INFLUENCE OF SPIKES ON THE PULLOUT BEHAVIOUR OF BIAXIAL GEOGRID IN REINFORCED SOIL

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ABSTRACT:
Pullout tests were conducted on polymer biaxial geogrid fitted with rigid aluminium studs (herein referred to as spikes) on the nodes. The number, height, and arrangement of the spikes were varied to optimise the pullout resistance. The pullout tests were conducted using silica sand number 5 as the backfill soil at relative density of 90%. Many factors affecting the pullout resistance due to addition of spikes were identified. It was found that adding spikes does not eliminate the need for good compaction of backfill in reinforced soil construction. Also, that the spikes generate higher pullout resistance when attached in equal heights on both sides of the geogrid. Furthermore, that the pullout resistance depends on the proximity of the spikes to each other; in the transverse and longitudinal direction. Closer longitudinal spacing leads to higher peak pullout strength. For transverse spacing, there is an optimum spacing associated with the height of the spikes which results into maximum peak pullout resistance. However, closer transverse and longitudinal spacing result into rapid strain softening in the post peak state and low residual strength. The number and height of spikes was also found to play important roles in the pullout performance of geogrid. Increase in the number and height of spikes led to increase in the pullout strength. However, there was an optimum number and height of spikes beyond which the pullout resistance did not increase.

Key Words: geogrid, spikes, pullout resistance

INTRODUCTION

This study aimed at improving the pullout resistance of biaxial geogrid in reinforced soil. However, to be able to improve the performance of geogrid or any other geosynthetic in general, it is important to understand the mode of interaction between the geosynthetic and the surrounding soil. Several studies have identified skin friction between the surface of the geosynthetic and soil together with bearing or passive resistance as the main mechanism behind its pullout strength (Palmeira & Milligan, 1989), (Teixeira, et al., 2007), (Palmeira, 2004). These mechanisms depend on several other factors such as backfill soil density, confining pressure, the rate of pullout, geogrid geometry, geogrid mechanical properties, surface roughness, soil type, etc. (Palmeira, 2004), (Lopes & Ladeira, 1996), (Lopes & Lopes, 1999). The passive resistance provided by the bearing/transverse members is known to contribute the most to the overall pullout strength (Lopes & Lopes, 1999), (Palmeira & Milligan, 1989), (Calvarano, et al., 2013). It is believed that the frictional contribution occurs first at small

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displacement as compared to bearing resistance which occurs later at large displacement (Milligan, et al., 1990). Also, the bearing resistance development is affected by the stiffness and length of the geosynthetic material. Inextensible materials such metal grid achieve bearing resistance almost instantly along the entire length while extensible materials such as polymer geogrid and geotextile develop bearing resistance gradually along their length and it is more pronounced for longer sizes of the specimen (Moraci & Recalcati, 2006), (Cardile, et al., 2016). The bearing resistance is further affected by the spacing of the transverse members (Palmeira & Milligan, 1989), (Palmeira, 2004), (Horpibulsuk & Niramitkornburee, 2010). For a certain ratio of spacing to height of bearing/transverse member, the transverse members interfere with each other leading to lower contribution by each member to the overall pullout resistance. (Palmeira, 2004), attributed this to two principle mechanisms; firstly, the increase in the magnitude of stresses and rotation of the principle stressed in front of each transverse member due to mobilisation of passive resistance. Secondly, as each transverse member is pulled forward, it leaves behind it a region of low stress which reduces the bearing strength of the next transverse member.

Therefore, the use of spikes (studs) aims to improve pullout resistance by increasing the bearing surface, hence the passive resistance contribution of the geogrid.

TEST APPARATUS, PROCEDURES, AND MATERIALS

Pullout test apparatus

The pullout apparatus used in study consisted of a metallic box; a loading system comprised of a clamp, electric motor, and load cell; displacement transducers; data logger, and sachets of lead shots for application of constant 1kPa surcharge. The metallic box was 70cm long, 40cm wide and 50cm deep. The tensile load cell had a capacity of 49kN. Six linear differential variable transducers (LVDT) were used to measure the horizontal displacement of geogrid and surface deformation of backfill. The data from the load cell and transducers were recorded automatically by a data logger, at an interval of 3 seconds. The schematic of the apparatus is shown in Figure 5.

