Prediction of Excessive Stresses in Railway Track Elements Due to Soil Defects

Ahmed N.Ramadan*¹, Haytham N. Zohny*², Hany S. Riad*³

Abstract—Many-sidedness that cause decrease in lifetime of all railway track elements; rails, fasteners, sleepers, ballast layer, sub-ballast layer and sub-grade soil is due to settlement in sub-grade soil caused from change in ground water level, settlement in civil works beneath the track, presence of organic soil, etc., where stresses increased in those elements. The main purpose of this study is to determine the excessive stresses in rails, sleepers, and ballast due to defects in sub-grade soil. To realize this goal, two dimensional finite element model using (ANSYS Workbench V.14.0) software was adopted by making regular gradually increasing in settlement in a part of the sub-grade soil.

Index Terms—ANSYS, railway, ballasted track, wheel/rail contact, sub grade soil, transient loads.

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1. INTRODUCTION

As increasing of railway transport system demand around the world, development in this field is required to decrease maintenance works and the waste time that may delay trains travels.

Decreasing maintenance works and life cost of railway elements will make the system more efficient. Maintenance costs for passenger and freight trains per kilometer in one year are about 56,356 $ and 73,000 $, (lopez-pita et al., 2008).

Nguyen et al. (2015) pointed out permanent deformation is related to train loads and number of train travels.

Field tests used to evaluate the performance, stresses, strains, deformation and to determine the life time for track elements, which are consuming time and money.

Two methods can be used to predict the behavior of elements, these two methods are: multi body dynamics (MBD) and finite element analysis (FEA) programs.

So by using ANSYS as FEA, it can simulate the model that is needed to know its behavior by defining the material properties for each element inserted in the model and determine the boundary conditions exactly to give accurate results and informations.

The track sub-structure is consisting of ballast, sub-ballast and sub-grade layers as shown in fig. 1.

Deflection in the sub-grade may occured due to settlement in civil works ex., (box culvert, pipe lines, tunnels, etc.), presence of soil that has small value of young modulus and bad shear strength properties, etc.

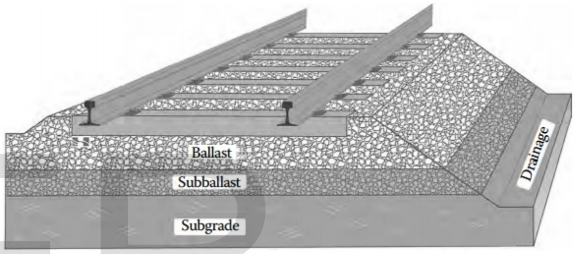

Fig. 1: Railway track isometric [1].

2. DEFINATION OF THE MODEL

2.1 Model analysis type

The model is analisied in two-dimensional (2D) plane stresses in ANSYS by making vertically longitudinal section in the all elements of track that passes throw the top point of the rail head considering that the rail base is exactly on horizontal level without any inclination. 2D analysis is selected to decrease the solution time and able to decrease element size where it introduces more data in the model that include; wheel, rail, rail pads, fasteners, sleepers, ballast layer, sub-ballast layer and sub-grade layer where analysis by using 2D had been choosen before for modeling railway track [2] and [3].

2.2 The track model description

Track is consisting of:

1. Wheel with diameter equal to 920 mm.
2. Rail UIC 54.
3. 21 timber sleepers b=250mm, t=150mm.
4. 21 rail-pads and fasteners.
5. Ballast layer with thickness equal 300mm.
6. Sub-ballast layer with thickness equal 300mm.

- *[1] center of researchs and thesises of civil engineering, Faculty of Engineering, Cairo University, Egypt, PH-00201014753897. E-mail: nabilahmed466@gmail.com
- *[2] Lecturer of railway engineering, puplic Works Department, Faculty of Engineering, Ain Shams University, Egypt. E-mail: hnzohny@eng.asu.edu.eg
- *[3] Associate professor of railway engineering, Public Works Department,Faculty of Engineering, Ain Shams University, Egypt. . E-mail: hsobhy@yahoo.com

7. Sub-grade layer with thickness equal 500mm.

The length of the model is equal 12710mm. Fig. 2 illustrate longitudenal section of track model.

