Modeling Reinforced Ballast Underneath Railway Using Finite Element Method

Saad Farhan Ibrahim, B.Sc, M.Sc.Ph.D (C.E.).MIASCE, MISSMGE

College of Engineering, Al Minstansiria University; Baghdad, Iraq, drsaadfarhan @yahoo.com

ABSTRACT

Ballast provides a firm and stable platform, and support sleeper uniformly with high bearing capacity, can be improved using reinforcement at different spacing. The main purpose of this study is to evaluate the degree of improvement in bearing capacity of the ballast layer underneath railway using geogrids as reinforced materials. To study the effect of ballast thickness, mechanical properties of soft soil undrained shear strength and modulus of elasticity E, reinforcement by using Geogrid layer, a Three-dimensional finite element analysis program (ANSYS v.11.0) was adopted. It is concluded that Presence of geogrid layers leads to reduce the vertical displacement (settlement), while the corresponding load carrying capacity increased significantly. The uniformly oriented geogrid and its ability to improve soft soils cause an increase in the load carrying capacity. This was combined with the ability of ballast layer to sustain larger compressive force at advanced stages of loading. It is noticed that Theoretical solution using ANSYS Finite Element program can be adopted in the evaluation of loads and the amount of settlement for the soil layers beneath the railway lines as well as Ballast .The program gives good correlation and a sufficient degree of convergence in behavior.

Key words: ANSYS, geogrid, ballast, reinforcement, soft soil, improvement

1 INTRODUCTION

Ballasted railway tracks are those constructed on granular base material layers. The most important functions are to retain track position, reduce the sleeper bearing pressure for the underlying materials, store fouling materials, provide drainage for water falling onto the track, and rearrange during maintenance to restore track geometry. The FEM was carried out using ANSYS computer program is a large-scale multipurpose finite element program which may be used for solving several classes of engineering analyses The program contains many special features which allow nonlinearities or secondary effects to be included in the solution, such as plasticity, large strain, hyper elasticity, creep, swelling, large deflections, contact, stress stiffening, temperature dependency, material anisotropy and radiation.

2 AIM OF THE STUDY

The main aims of this study are to investigate theoretically the improvement of soft soil reinforced with Geogrid layers with or without ballast.

3 COMPRESSIVE STRENGTH OF BALLAST

Compression Strength of Ballast the compressive test strength of Ballast should be performed on cubic samples measuring (7 cm) on each edge. For each test, four samples shall be taken from quarry face, in such way as to reflect parent rock characteristics. The average compression strength of four samples shall not be less than 600 Kg/cm^2 (60MPa).

Experimental results (McDowell and Bolton) show that the mean tensile strength (σ_f) of single particle can be considered as a function of average particle size (d) as shown in the following empirical equation:-

$$\sigma_f = \frac{F}{d^2} \qquad \text{.....................} (1)$$

Where (σ_f) is the characteristic tensile stress induced within particle at failure, (F) is the force applied and (d) is the particle size. It may be noted that the tensile strength of Ballast are ignored and not considered in the present study.

4 FAILURE CRITERIA FOR SOFT SOIL

Yield criterion is widely used for finite element analysis of granular material problems (such as soil, gravel, sand, rocks….etc). In ANSYS (Drucker-Prager, 1953), the option uses the Drucker-Prager yield criterion is available with either an associated or non-associated flow rule(Figure 1).

