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LOW VIBRATION TRACK SYSTEM - LVT

Heavy Haul Conditions

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Contents

1. General information

The slab track system Low Vibration Track (LVT), well experienced under different conditions, was developed in the nineties on the basis of the twin block sleeper system for ballastless track.

In 2000 the Portland Cement Association (PCA) initiated the “Cooperative Slab Track Research and Demonstration Program for Shared Freight and High Speed Passenger Service” due to requirements for upcoming projects of heavily stressed railway lines. Part of the program was a test of the LVT slab track system.

Excellent results of intense test series were veryfied by a test section of LVT slab track integrated in the High Tonnage Loop (HTL). From 2003 – 2006 the Transportation Technologiy Center Inc (TTCI) in Pueblo, Colorado, a subsidiary of the Association of American Railroads, carried out the “Slab Track Field Testing and Demonstration Program”, in which the durability of slab track for 39 tons (US) (36 metric tons) axle loads was tested.

2. System description

The LVT system is an independent block system which is composed of a reinforced concrete block, a resilient block pad, a rubber boot and a rail fixation (depending on customers’ preference) with an elastic rail pad of about 856.5 kips/in (150 kN/mm) dynamic stiffness.

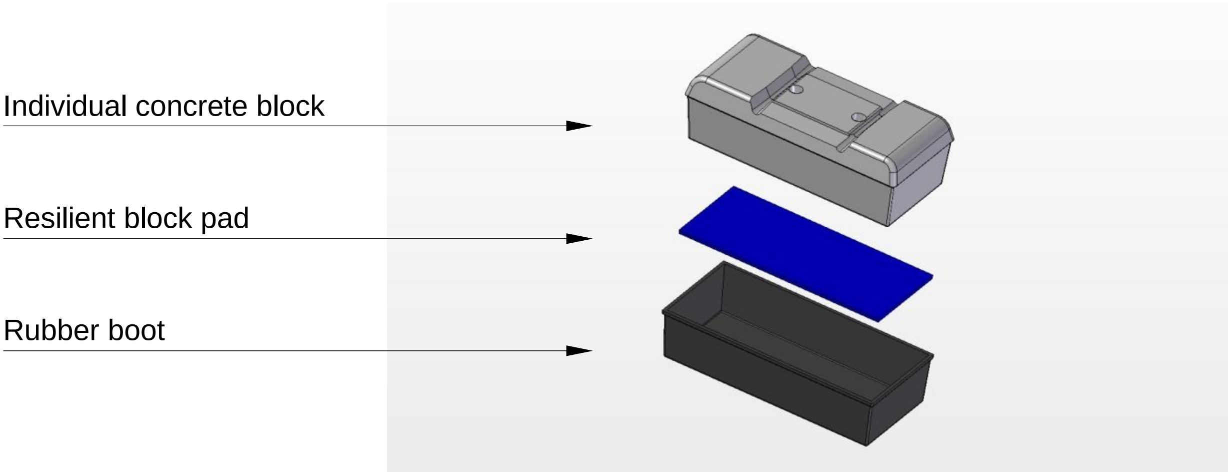


Figure 1: Main LVT support components

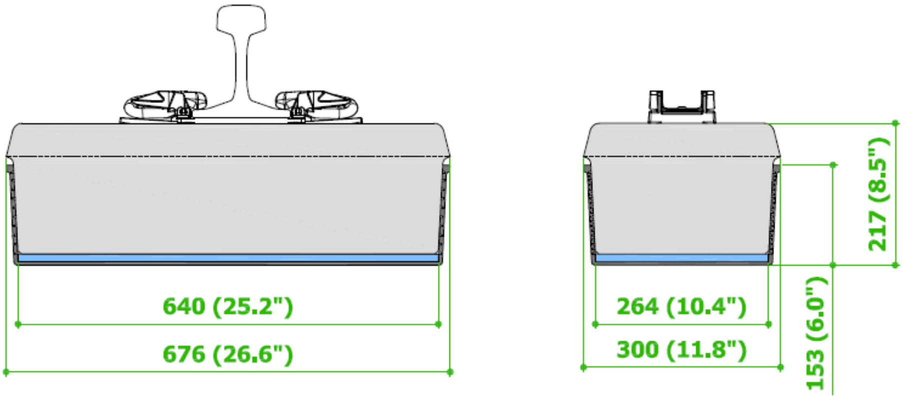


Figure 2: Typical cross section of the LVT standard support

The base of the LVT standard support is 10.4 inch (264 mm) wide, the resilient pad is 0.5 inch (12 mm) thick and allows improved load distribution.