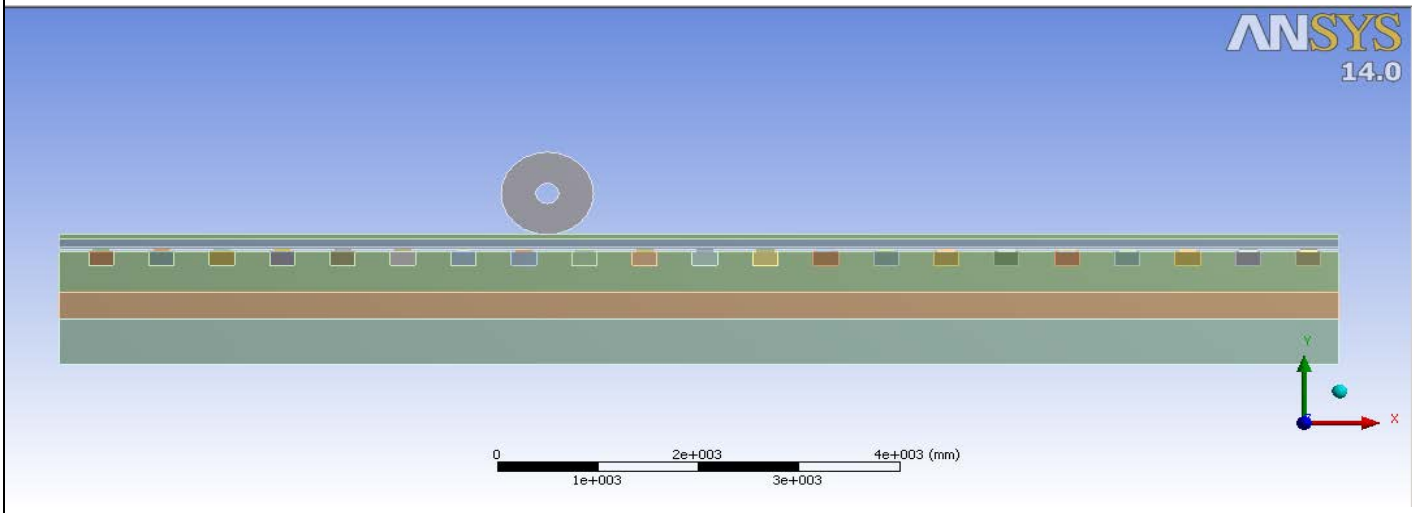

Fig. 2: Longitudinal section of ideal model case.

2.3 Model preparation

The model is representing the dynamic state, where the wheel moved on the track with the train speed (S=100 km/hr). The wheel is moved for distance equal 2017.8 mm in the positive direction of the X-axis. The study of moving wheel is selected to be in the middle zone of the track to be similar to the real case where two rail ends are fixed as expression of track continuity [4].

Two cases studied; the first is the ideal case without any defects where the subgrade soil is loose sand soil with 500mm depth, properties of soil are presented in table 1. , the second case is the defect case when a part of sub-grade will settle 5mm, 6mm, 7mm, 8mm, 9mm and 10mm. the part that would be affected by the settlement has length equal 4000 mm and the center of that length exsisted under the middle sleeper of the modeled track. The middle sleeper is the eleventh sleeper of the track.

Deformation and equivalent von mises stress for the two cases are shown in fig. 5, 6, 7, 8, 9, 10, 11 and fig. 12.

The analysis system that choosen to simulate the movement of wheel on the track is transient structure system. The contact between wheel and rail has frictional coefficient equal 0.15 with pure penalty algorithm.

