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# Bending tests on a beam of grid-reinforced and cement-mixed well-graded gravel

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ABSTRACT: Concrete engineers have developed RCC (roller compacted concrete) and CSG (cemented sand and gravel) as low cost concrete for construction of dams, which are mixture materials of aggregate, cement, and water with lower cement contents than usual concrete. Recently, geotechnical engineers are developing cement-mixed well-graded gravels as high quality geo-materials for backfilling and embankments. Such materials are similar to each other in the quality of well-graded gravel (or aggregate), mixture ratio of cement and water, and compaction quality control methods. Thus, these materials could be dealt with unified concepts of evaluation, designing, and construction methods. In this view point, the authors have compared these materials on the basic properties of compaction and strength characteristics. In this paper, as an application of such materials, bending behaviours of scaled model beams consisting of cement-mixed well-graded gravel with reinforcement are discussed in comparison with steel-reinforced concrete beams.

## 1 INTRODUCTION

### 1.1 *Concrete and cement-mixed gravel*

Concrete engineers have developed RCD and CSG methods, which use mixture materials of aggregate, cement and water with lower cement contents than usual concrete (Nagayama and Jikan, 2003). Such materials can be filled and mechanically compacted as like geo-materials to construct massive structures of dams. On the other hand, geo-technical engineers are developing cemented well-graded gravels as a new backfill material, in order to construct more rigid and stable soil structures. An example of railway bridge abutment with such materials with geogrid reinforcement is reported by Kongsukprasert, et al. (2005).

These materials are quite similar to each other in the quality of aggregate (or well-graded gravel), mixture ratio of cement and water, and compaction quality control methods (Uchimura et. al., 2006). So, they could be dealt with unique concepts, intermediate between two disciplines of concrete engineering and geotechnical engineering, on their material design, structure design, quality control, and construction methods. Figure 1 shows typical ranges of mixture ratios of several materials mixed with cement. With this chart, we can compare these materials in a unified way. The lateral axis (w/g = weight of water per weight of aggregate) and the vertical axis (c/g = weight of cement per weight of aggregate) are in geotechnical terms. Then, each straight line from the origin corresponds to a water-cement ratio (w/c), which is the most important index in concrete engineering. Uchimura et. al. (2006) compared these materials on their compaction and strength characteristics with some experimental results, showing Figures 2a and 2b as conclusions. In these figures, the compaction density is the ratio of the weight of well-graded gravel versus the total volume, excluding the weight of cement and water. The compaction dry density of the gravel (excluding the weight of cement) with a standard energy of 4.56 MN/m$^3$, and the triaxial peak strength of the specimens with a confining pressure of 20 kPa are measured with various mixture ratios, and shown with their contours respectively. For the triaxial tests, the specimen density was chosen as the value obtained from the compaction test at each mixture ratio, so that the strength was evaluated under the same compaction energy. It was found in Figure 2a that the higher cement content results in higher optimum water contents and lower compaction density if tested under constant compaction energy.

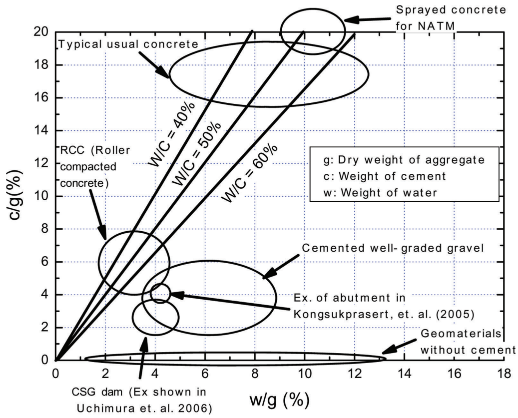


Figure 1. Mixture ratios of various materials with cement.

