Strength and deformation characteristics of recycled concrete aggregate

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Introduction: The aggregates required for concrete, embankments, backfills and road bases are usually obtained either from the natural sources such as river beds, natural quarries, or by crushing rock masses. However, the availability of a high quality aggregate have been depleted at many places due to large construction activities. On the other hand, modern structures have been constructed using a significant amount of concrete. Dismantling and reconstructing work of them are growing at an increasing rate, while discharging large amount of used concrete waste. It is recommended to use such waste materials as much as possible for:

1. Environmental and natural resource aspect: Utilization of used concrete contributes to the maximum use of limited natural resources; and
2. Economical aspect: Aggregate produced by crushing the dismantled concrete may be cheaper, depending upon the locations.

While there are a number of researches to use such a waste material as a coarse aggregate in concrete (e.g. RILEM report, 1998), its use as backfill for embankments or other earth works has been studied to a only limited extent. In the present study, stress-strain behaviors of such material were evaluated by performing triaxial compression tests with precise measurements.

Material and sample preparation: The main material tested was a crushed-concrete aggregate (R-aggregate) obtained from the sub-base of a temporarily built embankment for a railway line. The specific gravity was 2.65 for the particle size less than 10 mm and 2.12 for the coarser fraction. Fig. 1 shows the gradation curves of R-aggregate along with i) well-graded gravels (model Chiba and Kyushu gravels; Lohani et al., 2003), ii) Toyoura sand, and iii) glass beads. Smaller fraction of R-aggregate obtained by screening out the particle sizes larger than 2 mm (R-agg. (<2 mm)) was also tested in this study. Fig. 2 shows the gradation curves of R-aggregate before and after compaction with 2.48 Nm/cm^3 energy. The results show a large amount of crushing of coarser fractions during compaction process. This property can be taken as a qualitative index of particle strength. It is most likely that mortar attached on the surface of natural aggregate is ripped off and crashed rather than the natural aggregate itself is broken during compaction. The specimens of R-aggregate as well as model Chiba gravel and Kyushu gravels were prepared by compacting the material at around the respective optimum moisture content. The specimens of Toyoura sand (relative density, Dr=70%) and glass beads (Dr=90%) were prepared by air-pluviation using air-dried particles. Drained triaxial compression tests were performed on cylindrical specimens of 10 cm in diameter and 20 cm in height, that were moist or air-dried as prepared. The confining pressure was varied from 20 to 90 kPa to evaluate its effect (Fig. 7 shown later) in one series of the tests, while it was only 20 kPa for all other tests.

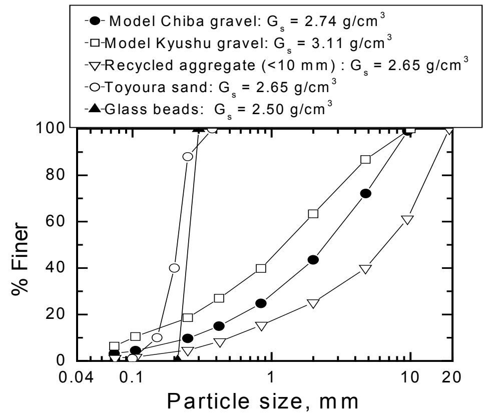

Figure 1. Grain size distribution curves

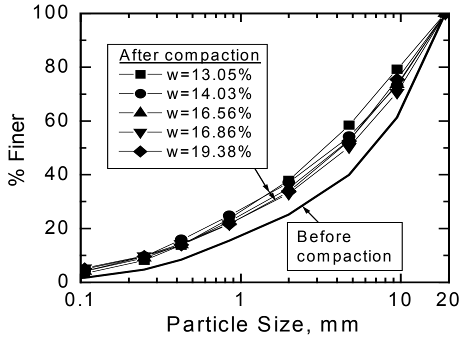

Figure 2. Grain size distribution curves of R-aggregate before and after compaction.

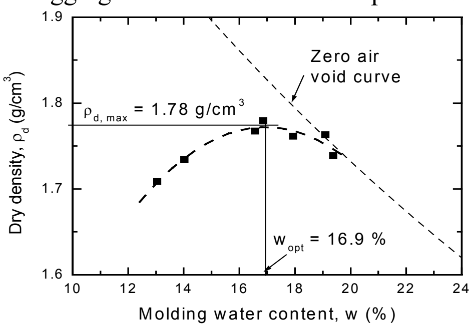

Figure 3. Compaction curve of recycled concrete aggregates.

