

Visualization of Interlock Action in Granular Medium for Modeling Geogrids

O. Pekcan

Middle East Technical University, Turkey (opekcan@metu.edu.tr)

M. Gürbüz

Middle East Technical University, Turkey (mucahit.gurbuz@metu.edu.tr)

ABSTRACT: Accurate modelling of granular particles' effects plays a crucial role when analyzing the behavior of soils reinforced with geogrids. In addition to the field and laboratory tests, computer simulations help understanding influences of geogrid interlock actions in the overall behavior. In this study, we present the results of our first attempt for simulating ballast particles together with geogrid reinforcements using our own simulation tool. For this purpose, a simulation game software is written with a graphical user interface, that will allow the user to interact with the soil – geogrid medium. With the introduction of geogrid type and ballast gradation information, the software can generate a model that shows how ballast fills the voids of the geogrid. The model is developed based on both physical and mathematical constraints. Various geogrid types produced by different companies are embedded in the software. A powerful feature of the software is that custom geogrid types can be generated by the user through the interacting with the geotechnical designer. In addition, the software can analyze various gradation curves and their proper models very fast. The results may influence the design of new geogrids to produce more effective improvement solutions.

Keywords: Geogrid Simulation, interlock action, modelling new geosynthetics

1 INTRODUCTION

Recently, the use of geosynthetic materials have become highly popular regarding to their wide range of applications in various earthwork projects. Several advantageous features such as less effort requirement for installation, less space necessity for construction, and environmentally friendly perspective, i.e., less CO₂ footprints make them very appealing (Müller & Saathoff, 2016). Among the geosynthetic materials, geogrids are the main ones, which are widely used in different projects such as stabilization of earth slopes, railroads and pavements, etc. They work through increasing the strength of soils, and therefore improving bearing capacity, which also help having less settlements. In geogrid based railroad applications, reinforcement of the subgrade ballast is the key issue to deal with relatively high lateral displacements. Geogrids are placed between ballast and subgrade layer as reinforcing elements, and they result in an interlock action between ballast and geogrid to reduce the lateral movement and settlement of railroad truck.

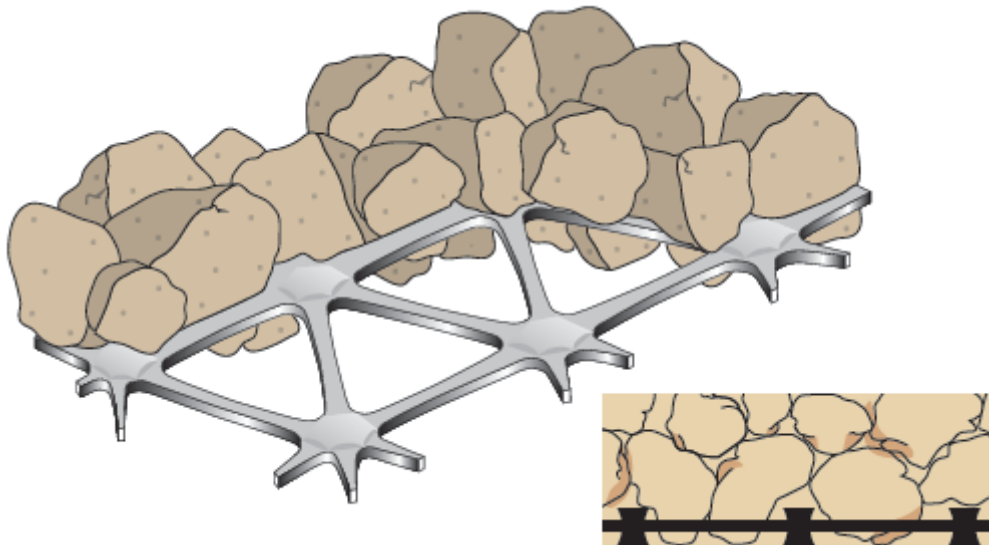


Figure 1: Interlock action between geogrid and ballast particles (Tensar International, 2009)

