Fig.27 to Fig.29) which indicates that the compression behavior of these mixtures are fully convergent. When the clay contents increase to 50% and 65%, the values of M are up to 0.6 and 0.7 which is close to 1. The same results can be found as from the compression curves that the 35% and 50% sand content mixtures are transitional soils. For the 5%, 15%, and 25% clay content mixtures, the slopes are too small (M=0.1) so that these three type of soils can also be determined to be non-transitional.

For the second group of mixtures composed of kaolin with completely decomposed granite (fraction 0.30-1.18mm), the void ratios at 10kPa are also plotted against the void ratios at 6000kPa in Fig.35 to Fig.37 and the values of slope M are determined to evaluate the extent of the transitional behavior of these soils. For the 25% clay content mixtures, the value of M is equal to 0.4 which is not larger than 0.5. It seems that the compression data of this type of soils can converge at much higher stress levels than 7MPa, but the space between the curves and the horizontal axis is not enough for the unique normal compression line. The M values of 50% and 75% clay contents are 0.1 and zero respectively (as shown in Fig.36to Fig.37), thus it can be proved that these three soils are not transitional though there is a little bit scatter of the data of 50% clay content mixtures which may be neglected. The $e_{6000kPa}$-e_{10kPa} plots of reconstituted kaolin and decomposed granites (fractions 2.36-5.00mm and 0.30-1.18mm) are shown in Figs. 38 to 39. For the clayey samples the data are scattered and it was decided not to calculate a value of M since more experiments may be needed for a reliable M value.

The slope M are plotted together with clay contents to see the effect of the fine fraction in Fig.40 and Fig.41. It is indicated that, for both the two groups of mixtures the fine fraction affects the soils and make the soils transitional, but the clay contents at which the transitional behavior appears and the fine fraction start to dominate the behavior of the mixtures are different. For the mixtures composed of kaolin with decomposed granite (fraction 0.30-1.18mm), the clay contents at which the transitional behavior was shown and the compression behavior returned to one of a unique normal compression line were 25% and 50% respectively while those of the mixtures of kaolin and completely decomposed granite (fraction 2.36-5.00mm) were 50% and 75%.

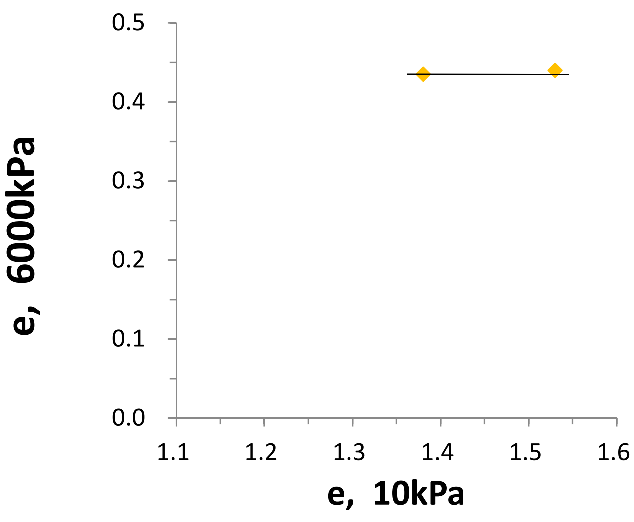

Fig. 27 Variation of void ratios at 10kPa against void ratios at 6000kPa of 5% kaolin-95% decomposed granite (2.36-5.00mm) mixtures with different initial void ratios (M=0).

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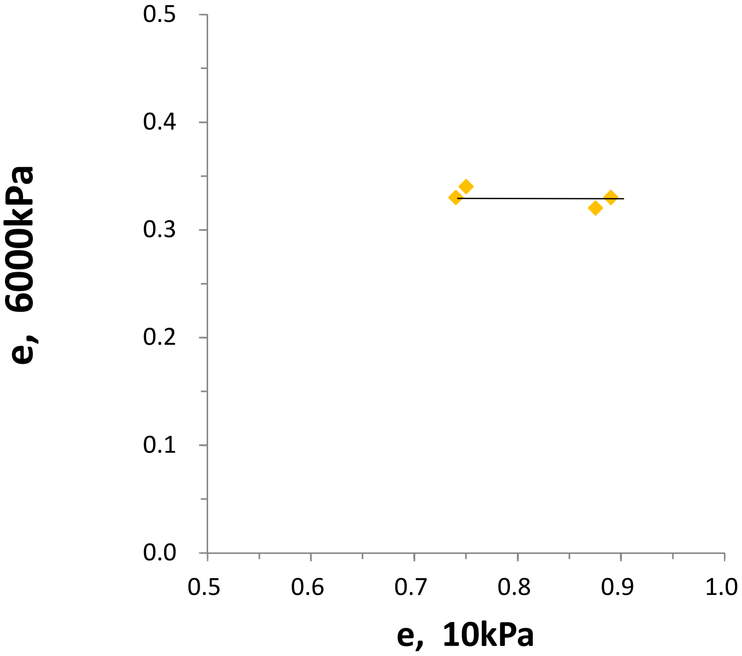

Fig. 28 Variation of void ratios at 10kPa against void ratios at 6000kPa of 25% kaolin-75% decomposed granite (2.36-5.00mm) mixtures with different initial void ratios (M=0; the data are from Chan, 2012).

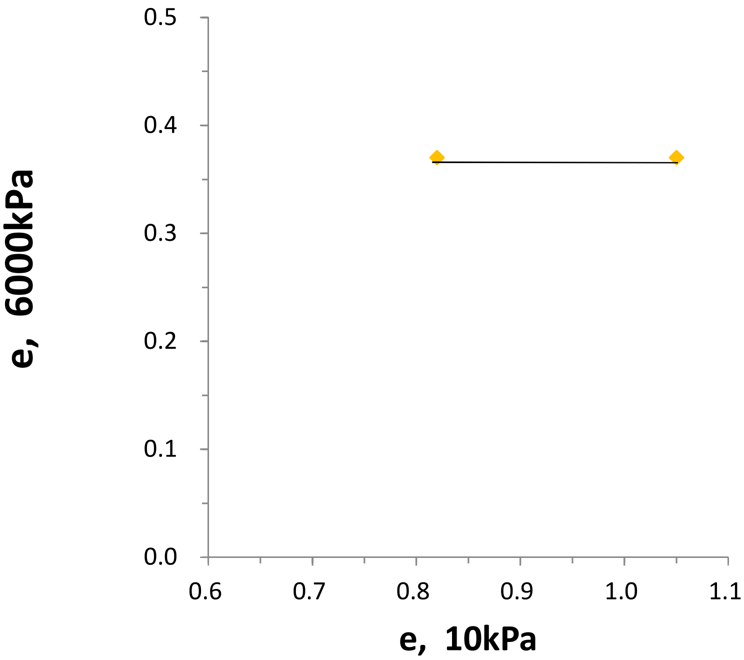

Fig. 29 Variation of void ratios at 10kPa against void ratios at 6000kPa of 35% kaolin-65% decomposed granite (2.36-5.00mm) mixtures with different initial void ratios (M=0).

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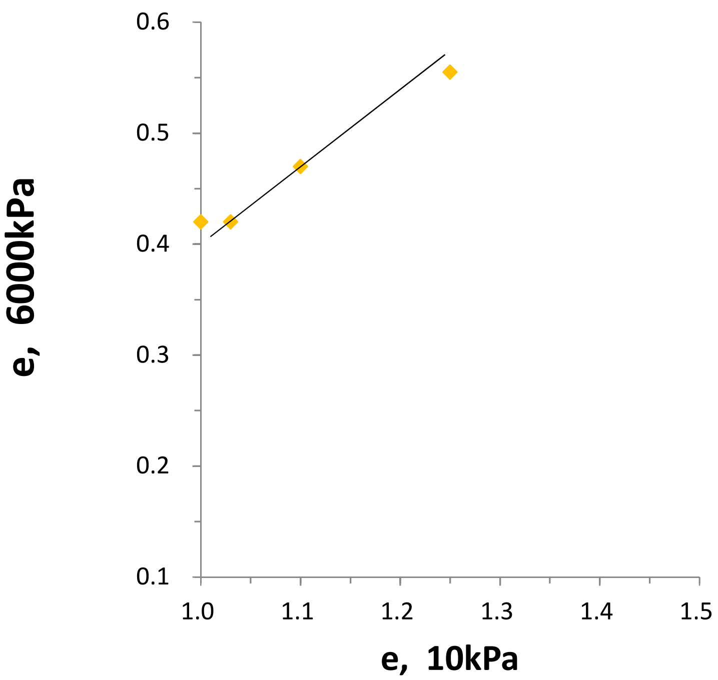

Fig. 30 Variation of void ratios at 10kPa against void ratios at 6000kPa of 50% kaolin-50% decomposed granite (2.36-5.00mm) mixtures with different initial void ratios (M=0.6; the data are from Chan, 2012).

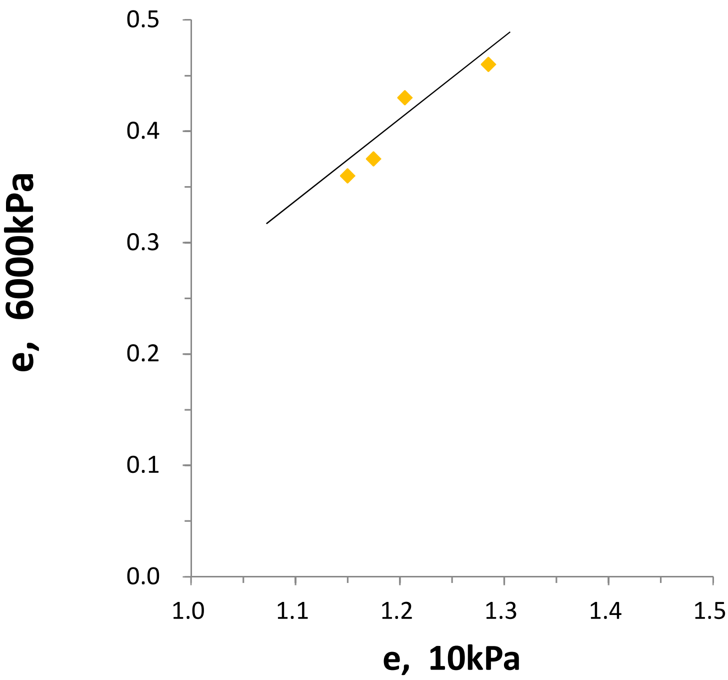

Fig. 31 Variation of void ratios at 10kPa against void ratios at 6000kPa of 65% kaolin-35% decomposed granite (2.36-5.00mm) mixtures with different initial void ratios (M=0.7).

