Appendix 4.7

Tunnel Coupling Factor

Description of the Measurements

The measurements involves impacting on the tunnel invert or ground surface and measuring the resulting vibration levels at sensors placed on the ground surface. Vibration sensors were orientated in a line (array or string) running radially outward from the point of impact, and transverse to the tunnel alignment. Vibration sensors of higher sensitivity were placed at greater setback distances.

Vibration measurements were made on 27 October 2005 during Metro-Cammell EMU (M-stock) passbys and during impact hammering on the trackform between Po Lam and Hang Hau Station (King Lam Estate) of Tseung Kwan O Line at CH64.063. Figure 2 & 3 shows the schematic drawings of measurement location. The impact hammering test performed on the centre of LVT trackform at down track CH64.063 in the tunnel and on the ground level above the tunnel (12m away from down track) is shown in Photos 1 and 2. Photo 3 shows the impact hammer for tunnel invert impact test and surface impact test.

Measurements during train passbys and hammer impacting were taken with the same linear array of geophones and accelerometers located radially outward from the point of impact, and transverse to the alignment, as shown in Photos 4 and 5. During impact or train passby, surface vibration measurements were simultaneously taken at eight setback locations of 12 m, 24 m, 27 m, 34 m, 44 m, 54 m, 64 m, and 74 m, respectively, from the tunnel impact point.

Instrumentation

The vibration sensor equipment used for the measurements is given in Table 1. Medium sensitivity accelerometres (Geospace Digiphones) were used for near location from the trackform, and high sensitivity accelerometres (10 V/g Wilcoxon 731A) were used at locations distant from the trackform.

The impact hammer drops a weight of 20 kg through a distance of 1.2m. A vacuum assist system is used both to lift the weight and to push on the down stroke, thus increasing the imparted energy to the ground by about 25%. Also, reversal of the airflow after the drop impact eliminates “multiple bounces” of the weight, which can ruin the data.

Other instruments used in the performance of test are shown in Table 2 and Photo 6. Signal conditioning and amplification was performed during measurements by either WIA Type 222 or B%K Nexus Type 2693 A 014 multi channel Conditioning Amplifiers. The vibration measurement data was recorded on a 8 channel DAT recorder. For surface impacting, the imparted load from the impact hammer was also recorded on this DAT. For tunnel impacting, the imparted load was recorded on a second DAT tape recorder located within the tunnel; in this case, vibration and load data was combined later during data analysis. The vibration data were analysed with a B&K Pulse 22 Channel Spectrum Analyser, Model 3560D, Serial #2382079 in 1/3 octave bands.

Measurement Data Analysis

Between 20 and 40 impacts were performed at each measurement location, and using the 22 channel B&K Pulse spectrum analyser, the data was time averaged to improve the signal to noise ratio. Transfer mobilities were determined in one-third octave bands using the time averaged data from each vibration sensor and the imparted load.

Indicative Results

TCF is the difference of the LSR obtained from impact tests (yielding PSRs) where impacts are performed in the tunnel and on the ground surface just outside of the tunnel. The LSRs are obtained from the PSRs in the same way as described in Appendix 4.5 and Appendix 4.8. Interestingly, in Figure 1, the TCF curve is similar to the BCF curve for type 2 (1-2 story residential complexes). The TCF taken for the WIL projection is the maximum envelope of TCF obtained and the type 2 BCF curve. Although other experimental evidence suggests that heavier tunnel structures will result in even greater attenuation, just as heavier foundations result in BCFs with greater attenuation, comprehensive data is not yet available. Thus we apply that which has been measured on the MTR system to all tunnel types. As with building coupling factors, the TCF obtained herein is only valid for soil based tunnels – in rock, the TCF is assumed to be zero.

References

1. Nelson, J.T. and H.J. Saurenman, “Procedures for Prediction of Ground-Borne Noise and Vibration from Rail Transit Trains”, May 1986. Preliminary Draft prepared by Wilson, Ihrig & Associates, Inc., Oakland, CA for the Transportation Systems Centre of the US Department of Transportation.

