Proceedings of the Sixth International Conference on
Railway Technology: Research, Development and Maintenance
Edited by: J. Pombo
Civil-Comp Conferences, Volume 7, Paper 17.1
Civil-Comp Press, Edinburgh, United Kingdom, 2024
ISSN: 2753-3239, doi: 10.4203/ccc.7.17.1


# Evaluation of a Novel Mitigation Measure for Two Different Types of Railway Transition Zones.

**A. Jain, A. V. Metrikine, M. J. M. M. Steenbergen and K. N. van Dalen**

**Faculty of Civil Engineering and Geosciences,
Delft University of Technology, Netherlands**

## Abstract

Railway transition zones are the most critical part of the railway infrastructures that experience 4-8 times more degradation compared to open tracks. Despite several attempts to reduce the maintenance and operation costs in these critical zones, a robust and comprehensive solution remains unknown. In recent studies, a robust safe hull inspired energy limiting design of a transition structure was proposed for an embankment-bridge transition (without ballast layer over the bridge) to deal with operation-induced degradation. However, this solution was investigated in detail for only this particular type of transition. In this work, the scope of this mitigation measure is extended for an embankment-bridge transition with ballast running over the bridge and its performance is evaluated using a strain-energy criterion. It was concluded in the end that the safe hull inspired energy limiting design can effectively mitigate the operation-induced dynamic amplification for more than one type of railway transition zones.

**Keywords:** railway transition zones, types of transition zones, embankment-bridge transition, energy based criterion, safe hull inspired energy limiting design, finite element model.

# 1 Introduction

Railway transition zones (RTZs), where rail tracks undergo abrupt changes in foundation types, represent critical challenges in railway infrastructure due to their higher degradation rates compared to open tracks. A detailed overview of the problems and solutions associated to amplified degradation in RTZs is presented in [1, 2]. There are various types of RTZ such as an embankment-bridge transition, a culvert transition, level crossing etc. According to various studies, an embankment-bridge transition undergoes the most amount of degradation among all. Moreover, there can be two types of embankment-bridge transition, with and without the ballast layer over the bridge. The distribution of materials in these two types of railway transitions is different. This study utilises the insights from multiple research efforts [3–7] that have been made to propose robust design solutions for an embankment-bridge transition without a ballast layer over the bridge. In [3], a strain energy-based design criterion was proposed, asserting that minimizing and uniformly distributing total strain energy across the longitudinal track direction and in each trackbed layer can significantly mitigate uneven track geometry and reduce operation-induced degradation. In this work, an embankment-bridge transition with a ballast layer running over the bridge is evaluated without and with a transition structure called "safe hull-inspired energy limiting design (SHIELD)" using the above mentioned energy-based criterion proposed in [3]. Even though the mitigation measure used in this work was developed for a different type of transition [4, 6], the results demonstrate a wider application of SHIELD for other transition types as well. A comparison with the previous works associated to the embankment-bridge transition with the ballast layer discontinued over bridge is also presented.

# 2 Models

In this work, two three dimensional (3-D) models are used to represent an embankment bridge transition without (Figure 1a) and with SHIELD (Figure 1b). Both the models have been divided into 5 zones. The zones are mainly categorised as open track (OT-I, OT-II) or approach zones (AZ-I, AZ-II, AZ-III). The open track is unaffected by transition effects and approach zones are in the vicinity of the transition interface showing dynamic amplifications due to transition effects. The soft-side (consists of ballast, embankment and subgrade) of the RTZ under study includes OT-I, AZ-I and AZ-II and the stiff-side (ballast layer running over bridge) of the RTZ comprises AZ-III and OT-II. The cross section details of both models are shown in Figure 1. The material properties of the track components (rail, sleepers, ballast, embankment, subgrade, SHIELD and bridge) are tabulated in Table 1. The models used in this work have been validated in [7]. The material properties used in this work are according to design limits proposed in [6]. A detailed description of the numerical models and the loading conditions can be found in [7].

