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Full Length Research Paper

STRUCTURAL BEHAVIOR OF R.C. FOLDED STRIP FOOTINGS

S. Abdel Salam[1], G. Attia[2], T. Nageeb[3], M. Samir[4]

1. Professor of Structural Engineering, Faculty of Engineering, Zagazig University, Zagazig, Egypt
2. Professor of Structural Engineering, Faculty of Engineering, Zagazig University, Zagazig, Egypt
3. Professor of Geotechnical Engineering, Faculty of Engineering, Zagazig University, Zagazig, Egypt
4. Ass. Lecturer of Structural Engineering, Faculty of Engineering, Zagazig University, Zagazig, Egypt

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Abstract: Folded foundations have been used as an alternative to the conventional flat shallow foundations, in situations involving heavy loads or weak soils. They can be geometrically shaped in many forms especially for continuous footings such as strip footing. The purpose of this study is introducing an alternative foundation shape that reduces the cost of foundations by reducing the amount of reinforcing steel through choosing the most effective folded strip footing shape. The study is performed in two main phases. First, experimental study is performed using eighteen (18) half scale footings of which nine (9) footings of rectangular shape and nine (9) footings of folded shape by folding angle of 20o. The experimental setup is composed of steel tank with dimensions of 2.5m length * 2.5m width * 2.10m height. The tank is filled with medium dense sand. A numerical study using the finite element software ADINA in also performed in which the soil underneath the footing is modeled with a nonlinear Mohr-Coulomb soil model with model parameters obtained from the experimental phase of the study. Experimental results showed that maximum compression stresses in footing body decreased within a range of 45%, and the tension stresses are also reduced by the same amount in folded strip footing when compared with conventional rectangular footing. Measured settlements also decreased within a range of 13% up to 25% in folded strip footings over the conventional rectangular ones. There is a good agreement between the numerical and experimental studies of which about 10% difference in settlements, and about 15% difference in compression and tension stresses.

Keywords: Shallow Foundations, Folded Strip Footings, Finite Element, Settlement.

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Introduction

In this paper, the structural and geotechnical behavior of folded strip footings are studied experimentally using footings of both folded shape and rectangular shape as reference samples. The influence of interaction between plain strip footing and soil beneath it, on the distribution of contact pressure and internal stresses subjected to static or dynamic loads, has been described by many researchers, e.g. the effect of footing dimensions on the contact pressure and internal stresses for a strip footing, (Abdel Salam, S. S. and Mashhour, 1985). Abdel Salam, (1989), presented an analytical study of a reinforced folded strip footing and pointed that the most preferable value of the angle of inclination, is equal to 20^{o}. Attia (2000) presented an experimental and numerical study of folded strip footing by using photo-elasticity and finite element methods to investigate the folded strip footing subjected to vertical load accounting for the soil-structure interaction effect. The author concluded that the normal stresses and displacements of soil under folded strip footing decrease with increasing the inclination angle and soil modulus of sub-grade reaction. More research in numerical and experimental analysis of the folded strip footings are presented in references(Mashhour and Abd El Salam 1987; Zeinkiwiez, 1977).

Experimental Model

The structural behavior of folded and rectangular strip footings is studied experimentally using eighteen (18) (nine (9) footings of rectangular shape which used as reference footings and nine (9) footings of folded shape). Previous studies indicated that folding the rectangular strip footing by 20^o resulted in much better behavior when compared with the rectangular ones (Abdel Salam 1979). So, the folded strip footing angle is chosen to be 20^o to allow for ease in experimental study and also for the footing construction process in the field. The footing material is reinforced concrete with modulus of elasticity of concrete $E_c = 1.97*10^6$ t/m^2, and Poisson's ratio $\mu = 0.16$. Soil boundaries are simulated by a soil model with dimensions (2.5m length * 2.5m width * 2.10m height). The side boundaries are restricted to allow for settlements to take place at model edges, without allowing for lateral movement. However, the movement of the lower boundary is restricted in both directions. Figure (1) shows general layout of the soil model showing restrictions. Medium dense sand is used in analysis to cover the most frequently encountered soils in many parts of Egypt, as shown in table (1). Figure (2) shows general layout of the soil model showing the footing dimensions, loading position, and strain gauges arrangements. Strip footings are precast bored with half scaled dimensions when compared with numerical model.