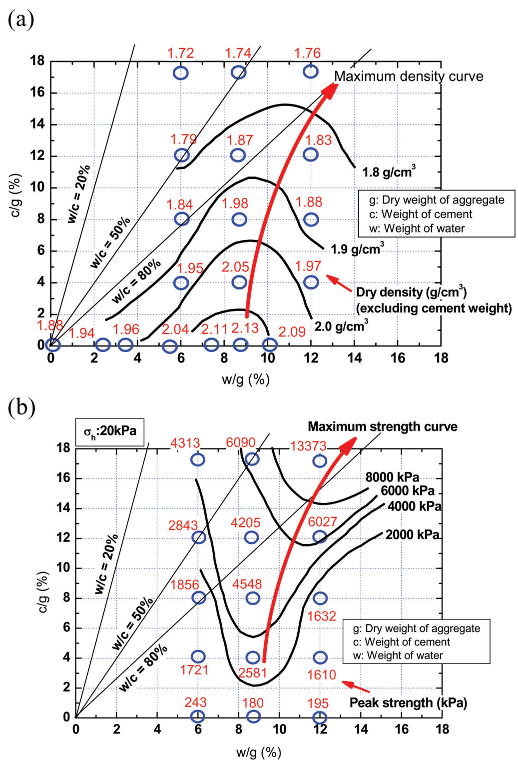


Figure 2. Material properties of cement-mixed well-graded gravel: a) compaction density, and b) triaxial strength.

Figure 2b shows that the strength of the specimens after curing was strongly dependent on the compaction density, rather than the effect of the cement-water ratio which is a dominant parameter in concrete engineering, if compared with the same cement contents.

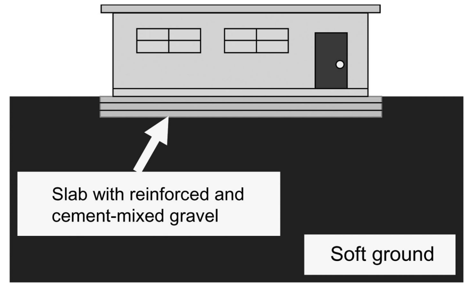


Figure 3. Example of use of reinforced and cement-mixed well-graded gravel for a foundation on a soft ground.

### 1.2 *Concepts of composite structure with reinforced and cement-mixed well-graded gravel*

In this paper, a combination technique of reinforcement with cement-mixed well-graded gravel is discussed. One of possible applications of this technique is schematically shown in Figure 3. When a small building is to be constructed on a soft ground, a slab of cement-mixed well-graded gravel is constructed with a high quality compaction, with layers of geogrid sandwiched. Such foundation structure could be low-cost and effective to prevent harmful differential settlement, as well as to achieve high seismic stability. High strength and rigidity are required to the slab, but it is hopefully ensured by the cementation and the function of geogrid layers. As the material components and structure are similar to those of reinforced concrete, the characteristics of grid-reinforced and cement-mixed well-graded gravel are possibly discussed in analogy with steel-reinforced concrete.

## 2 MODEL TESTS ON MODEL BEAMS

### 2.1 *Test method*

Bending tests were performed on short beams made of cement-mixed well-graded gravel, with one or two layers of geogrid or metal grid, and their deflection and failure sequences were observed.

The beam models were compacted in a steel mould into a rectangular shape (Length: 500 mm, Height: 200 mm, Width: 150 mm) as shown in Figure 4. The backfill material was well-graded gravel ($G_s = 2.71$, $D_{max} = 10$ mm, $D_{50} = 2.03$ mm, $U_c = 15.8$, fine contents = 4.3%), which is the same as the material used in the element tests shown in Figure 2. After standard portland cement and water were mixed with prescribed ratios, it was compacted to be the density shown in Figure 2a according to each mixture ratio assuming the same compaction energy. The mixture ratios and compaction density of the material were evaluated in the similar way

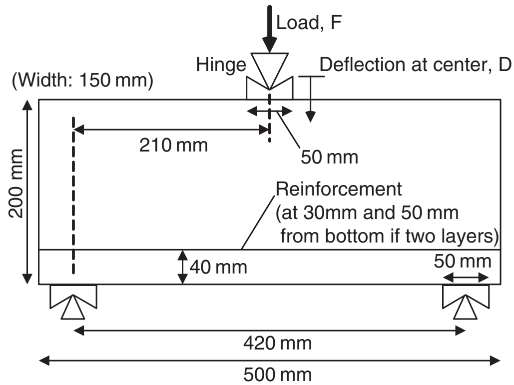


Figure 4. Beam models for bending loading tests.