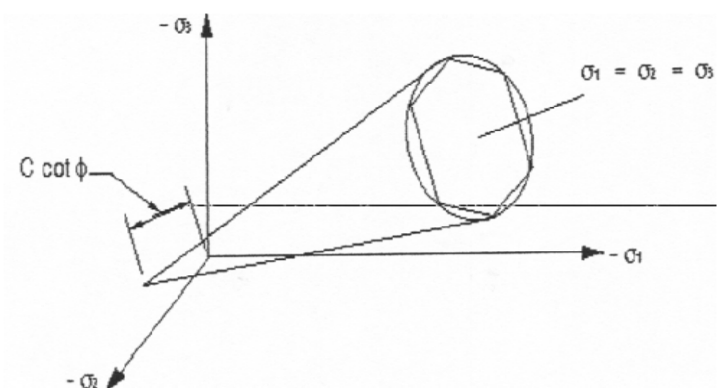


Figure 1: Drucker- Prager and Mohr-Coulomb Yield Surfaces

5 FAILURE CRITERIA FOR BALLAST

The actual behavior and strength of ballast materials are very complex because they depend on many factors such as the physical and mechanical properties of the particles such as ballast size, air voids, friction between particle and the nature of loading. No single mathematical model can describe the strength of real ballast materials completely under all conditions; so, simple models or criteria are used to represent the properties that are essential to the problem being considered.(Willam and Warnke, 1975) developed a mathematical model capable of predicting failure for the solid cracking in tension and crushing in compression(Chen 1982)(Figure 2). Other cases for which the model is also applicable would be reinforced composites (such as fiberglass), and geological materials (such as rocks) (ANSYS, 2007)

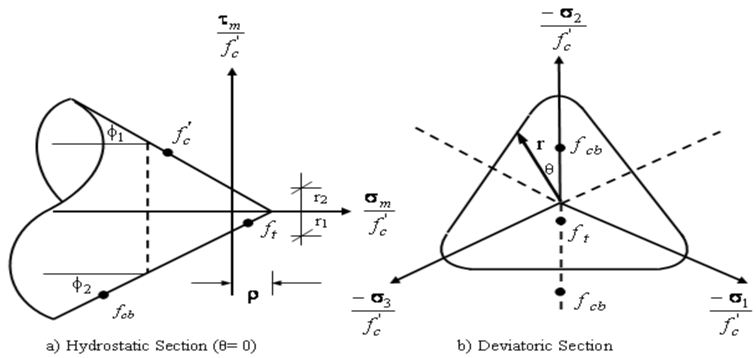


Figure 2: Failure Surface (Chen, 1982**)**

6 FAILURE CRITERIA FOR GEOGRID AND STEEL PLATE

For most metals, Von-Mises yield criterion is used because is simpler to use in theoretical application (Chen, 1982),assung that failure occurs when octahedral shear stress (τ_{oct}) reached critical value. Mathematically, this criterion can be expressed in the following form:-

$f(J_2)=J_2-k^2=0$ … (2) Where k= Failure (yield) stress in pure shear= $\frac{1}{\sqrt{3}} f_y$

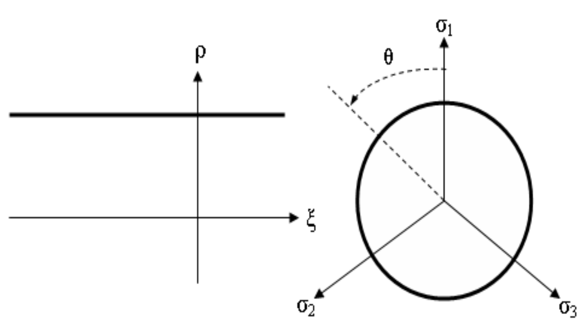


Figure 3: Meridian and Deviatoric Sections for Von-Mises Criterion

7 FINITE ELEMENT MODELING

As mentioned before, the **ANSYS** computer program was utilized for analyzing all models. Model components encountered throughout the current study, corresponding finite element representation and corresponding elements designation in **ANSYS** are presented in Table 1.

