# A review on the use of marginal fills for geogrid-reinforced walls and slopes

A. Ekici
*Ph.D. student and Geosynthetic Institute Fellow, Middle East Technical University, Civil Engineering Department, Turkey (anil.ekici@metu.edu.tr)*

N. Huvaj*
*Assistant Professor, Middle East Technical University, Civil Engineering Department, Turkey (nejan@metu.edu.tr)*

ABSTRACT: For geogrid-reinforced soil walls and slopes, most of the design guidelines require use of clean granular material as backfill soil. Considering the high cost, limited availability and transportation problems related with clean granular fill, use of locally available marginal fills (predominantly granular materials containing significant percentage of fines) is becoming a challenging topic for design and construction of geogrid-reinforced soil walls and slopes. Although marginal fills are known to have poor drainage and shear strength characteristics, they can provide environmental benefits in terms of saving natural resources (such as sand and gravel), reduced construction waste and waste disposal cost, sustainability, reduced carbon footprint and life-cycle assessment of projects. Recent research and applications indicate that granular soils containing fine grained materials can also be successfully used as backfill material as long as adequate drainage is provided in the body of the structure. There is a lack of consensus in the current practice of design and analysis for the reinforcement of predominantly granular material which has high fines content (marginal material). The objectives of this study are to present a review on the definition of a marginal fill and fill material selection criteria used around the world, together with presenting examples of case studies of using marginal fills in GRSWS.

Keywords: *marginal fill, geogrid, reinforcement*

## 1 INTRODUCTION

For geogrid-reinforced soil walls and slopes (GRSWS), majority of design guidelines and technical manuals recommend use of good quality, freely draining granular fill materials because of their advantages of high frictional resistance, long term constant engineering properties that are not significantly affected by changes in moisture content or other environmental factors, and good compaction and drainage characteristics. Research conducted in the area of soil – geogrid interaction also focused on the reinforcement with clean granular materials. The cost, availability and transportation of granular material could raise the cost of construction of GRSWS. Durukan and Tezcan (1992) reported that granular fill supply is the most expensive component of a reinforced soil retaining system, typically corresponding to 40% of the total construction costs. National Cooperative Highway Research Program (NCHRP 24-22) study indicated that potential savings from replacing AASHTO-specified fill materials with marginal fill materials could be in the range of 20 to 30% of current MSE wall costs. Cristopher and Stulgis (2005) points out that the fill material makes up about 30-40 percent of the cost of a reinforced soil wall and high quality, permeable fill can cost two to three times that of lower quality, high fines content fill. In addition, considering life-cycle cost assessment, sustainability, saving natural resources (such as sand and gravel), reduced construction waste and waste disposal cost, green construction aspects, and environmental benefits such as reducing the carbon footprint of projects, the use of locally available fill material is becoming more popular. Recent research indicates that granular soils containing fine grained (cohesive) materials can also be successfully used as backfill material as long as adequate drainage is provided in the body of the structure (Kempton et al, 2000, Lopez et al, 2005, Zornberg & Kang, 2005) and only a few design methods are proposed considering the effect of fines content in a fill. Therefore, use of marginal fills in geogrid-reinforcement applications have become a topic of research especially in the recent years, where marginal fill is defined as a poor quality fill material that is predominantly composed of coarse-grained soils and includes high fines content (silt and/or clay-size). Marginal fills could often be found at or near the construction sites. The objectives of this study are to present a review on the definition of marginal fill and fill material selection criteria used around the world, and to present examples of case studies using marginal fills in GRSWS.

## 2 LITERATURE REVIEW

There is significant body of literature on experimental and numerical studies investigating soil – geogrid interaction with clean granular materials. Experimental research on geogrid-reinforced granular materials (pull-out resistance and shear stress-strain characteristics) were conducted to study the effect of normal pressure, moisture content, density, particle size and shape, gradation, deformation rate, geogrid stiffness, aperture size and pattern etc. Although there were some studies investigating interaction of cohesive materials with geogrids in the past, extensive research about this topic has accelerated in the last 15 years (e.g. Bergado et al. 1991, Long et al. 2007, O'Kelly and Naughton, 2008). Advances in production technologies and in geosynthetics having multi-functions, together with economic and environmental benefits, keep the research in the agenda.

