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Numerical and experimental study of tunneled raft foundation

Estudio numérico y experimental de la base tunelada

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ABSTRACT

Models are created, inspected in the experimental research, and compared to the numerical study in the PLAXIS 3D.V20 program in order to stay up with the advancement of studies in the area of geotechnical engineering. The purpose of the model is to investigate how existing tunnels affect shallow foundations. a simulation of reality a tunnel with specifications [Elastic modulus = 70 Gpa, Poisson's ratio = 0.33] with three locations for the tunnel 15, 30, 45 cm measured from the bottom of the foundation), an iron box with dimensions (80*80*60 cm), and a foundation with dimensions (20*20 cm). It was discovered that the tunnel's position significantly affects the soil's ability to support additional loads, and that the effect diminishes as the distance between the foundation and the tunnel grows. The tunnel's depth (15 cm) increased by the most—105.9%—followed by its depth (30 cm), which increased by 21.5%, and its depth (45 cm), which increased by 3.9%.

Keywords: Numerical; Experimental; Tunnel; Raft Foundation.

RESUMEN

Los modelos son creados, inspeccionados en la investigación experimental y comparados con el estudio numérico en el programa PLAXIS 3D.V20 para mantenerse al día con el avance de los estudios en el área de la ingeniería geotécnica. El propósito del modelo es investigar cómo los túneles existentes afectan las cimentaciones poco profundas. una simulación de la realidad un túnel con especificaciones [módulo elástico = 70 Gpa, relación de Poisson = 0,33] con tres ubicaciones para el túnel 15, 30, 45 cm medidos desde el fondo de la cimentación), una caja de hierro con dimensiones (80*80 *60 cm), y una base con dimensiones (20*20 cm). Se descubrió que la posición del túnel afecta significativamente la capacidad del suelo para soportar cargas adicionales y que el efecto disminuye a medida que crece la distancia entre los cimientos y el túnel. La profundidad del túnel (15 cm) fue la que más aumentó (105,9%), seguida de su profundidad (30 cm), que aumentó un 21,5%, y su profundidad (45 cm), que aumentó un 3,9%.

Palabras claves: Numérico; Experimental; Túnel; Fundación balsa.

1. INTRODUCTION

Over the past few decades, tunneling has seen extensive use. Such infrastructures are now ubiquitous in metropolitan areas, providing a wide range of utilities (transportation, power lines, ditches, etc.) as a result of the rapid population expansion and industrial activity. Because tunnels pass through a variety of geological conditions and overburden pressures, appropriate tunnel construction is critical to their long-term stability. Rapid demand for both surface and subterranean construction. This occasionally required us to build over tunnels or tunnel beneath built-up areas. Many structures have been developed and built near existing tunnels in recent years to take use of the limited space available in congested metropolitan areas. It is critical in the design of the project to guarantee that any existing subsurface transit infrastructure near the proposed construction site can continue to operate securely both during and after construction. If the erection of a structure affects the integrity of an existing tunnel, substantial damage may occur, necessitating costly repairs and time waste. As a result, understanding the interaction and effect of a newly constructed building covering an old subterranean tube is critical for stability. New developments adjacent to pre-existing tunnels disturb the stress path in the ground, which can affect the durability and safety of the tunnels. The relationship between a tunnel and buildings has been studied by several researchers. For instance, one of them studied the response of a structure to surface deformations caused by digging, taking into consideration the presence of fractures in the structure, the impact of the type of construction, and ground rigidity (Son & Cording, 2011). Another one used centrifuge experiments to assess the reaction of buildings to tunnelling, taking into account elastic and non-elastic building behaviour with varying shape and rigidity (Farrell et al., 2014). In several studies, researchers analyzed how new buildings' foundations, excavations, and gaps will affect preexisting tunnels. For example, the impact of building a structure above metro tunnels was investigated (Naqvi et al., 2021). The scientists used OptumG2 finite element software to replicate the Delhi Metro phase 3 tunnel project. Model elastoplastic testing employed the tunnel's 20-meter depth. To assess ground settlement, empirical and semi-empirical studies have been conducted in clay and sand (Franza & Marshall, 2019). The ground settlement is examined using a 2D analysis, which reveals that the primary influencing parameter is the elastic parameter of the soil (Hamrouni et al., 2019). The study is based on various assumptions. According to frame structure finite element modeling, the existence of structure can decrease differential settlement and horizontal ground displacement compared to greenfield condition (Boldini et al., 2018)v.