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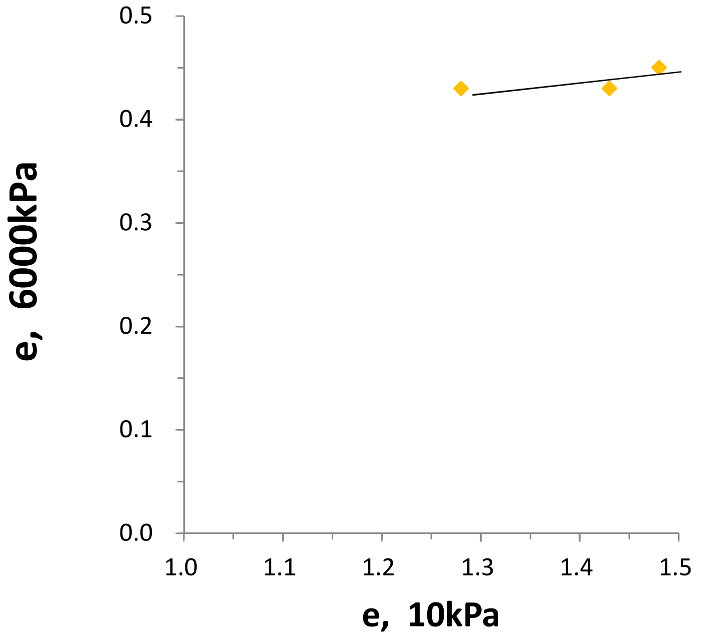

Fig. 32 Variation of void ratios at 10kPa against void ratios at 6000kPa of 75% kaolin-25% decomposed granite (2.36-5.00mm) mixtures with different initial void ratios (M=0.1).

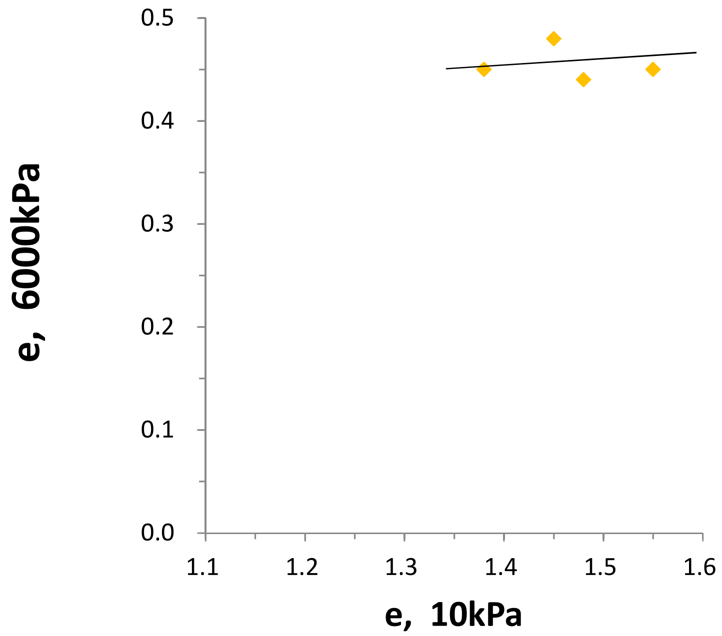

Fig. 33 Variation of void ratios at 10kPa against void ratios at 6000kPa of 85% kaolin-15% decomposed granite (2.36-5.00mm) mixtures with different initial void ratios (M=0.1).

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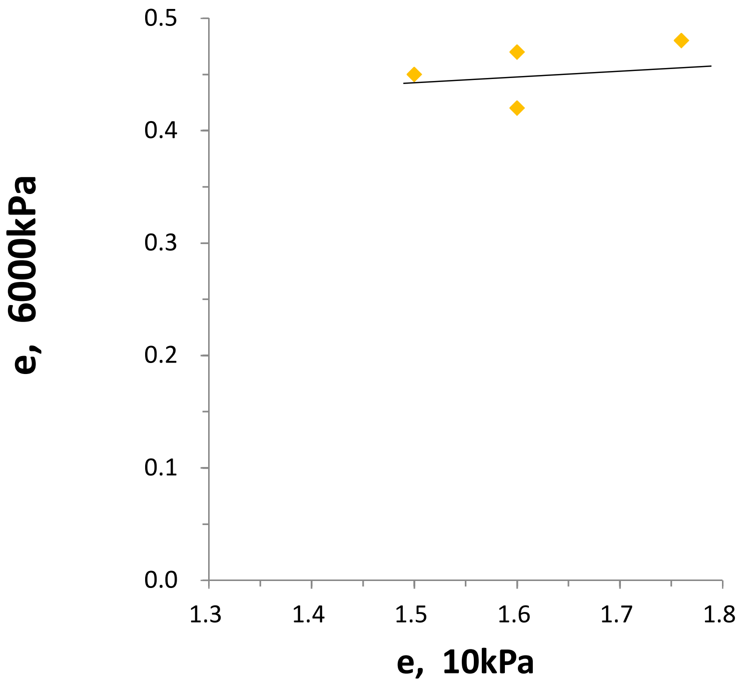

Fig. 34 Variation of void ratios at 10kPa against void ratios at 6000kPa of 95% kaolin-5% decomposed granite (2.36-5.00mm) mixtures with different initial void ratios (M=0.1).

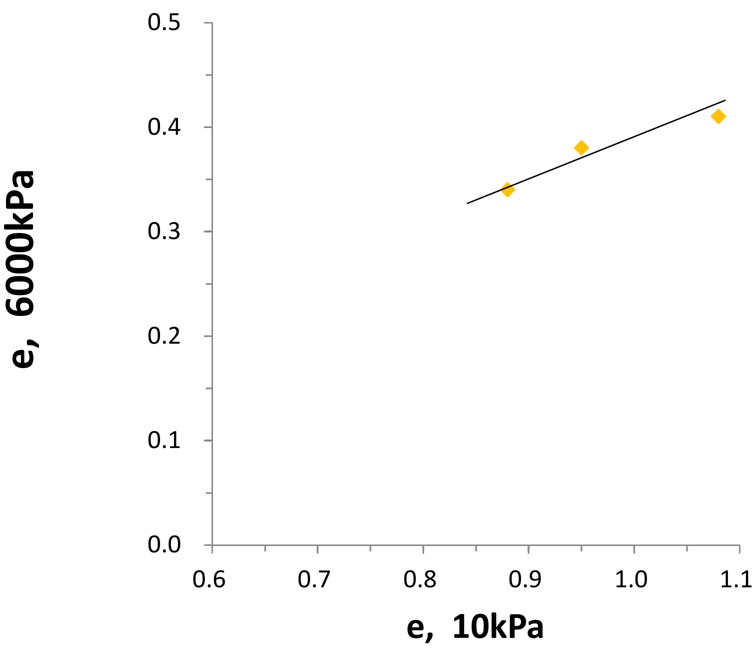

Fig. 35 Variation of void ratios at 10kPa against void ratios at 6000kPa of 25% kaolin-75% decomposed granite (0.30-1.18mm) mixtures with different initial void ratios (M=0.4).

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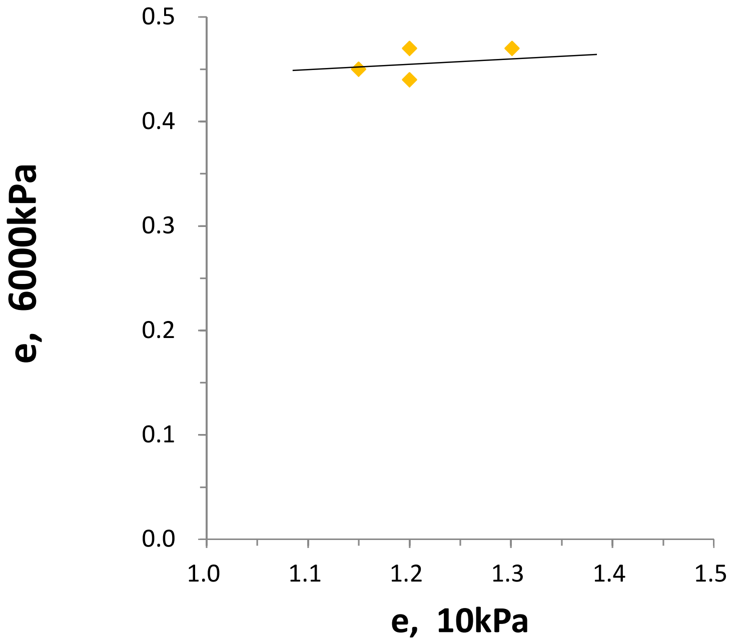

Fig. 36 Variation of void ratios at 10kPa against void ratios at 6000kPa of 50% kaolin-50% decomposed granite (0.30-1.18mm) mixtures with different initial void ratios (M=0.1).

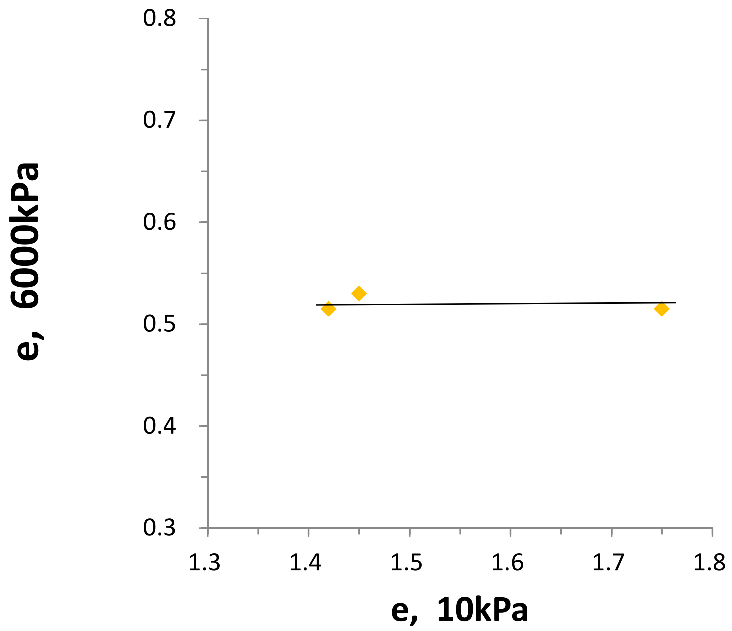

Fig. 37 Variation of void ratios at 10kPa against void ratios at 6000kPa of 75% kaolin-25% decomposed granite (0.30-1.18mm) mixtures with different initial void ratios (M=0).