Figure (1) Configurations of the Soil Model

Figure (2) Sample Loading and Strain Gauges Arrangement

To account for the effect of increasing the number of floors in the building, five cases of loading are applied to model buildings of from one up to six floors respectively. These loads are 50, 100, 150, 200, 250 and 300 kN/m'. Analysis of results will be due to previous parameters in addition to the effect of footing steel reinforcement ratio which will be equal to (0.15%, 0.25%, and 0.35% of the total concrete area) as shown in table (2).

Table (1): Soil Parameters for Model.

Unified Classification	Medium Dense Sand
E_s (MN/m^2)	50.0
ϕ (deg)	34.0
C (kN/m^2)	0.0
ν (Poisson's ratio)	0.30

Table (2): Model Parameters.

Angle of inclination(ɵ)	0	20	-------
t/L	0.20	0.30	0.40
Reinforcement %	0.15	0.25	0.35

Analysis of Results

Analysis included the effect of increasing the applied pressure over the footing on the underlying soil settlements. Stresses within the concrete footing are also presented showing the maximum compression stresses, and tensile stresses along the steel bars.

Effect of Increasing the Footing Applied Pressure on Soil Settlements

The applied pressures are typical values for one up to six floors with one floor increment respectively. Figure (3) shows that increasing the applied pressure resulted in a noticeable increase in the underlying soil settlement for both folded and rectangular strip footing cases. Also, it is noticed that soil is failed by shear and average settlement is calculated for every footing by two LVDT (Load Versus Displacement Transducer) which are put at the ends of the strip footing. Figures (4-6) show that soil settlement levels under folded strip footings are noticeably lower than those of the rectangular strip footings, especially at higher stress levels. The maximum soil settlement in the soil under the folded strip footings are about two thirds of those taking place under rectangular strip footings, at the same loading values. Moreover, the rate of increase in soil settlement due to increasing the stress levels is noticeably higher in strip footings than those in folded strip footings.

Figure (3) Measuring of Soil Settlement

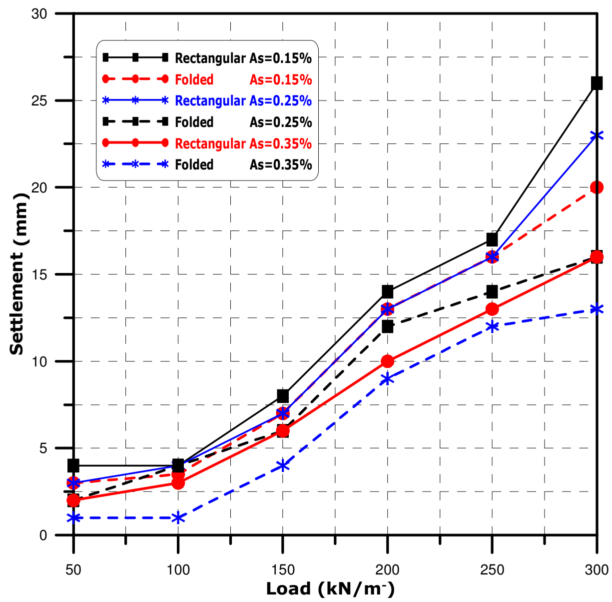


Figure (4) Effect of Increasing the Applied Load on Settlements under Folded and Rectangular Strip Footings for (t/L=0.20)

