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NUMERICAL STUDY FOR THE BEHAVIOR OF STRIP FOOTING ON SAND IN THE EXISTENCE OF A BURIED ROCK

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ABSTRACT

This paper investigates numerically, the effect of a buried rock under strip footing resting on sand. This buried rock can be a part of an old footing or rock that was embedded without any knowledge about its location. In this study, the effect of the buried rock on contact stresses, under the strip footing is analyzed using finite element technique. The rock is proposed to have a cross section of 0.5x0.5 m continuously under the strip footing. The effect of rock position and depth is analyzed under the strip footing. The final results showed that the stresses under the strip footing have increased by 40%, when rock is encountered under the middle of the footing at depth D=0.5m. Moreover, the analyses showed that the stresses under footing had altered when the buried rock lies away from middle footing reaching to the instability of the footing.

KEYWORDS: Embedded rock, Strip footing, Medium sand

1. INTRODUCTION

In nature, soil parameters such as physical and hydraulic properties generally vary spatially in both the horizontal and vertical directions. The distribution of these soil properties at a site depends on the heterogeneity of the soil matrix, the geological history of soil formation, and its continuous modification by nature. A uniform soil condition is seldom encountered in practical conditions. In most site conditions, soil properties show a significant variation over space. Geotechnical analyses are generally based on testing of soil samples extracted through boreholes that are carried out according to the standards of each construction. Numerical techniques such as finite difference or finite element methods have facilitated modelling of the layered soil system. The variation of soil properties in the horizontal direction is generally ignored. This may be due to the fact that the variation in the horizontal direction is not so significant in many situations, and a greater number of boreholes is required to establish such horizontal variation. It is also impractical due to economical considerations. Thus, the results of deterministic analyses are only approximations which may widely vary from reality. Common causes of discrepancy between the estimated and actual performance of any geotechnical system may be summarized as follows [1]:

1- Variability of the soil properties at a specific site.

2- Sampling techniques.
3- Laboratory test conditions.
4- Selection of design parameters from limited field and laboratory test results.
5- Assumptions used to simplify the problem for analytical or numerical study.
6- Model error.
7- Construction methods and materials used.
8- Hidden things which are buried in the soil which lies between the carried boreholes.

In the present study, the existence of the hidden things is considered. A block of continuous buried rock is proposed under a strip footing resting on medium sand. A numerical study is carried out to show the effect of the position of the rock under the strip footing, on the contact stresses and settlement.

1.1 Stresses Under Strip Footing

Terzaghi had proposed the first relationship for effective stress [2]. He expressed that the term ‘effective’ means the calculated stress that was effective in moving soil, or causing displacements. It represents the average stress carried by the soil skeleton. The addition of a surface surcharge load will increase the total stresses below it. If the surcharge loading is extensively wide, the increase in vertical total stress below may be considered constant with depth and equal to the magnitude of the surcharge.

1.2 Previous Work

The changes of bearing capacity of a strip footing on stiff ground with voids are considered [3, 4]. The soft ground tunnel gives stress concentration under the strip footing. Its value depends on the tunnel dimensions [5].

The effect of the eccentricity on the stress under the strip footing is studied. The footing is assumed to lose contact when eccentricity increases, and the failure occurs on the same side of the eccentricity [6].

Void shape and its location under the strip footing are investigated using finite element [7]. Results of the study indicated that footing stability will be affected by the underground void only when the void is located above the critical depth. The critical depth is not constant but varies with the shapes of footing, void orientation, void size, and soil type.

1.3 Aim of Study

The actual behavior of soil when subjected to external forces is a complex problem due to its non-homogeneity formation in nature. The modern theoretical investigations started with the simplest case of homogeneous, isotropic medium of semi-infinite extent with strip loading. To consider the stability of the structures, investigators presumed that the center of loading coincides with the center of foundation to avoid the moment at the base [8-10]. This is approximately reasonable when the soil layers are homogeneous and isotropic in the vertical and horizontal directions. But, if there are drop variations in the soil type and properties such as the existence of a buried rock or residue of an old building under the footing, the stresses will not be uniform. This assumption will be analyzed analytically in this paper using the PLAXIS 8.2 finite element program. The existence of the buried rock, under the footing will alter the uniformity of the contact stresses under footing. The footing will lose in some parts, its contact with the soil, which generates some eccentricity. The higher eccentricity generates a large contact free area under the footing [11-13].

2. FINITE ELEMENT ANALYSIS

2.1. Proposed Finite Element Modeling

A series of two-dimensional finite element analyses (FEA) on a constitutive model strip footing is performed. The analysis was carried out using the finite element program PLAXIS 8.2 software package. PLAXIS enables users to handle a broad range of geotechnical problems such as deep excavations, tunnels, and earth structures such as retaining walls and slopes. The sand layer in this present analytical study was assumed to be dry, so there was no need to introduce ground water condition in the analyses. The geometry of the footing was a strip footing with width ***B*** = 2.0 m and thickness, **t**, of 0.3 m. The soil under the strip footing was medium dense sand.

A variety of soil models is built in the computer code of PLAXIS program software; however it was decided to use the non-linear Mohr–Coulomb criteria to model the sand for its simplicity, practical importance and the availability of the needed parameters. The interaction between the buried rock block and soil was modelled by means of interface elements. The parameters used for numerical analysis are summarized in Tables 1 and 2. The geometry of a typical finite element model verified for the analysis is shown in Figure (1). The left and right sides of the constitutive model are constrained in horizontal direction, while the bottom side is constrained in both the horizontal and vertical directions.