Table 1: Finite Element Representation of Model Components

Model Component	Finite Element Representation	Element Designation in ANSYS
Ballast (Rocks)	8-Nodes Brick Element (3-Translation DOF per node)	SOLID-65
Soft Soil	8-Nodes Brick Element (3-Translation DOF per node)	SOLID-45
Steel Plates		

8 NUMERICAL APPLICATIONS

8.1 Geometry and Model Creation

In actual field condition, the soil is usually of infinite extent both in horizontal and vertical directions. In the finite element idealization the horizontal boundary of the soil blocks in the (x) and (y) directions. The dimensions of the soft soil considered in the analysis were (2000x800x300mm)(Figure 4). All dimensions of soft soil layer have been kept constant for all analyses and, the depth (thickness) of ballast layers were (100mm)

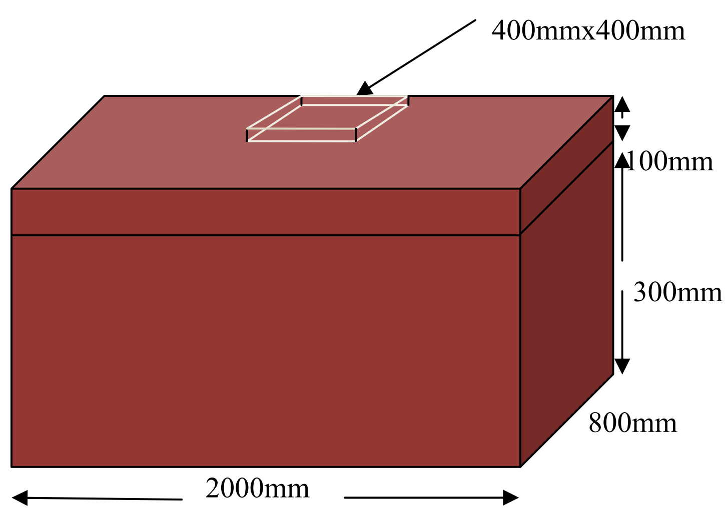


Figure 4: Dimensions of Adopted Models

8.2 Loading and Boundary Conditions

Displacement boundary conditions (which represent the conditions at the interface of model) are needed to constrain the model to get a unique solution. To ensure that the model acts the same way as a real case, boundary conditions need to be applied at all sides of the model, and where the loadings exist. The type of loading were used in this study was concentrated loads with different value; Due to load concentration on ballast elements, crushing of the ballast started to develop in the elements located directly under the loads. Subsequently, adjacent ballast elements crushed within several load steps. As a result, the model showed a large displacement, solution diverged and finally, the finite element model fails prematurely. Therefore, to prevent this phenomenon, two techniques were used:-

1-Finer mesh was used under applied load.

2-Steel plates were used under load.

In the present study, the second technique was adopted, and the employed boundary conditions were as follows:-

1. *Hinges**,** at the side of model in x and z-directions and, Rollers in y-directions.*
2. *Fixed at the bottom face of model (restrained the nodes in x, y and z-directions).*

9 MODELS PARAMETEIS

Table 2, 3 & 4 shows the properties for each material used in the finite element models

Table 2 Soft Soil Property Parameters

Parameter	Definition	value	Note
Cu	Unrained shear strength (kPa)	10	CUT
		15	
E	Elastic Modulus of Elasticity (MPa)	5	$E=250C_u-500C_u$*
		7.5	
ν	Poisson’s ratio	0.15	*
ϕ	Angle of Friction	0	

***** From Consolidated undrained Trixial Test

Table 3 Ballast Property Parameters

Parameter	Definition	value	Note
f_c'	Ultimate Compressive Strength (MPa)	48	Iraq Railway Company
E	Elastic Modulus of Elasticity (MPa)	130	CUT
ν	Poisson’s ratio	0.35	Cross Hole
βc	Shear transfer Coefficient	0.22	measured
βo	Shear transfer Coefficient	0.2	

Table 4 Geogrid and Steel Plate Property Parameters

Parameter	Definition	Value Geogrid	Value Steel Plate	Note
f_y	Ultimate tensile strength (MPa)	420*	13.5	measured
E	Elastic Modulus of Elasticity (MPa)	$200x10^3$*	25	measured
ν	Poisson's ratio	0.3*	0.3	measured
t	Thickness (mm)	30*	3	measured

*Saudi Arabian stander organization (SASO) test method ISO10319

10 RESULTS OF THE ANALYSIS

The ANSYS divides the load into a number of sub-steps and performs the iteration for each sub-step until reaching the convergence Figure 5 and Figure 6 show the deformed shape of model for two undrained shear strength when the undrained shear strengths of untreated soil changed from (9kPa) to (25kPa), the modulus of elasticity increased and the load capacity increased for about (160%), while, the settlement decreased for about (47%). This means the undrained shear strengths represent important parameters to improve soil and as a result, the load capacity increased. Table 5 shows the result and fig 7 shows the effect of undrained shear strength and modulus of elasticity on the load-settlement relationship.

