ADJUSTABLE RAIL FASTENINGS ABATE MAINTENANCE OF TRANSITIONS

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ABSTRACT
Discontinuities in the track caused by transitions from ballast to bridges, viaducts or level crossings require extra maintenance effort in order to preserve track alignment. At these locations variation of the vertical stiffness causes amplification of the dynamic forces acting on the track, resulting in differential track settlement. Correction of the track alignment using ballast tamping in this case is not effective because of the memory effect of ballast. Such a method is also hardly sustainable because it accelerates the deterioration process of the ballast bed.

To create a structural solution for this problem, Movares in collaboration with BAM Rail, developed an alternative method to correct the track alignment. In this method, the compacted ballast bed is not affected by tamping, but only the rail is lifted relative to the sleeper. With this adjustable rail fastening system, the track can be corrected up to 29 mm in height before tamping is required. If it is ultimately necessary to correct the track alignment by tamping after many years, resetting the fasteners will create sufficient space under the sleepers to effectively tamp the track.

This solution has been applied at numerous locations in heavy and light rail track in the Netherlands, Belgium and Germany and has proven to be effective. It has become evident that the correction of settlements this way yields prolonged track alignment.

1. INTRODUCTION

Ballasted track has proven to be an inexpensive and easy to maintain track construction. Current systems with concrete sleepers and ballast stones that are sufficiently hard and angular, constitute a good track foundation. The horizontal and vertical position of the track can be properly maintained with modern tamping machines. If the track is sufficiently stable and settlements are evenly distributed, smooth track alignment can be maintained. In this situation, passenger comfort is high and dynamic loads of both passenger and freight trains are limited.

It is a different situation when discontinuities in the track construction arise, for example at transitions from ballast to bridges and viaducts or level crossings. In these cases a lot of effort is required to preserve the alignment. This also applies to places where the rail is interrupted by Insulated Rail Joints or expansion joints. In all of these cases, the discontinuity causes dynamic loads on the sleepers and creates uneven settlement. This in turn, leads to accelerated deterioration and damage to the track structure. Extra wear occurs on all components: ballast bed, sleepers, rail fastening and rails. Even the track body and foundation are loaded more heavily as a consequence.

Maintenance at these locations is expensive. For instance, in the Netherlands, maintenance activities at transition zones are performed up to 4-8 times more often compared to free tracks (Wang, H). Transition zones in the other European countries and the US also require additional maintenance.

According to a US survey, approximately half of all railway bridges are affected by this phenomenon of differential settlement (Nicks, J.E.). In 2005 the AAR (Association of American Railroads) estimated the total annual cost for track transition maintenance to be $200 million. In 1999 ERRI has estimated more than $110 million for transition maintenance in Europe (Hyslip, J).

The above shows that a relatively small part of the track takes up a large part of the maintenance budget and requires additional deployment of equipment and personnel. This has negative consequences for track availability, life cycle costs and costs associated with speed reductions that railroads must place on trains at these locations.

2. UNDERSTANDING THE ISSUES AT TRANSITION ZONES

Extensive research has been executed on settlement behavior of track transitions in the last decades. The biggest problem associated with transition from ballast to non-ballasted track and vice versa, is arguably not the transition in track stiffness or damping, but the differential settlement. This leads to voiding of sleepers that adjoin the non-ballasted area. Recently a study on this subject has been published by Haoyu Wang in the context of his PhD study. More on this will follow in the next paragraphs.

The settlement phenomenon becomes clear from figure 1 below (Selig, E.) which represents the settlement in time after ballast tamping. Most of the settlement that leads to voids under the sleepers originate from ballast behavior. The contribution from the ballast layer will be even higher for track that has been in service for a longer period of time.

