Proceedings of the 16th International Conference on Soil Mechanics and Geotechnical Engineering

doi:10.3233/978-1-61499-656-9-619

Strength characteristics and construction management of cement-mixed gravel

Caractéristiques de résistance et gestion de la construction du gravier mélangé de ciment

K. Watanabe & M. Tateyama
Railway Technical Research Institute, Tokyo, Japan

T. Yonezawa & H. Aoki
Japan Railway Construction Transport and Technology Agency, Japan

ABSTRACT

Aiming at cost-effective use of cement-mixed gravel as the backfill of critical civil structures allowing small deformation, such as bridge abutments, a series of drained triaxial compression tests were performed on cement-mixed well-graded gravel. Based on these test results, new construction management standard for the cement-mixed gravel for the backfill of bridge abutment was prescirbed and it was applied to the current project of new bullet line at Kyushu. Additional large triaxial tests on core-sampled cement-mixed gravel specimen at Kyushu were also carried out and these specimens cleared the required strength, indicating that the standard is reasonable and practical.

RÉSUMÉ

Une série d'essais de compression triaxiale de grande envergure a eu lieu sur le ciment mélangé de gravier bien calibré en vue d'assurer la rentabilité par emploi de gravier mélangé de ciment pour le remblai de structures de génie civil essentielles autorisant une faible déformation, comme la culée d'un pont. Un nouveau mode de gestion de la construction pour le gravier mélangé de ciment pour le remblai de la culée des ponts a été défini sur la base des résultats des essais et appliqué au projet actuel du Shinkansen de Kyushu. Des essais de compression triaxiale de grande envergure complémentaires effectués sur des spécimens de gravier mélangé de ciment collectés sur le site de construction du Shinkansen de Kyushu ont permis de vérifier que la résistance requise était obtenue, démontrant que ce mode de gestion est rationnel.

1 INTRODUCTION

A research project to use well-compacted cement-mixed gravel as the backfill material for important permanent structures allowing a limited amount of deformation, such as bridge abutments for railway, has started, aiming at reducing the seismic-induced settlement of the backfill while increasing the cost-effectiveness. Fig. 1 is a schematic diagram of the first bridge abutment of this type for a bullet train railway constructed in Kyushu for a period of 2002 – 2003 (Watanabe et al. 2002). For this type of bridge abutment, the cement-mixed gravel backfill is much stable against seismic load and does not apply external force such as seismic earth pressure to the abutment. Further, since the abutment is connected to the backfill by reinforcement (Polymer geogrid), the backfill could laterally support the bridge abutment when the inertia force is oriented toward active direction during earthquake. For this reason, the abutment can be substantially slenderer than conventional RC bridge abutment.

In the limit state-based design of the proposed structure, it is required to evaluate the deformation and displacements of the structure at working loads as well as the closeness to the ultimate failure state of the structure under severe seismic loading conditions. To this end, the strength and deformation characteristics of cement-mixed gravel should be evaluated more accurately and more comprehensively than when used to construct secondary structures (such as road base). At the same time, as high as possible cost-effective proportion of components and construction method for cement-mixed gravel (i.e., a higher strength per unit cost) should be sought so that the construction of this type of structure can become a standard construction method.

In the present study, a series of drained triaxial compression (TC) tests were performed on cement-mixed specimens of two types of well-graded quarry gravels, crushed sandstone and crushed gabbro. Lohani et al. (2003 and 2004) studied the effects of moulding water content and grading characteristics of gravel by means of drained TC tests using smaller specimens (7.5 cm in diameter and 15 cm high) of model gravel (explained later). Kongsukprasert et al. (2003) studied the effects of stress condition during curing on the strength and deformation characteristics also by using smaller specimens of model Chiba gravel. In the present study, relatively large cement-mixed specimens were prepared by using the original gravel type as used in actual construction projects. To the best knowledge of the authors, such TC tests as above have not been reported in the literature. The effects of compacted dry density and moulding water content on the strength characteristics of cement-mixed gravel were mainly investigated, while the effects of grading characteristics were investigated to a limited extent. In addition, the strength characteristics of cement-mixed gravel were compared with those of uncemented original gravel.

