Chapter 1
Experimental and Numerical Analysis of Buckling in Welded Rail Systems

Ganesh Ramaswamy, K. Ramesh, and U. Saravanan

Abstract Modern rail networks are increasingly adopting welded rail systems over jointed rails due to better rider comfort. Welding restricts free expansion of rails due to ambient temperature change. Rail Neutral Temperature (RNT) refers to that temperature at which welded rails are stress-free. Hence, at any given rail temperature above RNT, the rails experience a compressive stress build-up due to restricted strains. This can precipitate buckling of the rails thereby compromising safety and there is a need to study this closely. Multiple factors such as rail imperfections, fastener stiffness, ballast lateral stiffness and vehicular loads influence the phenomenon of rail buckling. Given that field tests to study this problem are cumbersome and cost-intensive, simplified model studies are desirable for understanding the influence and interaction between these contributing factors alongside validated numerical models. Towards this, model experiments are carried out using 3D printed rails. The sleeper systems are fabricated using filament-based printing and polyurethane is used to simulate the lateral supports offered by the ballast bed. A jig is designed to achieve the load application with the required end support conditions in the experiment. The system level response including the mobilization of lateral resistance offered by ballast bed is studied using transmission photoelasticity. The key connection identified using photoelasticity is studied for effect of fastener failure on lateral displacement using digital image correlation. The results from a finite element simulation are compared with experimental results to bring out the need for refinement. This study showcases the utility of simple model experiments to identify critical parameters and combinations that influence rail buckling which can be further used to refine numerical models. The knowledge acquired using cost-effective model experiments can also help guide field tests to better understand the problem of rail instability.

Keywords Photoelasticity · DIC · CWR Buckling · RNT · Instability

Introduction

Welded rails are widely adopted over jointed rails due to enhanced rider comfort. However, welding restricts the free expansion of rails due to ambient temperature changes and causes thermal stress build-up. Rail Neutral Temperature (RNT) is a crucial factor in determining the stress state of welded rails. At low temperatures, the rails are subjected to tension which poses the risk of rail fracture. However, when rail temperature exceeds RNT, compressive stress builds up, potentially leading to rail buckling and compromising safety. Multiple factors such as rail imperfections, fastener stiffness, ballast lateral stiffness, and vehicular loads influence rail buckling [1]. Researchers have attempted to study the problem using analytical methods [2, 3] as well as numerical models [1, 4]. While these can be helpful in studying the problem, experimental information is often invaluable for validating the idealizations involved. Data from multiple field tests have been reported in literature [2, 5] and researchers have also attempted to study the problem using prototype experiments [6] for ballastless

Ganesh Ramaswamy · K. Ramesh
Department of Applied Mechanics and Biomedical Engineering,
Indian Institute of Technology Madras, Chennai, India - 600036
e-mail: ganeshrvenkatraman@gmail.com; kramesh@zmail.iitm.ac.in

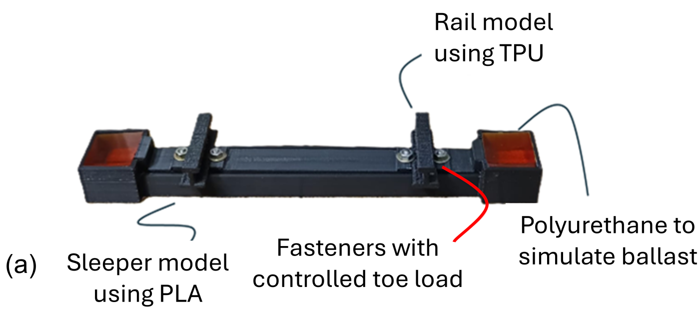
U. Saravanan
Department of Civil Engineering,
Indian Institute of Technology Madras, Chennai, India - 600036
e-mail: saran@zmail.iitm.ac.in

Chi-Hung Hwang et al. (eds.), *Advancement of Optical Methods & Digital Image Correlation in Experimental Mechanics, Vol. 2*, Conference Proceedings
of the Society for Experimental Mechanics Series, https://doi.org/10.13052/97887-438-0828-2_1

tracks. Given the challenges associated with such cost-intensive testing, simplified model studies that can complement such analyses are desirable for developing better understanding. Model experiments have been used previously to understand welded rail fracture [7]. In this work, an experimental study is carried out using a scaled down model of a track system with rails and sleepers alongside numerical modelling. The experimental technique of photoelasticity is used to examine the mobilization of lateral resistance and digital image correlation is used to study the effect of fastener failure on the lateral displacement at a connection. The result for this case from a finite element model developed in Abaqus® is compared with the experimental results to understand certain shortcomings and the need for further refinement.

