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The Effect of Geogrid Reinforcement Pre-Stressing on the Performance of Sand Bed Supporting a Strip Foundation

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Abstract**—**In this paper, an experimental and numerical study was adopted to investigate the effect geogrid soil reinforcement pre-stressing on the pressure settlement relation of sand bed supporting a strip foundation. The studied parameters include foundation depth and pre-stress ratio for the cases of one and two pre-stressed reinforcement layers. The study reflected that pre-stressing of soil reinforcement resulted in a marked enhancement in reinforced bed soil stiffness compared to the reinforced soil without pre-stress. The best benefit of pre-stressing reinforcement was obtained as the overburden pressure and pre-straining ratio increase. Pre-stressing of double reinforcement topmost layers results in further enhancement of stress strain relation of bed soil.

Keywords**—**Geogrid reinforcement, strip footing, pre-stress, bearing capacity.

I. Introduction

REINFORCING soil with geosynthetic sheets - including geotextile, geogrid, and geocomposite - has proven to be an effective technique in geotechnical engineering practice. Over the past three decades, researchers such as Guido et al. [1], Yetimoglu et al. [2], Adams and Collin [3], Shin and Das [4], Sitharam and Sireesh [5], Shakla and Chandra [6], have investigated different parameters affecting soil reinforcement process including depth of top reinforcement layer, vertical spacing between layers, extension of reinforcement, and material properties. It was concluded that soil reinforcement is effective in reducing shallow foundation settlement and increasing bearing capacity of soil (B.C.). The interaction between the reinforcement and the surrounding soil should be enhanced to gain the extreme reinforcement effect. Performance of soil reinforcing material such as geotextile is highly affected by the friction development with soil, whereas geogrid is more affected by interlocking soil particles through apertures [7]. As for the reinforcement to function probably, large settlement should be achieved which is not a desirable feature for shallow foundation [8]-[11]. In the last few years, a number of researchers investigated the effect of pre-stressing of soil reinforcement before applying the foundation load [12]. Lovisa et al. [7] conducted a number of laboratory physical model tests and finite element analysis to study the behavior of pre-stressed geotextile-reinforced sand bed supporting a loaded circular footing. It was concluded that geotextile pre-stressing with 2% of the allowable tensile strength resulted in nearly doubling the load carrying Capacity at 5 mm of foundation settlement. Pre-stressing was more effective in enhancing the (B.C.) of shallow foundation for greater foundation depth, and the researcher suggested that the pre-stressed geosynthetic should be pulled out and anchored in trenches surrounding the reinforced area before placement of granular fill over it. Balamaheswari and Ilamparuthi [13] investigated the effect of depth and width of reinforcement and magnitude of pre-stressing force on the (B.C.) of a model strip footing. It was concluded that the geogrid reinforcement pre-stressing contributes considerably to load bearing capacity of footing with reduction in settlement. They also concluded that biaxial pre-stressing results in higher improvement of the foundation soil performance compared to the uniaxial pre-stressing. Dhatrak and Khan [14] investigated the effect of magnitude and direction of pre-stressing force on (B.C.) and settlement of a square model footing resting on a multiple reinforced sand layer. The researchers observed marked enhancement in (B.C.) and reduction in the settlement with reinforcement depth of 1/4 footing width with 2 and 3% of the allowable tensile strength for biaxial and uniaxial pre-stressing. Alamshahi and Hataf [15] studied the effect of providing grid anchors to geogrid. The laboratory model study and finite element analysis concluded that anchors significantly enhance the bearing capacity of reinforced foundation bed. As soil reinforcement can be applied to a number of application including, foundation, slopes and embankment [16], reinforcement pre-stressing may be applied on a wide range to enhance the performance of reinforced soil.

