Civil infrastructure, such as roads, continues to age and underperform and there is a growing need to replace and upgrade these assets. Concurrently, the materials traditionally used in construction of roads and other civil infrastructure continue to increase in cost and scarcity, particularly due to the environmental impacts of quarrying for high quality natural aggregates. As a result, there is a growing need for use of materials that are more readily available and that have lower environmental impacts in sourcing. Typically, these materials differ in their properties from traditional materials, and often have lower performance capabilities.

Therefore, a commercial and environmental need exists for a geogrid material that can facilitate improved performance and economies while at the same time lessen the environmental impact of civil infrastructure such as roads. A need therefore exists for an integral geogrid having a geometry that can engage with, confine and stabilize a greater variety and range of quality of aggregates than geometries associated with conventional geogrids, and having a geometry that includes continuous strands in at least two directions, while simultaneously providing a variety of degrees of localized out-of-plane stiffness, in addition to other desirable properties not available with current integral geogrids.

SUMMARY ~~OF THE INVENTION~~

In an aspect, the present disclosure refers to a multi-axial integral geogrid comprising:

a plurality of interconnected oriented strands and partially oriented junctions forming a repeating pattern of outer hexagons having an array of openings therein,

supporting ribs extending inwardly from each of said outer hexagons to support inside each of said outer hexagons a smaller inner hexagon having an unobstructed, open center and oriented strands and tri-nodes, each of said tri-nodes interconnecting only one of said supporting ribs and two of said oriented strands of the inner hexagon,

said outer hexagons, said supporting ribs and said inner hexagons defining three different geometric configurations which are repeating throughout an entirety of the geogrid, and

said oriented strands and said partially oriented junctions of said outer hexagons defining a plurality of linear strands that extend continuously throughout an entirety of the geogrid.

In an aspect, the present disclosure refers to a starting material for making a multi-axial integral geogrid comprising a polymer sheet having a pattern of holes or depressions therein that provide three different shaped openings, including an outer hexagon and a smaller inner hexagon having an unobstructed, open center and oriented strands and tri-nodes, and a plurality of linear strands that extend continuously throughout an entirety of the geogrid without intersecting an inside of the outer hexagon, when the sheet is biaxially stretched.

In an aspect, the present disclosure refers to a method of making a multi-axial integral geogrid, comprising:

providing a polymer sheet;

providing a patterned plurality of holes or depressions in the polymer sheet; and

orienting the polymer sheet having the patterned plurality of holes or depressions therein to provide a plurality of interconnected oriented strands and partially oriented junctions forming a repeating pattern of outer hexagons having an array of openings therein, supporting ribs extending inwardly from each of said outer hexagons to support inside each of said outer hexagons a smaller inner hexagon having an unobstructed, open center and oriented strands and tri-nodes, each of said tri-nodes interconnecting only one of said supporting

ribs and two of said oriented strands of the inner hexagon, said outer hexagons, said supporting ribs and said inner hexagons defining three different geometric configurations which are repeating throughout an entirety of the geogrid, and said oriented strands and said partially oriented junctions of said outer hexagons forming a plurality of linear strands that extend continuously throughout an entirety of the multi-axial integral geogrid.

In an aspect, the present disclosure refers to a method of making a multi-axial integral geogrid, comprising:

providing a polymer sheet;

providing a patterned plurality of holes or depressions in the polymer sheet; an orienting the polymer sheet having the patterned plurality of holes or depressions therein to provide a plurality of interconnected oriented strands and partially oriented junctions forming a repeating pattern of outer hexagons having an array of openings therein, supporting ribs extending inwardly from each of said outer hexagons to support inside each of said outer hexagons a smaller inner hexagon having an unobstructed, open center and oriented strands and tri-nodes, each of said tri-nodes interconnecting only one of said supporting ribs and two of said oriented strands of the inner hexagon so as to enable the inner hexagon to float up and down relative to a plane of the associated outer hexagon, said outer hexagons, said supporting ribs and said inner hexagons defining three different geometric configurations which are repeating throughout an entirety of the geogrid, and said oriented strands and said partially oriented junctions of said outer hexagons defining a plurality of linear strands that extend continuously throughout an entirety of the multi-axial integral geogrid.

