Investigations within the CONVURT Project into Effectiveness of Different Track Structures in Controlling Ground Vibration.

S. J. Cox[1], A. Wang[1], C. Morison[1], P. Carels[2], R. Kelly[2], O.G. Bewes[3]

[1]*Pandrol Rail Fastenings Ltd, 63 Station Road, Addlestone, Surrey, KT15 2AR, UK*

[2]*CDM Inc., Reutenbeek 9-11, B3090 Overije, Belgium*

[3]*ISVR, University of Southampton, Southampton SO17 1BJ, UK*

Corresponding author:

A. Wang

Pandrol Rail Fastenings Ltd

63 Station Road,

Addlestone,

Surrey,

KT15 2AR,

UK

e-mail: A.Wang@pandrol.com

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Abstract

This paper describes a test rig developed within the CONVURT project in an attempt to bridge the gap between bench top tests on individual components and full-scale installation on service track. An intermediate size test rig has been constructed based on three 2.5 m long full-scale floating track slab elements. These can be directly connected to the base slab, or resiliently supported. Two 12 m long rails are attached to the slab elements with different fastener systems that can provide a wide range of stiffness values. The track can be pre-loaded, and the protruding ends of the rail are damped to reduce end reflections. Results are presented that illustrate the ways in which the test rig can be used. Different track structures can be evaluated and compared. Mathematical models on the test rig and of track can be used to extrapolate from results obtained on the rig to expected performance in track. Results obtained from this process can be compared with those measured under traffic where installations of similar configurations have been made in the track.

1. Introduction

There is increasing interest around the world in the issue of ground borne vibration from railway tracks, and how this can be controlled through the track structure. A wide range of different track structures is available, providing different levels of performance. At one end of this spectrum, direct fixation fastening systems are relatively inexpensive and can be fitted to existing tracks if necessary, while at the other floating slab track provides superior performance but is expensive and cannot normally be installed after initial construction.

An accurate knowledge of the comparative level of performance of different track structures is necessary to select cost effective solutions. Directly comparable data on the performance of fundamentally different solutions is rare, and comparisons between implementations in different circumstances, where different measurement methods have been employed, are potentially misleading. Mathematical models allow theoretical comparisons to be made based on measurement of the relevant parameters such as dynamic stiffness and damping associated with individual components in laboratory tests, but whole track support systems cannot be tested. A gap exists between bench top tests on individual components and full-scale installations on service track. This paper presents a large-scale test rig that has been developed with a view to bridging this gap.

2. The CONVURT project

CONVURT[1] is a part EU funded research project into a range of issues related to ground borne vibration from trains running in tunnels, including modelling, measurements, and the development of solutions and of standards. A number of the partner organizations in the project have contributed to the work described here. The test rig itself was a collaboration between the organisations represented by the authors of the paper. These same partners also worked on the development of a number of track based vibration control measures, and worked with another project partner, the Milan metro system ATM, to make two installations[2, 3] of one of these systems in service track. Some of the measurements made in Milan have subsequently been used in evaluating the performance of the test rig that is described here. The French consultancy Vibratec developed models[4] of the vehicle-track system within the project that have been used to make predictions based on parameters extracted from the measurements on the rig.

3. Test rig development, validation, and use

In outline, this paper describes the test rig; gives comparisons between the dynamic behaviour measured on the test rig and on track in Milan with similar track configurations; gives the results of measurements made using the test rig; describes how parameters are extracted from the test rig results; gives the results of calculations made using a vehicle track model using parameters drawn from the rig; discusses the conclusions and limitations of the process; and discusses future work.

4. Description of the test rig

The test rig has been constructed from three 2.5 m long full-scale floating track slab elements. These can be lowered so that they are directly connected to a base slab, or raised up and pads or springs installed beneath so that they are resiliently supported. Two 12 m long rails are attached to the slab elements at standard track gauge with different fastener systems that can provide a wide range of stiffness values. The rails can, in principle, be changed although in all the tests described here, S49 rails were used. There are four fasteners on each floating slab unit, so that there are twelve fasteners in total supporting each rail. The stiffness of the base slab and the background vibration level on the base slab were measured before the test rig was constructed.