For meshing element with type of plane 183 we have:

1. number of nodes= 184859
2. number of elements= 58138

The mesh size element of ballast layer is from 30mm to 50mm, sub-ballast is 50mm, sub-grade is 70mm, rail-pads and fasteners is 53mm and for sleepers is 30mm. The mesh size of rail and wheel are as shown in fig. 3.

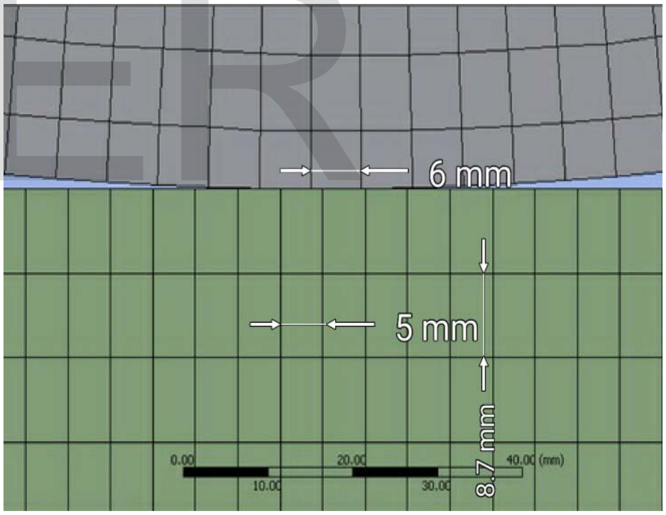

Fig. 3: Rail and Wheel element size of mesh.

The cross section of all elements of track:

- Rail is about base, flang and head with dimensions as shown in fig. 4.
- The radius of wheel equal 460 mm and its width (2b) equal 4.7mm that is due to the contact between rail and wheel [5].
- Width of Ballast, Sub-ballast, Sub-grade, Sleeper equal 400mm
- Width of base plate equal 182.5mm
- Width of Rail-pad equal 73mm

The boundary conditions for the model are fixed to the rail ends from two sides and fixed support to the bottom of subgrade layer. The wheel is applied to load with 10 tons.

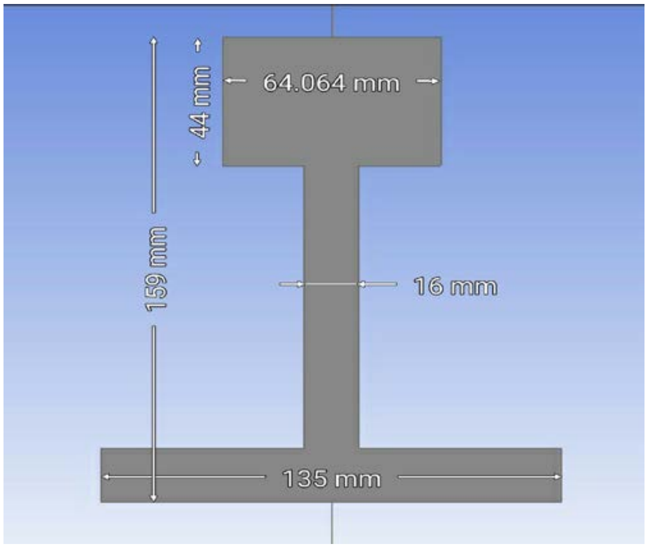

Fig. 4: Cross section of rail.

2.4 Materials of the model

All elements have physical properties that are defined in engineering data as shown in table 1.

Table 1: Material properties of all elements of railway track [6], [7], [8] and [9].