2. METHODOLOGY

A well graded sandy soil is used in this studying. The model of raft was made as alloy aluminum and The tunnels are modeled using smooth aluminum hollow section. The laboratory work was analyzed using the PLAXIS 3D V.20 finite element software. Figure 1 shows the sieve analysis for sandy soil.

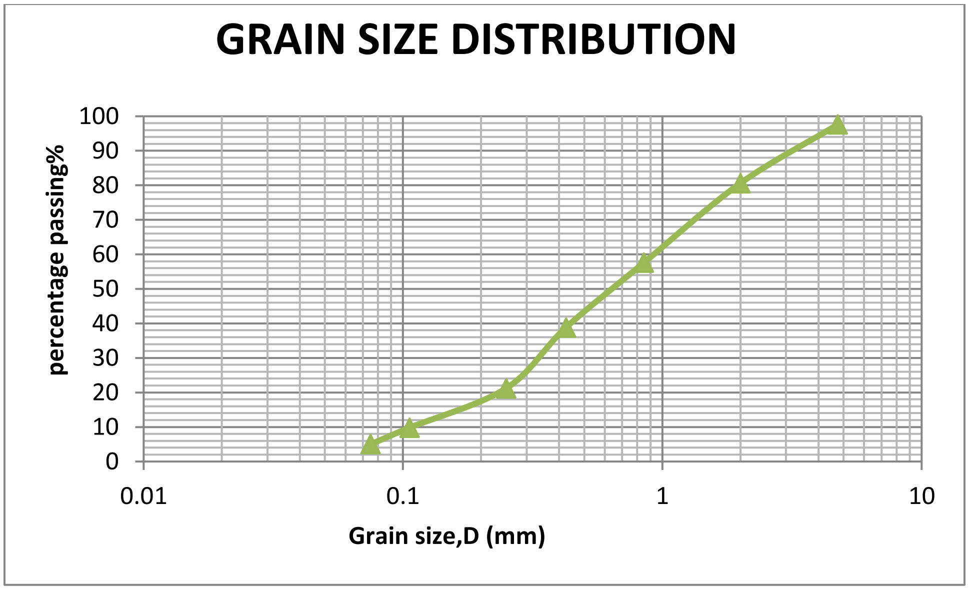

Figure 1. Sieve analysis of sandy soil

2.1. Case Study

A computer-guided finite element technique to numerical modeling of structural response is one of the most effective approaches for comprehending engineering problems. As a result, a validation case is selected between the PLAXIS 3D V.20 findings and those of the experimental attempt, lending confidence to the computer program outcomes.

2.1.1. Experimental Study

The experimental model study was performed with the size of the raft (20×20×1.2) cm. The tunnel dimensions are embedding length, L = 80 cm and hollow section having a square cross section of 10cm× 10 cm and a thickness of 2 mm. With three depth of tunnel (15,30,45) cm.

2.1.2. Numerical Study

The numerical model study is performed on PLAXIS 3D V.20 software. the raft (20 × 20 × 1.2) cm. The tunnel dimensions are embedding length, L = 80 cm and hollow section having a square cross section of 10cm× 10 cm and a thickness of 2 mm. With three depth of tunnel (15,30,45) cm.

3. TEST SETUP

A labor test model with dimensions of (800*800*600) mm was created in the laboratory to approximate reality, as illustrated in Figure 2. To withstand the imposed forces, this tank was housed in an iron framework. This structure is equipped with a hydraulic jack with a capacity of 50 tons and a load cell with a capacity of 5 tons. To assess the weight on the raft, the cell was linked to a data logger. To measure the stresses in the tunnel, accurate stress gauges were installed to the tunnel and linked to a data logger. To measure the settlement, utilize (LVDT) 100 mm and link it to the data logger.

4. MATERIAL MODEL

4.1. Soil, Raft and tunnel

Various materials are used to construct the test model: sandy soil, alloy aluminum raft, and aluminum tunnel The soil sample was obtained from thi-Qar Governorate, southern Iraq. Many laboratory tests are conducted on it in Table 1 this table shows the material properties for numerical and experimental modelling. The use of aluminum pipe with square section as a model for the tunnel. Aluminum alloy as a raft.

