NeTIRail

Needs Tailored Interoperable Railway Infrastructure

Deliverable D2.10

Cost effective transition zone design tailored to line type and traffic

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Executive Summary

Transition zones are the location which discontinuity occurs at the supports, like where the track reaches the bridges, culverts and tunnels. These locations often need substantial extra maintenance costs to protect the track level and its ride quality. As transition area are important, however their poor behaviour are still not fully understood [1][2]

Transition zones have higher rate of degradation compare to other parts of the track [3], and the reason behind this problem is the changes in the track alignment which makes the variations in dynamic axle loads applied the track in those areas[4].

Many different suggestions and recommendations are exist based on careful design and construction to mitigate this problem, however research based on maintenance records of high speed lines indicate that degradation of tracks associated with stiffness variations of the soil is far from being solved [4].

It is hard to understand the fundamental behind the performance of transition zones and as much as it is very important to railway infrastructure owners, the behaviour still not fully understood [2].

One of the best options on studying the behaviour of transition zones is to develop a finite element model of these tracks and validate it against a real-life measurement of these areas. This report provides the steps on how these finite element models have been developed and how they are going to be validated. Also a plan is provided how these models will be used to understand the behaviour and give some recommendation to make transition zones behave better.

The method of finite element modelling to study the behaviour of transition zones has been used by different studies, like Coelho et al. [2] or Varandas et al. [3] which used field data obtained from an extensive field survey conducted in two transition zones in Netherlands. Their results show that the forces were vary significantly both in time and space on a transition zones, especially by developing the voids under the sleepers. Shan et al. [5] modelled a railway tract subgrade system using finite element method and studied two different transition zones between the ordinary subgrade and bridges which was used mainly for high speed passenger lines. They have found out that the dynamic response of the track subgrade system changed sharply after the first 3m of the transition zone section, measured from the bridge abutment.

As Coelho et al. [1] pointed out a fair agreement between the experimental and numerical results are necessary. And validated numerical analysis allows the analysis of the behaviour of transition zones at critical train speed and they suggested some recommendations on the shape and combination of concrete slabs and sleepers.

To be able to validate the finite element models, a case study of a transition zone on a new Portuguese railway line has been provided from design and construction. The importance of this study was to provide the results from conventional laboratory and cyclic load triaxial testing on granular materials and in situ mechanical characterization of the different layers are presented. At last the measurements obtained at different substructure level indicated that the design was successful in reducing the settlement and achieving a gradual stiffness increase as a bridge is approached [4]

After validation of the model with the Portuguese data, the validated model used to study the effect of having lighter and heavier sleepers. These studies showed that heavier sleepers potentially can be a good solution to replace the old fashion and expensive transition zones construction with on the surface and easy to maintain sleepers. As the time ran out in this project, further study is needed to complete this solution, like to find out the best arrangement of these sleepers by distance and shape. Also, it could be useful to know the influence of having different material thickness for rail sub-structure.

This task was carried out according to the NeTIRail-INFRA grant agreement, except during this deliverable SZ was supposed to provide measurement of a track movement around a transition zone, but as finite element model needed a high level of design input, like all the substructure dimensions, material properties and at the end the measurement, it was decided to use the Portuguese study instead and SZ provided all the information they could supply on transition zones design instead.

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Abbreviations

dof *degree of freedom*

CBM *cement bound mixture*

BC *binder content*

UGM *unbound granular material*

1. Introduction

WP2 (tailored track infrastructure, design and maintenance) is a technical work package investigating technical issues that drive investment and ongoing operational costs. This work package will make contribution to the business case being developed in WP1 and provide technical solutions which will be disseminated to the end users through the training and dissemination activity in WP7 and the decision-making tools within WP6.

The output from this work package will help on evidence-based decision making grounded in technical performance of rail infrastructure. WP2 gather the data needed by rail operators and infrastructure managers with the help of research partners, based on their technical expertise. The area of activities as mentioned in the *Project Description* are:

- "Geospatial comparison of rail infrastructure cost and maintenance drivers for high- and low-density lines. Mapping maintenance data with a Geographic Information System (GIS) and analysis of the data sets in this novel manner will help to reveal the drivers of cost and dependence on line type.
- Application of lean and automotive industry techniques to railway switches and crossings (S&C). Use of lean techniques to identify opportunities in adding value and removing non-value adding costs within S&C operations and maintenance, optimised for specific line types.
- Life extension for plain line through preventing corrugation. Optimising fasteners, rail pads and other components to eliminate the root causes of corrugation and extend rail life.
- Tailoring lubrication to duty and climate. Optimising rail and wheel lubrication techniques for different geographical locations and line classifications, helping end users to identify the most appropriate lubrication method for particular traffic and climatic conditions.
- Cost effective transition zone design. Using novel methods for optimising vertical stiffness, reducing a cause of rail failure at the transition from ballasted track to stiffer structures such as bridges. Optimisation of sleeper size, spacing and width will deliver a cheaper solution than the major geotechnical rebuilding currently employed. Testing to support these tasks will take place in a lab environment, on the networks of SZ and RCCF, and at the AFER Faurei Test Track. Outputs will be in the form of technical solutions (modular infrastructure) and guidelines for operation."

This deliverable provides the details of "***Cost effective transition zone design tailored to line type and traffic***". University of Sheffield is the lead partner in this task and undertook the development of the finite element model and validate this model. After validation this model used to study different arrangements of sleepers. Study on sleepers is on how varying their mass changes the dynamic behaviour of these transition zones. Despite this, it must be pointed out that there are other methods to manage the transition areas with the sleepers, such as the spacing distance between sleepers, or the layout of guard rails on then, as well as actions on other elements like gluing ballast or special design of the support layers of the track, in sub-ballast, backfill or intermediate/foundation layers.

The rail industry believes that the ballast is the layer which contributes most in degradation of the track geometry quality, if it's a normal ballasted railway track and resting on a good foundation and after the initial stabilization of the supporting layers. Many studies have been done to create more efficient rail operations, many empirical relations been proposed over the years to predict the track degradation. The experience from operating on conventional and high-speed railway lines (HSLs) has proven that at some locations the track degradation process was faster than normal and using the empirical degradation relationships to predict settlements is invalid. In these areas, more maintenance than normal is needed to re-establish the quality of the track geometry in order to maintain the standard passenger comfort and safety levels. Furthermore, these locations usually correspond to specific points in the track, which show discontinuities in vertical stiffness related to the change in the tracks superstructure (rail, fastening system, sleeper and ballast) or substructure. Measurements carried out between 1992 and 2002 on the Madrid-Seville HSL in Spain reported such occurrences and the results indicated that maintenance work at transitions to bridges or to box culverts was three to six times higher compared to open tracks [4].

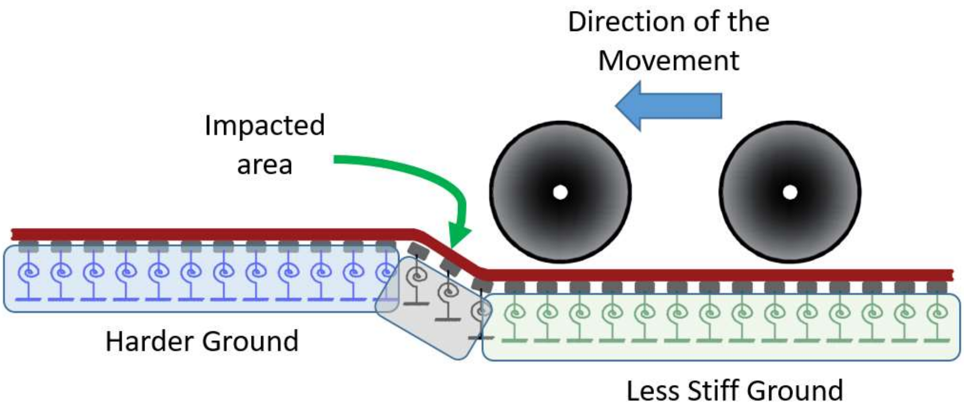

Figure 1: Transition zones less stiff ground to harder ground direction

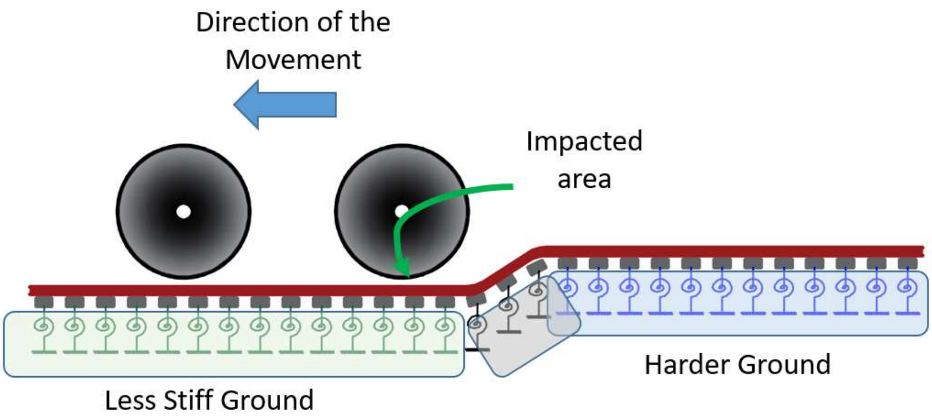

Figure 2: Transition zones harder ground to less stiff ground direction

Figure 1-2 show how track can be deformed under the train load and different ground stiffness. The impact location and magnitude also depend on the train direction of moving.

It is almost a century that studies have been conducted on railway dynamics. Knothe and Grassie [6] have reviewed the history behind of modelling of railway vehicle-track interaction. In 1926 Timoshenko [7] started to study the dynamic of vehicle-track to find out the effect of wheel flats. Also in the last century hundreds of papers and reports on dynamics of vehicle-track have been published [8].

Finite element analysis has become more popular in geotechnical practices to control and optimise the engineering tasks. Specially finite element models are very useful to study the behaviour of the track [9]. As the engineering problems are usually complex, there is always a need to simplify the problem when simulations are used to save time and money. To understand the dynamic behaviour of transition zones, they need to be analysed, including the displacement, acceleration and stress distribution of each part of these transition areas [10].

In this study 3D & 2D finite element models were developed to study the behaviour of transition zones under the passing of high speed trains. No field tests were conducted for this work, however another study which has been done on a new Portuguese railway [4] is going to be used to validate these models.

Time domain and frequency domain are the two different methods which can be used to analyse the finite element models. Frequency domain is simplified solution for wheel/rail interaction. It builds a relationship between the external force and receptance at different frequencies by avoiding the complicated differential equations and using mathematical transformation under set of assumptions. First person who used the frequency domain solution to analyse the dynamic behaviour of the track was Timoshenko [7] and he introduced the concept of receptance for a continuously supported Euler beam. Sato [11] calculated the receptance of an Euler beam on a separate layer of rigid sleepers for the first time. Grassie et al. [12] have introduced a system and studied the dynamic response of railway track using a frequency domain modelling technique [8].

Time domain modelling uses the time instead of frequencies to solve the wheel/rail interaction. The advantage of this method is the ability to solve the vehicle/track interaction using wheel/rail contact to give displacement, velocity, accelerations and forces generated in the model on all different components. In this method frequencies of different parts can be calculated based on displacement and time relationship. There are many researches which either contribute or use time domain finite element modelling. The models developed before 1980 were simpler compared to recent FE models which was due to the computer limitation at that time. Cai and Raymond [13] could only present 40 sleepers long discretely supported track and 4 different vehicle models and do the dynamic studies of the vehicle/track interaction [8]. Comparison to the model developed in this study can show how much computer power meanwhile increased. The current model presented in this deliverable consist of 6 coaches, 600m long rail, different parts like springs, dampers and pads, different substructures under the track like ballast, sub-ballast, capping layer and different soils. All wheels are in contact with the rail to be able move with the high speed.

Validation of this model is provided in chapter 3 of this report against the study done in Portugal [4] as this study had all the information on construction design and material, and also controlled measurements of track movement after passing train. In chapter 4, four different studies are provided to show the effect of invention which is increasing the mass of sleepers close to the bridge. SZ and INTADER provided extra information about different designs and literature review on different methods of maintenance and design of transition zones which are included in the Appendix).

2. Development of two different finite element models

Two different finite element models are developed. One model with higher resolution using solid 3D elements to be able to do stress analysis on smaller parts of the wheel and the rail. This model also is capable to simulate the failure in different areas. The second model is developed using faster 2D elements like beams and shells and can give the linear and non-linear deformation results which will be applied to the first high detailed model to check for failures.

ANSYS software was used to develop the model and LS-Dyna was used to solve the problem. Three different types of elements have been used in development of these two models. A brief description of these elements is provided as follows:

- **SOLID164 Element**

SOLID164 is used for the 3-D modelling of solid structures. The element is defined by eight nodes having the following degrees of freedom at each node: translations, velocities, and accelerations in the nodal x, y, and z directions [14].

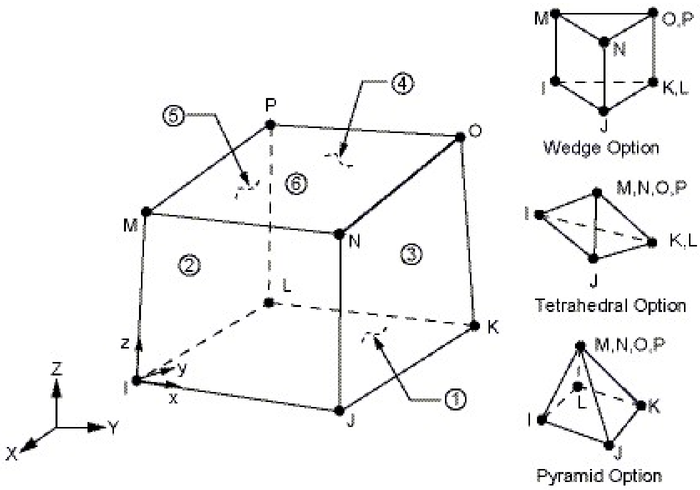

Figure 3: Solid element nodes and arrangement

- **SHELL163 Element**

SHELL163 is a 4-node element with both bending and membrane capabilities. Both in-plane and normal loads are permitted. The element has 12 degrees of freedom at each node: translations, accelerations, and velocities in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes [14].

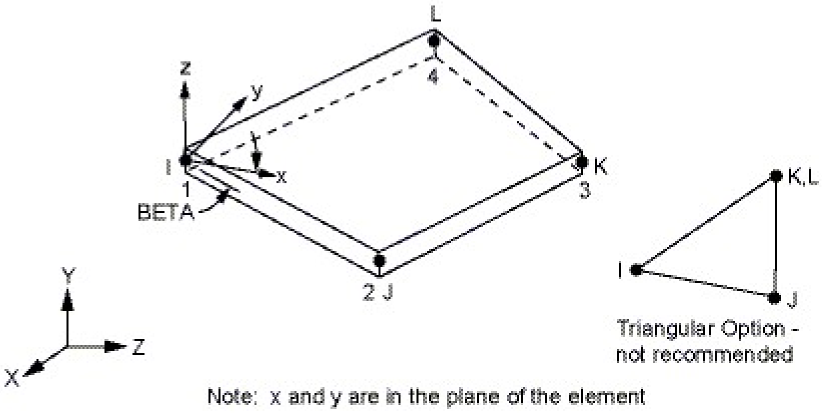

Figure 4: Shell elements nodes and arrangements

- **BEAM161 Element**

It is incrementally objective (rigid body rotations do not generate strains), allowing for the treatment of finite strains that occur in many practical applications. It is simple for computational efficiency and robustness. It is compatible with the brick elements. and includes finite transverse shear strains. However, a significant amount of additional computations is needed to retain this strain component, compared to those for the assumption of no transverse shear strain. The Belytschko beam element formulation is part of a family of structural finite elements that use a "co-rotational technique" for treating large rotation [14].

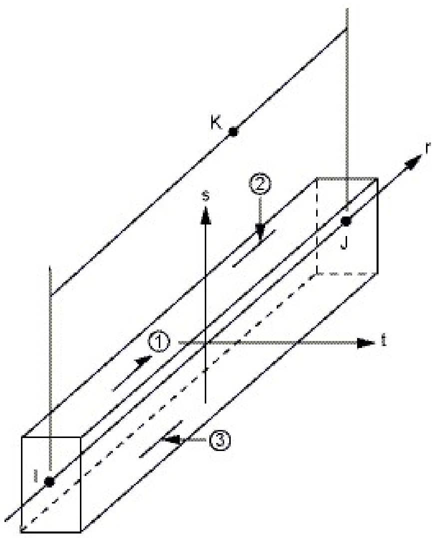

Figure 5: Beam element node and arrangement

These two models can be solved with both Implicit and Explicit methods. To maintain the stability of the solution different control cards are used in the code which made it possible to reach the convergence:

- CONTROL_IMPLICIT_AUTO
- CONTROL_IMPLICIT_FORMING
- CONTROL_IMPLICIT_GENERAL
- CONTROL_IMPLICIT_DYNAMICS
- CONTROL_IMPLICIT_EIGENVALUE
- CONTROL_IMPLICIT_SOLUTION
- CONTROL_IMPLICIT_SOLVER
- CONTROL_MPP_DECOMPOSITION_AUTOMATIC
- CONTROL_MPP_DECOMPOSITION_CHECK_SPEED
- CONTROL_MPP_DECOMPOSITION_CONTACT_DISTRIBUTE
- CONTROL_ENERGY
- CONTROL_SHELL
- CONTROL_CONTACT
- CONTROL_TIMESTEP
- CONTROL_TERMINATION
- CONTROL_DYNAMIC_RELAXATION

And to prevent both models from developing an hour glassing instability the HOURGLASS card is included in the code also.

2.1 Building the 3D model, using solid elements

This high resolution finite element model is developed to have the opportunity to study the stress and failure inside different parts of the wheel and rail. However, there is a limitation on running time and PC capacity. It is only possible to model one wheel and few meters of the track. Material properties used for this model is *MAT_ELASTIC for all the parts which can be changed to non-linear materials later.

*CONTACT_SURFACE_TO_SURFACE is used between the wheel and the rail to provide the contact between them. Also, the contact stiffnesses are tuned to give the correct contact force between the wheel and the track. Figures below show the model from different angles. Those solid parts in contact had full integration elements to prevent hour-glassing or other kind of instabilities in the model.

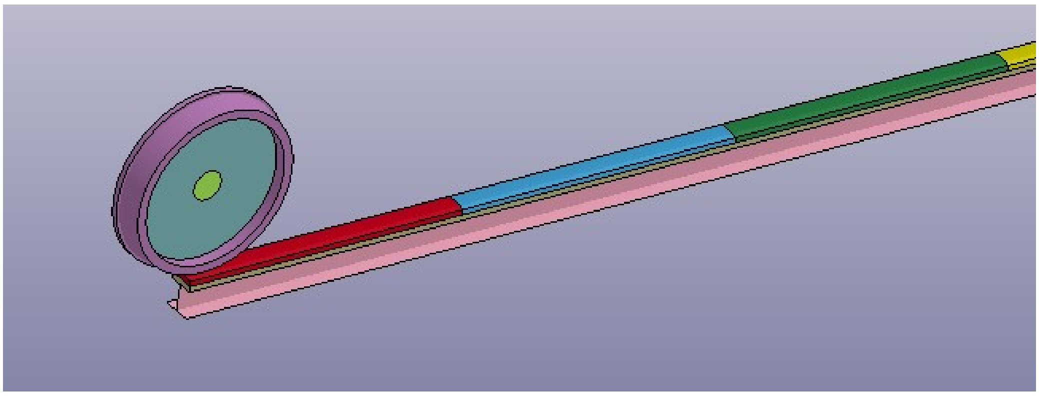

Figure 6: Top view of the wheel on the track, in finite element model

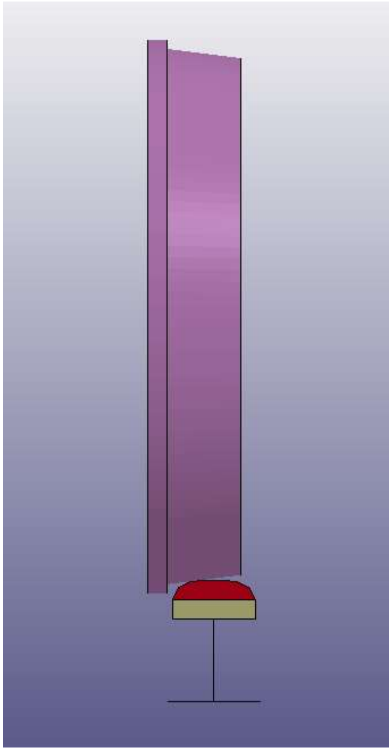

Figure 7: Longitudinal view of the wheel positioning on the track, in finite element model

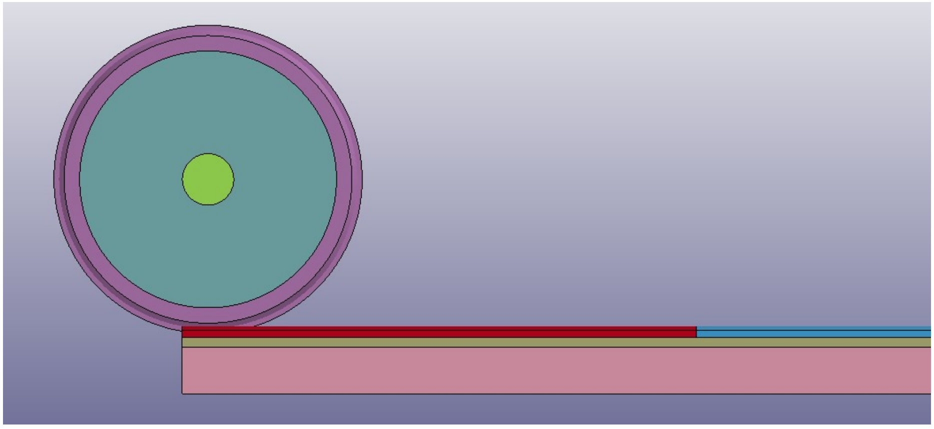

Figure 8: Side view of the wheel positioning on the track, in finite element model

2.2 Building the 2D model, using Shell and Beam elements

This model has a lower resolution than the 3D model, however it is possible to study a much longer track up to approximately 500 metres. Also, it is possible to model all of the layers of the soil which had a height of 9m and length of 60m. The first and last 200m parts of the track are made of rigid material *MAT_RIGID, and the 100m track in the middle is elastic and using *MAT_ELASTIC. Also, elastic material is used for the shell elements representing the soil in the model. The properties for each part are provided in Table 2. Figure 18 shows the details of one vehicle, using different springs and dampers connected to the wheels. *MAT_SPRING_ELASTIC and *MAT_DAMPER_VISCOUS to provide elasticity and viscosity to each wheel, Table 1 provide the parameters.

