East – West Rail: Phase 1

Chiltern Railways Company Limited

Vibration from Switches & Crossings – Assessment and Mitigation

5114534-ATK-VIB-RPT-80003
Revisions A01

21 January 2014

Plan Design Enable

Notice

This document and its contents have been prepared and are intended solely for Chiltern Railway Company Limited's and Network Rail's information and use in relation to the East West Rail Phase 1 single option development.

Atkins Rail assumes no responsibility to any other party in respect of or arising out of or in connection with this document and/or its contents.

This document has 89 pages including the cover.

Document history

Job number: 5114534			Document ref: 5114534-ATK-VIB-RPT-80003			
Revision	Purpose description	Originated	Checked	Reviewed	Authorised	Date
P01	Working Draft for comment	I. Ekici	-	-	-	3/12/2013
P02	Revised Draft for comment	I. Ekici	P. Hainsworth	-	-	13/12/2013
P03	Issue for Comment	I. Ekici	P. Hainsworth	-	-	17/01/2014
A01	Formal Issue	I. Ekici	P. Hainsworth	D. Terry	P. Hampshire	21/01/2014

Client signoff

Client	Chiltern Railway
Project	East West Rail Phase 1
Document title	Switches & Crossings Vibration Assessment and Mitigation
Job no.	5114534
Copy no.	1
Document reference	Switches & Crossings Vibration Assessment and Mitigation

Table of contents

Tables

Executive summary

Atkins is currently undertaking the detailed design of the proposed double-tracking of Oxford to Bicester Rail line (referred to as the 'Scheme' in this document). There are a number of vibration conditions which need to be discharged with the local planning authority before the Scheme can be built.

This is a supplementary report which deals with vibration from the switches and crossings. It should be read in conjunction with a more comprehensive report on vibration from the plain line (see reference 1).

The assessment showed that at the S&C sites, despite conservative assumptions, the day and night-time VDV targets would not be exceeded. However, particularly at Whimbrel Close and London Road, the predicted night-time levels are close to target VDVs.

It is understood that the proposed S&C design is standard and there is limited scope for changing the geometry. It is recommended that the crossing nose impact is kept to a minimum by maintaining a good vertical track and switching nose geometries throughout the design life of the crossing. This will ensure rail wheel transition over the crossing point is as smooth as possible, and minimise levels of vibration generated.

1. Introduction

1.1. Atkins is currently undertaking the detailed design of the proposed double-tracking of Oxford to Bicester Rail line (referred to as the 'Scheme' in this document). There are a number of vibration conditions which need to be discharged with the local planning authority before the Scheme can be built.

1.2. This is a supplementary report which deals with vibration form the switches and crossings (S&C). It should be read in conjunction with a more comprehensive report on vibration from the plain line (see reference 1). The aim of this report is to present appropriate data and analysis, and based on the relevant vibration conditions, make recommendations on suitable forms of mitigation measures, to support the application process.

1.3. The structure of the report is as follows;

- Section 3 describes the scheme proposals related to switches and crossings
- Section 4 gives details of vibration monitoring undertaken at an appropriate S&C site
- Section 5 identifies the main parameters of importance in assessing vibration generation from S&Cs and derives appropriate vibration amplification factors from measurements undertaken as part of this project.
- Section 6 provides details of calculations to determine the resulting vibration levels from S&Cs using amplification factors derived in previous section.
- Section 7 presents main conclusions of this study.

1.4. A glossary of technical terms is provided in **Appendix A** and a list of technical references are given in **Appendix B**.

2. Scheme Proposals

Background

2.1. All scheme-wide assumptions are contained in a separate report **[1]**.

Project Vibration Limits

2.2. The vibration limits, in Vibration Dose Value (VDV), which the Scheme is required to meet in occupied vibration-sensitive receptor buildings adjacent to the Scheme are summarised below;

- Day (0700 – 2300 hours) - 0.4 $m/s^{1.75}$
- Night (2300 – 0700 hours) - 0.2 $m/s^{1.75}$

2.3. Vibration Dose Value (VDV) is a measure of the accumulated level of vibration over a period, and, through the application of BS6472 **[2]**, is a standard metric for predicting the likelihood of adverse comments from building occupants. According to the guidance contained in the standard, the probability of adverse comment at or below the described threshold VDV levels, as adopted by the Scheme, is low.

Receptors

2.4. Along the proposed scheme, there would be eight different Switches and Crossing (S&C) locations. The locations of the S&C have been reviewed and the nearest residential receptors have been identified from the toe of the turnout or crossover, as shown in Table 1.

Table 1. Receptors near proposed S&Cs

S&C Location	Nearest Residential Receptor	Approximate Distance to Crossing Point (m)	Other Nearby Receptors
Woodstock Road Junction	4 Bladon Close	<50	12 & 16 The Quadrangle 79 Blenheim Drive 4 & 8 The Quadrangle
Water Eaton Junction	Middle Cottage (Nr Middle Farm)	400	Middle Farm
Bicester Depot West Junction	Property Off Langford Lane	280	Central Ordnance Depot
Bicester Depot East Junction	Langford Park Farm	130	N/A
Gavray Junction	16 Whimbrel Close	<50	Several Properties on Whimbrel Close
Jarvis Lane Junction	N/A	N/A	Industrial Use Buildings (5 to 20m)
Bicester South Junction	105 Heron Drive	>300	Bicester Park Industrial Use Buildings (30 to 35m)
London Road Level Crossing	21 London Road	<50	5 London Road

2.5. The table above shows that at most locations the vibration sensitive properties are located far away from the S&Cs (greater than 100m) and the project VDV limits are not expected to be exceeded at these distances.

2.6. At three locations (Woodstock Road Junction, Gavray Junction and London Road Level Crossing), the dwellings would be within 50m of S&Cs, where there is a risk of increased vibration from the presence of proposed crossing points. As illustrated in Figures 1-3, the nearest dwellings to the crossing points are No.4 at Bladon Close, No.16 at Whimbrel Close and No.21 London Road, respectively at Woodstock Road Junction, Gavray Junction and London Road Level Crossing, and the assessments have been based on these properties.

2.7. The distance between each track and the properties are summarised below;

- No.16 at Whimbrel Close – 6.8m from chord line, 10.9m from track 1 and 14.3m from track 2
- No.4 at Bladon Close – 14.7m from track 1 and 16.5m from track 2
- No.21 at London Road – 9.7m from track 1 and 13.1m from track 2

2.8. The distance between the crossing point and the properties are summarised below;

- No.16 at Whimbrel Close – 12.5m from crossing point 1, 21.8m from crossing point 2
- No.4 at Bladon Close – 19.2m from crossing point
- No.21 at London Road – 11.2m from crossing point 1, 17.0m from crossing point 2