The interlock action depends on some factors such as size, shape, angularity, and gradation of aggregates, as well as geogrid types and properties. Installation process and loading type is also effective in producing an interlock (Qian et al. 2015). Among those, interlock action level is mainly affected by the combination of geogrid, aggregate type and aggregate gradation. To obtain more efficient interlock, different combinations of geogrid-aggregate should be evaluated (Wu et al. 2010). Better interlock actions have been searched by some laboratory and field tests. These studies aimed to find the optimum relation of aggregate size and geogrid type, which is key point of obtaining successful interlock action (Brown et al. 2007). In addition to a successful interlock, a well-chosen geogrid type can decrease the requirement of pavement layer thickness and it can significantly increase service life of pavement. Thus, better economical solution can be obtained which is one of the main targets of optimizing the thickness of pavement layers (Kwon & Tutumluer, 2009).

To understand the behavior of geogrid interlock actions and their effects in overall behavior of soils, computer simulations can be helpful in addition to the field and laboratory tests. This paper represents the results of our first attempt for simulating ballast particles with geogrid reinforcements. For this purpose, a simulation software based on a game engine is written. Although there is several research studies made to simulate this environment by using discrete element method (DEM), they do not give complete freedom to create realistic random ballast particle and custom geogrid types. On the contrary, in our 3D simulating game, the one can form any kind of ballast type, ballast gradation and geogrid type. In addition, previously defined ballast and commonly used geogrid types can be used. Besides, a graphical user interface which allows user to interact with the soil-geogrid medium is used. With the introduction of geogrid type and ballast gradation information, the software can generate a model that shows how ballast fills the voids of the geogrid. Some powerful features of the software are those custom geogrid and rock type generation, embedded geogrid types which are produced by different companies, analyzing various gradation curves very fast etc. The main purpose of this study is to have a completely free manipulation environment which can help researchers to design new geosynthetics and to observe their interaction effects with the soils.

2 ALGORITHM DEVELOPMENT

2.1 *Computer modelling environment*

One of the main purposes of geogrid modelling studies is to seek for the best solution which gives the best response of geogrid-soil interaction. Therefore, together with the existing geogrid type or ballast type, one may need to look for other options such as new geogrid geometries. To do this, a flexible software environment would be preferable for defining geogrid and ballast. In previous studies, various discrete element modelling software were used such as PFC^{3D}(Chen et al. 2014), BLOKS3D(Qian et al 2015) and PFC^{2D}(Wang et al. 2014)- Although these software products are reliable and sufficiently fast and for discrete element modelling, they have limited capability on defining irregular aggregate shapes or new geogrid geometries in a reasonable amount of time. In addition, users may not observe or interact with the backhand process of these software products which may lead to limited understanding and/or productivity. To cope with such features and to have a fully flexible inspirational environment, a new software is written. MATLAB software is chosen for this purpose as exploring data, creating algorithms and creating custom tools are easy with MATLAB's open architecture which provides early insights and competitive advantages (Dukkipati, 2010). Its open architecture makes it possible to share all source codes among the user community and it has one of the rich user communities in software world (Leite, 2010). Mostly, engineering graphics and scientific visualization side of MATLAB is used to develop our simulation game. The algorithms have been implemented on the main body of MATLAB code and Graphical User Interface (GUI) is provided to user interactions. Therefore, with the algorithms geogrid bodies can be formed and ballast particles can be defined as any shape the user wants. Moreover, gradation and interlock action can be changed or improved with the computer codes. With the help of GUI, users can easily set the parameters and see simulation results.

2.2 *Built-in functions used in software*

MATLAB also has built in computational geometry functions to help modelling processes. In this study, built-in functions have been used to develop algorithms to develop contacts in fast and easy way. Some of built-in functions used in software are explained as follows.

2.2.1 *alphaShape*

AlphaShape is bounding region function in MATLAB built-in functions library. It creates polyhedra from points in 3-Dimensions (3-D). Polyhedra is a solid shape created with collection of polygons. After defining points in 3-D, an alpha radius to decide what will be the range of points included in alphaShape is chosen. Then, from points within the range, function creates an alpha shape which is a polyhedra. In this study, alpha shapes are used at every stage of the algorithm, i.e., from defining ballast and geogrid to rigid body contact implementation.