### 2.1 *Definitions of Suitable Fill and Marginal Fill*

Marginal fills are typically coarse-grained soils having significant percentage of fine-grained soils, which could be cohesive or non-cohesive. These soils can be locally found at or near the construction sites. Marginal fills are known to have poor engineering properties compared to select backfill materials. Early research showed that the relative volume of the fine grained portion of the fill controls the shear strength of the reinforced soil (Schlosser & Long, 1974). The inclusion of even a few percent of fines in a fill may cause it to be not free draining (FHWA 2009). According to Raja et. al. (2012), marginal fills with lower fines content have increased shear strength properties compared to those with higher fines content.

Balakrishnan and Viswanadham (2015) emphasized that various geogrid reinforced wall failures were also reported (Mitchell and Zornberg 1995, Koerner and Soong 2001, Koerner et al. 2005, and Hossain et al. 2012). Case studies of wall failures have mentioned that the use of poor quality backfill (or marginal backfill) and lack of proper drainage measures are few of the major reasons for the wall failures that are reported. There are several concerns regarding the use of marginal soils as backfill materials, some of which are (1) reduction in shear strength upon wetting and/or build-up of positive pore water (Mitchell (1981), Naughton et al. (2001)), (2) low frictional strength and high post-construction creep potential (Mitchell, 1981), (3) difficulty in compaction and required longer construction time when the moisture content is high (Zornberg and Mitchell 1994), (4) possibility of problems with seepage within the fill (Sandri 2005). However, research (Kempton et al, 2000, Lopez et al, 2005, Zornberg & Kang, 2005) has shown that soils containing cohesive materials can be successfully used as backfill material as long as adequate drainage is provided in the body of the structure. Abu Farsakh et. al (2004) indicated that successful use of marginal soils as backfill has been documented in a number of case studies (Bergado et. al 1991).

Because of the problems and concerns, definition of a suitable fill and marginal fill are important. Percentage of fines, plasticity index and particle size distribution are critical factors that affect the interaction. Technical design codes bring restrictions about the fines content of a fill. For example, according to FHWA (2009, NHI-10-025), suitable backfill material used in GRSWS should have fines content (percentage smaller then the 0.075 mm sieve size) less than 15% and plasticity index lower than 6% for walls, and lower than 20% for slopes. Summary of existing guidelines on suitable fill material is presented in Table 1.