Tables

Table 1 Location of Vibration Measurements at King Lam Estate for TCF Measurements and Equipment Used

Setback (m)	Accelerometer/ Geophone	Charge Amp/ Preamp
12	Geospace Digiphone #1	WIA Geophone Preamp Unit #1
24	Geospace Digiphone #3	WIA Geophone Preamp Unit #3
27	Geospace Digiphone #2	WIA Geophone Preamp Unit #2
34	Geospace Digiphone #4	WIA Geophone Preamp Unit #4
44	Geospace Digiphone #5	WIA Geophone Preamp Unit #5
54	Wilcoxon Seismic Accelerometer Model 731A Serial # 2181	Wilcoxon P31 Power Unit/ Amplifier Serial #1504
64	Wilcoxon Seismic Accelerometer Model 731A Serial # 2182	Wilcoxon P31 Power Unit/ Amplifier Serial #1505
74	Wilcoxon Seismic Accelerometer Model 731A Serial # 2183	Wilcoxon P31 Power Unit/ Amplifier Serial #1506

Table 2 Other Instruments Used in the Performance of Impact Testing and Analysis

Instrument	Manufacturer / Model No.	Serial Number
22-Channel Spectrum Analyser,	B&K Pulse, Model 3560D,	2382079
8-channel DAT Recorder	Teac RD130TE	512826
8-channel DAT Recorder	Teac RD135T	731107
4-channel Conditioning Amplifier	B&K Nexus, Type 2693 A 014	2407019
2-Channel Conditioning Amplifier	WIA Type 222	-
20 kg vacuum assisted impact hammed with load cell	WIA	-
Strain Gauge Preamplifier	WIA	-