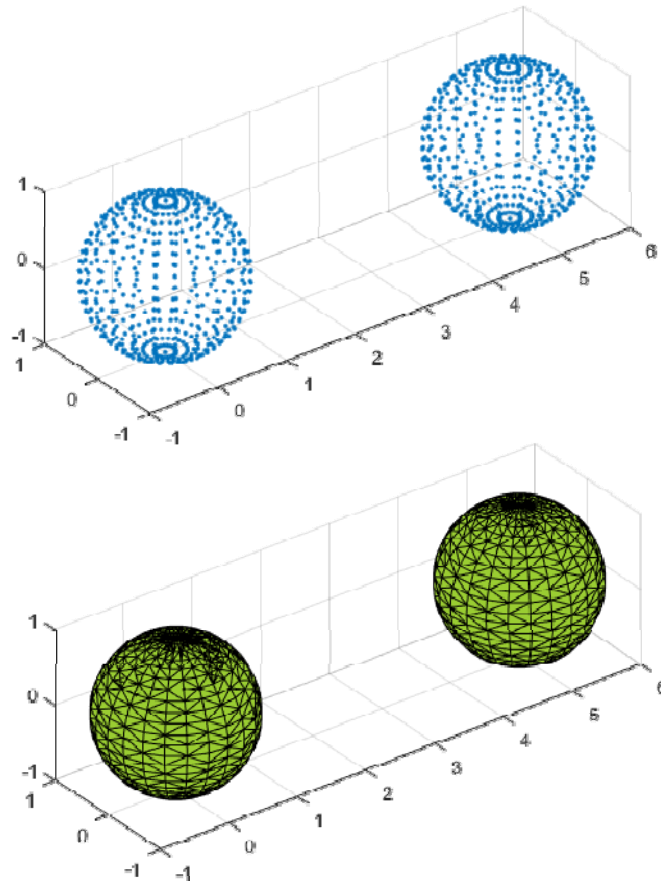


Figure 2: alphaShape from 3-D point cloud (MathWorks, 2016)

2.2.2 *inShape*

InShape is one of the sub-function of alphaShape function. It determines if a point is inside alpha shape or not. Output of the inShape function is logical statement. It returns logical 1 (true) or 0 (false) with respect to the condition of 3-D query points whether it is inside the alpha shape or not. For the contact detection between geogrid-ballast or ballast-to-ballast, inShape function is used geometrically.

2.2.3 *randn*

One of the most widely used random number generator functions in MATLAB is “randn”, which creates normally distributed random numbers. In any size of array, it can create normally distributed random numbers and assign them to array. This function is used to form a ballast shape with irregularities on the surface.

2.3 *Forming geogrid bodies*

Forming geogrid bodies is an important process to have a realistic visualization. Through our simulation software, a geogrid can be modelled with its rib and junction regions geometrically. First, points in 3-D which are on geogrid’s corners, edges and surfaces, are defined. More points lead to better geogrid model when many irregularities on geogrid exist. Then, this 3-D point cloud is turned to polyhedra by using alphaShape function. With the help of this procedure, one can easily define the uniaxial, biaxial, triaxial geogrid type can be defined or a new type of geogrid model can be created. There are biaxial and uniaxial models of Tensar[®] company and quaxial model of Jinan GTM Building Materials Co., Ltd as an example for already available geogrid types (Figure 3).

