Construction of reinforced retaining structures using tire treads
Construction de la structure renforcée et retenue utilisant les chapes du pneu

Y. W. Yoon
Dept. of Civil and Environmental Engr., Inha University, Korea
K. S. Kim & S. B. Heo
Graduate school, Inha University, Korea
G. L. Yoon
Korea Ocean Research & Development Institute, Korea

ABSTRACT
Reuse of waste tires in construction site has advantages not only in the consumption of large quantities but also in substitution of commercial geosynthetics for soil improvement. Field pull-out tests were carried out for Tirecell which was made of treads without both sidewalls. As a result, pull-out characteristic of Tirecell was better than geocell. And Tirecell applied to reinforced retaining structures as reinforcement material instead of geocell and confirmed its reinforcing effect.

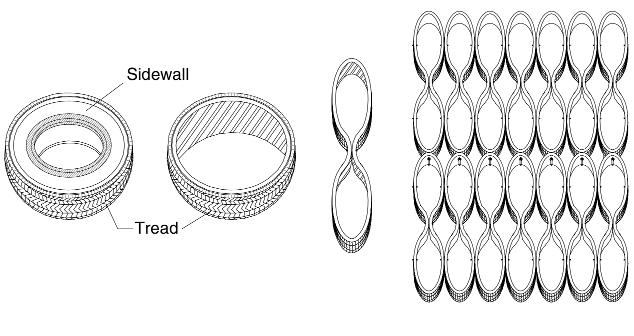
RÉSUMÉ
Recyclage du pneu utilisé dans le chantier a des avanta Recyclage du pneu utilisé dans le chantier a des avantager non seulement dans la consommation de grandes quantités, mais aussi dans la géosththénique commerciale pour l'amérilation du sol. L'épreuve sur place dans l'usure accomplit pour pneu l'usure accomplit pour le pneu de type-cellule qui ont été fabriqués par le tread sane sidewall. En conclusion le pneu type-cellupe a été mielleur que celui de geocell. En le type-cellule de pneu a été appliqué pour renfonrcer la structure conservée comme renfoncement matériel au lieu du geocell et l'acte du mur a été mesuré.

Keywords : waste tire, Tirecell, geocell, pull-out test, reinforced retaining structure

1 INTRODUCTION

Waste tire disposal has become a major environmental issue in many countries. Korea has generated waste tires of approximately 20 millions per year since 1998, and some of the tires are utilized for rubber tiles and blocks or cement materials. However, the cost of making rubber powder from a tire is very high. Therefore, several beneficial uses of waste tires have been proposed in the last decade, and some of them have already been applied in construction. Waste tires are desirable as construction material because of their excellent mechanical properties and durabilities. Tire chips can be used for lightweight fill(Humphrey & Manion, 1992; Foose et al., 1996; Humphrey et al., 1998; Reid et al., 1998); tire treads can be used as a form of grid(Yoon et al., 2004); whole tires or tires with one sidewall removed can be used(Garga & O'Shaughnessy, 2000).

In this research, tire sidewalls were removed and a shallow, large diameter and cylinder-type tire(Figure 1b) was folded to make small two cells forming an Arabic number 8 type.



(a) (b) (c) (d)
Figure 1. Combination process to make Tirecell

Many Tirecell units(Figure 1c) were combined to complete a Tirecell(Figure 1d), which can be used in the same way as a commercial geocell. The pull-out tests of Tirecell for various conditions were performed to study pull-out resistance. And retaining wall using Tirecell was constructed and the behavior was monitored.

2 PULL-OUT TESTS

2.1 *Geotechnical properties of test fill material*

2.1.1 *Index properties*

The index properties of the weathered soil used in the test fill were given in Table 1. The soil contains about 30% fines with mostly sandy soil.

Table 1. Index properties of sample

Sample	G_s	D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	C_u	C_g	USCS
Weathered soil	2.71	0.02	0.08	0.25	12.5	1.28	SM

The result of the modified proctor method for field test was shown in Figure 2. Maximum dry density was 18.4kN/m^3 at an optimum moisture content of 10.7% .

