SUMMARY ~~OF THE INVENTION~~

In an aspect, the present disclosure refers to a multilayer integral geogrid for interlocking with, stabilizing, and strengthening aggregate comprising:

a plurality of oriented strands interconnected by partially oriented junctions and having an array of openings therebetween,

said integral geogrid having a plurality of layers each of a polymeric material,

with at least a first outer layer and a second outer layer of said plurality of layers having a cellular structure to improve the initial interaction between and compatibility of a soil or aggregate and the integral geogrid to maximize soil or aggregate density and properties after compaction.

In another aspect, the present disclosure refers to a starting material for making a multilayer integral geogrid, said starting material comprising a multilayer polymer sheet having a plurality of layers each of a polymeric material, with at least a first outer layer and a second outer layer of said plurality of layers having an expansion structure capable of forming a cellular structure in a first outer layer and a second outer layer of the multilayer integral geogrid, the multilayer polymer sheet having holes or depressions therein that provide openings when the sheet is biaxially stretched.

In another aspect, the present disclosure refers to a soil construction comprising a mass of particulate material strengthened by embedding therein a multilayer integral geogrid of the above aspect.

In another aspect, the present disclosure refers to a method of strengthening a mass of particulate material, comprising embedding in the mass of particulate material the multilayer integral geogrid of the above aspect.

In another aspect, the present disclosure refers to a method of making a multilayer integral geogrid, comprising:

providing a multilayer polymer sheet having a plurality of layers each of a polymeric material, with at least a first outer layer and a second outer layer of said plurality of layers having an expansion structure capable of forming a cellular structure in said first and second outer layers of the multilayer integral geogrid; providing a patterned plurality of holes or depressions in the multilayer polymer sheet; and biaxially orienting the multilayer polymer sheet having the patterned plurality of holes or depressions therein to provide a plurality of oriented strands interconnected by partially oriented junctions, and to configure the holes or depressions as grid openings, said first and second outer layers having a cellular structure.

In another aspect, the present disclosure refers to a method of strengthening a mass of particulate material, said method comprising: providing a multilayer integral geogrid having at least a first outer layer and a second outer layer with a cellular structure construction, including biaxially stretching

a starting material that is a multilayer polymer sheet having the first outer layer and the second outer layer with the cellular structure and a patterned plurality of holes or depressions therein to provide a multilayer integral geogrid having the first outer layer and the second outer layer with the cellular structure and having a plurality of oriented strands, a plurality of partially oriented junctions, and a plurality of grid openings; and embedding the integral geogrid in a mass of particulate material.

In another aspect, the present disclosure refers to a multilayer integral geogrid comprising: a plurality of interconnected oriented first 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 open center and oriented second 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 first strands and said partially oriented junctions of said outer hexagon forming a plurality of linear strands that extend continuously throughout the entirety of the multilayer integral geogrid, said integral geogrid having a plurality of layers each of a polymeric material extending throughout said geogrid, and at least one layer of said plurality of layers having a cellular structure.

The object of the instant ~~invention~~disclosure, therefore, is to deliver improved functional performance from multiaxial integral geogrids by enhancing

certain physical, mechanical, and geometrical properties of the multiaxial integral geogrid structure that improves functional performance, such as by modifying and/or incorporating other new physical, mechanical, and geometrical properties. By careful physical positioning and manipulating of the amount of different polymeric materials that have the desired mechanical and physical properties in specific locations of integral geogrid structures, and by optimizing all other physical parameters of the geogrid structure, significant performance improvements can be achieved.

Another object of the instant ~~invention~~ disclosure is to provide a multilayer integral geogrid in which layers thereof are modified to reduce the amount of polymer required by converting the polymer in those layers from a solid, i.e., continuous, structure to a cellular structure, i.e., a structure having dispersed therein a plurality of voids, cavities, pores, fissures, bubbles, holes, or other types of openings, i.e., cellular openings, produced according to the methods described herein.

More specifically, subsequent to the filing of the '960 application, it has been surprisingly discovered that improved initial compatibility between the aggregate and layers of the multilayer integral geogrid having the cellular structure can be achieved if certain parameters for the layers with the cellular

structure are included in the geogrid, as disclosed herein. These parameters include the following:

1. the minimum rib thickness or height of the multilayer integral geogrid having one or more cellular layers in accordance with the present ~~invention~~ disclosure is preferably from about 0.5 mm to about 6 mm, and more preferably from about 1.15 mm to about 4 mm.