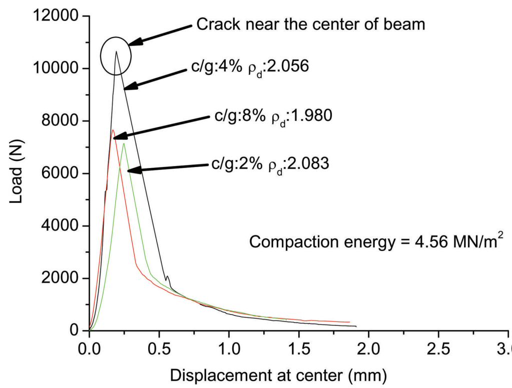


Figure 5. Behaviours of unreinforced beams with various cement contents.

as Figures 1 and 2. A geogrid (nominal rapture strength: 49.4 kN/m, aperture: 20 mm) and a metal grid (alminum, thickness: 1 mm, aperture: 10 mm, rib width: 3 mm) were used as reinforcement. They were laid at the height of 40 mm from the bottom of the beam for the models with one layer, and at 30 mm and 50 mm from the bottom for the models with two layers.

The beams were supported with hinges at both side of bottom with a beam length of 420 mm, and vertically loaded with a constant displacement rate at the center of the top surface with a hinge to make bending deformation. Steel plates with a length of 50 mm, which were attached to the surface of beam with gypsum, were placed at the hinges to prevent local failure due to stress concentration.

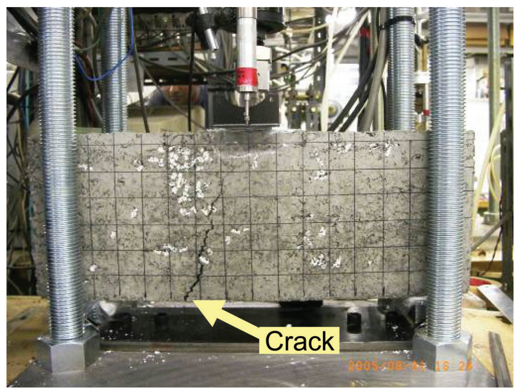


Photo 1. Failure of unreinforced beam model (c/g = 4%).

### 2.2 *Behaviours of unreinforced beams*

Figure 5 shows the relationships between the deflection and the load at the center of the beam without reinforcement. The cement mixture ratios for the backfill were and c/g = 2%, 4%, and 8%. The water contents was w/g = 8.75% for all the models, which is nearly the optimum water content for these cement ratios as shown in Figure 2a.

The curves show sharp peak strength at very small deflection of sub-millimeter order. A nearly vertical crack starting from the loading point was found at the peak stage of each beam as shown in Photo 1. The peak strength of the model with c/g = 4% was higher than that with a lower cement contents of c/g = 2%, to be easily understood. However, the peak strength of the model with higher cement contents of c/g = 8% was lower than that with c/g = 4%, probably due to the compaction density with c/g = 8% lower than that with c/g = 4% under the same compaction energy. Thus, the compaction density of cement-mixed well-graded gravel is important, as well as the cement contents.

### 2.3 *Behaviours of geogrid-reinforced beams*

Figure 6 shows the relationships between the deflection and the load at the center of the beam with one layer of geogrid, with c/g = 0% (uncemented), 2%, and 4%, and w/g = 8.75%.

As seen in Figure 6b, the beams with cement showed sharp peak strength at the beginning of loading, with a crack found at the center of the beam. The load and deflection at the peak were similar to those of the unreinforced models with corresponding cement contents shown in Figure 5. These results show that the reinforcement was not working at this stage with such small deformations.