*CONTACT_AUTOMATIC_BEAMS_TO_SURFACE is used between the wheel and the rail to provide the contact between them. Further the contact stiffnesses are tuned to give the correct contact force between the wheel and track. Figures below show the model from different angles. Those shell parts (wheel) in contact had full integration elements to prevent hour-glassing or other kind of instabilities in the model.

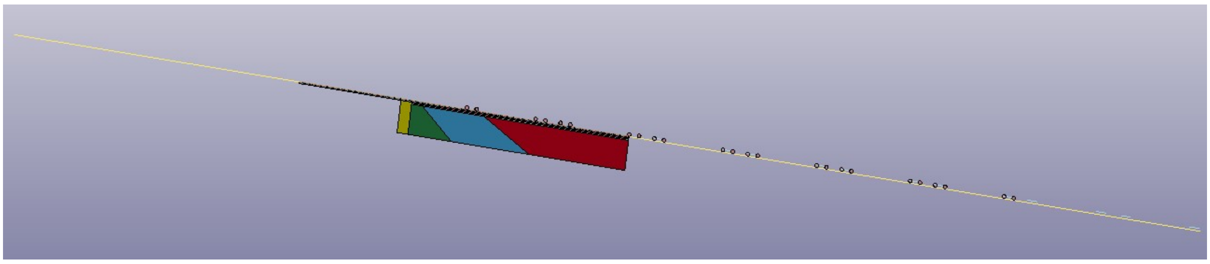

Figure 9: Full length of track, 2D finite element model

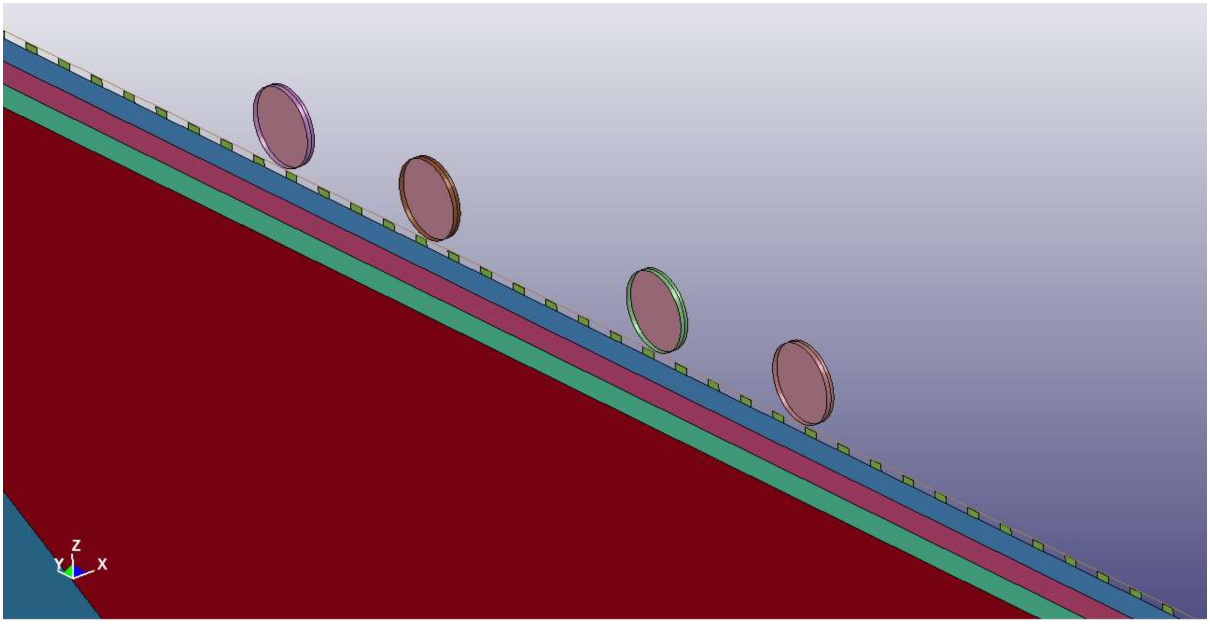

Figure 10: Top view of four wheels on the track, different layers of the soil and sleepers

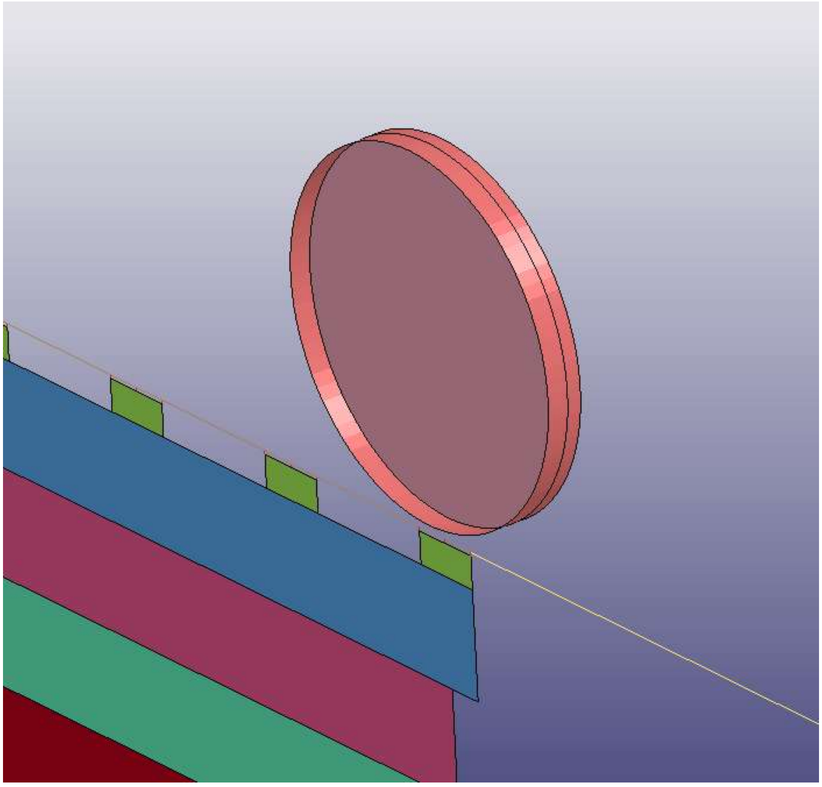

Figure 11: Zoomed in view of one wheel made by shell elements moving on the track

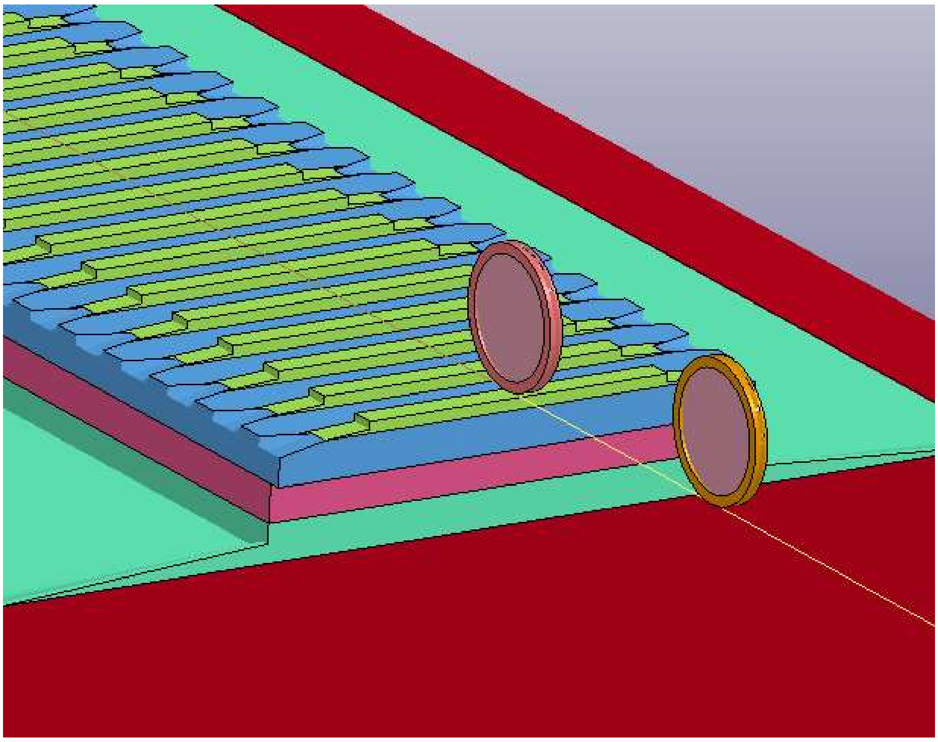

Figure 12: Extrude version of 2D model showing the thickness of the shell elements

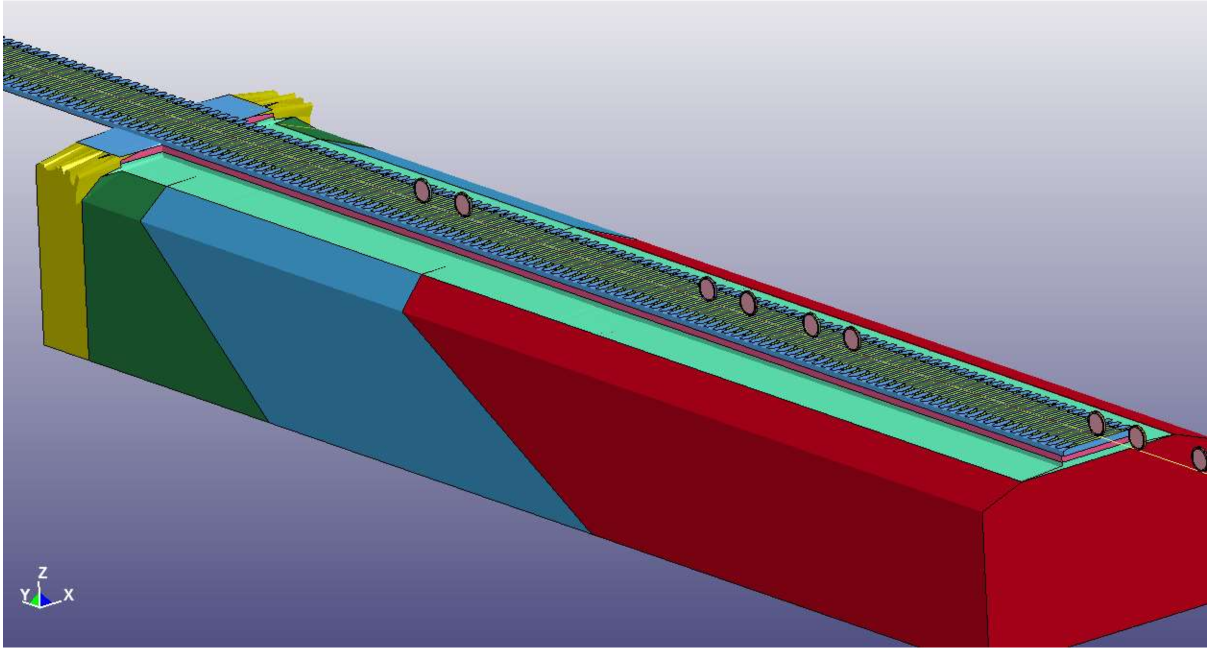

Figure 13: Full extrude version of the whole transition zone

3. Validating with measurements at Portuguese South Main Line

For the purpose of validation a case study of transition zone at the southern approach of the new railway bridge over Sado river, located in the Portuguese South Main Line (coordinates: 3823.7780N, 835.6700W), in the 29 km-long Alcácer bypass is chosen [4].

This line was opened in late 2010, allowing mixed traffic, with maximum axle loads of 250 kN and maximum speeds of 220 km/h for the Portuguese tilting passenger trains (Alfa Pendular). It comprises a single track with Iberian gauge (1.668 m) using continuously welded UIC60E1 rails, 2.6 m long mono block concrete sleepers (spaced 0.6 m), Vossloh W14 fastening system with elastomer rail pads Zw700/148/165 (static stiffness of 50–70 kN/mm, measured under a load between 18 and 68 kN, as provided by the manufacturer) [4].

The southern part of the bridge deck is a composite structure with a concrete slab supported by a steel plate girder with multiple spans of 37.5 m. The last span rests on a counterfort abutment in reinforced concrete, founded on ten 21 m-deep piles, with a large opening at the front. The natural foundation of the transition zone consists mostly of mono granular fine grained sands that provide good foundation conditions to the track [4].

The transition zone includes a backfill, about 9 m high, that was constructed using materials with better performance (higher stiffness and lower plastic deformation) than the embankment soils. The backfill comprises two zones, forming a wedge-shape with the geometry depicted in Figure 15. The first zone is located behind the abutment and comprises layers of cement bound mixture (CBM), with binder content (BC) of 5%. The other zone is located between the CBM and the embankment with soils. It comprises unbound granular material (UGM): a well graded crushed limestone aggregate with min./max. particle sizes of 0/31.5 mm [4].

Figure 14: Side view of the transition zone before construction and general view of the track [4]

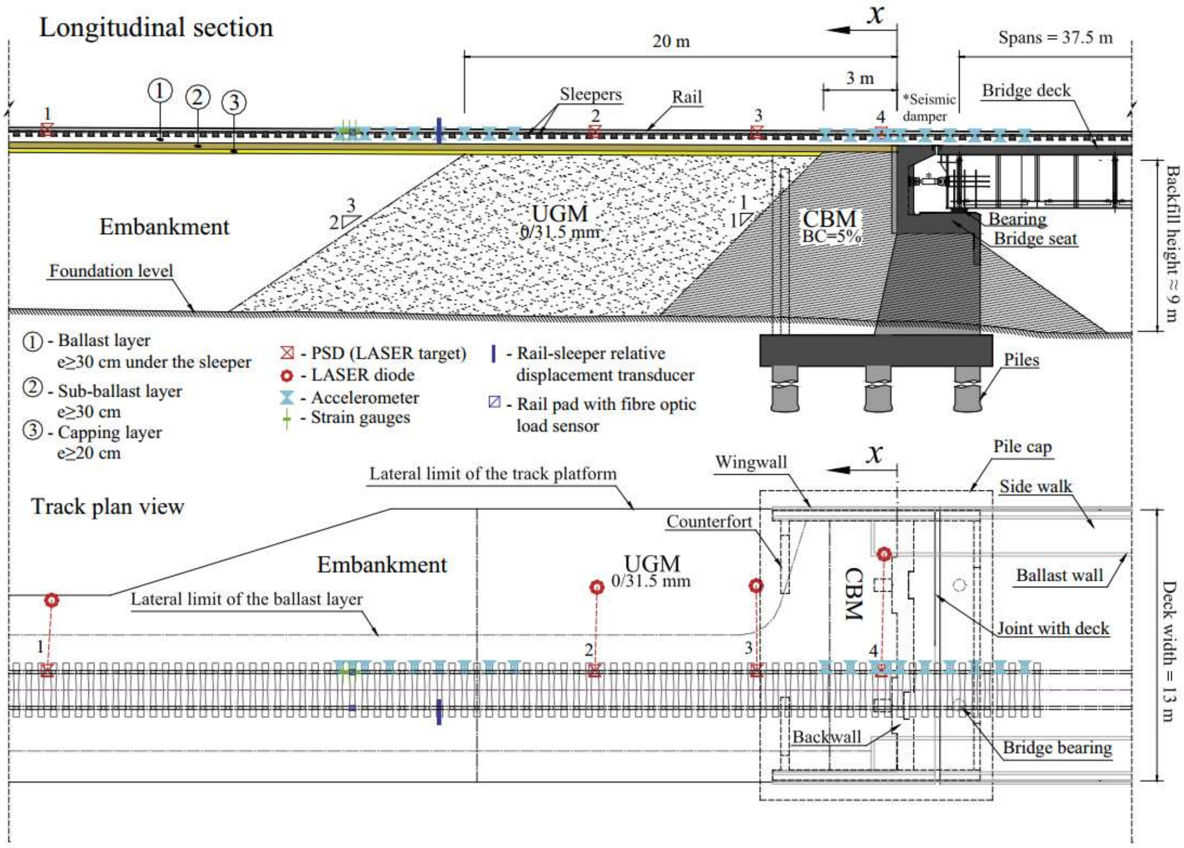

Figure 15: Schematic longitudinal profile and plan view of the transition zone [4]

A minimum ballast thickness (e) of 0.30m under the sleepers was established both for track on embankment and on the bridge. To analyse the response of the track along the transition zone when the Alfa Pendular trains passed by, the measurements has been carried out in two separate occasions: (i) October 18th, 2011; (ii) April 19th–20th, 2012. It was possible to record 4 and 8 trains, respectively in each period, with speeds of about 220 km/h. The monitoring comprised various types of transducers connected to a single acquisition system [4].

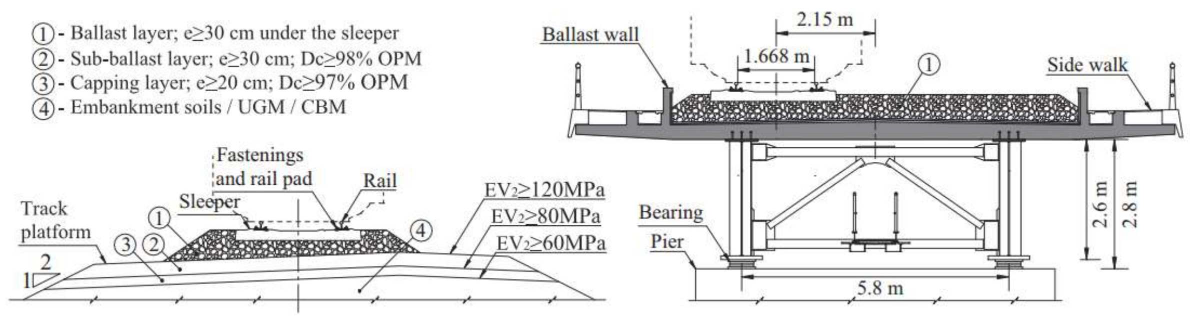

Figure 16: Track cross sections on earthworks and on the bridge [4]

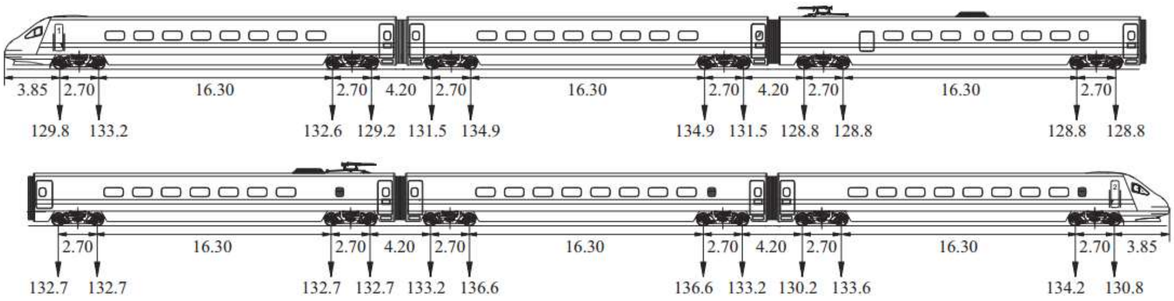

Figure 17: Train configuration: distances between axles (in m) and approximate loads (in kN) [4]

Table 1: Characteristics of the coach model [4]

Parameter	Value
Car body mass, M_c	36,901 kg
Secondary suspension stiffness, K_s	256.4 kN/m
Secondary suspension damping, C_s	35 kN s/m
Bogie mass (without axles), M_b	4932 kg
Primary suspension stiffness, K_p	564 kN/m
Primary suspension damping, C_p	18 kN s/m
Axle mass, M_a	1800 kg
Hertzian wheel–rail contact spring stiffness, K_h	1.24×10^6 kN/m

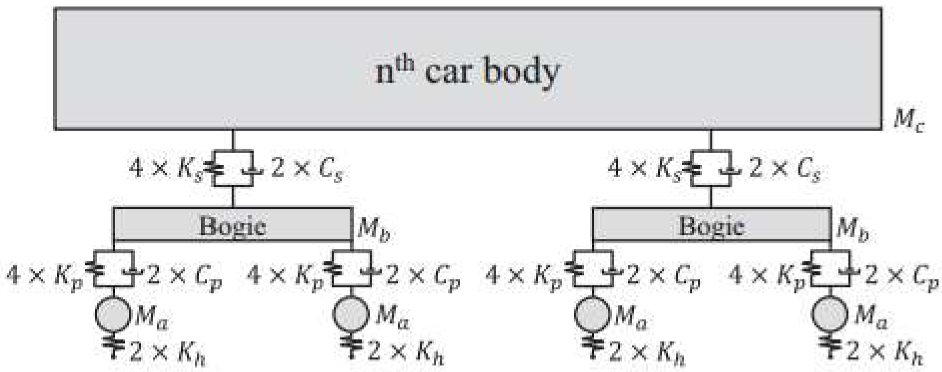

Figure 18: Model of one of the 6 coaches of the train (see parameters in Table 1) [4]

Table 2: Properties of the materials of the track and its substructure [4]

Component or material	Young modulus E_i (MPa)	Poisson's ratio ν_i (–)	Rayleigh damping β_i (s × 10^3)	Density ρ_i (kg/m^3)
Steel (rails and deck)	210×10^3	0.35	–	7850
Sleepers	30×10^3	0.25	–	6360[a]
Ballast	130	0.20	0.4	1530
Sub-ballast	200	0.30	0.4	1935
Capping layer	3020	0.30	2.6	1935
UGM	1030	0.30	2.6	1935
CBM	10×10^3	0.30	0.4	2200
Embankment soils	80	0.30	2.9	2040
Abutment	30×10^3	0.25	–	2500

[a] An equivalent density value was calculated to obtain a total weight of 315 kg for each sleeper.

