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INVESTIGATION OF USING A BITUMINOUS SUB-BALLAST LAYER TO ENHANCE THE STRUCTURAL BEHAVIOR OF HIGH-SPEED BALLASTED TRACKS

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ABSTRACT: This paper evaluates the most suitable thickness of both asphalt and ballast layers to improve the conventional high-speed ballasted tracks. The work was conducted by designing asphalt mixture using the Marshal method in the laboratory and using the ANSYS software to evaluate the best thickness of both the ballast and asphalt layer to minimize vertical deformations and corresponding stresses. The results of the numerical analysis showed that the minimum deformations and stresses for a track containing a bituminous sub-ballast system are lower than the deformations and stresses for a conventional system when the thickness of the ballast layer was 250 mm. However, when the thickness of the ballast layer was 300 mm, the vertical deformation increased when the asphalt layer thickness increased. This theoretical analysis proved that a track that consists of 250 mm ballast and 120 mm bituminous sub-ballast layers enhances the structural behavior of the high-speed ballasted tracks.

Keywords: railway tracks; trackbed; bituminous sub-ballast; stresses; deformations; ANSYS

INTRODUCTION

Railways have been one of the world's oldest modes of transport for goods and passengers for 175 years. However, during this period, the track structure, axle load, train-speed, and gross ton have changed significantly [1]. As a result of these modifications, there are many problems and collapses that affect the efficiency of the railway and the deterioration of both subgrade and components of the railway. In order, the traditional system to remain resistant and stable to all these changes, continuous maintenance is required throughout the life of the track, as demonstrated by [2]. However, maintenance costs continuously are huge and to reduce maintenance costs and get good results, and there is a midway solution (bituminous sub-ballast system). Sometimes the cost of construction of this system is higher than the traditional system, yet the maintenance cost is lower than the similar cost of the traditional system [3].

A bituminous system supports the subgrade layer and improves the bearing capacity of this layer [4,5]. Besides, it reduces the deterioration of track geometry and also makes its vertical stiffness always within the permissible limits. The bituminous system consists of ballast, asphalt, sub-ballast, and subgrade layers. The bituminous layer is placed between the ballast and sub-ballast layer to enhance the trackbed performance, distribute the train loads regularly, and resist dynamic vibrations, mainly when the trackbed thickness ranges from 0 m to 2 m [6]. Also, no cracking and no damage for the asphalt layer appeared after many years of passing the maximum train loads, and heavy traffics under various conditions [7]. The bituminous sub-ballast system, which is known as the combination, is widely used in railway tracks, especially in high-speed around the world, such as the United States, where this application was carried out for the first time in 1960 [2]. However, many countries had used a bituminous sub-ballast system in new rail lines to reduce the need for maintenance continuously [7-9]. In 1970, Japan used a bituminous sub-ballast system in the construction of both standard and high-speed rail tracks [10]. Also, the Italian National Railway used a bituminous sub-ballast system in high-speed rail tracks to reduce the ground-borne vibrations [11].

The design and construction of the embankment uphold structure is essential for controlling railway settlement, dynamic deflection, and the characteristic properties of the trackbed. These factors are profoundly affecting the long-range performance of the railway relation, maintaining suitable geometric characteristics for efficient and trusting train operations. The performance-based design approach provides a design standard to insert the relation impact of different factors affecting the long-range performance of different railway designs. These designs include, in significant part, choose layer thicknesses and fundamental materials various properties inherent to effective long-range track performance. Computer programs have existed for performance-based design and analysis of trackbeds. [11] used the" KENTRACK" design program to explain the effects of different axle loads, layer thickness, and subgrade resilient modulus on the fatigue lives of different layers. The service lives of the asphalt and subgrade layer were predicted by deterioration analysis [11]. KENTRACK software used the finite element method to analyze and design trackbeds of railway tracks. It was firstly developed by [12] to design conventional all-granular and asphalt layered trackbeds. After that, it was expanded to analyze and design trackbeds containing granular and asphalt layers [11]. The primary factor in the analysis was to restrict the subgrade stress. The service lives of the single trackbed layers were checked by deterioration analysis for subgrade support thicknesses, component layer properties, and variant combinations of traffic.