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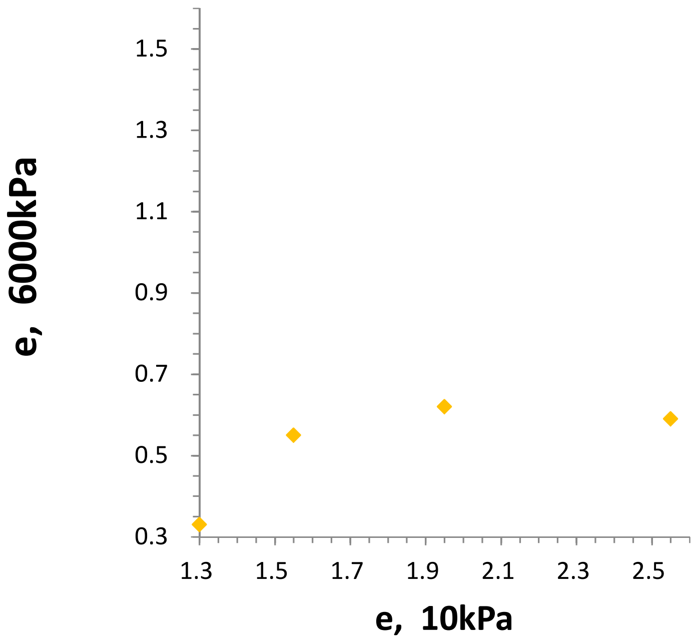

Fig. 38 Variation of void ratios at 10kPa against void ratios at 6000kPa of reconstituted kaolin with different initial void ratios.

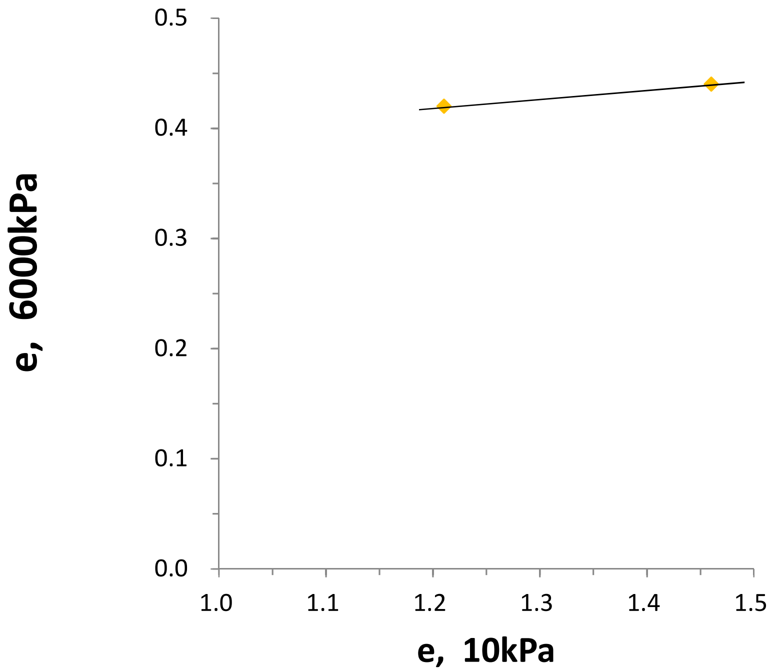

Fig. 39 Variation of void ratios at 10kPa against void ratios at 6000kPa of pure decomposed granite (0.30-1.18mm) mixtures with different initial void ratios (M=0.08).

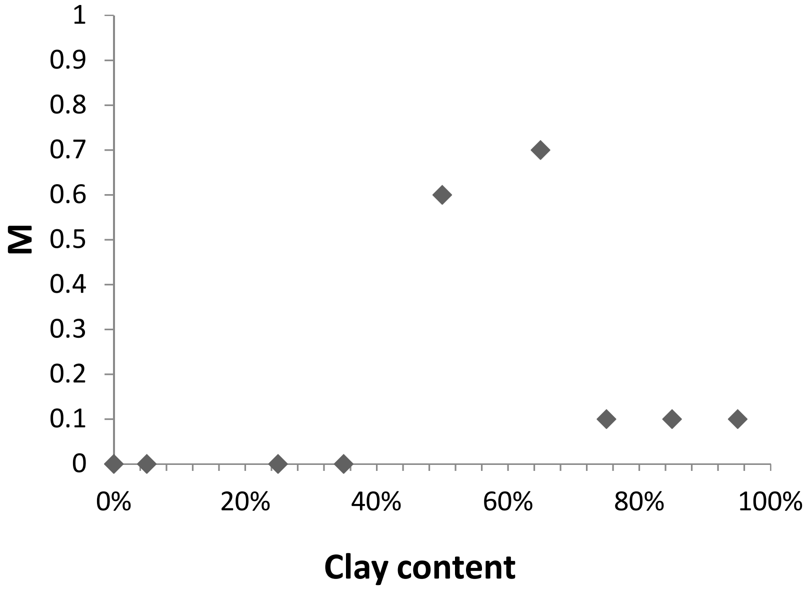

Fig. 40 Slope M (e6000kPa-e10kPa) depending on the clay content of kaolin-decomposed granite (2.36-5.00mm) mixtures.

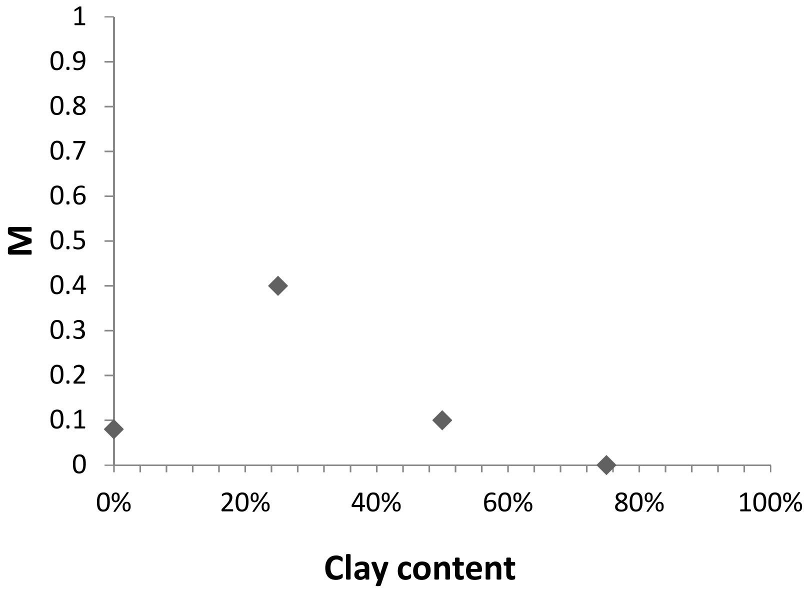

Fig. 41 Slope M (e6000kPa-e10kPa) depending on the clay content of kaolin-decomposed granite (0.30-1.18mm) mixtures.

4. Particle Breakage

All the samples after being tested in the oedometer were sieved in order to examine the amount of breakage of the coarse grained particles. The method proposed by Hardin (1985) was used in order to quantify the amount of particle breakage in terms of relative breakage values[6]. At here the reference 0.074mm is replaced by 0.063mm which is the size of finest sieve used in the Soil Mechanics and Geotechnical Laboratory of City University of Hong Kong.

The evolving grading curves for the final samples of each oedometer test are plotted in Figs. 42 to 47 . From these curves and the original grading curve of the decomposed granite (fraction

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2.36-5.00mm), the values of relative breakage can be calculated which are summarized in Table 4. To check in more details the relationship between the relative breakage and the soil behavior, the initial void ratio and the clay content are plotted against the relative breakage in Fig.48 to 55 respectively including the data from Chan (2012) .

As shown in Figs. 49 to 56, it is indicated that there might be a linear relationship between the relative breakage and the initial void ratios as presented by Altuhafi and Coop[2]. For t the 5% clay content mixtures (Fig. 48), the relative breakage does not change significantly. For the other data, the relative breakage increased with increasing initial void ratio no matter what slope of the variation trend is. Some of the data which not match this relationship because the accuracy of the balance used in the sieving tests is ±0.1g while the mass of sands in each high clay content sample (e.g., 65% to 95% clay contents) is no more than 10g and the grading curves can be altered significantly due to the large errors. To confirm this inference, the QICPIC apparatus should be used in future studies because the sieving analysis procedure may produce some additional breakage to the sand particles as well. Fig.56 illustrates that the relative breakage decreased as the clay content increasing. It is interesting that there are no significant relative breakage changes at 50% to 75% clay contents while the transitional was identified at 50% and 65% clay contents.

The sieving analysis results of the second group of tests are presented in Figs.57 to 65. For a given type of mixtures with different initial void ratios, the differences between the evolving grading curves are not significant and the values of relative breakage are lower than those of the previous group of mixtures. The linear relationship between relative breakage and initial void ratio is also indentified, but the variation trends are all nearly horizontal except the 50% clay content mixtures. As the strength of the particles of fraction 0.30-1.18mm is in general larger than the corresponding strength of fraction 2.36-5.00mm, the total amount of breakage is in general lower in the coarse-grained sand.