2. the aspect ratio of the ribs of the multilayer integral geogrid having one or more cellular layers in accordance with the present ~~invention~~ disclosure is preferably from about 0.75 to about 3.0, and more preferably from about 1 to about 2.

3. the initial height or thickness of the one or more cellular layers at their thinnest height (likely the midpoint of the strands or ribs) after stretching is from about 0.1 mm to about 4 mm, and more preferably from about 0.5 to about 3 mm;

4. the cellular openings of the one or more cellular layers comprise at least 20% by volume of the one or more cellular layers, and preferably from about 30% to about 50%;

5. the one or more cellular layers have a minimum "crushability" or height reduction under load of at least 20% and preferably from about 30% to about 50%; and

6. the one or more cellular layers have a height or thickness that is at least 10% of the overall height of the final integral geogrid, and preferably from about 20% to about 35%.

By including the above physical properties in the multilayer integral geogrid having the one or more cellular layers in accordance with the present ~~invention~~disclosure, the initial compatibility between the aggregate and the geogrid is improved after compaction is complete. And, by improving the initial compatibility, any possible remaining aggregate movement or repositioning that would normally occur during and after compaction in the initial phases of "in service" loading is reduced. Thus, the roadway or other transporting surface, or aggregate or soil layer, is better stabilized and improved at the time of construction, and any deformation or movements that occur during in service use or loadings is reduced.

More specifically, by virtue of using the multilayer integral geogrid having the one or more cellular layers, the ~~instant invention~~present disclosure provides for improved micro-interaction as the layers of compressible polymer serve to nest aggregate particles and facilitate and maintain maximum properties of the aggregate.

In addition, by carefully modifying the polymer to reduce the density and/or volume of polymer used in one or more of the layers of the extruded sheet used to manufacture the multilayer integral geogrid, an integral

geogrid structure can be created that has equivalent physical dimensions to traditional integral geogrids, but with less polymer material use and thus less cost.

Accordingly, to attain the aforementioned objects, the present ~~invention~~ disclosure is directed to integral geogrids having a multilayer construction, with at least one layer thereof having a cellular structure. These multilayer geogrids are often referred to herein as integral geogrids having at least one layer thereof with a cellular structure, or, more simply, a "multilayer integral geogrid having one or more cellular layers" or "multilayer integral geogrids having one or more cellular layers." By virtue of the multilayer integral geogrids having one or more cellular layers, the multilayer integral geogrids of the present invention provide for increased layer compressibility under load, and other desirable characteristics.

More specifically, the layer or layers having the cellular structure contain a distribution of a plurality of cellular openings, i.e., voids, cavities, pores, fissures, bubbles, holes, or other types of openings therein. The cellular structure may be associated with a foamed construction of the layer, or may be associated with a particulate filler that is distributed throughout the layer, or may be any other method of creating cellular openings in the cellular layer.

And, for an ~~embodiment~~ example~~of the present invention~~ having three or more layers, the compressible layers thereof having a cellular structure are preferably positioned at least as the two outer (or exterior or "cap") layers of the

multilayer integral geogrid. There are unique geo-mechanical advantages to having the two outer layers be compressible. One important advantage: the compressible outer layers allow for the aggregate to not only strike through the apertures and be confined in the apertures, but also to become embedded in the outer layers of the integral geogrid surface, thereby creating what is sometimes referred to herein as a "crush-fit" phenomenon. With the aggregate being "crush-fit" into the surface of the cellular outer layers of the integral geogrid, the integral geogrid is able to provide enhanced lateral restraint of the aggregate under loading by resisting movement of the aggregate via enhanced frictional characteristics of the surface of the cellular outer layers, and by the binding action that occurs by the aggregate particles partially crushing into the surface of the cellular outer layers.

Because the crushable character of the cellular outer layers provides both plastic and elastic deformation, the aggregate pushes into the outer layer and binds into the surface thereof. At the same time, the surface of the outer layer pushes back, enhancing the bond and "crush-fit" between the aggregate and the multilayer integral geogrid. And, according to certain ~~embodiments~~ examples~~of the invention~~, the crushable character of the cellular outer layers may have the potential to create a chemical bond with the surrounding soils. By combining an improved geometry as described herein with an enhanced engineered outer layer structure, the multilayer integral geogrid according to the

present disclosure ~~invention~~ provides for enhanced performance via improved confinement and lateral restraint of the aggregate.