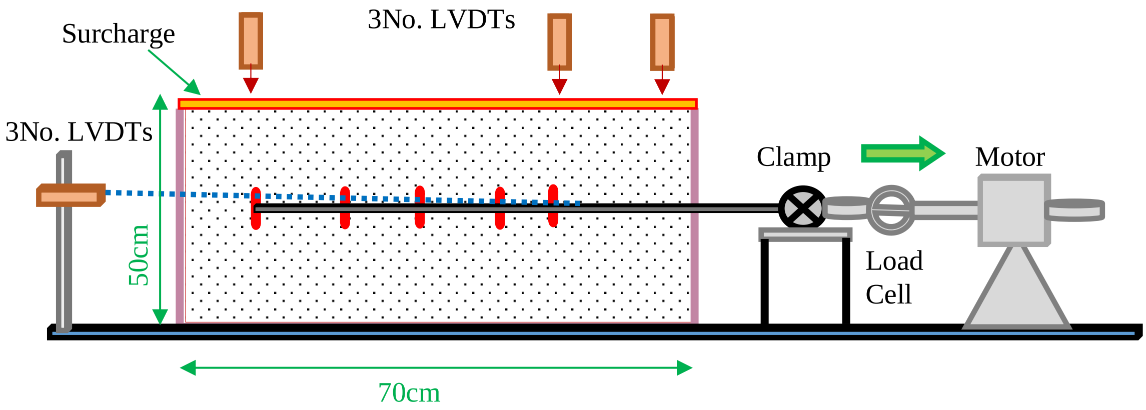

Figure 1 Schematic of the pullout test apparatus

Geogrid, spikes and backfill material

Polypropylene biaxial geogrid Tensar SS1, SS2, and SS35 were used, but most of the tests were conducted with SS35 because of its higher tensile strength. The spikes were 5mm square section aluminum studs connected to the geogrid nodes using 3mm set screws. Figure 2 show the geogrid and spikes. Silica sand number 5 was used as the backfill material. Figure 3 shows the particle size distribution of silica sand number 5.

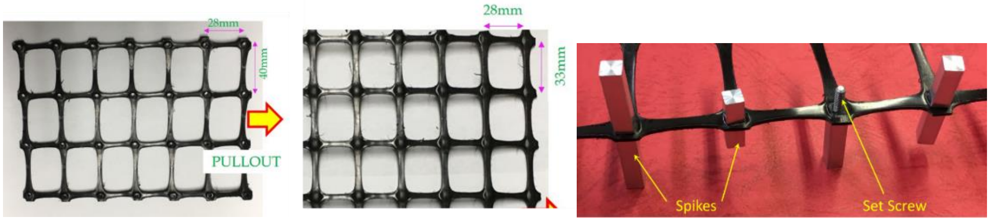

Figure 2 SS2, SS35 geogrid and sample spikes attached onto geogrid

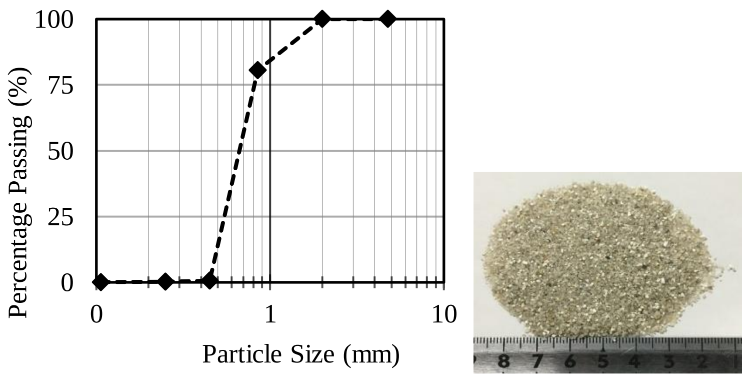

Figure 3 Particle size distribution of silica sand number 5

Test Procedure

The geogrid model within the pullout box was made 55cm for SS1, SS2 and 48cm for SS35 long. The section with spikes was 40cm long and 24cm wide for SS1 and SS2; and 34cm long and 26cm wide for SS35. The transverse/bearing ribs of the geogrid within 15cm of the front wall were removed to reduce the influence of friction on the front wall as well as ensure that the section with spikes remained inside the box during the entire test. The backfill soil was laid in 5cm layers, each compacted by hand tamping to relative density (Dr) of 90%. The geogrid model was placed at mid-height of the box, on the fifth layer of backfill sand. After its connection to the horizontal LVDT and clamp, as schematically shown in Figure 4, the backfill preparation was completed. 1kPa surcharge was then placed on the surface of the backfill soil, as well as the three LVDT for monitoring vertical deformation of the backfill surface. The pullout test was executed at a constant rate of 2.5mm/min until a total horizontal displacement of 80mm or rupture of the reinforcement was achieved.