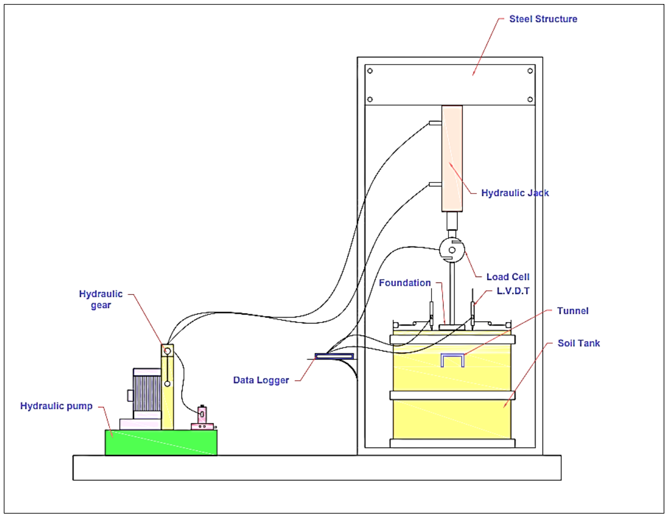

Figure 1: Scheme of the experimental work

Table 1. Material properties for numerical and experimental modeling

Material	Type of material behaviour	Size (mm)	Density KN/ m^3	Elastic modulus $\frac{kN}{m2}$	Poisson's ratio	Angle of internal friction φ
Sandy soil	Mohr Coulomb Model	800×800×600	17.08	20×103	0.25	35
Tunnel (aluminum)	Linear Elastic Model	L800×(100*100)	27.5	70×106	0.33	-
Raft (alloy aluminum)	Linear Elastic Model	200×200×12	28	70×106	0.33	-

5. TUNNELED RAFT MODELS

Model for the tunnel in this study were created using smooth aluminum hollow sections with 2 mm thicknesses and a square cross section (10*10) cm, there are three depth of tunnel to the detection effect of presence of tunnel on shallow foundation. was also used model of the raft in the test (20*20*1.2) cm.

6. DENSITY METHOD

The soil used in the test is sandy soil, which was compacted into a steel container in 12 layers at a height of 5cm using a steel tamping hammer with equally distributed strokes and density (1.708g/cm). to guarantee minimum cementation of the soil prior to testing, a 3% hygroscopic water content was added to the sand before compaction and pouring.

7. THE EMPLOYING OF A VERTICAL LOAD:

A vertical load was applied using a mechanical jack. The test was continued recording a continuous settlement of the tunnel raft under specific load incremental. The value of applied load was read using a load cell, while the central Settlement of the raft was measured using LVDT of (LIN: ±0.1%) resolution. The above steps were repeated for each test.

8. PLAXIS COMPUTER PROGRAM

Geotechnical applications frequently necessitate Anisotropic and influenced by time behavior of soils and rocks. complex constitutive models for simulating the nonlinear, PLAXIS, The finite element software, created by Bentley Systems, is user-friendly, provides reliable results that geotechnical experts around the world use. Users can compute deformation and stability to evaluate geotechnical risk in a variety of geomechanics applications, including excavations, embankments, foundations, tunneling, mining, and reservoirs. To meet the project's goals and budget, a variety of 2D and 3D versions are available, including ones with finite element analysis (FEA), limit equilibrium, dynamics, transient ground water flow, and thermal capabilities. With little prior knowledge, you may solve geotechnical problems quickly and precisely using geometry design tools and automatic settings.

8.1 Mesh generation

The 10-node tetrahedral element serves as the foundational soil element in the 3D finite element mesh. Raft and tunnel represented by plate element which is a structural element use to model thin two- dimensional structures in the ground with the significant flexural rigidity. plates are composed of 6-node triangular plate element. Tunnel-soil interaction modeled by use joint element, interfaces element are composed of 12-node interface elements (joint element). relative stiffness of the interface element (Rin)=0.75 (Brinkgreve et al., 2013).

8.2 Meshing

The meaning of meshing–or mesh generation–is: defining continuous geometric shapes (such as 3D models) using 1D, 2D, and 3D shapes (medium mesh) as shown in Figure 3.