Element	parameter	Symboll	value	unite
Rail (uic 54), wheel and fastners	Poisson's ratio	v	0.3	
	Young modulus	E	2*10^5	Mpa
	Mass density	σ	7850	Kg/m^3
	Inertia about X-axis for rail	Ix	2346.0433	Cm^4
	Area of rail cross section	A	6860.0162	Cm^2
Rail-pad	Mass density	σ	950	Kg/m^3
	Young modulus	E	850	Mpa
	Poisson's ratio	v	0.45	
Sleeper	Mass density	σ	1084	Kg/m^3
	Young modulus	E	1000	Mpa
	Poisson's ratio	v	0.4	
Ballasted layer	Mass density	σ	2000	Kg/m^3
	Damping factor	β	0.01	
	Poisson's ratio	v	0.37	
	Young modulus	E	200	Mpa
Sub-ballast layer	Mass density	σ	1920	Kg/m^3
	Damping factor	β	0.01	
	Poisson's ratio	v	0.37	
	Young modulus	E	138	
Sub-grade soil	Mass density	σ	1800	Kg/m^3
	Damping factor	β	0.01	
	Poisson's ratio	v	0.3	
	Young modulus	E	19	Mpa
	Friction angle	ϕ	35	degree
	Dilation angle	ψ	5	degree
	cohession	c	0	Mpa

2.5 Verification of the model results

Fig. 5 illustrated that the maximum vertical deflection occurred on the rail when the vertical wheel load exsisted between two sleepers.

The results of deflection obtained are compared with the calculated values from Zimmerman method in fig. 6. The maximum value of deflection from FE model was 2.299 mm where the maximum value of deflection obtained from Zimmerman method was 2.24 mm with track modulus equal 47.42 Mpa [10]. The value of track modulus is depende on the elastic modulus and dimensions of materials which are choosen in the FEM. The peak value of deflection is obtained under the wheel load and gradually decreased by being in a distance from wheel-rail contact point. It should be noted that the shape of deflection distribution is not symmetric in the FEM due to the dynamic response of track where transient system analysis is run to simulate the real movement of wheel on the track also the element size has important factor of the difference obtained in values. [6]

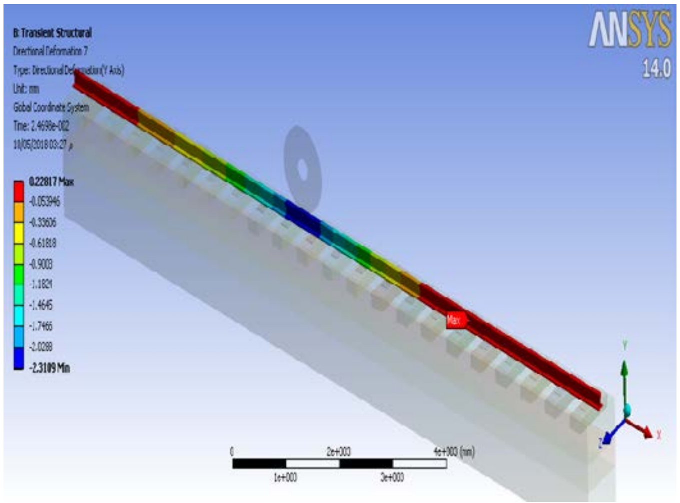

Fig. 5:.Vertical deflection of rail.

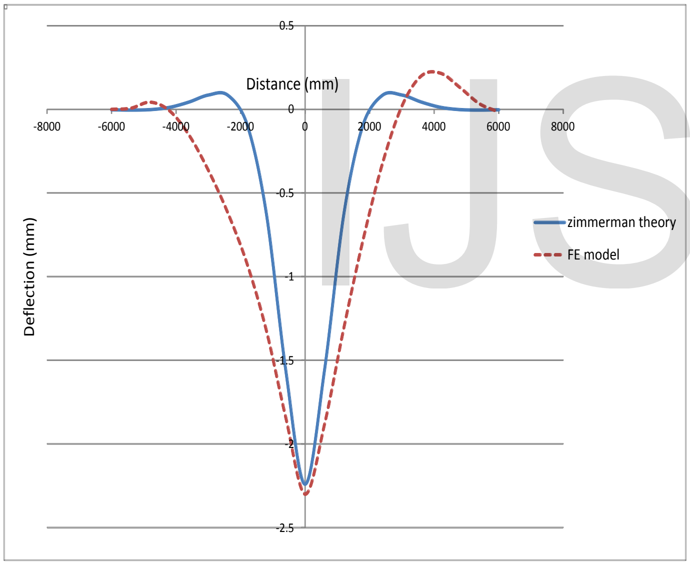

Fig. 6: Comparison between Zimmermann and results of FEM.