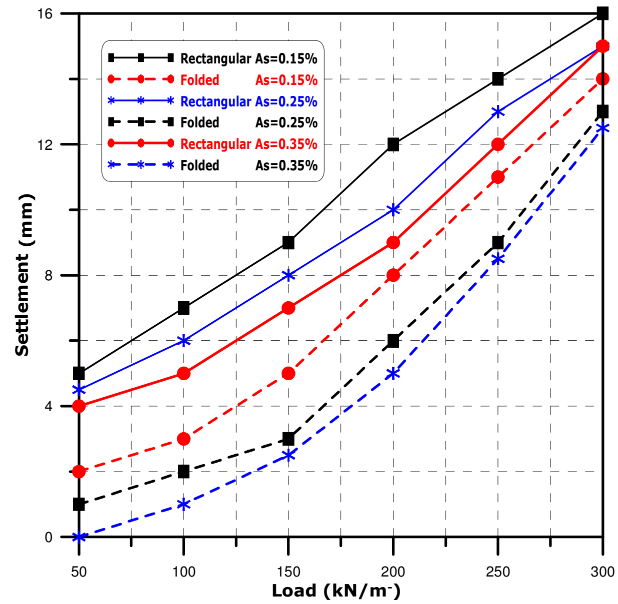


Figure (5) Effect of Increasing the Applied Load on Settlements under Folded and Rectangular Strip Footings for (t/L=0.30)

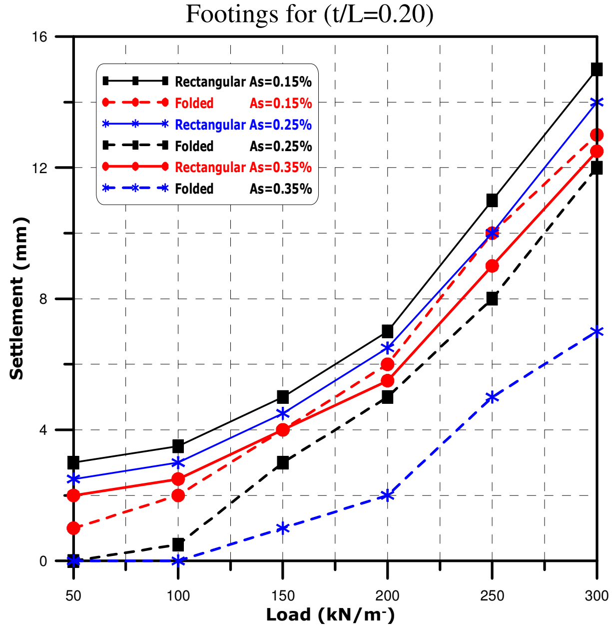


Figure (6) Effect of Increasing the Applied Load on Settlements under Folded and Rectangular Strip Footings for (t/L=0.40)

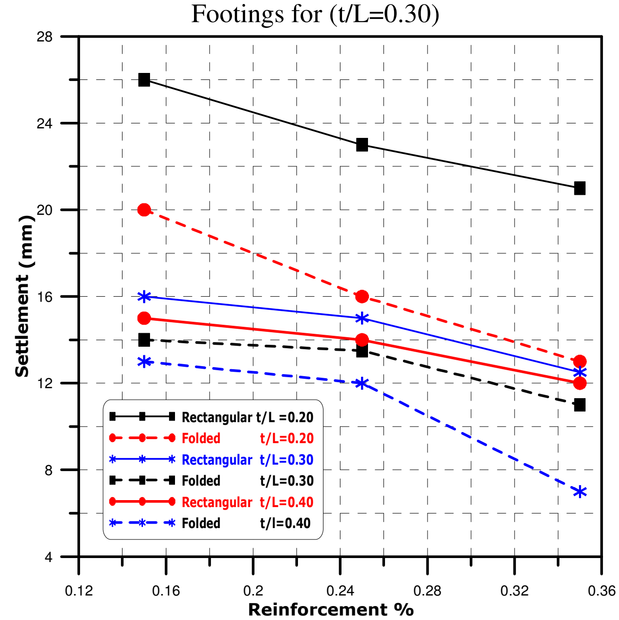


Figure (7) Effect of Reinforcement Ratio on Settlements under Folded and Rectangular Strip Footings

Effect of Increasing the Footing Applied Pressure on Maximum Compression Stresses

The maximum concrete compression stresses occurs at the wall face where the position of maximum bending moment. It is noticed that concrete compression stresses in folded strip footings are about two thirds of those encountered in rectangular strip footings as shown in figures (11-12). Thus, more economic concrete mix design can be performed to account for the reduction in the needed concrete compressive strength.

