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Interaction between longitudinal ribs of geogrid during pullout

Interaction entre les ctes longitudinales de la geogrid pendant l'extraction

Riya Bhowmik
Department of Civil Engineering, Indian Institute of Technology Jammu, India, riya.bhowmik@iitjammu.ac.in

J.T. Shahu & Manoj Datta
Department of Civil Engineering, Indian Institute of Technology Delhi, India

ABSTRACT: Pullout tests were conducted on single and multiple longitudinal ribs (L-ribs) of uniaxial polyester-yarn geogrid with constant and varying spacing between them. The objective of this study is to investigate the interaction among the L-ribs and their effect on the overall pullout response. The tests were carried out at a normal stress of 5 kPa. In the first set of tests, the spacing between two L-ribs was varied from 10 mm to 150 mm. The results, which were analyzed in the form of pullout force per L-rib for each test case, showed that for spacing up to 50 mm, the pullout force per L-rib was 8-19% lower than the single L-rib resistance. However, for spacing greater than or equal to 70 mm, the pullout resistance per L-rib becomes almost identical to the single L-rib resistance. In the second set of tests, when two, three, five, and seven ribs, all spaced at 20 mm were pulled together, the pullout force per L-rib was 16-62% lower than the single L-rib resistance. The results show that the influence zones of each L-rib get mobilised during pullout. However, the mobilization of these zones gets influenced based on the spacing between the ribs and the number of ribs.

RÉSUMÉ : Des essais d'arrachement ont été menés sur des nervures longitudinales simples et multiples (nervures en L) de géogrille uniaxiale en fil de polyester avec un espacement constant et variable entre elles. L'objectif de cette étude est d'étudier l'interaction entre les L-ribs et leur effet sur la réponse globale à l'arrachement. Les essais ont été effectués à une contrainte normale de 5 kPa. Dans la première série d'essais, l'espacement entre deux nervures en L a varié de 10 mm à 150 mm. Les résultats qui ont été analysés sous forme de force d'arrachement par nervure en L pour chaque cas de test ont montré que pour un espacement jusqu'à 50 mm, la force d'arrachement par nervure en L était de 8 à 19 % inférieure à la résistance d'une seule nervure en L. Cependant, pour un espacement supérieur ou égal à 70 mm, la résistance à l'arrachement par nervure L devient presque identique à la résistance à la nervure L simple. Dans la deuxième série de tests, lorsque deux, trois et cinq nervures, toutes espacées de 20 mm, ont été rapprochées, la force d'arrachement par nervure en L était de 16 à 41 % inférieure à la résistance d'une seule nervure en L. Les résultats montrent que les zones d'influence de chaque nervure L se mobilisent lors de l'arrachement. Cependant, la mobilisation de ces zones est influencée en fonction de l'espacement entre les côtes et du nombre de côtes.

KEYWORDS: geogrid, pullout test, longitudinal ribs, interaction, low normal stress

1 INTRODUCTION

The peak pullout resistance of a geogrid is assumed to be the sum of interface shearing resistance of longitudinal ribs (L-ribs) and bearing resistance of the transverse ribs (T-ribs). Various researchers have proposed different formulations for the peak pullout resistance of geogrid based on varying assumptions of the mobilised resistance (Jewell 1990, Peterson and Anderson 1980, Matsui et al. 1996, Bergado et al. 1996). These expressions depend on the dimensions of the reinforcement, normal stress induced on the soil-geogrid interface, and the angle of shearing resistance of the backfill material. However, these proposed formulations assume equal contributions from all L-ribs and T-ribs and do not account for any interactions among them during pullout.

Lopes & Lopes (1999), Alagiyawanna et al. (2001), Teixeira et al. (2007), Bathurst & Ezzein (2016), and Suksiripattanapong et al. (2013) performed pullout tests on L-ribs and T-ribs with varying spacing to understand their contributions to the pullout resistance of polymeric geogrids and study their interactions during pullout. However, all these tests were conducted at medium to high normal stresses (σ_n > 25 kPa) wherein the polymeric ribs show extensibility. However, at low normal stresses (σ_n < 15 kPa) that are expected in landfill cover systems and top layers of reinforced earth systems, it is reported that the ribs show negligible deformability. Thus, for a better understanding of the interactive behaviour of the L-ribs under such low-stress conditions, pullout tests were conducted on single and multiple longitudinal ribs (L-ribs) of uniaxial polyester-yarn geogrid with constant and varying spacing between them. The objective of this study is to investigate the interaction among the L-ribs and their effect on the overall pullout response. Another objective is to investigate the possibility of optimizing the spacing between the ribs which will result in optimization of the material required for the geogrid without compromising the peak pullout resistance. The results obtained from this study can also aid in understanding the pullout behaviour of geosynthetic straps which are currently gaining popularity as a medium of reinforcement in soil structures (Abdelouhab et al. 2011, Razzazan et al. 2018).