In an aspect, the present disclosure refers to a method of providing a multi-axial integral geogrid construction, comprising:

biaxially stretching a starting material that is a polymer sheet having a patterned plurality of holes or depressions therein to provide a multi-axial integral geogrid having a plurality of interconnected oriented strands and partially oriented junctions forming a repeating pattern of outer hexagons

having an array of openings therein, supporting ribs extending inwardly from each of said outer hexagons to support inside each of said outer hexagons a smaller inner hexagon having an unobstructed, open center and oriented strands and tri-nodes, each of said tri-nodes interconnecting only one of said supporting ribs and two of said oriented strands of the inner hexagon, said outer hexagons, said supporting ribs and said inner hexagons defining three different geometric configurations which are repeating throughout an entirety of the geogrid, and said oriented strands and said partially oriented junctions of said outer hexagons defining a plurality of linear strands that extend continuously throughout an entirety of the multi-axial integral geogrid; and

embedding the multi-axial integral geogrid in a mass of particulate material.

In an aspect, the present disclosure refers to a multi-axial integral geogrid comprising:

a plurality of interconnecting oriented strands and partially oriented junctions forming a repeating pattern of a selected outer geometric shape having an array of openings therein;

each of said outer geometric shapes supporting and surrounding a smaller inner geometric shape having an unobstructed, open center and oriented strands, which inner geometric shape is the same as or different from the outer geometric shape;

said oriented strands and said partially oriented junctions of said outer geometric shape forming at least two sets of substantially parallel linear strands that extend continuously throughout the entirety of the geogrid, and

said geogrid having a thickness of from about 3 mm to about 9 mm.

In an aspect, the present disclosure refers to a reinforced and stabilized composite soil structure comprising:

a mass of particulate material; and

a multi-axial integral geogrid embedded in and engaging with said particulate material and having a plurality of interconnected oriented strands and partially

oriented junctions forming a repeating pattern of outer hexagons having an array of openings therein,

supporting ribs extending inwardly from each of said outer hexagons to support inside each of said outer hexagons a smaller inner hexagon having an unobstructed, open center and oriented strands and tri-nodes, each of said tri-nodes interconnecting only one of said supporting ribs and two of said oriented strands of the inner hexagon,

said outer hexagons, said supporting ribs and said inner hexagons defining three different geometric configurations which are repeating throughout an entirety of the geogrid, and

said oriented strands and said partially oriented junctions of said outer hexagons forming a plurality of linear strands that extend continuously throughout an entirety of the multi-axial integral geogrid.

In an aspect, the present disclosure refers to a multi-axial integral geogrid comprising:

a plurality of interconnected oriented strands and partially oriented junctions forming a repeating pattern of outer hexagons having an array of openings therein,

supporting ribs extending inwardly from each of said outer hexagons to support inside each of said outer hexagons a smaller inner hexagon having an unobstructed, open center and oriented strands and tri-nodes, each of said tri-nodes interconnecting only one of said supporting ribs and two of said oriented strands of the inner hexagon,

said oriented strands, said partially oriented junctions, said supporting ribs, and said inner hexagons forming at least three different geometric configurations which are repeating throughout an entirety of the geogrid, and

said oriented strands and said partially oriented junctions of said outer hexagon defining a plurality of linear strands that extend continuously throughout the entirety of the geogrid.

In an aspect, the present disclosure refers to a method of determining the performance of a particular geogrid in connection with a particular aggregate which comprises:

conducting a standardized retention test with said geogrid and a quantity of said aggregate, and

determining whether the geogrid captures at least about 50% of said aggregate during said test.

To attain the aforementioned geometry that can engage with, confine and stabilize a greater variety and range of quality of aggregates than geometries associated with prior geogrid structures, and having a geometry that includes continuous strands in at least two directions, while simultaneously providing a variety of degrees of localized out-of-plane and in-plane stiffness, and other desirable characteristics, the present invention provides a monolayer multi-axial grid having a repeating geometry comprising different shapes and sizes of apertures, formed from ribs of different lengths, heights and widths, in which the ribs preferably have an aspect ratio greater than 1.0, and in which

some of the ribs extend transversely and diagonally in a continuous linear fashion across the grid, while other strands are interrupted to provide zones of local compliance.

More specifically, the multi-axial geogrid according to the present invention combines the following features:

- ribs of differing width and depth while preferably retaining high aspect ratios
- different aperture shapes and sizes to better accommodate varying granular materials
- a repeating geometry that increases the number of oriented ribs per unit area to better confine granular material
- a repeating geometry that increases the number of angles formed between oriented ribs per unit area to better confine granular material
- a repeating geometry that contains different angles of confinement formed between oriented ribs per unit area to better confine granular material
- integral junctions to facilitate load distribution
- stabilizing and strengthening strong axis strands which extend continuously in a plurality of directions throughout the entirety of the geogrid to optimize load distribution
- locally variable in-plane and out-of-plane stiffness.