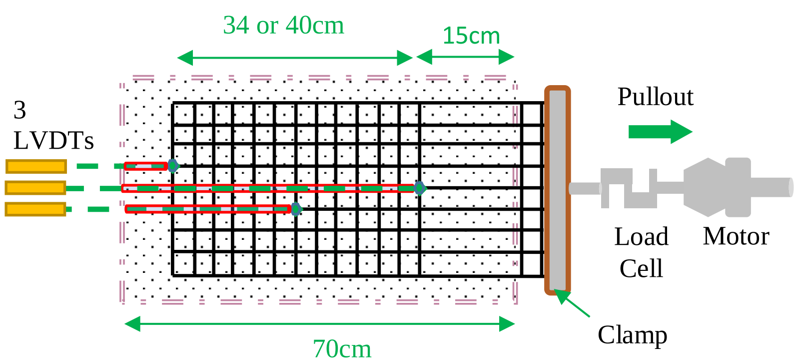

Figure 4 Schematic plan view of the test setup

TEST RESULTS AND DISCUSSION

The pullout behavior of geogrid fitted with spikes in silica sand backfill soil was found to be affected by many factors such as the arrangement of spikes in the form of spacing, height, and number, as well as the density of the backfill soil. Also, the method of attaching the spikes on the geogrid, that is, whether they are on one or both faces of the geogrid.

Effects of longitudinal and transverse spacing of spikes

Figure 5 shows the arrangement of 30mm spikes on SS-35 geogrid models to investigate the effect of longitudinal spacing of spikes and Figure 6 shows the results of the pullout tests. It was found that, as the spacing reduced, the peak pullout resistance increased by up 84% while the residual strength remained almost the same but higher than geogrid without spikes by about 20%. Also, in the post peak region as the spacing reduced, there was rapid strain softening tendency.

The effect of transverse spacing of spikes was investigated by maintaining the longitudinal spacing constant. By using a constant longitudinal spacing as in case (c) of Figure 5; the peak pullout resistance in Figure 7 increased with reduction in the transverse spacing of spikes of 30mm. In a similar manner as longitudinal spacing, at closer transverse spacing, rapid strain softening was observed in the post peak state. Also, as in Figure 9, it was found that the increase of peak strength is continuous for short spikes, especially 20 and 30mm with no optimum peak pullout resistance within the test range; while in the case of taller spikes of 40 and 60mm, the rate of increase slowed as the spacing further reduced as shown in Figure 9. The 60mm spikes showed an optimum peak pullout resistance at 84mm transverse spacing. The reduction in the rate of rising of peak pullout resistance could be associated with the effect of bearing interference similar that noted by (Palmeira, 2004), (Palmeira & Milligan, 1989) and (Horpibulsuk & Niramitkornburee, 2010) between transverse members of geogrid. This leads to insufficient passive strength development of each spike, hence low overall pullout resistance. According to (Palmeira, 2004), an area of low stress develops behind transverse members as they are pullout. In the case of spikes, this area of low stress is thought to take the form of a triangular active pressure zone that is created as the spikes move forward.

However, in Figure 8, by using the longitudinal spacing in case (b) of Figure 5, which is wider, varying the transverse spacing of the spikes hardly affected the peak pullout resistance, but instead, the residual strength reduced steadily with a reduction in the transverse spacing of the spikes. This may indicate that the effect of spikes is limited by the spacing in the longitudinal direction, that is, traverse spacing causes increase in peak strength predominantly for closer spacing in longitudinal direction. Also noticeable is that when the spikes are widely spaced in both transverse and longitudinal direction, the peak strength is larger than for geogrid without spikes but the characteristic curves are nearly parallel with gradual strain softening in the post peak state.