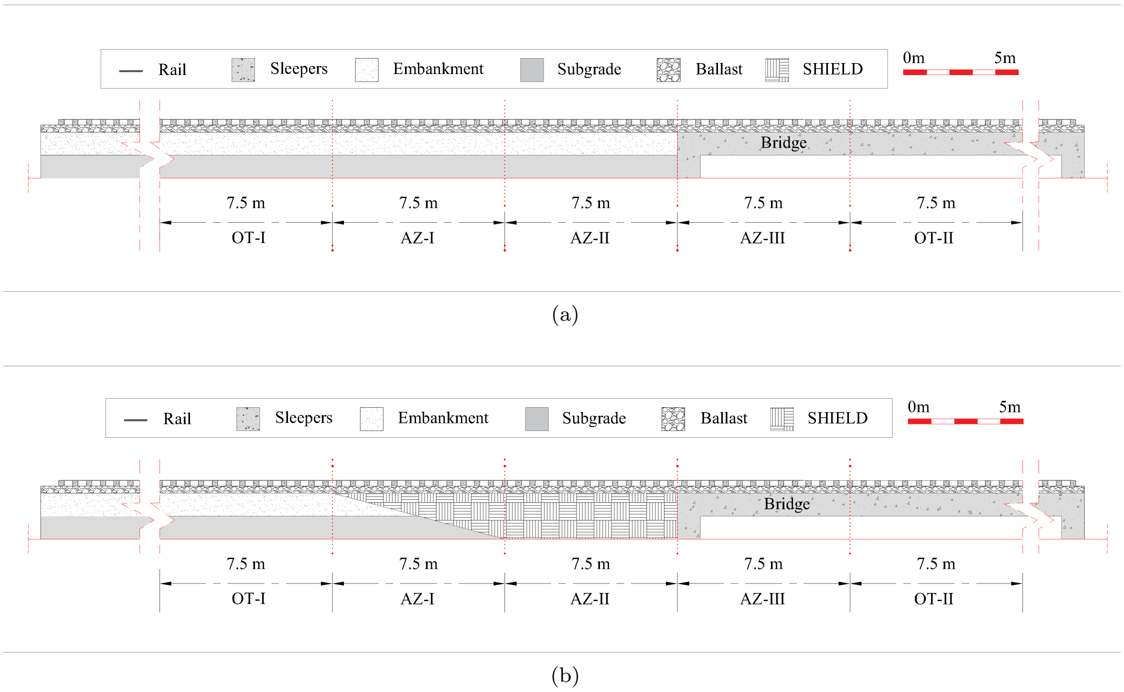


Figure 1: Cross-section details of a standard embankment-bridge transition (a) without and (b) with SHIELD.

## 2.1 Standard embankment-bridge transition without any transition structure

A standard embankment-bridge transition without a ballast layer running over the bridge was studied in detail in [3–7] and it was found that there are significant strain energy amplifications in the proximity of the transition interface in the track-bed layers (ballast, embankment and subgrade) on the soft side of the system. The strain energy magnitudes on the stiff side were an order of magnitude lower (negligible) compared to the soft side. However, this is expected to be different in the case of a standard embankment-bridge transition with the ballast layer continuing over the bridge.

## 2.2 Safe hull inspired energy limiting design: SHIELD

SHIELD was first proposed and evaluated using the strain-energy criterion in [4] using a 2-D plane strain model, and it was compared with the traditional transition structures like approach slabs and transition wedges. It was shown that SHIELD outperforms all

Table 1: Mechanical properties of the track components.