Table 1. Restrictions for Suitable Fill material for GRSWS

<table>
<tr><th>Code of practice</th><th>Restrictions about fill material</th></tr>
<tr><td>BS 8006 (1996) UK</td><td>Cohesive fills may be used in new or reinstated slopes in combination with the appropriate reinforcement</td></tr>
<tr><td>BS 8006 (2010) UK</td><td>General cohesive fill as defined in the Specification for Highway Works should not be used in the construction of reinforced soil walls or abutments and may be used with caution in steep slopes.</td></tr>
<tr><td>HA 68/94 (1994) UK</td><td>Does not prohibit the use of cohesive fills</td></tr>
<tr><td>FHWA (2001) USA</td><td>Permits the use of soils with up to 15% passing the No.200 sieve (0.075mm)</td></tr>
<tr><td rowspan="2">FHWA (2009) USA</td><td>Gradation (AASHTO T-27)
<table>
<tr><td>US. Seive Size</td><td>Percent Passing (%)</td></tr>
<tr><td>4 in (102mm)</td><td>100</td></tr>
<tr><td>No. 40 (0.425mm)</td><td>0-60</td></tr>
<tr><td>No.200 (0.075mm)</td><td>0-15</td></tr>
</table>
Plasticity Index, PI ≤ 6% (AASHTO T-90)<br>
Compaction moisture control should be ±2% of optimum moisture, $w_{opt}$.<br>
To apply default F* values, Cu ≥ 4.</td></tr>
<tr><td>According to NCHRP (24-22) study, reinforced fill with up to 35% passing a No. 200 (0.075 mm) sieve could be allowed in the reinforced fill provided that<br>
* Properties of the materials are well defined<br>
* Drainage, corrosion deformations, short-long term pullout reinforcement must be carefully issued<br>
* Tests to analyze soil/reinforcement interface must be performed.</td></tr>
<tr><td>Geoguide 6 (2002) Hong Kong</td><td>Permits the use of soils with up to 30% passing the No.200 sieve (0.075 mm)</td></tr>
<tr><td>Turkish General Directorate of Highways (2013)</td><td>Backfill material property for strip reinforced earth walls (No information for geogrid).
<table>
<tr><td>Sieve Size (mm)</td><td>% Passing</td></tr>
<tr><td>125 (5”)</td><td>100</td></tr>
<tr><td>75(3”)</td><td>85-100</td></tr>
<tr><td>12.5 (1/2”)</td><td>25-100</td></tr>
<tr><td>2 (No.10)</td><td>15-100</td></tr>
<tr><td>0.60 (No.30)</td><td>10-65</td></tr>
<tr><td>0.075 (No.200)</td><td><15</td></tr>
</table>
Cu > 5, PI < 6%</td></tr>
<tr><td>NCMA (2006) Design of Segmental Retaining Wall</td><td>
<table>
<tr><td>US. Seive Size</td><td>Percent Passing (%)</td></tr>
<tr><td>4 in (102 mm)</td><td>100-75</td></tr>
<tr><td>No. 4 (4.76 mm)</td><td>100-20</td></tr>
<tr><td>No. 40 (0.425 mm)</td><td>0-60</td></tr>
<tr><td>No.200 (0.075 mm)</td><td>0-35</td></tr>
</table>
Soils with low plasticity should be used: LL < 40%, PI < 20%<br>
The Reinforced backfill soils could be one of GP, GW, GM, SW, SP, SM acc. to USCS.<br>
Provided that,<br>
* Proper internal drainage is installed<br>
* Internal cohesive strength (c) is ignored in stability analysis.<br>
* Time dependent movements should be carefully checked</td></tr>
<tr><td>AASHTO 2000 Standard Specifications for Highway Bridges</td><td>
<table>
<tr><td>US. Seive Size</td><td>Percent Passing (%)</td></tr>
<tr><td>4 in (102 mm)</td><td>100</td></tr>
<tr><td>No. 40 (0.425 mm)</td><td>0-60</td></tr>
<tr><td>No.200 (0.075 mm)</td><td>0-15</td></tr>
</table>
PI ≤ 6% (AASHTO T-90)</td></tr>
</table>

### 2.2 *Questionnaire on Restrictions on Fill Properties*

A questionnaire is conducted to U.S. State Transportation Agencies regarding fill requirements in MSE retaining walls in NCHRP (24-22) study. Current practice in USA in public works agencies encourage fill material with low fines content (i.e. less than 15% finer than 0.075 mm as required by AASHTO specifications and FHWA guidelines). In the private sector, the standard design guide (i.e., NCMA) suggests that backfill fines content be limited to 35 %, however it does not preclude a greater amount of fines, and a number of structures have been constructed with a much greater fines content. Cristopher and Stulgis (2005) showed differences in understanding about the "high fines content". "High fines", defined as the percent passing a No.200 sieve, was indicated by one consultant as 3-10%, whereas the second consultant indicated 15-35% and NCMA stated 35-55%.

With the exception of California and Arkansas, all responding states limit the material passing the #200 sieve (< 0.075 mm) to no more than 15%, which conforms to AASHTO requirements. Arkansas indicated that they have allowed the use of materials with a high fines content (i.e. greater than 25%, but generally less than 35%, passing the #200 sieve). These soils, however, have a high internal angle of friction. They do not allow a material with high plasticity. Out of 38 states, 7 states defined "high fines content" as 10-15%, 22 states defined as 15-35%, 1 state defined it as 35-50%, and 3 states defined as >50%.