Citing the previously presented research work, it can be concluded that the technique of reinforcement pre-stressing reflected efficiency in enhancing the load carrying capacity and reducing settlement of shallow foundation. More detailed studies on this technique must be conducted to cover different parameters that may affect the performance of soil reinforced by pre-stressed reinforcement. In the current study, the effect of foundation depth and pre-stress ratio for the cases of one and two reinforcement layers on the carrying capacity of strip foundation was investigated. The study involved an experimental investigation for a number of selected cases to verify the extension of the study to cover the investigated parameters with non-linear finite element analysis carried out by using finite element program PLAXIS version 8.

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II. Experimental Investigation

A. Materials

Washed, air dried siliceous yellow sand was used as the granular bed. The grain size distribution is shown in Fig. 1, and sand properties are illustrated in Table I. Properties of Geogrid reinforcement (CE121) are illustrated in Table II.

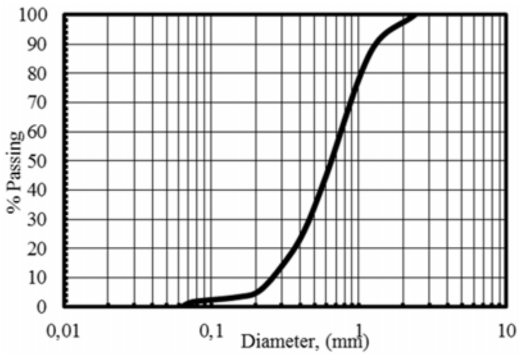


Fig. 1 Particle size distribution of sand

B. Test Setup

Fig. 2 illustrates the sand container mounted under the loading frame with hydraulic loading system. The tank dimensions were 500 * 1200 mm with depth of 1000 mm. The strip model footing of width (B) of 100 mm, 500 mm in length was made of aluminum. The spacing aluminum blocks are placed over the model footing strip until reaching the loading post level. Fig. 3 illustrates a photo of the sand container and lateral straining mechanism. Manual torque is applied to the mechanical jack to laterally push the beam which laterally drive geogrid pre-stressing wires. The bottom and sides of the footing was covered by a sand paper to mobilize the interface between footing and sand. Two dial gauges were mounted on the model footing on each side of loading post to measure an average value of resulting settlement.

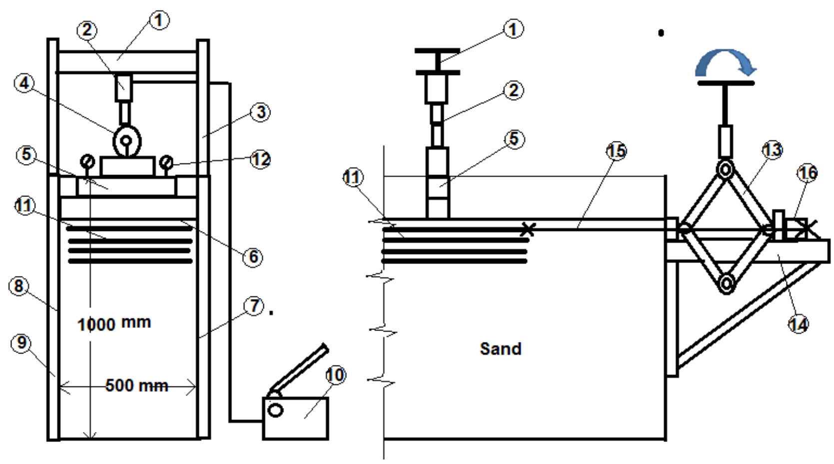
TABLE I
PROPERTIES OF SAND

Specific gravity	2.66
Maximum dry unit weight (kN/m^3)	17.22
Minimum dry unit weight (kN/m^3)	14.46
Dry unit weight (kN/m^3)	15.70
Relative density for model test (%)	55.0
Effective grain size D_{10} (mm)	0.27
D_{60} (mm)	0.45
D_{30} (mm)	0.75
Coefficient of uniformity C_u	2.78
Coefficient of curvature C_c	1.0
Friction angle φ (^{o})	36
Cohesion C (kPa)	0
Classification	SP

