Integrated Project (IP)
Project No. TIP5-CT-2006-031415

Thematic Priority 6:
Sustainable Development,
Global Change and Ecosystems

A novel two-layer steel-concrete trackform for low maintenance S&C

Innotrack Guideline

Deliverable D2.3.5

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1. Executive Summary

The Innotrack Sub -Project 2 WP 2.3 has included development of a new 2-layer track form, which is completely different to previous systems. The work programme of concept development, detailed track design and test track installation showed that a practical system could be implemented, with long term benefits for track stability and reduced maintenance possessions.

The basic principles of the system are:

1) Pressure on the formation is reduced by use of a stiff frame supported on a load-spreading platform.

2) The components are delivered to site pre-assembled.

3) The upper steel frame can transmit loads directly to the formation independently of the base during the period of concrete curing.

4) The frame and base can be adjusted relative to each other both at installation and if there are changes of the formation due to subsidence or severe flooding

This report gives the basis for deciding where this system may be used effectively, using a judgement on the benefits from reduced maintenance or faster installation compared with the alternatives and their costs.

Methods of installation are presented in the report, so that Infrastructure Managers have a clear view of how work can be planned for their particular possession management arrangements. Requirements for specialised equipment or technical abilities are underlined. Overall impact on project costs are discussed and placed in the context of existing methods, so that recommendations can be made where the system will or will not be worthwhile. This solution will not replace normal plain line ballasted track renewal, except for instances where operational constraints demand a rapid stable installation for enabling traffic to flow over a difficult formation area. Additionally the system is not intended as a “poor-man's” substitute for green field slab track. The greatest benefit/cost ratio arises for replacement of existing heavily used S&C, where the time of possession is critical and the ability to run immediately at full line speed of major importance at bottlenecks.

2. Introduction

The Innotrack Sub -Project 2 WP 2.3 2-layer track systems has been brought from design concept to plain line test track installation during the Innotrack project.

Previous reports covered the overall requirements for a new track structure of this type (D 2.3.1 Validation methodology and criteria for the evaluation of superstructure innovations), and the detailed design analysis for the prototype (D 2.3.2 Optimised design of steel-concrete-steel track form). All technical references for this work are contained in D2.3.2.

The basic principles of the new 2-layer track form system are illustrated in Figure 1.

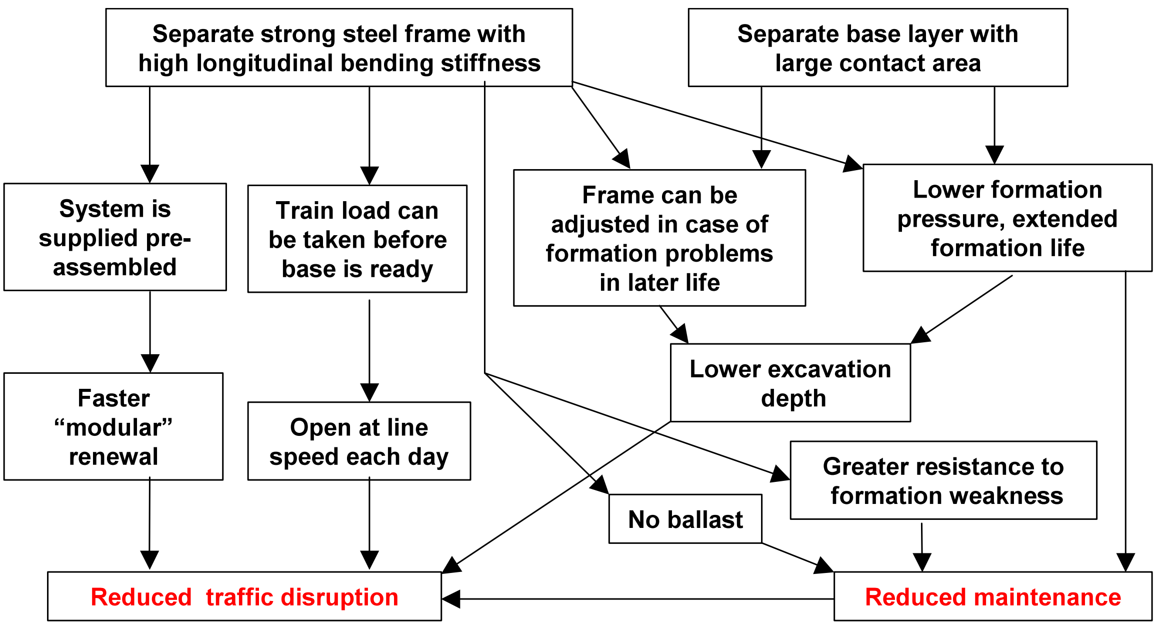


Figure 1 Concepts and benefits of a two layer steel-concrete system

The research findings have been presented in summary form so that users can see the basis of the recommendations made. The application areas are then summarised together with costs & benefits, and then the principle applications are described in detail.

3. Scope and concepts

The primary objective of INNOTRACK task 2.3.6 is to develop a consistently supported track system using steel based composite structural systems while ensuring that the installed cost of such a system is maintained as close as possible to that of conventional ballasted track.

Subsidiary objectives include: Low maintenance tracks (less activities, easier/automatic/self-inspection, diagnosis and monitoring), changes in track-structure to provide better load distributions and/or higher load carrying capabilities, cheaper materials (e.g. in new build formation), cheaper construction, shorter construction time, reduced renewal possession time and maintenance with minimal traffic interruptions

Ballasted track provides a cushioned support to the sleeper/rail system, however the displacement of the ballast that this implies is also responsible for the degradation of ballast leading to poor track quality and maintenance. Non-ballasted tracks are designed to transform the durability of the track whilst maintaining the necessary dynamic behaviour. This is achieved by the introduction of structural elements, which distribute the load onto the formation, reducing the pressure and giving a long life without the need for tamping, reballasting etc. The dynamic cushioning is achieved by placing resilient elastomer support under the baseplates carrying the rail or directly under the rail.

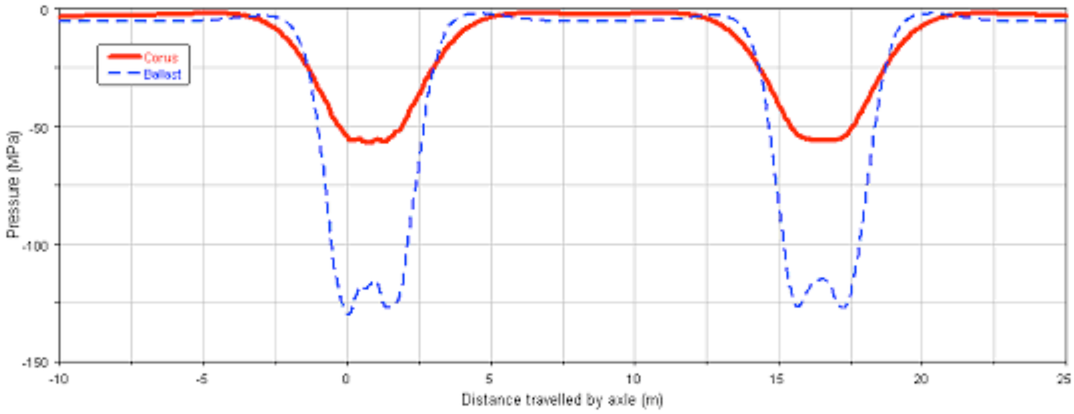


Figure 2 Pressure distribution under 25 t freight vehicles

The figure above shows the redistribution of pressure on the formation, which results from the introduction of the strong beam structure, combined with increased area of contact.

Achieving a slab-track design which can also be installed at low cost and with reduced possession time requires a step change from past slab track designs. In common with recent S&C developments, the methodology adopted is modular, i.e. pre-assembled systems are used to minimise the work on site (see figure 3).

Figure 3 Pre-assembled panel lowered onto formation

Plain Line Design

The system was initially developed by considering plain line requirements, which is also the version installed in the demonstration track.

Figure 4 below shows the principal layers of the system – The lower purple layer is the original formation, the yellow layer is new hardcore, the green layer is the concrete raft which distributes the load from the blue cross members of the steel frame. Also shown is the longitudinal specially suited heavy asymmetrical beam section, which gives the principal strength to the frame. This beam was designed for achieving low height construction. The rails are supported on resilient baseplates (not shown), which can be proprietary and/or customised to the specific application. Also shown in red are the locations of elastomer pads for load distribution

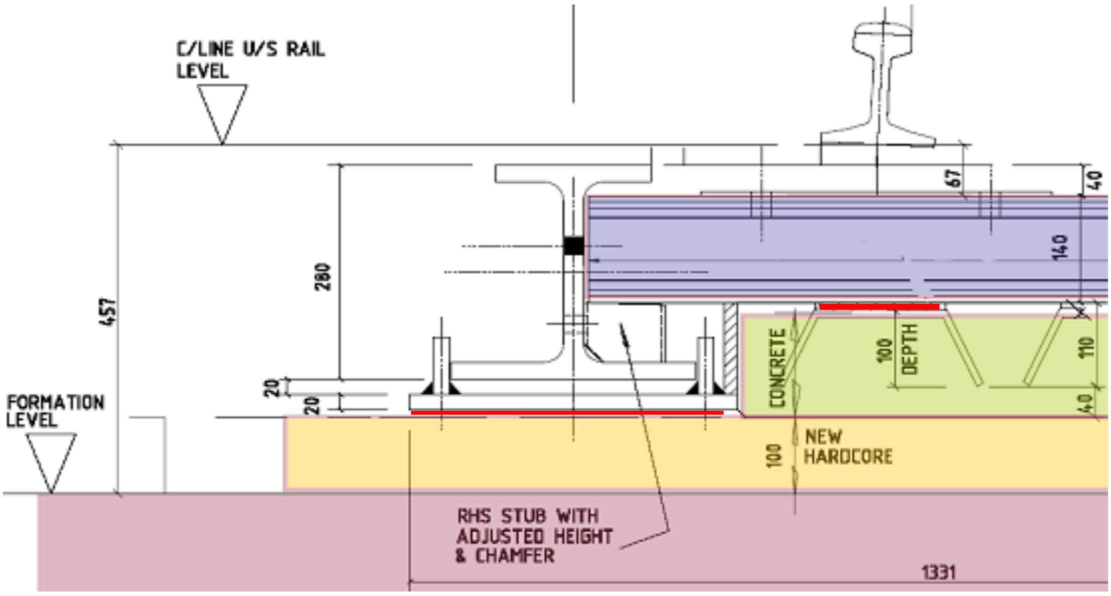


Figure 4 Illustration of the different layers of the design

4. Installation Methods

Pre-assembled panels

Methods of reducing the time of track renewal includes the use of dedicated track renewal trains for concrete sleepered track, achieving high rates of track installation. Other work has resulted in distribution of the track as plain panels, or with vehicles designed to place sleepers into position simultaneously. Installation of S&C track on bearers has focussed on providing pre-assembled panels which are transported on wagons by rail to the work-site (e.g. Network Rail/ Kirow wagons for S&C)

The Corus Two Layer Steel Track system is designed to be pre-assembled in panels (including fastenings), and transported by rail to site.

