THE RESPONSE OF GEOGRID-REINFORCED SOILS TO SUBSURFACE EROSION

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BREAKING GROUND IN THE NATION'S CAPITAL · L'AVENIR SUR UNE BASE SOLIDE DANS LA CAPITALE NATIONALE
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ABSTRACT
Physical modeling of the process of subsurface soil erosion and the corresponding volume loss is noticeably absent from the literature. A research program was developed to investigate this phenomenon with an emphasis placed on understanding the ground response to subsurface volume loss for both geogrid-reinforced and non-reinforced soils. This paper presents a brief introduction to this research and summarizes the corresponding experimental results obtained through preliminary testing. The results of these initial investigations show that the presence of a geogrid-reinforcing layer aids in limiting the propagation of soil movements and reducing the corresponding surface settlement.

RÉSUMÉ
La modélisation physique du processus d'érosion souterraine ainsi que les pertes de volume qui en résultent sont manifestement absentes de la littérature. Dans cet esprit, un programme expérimental a été élaboré afin d'étudier les réponses reçues par le sol en surface en comparant l'effet d'une perte de volume en profondeur avec et sans renforcements par géogrille. Cet article introduit brièvement ce programme expérimental et présente les résultats obtenus à travers des tests. Les premiers résultats de cette recherche montrent que l'introduction d'une couche renforcée par géogrille limite la propagation des mouvements dans le sol et contribue à la diminution des tassements.

1 INTRODUCTION

An increasing number of road pavements throughout the world are suffering form an advanced state of deterioration. One of the major contributing factors to this problem is the presence of subsurface voids or cavities beneath the road surface. The formation and subsequent propagation of cavities leads to the eventual development of sinkholes, surface pits, potholes and other surface deformations. Much of the literature attributes the process of subsurface soil erosion to be a contributing factor in the formation of cavities (Newton 1984, Tharp 1999, Augarde *et al*., 2003) although no research has attempted to model the physical behavior of soils under these conditions.

Erosion of the subgrade is usually characterized by a volume loss of soil. The volume loss creates a local loss of support and variations in the soil properties which then facilitates the formation of a subsurface cavity (Sterpi, 2003). The soil erosion or volume loss may result from the dissolution of soluble soils such as limestone, dolostone, marble, gypsum, and carbonate rocks that cover varying layers of unconsolidated soils. These geological formations are more susceptible to erosion as the subsurface is composed of highly soluble rocks often contains a significant number of joints that accelerate the rate of internal seepage. Water entering in the soil is allowed to penetrate into the joints causing erosion of the overburden soil. This type of erosion is usually limited to Karst terrain (Newton, 1984, Benson and La Fountain, 1984, Giroud *et al.,* 1990, Gabr and Hunter, 1994). Bedrock weathering as described by Kemmerly (1993) also contributes to subsurface erosion. The presence of joints and fissures facilitates seepage of water into the bedrock. This allows for uneven weathering of bedrock which in turn causes a local loss of support within the above soil. Finally, dynamic loading, usually caused by construction related processes of varying load intensities (Newton, 1984, Newton and Tanner, 1987, Tharp, 1999) and the presence of leaking underground water or sewer pipes (Figure 1) also contributes to the erosion of surface soils and pavement subgrades (Giroud *et al,*.1990, Tharp, 1999).

To understand the ground response to subsurface erosion, consider the case of a soil subject to a volume loss induced by a leaking pipe, as illustrated in Figure 1. Upon the formation of the initial crack along the pipe surface, usually a few millimeters in width, a small volume of the surrounding backfill or natural soil will penetrate into the pipe (Fig 1(a)). As the crack continues to grow, more soil will erode causing a larger volume loss in the close vicinity of the pipe. If the volume loss is significant enough, a depreciation or settlement of the ground surface will occur (Fig 1(b)). The volume loss will also force the soil overlying the pipe to redistribute over the crack and arching will develop in the soil. Terzaghi (1943) describes the arching process for ideal soils as occurring when one section of soil mass yields while the rest remains in place thus allowing the movement of soil adjacent to the yielded section. The only resistance to these movements is shearing forces that exist in the soil. This process will continue as the crack size continues to increase resulting in a larger surface settlement (Fig 1(c)) until the eventual failure of the ground surface.

