FIELD MEASUREMENTS OF SLAB TRACK VIBRATION TO DEMONSTRATE THE INSERTION LOSS OF LOW STIFFNESS RAIL FASTENERS.

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Abstract

Structural vibration from railways in the range 10Hz to 400Hz can cause considerable disturbance in adjacent structures. The primary method of reducing the transmission of vibration from rail traffic is by means of adding mass and/or reducing the dynamic stiffness of the track support. An example of reduced stiffness support is the Pandrol Vanguard® system, which uses the principle of rubber in shear to support the running rail by the web and the underside of the railhead, rather than using rubber in compression under the rail foot. The Vanguard system has been installed on concrete slab track in a number of metro systems throughout the world and under varying local traffic conditions. In each case slab vibration has been monitored in broadly similar ways, data being obtained before and after installation of the low stiffness trackform. The degree of insertion loss is shown to be largely dependent on the degree of stiffness change between the original and replacement fastener. Methods of fastener installation, vibration measurements and data from several locations are shown and the results discussed.

Introduction

In the EU, the USA and certain parts of Asia-Pacific, onerous environmental legislation now exists to effectively control the amount of vibration energy that can be transmitted into a structure adjacent to a railway. For new build projects it is often the case that the structures themselves can be isolated using resilient bearings. It is most common however for the railway itself to be treated by means of resilient supports.

The means by which ground borne vibration is generated and propagates into structures is dealt with in other studies [1]. The purpose of this study is to consider only the vibration as measured on the track itself. This will give an indication of the vibration levels at remote locations.

It is increasingly the case that, particularly in tunnels, the track formation will be concrete slab. Slab is replacing ballasted track in areas where the railway does not run at grade as it has cost and maintenance benefits. Slab track has evolved considerably over the last two decades and there are now a large variety of different concepts and construction methodologies available to the designer. Principle amongst these is the baseplate, which directly anchors the rail into position.

A large number of proprietary baseplates are available that provide low track dynamic stiffness. Typically these are designed to fasten the rail at its foot by means of spring clips. The resilience of this type of baseplate is limited by the amount of dynamic gauge widening (lateral rail separation) that can be tolerated under passing axles.

A baseplate has been designed that fastens the rail under the railhead and by the rail web [see Figure 1]. The rail is now clamped directly by two rubber blocks that give a good degree of lateral stability but have very low vertical stiffness. Since the rail is supported about its longitudinal axis, the tendency for it to roll outward will be lessened. The result is that large vertical deflections can be tolerated giving low dynamic vertical stiffness.

For example, it would be normal for a conventional baseplate (utilizing spring clips attached to the rail foot) to exhibit vertical deflection between 0.5mm to 2.5mm under axle load. This corresponds to a static vertical secant stiffness in the range 20 to 100kN/mm.

The fastener shown in Figure 1 will exhibit vertical deflections in excess of 5mm and measured static secant stiffness as low as 3kN/mm

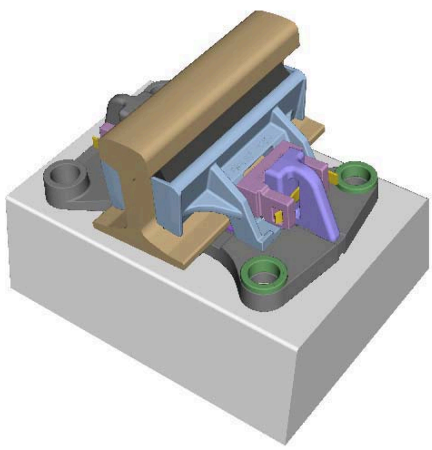

Figure 1 Low stiffness Vanguard rail fastener

Scope of study

Measurements of vibration insertion loss were taken in similar circumstances on metro systems around the world. In each location trains were running on slab tracks of different stiffness. The existing fasteners were changed for the low stiffness fasteners described above.

