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Behavior of Different Shapes of Twin Tunnels in Soft Clay Soil

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Abstract*— The design of tunnel cross section depends on the values of internal forces and deformations induced in the lining. These values are influenced by many factors such as type of soil, dimensions and shape of the tunnel. In the present study, a finite element analysis is proposed using computer program Adina version 8.5 (A finite element code for soil and rock analyses). A numerical model is presented as a plane strain problem taking into consideration the soil-structure-interaction .Mohr-Coulomb is used to model the nonlinearity of soft clay soil. Two node linear beam element is used to simulate the lining of the different three shape (circular, elliptical, and rectangle with circular arch) twin tunnels. The material of the lining was chosen as a reinforcement concrete. The effect of the change of soft clay soils using different values of the modulus of elasticity (E_s) and the Poisson ratio (ν) in the tunnels internal forces and displacement and soil stresses at different case of loading for different shape of tunnels was studied. Also The effect of thickness-radius ratio (t/r) on the tunnels displacement, internal forces and soil stresses was studied .Also the ground surface displacement was studied at different shape and dimensions of different twin tunnels for different soft clay soil properties .The results show that the circular tunnel is best shape of twin tunnels in soft clay soil with different values for (E_s) and (ν) . Design charts for the internal forces as well as settlement to predict the maximum bending moments as well as the maximum normal forces induced in the lining have been introduced.

***Index Terms*— Soil-Structure-Interaction, Circular Tunnel, Elliptical Tunnel, Rectangle With Circular Arch Tunnel, Finite Element, Soft Clay Soil.**

I. INTRODUCTION

The construction and use of tunnels can be considered one of the most important features of civilization in developed nations. It became one of the necessities of life. It is found that tunnels effectively helped in the consistency and fluency of traffic as means to carry passengers from one place to another, particularly in over-populated cities. There are variety of uses for tunnels used in the purposes of security and industry. They can be constructed under dams and reservoirs and water canals to transport water and to move electric turbines. Egypt has taken vast steps in this field where tunnels were built under Suez Canal for irrigation and transportation purposes. Tunnels have been constructed inside Great Cairo particularly in jammed traffic areas lately. The effect of using tunnels in consistency of traffic movement is obvious. Also, tunnels have been used in Egypt in the sanitary drainage, electricity and telephones project. So the study of the soil-structure interaction is very important, because one of its important problems which face many tunnels especially in case of week or soft clay soil around the tunnels. The finite element analysis technique has a great versatility in analyzing one or two tunnels at different type of soil not including soft clay soil **[1],[2],[3],[4],[5],[6],[7],[8],[9],[10],[11],[12],[13]and[14]**. Some of authors investigated one shape of the tunnel-soil interaction problem numerically and experimentally **[15],[16],[17]and [18]**. The objective of this study is to investigate the behavior of two adjacent different shapes of tunnels in soft clay soil at different case of loading with considering the effect of some variable factors using existing finite element software, while the numerical model is represented by a plane strain problem. The program which was used is the ADINA 8.5 **[19]**.

II. FINITE ELEMENT MODEL

In order to model satisfactorily the soil-structure interaction effects under static loading, it is often necessary to model a large domain of the soil surrounding the structure of interest. High spatial temporal resolution is another challenge in analyzing such models. The nonlinear finite element analysis program, ADINA8.5 **[19]** was employed to study such high fidelity large-scale soil-structure interaction models. Plane stress 2-node beam element was used to simulate the concrete lining of different shapes twin tunnels. **2**-D solid 3-node triangle plane strain element was used to simulate the surrounding soil taking into consideration the nonlinearity of the clay soil by using Mohr-Coulomb model [20],[21].For the analysis of the problem, a finite element mesh was constructed for three shapes of twin tunnels as shown in Figs.2, for the models have a dimension are showing in Figs. 1