Formation

The two layer steel system is designed to be used on a formation which has a lower strength than that required for concrete slab track, and this means that the preparation of the formation is reduced -

however the main application is intended to be on existing tracks with well consolidated formation. Serious wet spots must be rectified, however lower stiffness ground is tolerated.

Principle steps in the preparation are:

Removal existing track

Excavate to approx 300mm below sleeper bottom

Compact and apply 100mm special ballast mix

Level and compact to +0/- 30 mm

Apply fines and place and align central spine of support blocks (Figure 5) or steel beam supported on jacks for rapid vertical level adjustment.

Figure 5 Central spine of support blocks. This can also be a steel beam with intermediate screw jacks. In the foreground is the concrete base for a transition.

Track Completion

The track panel is lifted into a position 50 mm above the final position on the central spine of support blocks or a steel beam and screw jacks, held at the correct cant by jacks under the longitudinal beams jacking points (an example of the layout is shown in figure 6). Intermediate screw jacks are in position and ready to take load in between the support blocks.

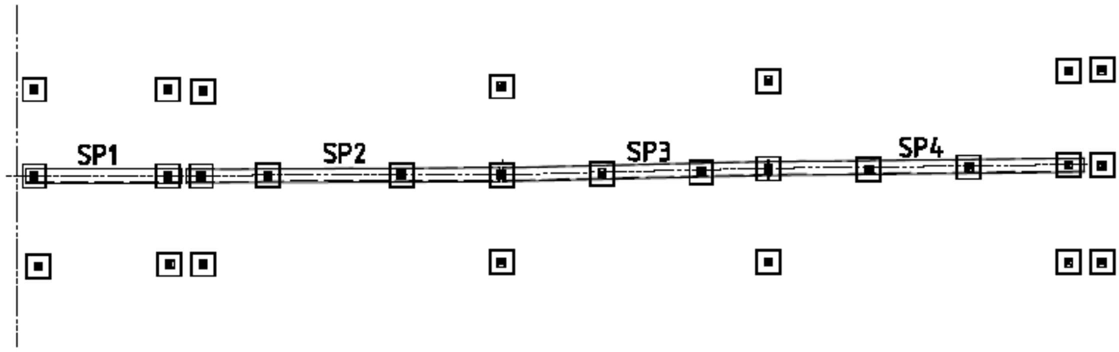


Figure 6 Configuration of spine beams and jacks for first 25 metres of a 1:8 turnout

Previously attached packs are removed or inserted in accordance with the clearance between the frame and the ground bearing plates, and then the frame is lowered into place. At this stage it is supported on the central spine and the formation packs under the longitudinal beams

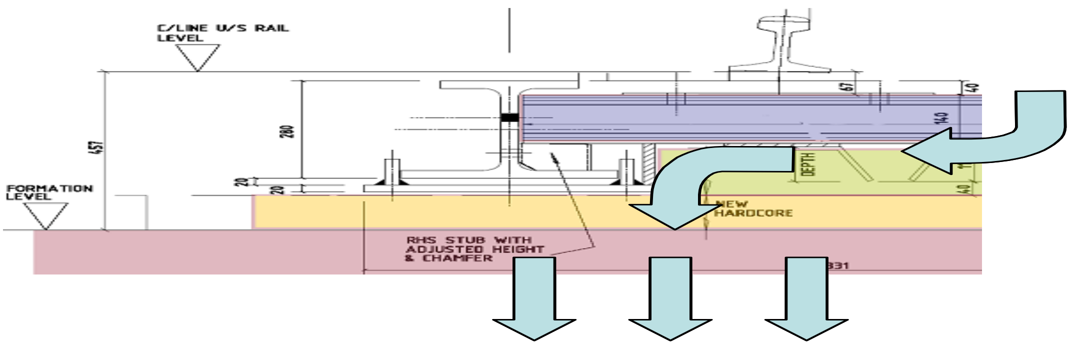


Figure 7 Load path before concrete base completed

Following the placing in position of the frame, rail (if not part of the pre-assembly) can be laid into the fastenings and welds/joints completed. For lateral stability the sides of the track are brought up to the level of the top of the frame using ballast. At this point trains can run at line speed, depending on whether neighbouring track has required re-ballast and tamp. Figure 7 shows the load path to the ASB longitudinal beam for this condition

During the same possession, or on another , concrete is poured (figure 8) to form the base layer under the frame cross-members, with a 2mm clearance. The concrete encases the load spreader longitudinal inverted 'U' section under the cross members – it does not extend under the ASB longitudinal beams.

Figure 8 Concrete pour to form base during a later possession after track has been opened to traffic.

At this point the system can also be opened up to traffic, and in a later possession the clearance between frame and base is taken up by raising the frame, inserting packs or removing shims and lowering.

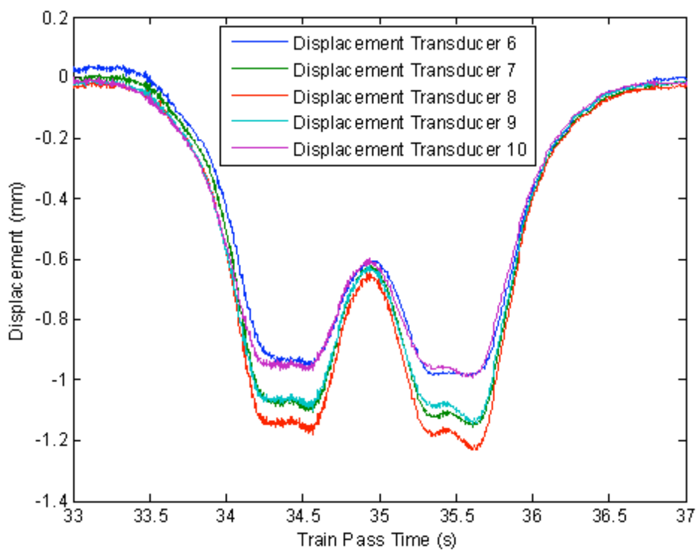


Figure 9 Time history of cross member deflections on elastomer pads showing uniformity of loading: 8- centre line, 7+9 between centre-line and rail, 6+10 under rail.

Load distribution is assisted by the presence of pre-attached elastomer pads under the cross members and longitudinal beams see Figure 9, showing the relative uniformity of vertical displacement across the track which is within +/- 0.1 mm. The appearance of the track is shown in Figure 10, before the gaps between cross members have been filled (figure 11). This is most conveniently done with ballast, however noise absorbing or thermally insulating layers may also be considered.

Figure 10 Two - layer system and components

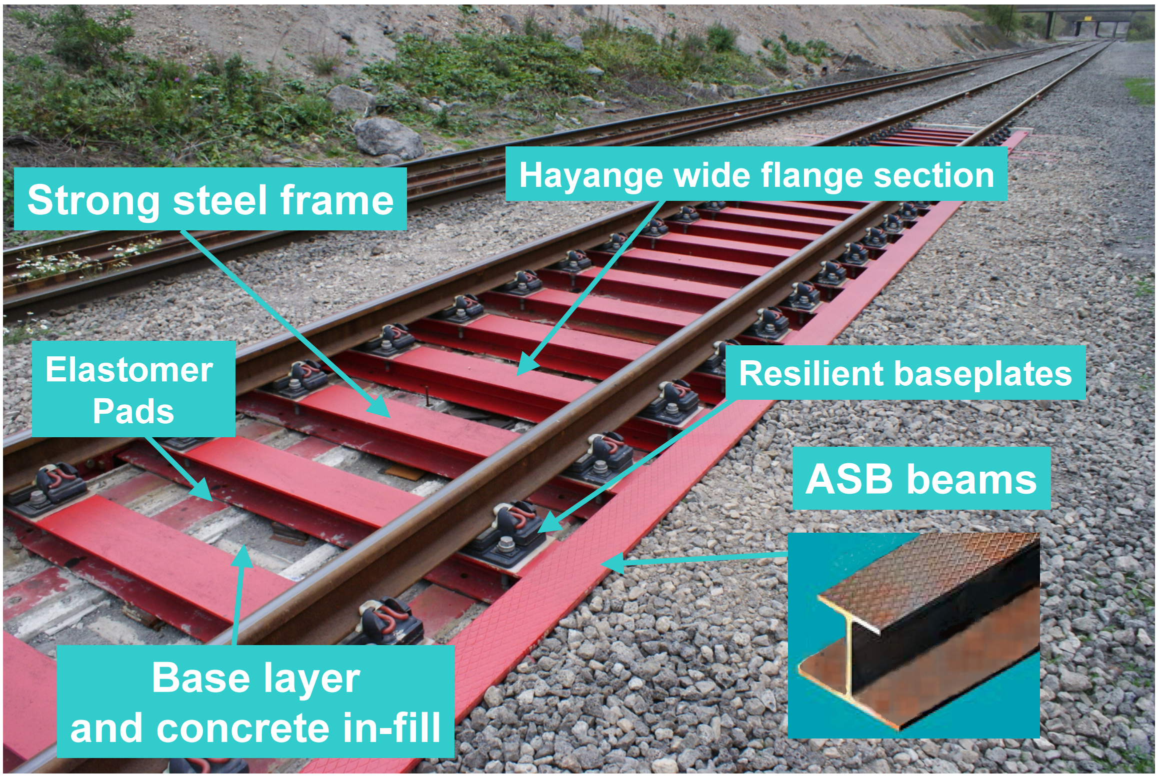


Figure 11 Two layer track system with ballast in-fill. The reflective area is a viewing window.

5. Performance

The dynamic response under various train loadings has been predicted by Manchester Metropolitan University. The aim of the modelling work was to provide quantitative information on the behaviour of the new system and to compare it with ballasted track. Load cases included the passage of a fully laden 22.5t axle load freight vehicle at a speed of 100 kph, and the passage of a typical multiple unit passenger vehicle at speeds from 40 to180 kph. A series of scenarios were tested by introducing hanging sleepers (ballasted track only) and simulating a washout (local weak support stiffness). The simulation software used is VI-Rail (MSC Adams), and further

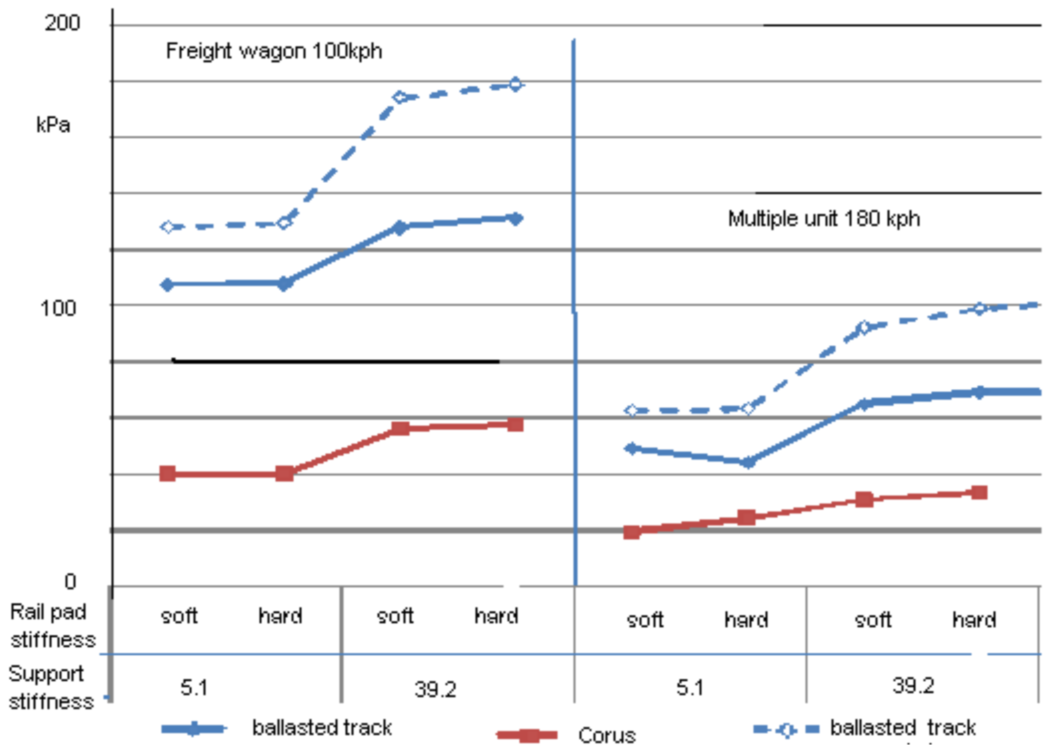


Figure 12 Ground pressure comparing ballasted and Corus track

details about the modelling are given in Annex I.