Table1: Boundary conditions of soil and buried rock

Property	Sand	Rock
Dry unit weight (kN/m^3)	15	20
E (kN/m^2)	$4*10^4$	$3.488*10^7$
μ	0.35	0.2
c (kN/m^2)	0.1	20
φ (Degree)	30	45
ψ (Degree)	3	12
Soil model	Mohr-Coulomb	Mohr-Coulomb
$R_{interface}$	0.9	0.8

Table 2: Concrete footing properties

Property	Strip footing
EA	$1.046*10^7$ kN/m
EI	$7.848*10^4$ kNm^2/m
t	0.3 m

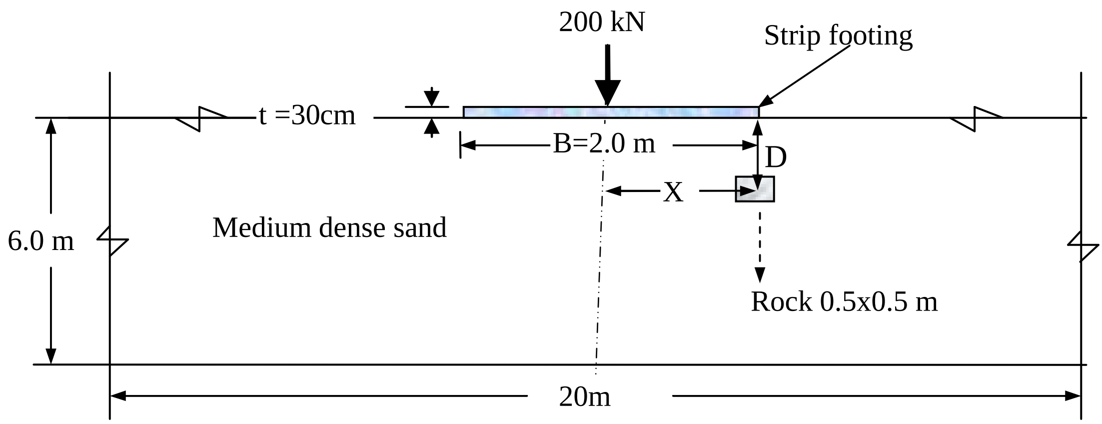

Fig. 1: The geometry of the strip footing over medium dense sand

Having examined different finite element meshes, a medium mesh was introduced to decrease the effect of mesh dependency on the finite element modelling of cases that the rock is close to strip footing. Also, the interface conditions between the footing and the soil are taken into consideration. The generated deformed mesh and the boundary conditions are shown in Figure (2).

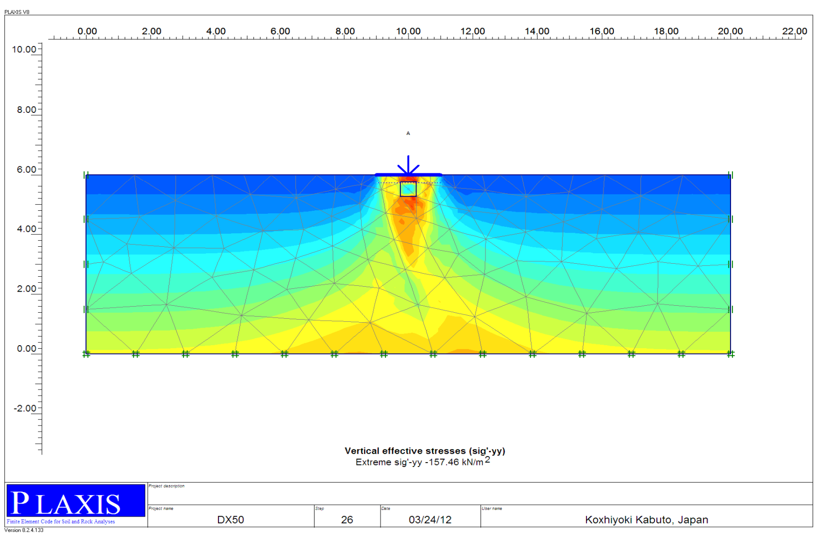

Fig. 2: The deformed mesh when the rock lies at D= 0.5m & X=0 m

3. RESULTS AND DISCUSSIONS

The concrete rock is assumed to have a cross section of 0.5 x 0.5 m extended continuously under the strip footing. The distances of rock from the footing centerline X of 0.0, B/4 and B/2 are studied. The depth D of the rock is studied at D = 0.5, 1.0, 1.5 and 2.0 m below the strip footing. The results are calculated, analyzed and plotted.

3.1. Stresses under Strip Footing

Figures 3 to 6 represent the stress distribution under strip footing. All figures represent the variation of stresses under the strip footing in the existence of extended rock of 0.5x0.5 m. In Figures 3 through 6, rock lies at depth D equal to 0.5, 1.0, 1.5 and 2m. Every studied case has a buried rock 0.5x0.5 m extended below footing at X = 0.0, B/4 and B/2. Observing these figures, we can see that stress under footing increases by 40% when the rock lies directly under the middle footing at depth D =0.5 m. These contact stresses, increased by 20% when rock lies directltly under the middle of footing but at depth D =1.0 m. When depth of rock D increases, the contact stress decreases till D=B. Also, when the buried rock is encountered away from the middle of the footing, the distribution of stresses under footing will not be uniform. The rock in these cases acts as a rigid support which concentrates the contact stresses above it. When X= B/2, the footing will be unstable, till D= 0.75 B. Figure (7) shows the variation of contact stress with depth, D= 0.5, 1.0, 1.5 and 2.0 m, respectively.

