EFFECT OF GEOGRID TYPE ON PERFORMANCE OF REINFORCED DENSE-GRADED AGGREGATE BASE

R. Ghabchi[1], T. Mahmood[1], K. Hatami[2], and M. Zaman[3]
[1]Doctoral Candidate, School of Civil Engineering and Environmental Science, The University of Oklahoma, Norman, OK, USA. Tel: +1(405) 325-4236; Fax: +1(405) 325-4217; Email: ghabchi@ou.edu, tahsina@ou.edu
[2]Associate Professor of Civil Engineering and Environmental Science, The University of Oklahoma, Norman, OK, USA. Tel: +1(405) 325-3674; Fax: +1(405) 325-4217; Email: kianoosh@ou.edu
[3]Associate Dean for Research and Graduate Programs, College of Engineering, The University of Oklahoma, Norman, OK, USA. Tel: +1(405) 325-2626; Fax: +1(405) 325-4217; Email: zaman@ou.edu

ABSTRACT

A series of in-isolation tensile tests and pullout tests were carried out to examine the influence of fabrication technique and selected index properties of geogrids on their in-aggregate performance. The geogrids in this study were selected following a comprehensive survey of commonly used geogrids in highway projects in the United States. The dense-graded base aggregate used in this study (i.e. ODOT Type-A) is the most commonly used aggregate in Oklahoma highway projects. The in-isolation tests showed that the extruded geogrids have greater junction strengths than the non-extruded geogrids. Based on the pullout test data, it was observed that a higher junction strength value results in a better in-aggregate performance. The pullout force was found to be directly correlated with the rib strength values at 2% and more closely at 5% strain levels. Also, it was found that the pullout force of the non-extruded geogrids was more sensitive to the junction strength than that of extruded geogrids. Correlations were also developed between geogrids index properties and their pullout performance.

Keywords: Geogrid, pullout test, aggregate base

INTRODUCTION

Excessive deformations in pavements such as rutting and other types of distress result in millions of dollars in repair and maintenance costs for departments of transportation (DOTs) across the United States. Improved pavement performance with the use of geosynthetics has been reported by several researchers (Berg et al. 2000, Giroud and Han 2004, Perkins et al. 2004, Gabr et al. 2006, Aran 2006, Holtz et al. 2008, Kwon and Tutumluer 2009). It has been shown that proper selection and installation of geosynthetic reinforcement can help reduce the minimum required thickness of a pavement layer and extend the service life of the pavement. Use of geosynthetics can also reduce construction and/or maintenance costs.

Although geogrids are widely used to reinforce aggregate bases, there are currently no universally accepted guidelines/specifications available to DOTs for their use in such applications (Holtz et al. 2008). Effectiveness of the load transferred between longitudinal and transverse ribs in a geogrid for base reinforcement applications highly depends on the junction strength and transverse rib flexural stiffness (Perkins et al. 2004, Chehab et al. 2007, Christopher et al. 2008, Tang et al. 2008). The significance of the geogrid type and index properties on its in-aggregate performance is not well established. Hence, there is a need to study the effect of junction and rib strength properties on geogrid-reinforced aggregate base performance under serviceability and construction conditions. Under the serviceability conditions, geogrids undergo small strains (up to 2%). However, they are subjected to greater strains during construction (Christopher et al. 2008). Two major types of geogrids are used for aggregate base reinforcement: extruded geogrids (EGG) and non-extruded geogrids (NEGG). Rib and junction strength values of geogrids can be significantly different, depending on the type of products.

Perkins et al. (2004) conducted wide-width tensile and cyclic pullout tests on three geosynthetic reinforcement products, in accordance with the ASTM D4595 and the ASTM D6706 test methods, respectively. It was reported that the elastic tensile modulus, equivalent isotropic modulus, and Poisson's ratio of geogrids influence their in-aggregate performance. Their cyclic pullout tests results showed that the interface shear modulus was dependent on the normal and shear stresses on the interface.

