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The Function of Basal Geogrids in Minimizing Rutting of Geocell Reinforced Subgrades

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ABSTRACT:

Rutting is a common phenomenon encountered in flexible pavements supported by weak subgrades. Reinforcing the weak subgrades is one of the promising alternatives to alleviate the pavement surface rutting. This paper presents the results of laboratory model tests on a circular plate supported by geocell reinforced sand subgrades. A series of tests were carried out by varying the height of the geocell mattress with an additional layer of basal geogrid placed underneath the geocell mattress. The surface settlements (rutting) were measured through displacement gauges. Strain gauges were placed along the width of the basal geogrid to verify their performance as a base layer. A substantial reduction in surface rutting is observed in the case of geocell reinforced beds with basal geogrids. A seven fold improvement in bearing capacity was obtained with the provision of an additional geogrid layer over unreinforced subgrades. Overall, a basal geogrid layer provides higher structural support mobilized through membrane effect to the geocell reinforced pavement layers.

INTRODUCTION

It is always a challenging task for a design engineer to develop and build pavement infrastructure with limited financial resources available without compromising on the structural strength. The traditional pavement design and construction practices demand for high quality materials to meet the construction standards. In many parts of the world, there is a scarcity for good quality materials. Hence, either alternate construction materials are always looked for or alternate design standards are developed. The use of geosynthetics in pavement construction is one of the options looked at by several researchers for the past two decades. Extensive research on flexible pavement design methods has been carried throughout the world by several researchers. They confirmed that the thickness of the base layer could be reduced if the geogrids are used in the design (Barksdale et al., 1986; Al-Qadi et al., 1994 & 1997). The primary advantage of using geogrids in pavement structures is known for their separation and reinforcement functions. However, the rutting on the hot mix asphalt (HMA) surface is a common phenomenon that is often seen in flexible pavements supported by weak subgrade soils. The deformation in any pavement layers is mainly due to poor consolidation and lateral spreading of the weak subgrade under traffic loading. At times, the lateral spreading of an unbound pavement layer could also be seen which are attributed to inferior compaction.

In recent past, soil reinforcement in the form of *geocell mattress* has been showing its efficacy in the fields of highway and embankment construction. Geocell is a three dimensional, polymeric, honeycomb like structure of cells interconnected at joints. The cell walls keep the encapsulated material from being pushed away from the applied load and offer an all-around confinement to it by virtue of its three-dimensional nature. Besides, the panel acts like a large mat which spreads the applied load over an extended area, instead of directing to the point of contact, leading to an improvement in the overall performance. Several investigations have been reported highlighting the beneficial use of geocell reinforcement in the construction of foundations and embankments. Rea and Mitchell (1978) and Mitchell et al. (1979) have carried out a series of small scale laboratory tests on footings supported over sand beds reinforced with square shaped paper grid cells and brought out different modes of failure. Dash et al. (2001) investigated the reinforcing efficacy of the geocell mattress within a homogeneous sand bed supporting a strip footing. Dash et al. (2003) and Sitharam and Sireesh (2005) have also reported load test results on model circular footings supported on geocell reinforced sand beds. These studies highlighted that the efficacy of using geocells in the place of geogrids for higher bearing capacity and higher reduction in surface rutting.

However, it is to be noted that the separation function is not fully achieved in geocell reinforcement unlike geogrids. It can be noticed that the separation is a primary functional requirement of any reinforcement system to reduce the surface rutting on the pavement surface. In this research an attempt has been made to understand the combined behavior of geocell mattress along with a basal geogrid in reducing the pavement surface rutting. A series of laboratory model experiments under monotonic loading was performed on geocell reinforced subgrade layers to quantify the structural conditions as follows.

LABORATORY MODEL TESTS

Materials

The test sand used in this investigation was dry with coefficient of uniformity (C_u) of 2.22, coefficient of curvature (C_c) of 1.05, effective size of particle (D_{10}) 0.36 mm, specific gravity of 2.63, maximum void ratio (e_{max}) of 0.66 and minimum void ratio (e_{min}) of 0.48. According to Unified Soil Classification System (USCS), the soil is classified as poorly graded sand with letter symbol SP. The friction angle of the sand at 70 % relative density (D_r) as determined from standard triaxial compression tests was found to be 41^o.