3.2 Average and Maximum Stress under the Strip Footing

Figure (8) shows the average and maximum contact stresses under the middle of the strip footing in existence of the buried rock. It is clear that rock existence increases both the average and maximum contact stresses. But when rock lies away from the middle of the footing, the stress will be concentrated over the rock position, and will be decreased in the opposite side. This will alter the uniformity of the contact stresses under the strip footing till X= B/4. When X increases above B/4, the footing approaches instability conditions.

It is noticeable that, the presence of the rock acts as an additional support under the footing. This support alters the uniform stresses under the footing as mentioned before. The stresses at the right side of the footing are less than the stresses at the left side of the footing. This is due to the fact that the rock behaves like a rigid support under the footing. This action is similar to the action studied by Zoynul abedin, [13], through his investigation on eccentrically loaded strip footing; he found that due to the load eccentricity, the footing started to lose contact with the soil. He also found that the higher eccentricity generates large contact free area under the footing. Always the stress under footing center, has the greatest values when the rock lies at X = 0.0 m from the center.

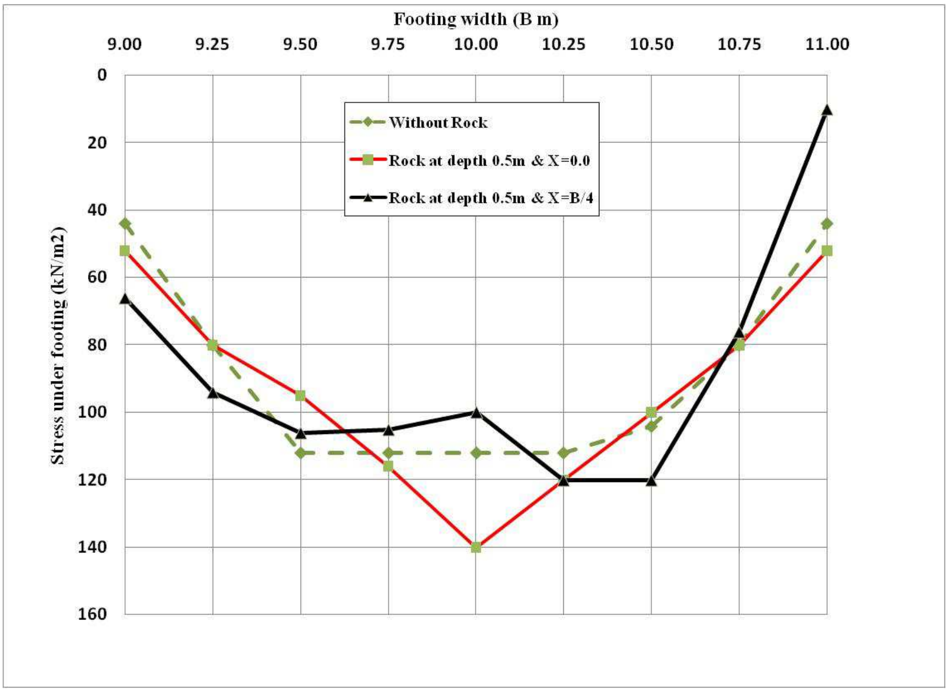

Fig. 3: Contact stresses under footing when rock is at D= 0.5 m

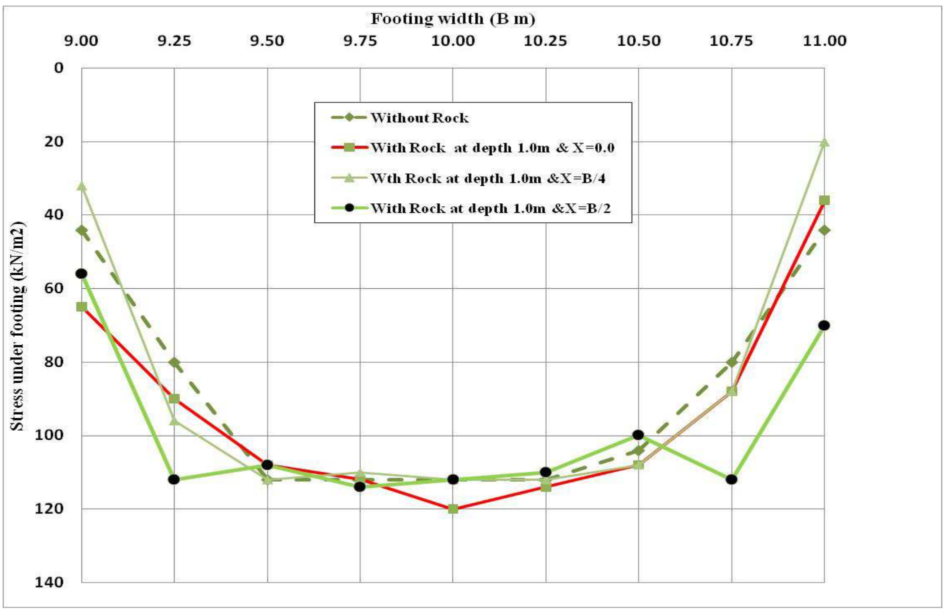

Fig. 4: Contact stresses under footing when rock is at D=1.0 m

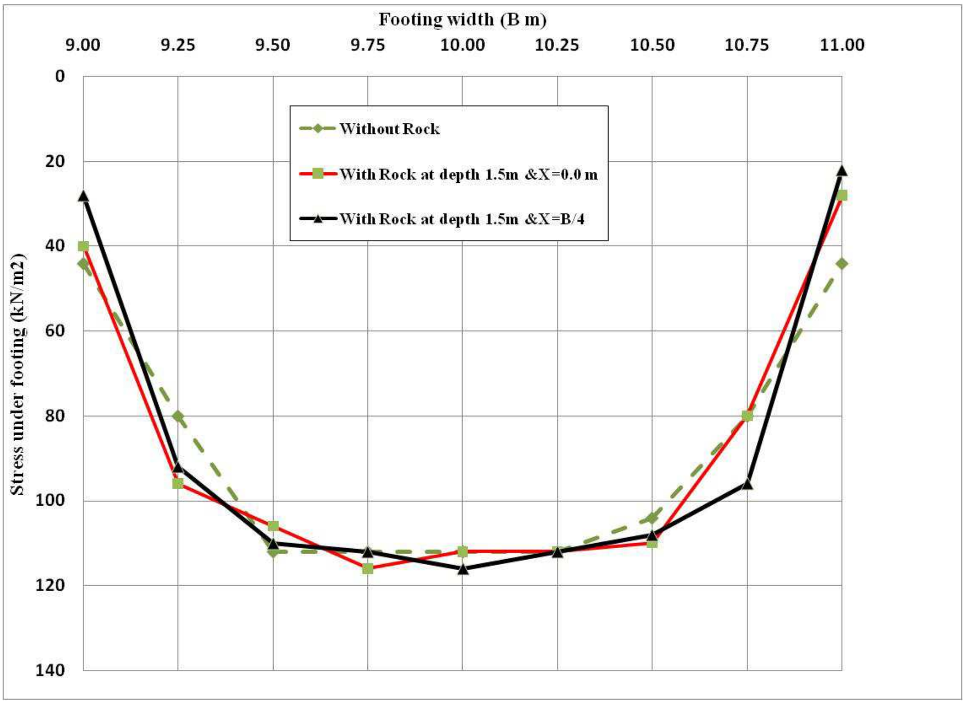

Fig. 5: Contact stresses under footing when rock is at D=1.5 m

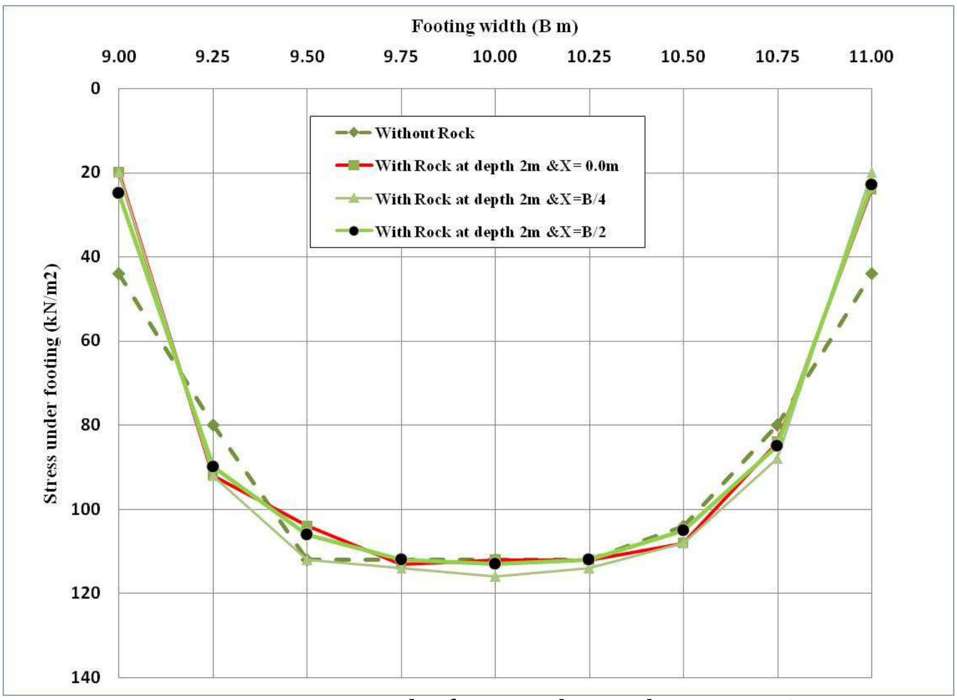

Fig. 6: Contact stresses under footing when rock is at D=2.0 m