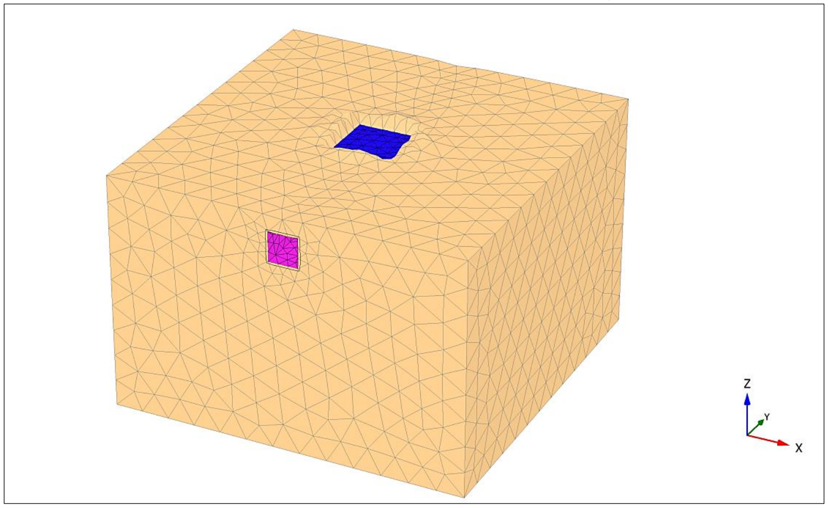

Figure 3. mesh of raft-tunnel model

8.3 Problem of Modeling

Mohr’s-Coulombs Model is selected to model how soil will behave in PLAXIS for practical importance, simplicity and the availability of the parameters needed. tunnel and foundation are representing in program by linear elastic model, it's based on Hooks law.

8.4 Boundary Conditions

The default parameters for PLAXIS 3D.V20's boundary conditions were used. Ui denotes movement in the i-direction. The bottom limits are fixed horizontally. The horizontally fixed and unrestricted vertical limits in the upward direction. There is no restriction on the upper horizontal boundary in any direction. Figure 4 shows the boundaries.

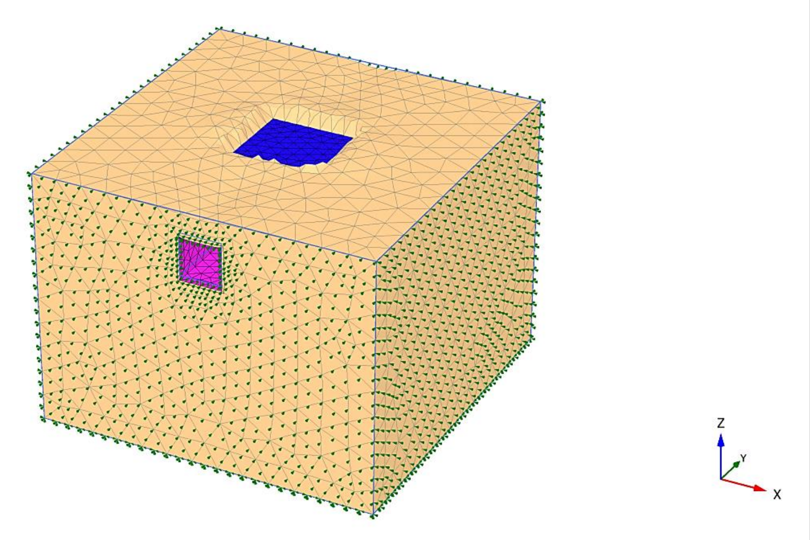

Figure 4. boundary condition

8.5 Effect Location of Tunnel on Bearing Capacity of Raft-Tunnel

The displacement control approach (The displacement was constant and its value was 2.5 cm) use in PLXIS 3D.V20 To analyze a shallow foundation with a tunnel under it model, three different depths were chosen from the bottom of the foundation surface (15,30,45) cm respectively. Notes that depth 15cm the highest bearing capacity increasing (105.9%) because The tunnel's location is near to the foundation, acting as a supporting foundation that contributes to the transmit and distribute soil loads, enhancing the soil's capacity to withstand external stresses. The depth of 30 cm was far from the impact area, so the contribution was significantly reduced, so the amount of increase was (21.5%).that last depth is 45 cm. The effect of the tunnel has reduced to (3,9%), so the foundation has become the carrier of external loads. Figures (5-7) Show the impact of the tunnel site. Table 2 show the details of bearing capacity

