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# Alternative Backfill Materials for Geosynthetically Reinforced MSE Walls

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SUMMARY: This study aims to facilitate the use of Recycled Concrete Aggregate (RCA) and Recycled Asphalt Pavement (RAP) in lieu of natural aggregates as alternative backfill for Mechanically Stabilized Earth (MSE) walls. The use of RCA and RAP as backfill can reduce costs associated with mining and transportation of natural aggregates, which can dominate the total cost of MSE wall. In addition, the disposal of RCA and RAP into landfills is costly and can pose environmental risks to air and groundwater alike. Mechanical interaction between these recycled aggregates with four types of geosynthetic is presented in this study. Interface shear resistance between geosynthetics and the recycled materials is measured using a pullout table and a large-scale direct shear machine. The internal angle of friction of each recycled aggregate was measured using a large-scale triaxial apparatus. Two types of geotextiles (woven and non-woven) and 2 types of geogrids (uniaxial and biaxial) are used. The preliminary results indicate that RCA and RAP can be used in geotechnical construction. The friction angle of 48º and the apparent cohesion of 78kPa were measured in RCA. The friction angle of 29.2º and the apparent cohesion of 25 kPa were measured in RAP. Interface friction angles between RCA-geosynthetics and RAP-geosynthetics generally range between 18º-36º, and 17º-40º respectively. Efficiency factor ($E_{\varphi}$) between 0.30-0.62; and 0.56-1.50 were obtained for RCA and RAP respectively. Pullout tests were performed only with woven geotextile and uniaxial geogrid, yielding interaction coefficients (Ci) ranging between 0.13-0.52 for RCA, and between 0.11-0.32 for RAP.

KEYWORDS: MSE Wall, Geosynthetics, RCA, RAP, Alternative Backfill, Recycled Materials.

## 1 INTROCTION

### 1.1 Common Types of Recycled Materials

The use of recycled materials in engineering applications presents economic and environmental benefits. The disposal of these materials in landfills is costly and presents an environmental threat to air and groundwater. Common recycled materials used in engineering applications include Recycled Concrete Aggregate (RCA), Recycled Asphalt Pavement (RAP), Bottom Ash (BA), Fly Ash (FA), Recycled Asphalt Shingles (RAS) and Foundry Sand (FSD). These materials serve as base coarse for roadways, backfill for Mechanically Stabilized Earth (MSE) walls, aggregates for construction of highways and embankments, and the production of new asphalt and cement (FHWA 2004a; Anderson et al. 2009;

Soleimanbeigi 2012).

RAP and RCA are the most recycled construction materials used in the United States to date (Edil et al. 2012). Over 140 million tons of RCA (EPA 2015) and 75.8 million tons of RAP (NAPA 2014) are produced per year.

### 1.2 Engineering Properties

RCA differs from natural aggregates in composition (e.g. presence of mortar). It is more angular and has rougher surface than its virgin aggregate counterparts (Griffiths et al. 2002, Juan et al. 2009; Rathje et al. 2006). These physical characteristics are believed to augment the friction angle of RCA (Tatsuoka et al. 2005; Rathje et al. 2006). RCA is susceptible to higher-than-normal particles breakdown which can potentially increase the amount of fines (e.g. particles passing No. 200 sieve) reducing the hydraulic conductivity and altering the material's compaction characteristics (Rathje et al 2006).

RAP consists of nearly 92-97% aggregates that are coated with asphalt binder (Rathje et al. 2006), which has specific gravities ranging between 1.0-1.04 (Roberts et al. 1996). The low specific gravity of asphalt binder contributes to lower values of specific gravity and dry unit weight of the RAP. RAP particles have low absorption potential and low content of fines. Because the material consists of angular particles, the values of internal friction angles observed in the literature are equivalent to or higher than natural aggregates (Rathje et al. 2006; Soleimanbeigi et al. 2012; Edil et al. 2012). A critical characteristic of RAP is its creep potential. The viscoelastic properties of the bituminous coating in RAP may cause creep to develop when RAP is subjected to sustained deviatoric stresses (Rathje et al. 2006).

## 2 MATERIALS AND METHODS

Index and mechanical properties of RAP and RCA were measured according to the American Society for Testing and Materials (ASTM) standards, except when such standards were not available. The testes performed include grain size distribution, specific gravity, standard Proctor compaction and large-scale triaxial test.