3.1 Comparison between measurements and finite element results

Figure 19 provides the measurements from both before and after the bridge transition zones. The maximum deformation was around 0.8mm. Rail and sleeper relative displacement was around 0.2mm, which is mainly due to the rail pads. This means the ground deformation was around 0.6mm maximum.

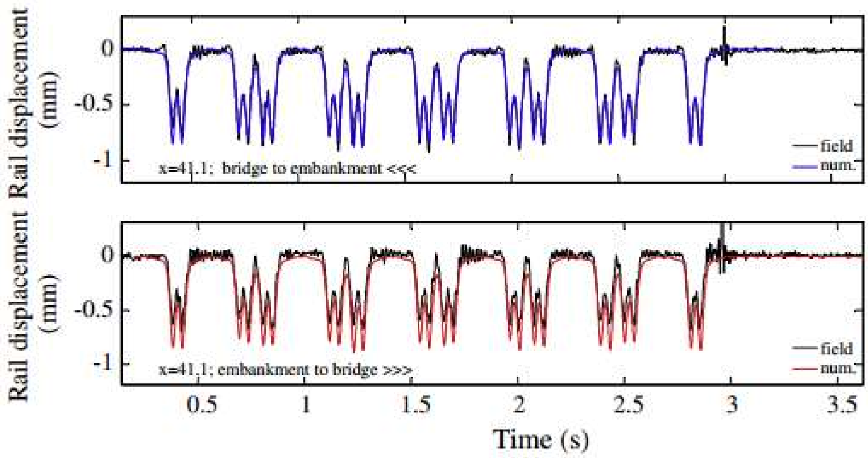

Figure 19: Rail displacements at position 1 in plan track, Portuguese numerical simulation [4]

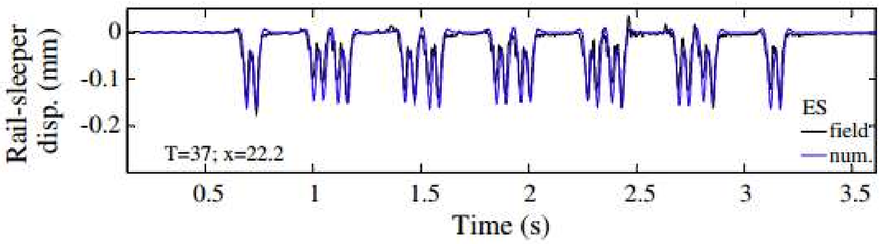

Figure 20: Rail sleeper relative displacement at position 1, Portuguese numerical simulation [4]

Finite element results showed a similar behaviour to the real measurements and maximum ground deformation was around 0.55mm. Results from the same location are provided in Figure 21 & 22. The results have been compared between two points: one at 41m and the second at 14.7m from the bridge.

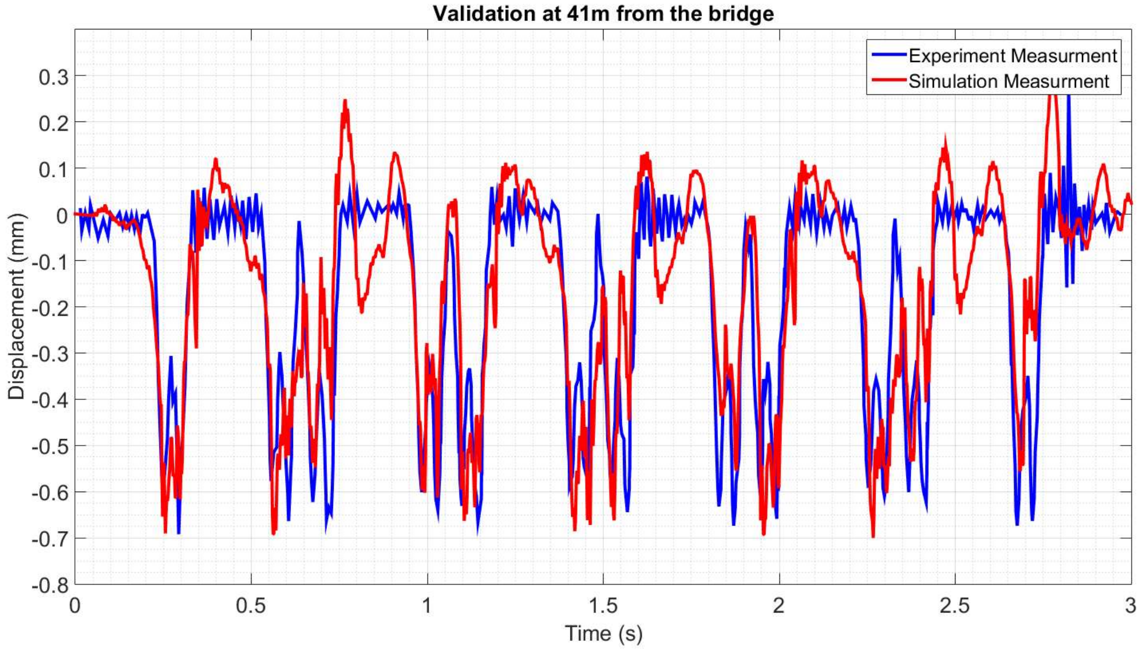

Figure 21: Vertical displacement of the tract at the 41m away from the bridge

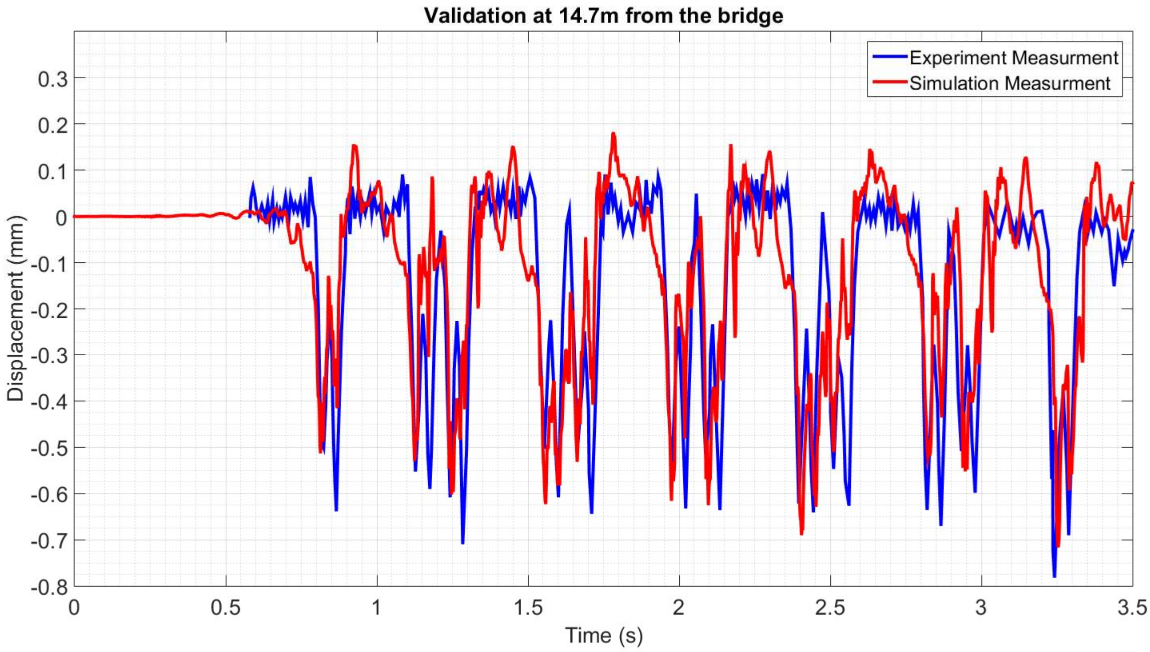

Figure 22: Vertical displacement of the tract at the 14.7m away from the bridge

Figure 23 shows the deformation of the soil at different locations. As expected the embankment had the maximum deformations compared to the bounded layers and bridge abutment.

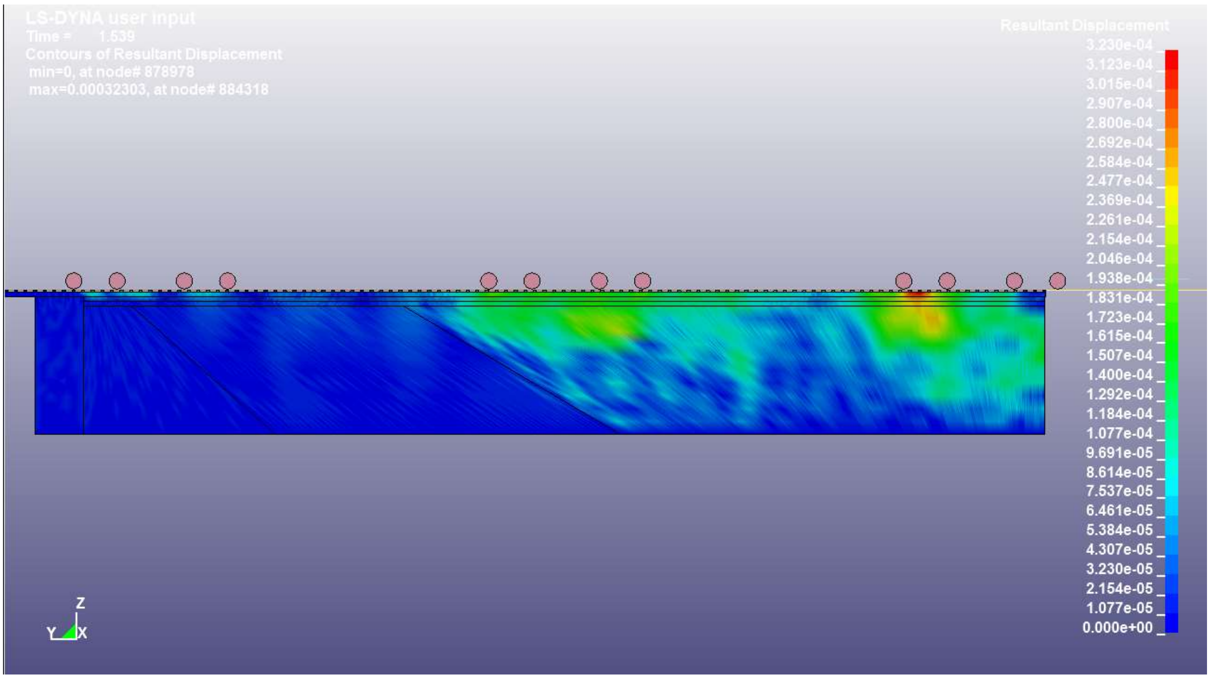

Figure 23: Vertical deformation predicted by the 2D finite element model

4. Parametric studies and testing the innovation

As explained the Portugal transition zone had used many layers of material like CBM, UGM and embankment. And the measurements were done at two points of 41m and 14.7m from the bridge. To test the innovation a series of parametric studies (Table 3) were done as listed below and results are provided in figures 28 to 60. These tests assessed the influence of the sleepers' mass by changing different conditions of the material and the width of these layers of soil as shown in figures 24& 25.

	Sleepers Mass	Sub-Structure Material	Sub-Structure Width
Original Geometry (Fig 24)	0.5x,1x,2x,3x	Embankment, UGM, CBM	Tapered
Same Width at All Layers (Fig 24)	0.5x,1x,2x	Embankment, UGM, CBM	13m
Same Width and Material at All Layers (Fig 25)	0.5x,1x,2x	Embankment	13m
Same Material (Fig 25)	0.5x,1x,2x	Embankment	Tapered

Table 3: different studies

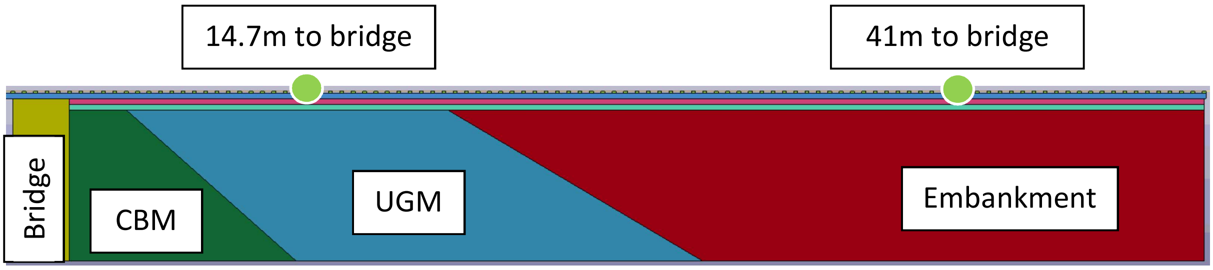

Figure 24: the Portugal arrangement of the transition zone

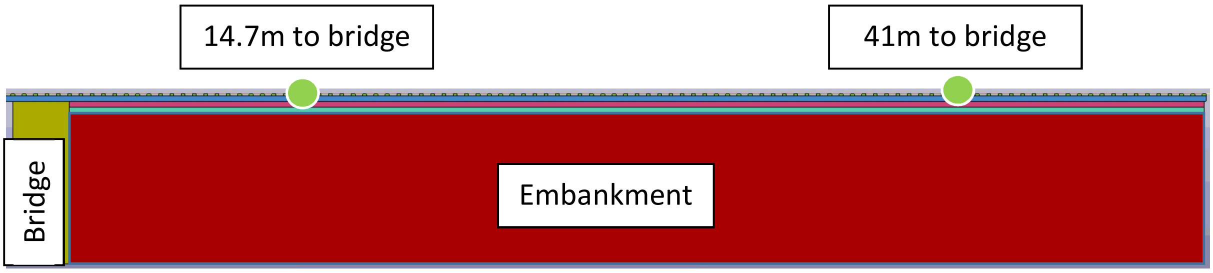

Figure 25: having no sub-structure transition zone

To understand the effect of the Portuguese transition zone solution, it is compared with the same geometry but having the same embankment material at all the different layers (figure 25). Figures 26 & 27 shows the effect of having this transition zone which is less effective at 41m away from the bridge as in both case the layer underneath that region was the embankment. However, it was more effective at 14.7m to the bridge as the Unbounded Granular Material had been changed with the embankment.

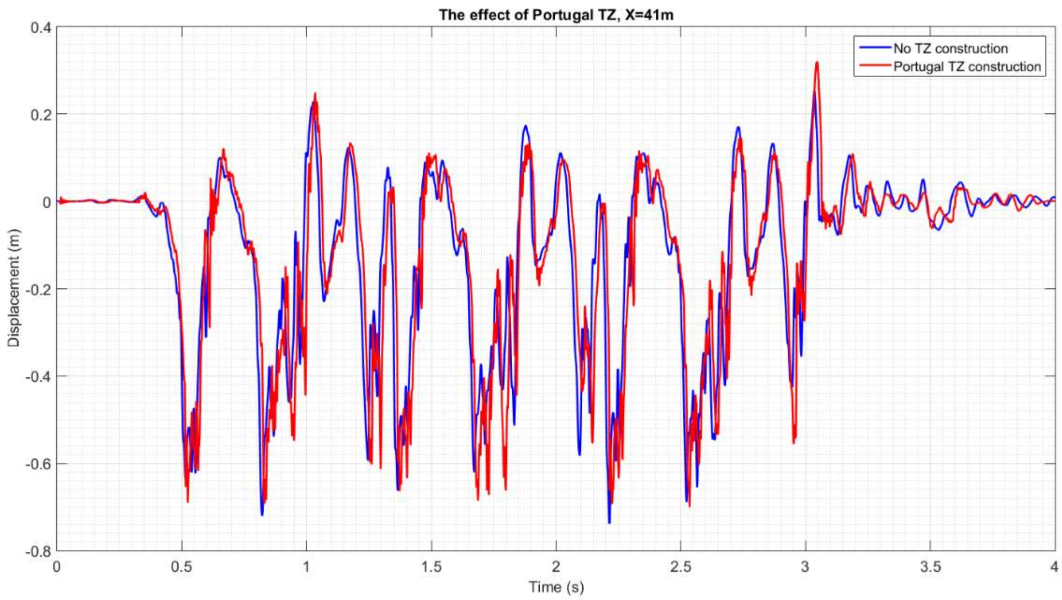

Figure 26: the effect of Portugal transition zone design at 41m from the bridge

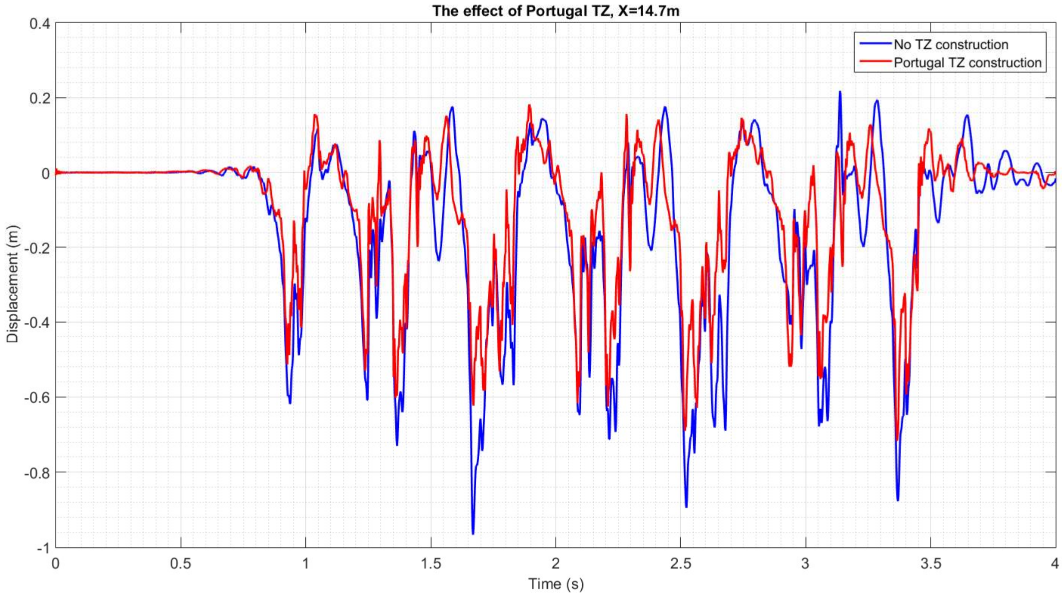

Figure 27: the effect of Portugal transition zone design at 14.7m from the bridge

4.1 Original geometry

Changing the sleeper's mass from half to three times more had no clear effect on the transition zone behaviour for the arrangement used in Portugal. Figure 28-31 shows the displacement of the rail at 14.7m and 41m from the bridge. To be able to understand the graphs better histograms are provided in figure 32-37.