Figure 1. Switches and Crossings near Whimbrel Close

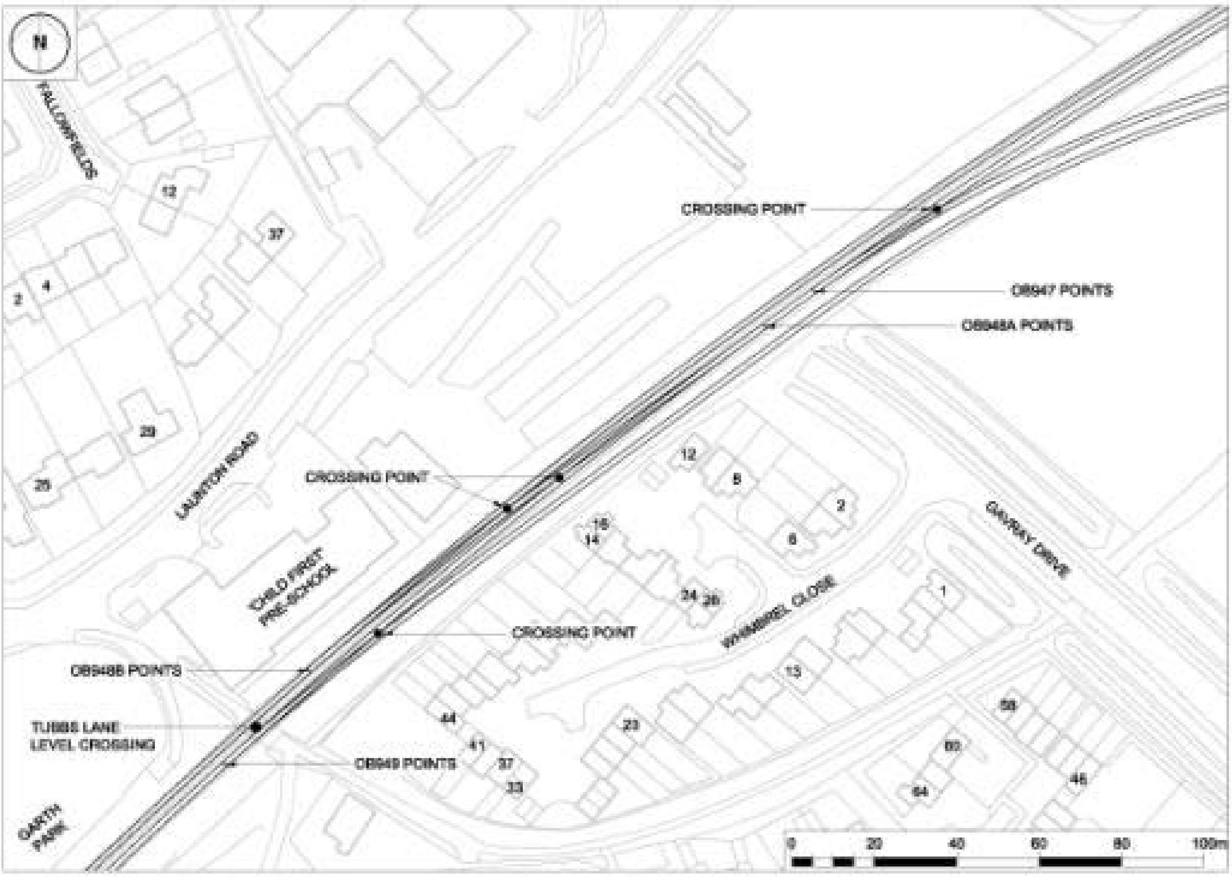


Figure 2. Switches and Crossings near Bladon Close

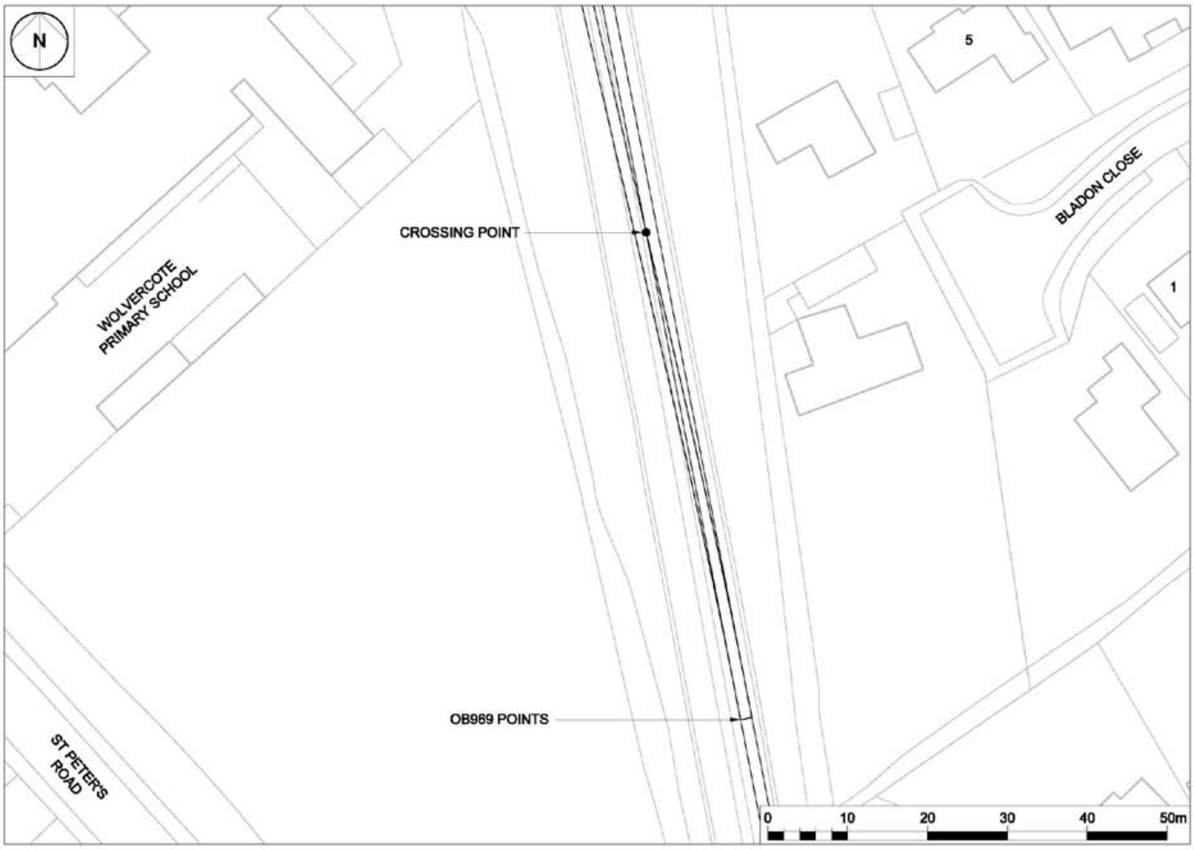
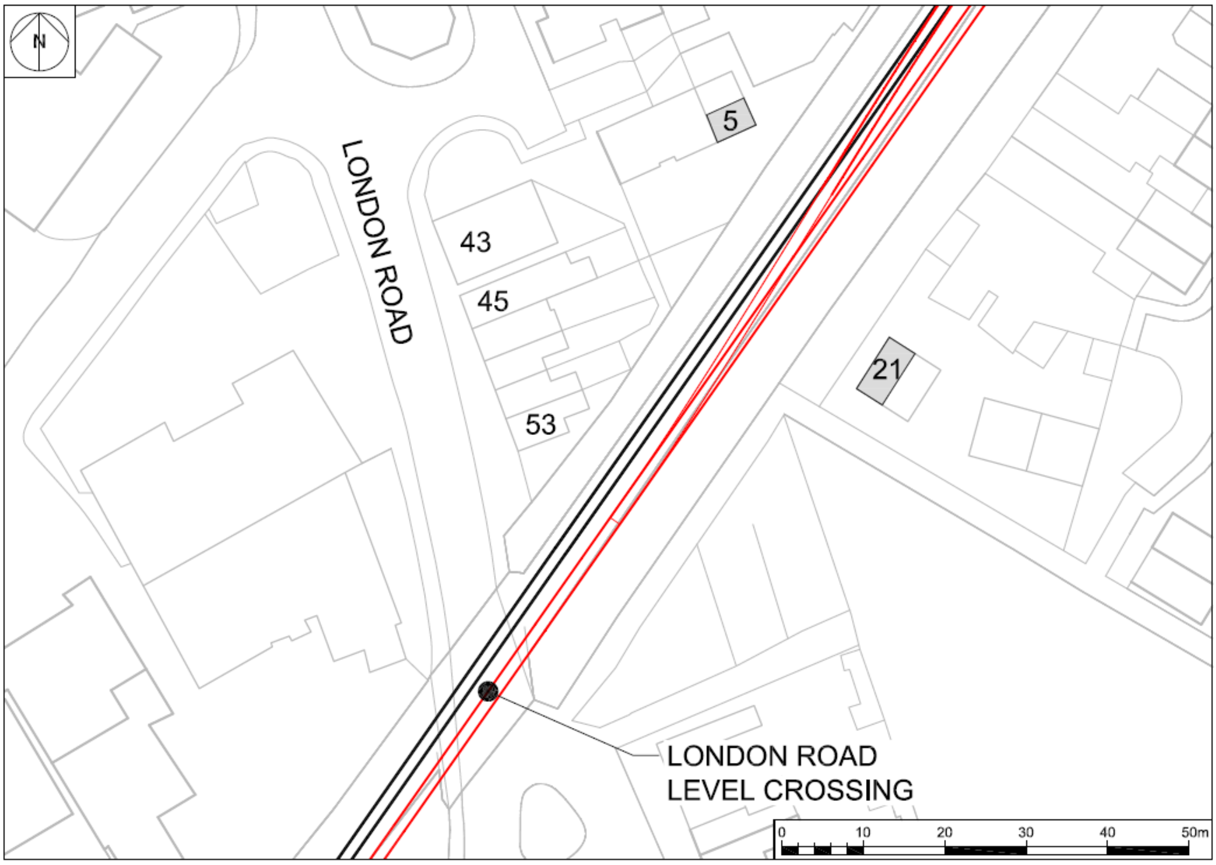


Figure 3. Switches and Crossings near London Road



Proposed S&Cs

2.9. The details of the proposed S&C designs are summarised below.

Table 2. Proposed S&C Designs

Details	OB947	OB948 A/B	OB949	OB969
Rail type	NR60	NR60	NR60	NR60
Switch Type	E Switch	SG transitioned	F Transition	SG transitioned
Crossing angle	1/12.5	1/27	1/21.5	1/27
Bearer type	Concrete	Concrete	Concrete	Concrete
Depth of switch	Shallow depth	Shallow depth	Shallow depth	Shallow depth
Turnout radius	350m	665m	485m	1539m
Train types and speed through crossing	Passenger on chord 40mph Passenger on mainline 100mph Freight on mainline 70mph	Passenger on chord 40mph Passenger on mainline 100mph Freight on mainline 70mph	Passenger on chord 40mph Passenger on mainline 100mph Freight on mainline 70mph	Passenger on mainline 100mph Freight on mainline 70mph Freight on ‘other mainline’ 60mph

2.10. The following section describes the findings of vibration monitoring to determine likely amplification in vibration levels in the vicinity of switches and crossings, compared with vibration from a plain line.

3. Vibration Monitoring Survey

3.1. This section gives details of vibration monitoring undertaken at an appropriate S&C site. Vibration measurements were undertaken by Atkins during a site visit on the 12th and 13th November 2013.

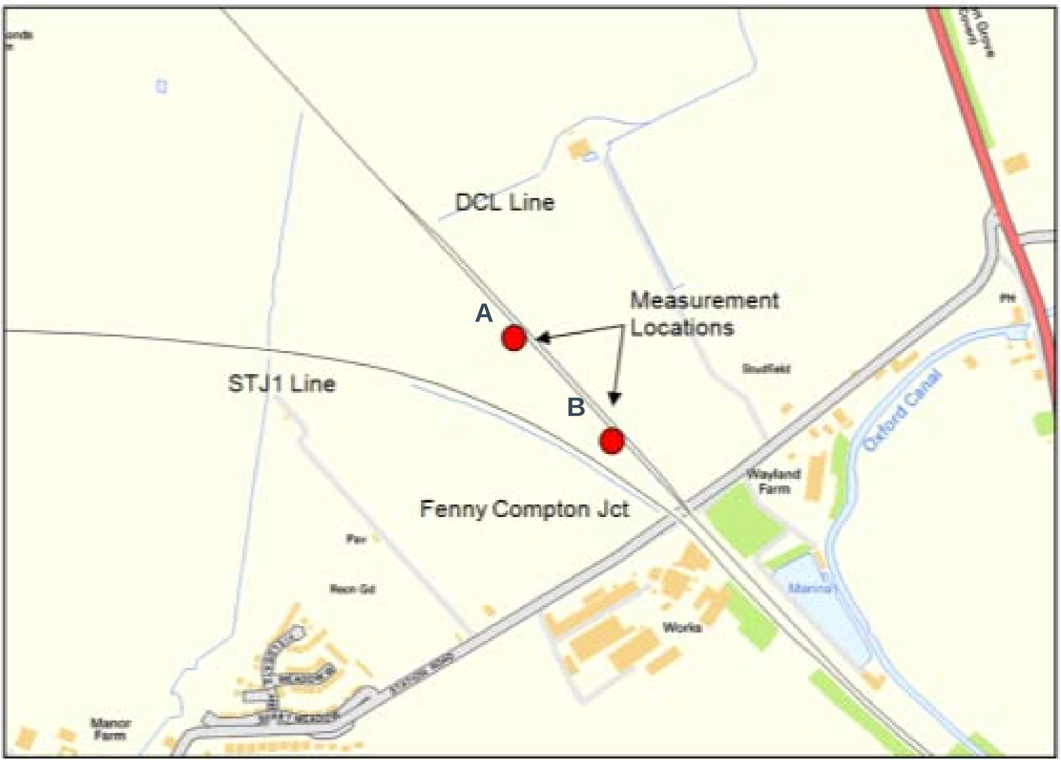
Introduction

3.2. An initial desk-based investigation identified ten potential S&C vibration monitoring sites.

3.3. A comparative study of the potential S&C sites was undertaken using British Geological Society maps, OS mapping and aerial site photography. These references were used to determine; the underlying geology (bedrock); the surrounding earthworks; the similarity of S&Cs to Gavray Junction and/or Woodstock Road S&Cs, and if the site appeared to have suitable locations for vibration monitoring. Through this exercise and subsequent site visits by Atkins, it was ascertained that only one of the potential sites, Fenny Compton Junction North, was suitable for the desired vibration measurement procedure.