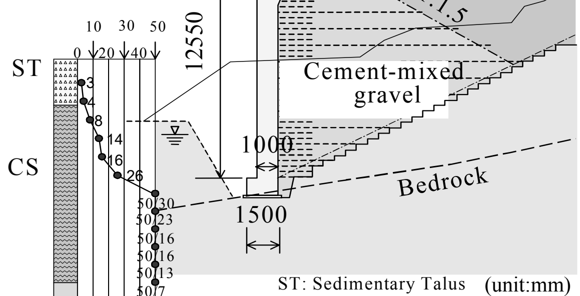


Figure 1. Typical bridge abutment with geogrid-reinforced backfill of cement mixed gravel for a bullet train railway in Kyushu, Japan

Based on these test results, designing and construction management standard was established for constructing new type bridge abutment with geogrid-reinforced cement-mixed gravel (Fig.1). This standard prescribes to compact cement-mixed gravel with higher compaction energy at the optimum water content. Further, unconfined compression tests using relatively large specimen should be performed before the construction in order to determine the appropriate mix proportion of cement-mixed gravel which satisfy the expected level.

In this study, additional large triaxial tests on core-sampled cement-mixed gravel specimen which was constructed in accordance with the newly prescribed construction management standard at Kyushu (Fig.1) were also carried out. These specimens cleared the required strength, indicating that the standard is reasonable and practical.

2 TESTING APPARATUS AND SAMPLE PREPARATION

Table 1 shows the list of the tests performed in this study, and Fig. 2 shows the compaction curves of two types of cement-mixed gravel called Chiba gravel and Kyushu gravel. This curve was obtained by standard compaction tests and the sizes of mould and compaction energy levels are also listed in Fig. 2. The specimens for TC tests were 20 cm in diameter and 40 cm high for cement-mixed Chiba gravel and 15 cm in diameter and 30 cm high for cement-mixed Kyushu gravel. This smaller dimension was chosen to meet a limited capacity of the loading machine compared to a large strength of cement-mixed Kyushu gravel specimens.

To investigate the effect of grading characteristic on the strength and deformation characteristics of cement-mixed gravel, another TC test was performed on a cement-mixed specimen of model Chiba gravel that was obtained by removing particles larger than 10 mm from the original Chiba gravel.

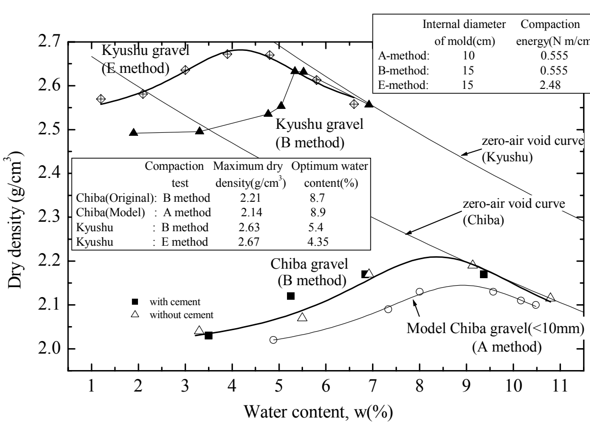


Figure 2. Compaction curves of Chiba gravel and Kyushu gravel

All the drained TC tests were performed using a large triaxial testing apparatus at Railway Technical Research Institute. The apparatus is able to control axial displacements to an accuracy of less than 1 μ m. Watanabe et al (2003) reported the detail of this apparatus. The specimens were initially isotropically compressed to the prescribed confining pressure and then sheared in drained TC at a constant axial strain rate of 0.01 %/min under constant confining pressure until the axial strain became 15 %. Three axial unload-reload cycles with a small axial strain amplitude were applied at various deviator stresses during otherwise monotonic loading to evaluate the equivalent elastic vertical Young's modulus (E_{eq}) and Poisson's ratio (ν_{vh}).

