ASGE Vol. 06 (01), pp. 58-67, 2022

International Journal of Advances in Structural and Geotechnical Engineering

https://asge.journals.ekb.eg/

Print ISSN 2785-9509 Online ISSN 2812-5142

Improvement the Performance of an Open Tunnel Based on a Numerical Study

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ABSTRACT

Due to the traffic congestion in a main street within the downtown of some cities, a roundabout has been changed to tunnel as a best solution. The objective of the current research is to evaluates the performance of an open tunnel part. The open tunnel part consists of two cantilever retaining walls possessing a combined foundation. The tunnel under study has a width of 25.6 m and a depth of 7.2 m. The open tunnel has been simulated utilizing Plaxis 2D FEM program. The cantilever walls retained and rested on silty sand soil. The excavation of the tunnel has also been idealized. The retaining walls sustains from somewhat high values of lateral displacement at the top. As well as the combined foundation implies high vertical displacement and internal forces values. The geogrid materials have been used as reinforced layers in the backfill soil and in the foundation soil. The reinforced soil with geogrid causes only a small reduction on the foundation vertical displacement. But once applying vertical loads on the foundation, the lateral displacement of the walls, and vertical displacement and the internal forces of the foundation have been minimized. The own weigh of the tunnel floor and the vehicles weight are represented the applied loads. Therefore, the applied loads enhance effectively the performance of the open tunnel part.

Keywords; *lateral displacement, vertical displacement, retaining walls, silty sand, geogrid*

INTRODUCTION

In order to retain soil safely, retaining walls should be constructed. Retaining soils can be utilized in different conditions such as vertical cuts, ground slope, two parallel roads with different levels, ports platform, part of a bridge, open part of tunnel……..etc. The retaining walls are classified according to the type of support (i.e., rigid or flexible), construction materials (e.g., masonry, plain concrete, reinforced concrete, reinforced earth systems, steel sheet pile walls), structural system (e.g., cantilever, diaphragm, anchored sheet pile wall), etc. Based on the geotechnical properties of the soil backfill and the foundation soil under the wall, the retaining walls are designed to guarantee the safety and the economic. The cantilever wall is one of the traditional retaining walls in the last decades. The reinforced earth systems walls were somewhat recently utilized. In the later walls, the geosynthetic materials are used as a layers supported by facing wall. The performance of the reinforced soil systems walls were studied by many researchers [1-3] while another researcher investigated the performance of a wall stabilizing backfill soil with cement material [4]. The performance of the cantilever retaining walls were studied by several researchers considering deflections, earth pressures and wall configurations [5-7]. Subsequently, the higher cantilever walls sustain from high lateral deformations and pressures. The lateral deformations can be mitigated using pressure relieving shelves [8].

In the current research, the performance of an open tunnel part, as a case study, consisting of two cantilever walls and a combined foundation is numerically studied. The numerical simulation is achieved using 2D Plaxis program. The performance of the open tunnel are improved by reinforcing the soil backfill and the foundation soil with geogrid materials and by applying loads on the tunnel floor. The performances of the conventional tunnel and the improved tunnel are numerically evaluated by calculating deflections and internal forces of the walls and foundation.

CASE STUDY DESCRIPTION

The tunnel was constructed to prevent the traffic congestion in a main intersection in the downtown any big city. As known, the roundabout is valid only for low and average traffic. But it causes many serious problems as the traffic converted to heavy. Therefore, the tunnel was constructed instead of the roundabout to overcome the problems associated with the intersection. The tunnel under study has a length of 780 m and a width of 25.6 m as three traffic lanes in each direction. The open tunnel was selected to be numerically studied. The open tunnel consists of two cantilever retaining walls and a combined foundation under them as depicted in Fig. 1. The reinforced concrete (RC) retaining walls have a depth of 8.56 m and a thickness of 1.5 m. The RC combined foundation has also a thickness of 2.8 m.