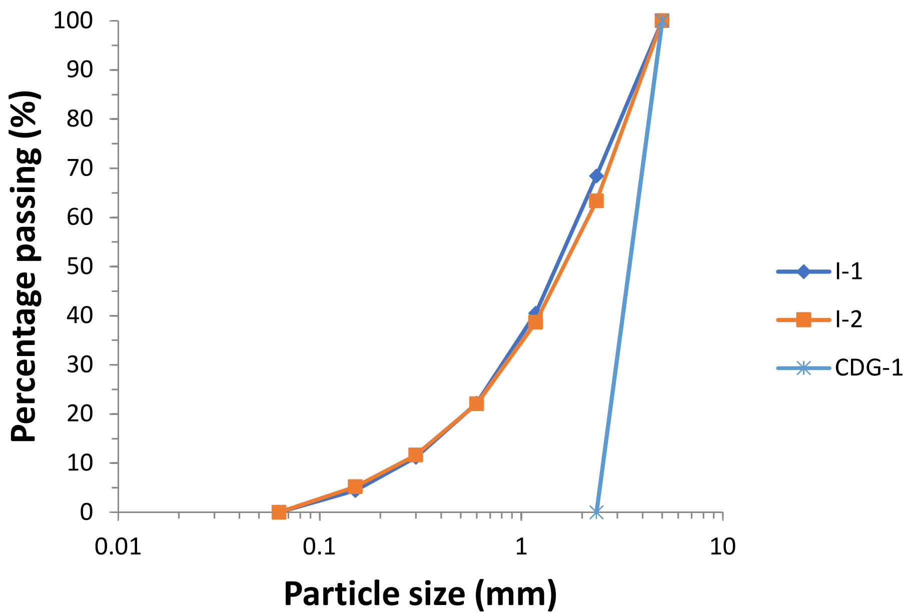

Fig. 42 Comparison of the evolving grading distributions of 5% kaolin and 95% completely decomposed granite fraction 2.36-5.00mm (CDG-1) mixtures with the original grading curve of CDG-1.

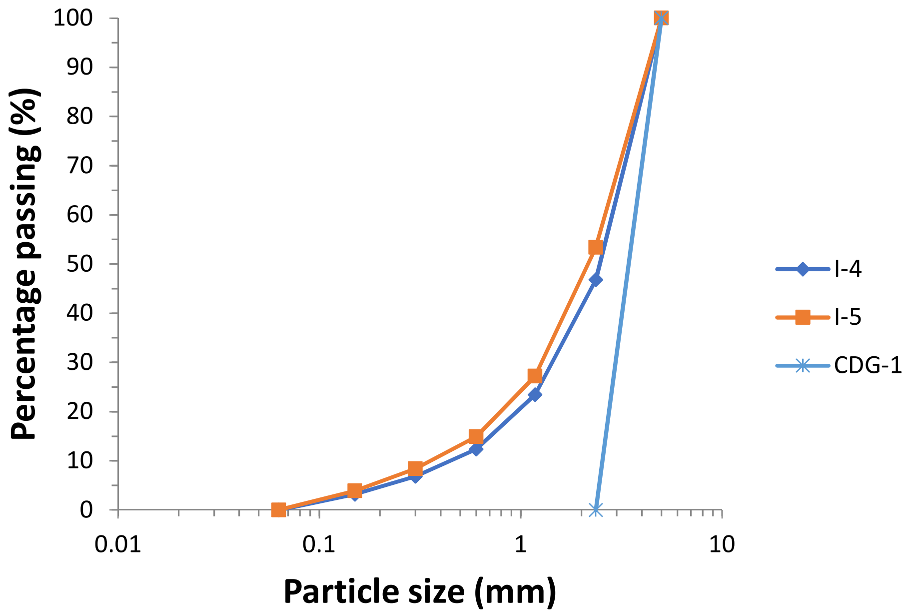

Fig. 43 Comparison of the evolving grading distributions of 35% kaolin and 65% completely decomposed granite fraction 2.36-5.00mm (CDG-1) mixtures with the original grading curve of CDG-1.

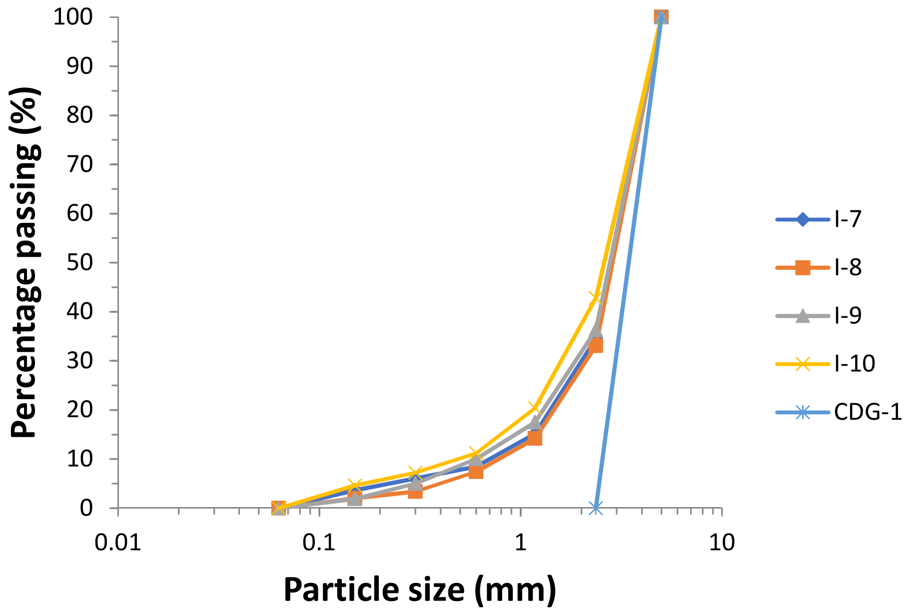

Fig. 44 Comparison of the evolving grading distributions of 65% kaolin and 35% completely decomposed granite fraction 2.36-5.00mm (CDG-1) mixtures with the original grading curve of CDG-1.

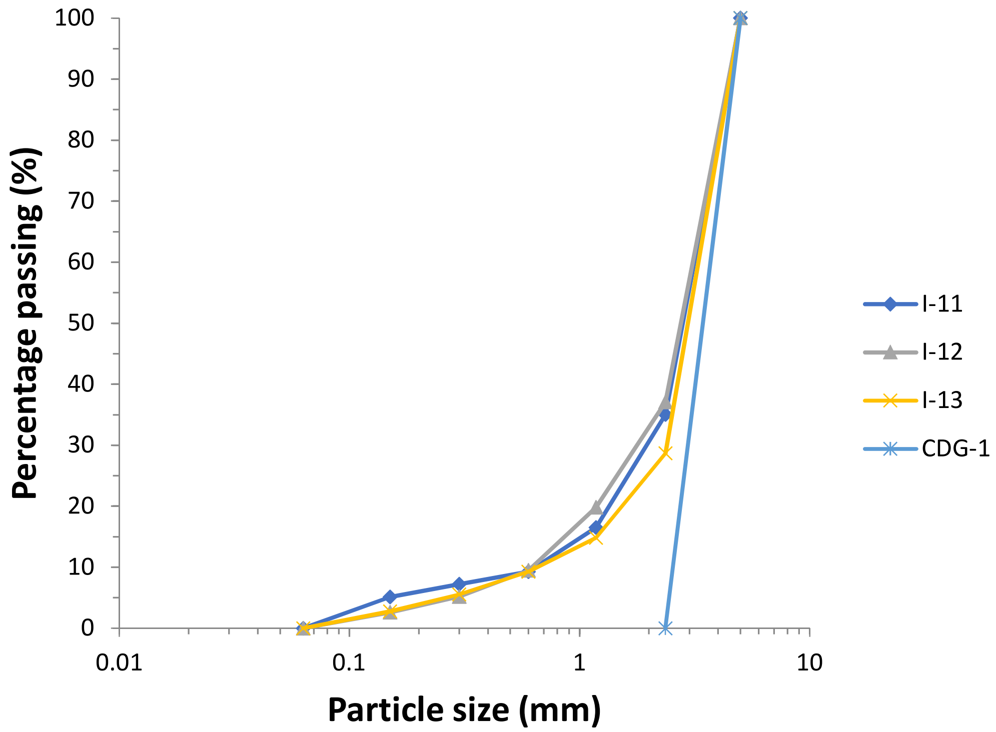

Fig. 45 Comparison of the evolving grading distributions of 75% kaolin and 25% completely decomposed granite fraction 2.36-5.00mm (CDG-1) mixtures with the original grading curve of CDG-1.

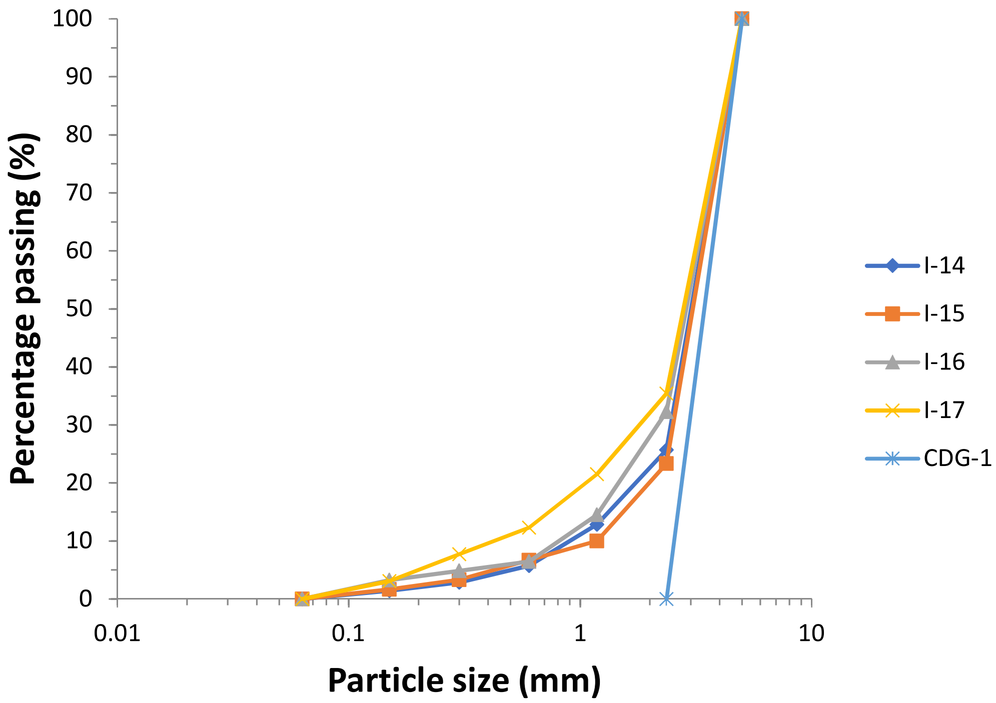

Fig. 46 Comparison of the evolving grading distributions of 85% kaolin and 15% completely decomposed granite fraction 2.36-5.00mm (CDG-1) mixtures with the original grading curve of CDG-1.