Chehab et al. (2007) studied the rutting performance of small-scale roadway models reinforced with geogrids of different properties. They identified aperture size, tensile strength at small strain (2%), junction strength, and flexural rigidity of the cross ribs among the most important properties of geogrids in pavement subgrade stabilization. They concluded that the tensile strength at a smaller strain was a critical factor in direct shear test performance of geogrids, while their ultimate tensile strength was a more important parameter in pullout tests. They also reported a better correlation between geogrids ultimate rib strength with pullout test results than with the accelerated pavement test (APT) results. Overall, both tensile and junction strength showed reasonable correlations with the pullout capacity of geogrids in aggregates.

Christopher et al. (2008) suggested that junction strength at a 2% strain could be considered an appropriate value for design to transfer load through the ribs in geogrids. They also argued that the junction strength values should be based on the junction strength required to achieve 2% strain in geogrids.

Tang et al. (2008) studied the effect of aperture size, wide-width tensile strength and junction strength of four geogrid products on direct shear and pullout test results. They reported a strong relationship between in-aggregate performance and junction and tensile strength properties of geogrids at small strains. The geogrid with the largest apertures, among the four geogrids, was found to have the highest interaction coefficient in pullout tests.

Cuelho and Perkins (2009) studied the effect of tensile strength at 2% strain, 5% strain, ultimate tensile strength, and aperture stability modulus on the rutting performance of geogrid-reinforced roadway test sections. The welded geogrids, woven geogrids and the stronger, integrally-formed geogrids exhibited the best overall rutting performance. They stated that, comparative in-aggregate performance of geogrids is likely related to their tensile strength in the cross-machine direction, especially at a 2% strain.

The primary focus of the present study is to evaluate the influence of geogrid type and rib and junction strength properties on their in-aggregate performance. The performances of two EGG and three NEGG geogrids are investigated in a dense-graded aggregate through a series of junction tests, rib tests and large-scale pullout tests. The selected geogrids have comparable rib strength at 2% strain and aperture size but they are made using fabrication techniques. Test results on EGG and NEGG products are compared and discussed. Correlations were also developed between the geogrids pullout capacity and their index properties.

MATERIALS

Aggregate

A dense-graded aggregate, ODOT Type-A, was used in this study. This gradation is widely used by ODOT in highway projects involving aggregate bases. Bulk aggregates were collected from the Dolese Hartshorne quarry in Pittsburg County, Oklahoma. The collected aggregate type was limestone, according to the ODOT Aggregate Information database (ODOT 2009).

Los Angeles (LA) abrasion tests were conducted to determine durability of the aggregate according to AASHTO T 96. The loss values obtained from LA abrasion testing on at least three samples varied between 20.1% and 21.0%, with an average of 20.5%. This LA loss value is less than the 50% maximum acceptable limit for base aggregates, according to the ODOT guidelines (ODOT 2009). According to the moisture-density tests, the optimum moisture contents (OMC) of the upper (UL) and lower limits (LL) of ODOT Type-A gradations were 6.2% and 5.0%, respectively. The corresponding maximum dry unit weights for the UL and LL gradations were 22.9 and 22.6 kN/m^3, respectively. Figure 1 shows the UL, LL and actual gradations used in this study.

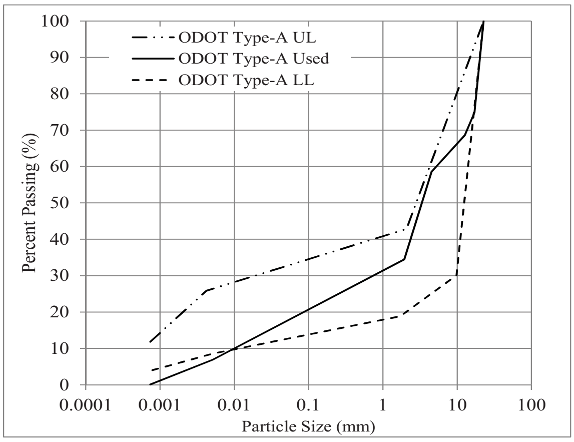

Fig. 1 ODOT Type-A aggregate gradation

Geogrids

The geogrids used in this study (Table 1), consisted of two polypropylene (PP) type extruded geogrids and three NEGG multifilament yarn polyester (PET) geogrids. PET yarns in NEGG-1 and NEGG-3 geogrids have polyvinylchloride (PVC) coating. Selection of these geogrids was based on their comparable aperture sizes and rib tensile strength values at 2% strain.

