The Fifth International Conference on Railway Technology
RAILWAYS 2022
22–25 August 2022
Montpellier, France

Proceedings of the Fifth International Conference on
Railway Technology:
Research, Development and Maintenance
Edited by J. Pombo
Civil-Comp Conferences, Volume 1, Paper 19.3
Civil-Comp Press, Edinburgh, United Kingdom, 2022, doi: 10.4203/ccc.1.19.3

Numerical study of auxiliary rails application at railway transition zones

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Abstract

Railway track transition zones are problematic areas with rapid track deterioration and frequent track maintenance due to a sudden change in the track-soil structure, corresponding to differential track stiffness. Changes can be related to the connection between ballasted and slab track, bridge approaches, and tunnel entry/exits. To deal with this dynamic effect, the usage of auxiliary rails between the running rails is one of the well-known and effective techniques for railway transition zones. However, there is some shortage of knowledge about the influence of the spacing between auxiliary rails. Therefore, this paper develop a 3D finite element transition zones model of ballast-slab track with auxiliary rails, using eight-node solid elements and a perfectly matched layer (PML) for absorbing boundary conditions. The material properties for all track-soil components are defined as the isotropic and linear elastic. A moving train load is modelled using a sprung mass model to represent train-track interaction. After the simulation, the numerical results is validated against field data at a transition zone. Once validated, the model analysis of transition zones with auxiliary rails indicates that using two auxiliary rails is sufficient to improve the dynamic track characteristics across the transition. Further, the effect of three different spacing between two auxiliary rails is investigated and compared. It is found that the widely spaced auxiliary rails provide a more significant advantage on dynamic performance than closely-spaced ones, considering on receptance responses, rail displacements and stress distributions from ballast to natural soil layer.

Keywords: railway transition zones, ballast-slab track, differential track stiffness, 3D numerical railway model, auxiliary rail application, dynamic track responses

1 Introduction

Railway transition zones between ballasted and slab track are typical problematic areas for track maintenance in which the incidence frequency can be up to eight times higher than the free zones [1]. This is because they impose a sudden change in the structure, geometry and/or material properties of the track-soil component within a short distance, corresponding to the differing track stiffness, stress field, and wave propagation across the transition [2],[3]. These variations eventually result in uneven track-soil deterioration, loss in passenger comfort and reduced ride quality. Further, the quality of ballast, the presence of singular rail and wheel surface defect, including the increase of train speed and axle load can generate high-level of track-ground vibration which play an important role for track transition degradation [1],[4].

Several studies use the 3D numerical techniques to determine the dynamic track responses [5] and find the solutions that provide a smoother variation of track stiffness at transition zones, by placing the special material or modifying the existing components. The examples of transition solutions are the application of under sleeper pads, the adjustable rail fasteners, using the sleeper with varied size and spacing, laying the geosynthetic materials, the hot-mix asphalt and backfilling as the wedge-shaped design using the cement bond granular, unbound granular and graded gravels [1].

Another common solution that focuses on this study is installing auxiliary rails between two main rails. Although this approach has been investigated in a few research, the potential benefits have been proposed. For example, they offer an even dynamic load distribution and improve the bending track stiffness, corresponding to the smoother track behaviour across the transition. Further, by comparison with other solutions, they have been shown to provide greater performance in dynamic responses than the extra-long sleeper and the special subgrade material [6]. However, a limited number of studies have been performed about the influence of different spacing of auxiliary rail on the dynamic track characteristics.

Therefore, this paper develops a track transition zone with symmetry around the track centreline using the 3D finite element method and PML approach for absorbing boundary conditions. Then, the model validation with field measurement data is described. The analysis of dynamic responses regarding the auxiliary rails are presented in the final section.

2 Methods

In this study, the model is pre-processed using MATLAB, then simulating and solving on LS-DYNA software using the explicit scheme with a time step of 4.94 × 10-6 s. The simulation starts with the static analysis using the dynamic relaxation technique to set the model's initial conditions, thus ensuring it is in static equilibrium. Then, transient dynamic analysis determines the track response due to the moving loads. The standard routines are developed to maximise control over the simulation instead of using LS-DYNA's in-built keywords of *RAIL_TRACK and *RAIL_TRAIN.