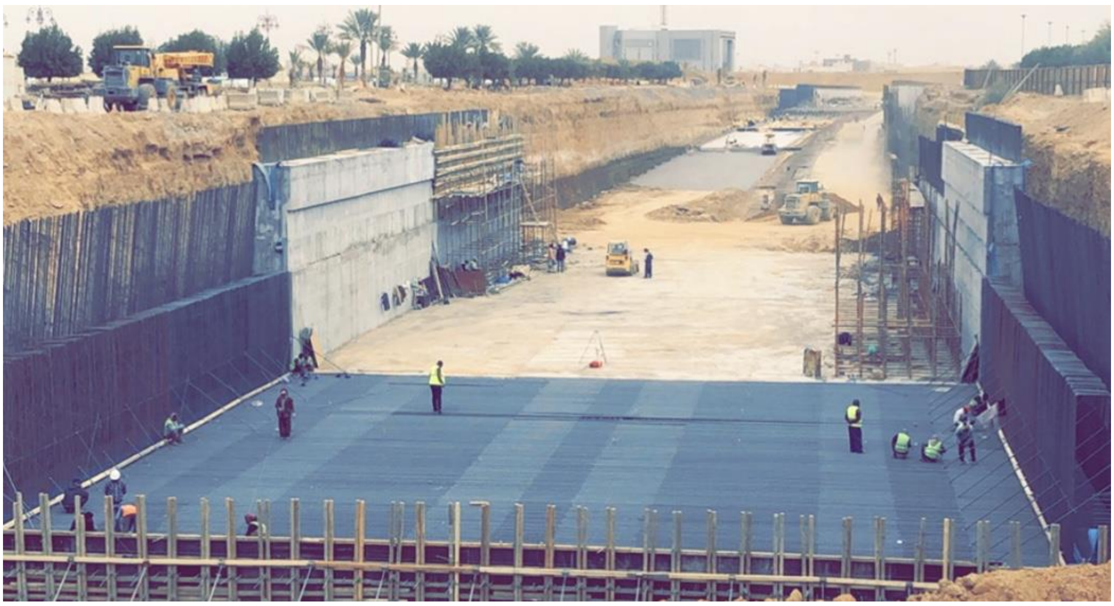

Fig. 1: Open tunnel part

NUMERICAL SIMULATION AND SELECTION PARAMETERS

The open tunnel has been constructed in a silty sand soil. The silty sand soil extends to 20 m below the tunnel. The open tunnel consists from two cantilever retaining walls rested on combined footing. The open tunnel has a 25.6 m width. The retaining walls have a thickness of (d_w =1.5 m) while the combined foundation has a thickness of (d_r = 2.8 m). The combined foundation extends 2.0 m beyond the wall at each side as depicted in Fig. 2. The ground water table is located at a depth of 7.2 m under the ground surface level. Half of the tunnel has been simulated using 2D Plaxis program. Plane strain technique has been used to model the tunnel because of its cross section is constant along 780 m. The half of the model has 76.8 m width and 28.56 m depth as illustrated in Fig. 2. The interface between the walls and the soil is considered. The adhesion is taken as equal the shear strength of the silty sand soil. The horizontal and the vertical displacements are prevented at the bottom boundaries while the horizontal displacements are only restrained in the lateral boundaries. The parameters of the silty sand soil was determined from the boreholes under the tunnel. The silty sand soil has been idealized by Mohr Coulomb model under drained condition. A medium finite mesh has been used with 15-node triangular elements, as shown in Fig. 3. The retaining walls and the combined foundation have been modeled as elastic plate. The parameters of the silty sand soil, the walls, and the combined foundation are tabulated in Tables 1, 2 and 3 respectively.

