Increasingly, environmental legislation aims to control the amount of vibration energy that can be transmitted into sensitive structures adjacent to railways. Where new buildings are erected it can be the case that the structures themselves are isolated using resilient bearings. It is most common, however for the railway itself to be treated by means of resilient track supports. This is known as “vibration isolation at source”.

In tunnels on Singapore MRT, the track formation is concrete slab. Slab track has evolved considerably over the last few decades and there are numerous rail fastening options available to the track designer. Principal amongst these is the resilient baseplate, which directly anchors the rail to the correct alignment.

LOW STIFFNESS BASEPLATES
The baseplate most widely used on Singapore MRT slab track is the Double FASTCLIP (DFC) (Figure 1). It is characterised by having four FASTCLIP spring fastener clips per rail seat. Two outer FASTCLIPS fix a baseplate on a resilient studded rubber pad. Two inner FASTCLIPS anchor the rail on top of another resilient rubber rail seat pad.

As with all baseplates that utilise spring clip fasteners, there are limits to the lowest vertical stiffness that can be provided. Since the efficiency of fastener vibration isolation is directly related to low vertical stiffness, spring clip fasteners are useful to a point, but for increased vibration mitigation alternative track support products must be considered.

Typically, DFC has a vertical static secant stiffness of around 20kN/mm. In order to significantly improve the vibration performance of such a fastener, a step change in the vertical stiffness value is required.

The wedge-shaped elastomeric elements are compressed against the rail, so that as well as being supported, the rail is also fastened to the track foundation and maintains the required resistance to longitudinal loads. The principal advantage of the system over more conventional rail fastenings is that it allows significantly greater vertical deflections under traffic without unacceptably high rail roll. The low stiffness of the track leads to an improved attenuation in the dynamic forces generated at the wheel-rail interface, reducing the level of dynamic forces transmitted through the fastening, into the track foundation and beyond.

These elastic elements now act in shear, rather than in compression, which is the case with DFC. Natural rubber, which also provides resilient vertical support in DFC, exhibits outstanding dynamic performance when used in the shear mode in the VANGUARD assembly. Unlike a permanently bonded baseplate, the whole system does not need to be replaced if the rubber eventually wears in time – the rubber elements can be removed and replaced in-situ.

Using this system Pandrol VANGUARD delivers a vertical static stiffness of approximately 5 kN/mm and a dynamic stiffness of around 7 kN/mm in a safe manner and without excessive rail roll. The loaded track resonance of Pandrol VANGUARD in combination with typical railway vehicles - which have an un-sprung wheel mass in the range 600-900kg – occurs in the low 20’s of Hz. This means that the Pandrol VANGUARD system is effective in eliminating many railway vibration problems.

In 2008, together with the LTA, Pandrol set about designing a version of the VANGUARD system that would directly retrofit into the
locating shoulders used by the DFC baseplate. Retrofitting VANGUARD for DFC (Figure 2) is a direct swap. This has advantages for Singapore MRT in terms of a reduced stockholding inventory. There is no change to the track structure or the means of anchoring the baseplate. The rail will remain in the same position geometrically for both fasteners. By swapping to VANGUARD from DFC, large reductions in ground vibration can be achieved with minimal impact on operational parameters.

In a trial, the rate of baseplate changeover from DFC to VANGUARD was timed at 40 units per hour.

SCOPE OF STUDY
Having devised a concept for a retrofit VANGUARD baseplate and demonstrated its function and safety in laboratory tests, a full live track trial was proposed (Figure 3). For this new application on Singapore MRT, the purpose of a track trial was twofold. Firstly, to demonstrate the ease with which this new VANGUARD fastener could replace existing DFC. Secondly, to show the typical reductions in vibration that could be achieved on the tunnel floor. A 40 metre length of single track was chosen to confirm both conjectures – see map Figure 4.

The track chosen was on a curve of 300 metre radius. Superelevation was 80mm and the equilibrium speed was 46kmh. Singapore MRT uses UIC60 head-hardened rail with a fastener spacing of 700mm. The trial was conducted during September 2009. At this time the CCL2 was not open to revenue traffic, hence test trains were running at tare weight.