Table 1 Geogrids used in this study

Geogrid Type-No.	Polymer Type	Geometry	Fabrication Technique	Aperture size (mm)	
				MD	XD
EGG-1	PP	Biaxial	P/D*	25	33
EGG-2	PP	Triaxial	P/D*	40**	40
NEGG-1	PET	Biaxial	Woven	25.4	25.4
NEGG-2	PET	Biaxial	Knitted	25.4	24.1
NEGG-3	PET	Biaxial	Woven	25.0	25.0

* Punched and Drawn ** Measured in diagonal direction.

METHODOLOGY

Prior to in-aggregate tests, a series of in-isolation rib and junction strength tests were carried out on the EGG and NEGG geogrids to determine their mechanical properties. Pullout tests were used to evaluate the geogrids in-aggregate performance.

Junction Strength Test

The junction strength tests were conducted according to the GRI-GG2 guidelines (GRI 2005). Specimens were tested in equal numbers (at least 3 specimens for each case) in both machine direction (MD) and cross-machine direction (XD). Two aperture-size wide and 3½ aperture-sizes long, T-shaped specimens were cut for the junction tests. Junctions were marked and a non-contact digital imagery technique was used to measure junction deformations. In this technique, digitally captured images were scaled and deformations were tracked and calculated in sequential images using graph digitizer software. The magnitude of junction strain was determined from the movement of selected points using the graph scale that was set in the software. Details of the digital imagery technique employed to measure junction strains are described by Wang (2009).

Rib Tensile Strength Tests

Rib tensile strength tests were carried out according to the ASTM D6637 test method. The rib deformation was tracked using the digital imagery system noted in the previous section. The EGG ribs were tested using a clamping system made of 102 mm × 102 mm × 6 mm steel plates that were lined with two layers of sandpaper on the inside

The NEGG geogrids tested using this test setup revealed that in some specimens polyester yarns were pulled out of the PVC coating, leaving a piece of the coating in the clamp. This observation raised a possible concern regarding the strength of the coating-yarn bonding in such products. In order to test the NEGG products, a different clamping technique was used. Details of the clamping techniques used for rib strength tests conducted on EGG and NEGG geogrids are presented in Figs 2a and 2b, respectively.

Fig. 2 Rib tensile strength test clamps modified for (a) EGG, (b) NEGG geogrids (Hatami et al. 2011.a)

Pullout Tests

Pullout tests can provide a suitable means to study geogrid-aggregate interactions at different stress levels under controlled conditions. Several benefits are included in this test when studying geogrids in aggregate base reinforcement applications. According to Holtz et al. (2008), geogrids placed in an aggregate base layer can be subjected to significant stresses from compaction equipment during the construction stage. Therefore, installation damage tests are necessary for the selection of suitable geogrids in base reinforcement projects. However, installation damage tests alone do not provide sufficient information on the interactions between given aggregates and geogrids. In this regard, pullout tests can serve as a complementary method to study geogrid-aggregate interactions at different stress levels. In addition, pullout tests can help isolate the planar tensile performance of geogrids from their tensioned membrane action. It is important to consider such membrane actions when geogrids are subjected to vertical load in plate load tests (Hatami et al. 2011.b).