2 EXPERIMENTAL INVESTIGATIONS

The pullout tests were conducted in a large-size pullout device that can pull horizontally as well as in an inclined direction, as shown in Fig. 1. A detailed description of this device is given in Bhowmik (2019) and Bhowmik et al. (2020). The device can pull at a constant displacement rate varying from 0.001 mm/min to 22 mm/min. The present tests were conducted at a constant displacement rate of 1 mm/min. The test box was 1400 mm long, 900 mm wide, and 1000 mm deep. The clamp of the test device which was used for gripping geosynthetics was 300 mm long and 150 mm wide. The clamp was attached to load and displacement transducers and then to data acquisition system to continuously log and monitor the pullout force and displacement during tests.

Figure 1. The pullout test set-up for rib tests

All tests were conducted in locally available alluvial sand, known as Yamuna river sand. The sand was poorly graded sand with sub-rounded to rounded particles and with an angle of shearing resistance of 43°. The sand was backfilled at a target relative density of 75-80%. The details of the test procedure are given in Bhowmik et al. (2019a, 2019b).

The L-ribs used in the study were extracted from a PET-yarn geogrid after trimming the T-ribs. The geogrid had a uniaxial tensile strength of 60 kN/m and individual rib strength of 1.47 kN. The L-ribs were 4.5 mm wide and 1.2 mm thick, and had a clear distance of 20 mm with the adjoining L-rib in the geogrid. All the tests were conducted at a normal stress of 5 kPa. The very low normal stress in the tests corresponds to the normal stress values prevalent in the top geogrid layers of reinforced retaining structures and veneer reinforcement in landfill cover systems.

Tests were performed on L-ribs placed at various spacing and numbers. The first set of tests was carried out with two L-ribs placed at spacing varying between 10 mm to 150 mm, as shown in Figs. 2(a) and (b). In the second set, tests were carried out on two, three, five, and seven L-ribs, all placed at 20 mm clear spacing and pulled out together, as shown in Figs. 3(a) and (b). Since the objective of this study is to investigate the effect of neighboring ribs on single rib pullout capacity, pullout test was conducted on a single rib too for comparison purposes. Fig. 4 shows the photograph taken at the end of the test on two L-ribs at 150 mm spacing. All tests were checked for repeatability. It may be noticed that the test configuration followed in the present study also simulates the possible behaviour of geosynthetic straps.

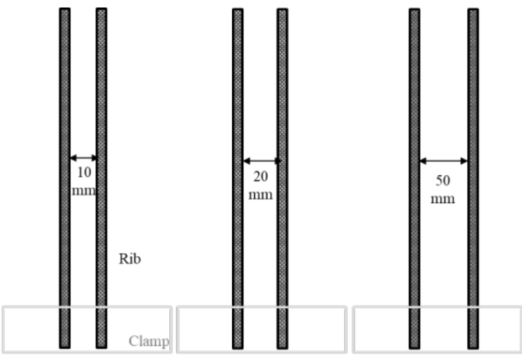

Figure 2(a). Arrangement of two L-ribs with spacing varying between 10 mm to 50 mm

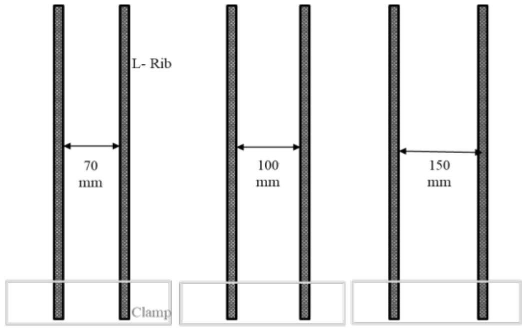

Figure 2(b). Arrangement of two L-ribs with spacing varying between 70 mm to 150 mm

Figure 2. The schematic diagram of the arrangement of L-ribs under first set of tests