There were a number of common factors linking each of the measurement sites, including:

- Pandrol Rail Fastenings Ltd. undertook all of the recordings using the same transducers, recording equipment and analytical procedures.
- The same method of recording and reporting the results was used.
- Train speeds were similar (between 40 and 60kmh).

Data from all sites was collated to check for consistency and to investigate the potential for field measurements acting as a predictive model [2]. In theory insertion loss is related to the change in fastener stiffness.

In this study, only slab insertion loss measurements are considered. That is, the total vibration level measured on the track slab with the existing fasteners, less the total vibration level measured at the *same position* on the slab with new fasteners.

At each location multiple vibration and deflection measurements were made to give full analysis of the systemic changes brought about by a change in stiffness. These matters are more fully dealt with in published reports for each separate location. [3, 4]

Methods of fastener installation

In all cases considered here, low stiffness track fasteners have replaced an existing, stiffer system. The track parameters have largely remained constant (sleeper spacing, rail, traffic etc.). Table 1 describes the track form in each location

Some replacements simply involved swapping of baseplates (locations 1 and 2). Even in these locations, a good deal of care had to be taken to ensure that the track geometry was maintained throughout. This was achieved by changing out the baseplates one rail at a time whilst using the other rail as a datum. The same operation would then be conducted on the other rail. Figures 2, 3 and 4 show different stages of the changeover.

Figure 2 Removing existing fastener

Figure 3 Attaching new fastener

Figure 4 Completed changeover

In one location due to engineering constraints, the new baseplates had to be installed at the mid-position between existing fasteners. Existing fasteners were anchored to timber sleepers embedded in the mass concrete. Normal commuter train operations had to continue throughout the construction period, thus it was necessary to build a second fastening system alongside the existing one. This was achieved by removing portions of the existing concrete slab leaving sufficient space to insert and embed a new, modified concrete sleeper housing the low stiffness fastener. Figure 5 shows a new sleeper being inserted at mid-span into the slab.

Figure 5 Inserting a new sleeper at mid-span

Factors affecting results

Each site had a unique set of conditions. It is therefore difficult to compare data between sites. There are a number of factors that need to be considered when collating vibration data from multiple sources.

Rail condition and geometry

The condition of the railhead roughness (running surface) and the track geometry affect vibration considerably. In theory, these parameters can be measured and accounted for within the results. However this is very difficult and highly impractical.

If vibration readings 'before' and 'after' are taken in close succession, the rail roughness will remain approximately constant for the duration of the tests.

By measuring vibration insertion loss, the variability caused by differing rail conditions is reduced. This enables an easier comparison of results from different sites.

Care also has to be given to ensuring that the rail alignment remains the same before and after. Alignment includes, rail elevation, inclination and most importantly the position of one rail relative to the other (gauge and cant). In every case in this study extensive precautions were taken to ensure that rail alignment remained constant.

Wheel Condition

It follows that if rail roughness varies, then so too does wheel roughness. It is impractical to take direct measurements of wheel roughness, so by using averages over a large number of train passing events, the effect of varying wheel conditions on the results is minimized, but not eliminated.

Train speed

Vibration energy in the rail and slab is dependent on train speed. One reason for this is that a given imperfection (or roughness) in the rail/wheel contact area will excite different frequency modes at differing speeds. Thus the attenuation response of a given location can vary considerably with train speed

In each of the cases presented here, a large number of train pass-by events were recorded (between 10 and 40). Trains with speeds more than 10% different from the mean value were omitted from the analysis and results.

Local conditions

No attempt has been made in this study to allow for the local conditions applicable in each case. Variables include ground or soil type, slab density/thickness/stiffness, tunnel geometry and structure, background vibration characteristics and coupling characteristics between tunnel and ground.

The track, tunnel (or viaduct) and surrounds all form part of an interactive system. Two sites with identical track stiffness can give completely different results.

In order to minimize the effects of these local parameters, only vibration measurements taken on the slab immediately adjacent to the rail have been used. The exception is the one set of measurements taken on a viaduct [location 2], where the slab vibration was recorded beneath the box section support structure.