| Material | Elastic modulus E $[N/m^2]$ | Density $\rho[kg/m^3]$ | Poisson's ratio $\nu$ | Rayleigh Damping $\alpha$ | $\beta$ |
|---|---|---|---|---|---|
| Steel (Rail) | $21\text{x}10^{10}$ | 7850 | 0.3 | – | – |
| Concrete (sleeper, bridge) | $3.5\text{x}10^{10}$ | 2400 | 0.15 | – | – |
| Ballast | $1.5\text{x}10^{8}$ | 1560 | 0.2 | 0.0439 | 0.0091 |
| Sand (embankment) | $8\text{x}10^{7}$ | 1810 | 0.3 | 8.52 | 0.0004 |
| Clay (Subgrade) | $2.55\text{x}10^{7}$ | 1730 | 0.3 | 8.52 | 0.0029 |
| SHIELD | $5.5\text{x}10^{8}$ | 1900 | 0.15 | 0.0439 | 0.0091 |

other traditional transition structures in not only mitigating the dynamic amplifications in RTZs but also in obtaining a rather uniform strain-energy distribution. In [7], a detailed evaluation of different geometric profiles of SHIELD was performed to suggest an optimal geometry that aims at an optimal energy redistribution in RTZ according to the energy-criterion. However, all these studies were performed for an embankment-bridge transition where the ballast layer does not continue over the bridge. Therefore, in this paper the same geometric profile as proposed in [7] was used to mitigate dynamic amplification for the case where the ballast layer continues over the bridge. Figure 2 shows the 3-D view and cross-section details of the SHIELD used in this work.

# 3 Results

In this section, the time history of strain energy has been studied for an embankment-bridge transition without and with SHIELD for the layers of ballast, embankment and subgrade. In the ballast layer, 5 zones have been studied as discussed in the above-mentioned sections. For the embankment and subgrade layers, only 3 zones on the soft-side have been studied as the strain energy magnitudes are null on the stiff-side of the system.

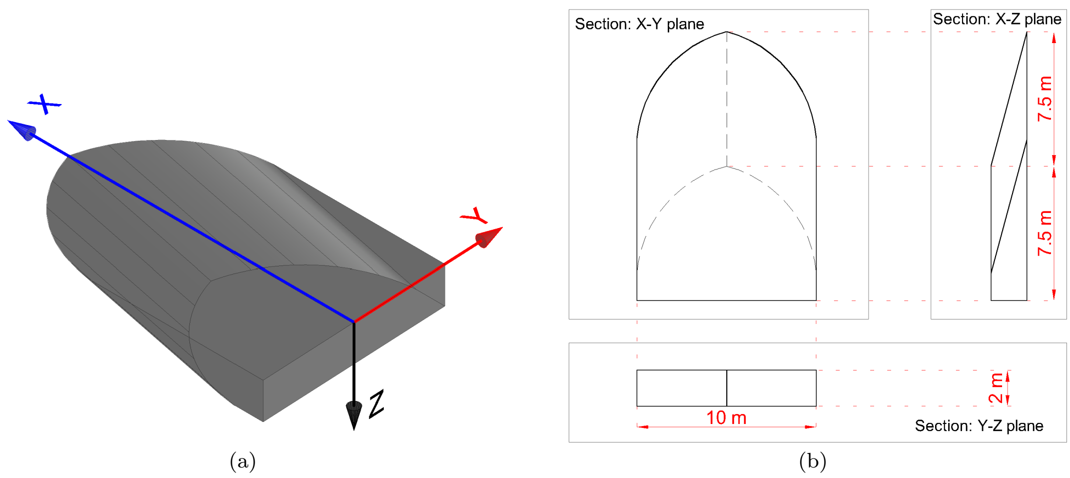


Figure 2: Geometric details of SHIELD (a) 3-D view and (b) cross-sections.

### 3.1 Ballast

Figure 3a shows the time history of total strain energy in the 5 zones under study for the model without SHIELD. It can be clearly seen that there is a significant amplification of strain energy in AZ-II on the soft-side and AZ-III on the stiff-side of the transition structure compared to the open tracks on each side. In Figure 3b, the presence of SHIELD not only mitigates the local amplifications in the vicinity of the transition interface but also provides a gradual decrease in strain energy magnitudes from open track on the soft-side (OT-I) to the open track on the stiff-side (OT-II).