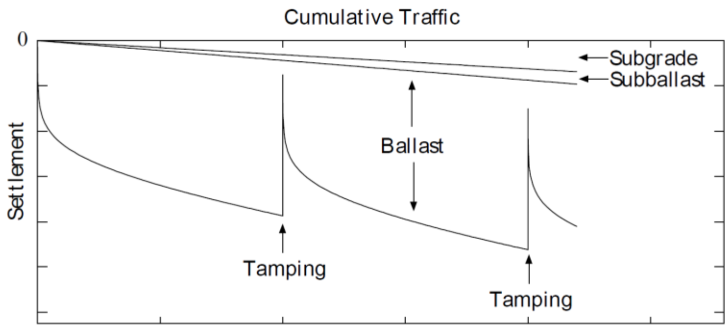

Figure 1. Settlement of ballast track in time (Source: Selig & Waters)

The University of Dresden issued a study on the settling behavior of track ballast (Gerber & Fengler). This combined theoretical and practical research shows that the ballast suffers from 'memory effect'. After tamping, the track tends to quickly return to its former, settled position under the influence of the train load. This research exactly represents the ballast behavior in the figure 1.

According to the research of TU Dresden, settlement of ballast after temping has two phases (figure 2). Stage 1 is the rapid settlement process (up to 10 mm in a few months!), caused by the volumetric compaction and abrasion of ballast particles. Stage 2 is the long time settlement process caused by the frictional wear caused by sliding of the particles. During tamping the opposite of phase 1 happens: ballast stones are pushed into a more bulky upright position. Because it provokes rapid settlement, tamping is not so effective, especially not at transitions.

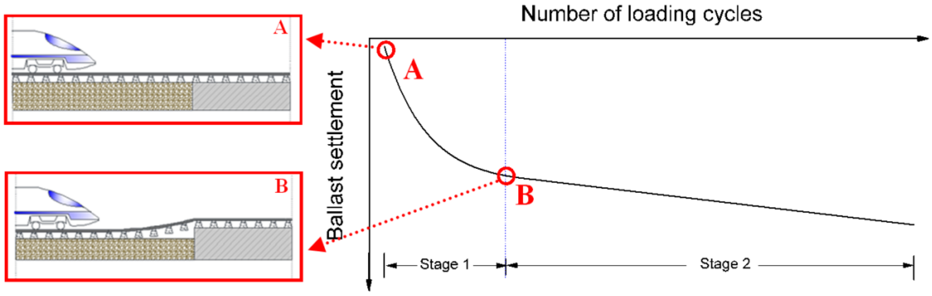

Figure 2. Settlement of ballast as a function of load cycles (at free ballast tracks).

The problem with transitions is differential settlement and associated voiding. This is because the rigid, non-ballasted structure barely settles. This explains why tamping at transitions has only short term effect. Because the lifting height is limited, the effect of tamping may disappear after just nine weeks (McNaughton, A.). It is not only the short term effect, at every tamping session the ballast more or less deteriorates. Through stirring, the stones become less angular and the ballast gets contaminated, making it less stable and causing it to lose its draining function. Tamping ballast at transitions should therefore be kept to a minimum.

3. PREVIOUS SOLUTIONS FURTHER ASSESSED

Because of the above, alternative solution have been tried. Stone blowing is a track aligning method at which little stones are blown into the voids under the sleepers. McNaughton and Abrashitov c.s. have found that stone blowing has a longer lasting effect compared to ballast tamping. This can be understood by the fact that fine granules under the sleepers, results in less memory effect.
Though the method has been propagated as a promising solution, stone blowing more or less contaminates the ballast at the transition zone too. Because of this it contributes to the deterioration of ballast, especially in transition zones where drainage is crucial.

Quite another solution – also using ‘fine granules’ – comes from the researchers of the Railway Technical Research Institute of Japan Railways. They have tested the Automatically Irregularity Correcting Sleeper "AICS". This sleeper automatically corrects track irregularity through ‘readjustment’ by little steel balls inside the sleeper (Takay, H). This special sleeper is said to be functional for situations like Rail Joints and Transitions from ballasted to fixed track. Disadvantage of this solution is that sleepers have to be replaced, making it a more expensive method. Though it clearly improves a transition, it does not completely take away the vertical movement of the rails. Some 3 mm residual voiding remains.

Both alternatives have in common that the track level only can be lifted – not lowered – as it is the case with tamping. In the next paragraph a new solution will be discussed that enables lifting and lowering of rails.