Initial cracks and total failure are noticeable in both rectangular and folded strip footings with (t/L=0.20, and As=0.15%Ac) as shown in figures (9-10). But capacity of folded strip footing at failure is the larger by about 30kN/m-.

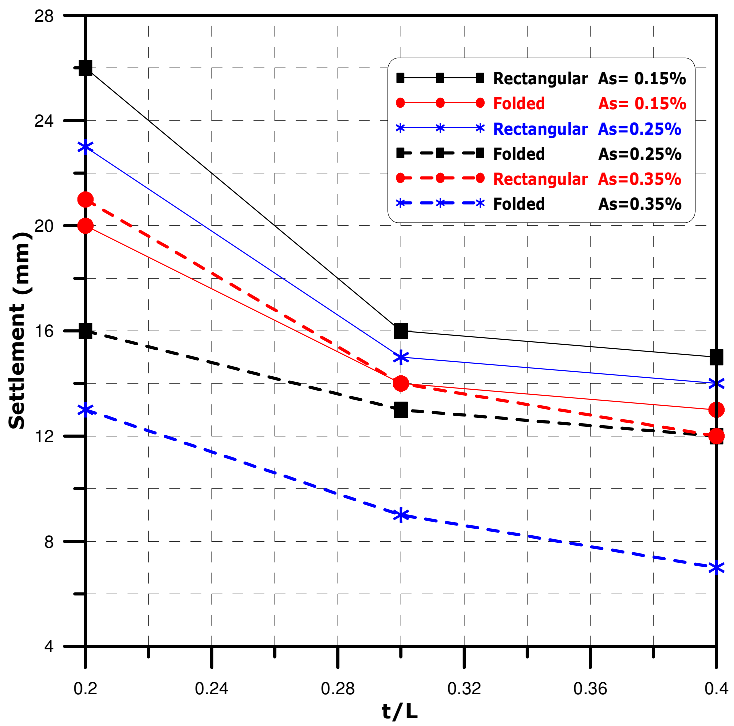


Figure (8) Effect of Depth to Span Ratio on Settlements under Folded and Rectangular Strip Footings

Figure (9) Failure Shape of Rectangular Strip Footing

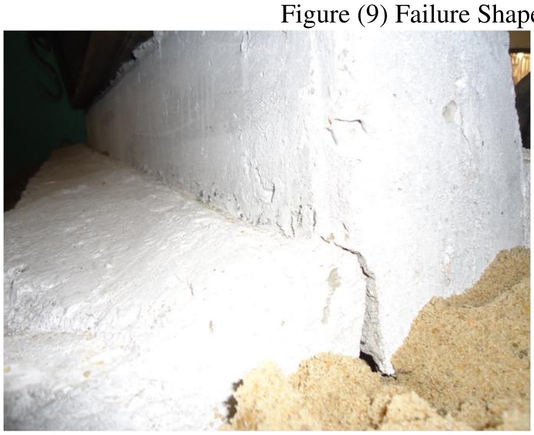


Figure (10) Failure Shape of Folded Strip Footing

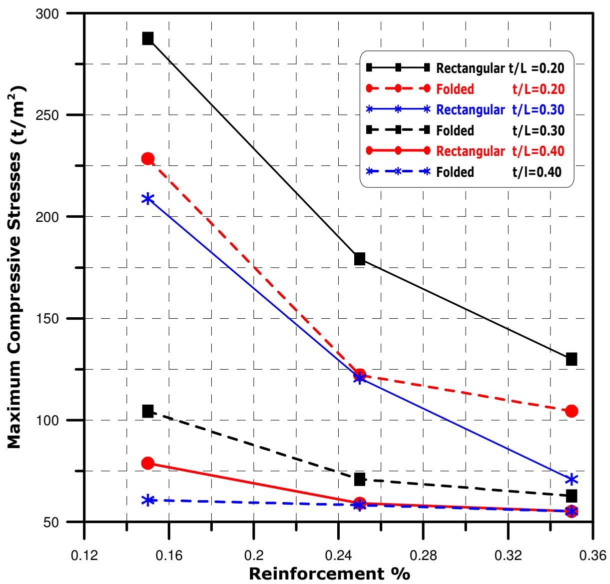


Figure (11) Effect of Reinforcement Ratio on Maximum Compressive Stresses under Folded and Rectangular Strip Footings