### 3.2 Embankment

Figure 4 shows the time history of strain energy in the embankment layer for a standard embankment-bridge transition without (Figure 4a) and with (Figure 4b) SHIELD. Figure 4a shows an amplification of strain energy in AZ-II compared to OT-I. Similar to ballast layer, also in the embankment layer the amplification of strain energy is mitigated (Figure 4b) by the presence of SHIELD showing a gradual decrease in the magnitude of strain energy from OT-I to AZ-I to AZ-II and finally to null on the concrete bridge.

### 3.3 Subgrade

Figure 5 shows the time history of strain energy in the subgrade layer for a standard embankment-bridge transition without (Figure 5a) and with (Figure 5b) SHIELD. Even though the model without SHIELD (Figure 5a) shows no amplification of strain

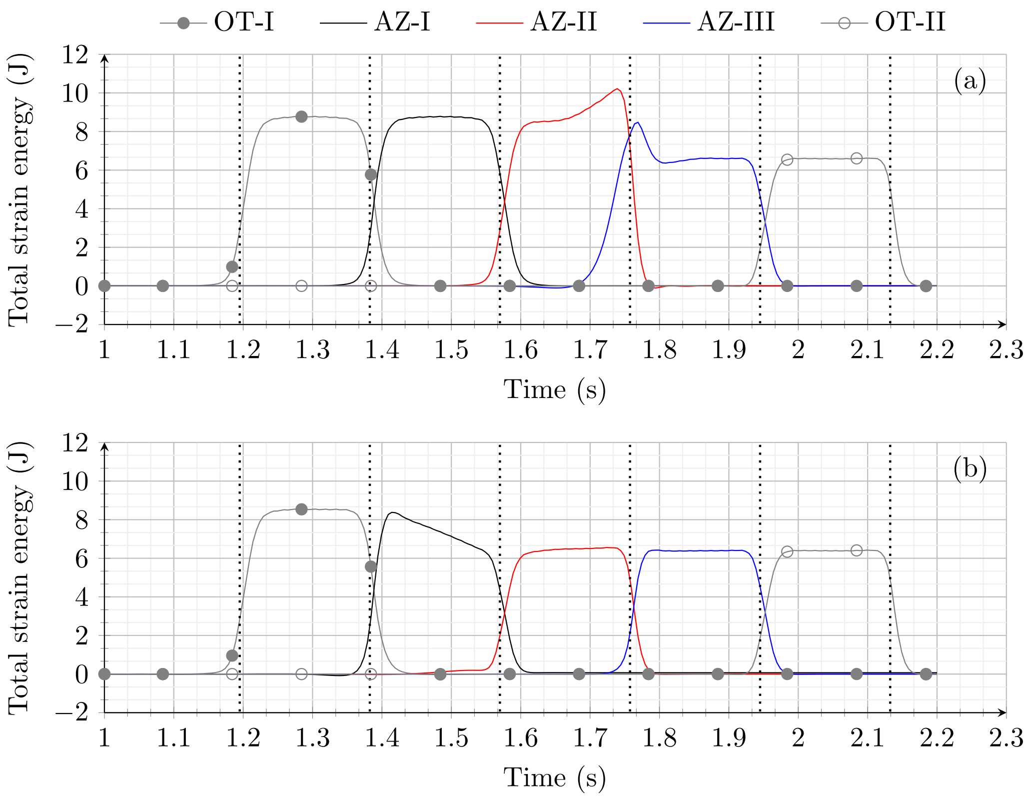


Figure 3: Time history of the total strain energy in the ballast layer for a standard embankment-bridge transition (a) without and (b) with SHIELD.