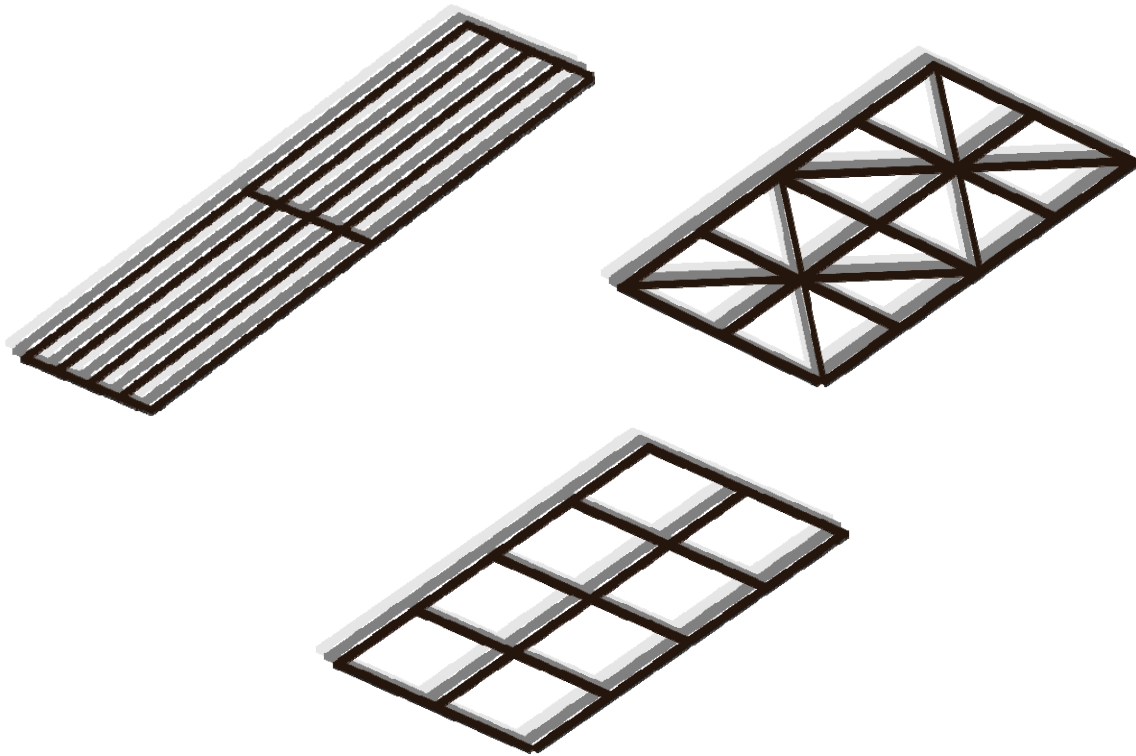


Figure 3: Generated uniaxial, quaxial and biaxial geogrid models

2.4 Defining ballast particles

Ballast particle shape is prominent feature of MATLAB modelling environment for this study. Flat and elongated ratio, angularity, and surface roughness have major effects on ballast performance (Qian et al., 2015). These indices affect the contact behavior and consequently interlock action between geogrid and ballast particles. In other ballast modelling studies, due to computing time or software restrictions, ballast particles have been modelled with rounded or sub rounded angularity (Figure 4). However, some other studies show that the stresses induced by weight become more homogenous with increasing angularity and interlocking effect provided with surface roughness gives much reduced particle rotation and displacement. Angularities and roughness gives more realistic responses (Lu & Mcdowell, 2007).

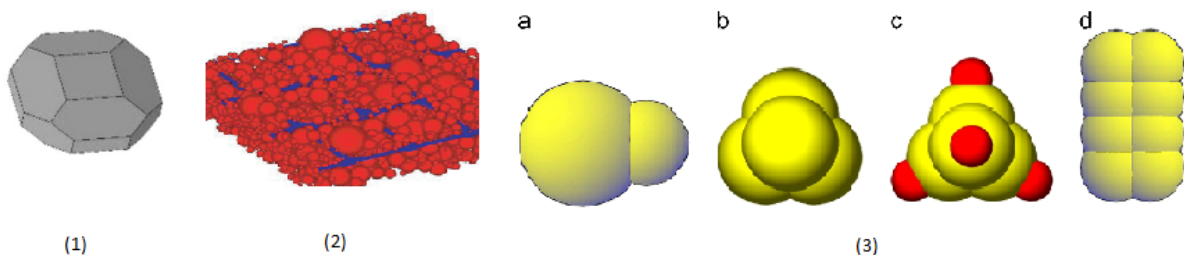


Figure 4: (1) Sub-rounded ballast model (Qian et al., 2015), (2) Sphere ballast model (Kwon & Tutumluer, 2009), (3) Ballast with clumps model (Chen et al., 2014)

Modelling ballast particle for this study starts with defining 3-D point cloud with using randn function. Creating normally distributed points on x, y and z axis forms a point cloud with dense center and light edge. Then by using alphaShape function, point cloud turns to a polyhedra which represent ballast particle in software (Figure 5).