In one preferred ~~embodiment~~example, the present ~~invention~~disclosure employs a repeating pattern of interconnected oriented strands and partially oriented junctions forming a repeating pattern of outer hexagons, each of which supports and surrounds an inner smaller hexagon to define three different shaped openings of a monolayer multi-axial integral geogrid. In addition, to provide additional strength and stability, the geometry of the outer hexagons form or define a plurality of linear strands, or strong axis strands or ribs, that extend continuously throughout the entirety of the multi-axial integral geogrid without

According to one ~~embodiment~~example of the present ~~invention~~disclosure, a starting material for making a multi-axial integral geogrid includes a polymer sheet having holes or depressions therein that provide a variety of shaped openings when the starting material is biaxially stretched.

According to another ~~embodiment~~example of the present ~~invention~~disclosure, a multi-axial integral geogrid includes a repeating floating hexagon within a hexagon pattern.

According to still another ~~embodiment~~example of the present ~~invention~~disclosure, a soil construction includes a mass of particulate material strengthened and stabilized by embedding therein a multi-axial integral geogrid having a repeating floating hexagon within a hexagon pattern produced from a polymer starting sheet.

According to yet another ~~embodiment~~example of the present ~~invention~~disclosure, a method of making a starting material for a multi-axial integral geogrid includes providing a polymer sheet, and providing holes or depressions therein to form a multi-axial integral geogrid having a repeating floating hexagon within a hexagon pattern of interconnected, oriented strands, and openings.

According to another ~~embodiment~~example of the present ~~invention~~disclosure, a method of making a multi-axial integral geogrid includes providing a polymer sheet, providing holes or depressions therein, and biaxially stretching the polymer sheet having the holes or depressions therein so as to provide a plurality of interconnected, oriented strands having a variety of shaped openings therein in the form of a repeating floating hexagon within a hexagon pattern.

And, according to yet another ~~embodiment~~example of the present ~~invention~~disclosure, a method of strengthening a mass of particulate material includes embedding in the mass of particulate material a multi-axial integral geogrid having a repeating floating hexagon within a hexagon pattern produced from a polymer sheet that is suitable for use in stabilizing the mass of particulate material.

Accordingly, it is an ~~object~~example of the present ~~invention~~disclosure to provide a starting material for making a multi-axial integral geogrid having a repeating

floating hexagon within a hexagon pattern. The starting material includes a polymer sheet having holes or depressions therein that provide openings when the starting material is biaxially stretched.

Another ~~object~~example of the present ~~invention~~disclosure is to provide a multi-axial integral geogrid suitable for stabilizing and strengthening aggregate that includes a repeating floating hexagon within a hexagon pattern that is produced from a polymer sheet, with linear strands that extend continuously throughout the entirety of the multi-axial integral geogrid. An associated ~~object~~example of the ~~invention~~disclosure is to provide a geometry that can engage with, confine and stabilize a greater variety and range of quality of aggregates than geometries associated with prior geogrid structures, while at the same time providing a variety of degrees of localized out-of-plane and in-plane stiffness, and other desirable characteristics.

Still another ~~object~~example of the present ~~invention~~disclosure is to provide a soil construction that includes a mass of particulate material strengthened and stabilized by embedding therein a multi-axial integral geogrid having a repeating floating hexagon within a hexagon pattern produced from a polymer sheet.

Yet another ~~object~~example of the present ~~invention~~disclosure is to provide a method of making a starting material for a multi-axial integral geogrid that includes providing a polymer sheet, and providing holes or depressions therein to form a multi-axial integral geogrid having a repeating floating hexagon within a hexagon pattern of interconnected, oriented strands, and openings.

Another ~~object~~example of the present ~~invention~~disclosure is to provide a method of making an integral geogrid. The method includes providing a polymer sheet, providing holes or depressions therein, and biaxially stretching the polymer sheet having the holes or depressions therein so as to provide a plurality of interconnected, oriented strands having an array of openings therein, a repeating floating hexagon within a hexagon pattern of the interconnected, oriented strands and openings, including linear strands that extend continuously

throughout an entirety of the multi-axial integral geogrid. The method can employ known geogrid fabrication methods, such as those described in the aforementioned U.S. Patent Nos. 4,374,798, 4,590,029, 4,743,486, 5,419,659, 7,001,112, 9,556,580, 10,024,002, and 10,501,896 as well as in other patents.

The numerous advantages associated with the multi-axial integral geogrid according to the present ~~invention~~disclosure are varied in nature. By virtue of the repeating floating hexagon within a hexagon pattern of the interconnected, oriented strands and openings, the multi-axial integral geogrid can better accommodate varying aggregate sizes, i.e., by varying the limiting aperture dimensions. While prior commercial integral geogrid structures typically have one basic shape and one limiting dimension, the multi-axial integral geogrid of the present ~~invention~~disclosure leverages three different basic shapes – in this example, a hexagon, a trapezoid, and a triangle. In turn, these shapes are defined and bound by oriented strands or ribs of varying shape and dimension. As such, the multi-axial integral geogrid of the present ~~invention~~disclosure can better accommodate the normally occurring varying angles, orientation, and sizes of aggregate as it is distributed across the geogrid.

