NUMERICAL ANALYSES OF HIGH-FILLED CUT-AND-COVER TUNNEL USING PLAXIS 3D

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ABSTRACT

Huge fill soil in high-fill cut-and-cover tunnels (HFCCT) generates high pressure above the tunnel, while rubber soil serves as an effective lightweight fill material to reduce weight. The main factor affecting the stability of the cut-and-cover (CCT) is reducing the load and settlement on the CCT. This paper employs finite element software, PLAXIS 3D, to conduct a numerical analysis of the HFCCT model, which includes a replacement part of sand soil and a rubber-sand mixture. Both data sets are simultaneously gathered in a direct shear test and a relative density test. Data are analyzed in the context of mixture theory and with the aid of numerical simulations. The Mohr Coulomb model uses rubber sand, and the Hardening Soil model uses sand. A numerical model is built to simulate such conditions for filling sand above (CCT) to the rubber-sand layer above the tunnel. And, using a concrete model to simulate the lining of CCT, the performance of rubber sand is measured, while the soil layer increases through the numerical results. The effect of rubber on vertical earth pressure (VEP) on CCT is compared with the varying thickness of the rubber-sand layer to obtain the best economic thickness. This study also considers the impact of settlement on CCT. The PLAXIS output shows the layer mechanism and the minimum earth pressure in VEP that will be reached when using rubber-sand. The utilization of rubber as a substitute for soil results in a uniform load reduction mechanism and increases the bearing capacity of sand.

Keyword: - *Load reduction; Tunnels; Vertical earth pressure; Crumb rubber.*

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1. INTRODUCTION

Using a high-filled cut-and-cover tunnel (HFCCT) to create urban space is effective. The backfilling height of an HFCCT is 30 to 50 meters, more than five times that of a CCT [1]. However, a large earth column stresses the structure. Fractures in the lining cause structural degradation and make daily life harder. Thus, it is essential to study how generated earth pressure affects cut-and-cover tunnel (CCT) liner safety and stability. The test should focus on load transmission and reduction strategies. Load reduction techniques for pipes and culverts are well-studied, whereas HFCCTs are not [1]. To sustain ground pressure, a (HFCCT) lining construction must be thicker than a CCT [2]. The CCT's lining construction may be fine-tuned to increase safety and reduce thickness due to backfilled ground pressure [3]. However, an extremely thick lining may cause concrete fractures from shrinkage after hardening, reducing tunnel durability. Cracks occur due to CCT displacement and internal pressures. Any unwarranted lining movement might cause a structural system change, rendering the whole structure unstable and vulnerable [4]. To reduce soil column pressure on the HFCCT, rubber might be used as a lightweight fill material. This reduces tunnel pressure. Under confinement, stiff particles interact more, making transition mixes rubber-like at low confinement and sand-like at high confinement [5]. Confinement stress affects transition mixes greatly [6],[7]. Rubber content decreases anisotropic characteristics, resulting in a minimum in an intermediate combination (sf≈0.4–0.5). However, a rise in rubber percentage in the mixture increases shear stress at the contact, making it more anisotropic owing to its high particle friction angle [8]. Rubber particle size and proportion depend on the combination purpose. A 50:50 mix of sand and rubber reduces tension [9]. Standard automotive tires with a 40% ratio reduce vertical ground pressure at the CCT's center. About four times the size of sand, rubber particles average 1.22mm (d_{50}). Lightweight fill material (LFM) thickness also affects the reduction ratio [10].

2. PROGRAM VERIFICATION

As previously stated, PLAXIS 3D is not being utilized to address these common issues. An evaluation of the paradigm in PLAXIS was conducted by comparing the outcomes produced by the ABAQS [11] and PLAXIS programs. The finite element model utilized in ABAQS operates under the assumption of rigid gradients. A type of element with a plane strain is chosen to represent the HFCCT. The material properties were simulated using the linear elastic model to represent the structure of CCT. The backfill was modeled using the Mohr-Coulomb elastoplastic criterion. The simulation of the ABAQUS model was conducted using PLAXIS. A comparison of stress and displacement in the finite element analysis for both PLAXIS and ABAQUS is illustrated in Figures 1 and 2.