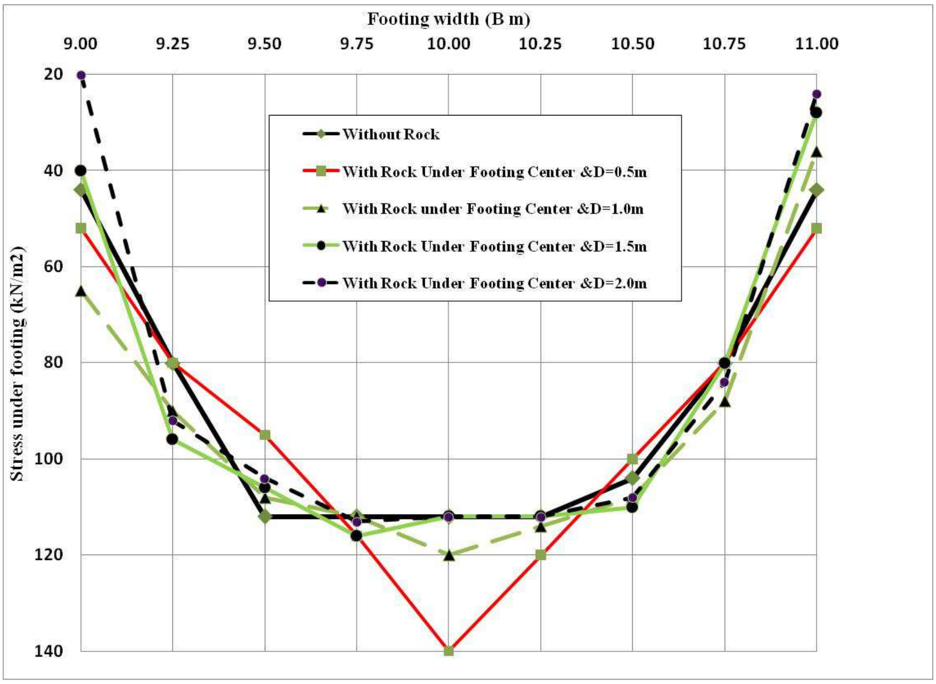

Fig. 7: Contact stresses while rock lies under footing center

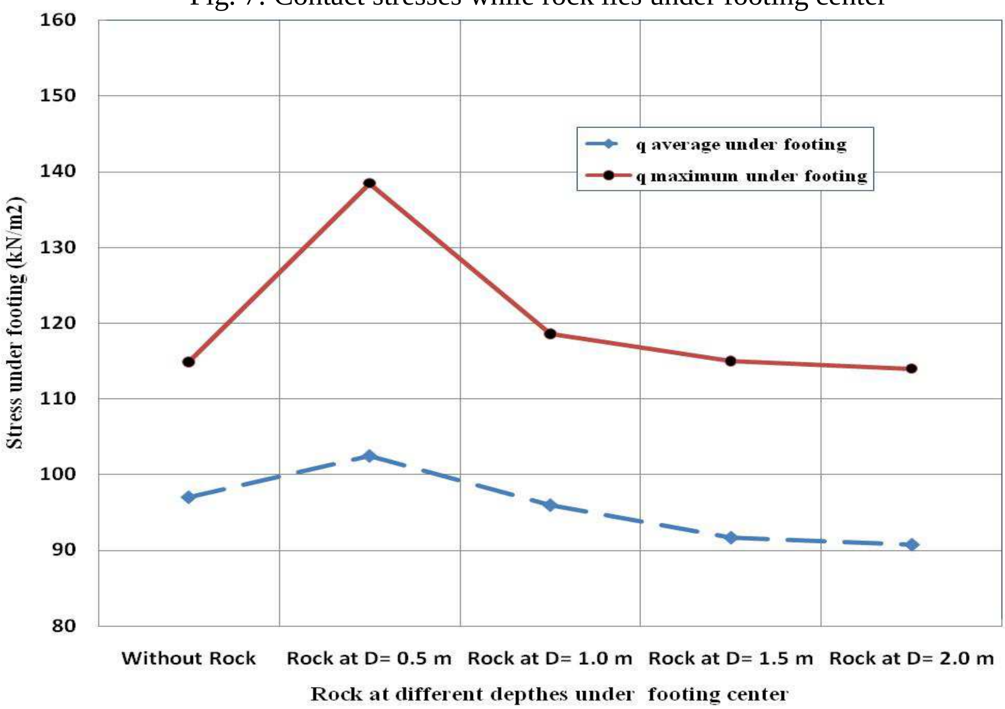

Fig. 8: Effect of rock depth on the stress under footing center

3.3. Vertical Stress Distribution Under the Middle of the Footing Section

Figures 9 through 13 show, the vertical stress distribution under middle of the footing section in case of rock existence, with X=0.0,B/4 and B/2 with different depths. It is found that, the vertical stresses is highly increased when X= 0.0. The vertical stress at the middle of the footing, decreased with distance X increasing. When X= B/2 and rock depth D=0.5m till 1.5m, the stability of the strip footing is changed to instability conditions, especially when X=B/2. Also, when the rock depth D is equal to or greater than B, the vertical stress distribution is not affected very much with rock existence.