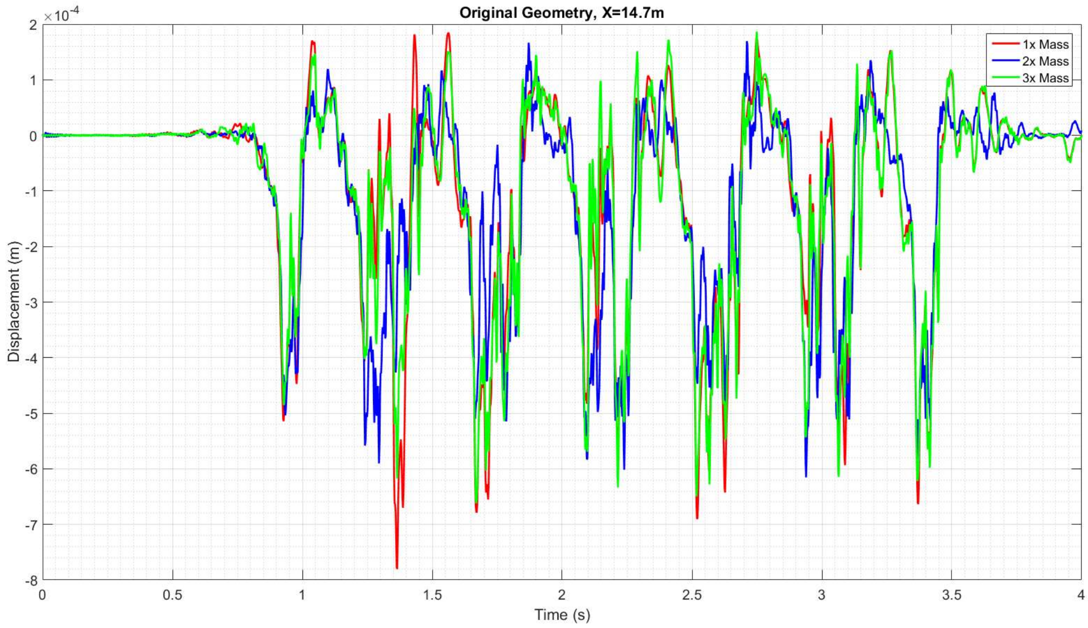

Figure 28: Portugal arrangement for transition zone with heavier sleepers at 14.7m from the bridge

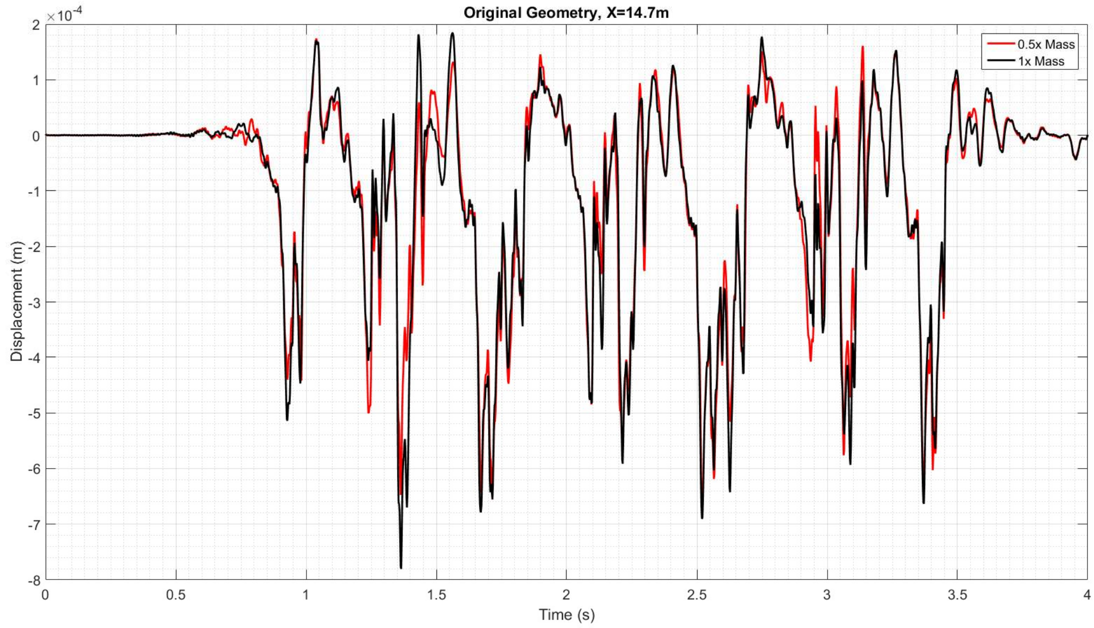

Figure 29: Portugal arrangement for transition zone with lighter sleepers at 14.7m from the bridge

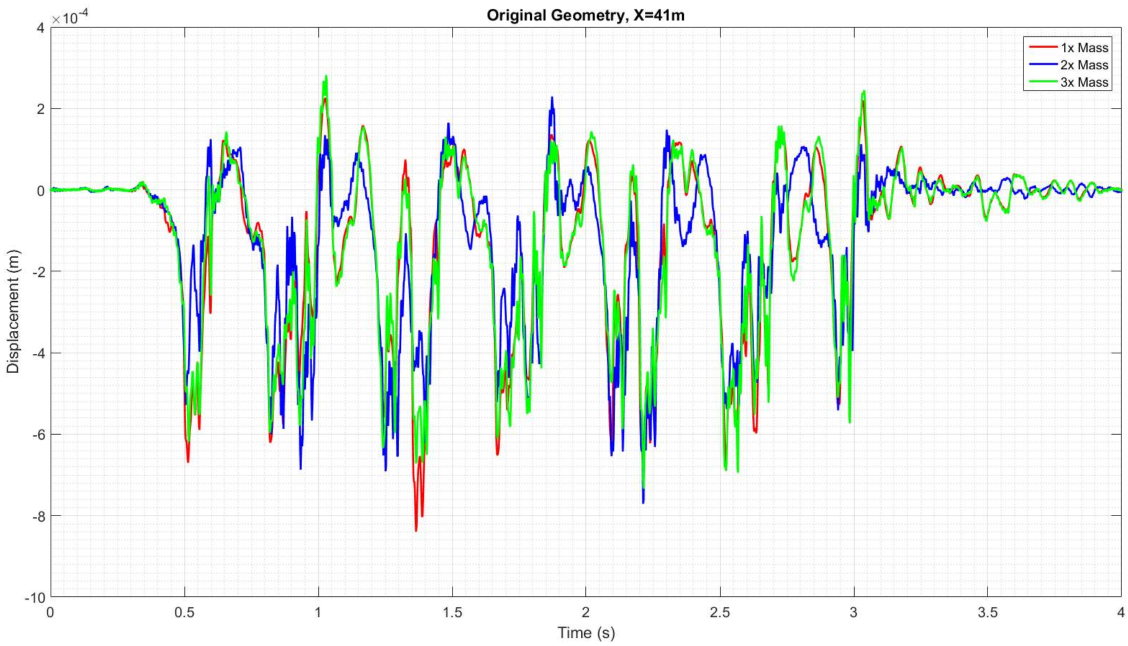

Figure 30: Portugal arrangement for transition zone with heavier sleepers at 41m from the bridge

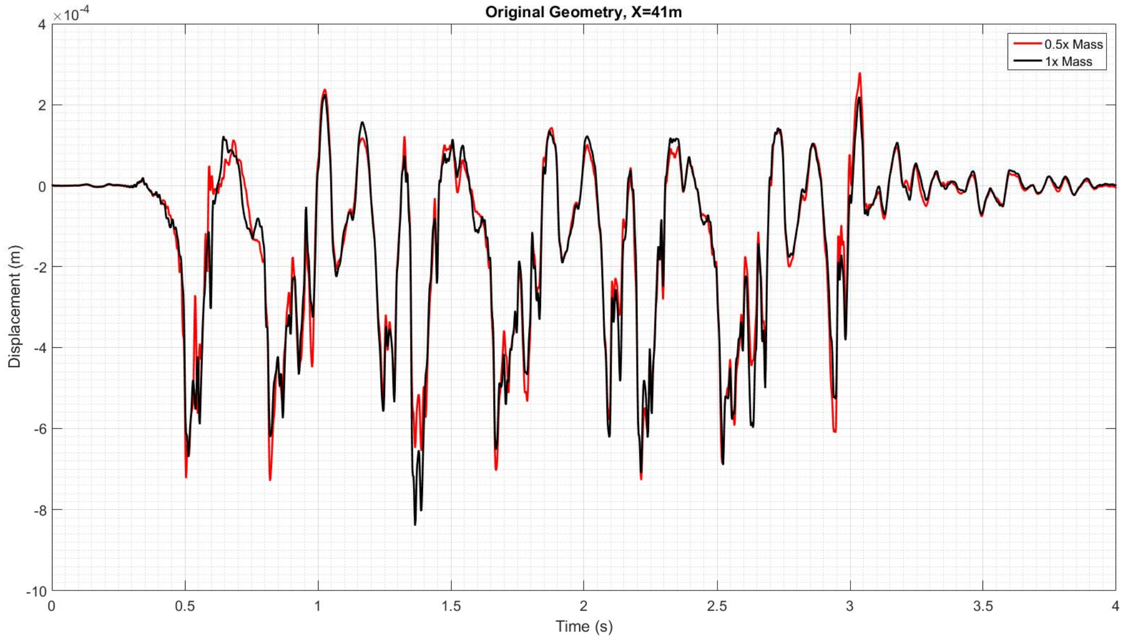

Figure 31: Portugal arrangement for transition zone with lighter sleepers at 41m from the bridge

To understand the histograms better, the positive and negative histogram of the data is presenting separately in figure 33-34 and figure 36-37. However, all these histograms proved using different sleeper's mass is not the best option for traditionally prepared transition zones. However, better effects resulted in other studies which follows.

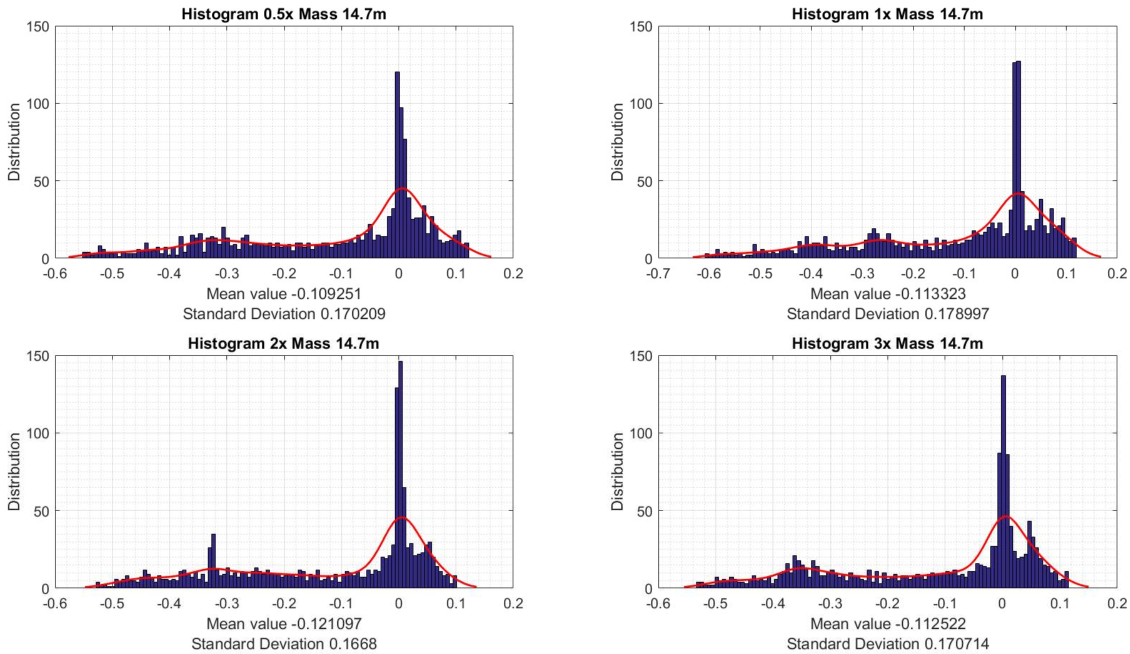

Figure 32: histogram of the whole data (displacement in mm) for the original geometry of Portugal transition zone, with different size of sleepers at 14.7m from the bridge

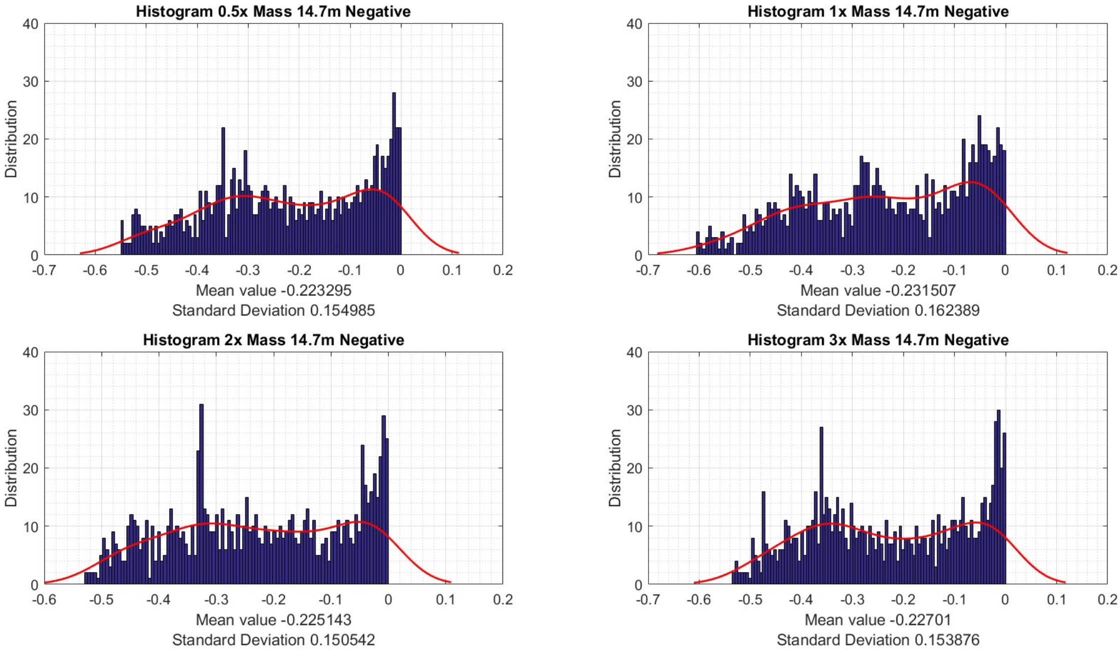

Figure 33: histogram of the negative part of data (displacement in mm) for the original geometry of Portugal transition zone, with different size of sleepers at 14.7m from the bridge

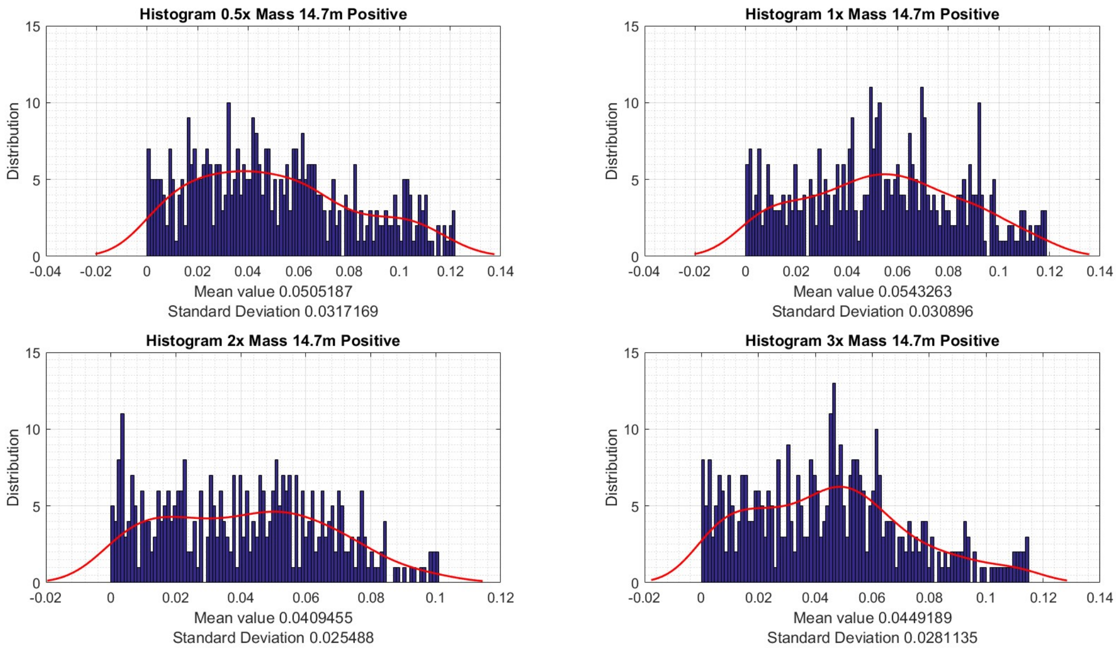

Figure 34: histogram of the positive part of data (displacement in mm) for the original geometry of Portugal transition zone, with different size of sleepers at 14.7m from the bridge

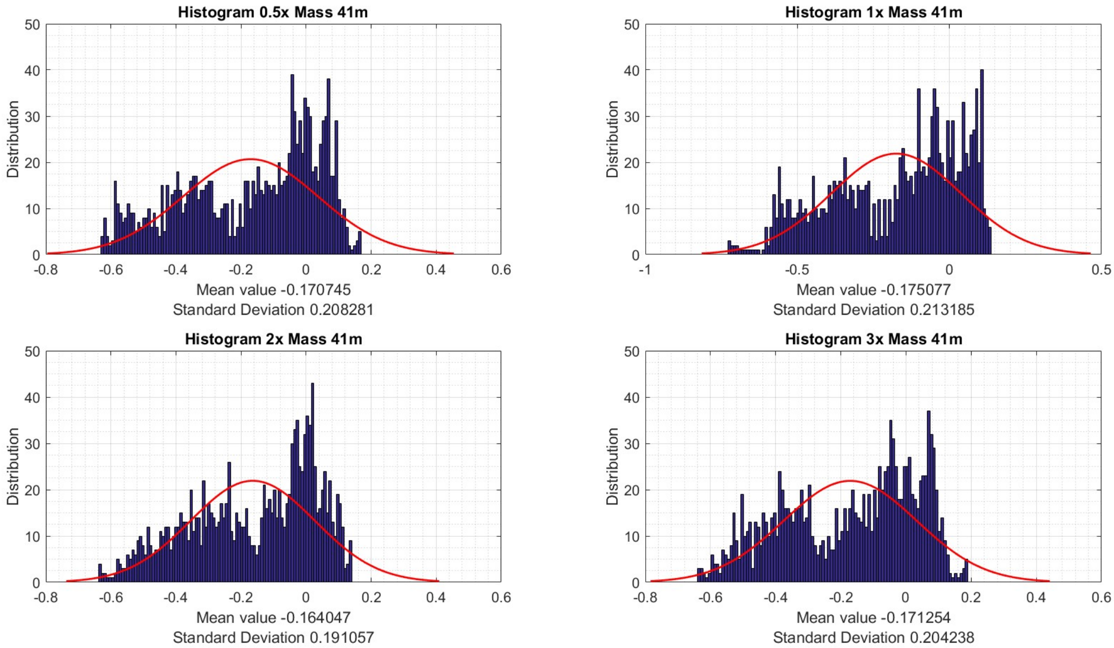

Figure 35: histogram of the whole data (displacement in mm) for the original geometry of Portugal transition zone, with different size of sleepers at 41m from the bridge

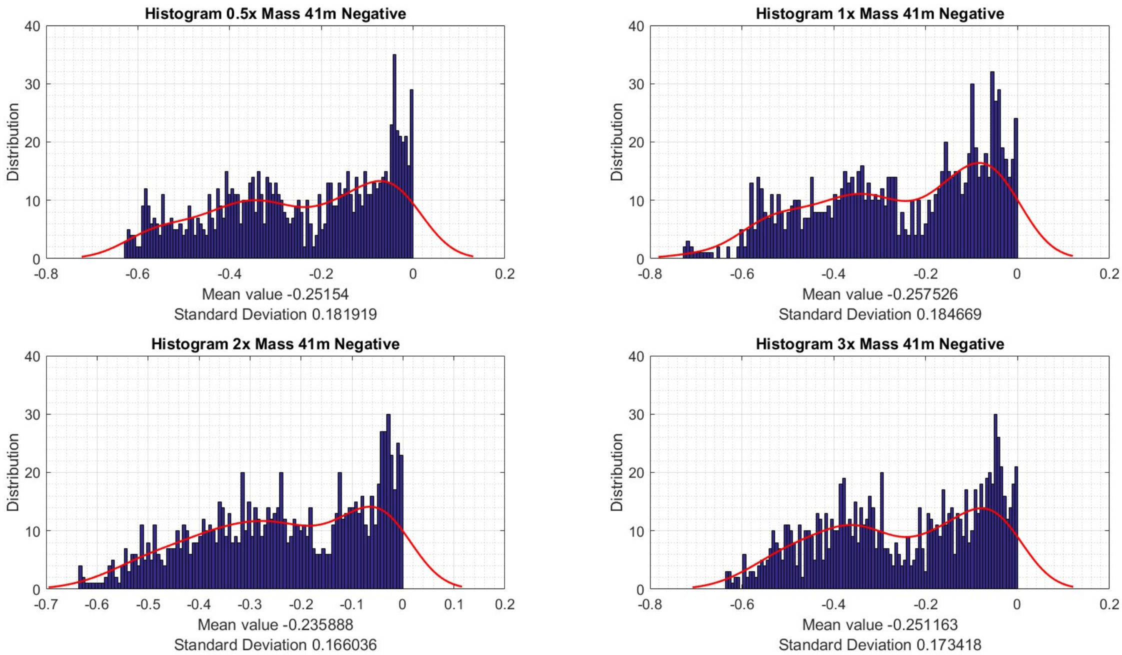

Figure 36: histogram of the negative part of data (displacement in mm) for the original geometry of Portugal transition zone, with different size of sleepers at 41m from the bridge