MEASUREMENT AND RECORDING
Readings of rail dynamic deflection, slab vibration and tunnel wall vibration were taken.

Rail deflection
Deflections of the rail relative to the concrete slab were measured using strain gauge displacement transducers. The transducers were mounted on brackets, which were fixed to metal plates glued down to the slab. The transducers measure deflections of up to ±5mm, with an accuracy of 0.1%. All deflection measurements were made at mid-span between baseplate positions.

Vibration measurement
Rail vertical and lateral vibration was measured on both gauge and field side rails using calibrated accelerometers. Concrete slab vibrations were measured on the centre line of the track and at mid-span relative to the rail fastening assemblies. In addition tunnel wall vibration measurements were taken in both the lateral and vertical axes.

RESULTS AND DISCUSSION
The average speed of the trains was measured to be 61km/h and all trains travelling between 60km/h to 62km/h were analysed. Recordings for trains within this speed bracket were averaged. The vertical deflections of the rail foot at both field and gauge side were averaged to estimate the rail deflection at the centre. The rail roll was calculated by subtracting the field side recordings from the gauge side recordings. This method was used because the gauge and field side deflections can be easily found by adding and subtracting the roll component to the centre position. The rail head lateral deflection was calculated by multiplying an appropriate factor derived from the geometry of the rail to the rail roll and then adding the average lateral deflection of the rail foot. This multiplying factor is the ratio between the height of the gauge corner and half the width of the rail base.
Rail deflection
The mean deflection values for both the leading and trailing axles on low and high rails are given separately as shown in Table 1. Negative vertical values represent a downward deflection relative to the slab. Positive values for the rail roll and lateral deflection indicate a gauge increase or outward deflection from the track centre line. The maximum lateral deflection of the head of the rail is shown in bold.

Averaging all leading and trailing axles on all bogies reveals that the net rail vertical deflection for DFC and VANGUARD is 0.83mm and 3.30mm respectively. The maximum rail head lateral deflection values for the DFC and VANGUARD fastening systems are 1.76mm and 1.20mm respectively. It is therefore clear that VANGUARD has a much lower vertical stiffness than DFC without compromising the lateral rail stability.

Table 1
<table>
<thead>
<tr>
<th></th>
<th>Vertical (mm)</th>
<th>Foot Lateral (mm)</th>
<th>Roll (mm)</th>
<th>Head Lateral (mm)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>DFC</td>
<td>VG</td>
<td>DFC</td>
<td>VG</td>
</tr>
<tr>
<td><strong>High Rail</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leading axle</td>
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<td>0.56</td>
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<td>Trailing axle</td>
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<td>-3.52</td>
<td>0.31</td>
<td>0.53</td>
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<td><strong>Low Rail</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leading axle</td>
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<td>-2.81</td>
<td>0.57</td>
<td>-0.90</td>
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<tr>
<td>Trailing axle</td>
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<td>-3.34</td>
<td>0.11</td>
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<tr>
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<td>-3.08</td>
<td>0.34</td>
<td>-0.78</td>
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<td><strong>Average</strong></td>
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<td>-3.30</td>
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</table>

CONCLUSIONS
Average rail deflection in the vertical direction has been shown to be 0.83mm for DFC and 3.30mm for VANGUARD, whilst lateral rail deflections remain more or less the same for both fasteners. This demonstrates one principle advantage of VANGUARD, which is that it will prevent excessive rail roll whilst providing very low vertical stiffness.

The main purpose for installing PANDROL VANGUARD system is to reduce transmitted vibration and the slab insertion loss showed a substantial vibration reduction of 10dB at 50Hz and 5.7dB overall. This means that the VANGUARD rail fastener can be swapped for DFC to substantially reduce ground borne vibration in areas of high sensitivity.

The Singapore MRT authorities now have a new option for combating ground vibration where this has reached nuisance levels. VANGUARD can be deployed as a fastener for new lines in areas where higher attenuation is required than can be provided with conventional fastening systems.

In both new and retrofit applications the DFC fastener can be simply swapped for VANGUARD without any geometrical implications on the track.