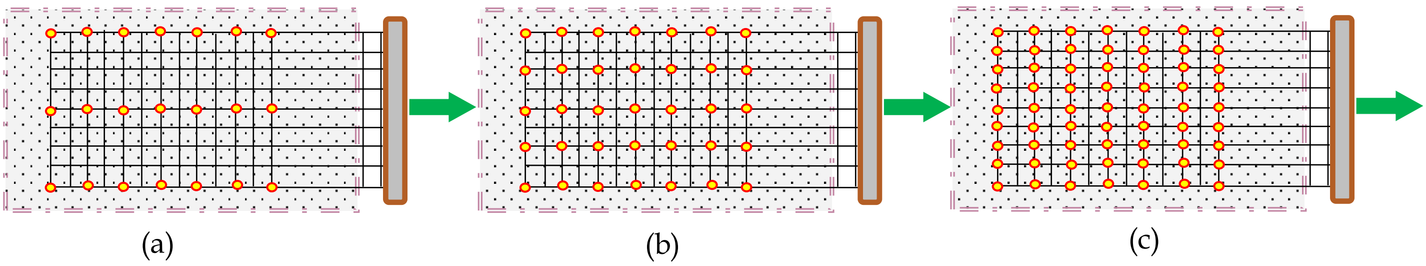

Figure 5 Sketch of the test cases for the effect of longitudinal spacing of spikes