Comparing ballasted track and Corus Track in the “as built” condition, the principal differences are in the pressure distribution along the track (see main report figure 2 and figure 12 above, together with significantly lower levels of rail acceleration under high speed passenger traffic. From the point of view of rail- wheel contact force, there are no big effects for either the nominal (track without defects) condition or degraded condition. These features will be common with other forms of slab track, with the exception of continuously supported rail which may have benefits under curving conditions. As ballasted track starts to deteriorate the support conditions for the sleepers change, leading in some locations to voided (hanging) sleepers, and in some cases weakened formation over longer distances. Whilst it is acknowledged that maintenance practices are intended to remove this type of defect, they will exist for a period until detected and until resources are available for rectification. As an example, voided sleepers give rise to significant increase in rail vertical deflection, rail bending stresses, ballast pressure and rail and sleeper accelerations (reference D 4.2.6). These are responsible for further track damage in the vicinity of the voided sleeper. A slab track construction of the type analysed here would not be vulnerable to that type of degradation.

More general weakening of formation may happen as a function of drainage issues, soil type and other sources of earth movement. This study examined behaviour of track that has very low stiffness as an example. On low stiffness support the Corus system reduces the deflections of both formation and rail, and the rail stresses, by a factor of 2, with the consequence that life under weakening support will be much longer and not subject to the same degree of accelerating change (see Annex figures 2, 3 and 4).

The Corus system is intended to be built without replacement of existing formations on the basis that it can easily be adjusted if changes of formation condition, such as subsidence, occur. Normal slab track constructions do not allow anything other than re-engineered formation, sometimes to a substantial depth (and specify that the formation must be replaced if not of sufficient quality to achieve required performance). The Corus system does not change the formation, so it might be regarded as more vulnerable to natural disasters and hidden problems. For this reason the study also examined an adverse event where the track support changed radically over a significant distance (5 metres), leading to a dependence on the ability of the track to bridge the gap. This might be caused by flooding for example, where parts of the support material are washed away. In such cases the rail deflection will become large – increasing by factor of 3 or 4 and rail stresses will double, as will the level of acceleration of the rails and of the structure. The Corus slab track design was shown to limit the track level of deflection and acceleration to tolerable levels for safety (see

Annex figures 8-11). The rail stresses are virtually unchanged. To understand how long such a weakening could be tolerated is difficult, but it would evidently be safer than with normal track. Examining the ground pressure allows some extrapolation into the future – peak values at the ends of the washout only reach 70-75% of the normal under sleeper pressures, whilst for conventional track the values are very high and will very quickly lead to progressive failure of the formation and dangerous extension of the track defect, see figure 13 below.

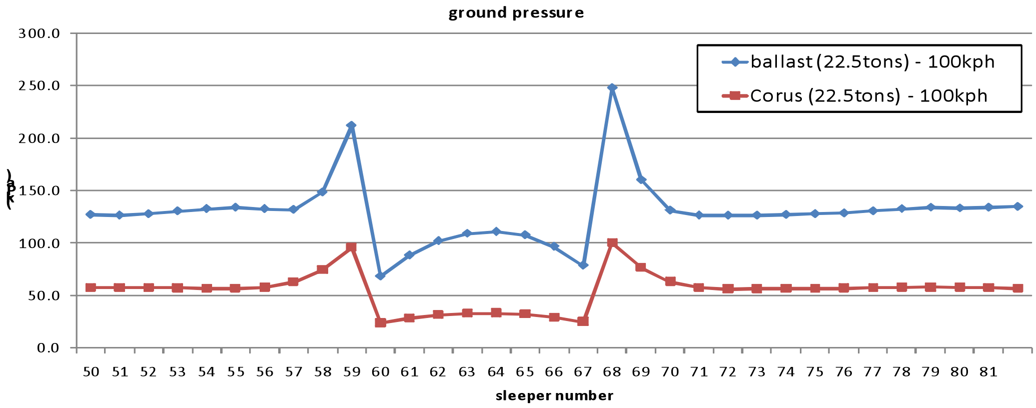


Figure 13 Ground pressure around weakened formation

6. Noise and Vibration

Predictions and measurements of noise levels, ground vibration and roughness growth were carried out by the Southampton University Institute of Sound & Vibration Research

Ground Vibration

In general for a likely baseplate stiffness of 20MN/m, the slab track designs are an improvement in terms of ground-borne vibration over a typical ballasted track at frequencies of 63Hz and above. Theoretical attenuation in the range 10- 30 dB was predicted in the frequency range 63Hz – 200 Hz, however with little effect in very soft soils. The new Corus track design has similar behaviour to more traditional concrete slab designs.

Ground vibration benefits were measured on the demonstration track installation at Scunthorpe U.K. Figure 14 shows the new track values (red) compared with ballasted track (blue) at 3 m from the track.

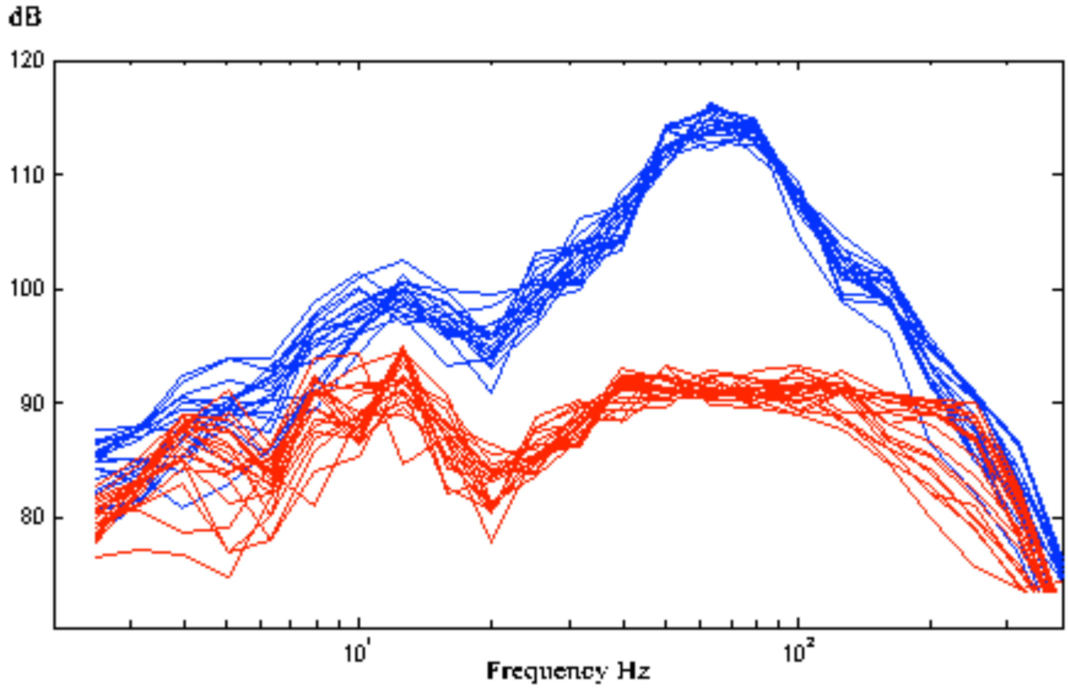


Figure 14 Ground vibration measured adjacent to the demonstration track Scunthorpe, U.K.

There is considerable reduction (10 to 25 dB) between 10 Hz and nearly 200 Hz. It is a very positive point that shock loadings can be significantly attenuated through the choice of a soft padded baseplate. This could be particularly important for reducing ground vibration near Switches and Crossings applications.

Noise

In common with other slab track designs, the system can introduce higher noise levels due to the use of softer rail supports which allow the rail to vibrate more at acoustic frequencies. An interesting aspect of the use of resilient baseplates is the fact that a heavy baseplate can also act as a tuned absorber and reduce the rail vibration. Compared to ballasted track, the predicted overall sound power levels for slab track with large baseplates are predicted to be very similar for higher vehicle speeds – at 160km/h there is no change of noise level. Slab track with heavy baseplates is predicted to be 2-3dB noisier than ballasted track at 100km/h.

In the case of the demonstration track, a heavy baseplate was not used and this results in a correspondingly higher level of rail vibration in the acoustic range, as shown by measurements of the track decay rate (damping per metre of rail).

An additional feature of the Corus track is that the gaps between cross-members are easily filled with noise absorbent material which can range from ballast to specialised materials. This means that the system is potentially quieter than a concrete slab track where noise is reflected from the hard horizontal surface – but note that these can also be covered with (less effective) noise absorbent bricks.

Additional evaluation of these factors is in progress, but it can be noted that rail absorbers will be particularly effective because of the soft support, giving potential for 6 dB reductions, more than compensating for the effects of the design, giving a net reduction compared with as ballasted track.

7. Review of applications and benefits

Balancing cost and reduced installation time in comparison with slabtrack

Based on the costs of manufacture for a one-off prototype trial, costs of the two layer track system are significantly higher than for ballasted plain line, and they are typical of reported slab track costs. Evidently these costs are not competitive for plain line, but can be for repairs to problem areas or for use in S&C form, especially when the speed of construction is considered - the guideline therefore focuses on these areas.

Components

In contrast to ballasted track, the hardware costs for the two layer track system are similar to those for the labour and plant used in installation. Thus although the system has been designed along bridge code guidelines with very low stresses for a long life, an LCC analysis for plain line would not show a benefit to recoup the cost of the materials alone.

Logistics & Installation

As is the case for the other track recovery solutions of SP2, the estimation of benefit from logistics and installation has to be based on a very specific comparison depending on the type of project being undertaken. For S&C the comparison can be made more generically - see below

Maintenance

The principal justification for this type of higher capital cost solution is the reduction of maintenance, following a circumstance where this has been particularly high. The basic premise for the two-layer system is that it can be installed with similar speed to conventional track, but with inherent advantages of reducing later possessions for maintenance.