3.4. The Fenny Compton Junction North was the only suitable accessible site with similar underlying geology (Charmouth Mudstone - stiff silty clay/blue lias), sufficient space to undertake the simultaneous vibration measurements and no site restrictions such as cuttings or features which would affect vibration measurements. The approximate location of the measurement site is shown in Figure 4 below.

Figure 4. Vibration Monitoring Locations at Fenny Compton



3.5. The measurement locations were at the Fenny Compton Junction, where the STJ1 line (Line to Kineton MOD) merges with the DCL lines (Banbury to Leamington Spa) on an embankment area of made ground understood to be on bedrock of Charmouth mudstone, a stiff silty clay/blue lias. Local ground conditions at the junction also included an amount of fill material consisting of ballast, rubble and stiff silty clay/blue lias similar to the surrounding geology.

3.6. Photographs of the measurement location are presented In Figures 5 and 6 below:

Figure 5. Position A

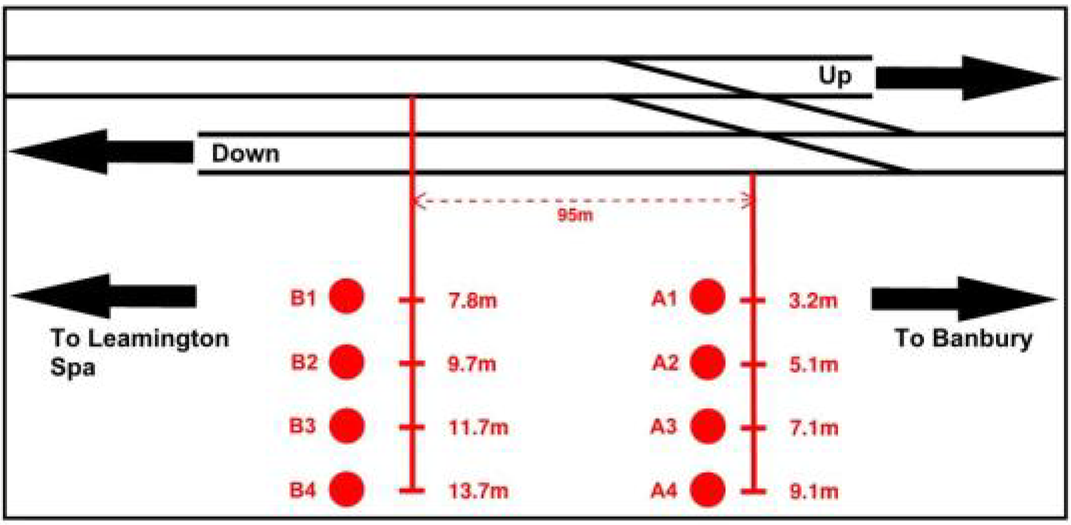
Figure 6. Position B

Measurement Positions

3.7. The ground was prepared for each measurement position by using a trowel to dig a shallow hole, approximately 150mm deep, which was made level and any loose material removed. Plaster of Paris was poured into the hole, then a solid steel plate (dimensions 100mm x 100mm x 15mm) was placed level in to the plaster. The heavy metal platform was then used to mount the accelerometers.

3.8. Four measurement positions (A1 to A4) were set up at sequential distances, perpendicular to track 1 (nearest track) at the crossing point to measure the vibration as the trains move over the crossing point. The crossing point on track 2 (further track) was horizontally offset 25m, as well as the vertical separation shown in Figure 7. Four more positions (B1 to B4) were set up 95 metres away along the line at equal distances from the track, to act as a measure of the passing trains on normal track.

Figure 7. Measurement Positions in Relation to Track



3.9. At the two positions nearest to the track tri-axial accelerometers were used. For the remaining positions, mono-axial accelerometers were used to measure the Z-axis only. The orientation of the accelerometers in relation to the railway track as follows:

- X axis (horizontal) – perpendicular to the tracks
- Y axis (horizontal) – parallel to the tracks
- Z axis (vertical) – vertical to the tracks

3.10. An example of the measurement position set up can be seen in the Figure 8:

Figure 8. Example Measurement Position Accelerometer Set Up

Equipment Set Up

3.11. Instruments used to undertake ground vibration measurements were provided by Acoustic1 Limited, Gracey & Associates and Campbell Associates. The general set up was a combination of tri-axial and mono-axial accelerometer connected to NetdB, a multi-channel acquisition unit, which communicated real-time with the dBFA software suite. The software (dBTrig) recorded the signals and gave the opportunity for real-time analysis and checks on-site. This set up is demonstrated in Figure 9 below.

Figure 9. Measurement Equipment Set Up

3.3.1 Table 3 details the vibration equipment details.

Table 3. Vibration Equipment Details

Equipment	Type	Serial Number
Multi-Channel Acquisition Unit and Analyser	01db – Net dB	LCF011500-142
Tri-axial Accelerometer	(Piezoelectric) PCB 356B18	LW133898
Mono-axial Accelerometer	(Piezoelectric) CTC – AC133-1D	1044
Mono-axial Accelerometer	(Piezoelectric) CTC – AC133-1D	1045

Equipment	Type	Serial Number
Mono-axial Accelerometer	(Piezoelectric) CTC – AC133-1D	1046
Mono-axial Accelerometer	(Piezoelectric) CTC – AC133-1D	1047
Mono-axial Accelerometer	(Piezoelectric) CTC – AC133-1D	799M11729
Tri-axial Accelerometer	MMF – KS823B	10074
Mono-axial Accelerometer	B&K 4507 002	10412
Mono-axial Accelerometer	B&K 4507 002	10413
Mono-axial Accelerometer	B&K 4507 002	10414

3.12. All vibration measurement equipment had been reference calibrated within the last two years. Calibration certificates for all accelerometers are provided in **Appendix C**.

3.13. Other equipment used on the site surveys included:

- Digital Camera
- Digital Video Recorder
- Tape measure
- Anemometer
- Trowel, Plaster of Paris & water

Survey Details

3.14. During the period of time spent on site, the weather was cold with clear skies and negligible levels of wind. The conditions were considered suitable for vibration measurements.

3.15. As shown in Figure 7, there were eight measurement positions set up at this location, each 2 metres apart in a direct line perpendicular to the railway tracks. Details of each position are summarised in Table 4:

Table 4. Measurement Position Details

Position (From Figure 7)	Accelerometer set up	Distance to nearest rail head of Main Down line (m)	Distance to nearest rail head of Main Up line (m)
A1/ B1	Tri-axial (x, y & z)	3.2	7.8
A2/ B2	Mono-axial (z)	5.1	9.7
A3/ B3	Mono-axial (z)	7.1	11.7
A4/ B4	Mono-axial (z)	9.1	13.7

3.16. There were 71 pass-by events recorded which included 18 freight and 52 passenger trains.

Permanent Way Inspection

3.17. A permanent way inspection was conducted on the 20th November 2013 by Julien Green at the Fenny Compton Junction (ELR – DCR). The results are contained in Atkins technical note

5114534-ATK-GEN-TN-00044 PO2 which is included in **Appendix D**. The turnout radius was 448m.

3.18. The scope of the inspection was to determine the overall condition of the permanent way and to identify factors that would affect the general integrity of the track.

3.19. The report concludes that the track is in a good condition, with no evidence of "track pumping" or other that would be outside of the normal parameters for a well-maintained line for the track category currently in service.

Measurement Results

3.20. The table in **Appendix E** provides a summary of the pass-by events observed at both measurement locations. Each pass-by event has a unique event number which are subsequently used to refer to the different events in this report.

3.21. The acceleration signal was measured for each pass-by event and this was processed as required to obtain the relevant outputs for this study. Before the weighted RMS acceleration and VDV/eVDV values could be determined, a fourth order high pass filter was used on all measured signals with a 1 Hz cut-off, in order to remove unwanted low frequency interference in the signal.

3.22. The VDV and eVDV values for all events during both site surveys are presented in **Appendix F** along with weighted RMS acceleration data for selected events. In accordance with the guidance of BS6472 Part 1:2008 – "Guide to evaluation of human exposure to vibration in buildings" **[2]**, the measured acceleration has been frequency weighted using the following correction weightings for the different axes:

- X axis = Wd weighting
- Y axis = Wd weighting
- Z axis = Wb weighting

As defined in **[2]**.

3.23. From these the weighted acceleration values the VDV and eVDV values have been derived by the analysis software.

3.24. The next section presents an analysis of data to determine the influence of switches and crossings on vibration levels.

4. Vibration from S&Cs

4.1. This section identifies the main parameters of importance in assessing vibration generation from S&Cs and derives appropriate vibration amplification factors from measurements undertaken as part of this project.

Main Parameters

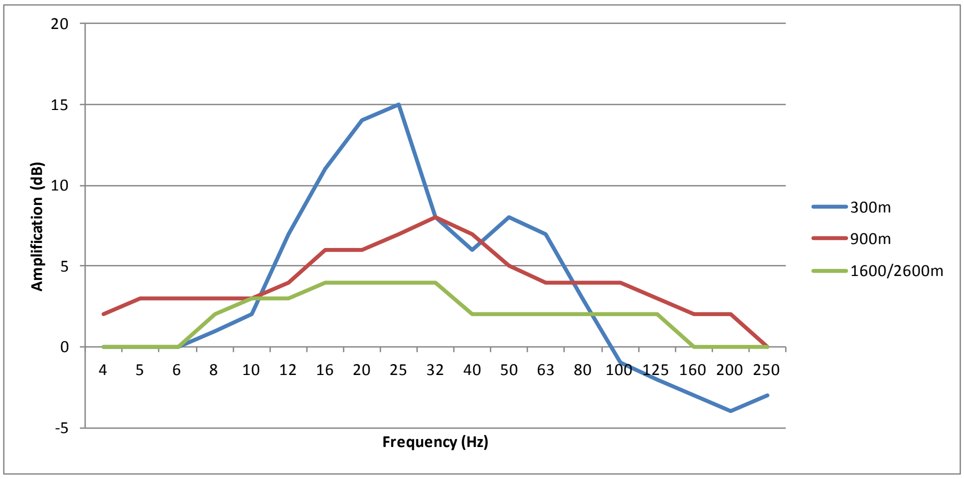
4.2. A desk-based review was undertaken of a study carried out as part of the RIVAS project to identify the main parameters of significance affecting vibration generation from S&Cs **[3]**.

