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Research Note

Investigation on Modeling of Railway Track System

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In this paper, limitations and requirements in modeling of railway track systems are studied. The minimum required number of sleepers, minimum required depth and width of subgrade layers as well as consideration of tensile stress for the ballast are investigated. This investigation is conducted by using finite element models, considering different characteristics of track components and applying different analysis procedures. The results of dynamic analysis of two different analytical models are compared with experimental results in order to evaluate the accuracy and reliability of the analytical methods in predicting track behavior.

INTRODUCTION

Today's most important need in the field of railway engineering is to improve track durability, strength and stability as well as increasing efficiency, especially for heavier axle loads and higher speeds. This goal can be achieved by providing a better understanding of the static and dynamic behavior of track systems through provision of an appropriate mathematical model.

Prior to conducting any analytical investigation, limitations in track modeling and its geometrical requirements for obtaining a desired accuracy should be studied. The main needs in this regard are to determine the minimum dimensions of the track components in track models, define a suitable interface between track components and find appropriate boundary conditions for track models. Using sensitivity analysis:

- The minimum required number of sleepers,
- The minimum required length of track models,
- The minimum required dimensions of subgrade layers,
- Consideration of tensile stress for the ballast layer,

are investigated.

There is also a need to investigate the accuracy of the results obtained from analytical models [1,2]. Towards this aim, natural frequencies of two different analytical approaches are compared with experimental results obtained from tests in a track field.

NUMBER OF SLEEPERS

In track modeling, it is necessary to determine the minimum number of sleepers required in a track model. For this purpose, a three-dimensional model of track systems developed in [3,4] was analyzed with different number of sleepers. This model, called the 3D model, is a finite element model, which considers all the track elements including subgrade, ballast, sleepers and rail. The number of elements varies from 10,000 to 30,000. It takes gap element between the track components into consideration and uses a modified (elastic-plastic) stress-strain relationship for the track sub-components [5]. Applying a single loading system (load exerted by a wheel of Victorian X locomotive [6]), the maximum rail deflection is obtained. Maximum rail deflections obtained from analyses of the model with 8, 10, 12, 16, 20, 24, 32 and 72 sleepers are presented in Figure 1.

As shown in Figure 1, there is a very slight change in maximum rail deflection obtained from analysis of the models with more than 20 sleepers. The results indicate that consideration of at least 20 sleepers in a track model is sufficient to remove the dependency of the maximum rail deflection on the number of sleepers.

Figures 2 and 3 present number of sleepers against maximum ballast contact pressure and maximum subgrade stress, respectively. Based on the results presented in these figures, there is only a 2% increase in

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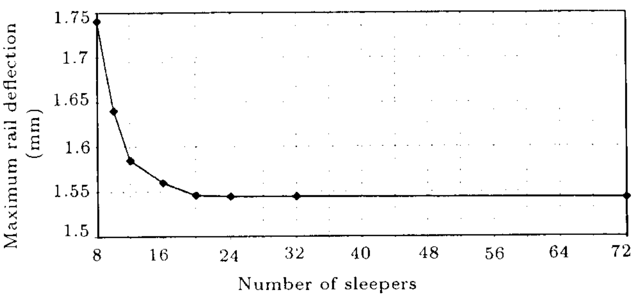

Figure 1. Maximum rail deflection versus number of sleepers.

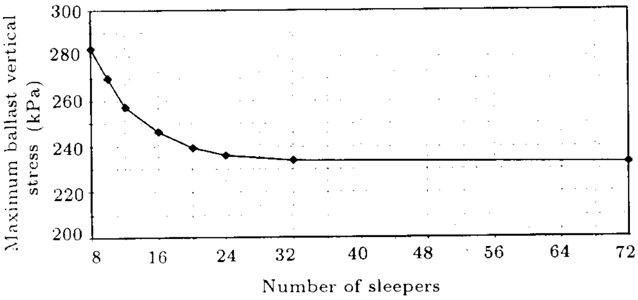

Figure 2. Maximum ballast contact pressure versus number of sleepers.

