Replacement of soft clay by geofoam under eccentric strip footing

Remplacement d'argile molle par Geofoam sous Footing bande excentrique

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ABSTRACT

Geofoam is an industrial material, characterized by a very light unit weight compared to soil (average of 20 kg/m^3). Geofoam materials are defined as any light weight material that is applied, placed or mixed in the soil. This paper presents the using of Geofoam as a light-weight-fill material under eccentric strip footings on soft clay soil to improve bearing capacity, reduce settlements and decreasing the angle of tilt through footing. ABAQUS software package (version 6.8.1) is used to model the problem and evaluate the total settlement under the eccentric strip footing. The constitutive model for the soft clay soil is the modified Cam-Clay yield criterion. ABAQUS finite element program is used to investigate the effect various parameters including width, thickness and density of EPS blocks and the spacing between strip footings under eccentric load which varying from 0.0 m to 0.5 m with increment of 0.10 m. numerical results show that the using of Geofoam as a light weight material of soft clay under eccentric strip footing could be used efficiently to limit foundation settlement of lightly loaded strip footings within tolerable values, without the need for other more expensive soil improvement schemes or deep foundations.

RÉSUMÉ

Geofoam est un matériau industriel, caractérisé par une unité de poids très léger par rapport au sol (moyenne de 20 kg/m3). Geofoam matériaux sont définis comme tout matériau léger qui est appliqué, placés ou mélangés dans le sol. Cet article présente l'utilisation de Geofoam comme un matériau léger de remplissage sous semelles filantes excentriques sur le sol d'argile molle pour améliorer la capacité portante, de réduire les colonies de peuplement et la diminution de l'angle d'inclinaison par pied. Logiciel ABAQUS (version 6.8.1) est utilisé pour modéliser le problème et évaluer le total de la colonisation sous la semelle filante excentrée. Le modèle constitutif de l'argile plastique est le critère de rendement Cam-Clay modifié. Programme éléments finis ABAQUS est utilisé pour étudier l'effet de différents paramètres dont la largeur, l'épaisseur et la densité des blocs EPS et l'espacement entre les semelles filantes sous charge excentrique qui varie de 0,0 m à 0,5 m avec incrément de 0,10 m. résultats numériques montrent que l'utilisation de Geofoam comme un matériau léger d'argile molle sous semelle filante excentrée pourrait être utilisé efficacement pour limiter tassement des fondations des semelles filantes légèrement chargés dans des valeurs tolérables, sans avoir besoin d'autres plus coûteux programmes d'amélioration du sol ou des fondations profondes.

Keywords: Geofoam, eccentric strip footing, Abaqus (version 6.8.1), soft clay replacement.

1 INTRODUCTION

Very soft to soft clay posses lower values of undrained shear strength; buildings on this type of soil are subjected to huge settlements (immediate, secondary and creep). Thus, deep foundations are considered the most traditional suitable type to support building loads. Another economic solution is to use a lightweight material as a partial replacement under footings to decrease the stress on soil and consequently reduce the expected settlements. EPS Geofoam blocks are used in a wide range of geotechnical applications as a light weight fill, a compressible inclusion and also as a seismic and lateral buffer behind earth retaining structures Horvath (1997, 1995, 1996, and 2005).

The basic EPS product is white, although it can be colored otherwise. Geofoam Material prices vary depending on the type and density of Geofoam, as well as on the job, size and location. Figure (1) shows pictures of PS and EPS beads (Lee-kuo Lin, 2011). Figure (2) shows the overall steps of EPS Geofoam manufacture (after Negussey, 1993 and Lee-kuo Lin, 2011).