Measuring and recording

Measuring equipment

Vibration measurements were made using Kistler type 8702 and 8712 accelerometers and a Kistler type 5128AM coupler unit. The accelerometers used on the slab had a peak input level of 5g or 25g, depending on the site.

Data was recorded onto a digital tape recorder, although in later cases, a PC card with direct capture and analysis capability was used.

Measurement positions

The accelerometers for measuring vibration were located at the same measurement positions both before and after the fastener change. In certain cases, where the track structure was altered, this meant measuring at the quarter span position between fasteners.

Accelerometers were screwed to steel plates that were firmly bonded to the concrete surface. These in turn were glued to the concrete surface close to the edge of the rail. Figure 6 shows a typical arrangement with the accelerometer positioned at mid-span position on the slab

Figure 6 Typical location of slab accelerometer

Analysis of measurements

In published reports [3, 4], a client may have asked for data to be presented in a particular way. In this study, the raw data has been re-used to extract results that are processed in the same way for all locations. Therefore, there may be small differences between results published elsewhere and in this study.

The duration and the speed of each train pass were identified from the recordings. Vibration recordings were only used during the train pass itself. Each train pass event was then subdivided into a large number of over-lapping blocks with each one being analysed using a uniform windowing and Fast Fourier Transform routine to give the power spectral density.

The content at each frequency (up to 2.5kHz) was averaged across all of the blocks.

In some cases, signals from more than one similarly positioned transducer were averaged.

Levels in ⅓ octave bands were then determined. All results and plots shown herein are based on these ⅓ octave band vibration levels. Velocity was derived from the acceleration based on the centre frequency of each band. The total level across the entire frequency range was also calculated. All vibration results were expressed in decibels relative to a reference velocity of 5x10e-8 m/s.

Discussion of results

Figures 7 to 10 show the vibration frequency response measured on the slab, before and after fastener replacement for four different locations. The total vibration level (calculated as discussed above) is also given for each location.. The insertion loss as shown is the difference between these total vibration levels.

Table 2 shows the insertion loss against the known static stiffness for the track support fastener. Figure 11 shows a plot of these values with the stiffness change given on a logarithmic scale.

The static stiffness values used are the static 'secant' stiffness (measured between two points on the load/deflection curve for a single fastener). For consistency and where possible the same method for calculating static stiffness has been used in each case.

Strictly speaking, it is the dynamic stiffness which influences the vibration behaviour of a fastener. Dynamic stiffness can be measured and reported in many different ways and the value derived is method dependant. Therefore this report considers only the static stiffness. The dynamic and static stiffness are related (often an "acoustic ratio" or multiplier is quoted of between 1.2 and 1.5 for most natural rubber based resilient supports in the frequency range of interest). This study uses static secant stiffness to compare different locations rather than trying to use absolute stiffness values.

This study considers the frequency response up to 2.5kHz. It is useful to consider this frequency range, especially to see if there are any adverse resonances associated with the fastener/slab interface.

For ground borne vibration however, the frequencies of greatest interest are usually below 250Hz. In general, the peak levels of slab vibration measured in all locations within this report were between 40 and 80Hz which is the range being targeted with the low stiffness fastener.

Although it is not shown here, the insertion loss was also calculated in the sub-250Hz octave bands. Interestingly, there was very little difference in the measured insertion loss values. This is due to the predominance of the peaks in the sub-250Hz region.

In a previous study [2] of the relationship between vibration attenuation and dynamic stiffness several conclusions were drawn. One was that there is approximately a 13dB change in vibration level per decade change in dynamic stiffness of the fastener.

In this study the relationship (slope) from Figure 11 is a 15dB insertion loss change per decade static stiffness change.

Note that other measurements [3, 4] show that the insertion loss measured on the slab does not necessarily have a corresponding reduction in the vibration measured in structures adjacent to the track.

