Experimental and numerical evaluation of longitudinal vehicular forces on bridges of Indian railways

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1. Introduction

There are more than 1,47,000 bridges in Indian Railways (IR). With the advent of modern locomotives in IR, tractive efforts have increased substantially following the considerably increasing longitudinal loads. Currently bridges are designed by considering all the longitudinal loads getting transferred to the girders, therefore; a rational analysis of longitudinal forces on railway bridges considering its dispersion to the adjoining areas is required. In this study, identification of different phenomena behind longitudinal load transferred from rail level to substructure was investigated. First, an experimental investigation for the evaluation of longitudinal force on a steel plate girder bridge was performed by various static and dynamic test train formations. Furthermore, a numerical study of the flow of longitudinal forces from locomotives to sub-structures was performed for the measured bridge. are the focus of this research.

2. Experimental investigation

Field experiments were performed by Indian railways on a girder bridge as shown in Figure 1. Different static and dynamic tests were carried out over the instrumented bridge girder. Longitudinal loads were generated by accelerating locomotive and applying brakes at different speeds. Using the observed strain gauge readings at track and girders, percentage of longitudinal load transferred to the girder can be estimated. As shown in Table 1, less than 60% of the longitudinal load applied by locomotives gets transferred to the girder , which validates the safety of the existing bridges for the increased longitudinal loads.

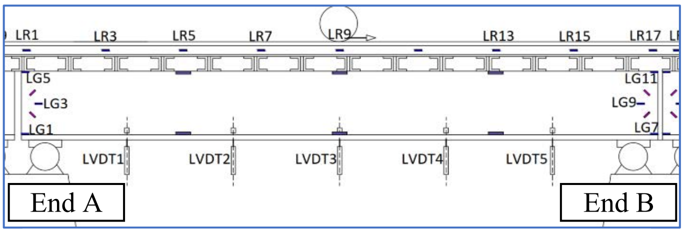

Figure 1- Instrumented span and its details

Table 1- Summary of load transfer for tractive effort case

Test Case	F.L. at the rail level on main span	F.L. at the rail level on adjacent span	Difference in rail force transferred	Percentage load transferred
Acceleration from end A towards B	18.29	7.47	10.81	59.10%
Acceleration from the centre to B	18.59	9.17	9.41	50.62%
Acceleration from end B towards B	15.46	6.86	8.61	55.69%

3. Numerical model and proposed analysis method on rail wheel contact

Rail-wheel contact is the foundation of all research related to vehicle-track interaction. Stress distribution at rail wheel interface becomes very complicated if surface roughness and longitudinal forces imparted by trains are included. As a result, modern research on rail-wheel contact interactions is performed by finite element modelling of a very limited length of track (3-5 sleepers) due to the requirement of very refined mesh at the interacting interface of contacting bodies. For simulating the longitudinal loads in a railway bridge, the required model size might become very large , which requires some reasonable approximations in the simulation procedure.

Analytical solutions can serve as a computationally efficient alternative of physical modelling of the complete phenomena. User-subroutines in ABAQUS provide this capability to apply spatio-temporal load application in the model which can simulate the loading as the function of time, space and other parameters, which can be used in contact interaction analysis. In the model proposed in this study, "DLOAD" and "UTRACLOAD" subroutines are used for the application of vertical and longitudinal forces, respectively. For validating the use of spatio-temporal load application, a track model of 6.0 m length is developed. Load is applied using user-subroutines (“user subroutine model”). A similar model in which wheel is physically modeled is also developed (“wheel model”). In the wheel model, contact interaction between wheel and rail are simulated, and loading is applied on the track by imparting a rotation acceleration on the wheel. Equivalence between the two models is investigated by comparing the longitudinal strains developed on rails and total longitudinal load transferred to sleepers.

Furthermore, to model the rail-free fastening system, which is used in railway bridges to isolate tracks from bridge structures, a system of non-linear connector elements is developed as the interaction between rails and bolt clamps is relatively complex due to the gap between them. It will reduce the number of contacting interfaces in the model. To use user-subroutine in place of wheel rail interaction, results obtained from the two methods are validated. Longitudinal strains obtained at the same location of the rail are compared in figure 4. It is evident that the difference in the strains obtained from the two models is around 10%, which is acceptable for the approximations made in the loading procedure. Computational cost of analysis in the ‘user-subroutine model’ is around 30% of that of the ‘wheel model’. With more wheels, this saving in computational cost will

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be much greater as number of interacting surfaces will reduce drastically. Total longitudinal load transfer to the sleeper level is also measured and observed to be consistent. Therefore, user-subroutine loading method can be used for modeling the integrated track-bridge structure in accordance with the experimental studies.