The test results were compared with those on the same type of uncemented Chiba gravel which was performed by Jiang et al. (1999).

3 TEST RESULTS AND DISCUSSION

3.1 *Strength characteristic at different compacted dry densities*

Figs. 3a, b and c show test results typical of those for cement-mixed Chiba gravel compacted to different densities. It may be seen that, at W_{cement}/W_{gravel}= 2.5 %, the peak strength increases significantly with the compacted dry density. On the other hand, the effects of compacted dry density on the residual strength, defined at an axial strain of 15 %, is very small, if any. Figs. 4 show the peak plotted against the compacted dry density of solid material (gravel and cement). The following trends of behaviour may be seen:

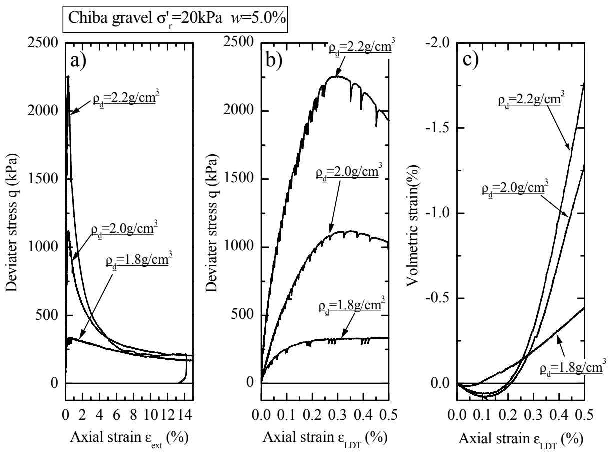


Figure 3. Typical overall deviator stress-axial strain relation, and local volumetric and axial strain relation of cement-mixed gravel at different dry densities

Table 1. List of the tests performed in the present study

Type of gravel	Dry density (g/cm^3)	Confining pressure (kPa)	Water content (%)	Cement/gravel ratio in weight(%) (W_{cement}/W_{gravel})	Cement/gravel ratio in volume(%) (V_{cement}/V_{gravel})	Size of specimen (mm)
Chiba (cement mixed)	1.8, 2.0, 2.2	0, 20, 50	3.5, 5.0, 8.7, 10.5	2.5	6.78	φ 200*H400
model Chiba (<10mm) (cement mixed)	2.0	20	8.7	2.5	6.78	φ 200*H400
Chiba (without cement)	1.8, 2.0, 2.2	0, 20, 80	4.0	-	-	φ 300*H600
Kyushu (cement mixed)	2.41, 2.56, 2.64	0, 20, 50	4.35	2.5	7.58	φ 150*H300
Kyushu (without cement)	2.41, 2.56, 2.64	0, 20, 50	4.35	-	-	φ 200*H400