Conclusions

Slab track stiffness has been changed by inserting low stiffness rail fasteners at various locations around the world. In all cases, the insertion of replacement fasteners has resulted in greatly reduced vibration levels on the slab adjacent to the rail.

An attempt has been made to relate the vibration insertion loss to the fastener stiffness change. This is despite the difficulties of comparing measurements from different sites. The relationship that emerges is a 15dB change in insertion loss for each tenfold change in fastener static stiffness. This result compares favourably with previously published findings.

References

[1] D.Thompson, C. Jones "Low noise track meets environmental concerns". Railway Gazette International July 2002.

[2] S. J. Cox and A. Wang "Effect of track stiffness on vibration levels in tunnels". Proceedings IWRN7 October 2001.

[3] Pandrol published reports numbers 85171-9, 85171-17, 85171-19

[4] V. Sunley and S. J. Cox "Pandrol Vanguard on London Underground". Proceedings of Railtex 2000 (99-104)

Appendix

Table 1 Description of track form

Location Reference	Track structure	Track type	Method of changeover to low stiffness rail fastener
1.	Plain slab at grade	Direct fixation baseplate	Straight swap for new baseplates
2.	Elevated box-section viaduct	Direct fixation baseplate	Straight swap for new baseplates
3.	Bored tunnel with iron ring segments	Embedded sleeper	New sleeper at mid-span between existing fasteners
4.	Rectangular section tunnel	Resiliently mounted concrete block	Retrofit with new, modified blocks