The geocell mattress was formed using a biaxial geogrid having an aperture size of 35 mm x 35 mm. The properties of the geogrid obtained from standard wide width tension test (as per the specifications laid down by American Society for Testing and Materials, ASTM: D 6637 – 2001) are, ultimate tensile strength of 20 kN/m, initial modulus of 183 kN/m and secant modulus at 5% strain of 160 kN/m.

Test set-up

Model load tests were conducted in a test bed-cum-loading frame assembly. The beds were prepared in a square shaped test tank measures with inside dimensions of 900 mm × 900 mm × 600 mm (length × width × height). The monotonic loading was applied through a circular plate made of rigid steel and measured 150-mm diameter and 30 mm thickness. A hydraulic jack was used to push the plate in to the bed, which was welded against the reaction frame. Further details can be obtained from Sitharam and Sireesh (2005). The geometry of geocell reinforced sand bed is shown in Figure 1.

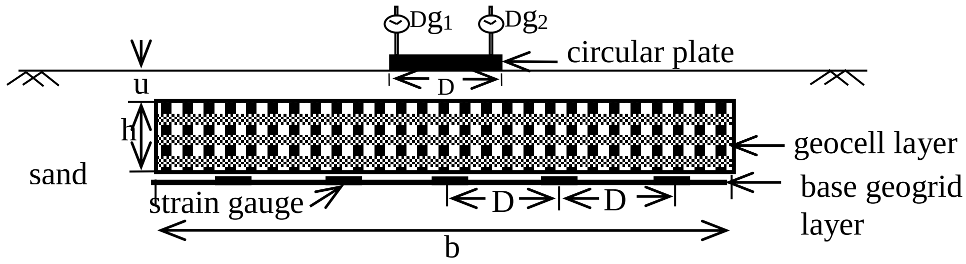

Figure 1 Geometry of reinforced sand bed

Preparation of beds

The sand was placed in the test tank using *raining technique*. The height of fall to achieve the desired relative density was determined *a priori* by performing a series of trials with different heights of fall. Sand was rained from a pre-calibrated height to consistently maintain 70% relative density in all the experiments. The average unit weight corresponding to this relative density is 16.8 KN/m^3.

In case of reinforced subgrade layer, the sand was rained up to the predetermined depth using depth marking on the sides of the box as guide. Then the geocell mattress was formed on top of the levelled sand bed. The geocell layer was prepared by cutting the geogrids to required length and height from full rolls and placing them in transverse and diagonal directions with bodkin joints (plastic strips) inserted at the connections (Bush et al. 1990). All the geocell layers in the present investigation were prepared in chevron pattern (Figure 2), as it gives better performance improvement in comparison to the diamond pattern (Dash et al. 2001). After formation of geocell layer the geocell pockets were filled with sand using sand raining technique. The density of the soil placed within the geocell mattress was also monitored by collecting soil samples from this layer as explained earlier. In the case of basal geogrids, an intermediate planar geogrid layer was placed between the levelled sand layer and the geocell mattress. It is to be noted that the basal geogrid was not attached to the geocell in this case. Electric resistant strain gauges have a gauge length of 10mm; gauge factor of 2.1 ± 2% and resistance of 120 ± 0.2Ω were fixed to the basal geogrid along the width of the grid at the centre line of the loading as shown in Figure 1.