Pullout tests were carried out in the machine direction at a nominal rate of 1 mm/min as per ASTM D6706 test protocol (ASTM 2009). The pullout box used in this study was 1800 mm long, 900 mm wide and 750 mm high. This pullout box also included a pair of 200 mm steel sleeves on the front at the elevation of the geogrid. The gap between the sleeves was 50 mm which was protected against the intrusion of aggregates during the pullout procedure using styrofoam blocks. Geogrid specimens were attached to a roller clamp and were placed with a net length of 150 mm in direct contact with the aggregate layer. Four wireline extensometers were installed at the back of the box and attached to the geogrid nodes along their length on different longitudinal ribs to measure the nodal displacements at 35 mm longitudinal intervals. Average strains along the length of the geogrid specimens were calculated using the measured nodal displacements and their corresponding distances. The tests were conducted on aggregates compacted at 95% of the maximum dry unit weight and were subjected to 3.3 kPa, 6.6 kPa and 11.5 kPa vertical confining pressures. These pressures on the geogrid-aggregate interface were primarily due to the weight of the compacted aggregate layer with different heights on the top of the interface in the pullout box. These pressure levels resemble field conditions (outside the tire pressure bulb) where pullout (as opposed to geogrid rupture) is likely to be the failure mechanism.

RESULTS AND DISCUSSIONS

Junction Strength

The ultimate junction strength test results in MD and XD for the tested geogrids are summarized in Table 2. The averages test results for a minimum of three samples are presented for each geogrid in each direction. Each geogrid is also evaluated based on satisfying the minimum required ultimate junction strength (111 N) for construction survivability, as per the FHWA recommendations (Holtz et al. 2008). According to Table 2, the ultimate junction strength values of EGG geogrids in both MD and XD, and only the ultimate junction strength value of NEGG-1 in MD, exceed the minimum FHWA requirements.

Table 2 Junction strength test results summary

Geogrid Type-No.	Junction Strength (N)		Meets Minimum FHWA Requirement*	
	MD	XD	MD	XD
EGG-1	602	671	Yes	Yes
EGG-2	795	792	Yes	Yes
NEGG-1	154	89	Yes	No
NEGG-2	61	30	No	No
NEGG-3	73	50	No	No

* 111 N as per Holtz et al. (2008)

A comparison between junction strength values of EGG and NEGG geogrids reveals that the junction strength values of EGG geogrids are considerably (approximately 4 to 26 times) greater than those of NEGG type in both MD and XD. It is also evident that junction strength values of NEGG-1 in both directions are measurably (at least two times) greater than those of the NEGG-2 and NEGG-3 geogrids. It should be noted that junction strength values in both MD and XD directions are important in the performance of biaxial geogrids in base reinforcement applications. Therefore, the FHWA minimum required value of 111 N for junction strength should be applicable to both MD and XD directions. The pullout tests in this study, however, were meant to isolate the geogrid junction strength in one direction to examine its influence on the pullout capacity of the reinforcement in the same direction.

Rib Tensile Strength

The rib strength test results in MD and XD, at 2%, 5% and ultimate strain of the tested geogrids, are summarized in Table 3. Table 3 presents the mean strength values of a minimum of three replicate specimens.

Table 3 Summary of rib tensile strength test results

Geogrid Type-No.	Rib Strength (kN/m)					
	2% Strain		5% Strain		Ultimate	
	MD	XD	MD	XD	MD	XD
EGG-1	13	22	22	34	26	38
EGG-2	7	12	14	20	21	23
NEGG-1	9	10	18	22	65	34
NEGG-2	7	6	9	8	33	28
NEGG-3	9	12	16	16	44	60

Table 3 shows that rib strength values of EGG geogrids at 2% strain vary over a wide range (7 to 22 kN/m). In contrast, rib strength values of all tested NEGG products at 2% strain in both MD and XD vary over a relatively narrow range (9 to 12 kN/m). However, the ultimate rib strength values of the EGG and NEGG geogrids are measurably different from one another with the greatest values observed for NEGG-1 in MD (65 kN/m) and NEGG-3 in XD (60 kN/m). The lowest ultimate rib strength was observed for EGG-2 in MD and XD directions (21 and 23 kN/m, respectively). An overall comparison between rib tensile strength values of EGG and NEGG geogrids reveals that the ultimate rib strength values of NEGG type geogrids examined in this study are slightly greater than those of the EGG geogrids in both MD and XD directions.