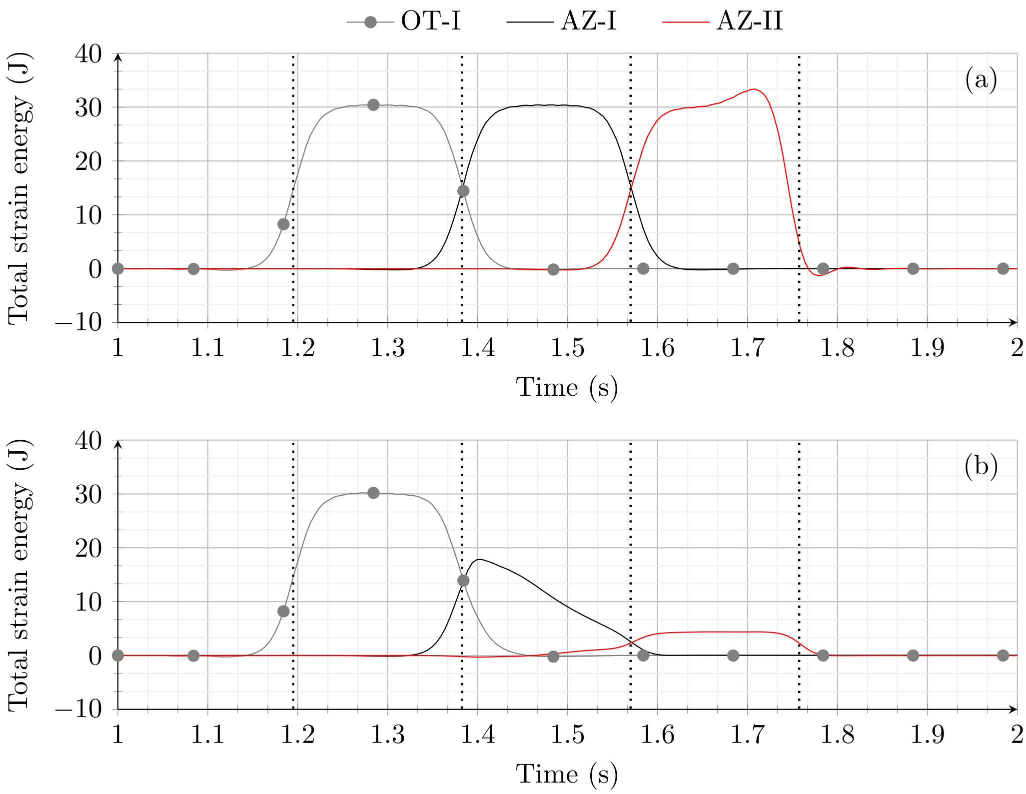


Figure 4: Time history of the total strain energy in the embankment layer for a standard embankment-bridge transition (a) without and (b) with SHIELD.