EPS Geofoam Having a density ranging from 1.0% to 2.5% of that of typical soils, EPS possesses a compressive strength ranging between 70.0 kPa and 140.0 kPa and an elastic modulus ranging between 5.0 MPa and 12.0 MPa. Table (1) illustrates the relation between EPS density and the compressive strength at 10% Strain according to ASTM C 578-04. Riad et al. (2003) have indicated that EPS is a true solid and not a particulate material like soil, and is therefore self-stable with vertical side slopes. Poisson's ratio is an index of the lateral pressure of EPS Geofoam, in contact, on adjacent structural elements for a certain applied vertical load on the EPS Geofoam mass. Value **of Poisson's ratios ranging between 0.05 and 0.33 are found in** the literature for EPS Geofoam, as shown in Table (2) (after Steven 2011).

Fig. 1. Pictures of PS and EPS Beads (Lee-kuo Lin, 2011).

Table 1. ASTM C 578-4 EPS Compressive Strength Values.

Density (kg/m^3)	12	15	18	22	29	35	48
Compressive Strength at 10% Strain, (kPa)	35	69	90	104	173	414	690

Table 2. Reported EPS Geofoam Poisson's Ratio.

Reference	Yamanaka (1991)	Negussey (1996)	Geo-Tech (1999)	Duskov (1998)	Oϕe (1996)
Poisson's ratio	0.075	0.09 up to 0.33	0.05	0.10	0.08

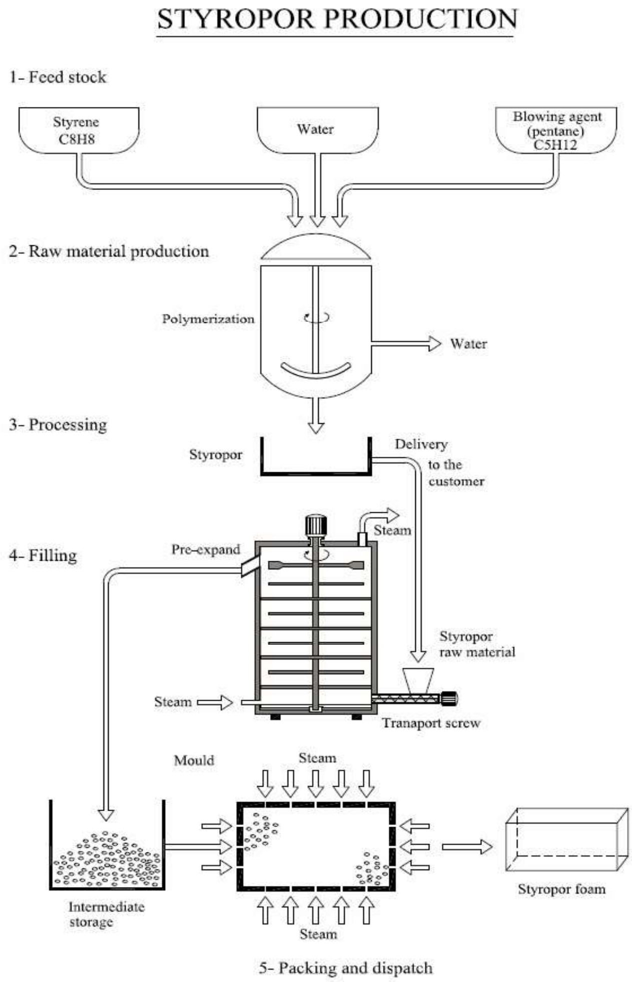


Fig. 2. The overall steps of EPS Geofoam manufacture (after Negussey, 1993).