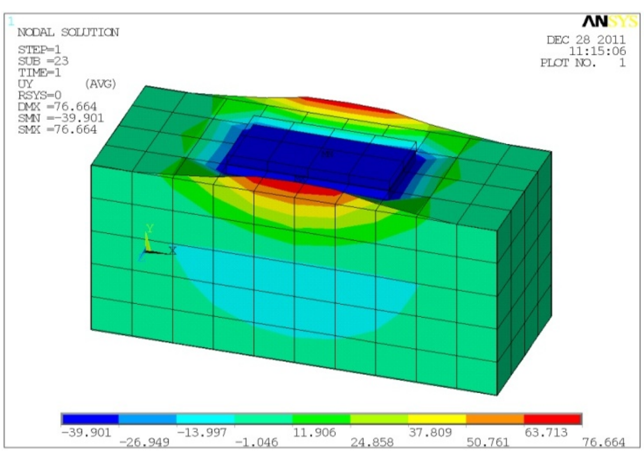


Figure 5: Failure Mode of Untreated Soil Model S-1

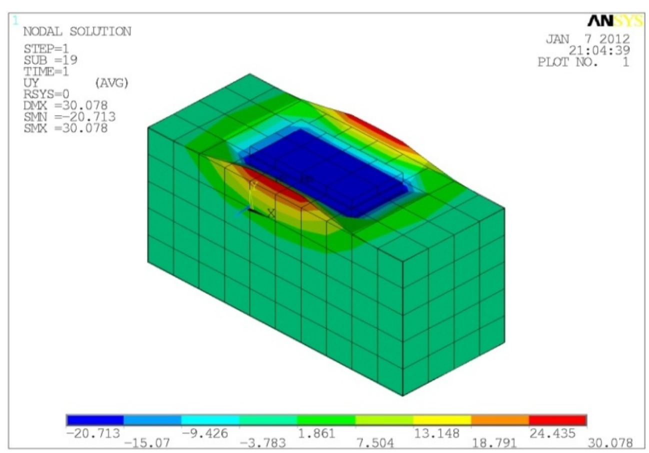


Figure 6: Failure Mode of Untreated Soil Model S-2

Table 5 Ultimate Load and Maximum Settlement for Group-1

Group	Model	E (kPa)*	P_u (kN)	$(P_u)_i/(P_u)_R$	S(mm)	$(S)_i/(S)_R$
G-1	S-1	2150	8.0	-	40	-
	S-2	45000	20.8	2.6	21	0.53

*From Equation E=250 C-500C (Das, 2006)