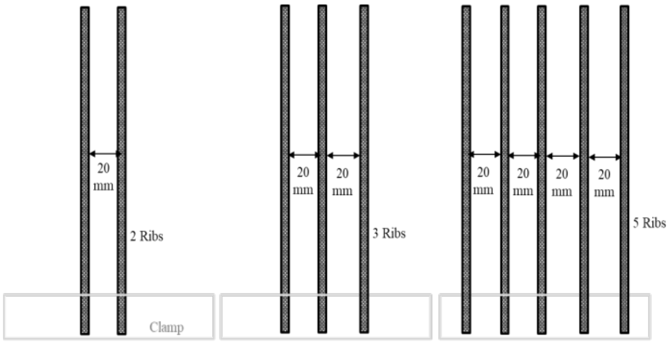

Figure 3(a). Two, three, and five L-ribs at 20 mm spacing

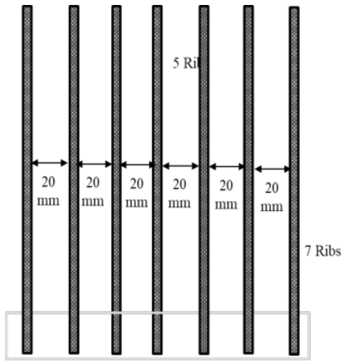

Figure 3(b). Seven L-ribs at 20 mm spacing

Figure 3. The schematic diagram of the arrangement of L-ribs under second set of tests

Figure 4. The photograph of the test on two L-ribs at 150 mm spacing.

3 RESULTS AND DISCUSSION

The results obtained from all tests were analysed in the form of pullout force per L-rib, i.e., the pullout response and the peak pullout force were normalized with the number of ribs. This value of the pullout force per L-rib is also an indicator of the zone of influence of the individual rib for each case of spacing. These normalized values were then compared with the pullout strength of the single L-rib to assess the influence of spacing. Fig. 5 shows the load-displacement curves per L-rib obtained for the first set of tests on two ribs with varying spacing, while Fig. 6 summarizes the corresponding normalized peak load resistance values. Fig. 7 shows the normalized peak pullout force values (per L-rib) for the second set of tests on multiple ribs with 20 mm spacing.

Figs. 5 and 6 show that only when the spacing between two L-ribs exceed 50 mm, the normalized pullout force per L-rib is similar to the single pullout force value of 243 N. For spacing of 10 mm, 20 mm, and 50 mm, the pullout force per L-rib was 18.5%, 11.5%, and 7.5% lower than the single rib strength, respectively. These interaction effects are possibly due to the overlapping of effective zones present around each rib wherein the bond stresses are mobilized (Alagiyawanna et al. 2001). These effective zones, also known as influence zones, are possibly isolated when the spacing was 70 mm and higher for the present test conditions. Thus, the results indicate that when the ribs are placed at an optimal spacing, the influence zones so mobilized also results in the optimum peak pullout force value for the geogrid or the geosynthetic strap. Any spacing lesser than the optimal spacing will result in diminished pullout strength values. It may be noticed that the configuration of the geogrid considered in the present study was also not optimal as its L-ribs were placed at 20 mm spacing. Thus, it is important to evaluate the interference of adjacent L-ribs in a geogrid specimen.

Fig. 5 also shows that the mobilization of the bond stress occurs linearly up to a displacement of 8-10 mm and then decreases to a constant residual value within pullout displacement of 20 mm. This decrease in the pullout force value can primarily be attributed to loss of contact between the surface of ribs and soil during pullout. It was observed during tests that even though the ribs were composed of extensible material (polyester), they displayed inextensibility during the pullout. This may be attributed to rapid mobilization of the bond stress along the complete length of the ribs owing to the low normal stress at the interface.

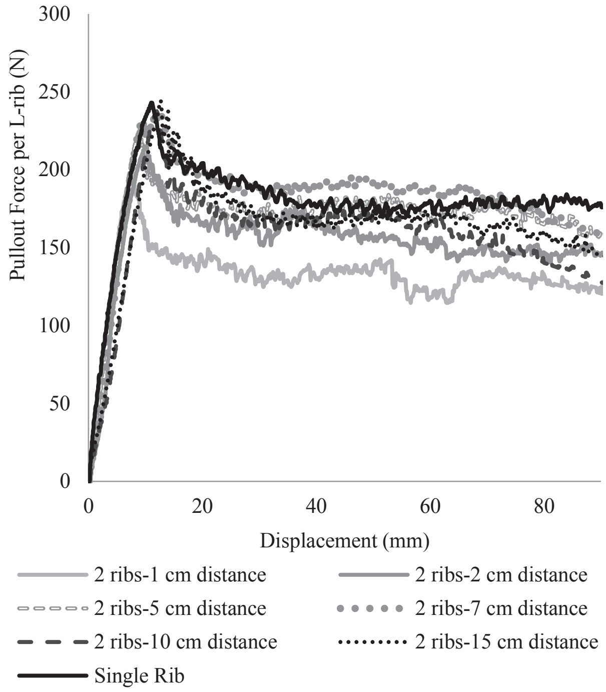

Figure 5: Comparison of Pullout force-displacement response of individual rib in each case of spacing to that of single rib response