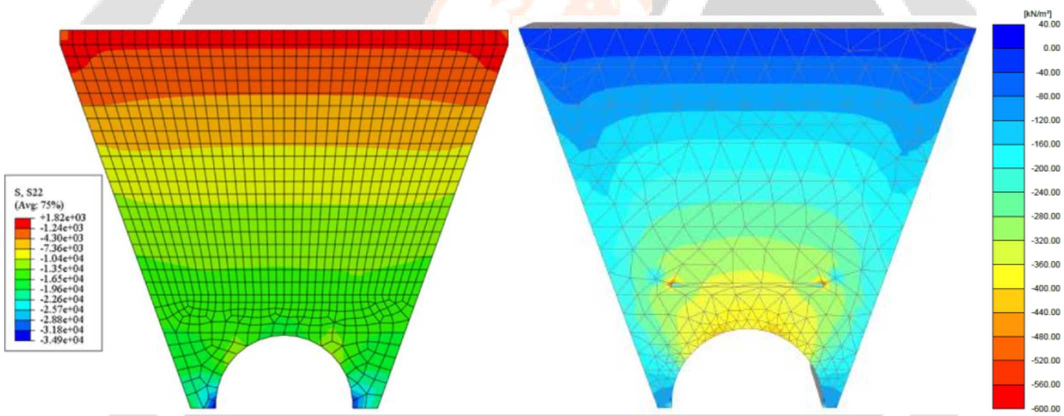

Fig -1: Comparison between stress in ABAQS with 1/25 scale and PLAXIS in real scale

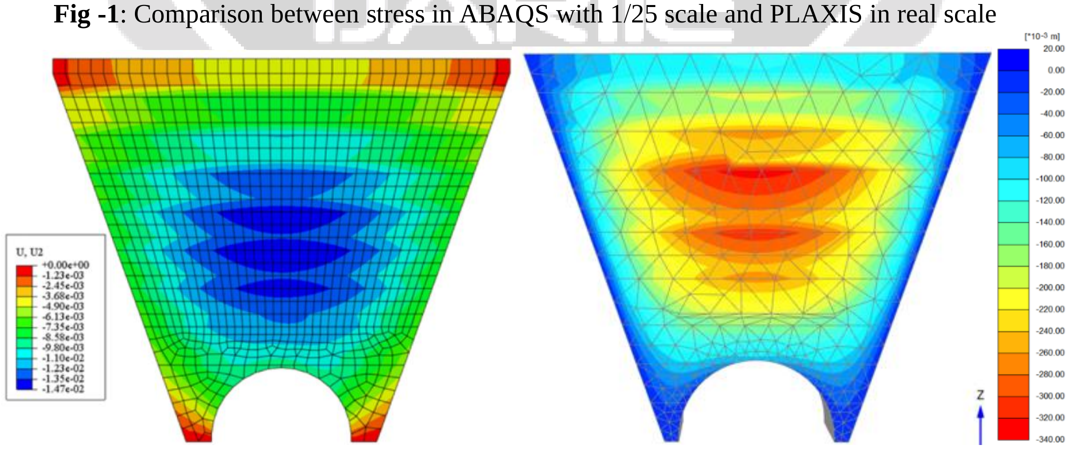

Fig -2: Comparison between displacement in ABAQS with 1/25 scale and PLAXIS in real scale

3. OUTLINE OF ANALYSIS

Numerical analysis has been carried out on 14 m diameter of tunnel lining with height 7m and thickness 0.7m. The backfill height above CCT is 28m filling with sand soil. We assumed that the slopes were rigid, simulated by concrete material. Mixture of rubber-sand with 40:60 ratio used over CCT to reduce the pressure. This mixture was placed with nine different thickness and placed at top of CCT. Table 1 illustrates parametric study for all cases in analysis with respect to height of tunnel (H).

Table -1: Testing Schemes

Case	Load Reduction Method	Thickness
R1	None	None
R2	Rubber-Sand	0.6H
R3	Rubber-Sand	0.9H
R4	Rubber-Sand	1.2H
R5	Rubber-Sand	1.5H
R6	Rubber-Sand	1.8H
R7	Rubber-Sand	2.1H
R8	Rubber-Sand	2.4H
R9	Rubber-Sand	2.7H
R10	Rubber-Sand	3H