Two types of geotextiles (woven and non-woven) and two types of geogrids (uniaxial and biaxial) were used as soil reinforcements. Interface shear resistance between the geosynthetics and the recycled material were measured using a pullout table and a large scale direct shear machine. Tests and equipment used to quantify the index and mechanical properties of the aggregates and their interaction with geosynthetics are discussed.

### 2.1 Recycled Aggregates and Geosynthetic Reinforcements

#### 2.1.1 Recycled Concrete Aggregate

Samples of RCA were obtained from Mandt Sandfill, located in Fitchburg, Wisconsin, USA. RCA particles are angular with rough surface and contain noticeable attached mortar. The material is medium gravel with approximately 8.7% fines content. RCA was classified as GP (e.g. poorly graded gravel) in the Unified Soil Classification System (USCS).

The specific gravity of 2.56 was measured according to ASTM C-127 and D-854. A maximum dry unit weight of 19.5 kN/m$^3$ was achieved at 11.0% water content. Inspection of the samples showed the presence of contaminant materials (e.g. wood chips, glass, tiles, plastic), consisting of approximately 0.6% of the bulk sample

#### 2.1.2 Recycled Asphalt Pavement

Samples of RAP were acquired from Payne and Dolan, located in Fitchburg, Wisconsin, USA. RAP particles are medium, angular and exhibit rough surface. Bituminous coating is noticeable around the surface of the particles. RAP has approximately 5.10% of fines and was classified as SP (e.g. poorly graded sand) in the USCS.

The specific gravity of 2.39 was measured. The maximum dry unit weight of 18.6 kN/m$^3$ was achieved at 4.0% optimum water content.

Table 1. Soil Classification and Gradation indices for RCA and RAP.

| | USCS classification | Fines (%) | $D_{10}$ | $D_{30}$ | $D_{50}$ | $D_{60}$ | Cu | Cc |
|---|---|---|---|---|---|---|---|---|
| RCA | GP | 8.7 | 0.11 | 2.90 | 9.0 | 10.7 | 97.27 | 7.145 |
| RAP | SP | 5.1 | 0.25 | 0.65 | 2.0 | 3.0 | 12.00 | 0.563 |

Table 1 and Figure 1 show the gradation indices and grains size distribution for RCA and RAP.

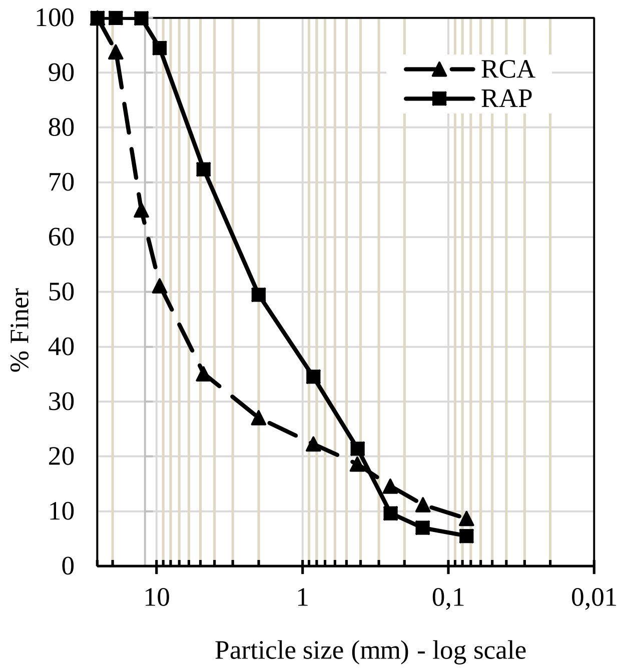


Figure 1. Grain size distribution and gradation indices for RCA and RAP

2.1.3 Geosynthetic Reinforcements

Four geosynthetic reinforcements were used in this study (e.g. uniaxial and biaxial geogrids, and woven and nonwoven geotextiles). The selection of these products considered strength, hydraulic properties and friction/interlock efficiency between the aggregate particles and geosynthetics.

The uniaxial geogrid chosen is the Tensar UX-1500MSE, commonly used as structural earth reinforcement. The material is made of high density polyethylene (HDPE) integrally formed punched, and uniaxially drawn. The aperture sizes were measured to 406.0 mm in MD (machine direction) and 17.0 mm in the XD (cross-machine direction). The rib thickness were measured to 1.5 mm in MD and 4.2 mm in MD and 4.2 mm in XD. This material was selected due to its extensive application by the industry as MSE wall reinforcement.