In order to reduce the horizontal displacement of the walls and the vertical displacement of the foundation, the backfill of the wall and replaced soil have been reinforced by geogrid material. A replacement gravel layer has been used under the foundation. A geogrid layer has been used in the middle of the gravel layer. The upper geogrid layer is located 0.5 m under the ground surface. the other geogrid layers have a spaced distance of 1.0 m as indicated in Fig. 2. The reinforced backfill has 8 m width beyond each wall. The reinforced open tunnel with geogrid layers has also been idealized to compare it with the non-reinforced open tunnel. The geogrid reinforcement has been modeled as a linear elastic continuum element with a series of one-dimensional bare (line) elements having no bending stiffness, using flexible elastic elements which can mobilize only axial tension forces. The elastic parameter used in modelling geogrid with Plaxis program is only the axial stiffness J = EA (forces per unit width per unit strain). The used geogrid has a stiffness of J = 2000 kN/m. The reinforcement is subjected to axial extension, and there are no other deformations: therefore, the Poisson's ratio of the geogrid equals zero Elsawy (2013).

In order to make realistic modelling, the reinforced open tunnel has also been idealized after construction considering floor dead loads and traffic live loads. A 100 kN/m^2 has been applied as dead and live loads as depicted in Fig. 2. The results of the non-reinforced, reinforced and reinforced with applied loads open tunnels are compared in the current research. In order to simulate which occurred in the construction field, the open tunnel has been excavated in two equal stages in each case. Every stage has a 4.28 m depth constructed during two weeks. In the second excavation stage, the ground water table has been lowered below the foundation level by 3 m.