3.1. Properties of Materials

Medium sand and rubber-sand were used in the present analysis. These materials were collected from locally available sites and tested in the Geotechnical engineering Lab, Building Research Center. The physical properties of sand are specific gravity = 2.65, angle of shear resistance = 40°, maximum dry unit weight = 17.7 KN/m^3, minimum dry unit weight = 15.1 KN/m^3, and with an average particle size (d_{50}) 0.7 mm. The rubber particles used in this investigation were generated by shredding scrap tires and had an average particle size (d_{50}) of 1.8 mm, a relative density (Gs) of 1.05, and a density of 0.47 g/cm^3. The rubber particles are characterized by their angular and irregular shapes, with an average size approximately four times larger than that of sand in the combination. The physical properties of rubber-sand were made of 40% rubber and 60% sand. The maximum and minimum dry unit weights of the mixture are 15.3 KN/m3 and 12.6 KN/m^3 respectively. The cohesion and angle of internal friction of mixture were 9 KN/m^2 and 23° respectively with specific gravity = 2. Tunnel lining material is concrete with mechanical parameters the elastic modulus 31 Gpa and uniaxial compressive strength 22.5 Mpa. The configuration of the sand and rubber used in the test is shown in Fig. 3.

Fig -3: (a) Sand in mixture, (b) Scrap tire rubber particles

3.2. Finite Element Model

FEM study was carried out by finite element software, PLAXIS 3D. A model was generated in PLAXIS 3D as shown in figure 3 and analyzed using Mohr–Coulomb failure criterion for both backfill sand and rubber-sand with Hardening soil model for soil model and Mohr model for rubber-sand. To get parameters for the backfill soil and rubber-sand material in hardening soil model, compression index and swelling index or reloading index were used as alternative parameters as shown in table 2. The Concrete model is an advanced model for simulating the behavior of concrete. The material parameters for lining and slope are given in table 3.

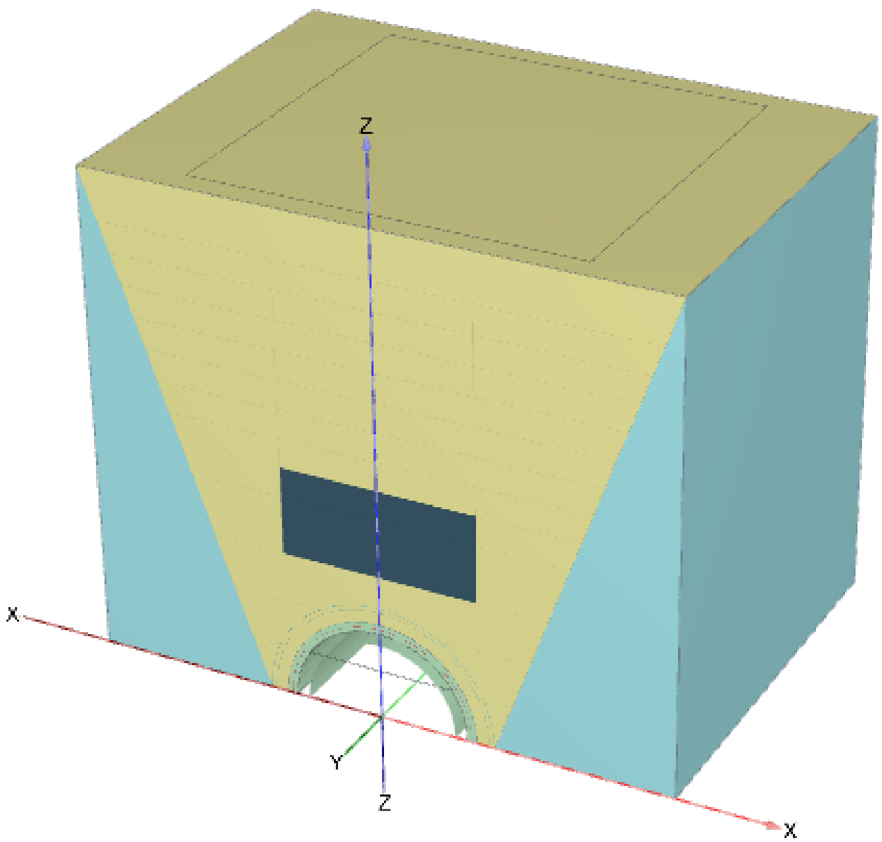

Fig -3: Schematic view of the of numerical model for R3

Table -2: The parameters utilized in The FEM analysis for both Sand and Rubber-Sand