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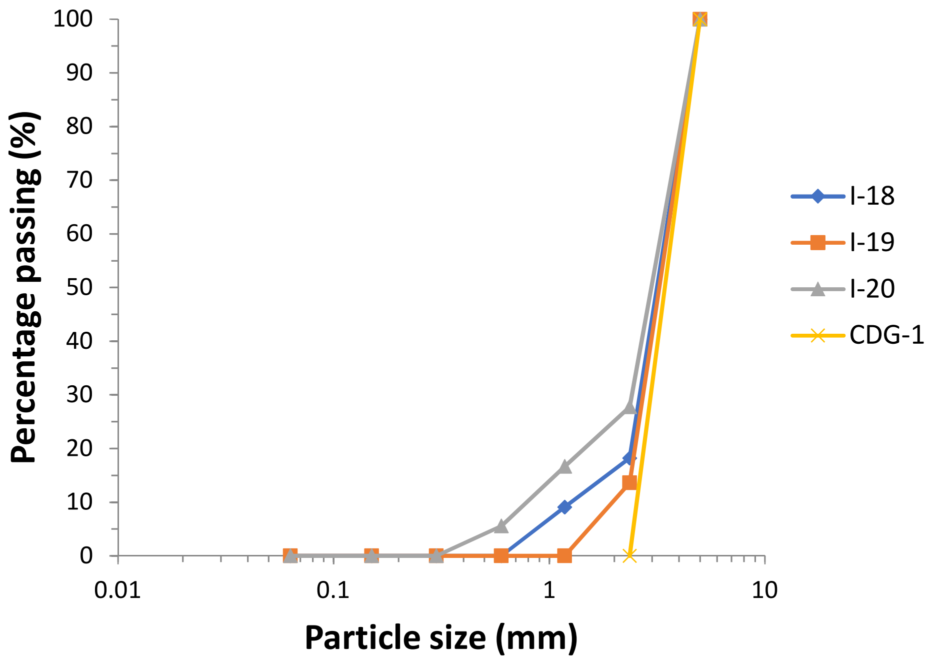

Fig. 47 Comparison of the evolving grading distributions of 95% kaolin and 5% completely decomposed granite fraction 2.36-5.00mm (CDG-1) mixtures with the original grading curve of CDG-1.

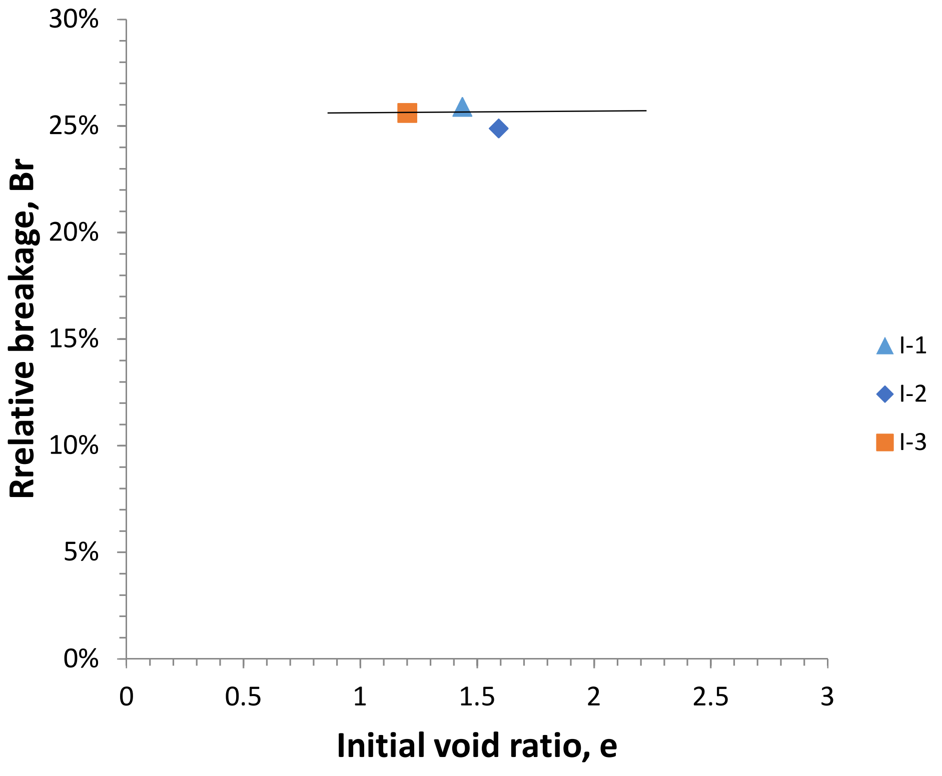

Fig. 48 Relationship between initial void ratio and relative breakage of kaolin and 2.36-5.00mm decomposed granite mixtures at 5% kaolin content.

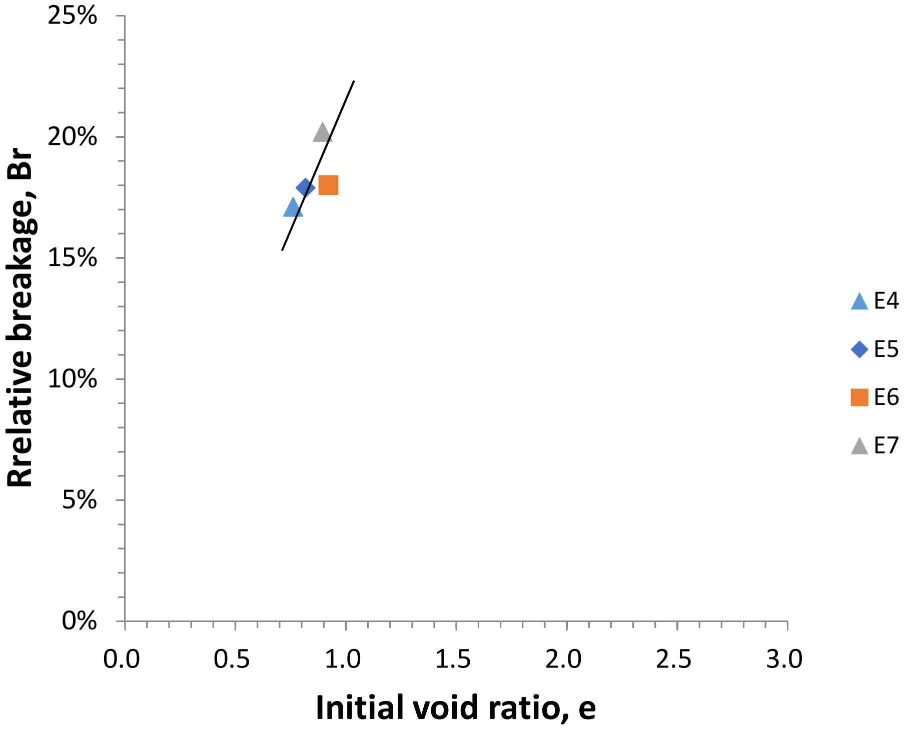

Fig. 49 Relationship between initial void ratio and relative breakage of kaolin and 2.36-5.00mm decomposed granite mixtures at 25% kaolin content (Chan,2012).

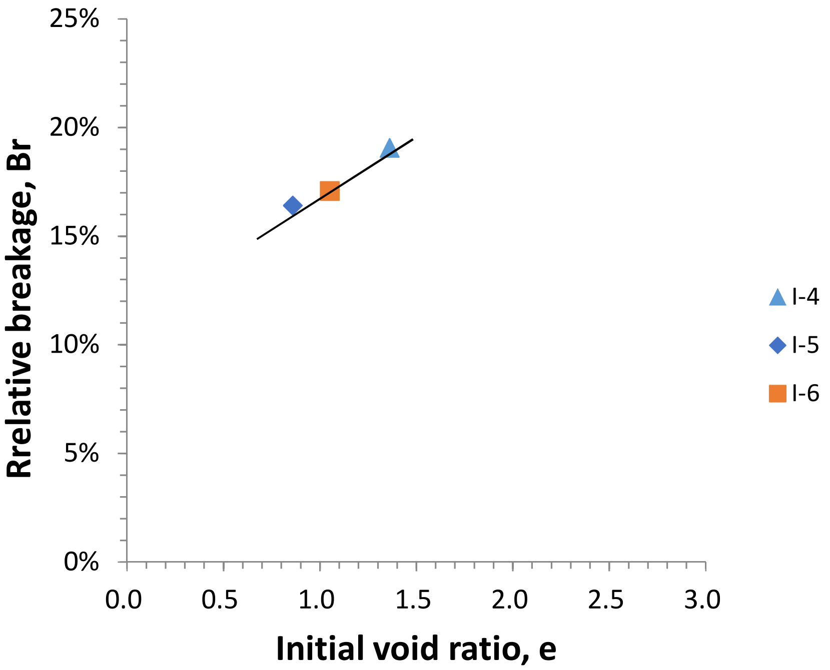

Fig. 50 Relationship between initial void ratio and relative breakage of kaolin and 2.36-5.00mm decomposed granite mixtures at 35% kaolin content.

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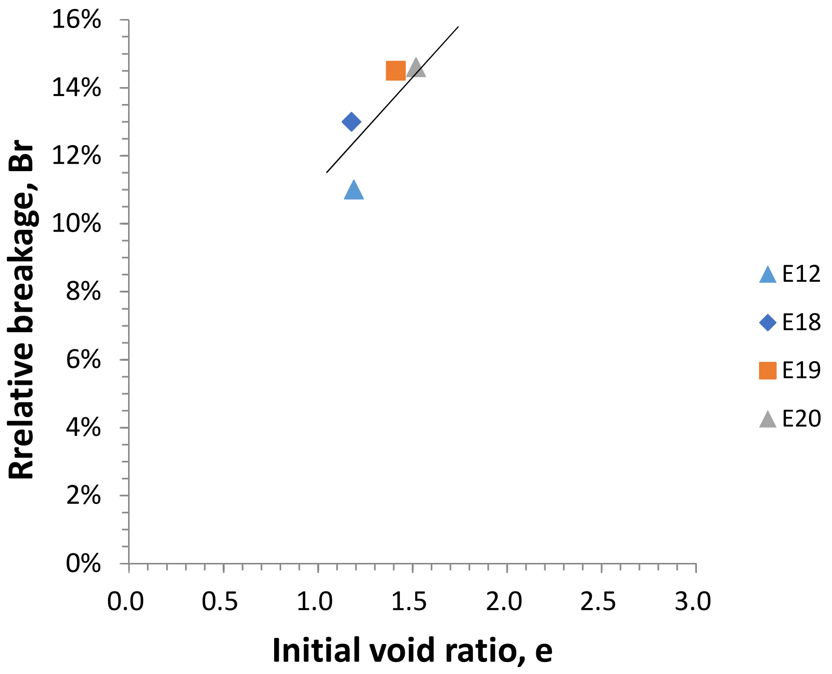

Fig. 51 Relationship between initial void ratio and relative breakage of kaolin and 2.36-5.00mm decomposed granite mixtures at 50% kaolin content (Chan,2012).