III. DIMENSIONS AND PARAMETERS OF THE MODEL

The model can be divided into two basic parts, which were as follow: a twin tunnels lining and surrounding soil . In the first, the twin tunnels, it was studied with three shapes (circular, elliptical and rectangle with arch) each shape was in one layer of soil deposit of constant distance equal to (7R) from center line of the tunnels where R is the radius of the tunnel as shown in Figs. (1). Linear performance was assumed for each twin tunnels wall material with an elasticity modulus equal $2.1*10^7$ KN/m^2 and Poisson ratio (ν =0.15). Also, the key plan of the tunnel results, (sl) is the left spring point, (cr) is the crown point and (sr) is the right spring point of the tunnel was indicated at Fig 1. Each shape of twin tunnels was

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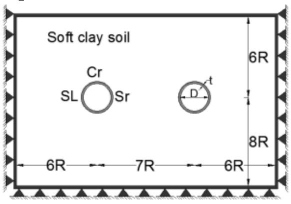
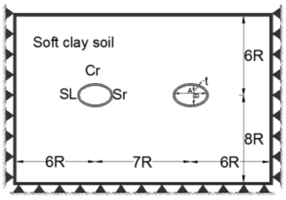
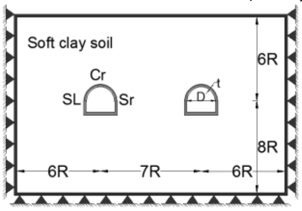
studied by varying its diameter D and wall-thickness ratio (t/r) as shown in table 1.The second part was the soft clay soil, it was studied with different types by varying its modulus of elasticity Es and Poisson ratio μ[22] as shown in table 1. **Fig. (3)** Shows the different cases of loading with uniform load equal P=100KN/m.



a) Circular tunnel

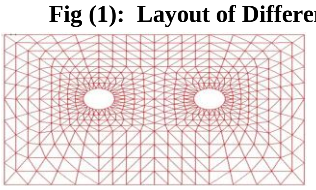


b) Elliptical tunnel

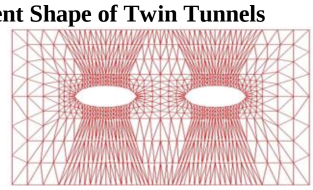


c) **Rectangular with circular arch**

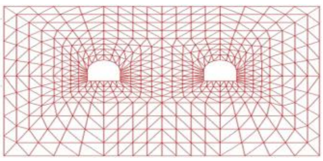
Fig (1): Layout of Different Shape of Twin Tunnels



a) Circular

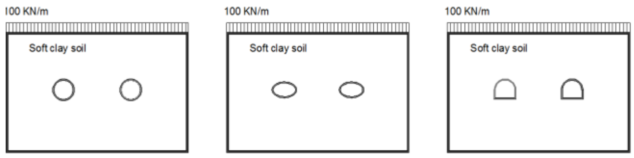


b) Elliptical

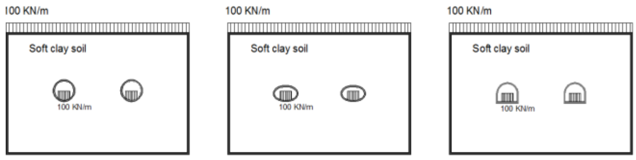


c) Rectangle with circular arch

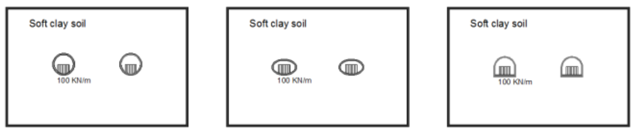
Fig (2): The Finite Elements Mesh of Different Shape of Twin Tunnels.



a) Case 1 of loading



b) Case 2 of loading



c) Case 3 of loading

Fig (3) Cases of the Different Shape of Tunnels Loading

Table 1. The Values of Utilized Constants and Variables used in the basic twin tunnels models studies.