Model Parameter		Backfill	Rubber-Sand
Soil model		Hardening soil	Mohr model
Unit weight		17.7 KN/m^3	15.3 KN/m^3
Stiffness	E_{50}^{ref}	50000	26000
	E_{oed}^{ref}	40000	
	E_{ur}^{ref}	120000	
Strength	C	1 KN/m^2	9 KN/m^2
	φ	40°	35°
	ψ	10°	0
Stress-dependency	Power(m)	0.5	0.5
	P_{ref}	100 KN/m^2	100 KN/m^2
Interfaces	Strength determination	Rigid	Rigid
	R_{inter}	1	1

Table -3: The parameters utilized in The FEM analysis for both Slope Face and CCT

Model Parameter	Slope	CCT Tunnel
Soil model	Concrete	Concrete

Unit weight		24 KN/m^3	25 KN/m^3
Stiffness	E_{28}	300e^5 KN/m^2	310e^5 KN/m^2
	v	0.15	0.2
	E_1/E_{28}	1	0.7
Strength	Fc_{28}	33000 KN/m^2	22500 KN/m^2
	φ_{max}	35°	35°
	ψ	13°	13°
Interfaces	Strength determination	Manual	Manual
	R_{inter}	0.8	0.8

4. RESULTS AND DISCUSSION

This study mainly focuses on discussing the VEP at the CCT and vertical displacements throughout the CCT's cross-section. In order to get the best thickness can used on rubber-sand layer to reduce the earth pressure above CCT and improve the behavior of soil.

4.1. Earth Pressure above CCT along Horizontal axis

Figure 4 shows the VEP above the CCT height when the backfill height is 35 m. The maximum VEP values appear close to the CCT; the values above the CCT are the lowest. For the normal model, the peak VEP values shown when x = 0, and the lowest value appears at the position of x = 7.0. It also shows using rubber can help to distribute the VEP more uniformly. The curves for case R5 with T = 1.5H show the uniform VEP above the CCT. In addition to uniform VEP, the earth pressure reduces by 13% at x = 0 and 8% at x = 7. However, an increase in the thickness of the rubber-sand layer decreases in VEP without uniform distribution in VEP.

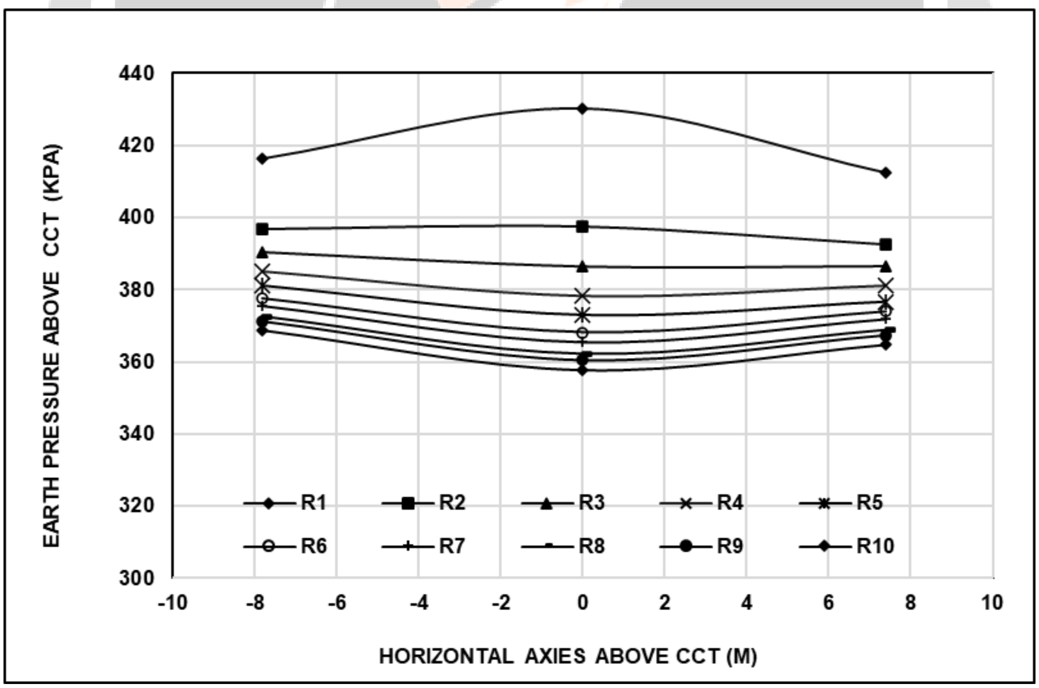

Fig -4: Earth pressure on CCT along the horizontal axis

4.2. Earth Pressure on The Vertical Axis

The VEP near the center top of the CCT, as depicted in Figure 5, is influenced by an increased backfill. The VEP exhibits a nonlinear increase when additional soil is backfilled. Also, the models with rubber-sand change the behavior of the VEP to linear increase specially in R5 model. Also, when rubber-sand layer thickness increases the VEP reduce above CCT. However, with increase of height of backfill soil slightly change in VEP.