4.3. The turnout-amplification is defined as the amplification, normally frequency dependent, of the measured vibrations at the turnout in comparison to the reference track. The turnout-amplification depends on the turnout type, the quality of the turnout-geometry, the maintenance state of the crossing as well as the characteristics of the track and the ground.

Effect of turnout radius

4.4. Average values of turnout amplification (TA), in dB, derived from a number of measurements are shown below for various turnout types (radius). The reference track was at grade and comparisons relate to a distance of 8m from the track.

Figure 10. Turnout Amplification with Radius (RIVAS project)



4.5. As shown above, the smaller the turnout radius, the higher the amplification caused by the crossing point. The frequencies affected were typically between 12.5Hz and 63Hz.

Effect of distance

4.6. The amplifications with distance can be assessed using a simple empirical relationship, according to which, beyond 50m no amplification is expected.

$$F = 1 - d / 50$$

4.7. Where;

- F is a factor that takes into account the influence of the distance on amplification factor due to a turnout
- d is the distance, in m, between the receptor and the crossing point

4.8. This factor could be used in the following equation to identify the resulting vibration levels due to a turnout.

$$V_{turnout} = V_{without\ turnout}\ (1 + F * (TA_{8m} - 1))$$

4.9. Where;

- $V_{turnout}$ and $V_{without\ turnout}$ are linear vibration levels, in mm/s, for with and without the turnout respectively
- F is the distance factor from above equation (no unit)
- TA_{8m} is the turnout amplification at 8m (no unit)

Effect of train speed and direction

4.10. It was observed that the vibration levels increased with increased train speeds, however the turnout amplifications did not change significantly.

4.11. There was no clear effect due to the direction of train.

Other parameters

4.12. The type of trains, the S&C design, quality of the turnout geometry, the maintenance state of the crossing were also identified as being significant factors affecting vibration emission from S&Cs.

4.13. It was observed that measurements from track in cuttings resulted in lower vibration levels when compared with those obtained from track on an embankment. This difference was attributed to the influence of track and subsoil. However the type and conditions of track and ground encountered as part of RIVAS studies are not described in detail. Although a large number of pass-by events were observed, the differences in the measurement methodology adopted by different research teams, as well as the geological differences between reference track and the track with S&C limit the analysis and reproducibility of results.

Measured Amplification from S&C on Track 1

4.14. In this section, only the pass-by events observed on the nearest track (track 1) have been described. The measured dB weighted acceleration level re 10^{-6} m/s^2, are shown against distance from nearest rail, along both the S&C and the plain line sections of the track. The difference between the levels for each pass-by event is identified as an amplification factor in dB, due to the presence of S&C. Figure 11 and 12 illustrate this information for freight and passenger trains respectively.

4.15. The highest amplifications are noted to be between 5.1m and 7.1m from the track depending on the vehicle type. At 9.1m from the track, the amplification in overall weighted acceleration vibration levels is approximately 8dB for freight trains and 11dB for passenger trains. This is consistent with published guidance values of 10dB (or a factor of 3.16) by FTA **[4]**.

4.16. On average, the amplification factors were found to decay at a rate of approximately 2dB every 10m from track for freight trains and 1dB for every 10m from track for passenger trains. This distance relationship is similar to the findings of the RIVAS study which observed a decay rate of around 1dB for every 10m between 8m and 35m from track.

4.17. The empirical relationship derived as part of the RIVAS study suggests that beyond around 50m, no further amplification is expected from a ‘turnout’. The results of measurements undertaken as part of this study are generally consistent and show that no S&C amplification is expected beyond around 40m from track for freight trains and 80m from track for passenger trains.

4.18. It is considered that the above observations support the use of amplification factors at the Fenny Compton site, and applying these to measured levels at Wolvercote for estimating the vibration levels with the scheme.

Figure 11. S&C Amplification due to Freight trains

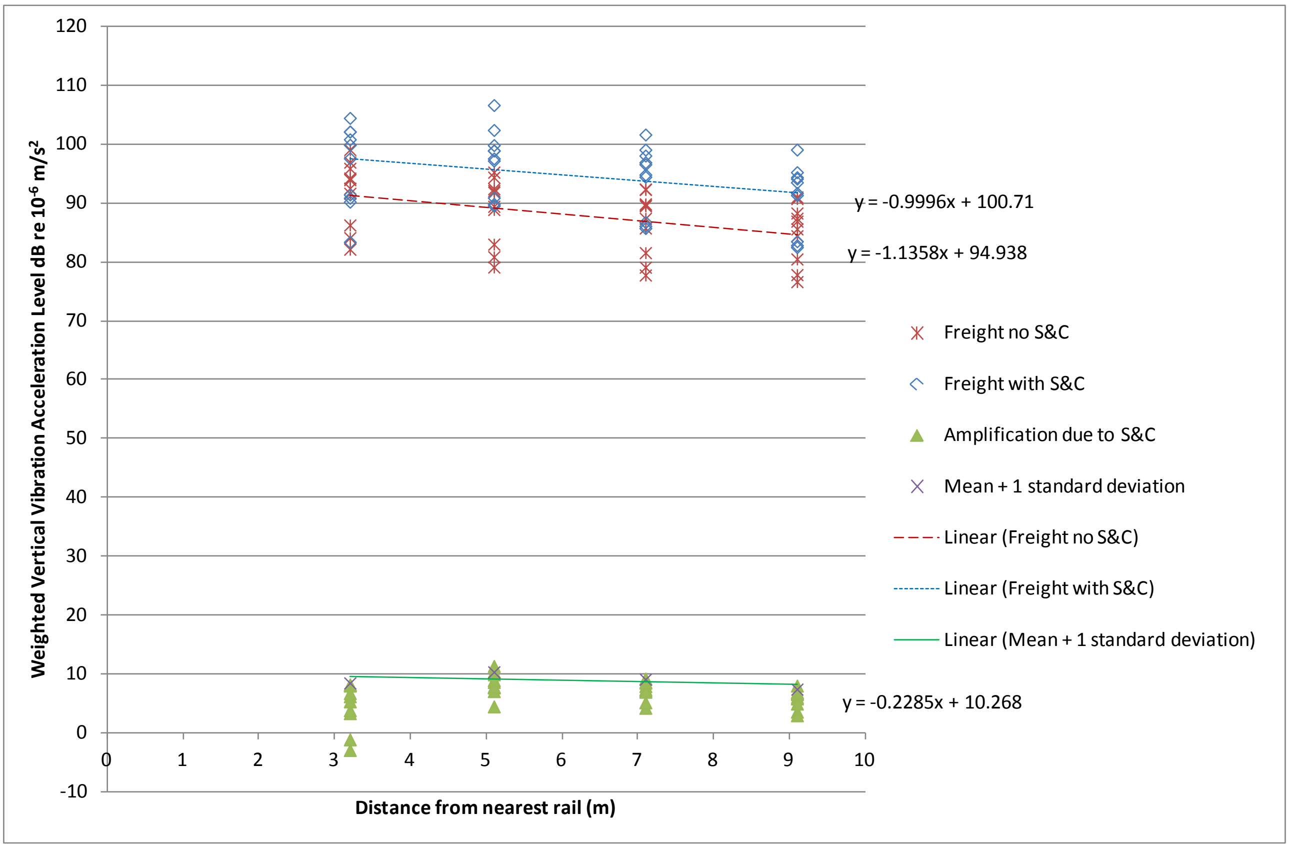
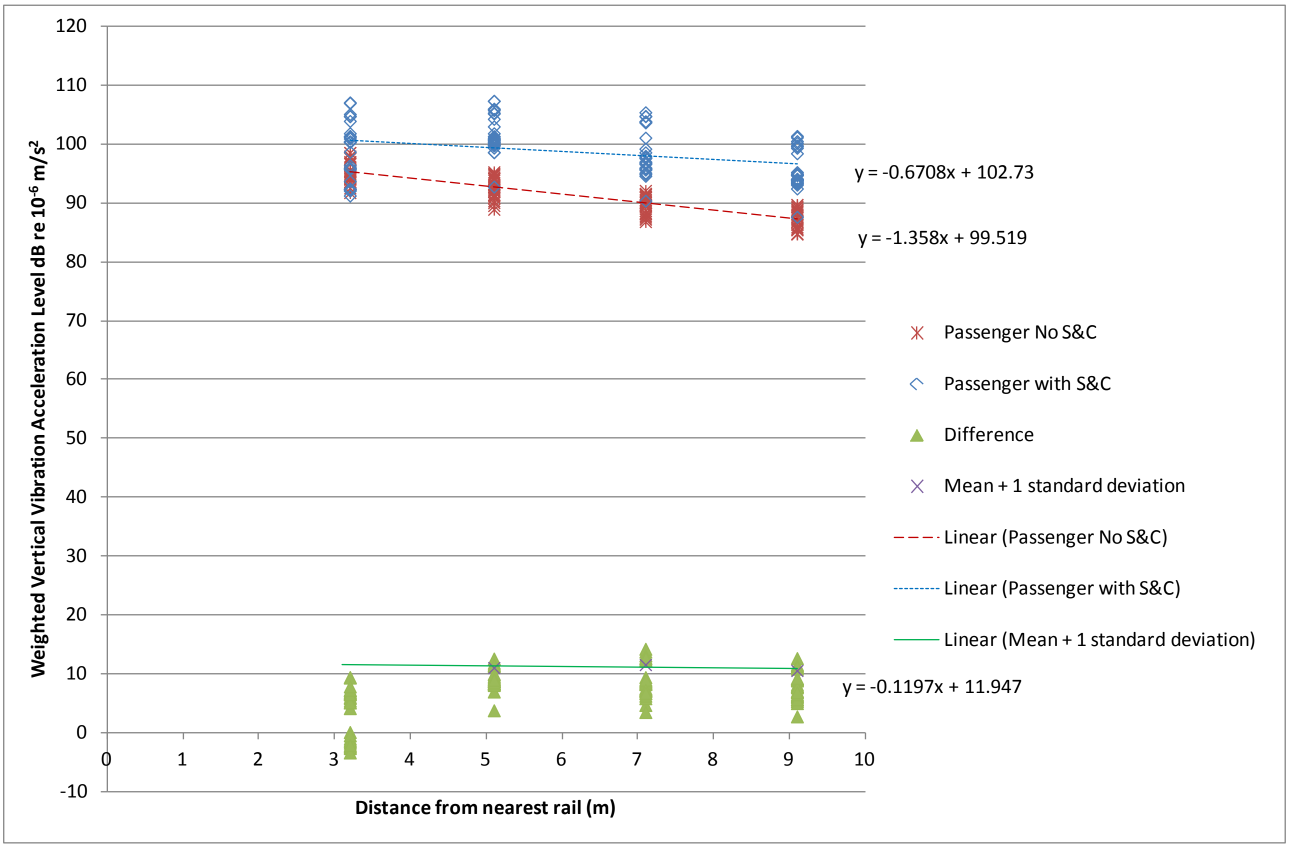