Pullout Response

Obtaining consistent pullout test data for geogrids in aggregate is challenging due to significant interlocking between these materials (Mahmood et al. 2011a, Mahmood et al. 2011b). Table 4 presents peak pullout resistance of geogrids at different vertical confining pressures for the

ODOT Type-A aggregate used in this study. The peak pullout resistance, P_r, for each test case was determined by the first hump in the pullout response curve that preceded a plateau, subsequent peaks, or a monotonic increase in the pullout resistance. Figs 3 and 4 show typical EGG and NEGG geogrids, respectively, after the pullout test. From Fig. 3, it is evident that EGG geogrids have experienced minimal damage on ribs and junctions due to the pullout test. However, Fig. 4 reveals that NEGG geogrids undergo significant junction failure, as a result of the pullout test.

Fig. 3 EGG-1 geogrid condition after pullout test

Fig. 4 NEGG-3 geogrid condition after pullout test

Table 4 presents the peak pullout resistance, *Pr,* for tested geogrids at different vertical confining pressures. It was observed from Table 4 that a greater overburden pressure resulted in a greater maximum pullout resistance, as expected.

Table 4 Summary of peak pullout resistance of tested geogrids subjected to different vertical confining pressures

Geogrid Type-No.	Peak Pullout Resistance, Pr (kN/m)		
	Normal Confining Pressure		
	3.3 kPa	6.6 kPa	11.5 kPa
EGG-1	10.25	15.50	17.25
EGG-2	7.38	8.75	10.86
NEGG-1	6.75	11.34	14.81
NEGG-2	3.55	4.63	6.92
NEGG-3	5.36	10.04	11.70

Figure 5 shows the relationships between the peak pullout resistance and the vertical confining pressures for all five geogrids examined in this study. From Fig. 5 it is evident that, with an increase in the vertical confining pressure, pullout force increases. The overall pullout response for all geogrids show reasonable trends with respect to the vertical confining pressures.

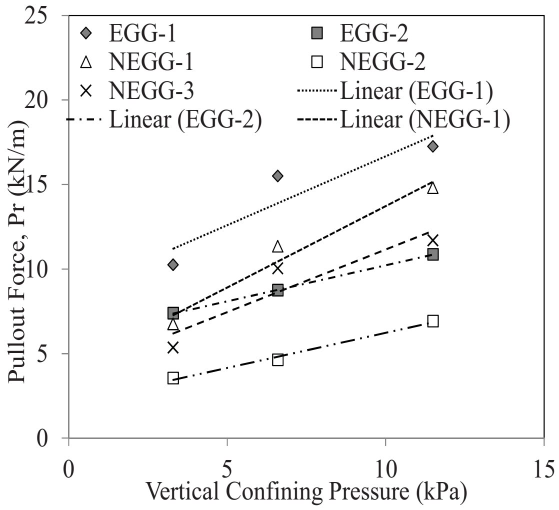

Fig. 5 Pullout force variation with different confining pressures for tested geogrids

Linear correlations between the pullout force (P_r) and vertical confining pressure (σ_n) for each type of geogrid tested in this study can be expressed in the form of Equation 1 as:

$$P_r = a\sigma_n + P_{r0} \quad (1)$$

where *a* is the slope of the linear equation which is a function of the friction and interlocking between the geogrid and the aggregate. P_{r0} is the intercept of this equation. Table 5 presents the parameters of the abovementioned linear correlations for each geogrid.

Table 5 Summary of the linear correlation parameters developed between P_r and σ_n for the tested geogrids

Geogrid Type-No.	Linear Correlation Parameters		
	a (m)	Pr_0 (kN/m)	R^2
EGG-1	0.82	5.5	0.85
EGG-2	0.42	6.0	1.00
NEGG-1	0.96	4.1	0.96
NEGG-2	0.42	2.1	0.99
NEGG-3	0.74	3.8	0.86

From the R^2 values in Table 5 it is evident that a very good correlation exists between the pullout force and vertical pressure for all types of tested geogrids. It was also observed that the highest slope, a value, an indicator of friction and interlocking, was recorded for NEGG-1 geogrid and the lowest a value, was recorded for EGG-2 and NEGG-2 geogrids.