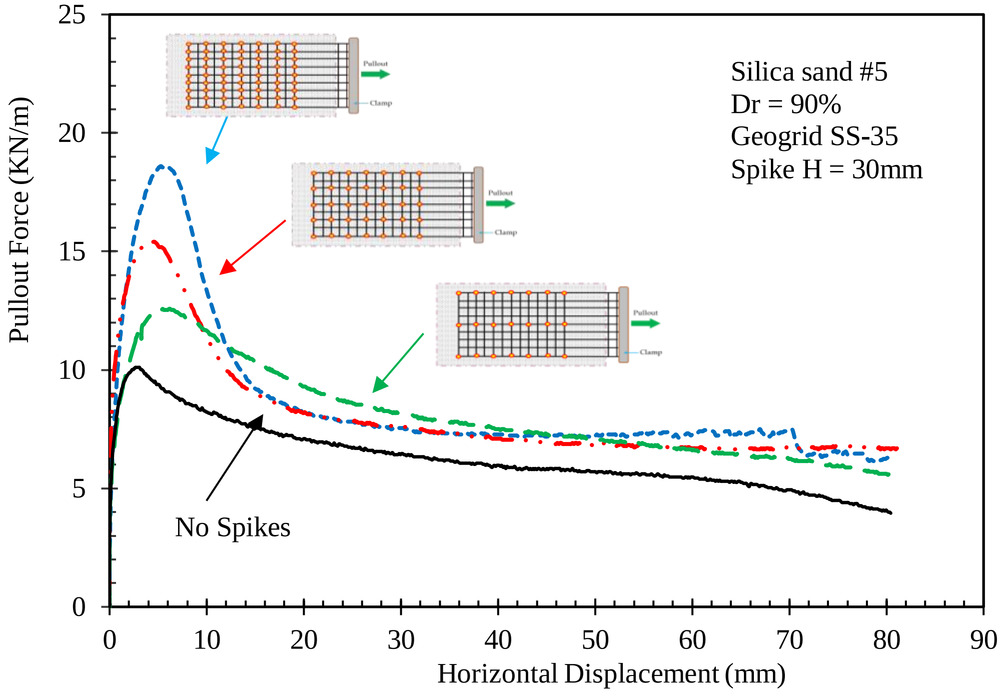

Figure 6 effect of longitudinal spacing of spikes on pullout resistance

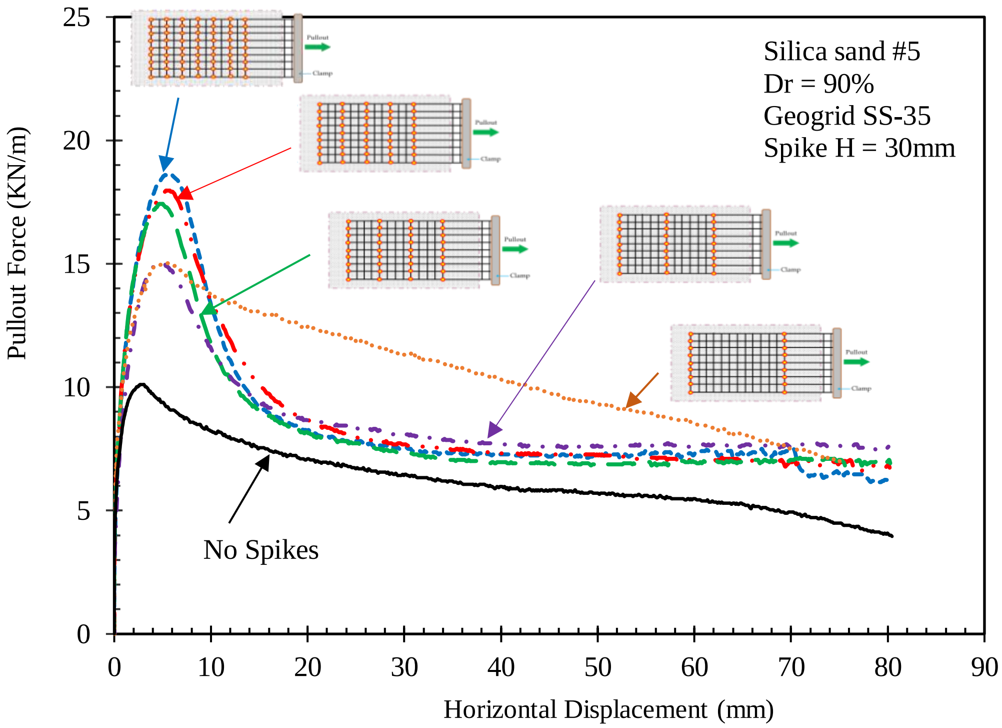

Figure 7 Effect of the transverse spacing of spikes on pullout resistance with a closer longitudinal spacing of 30mm spikes

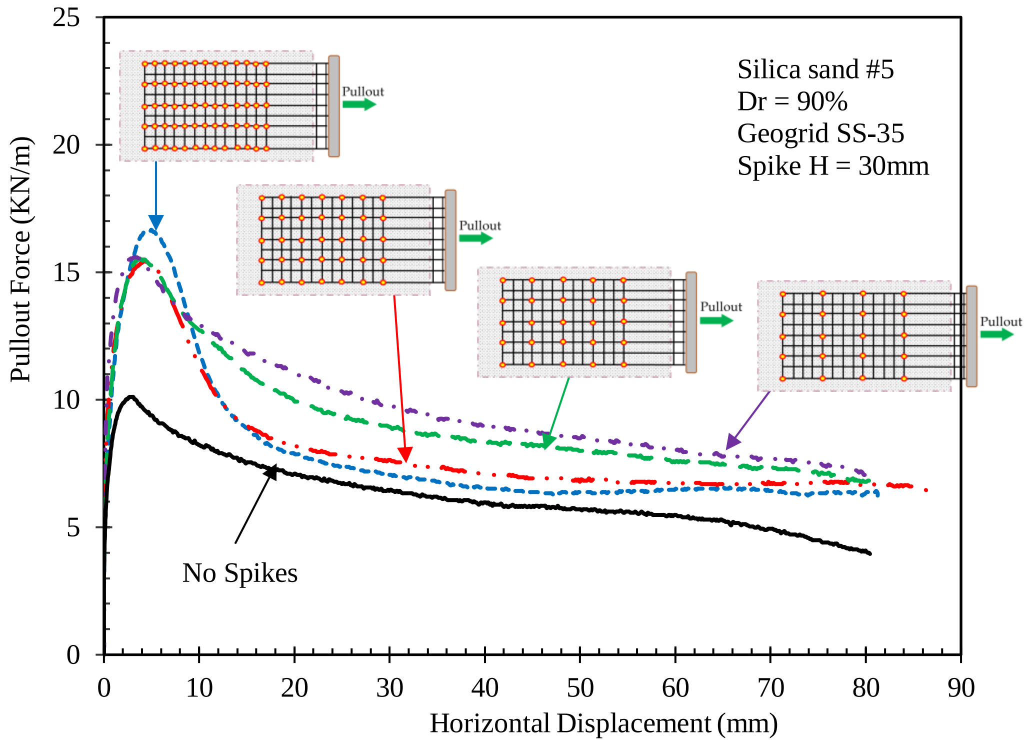

Figure 8 Effect of the transverse spacing of spikes on pullout resistance with a wider longitudinal spacing of 30mm spikes