No	Parameters	Status	Value/Values
1	External load	Constant	100.00 KN/m^2
2	internal load	Constant	100.00 KN/m^2
3	tunnel depth (h)	Constant	6Rm
4	L(distance between center line of tunnels)	Constant	7Rm
5	Shape of tunnel	Variable	Circular ,elliptical , circular arch with rectangular
6	Modulus of elasticity for tunnel (Ec)	Constant	21*10^7 KN/m^2
7	circular diameter (m)	Variable	D=8,10,12 m
	Elliptical dimension(m)		(A,B)=(4.8),(5,10) , (6,12) m
	Rectangle with circular arch width(m)		D=8,10,12 m
8	t/r	Variable	0.1,0.15,0.2
9	Native soil properties(E_s)	Variable	1000,1500,1900 KN/m^2
10	Poisson's ratio (μ) of soil	Variable	0.4,0.45,0.49

IV. EFFECT OF DIFFERENT PARAMETERS ON TWIN TUNNELS BEHAVIOR.

Figs (4-6) show the distribution of the internal forces [M, N, Q] for the different shapes of tunnels at the thickness-radius ratio (t/r) =0.1 for case1 of loading. It is noticed that the shapes of the tunnel in the soft clay soil have a significant effect on the internal forces which increase on elliptical shape up to 6 times at different places than in case of another shapes due to arch action effect. The effect of the change in the thickness–radius ratio (t/r) and change in the diameters of tunnels (D) on different shape of twin tunnels at different cases of loading on the twin tunnels behavior were studied. The results were expressed in non-dimensional form(N/N_0),(M/M_0),(Q/Q_0),(σ_z/σ_{z0}), (σ_y/σ_{y0}),(,δ_c/,δ_{c0}) and (,δ_s/ ,δ_{s0}) where(N_0,M_0,Q_0) and(σ_{z0}, σ_{y0} ,δ_{c0} , ,δ_{s0}) are the internal forces , stresses and displacement for the one circular tunnel with diameter D=8m and thickness-radius ratio (t/r) =0.1 at case1 of loading in soft clay soil with modulus elasticity Es=1900KN/m^2 and Poisson's ratio(μ) =0.49 .

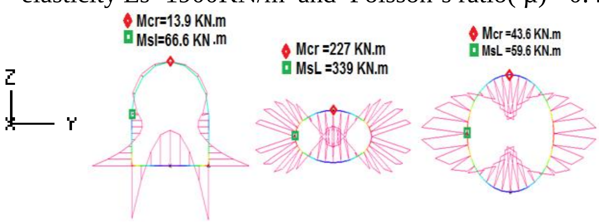


Fig (4): The Distribution of the Bending Moment in the Different Shapes of Tunnels at D=8 m, t/r=0.1 And Case 1 of Loading.

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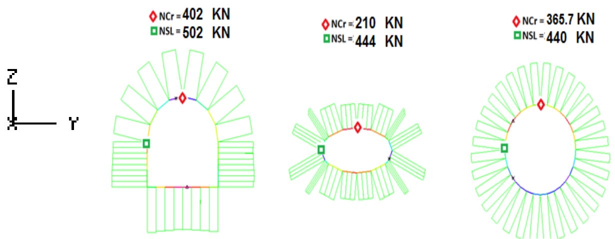


Fig (5): The Distribution of the Normal Forces in the Different Shapes of Tunnels at D=8 m, t/r=0.1 And Case 1 Of Loading.

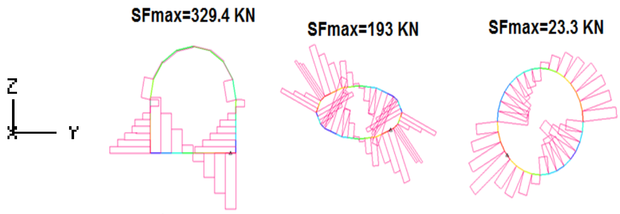
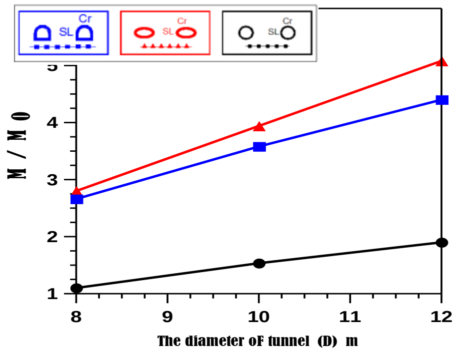
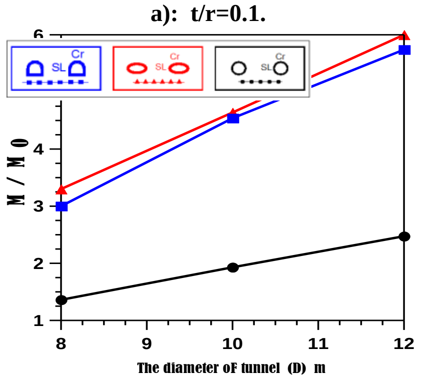