The spring rate of this pad will be designed individually for each project and depends on technical project parameters.

Regardless of the type of fastening system mounted, an elastic rail pad is used, as this is decisive for one of the characteristics of this system – the dual-level elasticity.

This concept of two elastic levels separated by an intermediate mass effectively attenuates vibrations and reduces stress on all components of the slab track.

3. LVT slab track for heavy haul traffic

The research program “Cooperative Slab Track Research and Demonstration Program for Shared Freight and High Speed Passenger Service” was initiated to advance slab track technology.

The program was carried out in three phases. After literature review and life cycle cost analysis in phase one of the program phase two followed up with the choice of two slab track systems – one of them the LVT system. They were subject to laboratory demonstration tests to pass stress and fatigue values. In the third phase a field slab track demonstration test was executed.

During the third phase throughout conducting the “Slab Track Field Testing and Demonstration Program” and testing the durability of slab track for 39 ton (36 to) axle loads, TTCI maintained the track geometry conditions of a Class-9 track safety standard (high speed track, max. speed 200 mph (322 km/h)) according FRA (Federal Railroad Administration), (PCA R&D Serial No. 2988[1]).

Prior to the field test the design procedure of the slab track had been specified (PCA R&D Serial No. 2832[2]), which included laboratory tests on slab sections under simulated heavy axle loads. The finite element method (FEM) software SAP2000 was used to calculate moments, shears, subgrade pressures and deflection, to enable a comparison of the structural analysis and the results of the field test. The program was funded by the Portland Cement Association (PCA) and Federal Railroad Administration (FRA).

4. Theoretical analysis of LVT slab track

A detailed 53-ft-long (17.50 m) straight finite element model was programmed for structural analysis. Laboratory tests were conducted in advance to obtain the normal load-displacement response of a complete assembled block system (PCA R&D Serial No. 2795[3]). These tests on the LVT system under simulated heavy axle loads demonstrated the ability of the LVT system to withstand these axle loads for 3 million cycles. The load displacement responses were used to find the secant stiffness, which was required for the finite element analysis. The finite element model used for the calculation operates with springs having three translational and three rotational stiffness.

4.1 Load distribution determined by finite element analysis of the slab track (Hamid R. Lotfi and Ralph G. Oesterle)[2]

Sum of wheel vertical live load and wheel dynamic load:	68 kips (302.5 kN)
Maximum load carried by a fastener:	27.2 kips (121 kN)
Rail pad vertical stiffness at 27.2 kips:	1000 kips/in. (175 kN/mm)
System vertical stiffness at 27.2 kips:	193 kips/in. (33.8 kN/mm)
Maximum lateral wheel load: (distribution factor 40%)	21.76 kips (96.8 kN)
Maximum lateral load carried by a fastener:	8.7 kips (38.7 kN)
Fastener lateral stiffness at 8.7 kips:	247 kips/in (43.26 kN/mm)
Longitudinal wheel load:	10 kips (44.5 kN)
Maximum longitudinal load carried by a fastener:	4 kips (17.8 kN)
Fastener longitudinal stiffness at 4 kips:	150 kips/in (26.3 kN/mm)
Vertical loads carried due to shear deformation of the boot wall's corrugation (PWC 2000[4]):	11% of vertical load

4.2 Finite element analysis of internal forces and deformations due to several load conditions (Hamid R. Lotfi and Ralph G. Oesterle)[2]