The model represents the connection between ballasted and slab tracks on the natural soil, consisting of a single rail resting on discrete pads corresponding to the sleeper spacing, as shown in Figure 1. The rail is modelled as a rectangular section with an equivalent moment of inertia to reduce the geometry complexity. The track-soil structures are discretised into a series of elements using eight-node solid hexahedral elements. The element size is defined using the relationship between wavelength, frequency and shear wave speed. The interfaces between each track component and the ballasted and slab track transition are fully coupled. For the boundary conditions, the symmetric definition is implemented in the horizontal track section (XY-plane at Z=0). In addition, the PML approach is applied by placing additional eight solid elements through the depth next to the boundary of the track domain and defining the fixed constraints at the outer surfaces, as shown in Figure 1.

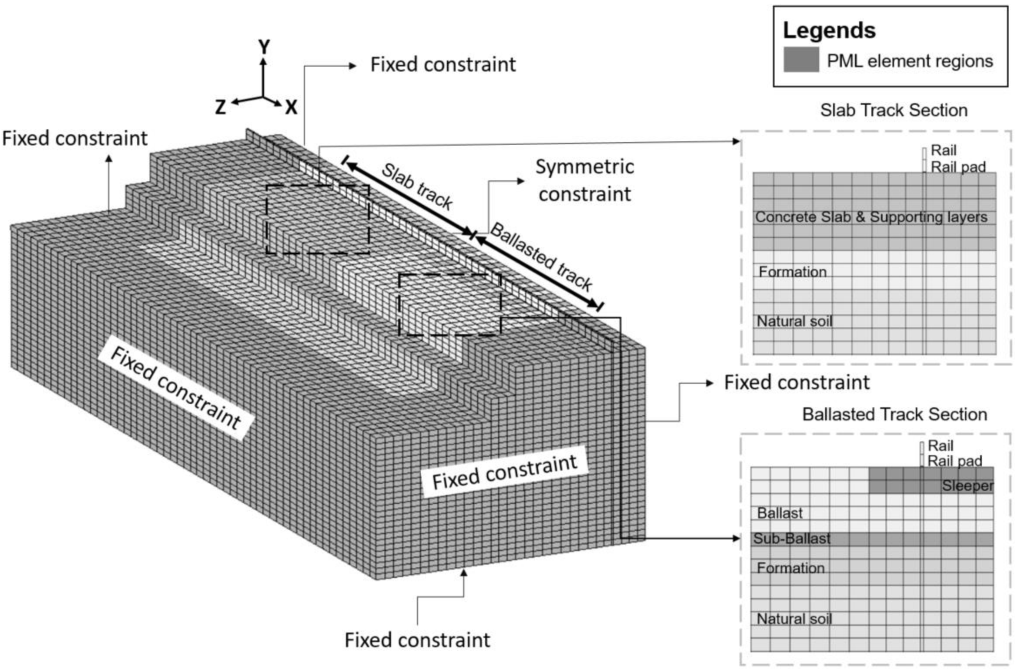

Figure 1 : Numerical modelling of track transition zones (truncated for viewability).

The material behaviour is isotropic and linear elastic for all track components and soil and requires four material parameters: density, Young's modulus, Poisson's ratio and damping for model formulation. The equivalent modulus of the railpad is required for considering the rail pad stiffness in solid element modelling, using the relationship between the rail pad dimensions and Poisson's ratio.

The vehicle-track coupling is simplified using a moving sprung mass model, as shown in Figure 2. They consist of the wheel mass and the proportional load of car bodies and bogies at the top level of the spring. The interaction between train and track is defined by the Hertzian spring. The bottom level of spring is always in contact with the top rail surface using the penalty-based approach, considering the surface as the master and bottom node as the slave segments. The additional details of track and vehicle modelling can be found in [7].