Figure 12. S&C Amplification due to Passenger trains



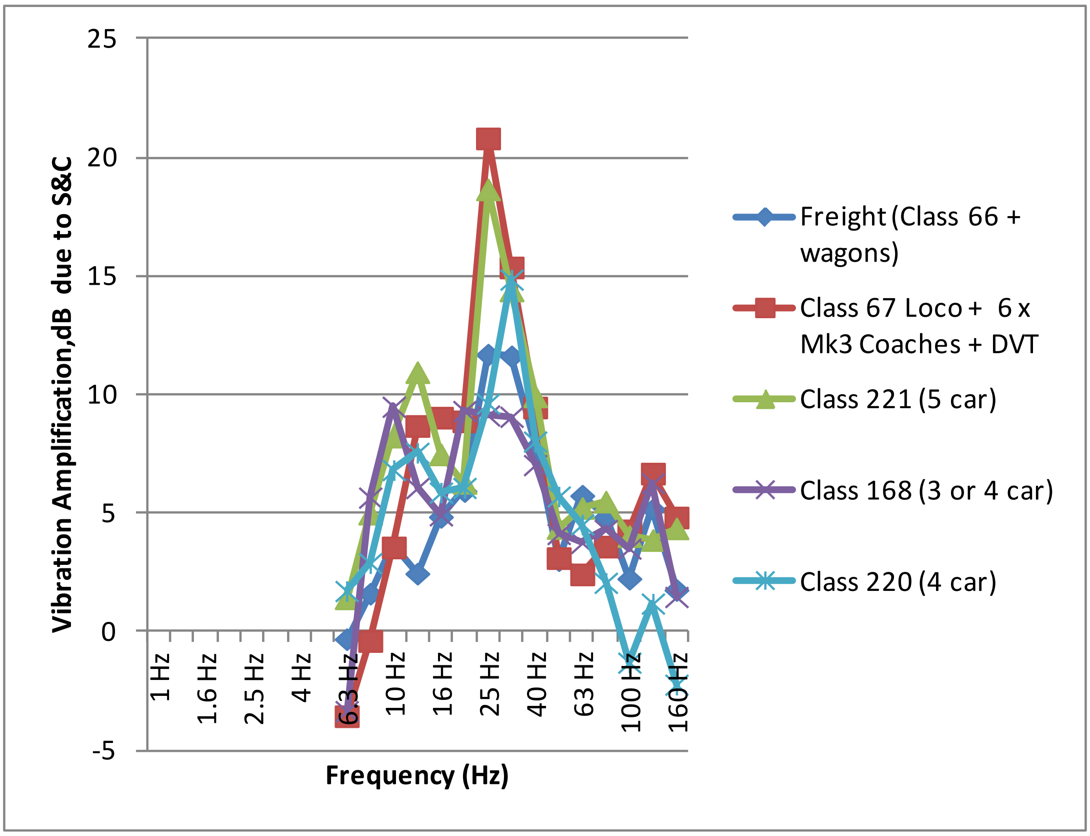
4.19. The variation in the amplification factors at each 1/3 octave band frequency is shown in **Appendix G** for all pass-by events on track 1.

4.20. Figure 13 shows average vibration amplification in dB at 9.1m from nearest track in each 1/3 octave band frequency, for different types of trains. This distance is representative of the distance between vibration sensitive properties and the nearest track. The average figures are based on the following number of pass-bys on the nearest track for each train type;

- Class 66 + wagons – 6 events
- Chiltern trains (comprising Class 67 locomotive + 6 x Mk3 Coaches + DVT) – 4 events
- Class 221 (5 car) – 4 events
- Class 220 (3/4 car) – 8 events
- Class 168 (3 car) - 8 events

4.21. The freight trains comprised Class 66 locomotive with variable number of wagons (between 14 and 36). Only the freight trains travelling at speeds of between 60mph and 80 mph have been considered in the assessment. The speed of passenger trains varied between 80mph and 90mph.

Figure 13. Average vibration amplification at 9.1m from track 1 for different types of trains



4.22. At 9.1m from the track 1, significant amplifications were observed at mid-frequencies of 25Hz and 31.5Hz. The highest amplifications were generated by the 8-car Chiltern trains (comprising Class 67 locomotive + 6 x Mk3 Coaches + DVT) and the Class 221 (5-car) trains. The amplification from Class 220 and Class 168 trains were noticeably lower. It was also observed that the amplifications from the freight trains (with varying number of wagons) were generally similar to those from Class 220 trains.

Measured Amplification from S&C on Track 2

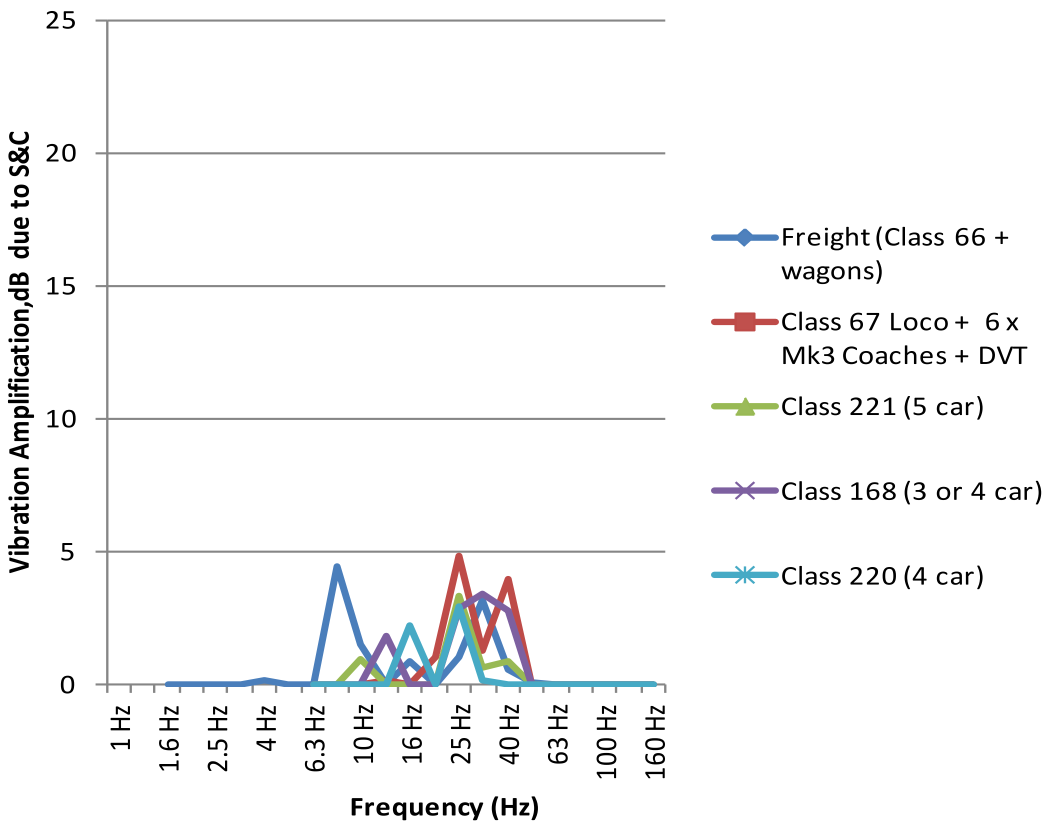
4.23. A similar assessment for track 2 indicates that amplification factors from track 2 were significantly lower.

4.24. Figure 14 shows average vibration amplification in dB at 13.7m from nearest track in each 1/3 octave band frequency, for different types of trains. This distance is representative of the distance between vibration sensitive properties and track 2. The average figures are based on the following number of pass-bys on the nearest track for each train type;

- Class 66 + wagons – 3 events
- Chiltern trains (comprising Class 67 locomotive + 6 x Mk3 Coaches + DVT) – 2 events
- Class 221 (5 car) – 6 events
- Class 220 (3/4 car) – 7 events
- Class 168 (3 car) - 9 events

4.25. The freight trains comprised Class 66 locomotive with variable number of wagons (between 14 and 36). The train speeds on track 2 were typically lower. Only 3 freight trains have been observed travelling at speeds of between 60mph and 70 mph. The speed of passenger trains varied between 75mph and 90mph.

Figure 14. Average vibration amplification at 13.7m from track 2 for different types of trains



4.26. At 13.7m from the track 2, amplifications were observed at 25Hz to 40Hz. A peak was additionally observed at 8Hz for the freight trains. However the magnitude of the peaks was significantly lower (less than 5dB) compared with amplifications near track 1.