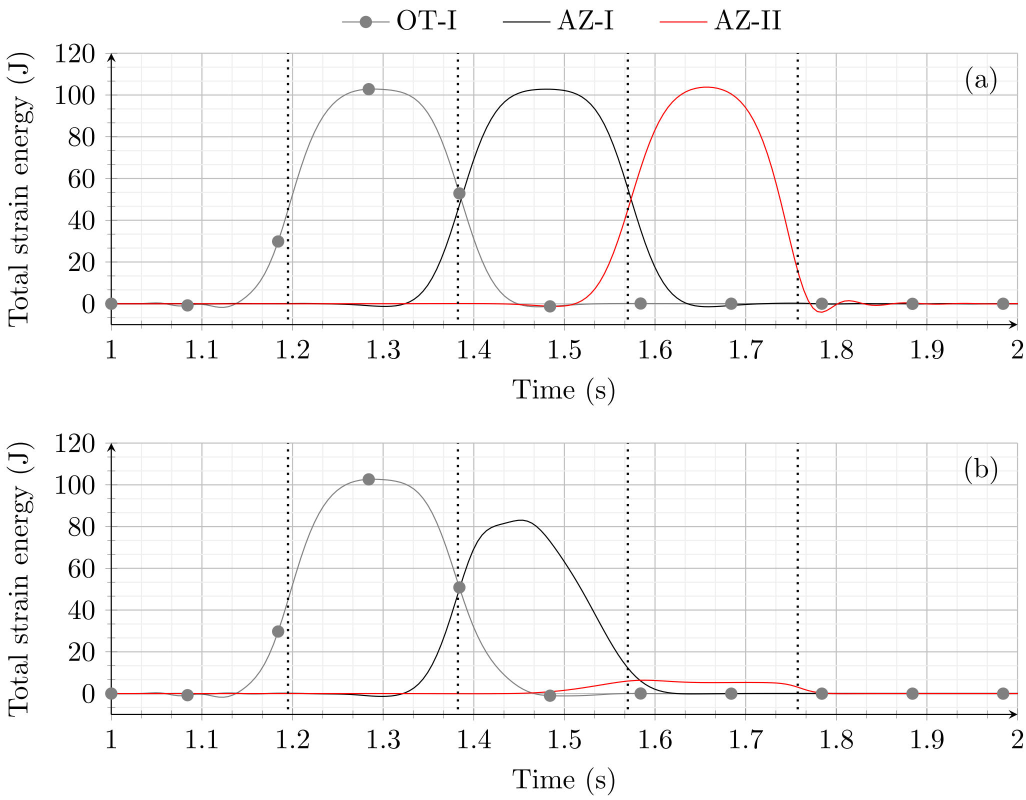


Figure 5: Time history of the total strain energy in the subgrade layer for a standard embankment-bridge transition (a) without and (b) with SHIELD.

energy in any of the zones under study, the presence of SHIELD provides a gradual decrease in strain energy (Figure 5b) from the soft-side (highest in the OT-I) of the system to the stiff-side (null).

# 4 Discussion

In [7], the spatial and temporal distribution of strain energy is investigated in detail using various three-dimensional models of an embankment bridge transition (ballast layer discontinued over the bridge) without and with SHIELD. Figure 6 shows the time history of the strain energy in the (a) ballast, (b) embankment and (c) subgrade for the embankment-bridge transition without any ballast layer over the bridge. Unlike the results shown in previous sections, the strain energy magnitudes on the bridge are null. The only zone (AZ-II) that shows an amplification of strain energy is on the soft side of the system. This amplification is mitigated using SHIELD as shown in the time history (see Figure 7) of the strain energy in the (a) ballast, (b) embankment and (c) subgrade for an embankment bridge transition (equipped with SHIELD) without any

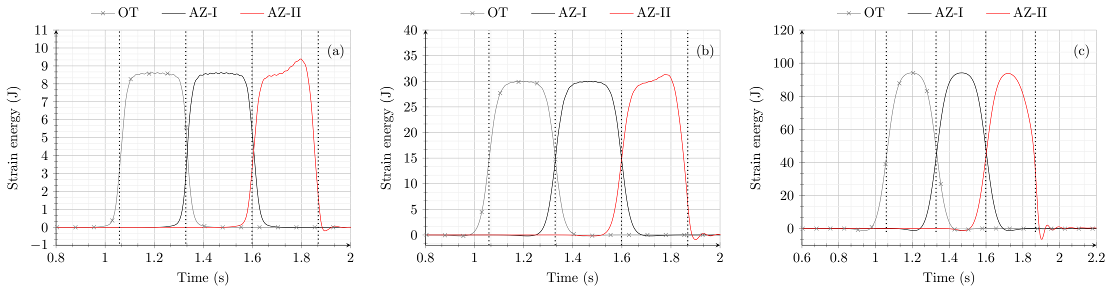


Figure 6: Time history of the total strain energy in the (a) ballast, (b) embankment and (c) subgrade layer for a standard embankment-bridge transition with ballast layer discontinued over the bridge.