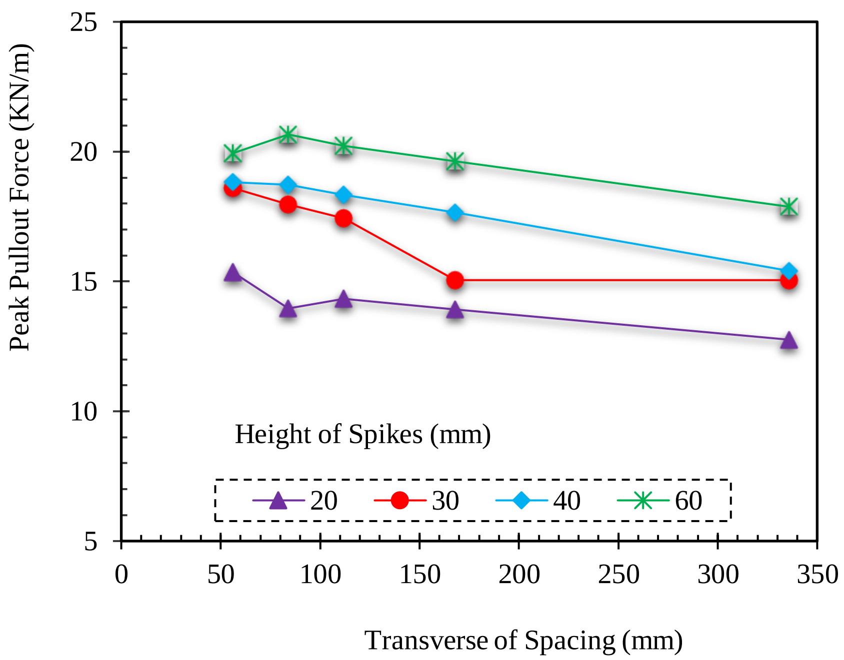

Figure 9 Variation Peak Pullout resistance with transverse spacing for different heights of spikes

Effect of Height and Number of Spikes

The height of spikes was found to directly affect peak pullout strength. In Figure 10, the peak pullout strength increased with increase in height of the spikes. For taller spikes, there is an optimum height beyond which the strength starts to reduce, while shorter spikes shown no optimum height. It is thought that for a fixed transverse spacing, increasing the height of spikes also introduces interference effect. Similarly, increasing the number of spikes causes similarly behavior as height of spikes.

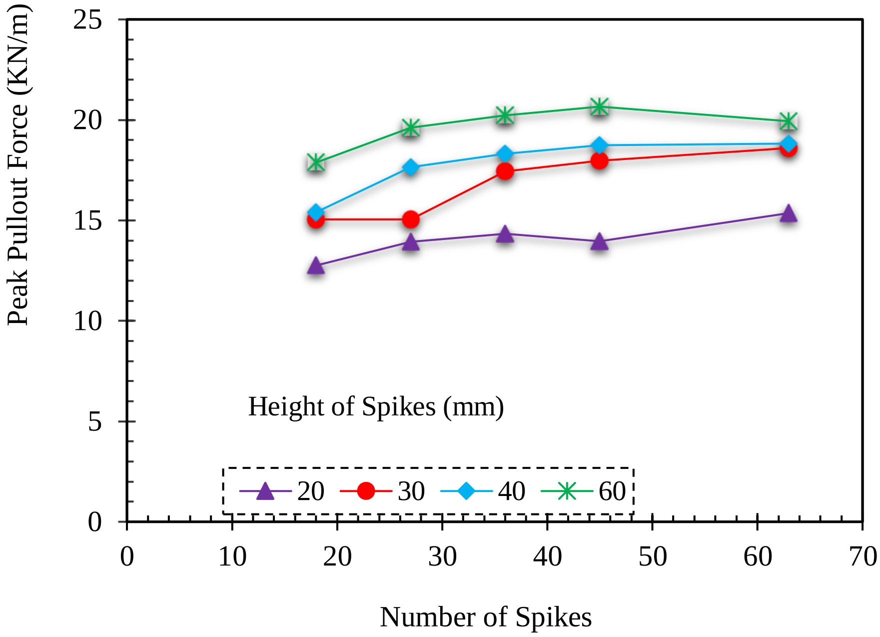

Figure 10 Effect of the number of spikes for different heights on peak pullout resistance

The density of backfill soil

The effect of backfill soil density on pullout resistance due to spike was investigated using plastic spikes as detailed in Figure 11. Spikes of height 23 and 41mm attached on to SS1 geogrid were tested in silica sand number 5 at relative density of 47% and 71%. The objective was to investigate whether the use of spikes could lead to a reduction in the requirement for the high degree of compaction.

As in Figure 12, it was observed that the pullout resistance increased with increase in the height of the spikes, both in loose and medium dense sandy backfill. The peak pullout strength of geogrid in medium dense sandy backfill almost doubles that in loose backfill for all samples and also the residual strength in medium dense backfill falls steadily after the peak state unlike in loose backfill where there is no defined residual strength Also noticeable, was the gradual attainment of peak strength at large displacement in loose backfill, while in medium dense backfill, the peak strength was achieved at short displacement. This may imply that for seismic resistance, the requirement for good compaction is still important even though spikes are used.