<*Figure 1*>

Figure 1 shows that a loading frame has been constructed above the centre of the test rig so that a static load can be applied through a spreader beam to each of the rails through a hydraulic cylinder. An isolation spring between the spreader beam and the loading cylinder is intended to isolate the loading arrangement from the rest of the test rig. The loading frame and cylinder have been designed to allow for loadings of up to 300kN on the test rig. However, tests to date have found that the isolation spring is not adequately isolating the frame. Dynamic test results given here therefore relate only to test rig in an unloaded condition.

For simplicity of notation, test configurations in which the floating slab track elements are resiliently mounted are referred to here as FST*n* where *n* is a particular configuration; and those with no resilience are DFF*n* (after Direct Fixation Fastener). Table 1 below gives a brief description of the configurations tested. The fastening system used to attach the rail to the slab for all of the FST configurations was the DFF1 system identified below.

<Table 1>

As Figure 1 also shows, the rails overhang at each end of the test slab. Sand boxes were designed, built, and installed at each end of each rail to damp out reflections from the ends of the rails. Figure 2 shows the receptance (dynamic characteristic as a function of frequency) of the rig with and without the sand box dampers installed, and also that of the track as measured in a tunnel on the ATM system. In both cases, the dynamic force was a large soft-tipped calibrated hammer and the resulting vibrations were measured with accelerometers. The configuration tested is with the type DFF4 fastener installed – this is that which is likely to have the lowest decay rate (i.e. where vibrations are likely to be transmitted the furthest along the rail). There is reasonable agreement between the receptance with sand boxes fitted and that measured on track.

<*Figure 2*>

5. Results obtained from the test rig

Although unable at present to give satisfactory dynamic test results, the loading frame can be used to load the test rig and to determine the resulting deflected shape. This was carried out for each test configuration using Strain Gauge type deflection transducers at a number of positions. Measurements are shown for FST track types for the resiliently mounted slab relative to the base slab in Figure 3(a) and for DFF track types for the rail relative to the top slab in Figure 3(b) below. Not shown are the deflections of the top slab for the DFF type configurations, which were negligible; or rail deflections for FST track types were very similar to the results shown for DFF1. The results are as expected and confirm that the rig is deflecting statically as expected. Note that there is no change of gradient at the ends of the FST sections, which indicates an effective transfer of shear loads between the elements.

<*Figure 3*>

For each configuration, the track was excited on one rail at the centre of the rig, and the resulting vibrations were measured at a number of points on the rail; on the top slab; on the base slab; and at a distance of 5 m from the near rail (on the same base slab). The excitation was provided by a large soft-tipped calibrated hammer. A large number of results are produced. The results shown in Figure 4 show the difference in vibration level (transfer function) between the rail and the base slab. For clarity, results for FST track types are shown in Figure 4(a) and those for DFF track types are shown in Figure 4(b). The results follow the pattern expected. For FST types there are peaks in the transfer function corresponding to vibration modes at low frequency where the floating slab vibrates on the stiffness of its resilient supports and at higher frequency an additional mode where the rail vibrates on the stiffness of the fastener. For the DFF track types only the latter mode is present, and the frequency varies as expected with fastener stiffness.

<Figure 4>

6. Extraction of parameters from the test rig

One of the main benefits of the test rig is that it allows realistic values to be obtained for the stiffness and damping parameters of the track elements in the different systems in a consistent and comparable way – although as discussed above, to date it has only been possible to do this for the unloaded track condition. The method used has to been to construct a mathematical model of the test rig into which the known parameters such as dimensions and stiffness values for the rail and floating slab elements can be entered. The other, unknown, parameters can be tuned until good agreement is obtained between the test rig output and the measurements. The best fit gives a good indication of the unknown parameters.

