Resilient Mats for Improved Performance of Rail Track Foundation

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Abstract. Transportation is the major factor in the economic, social and overall development of any country. Railways are the key to achieve such a fast track development in lesser time. Indian Railway (IR) has put itself in challenge of gaining competency and a large share of the transportation market, as was in the old days. And as these changes are happening very fast, a simultaneous development in the technology must undergo for swift transformation.

This paper presents application of globally tested and accepted technology of resilient mats made from recycled rubber, used in rail track foundation as Under Sleeper Pads (USP) or as Under Ballast Mats (UBM). But global standards are completely different from Indian Standards, so some modifications are necessary before application. In this paper a standard section of rail track currently adopted by Indian Railways is compared with the section modified with the application of resilient mat. When analysed, various benefits such as improved life cycle of track, reduced maintenance cost, etc, have been seen. So this could be a game changer technology for IR to achieve goal within the approved budget and the allocated time period. Also the stability of track was seen to be improved sufficiently with the use of resilient mats to operate semi high-speed trains and higher axle loads.

Keywords: Indian Railway, Track Foundation, USP, UBM.

1 Introduction

The railway network of many countries have a major role in the transport of freight and passenger traffic and the railways are trying for greater emphasis on operating fast and heavy freight corridors to provide more competitive and cost-efficient services. The rail track deterioration due to heavy dynamic loads from wheel is unavoidable over the years, which leads to frequent and high-cost maintenance. The ballast degradation contributes to a large maintenance costs, including affecting the life cycle and track stability. This problem becomes critical in isolated locations where the ballast has direct contact with comparatively stiffer interfaces such as decks of bridge and inverts of tunnel and also in locations where concrete sleepers of heavier sections are used. To minimize such track deterioration in mentioned isolated places, is the use of artificial reinforcements such as resilient rubber mats at the hard interfaces. Now a days, the use of synthetic rubber mats in rail track foundations to address track damage is becoming popular.

The movement of higher freight and passenger traffic has become one of the major challenges worldwide by improving stability of the rail track structure. Increased train speed and heavy axle load transfers high excessive stresses to ballast layer below the sleepers and underlying formation. Degradation of ballast is a factor of major importance affecting track life and stability. Shock mats can have the following type of application, such as Under Sleeper Pads (USPs) and Under Ballast Mats (UBMs) for reducing the plastic deformation and degradation of ballast. These resilient pads and mats avoids a hard interface between ballast and the sleeper, also for the underlying formations layers. This improves the area of surface contact for the ballast as aggregates rests into much softer mats which results in the reduction of the ballast stresses.

1.1 Existing Condition of Indian Railways

The Indian Railways (IR) is facing the demanding challenge of competency in recent times. IR has become totally observant of this fact and is trying in all ways to solve it as early as possible. The railways face highest demand for passenger traffic, mainly for long distance travelling. The IR is also serving for the suburban traffic in mega/metro cities like Mumbai, New Delhi, Kolkata, Chennai, Pune etc. Besides expected growth rate of about 10 % to 12 % every year, railways is growing at the rate of 4 % to 5 % per year in freight traffic transport. Transport market share of railways has shown consistently decline graph in past years. The railway has realised that the excessive increase in the charges for the transport of freight traffic have been proven counter-productive and resulted in diversion of traffic to roadways. The government of India has ignored for long time the reality that railways are becoming the major part of the very essential infrastructure of any country. To meet that requirement, the IR has came up with the significant Eastern Dedicated Freight Corridor from Kolkata to Punjab (Ludhiana) for the movement of bulk traffic like steel, coal, etc. and the Western Dedicated Freight Corridor from National Capital Region (NCR) to Mumbai for the movement of container traffic to the JNPT port, Mundra port and Pipavav.

