Evaluation of the Initial Shear Modulus of Clinker Ash through Bender Elements Tests

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1. Introduction

Clinker ash is formed in the boilers of coal-fired power plants. From the results of research so far, it has become clear that clinker ash has very angular particles, which have low particle density due to pores existing within and on the surface of the particles[1]. Compared with natural sands, clinker ash samples display high shear strength[2)3)] although the angular nature of the particles leaves them prone to particle breakage. In this research, the initial shear modulus of clinker ash is investigated using the bender element (BE) method under a variety of test conditions.

2. Materials Used

Samples of clinker ash from 6 power plants in Western Japan were used in this research, termed hereafter as C.A~C.F. The particle densities of the samples tested lie within the range of ρ_s=2.07-2.17g/cm^3 and the maximum densities are in the range of ρ_{dmax}=1.06~1.22g/cm^3. The particle distribution curves of the clinker ash samples are shown in Fig. 1. The range of particle distributions of clinker ash taken from 60 power plants across Japan is represented by the black curves in the figures[4]. It can be seen that the particle distributions of the samples used in this research lie mostly within this region.

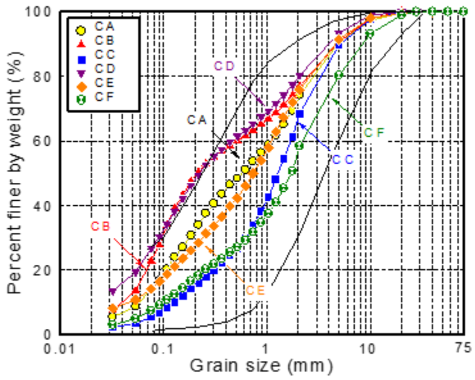

Fig. 1 – Particle Distribution Curves

3. Bender Element Tests

Bender elements fitted into triaxial testing apparatus where used to investigate the initial shear modulus of the samples of clinker ash. A series of experiments were performed on specimens with degrees of compaction of 85%, 90% and 100%. Specimens with lower density (D_c=85~90%) were prepared using the water pluviation method, whilst specimens with D_c=100% were prepared using a tamper and the sample was first frozen before being set in the apparatus and allowed to thaw. Specimen height was 10cm and diameter was 5cm. A voltage of 10V was applied and sinusoidal waves propagated through the specimens at frequencies of 10, 15 and 20kHz. The propagation time Δt of the wave was calculated using Eq. 1[5].

$$\Delta t = \frac{\Delta t_s + \Delta t_p}{2} - \Delta t_d \quad (1)$$

Where Δt_s is the propagation time between the starts of the waves, Δt_p is the propagation time between the peaks of the waves and Δt_d is the time delay of the measuring system. From this, the shear velocity V_s can be calculated and in turn the initial shear modulus G_0 as shown in Eq.2 and Eq.3 respectively.

$$V_s = \frac{L}{\Delta t} \quad (2) \qquad G_0 = \rho_t \cdot V_s^2 \quad (3)$$

Here, L is the distance between the tips of the bender elements and ρ_t is the wet density of the specimen.

4. Results

Figure 2 shows the relationship between G_0 and the confining pressure σ_c` for specimens prepared to degrees of compaction D_c=90% with results for Toyoura sand also shown for comparison.

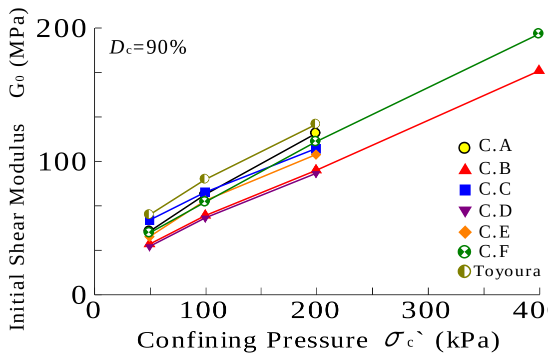

Fig.2 – Relationship between G_0 and σ_c`

An increase in confining pressure leads to higher values for G_0, with the values increasing in an almost linear fashion. Although C.A and C.C show some values close to those for Toyoura sand, clinker ash tends to have comparatively lower values of initial shear modulus. For the tests using samples C.B and C.F, the confining pressure was increased to 400kPa and then reduced to 200kPa, 100kPa and finally 50kPa in order to investigate the effect of an over-consolidated state on the initial shear modulus. The results for these tests are shown in Fig. 3. An over-consolidated state led to higher values of G_0 than when the specimen was in a normally consolidated state. It can be thought that this is due to the specimen having higher density in the over-consolidated state. Figure 4 shows the influence of degree of compaction on the initial shear modulus with results shown for specimens with degrees of compaction of 85%, 90% and 100%. From the figure it is clear that as degree of compaction increases the

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initial shear modulus also becomes larger.