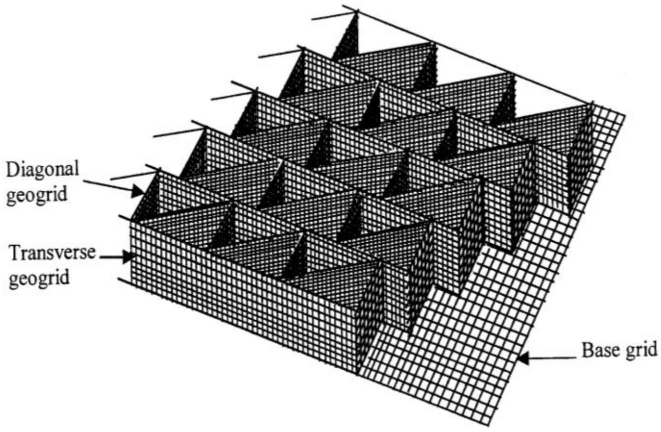

Figure 2 Chevron pattern of geocell mattress

Test procedure

Upon filling the tank up to the desired height, the fill surface was levelled and the circular plate was placed on a predetermined alignment such that the loads from the loading jack would be transferred concentrically to the footing. A recess was made into the plate at its centre to accommodate a ball bearing through which vertical loads were applied. The plate was pushed into the subgrade layer at a rate of nearly 2-mm per minute. The load transferred to the plate was measured through a pre-calibrated proving ring placed between the ball bearing and the loading jack. The strains developed along the width of the base layer were measured through electrical resistance type strain gauges fixed horizontally at various locations on the base geogrid layer as shown in Figure 1. The strains were recorded through a digital strain indicator.

Test variables

In all these experiments, the geocell is formed in square shape. The depth of placement of geocell mattress (u) and width of the geocell mattress (b) were kept constant at placement depth ratio (u/D) and width ratio (b/D) of 0.05 and 4.9 respectively (where, D = diameter of plate). These critical values are chosen from the work reported by Sitharam and Sireesh (2005) on geocell reinforced sand beds. The height ratio of the geocell mattress (h) was varied from 0.6 through 2.4 (i.e. h/D = 0.6, 1.2, 1.8, 2.4).

RESULTS AND DISCUSSION

The performance improvement due to the base geogrid layer is quantified in terms of the improvement factor (I_{fg}) which is defined as the ratio of bearing pressure of geocell mattress along with basal layer and the bearing pressure of geocell mattress alone (Sitharam and Sireesh, 2005). A percentage reduction in surface rutting can be calculated and is defined as the ratio of differential settlements obtained for the cases of with and without reinforcement to the settlement without reinforcement. In this paper, the strain measurements are reported at various normalized load levels i.e. Bearing Pressure Ratio (BPR). It is defined as the ratio between the bearing pressures at some settlement (both in case of with and without reinforcement) to the ultimate bearing pressure (q_{ult}) in case of unreinforced soil. In this analysis, the tensile strains are reported with positive sign (+) and the compressive strains with negative sign (-).

Effect of base geogrid

Figure 2 presents the variation of improvement factors with plate settlement for geocell mattress of different heights, with and without base geogrid. It is of interest to note that with the increase in height of geocell mattress along with the base layer, the overall performance improvement rate decreased. The Improvement factor (I_{fg}) is higher for thin geocell mattress (i.e., h/D = 0.6) along with base geogrid. In this case, the most of the traffic load is assumed to be shared by the base layer, which was embedded at shallow depth from the base of the circular plate. This would have mobilized ultimate membrane support in the basal layer by experiencing higher strains that lead to an I_{fg} of order as high as 2.1 times that of the geocell reinforced bed. For the cases of h/D ≥ 1.8, the beneficial effect of the same is observed to be minimal. It could be due to the increase in rigidity of the bed with increase in height of geocell mattress that in turn mobilizes a lower strain in the base geogrid. Besides, the height of the geocell mattress of this order will fall out of the influence depth of the loaded area (i.e. 1D, D = diameter of the plate). These factors would have brought down the performance with geocell (h/D ≥ 1.8) along with base geogrid that almost equal to that of the case without base geogrid. That means, the influence of geogrid is negligible for height ratio, h/D ≥ 1.8.

Figure 3 shows the variation of percentage reduction in surface settlement with the height of geocell mattress with and without the basal geogrid. The rutting on the pavement surface was observed to be drastically reduced for geocell reinforcement case. This reduction is observed to be increased with the height of the geocell mattress alone without basal geogrid. A maximum of 75% reduction in surface rutting was observed in this case. In contrary, the reduction in surface rutting is noted to be unchanged or slightly reduced with increase in height of the geocell mattress. It is noted that as high as 83 % reduction in rutting is observed with a nominal height of geocell mattress (h/D = 0.6). This could be attributed to the membrane support derived from the basal geogrid in the case of thin geocells which would become marginal for thick geocell mattresses. At lower embedment depths, higher strains will be accumulated in the base geogrid that mobilizes its ultimate upward reaction against applied loading. This observation can be further visualized with the help of strain measurements in the base geogrid. The accumulated axial strains measurements in the base geogrid at different locations along the grid for different load increments were shown in Figures 4 and 5.

