INFLUENCE OF THE DEGREE OF COMPACTION ON THE BEARING CAPACITY OF A ROAD STRUCTURE REINFORCED WITH TRIAXIAL GEOGRIDS

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Abstract

The degree of compaction for a crushed stone roadbed is one of the most important technical characteristics of road construction works. Insufficient compaction can have significant effects on the resulting bearing capacity, even in road structures reinforced with geosynthetic materials. The present study concernes the utility of using geosynthetic reinforcement in the base layer of a road structure, while varying the degree of compaction on 1:1 scale models.

Keywords: triaxial geogrid, degree of compaction, bearing capacity of a road structure.

1. Introduction

The present research involves the building of three full scale models of the base layer of a road structure. The base layer of two of the models was armed with a triaxial geogrid, and the third model was unreinforced. The road structures were built in a box with dimensions: (b × L × h) 1.50 × 2.00 × 1.00 m, having an opening in the middle as a retractable drawer of dimensions: 0.50 × 1.70 × 0.25 m, as shown in the **Figure 1.** In this way a sinkhole was formed.

After removing the drawer the structure was left to stand for about 20 hours to consolidate under its own weight. This procedure was followed on all three attempts. The geogrid used in the study was of the TriAx TX140 type, having 40 mm triangular openings, and a radial rigidity of 225 kN / m.

The lower layer was made of clay soil, and the base layer of the road structure was made of crushed stone with an optimal mixture of 0-63 mm. Both layers had a thickness of 40 cm.

The load bearing test was carried out by static loading of the model in the direction of the sinkhole, with a Lucas plate, and was carried out until the structure failed. The deformations were monitored at the level of the loading plate, the deformations of the hole, and the displacements of two nodes of the geogrid reinforcement, located in the center of the hole and the edge.
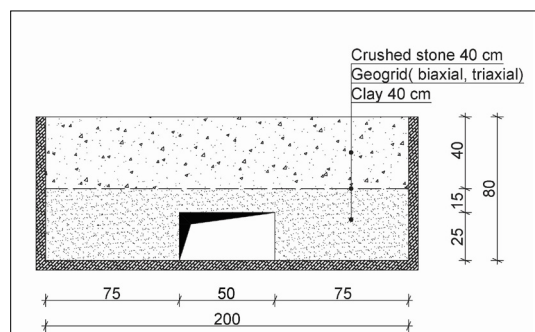
Figure 1. *Schematic of the road structure used for testing (in the case of the unreinforced structure the geogrid has been removed).*

2. Model building

The compaction was performed mechanically according to the regulations of GE-026-97 [1]. The degree of compaction was calculated by comparing the dry weight volume (γ_d) of the crushed stone from the top layer (determined by using the water bag method - according to STAS 1913-15/75 [2]) to the dry weight volume ($\gamma_{d\ max}$) of the material with optimum compaction moisture (determined in the laboratory by the normal Proctor method). In the case of the unreinforced model and the first reinforced model, a suitable compaction was executed, the two layers used being compacted in two stages (2 layers of 20 cm each), with multiple passes, and at least four strokes applied on each track. In the second reinforced model, the crushed stone layer was poorly compacted, with only 2 hits on each track, thus obtained a lower degree of compaction (81%), compared to previous models (93-95%).

3. Bearing capacity testing

3.1. Model reinforced with triaxial geogrid – optimal compaction

The first bearing test was performed on a model reinforced with the triaxial geogrid, with properly compacted layers. The loading was performed with a Lucas static plate, 300 mm in diameter, centrally located, in the direction of the formed sinkhole. The loading stages were established accordig to STAS 2914/4-89 [3] for road systems, with a loading increment of 50 kPa, and a stabilization limit of 0.05 mm at an average of consecutive readings, made at intervals of 5 minutes. By its nature, the test was carried out until the model failure either by collapse of the hole, or by excessive deformations on the loading surface. During the first test, we recorded approximately 1 mm settlement at 100 kPa, 1.5 mm at 150 kPa, and 3 mm under a load of 200 kPa [4]. The first noticeable deformation of the hole was found at the reading of 10 minutes under the load of 200 kPa, the ceiling of the hole deforming 2 mm. The consolidation time of the structure was relatively fast, 15 minutes at the 50 kPa stage, 15 minutes at the 100 kPa stage, 20 minutes under the 150 kPa loading, and 15 minutes under the 200 kPa loading. The 250 kPa step caused a first drop of medium-sized earth lumps (Figure 2.).