Research studies that were conducted in Germany demonstrate that rail track had been composed of the bituminous layer of thickness that ranges from 26 to 30cm. The asphalt mixtures in the railways were designed in the same way as the road design. However, the maximum grain size was varying between 22 - 25 mm [13]. The bituminous content was increased by 0.5 % rather than the optimum used for the highway when the thickness of the asphalt layer was 12 to 15 cm, and air voids were 1 to 3 % [14]. In Japan, track beds of asphalt have been mainly used in ballast tracks of the railway for multiple years on both high-speed and ordinary routes. The performance- relying on design standard respects the fatigue of the track relying on the number of passes of trains. Japan organization for bituminous tracks used three different methods according to performance. First Performance Rank I: formed from concrete or bituminous trackbed for a layer of ballast-less track. Second Performance Rank II: asphalt trackbed for a layer of ballasted track. Third Performance Rank III: broken stone trackbed for a layer of the ballasted track, [14].

The main objectives of the research that has been discussed in this paper are determining the engineering parameters of the bituminous layer which is laid under the ballast layer; therefore, experimental work is carried out in the laboratories of the Egyptian General Authority for Roads and Bridges. Thus, laboratory manufacturing and testing were done for samples according to the standards of The American Association of State Highway and Transportation Officials (AASHTO). The obtained parameters of the bituminous material are used in nonlinear analysis and a simulation process. Hence, this analysis and simulation are conducted using 3D- ANSYS software. The results of the simulation process will determine the maximum vertical deformations and stresses induced in the railway track cross-section for different ballast and the bituminous sub-ballast layers. Thus, the most suitable thicknesses of those layers are determined and compared with the similar behavior of conventional railway track cross-section of high-speed lines.

1. EXPERIMENTAL WORK

Asphalt mixture commonly consists of fine, coarse aggregates and bitumen content. These materials that have been used in manufacturing the bituminous layer were selected to meet the AASHTO standards. The purpose of this experimental work is to manufacture the mixture of asphalt and to test it according to the AASHTO requirements to obtain optimum ratios of the material content. Hence its engineering properties can be identified and be used in the next simulation process. Thus, the authors have conducted the manufacturing and testing processes in the labs of the Egyptian General Authority for Roads and Bridges.

1.1 Selection of Materials

The specifications of aggregates defined the minimum values for conducting the Los Angles test, specific gravity, absorption, and crushing tests. The selected, prepared samples of fine and coarse aggregates that are igneous rocks with sharp edges, as illustrated by photos taken in the lab, are shown in Fig.1. Records in Table 1 illustrate the specified and the physical and mechanical values that were resulted from conducting the required tests. Also, sieve analysis testing was carried out on the samples to meet the AASHTO standards T27 and T37 for fine and coarse aggregates, respectively. The obtained values are shown in Table 2.

Fig.1 Aggregate grain sizes as obtained from sieve analysis testing

Table 1 Specified and resulted in physical and mechanical values of aggregates

Experiment	Standard	Coarse aggregate	Fine aggregate
Los Angeles coefficient			
Resistance to fragmentation (L.A.) (%) after 100 roll	(AASHTO T96)(<8%)	5	---
Resistance to fragmentation (L.A.) (%) after 500 roll	(AASHTO T96)(<35%)	26	---
Specific gravity, absorption, and crushing			
Bulk Specific Gravity (Mg/m^3)	(AASHTO T 85)	2.544	2.485
Specific Gravity SSD (Mg/m^3)	(AASHTO T 85)	2.611	2.551
Apparent Specific Gravity (Mg/m^3)	(AASHTO T 85)	2.727	2.661
Absorption (%)	(AASHTO T 85)(<5%)	2.6	2.7
Crushing %	(AASHTO T 112)	1.4	---

Table 2 The main parameters of bitumen 60/70

Sieve size	%passing of coarse (BN3)	%passing of coarse (BN2)	%passing of coarse (BN1)	%passing of breaking sand	%passing of sand natural
1"	100	100	100	100	100
3/4"	37	100	100	100	100
1/2"	0	70	100	100	100
3/8"	0	30	100	100	100
No 4	0	10	27	100	100
No 8	0	0	0	92	100
No 16	0	0	0	62	92
No 30	0	0	0	41	62
No 50	0	0	0	24	21
No 100	0	0	0	10	9.0

1.2 Asphalt Binder

Some of the laboratory tests carried out on the asphalt binder to ensure its validity for use in the asphalt mixture. The most important tests are penetration test, softening point, flashpoint, and kinematic viscosity; according to the standards (AASHTO-T49), (AASHTO-T53), (AASHTO-T48), and (AASHTO – T201) respectively. The results of these tests are listed in Table 3. The results showed that the binder of asphalt used in this mixture was conforming to the required specifications.