The variations of the a value, maximum pullout resistance at intermediate confining pressure (6.6 kPa), and the index strength properties of the tested geogrids were investigated side-by-side to observe the effect of index properties on the interlocking/friction and pullout capacity of the geogrids. Figure 6 shows the variations of P_r at the intermediate confining pressure of 6.6 kPa and the a values with geogrids rib strength at 2% strain in MD.

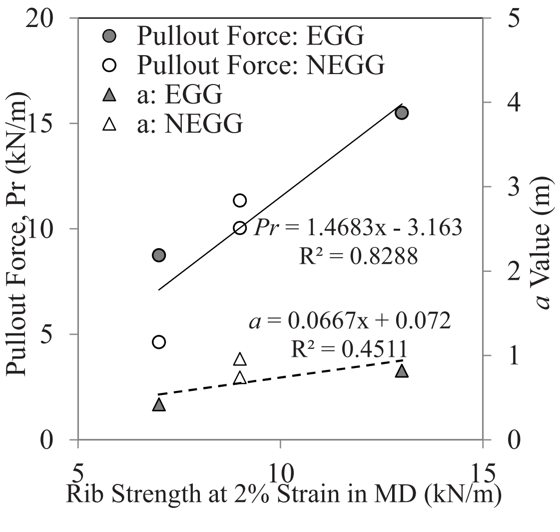

Fig. 6 Variations of P_r and a with rib strength at 2% strain for the tested geogrids

From Fig. 6, it can be observed that the pullout force increases with the rib strength at 2% strain ($T_{2\%}$) with a fairly strong correlation (i.e. $R^2 = 0.83$). The parameter a showed a weaker correlation with $T_{2\%}$. It can be attributed to the small values of deformation at 2% strain, which may not be representative of the full pullout force mobilization during the pullout test. Hence it is expected to see a better correlation between the P_r and a parameters and the rib strength at higher strains. Effect of rib strength at 5% strain ($T_{5\%}$) on the P_r and a values is shown in Fig. 7. Figure 7 shows a strong correlation between P_r and $T_{5\%}$ ($R^2 = 0.99$). The correlation between a and $T_{5\%}$ shows a higher R^2 value (i.e. 0.63) as compared to that between a and $T_{2\%}$. This is consistent with the earlier explanation related to a greater mobilization of pullout force at higher strains.

Figure 8 presents the variations of the P_r at intermediate confining pressure (6.6 kPa) and a values with the geogrids ultimate rib strength (T_u) in MD.

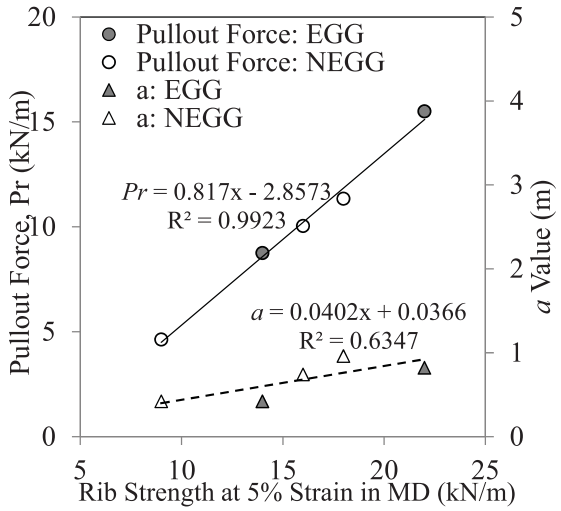

Fig. 7 Variations of P_r and a with the rib strength at 5% strain for the tested geogrids