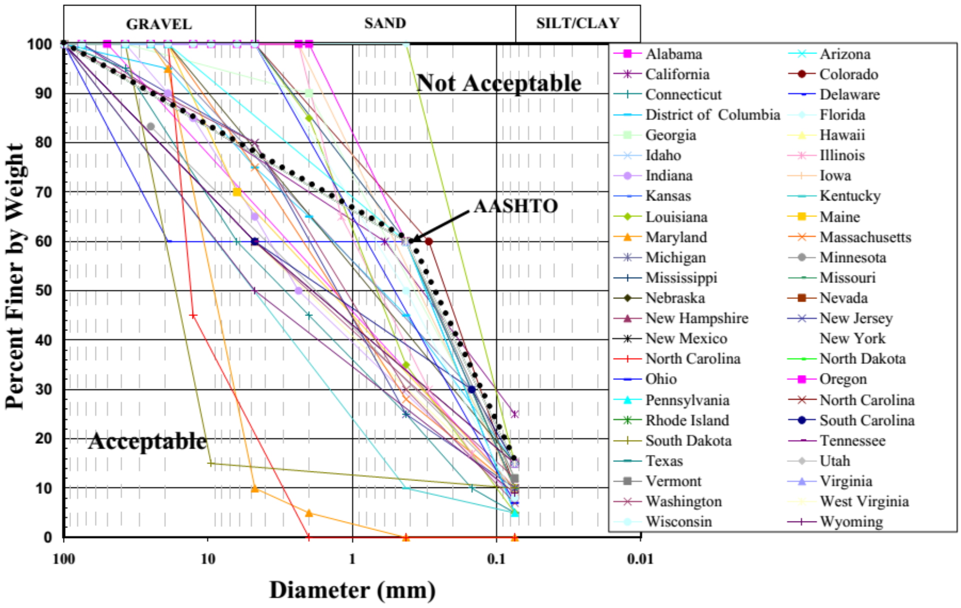


Figure 1. Acceptable "upper" gradation limit for reinforced fill from state responses to the survey

Of 35 States responding to this question, 24 indicated that they specify a maximum plasticity index (PI) of 6%. This value is in accordance with that recommended by AASHTO. Five States specify a PI less than 6%, and 6 States allow a PI greater than 6% (including two States that allow a maximum PI of 20%).

Majority of the respondents require that the soil in the reinforced fill zone must be compacted to a minimum of 95% of the maximum dry density determined by AASHTO T99 or by ASTM D 698 Standard Proctor density.

Majority of the respondents indicates the usage of $\phi$=34° Internal friction angle and c=0 cohesion in MSE wall design which is the criteria recommended by AASHTO.

Major concerns for marginal fills are poor drainage and low shear strength. One potential solution is to provide horizontal drains into the slope, or to reinforce the marginal soils with permeable geosynthetics, that function not only as reinforcement but also as lateral drains (Zornberg and Mitchell, 1994; O'Kelly and Naughton, 2008). There are commercially available products composed of geogrid and geotextile where nonwoven geotextile is placed in the straps of geogrids as drainage channels. Performance of such geocomposites has been tested by several researchers (Kempton et al 2000, Naughton & Kempton 2004, Zornberg & Kang, 2005, O'Kelly

& Naughton 2008) and indicated that the draining geogrid is effective in dissipating pore pressure and increasing the shear strength of soils (Simons and Cameron 2012). Second solution is called “sandwich technique”. This technique uses a thin layer of clean granular material at the immediate vicinity of geogrid (at the geogrid – fill contact), and allows using a marginal fill (having fines content) in between the layers of clean granular fill. Such a system benefits from a better interface properties near the geogrid and drainage provided by the clean granular material in between the marginal fill layers.

## 3 CASE HISTORIES

In the past 10 years there are increasing numbers of case histories using marginal, waste and locally won soils used in GRSWS, only a few of them will be mentioned here. Details of backfill soil properties, geogrid properties and design details will be useful information if instrumented and collected in a database. Simons and Cameron (2012) reported cases of reinforced marginal fill with geogrid having drainage channels, in Canada, one of which was a 4.2 m high slope having a 60° angle. Some of the other examples are presented in Table 2.