3. RESULTS

Due to the increase of element size of all track element, the results of stresses and deformation is not equal to the calculated from Zimmerman equations.

The maximum stresses on the rail parts (head, web and base) are shown in fig. 7 for first case where the maximum stresses is occured at the top of rail head because it is the first part that sustain loads came from wheels and begin to distribute it to the all element beneath the rail

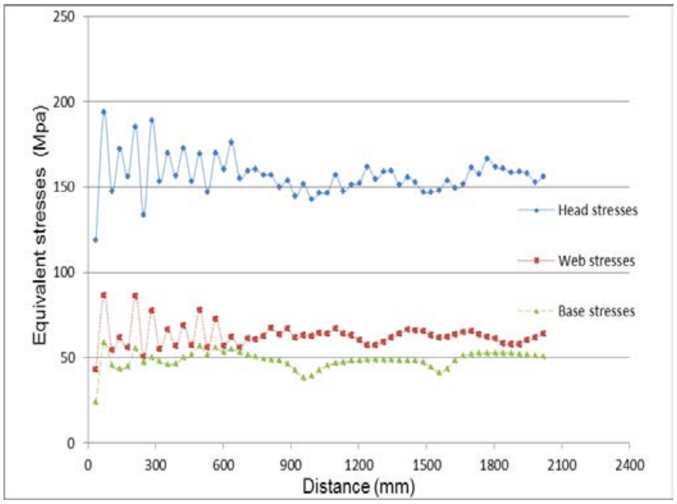

Fig. 7: Maximum stresses in rail parts in the ideal state.

In the base of rail it is obvious to see the bottom of curve in two points that expressed the wheel load is on the rail which is directly stand on the rail pad and fastner and the maximum value of stresses occurred between two sleepers. The maximum stresses decreased gradually when the wheel load moved to be near to the sleeper to reach to the minimum value of stresses.

Maximum stresses on the sub structure of track are explained in fig. 8 where the maximum values are portion of ballast layer. Ballast layer distribute stresses came from sleepers to sub-ballast and sub-grade layers. Sub-ballast layer distribute stresses to sub-grade layer with small value to avoid shear failure may happen in the sub-grade layer. In general the maximum values of stresses are occurred in the zone beneath sleepers.

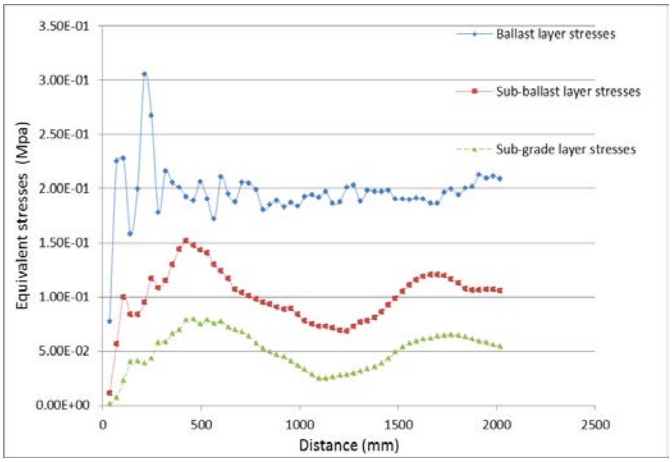

Fig. 8: Maximum stresses in sub structure layers in the ideal state.

The maximum vertical deformation for sub-structure layers is illustrated as shown in fig. 9. The maximum value of deformation is for ballast layer that has more value of stresses than sub-ballast and sub-grade. Sub-ballast layer also has more deformation than that happened to sub-grade layer. The maximum values of vertical deformation for three layers obtained in the zone under sleepers.