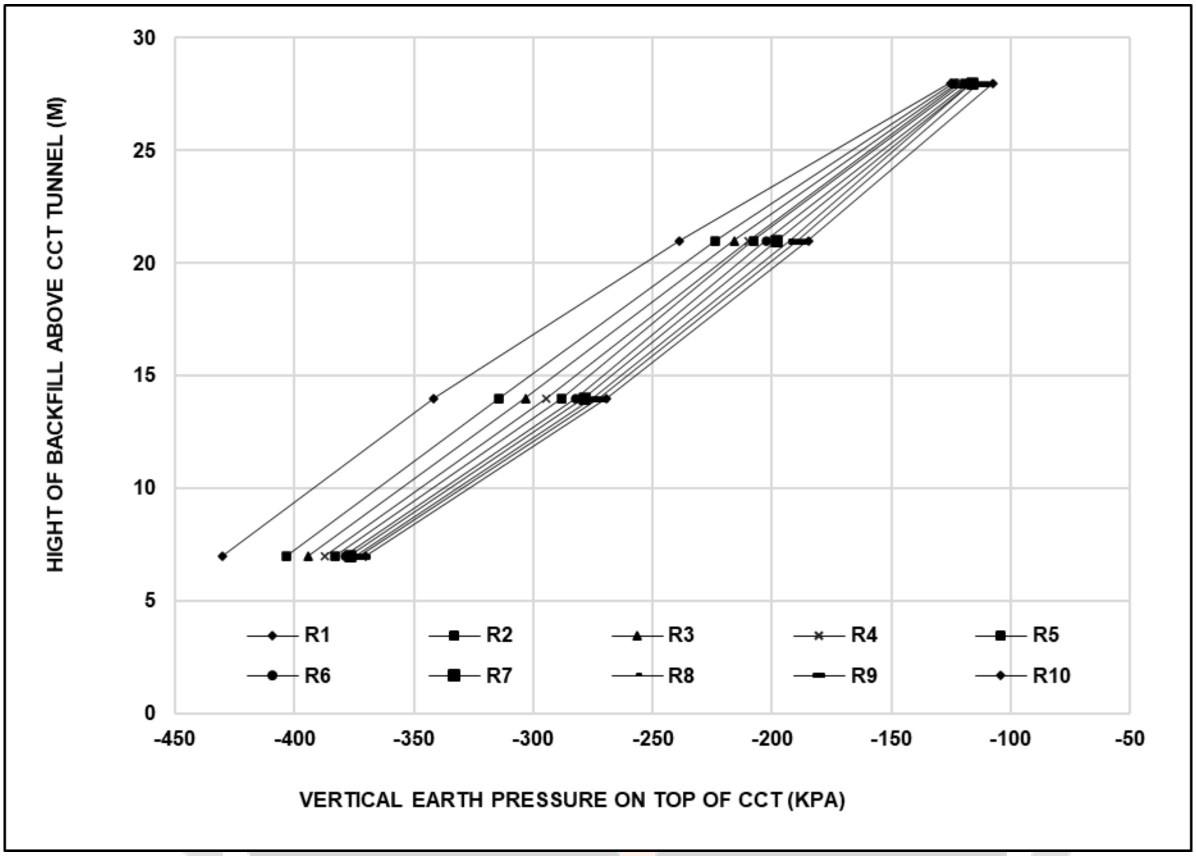

Fig -5: Vertical Earth Pressure and Height of Backfill over CCT

4.3. Soil Displacement Above Cut-and-Cover Tunnel

The vertical displacements of the soil for all cases shows on Figure 6. The settlement of on the middle top (X = 0) of the CCT for case S1 is equal to settlement in X=7 that led to U-shape and make a negative effect on the stability of CCT. Comparing cases with case S1, the difference on settlement decreases with increase in thickness of rubber-sand layer. Also, the U-shape slightly disappears with the increase in thickness of layer. According to stability condition for CCT the uniform settlement is the best solution. As mentioned before the best model for uniform earth pressure is R5, and with the analysis the results for settlement the R5 model also give the uniform Approximate values. The results from figures indicate that the rubber-sand not only gives good solution in load reduction above CCT, but also gives more stability in transmitting load.

