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Multi-layered UL700 arch-grid module with inelastic buckling for localized reinforcement of soft ground

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ABSTRACT

This research proposes the inelastic buckling and modal analysis to design optimal shape and size through UL700 steel arch-grid unit module which is for localized reinforcement of soft ground. The optimal arch-grid design is achieved among its most efficient design possibilities such as different plate type, extended grid, multi-story grid, combined grid. The steel arch-grid unit module is composed of a vertical member and a board member combined with the top and bottom sides of the said vertical member, including the horizontal member equipped with multiple arm parts combined with the center part into one body in the shape of a cross. The construction method for reinforcement of soft ground is proposed in detail in this research. Numerical experiments are provided to survey optimal shape and size of arch-grid structures with differential models applied to buckling analysis, modal and static load, in consideration of both linear and nonlinear behaviors, by using SAP2000 version 15.0.1 software. With sufficient features of steel arch-grid for supporting structural foundations, this research suggests the possibility of requiring more studies and of providing more applications in the field of constructional structures.

1. Introduction

Until now, geo-textile has been applied a great deal to the fields related to soil, including the reinforcement of soft ground, protection of retaining walls, drainage, and stabilization of slopes in the civil and architectural field [20,26,16]. This is because such geo-textile is simple to use, easy to transport, and has excellent functionality and properties, and is economically advantageous in comparison with such poor civil/architectural ground stiffeners as gravels, sand, and straw-mats used conventionally [24,6].

The geo-textile, a synthetic polymer textile product which has been applied since its development in 1960s, has an excellent durability, constructability, and economics, which has marked a new milestone in the civil/architectural field. However, such geo-textile products as fabrics and non-woven fabrics that had been used as the stiffeners of various civil and architectural structures up to 1970s have a limitation in the aspects of tensile strength, a tensile modulus of elasticity, and creep. Limiting its application to the civil and architectural structures requires a high tensile strength and tensile modulus of elasticity.

Since such a problem was solved by the development of geo-grid, the high-strength geo-textile product developed in England in 1979 [28,18,1], the geo-grid has been applied to a variety of uses to various architectural and civil constructions in the entire world, creating a rapid progress. In Korea, the use of geo-grid was attempted in 1990s [4,22] and in 1993, geo-grid was applied to design of reinforced earth retaining walls for the first time [17]. In the latter half of 1990s, the coating-type combination-type soft geo-grid was domestically produced [14], which has activated the use of geo-grid. For the conventional methods for reinforcement of the ground of buildings, available are such construction methods as the replacement method of soft ground, sand drain, paper drain, precast concrete pile, top pile, micropile, JSP method, and C.G.S method. However, the noise and vibration generated during construction cause civil complaints [8,23].

Thus, in order to solve this problem, lately activated is the use of geo-grid. The construction method of geo-grid currently used in general is to excavate the ground surface to a certain depth, tramp the ground, spread the geo-grid on ground, spread slit 40–60 cm deep, tramp the slit, spread again the geo-grid on the slit, fill the slit, and then repeat the spreading of geo-grid and the tramping of slit to reinforce soft ground.

However, the construction method of reinforcing soft ground by using this geo-grid is somewhat insufficient in reinforcing locally the pillar-like ground where loads of buildings are concentrated. In addition, the use of carbon fiber such as reinforcing strips [11] in case of the construction method for reinforcement of soft ground based on the geo-grid connected vertically and horizontally causes problems that the joints are damaged inside the ground or the connection details at the area of vertical and horizontal connection

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are insufficient to lower the ground adhesiveness and the connective constructability of geo-grid.

This research is proposed to solve such conventional problems as mentioned above. The objective is to provide the steel arch-grid, i.e., a steel grid structure to reinforce localized base ground of architectural buildings, unit module for reinforcement of soft ground in which the assembling and breakup are easy and the constructability and structural stability are improved to prevent the breakaway or the separation after installation, and to provide the construction method to reinforce the structure and soft ground by using the unit module. In addition, the objective of this research includes the steel arch-grid unit module for reinforcement of soft ground in which it is possible to locally reinforce the area of concentrated load on the ground and the construction method to reinforce the structure and soft ground by using the unit module.

For this purpose, used was the high strength steel material which is widely used in the engineering field [37,38], particularly, UL700 steel [35,36], easy assembling and breakup, and excellent joint performance [25] unlike the existing geo-grid material, and the steel arch-grid unit module with vertical/horizontal grid type was figured out to reinforce locally or entirely at the area where the reinforcement of soft ground is needed.