A primary attribute of the multilayer integral geogrid according to the present disclosure ~~invention~~ is the compressibility or crushability of the cellular layer or layers. For example, in the above-described three-layer embodiment, the compressibility of the two outer cellular layers is important to allowing the aggregate to bed into the surface of the integral geogrid. Ideally, each compressible layer is durable enough to tolerate the process of being embedded in particulate matter (i.e., in that it will resist delamination from other layers, or shred), and will compress at least about 20% under load. Additionally, the compressible layer will rebound by at least about 85%. A fundamental concept of the present invention is that the cellular layer be compressible enough to accommodate the aggregate during embedding, but also then to "rebound," as the compressible cellular layer pushes back against the aggregate to "bind" the multilayer integral geogrid in place. The crushing and the rebound are believed to improve performance via frictional and binding attributes that result in improved lateral restraint of the aggregate.

Furthermore, the construction of the multilayer integral geogrids having one or more cellular layers may include layers that are coextruded, or layers that are laminated. The creation of the cellular openings in the layer with the cellular structure may occur during extrusion/lamination or stretching/orientation, or both.

And, the resulting multilayer integral geogrids having a layer or layers with a cellular structure and having the plurality of oriented multilayer strands interconnected by the partially oriented multilayer junctions and having an array of openings therebetween may be configured in any of a variety of repeating geometric patterns, such as described herein.

According to an example~~the present invention~~, a starting material for making multilayer integral geogrids having one or more cellular layers includes a multilayer polymer starting sheet having holes or depressions therein that provide an array of shaped openings when the starting material is biaxially stretched. The multilayer polymer starting sheet includes one or more layers that are capable of forming the cellular structure. Two preferred ~~embodiments~~ examples are described in detail herein. In the first preferred ~~embodiment~~ example according to the present disclosure~~invention~~, the layer capable of forming the cellular structure includes a foaming agent which upon extrusion of the layer and/or stretching/orientation of the starting sheet forms the cellular layer as part of the final multilayer geogrid (hereinafter sometimes "the foamed embodiment").

In the second preferred ~~embodiment example according to the present invention~~, the layer capable of forming the cellular structure includes a particulate filler dispersed in the layer which upon stretching/orientation of the starting sheet creates the cellular structure in the layer as part of the final multilayer geogrid (hereinafter sometimes "the filler embodiment"). According to

preferred ~~embodiments~~examples, the layers of the multilayer polymer starting sheet may be coextruded, or may be laminated to one another.

In addition to the two preferred ~~embodiments~~ examples described in detail herein, the present disclosure ~~invention~~ also contemplates other methods of creating the cellular openings for the cellular layer or layers which may be devised by those skilled in the art, such as gas injection or the like, so long as the cellular openings that are in the cellular layer comport with the parameters set forth herein.

According to specific ~~embodiments~~ examples~~of the present invention~~, the multilayer integral geogrids having one or more cellular layers include a plurality of oriented multilayer strands interconnected by partially oriented multilayer oriented junctions and having an array of openings therebetween. According to one ~~embodiment~~example, a three-layer integral geogrid has a non-cellular layer interposed between two outer layers with cellular structures. According to another ~~embodiment~~example, a multilayer integral geogrid has a repeating pattern of a non-cellular layer interposed between two layers with cellular structures. According to still another ~~embodiment~~example, the multilayer integral geogrid has a non-cellular layer associated with an adjacent layer having a cellular structure.

According to one ~~embodiment~~example, the multilayer integral geogrid having one or more cellular layers is a rectangular geogrid having a repeating geometric pattern of partially oriented junctions interconnecting oriented strands which define rectangular openings. According to another ~~embodiment~~example,

the multilayer integral geogrid having one or more cellular layers is a triaxial geogrid having a repeating hexagonal geometric pattern of partially oriented junctions interconnecting oriented strands which define triangular openings. And, according to yet another ~~embodiment~~example, the multilayer integral geogrid having one or more cellular layers is a geogrid having a repeating geometric pattern of partially oriented junctions interconnecting oriented strands which form outer hexagons, each of which outer hexagons surrounds and supports six inner interconnected oriented strands formed into the shape of an inner hexagon and defining a smaller hexagonal opening, referred to herein as a "repeating floating hexagon within a hexagon pattern." This ~~embodiment~~ example ~~of the present~~ ~~invention~~ that has the "repeating floating hexagon within a hexagon pattern" is also sometimes referred to herein as the "hexagonal" embodiment.