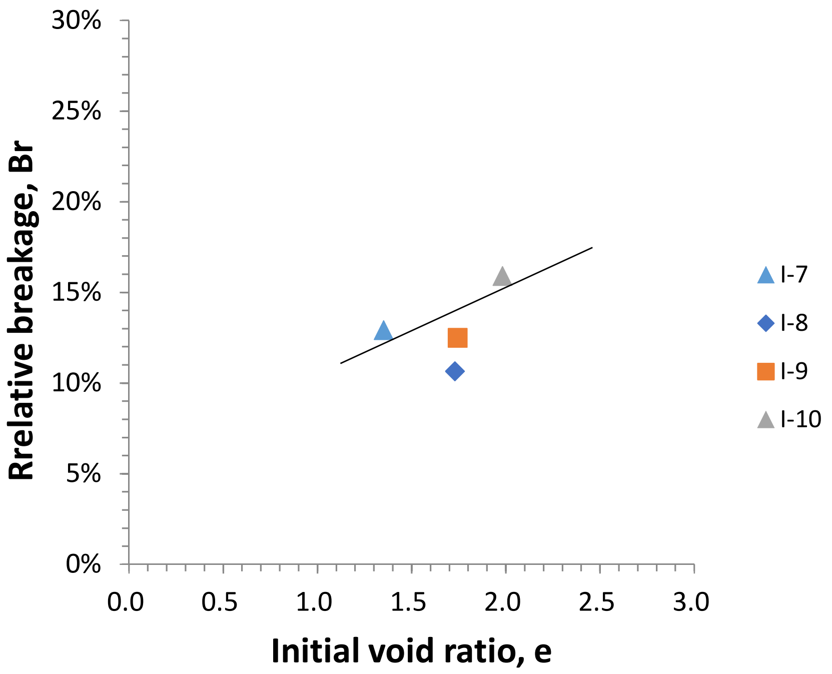

Fig. 52 Relationship between initial void ratio and relative breakage of kaolin and 2.36-5.00mm decomposed granite mixtures at 65% kaolin content.

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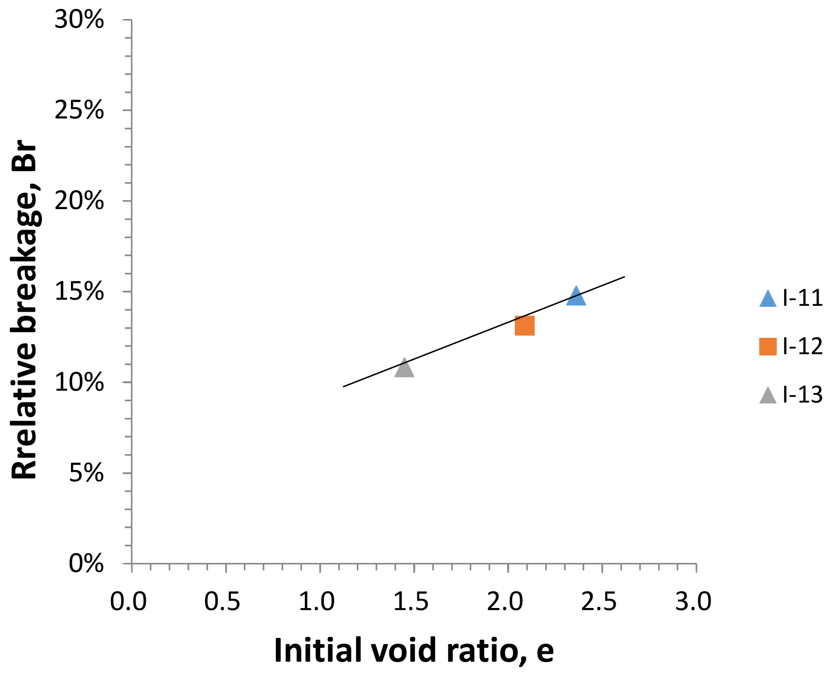

Fig. 53 Relationship between initial void ratio and relative breakage of kaolin and 2.36-5.00mm decomposed granite mixtures at 75% kaolin content.

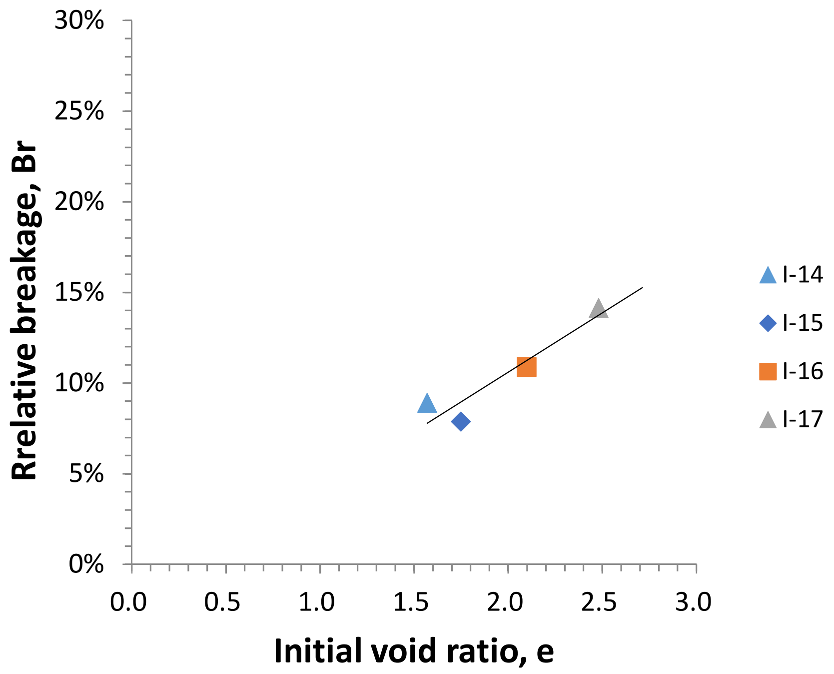

Fig. 54 Relationship between initial void ratio and relative breakage of kaolin and 2.36-5.00mm decomposed granite mixtures at 85% kaolin content.

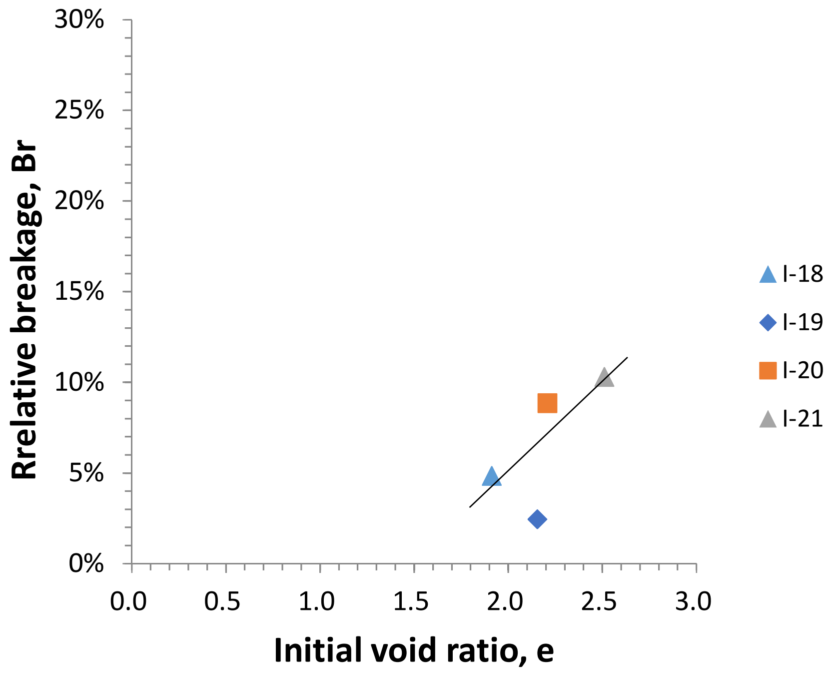

Fig. 55 Relationship between initial void ratio and relative breakage of kaolin and 2.36-5.00mm decomposed granite mixtures at 95% kaolin content.

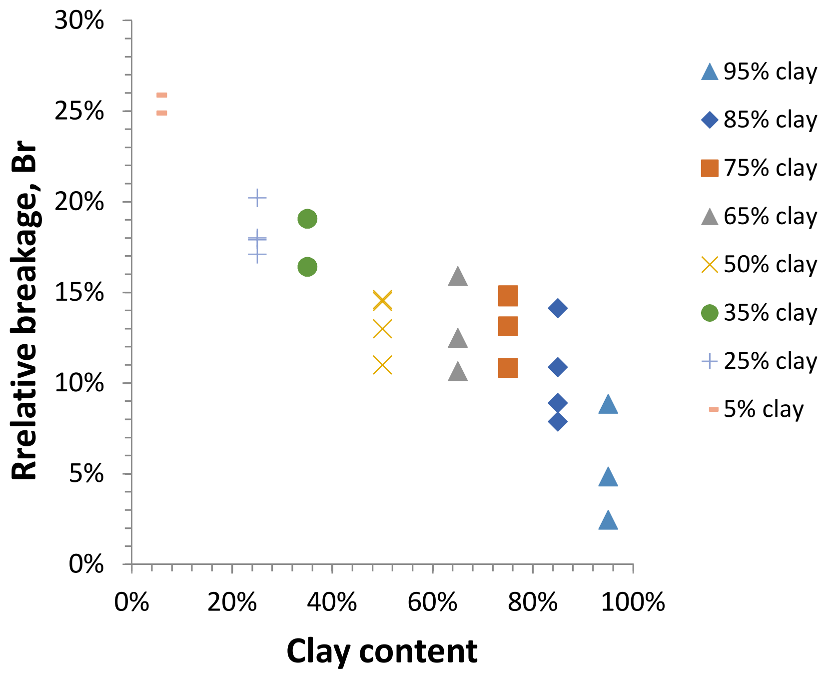

Fig. 56 Relationship between clay content and relative breakage of kaolin and 2.36-5.00mm decomposed granite mixtures (including the data from Chan, 2012).