4. A NEW APPROACH: ADJUSTABLE RAIL FASTENING ON SLEEPERS

To create a structural solution to address the problem above, Movares in collaboration with BAM Rail, developed an alternative method to correct the track alignment. In this method, the compacted ballast bed is not agitated, but the rail is placed in a higher position relative to the sleeper. With the developed ShimLift® rail fastener which is adjustable in height, the track can be corrected up to 30 mm in height while in all cases a robust fixation is guaranteed.
This solution, produced by Kampa BV, has been applied at numerous locations in the track of ProRail (Dutch infrastructure manager), Infrabel (Belgium) and Deutsche Bahn since 2012. It has also been applied in tram and metro tracks of HTM (the Hague) and GVB (Amsterdam). It has become evident that the correction of settlements in this way at level crossings, but also at settled Insulated Rail Joints yields a prolonged track alignment.

The ShimLift fastening uses plastic wedges (shims) that can be slid under the rail. To restore the prolapsed track, one only needs to loosen the fixation nuts and adjust the shims up to the required level. For this purpose five different thicknesses of shims up to 29 mm are available.
Because the sleeper sinks under its own load, the voids under the sleepers are eliminated. For a perfect track alignment and a long lasting effect, the rails are lifted with a jack during adjustment. The installation and adjustment of ShimLift is illustrated on https://player.vimeo.com/video/156403856

Figure 3. ShimLift® rail fastening type S, for sleepers without rail base plate

This innovation makes maintenance of local settlements easier and effective. It causes fewer track occupation than with the use of a tamping machine. Furthermore, applying ShimLift has a positive effect on the alignment of the track and the life of the ballast bed. This makes track maintenance of transitions manageable in terms of money and effort spent. ShimLift is available for different types of sleepers, such as flat concrete sleepers, wooden sleepers or concrete sleepers with various types of rail fastening.

5. SHIMLIFT PROJECTS

5.1 Existing Track Transitions

Below pictures show height adjustable fastenings used on transitions in light rail track for metro and tram. After a successful first project on transitions to a viaduct in Zoetermeer, HTM and GVB also decided that ShimLift should be applied at locations where track alignment at transitions is difficult.

Figure 4. ShimLift® type S, on HTM concrete sleepers designed for Vossloh rail fastening

The first heavy rail application of ShimLift was located on a level crossing in Gilze-Rijen, where it has been applied to sleepers at the transitions before and after the crossing. The experience here was so positive that it was soon decided to carry out a second pilot in a transition zone near the bridge at Ravenstein which, just like the above-mentioned level crossing, was fitted with embedded rails. Transitions to structures with this type of direct rail fastening are particularly difficult to maintain. Embedded rails cannot be raised, which makes proper track tamping of the transition zone even more of a challenge.

The bridge near Ravenstein between Nijmegen and Den Bosch, is part of a single track section in a line with high track load. After the sleepers were provided with ShimLift fasteners and adjusted to the correct level, the settlement problem appeared to be solved for a longer period of time. Only after two years little voiding was seen, which was remedied easily by correcting the height of the fastening.

Figure 5. First pilots using ShimLift with base plates at transition zones. Left: level crossing at Gilze-Rijen, right: transition to the Ravenstein bridge.

5.2 New Track Transitions

After pilots proved that height adjustable rail fastenings had a positive effect on maintenance of track alignment, ProRail decided to also apply ShimLift at new lines. One of the first projects involved was the rail extension between Utrecht and Houten, where the transition zones of two new bridges have been equipped with ShimLift rail fastenings on 10 sleepers before and after the structure.

Figure 6. ShimLift® with base plates on transition to the new bridges in the rail extension between Utrecht and Houten. (The first baseplate on the picture left is part of the direct rail fixation on the bridge.)

During track construction, all ShimLift fastenings were mounted in the lowest (zero) position. A week after the new tracks had been employed, it has been tamped only once, including the transition zones. After the tracks had been in service for seven weeks, the transitions were corrected for the first time by shimming. Corrections up to 10 mm were performed. Thirteen weeks later this task was performed again, adjusting the rails up to another 4 mm (Bos, J). In the next two years, no further maintenance of the transitions was needed. Only after this period of time a small height correction have been made.