Cost Benefit Analysis Summary.

The system has a high initial cost, but can significantly extend track life and significantly reduce subsequent maintenance costs whilst enabling a lower or similar installation time. This advantage distinguishes it from conventional slab track. The level of cost does not justify use in plain line where there are no formation problems to solve.

Recommendations

1. “Hot spots” in the network

The system is intended to be used where (a) speed of installation due to the panel based design, (b) rapid return of the track to line speed and (c) low maintenance benefits of slab track . This application is studied in the next section. The cost benefit analysis of such applications will have to include a means of identifying the operational disruption benefit.

2. Complete renewal due to life expiry of existing track

Not recommended in comparison with ballasted track.

3. Green field

Not recommended in comparison with full specification concrete slab track.

4. Improvement of poor formation/instability.

If the system is being considered in comparison with other methods of track repair to solve formation problems, the best technical solution has to be determined from the specific circumstances and problem to be tackled.

8. Switches and Crossings

A typical S&C design replicates the layered system for plain line, but with modifications to the frame to account for the rail positions and the crossing components - cast crossing, motors, levers. The system can be based on a layout of bearers similar to conventional S&C, or can be arranged to provide preferential support in critical areas, or to accommodate baseplate designs.

The use of underframe pads and resilient baseplates means that the variable stiffness presented to rail support in conventional S&C as a result of rail section changes and bearer length, can be ironed out by variable pad stifffnesses. This will reduce the amplification of forces due to transient higher frequency vertical response through the switch. The adoption of underframe pads also mean that this “tuning” can be carried out without introducing excessive rail rotation or relative movement between rail at different support points.

There are additional lateral forces present in the translation of a vehicle over Switch and Crossing elements – this has been modelled using the Manchester Metropolitan University software referred to in section 5. Figure 15 below shows an example of the effect of lateral motion on the wheel forces and reactions in the support structure for a fully laden freight vehicle negotiating a UIC60-760-1:15 turnout at 80 kph.

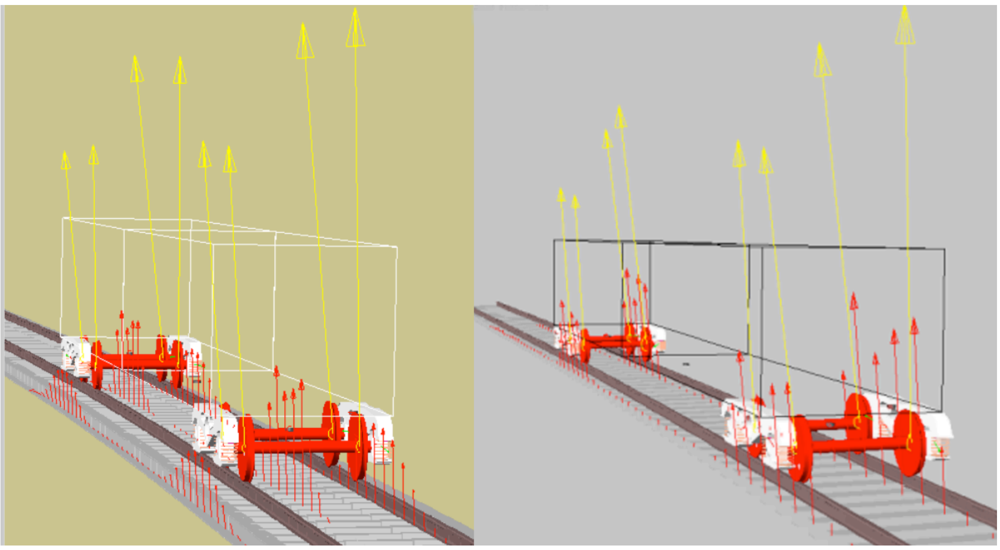


Figure 15 Force vectors from MMU model of S&C - LHS=Corus Track, RHS=Ballasted track

In both cases the percentage increase of vertical wheel force above the mean is approximately the same at approximately +20%. The track reaction vectors for the sleepered track show a typical value of 42% of wheel force per sleeper end, whilst the support force in the external beam per 0.6m in the Corus track is 20% of wheel load.

This example is for the installation phase when the cross-member is only partially supported across the span. Following transfer of load to the slab beneath the cross-members, the pressure for the above example becomes mean 68 kN/m^2 with variation +/- 14 compared with 152 +/- 30 on ballasted track. Since:

- the formation has been pre-consolidated by the cumulative passage of traffic over years,
- the historical imprint of previous sleepers will have largely been removed by the excavation of ballast /formation to 300mms
- additional transient forces are reduced by a balanced pad stiffness design through the switch
- pressure and pressure differential between sides are less than half

no further significant further deformation should be expected compared with ballasted track. In addition the ballasted track characteristic of differential settlement across a track due to lateral loading will be minimal.

A typical frame layout for a low speed 1 in 8 turnout is shown as an isometric view below in Figure 16.

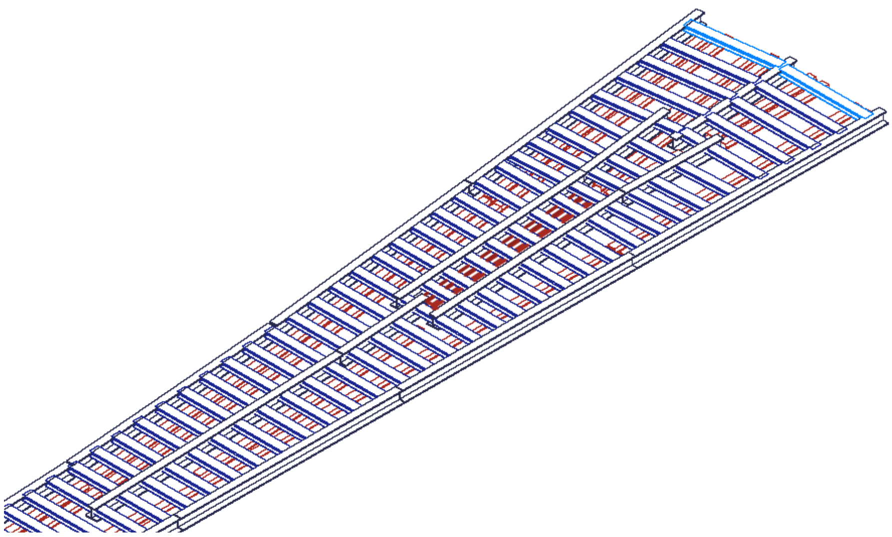


Figure 16 Isometric view of a frame supporting a low speed turnout

The jointing of the frame is a function of the transportation method. For normal possession installations, the frame is designed to be divided into segments which can be transported within the relevant structure gauge. Note that the jointing is not shown in figure 16.

Alternative jointing arrangements include an option to enable one line to be opened to traffic before the complete turnout is ready, if demanded by a very short possession time.

The rail support system for S&C requires a number of resilient base-plates for which the detailed geometry varies through the S&C as the distance between adjacent rails varies. It is recommended that proprietary systems (e.g. Delkor, Pandrol, Railtech, Vossloh) are used, however in-house systems can also be designed for specific applications.

Track excavation and formation preparation.

This is carried out to a similar depth to that needed for normal full renewal. There is no need for geotextile with the frame solution. Additional grade 1 material is applied in a 100 mm layer to provide a good bedding for concrete pour. A further layer of fines is used to help achieve more accurately flat surfaces where the packing and support blocks are located. Drainage must be re-instated. The transition from the existing neighbouring ballasted track to the frame is built into the design to match the traffic and surrounding trackbed characteristics.

Track placement and alignment

The system is placed in track as a set of frames (panels), compared with individual distribution of bearers or sleepers. The vertical levels are established by:-

(a) Dimensional checks on the assembled panel before dispatch to site. This has been designed to allow perfect dimensions regardless of steelwork tolerances.

(b) Provision of an accurately levelled support spine on the prepared formation. This requires high quality laser based surveying equipment – with back-up.

(c) Careful adjustment of the levels of the frames using jacks or screws.

To illustrate this a comparison Gantt chart has been compiled, shown in figure 17.

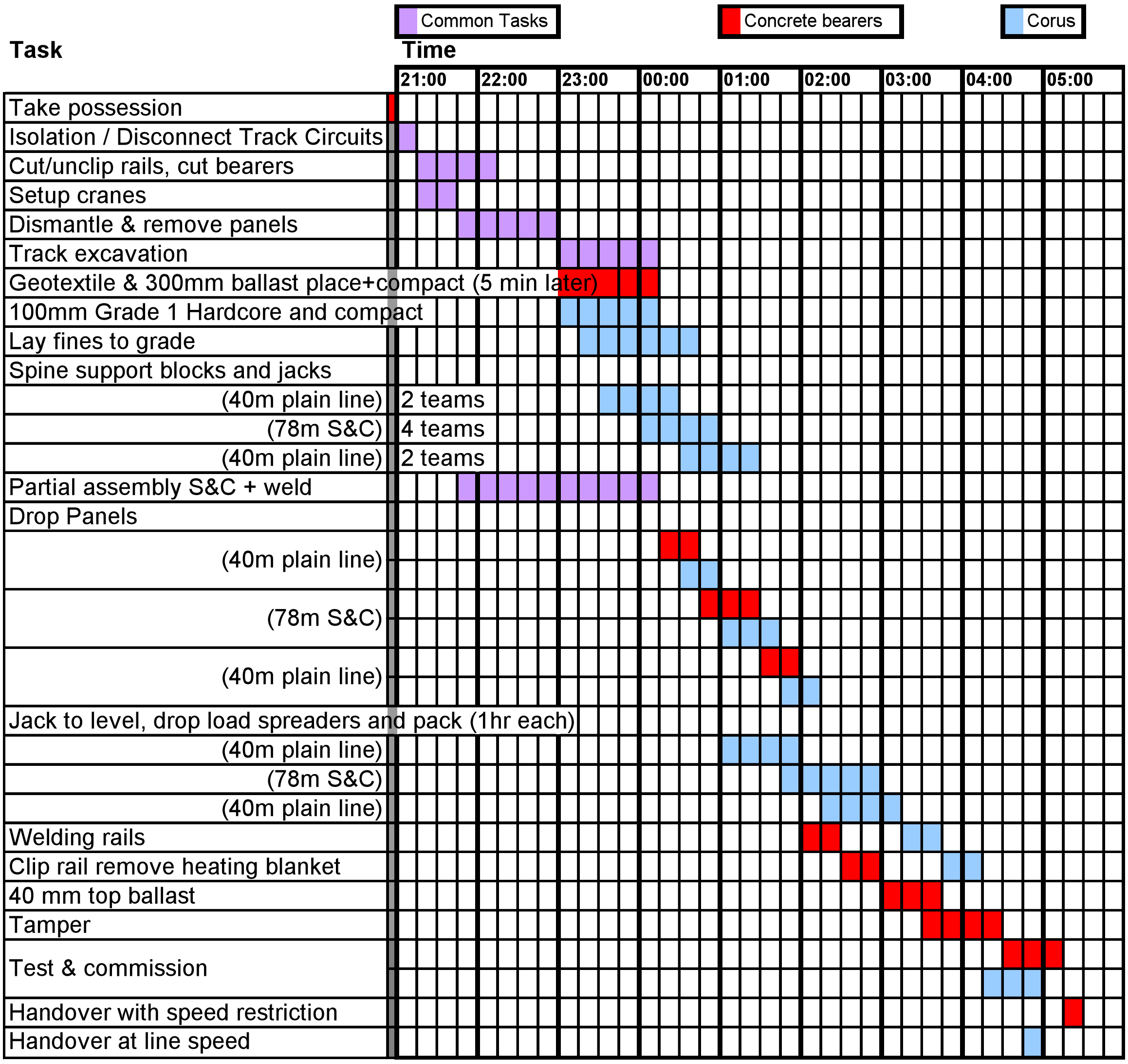


Figure 17 Gantt chart for panel based S&C renewal large radius crossover (first night only)

This underlying renewal process for the comparison is based around the use of "modular" pre-assembled "panels" of concrete bearers, a method being adopted in several European countries, but not universally available. It requires the use of some dedicated equipment, in particular for rapid ballast distribution and compacting, geotextile laying etc. However it is useful for making a like for like comparison, as the panels - groups of concrete bearers - are exchanged for steel frames, with some other operations remaining the same.