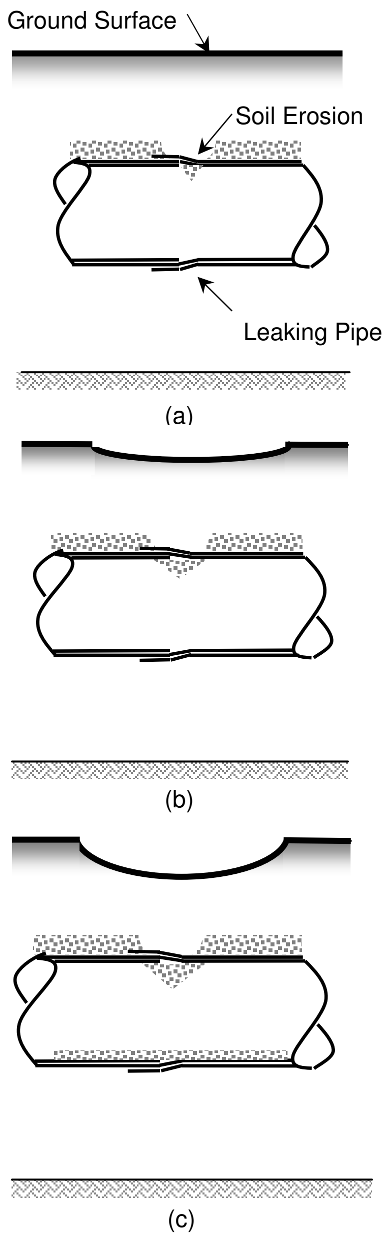

Figure 1: Soil response to subsurface erosion caused by a leaking pipe

Recent investigations in the area of geosynthetic reinforcements suggests that when used appropriately, geo-reinforcements increase the load carrying capacity of soils, decrease surface settlement while providing strain relief to the soil. Lytton (1989) observed that geo-reinforcements used in asphalt pavements provide adequate support, strain relief, undersealing and aid in delaying the formation of reflection cracking in pavements. Komastu *et al.* (1998) determined that the use of geogrids in asphalt-concrete increases the durability of the pavement by providing an increased resistance to both plastic flow and crack formation and propagation. Additionally several studies have been conducted to theoretically examine the response of geogrids underlain by subsurface voids. These include Giroud *et al.* (1990), Das and Khing (1994), Villard *et al.* (2000). It is therefore highly conceivable that the implementation of geo-reinforcements into a subgrade that is susceptible to subsurface erosion voids would improve the response of soils. However, there is again a shortage of experimental research in the literature which has attempted to quantify this response.

The objectives of this study are to understand the behavior of a flexible surface structure to an induced volume loss at a certain depth below the ground surface and to design a physical model that can accurately simulate the above conditions. A detailed review of the experimental procedure and selected results are provided. The response of flexible structure is examined for the two cases of geogrid-reinforced and non-reinforced soil subjected to identical volume loss conditions. A comparison between the induced strains and surface settlement is performed. An initial assessment of the efficiency of the geogrid as a reinforcing tool in such ground conditions is also described.