Maximum vertical displacement of the rails:	0.140 in. (3.56 mm)
Maximum vertical displacement of the slab:	0.064 in. (1.63 mm)
Maximum lateral displacement of the rails:	0.186 in. (4.72 mm)
Rail maximum vertical shear force:	20.7 kips (92.1 kN)
Maximum strong-axis bending moment:	299 in.-kips (33.8 kNm)
Rail maximum horizontal shear force:	13.2 kips (58.7 kN)
Maximum weak-axis bending moment:	138 in.-kips (15.6 kNm)

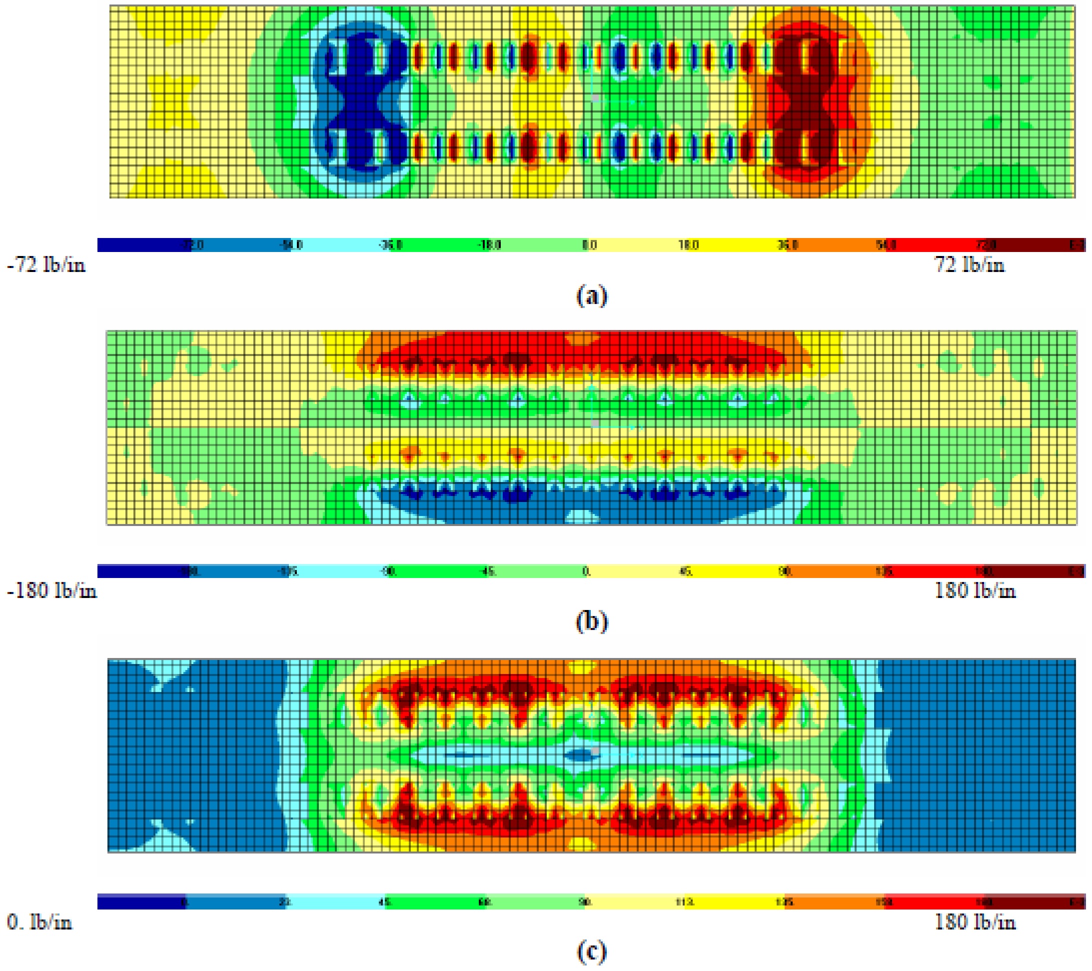


Figure 3: Slab shear forces due to unfactored uniform vertical loads:
(a) lontitudinal shear force
(b) transverse shear force
(c) principal shear force