Table 2. Case histories of marginal fills

| **Location, date of construction and reference** | **Fill material properties** | **Geogrid** | **Max. height (m) and slope angle** |
|---|---|---|---|
| Istanbul, Turkey, constructed in September 2015 (Ozcelik et al. 2016) | Mixture of clay, silt and alluvium (c′=10 kPa, ϕ′=28°) | High strength geogrid and draining geogrid (ultimate tensile strength of 200, 300 and 400 kN/m), vertically spaced at 76 cm (facing unit: PVC coated welded wire mesh panel) | 14.4 m (two parts: 7.6 m and 6.8 m heights), slope angle 70° |
| South Wales, UK, constructed in 2008 (Doulala-Rigby and Stone 2013) | Failed landfill waste material, typically sand and gravel with subordinate fractions of fine-grained soil comprising silt and clay of intermediate to high plasticity (c′=0 ϕ′=30°) | Uniaxial geogrids at 1 m vertical spacing (long term strength 24 kN/m), secondary biaxial geogrid (2-m long, 0.3 m vertical spacing) at the face | 19 m slope height at an angle of 28 to 45 (average 31) degrees |
| 5 cases in Germany and Netherlands (Naciri and Huybregts, 2008) | Recycled and locally won soils (building demolition material, excavation material from other construction projects, slightly contaminated on-site sand, reused soft soils) | Geogrids (for facing: gabion, concrete modular blocks, wraparound + steel mesh, or steel mesh) | 6 m, 7.5 m, 9.6 m and 10 m, 12 m heights, 60 to 85 degree slope angles |

## 4. CONCLUSIONS

Cristopher et al. (1998) provided a design guideline for GRSWS with marginal backfills. General assumption is that transmissivity of the geosynthetic inclusion should be selected such that the geosynthetic inclusions can carry the full in-plane flow without developing positive pore water pressures along the soil-reinforcement interface (i.e. no build-up of excess pore water pressure within the permeable reinforcements). Analyses take three adverse effects into consideration (a) the generation of pore water pressures within the reinforced fill (either during construction or subsequent loading); (b) a wetting front advancing into the reinforced fill, which may cause loss of soil shear strength in a compacted fill; and (c) a seepage flow configuration established within the reinforced fill due to seepage from the retained soil.

Naughton et al. (2001) proposed a limit of 0.5 m of the height of each lift to control short term stability of the slope face. The authors calculated the dissipation time based on the coefficient of consolidation and applied an appropriate factor of safety. (A construction time of 24 hours per layer is considered appropriate for steep slopes of short to medium length.) The settlement of each lift was shown to be related to the initial height of the lift, the coefficient of volume compressibility and the change in the vertical effective stress. The volume of water to be dissipated could then be determined from the magnitude of settlement assuming a saturated soil. The slope was then designed using an effective stress analysis for the ultimate limit state. The required transmissivity of the geogrid could be calculated once the time for consolidation and volume of water leaving the soil were known. This can then be compared to the available transmissivity in the geocomposite. If the transmissivity provided by the geosynthetic is insufficient, the height of the lift should be reduced and the design procedure repeated.

Although there exist some design guidelines, further research seems to be needed in relation to use of marginal fills in GRSWS. Some of these research needs are instrumentation and long term monitoring of already existing and newly planned GRSWS with marginal fills, and laboratory testing of interaction of geogrids (with or without drainage capability) with marginal soils to study the effect of percent fines, gradation (USCS classification, coefficient of uniformity etc), effect of the plasticity index of the fines, compaction density and moisture content, effect of normal stress, geogrid aperture size and its relation to soil gradation, geogrid type and stiffness.

## REFERENCES

Abu-Farsakh, M., Farrag, K., Almoh'd, I., and Mohiuddin, A., (2004). Evaluation of Interaction Between Geosynthetics and Marginal Cohesive Soils from Pullout Tests, Geo Jordan 2004, p. 299-310

Balakrishnan, S. and Viswanadham, B.V.S., (2015). Performance Evaluation of Geogrid Reinforced Soil Walls with Marginal Backfills through Centrifuge Model Tests, Geotextiles and Geomembranes. v.44(1), p.95-108,

Bergado, D. T., Chai, J. C., Abiera, H. O., Alfaro, M. C., and Balasubramaniam, A. S., (1993) Interaction between cohesive-frictional soil and various grid reinforcements, Geotextiles and Geomembranes, 124, 327–349.

Clancy, J., Naughton, P.J., (2008). Design of Steep Slopes Using Fine Grained Fills and Novel Multifunctional Geocomposites. Proceedings of the Fourth European Geosynthetics Conf., EuroGeo4, Edinburgh, Scotland. IGS. Paper 131.