It has been found that the total deformations did not have a major increase, at a reading at 25 minutes recording a value of about 4 mm. The

evolution was similar and below the next loading step, that of 300 kPa, earthquakes continued to occur, but the stabilization limit was reached after about 20 minutes, with a setting value of 5.5 mm. Under the load of 350 kPa, a significant part of the upper area of the hole collapsed. At the same time it was possible to observe the formation of the arching effect in soils, which dissipated the pressure from the center of the hollow to the side walls. The behavior of the reinforced structure was noted under the load of 400 kPa, where the deformations stabilized after only 25 minutes. The structure was quickly consolidated and at 450 kPa, after 20 minutes a deformation increase of only 0.3 mm (from 7.0 to 7.3 mm) was measured. Even the change to 500 kPa did not cause a major jump in the deformations, the initial increments increasing by 1 mm, and in the end, when stabilizing the earth (after 35 minutes of loading), the total settlement increased by 0.5 mm (from 8 to 8.5 mm). On this structure deformations greater than 10 mm were recorded at the end of the loading step of 550 kPa. The constancy of the consolidation durations was also maintained on the next two loading stages, at 600 kPa and 650 kPa respectively, this being achieved in 45 minutes. The road structure has deformed relatively little, under the load of 600 kPa, an average of the vertical displacements of 12.2 mm, and 15 mm was recorded at a load of 650 kPa. The first rupture cracks on the surface of the crushed stone layer were found under 700 kPa load. The next load (750 kPa) resulted in a constant increase of 2 mm, per reading interval. At the 35-minute interval, the first movement of the studied inner node was recorded. Under this load the displacement increased slightly, reaching 6.5 mm in 15 minutes.

Applying the following loading pressure of 800 kPa caused the model to fail after 5 minutes. After the collapse of the bare soil layer, it was possible to analyze how the crushed stone became stuck in the geogrid's eyes, and the way in which the triaxial geogrid broke (Figure 3).

After removing the crushed stone layer, and the triaxial geogrid, it was found that the rupture occurred on a portion of the pressure cone perimeter.

3.2. Model reinforced with triaxial geogrid – poor compaction

For the structure with a low degree of compaction, the 200 kPa step detected an increase of the deformations, visible from the first reading interval, measuring 211 mm on the center of the hole,

Figure 2. *The progressive collapse of the hole under static loads.*

Figure 4. *The load step of 350 kPa causes the ground layer to collapse.*

Figure 3. *The collapse of the ground revealed the geogrid rupture.*

Figure 5. *The collapse of the earth layer allows visualization of the confinement.*

and 585 mm on its edge. The cavern showed perceptible deformations and after the reading interval of 25 minutes, recorded a value of 210 mm, and the longitudinal cracks on the ceiling of the hole were accentuated. Below this level of loading the soil layer was consolidated in 40 minutes, the peak value of the settlements being 5.5 mm. The next value of the load (250 kPa) caused a visible jump in the adjustments, the hole being deformed, having a height of 208 mm in the center, and 586 mm on the edge. The shape and size of the central hole had changed continuously, reaching 205 mm in the center after the 55-minute interval. The consolidation of the ground was found after 65 minutes of loading, with a maximum tapping of 10.5 mm read on the last interval. The 300 kPa charge accelerated settlement in the first 20 minutes, reaching a difference of 3 mm from the lower step, then the settlement values were constantly increased by six tenths of a millimeter. At the application of this load, the ceiling of the

aperture sank by 5 mm at the first reading, a tendency that remained until the 40 minutes reading when 197 mm was registered on the central rod, that is a deformation of almost 20 mm compared to the initial value of 215 mm. The deformation was transmitted over the entire surface of the hole, the rod on the edge measuring successively 589, 590 and 591 mm. Although the deformations read on the plate showed a constant increase with a value of six tenths of a millimeter, the ground consolidated between the intervals of 100 and 110 minutes. The total settlement recorded at this point with the plate was approximately 22 mm.