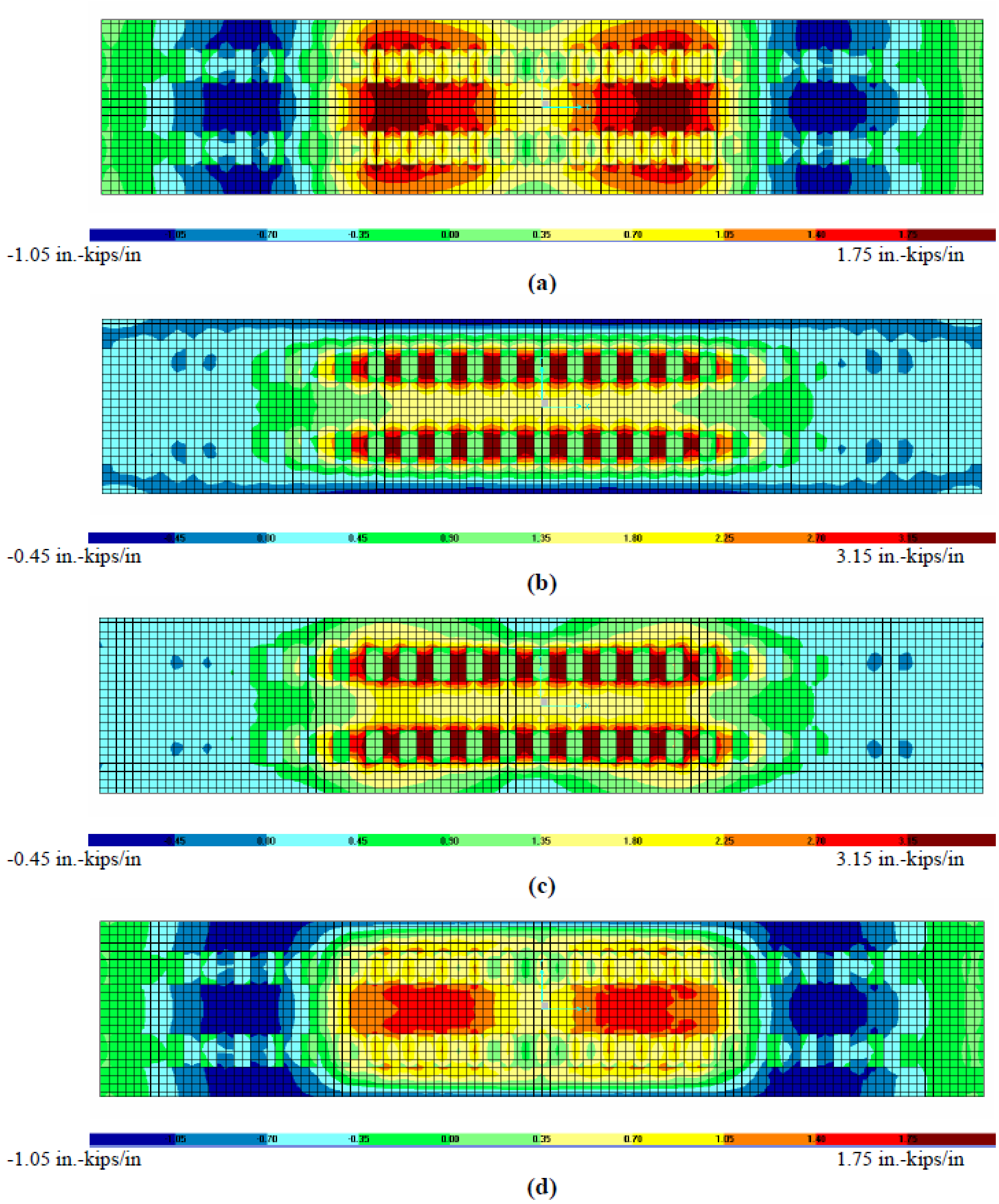
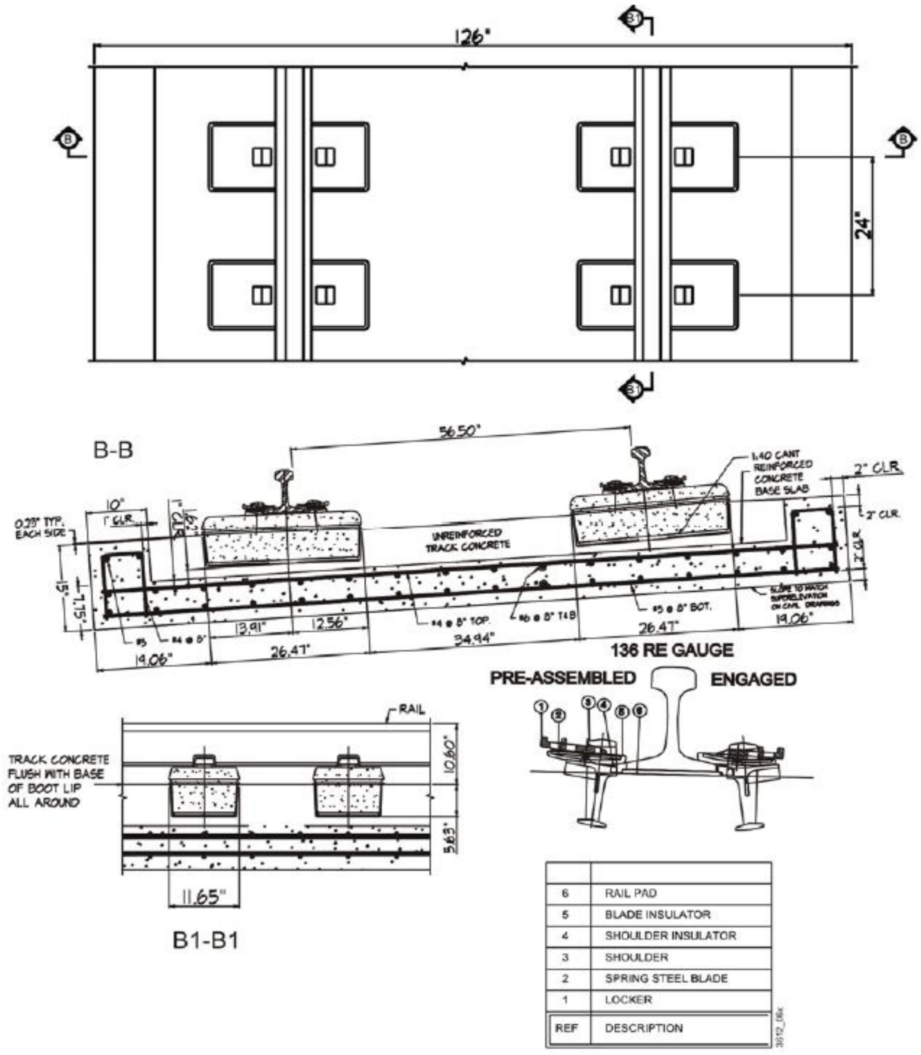