The selection of Tensar BX-4200 considered frictional efficiency, and it was based on aggregate particle sizes and geogrid aperture dimensions. Equation 1 gives the minimum aperture size of the geogrid as a function of average aggregate particle size, as shown in Sarsby (1985):

$$B_{GG} > 3.5\, d_{50} \qquad (1)$$

Where: $B_{GG}$= the minimum width of geogrid aperture, and $d_{50}$ = the average particle size of the backfilling aggregate.

The woven geotextile elected is Thrace-LINQ GTF-570. The geotextile is manufactured using high tenacity polypropylene multifilament, woven in a stable wave pattern. The apparent opening size was reported by the manufacturer as 0.6 mm, and the water flow rate as 1,222.00 l/min/$m^2$.

The non-woven geotextile used is Thrace-LINQ 160EX produced from polypropylene staple fibers randomly oriented, which form a stabilized needle punched fabric.

## 2.2 Laboratory Tests

### 2.2.1 Large Scale Triaxial Test

A large-scale triaxial test apparatus was used to evaluate the angles of friction of RCA and RAP. Monotonic loading tests were performed using a MTS closed-loop servo-electro-hydraulic system. Because no standard test procedure is available for unconsolidated-drained large-scale triaxial test of non-cohesive aggregates, the ASTM D-7181 was used as reference.

The triaxial testing equipment consists of a pressure board, which feeds pressurized water to the cell and aggregate samples, and a triaxial cell with capability to accommodate a sample of 152 mm in diameter and 310 mm high. Vertical force is applied to the sample by an actuator with a maximum load capacity of 22.4 kN. A piston attached to the actuator intrudes the cell and seats on top of the aggregate sample.

The sample is saturated and confining pressures is applied to the sample. Testes are run four different confining pressures of 34.4, 68.9, 103.4 and 137.9 kPa. When the target confining presser is achieved, loading is applied to the saturated sample at a rate of 0.2 mm/min. During the test pore water is allowed to escape the sample to model drained conditions. Tests are run until failure of the sample occur.

### 2.2.2 Large Scale Interface Direct Shear Test

The interface angle between RCA, RAP and the selected geosynthetics was evaluated by interface direct shear test (ASTM D-5321). The large scale direct shear testing machine comprises an upper box 300 mm long, 300 mm wide, and 76 mm deep, and a lower box 356 m long, 300 mm wide and 76 mm deep. The longer length of the lower box allows for stress calculations without requiring area correction.

RCA samples were compacted at 22 degrees Celsius while RAP samples were compacted at 22, 35 and 50 degrees Celsius. All tests were performed at 22 degrees Celsius at normal pressures of 50, 100 and 200 kPa. A displacement rate of 1 mm/min and the total test travel distance of 50 mm were used, except when the total limit of 17.8 kN was reach, or the geosynthetic ruptured.

### 2.2.3 Pullout Test

Pullout tests were carried on RCA and RAP samples reinforced with woven geotextile and uniaxial geogrid. The test procedures followed ASTM D-6706 standard using a large scale pullout box manufactured by GeoSyntec Consultants of Atlanta, Georgia. The steel pullout box is 152.4 cm long, 60.9 cm wide and 40.6 cm deep. Normal stress is applied by a rubber air bladder confined between the soil and three steel covers bolted to the top of the pullout box. Two hydraulic jacks attached to the either side of the pullout box apply pullout force. The hydraulic jacks are equipped with valves that control the pullout rate. An AC hydraulic power unit and a compressed air pump provide power to the hydraulic jacks. The AC hydraulic power is equipped with a valve that changes fluid flow direction, thus moving the hydraulic jacks in forward or backward motion. A compressed air unit applies constant load to the hydraulic jacks. A load cell mounted on the front of the pullout box measures pullout force.

LVDTs are used to measure the displacement at the front of the pullout box and along the length of the geosynthetics. The front LVDT is mounted on the head of the pullout box and measures the displacement of the pullout clamp. The back LVDTs were mounted in a rack outside of the box frame and measure the displacement at three different points along the geosynthetic length.