After the peak, the load dropped similarly to the unreinforced models. However, some load was retained due to the effect of reinforcement, and the load started to increase again. At several stages, the load dropped with some extent, due to separation of the backfill from the surface of geogrid (Photo 2). The tension in geogrid was still functioning to resist the bending force even after the separation, and the load

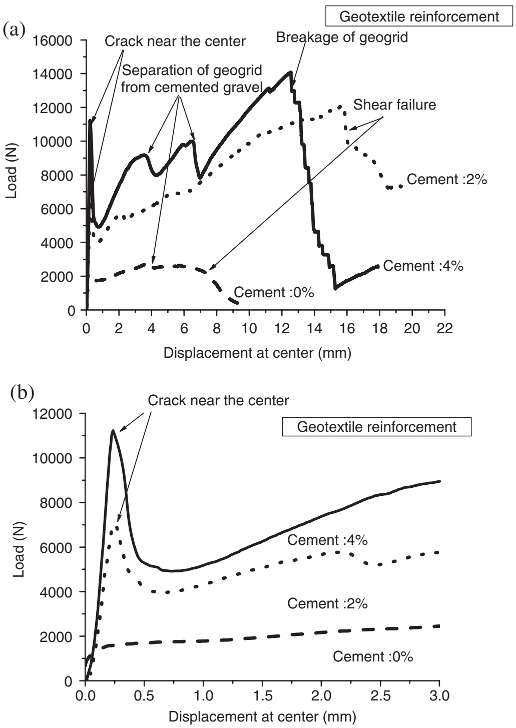


Figure 6. (a) Behaviours of geogrid-reinforced beams, (b) Detailed plot of (a) for the beginning of loading.

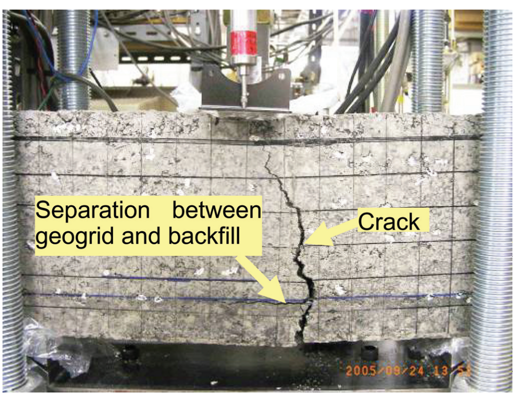


Photo 2. Crack at the center and separation along geogrid observed in reinforced beam (c/g = 4%).

continued to increase. Finally, the ultimate strength, which was higher than the first peak strength, was observed at breakage of failure in the geogrid or shear failure in the backfill (Photo 3a,b). The breakage in geogrid was observed at one end of the area of separation, not at the center of the beam.

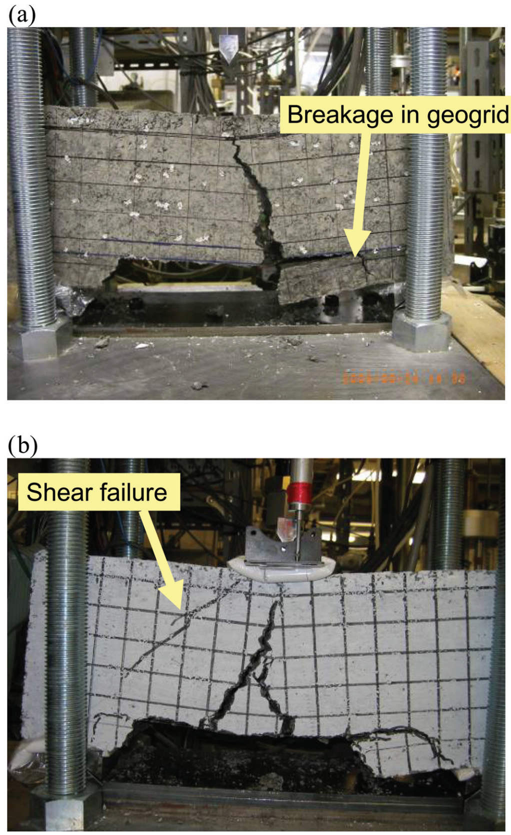


Photo 3. Ultimate failure of reinforced beam: a) breakage in geogrid (c/g = 4%); and b) shear failure in backfill (c/g = 2%).