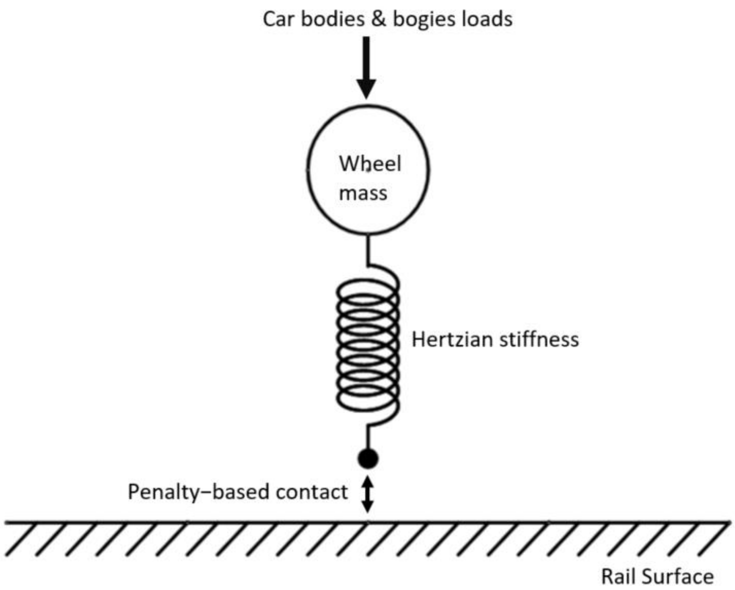

Figure 2 : Modelling of train-track interaction for single axle load.

3 Results

To ensure the model can predict the dynamic response of transition zones, the numerical results are validated against field data from Iran [8]. The test site, as shown in Figure 3, consists of 1.50 m gauge main rails and two auxiliary rails on the ballasted track with a spacing between them of 0.5 m. The OBW 10 train manufactured by Plasser & Theurer is used to simulate the test at 65 km/h. All track-soil geometries, properties ,the vehicle loads are taken from [8], and will be further used for the remaining simulation. There is good agreement between the numerical results and field data, hence validating the model, as shown in Figure 4.

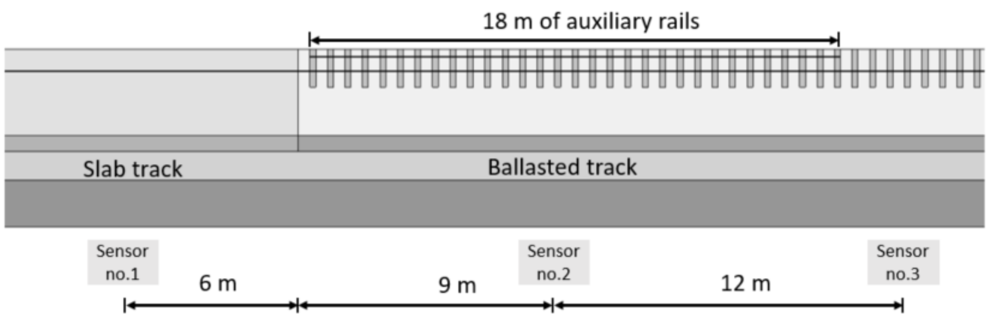

Figure 3 : Location of measurement sensors for model validation.