Consequentially, to verify reasonable practices and application of arch-grid on site, in this research, the structural inelastic buckling [2,12,21,29] and modal analysis of the steel arch-grid unit module for reinforcement of soft ground and the reinforcement structure based on the unit module was conducted using commercial software SAP2000. Underground structures are the type of structures whose failures are not easily to be seen, especially stability aspects. Therefore, considering the stability of the underground structures is an important and worthy to research work [13,19]. Regarding the numerical analysis of inelastic buckling analysis for steel arch grid, a powerful approach based on isogeometric analysis [30–34] could open many interesting points and promising researches in the future when it is integrated into the commercial software SAP2000. However, according to the scope of this research, the inelastic buckling behavior of arch-grid is only analyzed and evaluated through SAP2000.

The application of steel arch grid to support foundation structures still has limitations and has not been studied by many researchers and engineers. Little research was conducted in this field and the results have not been published yet. Especially, the research about the optimization of shape and size [9,27,15,5] is much less. This paper thus studies the shape and size optimization for the steel arch grid of supporting structural foundations as a basic step for later extension of this research.

The content structure of this research is as follows. In Section 2, proposed are the problem solutions to achieve the objective of structural reinforcement for the structures based on the steel arch-grid unit module for reinforcement of soft ground as mentioned above. In Section 3, the components and details for structural reinforcement mechanism are analyzed in the aspect of structure to provide effective construction methods. In Section 4, the performance evaluation of non-linear finite element structural analysis of inelastic buckling and modal behaviors for the characteristic parameters of connectivity, shape and size of the reinforcement structure composed of the steel arch-grid unit module is conducted by using SAP2000 15.0.1 version [7], including the capability test of linear and nonlinear behaviors by static loads. In Section 5, explained are the conclusions of comprehensively summarizing this research.

2. Solution means to reinforce soft ground by using steel arch-grid unit module

The technical aspect of this research is composed of a vertical member and a board member of joining the top and bottom of the vertical member, including a horizontal member with the multiple arm parts combined into one body in the form of a cross at the center. The vertical member is connected to the center of the horizontal member, and at the end of arm parts, provided is the steel arch-grid unit module for reinforcement of soft ground, which forms a joint part. The horizontal member may form in one body a fixing hole with a fixing groove so that the end of the vertical member may be inserted into one side of the center area joined with the vertical member. The fixing hole may form a screw thread on the inner surface so that the end of the vertical member may be screw-joined. The combination part may include the insertion hole of joints formed through the end of arm parts. The width of arm parts may get narrower as the end gets closer.

Meanwhile, in the structure for reinforcement of soft ground which contains the steel arch-grid unit modules connected multiply in the horizontal direction, the reinforced structure proposed in other aspects of this research provides the structure for reinforcement of soft ground which features that multiple steel arch-grid unit modules are connected to the end of arms parts and arranged in the form of grid. Closely-connected steel arch-grid unit modules are connected in overlaps so that the connector insertion holes prepared at the joint part may pass through. Combined through the connector insertion holes, more connectors may be included to connect the multiple steel arch-grid unit modules. The connector may be composed of a fastening bolt, which fastens in penetration the connector insertion hole, and a fixing nut, which fixes the fastening bolt. The connector may include the body part arranged vertically for connection between the combination parts of the top and bottom horizontal members, the screw thread part formed in extension at both ends of the body part and screw-combined with the connector insertion hole prepared at the combination part by forming screw thread on the outer circumference surface, and the fixing nut fastened to the screw thread part. These bolts are monitored by health monitoring method [3] in order to make sure that they are working properly.

Meanwhile, this research provides the construction method for reinforcement of soft ground, which includes the stage for fabrication of steel arch-grid unit modules, the stage for fabrication of reinforcement structures, in which the structure for reinforcement of soft ground is fabricated by arranging multiple steel arch-grid unit modules in the shape of grid and then connecting horizontally the ends of the arm part, the stage for installation of reinforcement structures in which the structure for reinforcement of soft ground is safely installed on the ground, and the concrete pumping stage in which concrete is pumped onto the ground so that the reinforcement structure may be buried to combine the base part of buildings and the reinforcement structure into one body.

The stage for installation of reinforcement structures may be implemented by installing the structure for reinforcement of soft ground so that it may be positioned at the bottom of building pillars.

The stage for installation of reinforcement structures may be implemented by connecting in overlaps and through-passing the connector insertion holes prepared at the combination part of closely-connected steel arch-grid unit modules and then connecting multiple steel arch-grid unit modules in a combination of the connectors through the passed-through connector insertion holes. The connector may be bolt-fastened to the connector insertion hole.

The stage for installation of reinforcement structures may include the stage for installation of reinforcement members in which reinforcement member are installed vertically on the top surface of the horizontal member to reinforce the base part of buildings by integrating the reinforcement member and the concrete pumped prior to the concrete pumping stage.