The aggregate sample is placed into the box and compacted with a hand temper to the target density. The bottom half of the machine is filed and the geosynthetic is placed on top of the soil. The pullout clamp that holds the geosynthetic exits the box through the front opening and is bolted to a metal bar. The hydraulic jacks are connected to either side of the metal bar, which is in contact to the load cell.

The air bladder is placed on top of the backfill and the covers are bolted into place. A hole in one of the cover plates allows access to the nipple of the air bladder. Compressed air fills the bladder until the target normal stress is reached. All pullout tests were carried at 20, 30, 50, 100 and 200 kPa normal stresses and a pullout displacement rate of 1.0 mm/minute was used. Tests ran for 100 mm or until failure of the geosynthetics occurred.

## 3 RESULTS

### 3.1 Large Scale Triaxial Test

Mohr-Coulomb failure envelops were developed from large scale drained triaxial tests conducted on compacted samples of RCA and RAP. Area correction was performed to attain corrected values of normal stress. Results were plotted in terms of normal stress (σ) versus axial strain (ε). Failures during strain-controlled tests were defined as the maximum value of normal stress ($\sigma_{max}$) for each test. Mohr circles were plotted utilizing the maximum and minimum stresses at failure (e.g. $\sigma_{1, max}$ and $\sigma_3$), and a best-fit Mohr-Coulomb failure envelops were constructed for each material.

3.1.1 RCA

The results of drained triaxial tests on RCA samples, and the Mohr-Coulomb failure criteria are effective friction angle (Φ) 48.0º and apparent cohesion of 78.0 kPa. RCA samples reached a peak normal stress at less than 2.0% strain, before descending to residual level. The strain softening behavior was observed at all three confining pressures. The samples suffered strain expansion between 2.8% and 4.0% at the end of the tests. All samples exhibited a typical failure plane expected for low compressible materials.

3.1.2 RAP

Results of drained triaxial tests on RAP samples, and the Mohr-Coulomb failure criteria are effective friction angle (Φ) 29.2º, and the apparent cohesion of 25.0 kPa.

RAP samples displayed smooth curves with undefined peaks of normal stress. Strain softening behavior were observed at confining pressures of 34.5 and 68.9 kPa, while the sample exhibited strain hardening behavior at a higher confining pressure of 103.4 kPa. At the highest confining pressure (103.4 kPa), the normal stress increased, with increasing strain, until the test reached the displacement limit of 30 mm.

3.2 Large Scale Interface Direct Shear

3.2.1 RCA

Results of large-scale interface direct shear tests between RCA and the four selected geosynthetic reinforcements, from Mohr-Coulomb failure criteria are the interface friction angles: 26º, 18.4º, 35.8º and 31.5º, for woven and nonwoven geotextile, and for uniaxial and biaxial geogrid respectively. Because information on interface friction angle between RCA and geosynthetics is scarce, results from different soils type were used for comparison. The interface friction angle of RCA woven geotextile is slightly lower, but comparable, to values reported for gravel and FDS (27.0º to 29.0º).

The machine direction of the geotextile, as used in this test, does not allow full baring resistance to develop between RCA and the treads of the geotextile, thus yielding a lower friction angle. In addition, the compacted RCA may have experience vibration during set up of the shear box into the direct shear machine, resulting in a more loose state of the material during test. Slight deformation in the geotextile was observed at the contact with the box clamp, which could have also have contributed to lower the value of friction efficiency or efficiency factor ($E_\varphi$).

Nonwoven geotextile and RCA yielded an unexpected lower value of interface friction angle (18.7º), when compared to rounded sand (26.0 º), and concrete sand (30.0 º) reported by Korner (2005).

Excessive tensional deformation was observed along the length of the extruded geotextile. Deformation was also significant at the clamp attachments, where the geotextile is fixed to the lower box.

Uniaxial geogrid yielded the largest values of interface friction angle (35.8º), and friction coefficients (0.62). Nevertheless, these values were lower than expected. The friction angle between RCA and uniaxial geogrid observed in this study is comparable to FDS (31.0 º) and sand (33.8º), reported by Goodhue et al (2001).

Significant error must be considered into the results of the uniaxial geogrid. The length of the internal aperture of the geogrid (457.0 mm), far exceeds the length of the shear box (300.0 mm). Therefore, full mobilization of the entire length of the geogrid was not achieved. In addition, only one transversal rib interacts with the soil in each test, restricting the observation of full baring type interaction between the soil and reinforcement that may be attained in field conditions.