TABLE II
MECHANICAL PROPERTIES OF GEOGRID REINFORCEMENT CE121

Thickness	1.35 mm
Mesh aperture size	8*6 mm
Weight of unit area	147 gm/m^2
Tensile strength	7.68 kN/m
Extension at max. load	20.2%
Load at 10% extension	6.8 kN/m
Elongation at ½ peak strength	3.22%
Axial stiffness, EA at 10% extension	6.8 kN/m

Three different cases were investigated according to soil reinforcement including unreinforced, reinforced, and pre-stressed reinforcement. As for the pre-stressed case, reinforcement was exposed to pre-stressing lateral movement with extension values (PS%) of 2, 4, and 6% of reinforcement length. Pre-stressing is applied on one layer only (top layer) and on two layers (topmost layer and the layer under it). After reaching the desired extension value the reinforcement sheet was fastened to resist drawback of the sheet, then the overlaying soil strata may be placed and compacted to the desired density. The effect of foundation depth ratio was investigated through adopting different (Df/B) values of 0.0, 0.5, 1.0, 1.5, and 2.0.



Legend:

1-Reaction beam	2- Hydraulic jack 50kN	3- Loading frame column	4- Load ring
5- Stepped strip footing	6- Foundation level	7- Perspex transparent side	8- Steel plate 3 mm
9- Stiffeners 2L 50*5 mm	10- Control unit of jack	11- Geogrid reinforcement	12- Dial gauge
13- Lateral straining jack	14-Supporting table	15- 4 wires 1mm	16-Reaction beam of wires

Fig. 2 Schematic representation of experimental setup

Fig. 3 Sand container and lateral stressing mechanism

C. Experimental Procedure

The sand was poured in the tank by sand raining technique with height of fall of 40 cm in order to maintain constant relative density, with dry unit weight of 17 kN/m^3 and internal friction angle of 35° representing the sand foundation soil. The sand was poured in layers of 50 mm up to the bottom of reinforcement layer. The sand was removed and refilled after each test. A hydraulic jack was used to apply the vertical load on the model strip footings. The load was applied in increments each of 0.05 kN until failure occurs. Reinforcement layers, number, level and length parameters are as illustrated in Fig. 4. The optimum parameters ratios (u, d and L) to model footing width (B) were chosen as u/B= 0.3, d/B=2 and L/B=8, from [17]-[19].

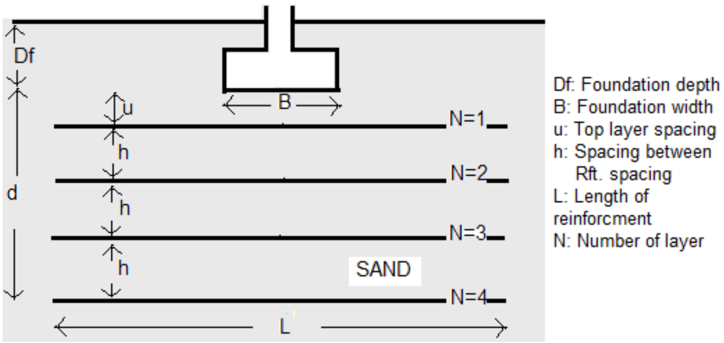


Fig. 4 Configuration of reinforcement layers

III. Numerical Analysis

A. Numerical Model

Numerical models in this study were analysed by using the finite element computer program PLAXIS 2-D V8, [20]. Finite element analysis was carried out using plain strain model. The dimensions of model are shown in Fig. 5. Model dimensions were selected such that the boundary distance does not affect the stresses and deformations values and distribution. The vertical boundaries of the model were constrained horizontally, and the bottom boundary was constrained in both horizontal and vertical directions. Mohr-Column model was adopted to simulate the behaviour of soil. This model is a non-linear model based on basic soil parameters that can be obtained from direct and triaxial shear tests. Sand soil was modelled by using 15-node triangular element. Parameters of footing and geogrid were assumed to maintain the same in all the finite element analyses. The footings were modelled as a plate element. Stiffness properties of footings section are: axial rigidity, EA, and flexural rigidity, EI. The geogrid reinforcement was modelled as a 5-node tension element. Table III illustrates the material properties used in the finite element analysis.