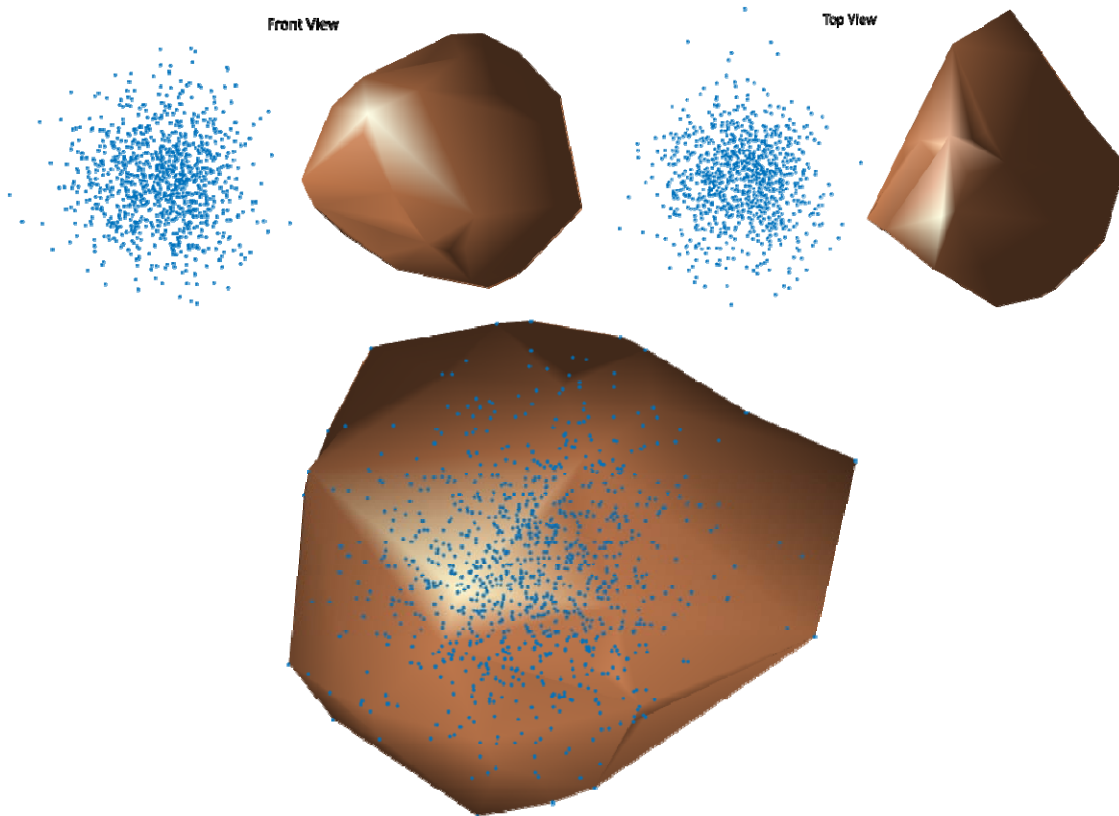


Figure 5: Front view, top view and overlaps of point cloud with alpha shape

When software converts the point cloud to an alpha shape, these random distributions create a rough surfaces and irregular shapes for each ballast model (Figure 6).

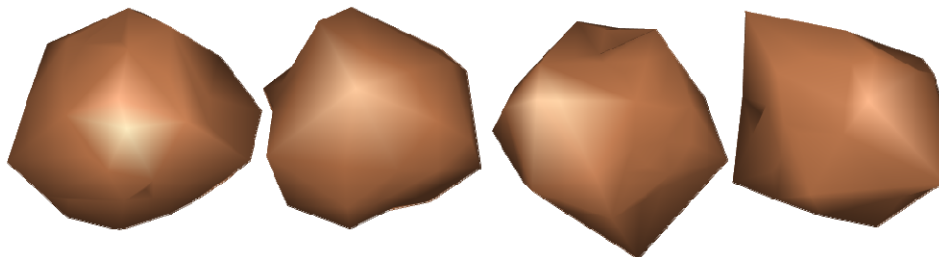


Figure 6: Different ballast shape for each model

With this fast and easy method, we can model huge number of ballast particles during simulation process which makes that possible to simulate large scale environment quite efficiently.