Biaxial geogrid was tests in cross-machine direction, due to the largest strength of the reinforcement in this direction. The interface friction angle of 31.5° was observed, representing a friction interaction of 55.0%. Arulrajah et al (2013) reported a friction angle of 50.0° between RCA and a similar biaxial geogrid, with an equivalent friction efficiency of 55.0%. Other coarser materials, such as sand, gravel, and crushed stone, exhibited interface friction angles ranging from 37.0° to 43.3°.

### 3.2.2 RAP

RAP samples were compacted at 22 °C, 35 °C and 50 °C, and tests were run at room temperature of 22 °C. Results of large scale interface direct shear tests between RAP and the four selected geosynthetic reinforcements, are summarized in Table 2.

The interface friction angles and efficiency factors between RAP and woven geotextile are comparable to values of concrete sand (26.0° at 22°C) (Koerner 2005), but slightly lower than of gravel and FDS (27.0° to 29.0°) (Goodhue et al. 2001). The efficiency factor, however, is noticeably higher for RAP (0.82) when compared to gravel and FDS (0.60 and 0.64) (Goodhue et al. 2001).

The results from this study indicate a decrease in interface friction angle, with increasing temperature. However, this trend is of insignificant magnitude (e.g ~ 1.0° per 15°C). Increasing temperature may have resulted in smoother RAP particles surfaces, reducing the effects of friction with the surface of the geotextile.

RAP and the biaxial geogrid attained the largest interface friction angle (40.0°) at 22 °C, representing a friction interaction of 150%. A similar interface friction angle (40.5°) was reported by Arulrajah et al. (2013), but with a significantly lower friction efficiency of 77.0%. RAP performed better than other coarser materials, such as sand and gravel, with interface friction angles of 37.0° and 38.6° respectively.

Compaction effectiveness could have increased the surface interaction between RAP and the reinforcement at 35 °C compaction. However, at 50 °C, the bituminous content in RAP may have induced the loss of roughness, which could have decreased the effects of friction. As observed in previous tests, the nonwoven geotextile suffered considerable deformation at its cross-section and at the clamp attachments, where the geotextile is fixed to the lower box.

Table 2. Interface Friction Angles, and Efficiency Factors between RAP and Selected Geosynthetic Reinforcements at Different Temperatures.

| Geosynthetic type | Temperature (C°) | Interface friction angle (δ) | Efficiency factor, $E_\varphi = \tan(\delta)/\tan(\varphi)$ |
|---|---|---|---|
| Woven Geotextile | 22 | 24.8 | 0.82 |
| | 35 | 23.3 | 0.77 |
| | 50 | 22.1 | 0.72 |
| Nonwoven Geotextile | 22 | 17.3 | 0.56 |
| | 35 | 20.4 | 0.67 |
| | 50 | 19.5 | 0.63 |
| Uniaxial Geogrid | 22 | 31.9 | 1.11 |
| | 35 | 36.7 | 1.33 |
| | 50 | 29.3 | 1.00 |
| Biaxial Geogrid | 22 | 40.0 | 1.50 |
| | 35 | 38.5 | 1.42 |
| | 50 | 36.5 | 1.32 |

The biaxial geogrid showed excessive interaction with the shear box. Failure due to geogrid rupture was observed at a normal pressure of 100 kPa (35°C), and at 200 kPa (50°C). The large scale direct shear equipment reached the force limit of 17.8 kN at the normal pressure of 200kPa (22°C and 35°C). At this point the test stopped and further shear was not possible.

## 3.3 Pullout Test

### 3.3.1 RCA

The pullout strength of RCA reinforced with woven geotextile and uniaxial geogrid were evaluated at different normal stresses. The geogrid presented higher pullout force than the geotextile at lower confining pressures (e.g. 20.0 and 30.0 kPa) which was expected. The pullout force of the geotextile gradually approaches of the geogrid with increasing confining pressures.

This behavior is also noted in the values of Coefficient of Interaction (Ci). The values of Ci for the geogrid are higher than of the geotextile at lower confining pressures (20.0 and 30.0 kPa), but become similar with increasing confining pressures (50.0, 100.0 and 200.0 kPa). The values observed for geotextile and geogrid indicate a weaker bond between RCA and each of the geosynthetics (e.g. Ci<0.5).