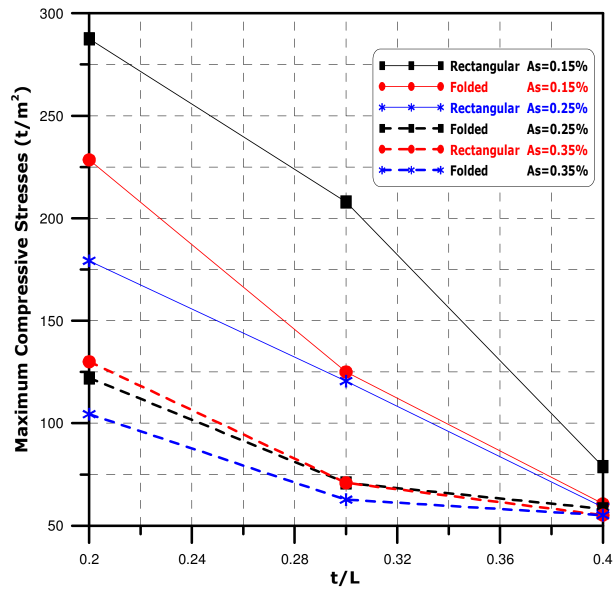


Figure (12) Effect of Depth to Span Ratio on Maximum Compressive Stresses under Folded and Rectangular Strip Footings

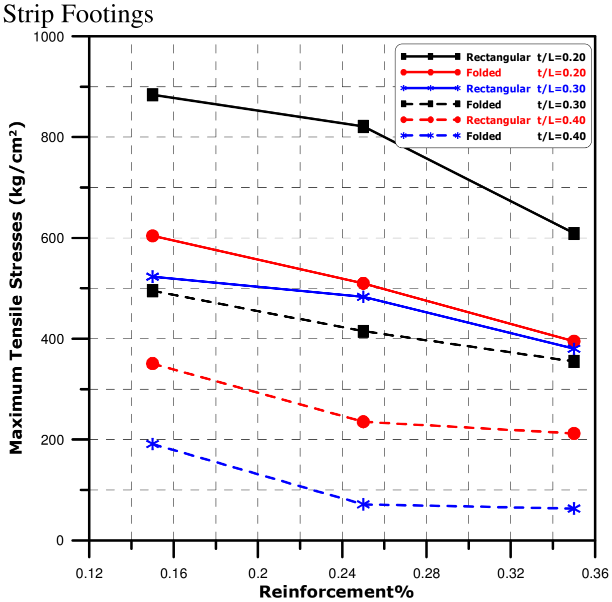


Figure (13) Effect of Reinforcement Ratio on Maximum Tensile Stresses under Folded and Rectangular Strip Footings

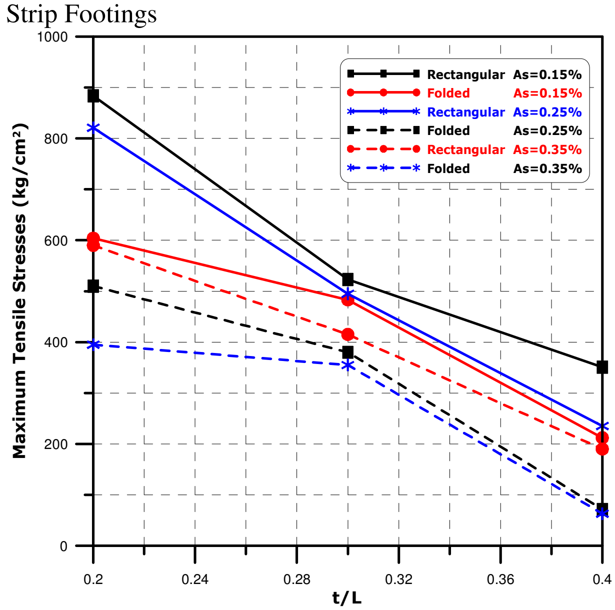


Figure (14) Effect of Depth to Span Ratio on Maximum Tensile Stresses under Folded and Rectangular Strip Footings