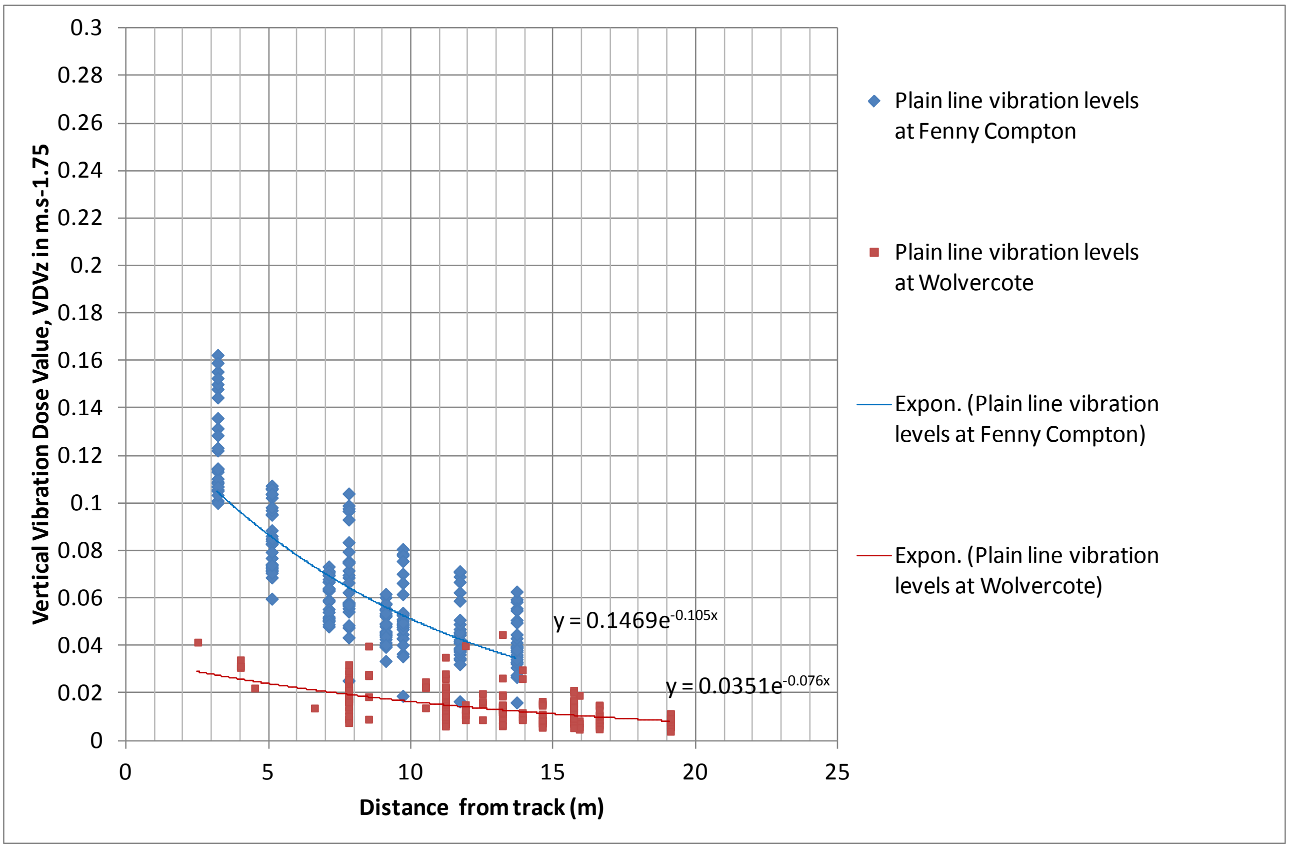
Comparison with measurements at Wolvercote

4.27. The underlying solid geology at both Wolvercote and Fenny Compton is broadly the same (firm to stiff clay). However there are significant differences in local ground conditions between the two sites. The track at Wolvercote is on a shallow embankment (1.5m high) and the measurement points are on natural ground, which is clear of the foot of the embankment. This measurement set-up was generally agreed to be representative of the study area. However, at the Fenny Compton Junction, the triangular area of land between the DCL line and STJ1 Line (see Figure 4) comprises approximately a 3m high embankment. Therefore the measurement points are located on made ground, which is anticipated to be softer when compared with the surrounding natural formation. This difference can result in increased measured levels of vibration.

4.28. The measurements at Fenny Compton have been compared with plain line measurements undertaken at Wolvercote to determine if the two sites were comparable. Full details of measurements undertaken at Wolvercote are described in **[1]**. Figure 15 illustrates the measured VDV, $m.s^{-1.75}$ for the following scenarios;

- Passenger data at plain line site at Wolvercote
- Passenger data at plain line section of the S&C site at Fenny Compton

Figure 15. Vibration Measurements at Wolvercote and Fenny Compton



4.29. It is shown that the plain line measurements at the Fenny Compton site are higher than the measurements at Wolvercote. At about 11m (typical distance between nearest property and the crossing point), the difference can be as high as a factor of three. This difference would then be reflected in the measurements undertaken near the crossing point. It is noted that these measurements have not been normalised for speed, and some of the discrepancy could be explained in terms of variation in train speeds.

4.30. Based on the observed differences between measurements at Wolvercote and Fenny Compton sites, it would not be appropriate to use the absolute levels measured near the S&C directly to estimate project VDVs. It is considered that, within the Fenny Compton site, the measurement positions near the crossing point and the plain line section of track 100m away share the same local geological characteristics. Both sets of measurements would be equally affected and the relative difference between the two is expected to be independent of the effect of local geology and predominantly due to the influence of the crossing point.

4.31. The amplification factors derived from measurements undertaken at Fenny Compton are described below. These are then applied to the plain line vibration levels measured at Wolvercote which is representative of the study area. This approach is consistent with industry guidance which supports the use of appropriate amplification factors **[4]**.

5. Assessment

5.1. This section calculates the resulting vibration levels from S&Cs using amplification factors derived in previous section. The calculations steps are summarised below.

5.2. Step 1 - The equivalent plain line vibration levels in VDV are determined using the same approach as the rest of the scheme, at speeds representative of trains passing over S&Cs and at receiver distances identified. This incorporates the influence of the clay geology, by nature of the empirical relationships derived for project area. Full details of prediction of vibration levels in VDV from plain line sections of the track are described in **[1]**.

5.3. Step 2 - The amplification factors at 9.1m from track 1 and 13.7m from track 2 are used as the basis of calculations, derived separately for passenger and freight trains, as shown below. The predictions are based on a reasonable worst-case assumption that all passenger trains would comprise Class 221 trains which were noted to generate higher amplification in vibration levels compared with Class 220 and Class 168 trains.

Table 5. Assumed amplification factors (dB)

	6.3 Hz	8 Hz	10 Hz	12.5 Hz	16 Hz	20 Hz	25 Hz	31.5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz
At 9.1m from Track 1 passenger	1	5	8	11	7	6	18	14	10	5	5	6	4	4	4
At 13.7m from Track 2 passenger	0	0	1	0	0	0	3	1	1	0	0	0	0	0	0
At 9.1m from Track 1 freight	0	1	2	3	6	8	12	9	8	3	5	6	4	6	3
At 13.7m from Track 2 freight	0	4	1	0	1	0	1	3	1	0	0	0	0	0	0

5.4. Step 3 - The amplification factors are adjusted for distance using the amplification decay relationships derived previously. The distance between the receivers and tracks/ crossing points are illustrated below for 16 Whimbrel Close, 4 Bladon Close and 21 London Road. This accounts for distance effects, however the effect of extra formation (i.e. the proposed chord line) is not taken into account.

Figure 16. Proposed Site Geometry at 16 Whimbrel Close

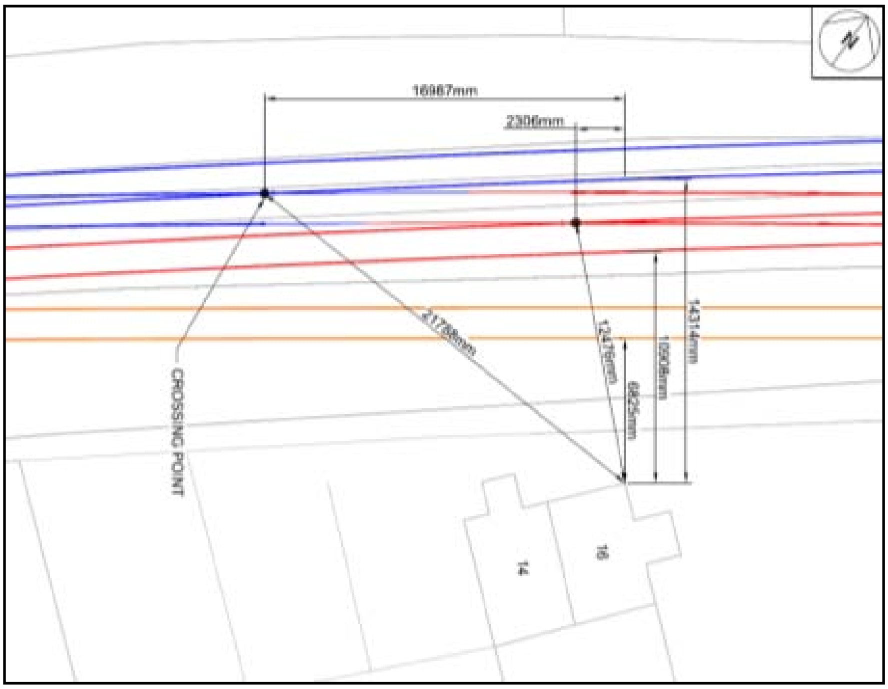


Figure 17. Proposed Site Geometry at 4 Bladon Close

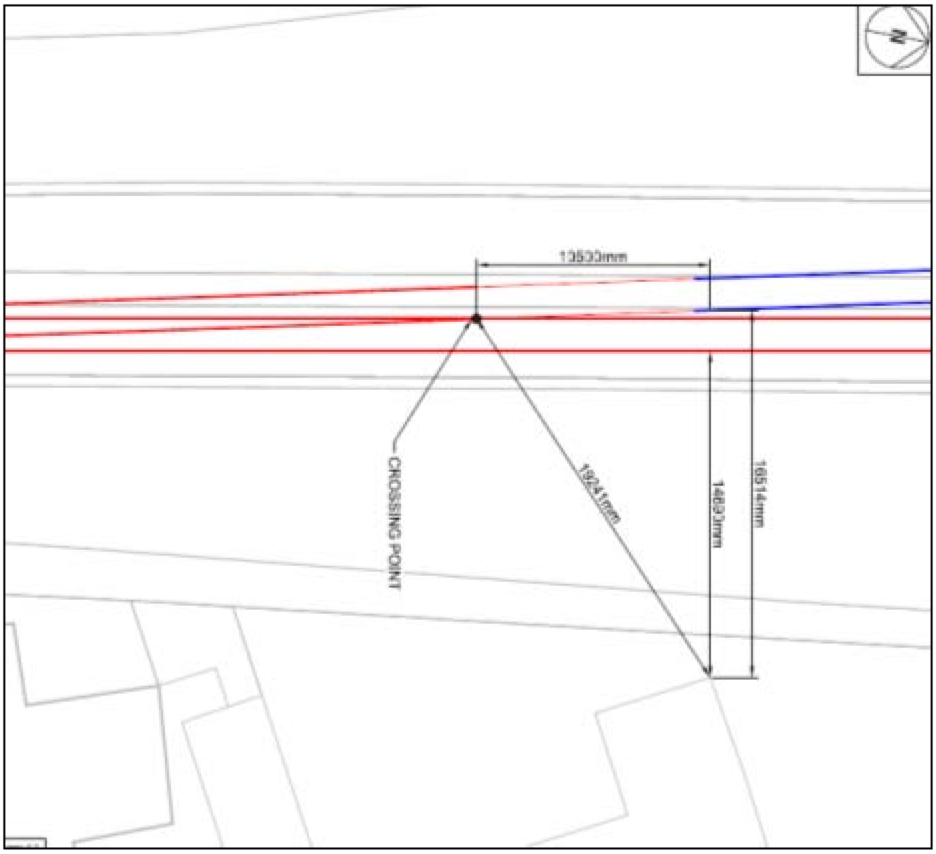


Figure 18. Proposed Site Geometry at 21 London Road

5.5. Step 4 - Using the equivalent plain line vibration levels at the crossing points, and the adjusted amplification factors, the resulting vibration levels are calculated at the receiver position, with the S&C.