2 NUMERICAL F.E.M. MODEL

3-D model is performed by Abaqus (Ver. 6.8.1) finite element program to simulate a soil domain of dimensions 20.0 m x 20.0 m x 10.0 m of soft clay soil, 2.0 m strip footing and Geofoam block, the strip footing is subjected to a vertical load extracts a vertical pressure of 50.0 kPa and horizontal force to extracts a moment as shown in Figure (3). Soft clay soil mass is described by an 8-node brick, trilinear-displacement trilinear-pore pressure element. The soft clay soil was modeled as an elasto-plastic material with a non-associated flow rule and using the modified cam clay plasticity model. Soft clay soil is partially replaced by Geofoam blocks with different widths and thicknesses under eccentric loads; the eccentricity varied from 0.0 to 0.5 m with increment of 0.1m, foam unit weights, and distance between footings in the parametric study. Geofoam and footing were modeled as an elastic material by an 8-node linear brick element with reduced integration and hourglass control. The material parameters used in this study were listed in Table (3). The finite element mesh, along with contours of total settlement for case of Geofoam width of 5.0 m and eccentricity of 0.1 m are shown in Figure (4-a). Figure (4-b) shows the cross section at the centerline of eccentric strip footing showing the settlement shading and values for case of Geofoam width of 5.0 m and eccentricity of 0.1 m. Figure (5-a) shows the finite element mesh and 3-D model showing the settlement shading for case of Geofoam width of 5.0 m and eccentricity of 0.5 m. figure (5-b) shows the cross section at the centerline of eccentric strip footing showing the settlement shading and values for case of Geofoam width of 5.0 m and eccentricity of 0.5 m.

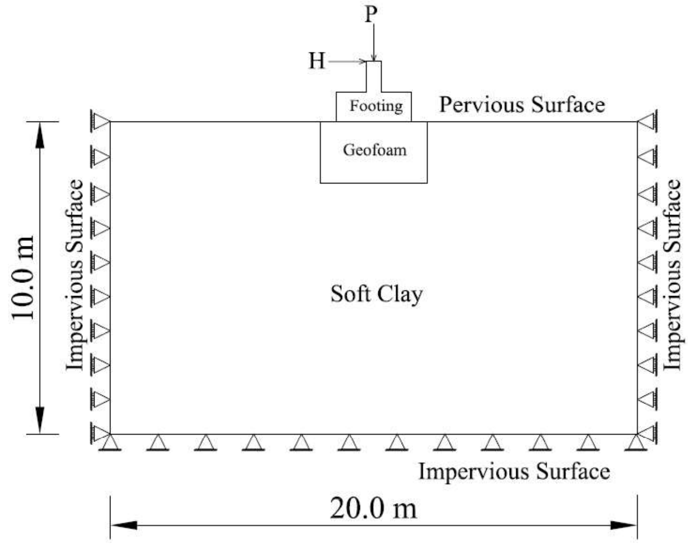


Fig. 3. Soft clay, Geofoam and eccentric footing model.

Table. 3. Material Parameters.

No.	1	2	3
Material	Soft clay	Geofoam	R.C. Footing
Model	Modified cam-clay plasticity	Elastic	Elastic
λ-factor	0.174	--	--
κ–factor	0.028	--	--
Void ratio	0.95	--	--
υ	0.45	0.10	0.15
γsat, (kN/m^3)	16	0.20	25.0
E, (kN/m^2)	600	8000	2.1E^{-7}
K, (m/sec.)	1E^{-8}	--	--
Ko	1.00	--	--

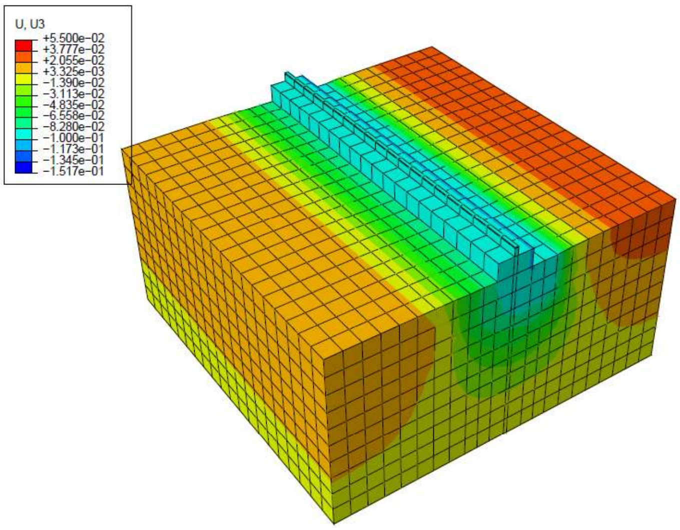


Fig. 4-a. Finite element mesh and 3-D model showing the settlement shading for case of Geofoam width of 5.0 m and eccentricity of 0.1 m.