The ultimate failure was observed at deflection of 12 to 16 mm, which is much larger than the deflection at the peak strength observed in the unreinforced beams. This means that the reinforced cement-mixed soil structures have significantly higher ductility than to unreinforced cases.

The tension in the reinforcement at the vertical crack near the center of the beam was estimated with a simplified assumption that the moment due to the vertical loading is fully supported by the tension in the reinforcement as shown in Figure 7. Figure 8 plots the obtained tension in the reinforcement when the first separation was observed against cement contents of the beams. The estimated tension at separation shows a good correlation with the cement contents. This correlation is probably corresponding to the difference in cohesion between the backfill material and reinforcement surfaces. This means that higher cement content contributes to the ductility of reinforced and cement-mixed well-graded gravel structures.

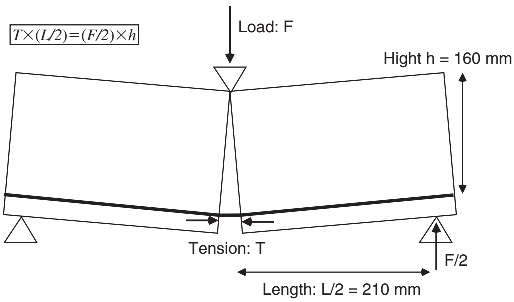


Figure 7. Schematic diagram of force equilibrium in a beam with reinforcement.

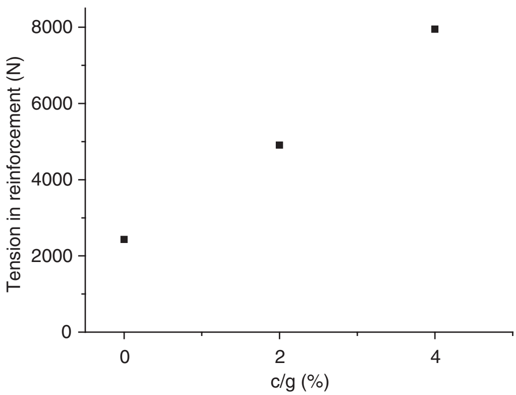


Figure 8. Relationships between load at separation along geogrid and estimated tension in geogrid.

## 2.4 *Behaviours of beams with stiffer reinforcement*

Figure 9 shows the relationships between the deflection and the load at the center of the beam with one layer of metal grid, with c/g = 2% and 4%, and w/g = 8.75%. Figure 10 compares its behaviour with those of the unreinforced beam and geogrid-reinforced beam, which are already shown in Figures 5 and 6, under the same cement content of c/g = 4%.

The metal-grid-reinforced beam again showed a peak at the beginning of loading, which is larger than the peak strength of the unreinfoeced and geogrid-reinforced beam. However, the load did not drop drastically, and then gradually increased to the ultimate failure. The ultimate failure mode was rupture in the metal grid or shear failure in the backfill depending on the cement contents. These behaviours are similar to what are typically observed in bending tests on steel reinforced concrete beams.

Figure 11 shows the relationships between the deflection and the load at the center of the beam with single and double reinforcement layers of geogrid,

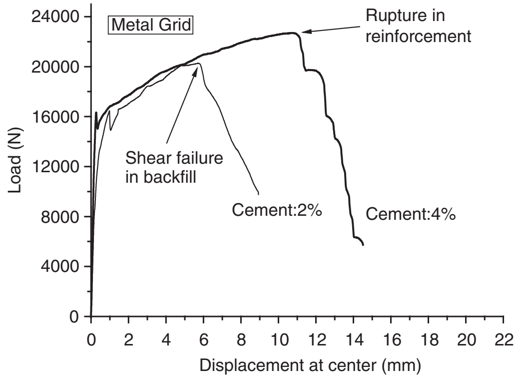


Figure 9. Behaviours of beams with metal reinforcement.