The model was programmed in MATLAB. An example of the fit between the model and measurements obtained from the rig for configuration DFF4 is shown below in Figure 5. Parameters for track elements extracted using this process for all of the different configurations tested are shown in Table 2.

<Figure 5>

<Table 2>

7. Calculations made based on parameters drawn from the test rig

Within the CONVURT project, the French consultancy Vibratec has produced a vehicle–track interaction model that can be used to estimate the dynamic forces transmitted to the base of a tunnel. This has been used to estimate vibration levels on the floor of a tunnel for each of the track configurations tested. Dynamic stiffness and damping track parameters are as found from the test rig model. Other inputs include a rail roughness spectrum, which was taken from the measured roughness on ATM[2], and parameters to represent the vehicle which were also drawn from measurements made in Milan on ATM vehicles[2]. The forces output from the model were used to calculate the vibration on the tunnel floor using a measurement of the mobility of the tunnel on the ATM system[2].

The spectra of vibration produced are shown in Figure 6(a) for FST type systems and in Figure 6(b) for DFF type systems. Peaks in response are generally at lower frequencies in these calculations than seen in the corresponding spectra measured on the test rig principally because of the additional unsprung mass of the train.

Note that all of the FST spectra feature a peak in the vibration level at 63 Hz, which is also shared (though is less apparent) in the spectrum for the DFF1 system. This is associated with a mode in which the vehicle unsprung mass moves on the stiffness of the fastener. In all these cases, since the fastener stiffness is the same, this response occurs at the same frequency. It is conventional wisdom that FST systems should use a fastener with a relatively high nominal stiffness of a type nominally similar to DFF1. The reason why this appears to have produced a less than optimum result here is probably because the actual stiffness of the DFF1 system as tested was rather low at 50 kN/mm/m, This is in turn a consequence of the fact that all of the tests described here have been on the test rig in an unloaded condition, which tends to give low stiffness values since many practical fasteners stiffen with increasing loading. To illustrate the improvements that can be obtained in FST systems by correct choice of fastening system (or indeed the adverse effect of choosing the wrong stiffness) calculations are also shown for configuration FST1 with fastener stiffness DFF4 (ie a much lower value) and also for a notional fastener with a much higher stiffness - five times higher than the value extracted here for DFF1 (FST1 + 5*DFF1).

<Figure 6>

The results for DFF type track fastener systems are generally in line with expectations. Fasteners with lower stiffness give lower vibration levels. To illustrate this further, the total vibration level across the whole frequency range given for each of the spectra shown in Figure 6 have been calculated and these are plotted in Figure 7 below against the total stiffness of the track configuration. For FST configurations, the total stiffness has been computed as the series stiffness of the fastener and the bearings. The total vibration levels decrease by approximately 24dB for each ten-fold decrease in slab support stiffness, and 19dB for each ten-fold decrease in fastener stiffness. The predicted decrease in vibration level against track stiffness on the test rig is higher than has been measured on track[5], where the slab vibration level was found to decrease by approximately 13dB for each ten-fold decrease in track support stiffness. This may be because of the lack of pre-load at present on the test rig. Further investigations should be made on the test rig with a pre-load applied to the various different track systems.

<Figure 7>

8. Conclusions and recommendations

A test rig has been developed within the CONVURT project. The rig can be configured with different resilient support and with different fastener systems that can provide a wide range of stiffness values. Sand boxes were designed, built, and installed to damp out reflections from the ends of the rails. A loading frame has been constructed above the centre of the test rig so that a static load can be applied.

The loading frame has been used to load the test rig and to determine the resulting deflected shape. The results are as expected and confirm that the rig is deflecting statically as expected.

Dynamic tests using an instrumented hammer without static load showed that the difference in vibration level between the rail and the base slab follows the pattern expected. For FST types there are peaks in the transfer function corresponding to vibration modes at low frequency where the floating slab vibrates on the stiffness of its resilient supports and at higher frequency an additional mode where the rail vibrates on the stiffness of the fastener. For the DFF track types only the latter mode is present, and the frequency varies as expected with fastener stiffness.