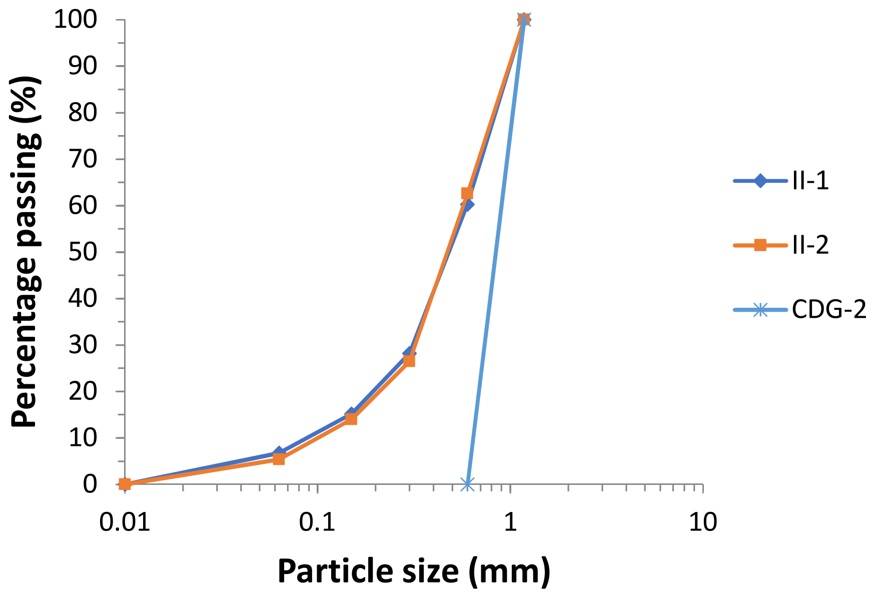

Fig. 57 Comparison of the evolving grading distributions of pure completely decomposed granite fraction 0.30-1.18mm (CDG-2) with the original grading curve of CDG-2.

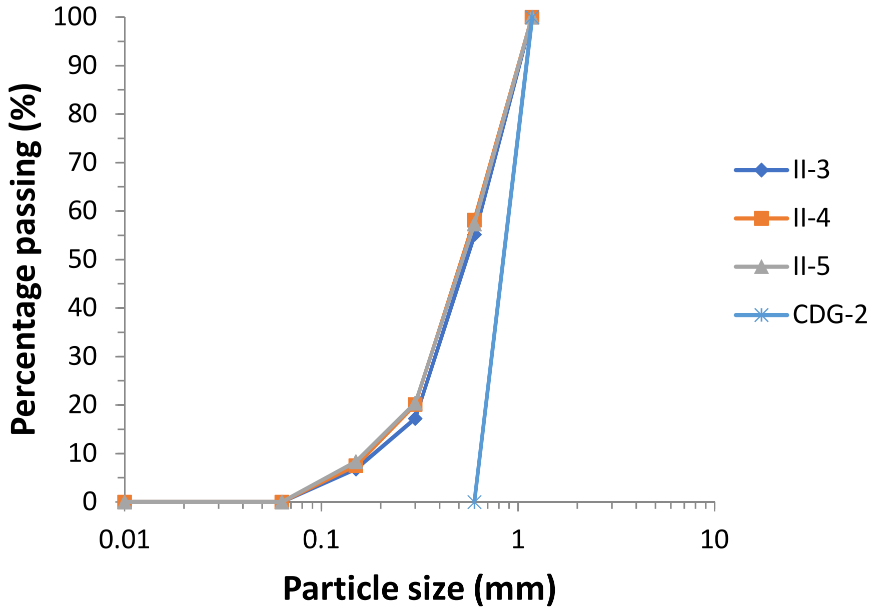

Fig. 58 Comparison of the evolving grading distributions of 25% kaolin and 75% completely decomposed granite fraction 0.30-1.18mm (CDG-2) mixtures with the original grading curve of CDG-2.

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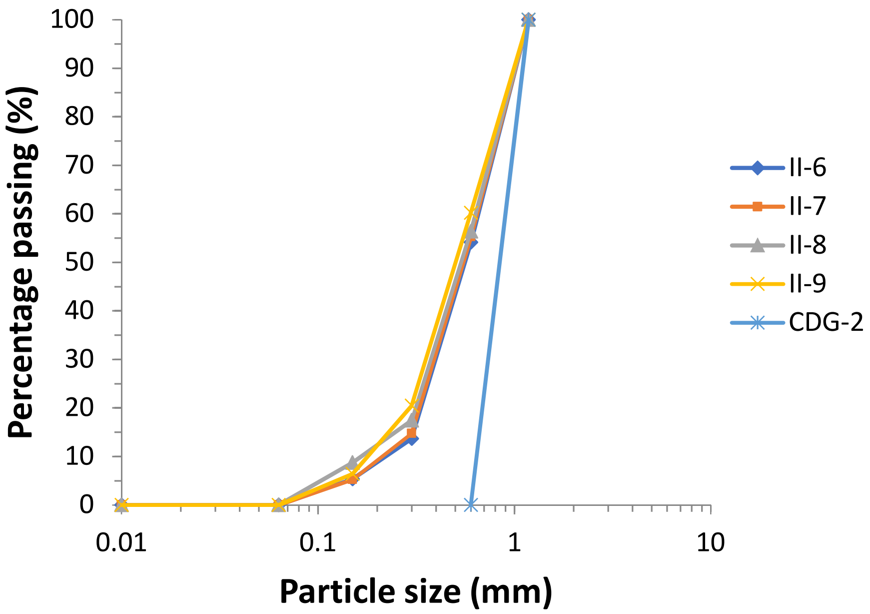

Fig. 59 Comparison of the evolving grading distributions of 50% kaolin and 50% completely decomposed granite fraction 0.30-1.18mm (CDG-2) mixtures with the original grading curve of CDG-2.

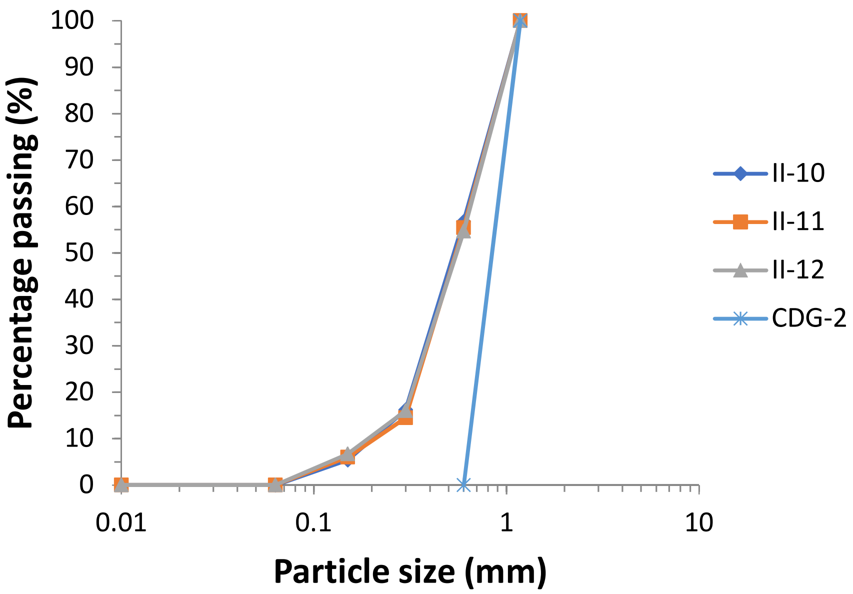

Fig. 60 Comparison of the evolving grading distributions of 75% kaolin and 25% completely decomposed granite fraction 0.30-1.18mm (CDG-2) mixtures with the original grading curve of CDG-2.

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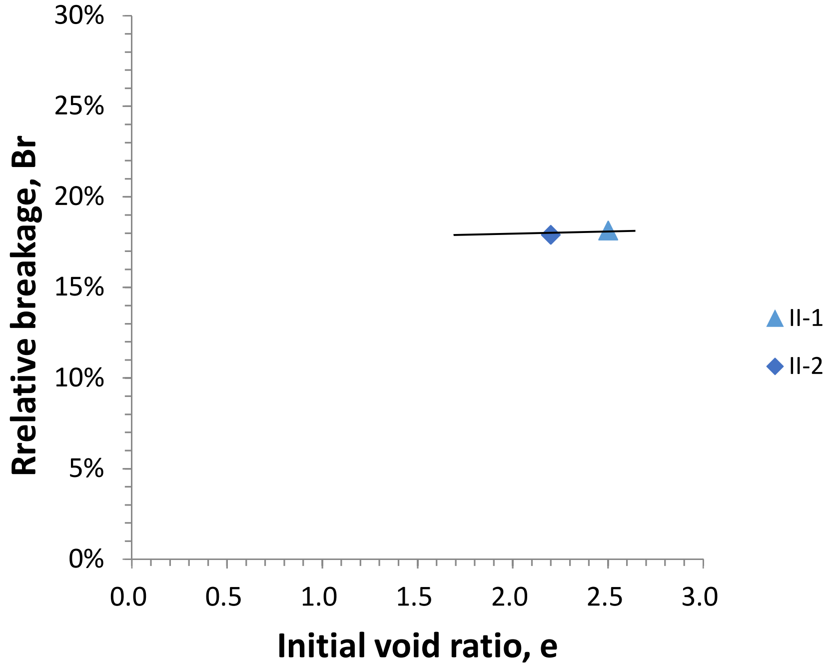

Fig. 61 Relationship between initial void ratio and relative breakage of pure decomposed granite fraction 0.30-1.18mm.