Effect of Increasing the Footing Applied Pressure on Maximum Tensile Stresses

Maximum tension took place at the position of the main footing steel reinforcements. One more time, the steel tension stresses in case of folded strip footing is almost two thirds that of the rectangular strip footings, indicating the need for lower quantity of steel reinforcements in the short direction also. Also, it is noticed that the maximum tension took place at the position of the main footing steel reinforcements. As shown in figures (13-14), the steel tension stresses in case of folded strip footing is almost two thirds that of the rectangular strip footings, indicating the need for lower quantity of steel reinforcements in the short direction also. Noticeable reductions in the tension forces took place in the inclined parts of the footing. Moreover, lower compression stresses are noticed at the compression zone of the folded strip footing than that took place in the rectangular ones. This assures the effectiveness of folded shape over the rectangular shape by requiring less concrete compressive strength

Verification Study

A verification study is conducted to confirm the proposed model is fundamentally correct by checking model predications against available solutions. Numerical results with finite element (F.E) modeling are used to validate the experimental study. The behavior of folded and rectangular strip footings is studied numerically using the finite element technique ADINA (Automatic Dynamic Incremental Nonlinear Analysis). The soil underneath the footing is modeled with a nonlinear Mohr-Coulomb soil model, with the same model parameters presented in Tables (1-2). The footing material is reinforced concrete modeled using elastic isotropic material model. The side boundaries are presented using rollers to allow for settlements to take place at these edges, without allowing for lateral movement. However, the movement of the lower boundary is restricted in both directions. Figure (15) shows general layout of the folded strip footing showing the footing dimensions, loading position. Figure (16) shows the finite element mesh used in the analysis, along with the boundary conditions.

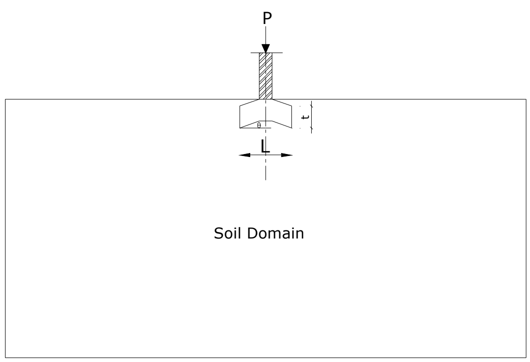


Figure (15) Configurations of the Folded Strip Footing.

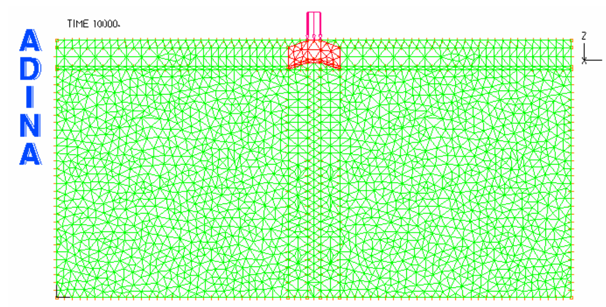
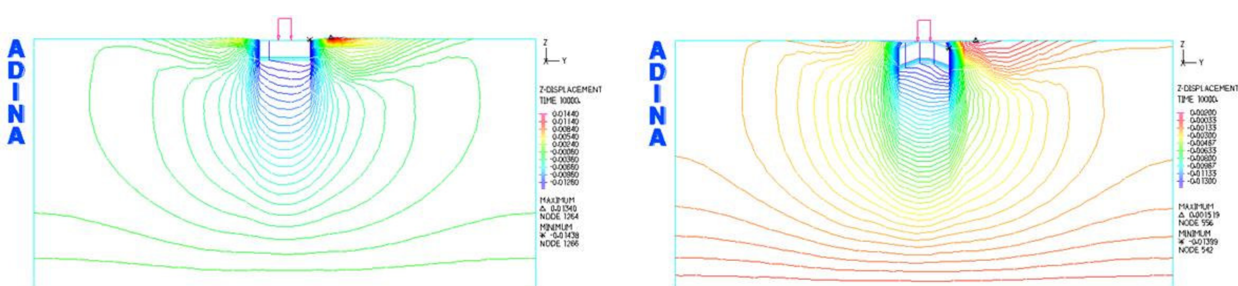