Photos

PHOTO 1 IMPACTING ON THE TRACK CENTRE INSIDE THE TUNNEL AT DOWNTRACK CH64.063 OF THE MTRC TSEUN KWAN O LINE

PHOTO 2 IMPACTING ON THE GROUND LEVEL (CENTRE OF THE PHOTO) ABOVE THE DOWNTRACK TUNNEL

PHOTO 3 WHAMMY IMPACTING WITH A HAMMER PLATFORM SETUP ON THE GROUND TO TRANSMIT THE IMPACT FORCE TO THE TUNNEL

PHOTO 4 GEOPHONE ARRAY DESIGNED TO SIMULTANEOUSLY MEASURE VIBRATION LEVELS AT DIFFERENT LOCATIONS FROM IMPACTING POINT

PHOTO 5 HIGH SENSITIVITY, LOW NOISE SEISMIC ACCELEROMETRE

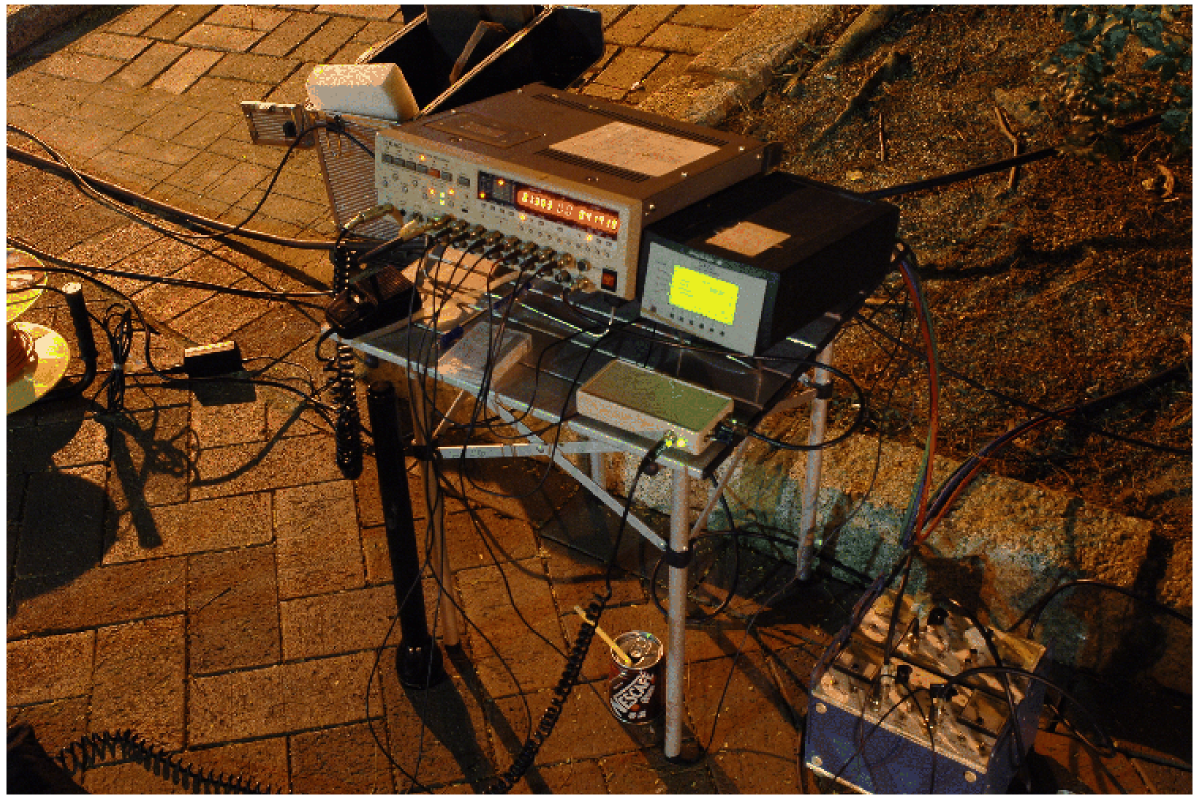

PHOTO 6 DATA ACQUISITION SYSTEM AND DIGITAL AUDIO TAPE RECORDER USED TO RECORD MEASUREMENT DATA

Figures

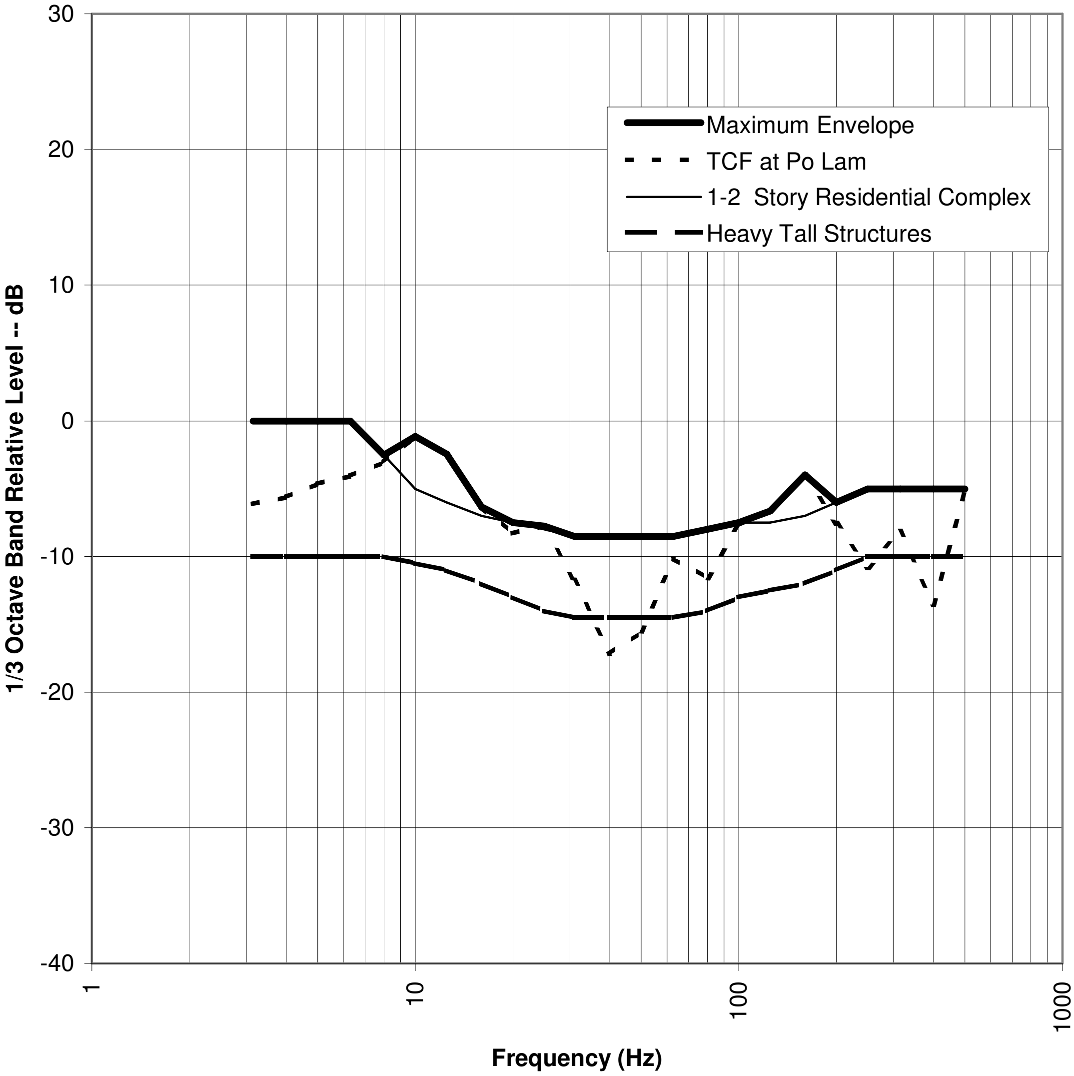

FIGURE 1 TCF AT PO LAM

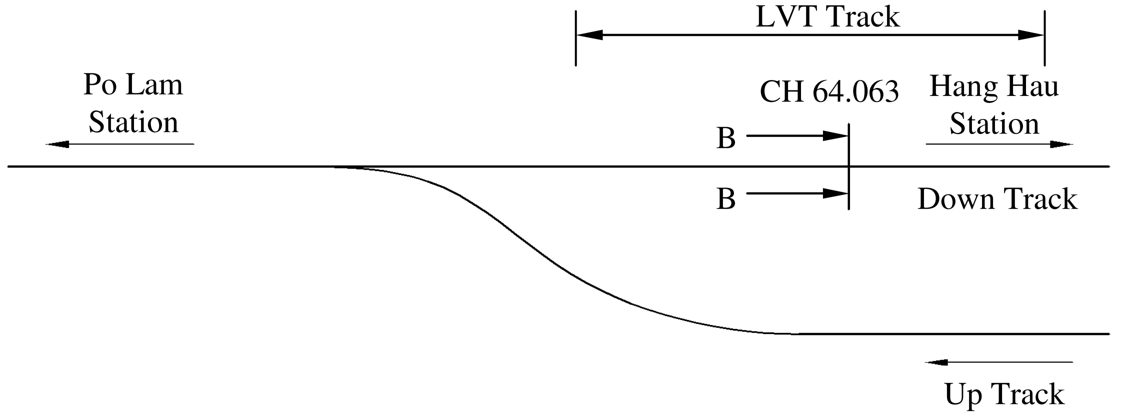

FIGURE 2 SCHEMATIC ARRANGEMENT OF PO LAM STATION MEASUREMENT

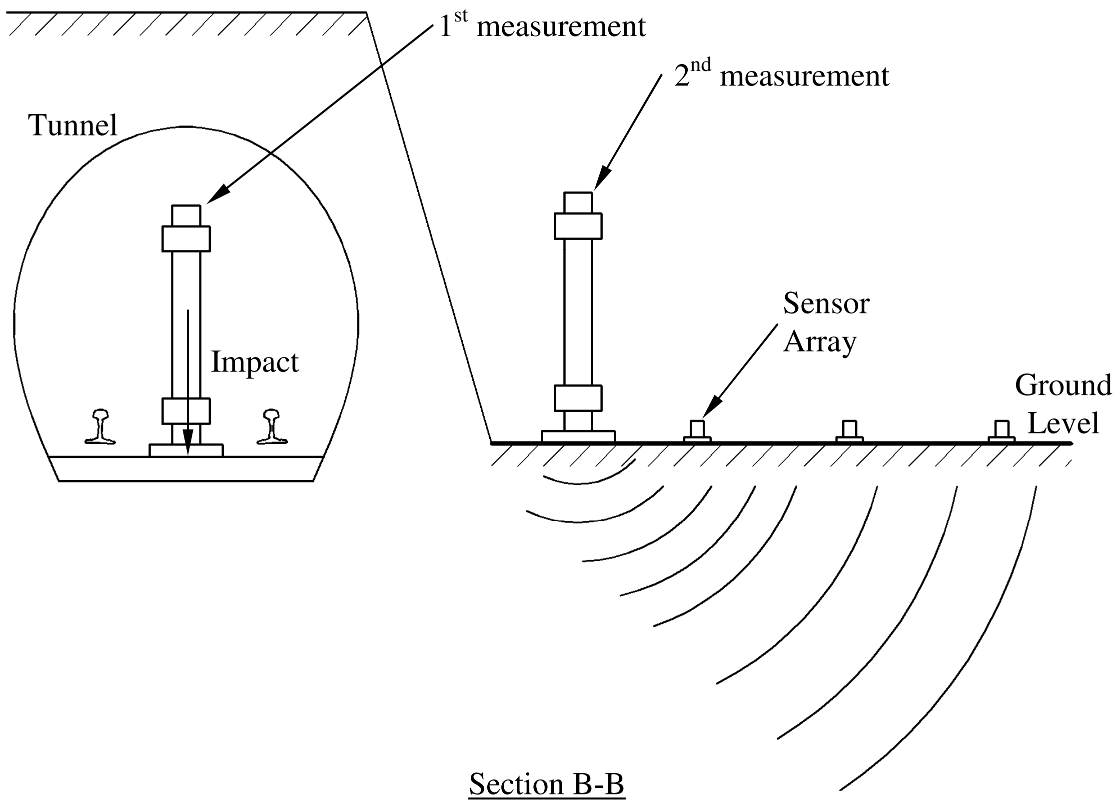

FIGURE 3 SECTION VIEW OF PO LAM STATION MEASUREMENT