2.5 Ballast gradation

Method of production and interlock performance of ballast layer affected by specified size and grading. Considering economy, both parameters have a considerable effect. Therefore, an effective optimization is necessary (Raymond & Diyaljee, 1979). In addition, to visualize the interlock action completely, ballast size and geogrid opening are important criterions. Thus, realistic gradation will have a great effect on the outcome scenes of the game. For the ballast gradation, probability analysis method is implemented during the research. Unlike previous studies which models use predefined ballast particles, this study takes in to account every ballast particle size in geogrid openings which are defined separately by using probability of defined gradation. By using GUI, user can select input D_{10} , D_{30} , D_{60} values. These parameters

are equal to diameters which %10, %30, and %60 passing obtained from grain size distribution (Figure 7).

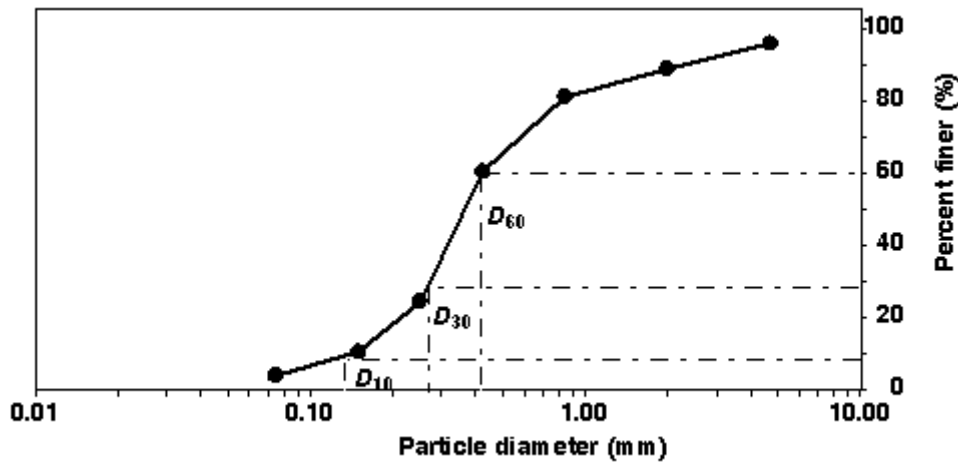


Figure 7: Grain size distribution curve with D10, D30 and D60 (Camp, n.d.)

By means of the user inputs, the software produces for conceptual diameter for each ballast produced. Table 1 shows that diameter intervals and probability of occurrence of those intervals.

Table 1. Gradation intervals

Probability of Occurrence	Diameter Interval
%10	0 – D ₁₀
%20	D ₁₀ – D ₃₀
%30	D ₃₀ – D ₆₀
%40	D ₆₀ – Max. Grain Size

This software allows us to work with any gradation type required at field, fast and easy. Additionally, working with unrelated event probability makes this process more realistic.

2.6 Simulation

Simulation algorithm is the most challenging part of the entire study. Visualization of interlock action obtained from output of simulation process. Through the GUI, users can choose predefined geogrid model and enter gradation parameters that will be used in simulation (Figure 8). Then, by pushing the simulate button, simulation process is initiated. With respect to defined input parameters, a suitable geogrid is formed. Then, ballast particles are created and are sent to one of the geogrid openings one by one with regard to input gradation parameters.