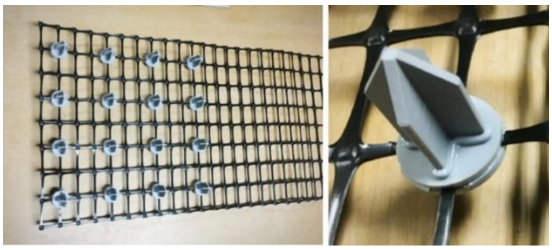

Figure 11 Plastic spikes on geogrid model

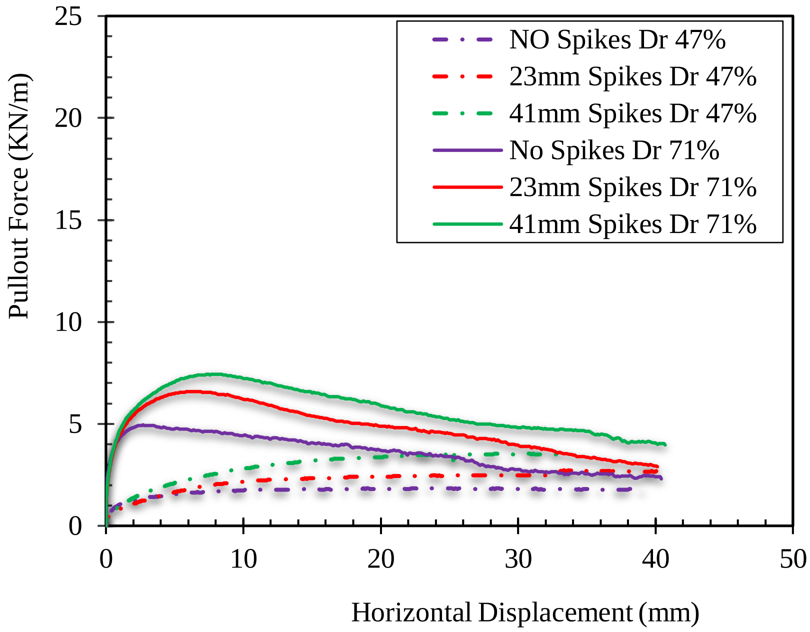

Figure 12 Effect of soil density on pullout resistance of geogrid with spikes

Configuration of spikes on the face of geogrid

This was an investigation into how to attach the spikes on to the geogrid. Five (5) pullout tests were carried out according to configurations (a) to (e) shown in Figure 13 using geogrid SS35 and silica sand number 5 as backfill soil at a relative density of 90%. A total of 20 spikes of fixed height 30mm where set up on the geogrid model in the same arrangement.

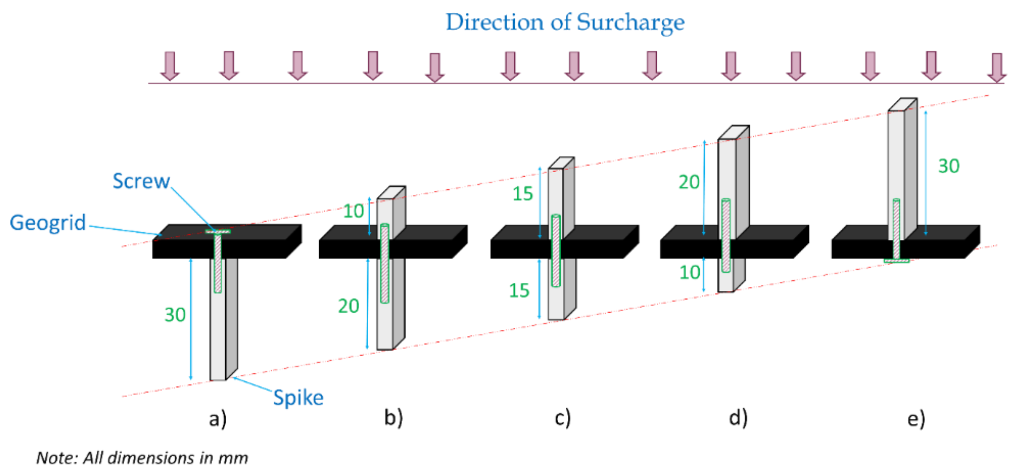

Figure 13 Schematic of spike configurations on the face of a geogrid model in pullout tests

As in Figure 14, it was observed that having the spikes equal in height on both faces of the geogrid (case (a)) is the most ideal. Cases (a) and (e) when spikes were on one face of geogrid produced the least peak pullout strength. It was also noted that when taller spikes were on the upper face as in cases (d) and (e), the peak strength was less than when it is on the lower face.