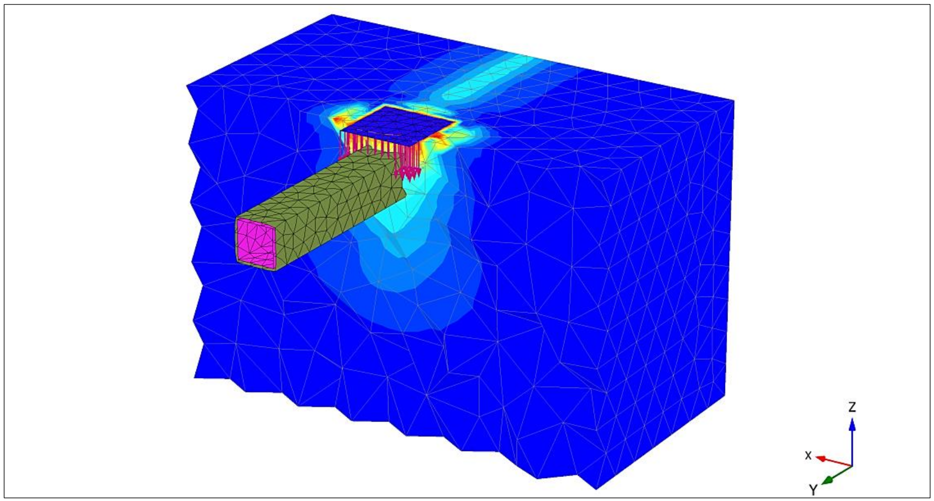

Figure 5. Total displacements |u| (scaled up 5.00 times) Maximum value = 2.740 cm (Element 4918 at Node 3573

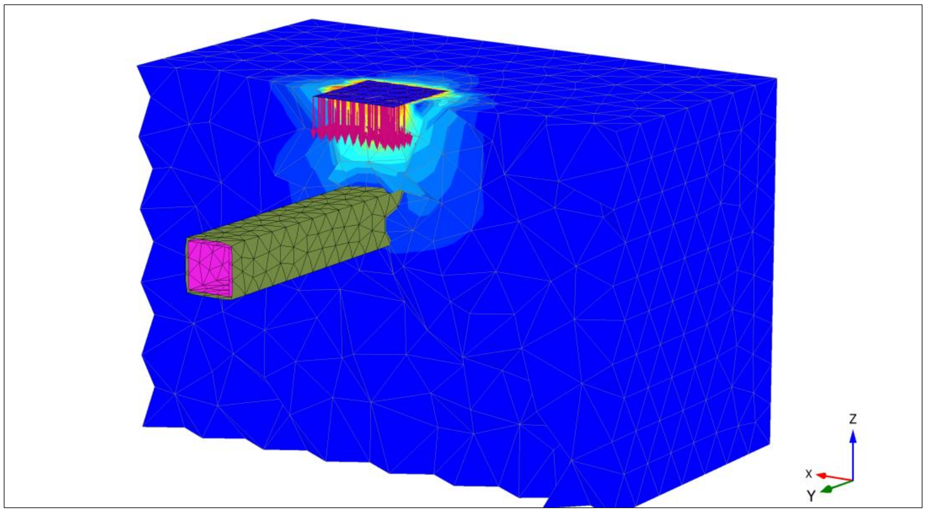

Figure 6. Total displacements |u| (scaled up 5.00 time) Maximum value = 3.033 cm (Element 2963 at Node 3527)

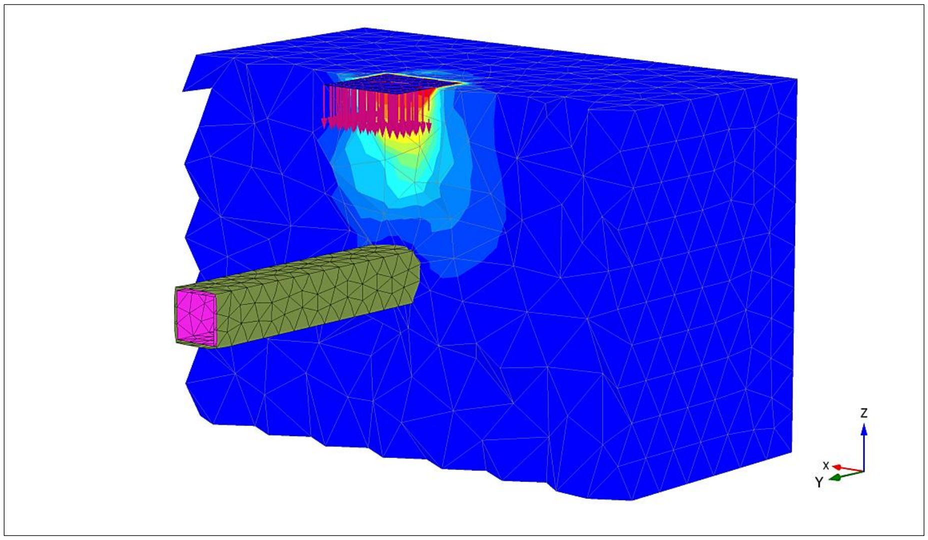

Figure 7. Total displacements |u| (scaled up 5.00 times Maximum value = 2.500 cm (Element 1744 at Node 372)