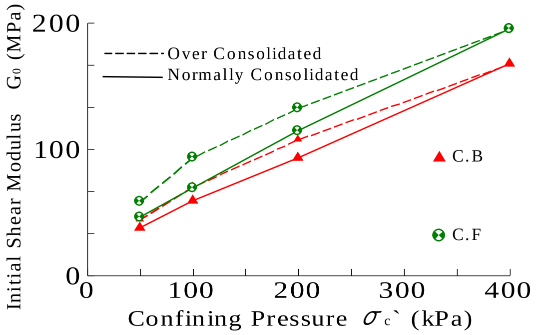

Fig.3 – Influence of over consolidation

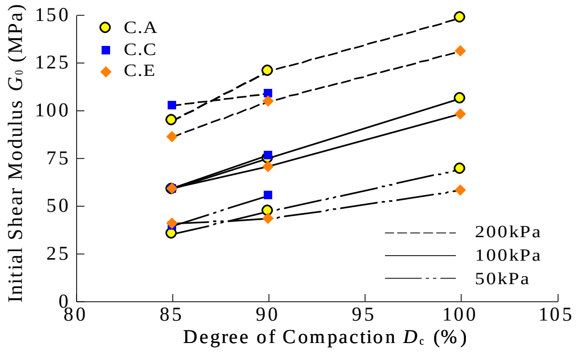

Fig.4 – Influence of D_c on G_0

Figure 5 shows the relationship between fines content F_c and initial shear modulus. Although there are some slight discrepancies, there is a trend for G_0 to decrease with increasing F_c.

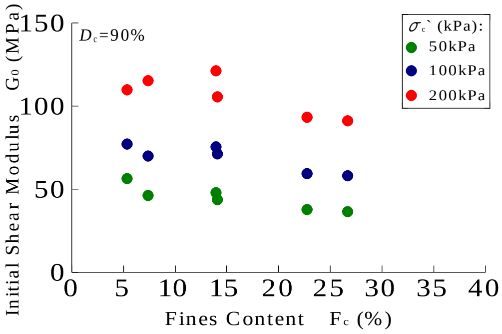

Fig.5 – Relationship between G_0 and F_c

Figure 6 shows the relationship between void ratio e and initial shear modulus. The broken lines represent the results for the over consolidated specimens. Although there are some slight discrepancies, on the whole there is a trend for G_0 to increase at lower void ratios. It be thought that this is one of the reasons for clinker ash displaying lower values for G_0 than Toyoura sand.

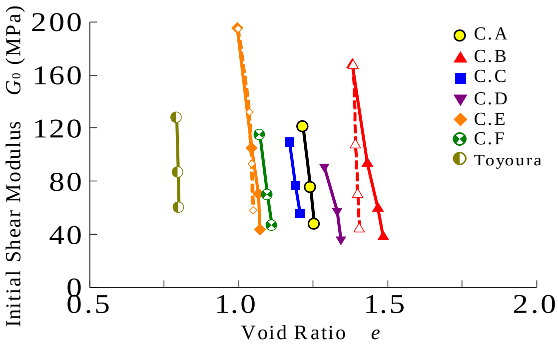

Fig.6 – Relationship between G_0 and e

A comparison of the initial shear modulus gained from the BE tests and hollow torsional (HT) and triaxial (T) tests is shown in Fig. 7. The shear modulus gained from the triaxial tests is calculated using Young's modulus E, as shown in Eq. 4.

$$G = \frac{E}{2(1+\nu)} \quad (4)$$

Poisson's ratio ν was taken as 0.5 in this research. Although the results for the T and BE tests are similar for C.D, on the whole the results from the BE tests are higher than those from the other tests. A similar trend has been shown in past research[6].

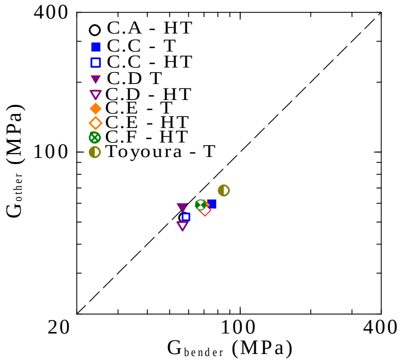

Fig. 7 – Comparison of results for G

5. Conclusions

In comparison with Toyoura sand, clinker ash display lower values of initial shear modulus, although G_0 increases with an increase in degree of compaction. Specimens in an over consolidated state give higher values of G_0 than in a normally consolidated state under the same confining pressure. From the relationship between fines content and initial shear modulus it can be seen that higher F_c leads to lower values for G_0. Also, although there are some discrepancies in the results, there if a trend for initial shear modulus to increase with decreasing void ratio. In comparison of the shear modulus gained from BE tests and from HT and T tests, the results for G_0 from the BE tests give slightly higher values.

6. References

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