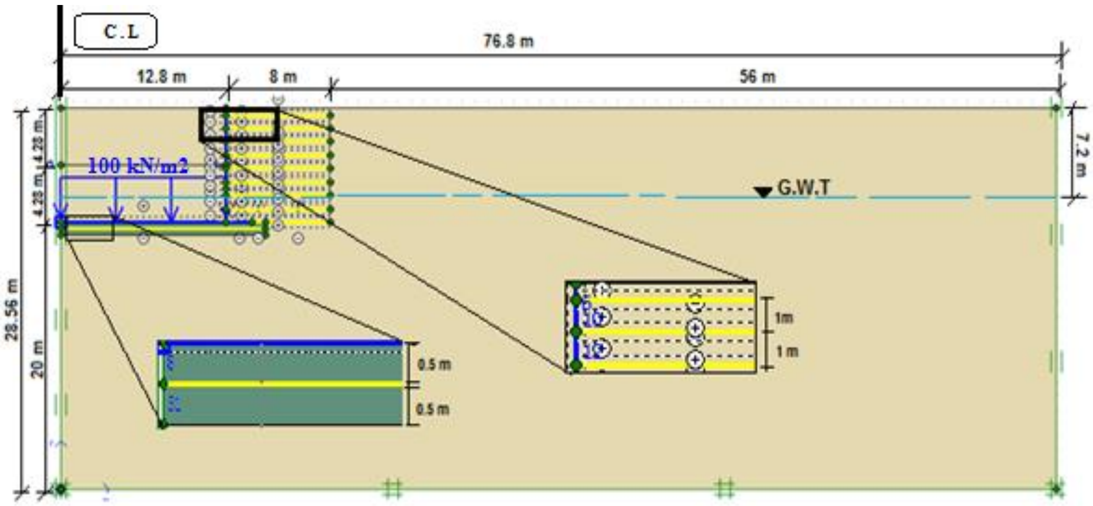

Fig. 2: Model parts

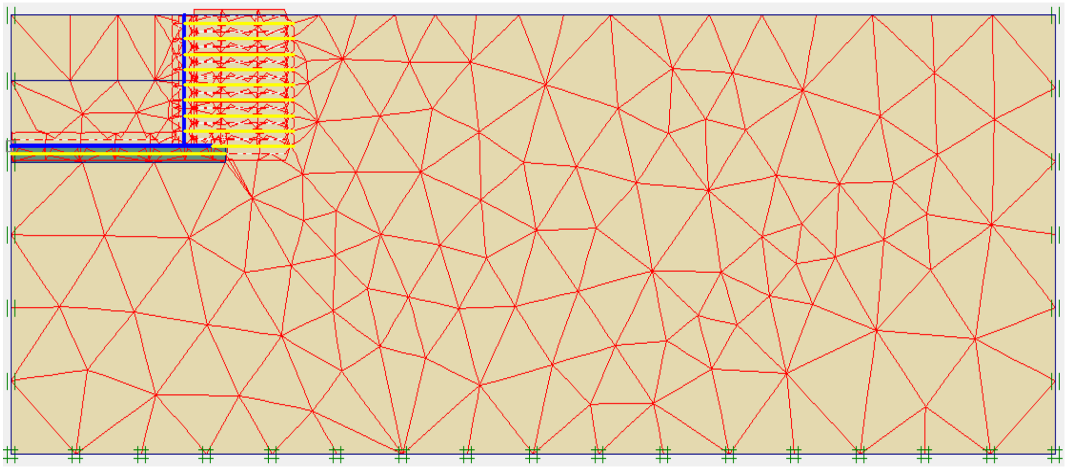

Fig. 3: FEM mesh

Table 1: Input parameters of the used soils

Parameter	Name	Unit	Silty sand	Gravel
Material model	Model	-	Mohr-model	Mohr-coulomb
Material behavior	condition	-	Drained	Drained
Soil unit weight above GWT	γ_{unsat}	kN/m^3	19.27	19
Soil unit weight below GWT	γ_{sat}	kN/m^3	19.56	20
Permeability in horizontal direction	K_h	m/day	1.118	10.022
Permeability in Vertical direction	K_v	m/day	0.559	10.022
Cohesion	C'	KPa	0.15	5
Friction angle	Φ	°	33.50	40
Young' modulus	E	KPa	35000	30000
Poisson's ratio	V	-	0.35	0.3

Table 2: Input parameters of retaining wall

Parameter	*Name*	*Value*	*Unit*
*Young's modulus * area*	*EA*	*4500000*	*kN/m*
*Young's modulus * moment of inertia*	*EI*	*843750*	*KN.m²/m*
Depth	*d*	*1.5*	*m*
Poison's ratio	*V*	*0.2*	*-*

RESULTS AND DISCUSSIONS

The non-reinforced soil, the reinforced soil with geogrid materials with and without applied loads of the tunnel were simulated. In each case, the vertical displacement of the combined foundation, the horizontal displacement of the wall and the internal forces of the wall and the foundation were calculated to study the effect of the reinforcement and the applied loads on the performance of the open tunnel.

Table 3: Input parameters of raft foundation

Parameter	*Name*	*Value*	*Unit*
*Young's modulus * area*	*EA*	*8400000*	*kN/m*
*Young's modulus * moment of inertia*	*EI*	*5488000*	*KN.m²/m*
Depth	*d*	*2.8*	*m*
Poison's ratio	*V*	*0.2*	*-*

Vertical displacement of the foundation

The combined foundation is subjected to upward vertical displacement as depicted in Fig. 4. The maximum value of the vertical displacement is at the tunnel centerline. Beyond the maximum value the vertical displacement decreases gradually reaching minimum value at the foundation end. The distribution of reinforced tunnel vertical displacement is similar to that of the non-reinforced tunnel. The existence of a geogrid layer in the middle of the gravely soil and geogrid layers in the wall backfill causes a reduction in the vertical displacement. Adding loads on the combined foundation leads to a furtherly significant reductions in the vertical displacement. The maximum value of the vertical displacement decreases from 51.2 mm to 16.6 mm when using geogrid layers and applied loads in the open tunnel. Therefore, applying loads on the tunnel floor beside the reinforcement layers improve effectively the upward vertical displacement.

Horizontal displacement of wall

The retaining walls imply maximum horizontal displacement values at the wall top. The horizontal displacement values decrease gradually with downward direction until reaching zero value at the wall base as illustrated in Fig. 5. The distribution of the lateral displacement along the wall is the same for the non-reinforced and the reinforced tunnel. The horizontal displacement values of the wall occurred toward the backfill. The reason of the later is upward displacement of the walls foundation. Reinforcing soil beyond the wall and below the foundation doesn't decrease the walls lateral deformation. Once applying loads on the tunnel floor, the lateral deformation of the wall is minimized as depicted in Fig. 5. Applying loads in the tunnel floor beside soil reinforcement leads to decrease the maximum horizontal displacement from 12.5 mm to 1.1 mm. the significant reductions in the walls lateral displacement occurred because of the effective decrement in the upward displacement of the walls foundation.