8.6 Bearing Capacity of Raft

Figure 8 depicts the load's impact only when the foundation is present, where the soil's carrying capacity was 140$\frac{KN}{m^2}$ As shown in Table 2.

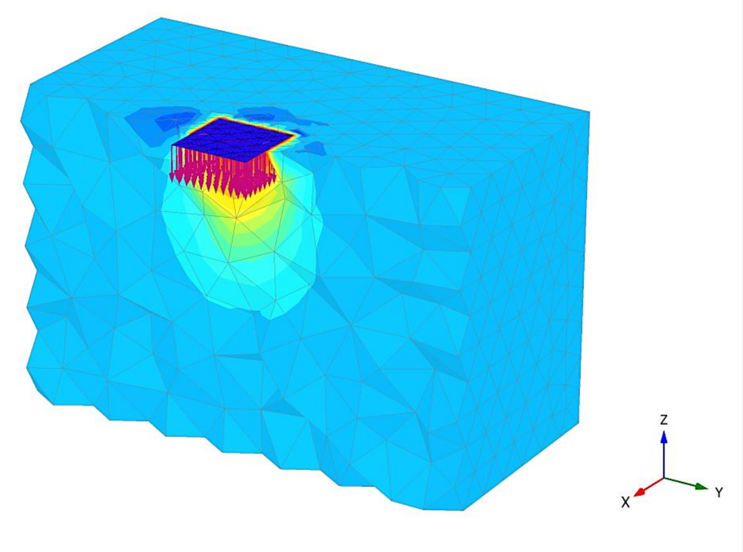

Figure 8. Total displacements uz(scaled up 5.00 times), Maximum value = 0.6284 cm (Element 3364 at Node 2257), Minimum value = -2.500 cm (Element 56 at Node 12)

Table 2. details of bearing capacity

Model (20x20)cm	Fu(KN)		Qu($\frac{KN}{m^2}$) numerical	Qu($\frac{KN}{m^2}$) experimental
	NU	EX		
Without tunnel	5.1	5.6	127.7	140
D 15	10.5	12	262.5	300
D30	6.2	6.4	155	160
D45	5.3	5.8	132.5	145

9. RESULTS AND DISCUSSION

After examining the model (the tunnel under the raft foundation 20 * 20 * 1.2 cm) and for three depths (15,30,45) cm, as well as examining the condition in the absence of a tunnel, the data was recorded by means of a data logger connected to a personal computer, and the data was plotted load _ settlement In the Excel program for analysis and comparison. In the numerical analysis of the model, the same samples were taken in the experimental studies with the same specifications, the displacement control approach, then the results were compared for the two studies in Figures (9-12), after reviewing the results in Figures (9-12), it was shown The results in both practical and theoretical cases are close, and the PLAXIS program can be scientifically adopted for analysis and finding solutions to problems in geotechnical engineering.