Figure (16) The Finite Element Mesh of the Footing Model.

Distribution of Settlements and stresses within the Soil Domain

Figures (17a) and (17b) shows the distribution of settlement shading within the soil domain under the rectangular and folded strip footings respectively. The settlement values and distribution are almost the same in both cases, with slightly lower settlement values occurring under the folded strip footings. Figure (18) shows a good agreement between both numerical and experimental study at the same conditions (As=0.15% of the concrete area, and depth to span ratio (t/L) =0.40). Also, different loads are applied to simulate number of floors from one up to six floors as follows (50, 100, 150, 200, 250 and 300 kN/m' respectively).



A) Rectangular Strip Footing B) Folded Strip Footing

Figure (17) Settlement Shading Distribution in Soil Domain for Rectangular and Folded Strip Footings for (As=0.15%Ac, t/L=0.40)

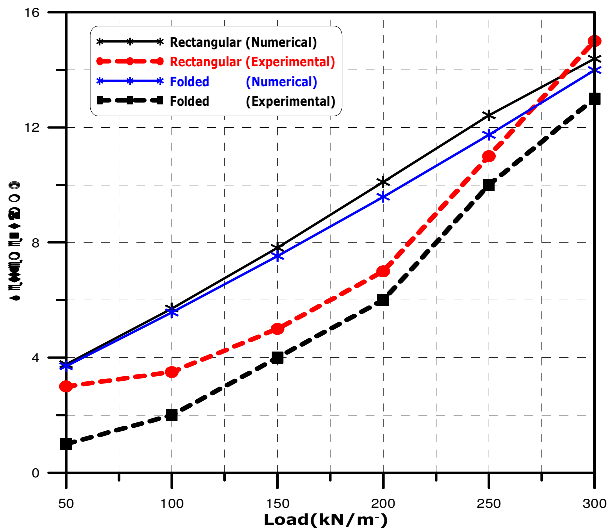


Figure (18) Comparison Between Numerical and Experimental Study for Load- Settlement Curve at (As=0.15%Ac, t/L=0.40)

Conclusions

This paper presents experimental study of the folded and rectangular strip footings. The aim of the paper is to highlight the effectiveness of the folded strip footings over the rectangular ones. Based on the results of the current paper, the following conclusions can be drawn:

1. Folded strip footings are more effective than the rectangular ones in both the needed steel reinforcement quantity to cover the generated tension stresses. In addition, lower concrete compression stresses are also noticed in the folded strip footings.
2. The effectiveness of the folded strip footings over the rectangular ones is not just in the main short direction of the footing, but rather in the secondary long direction as well, in which the reinforcements are mostly needed in the lower straight portion of the folded strip footing only, with large reductions in the steel tension stresses in the folded portions of the footing.
3. In general, the tension and compression stresses within the concrete folded strip footing body is about two thirds that occurred in the rectangular strip footing in both directions.
4. The vertical stresses are decreased by about 40% for folded strip footing compared with conventional rectangular footing in medium dense sand soil when increasing vertical static load from 50 to 300 (kN/m').
5. There is a good agreement for both numerical and experimental study.
6. The soil settlement is decreased by about 20% for folded strip footing compared with conventional rectangular footing in medium dense sand soil when increasing vertical static load from 50 to 300 (kN/m').

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