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Strength and stiffness of compacted crushed concrete aggregate

Fumio Tatsuoka[a,*], Yu-Ichi Tomita[b], Yusuke Iguchi[c], Daiki Hirakawa[d]

[a]*Department of Civil Engineering, Tokyo University of Science (TUS), Chiba, Japan*
[b]*Tokyu Construction Co. Ltd., Japan*
[c]*Chemical Grout Co. Ltd., Japan*
[d]*Department of Civil and Environmental Engineering, National Defence Academy of Japan, Japan*

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Abstract

A comprehensive series of drained triaxial compression tests were performed on crushed concrete aggregate (CCA) moist as compacted. When compared to ordinary natural well-graded gravelly soils, the peak strength and stiffness increase more significantly with dry density, while the effect of the degree of saturation during compaction is much less significant. In a range of confining pressure of 30–600 kPa, the strength and stiffness of well-compacted CCA is similar to, or, in some cases even higher than, typical selected high-class backfill materials (e.g., well-graded gravelly soil of crushed quarry hard rock). The strength and stiffness of CCA with a maximum particle size $D_{max}=37.5$ mm obtained from a typical concrete crushing plant are noticeably lower than CCA sieved to $D_{max}=19$ mm compacted using the same energy. However, when compacted to the same dry density, the original CCA exhibits the strength and stiffness higher than the sieved CCA. Effects of the strength of original concrete on the strength and stiffness of compacted CCA are insignificant, while the strength and stiffness of compacted CCA are, respectively, noticeably higher than, or similar to, the original concrete aggregate (i.e., natural gravelly soil) compacted using the same energy. All these results indicate that well-compacted CCA can be used as the backfill material for important civil engineering soil structures requiring a high stability while allowing a limited amount of deformation.
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Keywords: Compaction; Crushed concrete aggregate; Degree of compaction; Drained triaxial compression; Stiffness; Strength; IGC: D06; D07

1. Introduction

In Japan and many other countries, a great amount of crushed concrete aggregate (CCA) is being and will be produced by demolishing old and/or out-of-service concrete structures. The use of CCA as the backfill of soil structures, such as embankments and retaining walls, replacing costly selected natural backfill soil (i.e., well-graded gravelly soil) is highly required. This is because (1) dumping of concrete scraps in remote places is usually unacceptable due to a too high environmental impact; (2) in many countries, although CCA has been used extensively in secondary applications, such as the road base material, such a secondary use as above will soon become insufficient to deal with produced CCA; and (3) an intolerable amount of energy is necessary to crush and treat concrete scrap to produce recycled fine and coarse aggregates having essential no thin surface mortal layer so that concrete having similar peak strength as the one achieved by using original natural aggregates can be produced.

CCA consists of strong and stiff core gravel particles covered with relatively weak and soft mortar surface layers (Fig. 1a). For this reason, CCA is often considered to be an inferior backfill material having strength and stiffness much lower than selected

*Corresponding author.
E-mail address: tatsuoka@rs.noda.tus.ac.jp (F. Tatsuoka).
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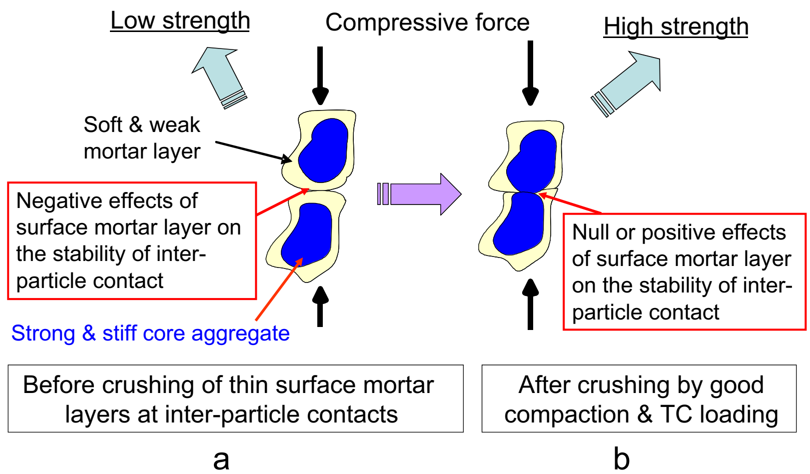

