Three Dimensional Finite Element Analysis of Railway Track

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ABSTRACT

A ballast and a subballast layer placed above a compacted subgrade (formation soil) is the conventional structure of a railway track system. Upgrading the tracks with the current traffic condition requires the new design methodologies and the parametric studies to investigate the effect on the track system. For this purpose the geotechnical and tunnelling software called MIDAS (GTS) was used to create three dimensional finite element models. This finite element model was used to predict the displacement and the vertical stress along the track components. To validate the model the results have been compared with other numerical models. The effect of modulus of each track component was evaluated through a parametric study. The influence of subgrade modulus was higher when compared to ballast and subballast modulus.

Keywords: 3D finite element model, Vertical stress, Displacement, Elastic modulus, Parametric study

1. INTRODUCTION

Railways form an important part of the transportation infrastructure of a country and plays an important role in sustaining a healthy economy. Indian Railways have now geared up to overhaul and upgrade its infrastructure to meet future demand of growing traffic. Special emphasis has been laid on spreading the railway network by laying new tracks and also on increasing transportation efficiency by running heavier, longer and faster trains. Indian railways have identified track-foundation-soil system as one of the key factors in bringing about these changes. Figure 1 shows the main components of ballasted track structures. These may be grouped into two main categories: superstructure and substructure. The superstructure consists of rails, the fastening system, and the sleepers (ties). The substructure consists of the subgrade, the subballast and the ballast. The superstructure and substructure are separated by the sleeper-ballast interface.

The extension of existing railway routes to take higher axle loads and faster trains coupled with increased frequency requires that the load bearing system is strengthened. In particular, the load bearing capacity of the subbase must be increased to avoid track subgrade failures. This requires an investigation into the effect of various track parameters on overall track performance. Such an investigation is very useful for railway geotechnical engineers to evaluate the track design and maintenance. The finite element analysis software MIDAS (GTS) version 3 (2009) is used to develop a reliable numerical model for predicting the accurate track response.

2. MIDAS (GTS)

MIDAS/GTS is a specially generated finite element program, designed to model the behavior of geotechnical and tunneling structures under externally applied loading. This software provides a consistent, graphical interface for creating geotechnical models, interactively submitting and monitoring and evaluating results from post work data simulations. MIDAS/GTS is divided into modules, where each module defines a logical aspect of the modelling process (e.g., defining the geometry, defining the material properties, and generating a mesh).

Evaluation of Model Predictions

In this study, a railway track section is numerically modelled using the finite element analysis (MIDAS/GTS). A detailed
analysis of the predictive capabilities of this model is carried out by comparing results predicted by the 3D MIDAS/GTS model for three different tracks. Selig et al. (1979) evaluated three models, namely MULTA, PSA and ILLITRACK. The present model results were compared with the above mentioned models. Details of FAST track dimensions and material properties, as given by Selig et al. (1979) and Stewart & Selig (1982), are given in Table 1. Figure 2 shows the FAST track section modelled in MIDAS (GTS) discredited utilizing 20 node quadrilateral elements for all part of the track section. Due to symmetry, only one half of the track is considered in numerical model. Rollers supports were applied on the lateral (vertical) faces and the bottom face was kept fixed. No boundary conditions were applied to the sloping face of ballast and sub-ballast, and to the sides of the rail.

The train load of 144.5kN was applied in the track model. Figures 3 and 4 show the results of vertical stress and displacement for FAST track models. The MIDAS/GTS model gives results quite similar to those from the MULTA model which is like a closed form solution. The measured value of vertical stress and displacement at the subgrade surface (0.856 m depth) beneath the rail seat of 44 kPa and 1.65mm compares rather well with the predicted value of 43.4 kPa and 1.68 mm from the MULTA and MIDAS models.