Figure 4: Slab bending moments due to unfactored uniform vertical loads:
(a) longitudinal moment
(b) transverse moment
(c) maximum moment
(d) minimum moment

5. Field slab track demonstration test (Dingqing Li 2007[1])

5.1 LVT slab track construction

The field slab track demonstration test was conducted at the Transportation Technology Center (TTC), Pueblo, Colorado. On the high tonnage loop (HTL) at the TTC's Facility for Accelerated Service Testing (FAST) a 500 feet (152.4 m) slab track, including 250 feet (76.2 m) of LVT slab track, was constructed in a 1148 feet (5-degree) curve (R=350 m) with 4 inch (102 mm) superelevation and a slight downhill grade of 0.4%. The slab track was built within Amtrak's Class-9 track construction tolerances. The slab track was mounted on a 6 inch (0.15 m) base cement layer with a target compressive strength of 700 psi (4.82 N/mm^2).



REF	DESCRIPTION
6	RAIL PAD
5	BLADE INSULATOR
4	SHOULDER INSULATOR
3	SHOULDER
2	SPRING STEEL BLADE
1	LOCKER

Figure 5: LVT- slab track drawing and detail

5.2 Operation and load environment at FAST

The trains on the test track consists of 3 to 4 locomotives with nominal axle loads of 32 tons (US) (29 metric tons) and 60 - 80 freight cars with a nominal axle load of 39 tons (US) (36 metric tons). The trains run at a nominal speed of 40 mph (64 km/h) and operate from late night to early morning accumulating 1 MGT (US) (0.9 metric MGT) per shift. After three years of testing, 169 MGT (US) (153 metric MGT) were accumulated.