Track parameters such as the stiffness and damping have been extracted from the test rig for the different systems tested. The base slab vibration spectra for different configurations have been predicted using a vehicle–track interaction model developed by Vibratec the model and the extracted parameters.

In order to better evaluate and compare different track structures under loaded track conditions, further investigations are planned using the rig with a pre-load applied to the different track systems.

References

[1]. CONVURT project website: **www.convurt.com**

[2]. "Installation and Testing of the PANDROL VANGUARD system on ATM line M1, Milan, February 2003", ***Pandrol Report No. 85671-1, 2003.***

[3]. "Installation and Testing of the PANDROL VANGUARD system on ATM line M2, Milan, May 2003", ***Pandrol Report No. 85671-2, 2003.***

[4]. VibraTec website: **www.vibratec.fr**

[5]. S.J. Cox, A. Wang, "Effect of track stiffness on vibration levels in railway tunnels", ***JSV 267 (2003) 565-573.***

Table 1: Configurations tested

Configuration	Description
FST1	Strips – high stiffness
FST2	Strips – medium stiffenss
FST3	Strips – low stiffness
FST4	Pads – low stiffness
FST5	Mats – low stiffness
DFF1	Simple fastener with nominally stiff railpad
DFF2	Simple fastener with nominally soft railpad
DFF3	Low stiffness two layer resilient baseplate
DFF4	Very low stiffness resilient rail chair system

Table 2: Dynamic parameters extracted from rig

Configuration	FST Stiffness (kN/mm/m)	FST Damping Loss Factor	DFF Stiffness (kN/mm/m)	DFF Damping Loss Factor
FST1	*12.5*	*0.5*	-	-
FST2	*8.0*	*0.5*	-	-
FST3	*6.4*	*0.5*	-	-
FST4	*10.0*	*0.5*	-	-
FST5	*5.0*	*0.5*	-	-
DFF1	-	-	*50*	*0.07*
DFF2	-	-	*30*	*0.1*
DFF3	-	-	*15*	*0.3*
DFF4	-	-	*5.3*	*0.3*

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Figure 1: Photograph of test rig

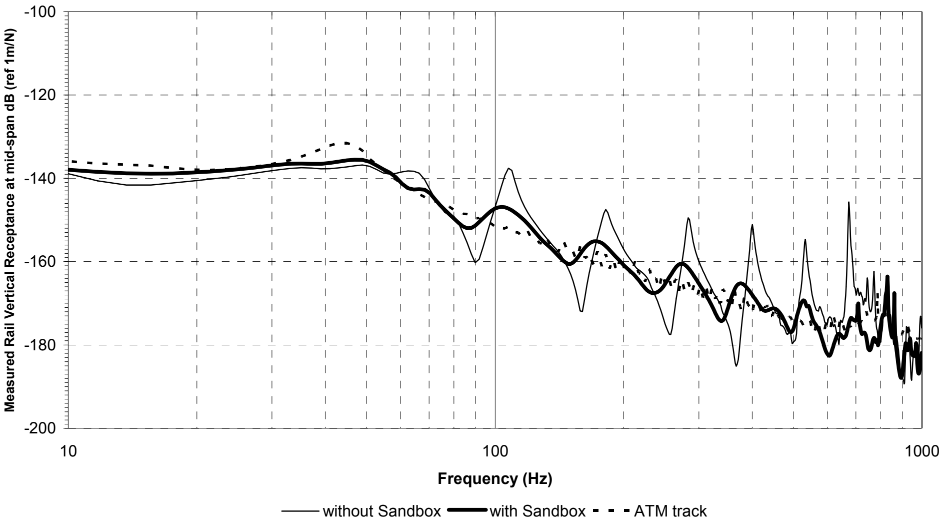
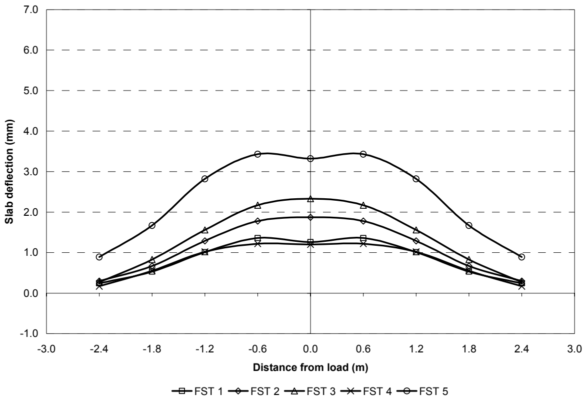
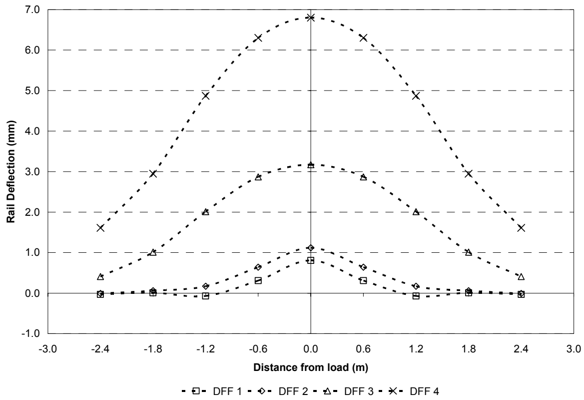