Frequent congestion of traffic and the demand of quicker and safer travelling have made the railways the most preferred mode of public transportation. The ballast layer provides the optimum resiliency, therefore transmitting the imposed wheel loads to an acceptable depth of the formation layers and below sub-grade soil, but prevents the excessive lateral and vertical displacements. Still, the time dependent deterioration and ballast breakages due to higher train speeds and heavier axle loads is a leading factor for the change in track geometry and excessive maintenance costs of track. Additionally, soft compressible clays, along the coastal regions of India often show extremely low bearing capacity. For the improvement of track conditions and optimisation of the rack Life-Cycle Cost (LCC), the use of geosynthetics (geogrids, geocomposites), resilient mats (UBM/USP), and prefabricated vertical drains is desirable.

Resilient mats placed under the sleepers and under the ballast are Under Sleeper Pads (USP) and Under Ballast Mats (UBM), respectively which are the energy absorbing in nature. USP and UBM are made from the resilient material for the improvement of the overall vertical elasticity of track substructure. In recent years, use of elastomeric soft pads attached underneath the concrete sleepers have become very popular and is of the primary target of track research.

2 Materials and method

The purpose of a railway track structure is to provide safe and economical rail transportation. This requires the track to serve as a stable guide-way with appropriate vertical and horizontal alignment. To achieve this role, each component of the system must perform its specific functions satisfactorily, in response to the traffic loads and the environmental factors imposed on the system.

The geometry and material property of the model are taken from the Guidelines and Specifications of the Design of formation for Heavy Axle load (2009) and various literatures. For the boundary conditions, both sides were allowed to move vertically and the bottom level was fixed to prevent any movement. Initial condition analyzed by simulating the stresses in the model due to self-weight of the layers followed by the simulation of the reinforcements using UBM & USP in the track substructure. An equivalent dynamic wheel load (Pdl) for the given static wheel load (Psl) for the traffic loading conditions, was obtained as per the Research Design and Standard Organization (RDSO 2009) approach and is given by:

$$Pdl = DIF \times Psl \quad (1)$$

The Dynamic Impact Factor (DIF), according to the RDSO HAL manual is considered as 1.5. Based on equation (1), an equivalent dynamic wheel load of 243.75 kN was applied for the train speed equal to 160 km/hour, 1.372 meter of wheel diameter, and 162.5 kN of static wheel load. For modelling of resilient mats, a geogrid element provided in PLAXIS was used along with interface elements which are connected with adjacent layers of track substructure. The geogrid data set has the only property in it, as the Elastic Axial stiffness (EA) in force per unit width. For the parametric study, EA value were taken to estimate the influence of its integrity on the rail track substructure response.

The railway embankment models consist of ballast, sub-ballast, embankment fill and subsoil, with superstructure of sleeper and rail. Resilients mats are used as an reinforcement to the embankment.

Table 1. Reference material properties used in the finite element analysis

Material	Rail	Sleeper	Ballast	Sub Ballast	Embankment Fill	Sub Soil	Resilient Mat
Model	Elastic	Elastic	HS	MC	MC	MC	Elastic
E (MPa)	$2.1 * 10^5$	$3 * 10^4$	-	140	67	40	-
E_{50}^{ref} (MPa)	_	_	65	_	_	_	_
E_{oed}^{ref} (MPa)	_	_	65	_	_	_	_
E_{ur}^{ref} (MPa)	_	_	195	_	_	_	_
EA (MPa)	-	-	-	-	-	-	1000

γ (kN/m^{3})	78	24	15.6	19	17	18	-
μ	0.3	0.2	-	0.37	0.37	0.37	-
μ_{ur}	-	-	0.2	-	-	-	-
C (kPa)	-	-	0	0	0	0	-
Φ	-	-	58	45	40	30	-
Ψ	-	-	0	0	0	0	-

In this study, the finite element program in PLAXIS 2D was used to analyze the strain conditions of 15 node elements for the parametric study. Due to symmetry, only one half of the track section was considered in the numerical model.

3 Finite element modelling

In this section, the 2D finite element modelling of railway embankments was performed using PLAXIS-2D software. The construction sequences were simulated following the RDSO Guidelines. The parameters used for the embankment were simplified into a 2D plan of strain and symmetry by assuming that the transversal profile of the track is uniform in the longitudinal direction due to the long track and location in the middle of the embankment.