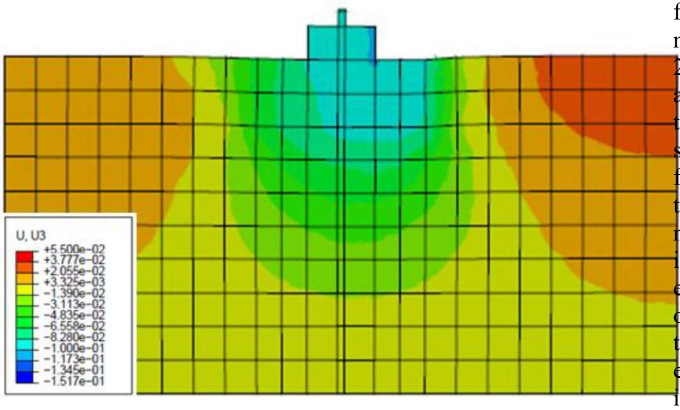


Fig. 4-b. Cross Section at the Centerline of Eccentric Strip Footing Showing the Settlement Shading and Values for Case of Geofoam Width of 5.0 m and Eccentricity of 0.1 m.

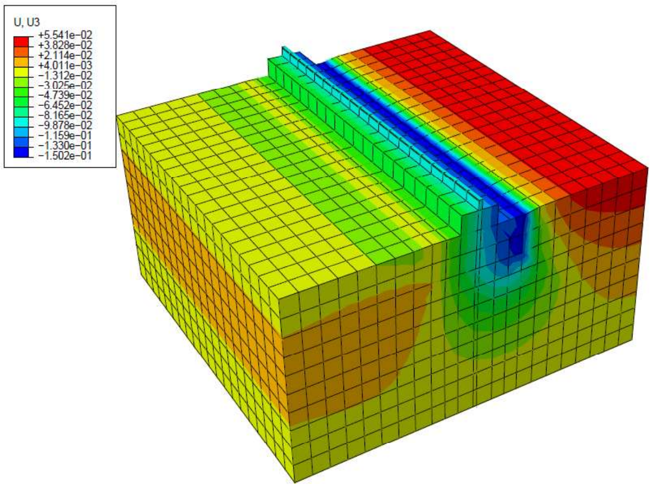


Fig. 5-a. Finite element mesh and 3-D model showing the settlement shading for case of Geofoam width of 5.0 m and eccentricity of 0.5 m.

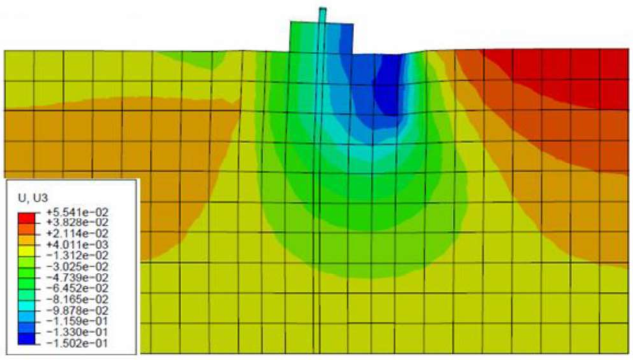


Fig. 5-b. Cross Section at the Centerline of Eccentric Strip Footing Showing the Settlement Shading and Values for Case of Geofoam Width of 5.0 m and Eccentricity of 0.5 m.