2 EXPERIMENTAL DESIGN

The preliminary model tests were conducted in a rigid steel test tank with the following dimensions: 1400 mm in length, 305 mm in width, and 1300 mm in depth. The tank was constructed with 6 mm thick steel plates with the steel members connected at 50 mm x 50 mm angles with 6 mm bolts and reinforced with 100 mm HSS sections. A 6 mm thick Plexiglas sheet replaced the steel plate at the front of the tank to enable full visibility of the sand movement throughout testing. The internal sides of the tank were painted and lined with plastic sheets to reduce friction between the sand and the sides of the tank. The same tank was used throughout all preliminary testing. The volume loss due to subsurface erosion was achieved by allowing a small rectangular opening, 5 mm wide at the base of the tank that could be easily opened or closed as required during testing. The opening forms by sliding two moveable plates attached along the base of the tank away from each other. To control soil erosion during each test and to keep experimental procedures consistent, the volume of soil loss was expressed in terms of the sand mass collected under the tank (see Figure 2). A total mass of 2.3 kg of sand was removed from the subgrade during each test. This corresponds to a volume loss of about 0.32% of the total sand volume. This mass was selected, by trial and error, to represent a volume loss that corresponds to a significant and visible surface settlement. It is worth mentioning that more sand (up to

3.5 kg) was allowed to flow out of the tank during the tests, however, the reliability of the strain gauge readings at that stage was questionable and therefore results that correspond to a volume loss above 0.32% were eliminated. Testing begins with a soil height of approximately 1 m and the sand is subsequently removed through the 5 mm opening at the base of the tank. Testing continues until a total mass of 2.3 kg of sand is removed and the opening is then closed. Upon completion of the test, strains and surface profiles are evaluated.

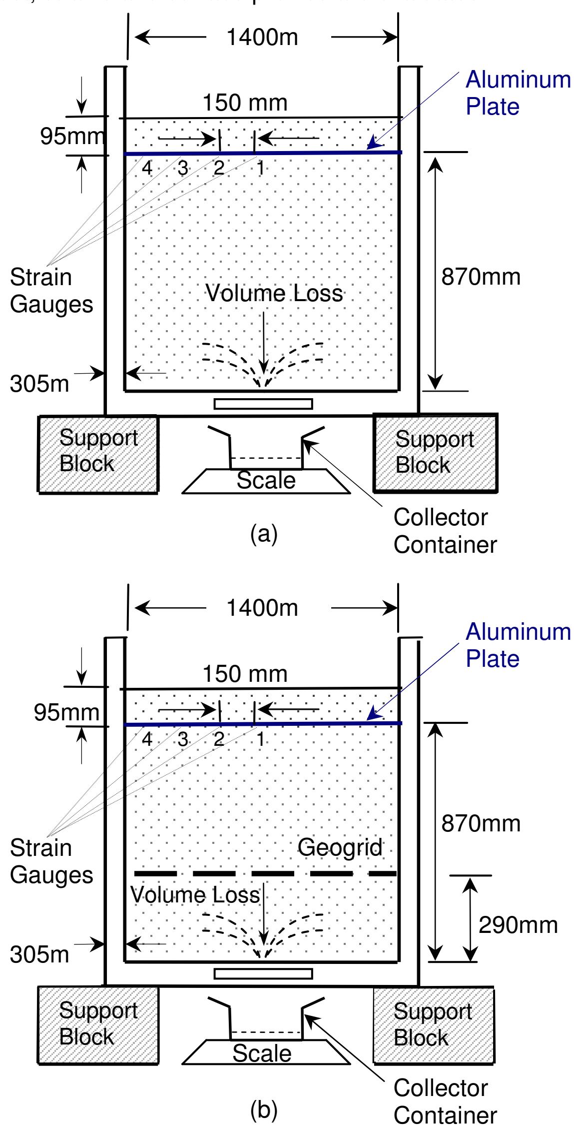

Figure 2: Experimental set-up

The strains are measured using strain gauges installed on a thin sheet of aluminum located at a depth 95 mm below the soil surface (Figure 2). Four strain gauges were installed symmetrically along the aluminum sheet from the center of the tank to the outer edge. Spacing between each geogrid was 150 mm. The strain gauges were connected to an IOtech (Strain Book /616) data acquisition unit which was connected to a Compaq Presario SR2170NX desktop computer. The data acquisition system was used to record the strain experienced by the aluminum sheet as a function of time. The time corresponds to that taken for the void to form and propagate until a total mass of 2.3 kg of sand was removed from the tank.