5.6. The findings are summarised below at the receivers identified to be at risk.

Table 6. Estimated Vibration Levels due to presence of S&Cs

VDV $m.s^{-1.75}$	No.16 at Whimbrel Close		No.4 at Bladon Close		No.21 at London Road	
	Day	Night	Day	Night	Day	Night
Predicted with plain line	0.12	0.08	0.09	0.05	0.1	0.07
Predicted with S&C	0.26	0.17	0.16	0.08	0.3	0.19
Project Targets	0.4	0.2	0.4	0.2	0.4	0.2

5.7. The assessment showed that the day and night-time levels would be below the project VDV targets. However, particularly at Whimbrel Close and London Road, the predicted night-time levels are close to target VDVs.

5.8. The resulting vibration acceleration spectra are shown below for night-time at a representative receiver (16 Whimbrel Close) for each track and each vehicle type, separately for the plain line and the S&C, in Figures 19 and 20 respectively.

Figure 19. Plain line vibration levels at 16 Whimbrel Close

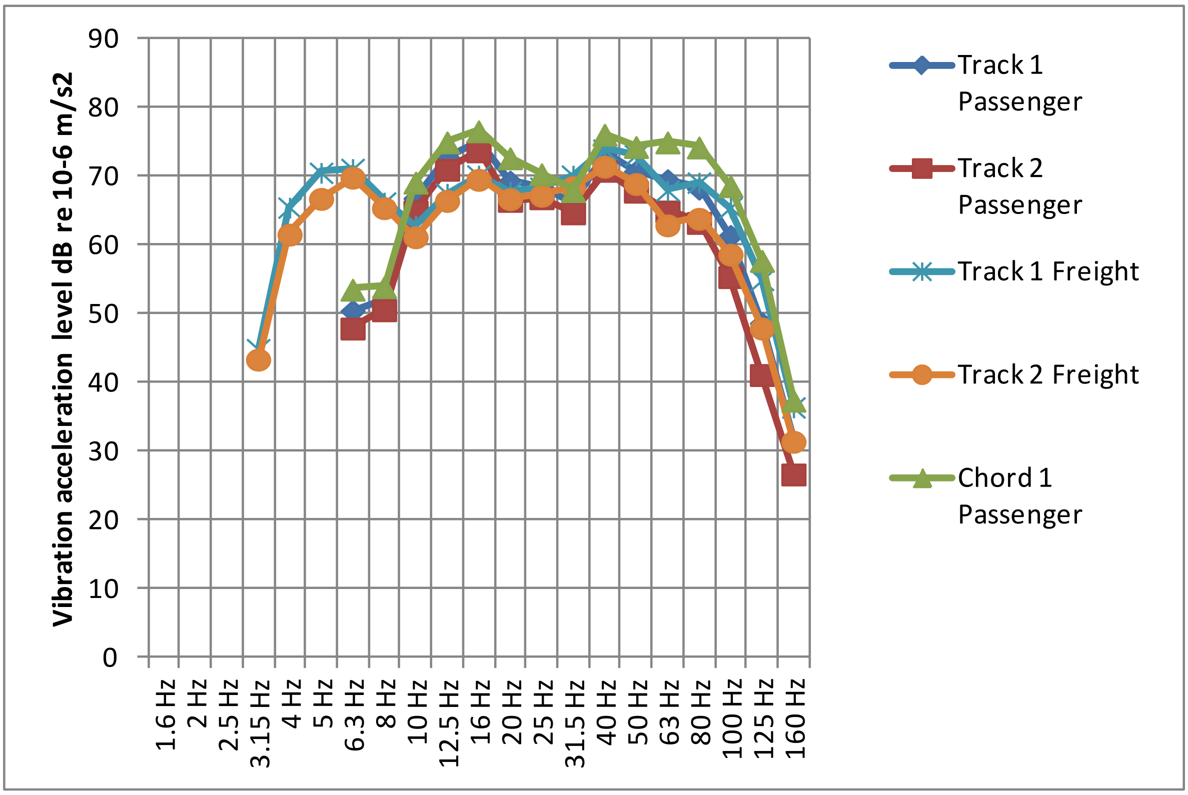
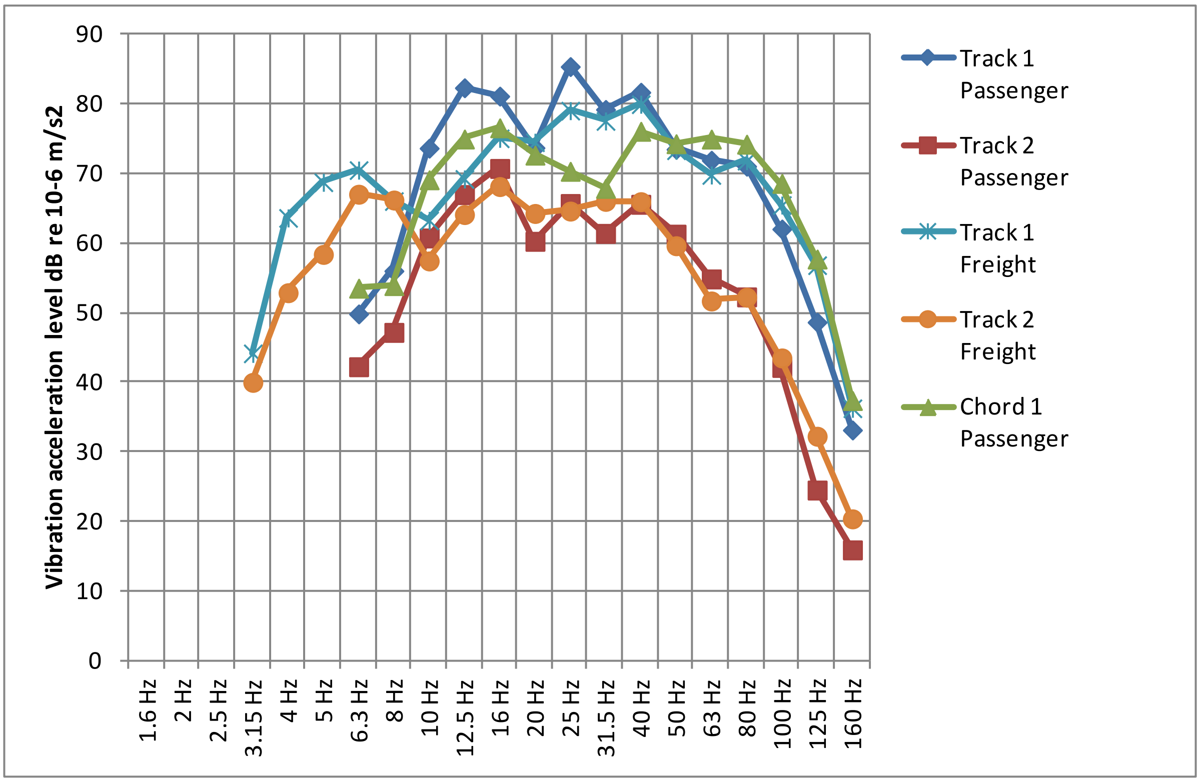


Figure 20. S&C vibration levels at 16 Whimbrel Close



5.9. The highest component of VDV would be the passenger trains on track 1 (nearest track). The vibration levels at 25Hz are shown to be highest.

5.10. The calculated levels represent a reasonable worst-case since it is assumed that;

- passenger trains in the future would entirely consist of Class 221 trains, which result in higher levels of vibration amplification over a crossing point compared with Class 168 and Class 220,
- the beneficial effect of extra formation (i.e. due to the presence of chord line) between track 1 and the receivers is not taken into account at Whimbrel Close.

6. Conclusions

6.1. Atkins is currently undertaking the detailed design of the proposed double-tracking of Oxford to Bicester Rail line (referred to as the 'Scheme' in this document). There are a number of vibration conditions which need to be discharged with the local planning authority before the Scheme can be built.

6.2. This is a supplementary report which deals with vibration form the switches and crossings. It should be read in conjunction with a more comprehensive report on vibration from the plain line (see reference 1 in Appendix B).

6.3. The assessment showed that at the S&C sites, despite conservative assumptions, the day and night-time VDV targets would not be exceeded. However particularly at Whimbrel Close and London Road, the predicted night-time levels are close to target VDVs.

6.4. It is understood that the proposed S&C design is standard and there is limited scope for changing the geometry. It is recommended that the crossing nose impact is kept to a minimum by maintaining a good vertical track and switching nose geometries throughout the design life of the crossing. This will ensure rail wheel transition over the crossing point is as smooth as possible, and minimise levels of vibration generated.

.

Appendices

Appendix A. Glossary of Technical Terms

Acceleration - The measure of the rate of change of particle velocity with respect to time, typically expressed in $m.s^{-2}$.

Weighted RMS acceleration is the root-mean-squared value of the frequency weighted acceleration, using W_b or W_d as appropriate.