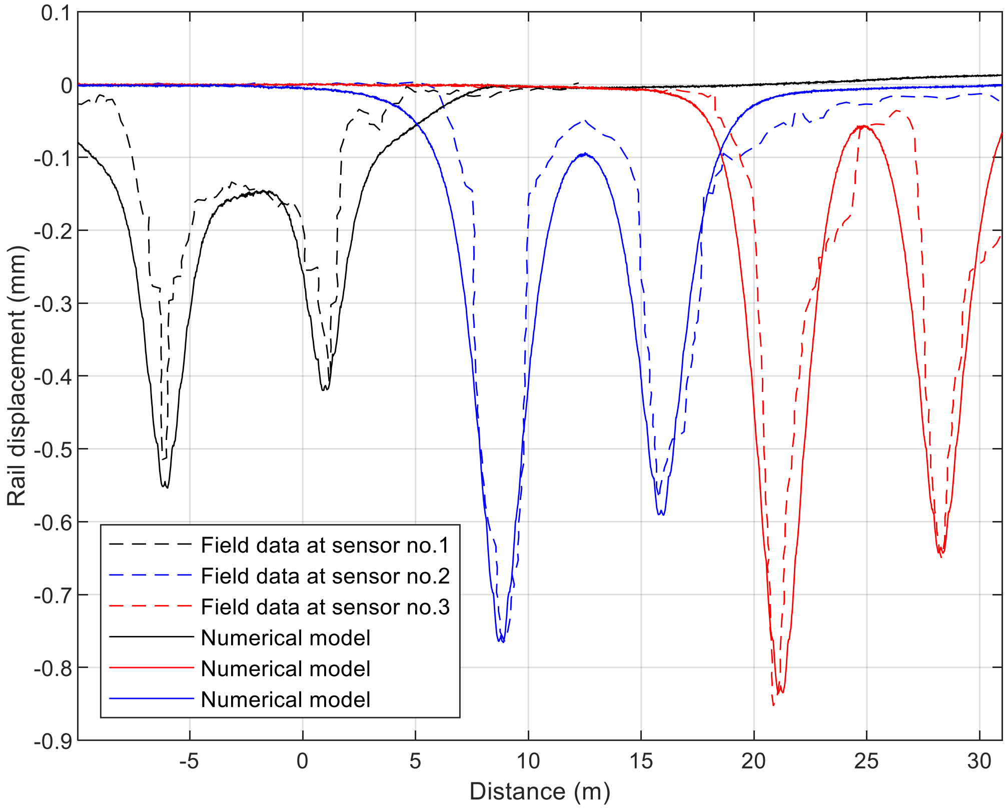

Figure 4 : Model validation for transition zones with auxiliary rails.

Next, the effect of three different spacing between two auxiliary rails (0.3, 0.8 and 1.2 m) is investigated. To understand the dynamic characteristics, the rail receptance tests are performed at the location as shown in Figure 5. It can be seen that auxiliary rail with wider spacing leads to a minor decrease in the receptance response for the frequency range 0-50 Hz, as shown in Figure 6, indicating that the ballasted track with wider auxiliary rail spacing is stiffer than the closer ones.

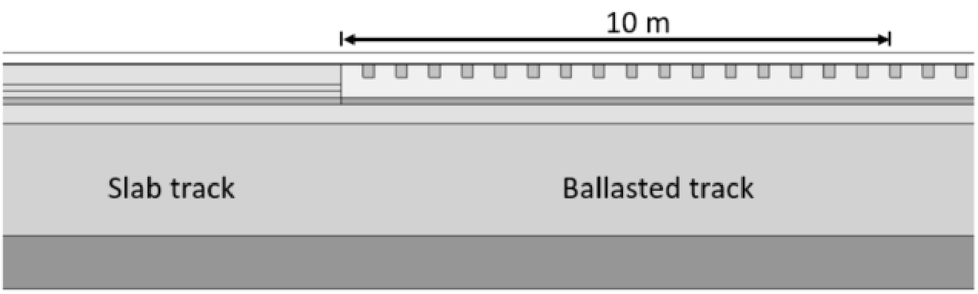

Figure 5 : Location of receptance impact and stress measurement.

