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Study of the Effect of Seismic Behavior of Twin Tunnels Position on Each Other

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***Abstract*—**Excavation of shallow tunnels such as subways in urban areas plays a significant role as a life line and investigation of the soil behavior against tunnel construction is one of the vital subjects studied in the geotechnical scope. Nowadays, urban tunnels are mostly drilled by T.B.Ms and changing the applied forces to tunnel lining is one of the most risky matters while drilling tunnels by these machines. Variation of soil cementation can change the behavior of these forces in the tunnel lining. Therefore, this article is designed to assess the impact of tunnel excavation in different soils and several amounts of cementation on applied loads to tunnel lining under static and dynamic loads. According to the obtained results, changing the cementation of soil will affect the applied loadings to the tunnel envelope significantly. It can be determined that axial force in tunnel lining decreases considerably when soil cementation increases. Also, bending moment and shear force in tunnel lining decreases as the soil cementation increases and causes bending and shear behavior of the segments to improve. Based on the dynamic analyses, as cohesion factor in soil increases, bending moment, axial and shear forces of segments decrease but lining behavior of the tunnel is the same as static state. The results show that decreasing the overburden applied to lining caused by cementation is different in two static and dynamic states.

***Keywords*—**Tunnel, Soil cementation, Static, Dynamic.

I. Introduction

THE effect of seismic loading on tunnels is too important. Extensive studies on the consequences of the earthquakes on tunnels show that the earthquakes cause great tunnel oval deformations and axial stress on tunnel lining [1]. Various models are dynamically loaded in laboratories. Then the same conditions are studied using numerical software. In both cases similar results are obtained [2]. In evaluation of dynamically loaded tunnels various parameters are relevant and extensive research is done in this respect [3]-[5]. But in above-mentioned research, changes in soil resistance parameters and changes of soil cohesion are not studied sufficiently with typical methods. The effect of soil resistance parameters on forces applied to linings is significant. Soil cohesion is one of the most effective soil parameters. Increased resistance of soils does not always lead to decrease in forces of structures being in touch with them. For example, friction angle can be mentioned which increases and leads to increase in the force existing in tunnel lining. Increased forces in tunnel linings cause faster degradation of tunnels. One of the parameters which have not completely been studied is soil cohesion. Designing of tunnel linings is structurally influenced by axial forces, shear forces and bending moment and the amount of soil cohesion can significantly affect these forces. Improvement easily increases soil cohesion. This increased cohesiveness is created by adding cementing materials to soil. The research is designed to evaluate the effect of changes in soil cementation on shear and axial forces and bending moment during dynamic loads.

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II. Modeling

In present modeling, a tunnel with diameter of 6.6m is placed in a depth of 9m to ground surface. Fig. 1 shows tunnel dimensions and its location with respect to surrounding environment. Also characteristics of soil materials around the tunnel are as shown in Table I.

At first step of modeling, a primary analysis is done to stabilize soil environment based on behavioral model of Mohr-Coulomb for soils. Drilling and conducting concrete segment and then numerical analysis are carried out. Segment characteristics are shown in Table II. A dynamic load of sinuous harmonic type with frequency of 1 HZ, amplitude of 0.1m and base acceleration of 0.2g are introduced to the model. Finally by comparing the results for static and dynamic conditions as depicted in Fig. 2, the obtained results are examined.

Looking at Fig. 2, it is seen that changes in axial and shear force and bending moment in static and dynamic analyses can be evaluated numerically. Based on the figure, it may be found that the amount of axial force in static is 223.8 (kN) that is increased to 386.2 (kN), in dynamic condition. Besides, the amount of shear force on static analysis increases from 39.87 (kN) to 92.44(kN) after a 10 sec earthquake. Regarding the figure, bending moment in static analysis is 66.59 (kN.m) and after seismic loading of tunnel has increased to 133 (kN.m) Hence shear force and bending moment increase to52.57 (kN) and 66.41 (kN) respectively. Thus it is clear that the earthquake leads to a decrease of 72.5% in axial force and an increase in bending moment and shear force respectively by 99% and 131%. Combining the forces in the tunnel, it is obvious that tunnel behavior is influenced intensively by harmful seismic forces during synchronous increase in shear force and bending moment. In order to study the effects of soil cementation degree, soil cohesion is respectively increased and then decreased regarding the base model. Applying the static and dynamic analyses for each model, the amounts of forces existing in tunnel linings are obtained. Table III shows the overburden seen in tunnel linings results from changes in soil cementation.