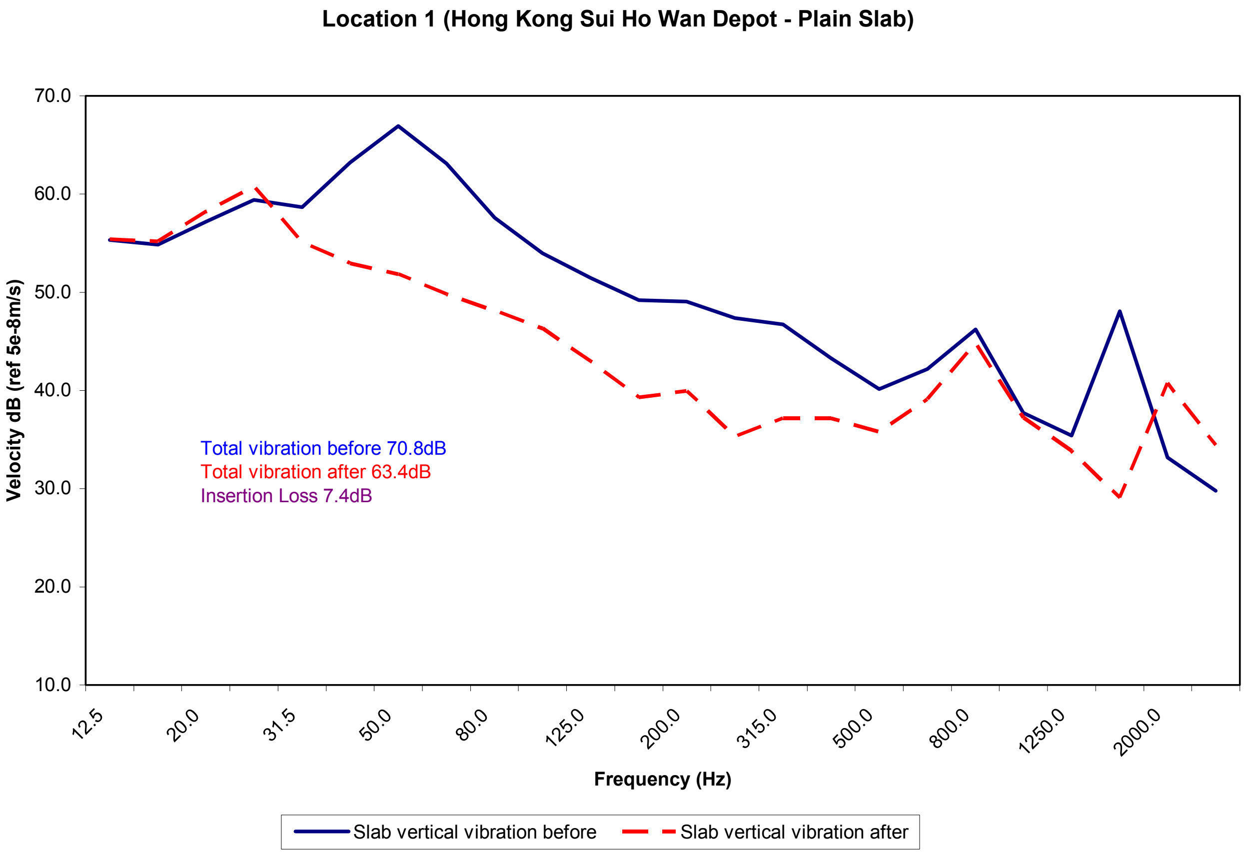

Figure 7 Vibration levels at location 1

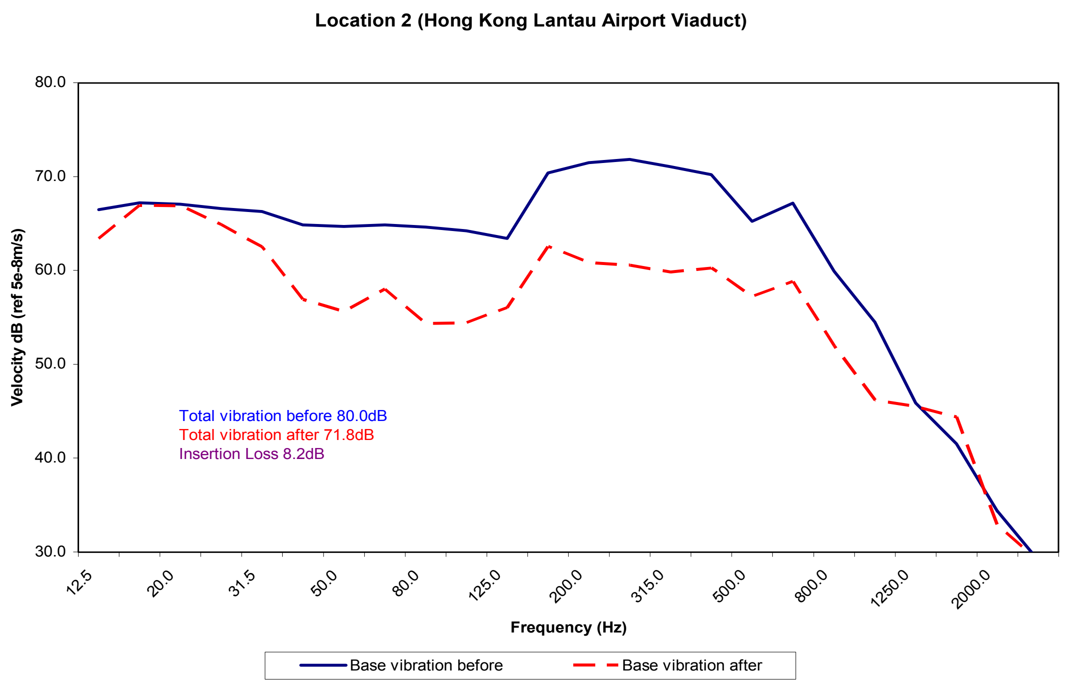

Figure 8 Vibration levels at location 2

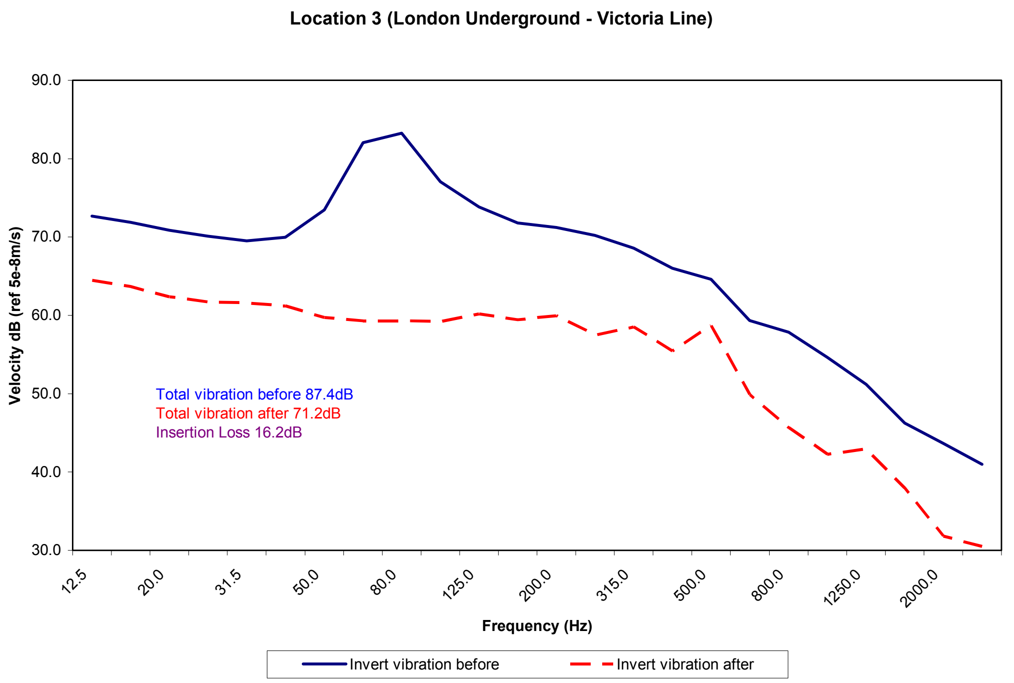

Figure 9 Vibration levels at location 3