Christopher, B.R., Zornberg, J.G., & Mitchell, J.K., (1998). Design Guidance for Reinforced Soil Structures with Marginal Soil Backfills. Proc. of the Sixth International Conf. on Geosynthetics, Atlanta, Georgia, March 1998, Vol. 2, pp. 797-804

Christopher, B.R., Stuglis, R.S., (2005). Low permeable backfill soils in geosynthetic reinforced soil wall: state of the practice in North America. In: Proc. of North American Geosynthetics Conf. (NAGS), Las Vegas, Nevada, USA, GRI-19, pp. 14-16.

Doulala-Rigby, C. and Stone, A. (2013). Landfill Slip Failure Repair With Geogrids Using Waste Fill Material at Danylan, Wales, Landslide Science and Practice, v.6, Margottini et al. (eds), p.675-681.

Durukan, Z. and Tezcan, S., (1992). Cost Analysis of Reinforced Soil Walls, Geotextiles&Geomembranes, Vol. 11(1), p. 29-43.

FHWA, Federal Highway Administration, (2009). Mechanically Stabilized Earth Walls and Reinforced Soil Slopes. Design and Construction Guidelines, Publication No. FHWA-NHI-10-025, Washington DC.

NCHRP, National Cooperative Highway Research Program (NCHRP 24-22). Assessing the Long Term Performance of Mechanically Stabilized Earth Walls, Transportation Research Board, National Research Council, Washington, D.C.

Kempton, G.T. Jones, C.J.F.P. Jewell, R.A. & Naughton, P.J., (2000). Construction of slopes using cohesive fills and a new innovative geosynthetic material. EuroGeo 2, Bologna: 825 - 828

Lopez, R.F., Kang, Y.C. & Zornberg, J., (2005). Geosynthetic With In-Plane Drainage As Reinforcement In Poorly Draining Soil, Inter American Conference on Non-Conventional Materials and Technologies in Ecological and Sustainable Construction IAC-NOCMAT 2005 - Rio de Janeiro - Brazil, November 11 – 15th

Naciri, O. and Huybregts, T. (2008). Appropriation of Recycled Material and Locally Won Soils As Fills in Geogrid Reinforced Structures: Case Studies, Proc. 4th European Conf. on Geosynthetics EuroGeo4, Edinburgh, Sept. 2008, paper 145, p.1-6.

Naughton, P.J., Jewell, R.A., Kempton, G.T., (2001). The design of steep slopes constructed from cohesive fills and a geogrid. Proc. of the International Symp. on Soil Reinforcement, IS Kyushu, Japan

Naughton, P., Kempton, G., 2004. Construction of steep slopes using cohesive fill and an innovative geogrid, International Conf. on Geosynthetics and Geoenvironmental Engineering (ICGGE), Bombay, India

NCMA, National Concrete Masonry Association (2006). Design Manual for Segmental Retaining Walls, 3rd Edition.

O'Kelly, B.C. & Naughton, P.J., (2008). On the interface shear resistance of a novel geogrid with in-plane drainage capacity, Technical Note, Geotextiles and Geomembranes

Ozcelik, H., Calisan, O. and Gundogdu, D. (2016). A Case Study On Geogrid Reinforced Slope Using Clayey Backfill, Proc. Of the 3rd Pan-American Conf. on Geosynthetics, GeoAmericas, 10-13 April 2016, Miami Beach, USA

Raja, J., Fraser, I., Fowmes, G., (2012). Designing with marginal Fills: Understanding and Practice, EuroGeo5: the 5th European Geosynthetics Congress, 16th-19th September 2012, Valencia, Spain

Sandri, D., (2005). Drainage Recommendations for MSE Walls Constructed with Marginal Fills, NAGS / GRI-19 Cooperative Conf. Proc.

Simons, M. J., Cameron, N., (2012). Use of an Innovative Geocomposite to Construct a Reinforced Soil Slope using Marginal Fill Soils in Canada, Geosynthetics 2013, Long Beach, 458-464

Zornberg, J.G. and Kang, Y. (2005). Pullout of Geosynthetic Reinforcement With In-Plane Drainage Capability, Proc. ASCE Geo-Frontiers, 24–26 January, Austin, Texas

Zornberg, J.G. and Mitchell, J.K. (1994). Reinforced soil structures with poorly draining backfills. Part I: Reinforcement interactions and functions. Geosynthetics International, Vol.1, No. 2, pp. 103-148