A silica-sand was used as the primary subgrade material throughout the entire experiments. Results of the sieve analysis (Figure 3) indicate that coarse sand with little or no fines was used throughout testing. The sand was graded manually in 145 mm layers with no compaction. Subsequently, each layer consisted of loose sand having a consistent density. Prior to the placement of the aluminum sheet, 6 sand layers, totaling 870 mm was placed in the tank for each experiment. The remaining 95 mm of sand was then placed above the aluminum sheet and subsequently graded manually prior to the commencement of each test. The total mass of sand used for each test was 714 kg. The only variation between tests was the introduction of a geogrid-reinforcement layer into the test tank. The geogrid, Tensar's BX 1100 biaxial geogrid, was placed on a graded layer of sand 290 mm above the base of the tank, as shown in Figure 2(b).

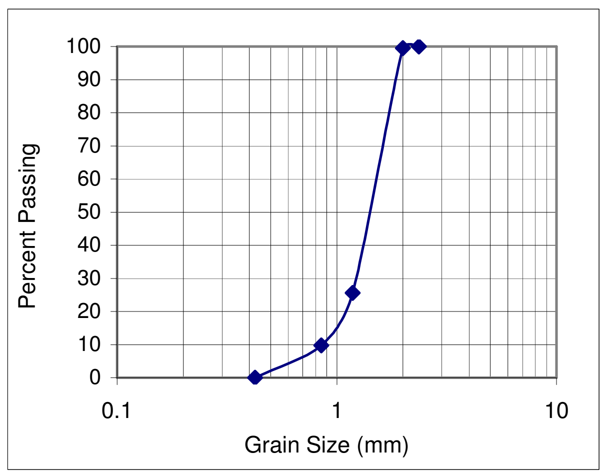

Figure 3: Sieve analysis results

3 PRELIMINARY EXPERIMENTAL RESULTS

Upon the completion of the respective experimental set-up, each model test was conducted under identical conditions. The response of geogrid-reinforced and non-reinforced soils to a subsurface soil loss was evaluated in terms of the strains developed on the aluminum sheet, and the apparent surface deformation resulting from this process. During each model test, the rate of volume loss (of soil) was not explicitly determined. However based on observations made during testing, the rate of volume loss can be reasonably approximated as being linear with respect to time. The rate of volume loss was estimated to be 0.175 kg/second. With this rate known it is possible to evaluate the strains occurring at varying volume losses.

Four strain gauges were placed at different locations along the aluminum sheet (Figure 2). However, strain gauge 3 dislodged during testing of the reinforced soil while strain gauge 4 became inactive during testing of the non-reinforced sand. Therefore only the measured strains at the remaining two locations are presented for the cases of reinforced and non-reinforced soil tests. Note that the strains presented in the following section are based on movements experienced by an aluminum sheet located 95 mm below the soil surface. However, as these strains are representative of the near surface strains it is possible to assume that similar if not larger strains will occur if the sheet was installed at the soil surface for an identical volume loss.