Experimetal setup

An experimental jig is designed and fabricated in order to study the problem using scaled down models. Geometric similarity is used with a scale factor of 14.35. Standard gauge is considered for scaling down the transverse spacing of the rails which is maintained at 100 mm centres along with a sleeper spacing of 45 mm centres. The models are made using fused deposition modeling based printing using an Anycubic Kobra 2 Neo 3D printer. The rail is printed using premium thermoplastic polyurethane (TPU) with a shore hardness rating of 95A and the sleeper models are made using Polylactide acid thermoplastic (PLA). The connection between the rail and the sleeper is simulated using fasteners with toe load controlled using Duratool adjustable torque wrench with a uniform tightening of 0.1 Nm maintained at all connections. The lateral support offered by the ballast bed is simulated using high quality polyurethane strips in order to study the mobilization of lateral reactions. The end conditions are controlled using end plates which arrest translation and rotation in order to analyze the middle third of a considered buckled track length of 10 m which is close to values reported in literature [8]. A finite element (FE) model is parallelly developed in Abaqus® using axial connectors and springs to simulate the rail-track system response. The schematic of a representative model and the finite element model is shown in Fig. 1.



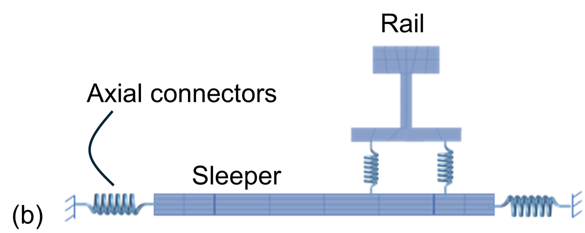


Fig. 1 (a) A representative scaled down experimental model of track system and (b) finite element model of rail and sleeper

Results and Discussion

Ballast offers lateral resistance to the sleeper systems to arrest in-plane movement of the welded rail track and the magnitude of this resistance is affected by changes in factors such as packing density, track alignment, etc. In this study, ballast action is simulated using transparent polyurethane which is photoelastically highly sensitive and exhibits stress-induced birefringence [9]. Hence, any minor deviations in the resistance offered can be identified by placing the setup in a polariscope and observing the photoelastic fringes as shown in Fig. 2

It is observed that resistance is mobilized in a slightly asymmetric manner when there is no compression applied (Fig. 2 b) which can be attributed to out-of-straightness of the rails and sleeper system. Further, when full compression is introduced, the right-side top (Fig. 2 c) shows a higher response indicating the tendency of the system to buckle. Buckling of CWRs can be at a system level as well as a local distortion which can contribute to flange climbing of wheelsets. The latter is more dangerous since it cannot be easily identified. Failure of rail-sleeper fasteners can aggravate this problem when the rail is subjected to high compression. Hence, it is of interest to examine the effect of fastener failure on the lateral displacement of the rails. Towards this, two sets of experiments are conducted using the technique of digital image correlation to evaluate the lateral displacement of the rail with and without fasteners. The critical connection to examine is chosen based on the lateral