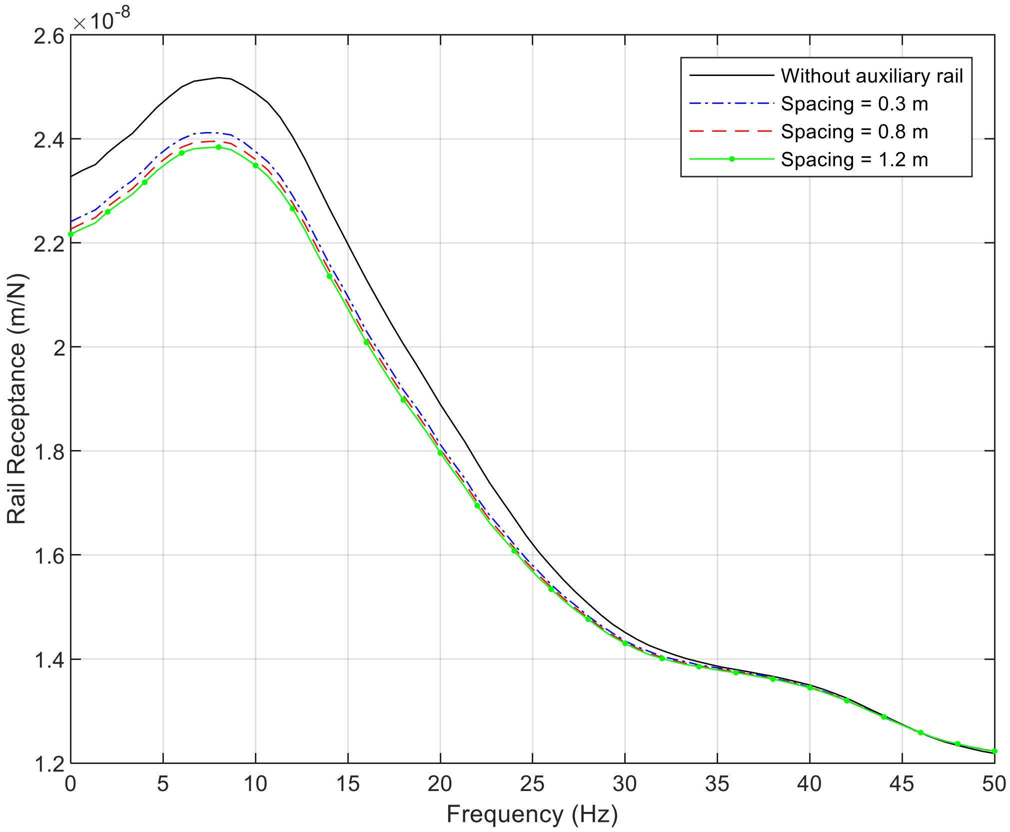

Figure 6 : Receptance responses for different auxiliary rails spacing.

Then, the moving load test is simulated with vehicle speed of 250 km/h. It is shown that the differential rail displacement can be reduced by 6.7 %, 7.3% and 7.7% in the transition zone for the spacing of 0.3, 0.8 and 1.2 m, respectively, as shown in Figure 7. After their termination, however, there is a slightly increased displacement in the ballasted track because the differing track stiffness's either side of the auxiliary rail can introduce the new small transition zones.

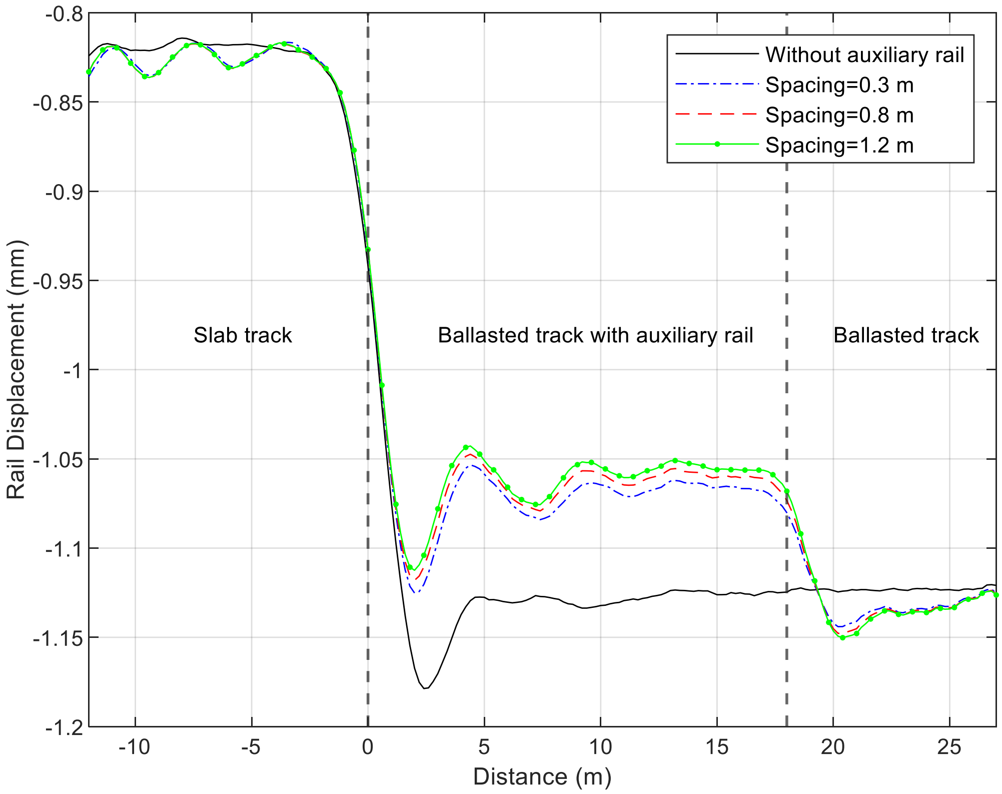

Figure 7 : Rail displacement for different auxiliary rails spacing.