Internal forces in the foundation

The shear force and the bending moment distributions were drawn for the non-reinforced and the reinforced open tunnel. The shear forces starts with a zero values at the foundation center. Then the shear forces increase gradually until reaching maximum value at the connection of the foundation with the wall as illustrated in Fig. 6. Beyond the maximum value, the shear forces decreases gradually until reaching zero value at the foundation edge. The foundation of the reinforced tunnel implies the same shear forces distribution of that of the non-reinforced tunnel. The existence of geogrid layers only in the soil doesn't reduce the shear forces values. On the other side, adding loads to the reinforced tunnel causes a significant decrement in the shear force values of the tunnel foundation.

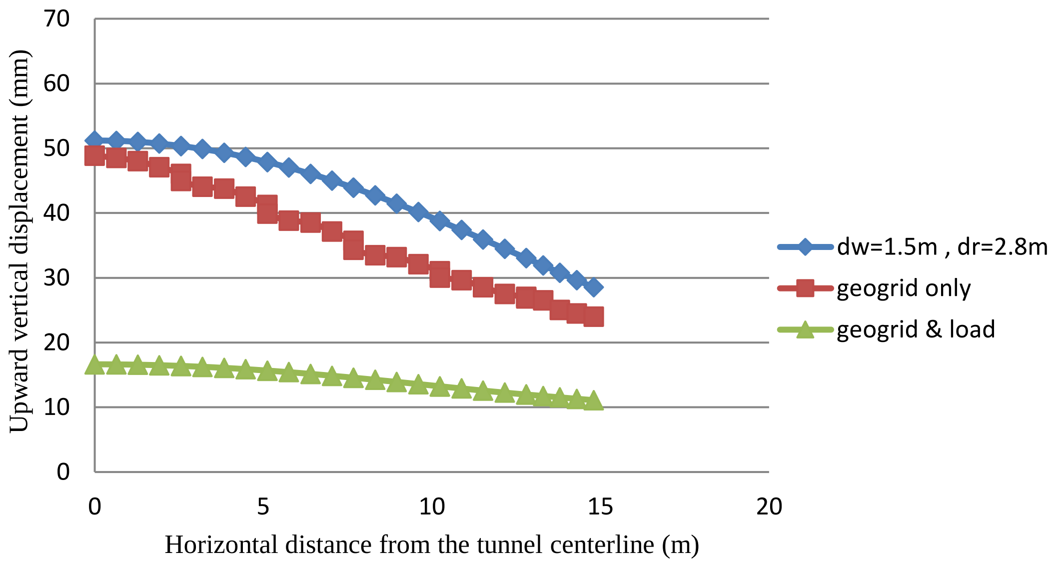

Fig. 4: Vertical displacement of the foundation for the non-reinforced and the reinforced tunnel.

The bending moment distribution starts with maximum positive value at the foundation center. Then, the bending moment decreases gradually reaching maximum negative value at the connection of the foundation with the wall. At the same place, the negative bending moment converts to positive with approximately the same value of the negative as depicted in Fig. 7. Beyond the positive bending moment value, the bending moment decrease gradually until reaching zero value at the foundation edge. The distribution of the foundation bending moment is approximately the same for the non-reinforced and the reinforced tunnel. The reinforced tunnel with geogrid material doesn't cause any improvement. While utilizing applied load in the reinforced tunnel leads to an important reduction in the bending moment values. This is attributable to the reduction in the differential vertical displacement of the foundation as using applied load in the reinforced tunnel.