Due to the strict requirements of the HAL track, the ground improvement is done at the subgrade soil level to enhance the performance of subgrade soil *i.e.,* increasing strength and stiffness.

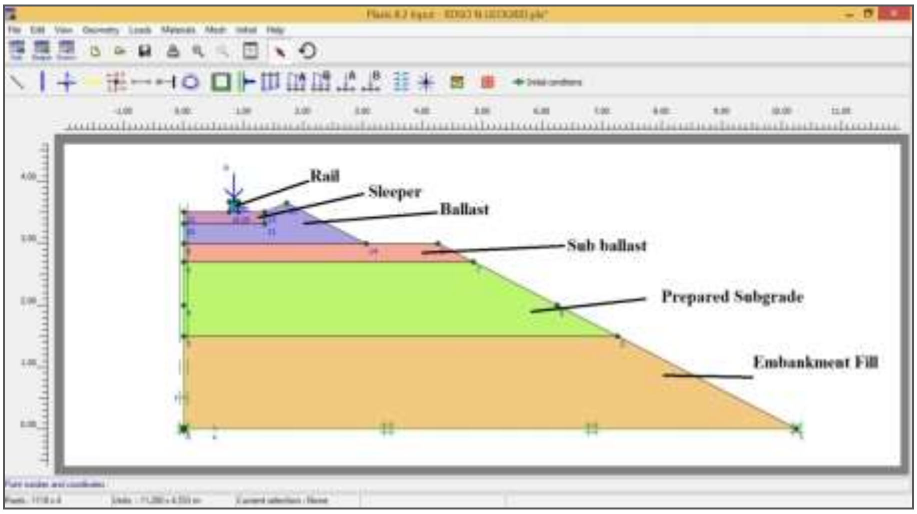

Fig. 1. Railway embankment without resilient mat

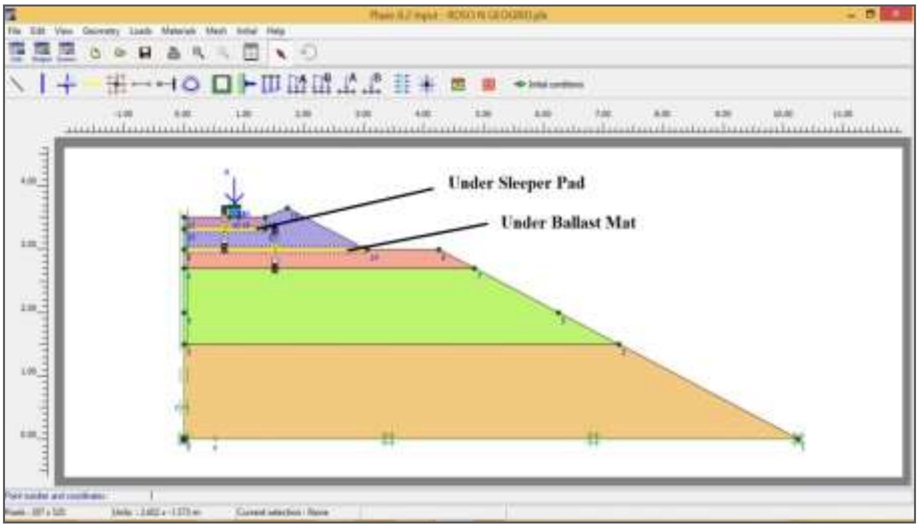

Fig. 2. Railway embankment with resilient mats

3.1 Mesh Generation

Triangular elements of each 15-nodes are used for modelling of the embankment and subsoil materials. Figures below shows the finite element models and mesh generation. It is noted that the very coarse meshes were used. Number of elements formed are 58 and nodes generated are 583 in number.