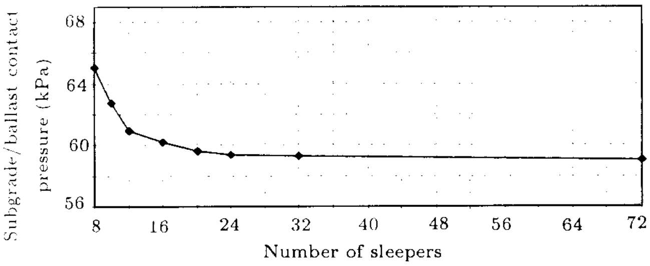

Figure 3. Maximum subgrade stress value versus number of sleepers in the model.

maximum ballast vertical stress and a 1% increase in maximum subgrade contact pressure when number of sleepers increases from 20 to 72. Therefore, 20 sleepers in a finite element model of track are adequate to remove the dependency of the stresses within the track sub-components on the number of sleepers.

Rail deflection, rail bending stress, maximum ballast vertical stress and subgrade contact pressure at different points obtained from analysis of the 3D model with the single loading system are shown in Table 1. A comparison of the results, presented in Table 1, indicates that the effects of loads on the deflection and stresses at points more than 5 m away from the load points are negligible (5 m is equivalent to 9 sleeper spacings or 10 sleepers at each side of the load point). This confirms the adequacy of a minimum of 20 sleepers in track models. The results also confirm the statement made by Talbot [7] in which he claimed that static track deflection caused by a single point load on a rail spreads over 7 to 9 sleepers in the track.

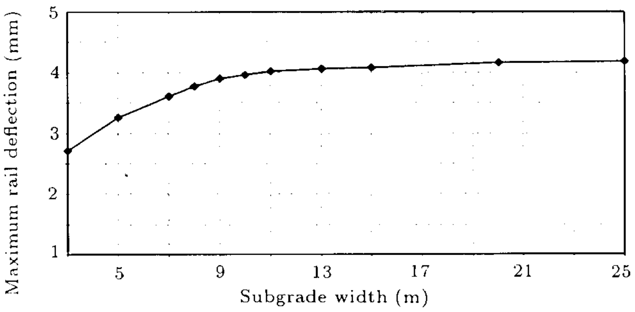

Figure 4. Maximum rail deflection versus subgrade width.

Based on the above results, it can be deduced that 20 is an appropriate suggestion for the minimum number of sleepers in track models.

SUBGRADE DIMENSIONS

To determine the minimum depth required for the subgrade layer in track models, a sensitivity analysis was carried out on the 3D model with different subgrade depths. A multiple loading system (loads induced by two adjacent Victorian X locomotives [6]) was used here. Summary of the results is presented in Table 2. A comparison of the results indicates that an increase in the depth of subgrade layers after 4.5 m (3 m for the bottom layer and 1.5 m for the top layer) does not have considerable effects on the results. Based on the analysis results, 4.5 m is a sufficient depth for a subgrade to remove the dependency of the rail deflection on any increase in the depth of the soil layers.

To determine the minimum required width of a subgrade in track models, the 3D model with different subgrade widths was analysed. The results of this analysis are presented in Figure 4. As shown in the figure, there is a slight change in maximum rail deflection when subgrade width is increased by more than 9 m. It is evident that 9 m width for track models is sufficient to remove the dependency of maximum rail deflection on subgrade width.

TENSILE STRESS IN BALLAST

To investigate tensile stresses between the ballast and sleepers, gap elements were used in the interface between ballast and sleepers. Gap elements in the model can only take compression stresses and in tension have negligible stresses. Deflection results of analysis of the 3D model with the single loading system for two cases, with and without gap elements, are presented in Figure 5. As shown in this figure, there is a negligible difference between the results of the two models, except at points away from the load where

Table 1. Stress and deflection results obtained from analysis of the reference model at points away from the load point.

Horizontal Distance from Load Point (m)	Rail Deflection (mm)	Rail Stress (Mpa)	Maximum Ballast Vertical Stress (kpa)	Ballast/Subgrade Contact Pressure (kpa)
0	1.543	57.61	232	59
1	0.73	-6.11	106	28
2	0.01	-4.87	10	7
3	-0.18	0.57	0.02	3.5
4	-0.09	2.67	0.2	0.40
4.5	-0.02	2.02	0.38	0.08
5	0.008	0.841	4.14	0.15
5.5	0.01	0.39	7.0	0.08
6	0.006	-0.01	0.57	-

Table 2. Maximum rail deflection for different subgrade depths.