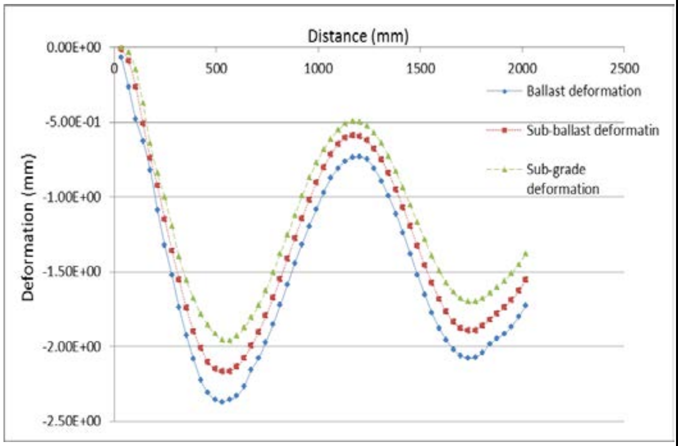

Fig. 9: Maximum deformation of sub structure layers in the ideal state.

Vertical deflection of all elements would be increased after applied settlement under the targeted part that explained in case 2. Also stresses would be increased to have the maximum values at parts that is near to the deflection and decreased gradually by rising to the level of rail. In fig. 10 and fig. 11, it can introduce the difference that happened in stresses. Finally, stresses increased by increaseing of deflection value.

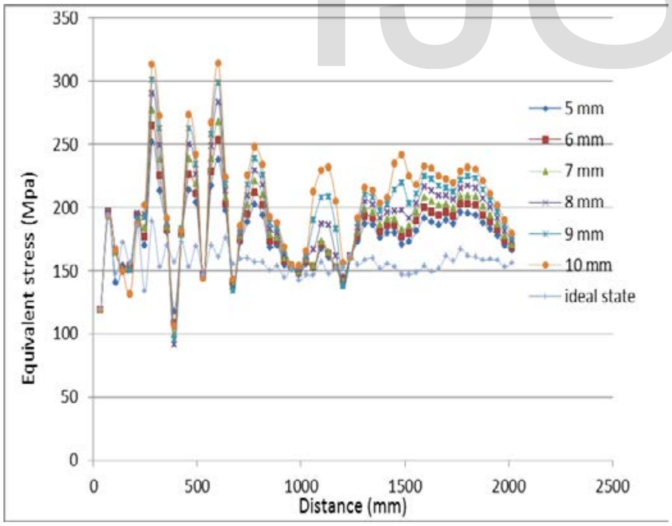

Fig. 10: Maximum stresses on rail head for case 1 and case 2

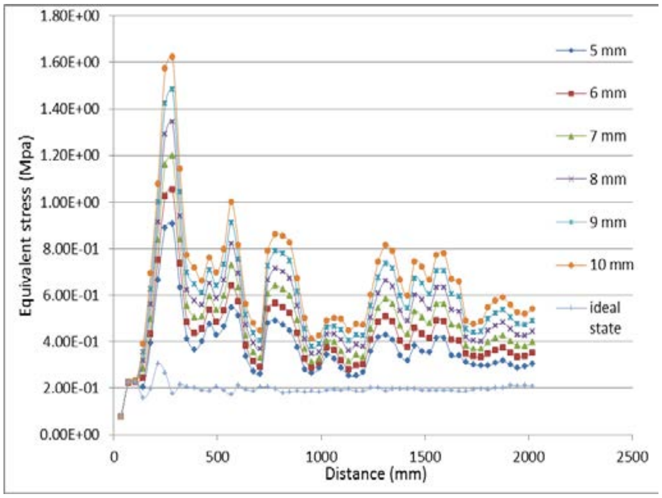

Fig. 11: Maximum stresses on ballast layer for ideal state and defect states.