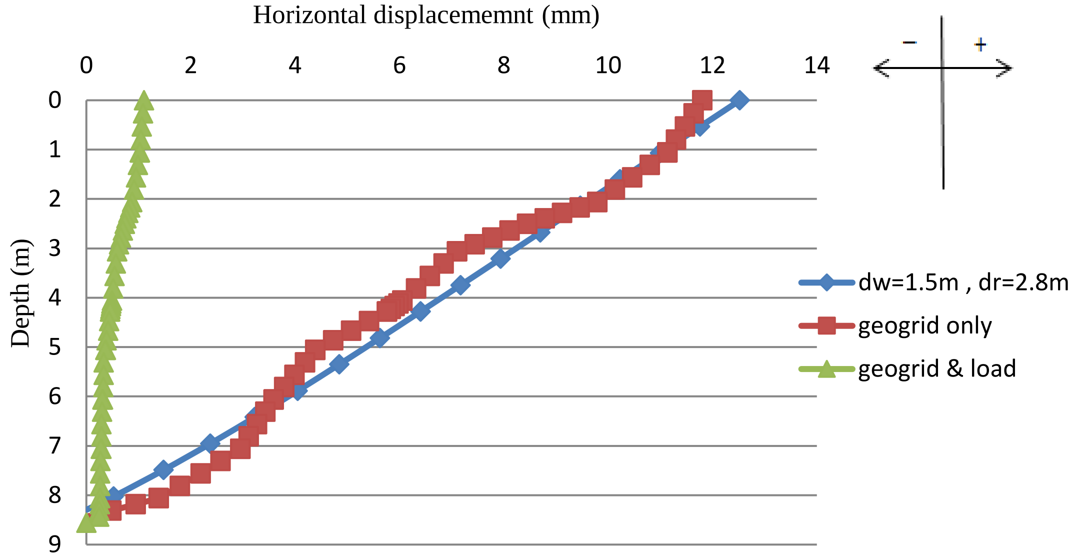

Fig. 5: Horizontal displacement of the walls for the non-reinforced and the reinforced tunnel

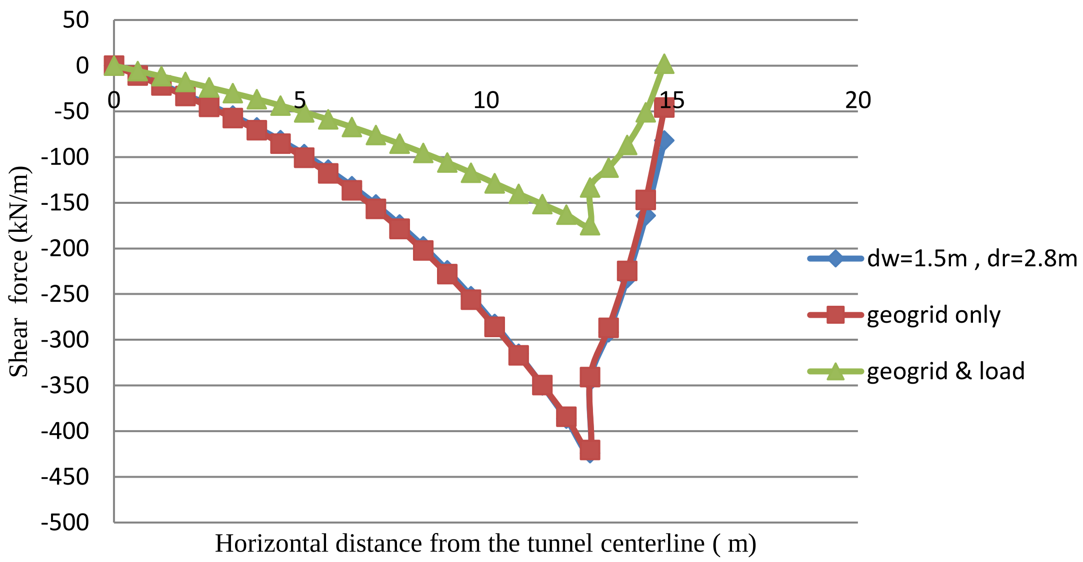

Fig. 6: Shear forces distribution in the foundation for the non-reinforced and the reinforced tunnel