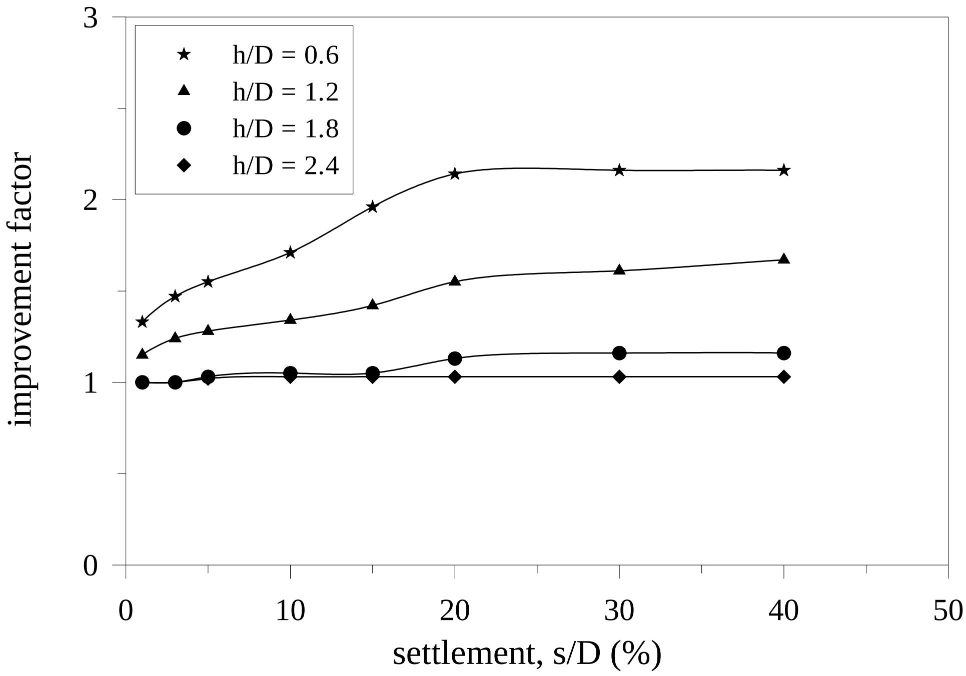

Figure 2 Influence of basal geogrids- improvement factors

Figures 4 and 5 depicts the variation of percentage strain along the width of base geogrid placed below the geocell mattress of different height ratios (h/D = 0.6 and 1.8). From these figures, it is clear that higher strains are accumulated in the base geogrid over an area just below the loading portion in case of thin geocell mattress (h/D = 0.6). Uniform strain distribution can be seen in the base geogrid when the height of the geocell mattress is 1.8D and beyond. This could be attributed to the flexural rigidity of the entire mattress which is less when the height of the mattress is of 0.6D, which deflects more and incurs more strain at the center of basal geogrid. But in case of optimal height of geocell mattress (h/D = 1.8), the footing pressures were distributed over an extended area of the geocell mattress and lower strains were transmitted to the basal geogrid.