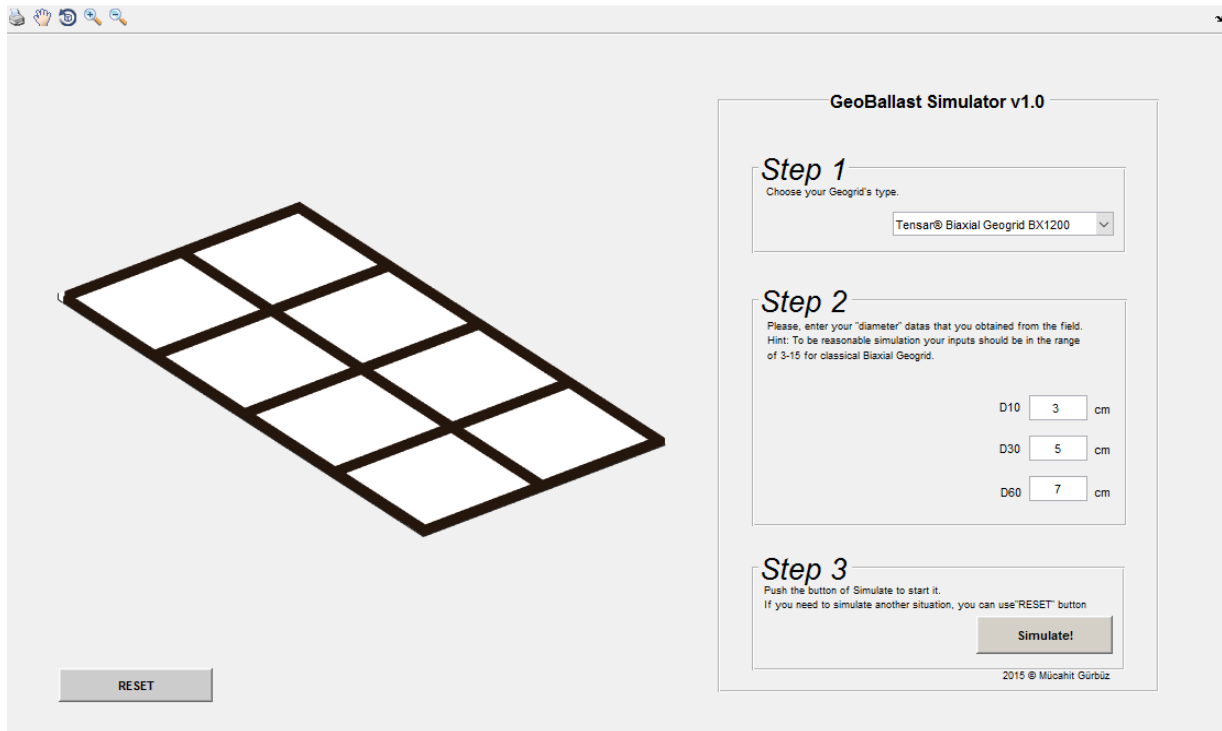


Figure 8: Graphical user interface (GUI) of the software

The main algorithm consists of several steps. First, ballast particle is created at one random point on the virtual L line which composed of left and top side of the outermost geogrid sides and on the same horizontal plane with geogrid. Next, with small steps, it approaches to right-bottom corner of geogrid by following random path. When ballast particle hits one of the edges regarding to contacted edge (right edge or bottom edge), the ballast moves down or right and parallel to contacted edge until reached to right-bottom corner. After contacting with other edge, the ballast particle stops and has the final position. Contact detection is made by using inShape function. For each step, the software controls if the ballast particle collides with another alpha shape (another ballast particle or geogrid edges). Having done with the first particle, other particles are laid out in the geogrid opening. For this time, the ballast particle stops when it hits to another ballast particle. This process continues until the geogrid opening fills completely by particles (Figure 9).