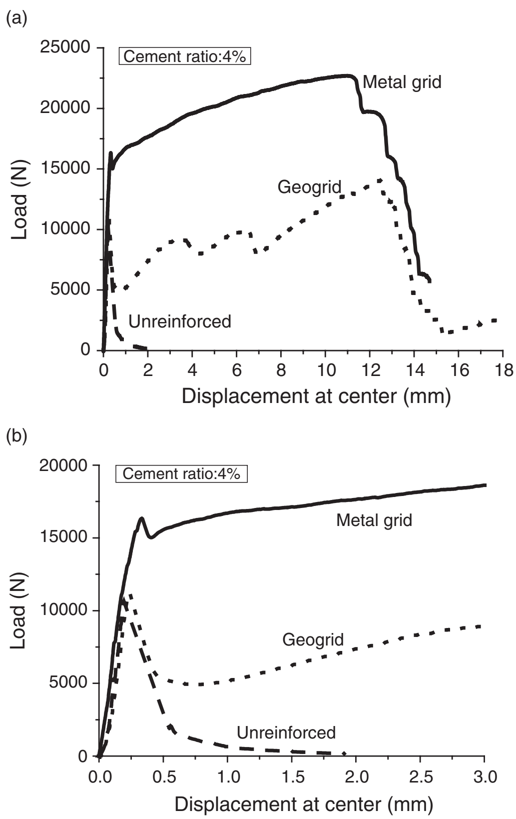


Figure 10. (a) Comparison of behaviours unreinforced, geogrid-reinforced, and metal-grid-reinforced beams; (b) Detailed plot of (a) for the beginning of loading.

with c/g = 4% and w/g = 8.75%. The behaviour of the beam with double reinforcement layers is similar to that with single layer. However, the amount of drop in the load after the first peak was smaller, and the

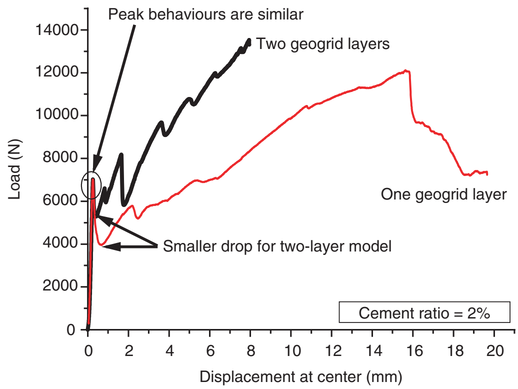


Figure 11. Behaviours of beams with single/double reinforcement.

ultimate strength was higher than the beam with single layer. It could be reasonable to understand that the beam became in an equilibrium state at smaller deformation of the double layer of reinforcement, and that resulted in lower drop in the load after cracking.

Thus, we can conclude that the behaviours of reinforced and cement-mixed well-graded gravel structures are largely affected by the stiffness of reinforcement, and it behaves like a reinforced concrete when the reinforcement is stiff enough.

## 3 CONCLUSIONS

Model beams made of reinforced and cement-mixed well-graded gravel were tested with bending load, and their characteristics were discussed with view points of concrete engineering and geotechnical engineering.

As like steel reinforced concrete beams, the reinforcement layers worked as a tensile member to resist to the bending force. The beams with reinforcement showed much more ductile behaviours compared to those of unreinforced beams. And their failure sequences are strongly affected by the stiffness of the reinforcement. When metal reinforcement was used, the beams behaved like reinforced concrete beam.

Besides, the beams showed some characteristics which are more familiar to geotechnical engineers. Not only the cement contents and water-cement ratio, but also the compaction density of the backfill material was an important factor for the strength of beams. The grid reinforcement did not contribute to the behaviour before a crack is observed at the center of beams, and after that, the load was dropped, and became supported by the tension in the reinforcement.

The progressive separation between the backfill and the reinforcement surfaces is also a specific characteristic of such structures.

In future, the reinforced and cement-mixed well-graded gravel could be useful as a new material who has higher quality than usual soils, as well as lower cost and better workability compared to concrete.

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