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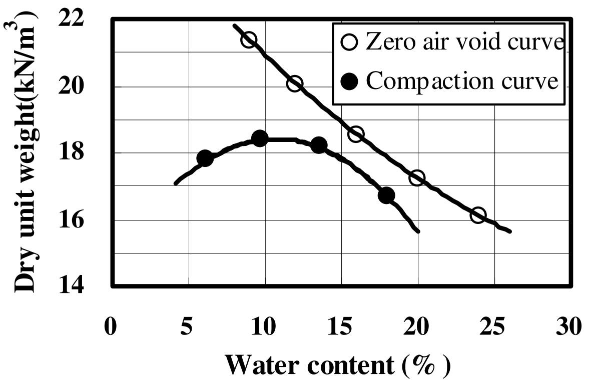

Figure 2. Compaction curve of the sample

2.1.2 *Frictional characteristics between soil and tread*

Large direct shear tests for both outside and inside of tread were performed to know frictional characteristics between soil and surface of treads as soil reinforcement material. The soil specimen was placed and competed in shear box(300mm×300mm×180mm). And the degree of relative compaction(RC) was 90% of max. dry density by modified proctor method. The tests were performed with 1.0mm/min speed under the vertical pressure of 39.2~313.8kN/m^2. In the test for soil-tread, dummy was placed below the tread to fix the tread and to adjust shear surface.

Figure 3 shows the results of large direct shear tests. The shear angles of friction were 34.7° for soil-soil, 33.9° for soil-outside surface of tread and 31.9° for soil-inside surface of tread. It means that the ratios of friction angle(δ/φ) for soil-outside and soil-inside surface of tread were 0.98, 0.92, respectively.

Considering the δ/φ ratio for concrete is approximately 2/3 or so, these ratios are generally very high. According to Koerner (2005), the ratios of friction angle(δ/φ) for geogrid of various types and well graded angular sand(SW) in dense compaction state were observed 0.72 ~ 1.07 in the large shear box(450×450mm).

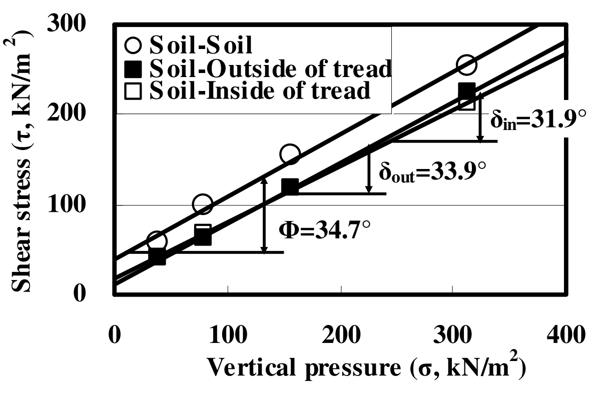

Figure 3. Mohr diagrams for sample(RC=90%)

2.2 *Field pull-out testing program*

In order to know pull-out characteristics with reinforcement material, field pull-out tests were carried out for various conditions of Tirecell in the same height of surcharge as shown Figure 4. In the same field condition, commercial geocell made by Presto company was tested also.

In Figure 4, the notation ① is the order of pull-out test; ② is the arrangement of Tirecell; ③ is the size for length and width of Tirecell; ④ is the distance from the end of slope to Tirecell at the embedded level. And 2×7 means 2 row and 7 column of Tirecell unit. Tirecells of 1×7, 2×7, 4×7 were prepared to compare the reinforcement effect by the reinforcement length. Also (F) indicates fully embedded up to the height of the embankment and (H) embedded from the edge of the slope. Therefore, (H) symbol indicates half is embedded on the slope and the other half is fully embedded.

Tirecells mostly were connected with high strength bolts at a point of contact between Tirecell units. But Tirecell 2×7(R) was connected with the polypropylene rope of 10mm diameter.

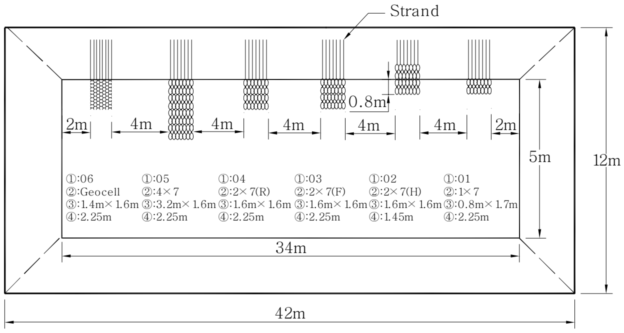

Figure 4. Field pull-out testing program for various conditions

2.3 *Construction of test fill*

For pull-out tests, backfill was designed to use conventional compaction techniques. 0.5 m height of backfill was completed before setting reinforcement materials and 1.5 m of backfill surcharge was placed after careful array of Tirecell and geocell. Each layer of 300mm thick per layer was compacted untill RC 90% with 98 kN vibratory roller.