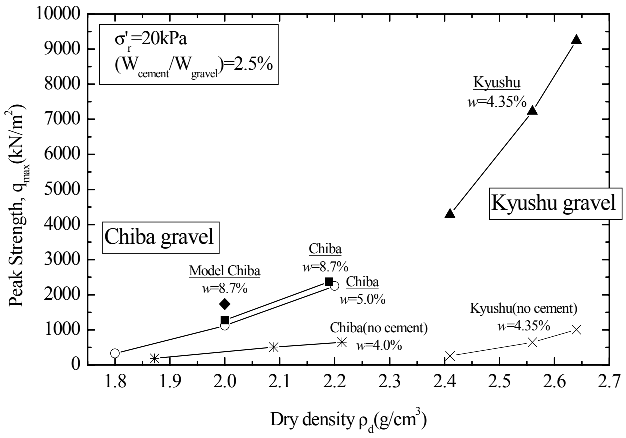


Figure 4. Relations between peak strength and dry density

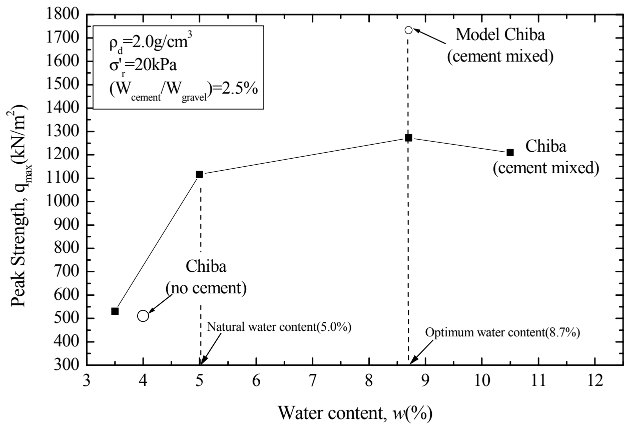


Figure 5. Relationship between peak strength and water content

1. With both cement-mixed and uncemented specimens of the two types of gravel, the peak strength increases with the compacted dry density. With both types of gravel, the difference in the peak strength between the cement-mixed and uncemented specimens increases with an increase in the compacted dry density. It is particularly the case with Kyushu gravel. This fact indicates the importance of increasing as much as possible the compacted dry density when the backfill is constructed by using cement-mixed gravel.
2. When compacted by using nearly the same energy and with the same cement/gravel ratio in weight (W_{cement}/W_{gravel}), the peak strength of cement-mixed Kyushu gravel is significantly larger than that of cement-mixed Chiba gravel. This is mainly caused by the difference of cement/gravel ratio in volume (V_{cement}/V_{gravel} , Table 1) which was caused by a higher specific gravity of Kyushu gravel particle (G_s=3.03 compared to 2.71 of Chiba gravel). Watanabe et al. (2003) and Lohani et al (2004) discussed this feature in detail.

The peak strength of the cement-mixed specimen of the model Chiba gravel, not including particles larger than 10 mm and having a smaller coefficient of uniformity, is noticeably larger than that of cement-mixed original Chiba gravel for the same dry density. This is because the compaction energy to achieve the same dry density is smaller with the original Chiba gravel than the model Chiba gravel.

3.2 *Effects of moulding water content*

Fig. 5 shows the relationship between the peak strength and the moulding water content for cement-mixed Chiba gravel. The following trends of behaviour may be seen. Firstly, the peak strength became largest at the optimum water content (w= 8.7%). This trend of behaviour is due mostly to the largest cement content per volume of specimen and the largest compacted dry density (or the smallest compacted void ratio) and partly to the effects of microstructure (Lohani et al. 2004) attained when compacted at the optimum water content.

Secondly, the peak strength when compacted at w= 3.5% is very small, becoming very close to the peak strength of uncemented gravel. It appears that this very low strength was due to an insufficient amount of cement slurry to be distributed uniformly at inter-particle contacts. The same trend of behaviour was also observed in the TC tests on small specimens of cement-mixed model Chiba gravel (Lohani et al. 2004).

These results indicate that the water content should be strictly controlled, possibly to be at the optimum water content, when compacting a given type of cement-mixed gravel in construction projects.

4 CONSTRUCTION MANAGEMENT STANDARD OF CEMENT-MIXED GRAVEL

A series of triaxial tests on cement-mixed gravel revealed that the peak strength of cement-mixed gravel increased with an increase of in the compacted dry density, especially at optimum water content. These tests also revealed that the strength characteristic between different gravel was significantly different, which could be attributed to the different grading characteristic and gravel type. All these strength characteristic of cement-mixed gravel are taken into account, new construction management standard for the cement-mixed gravel for the backfill of bridge abutment was prescribed and it was applied to the current project of new bullet line at Kyushu. The outline of this standard is as follows.