Fig (6): The Distribution Of The Shear Forces In The Different Shapes Of Tunnels At D=8 m, t/r=0.1 And Case 1 Of Loading

Figs. 7and 8 indicate that the effect of change in diameter (D) on the bending moment and normal forces at the upper crown point of the tunnel at different thickness –radius ratios (t/r)for three shapes of tunnels [circular, elliptical and rectangular with circular arch (like horse shoe) tunnels] in soft clay soil whose Es=1900 KN/m^{2}at case 2 of loading. It shows that, for all shape of tunnels, the bending moment ratio(M/M_0) increase up to 40% due to increase the diameters of tunnel from 8 to 12m due to effect of arch action. However, it increases up to 15% as the wall-thickness ratios (t/r) increase as shown in figs 7.



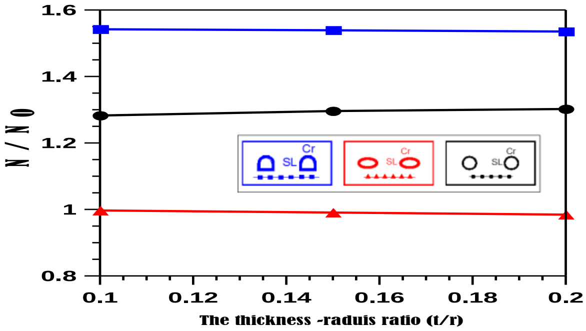
a): t/r=0.1.



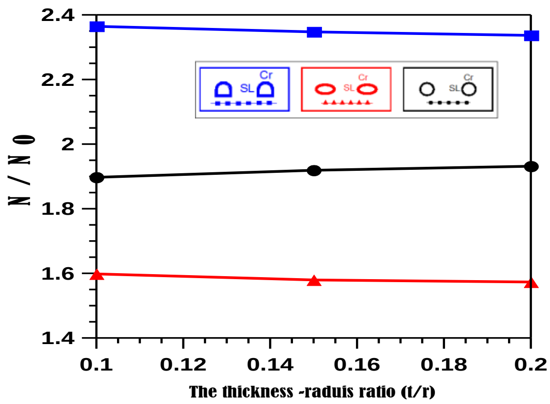
b) t/r=0.2

Fig (7): Effect of the Change in the Diameter (D) On the Bending Moment at Upper Crown Point of the Tunnels (Cr) At Different t/r ratios at case 2 of loading.

Figs .8 indicate that the normal forces ratios (N/N_0) rarely affected by the increase of (t/r) ratios ,however increase up to 50% as the diameter D increases .



a) D=8m



b)D=12m

Fig (8): Effect Of The Change In The Thickness-Radius Ratios (T/R) On The Normal Force At The Upper Crown Point Of The Tunnel (Cr) At Different Diameters And Case2 Of Loading.

Figs 9-13 show the effect of the shape of twin tunnels on the internal forces ,displacement and stresses at the spring point SL at different cases of loading ,D=8m and t/r=0.1.It is noticed that for each cases of loading the internal forces ,stresses and displacement of the circular shape of twin tunnels decrease to reach 6 times than in cases of elliptical and rectangle with circular arch shapes of twin tunnels due to effect of arch action .