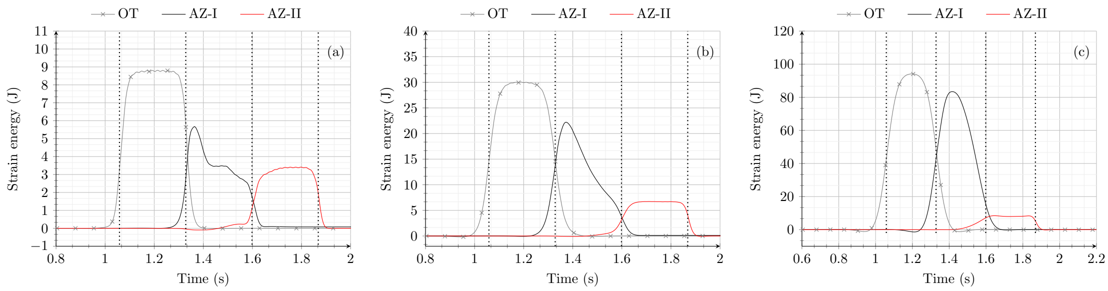


Figure 7: Time history of the total strain energy in the (a) ballast, (b) embankment and (c) subgrade layer for a standard embankment-bridge transition (equipped with SHIELD) without ballast layer over the bridge.

ballast layer over the bridge. In comparison to the influence of SHIELD discussed in previous sections, only the ballast layer behaves differently. The embankment and the subgrade layers show almost the same behaviour when these two types of transitions are subjected to operation induced dynamic loads. Additionally, it is observed that the strain energy distribution in the ballast layer is less uniform in the case of discontinued ballast layer (Figure 6a) than in the case of the continuous ballast layer (Figure 3b). This suggests that the operation-induced degradation will be even more uniform in the latter case.

It is worth mentioning that efforts could be made to further optimise the strain energy distribution (shown in Figure 3(b)) by means of under ballast pads. A thin layer of relatively soft material can be used under the ballast layer aimed at an even more (compared to Figure 3) uniform distribution of strain energy (within ballast layer) in the zones under study; this way, the expected operation-induced degradation can be made even more uniform across the transition.

# 5 Conclusions

This work presents a detailed evaluation of a novel design of a transition structure that has been recently developed for an embankment-bridge transition (without ballast layer over the bridge) and has been extended to a transition zone where the ballast layer continues over the bridge. Even though the distribution of materials forming trackbed layers (ballast) in these two types of transitions are different, the safe hull-inspired energy limiting design of the transition structure was equally efficient in mitigating the operation-induced dynamic amplification in both types of railway transition zones.

# Acknowledgements

This research is supported by the Dutch Technology Foundation TTW (Project 15968), a part of the Netherlands Organisation for Scientific Research (NWO), and which is partly funded by the Ministry of Economic Affairs.

# References

[1] Buddhima Indraratna, Muhammad Babar Sajjad, Trung Ngo, António Gomes Correia, Richard Kelly,”Improved performance of ballasted tracks at transition zones: A review of experimental and modelling approaches”, Transportation Geotechnics, 21, 100260, 2019.

[2] R. Sañudo, L. dell’Olio, J.A. Casado, I.A. Carrascal, S. Diego, ”Track transitions in railways: A review”, Construction and Building Materials, 112, 140-157, 2016.

[3] A. Jain, A.V. Metrikine, M.J.M.M. Steenbergen, K.N. van Dalen, ”Design of railway transition zones: A novel energy-based criterion”, Transportation Geotechnics, 46, 101223, 2024.

[4] A. Jain, A.V. Metrikine, M.J.M.M. Steenbergen and K.N. van Dalen, ”Railway transition zones: evaluation of existing transition structures and a newly proposed transition structure”, International Journal of Rail Transportation, 0, 1-21, 2023.

[5] A. Jain, A.V. Metrikine, M.J.M.M. Steenbergen, K.N. van Dalen, ”Dynamic amplifications in railway transition zones: performance evaluation of sleeper configurations using energy criterion”, Frontiers in Built Environment, 10, 2024.

[6] Avni Jain, Yuriy Marykovskiy, Andrei V. Metrikine, Karel N. van Dalen, ”Quantifying the impact of stiffness distributions on the dynamic behaviour of railway transition zones”, Transportation Geotechnics, 45, 101211, 2024.

[7] A. Jain, A.V. Metrikine, K.N. van Dalen, ”Energy redistribution in railway transition zones using a novel geometric design of a transition structure”, Structure and Infrastructure Engineering, 2024.