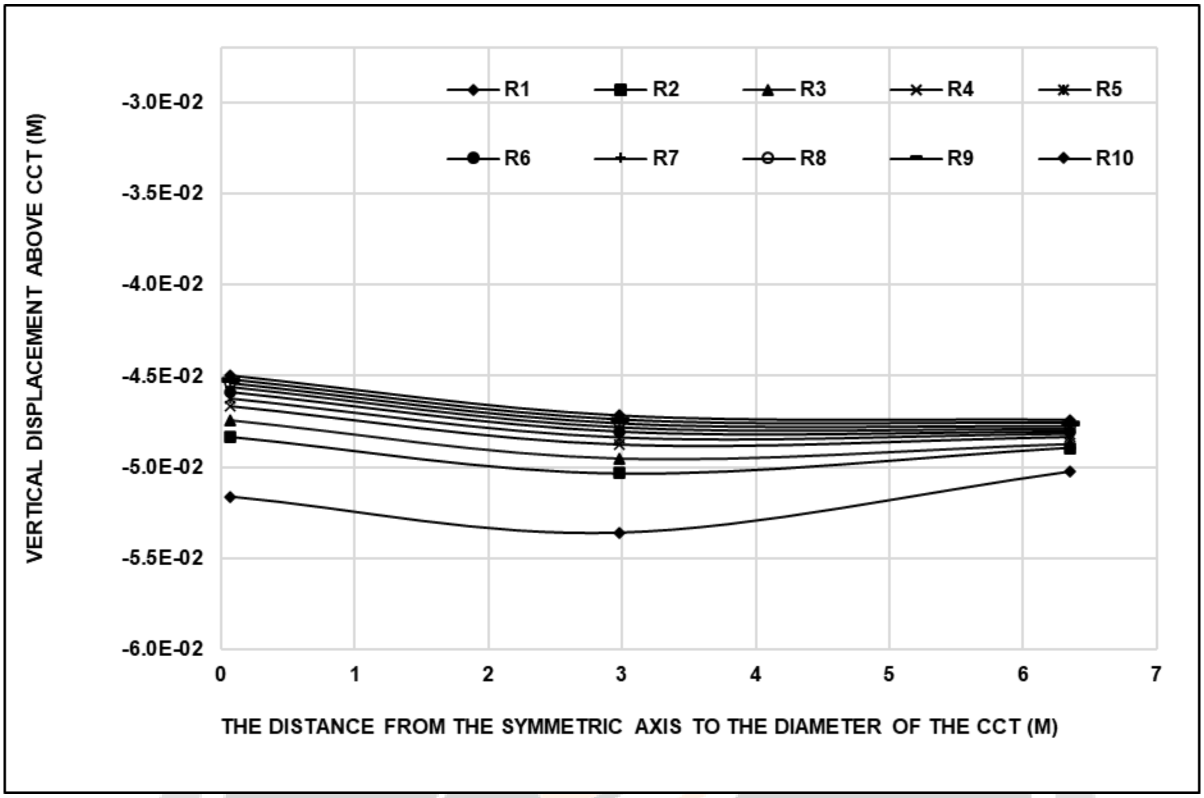

Fig -6: Vertical Displacements of Soil on Top of Middle Cross-Section of CCT

5. CONCLUSIONS

This research conducts a series of numerical model tests on HFCCTs to examine the mechanisms that reduce load. With load reduction using rubber replacement with sand the chosen thickness is 1.5H (H is the height of tunnel) give the best results in both the reduction in VEP and settlement above the CCT. Also, the layer with this thickness enhances the load mechanism that shows a uniform difference in earth pressure and settlement along the horizontal axis above CCT. The results also show that replacement of 40% of sand with rubber gives more cohesion and less in angle of internal friction of sand, that increase the bearing capacity of soil and show a linear effect along vertical axis above the CCT.

6. REFERENCES

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