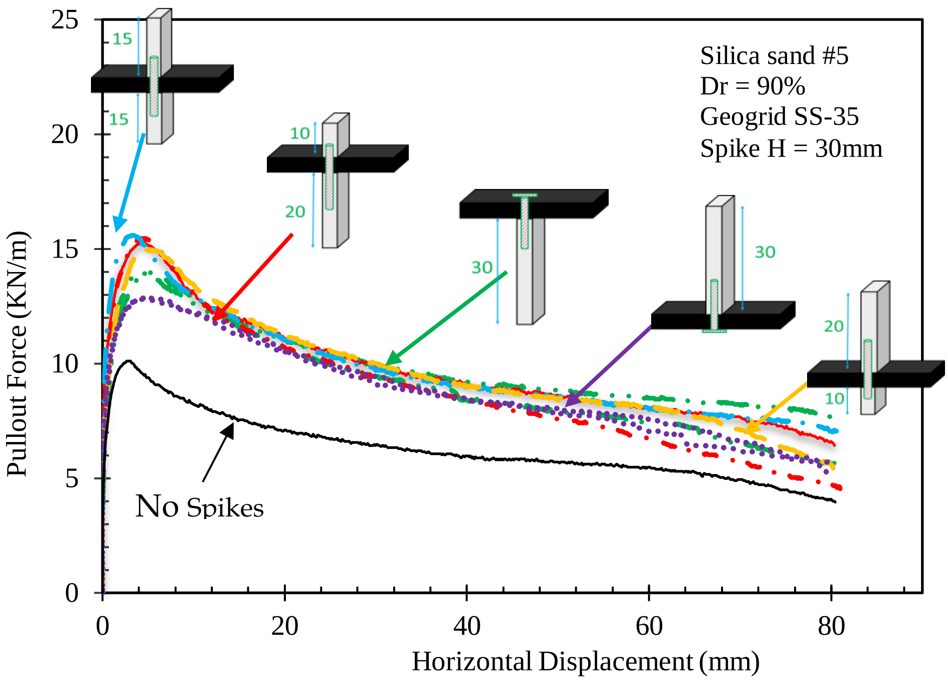

Figure 14 Pullout force against deformation for the various cases of spike configuration

CONCLUSIONS

Compaction of backfill material

It was initially envisaged that the use of spikes might eliminate the need for high degree of compaction of soil, thereby reducing construction cost by enabling the use of marginal construction material. However, when geogrid fitted with spikes was tested in the sand with different densities, higher pullout resistance was obtained at a higher degree of compaction of the backfill soil. The geogrid showed low stiffness in low-density backfill, a condition which is not suitable for seismic performance because sufficient strength is mobilised after large deformation.

Fitting spikes on the geogrid

It was necessary to optimise the impact of spikes on the performance of geogrid in the form of attachment method on the geogrid. A series of pullout tests revealed that when the spike is halved on both sides of the geogrid on the node, it develops higher pullout resistance as compared to when fitted to protrude on a single face of geogrid.

The longitudinal and transverse spacing of spikes

By varying the longitudinal spacing of spikes, it was found that peak pullout resistance increased continuously as the spacing reduced. The pullout behaviour as a result of varying the transverse spacing of spikes was affected by the longitudinal spacing of spike. For a constant value of very close longitudinal spacing of spikes, reduction in transverse spacing initially leads to increase in peak pullout resistance. However, as the reduction continues, the rate of increase reduces then the peak strength stops increasing. At the same time, as the peak strength is initially increasing with a reduction in transverse spacing, the residual strength starts reducing. Furthermore, at close transverse spacing, the soil develops rapid post-peak strain softening from the peak to residual state. This phenomenon at closer transverse spacing was thought to be caused by interference of spikes with each other. On the other hand, for wider but constant longitudinal spacing, reduction in transverse spacing was found not to influence the peak pullout resistance but to steadily reduce the residual strength as well as lead to rapid strain softening.

Height and Number of spikes

The effect of the height and number of spikes was found to directly lead to increase in peak pullout strength. If the transverse spacing is fixed constant; as the height and number of spikes is increased, the pullout strength increases steadily until some optimum height or number, then it starts to reduce. Therefore, the height and number of spikes directly affects the pullout resistance but eventually leads to interference behaviour similar to closer transverse spacing for tall spikes.

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