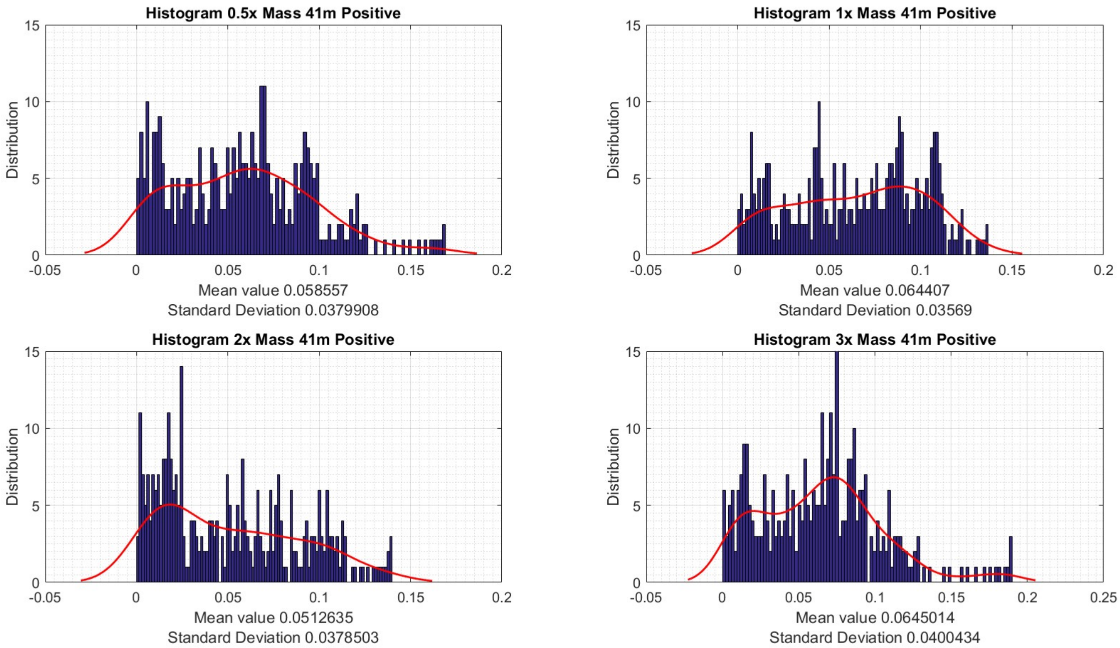

Figure 37: histogram of the positive part of data (displacement in mm) for the original geometry of Portugal transition zone, with different size of sleepers at 41m from the bridge

4.2 Same width at all layers

As the layers width were reduced as they got closer to the bridge, a second study is to check the traditional transition zone if all layers kept the same width at all locations. This change helps the heavier sleepers to have a better effect compared to original geometry. However, still the effect is lower closer to the bridge due to the ground getting harder. Figure 38-39 shows the displacement of the rail at 14.7m and 41m from the bridge. Figure 40-45 shows the histogram of these two displacements. There is a change in behavior as heavier sleepers have been used compared to next two scenarios.

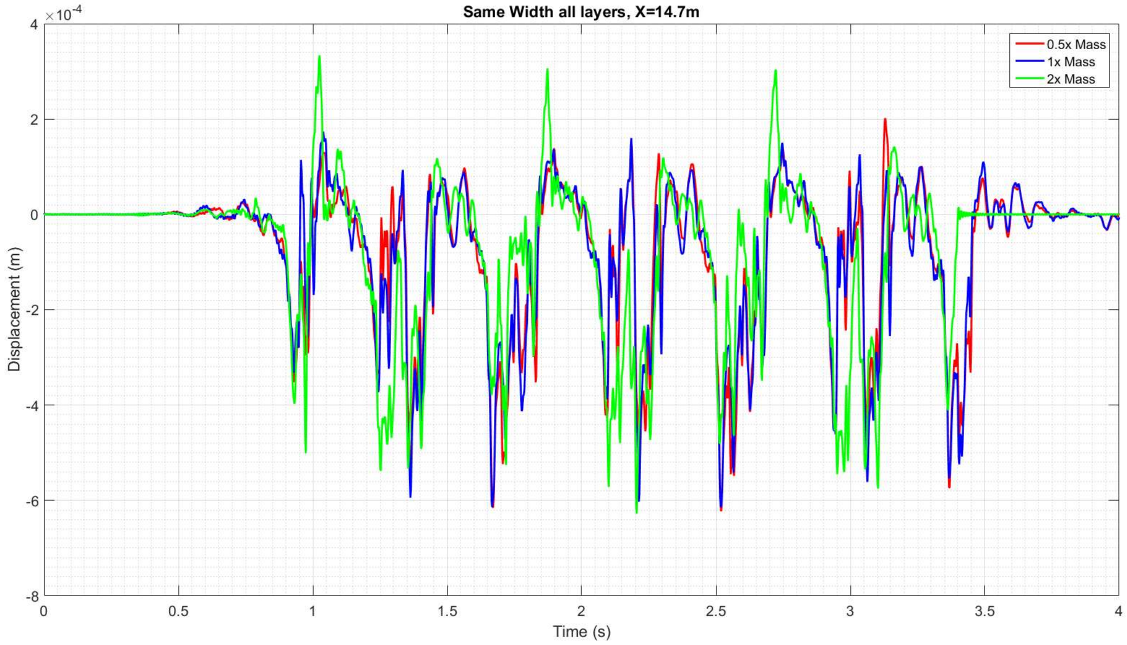

Figure 38: having heavier sleepers when all the layers have the same width, 14.7m from the bridge

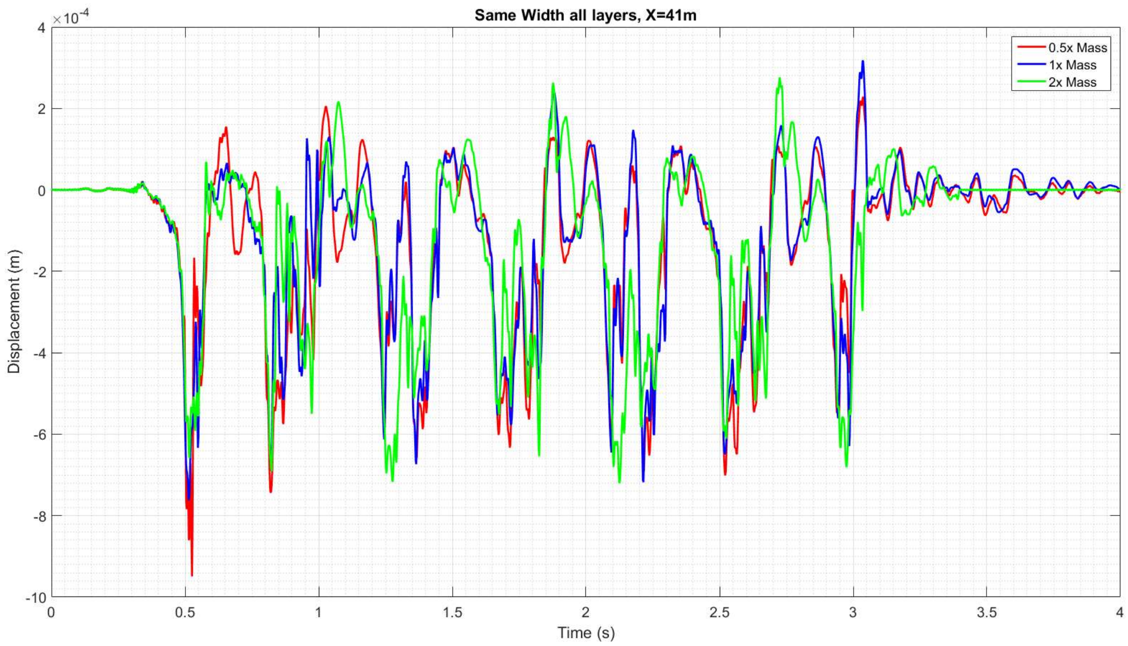

Figure 39: having heavier sleepers when all the layers have the same width, 41m from the bridge

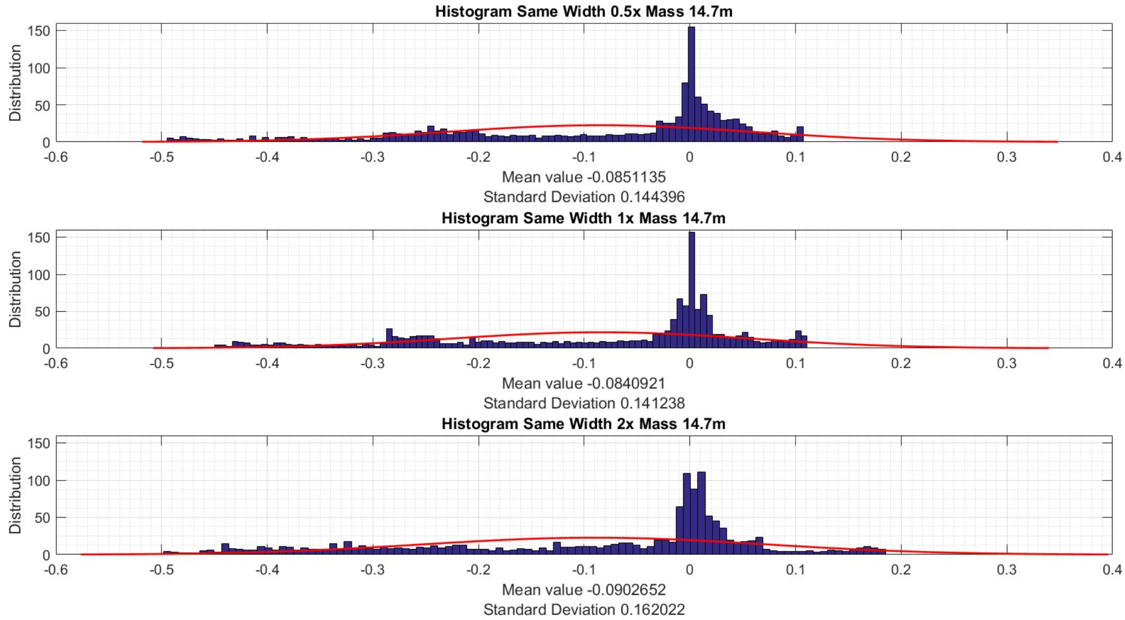

Figure 40: histogram of the whole data (displacement in mm) for having the same width of Portugal transition zone, with different size of sleepers at 14.7m from the bridge

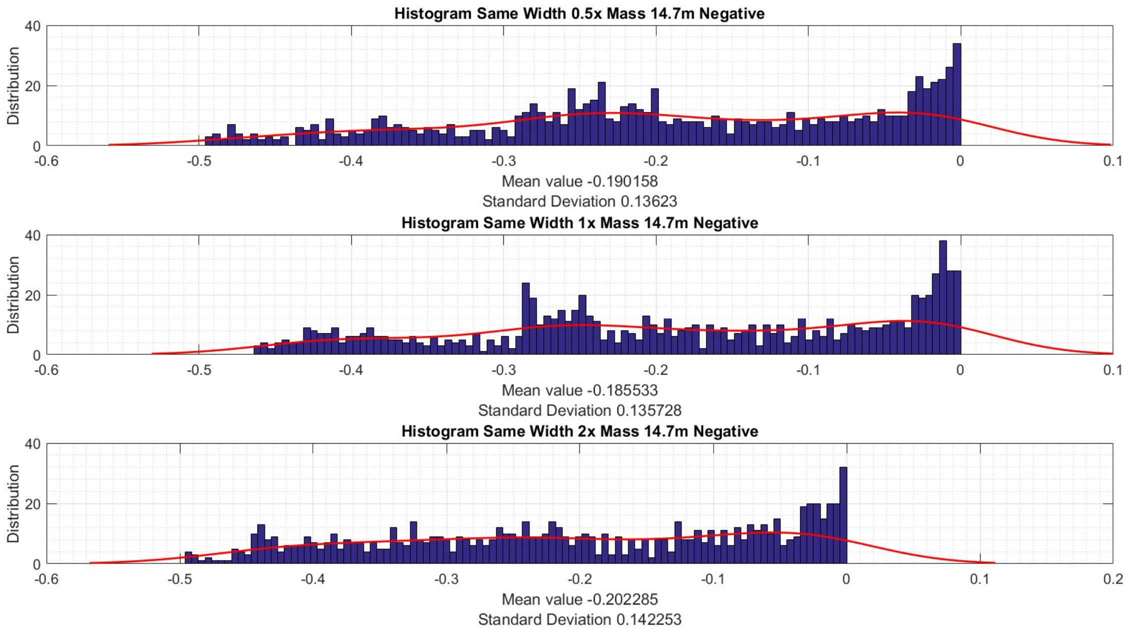

Figure 41: histogram of the negative part of data (displacement in mm) for having the same width of Portugal transition zone, with different size of sleepers at 14.7m from the bridge

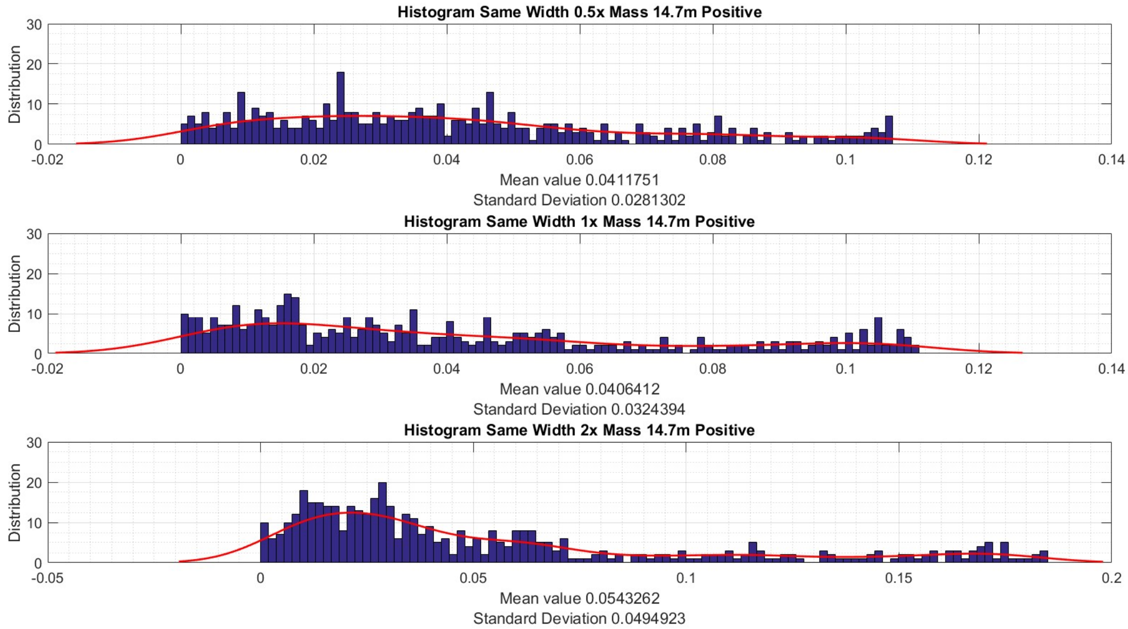

Figure 42: histogram of the positive part of data (displacement in mm) for having the same width of Portugal transition zone, with different size of sleepers at 14.7m from the bridge

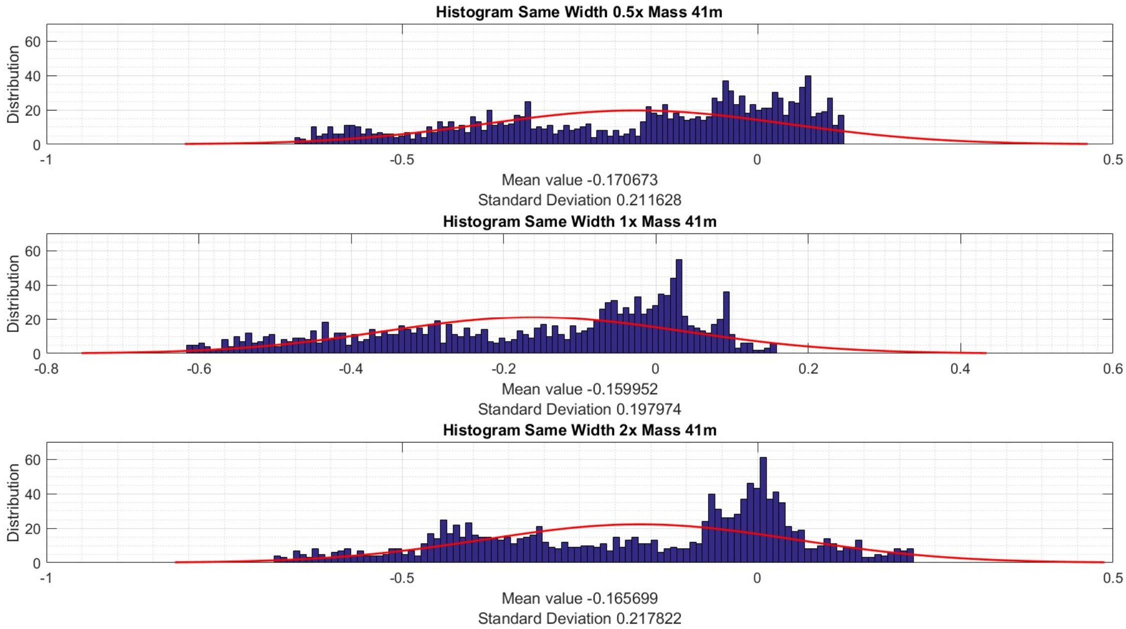

Figure 43: histogram of the whole data (displacement in mm) for having the same width of Portugal transition zone, with different size of sleepers at 41m from the bridge

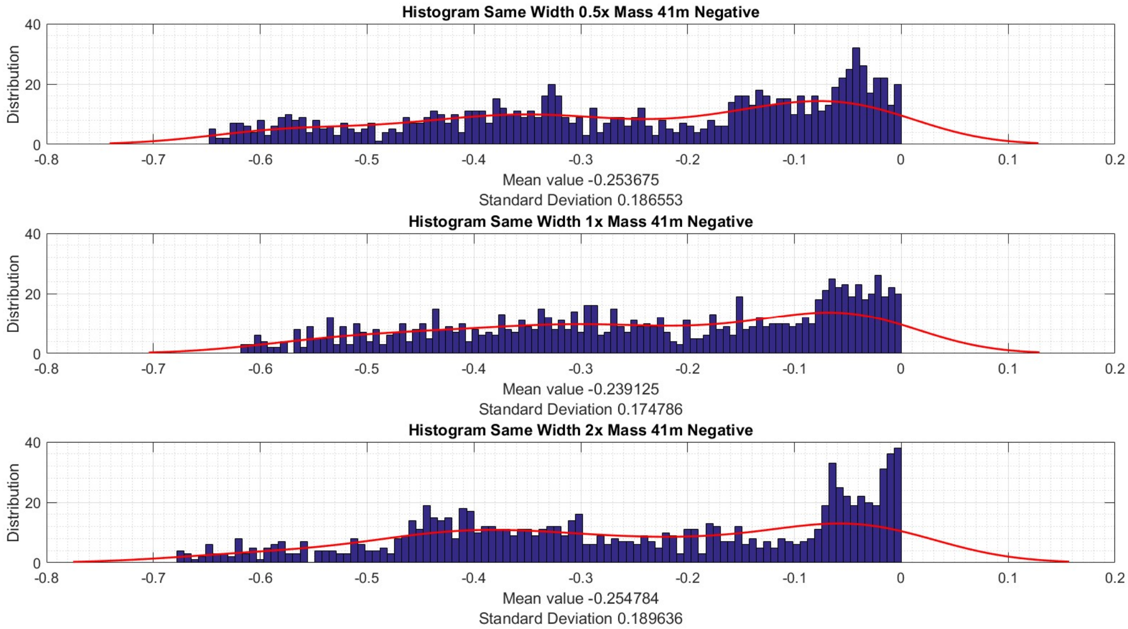

Figure 44: histogram of the negative part of data (displacement in mm) for having the same width of Portugal transition zone, with different size of sleepers at 41m from the bridge