Table 3 The main parameters of bitumen 60/70

Test	Units	Standard	Bituminous Results
Penetration @ 25°C	mm/10	60/70	67
Softening point °C	°C	45/55	49
Flashpoint °C	°C	250 min	270
Kinematic viscosity @ 135° C	CS (mm2/s)	320 min	443

1.3 Material Mixing and Testing

The hot mixture of the bituminous sub-ballast layer might be designed according to Marshal Method [15]. Marshal test is a method to determine the properties of the mixture of asphalt, such as air voids, stability, flow, Voids in the Mineral Aggregate (VMA), and Voids Filled with Asphalt (VFA). Samples manufacture was carried out according to the following steps;

a. Preparing and testing the validity of materials that were used in the mixture.
b. Preparing the percentages of materials to be used in one mold. The results of the testing are shown in Table 4.
c. Heating of materials to temperature degree (135 to 160 °C).
d. Mixing the binder of asphalt materials, as illustrated in Fig. 2.
e. Heating the mixture of asphalt to 150°C for pouring in mold 101mm (or 100 mm) in diameter and compacting this mold with 75 blows on each side by a Marshal hammer, as illustrated in Fig. 3.
f. Extracting the specimens from molds and leaving them for 24 hr.

g. Putting the specimens in a water bath at 60 °C for 40 min.
h. Breaking the specimens on Marshal Device and recording the results, as shown in Fig.4.

Repeating the previous steps to get five samples has been done, where three specimens have been taken from each sample. However, each time, increased asphalt binder by 0.5 % over the previous one. All different values of the required parameters were recorded in Table 5.

It was found that values of required parameters which met the AASHTO standards and Asphalt Institute 1998 were obtained when the bitumen content was 6% (sample No. 4). So, the recommended values were summarised in Table 6. Thus, the values were used in the next simulation process

Table 4 Preparing the percentages of materials for marshal molds

Design of marshal molds					
BN 1	BN2	BN 3	Broken Sand	Natural Sand	Fill
20%	25%	20%	20%	10%	5%
1200 Kg					
240	300	240	240	120	60
Gmm			2700		
BN 1	1" - 3/4"	63	151	151	340
	passing 3/4"	37	89	240	540
	3/4" - 1/2"	20	60	300	675
BN 2	1/2" - 3/8"	50	150	450	1013
	3/8" - 4#	20	60	510	1148
	passing 4#	10	30	540	1215
BN 3	4# -"1/2	73	175	715	1609
	passing 4#	27	65	780	1755
	8# -"3/8	8	19	799	1798
	16# - 8#	30	72	871	1960
Broken Sand	30# - 16#	21	50	922	2074
	50# - 30#	17	41	962	2165
	100# - 50#	14	34	996	2241
	passing 100#	10	24	1020	2295
	16# - 8#	8	10	1030	2317
	30# - 16#	30	36	1066	2398
Natural Sand	50# - 30#	41	49	1115	2508
	100# - 50#	12	14	1129	2541
	passing 100#	9	11	1140	2565
Fill			60	1200	2700
Asphalt binder %	4.5	5	5.5	6	6.5
Weigh of asphalt (g)	54	60	66	72	78

Table 5 Parameters of the mixture of asphalt

Properties	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Bitumen content (%)	4.5	5	5.5	6	6.5
Bulk density (tan/m)	2.284	2.335	2.359	2.372	2.383
Air voids (%)	8.2	5.6	3.9	2.8	1.7
Marshall stability (kg)	1547	1780	1813	1958	1635
Marshall flow (mm)	3.4	3.55	3.75	4.05	4.3
Voids in the mineral aggregate [VMA %]	92.2	94	94.5	95	96
Voids filled with asphalt [VFA %]	80.5	82	86	86.5	88

(a) (b)

Fig.2 (a) Adding the binder of asphalt to mix aggregates; (b) The mixture of asphalt after mixing.

(a) (b)

Fig.3 (a) Compacted the mixture into the mold. (b) Compaction of the asphalt molds mechanically.

(a) (b)

Fig.4 (a) Breaking the asphalt molds on the Marshal machine. (b) The form of asphalt molds after breaking.