5.3 Certified Rail Fastening saves costs and material use

After the projects listed, ProRail decided to further test and release the product. Prior to the pilots, a thorough mechanical testing of ShimLift already had been conducted by Delft University of Technology. Additionally, in Utrecht DEKRA Rail conducted all required tests, according to NEN EN 13146 and NEN EN 13481. Meanwhile ShimLift adjustable rail fastening has been released by ProRail for application at transitions zones and Insulated Rail Joints.

Until today the certified concept has proven successful at more than 200 transition zones. By applying height adjustable fastenings on transitions and Insulated Rail Joints, the frequency of track tamping has reduced drastically. The reduced use of tamping machines diminishes energy use and emission of CO_2 but the most profit is achieved through reduced track deterioration rate.

Since maintenance of transitions has become manageable, implementing ballastless structures becomes more attractive. The major environmental benefits thereof in bridges, overpasses and underpasses is in reducing the construction depth. Moreover, the structure can be made lighter because the weight of the ballasted track does not have to be carried and extraction and transport of ballast is eliminated. The result is a substantial saving of raw materials and CO_2 emissions.

Because the track does not settle as much as it does after tamping, dynamic load of the track transition reduces drastically, as it will become clear in the next chapter.

6. FEM-CALCULATION OF THE EFFECT OF VOIDING AT TRANSITION ZONES

6.1 Stresses in ballast under a sleeper close to the bridge

In 2018, the effect of the adjustable fasteners on the dynamic behavior of transition zones has been analyzed by TU-Delft, using the finite element model below (Wang, H). The calculations are made for a situation with maximum voiding of 8 mm, which is quite often experienced at transitions. The results show that the adjustable fasteners effectively reduce the stresses in ballast and other track components in the transition zones.

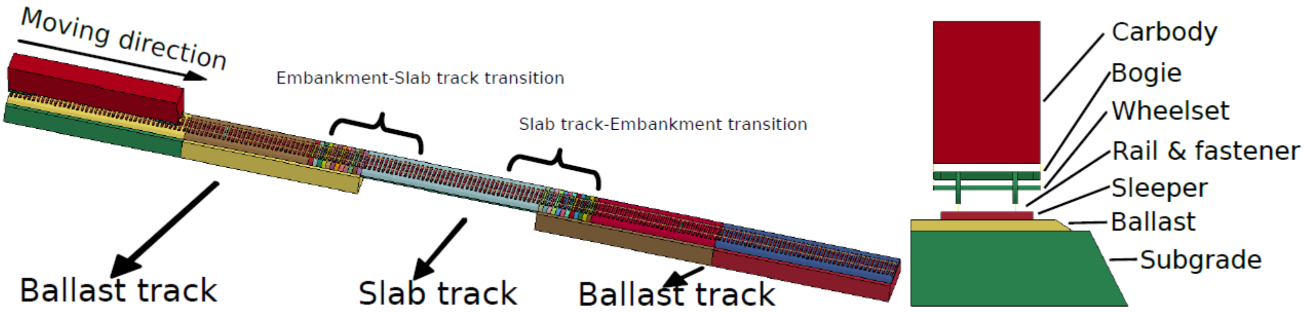

Figure 7. FE model of track transition zones: Overview and Cross section.

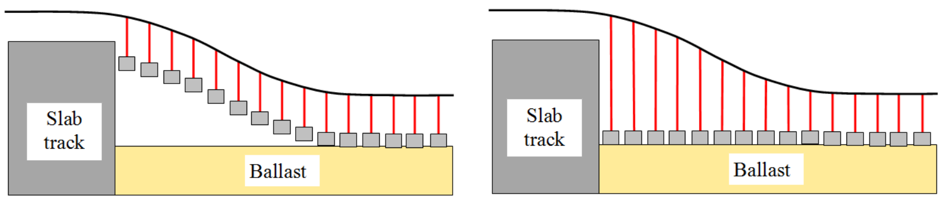

Figure 8. Schematic representation of the model (Left): Reference, (Right) With adjustable fasteners.
(the fasteners are indicated by the red lines)

The average and maximal stresses calculated for the ballast elements in each group along the track are shown in figure 9. The negative and positive numbers refer to the (ten) sleepers before and after the bridge, taking into account the driving direction of the train.