Bottom Layer of Subgrade (m)	Top Layer of Subgrade (m)	Ballast (m)	Maximum Rail Deflection (m)	Maximum Ballast Vertical Stress (kpa)	Ballast-Subgrade Contact Pressure (kpa)
0.5	0.5	0.3	2.347	997	191
1	0.5	0.3	2.644	910	184
1	1	0.3	3.156	842	177
1.5	1.5	0.3	3.636	760	164
2	1.5	0.3	3.908	687	159
3	1.5	0.3	3.988	624	152
4.5	1.5	0.3	4.012	615	151
6	1.5	0.3	4.026	608	150

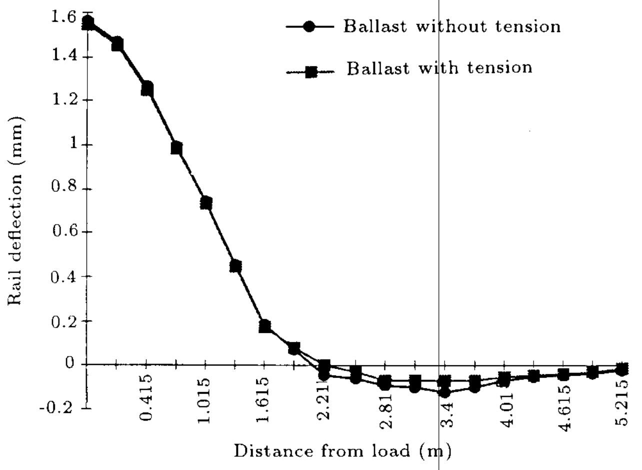

Figure 5. Rail deflection for cases in which ballast is considered with and without tensile stress.

ballast is under tension. Superposition of the results obtained from several loads (multiple loading) will reduce this difference. Based on the results obtained, it can be deduced that the consideration of tensile stress in track models has no significant effect on the analysis results.

EVALUATION OF RESULTS OBTAINED FROM ANALYTICAL MODELS

In order to evaluate the accuracy of the results obtained from analytical methods, the results of dynamic analysis of the 3D model and a two-dimensional model of the track, developed in [5], were compared with experimental results obtained from field tests detailed in [7,8]. The 2D model is a finite element model of the track in two dimensions. It considers all components of the track including rail, sleepers, ballast and subgrade. The advantage of the 2D over the 3D model is that it takes into account the nonlinear properties of the track substructures and nonlinear boundaries for the subgrade layer [5]. Experimental results were obtained by conducting modal analysis tests on the track system. These tests were carried out on a track field (NSW/Australia) using a spectrum analyzer [8]. The properties of track components in both models were the same as those in the test field. Tables 3 and 4 demonstrate the natural frequencies of track system with timber and concrete sleepers obtained from the 2D and 3D models. The natural frequencies obtained from the experiments are presented in Table 5.

Table 3. Natural frequencies obtained from analysis of the 2D model with timber and concrete sleepers (Hz).

Number of Frequency	Site with Concrete Sleepers	Site with Timber Sleepers
1	124	86
2	423	214
3	480	311
4	701	490
5	903	743
6	1234	766

Table 4. Natural frequencies obtained from analysis of the 3D model with timber and concrete sleepers (Hz).

Number of Frequency	Site with Concrete Sleepers	Site with Timber Sleepers
1	121.39	90.03
2	253.83	114.87
3	398.39	160.33
4	602.27	240.11
5	760.59	351.51
6	904.23	428.19

Table 5. Natural frequencies obtained from tests on sites with timber and concrete sleepers (Hz).

Number of Frequency	Site with Concrete Sleepers	Site with Timber Sleepers
1	101	83
2	330	155
3	379	190
4	637	306
5	872	351
6	1011	442

A comparison of the results indicates good agreement between the results obtained from analysis of the analytical models and the experiments. The results show a better agreement when using concrete sleepers. There are some differences between theoretical and experimental results particularly for higher frequencies. However, based on the above results, the analytical methods can provide a good prediction of the dynamic behavior of the track system.

CONCLUSIONS

Through a sensitivity analysis of track models, the limitations and requirements in track modeling were investigated. It was found that in track models:

- 20 sleepers are sufficient.
- 4.5 m depth and 9 m width are adequate subgrade dimensions.
- Consideration of tensile stress for ballast does not have significant effects on the results of static analysis of the track.

A comparison between the results obtained from dynamic analysis of analytical models and experiments indicates good agreement. The results also demonstrate that the 3D model of the track system provides better accuracy in comparison with the 2D model. Based on the results presented here, through analytical methods the dynamic behavior of the track system can be well predicted. However, there is a need for further development of the presented models in order to obtain a better accuracy. The methods suggested for developing these models are: incorporating the nonlinear properties of the track components, considering the transient characteristics of the load, and developing a better model for the interface between the track components, which is in progress.

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