Figure 2: Comparison between rig and track receptance with DFF4

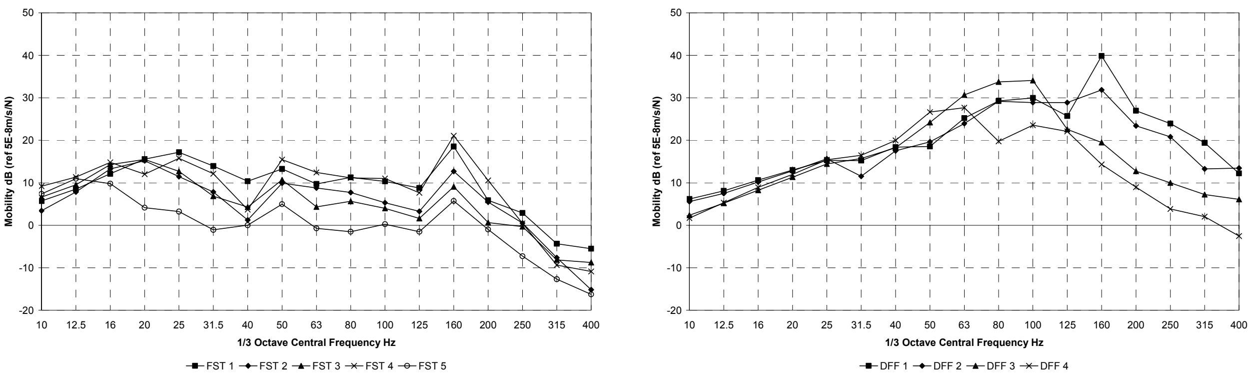




(a) Slab relative to the invert

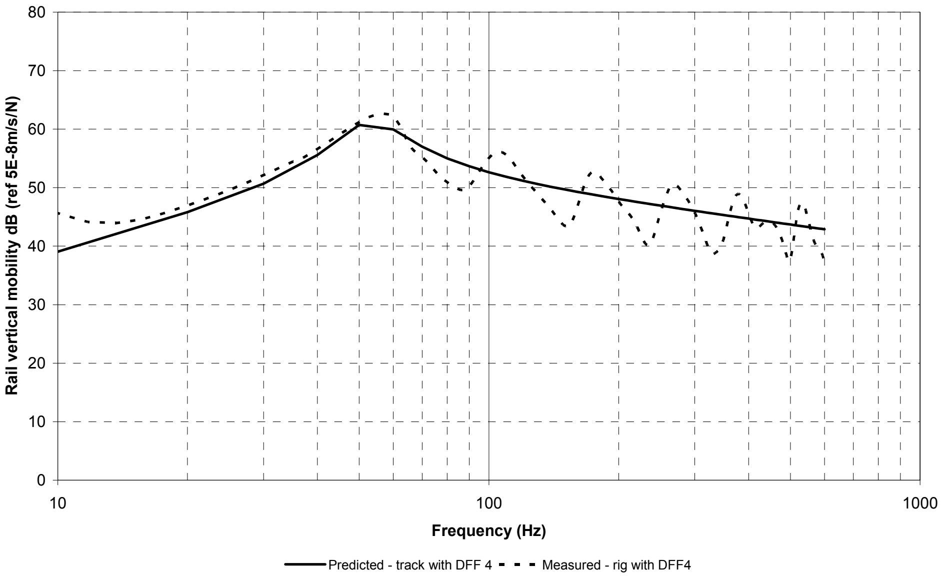
(b) Rail relative to the slab

Figure 3: Deflected shapes under static loading



(a) FST (b) DFF

Figure 4: Invert transfer frequency response function