The eleventh sleeper which is the farthest sleeper from the end of the track has the maximum stresses. So that sleeper is selected to be in study as it is the worest case of all sleepers. When the settlement is applied, stresses will increase as shown in fig. 12 where stresses values are observed on the 11th sleeper from the beginning of the wheel movement. The maximum value in graph happened when the wheel is affect directly on target sleeper.

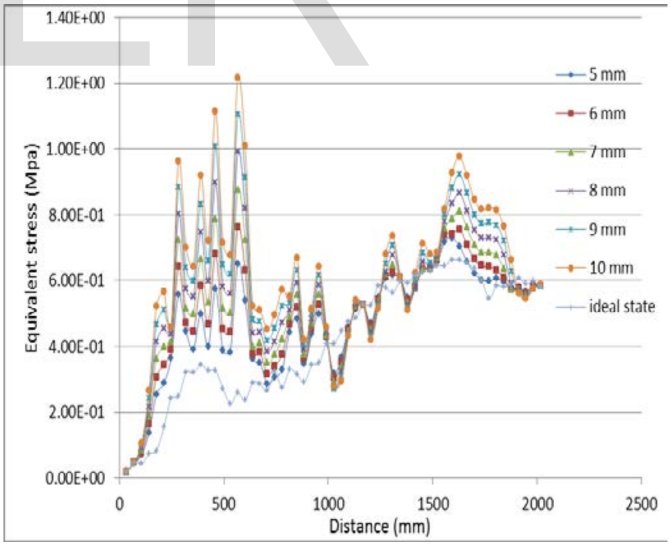

Fig. 12: Stresses on eleventh sleeper.

The rate of increasing percentage in stresses in rail head, ballast layer and the 11th sleepers are explained in Fig. 13, fig. 14, fig. 15 and fig. 16.

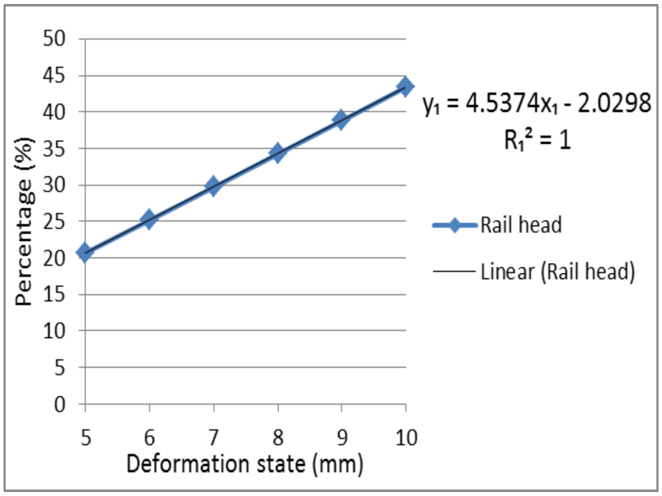

Fig. 13: Rate of increasing stress in rail head.

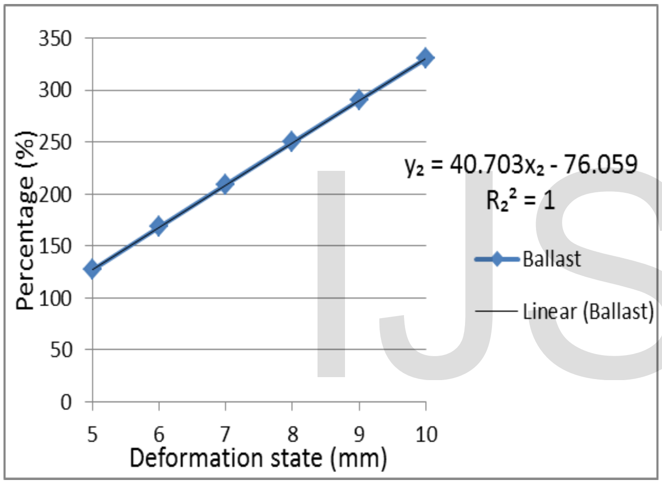

Fig. 14: Rate of increasing stress in ballast layer.