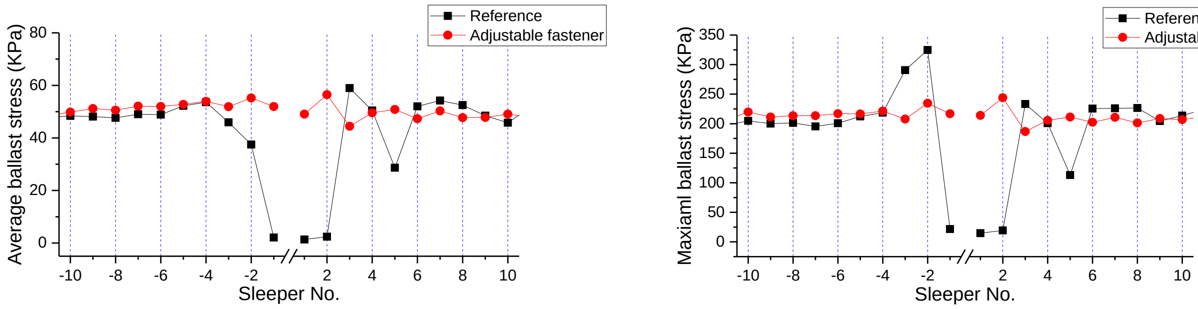

Figure 9. Ballast stresses along the track: Left: Average; Right: Maximum

It can be seen in figure 9 that adjustable fasteners more evenly distribute the ballast stresses along the track. In the reference case, the ballast stress closer to the bridge is lower than at locations at a larger distance. This is because of the bending stiffness of rails, preventing the sleepers from making full contact to the ballast. The stresses in the rails will be higher at this point, as will be discussed later.

Due to the poor support condition, the maximum ballast stress under sleeper no. -2 in figure 9 is high. It reaches a value of 325 kPa, which is approximately 60% higher compared to the stress in an evenly supported location further away from the bridge. The two dimensional stress distribution in ballast under this sleeper is shown in figure 10 for the two cases. The reduction of ballast stress can be clearly seen from the figure, where the maximal stress in ballast is reduced from 325 kPa to 235 kPa. Since the ballast stress is proportional to the settlement rate of ballast, the amplified stress may lead to a permanent settlement in ballast, which indicates that the settlement (track degradation) in the transition zone will increase continuously if no adjustable fasteners are applied.