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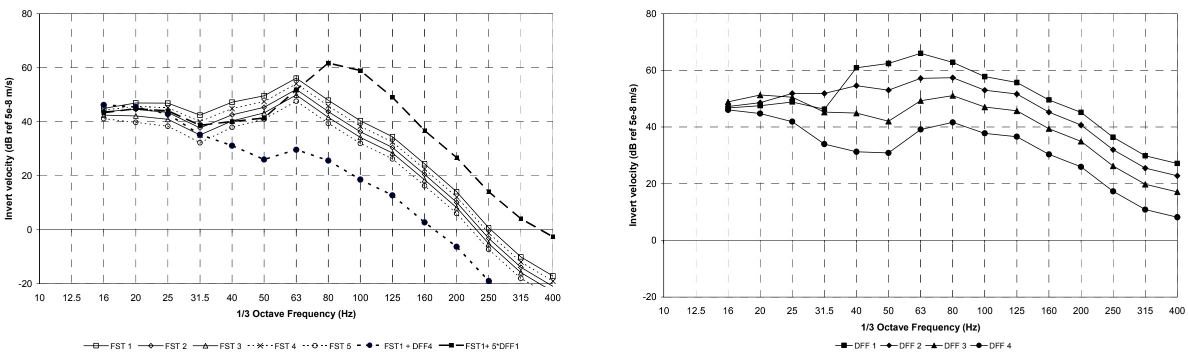

(a) FST (b) DFF

Figure 6: Vibration levels on tunnel floor predicted using model

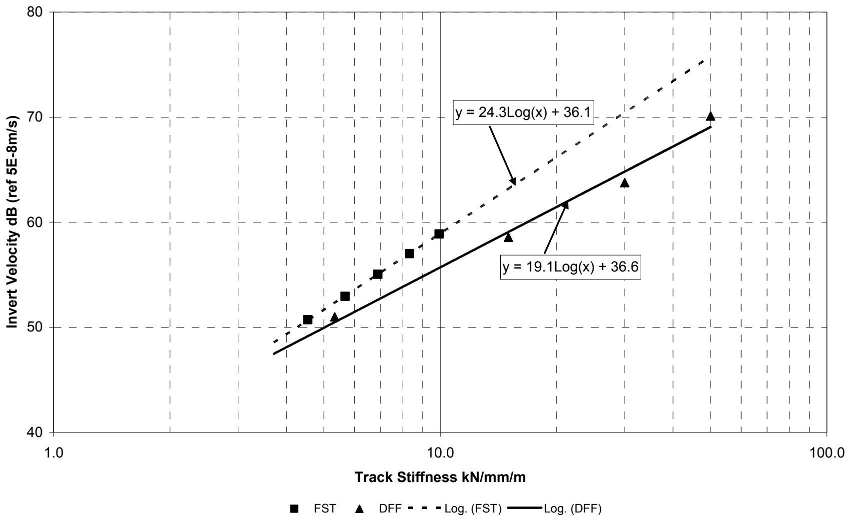

Figure 7: Calculated effect of track stiffness on vibration level