Please note that the timings in the Gantt charts present the desired best practice level. For more conventional installations extending over several possessions or a 2-3 day blockade, the duration of tasks will extend, for example where dedicated formation preparation and material distribution kit is not available. Tasks which have to be heavily mechanised such as those associated with placing and aligning the panels will remain similar, but can be adjusted to suit logistics planning and desired manning levels.

After partial completion the system permits a return to line speed next day, compared with awaiting track compaction under traffic. The effect of this on the complete renewal is shown in the summary gantt in figure 12 below, in which a night possession has a duration of 8 hours.

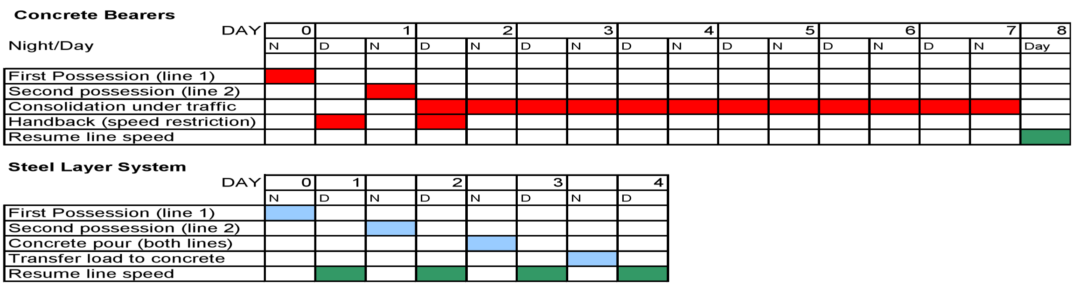


Figure 18 Summary of overall installation

9. Conclusions

1. The two-layer steel concrete track system incorporates a separable steel frame with high longitudinal bending stiffness, designed to be strong enough to carry track loads independently, as well as easily jacked and adjusted if necessary. The frame is augmented by a separate reinforced base layer to distribute the loads over a greater area.

2. The performance of the system has been modelled and tested to verify the mechanical response, and in particular to illustrate the reduction in formation pressure and dynamic forces, which will lead to an extended formation life

3. The system has a relatively neutral or slightly negative effect on noise levels, which can be counteracted by design, but in common

with other slab track designs, there is a large benefit for ground vibration

4. The design has focussed on installation; in particular the ability to be supplied pre-assembled and laid on a track after minimal excavation, as well as avoiding delays due to concreting, in distinction to normal slab track The different steps of the process have been described, including defining the method for achieving compatibility with modular S&C installation.

5. This system uses a design which requires a greater investment in hardware to achieve the benefits, so that the cost benefit will depend on the value of reducing traffic disruption, therefore it is more likely to be applied to traffic hotspots where maintenance is a continual problem.

6. It is estimated that the cost of using the proposed more permanent trackform for S&C would typically result in increased materials costs of approximately 10-15% of the whole project cost, based on average data across a wide range of projects. It is stressed that individual applications have to be assessed against a wide range of local parameters. These will include for example track duty, speed, vehicle type & loading, cost of unavailability, S&C type and design, number of tracks, access.

7. In addition to the benefits of slab track in terms of reduced maintenance costs, the total costs would be offset by logistics advantages through converting from traditional to panel based methods, and reduced train delays from the possibility of hand back at full line speed, particularly for highly trafficked layouts.

Annex I Vehicle Track Interaction

Partner: Manchester Metropolitan University

A1.1.Vehicle models

Two vehicle multibody system (MBS) models were used; one is a two bogie freight wagon in laden condition and the other is a typical multiple unit passenger vehicle in part laden condition. The freight wagon was simulated at a maximum speed of 100km/h and the multiple unit passenger vehicle was simulated at various speeds of 40, 60, 90, 120 and 180km/h. The models were built and simulated using the software VI-Rail (MSC Adams).

Vehicle	Freight wagon	Multiple Unit (MU)
Bogie wheelbase	1.8m (Y25 series bogies)	2.6m
Bogie spacing	15.7m	15.4m
Axle load	22.5t	11.6t
Primary suspension	6.13MN/m per wheel	800kN/m per wheel
Primary yaw angle stiffness	1.4MN/m/rad with 4mm axle box clearance, then metallic stiffness 120MN/m/rad	24MN/m/rad per axle

Table 1: Vehicle parameters

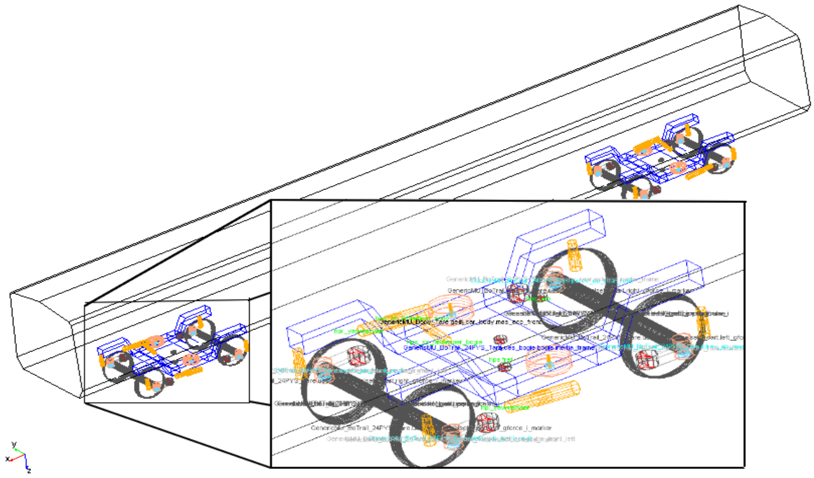


Figure 1: Multiple Unit MBS vehicle model

A1.2 Track models

	Ballasted track	Corus track
Pad stiffness soft	75MN/m (rail pad)	20MN/m (main line: baseplate pad)
Pad stiffness hard	150MN/m	70MN/m (S&C applications: baseplate pad)
Pad damping	30% of critical [0.3 x 2.SQRT(k.m)], k being the stiffness and m the mass of the rail per sleeper spacing.	
Ballast/soil stiffness	5,40,100 kN/mm per sleeper end	Equivalent values: ≈ 18, 135 and 207kN/mm per track section
Ballast / soil damping	60% critical	
Sleeper spacing	0.65 m	0.6 m

Table 2: Track parameters

A1.3 Load Cases

Several cases were simulated:

Case 1, A: Normal Track

Both vehicle models were simulated at various speeds on ballasted track and on Corus slab track. The track properties are homogeneous. This operational case shows the track response under ideal track conditions.

Case 1, B: Hanging sleeper

Hanging sleepers are simulated by means of variable stiffness spring-force deflection characteristics of the sleeper to ground force element. This includes zero stiffness for negative displacement to simulate the uplift, and a linear stiffness and damping characteristic for positive displacement (sleeper sinking into the ballast). The gap underneath the sleeper is set to 7mm , as representative of a poor conditions requiring maintenance.

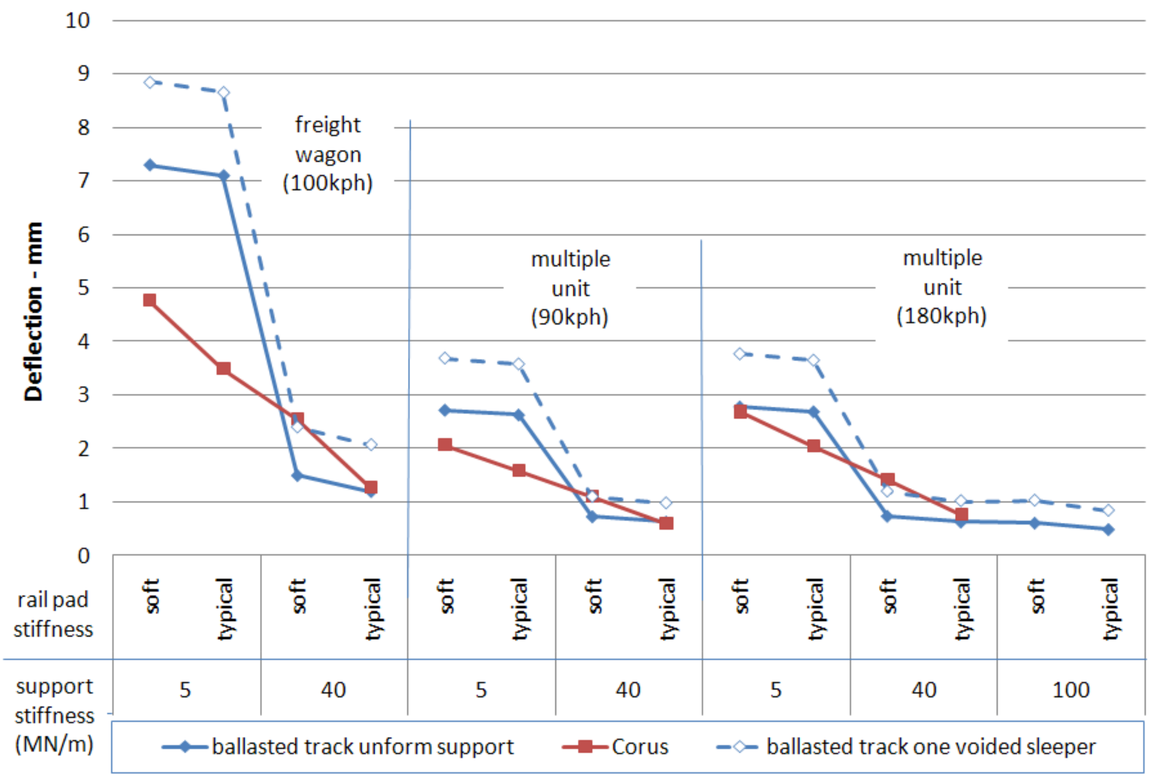
Case 2: Washout or weak spot

Weak spots are simulated by assigning a lower support stiffness value between the sleeper or superstructure and the ground at specific sleepers or track sections along the track over a distance of approximately 5 metres (≈ 7 sleepers spacing). Stiffness values are going from 40 down to 5 and back to 40kN/mm per sleeper end. This simulation aims at representing the track behaviour in the presence of a washout for example.