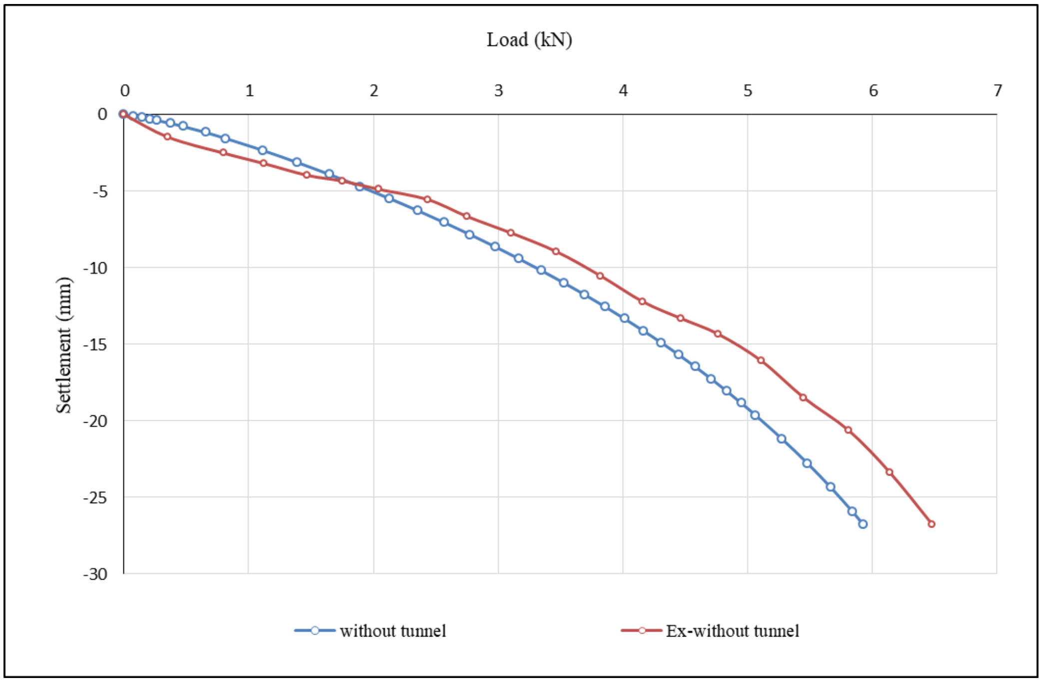

Figure 9. Load–Settlement Curve Raft (200*200) mm the parametric study.

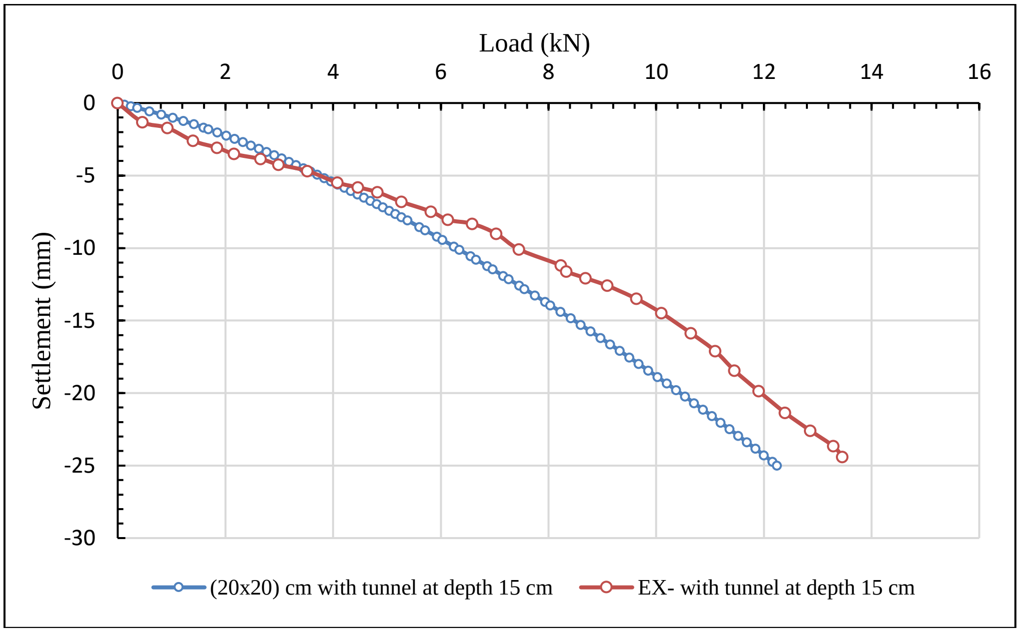

Figure 10. Load–Settlement Curve Raft (200*200) mm, depth (15)cm the parametric study.