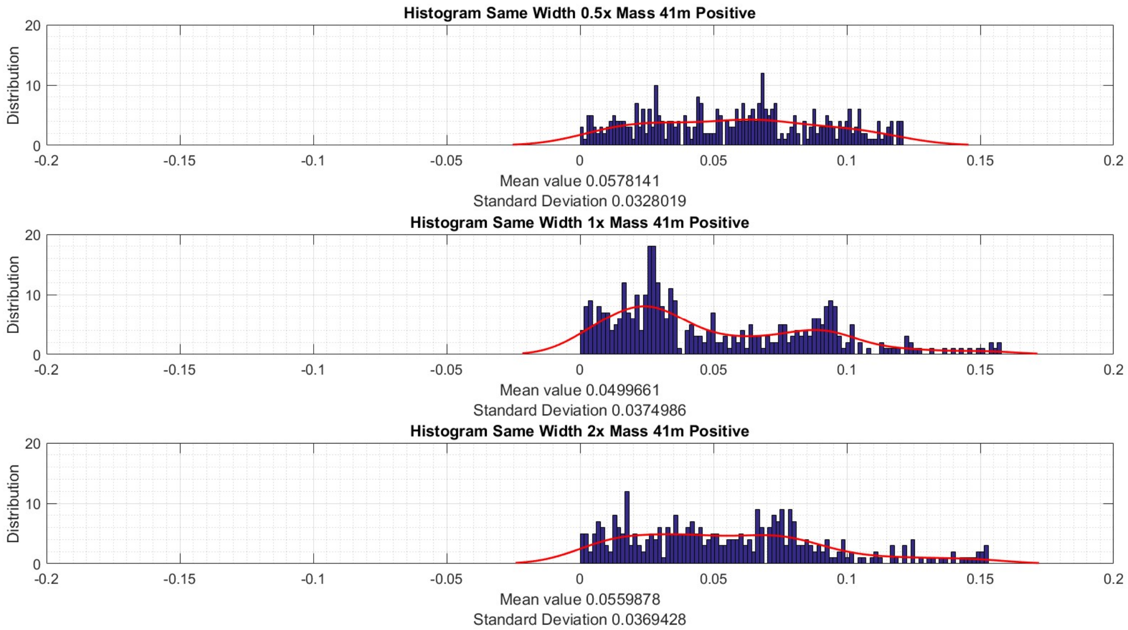

Figure 45: histogram of the positive part of data (displacement in mm) for having the same width of Portugal transition zone, with different size of sleepers at 41m from the bridge

4.3 Same width and material at all layers

To understand the influence of changing the sleepers mass all the layers material has been kept as embankment and three different sleepers are used. Figure 46-47 provides the displacement of the rail at 14.7m and 41m from the bridge. It is possible to see how effective the system is, as it is getting closer to the bridge. Figure 48-52 shows the effect of heavier sleepers as the histogram shows the displacement reduced dramatically and getting closer to zero.

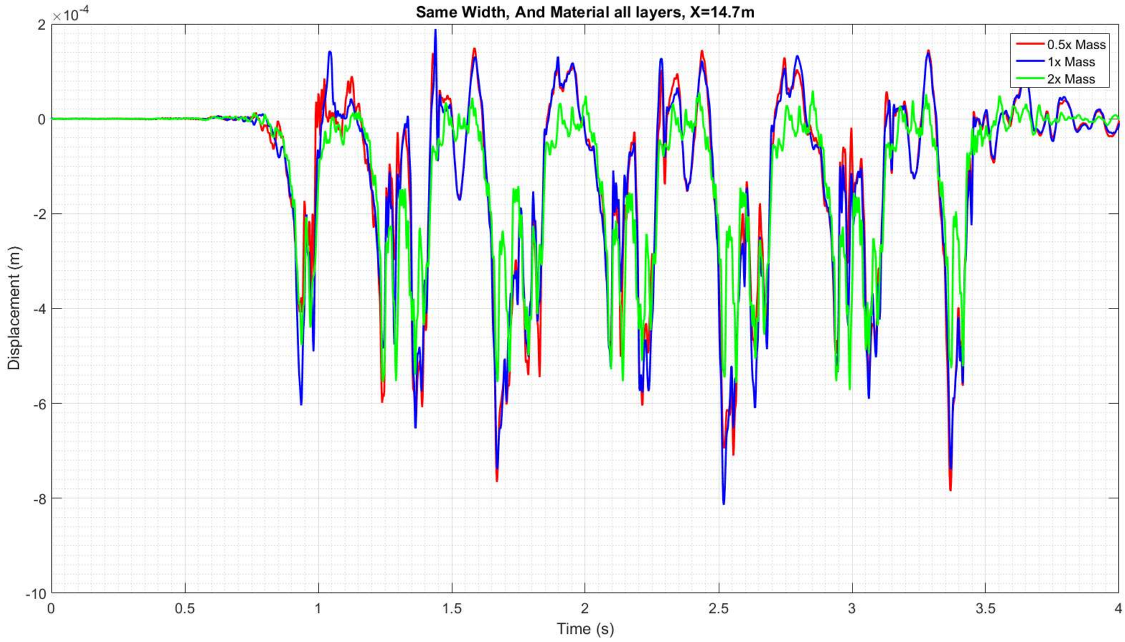

Figure 46: having the same width and embankment substructure everywhere at 14.7m from the bridge

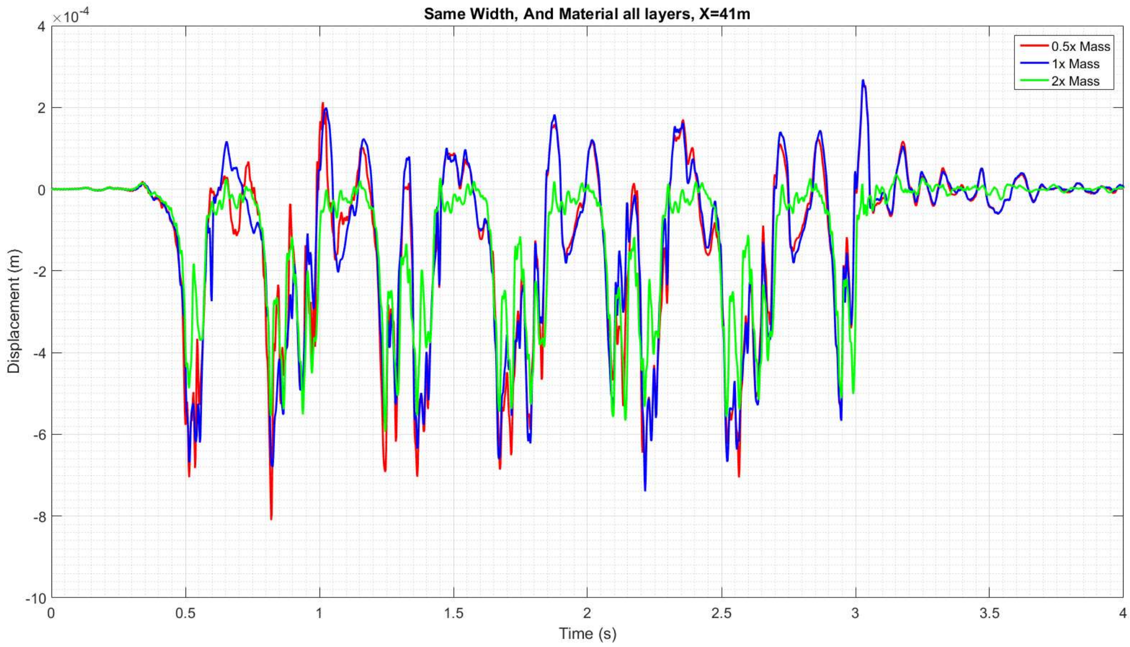

Figure 47: having the same width and embankment substructure everywhere at 41m from the bridge

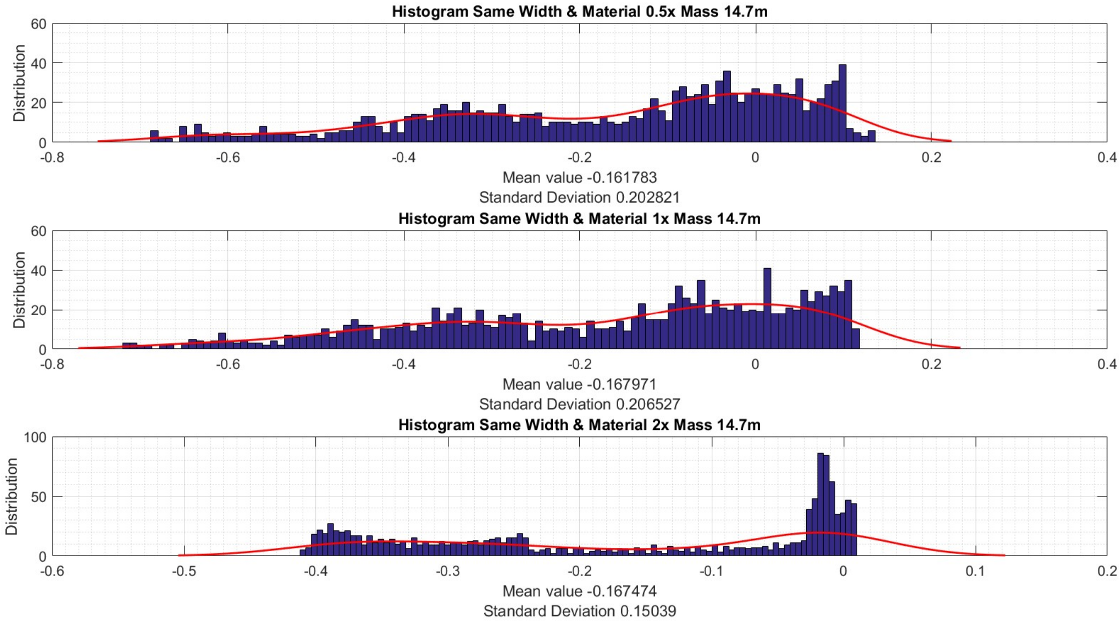

Figure 48: histogram of the whole data (displacement in mm) for having the same width, with different size of sleepers at 14.7m from the bridge

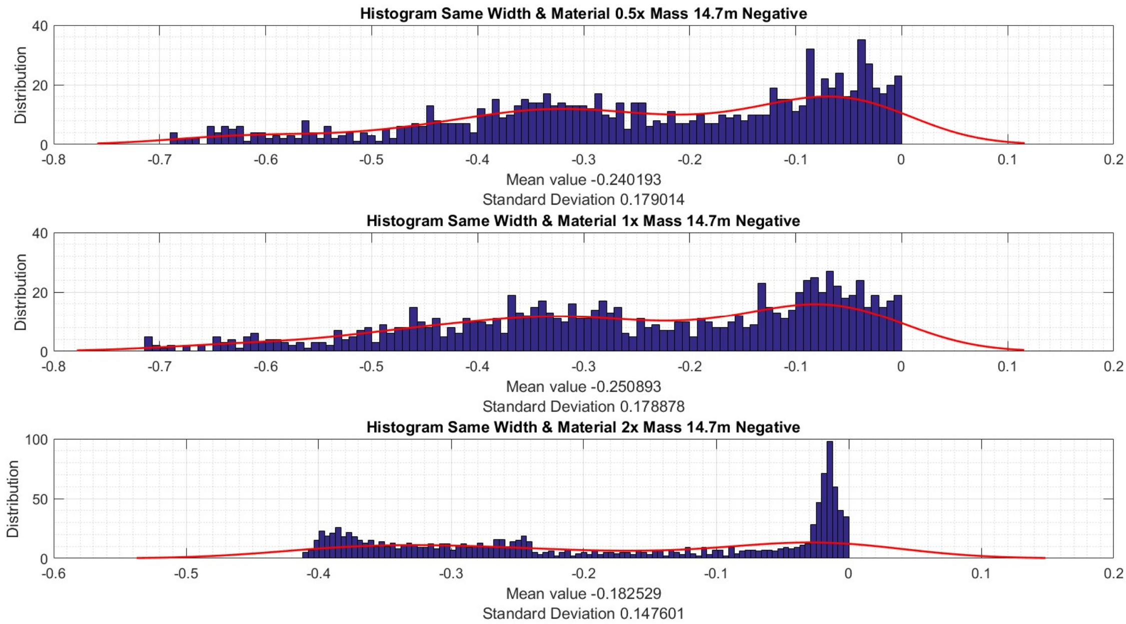

Figure 49: histogram of the negative part of data (displacement in mm) for having the same width, with different size of sleepers at 14.7m from the bridge

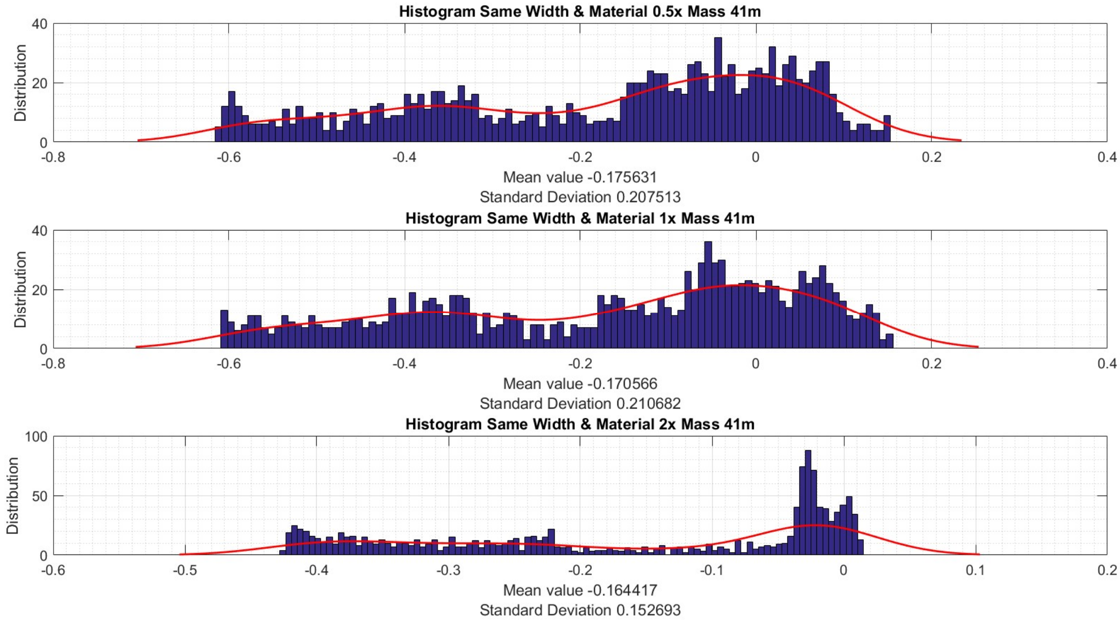

Figure 50: histogram of the whole data (displacement in mm) for having the same width & material, with different size of sleepers at 41m from the bridge

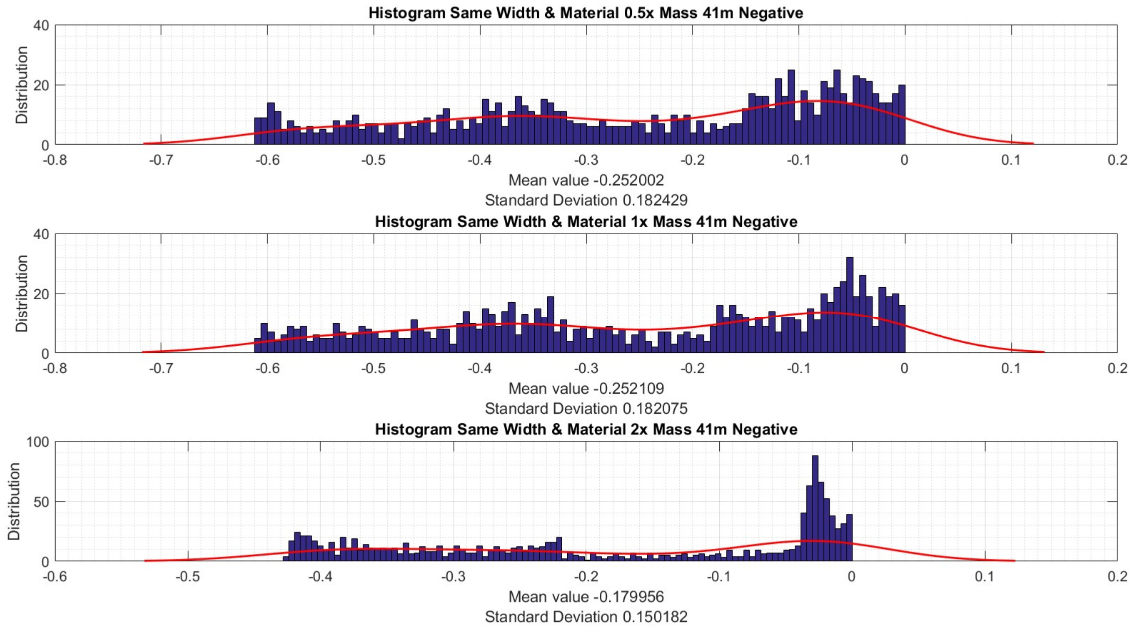

Figure 51: histogram of the negative part of data (displacement in mm) for having the same width, with different size of sleepers at 41m from the bridge

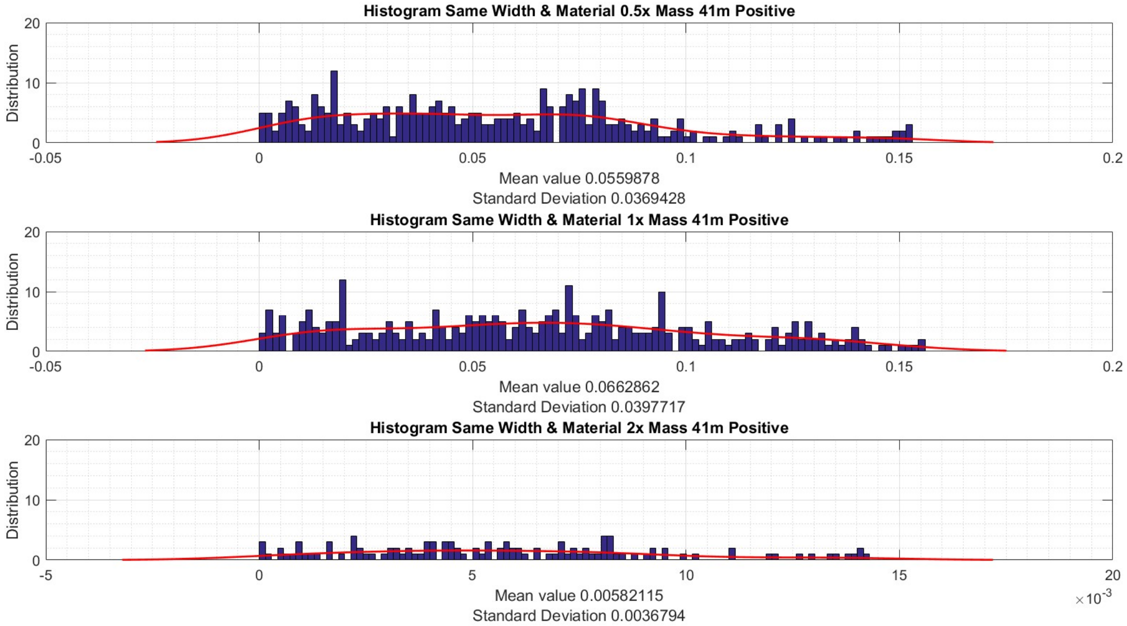

Figure 52: histogram of the positive part of data (displacement in mm) for having the same width, with different size of sleepers at 41m from the bridge

4.4 Same material at all layers

The best condition to test the innovation is to remove all the material used in traditional transition zone design in Portugal and to use the embankment material everywhere, while keeping the same geometry. Figure 53-54 provides the displacement of the rail at 14.7m and 41m from the bridge. It is possible to see how effective the system is, as it is getting closer to the bridge. Figure 55-60 shows the effect of heavier sleepers as the histogram shows the displacement reduced dramatically and getting closer to zero. These results show that this system works better compared to the old traditional transition zone design.