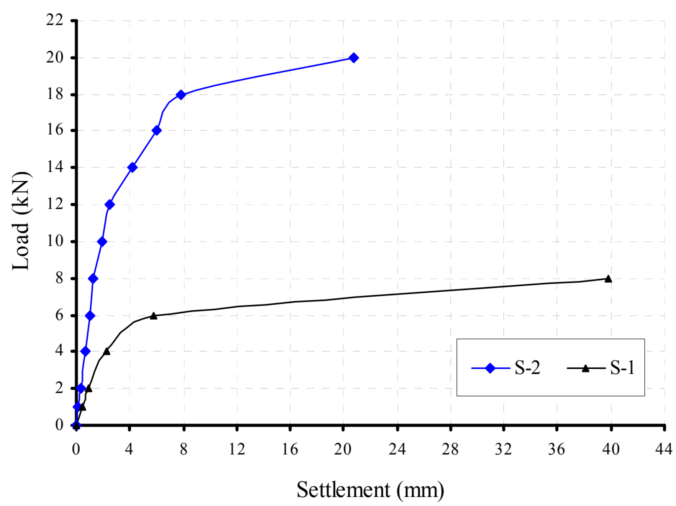


Figure 7: Load-Settlement Curve for Group-1

Table 6 Shows the second group consist of eight models (SB-1, SB-2, SB-3, SB-4, SB-5, SB-6, SB-7, and SB-8) performed with ballast layer overlaying the soft soil. The eight modes were performed using different ballast thickness (H) of (25, 50,75and 100mm). Four models were performed on each of the two undrained shear strengths (9kPa) and (25kPa).

Table 6 Ultimate Load and Maximum Settlement for Group-2

Group	Model	$(P_u)_R$ (kN)	P_u (kN)	$(P_u)_i/(P_u)_R$	$(S)_R$ (mm)	S (mm)	$(S)_i/(S)_R$
G-2	SB-1	8.0	23	2.88	40	16.33	0.41
	SB-2		30	3.75		17.19	0.43
	SB-3		43	5.38		24.47	0.61
	SB-4		61	7.63		34.43	0.86
	SB-5	20.8	35	1.70	21	8.87	0.42
	SB-6		41	1.97		8.53	0.41
	SB-7		52	2.50		10.41	0.50
	SB-8		66	3.18		12.94	0.62

*$(P_u)_R$= Ultimate Load of Untreated Soil for Two Undrained Shear Strength (S-1 & S-2)

While Table 7 shows the third group consist of eight models were performed with ballast layer reinforced with geogrid overlying the soft soil. These models were performed using different ballast thickness (H) of (25, 50, 75 and 100 mm). Four models were performed on each of the two undrained shear strengths (9kPa) and (25kPa).

Initially a single layer of geogrid was placed along the interface plane between the ballast and soft soil. The models reinforced with (25mm) ballast and a geogrid layer located between the soft soil and ballast layer and the effect of geogrid in settlement and ultimate load capacity for two undrained shear strength and shows comparison between the ultimate loads from the finite element analysis

Table 7 Ultimate Load and Maximum Settlement for Group-3

Group	Model	$(P_u)_R$ (kN)	P_u (kN)	$(P_u)_i/(P_u)_R$	$(S)_R$ (mm)	S (mm)	$(S)_i/(S)_R$
G-3	SGB-1	8.0	25	3.13	40	16.5	0.41
	SGB-2		32	4.00		18.6	0.47
	SGB-3		45	5.64		25.7	0.64
	SGB-4		63	7.88		36	0.9
	SGB-5	20.8	43	2.07	21	13.2	0.63
	SGB-6		43	2.07		9.5	0.45
	SGB-7		55	2.64		11	0.44
	SGB-8		68	3.27		13.5	0.64

*$(P_u)_R$= Ultimate Load of Untreated Soil for Two Undrained Shear Strength (S-1 & S-2)

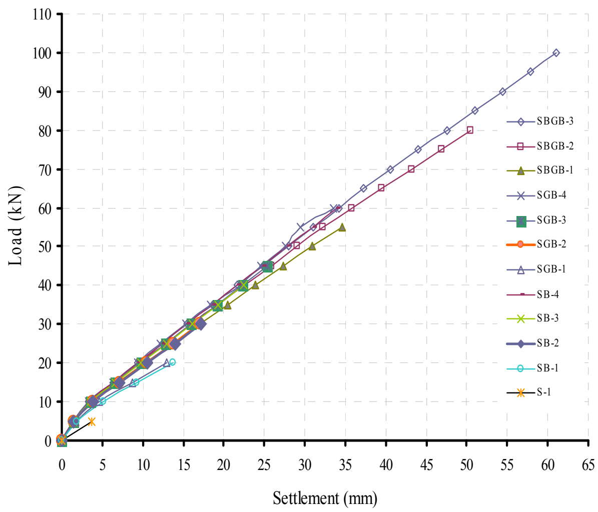
The fourth group consist of six models were performed with ballast layer reinforced with Geogrid layer in top these models were performed using ballast thickness (H) of (50, 75 and 100mm). The models performed by placing the Geogrid layer at a distance (25mm) below the level of ballast thickness. Fig8 and 9 shows the results demonstrate a substantial increase the ultimate load with increasing thickness of ballast due to the distribution of the applied load. Table 8 shows comparison between the ultimate loads from the finite element analysis. For the first three models of this group.