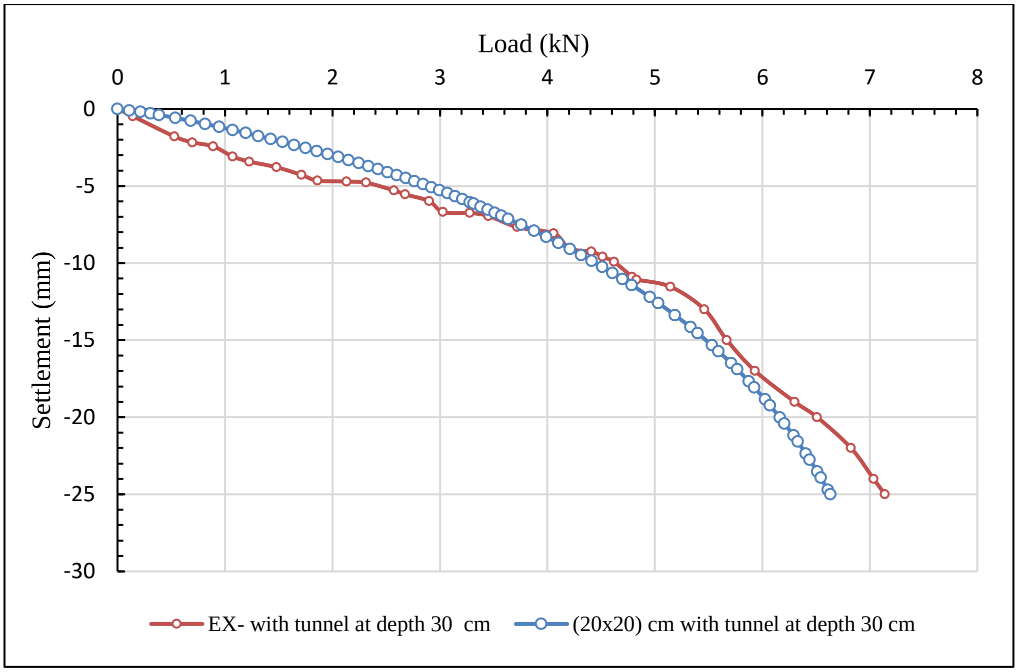

Figure 11. Load–Settlement Curve Raft (200*200) mm, depth (30)cm the parametric study.

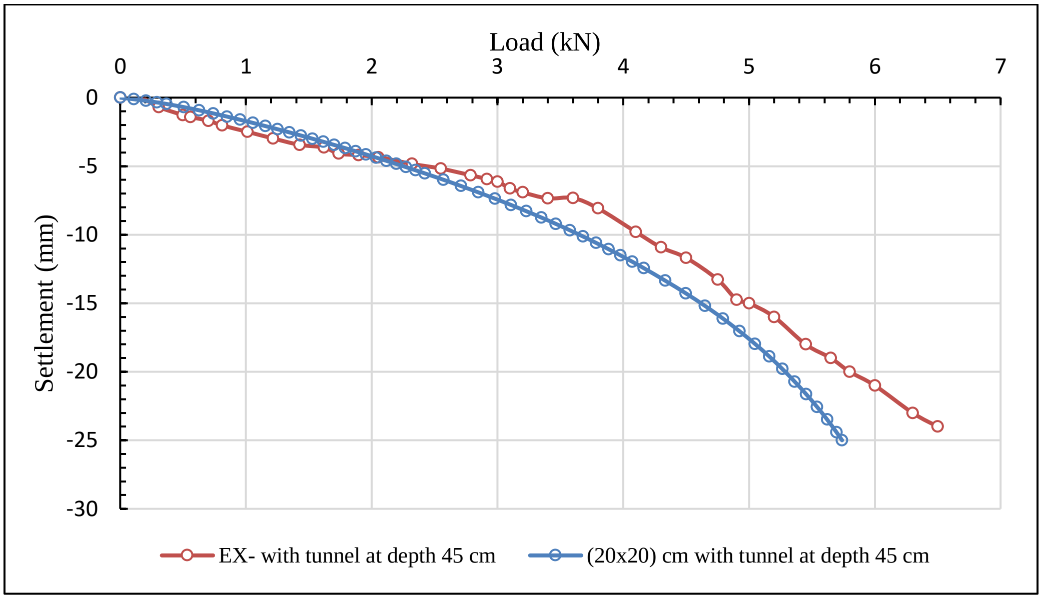

Figure 12. Load–Settlement Curve Raft (200*200) mm, depth (45)cm the parametric study.

10. CONCLUSIONS

- The location of tunnel is important parameter to detecting the effect of pre-existing of tunnel on superstructure.
- The depth 15 cm is the highest contribution to The capacity of the soil to carry heavier loads.
- other depths (30,45) cm the contribution decrease, so it disappeared in depth (45) cm permanently because it is too far from the area of influence

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SEMBLANZA DE LOS AUTORES

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