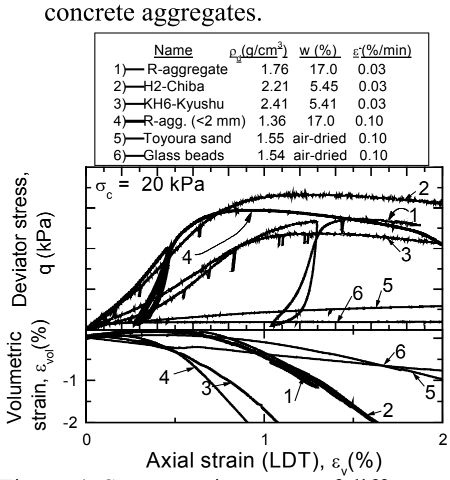

Figure 4. Stress-strain curves of different types of geomaterials.

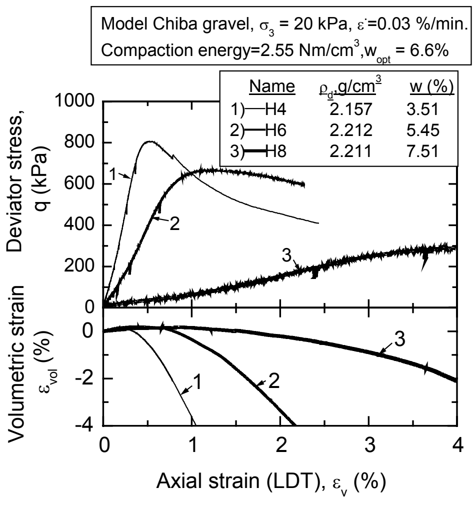

Figure 5. Effect of water content on stress-strain behavior in model Chiba gravel.

Results and Discussions: The compaction test result (Fig.3) shows the maximum dry density $\rho_{d,max}$ of 1.78 g/cm^3 and the optimum water content (w_{opt}) of 16.9%. Lohani et al. (2003) obtained $\rho_{d,max}$ of 2.22 and 2.49 g/cm^3 at w_{opt} of 6.6% and 5.8% for weakly cemented model Chiba gravel and Kyushu gravels respectively for nearly the same energy. Thus smaller $\rho_{d,max}$ and much higher w_{opt} values of the recycled material compared to the other gravels are confirmed. It is most likely that higher water absorption in R-aggregate and large breakage due to compaction affected the result. Despite the initial coarser gradation of R-aggregates (Fig. 1), the breakage of particles by compaction might have resulted in a similar gradation to the other gravels. Fig. 4 shows the relationships among the deviator stress, q (= $\sigma_v' - \sigma_h'$, where σ_v' and σ_h' are vertical and lateral stress respectively), the volumetric strain (ε_{vol}), and the axial strain. The following may be noted:

1) Glass beads with spherical grains showed the lowest strength. The tangent stiffness was high at the initial stage, but it decreased very fast with increase in the strain.
2) Toyoura sand at relative density of 70% also showed similar initial stiffness to glass beads, while showing much higher peak strength.
3) The other tested materials exhibited an increase in the tangent modulus with an increase in the axial strain until the respective certain strain level. The peak strength of R-aggregate (< 2 mm) was similar to the one of model chiba gravel, while the peak strength of R-aggregate and model Kyushu gravel were similar and noticeably smaller. Note that as the compaction curve was not obtained, the specimen of R-aggregate (< 2 mm) was compacted tentatively to ρ_d = 1.36 g/cm^3.

Figs. 5 and 6 show the effects of difference of the water content at sample preparation on the stress-strain behaviours for model Chiba gravel and R-aggregate, respectively. Fig. 7 plots the dry densities and peak strengths after compaction against the molding water content. Following may be noted:

1) Model Chiba gravel, having relatively small optimum water content, showed a relatively large sensitivity in peak strength as well as stiffness to a change in the water content whereas recycled aggregate samples exhibited a very small sensitivity.
2) With R-aggregate, the tangent modulus largely decreased as the deviator stress approached zero during unloading. This trend was similar for other water contents.