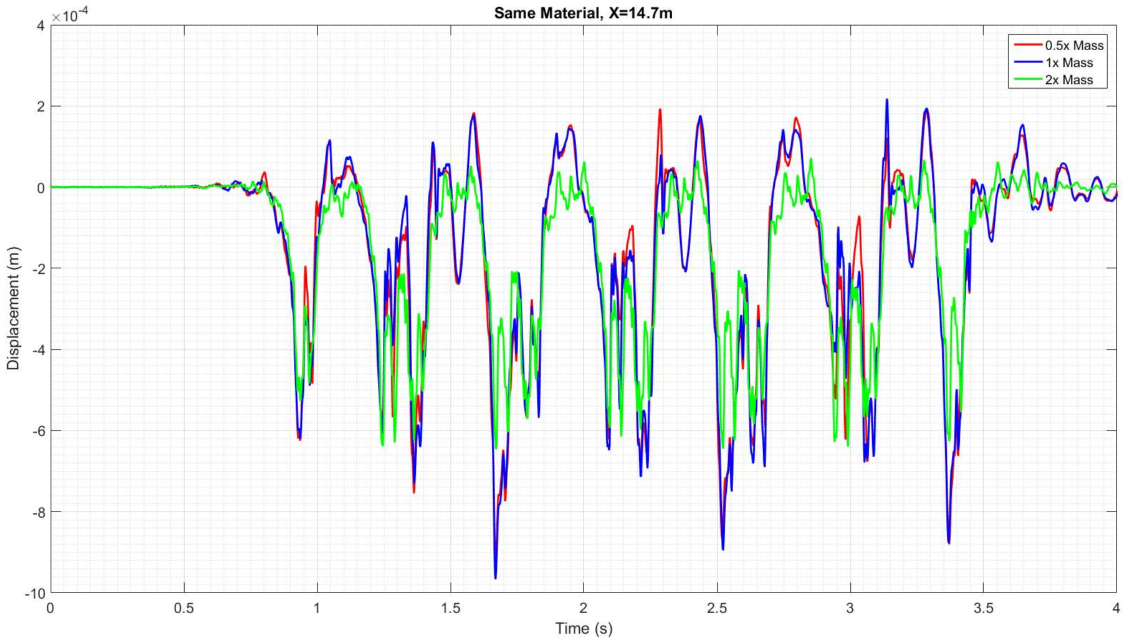

Figure 53: having the same material everywhere at 14.7m from the bridge

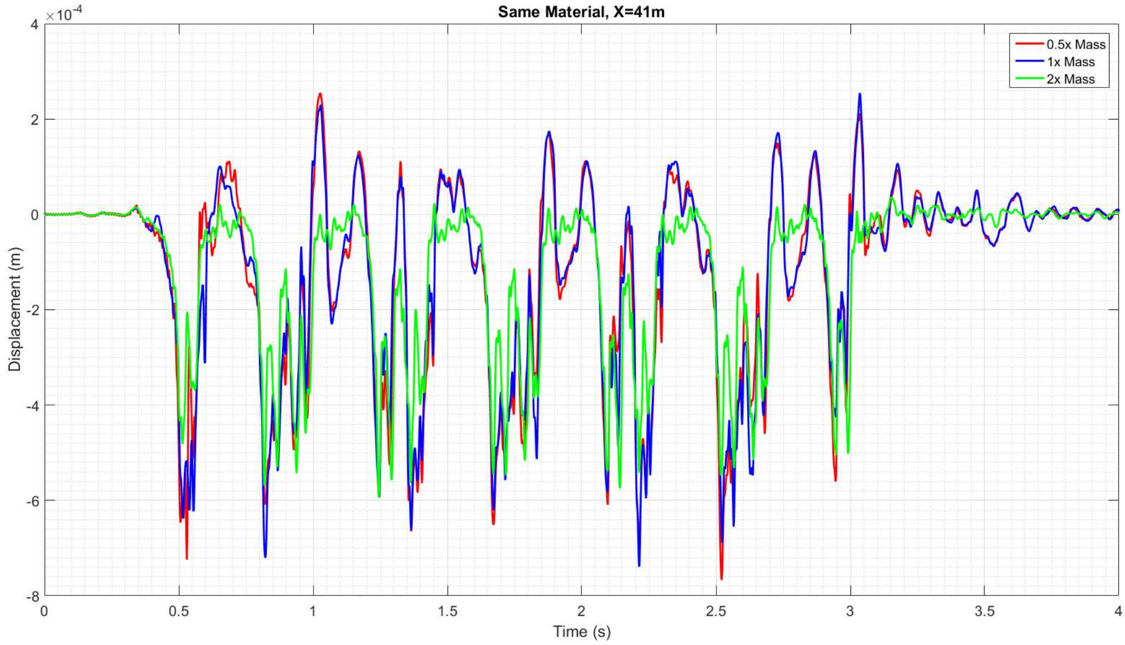

Figure 54: having the same material everywhere at 41m from the bridge

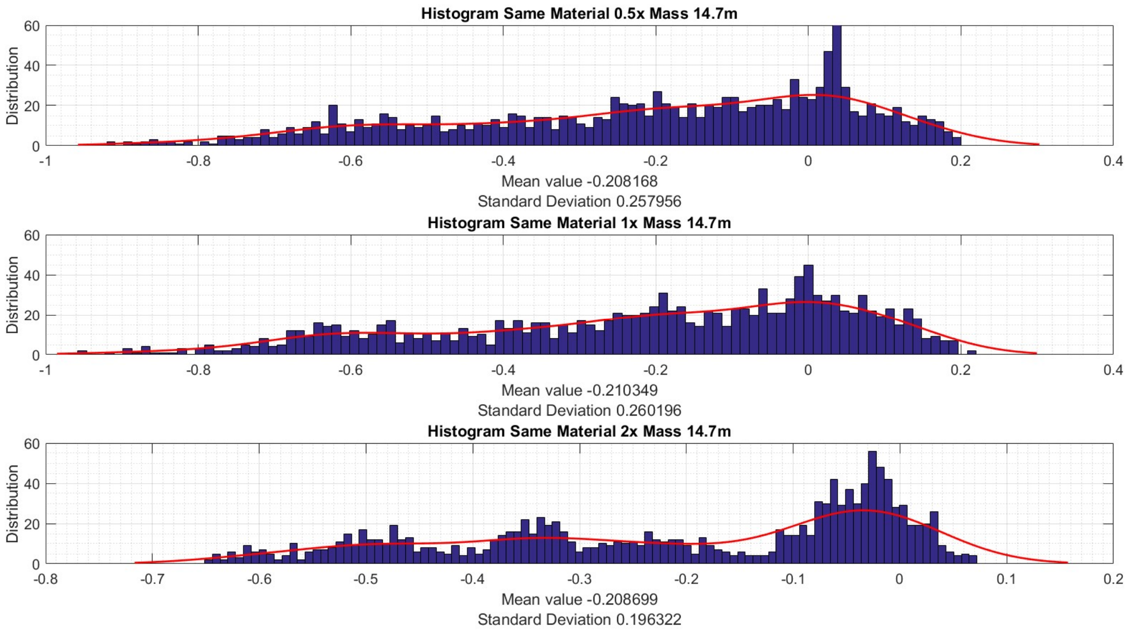

Figure 55: histogram of the whole data (displacement in mm) for having the same material, with different size of sleepers at 14.7m from the bridge

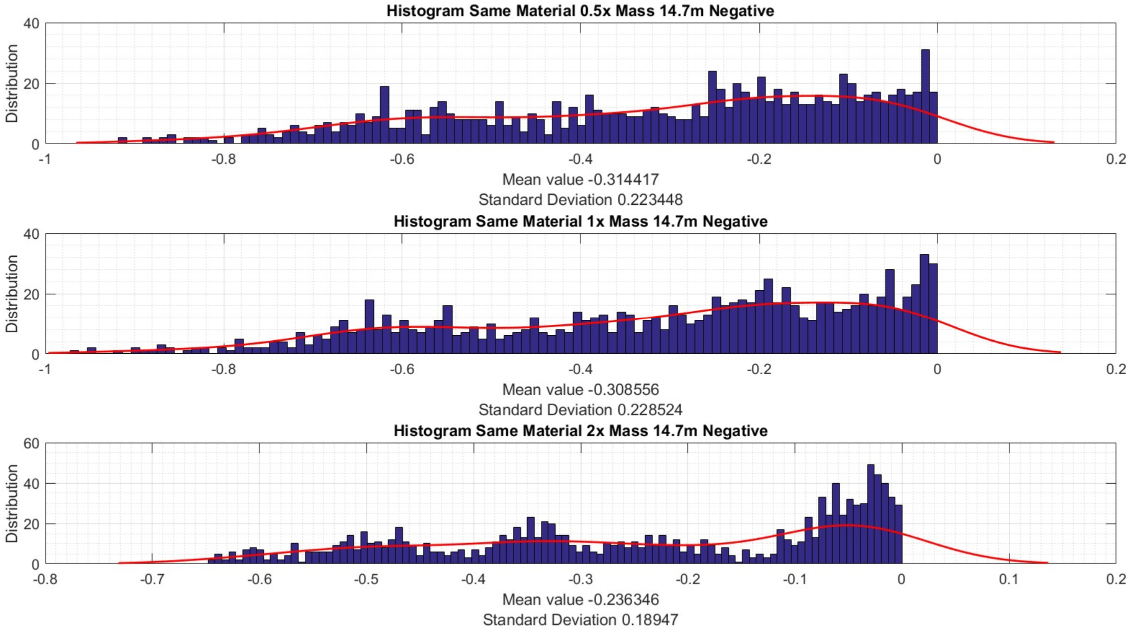

Figure 56: histogram of the negative part of data (displacement in mm) for having the same material, with different size of sleepers at 14.7m from the bridge

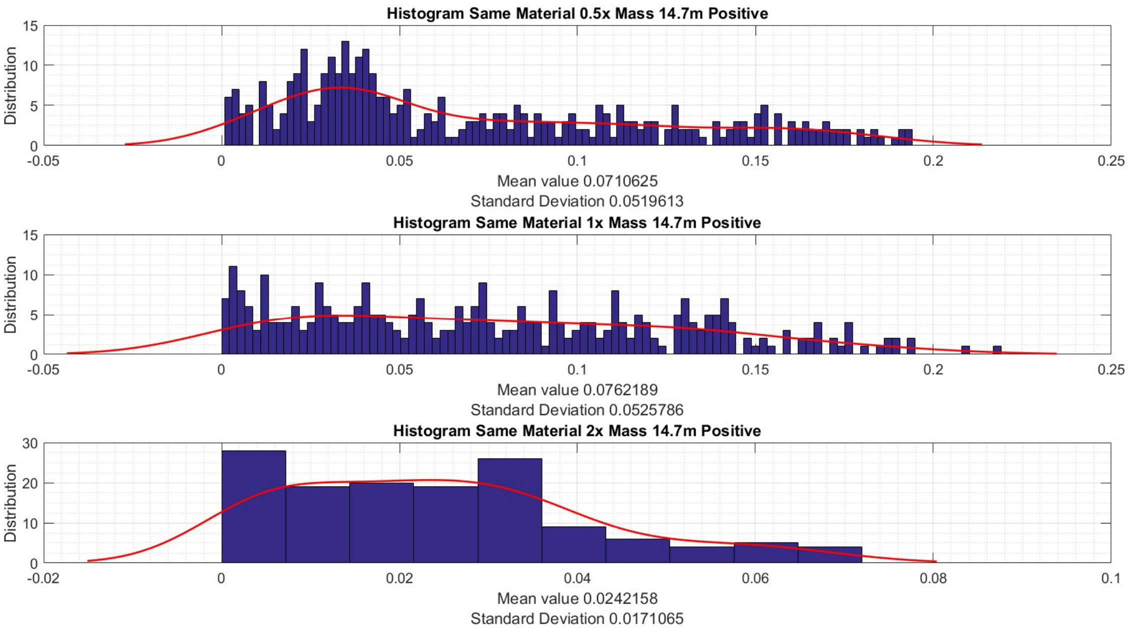

Figure 57: histogram of the positive part of data (displacement in mm) for having the same material, with different size of sleepers at 14.7m from the bridge

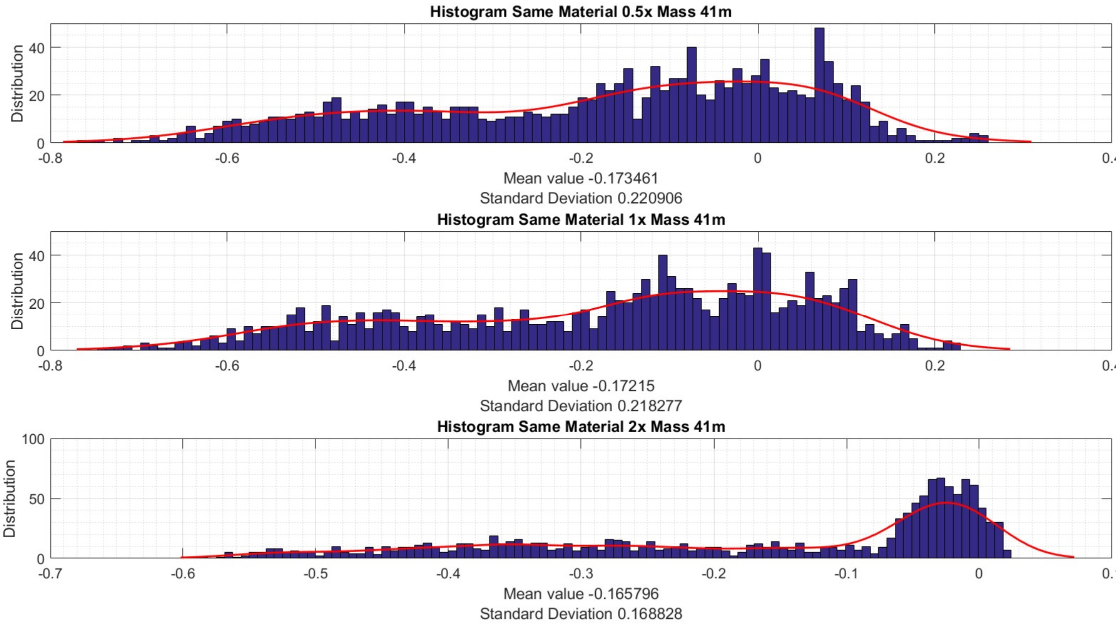

Figure 58: histogram of the whole data (displacement in mm) for having the same material, with different size of sleepers at 41m from the bridge

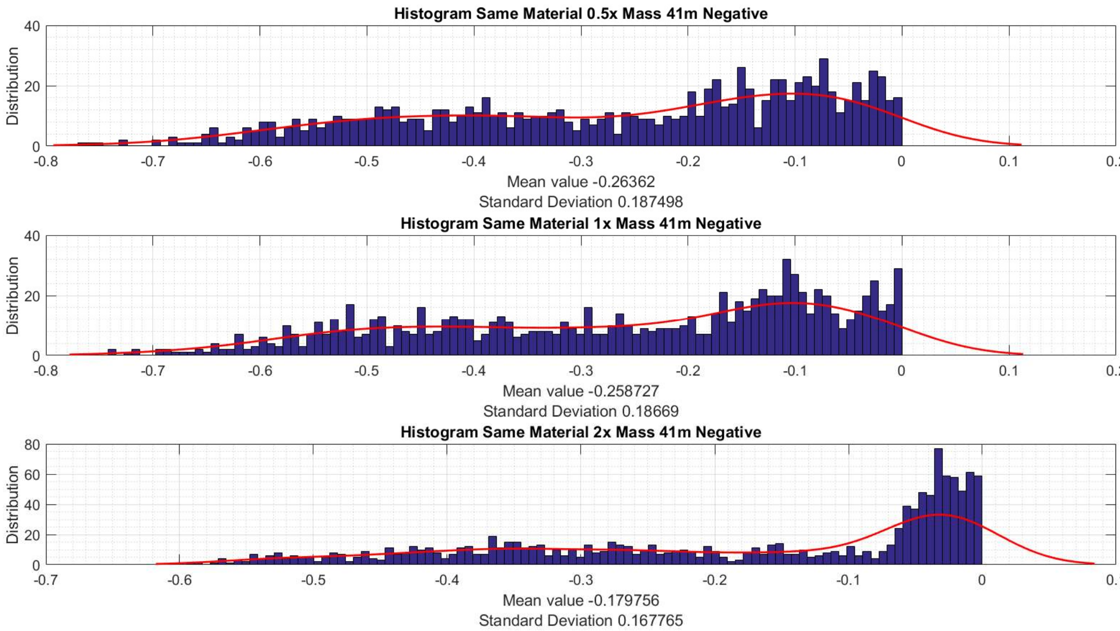

Figure 59: histogram of the negative part of data (displacement in mm) for having the same material, with different size of sleepers at 41m from the bridge

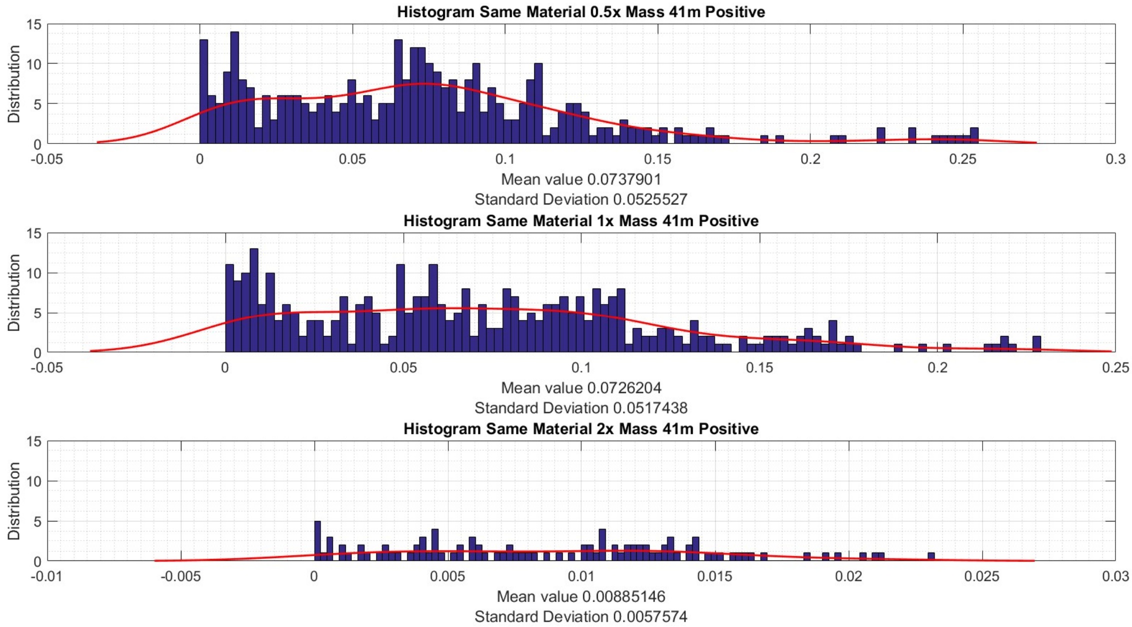

Figure 60: histogram of the positive part of data (displacement in mm) for having the same material, with different size of sleepers at 41m from the bridge

5. Conclusion

The model developed and validated in the frame of the study has been built in Portugal. The comparison of the model results with the field measurement show a good correlation. This model has been used to show how it could be the deformation of the same geometry without any transition zone built up, and then the comparison between having the Portuguese transition zone or not is provided in figure 27. This comparison proves how successful transition zone works, needing to change the displacement of the rail about 20%.

For the next part of this study, four different cases have been examined. In the first two studies "***Original Geometry***" and "***same width at all layers***" the material properties of the lower ground kept the same characteristics as the Portuguese study, but different sleepers mass have been applied. These two studies showed no improvement in the system, which can be either because there is no more room for improvement as the ground had been reinforced previously or these two systems cancel out some of their influence.

The other two studies have been done on "***Same width and material at all layers***" and "***Same material***". These two studies had a similar geometry as the others, but they had embankment material at all the ground layers. These two studies showed how effective this innovation is. Changing the sleepers mass has almost the same 20% effect as the traditional transition zone design can have. Therefore, a very low-cost transition zone, with less complicated substructure could be deployed with some of the impacts of the simplified design being mitigated by using heavier sleepers. This could be especially appropriate for underutilised lines where very simple transition zones have already been installed. By replacing the sleepers the track degradation in these areas could be significantly reduced.

This study proved that the idea of reducing the effect of impact coming from the train in transition zones by increasing the sleepers mass is effective and more detailed studies are needed on the shape, number and sub-layers materials.

6. References

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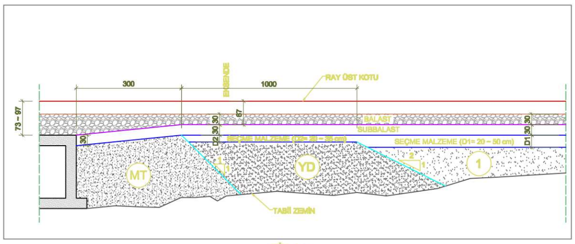
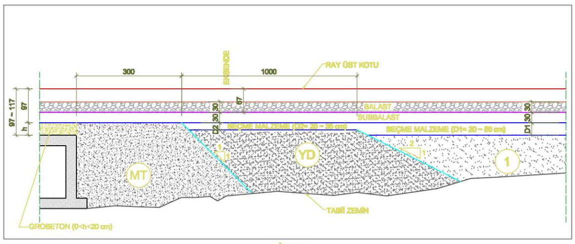
Appendix A

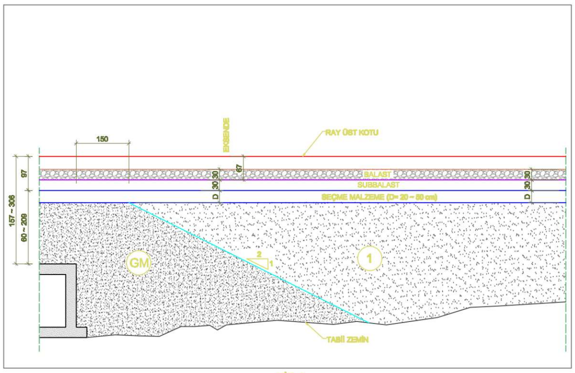
This picture shows examples of different transition zones provided by INTADER.