Table 6 Optimal values of asphalt according to the obtained results

Property	Result
Bitumen content (% over the total weight of the mixture)	6
Bulk density (tan/m3)	2.372
Air voids (%)	2.8
Marshall stability (kg)	1958
Marshall flow (mm)	4.05
voids in the mineral aggregate [VMA %]	95
moreover, voids filled with asphalt [VFA %]	86.5

2. SIMULATION WORK

ANSYS program was used to determine the vertical deformation and the stresses of the railway trackbed. The finite element method is the most common method of implementing different simulation cases that related to parameters of materials and boundary conditions. Many authors are utilizing the finite element method in track substructure studies [16], as well as in railway platforms design [17]. To obtain the optimum thickness of ballast and bituminous sub-ballast layers, the followed criterion in this simulation process is obtaining the vertical deformations and stresses affecting the railway track layers in two cases of applying two different ballast and three different bituminous sub-ballast layer thicknesses. These aimed cases are as follows:

a. First case: the ballast thickness is 250 mm and 120, 140, and 180 mm thickness of the bituminous sub-ballast layer, respectively.
b. Second case: the ballast thickness is 300 mm and 120, 140, and 180 mm thickness of the bituminous sub-ballast layer, respectively.

2.1 Geometric Dimensions

Dimensions of track models used in this paper were designed based on the new high-speed lines in Spain [18]. In these models, the x-axis indicates the cross direction, the y-axis is the vertical direction, and the z-axis is the longitudinal direction. Also, in the longitudinal direction, the distance between any two sleepers is 60 cm, as shown in Fig.5. The models consist of substructure and superstructure elements. These models were simplified regarding the x-axis to avoid any problems in the results. Also, the models consist of two tracks symmetrically about the z-axis. In this study, the asphalt layer was placed between the ballast and sub-ballast layer. Since all models consisted of four layers (ballast, asphalt, sub-ballast, and subgrade (soil), whereas the thickness of ballast, asphalt, and sub-ballast are varying related to every case study as will be illustrated later. Also, the side slope of the layer was taken 2:1 to be similar to the actual embankment.

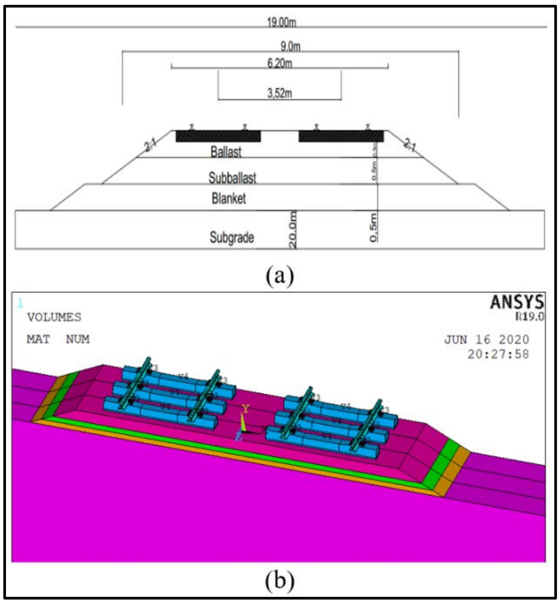

Fig.5 Geometric dimensions and 3D model mesh. (a) Full-cross section of the trackbed model and location of the sub-ballast asphalt layer. (b) 3D meshing model with 2.4 m in longitudinal length.

2.2 Elements Description

The used rails in these models are the UIC 60. Also, the used sleepers were represented as a concrete element. The rail pad was forming into new dimensions, which equal to the width of the rails and sleepers. Also, ensuring that the stiffness of the rail pad equals to the stiffness provided by the manufacturer. The ballast, asphalt, sub-ballast, and subgrade layers did not require any simplification as they were defined by their thicknesses, which had different values.

2.3 Modeling of Train Loads

3D models of the trackbed, which are different in layers thickness of the ballast and asphalt layer, were simulated in the ANSYS program. The vertical load had been applied by 130 KN in addition to 50 KN lateral for static loads, while the dynamic loads were applied by acceleration for one second, as shown in Figure 6. Whereas, the applied loads were considered maximum loads used by the Egyptian National Railways [19].