Lastly, the influence on stress distribution from ballast beneath the sleeper to natural soil is investigated at the same location shown in Figure 5. It can be seen that the effect diminishes with depth. Similar to the previous analysis, the wider spacing decreases the compressive stress of upper layers (ballast, sub-ballast and formation) while the impact in the soil is minimal, as shown in Figure 8.

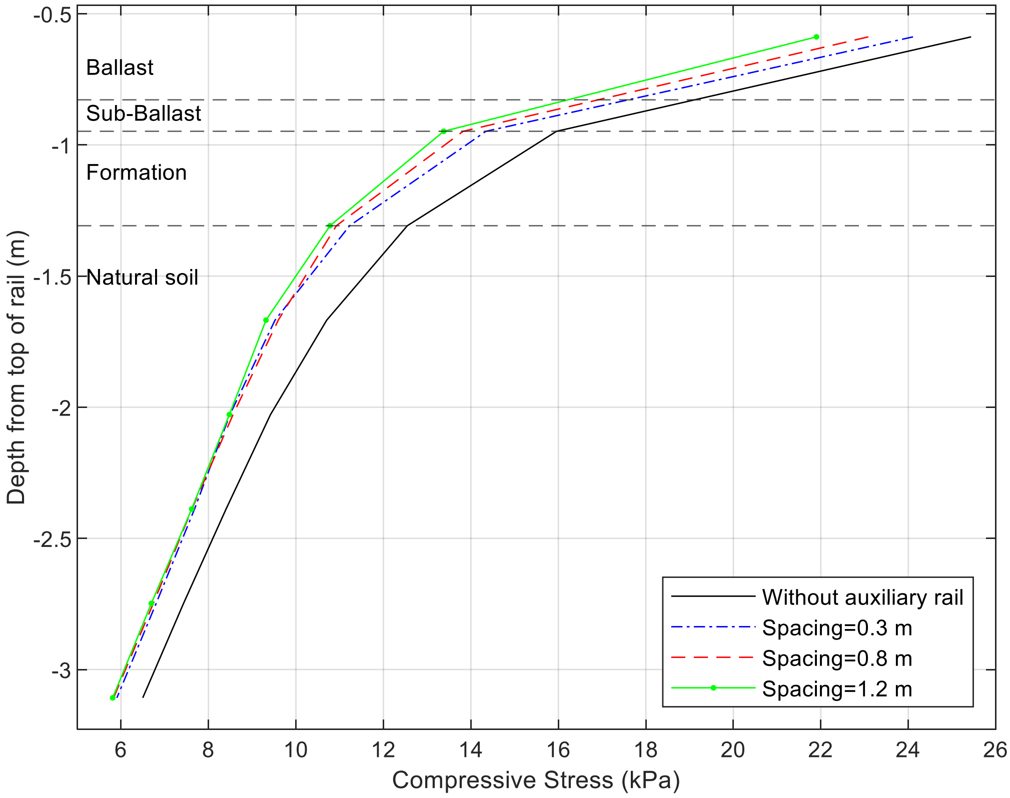

Figure 8 : Distribution of vertical compressive stress for different auxiliary rail spacing.

4 Conclusions and Contributions

This paper investigates the performance of the transition zones with auxiliary rails to minimise the track dynamic effect by developing the 3D finite element model of transitions between ballasted and slab track using eight-node solid elements and PML's for absorbing boundary. The train-track interaction is simplified for the moving load simulation using sprung mass modelling with the Hertzian spring and penalty-based contact. Two phases of the simulation process are static analysis using a dynamic relaxation approach and transient dynamic analysis solved by the explicit method. After the simulation, the time-domain numerical results present the well-agreement with field track data collected on the transition zones from slab to ballasted track with auxiliary rails. Then, the numerical analysis of different auxiliary rail spacing provides the following insights;

- The usage of two auxiliary rails with any spacing can improve the dynamic track characteristics, differential rail displacement, and stress distribution in the ballasted track at a transition zone.
- Placing auxiliary rails closer to the main rails contribute to the slight improvement of dynamic track performance, corresponding to the stiffer ballasted track.

- When using the auxiliary rails at transition zones, it is recommended to carefully consider the dynamic behaviour at the both end sides of the auxiliary rail to ensure that the new small transitions are not generated.

Acknowledgements

The authors are grateful to the European commission (GA: 101014571), the Leverhulme Trust (PLP-2016-270), University of Leeds and Delft University of Technology for supporting this work.

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