Further, the multi-axial integral geogrid of the present ~~invention~~disclosure is more suitable for stabilizing a greater variety of aggregate by providing an enhanced range of distribution of aperture size, resulting in the ability to engage with, confine and stabilize a greater variety and range of quality of aggregates compared to that of triangles or rectangles of generally a single size as presented in prior multi-axial integral geogrids. The pattern of the multi-axial integral geogrid of the present ~~invention~~disclosure has an unimpeded open inner hexagon, combined with the larger surrounding hexagon, which provides optimal aggregate confinement and lateral restraint. Further distribution of aperture size is achieved via repeating trapezoid and triangle shaped apertures.

In addition, the multi-axial integral geogrid of the present ~~invention~~disclosure provides higher aspect ratios on all strands compared to those of prior integral geogrids. Because the high aspect ratio of the present ~~invention~~disclosure increases

aggregate interlock, the multi-axial integral geogrid of the present ~~invention~~disclosure can better accommodate the varying aspect ratios of aggregate.

By virtue of the repeating floating hexagon within a hexagon pattern of the interconnected, oriented strands and openings, the multi-axial integral geogrid of the present ~~invention~~disclosure is also characterized by an increased number and type of strand elements relative to prior integral geogrids. And, the multi-axial integral geogrid of the present ~~invention~~disclosure has an increased number of oriented tensile elements and a reduced number of partially oriented junctions. As such, the multi-axial integral geogrid of the present ~~invention~~disclosure is characterized by a variety of degrees of out-of-plane and in-plane localized stiffness.

While the multi-axial geometry of the present ~~invention~~disclosure imparts overall greater in-plane rotational stiffness to the integral geogrid, the shorter length strands increase the rotational stiffness of the integral geogrid relative to that of prior integral geogrids. Thus, the multi-axial integral geogrid is characterized by a compliant, i.e., initial give or flexibility, that leads to better compaction and higher density, yet with a final horizontal aggregate geogrid composite stiffness that is greater as a result of the initial give.

And, the multi-axial integral geogrid of the present ~~invention~~disclosure has an increased number of confinement elements, i.e., strands, that provide concentric-like resistance to aggregate movement. In a like-for-like hexagon size, relative to a conventional triaxial integral geogrid, the multi-axial integral geogrid of the present ~~invention~~disclosure provides twice as many confinement elements to bear against radial loading motion during compaction and trafficking.

In summary, by virtue of the repeating floating hexagon within a hexagon pattern of the interconnected, oriented strands and openings, the preferred multi-axial integral geogrid of the present ~~invention~~disclosure has an increased number and type of strand elements and angles of confinement or "nooks," and has an inner hexagon suspended for restricted out of plane movement up and down. These characteristics result in more opportunities for accommodating and confining aggregate while maintaining the overall structural integrity of the

integral geogrid. Further, by including linear strands of connected oriented strands (or ribs) and partially oriented junctions that extend continuously throughout the entirety of the multi-axial integral geogrid, the multi-axial geogrid of the present ~~invention~~disclosure has increased strength and stability as an aggregate reinforcement.

These together with other ~~object~~examples and advantages which will become subsequently apparent reside in the details of construction and operation as more fully hereinafter described, reference being had to the accompanying drawings forming a part hereof, wherein like reference numbers refer to like parts throughout. The accompanying drawings are intended to illustrate the invention, but are not necessarily to scale.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a plan view of an integral geogrid according to the prior art Walsh '112 patent.

Figure 2 is a plan view of a multi-axial integral geogrid according to a preferred embodiment of the present invention.

Figure 3 is a top perspective view of a starting sheet material having holes or depressions formed therein for forming the multi-axial integral geogrid shown in Figure 2.

Figure 3A is a plan view of a possible size and spacing for the holes shown in the starting sheet material of Figure 3.

Figure 4 is a perspective view of the multi-axial integral geogrid shown in Figure 2.

Figure 5 is an enlarged perspective view of the multi-axial integral geogrid shown in Figure 4 rotated counter clockwise about 30 degrees.

Figure 5A is an enlarged side schematic drawing illustrating a partial section of Rib A and adjoining junctions of an outer hexagon (see Figure 13) which form or define a part of a strong axis strand of the multi-axial integral geogrid shown in Figure 5.