3 RESULTS AND DISCUSSION

3.1 Effect of Geofoam Width

The Geofoam width under the eccentric strip footing is increased from 2.0 m (equal to the strip footing width) up to 5.0 m (equal to 2.5 times of strip footing width) with width increments of 0.50 m. The Geofoam thickness in such case remains constant at 2.0 m, which is equivalent to the strip footing width, with unit weight of 20 kg/m^3. The strip footing material is modeled by an elastic model, with dimensions of 1 x 2 x 20 m and inducing a total vertical pressure of 50 kPa associated with an eccentricity varied from 0.0 to 0.5m atop of the underlying soft soil. Figure (6) shows the maximum settlement (after 30 years) versus Geofoam width under strip footing with different eccentricity. The maximum settlement in the case of no replacement by Geofoam and eccentricity of 0.0 m is 343.38 mm. The maximum settlement decreases with the increase of the Geofoam width and increasing with the load eccentricity, the maximum settlement of case of Geofoam width of 2.0 m and the load eccentricity of zero is 154.69 mm while the maximum settlement for the same Geofoam width and eccentricity of 0.5 m is 310.048 mm. Results indicate that increasing the Geofoam width to more than 4 m (which is equivalent to 2 times the footing width) is not that effective in reducing the maximum settlement for different eccentricities. Therefore, a Geofoam width of 2 times the width of the strip footing is considered optimal for all cases of eccentricities.

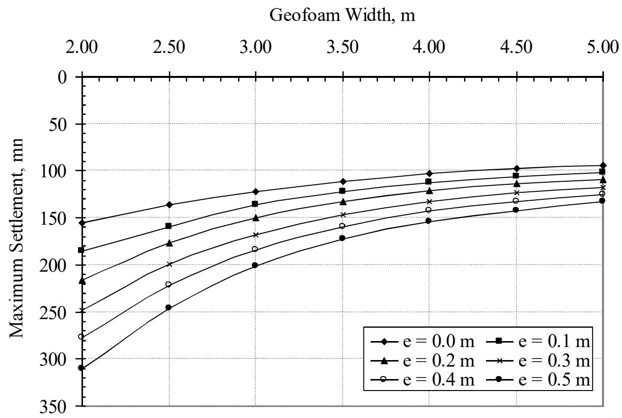


Fig. 6. Maximum Settlement versus Geofoam Width under Strip Footing with different eccentricity.

3.2 Effect of Geofoam Thickness

The Geofoam thickness under the eccentric strip footing is increased from 1.0 m up to 4.0 m, with an increment in thickness of 0.50 m. The Geofoam width in such case is kept constant at 3.0 m. Figure (7) shows the maximum settlement versus Geofoam thickness after about 30.0 years. The maximum settlement decreases with increasing the EPS Geofoam thickness and increasing with the load eccentricities. The rate of settlement reduction increases with Geofoam thickness. The computed total settlements for various Geofoam thickness showed that increasing the Geofoam thickness more than 2 m is not that effective in reducing the maximum settlement for different cases of load eccentricities. Thus, an efficient and economic Geofoam thickness of 2.0 m is recommended in such case.

3.3 Effect of Geofoam Unit Weight

The advantage of Geofoam is mainly its very low unit weight. However, for the sake of identifying the amount of elastic compressibility within the Geofoam block, the effect Geofoam unit weight in maximum settlement is studied. Figures (8) show the variation of maximum settlement with Geofoam unit weights for different load eccentricities. Slight differences are noticed between the maximum settlement values for the same load eccentricity. The settlement increasing with the load eccentricity by constant rate and this is mainly attributed to the elastic compressibility within the Geofoam body. For a

Geofoam unit weight of 15 kg/m^3, the compressibility is equal to12 mm, while it is equal to 5 mm for Geofoam unit weight of 40 kg/m^3.