The overburden pressure above foundation level was simulated as a distributed load. The program enables automated mesh generation to discretize the model into standard elements. Depending on experimental analysis and previous research work related to the soil reinforcement pre-stressing, e.g. [7], it was suggested that the medium mesh density was adopted for unreinforced and reinforced (without pre-stressing) analysis. A coarse density was adopted for the pre-stressed cases.

TABLE III
Material Properties Used in Finite Element Analysis

Parameter	Sand	Footing	Geogrid	Anchor
Soil dry unit weight (γ_d) (kN/m^3)	17	-	-	-
Cohesion (c) (kN/m^2)	1.0	-	-	-
Primary loading stiffness (kN/m^2)	28000	-	-	-
Ultimate friction angle (φ)	35°	-	-	-
Angle of dilatancy (Ψ)	12°	-	-	-
Poasion's ratio (υ)	0.3	-	-	-
Interface reduction factor (R)	0.8	-	-	-
Axial stiffness EA (kN/m)	-	8500	2000	2*10^5
Flexural rigidity EI (kN/m^2/m)	-	5*10^6	-	-

B. Parametric Study

Table IV illustrates the numerical study program for unreinforced, reinforced, and Pre-stressed cases.

TABLE IV
Parameters Investigated in the Numerical Study

Group	Varied parameters	No. of studied cases
Unreinforced	(Df/B)=0.0, 0.5, 1.0, 1.5, and 2.0	(5 cases)
Reinforced	(Df/B)=0.0, 0.5, 1.0, 1.5, and 2.0	(5 cases)
Pre-stressed	(Df/B)=0.0, 0.5, 1.0, 1.5, and 2.0	
	PS%=2, 4 and 6%	
	One layer only pre-stressed (1LPs)	(15 cases)
	Two layers pre-stressed (2LPs)	(15 cases)

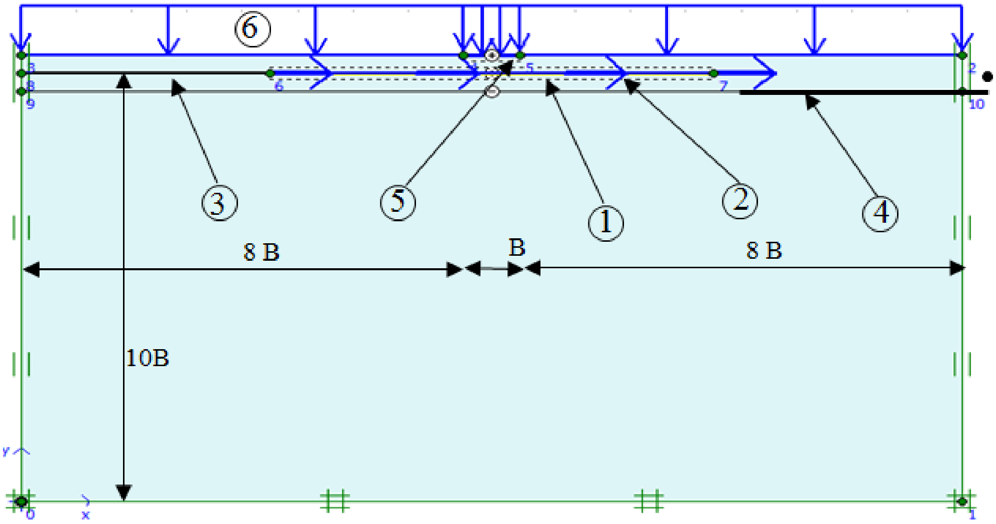


Fig. 5 General configuration of numerical model; 1-Geogrid sheet, 2- Pre-stressing direction, 3-Back anchor, 4-Front anchor, 5- Plate element (footing), 6-Overburden pressure