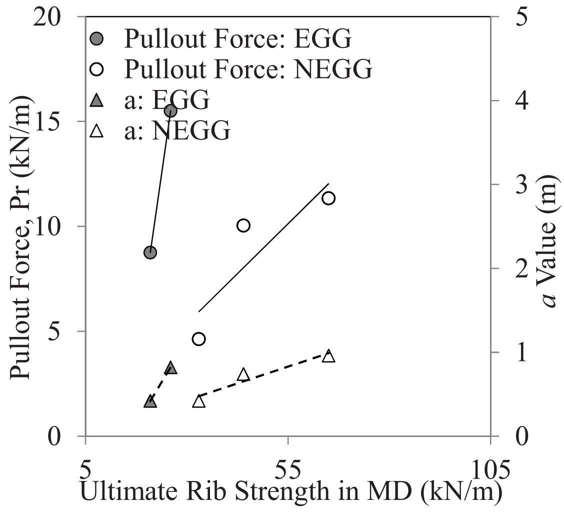

Fig. 8 Variations of P_r and a with the ultimate rib strength for the tested geogrids

None of the geogrids tested in this study experienced rib failure in the pullout tests (Fig. 3 and 4). Therefore, no direct correlations between P_r and T_u are observed or expected. However, since a higher T_u generally results in higher $T_{5\%}$ and $T_{2\%}$ values, it was observed that an increase in T_u for each type of geogrid overall results in higher P_r and *a* values.

Figure 9 presents the variations of P_r at an intermediate confining pressure (6.6 kPa) and *a* values with the geogrids junction strength (J_u) in MD, for the geogrids examined. Results in Figure 9 clearly indicate that meaningful correlations exist between P_r and *a* values and the junction strength of NEGG geogrids. The reason for this observation is attributed to the difference between failure mechanisms of the EGG and NEGG geogrids.

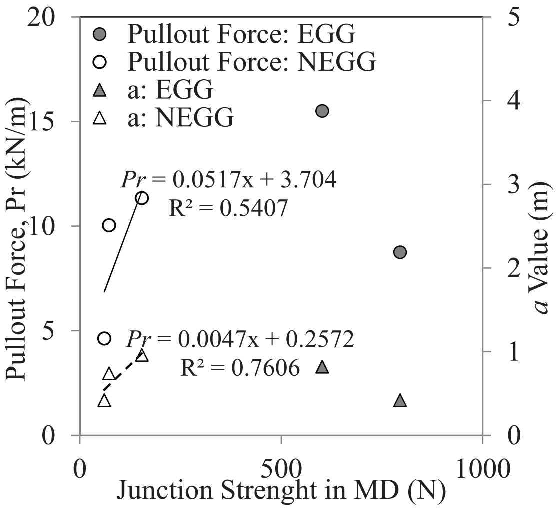

Fig. 9 Variations of P_r and *a* with the ultimate junction strength for the tested geogrids

As discussed before, none of the EGG geogrids failed in the pullout tests due to junction failure. Hence, due to its comparatively high value, the ultimate junction strength was never mobilized during the pullout tests on EGG geogrids. On the contrary, all of the NEGG type geogrids failure in the pullout tests involved junction failure. Junction failure results in a loss of aggregate-geogrid interlocking and reduced passive resistance. Therefore, the pullout force and *a* values are expected to be more sensitive to junction strength in NEGG geogrids than their EGG counterparts. This expectation is supported by the results shown in Fig. 9.

CONCLUSIONS

A series of in-isolation and pullout tests in a dense-graded aggregate were carried out on two extruded (EGG) and three non-extruded geogrids (NEGG). These tests were carried out to investigate the significance of the geogrids fabrication technique and index properties on their pullout performance. The dense-graded aggregate selected for this study was ODOT Type-A, which is a commonly used gradation in Oklahoma highway projects.

The pullout test data indicated that among the geogrids examined, the extruded geogrid with the largest junction strength and 5%-strain rib strength exhibited the largest pullout resistance. The pullout force was found to be directly correlated with the rib strength values at 2% and (more closely) at 5% strain levels. Also, it was found that the pullout force of the NEGG geogrids was more sensitive to the junction strength than that of EGG geogrids. Aggregate-geogrid friction and/or interlocking (*a* value) was found to increase with the NEGG junction strength and with the rib index properties for both EGG and NEGG geogrids. No clear or convincing correlations were found between the ultimate rib strength and the maximum pullout resistance for any types of geogrids examined.

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