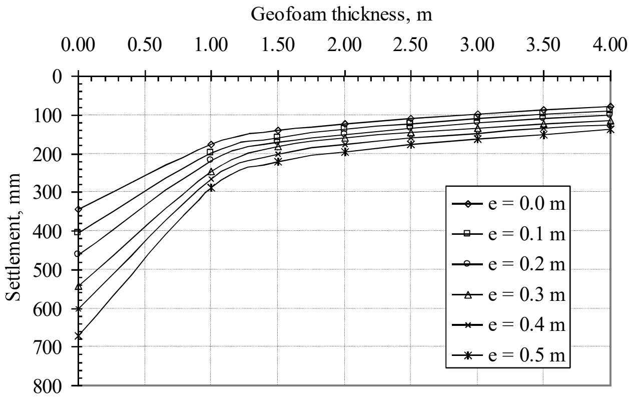


Fig. 7. Maximum Settlement versus Geofoam thickness under Strip Footing with different eccentricity.

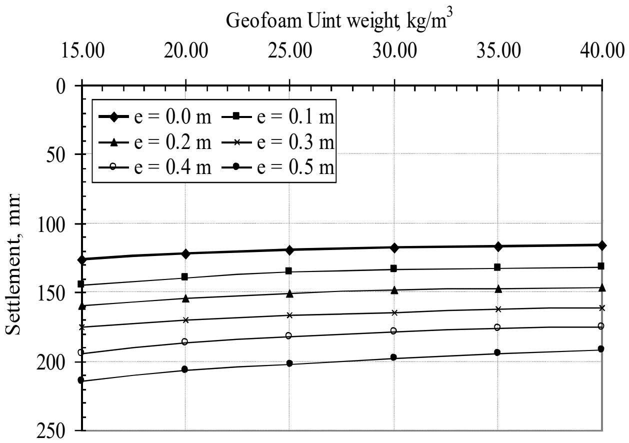


Fig. 8. Maximum Settlement versus Geofoam unit weight under Strip Footing with different eccentricity.

3.4 *Effect of Distance between Footings*

In practical cases, several footings are mostly aligned together under the same structure. However, in such soft clay soil, the interaction between the adjacent eccentric strip footings needs to be studied. The distance between the Geofoam blocks is varied between 3.0 up to 5.0 m, with an increment of 0.5 m. Figure (9) show that the computed total settlements are 145.8, 13.5.9, 120.6, 111.7, 104 mm for distances between footings of 3.0, 3.5, 4.0, 4.5, 5.0 m respectively for load eccentricity of 0.0 m. When compared to the computed total settlement for a single footing of 100 mm, results showed that the effect of footings interaction is relatively large. Such interaction increased the total settlements of contingent footings to about 50% over that of a single strip footing. However, increasing the clear gap between the strip footings is almost equivalent to the single ones for the case of eccentricity of 0.0m, while the maximum settlements for the case of load eccentricity of 0.5 m are 205.46, 216.56, 238.45, 249.45, 253.52 mm for distances between footings of 3.0, 3.5, 4.0, 4.5, 5.0 m respectively. For the case of load eccentricity of 0.3 m the maximum settlement remains constant with all values of distance between strip footings.

According to the above-mentioned numerical results of strip footing resting over soft clay soils, a simplified correlation is presented herein (Equation 1) to account for the various numerically studied parameters. Figure (10) shows the correlation between the settlement and the studied parameters, including Geofoam thickness, width, unit weight, footing pressure and distance between strip footings. It should be noted that the coefficient of correlation is relatively high indicating the accuracy of the presented equation in presenting the studied parameters. The simplified correlation represented by the following Equation:

$$\delta = 60.46 * Ln\left(\frac{q}{\sqrt{H_{foam} * B_{foam}}} + (\gamma + e) + \frac{q * (S + e)}{\gamma} \right) + 16.69$$

Where:

- δ = Total settlement, mm
- q = Footing pressure, kPa
- H_{foam} = Geofoam thickness, m
- B_{foam} = Geofoam width, m
- S = Distance between footings, m
- γ = Geofoam unit weight, kg/m^3
- e = Load eccentricity, m

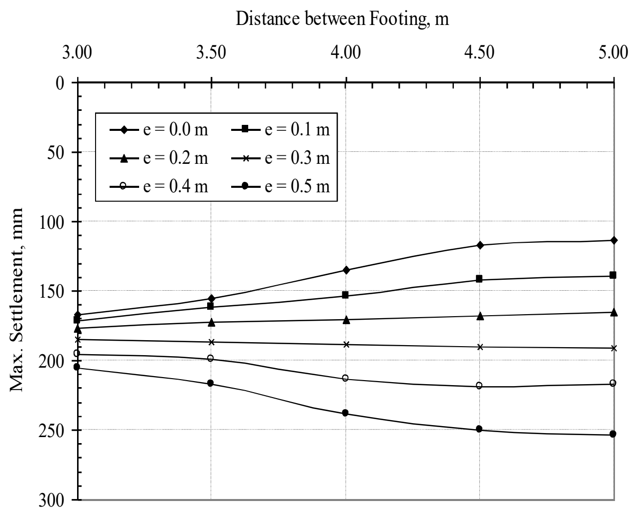
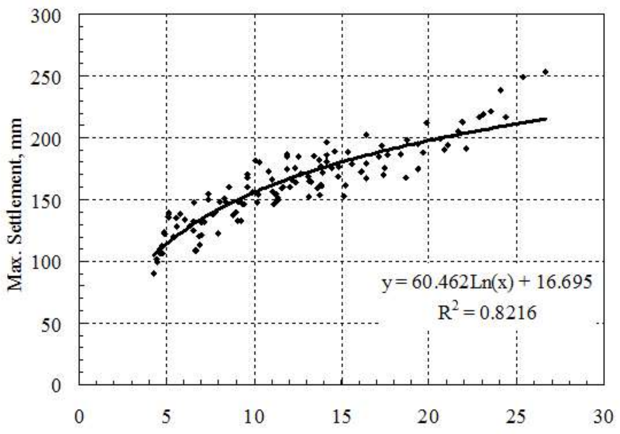


Fig. 9. Maximum Settlement versus distance between eccentric strip footings for different cases of eccentricities.

4 CONCLUSIONS

This study presents numerical analysis of replacement of soft clay by EPS under eccentric strip footings. Based on the results of the current research, the following conclusions may be drawn: Results indicated that increasing the Geofoam width more than 3.0 m is not that effective in reducing the total settlement. Therefore, a Geofoam width of 3.0 m under a 2.0 m width footing is considered efficient and economic for all cases of load eccentricities. The computed total settlements for various Geofoam thickness showed that increasing the Geofoam thickness more than 2.0 m is not that effective in reducing the total settlement. Thus, an efficient and economic Geofoam thickness of 2.0 m is recommended in such case for different cases of load eccentricities. Total settlement values are slight differences due to change the Geofoam unit weight, these difference depends on the elastic compressibility within the Geofoam body. For a Geofoam unit weight of 15 kg/m^3, the compressibility is equal to12 mm, while it is equal to 5 mm for Geofoam unit weight of 40 kg/m^3. Results showed that the effect of distance between footings is relatively large; the total settlement of contingent footings is about 50% over that of a single strip footing. The total settlement when the distance between the strip footings is 5.0 m is equivalent to the single ones for case of load eccentricity of 0.0 m. the maximum settlement increases with distance between strip footings for load eccentricities of 0.4 m and 0.5 m.



$$\frac{q}{\sqrt{h_{foam} * b_{foam}}} + (\gamma * e) + \frac{q * (S + e)}{\gamma}$$

Fig. 10. Total Correlation between Settlement and the Studies Parameters for eccentric Strip Footing.

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