C. Verification

Verification of numerical analysis program PLAXIS was performed through comparing the ultimate (B.C.) (q_u) for different investigated cases obtained from the numerical study with experimental analysis results and corresponding results obtained from ultimate (B.C.) equations according to Vesic [21] and Huang and Menq [22] method for the reinforced soil case. Fig. 6 illustrates (q_u) corresponding to different (Df/B) values for the unreinforced soil case as determined from experimental, numerical and (B.C.) equation analysis. As can be indicated from this figure for different analysis methods, (q_u) increases almost linearly with the increase of (Df/B) ratio. (q_u) determined from experimental analysis overestimates the corresponding values determined from Vesic (B.C.) equation by nearly 20%. The corresponding (q_u) values determined from PLAXIS program was in good agreement with the corresponding values determined from Vesic (B.C.) equation at (Df/B) ratio of 0 and 1.5. In between these values (q_u) from experimental analysis over estimate those determined from (B.C.) equation, while under estimate it at relatively deeper foundation depth at (Df/B) equals 2.0. As for the reinforced soil without pre-stressing, Fig. 7 illustrates the relation between (q_u) and (Df/B) for experimental, PLAXIS, and Hanq and Menq equation. The three analysis methods have the same trend for the relation between (q_u) and Df/B).

(q_u) exponentially increases with the increase of (Df/B). (q_u) values in case of foundation level at soil surface, i.e. (Df/B)=0, are nearly equal for the three methods of analysis. For deeper foundation levels, (q_u) determined by PLAXIS and experimental analysis over estimates the corresponding value determined by Hanq and Menq equation by average values of 1.2 and 1.9, respectively.

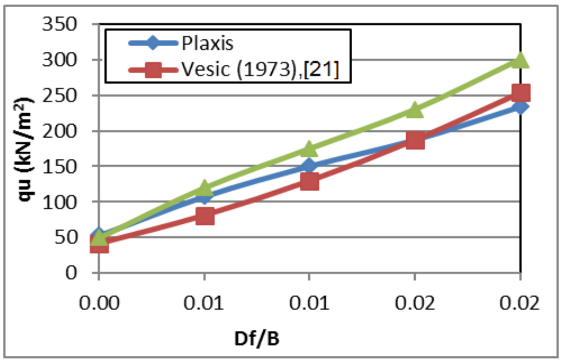


Fig. 6 Ultimate (B.C.) for different (Df /B) for unreinforced soil

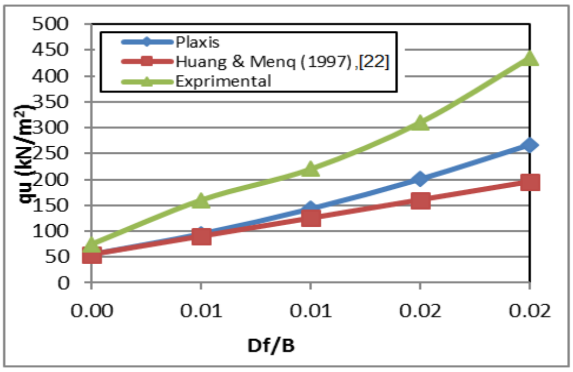


Fig. 7 Ultimate (B.C.) for different (Df /B) for reinforced soil without pre-stress

IV. Analyses And Results

The results of the investigation program of examining the efficiency of geogrid pre-stressing on the performance of strip footing will be presented and discussed. The effect of reinforcing soil and pre-stressing the reinforcement will be investigated through comparing stiffness modulus, ultimate (B.C.), and extreme axial force in reinforcement for different studied cases.