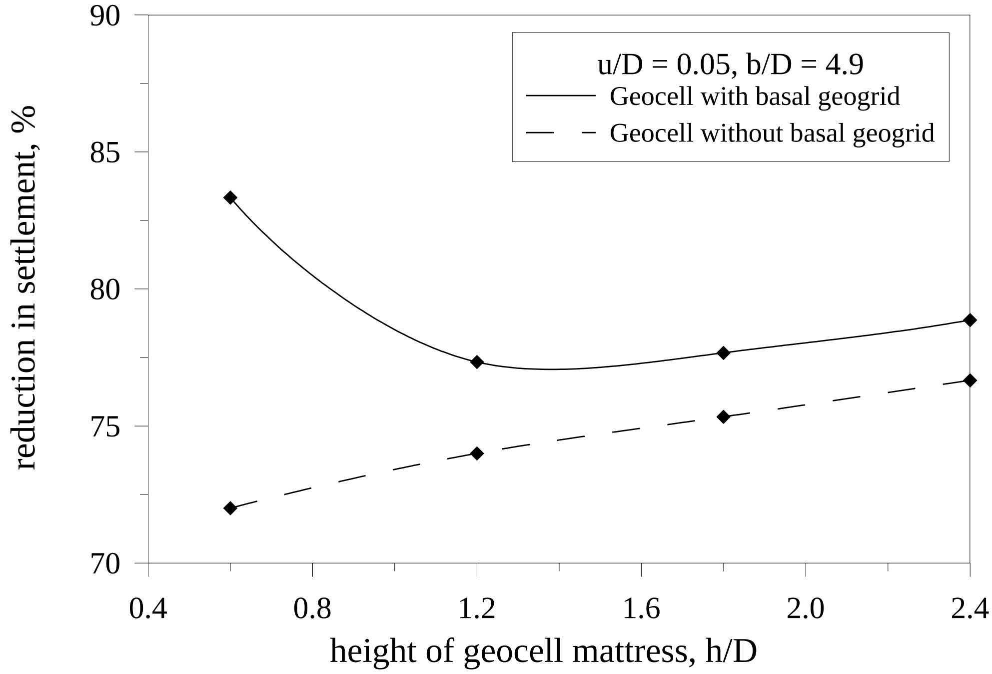

Figure 3 Influence of basal geogrids - reduction in surface settlements

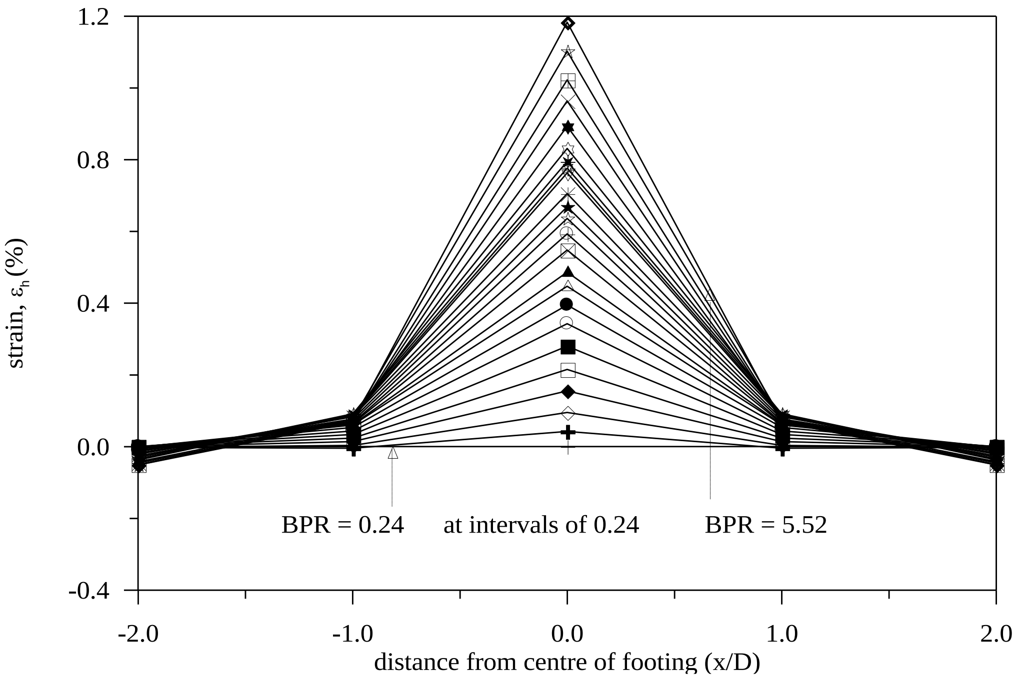

Figure 4 Variation of percent strain along the width of base geogrid layer – h/D = 0.6

Figure 4 depicts that negative strains (compressive) are induced in the base geogrid layer at its extreme points (x/D = ± 2), which are away from the loading region. Similar observations have been made by Huang and Tatsuoka (1990) in case of earth beds reinforced with planar geogrids. This could be due to the dilation-induced compression. The compression in the base geogrid layer could be attributed to the following two factors. First, the direction of strain measurement is close to the direction of potential major compressive principal strains in the soil in case of planar reinforcement as observed by Huang and Tatsuoka (1990). Second, the volume expansion of sand is due to dilation in the loading region. This localized transverse expansion is restrained by the sand in the adjacent regions. Such a restraint may be considered to be similar to the application of a confining pressure that induces compression in the geogrid layer (Dash, 2001).