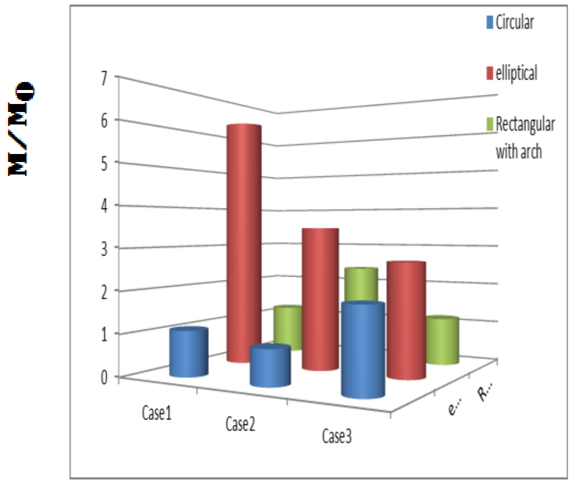


Fig (9): Bending Moment Chart Layout At Left Spring Point (SL) For the Different Shapes of Tunnel At t/r =0.1 and D=8m.

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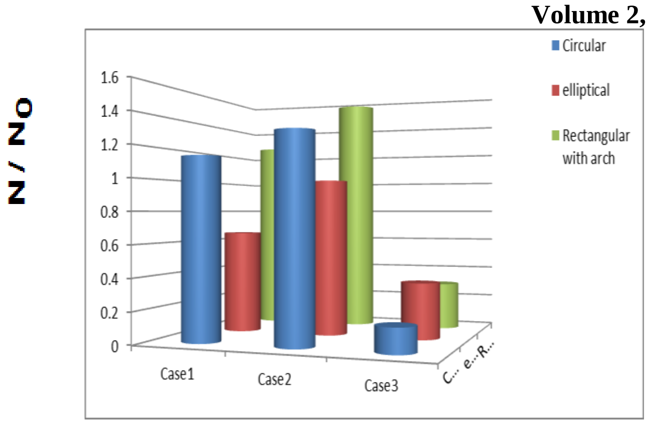


Fig (10): Normal Force Chart Layout At Left Spring Point (SL) For the Different Shapes of Tunnel at T/R =0.1 and D=8m.

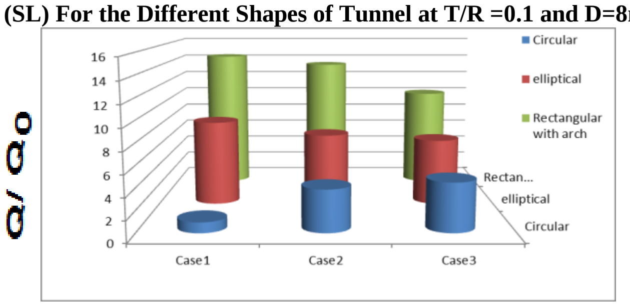


Fig (11): Shear force Chart Layout at left Spring point (SL) For the Different Shapes of Tunnel At t/r =0.1 and D=8m.

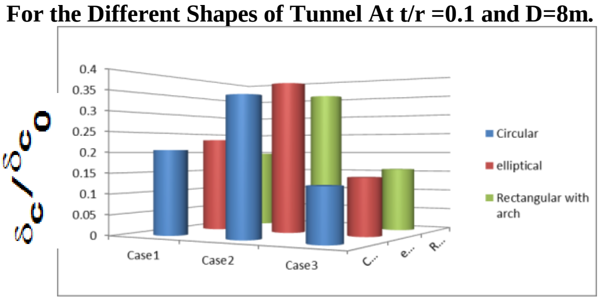


Fig (12): The vertical displacement Chart layout for the different shapes of tunnel at t/r =0.1 and D=8m.

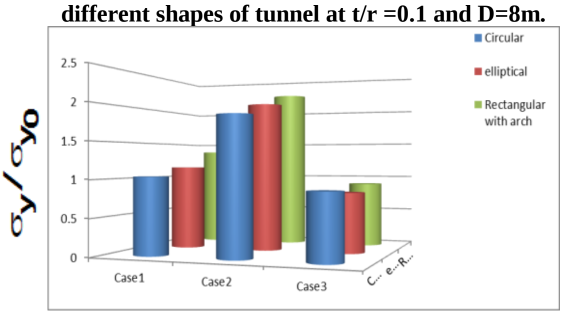


Fig (13): The Horizontal Stresses Chart Layout in The Soft Clay Soil Surrounding The Different Shapes Of Tunnel At T/R =0.1 and D=8m.