Fig. 8 shows a noticeable increase in the strength and stiffness of recycled aggregate when the specimens were compacted at the respective optimum water content. The strength and deformation characteristics of two types of recycled aggregates were similar to those of two types of well-graded gravel.

Conclusions: The following outcome for the recycled aggregates could be derived from the discussions so far.

1) The strength and deformation characteristics of two types of recycled aggregates were similar to those of two types of well-graded gravel.
2) The sensitivity of the strength and stiffness of R-aggregate to the molding water contents was much smaller than that of a well-graded gravel.
3) The strength and stiffness of R-aggregate noticeably increased with the confining pressure as well-graded gravel.

In summary, the tested recycled aggregate can be considered as a high-quality backfill material.

Reference: 1) Lohani, T. N., Kongsukprasent, L., Watanabe, K., & Tatsuoka, F. (2003), Strength and deformation characteristics of cement-mixed gravel for engineering use. Proc. 3rd Int. Symp. on Deformation Characteristics of Geomaterials, ISLyon 03, Balkema, Sept. 2003. 2)RILEM report 1998. Demolition and reuse of concrete and masonry, demolition methods and practice, Proc. 2nd int. Sym. By RILEM (Int. Union of Testing and Research Laboratories for Materials and Structures).

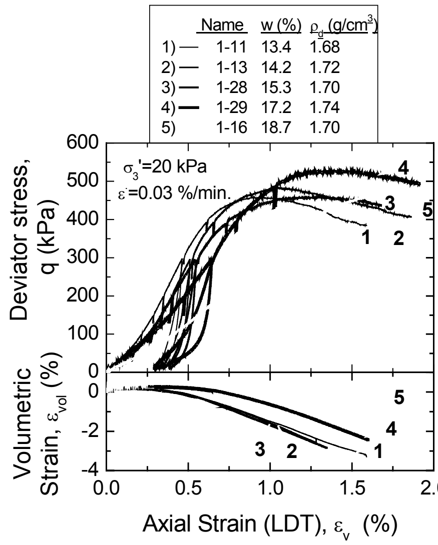

Figure 6. Effect of water content on stress-strain behaviours of recycled concrete aggregate.

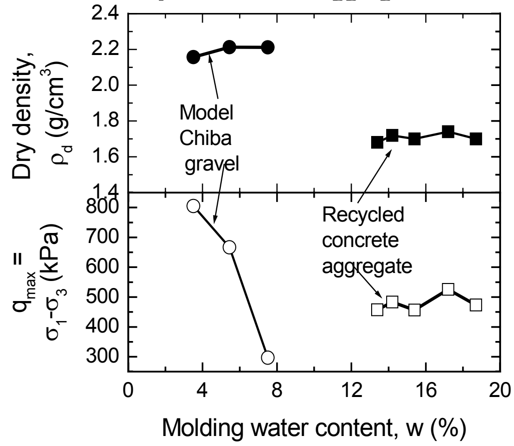

Figure 7. Compaction curves and (b) q_{max}-w relationships of model Chiba gravel and recycled aggregate.

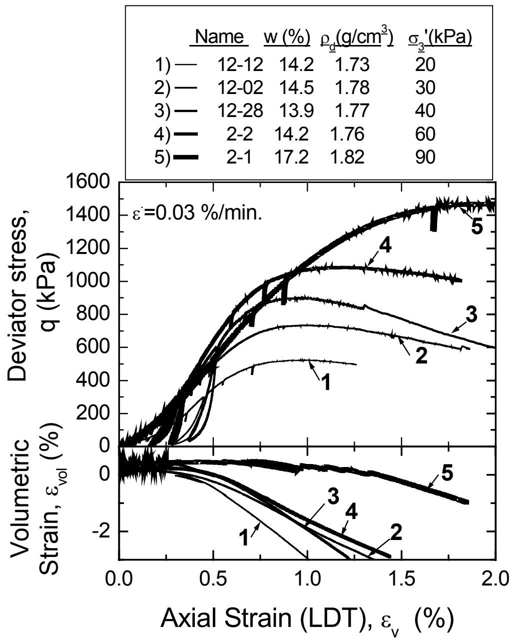

Figure 8. Effects of confining stress of recycled concrete aggregate.