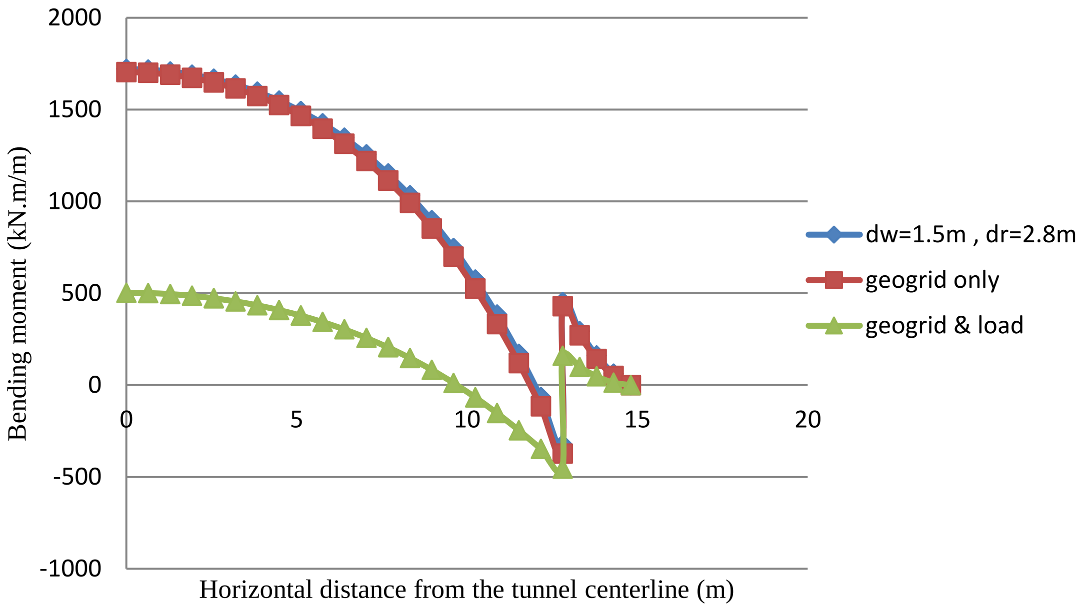

Fig. 7: Bending moment distribution in the foundation for the non-reinforced and the reinforced tunnel

Internal forces in the retaining walls

The shear force and bending moment distributions of the retaining walls were also calculated for the non-reinforced and the reinforced open tunnel. The shear force as well as the bending moment start with a zero value at the wall top. Then, their values increase gradually until reaching maximum value at the wall connection with the foundation. The non-reinforced and the reinforced tunnel induce the same trend for the shear forced and bending moment of the wall. Reinforcement of the tunnel soil with geogrid layer doesn't imply any improvement in the wall internal forces as shown in Figs. 8 and 9. While utilizing loads in the reinforced tunnel causes decrements in the internal forces of the wall especially in its lower parts. But the reduction in the internal forces of the foundation is greater than those of the walls.