A. Initial Stiffness Modulus

Fig. 8 illustrates the pressure settlement relation for different cases of unreinforced, reinforced and per-stressed with single and double geogrid sheets (pre-stress 1L and 2L) for (DF/B) ratio of 1.0. As can be concluded from this figure there was no measured effect of soil reinforcement without pre-stressing in enhancing the stiffness of reinforced soil as compared to unreinforced soil case. This was reflected through that the pressure settlement relation curves for the unreinforced and reinforced cases nearly coincide. This may be attributed to the relatively low overburden pressure for (DF/B) ratio of 1.0, the matter that results in insufficient interaction between reinforcement and surrounding soil. The stiffness of bed soil reflected through the initial tangent modulus of reinforced was 1.88 the corresponding value of unreinforced soil.

Pre-stressing of geogrid resulted in a marked enhancement in bed soil pressure settlement relation for both single and double reinforcement layers pre-stressing compared to reinforced soil without pre-stressing. The recorded initial tangent modulus for pre-stressed single and double geogrid layers were 3.8 and 4.3 times greater than the corresponding cases of reinforced without pre-stressing.

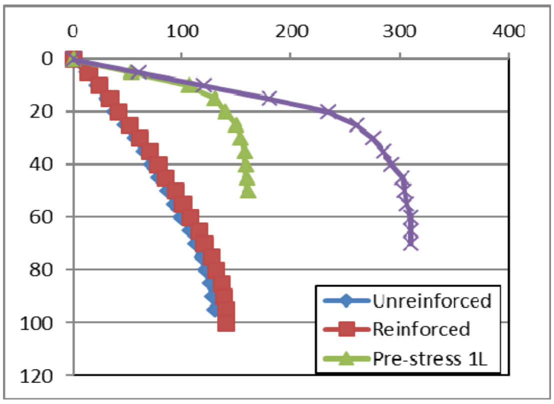


Fig. 8 Stress settlement relation for unreinforced, reinforced and pre-stressed cases at (Df/B = 1.0)

B. Ultimate Bearing Capacity

Enhancement in ultimate (B.C.) of different studied cases was reflected through (B.C.) increasing factor (BCF) which is the ratio of ultimate bearing capacity of any two compared cases, e.g. (reinforced to unreinforced case and reinforced with pre-stressing to reinforced without pre-stressing). Fig. 9 illustrates the ultimate pressure values corresponding to different (Df/B) and pre-stressing ratios for the top reinforcement layer. As can be concluded from this figure pre-stressing of reinforcement with (Ps%) ratio up to 6% was insignificant in improving soil bearing capacity of strip footing load when foundation level located at soil surface, i.e. (Df/B)=0. At deeper foundation levels (Df/B)=0.5, 1.0. 1.5 and 2.0 ultimate bearing pressure of soil exponentially increase as (Ps%) increase. At (Ps%) of 2% the recorded (BCF) values were 1.0, 1.29, 1.35 and 1.37 for (Df/B) of 0.5, 1.0, 1.5, and 2.0, respectively. (BCF) was further increased by about 1.46 and 1.81 for (Ps%) up to 4 and 6%. This indicates that pre-stressing is more effective with the increase of overburden pressure at relatively high (Ps%) up to 6%, similar results were obtained by, Omar et al., 1993 [23]. As for the case of pre-stressing two reinforcement layers a similar trend was observed as with single pre-stressed reinforcement layer of the relation between ultimate bearing pressure and (Ps%) as can be observed from Fig. 10. The recorded (BCF) were close to those recorded with the case of single reinforcement layer.

C. Extreme Axial Force in Reinforcement

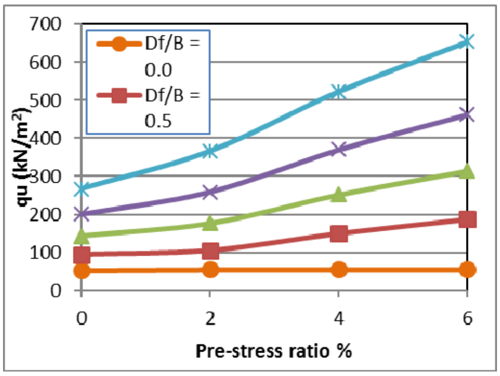


Fig. 9 Ultimate (B.C.) (qu) for varying pre-stressing ratios (PS%) of one reinforcement layer (1LPs).