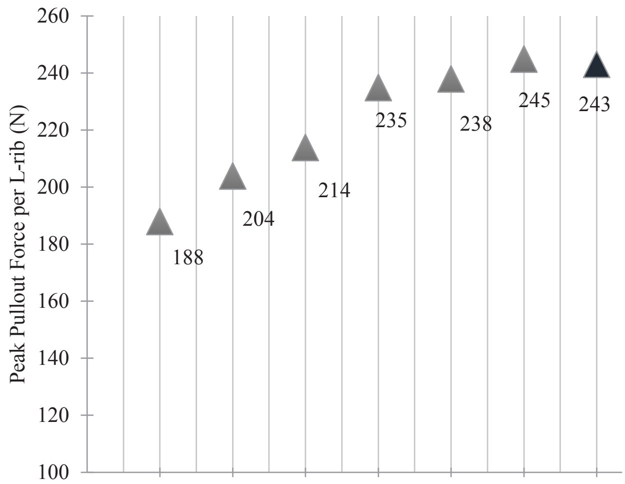

Figure 6: Comparison of normalized peak pullout force values of two L-ribs with varying spacing with that of single rib pullout capacity

Fig. 7 shows that when two, three, five, and seven L-ribs placed at 20 mm spacing were pulled together, the peak pullout force decreases by 16%, 34%, 52%, and 61%, respectively, with respect to the pullout capacity of the single rib. This implies that even when L-ribs are placed at the same spacing, the interaction among adjacent L-ribs increases with an increase in the number of ribs. This may also be inferred that when the L-ribs in the geogrid or geosynthetic straps are placed at optimal spacing, the pullout resistance will be directly proportional to the number of ribs in the specimen.

However, it may be noted that the present study is conducted only on the interactions of L-ribs. It doesn't present the effect of the inclusion of T-ribs on the overall results, which are typically present in a grid. Moreover, the results and observations are applicable for the range of stress and material parameters considered in the present study. Extrapolation of results and observations beyond the specified range is not advisable.

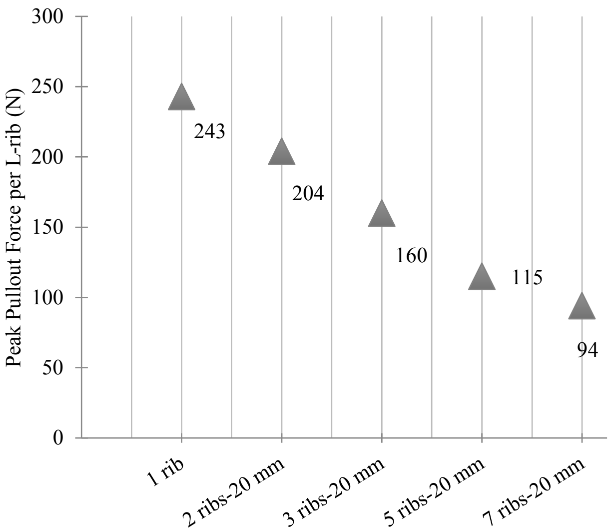

Figure 7: Comparison of normalized peak pullout force values of multiple L-ribs with 20 mm spacing with that of single rib pullout capacity

4 CONCLUSIONS

A series of pullout tests were conducted to study the interaction between longitudinal ribs of geogrid and investigate the influence of spacing and number on its pullout strength. This study was carried out on two L-ribs placed at a spacing of 10 mm, 20 mm, 50 mm, 70 mm, 100 mm, and 150 mm. Another set of the study was conducted to investigate the effect of the number of L-ribs (two, three, five, and seven) placed at the same spacing of 20 mm on the normalized pullout resistance per L-rib. These normalized values from the tests were then compared with the pullout strength of single L-rib to assess the influence. The following conclusions can be drawn from the present study:

- For the study conducted on two L-ribs at varying spacing, the normalized pullout force values of L-ribs were similar to the single rib strength for spacing equal to or greater than 70 mm.
- For L-ribs placed at spacing lesser than 70 mm, the normalized rib strength was 7.5-18.5% lower than the single rib strength. This indicates overlapping of influence zones during mobilization of pullout resistance.
- The pullout resistance was mobilised linearly up to a pullout displacement of 8-10 mm, before attaining a constant residual value at pullout displacement of 15-20 mm.
- The normalized L-rib strength reduced by 16-61% when the number of L-ribs placed at the same spacing of 20 mm increased. This shows that influence zones are affected by the number of ribs too.
- If the L-ribs are placed at optimal spacing, the pullout resistance will be directly proportional to the number of ribs.

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