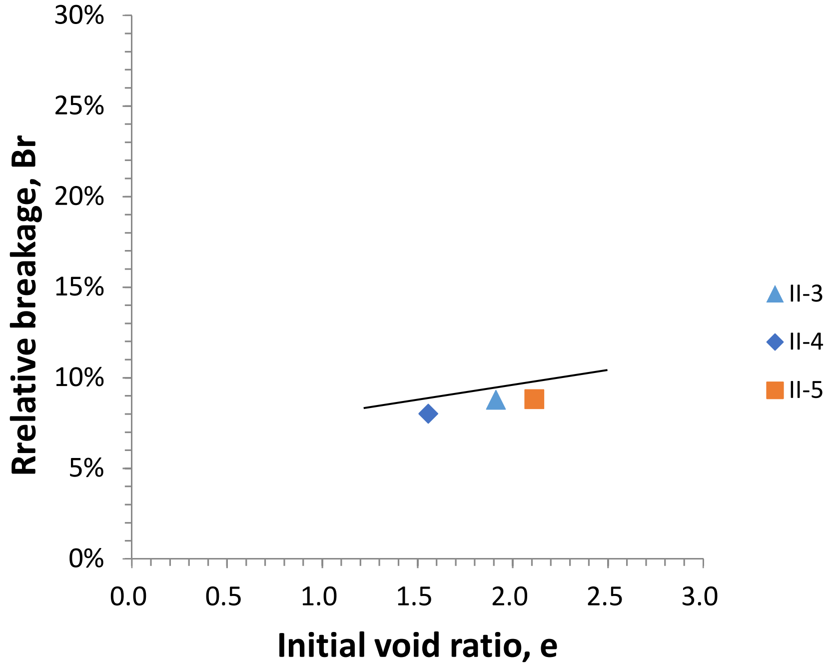

Fig. 62 Relationship between initial void ratio and relative breakage of kaolin and completely decomposed granite (fraction 0.30-1.18mm) mixtures at 25% kaolin content.

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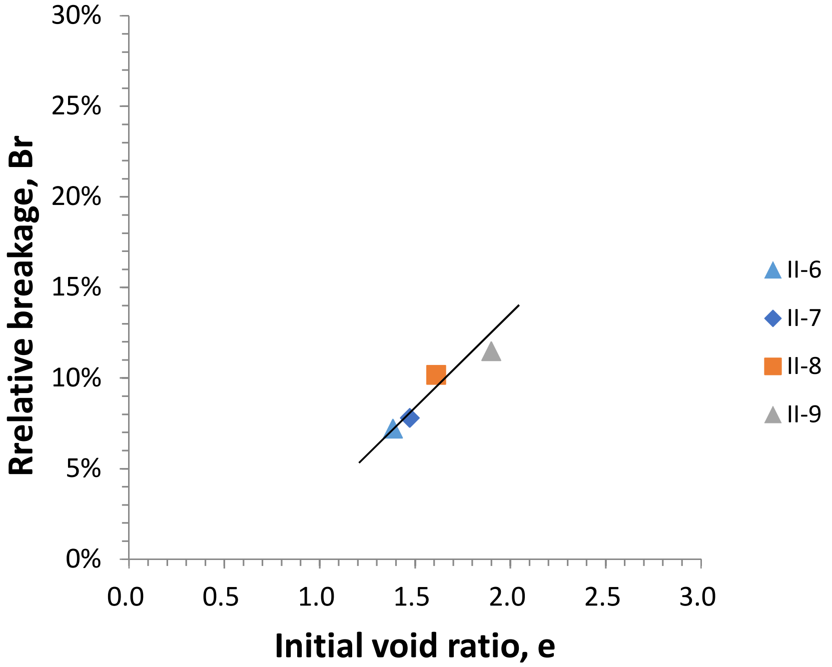

Fig. 63 Relationship between initial void ratio and relative breakage of kaolin and completely decomposed granite (fraction 0.30-1.18mm) mixtures at 50% kaolin content.

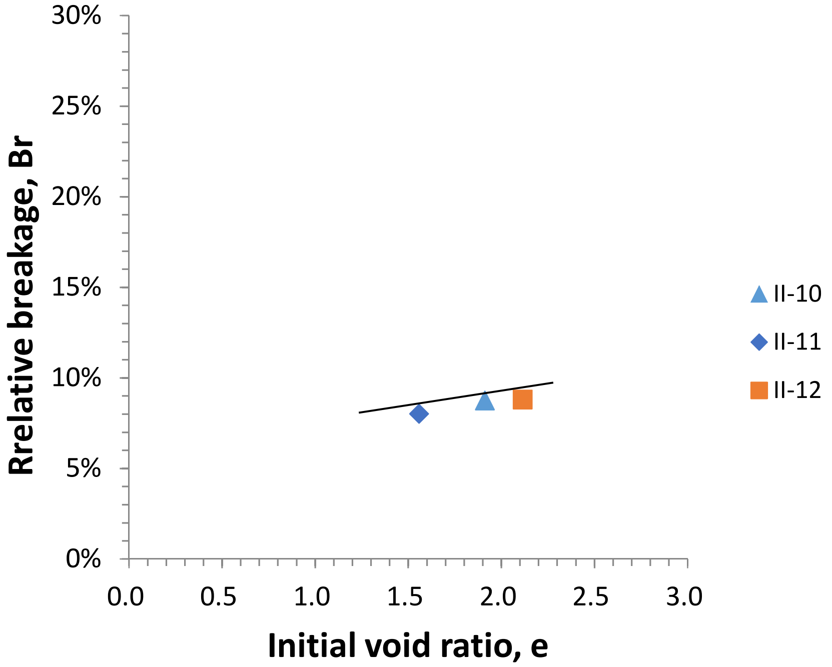

Fig. 64 Relationship between initial void ratio and relative breakage of kaolin and completely decomposed granite (fraction 0.30-1.18mm) mixtures at 75% kaolin content.

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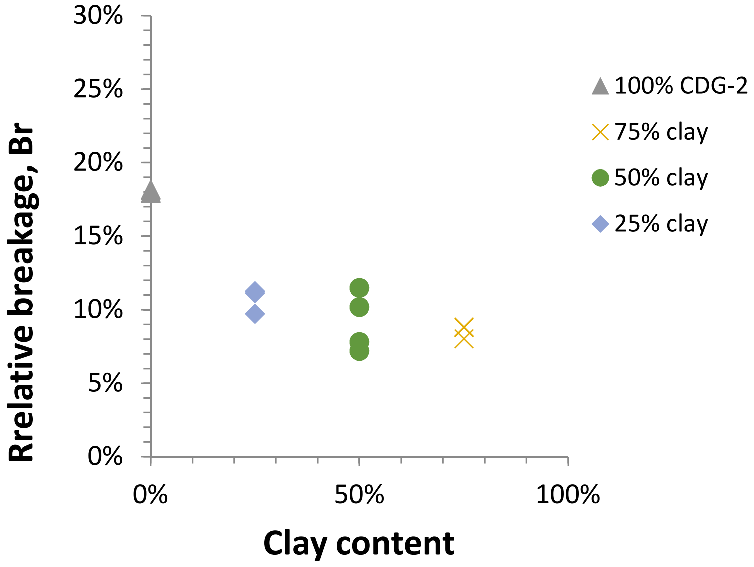

Fig. 65 Relationship between initial void ratio and relative breakage of kaolin and 2.36-5.00mm decomposed granite mixtures at 95% kaolin content.

5. Conclusion

In this research work, a series of oedometer tests was carried out on gap-graded soils in order to examine the compression behavior and the possible occurrence of transitional response. Reconstituted samples were constructed in the laboratory adopting the method of preparing slurries. Commercial kaolin was used as fine-grained portion while two fractions of completely decomposed granite (CDG-1, 2.36-5.00mm; CDG-2, 0.30-1.18mm) were used as coarse portion of the mixtures in which the percentages of clay in the mixtures range from 5% to 95% at intervals of 15% or 25%. Some additional unpublished data from mixtures as well as pure sand and reconstituted kaolin were also included in this project for further interpretations. In order to quantify the degree of transitional behavior in the mixtures, the void ratio at 6000 kPa, named $e_{6000kPa}$, was plotted against the void ratio at 10 kPa, named e_{10kPa}. By comparing different specimens from the same mixture prepared at variable initial void ratios, an horizontal line in the $e_{6000kPa}$- e_{10kPa} space could imply full convergence of the normal compression lines to a unique one, whereas a forty-five degrees slope could imply full transitional behavior and parallel NCLs. Particular emphasis was given in the accuracy of the initial void ratio determination in order to produce data of high quality and thus reliable interpretations. Almost all the tests had the required accuracy of initial void ratio calculation, thus the results may be assumed reliable.

For the mixtures composed of kaolin with completely decomposed granite (fraction 2.36-5.00mm), the compression behavior varied from sand type to clay type and at 50% to 65% content of clay transitional behavior was identified due to the non-convergence of the compression curves at high pressures and thus a unique NCL could not be observed in that cases. The transitional behavior of these mixtures was also confirmed from the $e_{6000kPa}$- e_{10kPa} diagrams. For percentages of clay lower that 50% and higher than 65% in the mixtures, the samples did not show transitional behavior with clear unique NCLs. However, for the reconstituted kaolin samples it was observed that the compression lines did not converge implying a possible transitional behavior for the clay but further experiments may be needed to verify this finding.

Significant particle breakage was found in both transitional and non-transitional behavior soils and the amount of breakage decreased with increasing clay content, so a correlation between

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particle breakage and transitional behavior could not be clear. However, the particle breakage of the mixtures composed of kaolin and completely decomposed granite (fraction 2.36-5.00mm) at 50% to 75% did not change significantly while the transitional behavior was found between 50% and 65% clay content. This observation implies that the transition from sandy soils to clayey soils is possibly within the range of 50% to 65% of clay content. An approximately linear relationship between the initial void ratio and the relative breakage was inferred from the plots, but because of the possible effect of the sieving procedure on the particle breakage further research using the QICPIC apparatus may be needed to verify these observations. Similar results were obtained from the tests conducted on the mixtures composed of kaolin and completely decomposed granite (fraction 0.30-1.18mm), but the amount of particle breakage and the clay content at which the transitional behavior appeared were lower.

From all the results above, it can be concluded that the compression behavior of gap-graded soils is complicated and the response will be dominated by either the coarse fraction or the fine fraction of the mixtures. If the coarse fraction is predominant, the compression behavior of gap-graded soils will follow a behavior more close to the sand whereas the compression response may be similar to clays if the fine-grained portion controls the response. When the proportions of these two fractions are about similar, this gives rise to transitional behavior resulting in non-convergence of the compression curves which means that the critical state framework may not be applicable to these soils. As this research work focused on the compression behavior of gap-graded soils so that the shearing behavior of the soils is unknown. In order to get insight into the critical state framework for this type of gap-graded soils, further experiments through triaxial testing may be necessary.

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