The last applied loading step (350 kPa) delayed the grounding until the recorded interval of 5 minutes (**Figure 4.**). From this point the vaulting effect of the ground from the lower part was canceled, the deformations being taken over only by the extension of the geosynthetic reinforcement.

In **Figure 5** it is possible to observe the cleavage of the crushed stone layer in the geographic

mesh, which indicates the confinement. From this moment the settlements increased rapidly, at a rate of 3 mm / minute, and the walls of the hole began to collapse.

The inner node of the triaxial geogrid, followed by a fleximeter, moved by 1 mm per minute. After 12 minutes below 350 kPa the geogrid broke. At the moment of failure, a 51.6 mm settlement was measured under the plate. The breaking cone formed at the top an angle of approximately 45 degrees. After removing the crushed stone layer, the geogrid was removed and the size of the footprint of the breaking cone at the base was measured, which was 105 cm. The uncovering of the crushed stone layer revealed a break point of the geogrid, produced along the fiber (**Figure 6**), and after complete extraction, two similar failure points were reported (**Figure 7**), thus totaling three failure points located on a diagonal, occurring on the opposite side of the load.

This phenomenon canceled the confinement effect, allowing a minor collapse of the crushed

Figure 6. *Fiber-failure of triaxial geogrids.*

Figure 7. *The pressure cone and the three failure points oriented after a diagonal.*

stone layer, inside the hole, and the monitored outer node was no longer mobilized at the stretching effort which thus became zero in its direction. A confinement state was only reached locally, in the area of the pressure cone, right below the Lucas loading plate.
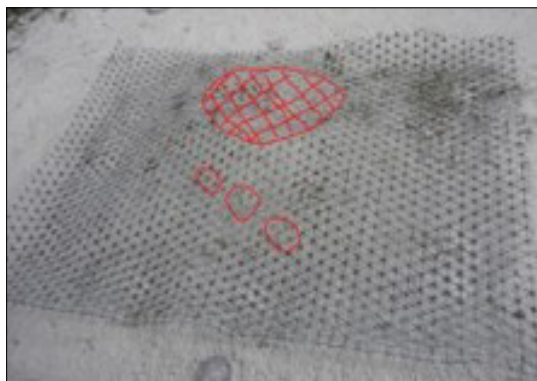
3.3. Unreinforced model

In order to determine the shear influence of geosynthetic reinforcement, a third model was built, without this time including the triaxial geogrid. The structure was made according to the steps described above, after extracting the drawer and being allowed to consolidate under its own weight over a period of about 20 hours. Unlike the reinforced structures, it suffered deformations as a result of the consolidation under its own weight, the graded hole centered on the hollow indicated after 24 hours a value of 210 mm, compared to the initial 215 mm.

The first load step of 50 kPa did not cause any noticeable deformation in the structure. The 100 kPa step was maintained for ten minutes, the equivalent of two reading cycles, resulting in approximately 0.6 mm settlement under the soleplate. The center hollow did not change in size or configuration even after applying the third load step of 150 kPa. Only at the 20-minute reading was a 2 mm change in the rod on the edge of the hole observed, which indicated the mobilization of the ground on the edge of the hole to take over the loading through the vault effect. As we were reading the result, the earth consolidated, therefore we proceeded to the next load value, 200 kPa. When reading for 15 minutes, the first deformation was observed on the center rod, with a value of 2 mm. The stem on the edge of the hole also dropped 2 mm, reaching the measured value of 577 mm. The earth consolidated after 30 minutes under this load step. The 250 kPa step caused some small pieces of earth to collapse. The pressure being not alleviated and distributed by geosynthetic materials, concentrations occurred only under the plate, resulting in such local failures. Apart from the collapse of ground on the hole ceiling, there was no increase in cracks, or deformations in the side walls. Under this load step the structure was consolidated in 25 minutes. Moving to the 300 kPa load resulted in a minor jump of deformations of about 0.2 mm per reading cycle, the deformation of the hole ceiling continued, the center rod indicated a value of 196 mm, measured from the bottom of the box. A 579 mm value was measured on the edge of the hole, which me-

ans that the side walls of the hole had deformed continuously. The total settlement at the time of consolidation under this loading step resulted in 4.5 mm, after 40 minutes, corresponding to eight reading cycles. The next loading step, that of 350 kPa, caused the collapse of the hole ceiling in the direction of the measuring rod (**Figure 8**).