TİP 1-a
ÖLÇEK: 1/100



TİP 1-b
ÖLÇEK: 1/100
(TABAN KALINLIĞININ YETERLİ KALINLIKTA OLMADIĞI YERDE)



TİP 2
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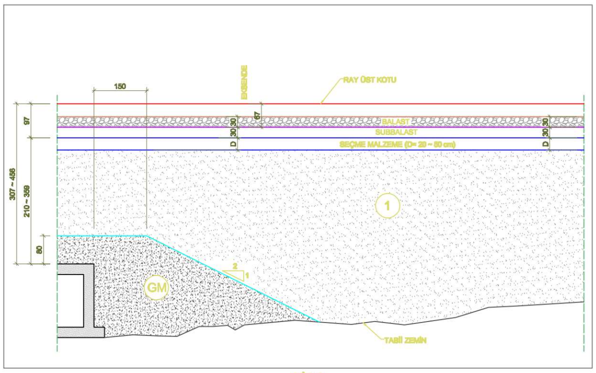

TİP 3
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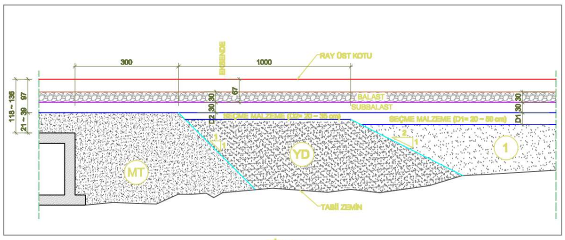

TİP 1-c
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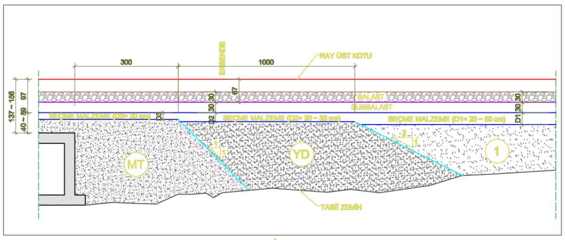

TİP 1-d
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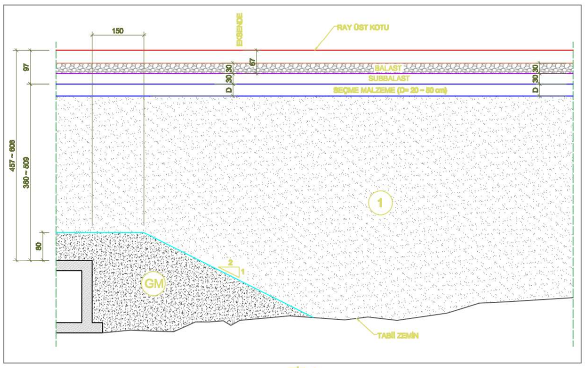

TİP 4
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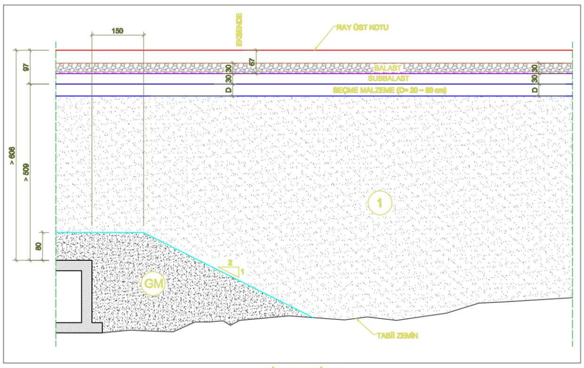
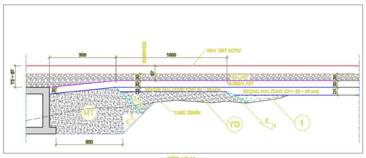
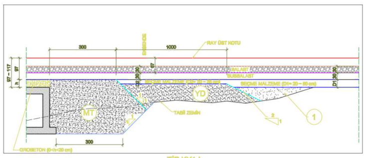


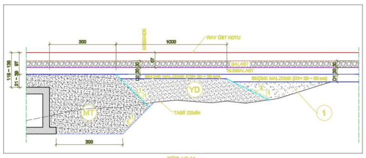
TİP 5 ve TİP 6
ÖLÇEK: 1/100



TİP KY1-a
ÖLÇEK: 1/100



TİP KY1-b
ÖLÇEK: 1/100
(TABAN KALINLIĞININ YETERLİ KALINLIKTA OLMADIĞI YERDE)



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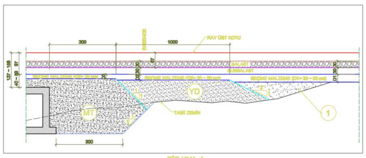

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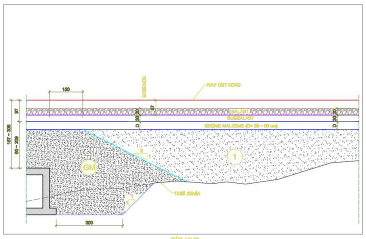
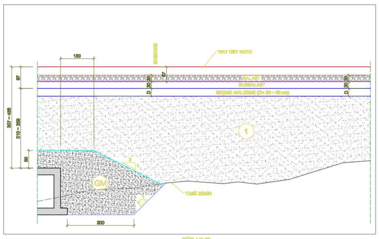


TİP KY2
ÖLÇEK: 1/100



TİP KY3
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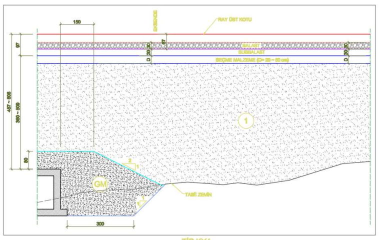
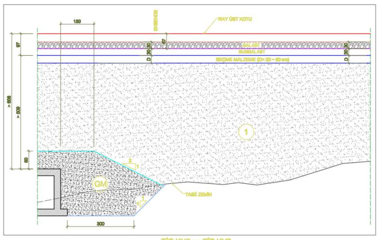
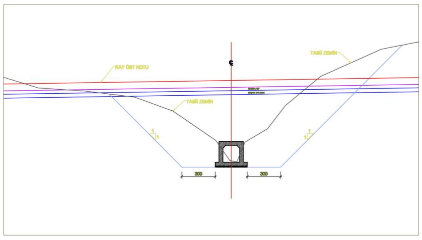


TİP KY4
ÖLÇEK: 1/100



TİP KY5 ve TİP KY6
ÖLÇEK: 1/100



TİP TY1
ÖLÇEK: 1/200

Appendix B

SZ provided good information on how transition zones are designed and maintained in Slovenia which was a part of Smart Rail project results and transition zones in Slovenia.

- Link to the web site of the project with all final reports by work packages and other documents: http://smartrail.fehrl.org/index.php?m=3&id_directory=7607
- The report for the transition zones (in English) is D3.2 with Transition Zones (chapter 4) and Case Study of the open track in Slovenia (chapter 5). The report on the life cycle costs (in English) is D4.3 with LCA tool for transition zone (chapter 3.2).

Also, they provided two more examples:

- **Tunnel Poganek and bridge across the river Sava**

The railway tunnel Poganek (123 m) is located on the electrified double-track line no. 10 between the national border (Zagreb, Croatia), Dobova, and Ljubljana. The railway line was opened in 1862.
Transition structure from the solid structure of the slab track to the elastic structure of the gravel base prevents large settlements and allows for corrections. It is made of 5.0 m long and 0.25 m thick reinforced concrete slab at each entrance of the tunnel.

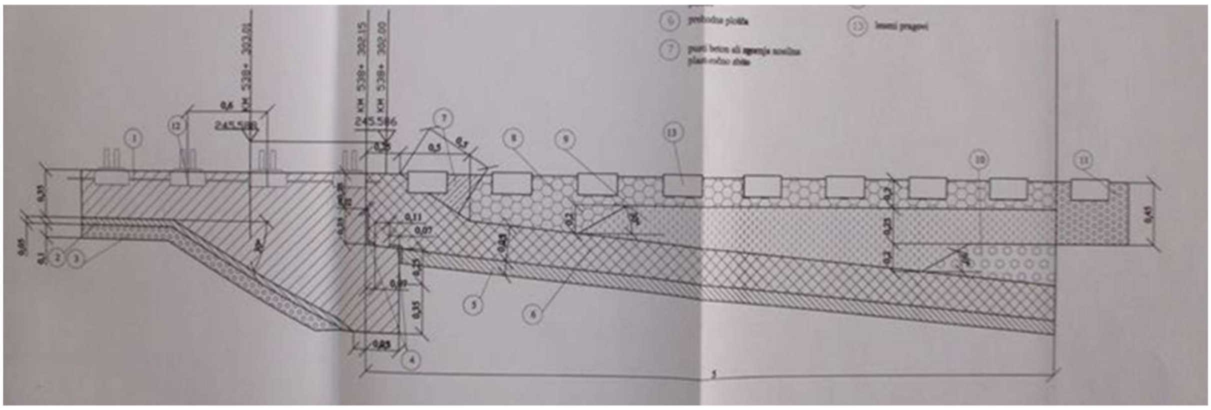


Figure 61: Transition zone from slab track in tunnel to gravel embankment

The slab track technical solution has increased the clearance profile of the tunnel and the stiffness of track has proven to be adequate. The transition zone performs its function. An added advantage is that the maintenance requirements for the tunnel have decreased.

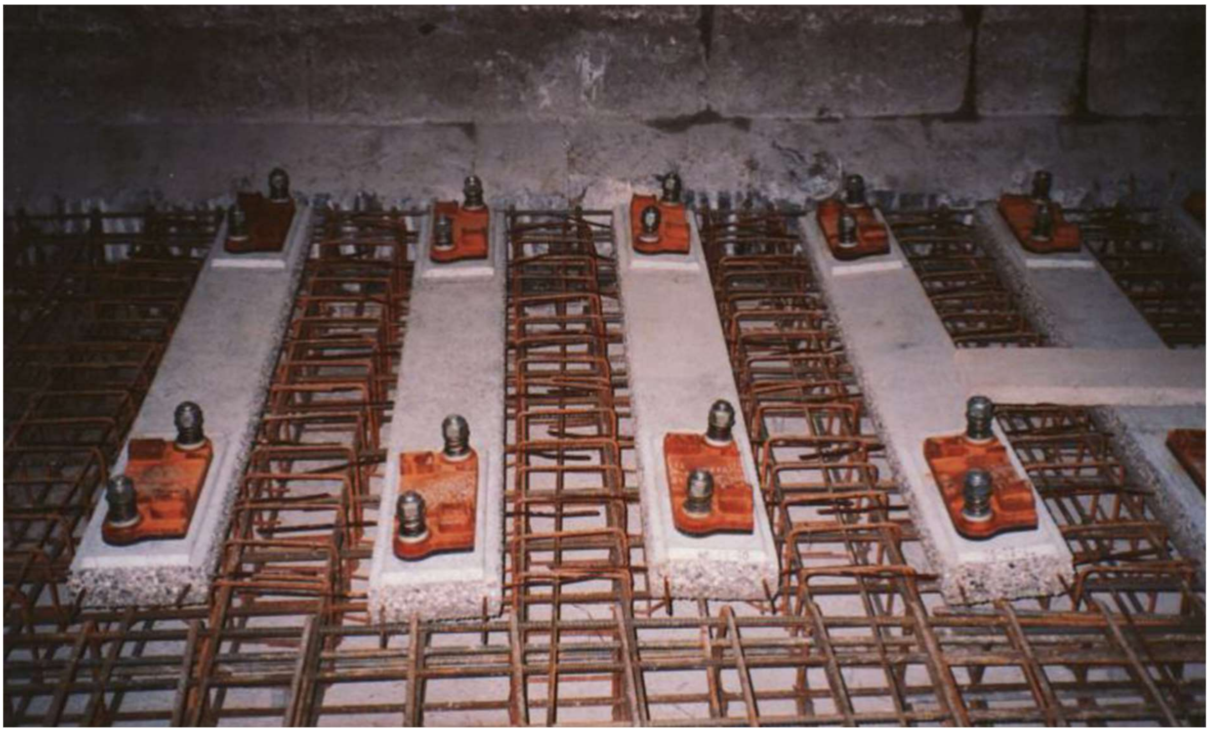


Figure 62: Installation of concrete blocks and reinforcement for concrete slab

Figure 63: Tunnel Poganek after rehabilitation

In the Poganek tunnel, after approximately 15 years problems with the fastening system occurred. Replacement of screws in concrete thresholds was carried out. The lower structure of the railway line is made in the Poganek tunnel from local material (gravel, mud, clay) with tampon layer and geosynthetics. The lower structure of the railway line to and behind the bridge over the Sava River and to and after/behind the Poganek tunnel is made of local material (gravel, mud, clay) without a buffer layer and geosynthetics.

- **Tunnels on the rail section Košana – Gornje Ležeče - Tunnels Križiški, Jurgovski in Ležeški**

The tunnels Križiški (326 m), Jurgovski (285 m) and Ležeški (360 m) are on the electrified double track line no. 50 Ljubljana - Sežana – state border (Trieste - Italy). The railway line was opened in 1848.

The transition zone from the slab track to the gravel embankment is constructed as a transition zone with additional rails, divided into 4 sections. This allows controlled decrease of the stiffness through different sections gradually decreasing from solid slab track construction to the elastic structure of gravel construction. The rail type used in the transition zone is 60 E1 (also additional rails), and the spacing between sleepers is 60 cm.

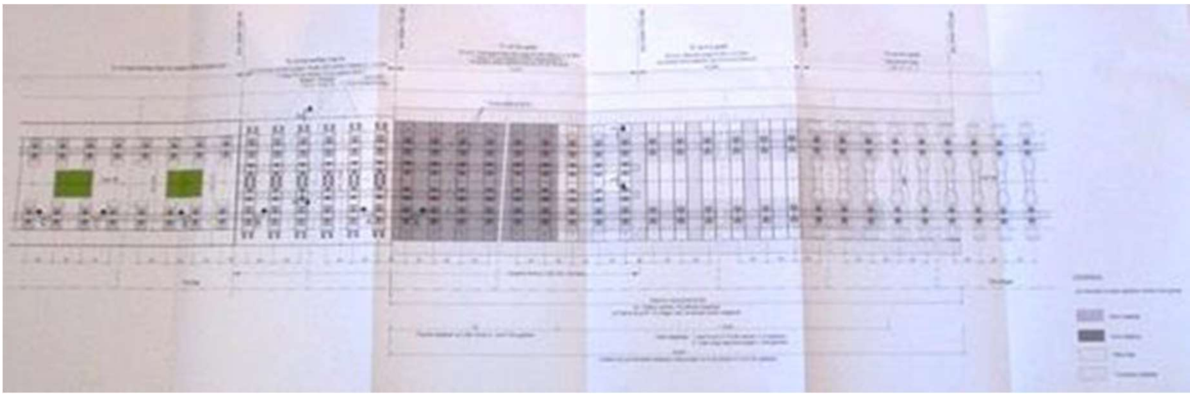


Figure 64 Transition zones layout

A description of transition zones:

1) Transition section no.1
    - Length of section L= 7.2m (in line) and 9.6 m (in curve).
    - Rails on 12 (in line) /16 (in curve) Bi-block-sleepers type RHEDA 2000 with IOARG 310 rail fastening equipment.
    - "Soft" rail fastening system (IOARV 300-1).
2) Transition section no.2
    - Length of section L= 15.0 m.
    - Rails on pre-stressed sleepers type B303 W-60ü with built-in system to fix additional parallel rails.
    - "Soft" rail fastening system (IOARV 300-1)
    - Gravel slope made of magmatic stone, fully glued on distance 7.2 m, then partially glued.
3) Transition section no.3
    - Length of section L=12.0 m.
    - Rails on pre-stressed sleepers type B303 W-60ü with built-in system to fix additional parallel rail.
    - "Hard" rail fastening system
    - Gravel slope made of magmatic stone, partially glued.
4) Transition section no.4
    - Length of section L=8.0 m.
    - Rails on concrete sleepers.
    - Gravel slope made of limestone, partially glued

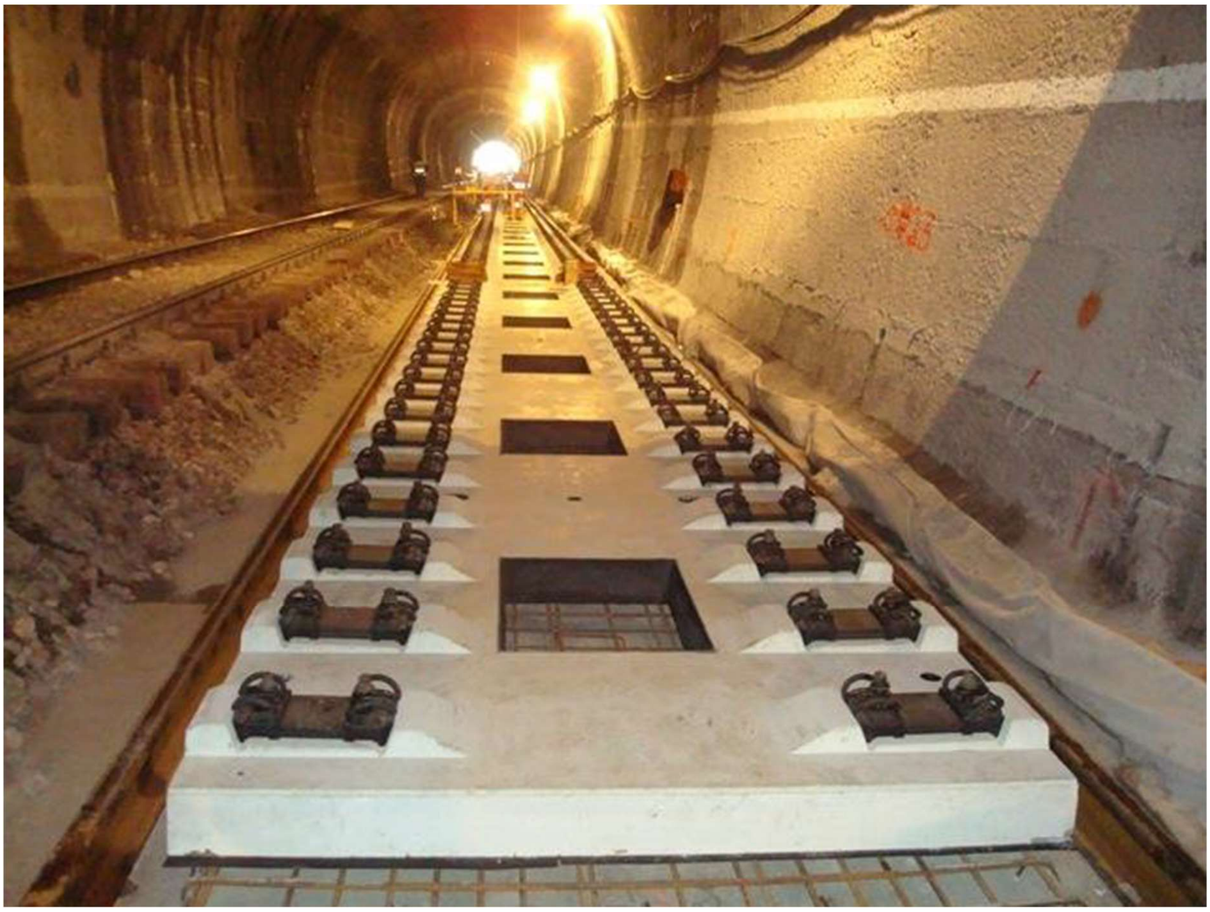


Figure 65: Construction of the slab track with OBB – PORR system

Figure 66: Transition zone – final state after rehabilitation

This technical solution, which was used for the first time on Slovenian railway network, has several advantages – reduced maintenance costs, longer lifecycle, and increased passenger comfort. While the construction cost is high, it is offset in the long term by lower maintenance costs.

In 2011, 2012 and 2013, the renovation of the two-track line no. 50 Ljubljana-Sežana-state border on the section from Košana station to the station Gornje Ležeče. There are four tunnels on this section. There were no failures and injuries on the Košana - Gornje Ležeče section. No deflection is possible because the track beam is glued. The lower structure of the railway line outside all tunnels is made of local material (gravel, mud, clay) without a buffer layer and geosynthetics.