Schematic for pull-out tests is shown in Figure 5. The pull-out force is transmitted from oil jack(①) to cross beam(②-Ⅱ,Ⅲ), strands(④) and reinforcement material embedded in test embankment. The reaction piles(⑥) of 10m length penetrated to 8.5m depth by driving are resist to pull-out force. For distribution of pull-out forces applied reaction piles, channel(⑦) was used. To ensure an equal transfer of pull-out force to each frontal Tirecell unit, the measuring system consist of two load cells(③) and two LVDTs(⑤) was installed on both side between cross beam(②-Ⅱ,Ⅲ). Supplementary beams were used to adjust the height of the equipment to the level of reinforcement material. And rigid rods(10mm dia., 300mm length) were put on to reduce the friction between cross beam and supplementary beam.

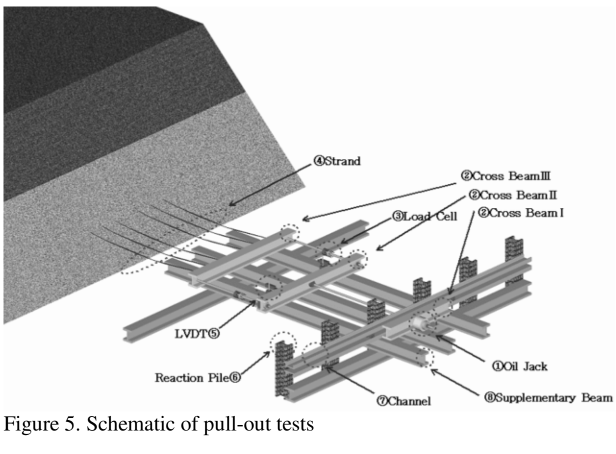

Figure 5. Schematic of pull-out tests

The pull-out force was measured every 4.9kN by load cell (capacity 196kN) and a standard error of 0.098kN. The test was not stopped until the strain ratio 15%, except for the case of definite peak value before the strain ratio 15%. The strain ratio is the ratio of displacement to reinforcement materials length,

2.4 *Test results and discussion*

Figure 6 shows the ultimate pull-out resistance for Tirecell of different length. In Figure 6, pull-out load represent the pull-out force per unit width of the reinforcement. In every test, pull-out behaviors of Tirecell have peak resistance value. Also it was observed that the ultimate pull-out resistance increased with the increase of Tirecell length. The total length of 2×7(H) and 2×7(F) is same. However the effective overburden surcharge of both are different and the 2×7(H) is rather similar to Tirecell 1×7 from the figure. Consequently, it can be seen that the surcharge by the slope is negligible.

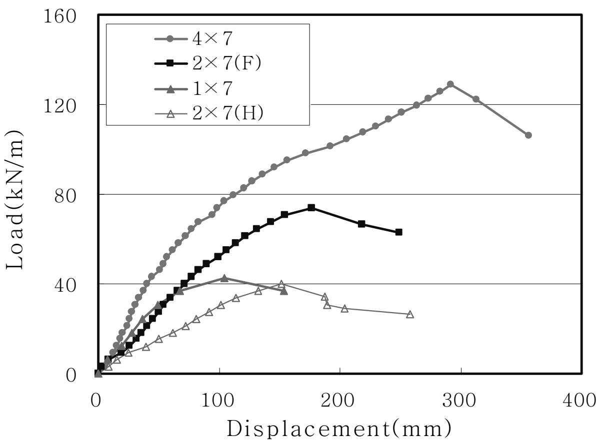

Figure 6. Pull-out behavior of Tirecell for different length

The pull-out test result of 2×7(F), 2×7(R) and geocell was shown in Figure 7. All curves in Figure 7 show clear peaks as in Figure 6. In Figure 7, Tirecell 2×7(F) is approximately 1.3 times higher the ultimate pull-out resistance of geocell. After the tests it can be seen that geocell was broken at frontal parts connected with pull-out strands whereas Tirecell 2×7(F), 2×7(R) was good condition.