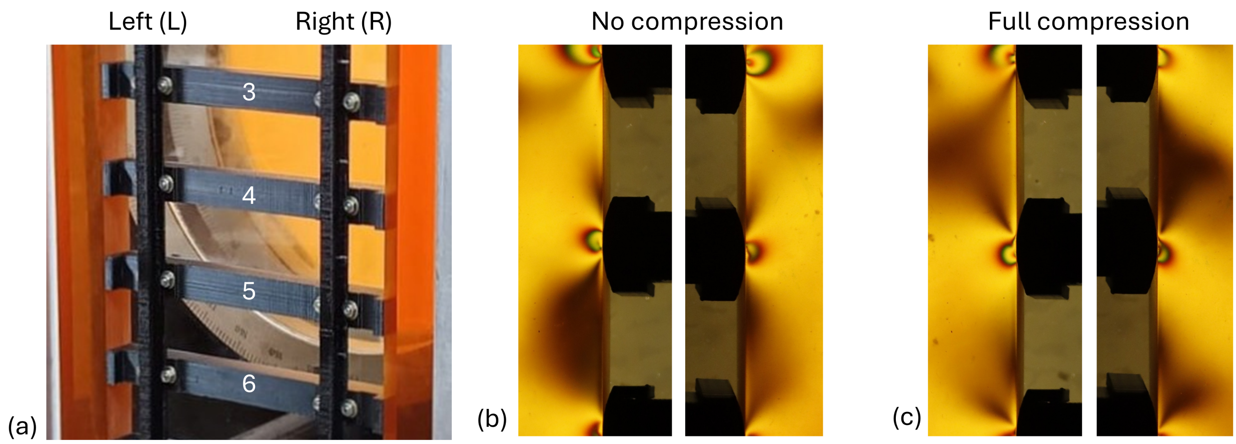


Fig. 2 (a) Model experimental setup placed in a polariscope with right and left rail indicated; photoelastic fringes on left and right at three sleeper levels 3-5 with (b) no compression and (c) full compression applied on the rails

mobilized reaction observed from photoelasticity (Fig. 2 c) and the processed results along with a displacement plot from the numerical model are presented in Fig. 3.

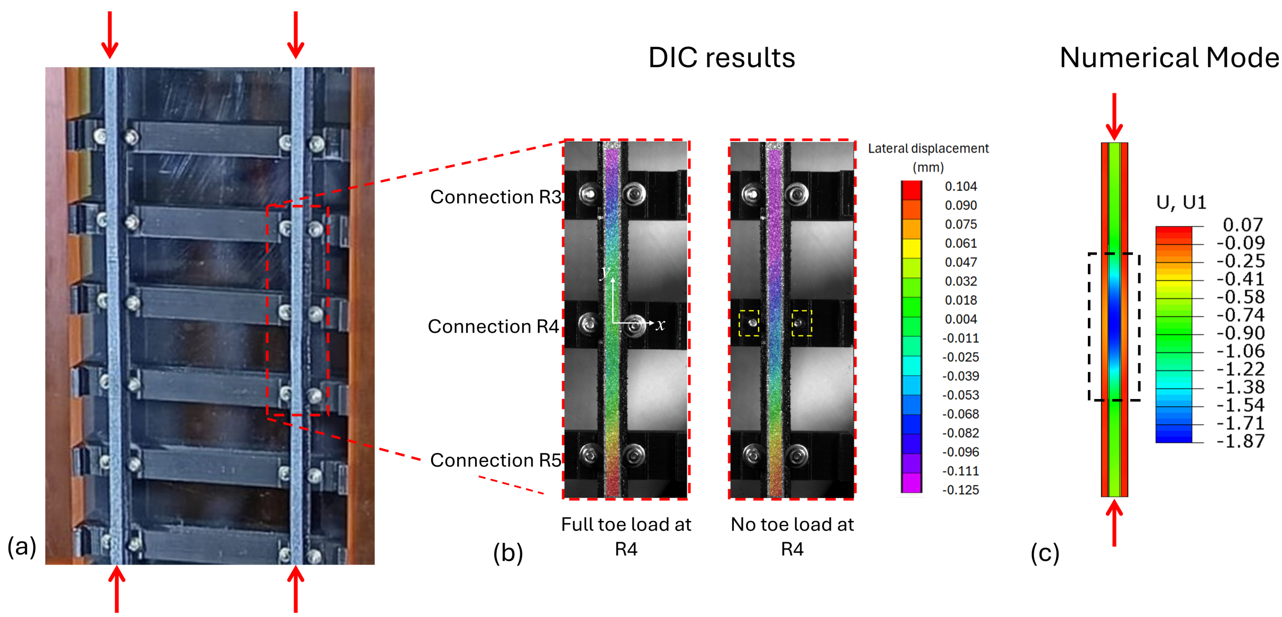


Fig. 3 (a) Loaded model with connections R3 to R5 considered for examining fastener failure, (b) DIC results for full toe load and no toe load at connection R4 and (c) displacement plot from finite element model with no fastener in the middle