2.4 Boundary Conditions

The boundary conditions, which are in the longitudinal, the lateral, and the vertical directions, were defined as follows. The surfaces of the longitudinal directions have been restricted displacements at the Z-axis. The surfaces of the cross directions have been restricted displacement at the X-axis. Finally, the surfaces of the vertical direction at the bottom of the model have been restricted at Y-axis. To bond between elements (rail, rail pad, ballast, asphalt, sub-ballast, and subgrade), they were adherent by the contact area, as shown in Fig 5 (b). Also, the type of the finite elements for rails and granular layers were nodes hexahedral elements SOLID185 and SOLID65, respectively.

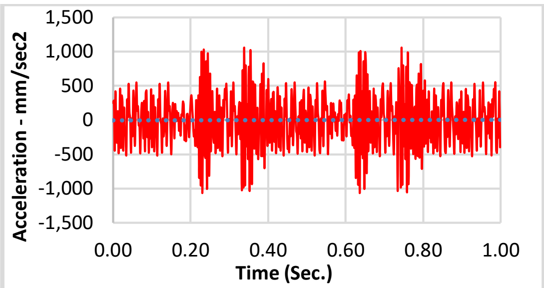

Fig.6 Time-history curve of vibration acceleration for high-speed railway train.

2.5 Material Properties and Main Parameters

The displacement and stress were used to determine the mechanical behavior of material used in a railway structure. The rails, rail pads, sleeper's concrete, and bituminous sub-ballast system, were represented in the models as elastic and visco-elastic liner materials, while the ballast, sub-ballast, and ground layers were represented as the Drucker-

Prager and Elasto-plastic model [20]. This phenomenon depended on the hydrostatic stress. The values of the parameters of rail steel, rail pad, sleeper, Igneous ballast layer, and foundation (soil) illustrated in Table 7 were chosen according to [21]. While the values of parameters of the bituminous sub-ballast layer were chosen and depended on the properties of the manufactured mixture that has been obtained in the experimental work, these properties are also shown in Table 7 [8].

Table 7 Parameters of track materials and layers

Material	E (Pa)	ν	c N/m^2	Φi (°)	Φd (°)	ρ kg/m^3	E (Pa)
Rail steel	2.1 E11	0.3	—	—	—	7500	2.1 E11
Rail pad	5.995 E8	0.45	—	—	—	---	5.995E8
Sleeper	3.144 E10	0.25	—	—	—	2132.38	3.144E 10
Ballast Igneous	1.3E8	0.2	0	45	45	1900	1.3E8
Asphalt	4.0E9	0.35	--	--	--	2400	4.0E9
Subballas	1.2E8	0.3	0	45	45	1900	1.2E8
Subgrade	3E9	0.2	-	-	-	2700	3E9

3. RESULTS AND DISCUSSION

Based on the experimental and numerical simulation works that have been conducted on the railway cross-section of high-speed lines, the results and effects of the optimization of the layer thickness of ballast and bituminous sub-ballast are described and discussed in this item of the paper. The most critical deformations and stresses are that occur under sleepers because they define the value of track modulus and control the elasticity of the railway track and the whole railway system [3].

3.1 Effect of Bituminous Layer Thickness in the Case of 250 mm Ballast Thickness

By analyzing the results of track models containing 250 mm of ballast layer thickness and different thicknesses of asphalt layers, it was found that the deformation and stress increased by increasing the thickness of the asphalt layer from 120 mm to 140 mm in cases of static and dynamic loads. The maximum deformation value under sleeper increased from 1.069 mm to 1.137 mm (which was resulted from simulation and illustrated in Fig. 7). The maximum vertical deformation under sleeper decreased from 1.137 mm to 1.104 mm when the thickness of the bituminous sub-ballast layer increased from 140 to 180 mm in case of static loads, as recorded in Table 8 and represented in Fig. 8. While the vertical deformation increased from 0.981 mm to 1.025 mm to 1.091 mm in case of 120 mm, 140 mm, and 180 mm thickness of the asphalt layer, respectively, according to dynamic loads.

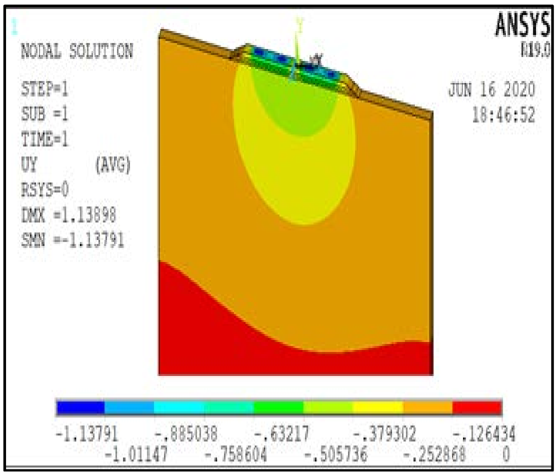

Fig.7 Vertical deformation contours for the case of 140 mm bituminous sub-ballast and 250 mm ballast.