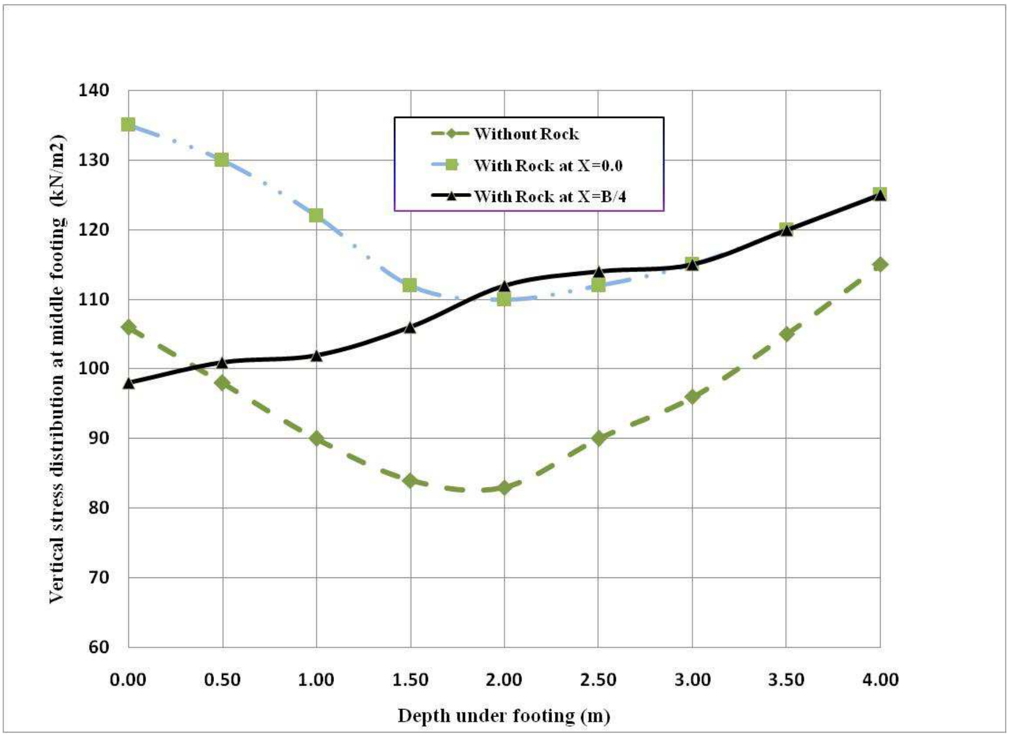

Fig.9: Vertical stress distribution when rock lies at depth D=0.5 m

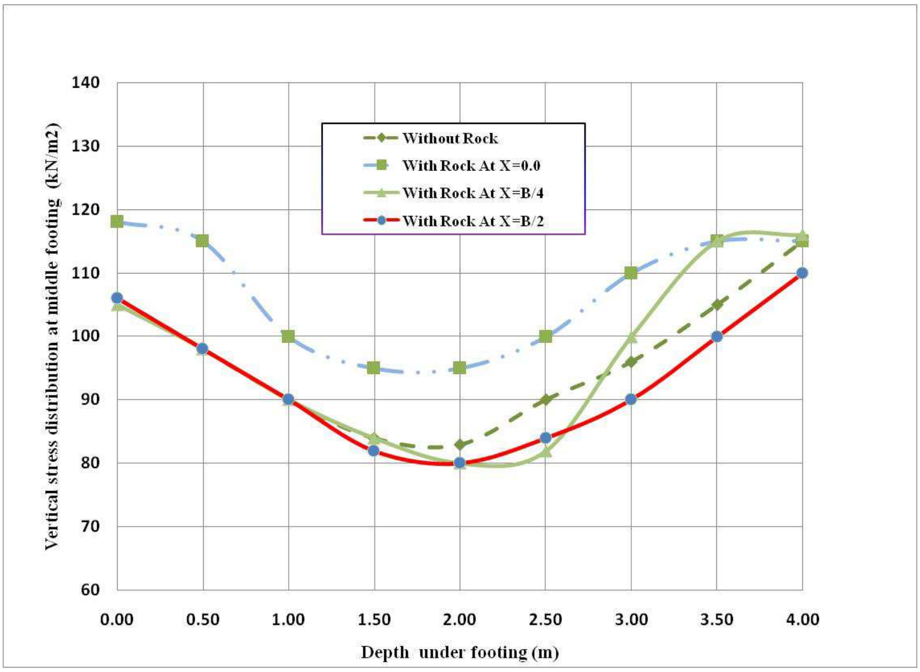

Fig.10: Vertical stress distribution when rock lies at depth D=1.0 m

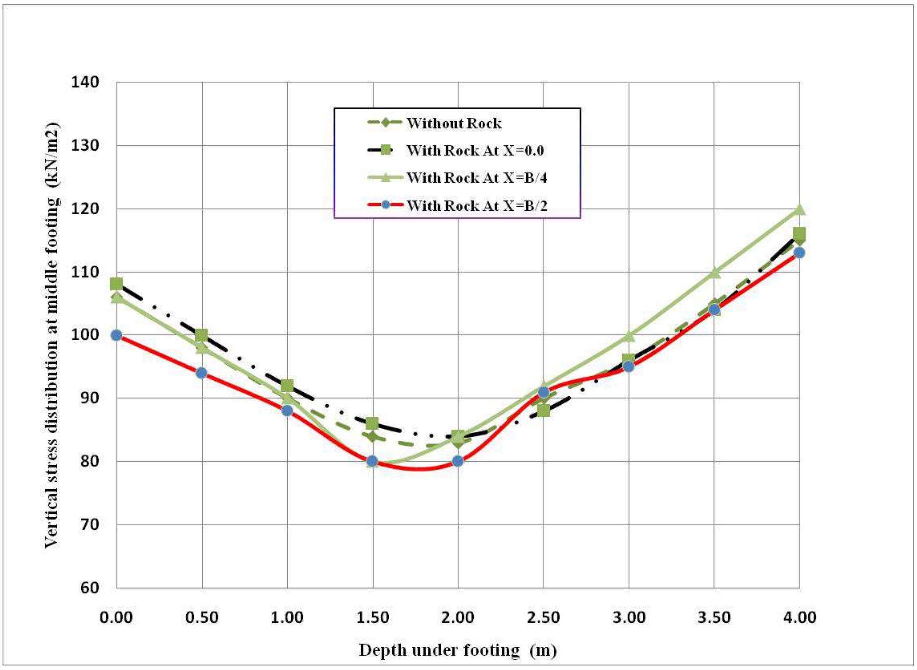

Fig.11: Vertical stress distribution when rock lies at depth D=1.5 m

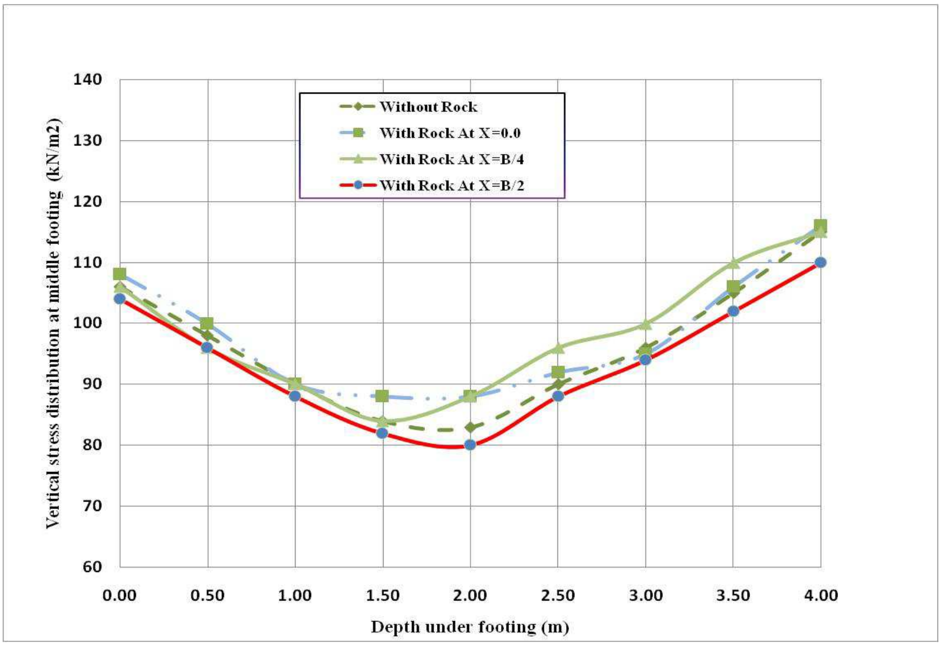

Fig. 12: Vertical stress distribution when rock lies at depth =2.0 m

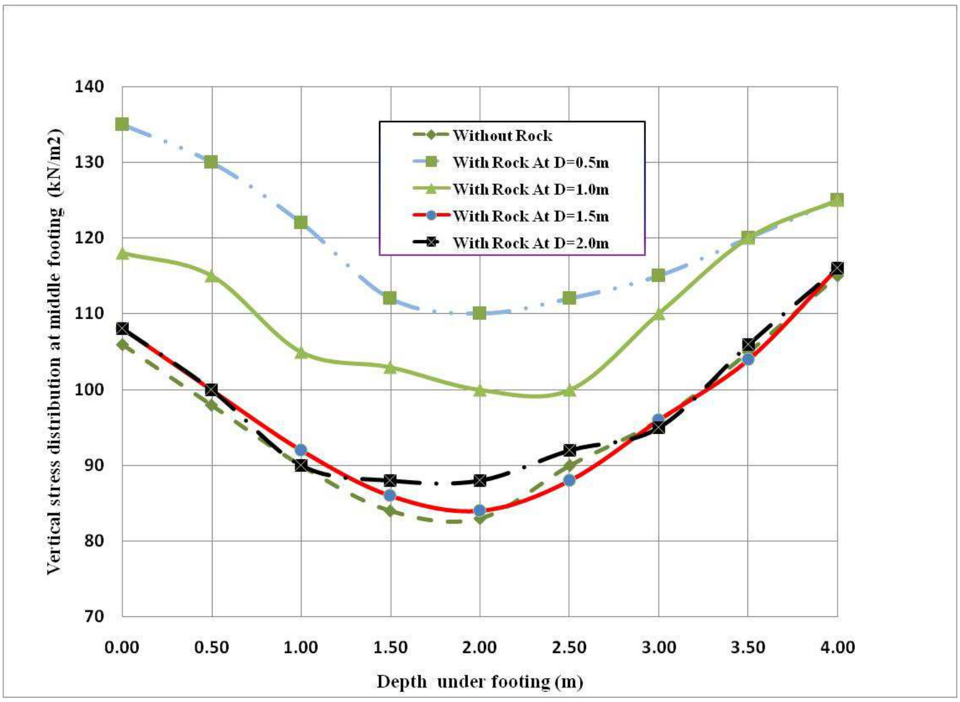

Fig. 13: Vertical stress distribution when rock lies under footing center

3.4 Effect of the Buried Rock on Footing Settlement

Figures 14 and 15 show the settlement of the strip footing at the middle and also at the two ends. Figure 14 shows a decrease in settlement when rock lies under the middle of the footing. Also, from Figure 15, the settlement at the two footing ends, is different. It is noticed that when rock lies directly under the footing center, the two footing ends settle equally. On the other hand, when the rock lies at X=B/4 with different rock depth, the settlement is differential i.e. the two ends are not equally settled. This settlement increases under one side of the footing and decreases on the other side where buried rock exists.