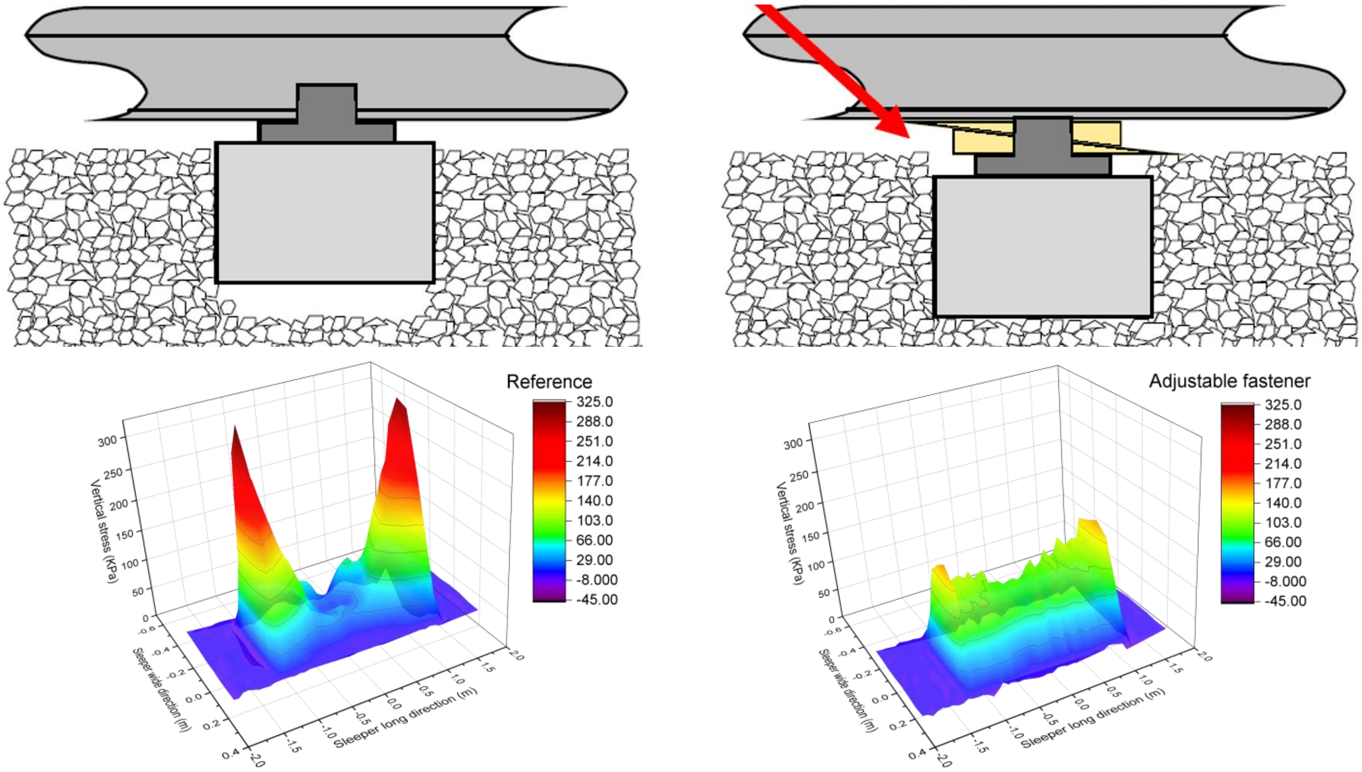

Figure 10. Stress distribution in ballast under sleeper no. -2; (L): Reference case, (R) Using ShimLift

6.2 Rail stress close to the bridge

The maximum bending stress in rails (with and without adjustable fastener) is shown in figure 11 for both cases. The rails are simulated by beam elements with a length of 75 mm (eight elements in a sleeper space). As expected, the results indicate that the bending stresses in the rails near the approach of the bridge are very high. Application of adjustable fasteners reduces the rail stress significantly: from more than 275 MPa to a value below 100 MPa. This indicates that adjustable fasteners has also positive influence on rail stress.

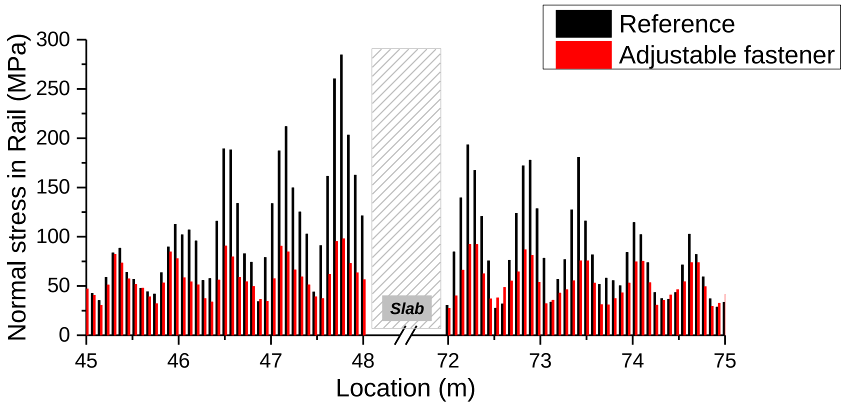

Figure 11. Bending stresses in rails in the reference case and the adjustable fastener case.

To conclude, the adjustable fasteners are effective to reduce the amplification of the wheel forces, to achieve a better ballast stress distribution under the hanging sleepers, and to decrease the bending stresses in rails in transition zones.

6.3 Parametric calculations

Since the differential settlement in transition zones may vary, different grades have been modelled. Three values of the differential settlement have been simulated: 4mm, 8mm (reference case) and 12mm. The vertical force of the first wheel (having a static load of 100 kN) for these cases has been compared in figure 12 (Wang, H).