1. Well-graded gravel which was determined by Japanese Industrial Standard (JIS A5001) should be used for the backfill material. In this standard, grading characteristic, sort of gravel are strictly restricted.
2. In order to decide the best mix proportion (i.e. best cement/gravel ratio) of cement-mixed gravel, unconfined compression test should be performed before the construction. The size of specimen should be relatively large (150mm in diameter, 300mm in height) in order to avoid the influence of particle size effect relative to the specimen size. The specimen should be compacted sufficiently so that the ratio of compacted dry density to the respective maximum dry density exceeds 95%. The compaction method for determining the maximum dry density and optimum water content should be in accordance with the standard compaction test (E-method) which was prescribed by Japan Industrial Standard (JIS A1210, Fig.2). The required unconfined compression strength at optimum water content after 28 days curing is 3460kPa and the allowable minimum cement/gravel content in weight is 2%. . This required strength was determined by considering the difference of peak strength of cement-mixed gravel specimen prepared in laboratory and peak strength of onsite specimen. (The required strength for onsite specimen is 2000 kPa)
3. In order to determine the compaction equipment and a number of compaction, rolling compaction tests should be performed. They should be determined so that the ratio of compacted dry density to the respective maximum dry density exceeds 95%.

The cement/gravel content in weight was strictly controlled to become 4% and water content to become optimum (5%) for the actual construction at Kyushu.

In order to confirm the strength characteristic of constructed cement-mixed backfill, additional triaxial compression tests on core-sampled specimen were performed. The specimens were sampled by Improved Fresh-Water Core Sampling method and

Table 2. Test condition and part of test results of core-sampled specimen

Name of specimen	Sampled depth (m)	Confining pressure(kPa)	Diameter (mm)	Height (mm)	Weight (Kg)	Density ρ_t (g/cm^3)	q_{max} (kPa)	q_{res} (kPa)	LDT, ε_a (%) at q_{max}
IFCS-A	5.65	29	128	254	8.160	2.51	2466	440	-
IFCS-B	5.32	29	128	228	7.200	2.46	3444	498	0.30
IFCS-C	4.10	29	128	224	6.814	2.37	2700	446	0.30
IFCS-D	8.95	29	128	252	8.060	2.50	4010	725	0.30

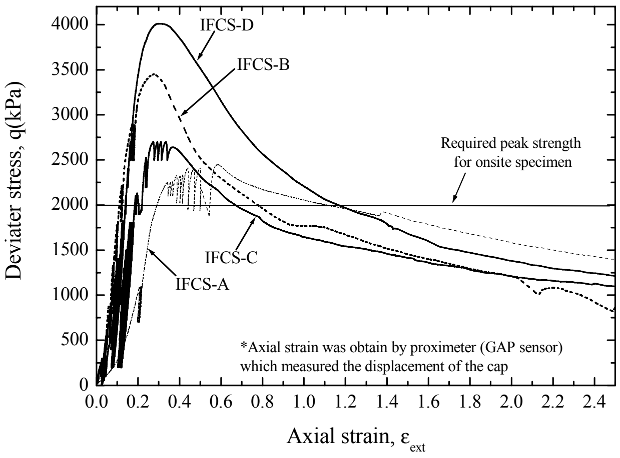


Figure 6. Deviator stress-axial strain(external) relations for all core-sampled specimen

Table 2 shows the lists of the performed test together with the peak strength of each specimen. The confining pressure for all specimen was 29kPa and end lubrication was arranged at the top and bottom of each specimen.

Fig.6 shows the deviator stress - axial strain relations for all specimen. Although variability of peak strength can be observed from these tests, all specimens satisfied the newly settled minimum requirement, 2000kPa, indicating that the new construction management standard is reasonable and practical.