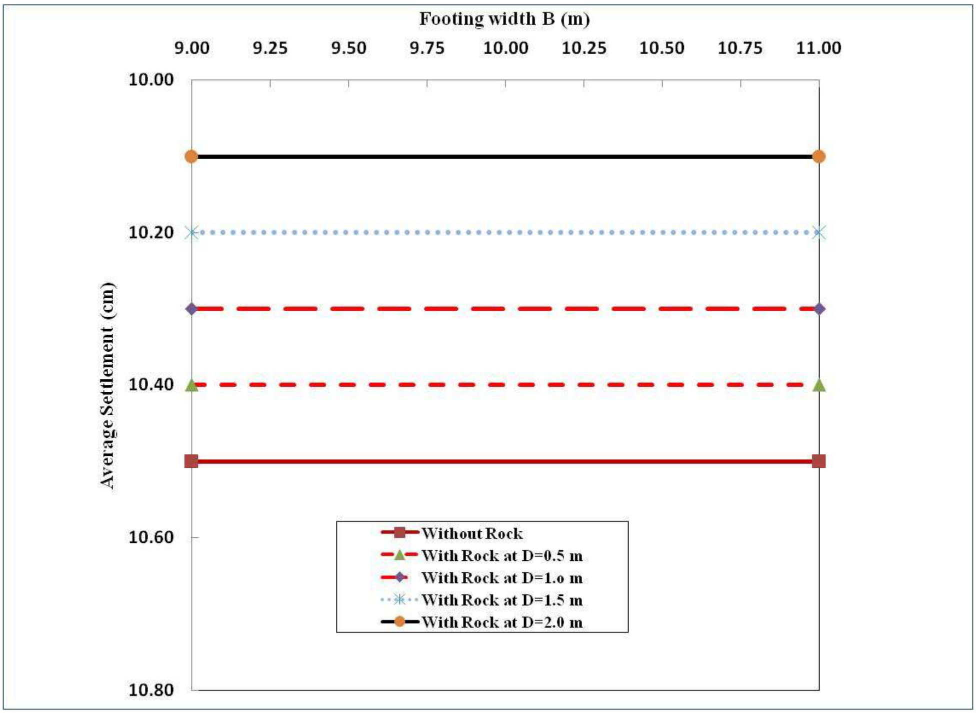

Fig. 14: Footing settlement when rock lies at different (D),and X= 0

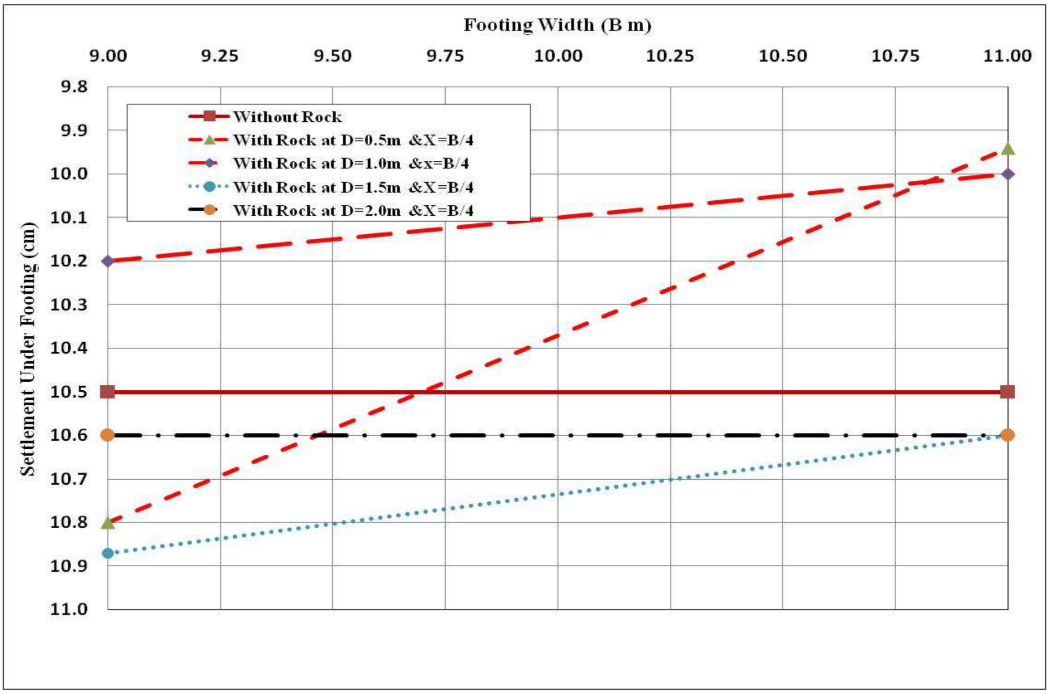

Fig. 15: Footing settlement with different rock depths, and X= B/4

4. CONCLUSIONS

A series of numerical model analyses has been carried out to evaluate the effect of a buried rock presence under a strip footing on the stress concentration and settlement. The results of the numerical analyses have shown that the presence of the rock under the strip footing, affects the stress distribution under the footing.

The maximum stress increases, at the middle of the footing especially when the rock lies under the middle of the footing by 40%. When the rock is located under the right side of the footing, the stresses increase more than the left most side of the footing. The rock works as a movable support which alters the uniformity of the stress distribution under the footing.

The stresses vary also according to the closeness of the rock to the footing. The settlement is smaller in the presence of the embedded rock than the normal case without rock. The buried rock improves the foundation behavior when it lies under the middle of the footing, and causes turbulence for the footing contact stresses when it lies away from the middle.

5. REFERENCES

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"دراسة نظرية لسلوك أساس شريطي علي الرمل في وجود صخرة مدفونة"

يقدم هذا البحث دراسة نظرية علي سلوك الأساس الشريطي الموضوع علي الرمل و ذلك في وجود صخرة مدفونة تحت ألأساس. الصخرة المدفونة هذه يمكن ان تكون جزء من أساس لمبني قديم و لم يزال من مكانه. في هذه الدراسة النظرية تم دراسة سلوك أساس شريطي علي الرمل في وجود صخرة مدفونة. لقد تم دراسة تأثير عمق الصخرة و أيضا مكان تواجدها بالنسبة للأساس. النتائج النهائية أثبتت أن الأجهادات بين التربة
و ألأساس زادت 40% من قيمتها الأصلية عندما كانت الصخرة واقعة تحت منتصف ألأساس وعلي بعد راسي قدره نصف المتر.أيضا الأجهادات تحت ألأساس قد تغيرت كثيرا بوجود هذه الصخرة و أيضا مكانها من نقطة منتصف ألأساس.