Fig.14 shows that the distribution of the vertical displacement affected by the shape of twin tunnels which it is more uniformly in case of circular shape twin tunnels. In general, the circular shape for tunnels is more suitable shape in soft clay soil, where achieve economic design by decreasing in quantities of concrete and reinforcement, because the internal forces, the vertical displacement for the lining of circular tunnels is less than the two adjacent elliptical and rectangle with circular arch tunnels .At case2 of loading the bending moment at crown point of the circular tunnel on the soft clay soil decreases about (10% to 40%) due to increase the stiffness of soft clay soil from 1000 to 1900 kN/m^2 as shown in Fig.15.However,in case1 of loading, the vertical stresses on the soft clay soil surrounding of the circular tunnel decrease about (5% to 8%) due to increase the stiffness of soft clay soil from 1000 to 1900 kN/m2 as show in Fig. 16 .

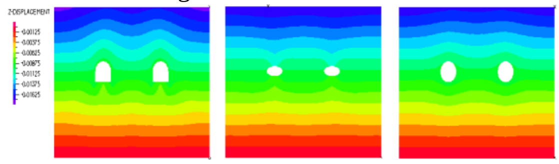


Fig (14): The Distribution Of The Vertical Displacement Shading In The Soil Domain for the Different Shapes Of Tunnel At D=8m, t/r =0.1 For Case1 Of Loading.

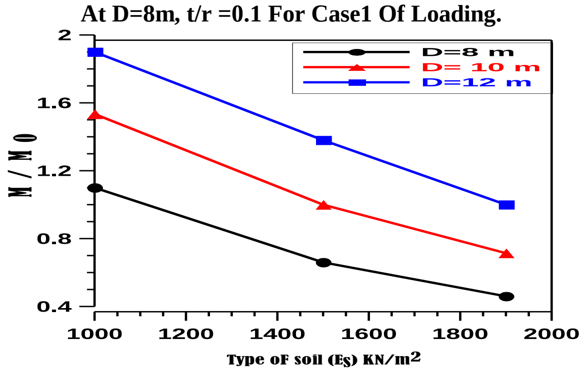


Fig (15): Effect Of The Change In The Soft Clay Soil (Es) OnThe Bending Moment (M) At The Upper Crown Point(Cr) Of twin Circular Tunnels At t/r=0.1 and case2 of loading.

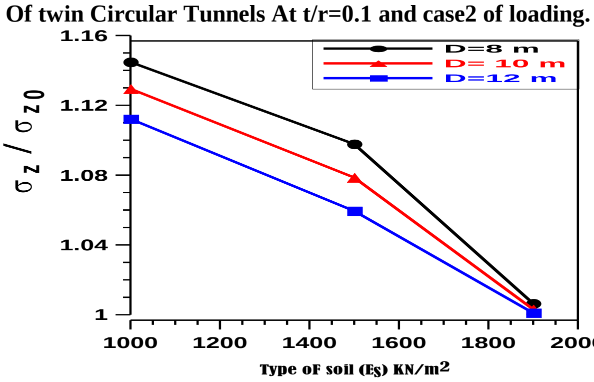
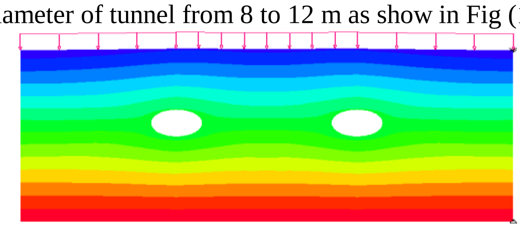


Fig (16): Effect Of The Change In The Soft Clay Soil (Es) On The Vertical Stresses (σzz)At t/r=0.1and cas1 of loading.