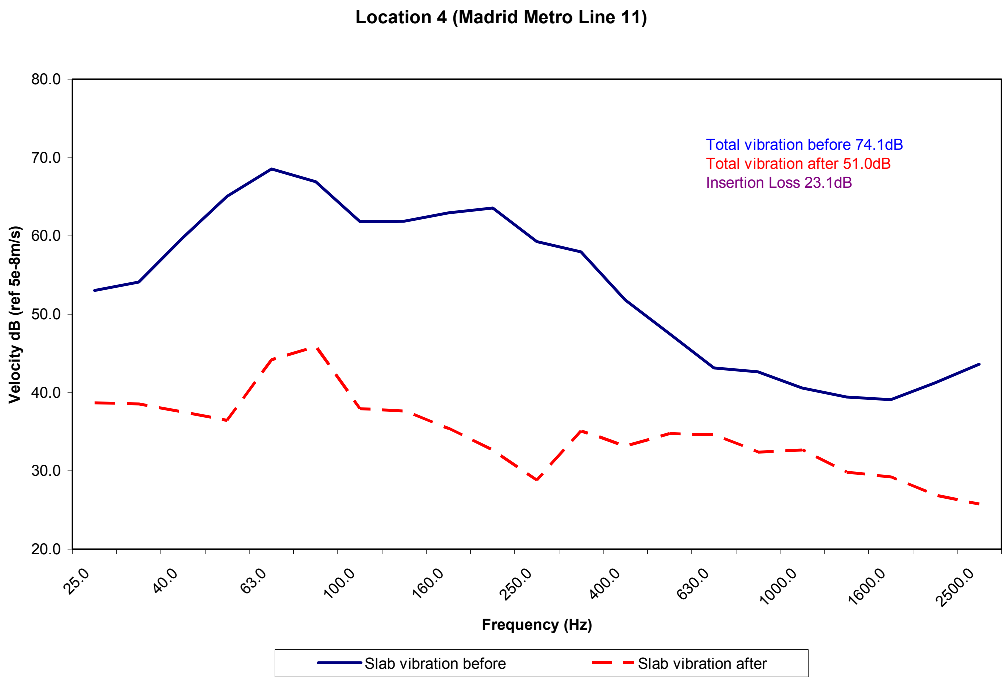

Figure 10 Vibration levels at location 4

Table 2 Static stiffness and insertion loss values

	Units	Location reference			
		1	2	3	4
Static secant stiffness before (Ks1)	kN/mm	21	21	133	130