A1.4 Results for normal track / voided sleeper

A1.4 (a) Track deflection

Figure 2 and 3 show the rail deflection and the superstructure deflection respectively. Figure 2 illustrates that, for traffic types and conditions that lead to excessive deflections, then the steel – concrete track is much less sensitive, exhibiting less than half the relative change of ballasted track (x2 instead of x6) when support stiffness is reduced by a factor of ~8. If ballasted track contains a voided sleeper then the differentials – and related transient effects, will increase further. Note that the absolute values for the steel concrete track are a function of the stiffness of the soft baseplate system modelled – the particular value used here might be used to reduce ground vibration or to match a track with lower stiffness than the reference track, to



avoid transition effects.

Figure 2: Maximum rail deflection

Figure 3 highlights the fact that, as would be expected, a voided sleeper on ballasted track suffers much more significant movement which will affect the continuing degradation of the track. Note that the two - layer steel track, despite having in this example a much softer resilient baseplate rail support, restricts the movement to be the same as the conventionally supported ballasted sleeper track. This has benefits for the forces and accelerations. The principle result in figure 6 is that under freight loading the deflections are significantly lower for the steel- concrete track.

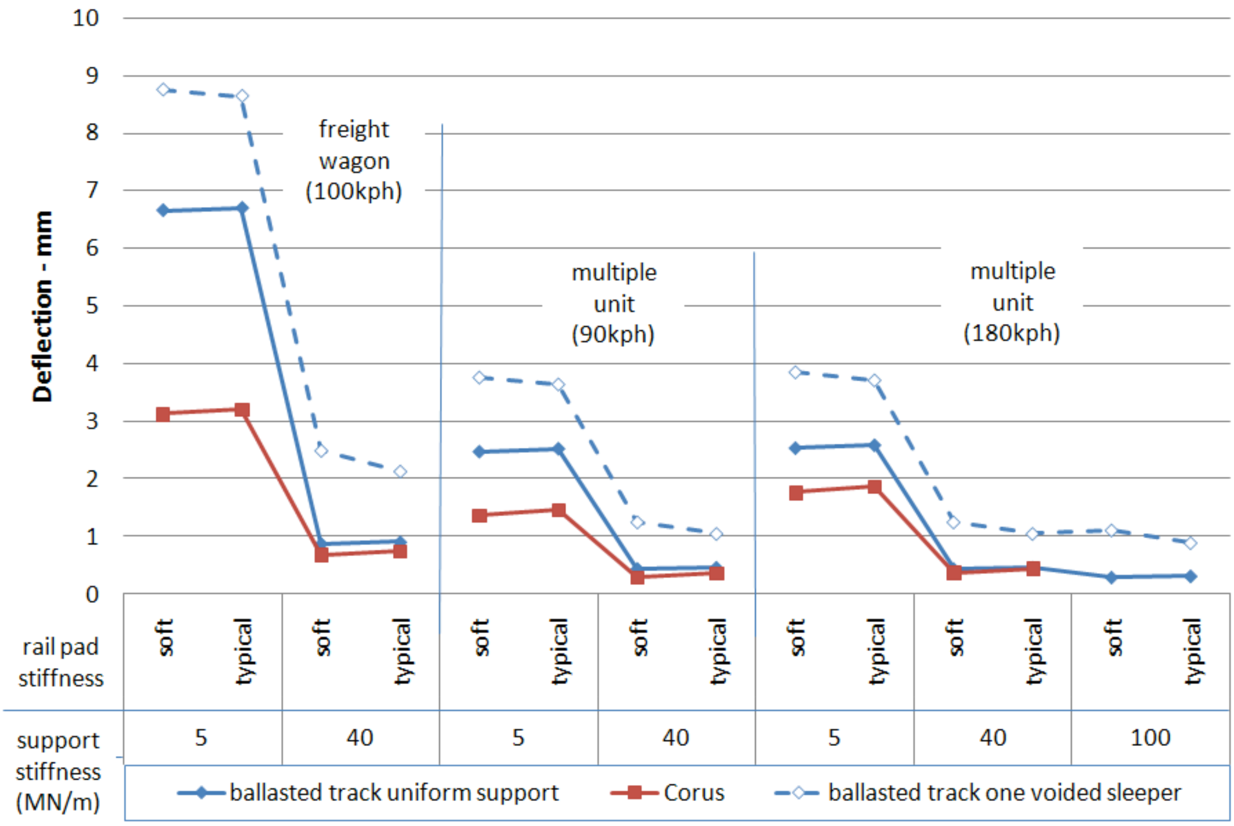


Figure 3: Maximum sleeper or structure deflection

A1.4 (b) Rail bending stresses

Figure 4 shows the amplitude in rail bending stresses in the rail foot on ballasted track (homogeneous and with one voided sleeper) and on the Corus track..

Main conclusions are:

> For the passenger vehicle (right hand side of graph), the stresses are very similar on both types of track and for all support stiffness condition. The stresses slowly reduce as the support stiffness increases, and the presence of the voided sleeper slightly increase the bending stress in the rail around the voided sleeper.
>
> For the case of the heavy freight axle load (left hand side of graph) however, a major difference is observed between the ballasted track and the Corus slab track on very soft soils. The Corus slab track prevents the rail bending stresses from

increasing (almost doubling in the case of the ballasted track) when the support stiffness is poor.

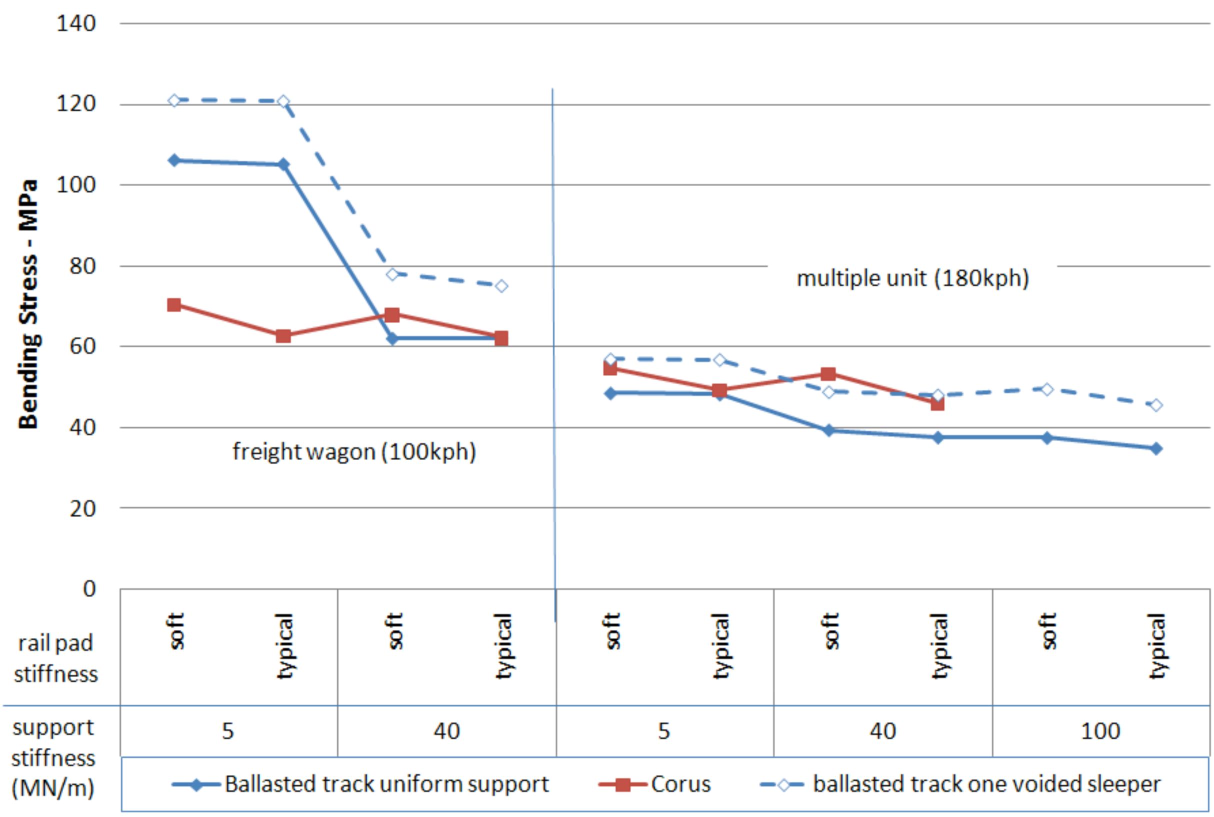


Figure 4: Rail foot bending stress amplitude for homogeneous ballasted track (—◆—), voided ballasted track (- -◇ - -) and Corus track (—■—)

A1.4 (c) Ground pressure

Figure 5 shows the ground pressure worked out as the force in the maximally loaded element of the track and the area of support – continuous in the case of the Corus track and over the sleeper width for ballasted track. As an approximation the effects of sleeper bending are not shown - measurements on the Corus system indicate that there is no significant variation. The main conclusions are:

The presence of a voided sleeper on ballasted track leads to a significant increase of the normal pressure at the sleepers around the voided one, especially on hard soils for heavy axle loads.

The Corus construction significantly reduces the maximum pressure on the supporting ground, especially for the case of stiff soils and high axles loads .

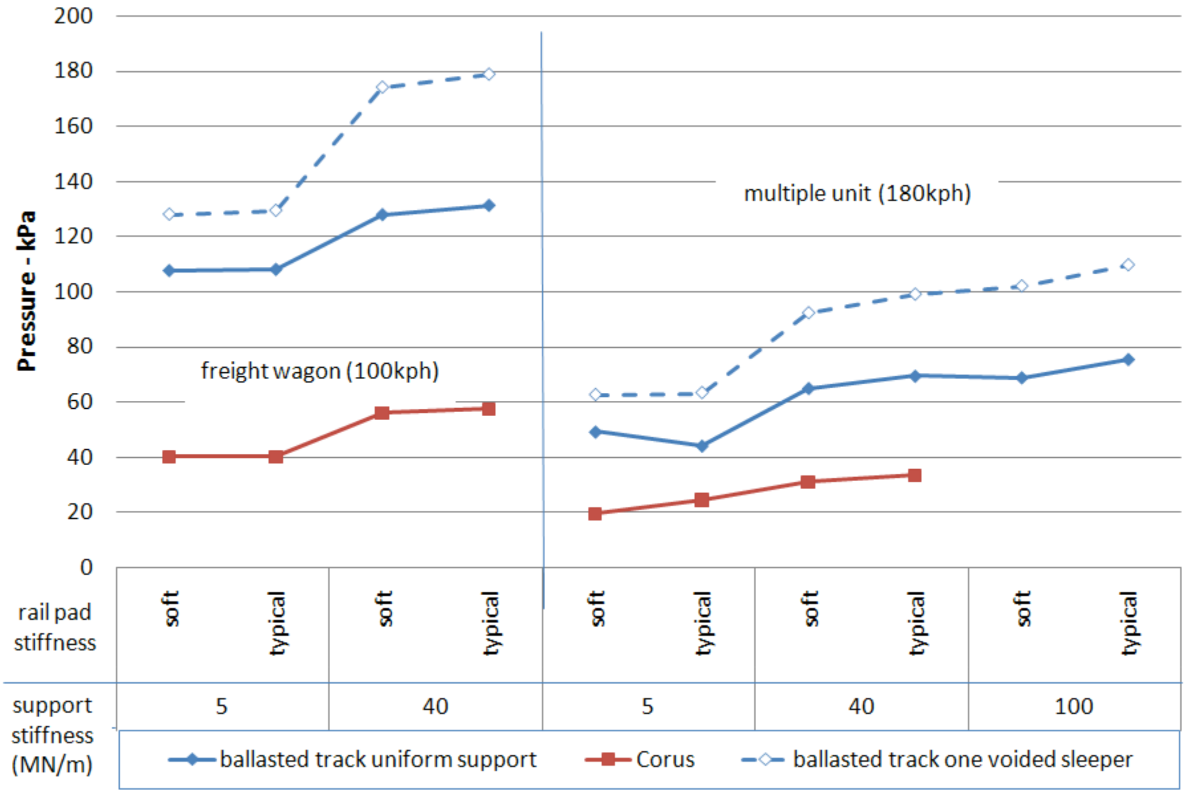


Figure 5: Ground pressure for homogeneous ballasted track (—◆—), voided ballasted track (- - ◇ - -) and Corus track (—■—)