Figure 5 shows that the MIDAS model not only predicts vertical stress distribution along the depth accurately but also predicts vertical stress along the tie at different depths quite satisfactorily and similar to those of MULTA model.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Rail</th>
<th>Sleeper</th>
<th>Ballast</th>
<th>Subballast</th>
<th>Subgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic Modulus, E (MPa)</td>
<td>211000</td>
<td>10349</td>
<td>207</td>
<td>138</td>
<td>34</td>
</tr>
<tr>
<td>Poisson’s ratio, ν</td>
<td>0.33</td>
<td>0.37</td>
<td>0.37</td>
<td>0.37</td>
<td>0.33</td>
</tr>
<tr>
<td>Inertia, I x 10^4 (mm^4)</td>
<td>3950</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>0</td>
<td>180</td>
<td>380</td>
<td>130</td>
<td>3276*</td>
</tr>
<tr>
<td>Length (m)</td>
<td>0</td>
<td>2.74</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* Assumed value

**Fig. 2:** Finite Element Discretization of FAST Track Model (MIDAS/GTS)

**Fig. 3:** Comparative Results for Vertical Stress Beneath the Rail Seat Versus Depth for FAST Track and the Present Work

**Fig. 4:** Comparative Results for Displacement Beneath the Rail Seat Versus Depth for FAST Track and the Present Work

**Fig. 5:** Predicted Vertical Stress Along the Tie at Different Depths for FAST Track (After Selig et al. 1979)
Figure 6 shows that the rail displacement results also comparatively matching with MULTA model.

3. TRACK PROPERTIES FOR PARAMETRIC STUDY

For the purpose of the parametric study, the performance of a nominal fixed track is obtained and used as a benchmark for the basis of comparison. This nominal track is representative of an Indian track which is given by Research Design and Standards Organisation (RDSO). The track dimensions and material properties for the nominal case and variable track properties used for comparison are given in Table 2 and 3, respectively. When changing any of the assumed variables given in Table 3, other track variables are assigned the values of the values of the nominal case shown in Table 2. The train wheel load used is 243.75kN.

### Table 2: Nominal Track Properties Used for the Parametric Study

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Rail</th>
<th>Sleeper</th>
<th>Ballast</th>
<th>Subballast</th>
<th>Subgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic Modulus, E (MPa)</td>
<td>20000</td>
<td>30000</td>
<td>150</td>
<td>80</td>
<td>40</td>
</tr>
<tr>
<td>Poisson’s ratio, ν</td>
<td>0.30</td>
<td>0.33</td>
<td>0.35</td>
<td>0.35</td>
<td>0.40</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>135</td>
<td>210</td>
<td>300</td>
<td>150</td>
<td>2700</td>
</tr>
<tr>
<td>Length (m)</td>
<td>6</td>
<td>2.75</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 3: Variable Track Properties Used for the Parametric Study

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nominal Value</th>
<th>Values used Keeping All Other Parameters at Nominal Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ballast, E_b</td>
<td>150</td>
<td>100, 200, 300</td>
</tr>
<tr>
<td>Subballast, E_sb</td>
<td>80</td>
<td>40, 60, 100</td>
</tr>
<tr>
<td>Subgrade, E_sg</td>
<td>40</td>
<td>10, 20, 60, 80</td>
</tr>
</tbody>
</table>

The results of the parametric study are shown in Figs 7a, b, c and d. Shahu et al. (1999) and Shahin et al. (2006) already carried out the detailed parametric study for different type of nominal track models with 3D20N, PLAXIS model respectively. In the present parametric study MIDAS (GTS) software was used. It can be seen from Fig. 7a that the most significant factors affecting rail deflection is the subgrade stiffness. An increase in subgrade stiffness leads to dramatic decrease in rail displacement. The track response in relation to the ballast and subballast surface vertical stress are almost identical, as shown in Figs 7b-7c.
An increase in subgrade stiffness leads to an increase in both ballast and subballast surface vertical stress. Figure 7d also shows that the effect of subgrade modulus in subgrade vertical was high when compared to that of ballast and subballast modulus.

Overall, it is clearly evident from Fig. 7 that the subgrade stiffness has the greatest influence on track response.

4. CONCLUSIONS

From the effect of modulus of various track components, it is clearly evident that the subgrade stiffness has the most significant impact on overall track response. It was shown that when subgrade elastic modulus decreases, the rail displacement increases dramatically, which indicates that the subgrade as a soft soil, then track maintenance would be the critical issue.

REFERENCES