According to still another ~~embodiment~~ example~~of the present invention~~, a soil construction includes a mass of particulate material strengthened and stabilized by embedding therein a multilayer integral geogrid having one or more cellular layers, and having a repeating geometric pattern of the type described in the preceding paragraph.

According to yet another ~~embodiment~~ example~~of the present invention~~, a method of making a starting material for a multilayer integral geogrid having one or more cellular layers includes providing a multilayer polymer starting sheet having one or more layers that are capable of forming such layers with a cellular structure as part of the final multilayer geogrid, and providing holes or

depressions therein that provide a repeating geometric pattern of partially oriented multilayer junctions interconnecting oriented multilayer strands, and defining openings when the starting material is biaxially stretched.

According to another ~~embodiment~~ example~~of the present invention~~, a method of making a multilayer integral geogrid having one or more cellular layers includes providing a multilayer polymer starting sheet having one or more layers that are capable of forming such layers with a cellular structure as part of the final multilayer geogrid, providing holes or depressions therein, and biaxially stretching the multilayer polymer sheet having the holes or depressions therein so as to provide a repeating geometric pattern of partially oriented multilayer junctions interconnecting oriented multilayer strands, and defining openings therein.

And, according to yet another ~~embodiment~~ example~~of the present invention~~, a method of strengthening a mass of particulate material includes embedding in the mass of particulate material a multilayer integral geogrid having one or more cellular layers and having a repeating geometric pattern of partially oriented multilayer junctions interconnecting oriented multilayer strands defining openings.

Accordingly, ~~it is~~ an ~~object~~ example of the present ~~invention~~ disclosure is to provide a multilayer integral geogrid having one or more cellular layers, so as to provide an integral geogrid having increased layer compressibility under load. The multilayer integral geogrid having one or more cellular layers may have a non-

cellular layer interposed between two layers with a cellular structure, may have a repeating pattern of a non-cellular layer interposed between two layers with a cellular structure, or may have a non-cellular layer associated with an adjacent layer having a cellular structure.

Thus, another ~~object~~ example~~of the present invention~~ is to provide a starting material for making a multilayer integral geogrid having one or more cellular layers. The multilayer polymer starting sheet includes one or more layers that are capable of forming the cellular structure. In a first ~~embodiment~~example, i.e., the foamed embodiment, according to the present ~~invention~~disclosure, the layer capable of forming the cellular structure includes a foaming agent which upon extrusion of the layer and/or stretching/orientation of the starting sheet forms the cellular layer as part of the final multilayer geogrid. In a second ~~embodiment~~example, i.e., the filler embodiment, according to the present ~~invention~~disclosure, the layer capable of forming the cellular structure includes a particulate filler dispersed in the layer which upon stretching/orientation of the starting sheet creates the cellular structure in the layer as part of the final multilayer geogrid.

Another ~~object~~ example~~of the present invention~~ is to provide multilayer integral geogrids having one or more cellular layers and having a plurality of oriented multilayer strands interconnected by partially oriented multilayer junctions and having an array of openings therebetween that is produced from a multilayer polymer starting sheet. The multilayer integral geogrid having one or more cellular layers may be a rectangular geogrid having a repeating geometric

pattern of partially oriented multilayer junctions interconnecting oriented multilayer strands defining rectangular openings, a triaxial geogrid having a repeating geometric pattern of partially oriented multilayer junctions interconnecting oriented multilayer strands defining triangular openings, or a geogrid having a repeating geometric pattern of partially oriented multilayer junctions interconnecting oriented multilayer strands defining outer hexagons, each of which surrounds and supports an inner oriented hexagon, i.e., the "repeating floating hexagon within a hexagon pattern."

An associated ~~object of the present invention~~example is to provide a geometry that can engage with and stabilize a greater variety and range of quality of aggregates than geometries associated with prior geogrid structures, while at the same time providing an enhanced compressibility, and other desirable characteristics.

Still another ~~object of the present invention~~example is to provide a soil construction that includes a mass of particulate material strengthened and stabilized by embedding therein a multilayer integral geogrid having one or more cellular layers and having a repeating geometric pattern as described herein.

Yet another ~~object of the present invention~~example is to provide a method of making a starting material for multilayer integral geogrids having one or more cellular layers that includes providing a multilayer polymer starting sheet having one or more layers that are capable of forming such layers with a cellular structure as part of the final multilayer geogrid, and providing holes or

depressions therein that provide a repeating geometric pattern of partially oriented multilayer junctions interconnecting oriented multilayer strands, and defining openings when the starting material is biaxially stretched.