It was also noticed that maximum vertical stress values under sleeper increased from 0.361to 0.386 MPa (which was resulted from simulation and illustrated in Fig.9) when the thickness of bituminous sub-ballast layer increased from 120 mm to 140 mm, whereas it decreased to 0.337 MPa by increasing the thickness to 180 mm in case of static loads. Also, it decreased from 0.381 to 0.357, and 0.329 MPa in case of dynamic loads, as represented in Fig.10. The results of vertical deformations and vertical stresses were recorded in Table 8 and Table 9, respectively. These results showed that the thickness of bituminous sub-ballast and ballast layers of 120 and 250 mm respectively gives the minimum vertical deformations under sleepers. In contrast, the thickness of bituminous sub-ballast and ballast layers of 180 and 250 mm respectively gives the minimum vertical stresses under the sleeper.

Table 8 Deformation values (mm) for the first case

Load Type	Layers	Thickness of layers	Under Sleeper	Under Ballast	Under Asphalt	Above Sub-grade
Static	Ballast Asphalt	25 12	1.069	0.616	0.611	0.474
	Ballast Asphalt	25 14	1.137	0.653	0.628	0.478
	Ballast Asphalt	25 18	1.104	0.657	0.622	0.476
Dyna-mic	Ballast Asphalt	25 12	0.9611	0.605	0.595	0.417
	Ballast Asphalt	25 14	1.025	0.634	0.606	0.435
	Ballast Asphalt	25 18	1.091	0.611	0.6002	0.415

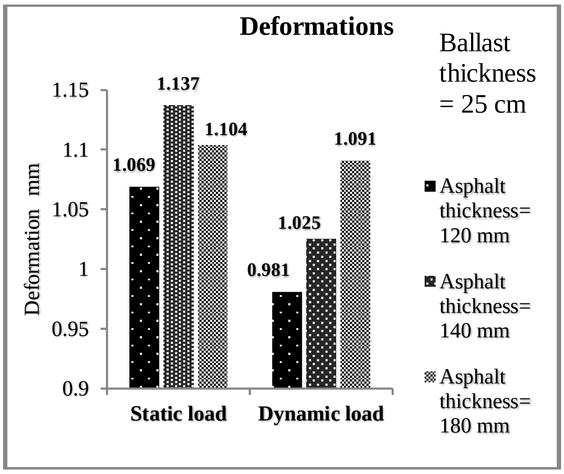

Fig.8 the maximum vertical deformations under sleepers with the thickness of ballast layers 250 mm.

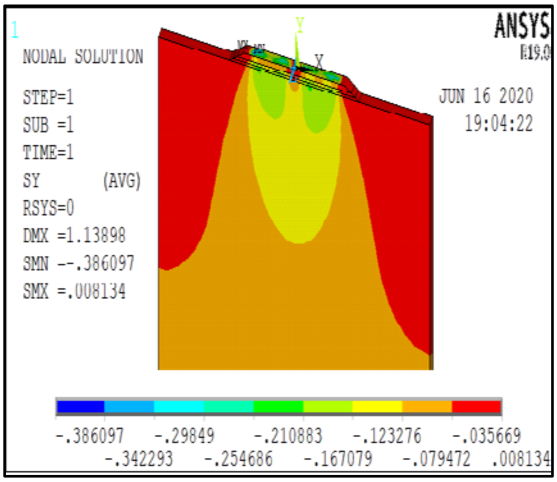

Fig.9 Vertical stress contours for the case of 140 mm bituminous sub-ballast and 250 mm ballast.