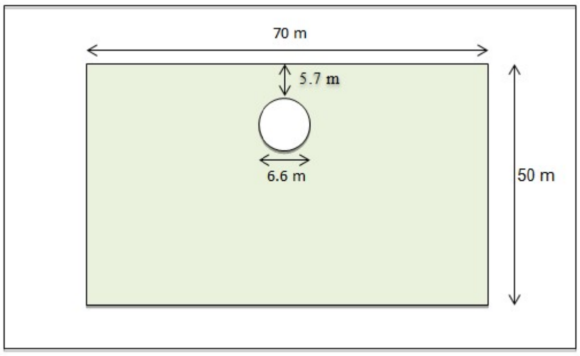

Fig. 1 Tunnel dimensions

TABLE I
SOIL CHARACTERISTICS

Soil type	Elasticity module (Mpa)	Poisson Ratio	Friction angle (°)	Cohesion (kPa)
Clay	23.54	0.3	30	20

TABLE II
TUNNEL SEGMENTS CHARACTERISTICS

Segment substance	Segment thickness (m)	Elasticity module (Mpa)	Poisson Ratio	Densityγ kN/m^3)
Concrete	0.3	25.5	0.2	24

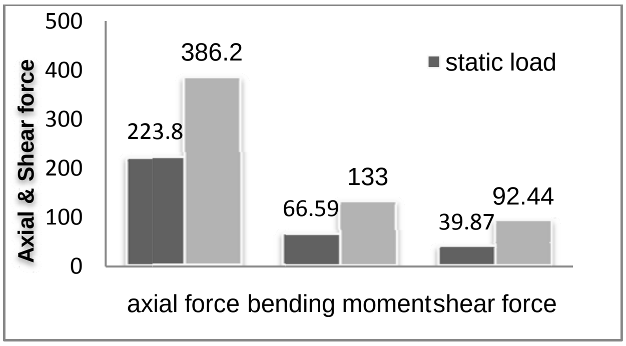

Fig. 2 Numerical comparison of static and dynamic analytic results

TABLE III
CHANGES IN FORCES APPLIED TO LININGS DUE TO CHANGES IN SOIL CEMENTATION

Cohesion of soil	variation of lining load under static analysis			variation of lining load under dynamic analysis		
	Axial force(kN)	Bending moment (kN.m)	Shear force(kN)	Axial force(kN)	Bending moment (kN.m)	Shear force (kN)
0	447.6	138.7	87.64	480.3	183.8	132.1
10	299.7	108.8	68.45	444.4	173.5	122.1
20	223.8	66.59	39.87	386.2	133	94.44
30	192.9	58.71	36.3	338.9	119.8	84.1
40	178.1	54.97	33.32	286.7	98.44	81.36

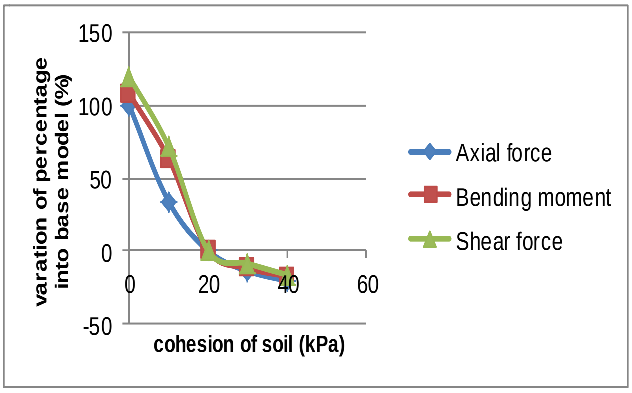

Fig. 3 Percent changes of axial and shear forces and bending moment as soil cohesion is changing in static analysis