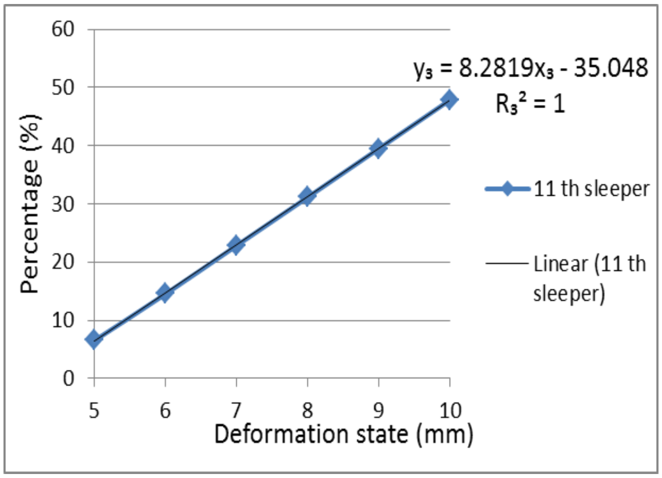

Fig. 15: Rate of increasing stress in the 11th sleeper.

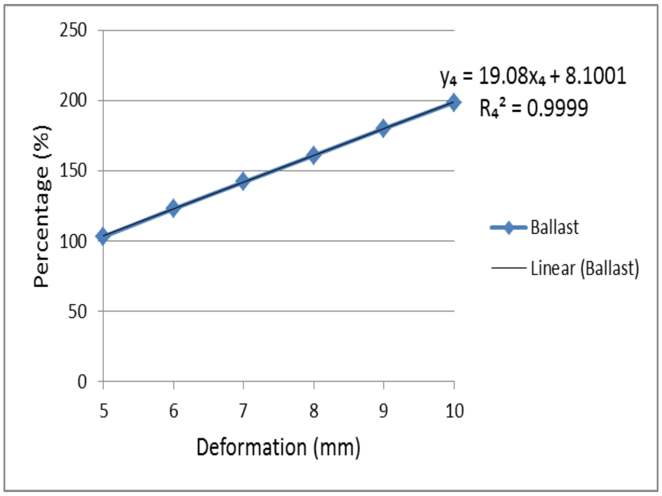

Fig. 16: Rate of increasing stress in ballast layer.

4. CONCLUSIONS

Stresses increased in rail head, ballast and 11th sleeper due to settlement that happened in sub-grade soil where:

1- For rail head; stresses increased by percentage (y_1) 4.468 % when the difference between settlement was 1 mm. the rate of increasing stresses was constant that can be calculated from the relation where $y_1 = 4.5374x_1 - 2.0298$.

2- For ballast layer; stresses increased by percentage (y_2) 41.257 % when the difference between was 1mm. the rate of increasing stresses was constant that can be calculated from the relation $y_2 = 40.703x_2 - 76.059$.

The maximum stresses in ballast that obtained after settlement in fig. 14 were at the beginning and the end of deformed part of sub grade layer.

3- For the 11th sleeper; stresses increased by percentage (y_3) 7.997 % when the difference between settlement was 1 mm. the rate of increasing stresses was constant that can be calculated from the relation $y_3 = 8.2819x_3 - 35.048$.

4- For ballast layer; stresses increased by percentage (y_4) 19.73 % when the difference between was 1mm. the rate of increasing stresses was constant that can be calculated from the relation $y_4 = 19.08x_4 + 8.1001$.

Fig. 16 introduces the increasing in stresses in ballast layer occurred under the 11th sleeper.

- The increasing in stresses will increase maintenance works in the track as it lead to decrease the life time of elements that face the problem of settlement.

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