Table 9 Stress values (Mpa) for the first case

Load Type	Layer	Thickness of layers	Under Sleeper	Under Ballast	Under Asphalt	above subgrade
Static	Ballast Asphalt	25 12	0.361	0.277	0.190	0.152
	Ballast Asphalt	25 14	0.386	0.224	0.187	0.176
	Ballast Asphalt	25 18	0.337	0.233	0.195	0.173
Dynamic	Ballast Asphalt	25 12	0.381	0.252	0.185	0.174
	Ballast Asphalt	25 14	0.357	0.210	0.176	0.169
	Ballast Asphalt	25 18	0.329	0.250	0.187	0.165

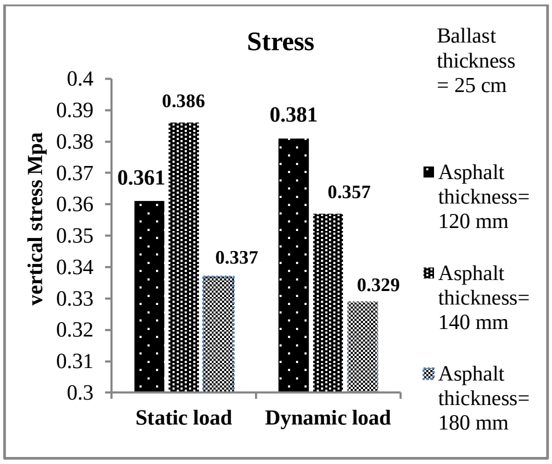

Fig. 10 The vertical stress under sleepers with the thickness of the ballast of 250 mm.

3.2 Effect of Bituminous Layer Thickness in the Case of 300 mm Ballast Thickness

The results of the vertical deformation for trackbed after increasing the thickness of the ballast from 250 mm to 300 mm with 120 mm, 140 mm, and 180 mm thickness of the bituminous sub-ballast layer were analyzed and illustrated in Table 10. It was noticed that the maximum values of the vertical deformations under sleepers are nearly the same in all cases of static and dynamic loads for different thicknesses of bituminous sub-ballast layers, and the maximum value was 1.254 mm as represented in Fig.11. Also, the maximum values of stresses under sleepers were indirectly proportional to the thickness of the bituminous sub-ballast layer for the case of dynamic loading where the maximum record was 0.538 MPa at 180 mm thickness as represented in Fig.12. All results of the vertical stresses were recorded in Table 11.

Table 10 Deformation values mm for the second case

Load Type	Layer	Thickness of layers	Under Sleeper	Under Ballast	Under Asphalt	above subgrade
Static	Ballast Asphalt	25 12	1.199	0.640	0.620	0.477
	Ballast Asphalt	25 14	1.214	0.640	0.618	0.477
	Ballast Asphalt	25 18	1.248	0.647	0.618	0.475
Dynamic	Ballast Asphalt	25 12	1.243	0.615	0.595	0.363
	Ballast Asphalt	25 14	1.254	0.610	0.519	0.361
	Ballast Asphalt	25 18	1.227	0.641	0.602	0.470

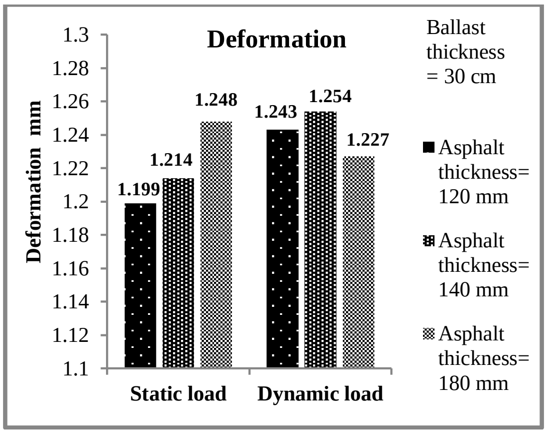

Fig. 11 Vertical deformation under sleepers with the thickness of the ballast of 300 mm.

Table 11 Vertical Stresses MPa for the second case

Load Type	Layer	Thickness of layers	Under Sleeper	Under Ballast	Under Asphalt	above subgrade
Static	Ballast Asphalt	25 12	0.501	0.208	0.191	0.174
	Ballast Asphalt	25 14	0.565	0.200	0.188	0.172
	Ballast Asphalt	25 18	0.547	0.215	0.192	0.173
Dynamic	Ballast Asphalt	25 12	0.415	0.155	0.190	0.171
	Ballast Asphalt	25 14	0.455	0.154	0.187	0.170
	Ballast Asphalt	25 18	0.538	0.194	0.171	0.172

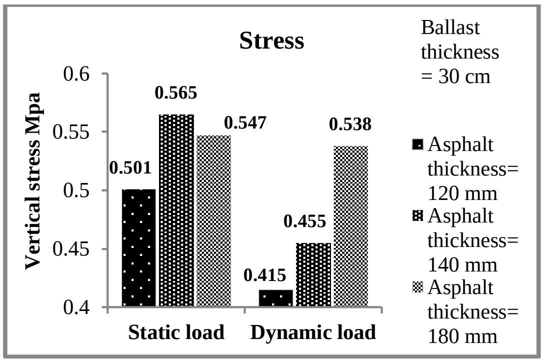

Fig.12 Vertical stress under sleepers with the thickness of the ballast of 300 m.