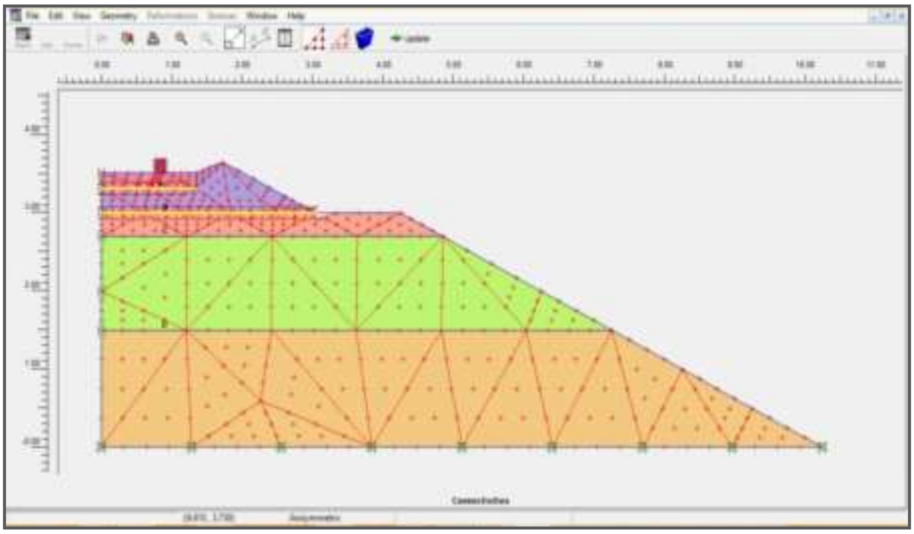

Fig. 3. Mesh with selected nodes A, B, C, D at top of each layer (exactly under the rail)

3.2 Boundary Conditions

Prior to performing the analysis, a suitable boundary size must be identified. It is commonly known that too big a size will increase the computational time while too small a size will cause the boundary to affect the calculation results. In this study, the geometries of the boundary were carefully adjusted. For the boundary conditions, both sides were allowed to move vertically and the bottom level was fixed to prevent any movement.

3.3 Constitutive Models and Their Parameters

The constitutive models for embankment and subsoils are described in this section. The ballast material was represented by the Hardening Soil model (HS), The HS model parameters for ballast used in the analyses are summarised in Table. The characteristics of ballast on drained granular material can be reasonably modelled by HS model and drained analysis. For Sub Ballast, Embankment fill, and Sub soil materials in the embankment, the Mohr-Coulomb model (MC) is used. Rail, sleeper are modelled with the Elastic model.

All the parameters for each of the above mentioned models is given in table 1 of section 2 of this paper.

4 Results And Analysis

In this section, the results of analyses are presented and discussed. The results are focused on the deformations.

Table 2. Extreme displacement of layers for various models

	Without Resilient Mat(USP/UBM)	With UBM	With USP	With Both USP & UBM
Extreme Total Displacements(m)	$6.90*10^{-3}$	$2.60*10^{-3}$	$8.57*10^{-3}$	$3.43*10^{-3}$
Extreme Horizontal Displacements(m)	$2.49*10^{-3}$	$1.04*10^{-3}$	$3.10*10^{-3}$	$1.42*10^{-3}$
Extreme Vertical Displacements(m)	$6.90*10^{-3}$	$2.60*10^{-3}$	$8.57*10^{-3}$	$3.43*10^{-3}$

Following is the comparative representation of the extreme displacements mentioned in above table 2, in graphical form:

(Unit of displacement is converted into ‘mm’ from ‘meter’, which is mentioned in the above table, for the convenience of representation)