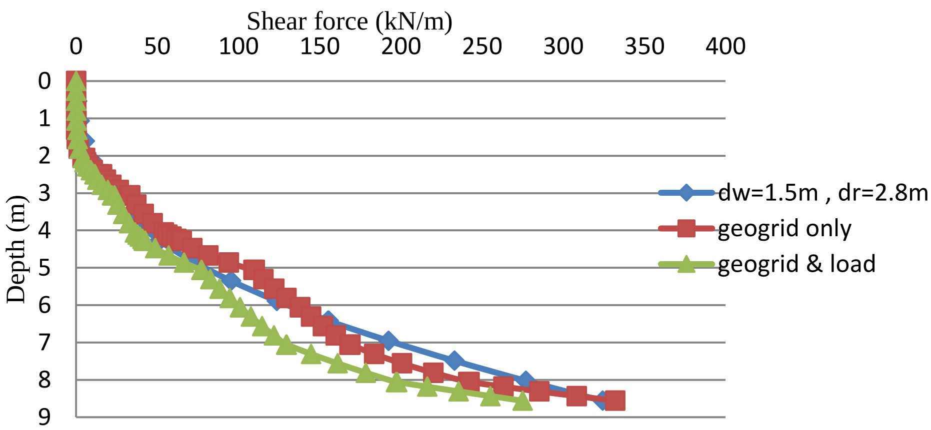

Fig. 8: Shear forces distribution in the walls for the non-reinforced and the reinforced tunnel

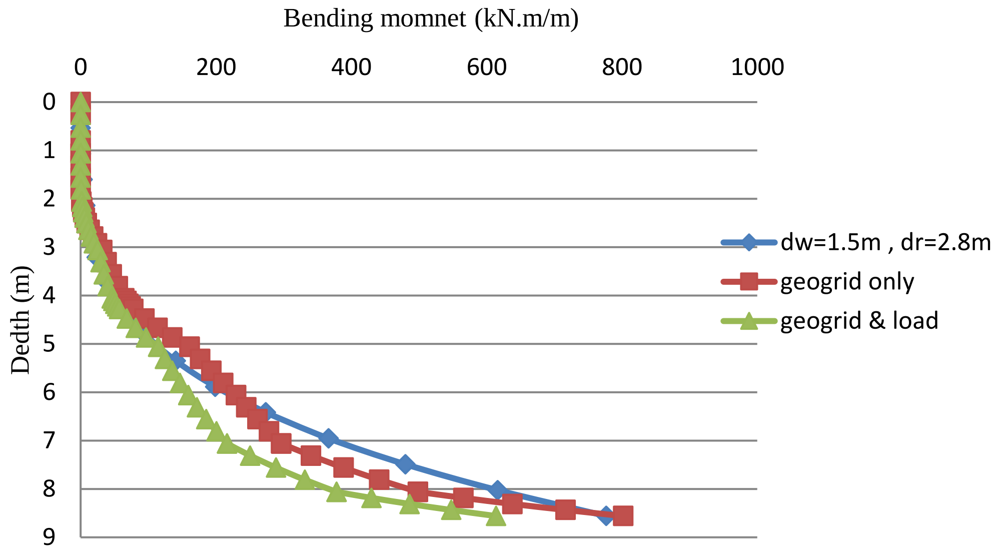

Fig. 9: Bending moment distribution in the walls for the non-reinforced and the reinforced tunnel

CONCLUSIONS

The open tunnel part was simulated in the current study containing non-treated and reinforced soil with and without loads utilizing 2D Plaxis program package. The open tunnel part consists of two walls and a combined foundation. The backfill soil of the wall was reinforced by geogrid layers as well as a geogrid layer was located in the middle of the gravel mat under the foundation. Based on the numerical analyses results, the followings can be concluded;

- The non-treated open tunnel sustains from somewhat high values of upward vertical displacement and internal forces in the combined foundation. Consequently, the cantilever retaining walls induce also somewhat high values of lateral displacement toward the backfill. Moreover, the retaining walls imply also high values of internal forces especially in lower wall parts.
- Reinforcing soil around the tunnel with geogrid material leads only to a slight reduction in the upward vertical displacement of the foundation. But there are no improvements in the bending moment and shear force values of the walls and the foundation as well as in the lateral deformation in the wall.
- Applying dead and live loads on the floor of the reinforced tunnel leads to a significant reduction in the upward vertical displacement, shear force and bending moment of the tunnel foundation. Consequently, the loads cause also an important reduction in the lateral displacements of the walls. But there is a slight enhancement in the shear force and bending moment values of the wall.
- Therefore, adding dead and live loads on the floor of the reinforced open tunnel part, as occurring in fact, improves effectively the performance of the tunnel. Moreover, applying loads has also an economical benefit by reducing the quantity of the used reinforced concrete especially in the tunnel foundation.

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