3.3 Comparing the Case of Using a Bituminous Sub-Ballast Layer with the Conventional Track

The model of the conventional trackbed consists of 300 mm, 500 mm, 500 mm, and 20000 mm thick of ballast, sub-ballast (granular layer), blanket, and subgrade layers, respectively. Fig.13 illustrated a typical conventional section of high-speed railway track showing the used layers. It should be noticed, for this case, that the depth of the conventional sub-ballast is 500 mm, which is more than the similar layer that was used in the case of a bituminous sub-ballast layer by 400 mm. Besides, in this case, a blanket layer was used with depth 500 mm, which was not found in the case of using a bituminous sub-ballast layer. It was also noticed, as shown in Table 12, that maximum deformation value under sleepers of the conventional track was 1.150 mm, where it was not significantly different from the case of the bituminous sub-ballast layer. Also, the maximum value of stress under sleepers (0.752 MPa) was higher than the values of stresses generated from the case of using a bituminous sub-ballast layer by about 15%. The results of the stress values of the case of conventional trackbed were illustrated in Table 13.

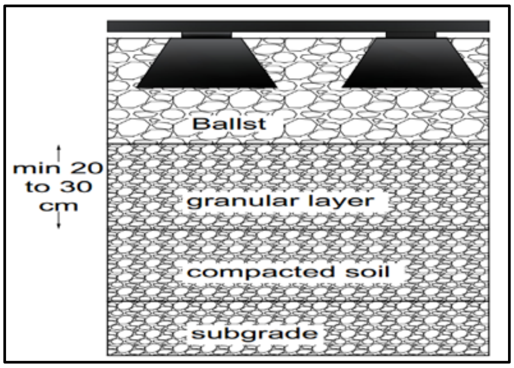

Fig.13 Typical conventional section of high-speed railway track showing the used layers.

Table 12 Deformation (mm) in the track model with the conventional trackbed

Type of Trackbed	Under Sleeper	Under Ballast	Under Sub Ballast	Under Blanket
Conventional Trackbed	1.150	0.921	0.672	0.346

Table 13 Vertical stresses (MPa) in the track model with the conventional trackbed

Type of Trackbed	Rail Head	Over Sleeper	Under Sleeper	Under Ballast	Under Sub Ballast	Under Blanket
Traditional trackbed	560.46	20.38	0.752	0.521	0.29	0.21

4. CONCLUSION

In this paper, the railway track cross-section was provided with a bituminous sub-ballast layer laid under the ballast. The main objectives of using this layer were to reduce the bearing load capacity of the subgrade layer, reduce the vertical deformations of the trackbed, thus the structural behavior of the cross-section will be enhanced, and the maintenance can be minimized. Also, nonlinear analyses have been carried out to get the minimum thickness of the bituminous layer, which causes minimum vertical deformation and stresses, especially under sleepers by using the ANSYS program. Experimental work was conducted on five samples of asphalt mixtures to obtain the most suitable parameters to be used in the simulation process. Based on the conducted analysis and discussions, the following conclusions are summarised as follows:

a. The case of using a bituminous sub-ballast layer of 120 mm thickness under the ballast of 250 mm thickness gives the minimum vertical deformations and stresses under the track sleepers.
b. The maximum vertical deformation under sleepers is 1.069 mm, and the maximum vertical stress is 0.361 MPa in the case of static loading. However, the maximum vertical deformation is 0.981 mm, and the maximum vertical stress is 0.381 MPa in case of dynamic loading.
c. The maximum value of stress under sleepers is lower than the similar vertical stress, which was induced in the case of conventional trackbed by about 15%.
d. Using of the bituminous layer under the ballast layer with the proved thickness in high-speed railway lines has a positive impact as it enhances the structural behavior of the railway track cross-section.

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