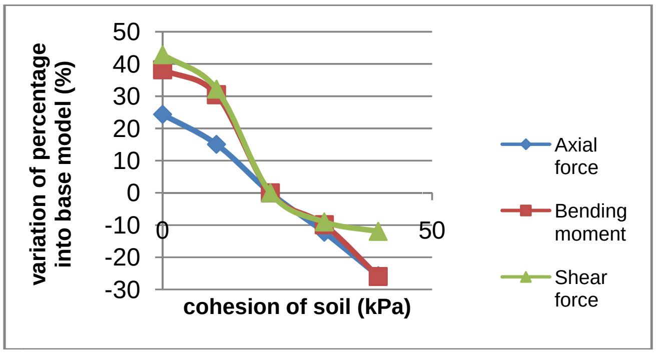

Fig. 4 Percent changes in axial force, shear force and bending moment with change in soil cohesion in dynamic analysis

Now the results from changes in soil cementation compared to the base model are illustrated as percentages and then obtained results are graphically shown. Fig. 3 presents static analysis results and Fig. 4 shows dynamic analysis results in graphical form. Decreasing trend of axial and shear forces and bending moment applied to tunnel lining due to an increase in soil cohesion, can be seen in Fig. 3. Referring the graph, it is seen that as the cohesion changes from 0 to 20 (kPa), axial force, shear force and bending moment decrease by 100%, 119.8% and 108.3% respectively. With further increase in soil cohesion up to 40 (kPa), axial force, shear force and bending moment decrease by 20.4%, 16.4% and 17.45% respectively. Great decrease in tunnel lining forces in range of 0 to 20 (kPa) shows significant importance of increase in cementing factors of soils at that level of cohesion. Also concerning the slow trend of decrease in tunnel lining forces in the range of 20 to 40 (kPa), a decrease in respect of cementing materials added to the soil is observed.

Fig. 4, like Fig. 3, shows a decrease in axial force, shear force and bending moment with increase in soil cohesion. Decreasing trend of axial force from 0 to 40 kPa is along with linear changes. But by increasing the soil cohesion, shear force and bending moment in tunnel linings do not decrease in linear form but the degree of decrease is varied in different cohesion ranges of soil. Change in cohesion value from 0 to 20 kPa leads to 24.4% decrease in axial farce, 38.2% decrease in bending moment and 43% decrease in shear force. Also with increase in soil cohesion from 0 to 20 kPa, 25.8% decrease in axial force, 26% decrease in bending moment and 12% decrease in shear force are observed. It can be determined that though the rate of decrease in tunnel lining force reduces after 20 kPa soil cohesion in shear force and bending moment, enhancing the cohesion causes to decrease the lining forces and to improve the conditions.

Results obtained from evaluation of Figs. 3 and 4 shows that though decrease in tunnel axial forces leads to oval deformation in tunnel segments, the fact that shear force and bending moment decrease intensively results in improving the condition of tunnel structure. Thus adding cementing materials to low-cohesive and non-cohesive soils, soil-related overburden can be reduced in tunnel structure. Despite the fact that the resulted decrease in static analysis is different from seismic analysis, decreasing trend of tunnel lining forces is seen in both static and dynamic cases.

III. Conclusion

In present study a tunnel with diameter of 6.6m and depth of 9m to ground surface is considered. After providing a static balance, it is subjected to seismic loading. Then by changing soil cohesion parameter, the effect of cementation is studied on tunnel lining resistance and the following results are obtained:

1. Changing soil cohesion from 0 to 40 kPa in static condition causes the amounts of axial and shear force and bending moment to decrease. The extent of this decrease is steeper in the range of 0 to 20 kPa compared to that of 20 to 40 kPa. The percent decrease in the former range is 100% for axial force, 108% for bending moment and 119.8% for shear force and the corresponding values for the latter one are respectively 20.4%, 17.45% and 16.4%.
2. In statistical analysis, addition of cementing materials to soils brings about more beneficial results for soils with cohesion below 20 kPa than those with cohesion above 20kPa. Also for soils with normal cohesion above 40 kPa, addition of cementing materials has no significant effects on decrease in forces created in tunnel lining.
3. Respecting the dynamic analysis, increasing the soil cohesion from 0 to 40 kPa axial force, bending moment and shear force respectively decrease by 50.2%, 64.2% and 55%.
4. Comparison of static results with dynamic ones shows that adding cementing materials to soil leads to more decrease in tunnel lining forces in static versus dynamic case.

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