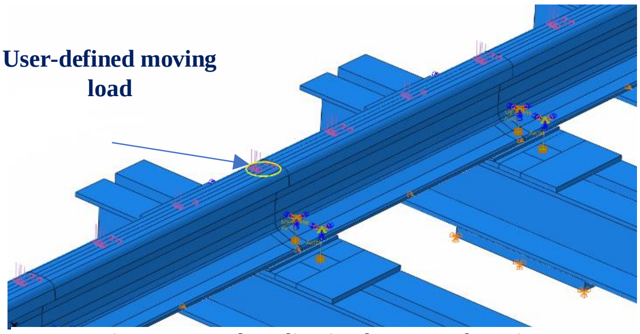

Figure 2- Load application by user-subroutine

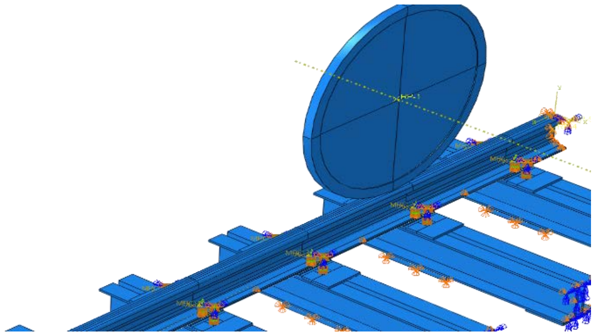

Figure 3- Load application by rotating the wheel.

4. Integrated track model and its validation

For carrying out the numerical analysis for simulating the flow of longitudinal loads, an integrated model is developed by physically modelling the girder along with tracks. Boundary conditions are simplified by modelling the adjoining track portions using MPC beams. Loads are applied using the 'user-subroutine' feature. Results obtained by the experimental studies are used for the validation of the integrated model. Parametric studies are carried out by changing the material properties and interaction parameters to identify the different phenomena behind longitudinal load transfer from rail level to substructure.

5. Conclusion and future scope of work

In the experimental studies, it was observed that less than 60% of the load gets transferred to the girder and subsequently to the substructure. Results from the experimental studies were used for validating the numerical model. There are various limitations in conducting experimental studies for longitudinal loads as in the current study, only 20% of the maximum loading capacity of the locomotives can be imparted to the bridge. Therefore, it is paramount to carry out numerical analysis of bridges in conjunction with experimental studies to simulate all possible conditions of loading and interactions. Current study covers a typical girder bridge in Indian railways. This study will be extended to include other types of bridges like ballasted deck bridges, composite bridges etc. which have different interaction mechanisms between its components. Finally it wiil be possible to develop comprehensive design code with a rational take on the longitudinal load application on bridges.

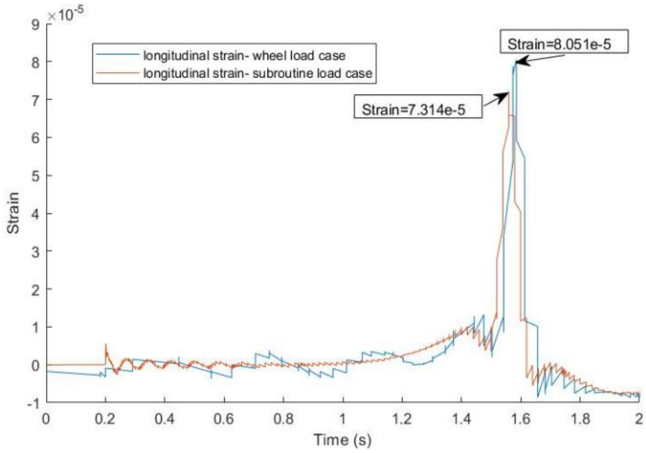

Figure 4-Comparison of longitudinal strains on rail web

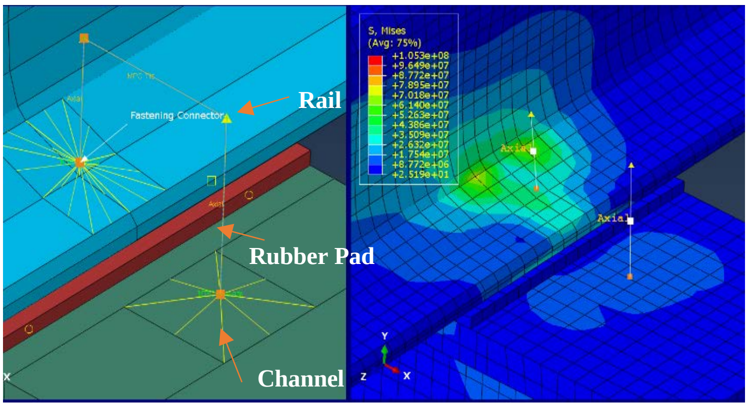

Figure 5- New fastening system using non-linear connector elements.

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