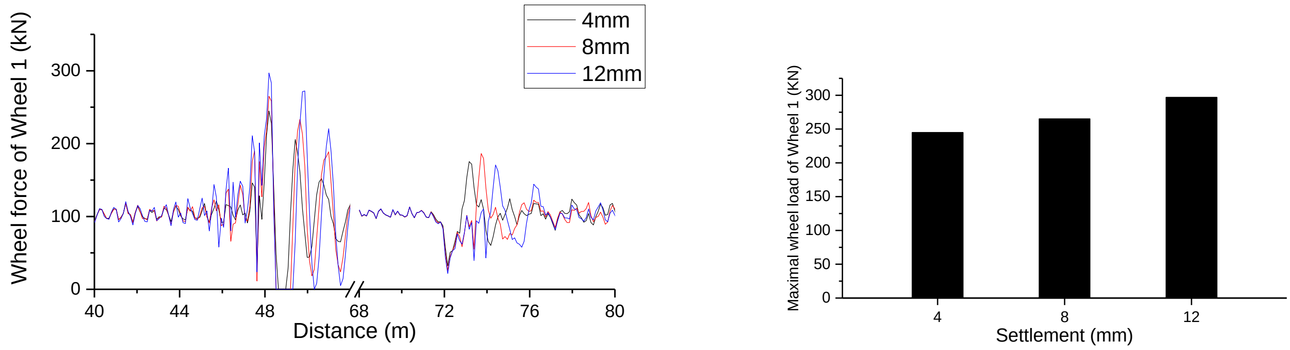

Figure12. Wheel force of the first train axle in three cases: Left: Time history; Right: Maximum.

As it can be learned from figure12, the wheel forces increase with the differential settlement near the bridge. This indicates that the adjustable fasteners should be used in the early stage of the differential settlement initiation. Since rapid compaction (stage 1 of the settlement process in figure 2) is inevitable, adjustable fasteners can be best adjusted when the ballast is compacted, that is to say, at the end of Stage 1. Stage 1 of the settlement process ends at 0.5 MGT (Selig, E).

Assuming five vehicles in a train, four trains in an operational hour, and fifteen operational hours a day, it takes approximately twenty days to complete Stage 1 of the settlement.

Transition zones with and without adjustable fasteners have been investigated for 4 and 12 mm voids (Wang, H). The wheel forces of the first axle of the train are shown in figure 13. It shows that adjustable fasteners significantly reduce the amplification of wheel forces in both cases, which indicates the positive effect of adjustable fasteners for these situations.

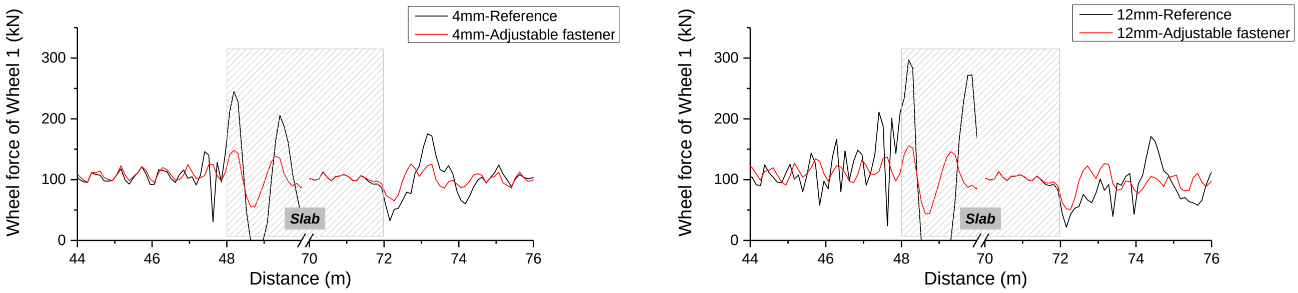

Figure 13. Wheel forces in the transition zones using adjustable fasteners. Left: 4mm differential settlement, Right: 12mm differential settlement.

The effect of the adjustable fasteners is also studied for different velocities, including 90 km/h, 144 km/h (ref.) and 198km/h. As expected, the wheel forces are considerably enhanced when the velocity increases. The comparison of the wheel forces in transition zones with and without adjustable fasteners is shown in figure14.