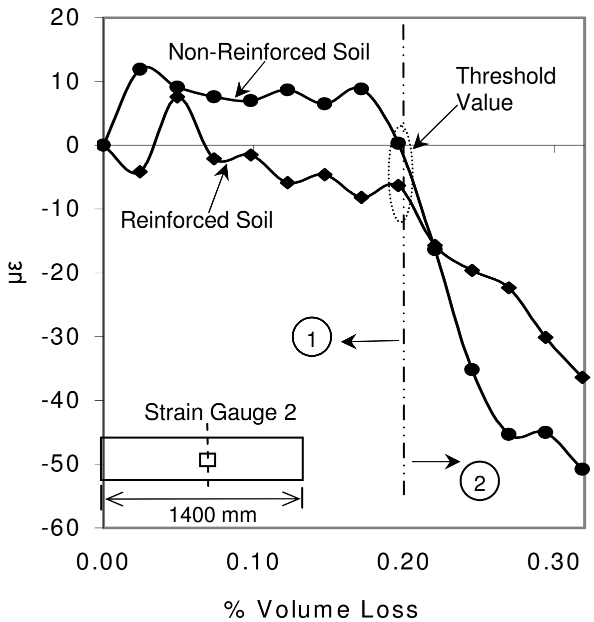

Figure 4: Measured strains: Strain Gauge 1

The strains measured at the center of the sheet (along the tank centerline) are presented in Figure 4. It is apparent from this figure that the response of the aluminum sheet to a reduction in the subgrade volume is highly dependent on the magnitude of volume loss. This response is best characterized as being a two-phase process as indicated in Figure 4. Phase 1 corresponds to a volume loss resulting in minimal strains (to a maximum of ±11 microstrains (με) while phase 2 can be described as having significantly higher strains resulting from the volume loss. A threshold value or the point at which a certain magnitude of volume loss will cause more pronounced strains to occur joins the two phases. If the strains experienced by the sheet are then related to the overlying soil (with an emphasis on the soil surface) it can be reasonably assumed that the threshold point corresponds to the point at which noticeable surface settlement will begin to develop. Preliminary experimental testing determined this point to be equal to a volume loss of about 0.20%.

Figure 4 also indicates that the presence of a geogrid reinforcement layer aids in restricting the movements experienced by the aluminum sheet. A comparison of the maximum strains occurring during each phase for the reinforced and non-reinforced soils confirms this. During phase 1 the aluminum sheet experiences a maximum strain of approximately ±10 με for both the non-reinforced and reinforced soils. Additionally, the strains obtained during the reinforced test model are consistently smaller than for the non-reinforced case. Similarly, during phase 2, the strains measured for the reinforced model are again consistently smaller than for the non-reinforced case. For a maximum volume loss of 0.32%, a compressive strain of 50 με was measured during the non-reinforced soil test as compared to a compressive strain of 38 με during the reinforced soil test. If these results are related to the surface profile of the tank it is expected that the geogrid-reinforced sand will experience less surface settlement as shown in Figure 5.

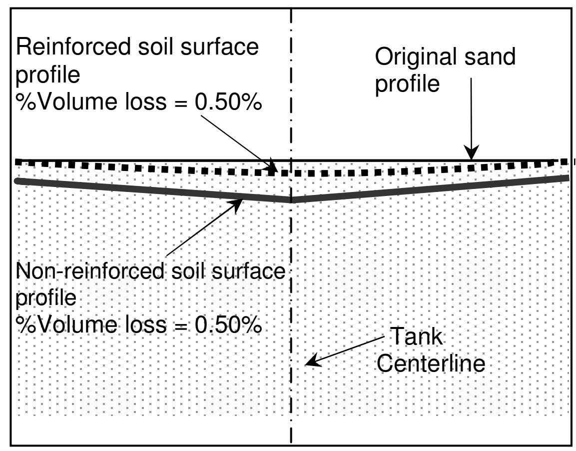

Figure 5: Schematic of surface profile following a subsurface volume loss

Figure 5 represents a schematic of the apparent surface profile after the occurrence of a 0.50% volume loss. The curves shown in figure 5 are derived from photographs taken for the surface profile immediately after the completion of each test and by then superimposing the profiles. These results fall into good agreement with existing research on geogrid reinforcement which has shown that when used correctly geogrids aid in limiting the foundation settlement while increasing the load carrying capacity of the soil (Khing *et al.* 1993, Mandal and Gupta 1994). Additionally the profiles also validate the assumption that the deformation of the aluminum sheet is representative of the surface movement.

Figure 6 shows the strains measured by the strain gauge located on the aluminum sheet, 150 mm from the centerline of the tank. Although it is again clear that the response of the sheet is highly dependent on the magnitude of volume loss. It can be also seen that the presence of geogrid layer has significantly reduced the strain measured along the sheet. This is particularly apparent when comparing the maximum strains that occur during each phase of testing as indicated in Figure 6. Additionally, the threshold value as determined by these measurements again corresponds to a volume loss of about 0.20%. These results are highly significant and indicate a possible relationship between volume loss and the onset of surface settlement. However, further testing is required to evaluate and validate this relationship for various other soils and testing conditions.