Static secant stiffness after (Ks2)	kN/mm	4	4	5.1	4
Stiffness change (Ks1/Ks2)		5.25	5.25	26.1	32.5
Insertion loss (total vibration)	(dB)	7.4	8.2	16.2	23.1

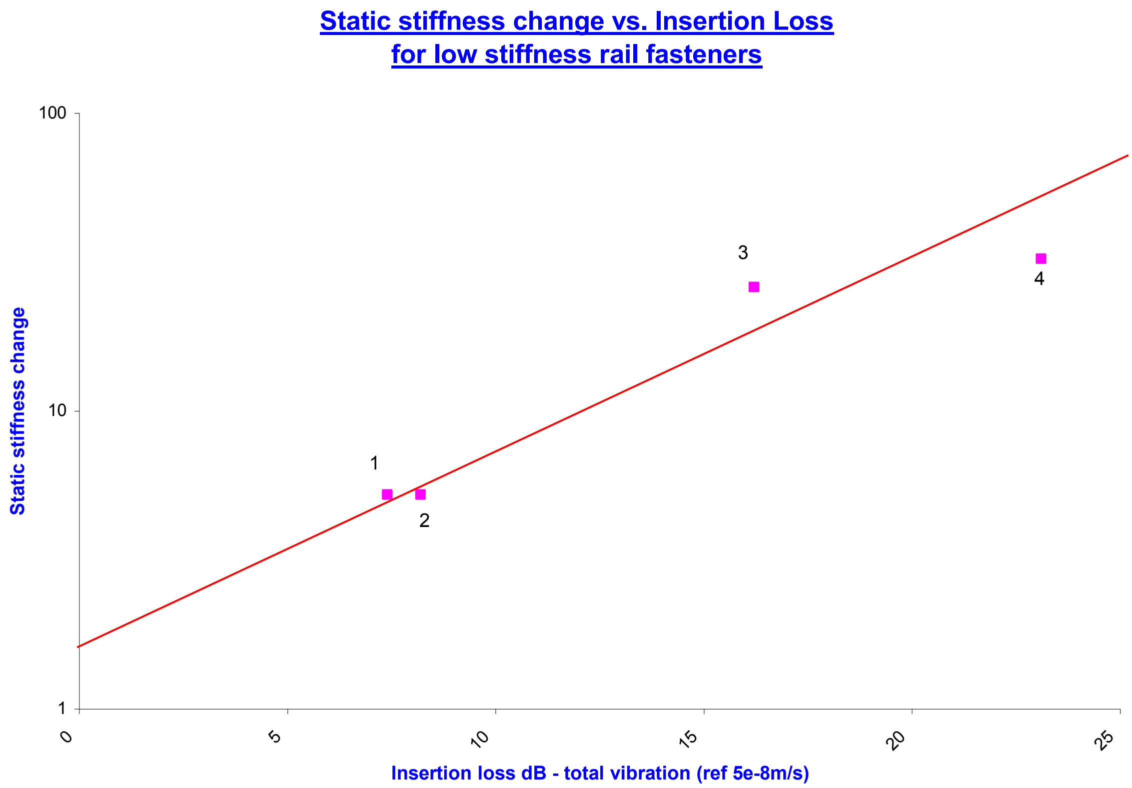

Figure 11 Static stiffness vs. insertion loss