The settlements were accentuated, at the first reading measuring a jump of 1.5 mm compared to the lower loading step. The gap was further deformed, a tendency noticeable especially by accentuating the cracks on the ceiling in the side area of the collapsed one. Small surprises also occurred on the side walls, a fact also indicated by the increase in values on the rod located at the edge of the hole.

After 45 minutes, a total settlement of approximately 7 mm was recorded, at which point the difference between consecutive readings allowed a higher loading step. At 400 kPa the 1 cm deformation was exceeded, the settlements showed a constant increase with a value of about 0.2 mm per reading interval. Under this load step the ground stabilized in 65 minutes. The move to the next loading step caused the collapse of medium-sized pieces of material, indicating that the moment of failure was near. At the 35 minute reading under 450 kPa, a 1 cm deformation of the hole ceiling was measured, which largely corresponds to the settlement measured on the microcomputer clocks on the test board. Without the geosynthetic reinforcement it can be said that the crushed stone layer deforms simultaneously with the ground one. The ground consolidation was recorded at 40 minutes under 450 kPa load. The next load resulted in another landslide collapse. The hole deformation was recorded at 20 and 90 minute intervals, with readings on the

central rod 187 mm and 183 mm respectively. After 110 minutes, the settlement values were recorded indicating the consolidation of the earth layer, at a total deformation of 3 cm. At the next loading phase, that of 550 kPa, the earth collapsed (**Figure 9**), the deformations were increased, increasing from 3 cm reaching 5 cm, , this all happened within 5 minutes, after which the plate sank under its own weight, and under the pressure of the hydraulic jack.

TConsidering the time elapsed from reaching the allowable values of the deformations to the collapse it can be stated that the failure was of a sudden character. A part of the upper layer of crushed stone flowed through the hole created in the ground. The failure cone formed at the top had a diameter of 45 cm. The removal of the crushed stone layer revealed the shape of the lower part of the cone, about 120 cm long, and 85 cm wide. The shape and size of the failure surface confirmed the initial hypothesis, of local failure, without the collapse of the entire surface of the hole.

4. Conclusions

The bearing capacity of the structures tested can be expressed in tonnes-force transmitted at the base of the plate using the following transformations: 1 kPa = 101.972 kgf/m^2 = 0.102 tf/m^2.

The surface of the test plate of ϕ 300 mm, amely in square meters is 0.071 m^2, very close to the footprint of the double axle used in the calculation of traffic loads. The weakly compacted structure yielded a lower load value than the structure without specific reinforcement. The difference between the two transfer steps was 36 % (350 kPa and 550 kPa). Compared with the 800 kPa value

Figure 8. *Large chunks in the hole ceiling collapse below the 350 kPa load step.*

Figure 9. *The hole is collapsed under the 550 kPa load step.*

obtained on the similar but properly compacted structure, the difference was 56 %, and the actual value of the bearing capacity was more than double.

From these results we conclude that the presence of the geogrid is useless if there is no proper compaction of the road layers **[5, 6, 7, 8]**.

Table 1. *Interpretation of the loading stages used according to the carrying capacity values*

Loading step	Equivalent concentrated force	Pressure value	Under plate pressure
[kPa]	[kN]	[tf]/m^2	[tf]
50	3,55	5,100	0,362
100	7,10	10,200	0,724
150	10,65	15,300	1,086
200	14,20	20,400	1,448
250	17,76	25,500	1,811
300	21,31	30,600	2,173
350	24,86	35,700	2,535
400	28,41	40,800	2,897
450	31,96	45,900	3,259
500	35,51	51,000	3,621
550	39,06	56,100	3,983
600	42,61	61,200	4,345
650	46,16	66,300	4,707
700	49,71	71,400	5,069
750	53,27	76,500	5,432
800	56,82	81,600	5,794

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