The width of the geocell mattress (b) also plays an important role in distributing the tyre pressures evenly to the foundation subgrade. It was noticed by the authors that the performance in terms of increased structural support can be obtained with increase in the width of cellular mattress until it reaches around four times the width of loading plate (b/D = 4). Thereafter, the increment in the performance is marginal and almost become negligible for b/D = 5. Further details on the width of the geocell mattress on the overall performance of the geocell reinforcement system can be found in Sitharam and Sireesh (2005).

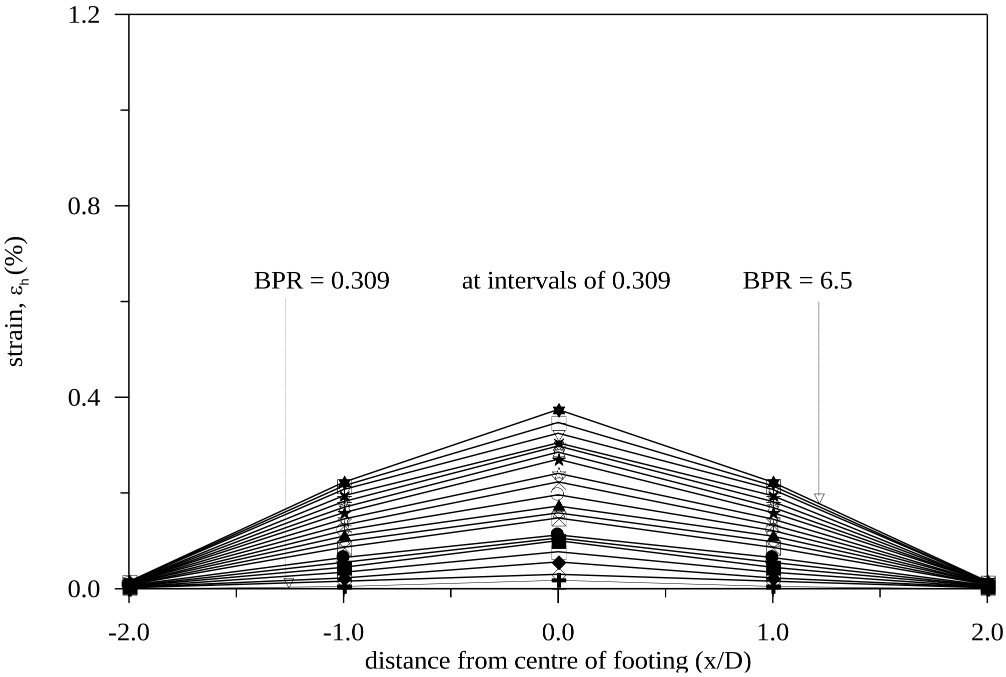

Figure 5 Variation of percent strain along the width of base geogrid layer – h/D = 1.8

CONCLUSIONS

In this paper, the performance improvement of the geocell mattress reinforced subgrade layer below a circular plate due to the additional layer of geogrid reinforcement has been investigated. Based on the results from this investigation, the following conclusions are drawn:

1. The additional layer of base geogrid placed below the geocell mattress further enhances the performance of the bed in terms of load-carrying capacity and the stiffness of the bed over geocell reinforced subgrades.
2. A total of seven fold improvement in bearing capacity is observed for geocell reinforcement with basal geogrid. A two fold increase in bearing pressure was observed with additional basal geogrid alone against geocell reinforcement.
3. The pavement surface rutting can be significantly controlled with the basal geogrid layer. As high as 83% reduction in surface rutting was observed.
4. The mobilized strain in the base geogrid shows that the ultimate membrane effect of the same can be drawn for thinner geocell mattresses (h/D = 0.6). There will be

a reduction in the ultimate membrane support due to local buckling of the geocell walls and due to the placement depth of geogrid beyond the significant depth.

5. The strain measurements in the basal geogrid also confirm that the pavement surface rutting can be substantially reduced with base geogrid and whose influence is minified with increase in height of geocell mattress.

Overall, a basal geogrid layer provides higher structural support and membrane affect to the geocell reinforced pavement layers. For all practical purposes, to reduce the pavement surface rutting, a basal geogrid layer needs to be adapted in conjunction with the geocell mattress.

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