A1.4 (d) Vertical track acceleration

Figure 6 and 7 shows the acceleration of the rail above the fastening and of the sleeper/superstructure beneath the fastening comparing the case of the ballasted track (homogenous and hanging sleeper condition) and of the Corus track, respectively. The presence of hanging sleepers leads to an important increase in acceleration both of the rail and the sleepers, more particularly in the case of heavy axle loads on soft soil (1.4g at the rail on soft soil and soft pad), and in the case of harder soils and vehicle running at higher speeds (1.45g at the rail on hard soil and soft pads).

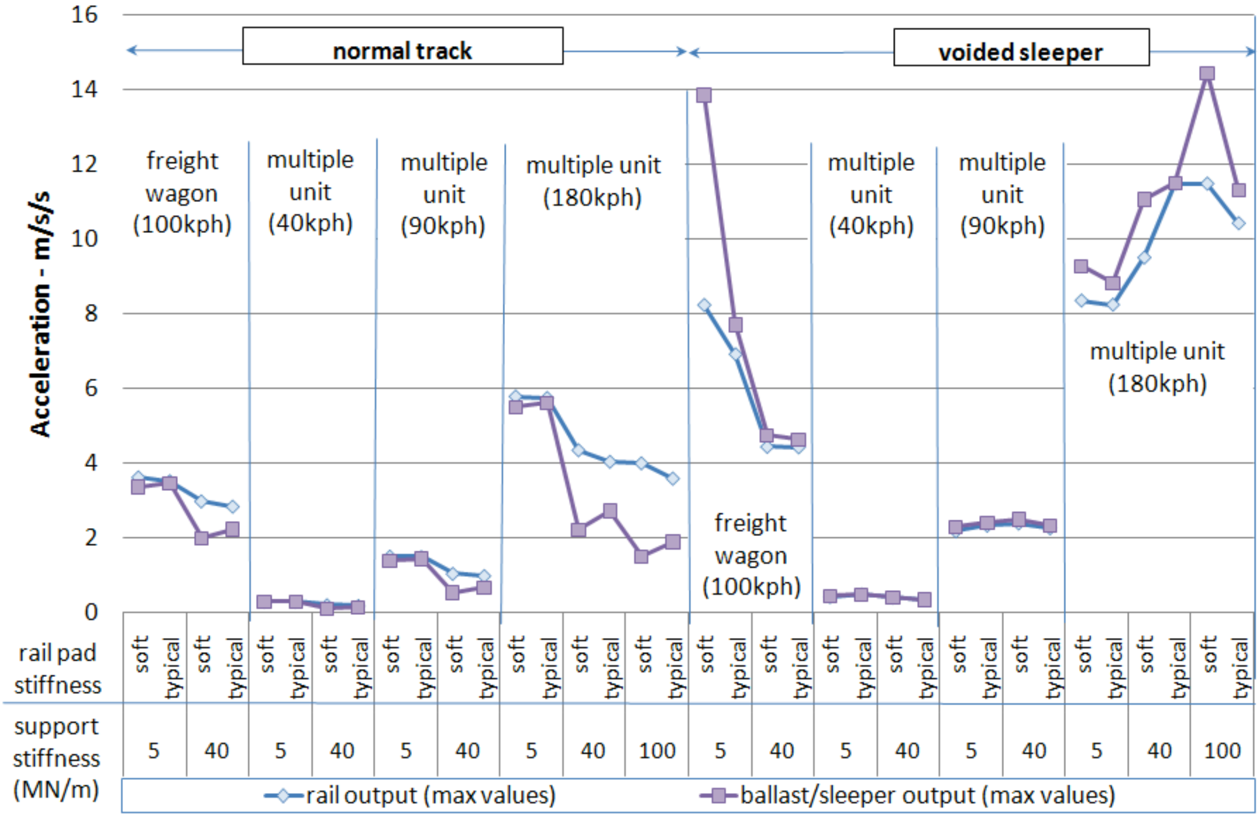


Figure 6: maximum vertical downward acceleration of rail (—◇—) and of ballast (—□—) for normal track condition (left hand side) and voided track (right hand side).

		Freight at 100 kph	Multiple unit at 180			
Stiffness	Ground	Soft	Soft		Typical	
	Rail pad	Soft	Soft	Typical	Soft	Typical
Rail accn. ms^{-2}	Ballasted	3.6	5.85	5.8	4.4	4
	Corus	3.2	3.25	2.8	2.7	2.2
	Corus/ballast	89%	56%	48%	61%	55%
Structure accn.	Ballast	3.4	5.5	5.7	2.3	2.75
	Corus	1.6	1.7	2.7	.7	1.2
	Corus/ballast	47%	31%	47%	30%	44%
Ratio rail/ structure	Ballast	94%	94%	98%	52%	69%
	Corus	50%	52%	96%	26%	55%

Table 3 Superstructure and rail acceleration values and ratios from figure 7

Table 3 and Figure 7 show that the acceleration of the rail is reduced, in particular for the highest values occurring under high speed passenger traffic the reduction is between 48% and 61% of the original. A further more significant impact is seen in the attenuation of acceleration passing from the rail down into the substructure. For a typical modern soft pad/typical formation stiffness combination the attenuation is down to 26% of original, and for the damaging condition of freight on softer formation it is 50%.

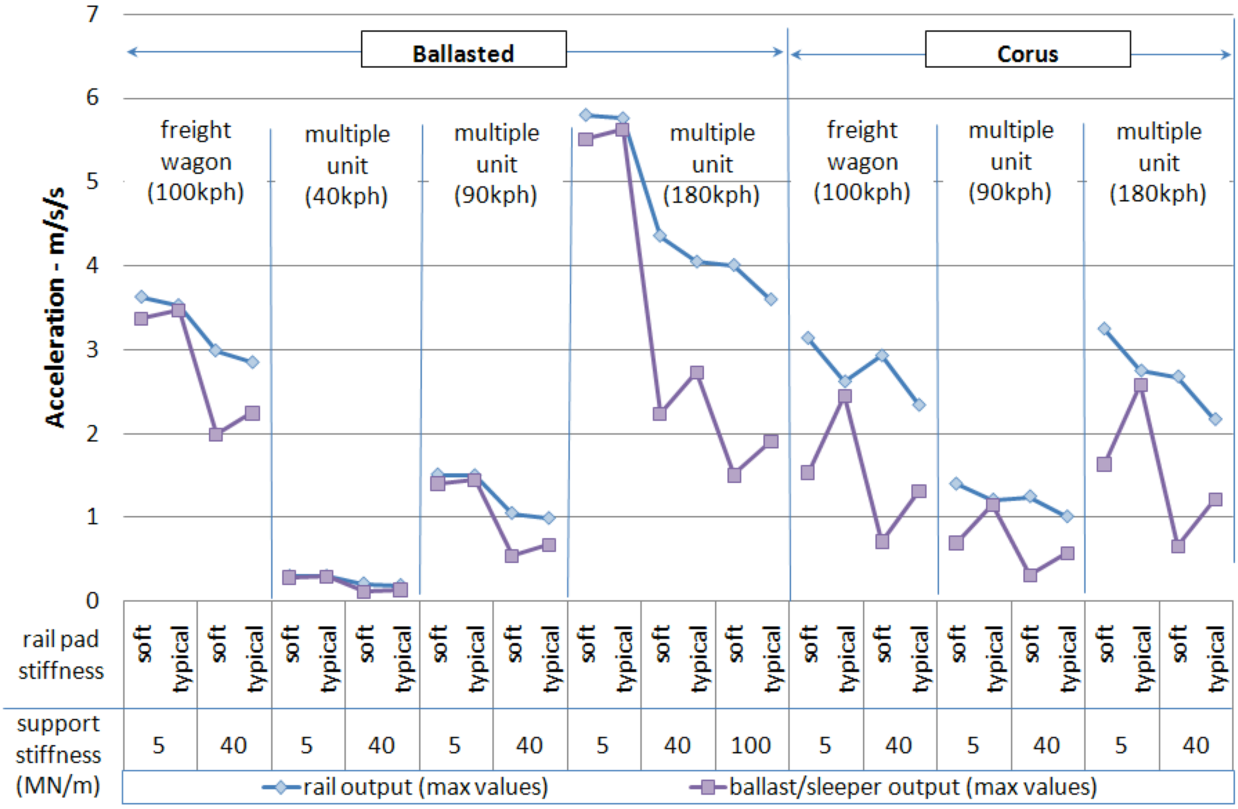


Figure 7: maximum vertical downward acceleration of rail (—¯—) and of ballast/superstructure (—o—) for ballasted track (left hand side) and Corus track (right hand side).

A1.5 Results for case 2: washout

A1.5 (a) Wheel rail contact normal force

The maximum increase was observed on ballasted track for the heavy freight vehicle on soft soil (15%) while the Corus track on the same support condition limited the increase to 4.6%.

A1.5 (b) Track deflection

Figures 8 and 9 show the change of deflection through a weak spot for ballasted track and for a soft base-plated steel – concrete system. The initial steady state value for the steel concrete system either side of the washout is purely a function of the chosen baseplate stiffness, so should be ignored for this comparison. The significant effect in figure 8 is in the relative difference between the deflection in the weak spot compared with either side. The ratio is clearly much greater for ballasted track than for the steel – concrete system. Figure

9 also shows the lifting of the sleepers on the ballasted track (dashed line) for 3 or 4 sleepers either side of the weak spot. This does not occur with the slab design.