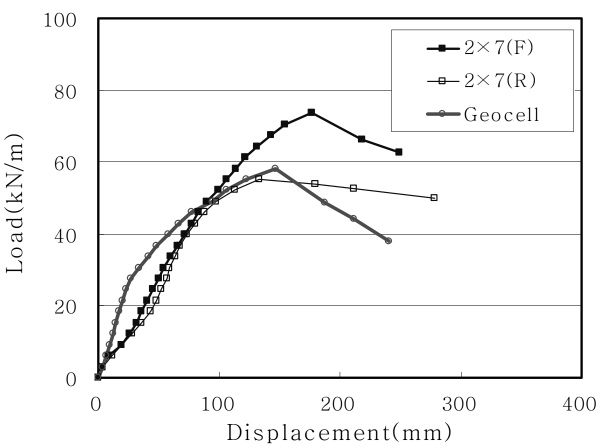

Figure 7. Comparison of behavior for commercial reinforcement material

3 REINFORCED RETAINING STRUCTURE

3.1 *Design and construction for reinforced retaining wall*

FHWA(2001) recommends a preliminary length of reinforcement to choose greater value between 0.7H and 2.5m, where H is the design height of the structure. Because the height of structure in this research is 3m, the Tirecell should be 2.5m at least. And because of the wall with a face batter of greater than 8 degrees, the coefficient by Coulomb's active earth pressure was used to calculate earth pressures developed on the wall.

External stabilities for sliding and overturning of the wall, internal stabilities for break and pull-out failure of Tirecell were satisfied for the factor of safety by FHWA(2001). The allowable tensile strength of Tirecell for evaluate internal stabilities was given in Table 2. And the depth of frost penetration in construction site was considered. Figure 8 shows the schematic of Tirecell reinforced retaining wall.

Table 2. Determining allowable tensile strength of Tirecell

RF_{CR}	RF_D	RF_{ID}	RF	FS	T_{ULT} (kN/m)	T_{al} (kN/m)	T_a (kN/m)
2.0	1.1	1.1	2.42	1.5	73.6	30.4	20.3

Where RF_{CR} is the reduction factor against creep(1.6~5.0); RF_D is the reduction factor against durable degradation(1.1~2.0); RF_{ID} is the reduction factor for installation damage(1.1~3.0); RF is the reduction factor(=$RF_{CR} \times RF_{FD} \times RF_{ID}$); FS is the factor of safety; T_{ULT} is the ultimate tensile strength of Tirecell 2×7(F) from pull-out test; T_{al} is the long-term material strength(=T_{ULT}/RF); T_a is the design long-term reinforcement tensile strength (=T_a/FS).

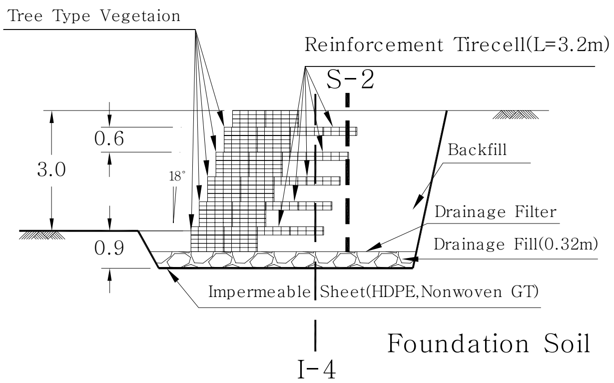

Figure 8. Schematic diagram of Tirecell reinforced retaining wall

3.2 *Displacement of retaining wall*

To monitor lateral displacements and settlements of retaining wall, inclinometer casing and settlement plate was installed. Figure 9 shows the results of inclinometer measurements. The max. lateral displacements of 1.39mm were measured. And 22 mm settlements occurred during construction, but at the end of construction it was converged into 2mm.

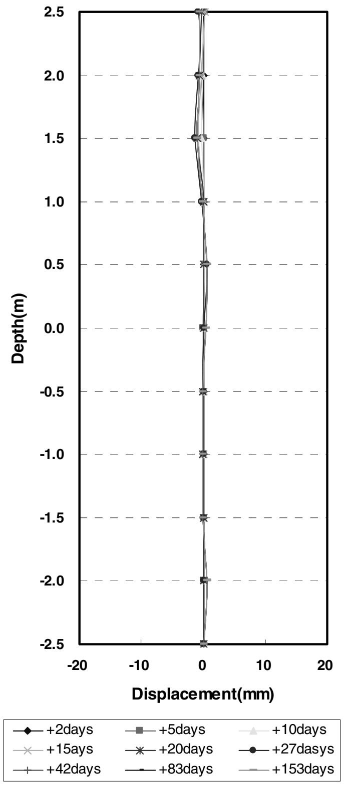

Figure 9. Lateral displacement of the retaining wall

4 CONCLUSIONS

This paper discussed a series of tests to utilize waste tire as reinforcement materials and compared to geosynthetics such as geocell. From the test results, the pull-out force to unit width of Tirecell was higher than that of geocell. That is, the utilization of waste tires as soil-reinforcing material proved to be excellent. And lateral displacements and settlement of Tirecell reinforced retaining wall was allowable. Therefore, the treatment method as form of mat, Tirecell could be useful not only as reinforcing material but also as a recycling of waste material.

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