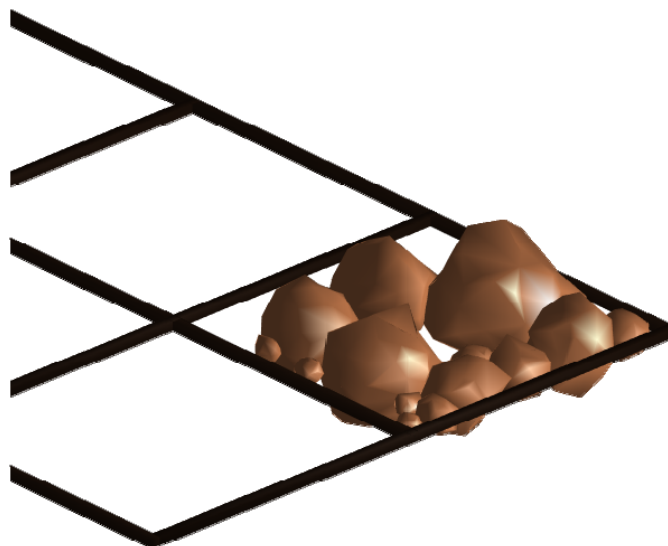


Figure 9: Simulation with biaxial geogrid

The main advantage of this software is derived from its freedom in a way that algorithms can be edited, improved and extended with %100 independence and no limits. In contrast to previous studies, this modelling software developed just for visualization geometrically. Computing time is significantly short for the proposed software. As a result, new or existing geogrid models can be tested with various gradation curves easily.

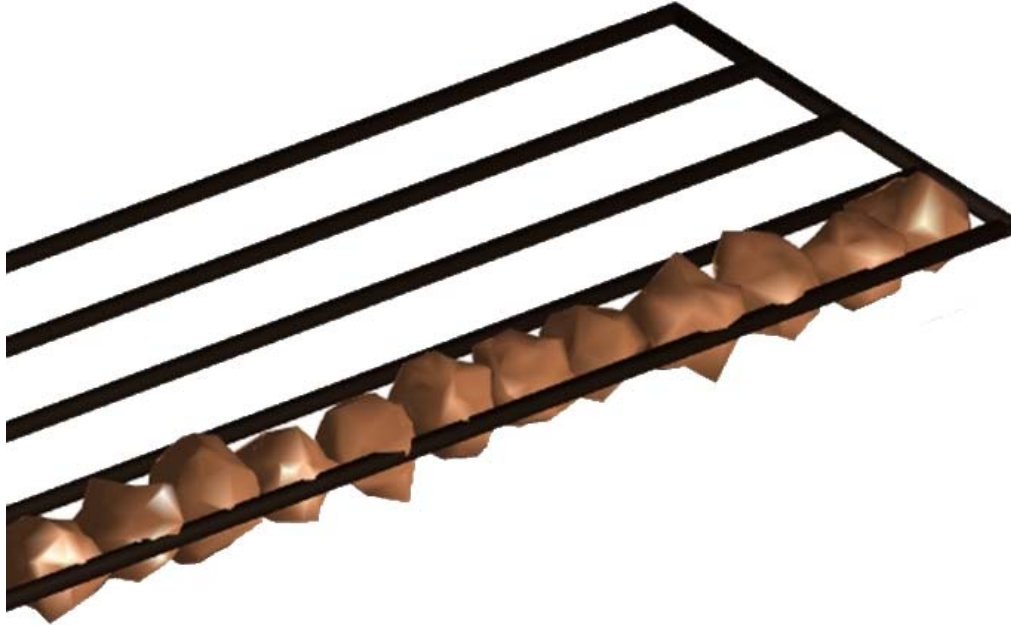


Figure 10: Simulation with uniaxial geogrid

3 SUMMARY AND CONCLUSIONS

This paper represents the result of our first attempt for simulating ballast particle with geogrid reinforcement and visualize the interlock action in granular particles. Successful interlock action depends on some parameters like ballast size, ballast angularity, ballast gradation, and geogrid types. There are field and laboratory tests to find the optimized engineering solutions at the design process. These tests consume time and money which are important for in terms of optimization and efficiency. On the other hand, numerical solutions are available for this purpose such as the use of discrete element method (DEM). Even though these alternatives provide reliable responses, they do have lots of limitations. Within this study, through the help of the game engine, one can easily create a custom geogrid, with various types of ballast particle and arrange gradation parameters. In favor of flexible and extendable body of program, algorithms in this simulation software will be improved and extended to have a more realistic response, which allows us to use this software environment for designing new geosynthetics and properly modelling their interaction effects with the soils. The authors are currently working to produce an environment that can be used for designing new geosynthetics for properly modeling their interaction effects with the soils physically together with the geometrical constraints.

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