The ground surface displacement in the soft clay soil is affected by the change in the modulus of elasticity of the soft clay soil (Es) and change the diameter of tunnels at different cases of loading. Fig (17) shows that the ground surface displacement in the soft clay soil which surrounding the tunnels is affected by the cases of loading, where the ground surface displacement in the soft clay soil at case 2 of loading is more than in case 1 and case 3 due increase loading area. In the case 2of loading, the ground surface displacement in the soft clay soil increase about (16% to 20%) due increase the diameter of tunnel from 8 to 12 m as show in Fig (18).



Case1

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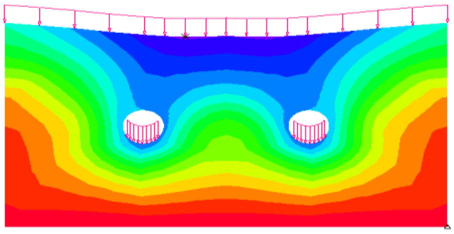
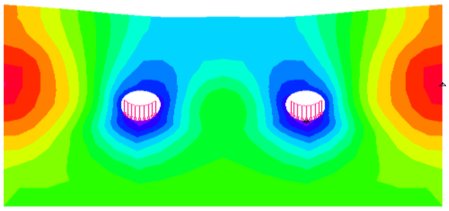


Case2



Case 3

Fig (17) The Distribution of the Ground Surface Displacement in The Soft Clay Soil At (Es) =1900KN/m2, t/r=0.1 And D=8m and different case of loading.

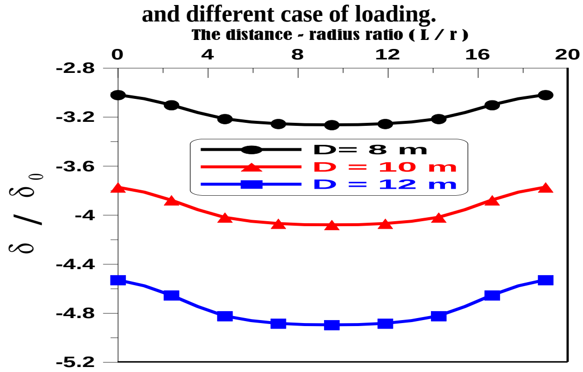


Fig (18) Effect of the Change In The Diameters Of Tunnel (D)On The Ground Surface Displacement (δ) In The Soft Clay Soil At (Es) =1000 KN/m2 And t/r=0.1and case2 of loading.

V. CONCLUSION

After many studies for the three shapes of tunnel and after Comparisons between the values of displacement at upper (cr), internal forces of lining and internal stress of soft clay soil for circular , elliptical and rectangle with circular arch twin tunnels, it is observed that :- Based on the results of the research, the following conclusions can be drawn:

1. In general ,the circular shape for tunnels is more suitable shape in soft clay soil, where achieve economic design by decreasing in quantities of concrete and reinforcement, because the internal forces, the vertical displacement for the lining of circular tunnels is less than the two adjacent elliptical and rectangle with circular arch tunnels.
2. The shapes of tunnel in soft clay soil more affected in the internal forces of tunnels, soil stresses and the tunnels-vertical displacement at different case of loading than the thickness-radius ratio (t/r) because of effect of arch action, The degree of curvature of the shapes of the tunnel in the soft clay soil has a significant effect on the displacement. Where the values and the distribution of vertical ground surface displacement increase as the degree of curvature increase .
3. In the soft clay soil, the internal forces, the soil stresses and the ground surface displacement are affected by the dimension of each shape of tunnels where the internal forces increase up to 40% due to change of tunnels diameters from 8 to 12m, the soil stresses tunnels increase up to 10% and the ground surface displacement increase up to 20% due to the change in the diameters from 8 to 12m .
4. In the soft clay soil, the displacement are affected by the interaction between the two circular tunnels at all types of soft clay soil (Es) where the vertical displacement at upper crown of the two adjacent circular tunnels is equal to 80% of the vertical displacement at upper crown of single circular tunnel .
5. In soft clay soil, the internal forces and internal stresses slightly affected as the stiffness of circular tunnel increasing, but it is more affected by the increasing of (Es) of soil, which the internal forces decreases up to 75%, at some cases duo to the relative stiffness between tunnels and soil.

VI. ACKNOWLEDGMENT

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