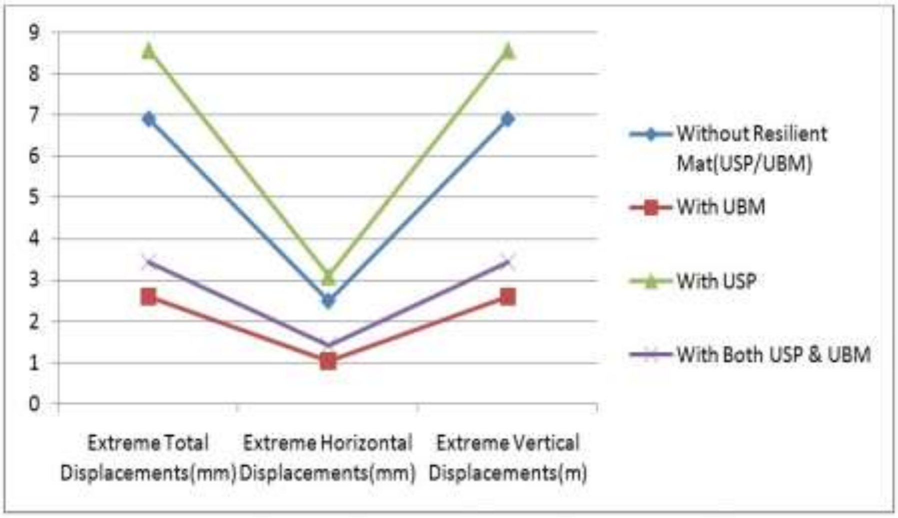

Fig. 4. Extreme displacement of layers for various models

From above comparative analysis it is clear that reinforcement of embankment by using only Under Ballast Mat (UBM) gives more resistance to the extreme displacements of the formation layers. From calculations it is evident that reduction in the extreme total displacements is nearly 63%, in the extreme horizontal displacements is nearly 52%, and in the extreme vertical displacements is nearly 63%, after the use of UBM as reinforcement.

Table 3. Horizontal displacement (mm) of nodes at top of each layer (exactly under the rail)

	Without Resilient Mat(USP/UBM)	With UBM	With USP	With Both USP & UBM
Node 125 (Node A)	0.001	0.000	0.005	-0.002
Node 141 (Node B)	0.045	0.004	0.047	0.003
Node 254 (Node C)	0.251	0.054	0.283	0.061
Node 316 (Node D)	1.712	0.622	2.172	0.879

Following is the comparative graphical representation of horizontal displacement of nodes:

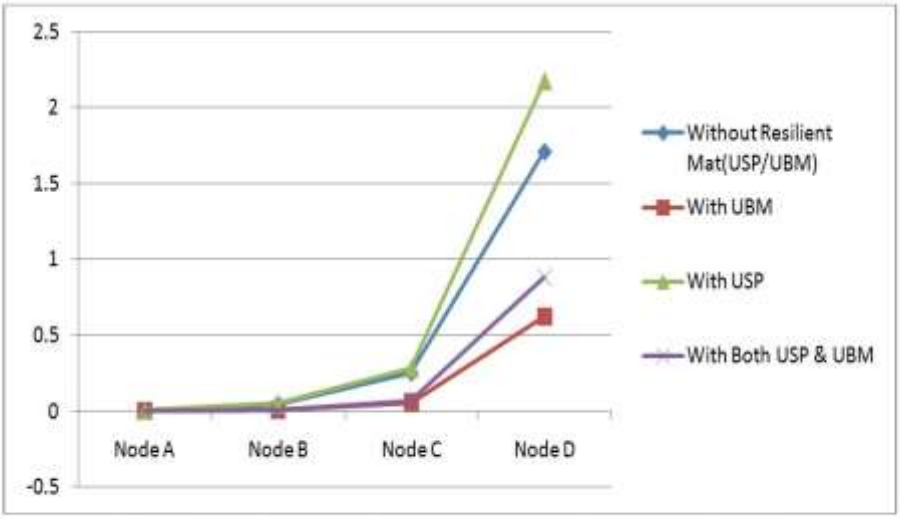

Fig. 5**.** Comparative horizontal diplacements (mm) for various models

From above graph it is seen that horizontal displacements are the minimum in case of reinforcement of embankment with UBM only. Though the reduction observed is not quite competitive, but we must be understood that when subjected to repetitive loading the combined effect in reduction of displacement will be really competitive.