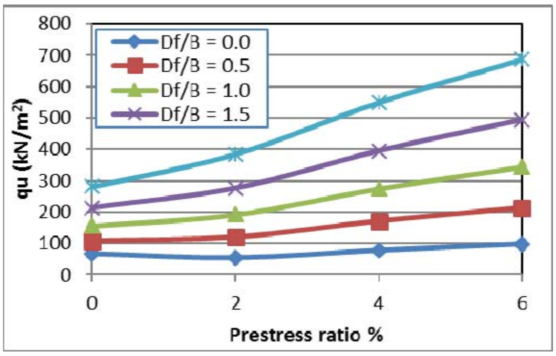


Fig. 10 Ultimate (B.C.) (qu) for different pre-stressing ratios (PS%) of double reinforcement layers (2LPs).

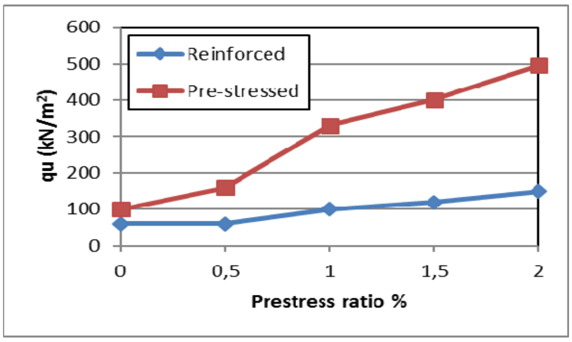


Fig. 11 Extreme axial force in reinforcement for single layer of reinforced and pre-stressed cases with varying (Df/B) ratio

Extreme axial force may be defined as the axial force in reinforcement layer at failure of soil bed under strip footing loading. Fig. 11 illustrates the variation of extreme axial force in the pre-stressed geogrid layer with (Df/B) ratio for one-layer pre-stressing. As can be indicated from figure, the extreme axial force without pre-stressing was increased as foundation depth increase. The recorded increasing ratios were 1.7, 2, and 2.5 for (Df/B) of 1, 1.5 and 2, respectively. This indicates that effectiveness of reinforcement increases as overburden pressure increases. Axial force for the case of pre-stressed reinforcement increased by 1.7, 2.7 and 3.3 times corresponding value without pre-stressing for (Df/B)=0, 0.5 and 1. No further increase was observed with deeper foundation depths of (Df/B)= 1.5 and 2 as the increasing ratio remained at the range of 3.3.

V. Conclusions

The effect of pre-stressing of soil reinforcement on the pressure settlement relation of strip footing was investigated by an experimental and numerical analysis. Depending on the obtained results and the conducted analysis, the following conclusions may be driven:

Soil geogrid reinforcement without pre-stressing was insignificant in improving stiffness of bed soil for relatively shallow foundation depth of down to one time footing depth. Pre-stressing of geogrid reinforcement significantly improved bed soil stiffness. Pre-stressing of reinforcement results in increasing interaction between reinforcement and surrounding soil resulting in higher axial force carried by reinforcement. Bed soil bearing pressure increases with the increase of pre-straining ratio. Pre-stressing of the two top most layers results in enhancing bed soil stiffness compared to single top layer pre-stressing.

To reach the maximum benefit of pre-stressing of geogrid reinforcement it is recommended that: Foundation depth should be more than one time footing width. It is only required to pre-strain the top layer only in case of using multiple reinforcement layers. Reinforcement should be anchored from one side before the pre-stressing process and then reinforcement layer should be fixed from the other side after pre-stressing to the desired extension to prevent it from back withdrawing. It is suggested that this may be performed by using micro short piles with a continuous top head beam that geogrid sheet is fastened to it.

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