Fig 8 & 9 shows summary of load-settlement for all groups. The models reinforced with (25mm) ballast and a geogrid layer located between the soft soil and ballast layer and the effect of geogrid in settlement and ultimate load capacity for two undrained shear strength and shows comparison between the ultimate loads from the finite element analysis

Table 8 Ultimate Load and Maximum Settlement for Group-4

Group	Model	$(P_u)_R$ (kN)	P_u (kN)	$(P_u)_i/(P_u)_R$	$(S)_R$ (mm)	S (mm)	$(S)_i/(S)_R$
G-4	SBGB-1	8.0	56	7.00	40	35	0.88
	SBGB-2		82	10.30		52	1.30
	SBGB-3		110	13.80		62	1.55
	SBGB-4	20.8	83	3.99	21	26	1.24
	SBGB-5		84	4.04		21	1.00
	SBGB-6		110	5.29		28	1.33

*$(P_u)_R$= Ultimate Load of Untreated Soil for Two Undrained Shear Strength (S-1 & S-2)



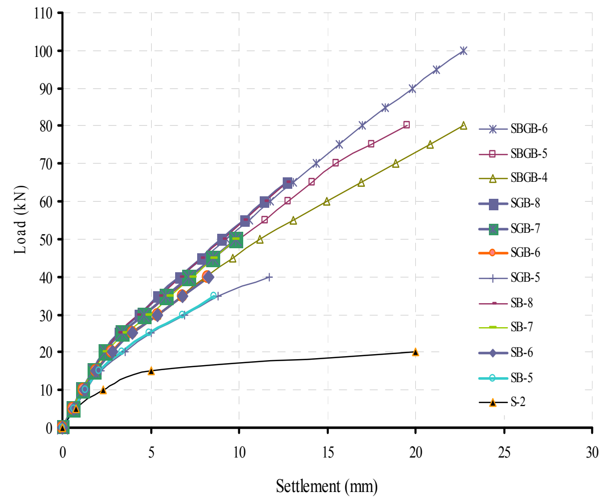


Figure 8:.Load-Settlement Curves for AllGroups and Untreated Model (S-1)

Figure 9: Load-Settlement Curves for Groups2&3&4 and Untreated Model (S-2)

11 CONCLUSIONS

Based on the results obtained from the finite element analysis for improvement of soft soil reinforced with or without Geogrid, the following conclusions are presented:

1. Theoretical solution using ANSYS Finite Element program can be adopted in the evaluation of loads and the amount of settlement for the soil layers beneath the railway lines as well as Ballast .The program gives good correlation and a sufficient degree of convergence in behavior .

2. Presence of geogrids layers leads to reduce the vertical displacement (settlement),
The vertical displacement (settlement) under the applied load decreases with the increase of shear strengths (C_u). Increasing of soil shear strength improve the load carrying capacity significantly. This enhancement starts even from the lower load and increases with increase in load.

3. The vertical displacement (settlement) under the applied load decreases with the increase of Modulus of Elasticity (E) of the soil. Increasing of soil modulus improve the load carrying capacity significantly.

4. The maximum vertical displacement under the applied load decreases with the increasing of the ballast thickness.

4. The uniformly oriented giogrid and its ability to improve soft soils cause an increase in the load carrying capacity. This was combined with the ability of ballast layer to sustain larger compressive force at advanced stages of loading.

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