Picture 6: Freight train at Facility for Accelerated Service Testing

5.3 Field test results

5.3.1 Track geometry

For the LVT slab track, only little change in the alignment could be determined. Higher magnitudes of alignment deviations arose in the adjacent ballast track which had a minor standard. During the testing program, no relevant settlement in the LVT slab track could be measured. The maximum vertical rail to slab deflection was 0.15 inch (3.8 mm) and the lateral rail to slab deflection was 0.07 inch (1.8 mm), both measured on the high rail. Over time, the measured vertical and lateral rail to slab deflections were decreasing.

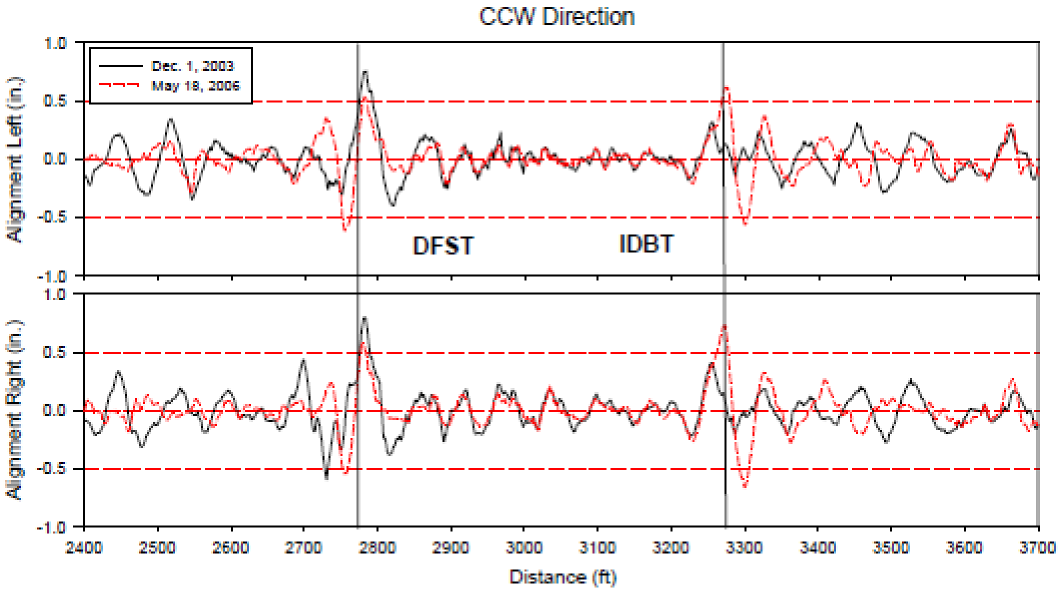


Figure 7: Change of track alignment over time

DFST – Direct fixation slab track

IDBT – Independent dual block track – LVT slab track

5.3.2 Gauge

In the LVT system only a small amount of gauge degradation occurred at the transition area, but the gauge stayed in the permitted limits shown in the table below. Neither wide gauge, narrow gauge nor the rate of change were exceeded throughout the testing program.

Parameter	**Class 4** (80 mph(129 km/h))	**Class 9** (200 mph (322 km/h))
Gauge	-0.5/+1.0 inch (-12.7/+25.4 mm)	-0.5/+0.75 inch (-12.7/+19.1 mm)
Gauge – rate of change (31') (9.45 m)		0.5 inch (12.7 mm)
Alignment (62 feet MCO) (18.90 m)	+/- 1.5 inch (+/- 38.1 mm)	+/- 0.5 inch (+/- 12.7 mm)
Surface (62 feet MCO) (18.90 m)	+/- 2.0 inch (+/- 50.8 mm)	+/- 0.75 inch (+/-19.7 mm)
Crosslevel	+/- 1.25 inch (+/- 31.8 mm)	
Cross-level variation (62') (18.90 m)	+/- 1.75 inch (+/- 44.4 mm)	+/- 1.5 inch (+/- 38.1 mm)