It is observed from Fig. 3 b that the lateral displacement gets modified at connection R4 when the fastener is removed. This indicates that such a failure becomes crucial in high temperature conditions when the compressive stress build-up is high. The resulting local distortion of the rail may precipitate derailment by flange climbing. A comparison of the relative lateral displacement from the finite element model shows qualitative match at the connection where the fastener fails (Fig. 3 c). However, at other connections, the nature of displacements show deviations which could be attributed to the absence of local imperfections in the finite element model. Hence, comparisons with experimental results can help refine the idealizations in the finite element model in order to obtain predictions closer to the actual behaviour of welded rails.

Conclusion

This study integrates photoelasticity and digital image correlation to study buckling of welded rails using scaled-down model experiments with components fabricated using FDM printing. Photoelasticity is used to examine the mobilization of lateral resistance and digital image correlation is used to bring out the effect of fastener failure on lateral displacement of rails. A finite element model is developed in Abaqus® and the result of fastener failure is compared with experiments which show a similar behavior at the failure location. The comparison also highlights the need to refine the model by including local and global imperfections in order to obtain more reliable predictions. This study offers some insights into rail buckling using cost-effective model experiments and can be helpful in guiding design of large-scale field studies aimed at improving rail stability.

Acknowledgments The first author would like to thankfully acknowledge the discussions and support extended by Mr. Anand C and Mr. Shins K from the Digital Photomechanics Group at the Indian Institute of Technology Madras.

References

1. I. Villalba, R. Insa, P. Salvador, and P. Martinez, "Methodology for evaluating thermal track buckling in dual gauge tracks with continuous welded rail," *Proc Inst Mech Eng F J Rail Rapid Transit*, vol. 231, no. 3, pp. 269–279, 2017, doi:10.1177/0954409715626957.
2. A. D. Kerr, "Lateral Buckling Of Railroad Tracks Due To Constrained Thermal Expansions — A Critical Survey," *Railroad Track Mechanics and Technology*, pp. 141–169, Jan. 1978, doi:10.1016/B978-0-08-021923-3.50013-9.
3. A. D. Kerr, "Determination of Admissible Temperature Increases to Prevent Vertical Track Buckling," *ASME*, vol. 45, no. September 1978, https://doi.org/10.1115/1.3424362
4. N. H. Lim, S. Y. Han, T. H. Han, and Y. J. Kang, "Parametric Study on Stability of Continuous Welded Rail Track - Ballast Resistance and Track Irregularity," *International Journal of Steel Structures*, vol. 8, no. 3, pp. 171–181, 2008.
5. N. Hasan, "Thermal buckling of ballasted tangent track," *Advances in Mechanical Engineering*, vol. 12, no. 10, pp. 1–11, 2020, doi: 10.1177/1687814020968992.
6. C. Kang, M. Bode, M. Wenner, and S. Marx, "Experimental and numerical investigations of rail behaviour under compressive force on ballastless track systems," *Eng Struct*, vol. 197, Oct. 2019, doi: 10.1016/j.engstruct.2019.109413.
7. G. Ramaswamy, N. Verma, U. Saravanan, and K. Ramesh, "Criticality of Cracks in Rails Using Photoelasticity and Finite Elements," in *Advancement of Optical Methods and Fracture and Fatigue, Volume 3*, C. Furlong, C.-H. Hwang, G. Shaw, R. Berke, G. Pataky, and S. Hutchens, Eds., Cham: Springer Nature Switzerland, 2024, pp. 85–88, https://doi.org/10.1007/978-3-031-50499-0_14
8. C. Ngamkhanong, C. M. Wey, and S. Kaewunruen, "Buckling Analysis of Interspersed Railway Tracks," *Applied Sciences*, vol. 10, no. 9, p. 3091, Apr. 2020, doi: 10.3390/app10093091.
9. K. Ramesh, *Developments in Photoelasticity A renaissance*. IOP Publishing, 2021, https://doi.org/10.1088/978-0-7503-2472-4