Fig. 1. Likely inter-particle contact conditions before and after good compaction of CCA.

natural backfill soils. When not well-compacted, the above could be the case (e.g., Mizukami et al., 1998). On the other hand, Aqil et al. (2005) and Tatsuoka et al. (2006) showed that, when well-compacted aiming at a good contact among stiff and strong core coarse aggregate particles (Fig. 1b), CCA can exhibit strength and stiffness equivalent to, or even better than, high-class backfill materials comprising well-graded strong and stiff particles. Recent other studies (e.g., Jitsangiam et al., 2012; Grégoire et al., 2009, 2013) also showed similar results. These results indicate that well-compacted CCA can be used as the backfill material for civil engineering soil structures requiring a high stability while allowing a limited amount of deformation, as the case reported by Hasegawa and Shimakawa (2004).

Although several important findings were obtained by the previous studies, the triaxial compression (TC) test conditions in those studies were rather limited in terms of the ranges of compaction energy (therefore specimen dry density); the confining pressure; the maximum particle diameter, D_{max}; and others. That is, although the D_{max} value of CCA provided by concrete crushing plants is usually around 40 mm, most of the previous TC tests used sieved materials having smaller D_{max} values. Besides, the compressive strength of original concrete and the TC strength of compacted concrete aggregate used to produce the original concrete were both unknown. In view of the above, more systematically, the following four series of consolidated drained (CD) TC tests were performed on CCA specimens:

series 1 to evaluate the effects of compaction energy and water content during compaction;
series 2 to evaluate the behaviour in a wider range of confining pressure;
series 3 to evaluate the effects of D_{max} ; and
series 4 to evaluate the effects of the compressive strength of original concrete.

For the same compaction energy, the strength and stiffness of CCA were compared with those of: (a) typical high-quality natural backfill materials in series 1, 2 and 3; and (b) the aggregate used to produce the original concrete in series 4. In each series, a number of tests were performed changing by small increments the

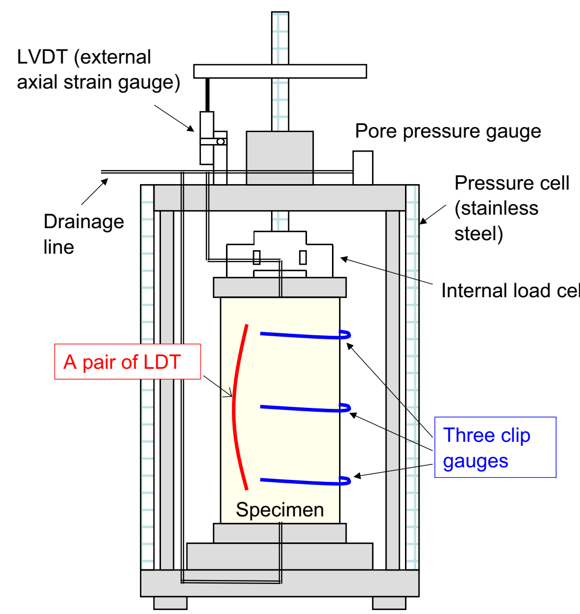

Fig. 2. Large triaxial apparatus for specimens of 30 cm-d and 60 cm-h (Tatsuoka et al., 1999b).

influencing factor to reliably capture the general trend of data that may scatter. The specimens during drained triaxial tests were kept moist as compacted. According to the test results showing that the difference between the strength and deformation characteristics of moist and saturated CCA specimens is very small (Aqil et al., 2005), the results from this study can be applied to saturated conditions. As the suction was not measured in the drained TC tests, exact effective stress values are not known. The effective stresses shown in this paper are those that were obtained ignoring suction.

2. Triaxial test method

A fully automated triaxial apparatus for small specimens (10 cm in diameter and 20 cm high) and another for large specimens (30 cm-d and 60 cm-h) (Fig. 2) were used. The small and large specimens were axially loaded by means of, respectively, a

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