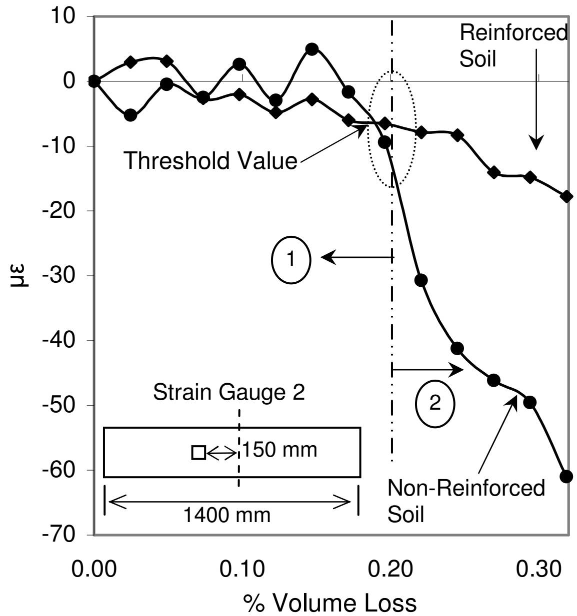

Figure 6: Measured strains: Strain Gauge 2

Initially the sheet placed in a reinforced soil yielded consistently small compressive strains with a maximum of 8 με (see Figure 6). However the response of the sheet in a non-reinforced soil is very similar, although slightly larger strains were measured for an identical volume loss. With further increase in volume loss, the benefits of using a geogrid to limit soil movement become very obvious as the magnitude of strain nearly triples from the reinforced to the non-reinforced soil test. Considering the case of maximum volume loss (equal to 0.32% occurs) the resulting strains are 19 με and 60 με respectively for the reinforced and non-reinforced soil. Relating these strain measurements to those expected along the soil surface it is evident that the geogrid-reinforced sand will experience significantly less surface movement than non-reinforced sand when subjected to an identical volume loss. This again confirms the apparent surface profiles illustrated in Figure 5.

4 CONCLUSION

Erosion of the subgrade is becoming more common within the context of urban environment. Although the literature has identified the mechanisms responsible for this phenomenon, no research has attempted to physically model this process. Consequently, an experimental program was developed to model the response of a soil to an induced volume loss occurring at a known depth below the soil surface. This research considered the response for two cases of geogrid-reinforced and non-reinforced soils. Responses were evaluated based on strains measured along an aluminum sheet, located 95 mm below the soil surface, subject to an identical volume loss. These strains were then related to the surface profile of the sand. The principle findings of this preliminary research program include:

- The response of soils to an induced volume loss is highly dependent on the magnitude of the volume loss. However, this response can be characterized as a two-phase process. Phase 1 corresponds to a volume loss resulting in minimal strain while significantly larger strains occur during Phase 2.
- A threshold value corresponding to the point at which the onset of surface settlement begins joins Phases 1 and 2. This threshold value was determined to correspond to a volume loss of approximately 0.20%.
- It is advantageous to install a geogrid-reinforcement layer within the subgrade of a soil experiencing a volume loss. Strains measured during testing of the non-reinforced sands are nearly triple those occurring within a reinforced soil.
- The apparent surface settlement is noticeably less for the reinforced soil as compared to non-reinforced soil subject to an identical volume loss. Therefore the geogrid-reinforcement aids in providing strain relief and limiting the magnitude of surface settlement

Future research will further investigate the relationships derived from this study program. An emphasis will be placed on evaluating the impact of geogrid location relative to an induced volume loss on surface settlement and soil strains. Additionally, the process of volume loss as a mechanism for subsurface void formation will be considered. The research will assess the response of geogrid-reinforced flexible pavements to subsurface voids of varying size, shape and depth.

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