The multilayer polymer starting sheet may be produced by coextruding the plurality of layers, or by laminating the plurality of layers to one another.

Another ~~object of the present invention~~example is to provide a method of making multilayer integral geogrids having one or more cellular layers, which includes providing a multilayer polymer starting sheet having one or more layers that are capable of forming such layers with a cellular structure as part of the final multilayer geogrid, providing holes or depressions therein, and biaxially stretching the multilayer polymer starting sheet so as to provide a repeating geometric pattern of partially oriented multilayer junctions interconnecting oriented multilayer strands, and openings. The method of making the above-described rectangular opening or triangular opening integral geogrids 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 method of making the above-described integral geogrid having a repeating geometric pattern of partially oriented multilayer junctions interconnecting oriented multilayer strands, and defining outer hexagons, each of which

surrounds and supports an oriented inner hexagon, can employ a fabrication method as described hereinafter.

More specifically, ~~it is~~ an ~~object~~ example of the present ~~invention~~ disclosure~~to~~ provides a method of making multilayer integral geogrids having one or more cellular layers in which the layer with the cellular structure is produced by first providing a foamed construction in a layer of the multilayer polymer starting sheet capable of forming such layers, and then orienting the multilayer polymer starting sheet so as to stretch the foamed material and create the cellular structure.

Correspondingly, it is another ~~object of the present invention~~example to provide a method of making multilayer integral geogrids having one or more cellular layers in which the layer with the cellular structure is produced by first dispersing a particulate filler in a layer of the multilayer polymer starting sheet capable of forming such layers, and then orienting the multilayer polymer starting sheet so as to stretch the dispersion of particulate filler and create the cellular structure as the particulate filler partially separates from the polymeric layer material.

And, still another ~~object of the present invention is to~~example provides a method of strengthening a mass of particulate material that includes embedding in the mass of particulate material a multilayer integral geogrid having one or more cellular layers, and having a repeating geometric pattern of partially

oriented multilayer junctions interconnecting oriented multilayer strands and openings.

The numerous advantages associated with the multilayer integral geogrid having one or more cellular layers according to the present ~~invention~~ disclosure are varied in nature.

By virtue of the multilayer integral geogrids having one or more cellular layers of the present invention having not only a multilayer construction, but with at least one layer thereof having a cellular structure, the integral geogrids provide for increased compressibility of the multilayer integral geogrid under load.

Furthermore, the multilayer nature of the multilayer integral geogrids having one or more cellular layers of the present disclosure ~~invention~~ provides for overall greater aggregate engagement by the integral geogrid relative to that of prior monolayer integral geogrids. In addition, by virtue of the one or more cellular layers, the multilayer integral geogrids of the present disclosure ~~invention~~ are characterized by a structural compliance, i.e., initial give or flexibility, that leads to better compaction and higher density, yet with a final integral geogrid composite stiffness when incorporated in a soil construction that is greater as a result of the initial give of the multilayer integral geogrid.

In addition, certain ~~embodiments~~ examples of the multilayer integral geogrids having one or more cellular layers of the present ~~invention~~ disclosure provide higher aspect ratios on all strands compared to those of prior integral geogrids. Because the

higher aspect ratio associated with certain embodiments of the integral geogrids of the present invention increases aggregate interlock, the multilayer integral geogrids having one or more cellular layers of the present invention can better accommodate the varying aspect ratios of aggregate.

In summary, the cellular layers of the multilayer integral geogrid according to the present ~~invention~~ disclosure create unique physical and mechanical properties and behaviors in the integral geogrid product. During placement and compaction of aggregate in the multilayer integral geogrid it is believed that the nature of the compressible, cellular outer layers in the ribs and nodes, along with other scientifically engineered aspects of the geogrid, provides for better initial compatibility between the aggregate and the geogrid, thus improving the aggregate density after compaction is complete, and lessening any possible remaining aggregate movement or repositioning that would normally occur after compaction and upon initial phases of in service loadings. While not intending to be bound, it is presently believed that the aforementioned initial compatibility of the multilayer integral geogrid according to the present disclosure ~~invention~~ is a key contributor to lessening the amount of deformation that occurs as the geogrid is in use. The benefit of the initial compatibility associated with the present invention is evidenced, for example, by the testing results on a laboratory trafficking device where significantly fewer passes are required to achieve a stabilized condition of the multilayer integral geogrid according to the present ~~invention~~disclosure. In addition, various embodiments of the multilayer integral geogrid