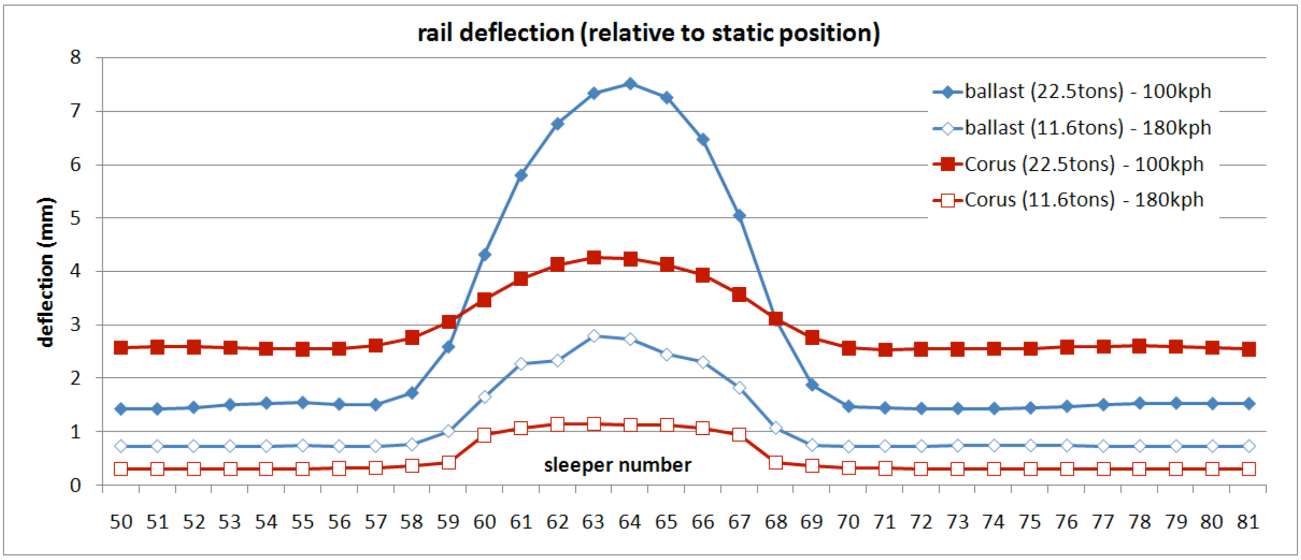


Figure 8: Rail maximum deflection given at every sleeper position along the track .

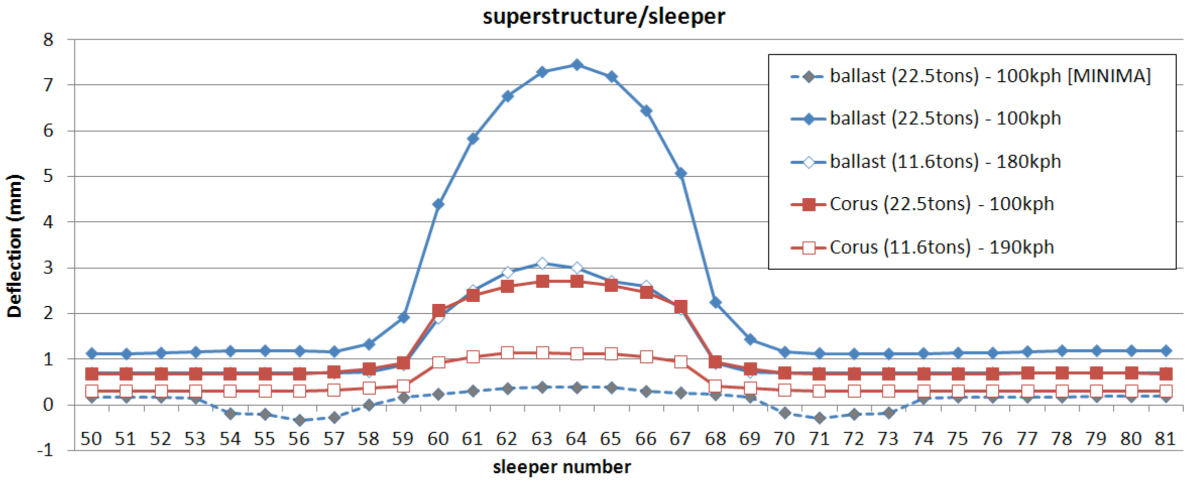


Figure 9: Maximum deflection of superstructure/sleeper given at every sleeper position along the track. The dotted line is the minimum value, to show locations of sleeper uplift.

A1.5 (c) Rail stress

Figure 12 shows the amplitude variation in vertical bending stresses at the foot of the rail. In the case of the Corus track, the rail remains almost unaffected by the weak spot, while for the ballasted track it more than doubles.

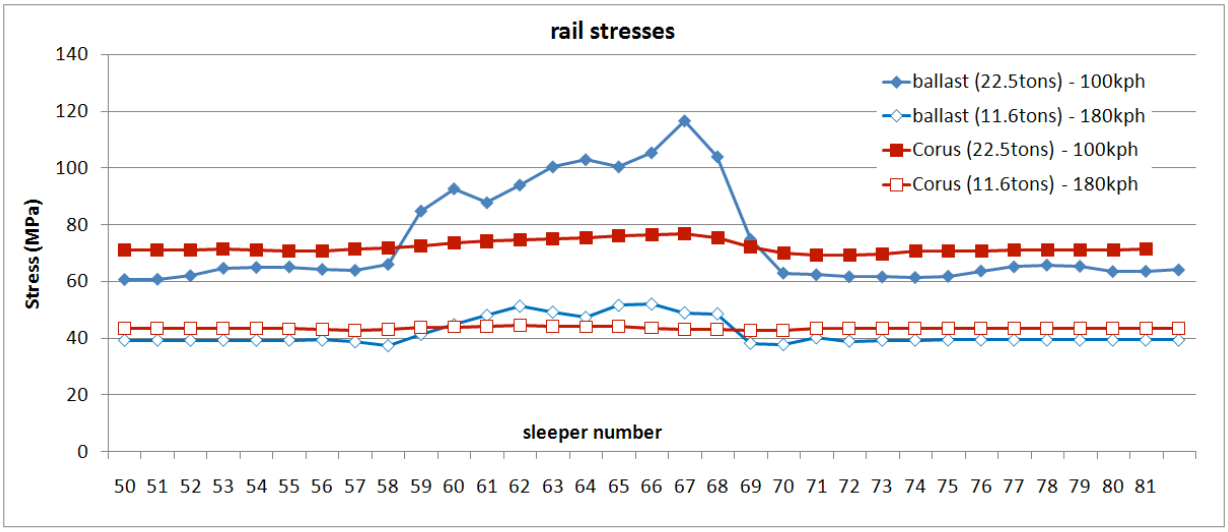


Figure 10: Maximum amplitude of bending stresses in rail foot

A1.5 (d) Track acceleration

Figure 11 shows that the acceleration of the rail under the passage of a heavy freight vehicle at 100kph is similar on ballasted and on the Corus track. However, for the passenger vehicle at the maximum speed of 180kph, the acceleration of the rail on the Corus track structure does not show the high variability observed on the ballasted track.

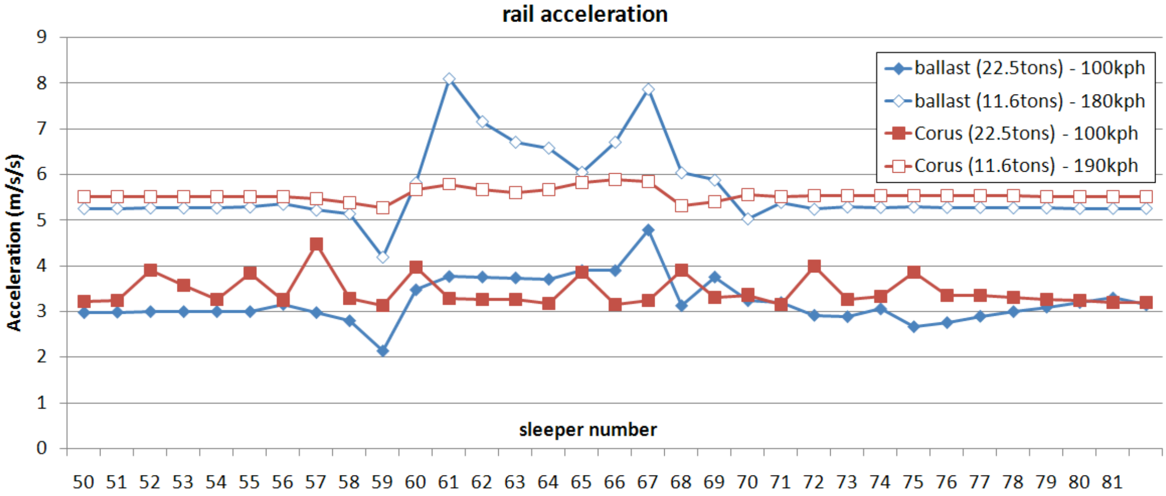


Figure 11: Rail acceleration

A1.5 (e) Ballast/ground pressure

Figure 12 shows the ground pressure under the passage of a heavy freight vehicle at 100kph evaluated as in A1.4(c). Similar trends are observed with an increased pressure on the edge of the washout for both track forms. Overall the Corus track minimises the pressure along the track in comparison with the ballasted track, and the pressure on the exit side of the washout is also better controlled (does not increase as much as for the case of the ballasted track in comparison with the pressure on the entry of the washout).

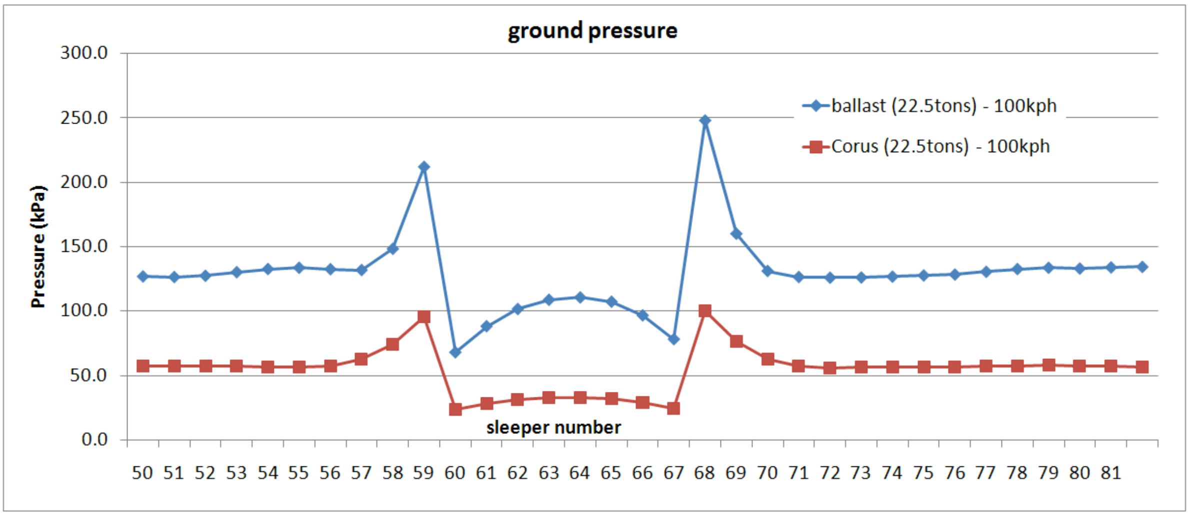


Figure 12: Ground pressure