The interaction between RCA and each of the two geosynthetic reinforcements exhibited distinct characteristics. The Ci values for geotextile increased with normal pressure, reaching a peak at the mid confining pressure of 50.0 kPa. Tatlisoz et al. (1996) report similar pattern. In contrast, Ci values for the geogrid peaked at the lowest confining pressure of 20.0 kPa, decreasing thereafter with increasing normal pressures.

The decrease in Ci values observed in the geogrid were expected. Typically, increasing normal stress causes increasing progressive failure in the reinforcements. Bakeer et al. (1998) reported similar values and a decreasing pattern, in his study of uniaxial geogrid reinforced lightweight aggregates. Tatlisoz et al. (1996) report this behavior also during tests on uniaxial geogrid reinforced sand/tire chips mixtures.

### 3.3.2 RAP

The interaction coefficient (Ci) between RAP and the reinforcements were calculated for each normal stress, and the average was obtained. The values of Ci are presented in Table 3.

The geotextile presented progressive deformation with increasing normal pressure, and ruptured at 100.0 and 200.0 kPa with displacements of 82.0 mm and 48.0 mm, respectively. The geotextile exhibited slightly larger pullout capacity than the geogrid. This compares with findings reported by Tatlisoz (1996), on her study of tire chips/sand mixture aggregate. In contrast, the geotextile achieved a lower pullout capacity than the geogrid at 200.0 kPa. This may be the result of tensile failure on the geotextile at just 55.0 mm of displacement, impeding further development of pullout resistance.

Ci values observed for RAP (0.11 to 0.32) follow similar characteristics observed in RCA. RAP/geotextile interaction yielded initial increase of Ci values, with increasing normal pressure. The peak Ci value occurred at 50.0 kPa normal stress, and declined thereafter. Ci values for RAP/geogrid initially increased from 20 to 30 kPa, but decline from 30 to 200 kPa normal pressures.

As observed previously, decrease in Ci values are expected in the geogrid. The original increase in Ci may be due to the inability of sand-size RAP particles to proper interlock with the geogrid at very low confining pressure (e.g. 20.0 kPa).

Table 3. RAP Coefficients of Interaction from Pullout Tests.

| Geosynthetic type | Normal Stress (kPa) | Coefficient of Interaction (Ci) |
|---|---|---|
| Geotextile | 20 | 0.21 |
| | 30 | 0.26 |
| | 50 | 0.32 |
| | 100 | 0.19 |
| | 200 | 0.11 |
| | Average | 0.22 |
| Geogrid | 20 | 0.16 |
| | 30 | 0.22 |
| | 50 | 0.21 |
| | 100 | 0.17 |
| | 200 | 0.12 |
| | Average | 0.18 |

## 4 RECOMMENDATIONS FOR DESIGNERS CONSIDERING RCA AND RAP

Results of the laboratory tests conducted in this study provide designers with the data to conduct preliminary design calculations for evaluating the efficacy of using RCA and RAP in geotechnical construction. Recommended design parameters are summarized in Table 4. These design parameters are intended for preliminary design calculations. Final design should be conducted using measured properties for the RCA, RAP and the geosynthetics to be used. Field conditions should be simulated as closely as possible when conducting tests for final design.

Table 4. Recommended Parameters for Preliminary Design with RCA and RAP

| Parameter | RCA | RAP |
|---|---|---|
| Internal friction angle Φ' [a] | 48.0 | 29.2 |
| Cohesion *c'* [a] | 0 | 0 |
| Frictional efficiency | | |
| Woven Geotextile | 0.41 | 0.77 |
| Nonwoven Geotextile | 0.30 | 0.62 |
| Uniaxial Geogrid | 0.62 | 1.15 |
| Biaxial Geogrid | 0.55 | 1.41 |
| Geogrid interaction coefficients [b] | | |
| Normal stress <20kPa | 0.52 | 0.16 |
| Normal stress >20kPa | 0.29 | 0.18 |
| Getextile interaction coefficients [b] | | |
| Normal stress <20kPa | 0.13 | 0.21 |
| Normal stress >20kPa | 0.24 | 0.22 |

[a]Drained strenght parameters.

[b]Ignore soil cohesion when using interaction coefficients.

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