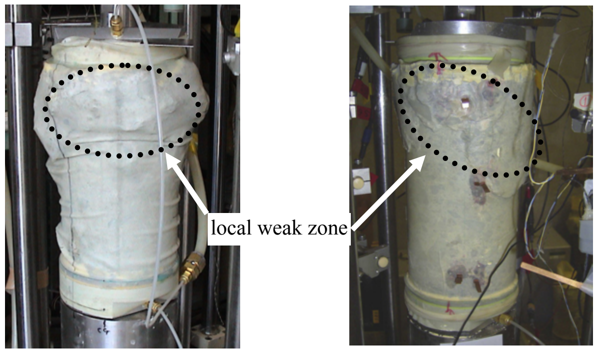
The main reason of this variability may be attributed to the insufficient mixture (distribution) of cement slurry into the gravel, which generated the locally strong and weak area in the specimen. As seen from Fig.7, strain was localized only at the upper part for some core-sampled specimens, indicating the existence of local strong and weak zone in the specimen.

Although local strong or weak zone was generated, this could not become the critical problem for the total strength and deformation characteristic of backfill. This was confirmed by the lateral loading tests against this bridge abutment at Kyushu where the residual displacement was quite small after large horizontal load, corresponding Level 2 earthquake, was applied to the abutment (Aoki et al. 2004). This may be the effect of the geogrid which reinforced the local weak area in the backfill (Fig.1). Further investigations are required on this issue, especially on the interaction between the cement-mixed gravel and the geogrid.

5 CONCLUSION

The following conclusions can be derived from the test results presented above:

1. The peak strength of cement-mixed gravel could become significantly larger than that of uncemented gravel and the difference increases with an increase in the compacted dry density, especially at the optimum water content. This result indicates the importance of compaction and water control when constructing the backfill of cement-mixed gravel
2. Based on the large triaxial test results, new construction management standard of the cement-mixed gravel for the backfill of bridge abutment was prescribed and it was applied to the current project of a new bullet train railway at Kyushu.
3. Triaxial compression tests on core-sampled cement-mixed gravel specimen which was obtained from the backfill of newly constructed bridge abutment were performed. Although variability of peak strength was observed from these tests, all specimens satisfied the required strength, indicating that the new construction management standard is reasonable and practical.



IFCS-A (ε_a=15%) IFCS-D (ε_a=5%)

Figure 7. Deformed specimen after peak state

REFERENCES

Aoki, H., Yonezawa, T., Tateyama, M., Shinoda, M. & Watanabe, K. (2004), Development of high seismic performance abutment with geogrid-reinforced cement treated backfill, this conference

Jiang, G. L., Kohata, Y., Tateyama, M. & Tatsuoka, F. (1999), Small strain deformation characteristic at low pressure of dense gravel, *Proc. of the Second International Symposium on Pre-Failure Deformation Characteristic of Geomaterials*, IS-Torino, pp.291-296

Kongsukprasert, L. Kuwano, R. Lohani, T. N. & Tatsuoka, F. (2003), Viscous effects coupled with ageing effects on the stress-strain behaviour of cement-mixed granular materials and a model simulation, *Proc. 3rd Int. Symp. on Deformation Characteristics of Geomaterials*, IS Lyon 03 (Di Benedetto et al. eds.), Balkema, pp.569-577

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*, *IS Lyon 03* (Di Benedetto et al. eds.), Balkema, pp.637-643

Lohani, T. N., Kongsukprasent, L., Watanabe, K., & Tatsuoka, F. (2004), Strength and deformation properties of compacted cement-mixed gravel evaluated by triaxial compression tests, *Soils and Foundation*, Vol.44, No.5, pp.95-108.

Watanabe, K., Tateyama, M., Yonezawa, T., Aoki, H., Tatsuoka, F., and Koseki, J. (2002), Shaking table tests on a new type bridge abutment with geogrid-reinforced cement treated backfill. *Proc. of the 7th international Conference on geosynthetics*, Nice, France, pp.119-122

Watanabe, K., Tateyama, M., Jiang, G. L., Lohani, T. N. & Tatsuoka, F. (2003), Strength characteristics of cement-mixed gravel evaluated by large triaxial compression tests, *Proc. 3rd Int. Symp. on Deformation Characteristics of Geomaterials*, IS Lyon 03 (Di Benedetto et al. eds.), Balkema, pp.683-693