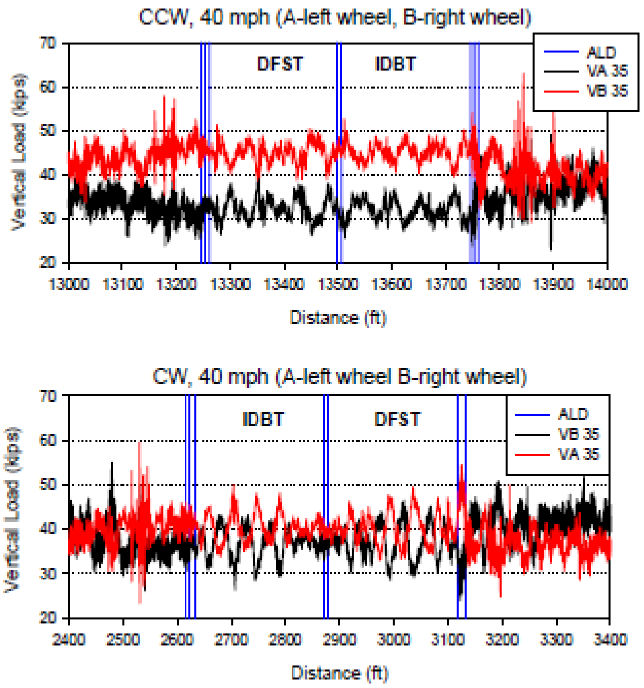
Figure 8: Permitted track geometry limits used in slab track testing

5.3.3 Dynamic wheel / rail forces on the slab track – vibration attenuation

During the field test, dynamic wheel and rail forces have been measured with a maximum vertical load of 58 kips (258 kN) and a maximum lateral wheel load of 20 kips (89 kN). Those forces generated in the slab track, were significantly lower than on the ballast track with the same curvature and superelevation, resulting from a superior track geometry as well as the resilient pads and boots.

Due to the resilient components of the LVT slab track, great vibration attenuation from the rails to the concrete slab has been achieved.

The vibration measurements were taken under heavy haul train operation at 40 mph (64 km/h). The maximum acceleration on the rails ranged between 10 g and 25 g (absolute value), whereas the maximum acceleration on the slab track ranged from 0.4 g to 2.0 g (absolute value).



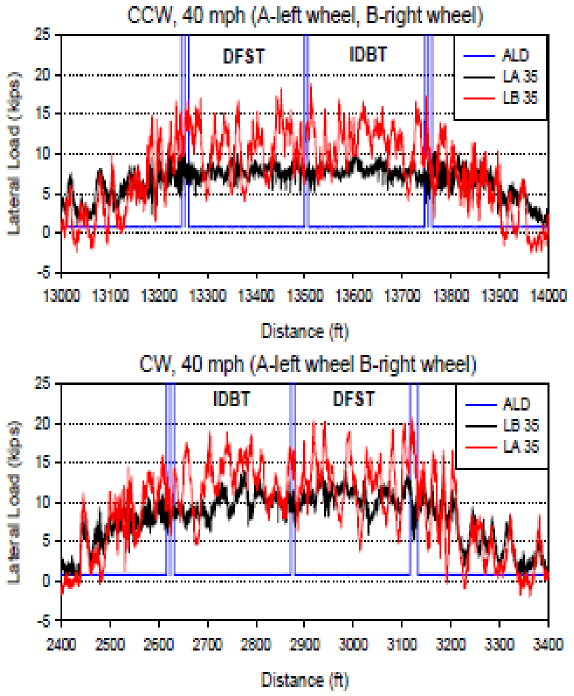


Figure 9: Vertical dynamic wheel loads measured via instrumented wheelsets
DFST – Direct fixation slab track
IDBT – Independent dual block track – LVT slab track

Figure 10: Vertical dynamic wheel loads measured via instrumented wheelsets
DFST – Direct fixation slab track
IDBT – Independent dual block track – LVT slab track

In general, the vertical and lateral loads were higher on the high rail due to the unbalanced speed at 40 mph (64 km/h). Analysing the signals of the instrumented wheelset, lower impact components of dynamic wheel loads were determined, compared to the finite element method analysis.