Table 4. Vertical displacement (mm) of nodes at the top of each layer (exactly under the rail)

	Without Resilient Mat(USP/UBM)	With UBM	With USP	With Both USP & UBM
Node 125 (Node A)	-6.864	-2.577	-8.538	-3.466
Node 141 (Node B)	-6.709	-2.467	-8.377	-3.354
Node 254 (Node C)	-6.510	-2.429	-8.149	-3.309
Node 316 (Node D)	-3.362	-1.421	-4.195	-1.913

Following is the comparative graphical representation of vertical displacement of nodes:

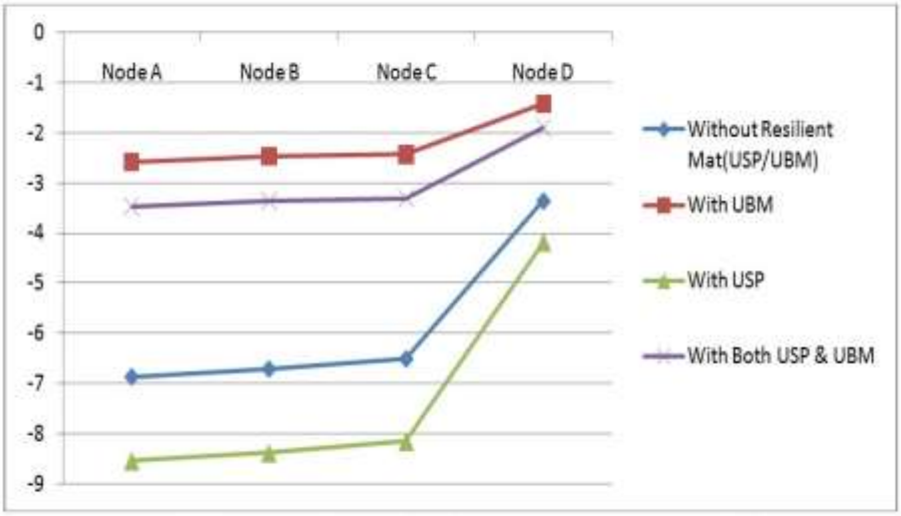

Fig. 6. Comparative vertical diplacements(mm) for various models

From above graph, it can be said that the again reinforcement of embankment with UBM is quite effective in minimising the vertical displacements, when compared to other models. Nearly 60% -63% reduction can be calculated as compared to non reinforced embankment (i.e. without resilient mats).

5 Conclusions

From this study, it is clearly evident that the reinforcement between sub-ballast and embankment fill (i.e. UBM), between ballast and subballast (i.e. USP) and the reinforcement at both the interfaces (i.e. UBM & USP) reduces the displacements significantly. So it is clear that to minimise the cost of maintenance and to reduce the shear failure, the reinforcement in the form of resilient mats between subballast and subgrade, between ballast and subballast and the reinforcement at both the interfaces are the options.

Though other options also reduces the displacements significantly, but the better option would be with UBM only. As this would not require USP, can reduce the material consumption and hence the cost of materials. Though the addition of UBM will require higher initial costs, but as displacements are reduced, less maintainance will be an added advantage. Also life of embankment layer materials will be increased due to less transfer of stresses(result of less displacements) and hence the Life Cycle (LC) of the embankment(ballast, sub ballast, embankment fill, etc) will be increased. Though initial costs look higher but overall Life Cycle Cost (LCC) will be much competitive.

The major benefit will be the reduced settlement problems, which are the major factor of maintainance and reduced train speeds. In this way higher speed can be achieved for the reinforced tracks. This will give edge over delay problems of train, and distances will get minimised in terms of time of travel between the stations.

In this way only one technological change in the embankment will give Indian Railway a hand in overcoming many problems such as frequent maintainance, train delays, reduced speed over sections, etc. This will bring back railways in the very competitive market of moving people and goods over distances.

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