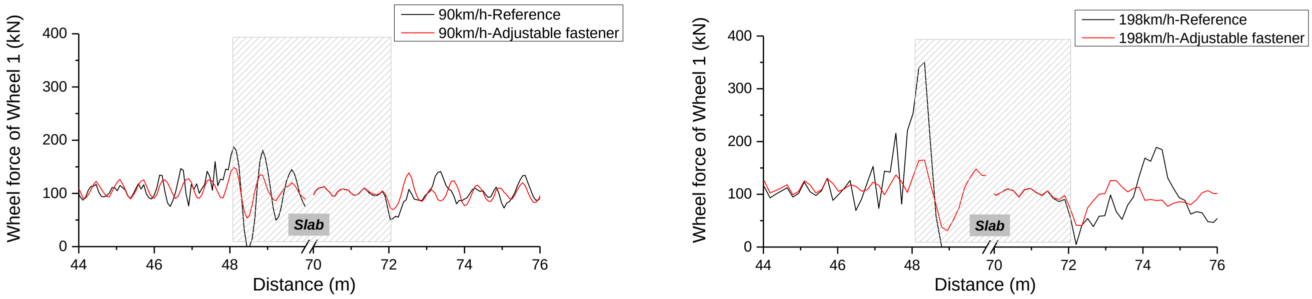

Figure 14. Wheel forces of the transition zones using adjustable fasteners: (a) 90km/h, (b) 198km/h.

The latter shows that the wheel forces are reduced in both cases. A considerable reduction can be found in the case of 198km/h train speed, which is over 50% (from 350kN to 165kN). This indicates that the adjustable fasteners work in both low- and high-velocity range but their benefits are significant in the higher velocity range.

7. CONCLUSIONS

This paper presents the experimental and numerical analysis of adjustable fastener at track transitions. Its working principle is to eliminate the gap under the hanging sleepers (also known as ‘voiding’) by leveling the height of the rail using shims in the fastening.

In the experimental study, the adjustable fasteners were installed on many transition zones to bridges and level crossings and adjusted after 2-month and 5-month operation. The experimental results show that the differential settlements in the transition zones range from 5mm to 11mm after 2-month of operation.
The differentials settlement in transitions to structures is high compared to open track. Adjustable fasteners, significantly reduce the growth of the differential settlement for these transitions.

In a numerical study executed by TU-Delft (Wang, H), the effect of the adjustable fasteners on dynamic behavior is analyzed using a Finite Element Model. The results show that adjustable fasteners are effective to reduce the amplification of wheel forces, and contribute to a better stress distribution of the train load on ballast. It also reduces the bending stress in rails at transition zones.

A parametric study shows that the applicability of adjustable fasteners is relatively wide. Since vertical wheel forces increase with the value of the differential settlement, it is recommended to adjust the fasteners as soon as the ballast track is compacted, which is the case after a few weeks of the track being in service.

The research also indicated that the ShimLift adjustable fasteners are effective in both low- and high-velocity range but the benefits are significant, especially in the higher velocity range.

Figure 15. ShimLift® adjustable fastener, including a base plate for 60E1 rail.

References:

1. Abrashitov, A., Semak, A., Experimental study of stone blowing track surfacing technique (Moscow State University, Elsevier 2017)
2. Bos, J., Evaluation of ShimLift Pilots (Movares, 2013)
3. Gerber, U., Fengler, W., Setzungsverhalten des Schotters (Dresden University of Technology, Eisenbahn Technische Rundschau, ETR 2010)
4. Hyslip, J. et al, Railway bridge transition case study (8th International BCR2A'09 Conference, 2009)
5. McMichael, P., McNaughton, A., The Stone blower - Delivering the Promise: Development, Testing and Operation of a New Track Maintenance System (TRB 2003 Annual Meeting 2003)
6. Nicks, J., The bump at the end of the railway bridge (Texas A&M University, Doctoral dissertation, 2009)
7. Selig, E., Waters, J., Track Geotechnology and Substructure Management (1994)
8. Takay, H., Research and Development on Ballasted Track in Japan (Railway Technical Research Institute 2010)
9. Wang, H., Markine, V., Corrective Countermeasure for Track Transition Zones in Railways (Delft University of Technology, Elsevier 2018)