5.3.4 Inspection of LVT blocks and stiffness of block pad

After 169 MGT (US) (153 metric MGT) of heavy haul traffic an inspection of the LVT blocks was conducted.

The rails with the LVT blocks were lifted to pull the blocks from the cavity in the slab track. No obvious damages could be identified on components of the LVT support. The stiffness of the block pad increased only slightly, still meeting the demands and observing the required tolerances.

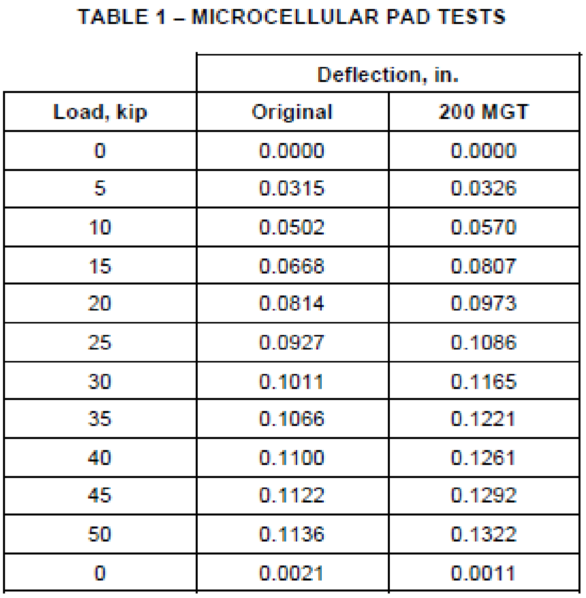


TABLE 1 – MICROCELLULAR PAD TESTS

	Deflection, in.	
Load, kip	Original	200 MGT
0	0.0000	0.0000
5	0.0315	0.0326
10	0.0502	0.0570
15	0.0668	0.0807
20	0.0814	0.0973
25	0.0927	0.1086
30	0.1011	0.1165
35	0.1066	0.1221
40	0.1100	0.1261
45	0.1122	0.1292
50	0.1136	0.1322
0	0.0021	0.0011

Table 1: Comparison of boot pad deflection under defined loads Original pads and pads after 200 MGT traffic operation

6. Conclusions

After 169 MGT (US) (153 metric MGT) of heavy haul traffic the LVT slab track system showed no signs of fatigue or defects of the LVT components. Additionally no rail defects, no significant wear of either high or low rail or rail corrugation were observed. During the time of test operation no gauge or alignment adjustment had to be made. Due to the design of the LVT system the dynamic vertical and lateral loads as well as the vibration from the rail to the slab were attenuated significantly.

The Transportation Technology Center recommends installing a test section of LVT slab track in revenue service with shared heavy freight and highspeed train operation, to receive additional empirical knowledge.

In this context, especially with the Eurotunnel - at 132 MGT (US) (120 metric MGT) per year the busiest tunnel in Europe - the LVT system shows important references all over the world for an economic slab track system provided with low maintenance needs as well as high availability and demanding liability.

7. References

[1] Dingqing Li, Slab Track Field Test and Demonstration Program for Shared Freight and High Speed Passenger Service, SN2988, Portland Cement Association (PCA), Skokie, Illinois, USA, 2007, 94 pages

[2] Hamid R. Lotfi and Ralph G. Oesterle, Slab Track for 39-Ton Axle Loads, Structural Design, SN2832 (revised 6/1/05), Portland Cement Association, Skokie, Illinois, USA, 2005, 94 pages

[3] Ball, G.B., Slab Track Laboratory Test Program, SN2795 (revised 6/11/04), Portland Cement Association, Skokie, Illinois, USA, 2004, 92 pages

[4] The Permanent Way Corporation (PWC), “Standard LVT Supports, Loading Design Document”, Alexandria, Virginia, USA, 2000