Frequency (Hertz) - The number of cycles per second (Hertz) at which a structure will oscillate when either; driven by a “forcing frequency” or when excited and then allowed to come to rest naturally, “natural frequency”.

Frequency Weightings - Different frequency weightings (value corrections) are required for different axes of motion because people perceive vibration differently depending on the frequency and the direction of movement. The frequency range concerned is 0.5 Hz to 80Hz for the thre axes. The weightings (Wb (for vertical motion) and Wd (for horizontal motion) are defined in BS 6841, “Guide to Measurement and evaluation of human exposure to whole-body vibration and repeated shock”.

Peak Particle Velocity (PPV) - Instantaneous maximum velocity reached by a vibrating element as it oscillates about its rest position, typically expressed in $mm.s^{-1}$.

Vibration Dose Value (VDV) - Measure of the total vibration experienced over a specified period of time, expressed in $m.s^{-1.75}$. The VDV is derived from the weighted RMS acceleration in each axis and provides a consistent approach to the assessment of continuous, intermittent, occasional and impulsive vibration, which correlates well with subjective human response.

estimated Vibration Dose Value (eVDV) – Is an approximation of the VDV and is sometimes appropriate to use where vibration is not time-varying in magnitude. It is over a specific time period and expressed in $m.s^{-1.75}$.

Appendix B. References

[1] Atkins technical report, East – West Rail: Phase 1, Plain Line Vibration Assessment and Mitigation, 5114534-ATK-VIB-RPT-80001, Revisions P07, 16 January 2014

[2] BS 6472-1:2008 Guide to evaluation of human exposure to vibration in buildings. Part 1: Vibration sources other than blasting, British Standards Institute, June 2008

[3] RIVAS Deliverable D3.6 entitled 'Description of the vibration generation mechanism of turnouts and the development of cost effective mitigation measures' dated 28/02/2013

[4] Federal Transit Administration, Transit Noise and Vibration Impact Assessment, 2006

Appendix C. Equipment Calibration Records

The calibration certificates and sensitivities are provided below for the accelerometers used during the vibration surveys.

Calibration Chart for Accelerometers

Type KS 823B
Serial number 10074

Reference Sensitivity at 20 Hz
and 22 °C

Voltage Sensitivity **

X-axis	53,14 mV/m/s² /	521,1 mV/g *
Y-axis	53,23 mV/m/s² /	522 mV/g *
Z-axis	53,28 mV/m/s² /	522,5 mV/g *

Output bias voltage (at 4 mA)

X: 12,7 V Y: 12,4 V Z: 12,3 V

date 08.04.2013 signature

* 1 g = 9,807 m/s²
** The calibration is traceable to the PTB

Operating temperature Tmin/Tmax	-30/90 °C
Maximum acceleration â+, â-	120 m/s²
Temperature coefficient TK(Bua)	-0,05 %/K

Polarity
Polarity is positive on the output pin of the connector for an acceleration directed from the mounting surface into the body of the accelerometer.

Environmental characteristics

Temperature transients baT	0,0005 m/s²/ K
Base strain baS	--
Magnetic field baB	--
Acoustic noise baP	--
Electric noise (20 .. 50000 Hz)	< 20 µV

Physical parameter

Material	Stainless steel / AlMg
Weight (without cable)	365 g
Electrical Connector	Binder 718
Mounting	M8 thread in base
Piezo design	Shear design

Current source
The current for the internal charge converter amount 2 ... 20 mA at a supply voltage of 24 - 30V.

Additional data IP 67

COPY

CERTIFICATE OF CALIBRATION

ISSUED BY	Gracey & Associates	BSI CERTIFICATE	FS 25913
DATE OF ISSUE	23 September 2013	CERTIFICATE NUMBER	2013-0329
DATE OF CALIBRATION	23 September 2013		
CALIBRATION INTERVAL	12 months		PAGE 1 OF 1

Gracey & Associates
Barn Court Shelton Road
Upper Dean PE28 0NQ
Tel: 01234 708835
Fax: 01234 252332
www.gracey.com

TEST ENGINEER
Greg Rice

APPROVING SIGNATORY
Greg Rice

Equipment **B&K 4507 002, s/n: 10412**
Description Accelerometer - IEPE - 100mV/ms2, Bruel & Kjaer UK Limited

Customer Gracey & Associates
High Street, Chelveston, Northamptonshire, NN9 6AS

Standards
Manufacturer's Original Specifications

Conditions

Atmospheric Pressure	101.9 kPa
Temperature	21.4 °C
Relative Humidity	48.8 %

Calibration Data

At Frequency (Hz) :	159.15
Voltage Sensitivity (mV/ms^{-2}) :	97.5130
Voltage Sensitivity (mV/g) :	956.2759
Charge Sensitivity (pC/ms^{-2}) :	n/a
Charge Sensitivity (pC/g) :	n/a

A value of g = 9.80665 ms^{-2} has been used in relevant caclulations.

Calibration Reference Sources

Equipment	S/N	Last Cal	Equipment	S/N	Last Cal
B&K 4294-002	1608724	25-Mar-13	B&K 8305	1483344	25-Mar-13
Druck DPI 141	479	27-Jul-11	HP 34401	3146A16728	18-Oct-12
Stanford DS36	33213	14-Jul-11			

Notes

We certify that the above product was duly tested and found to be within the specification at the points measured (except where indicated). Measurements are traceable to UKAS reference sources from the UK National Physical Laboratory. Where no national or international standards exist, traceability is to standards maintained by the manufacturer. Our Quality Management System has been assessed to comply with BS EN ISO 9001:2008 - BSI Certificate number FS 25913. Tests were carried out in environmental conditions controlled to the extent appropriate to the instrument's specification. All relevant test certificates are available for inspection.
The uncertainties are for a confidence probability of not less than 95%.

CERTIFICATE OF CALIBRATION

ISSUED BY	Gracey & Associates	BSI CERTIFICATE	FS 25913
DATE OF ISSUE	23 September 2013	CERTIFICATE NUMBER	2013-0331
DATE OF CALIBRATION	23 September 2013		
CALIBRATION INTERVAL	12 months		PAGE 1 OF 1

Gracey & Associates
Barn Court Shelton Road
Upper Dean PE28 0NQ
Tel: 01234 708835
Fax: 01234 252332
www.gracey.com

TEST ENGINEER: Greg Rice
APPROVING SIGNATORY: Greg Rice

Equipment: **B&K 4507 002, s/n: 10414**
Description: Accelerometer - IEPE - 100mV/ms2, Bruel & Kjaer UK Limited
Customer: Gracey & Associates
High Street, Chelveston, Northamptonshire, NN9 6AS

Standards
Manufacturer's Original Specifications

Conditions
Atmospheric Pressure 101.9 kPa
Temperature 21.4 °C
Relative Humidity 48.8 %

Calibration Data

At Frequency (Hz) :	159.15
Voltage Sensitivity (mV/ms^{-2}) :	98.5710
Voltage Sensitivity (mV/g) :	966.6513
Charge Sensitivity (pC/ms^{-2}) :	n/a
Charge Sensitivity (pC/g) :	n/a

A value of g = 9.80665 ms^{-2} has been used in relevant caclulations.

Calibration Reference Sources

Equipment	S/N	Last Cal	Equipment	S/N	Last Cal
B&K 4294-002	1608724	25-Mar-13	B&K 8305	1483344	25-Mar-13
Druck DPI 141	479	27-Jul-11	HP 34401	3146A16728	18-Oct-12
Stanford DS36	33213	14-Jul-11			

Notes
We certify that the above product was duly tested and found to be within the specification at the points measured (except where indicated). Measurements are traceable to UKAS reference sources from the UK National Physical Laboratory. Where no national or international standards exist, traceability is to standards maintained by the manufacturer. Our Quality Management System has been assessed to comply with BS EN ISO 9001:2008 - BSI Certificate number FS 25913. Tests were carried out in environmental conditions controlled to the extent appropriate to the instrument's specification. All relevant test certificates are available for inspection.
The uncertainties are for a confidence probability of not less than 95%.

CERTIFICATE OF CALIBRATION

ISSUED BY	Gracey & Associates	BSI CERTIFICATE	FS 25913
DATE OF ISSUE	23 September 2013	CERTIFICATE NUMBER	2013-0330
DATE OF CALIBRATION	23 September 2013		
CALIBRATION INTERVAL	12 months		PAGE 1 OF 1

Gracey & Associates
Barn Court Shelton Road
Upper Dean PE28 0NQ
Tel: 01234 708835
Fax: 01234 252332
www.gracey.com

TEST ENGINEER
Greg Rice

APPROVING SIGNATORY
Greg Rice

Equipment **B&K 4507 002, s/n: 10413**
Description Accelerometer - IEPE - 100mV/ms2, Bruel & Kjaer UK Limited

Customer Gracey & Associates
High Street, Chelveston, Northamptonshire, NN9 6AS

Standards
Manufacturer's Original Specifications

Conditions
Atmospheric Pressure 101.9 kPa
Temperature 21.4 °C
Relative Humidity 48.8 %

Calibration Data

At Frequency (Hz) :	159.15
Voltage Sensitivity (mV/ms^{-2}) :	99.0690
Voltage Sensitivity (mV/g) :	971.5350
Charge Sensitivity (pC/ms^{-2}) :	n/a
Charge Sensitivity (pC/g) :	n/a

A value of g = 9.80665 ms^{-2} has been used in relevant caclulations.

Calibration Reference Sources

Equipment	S/N	Last Cal	Equipment	S/N	Last Cal
B&K 4294-002	1608724	25-Mar-13	B&K 8305	1483344	25-Mar-13
Druck DPI 141	479	27-Jul-11	HP 34401	3146A16728	18-Oct-12
Stanford DS36	33213	14-Jul-11			

Notes

We certify that the above product was duly tested and found to be within the specification at the points measured (except where indicated). Measurements are traceable to UKAS reference sources from the UK National Physical Laboratory. Where no national or international standards exist, traceability is to standards maintained by the manufacturer. Our Quality Management System has been assessed to comply with BS EN ISO 9001:2008 - BSI Certificate number FS 25913. Tests were carried out in environmental conditions controlled to the extent appropriate to the instrument's specification. All relevant test certificates are available for inspection.

The uncertainties are for a confidence probability of not less than 95%.

~ *Calibration Certificate* ~

Per ISO 16063-21

Model Number: 356B18

Serial Number: LW133898 (y axis)

Description: ICP® Triaxial Accelerometer

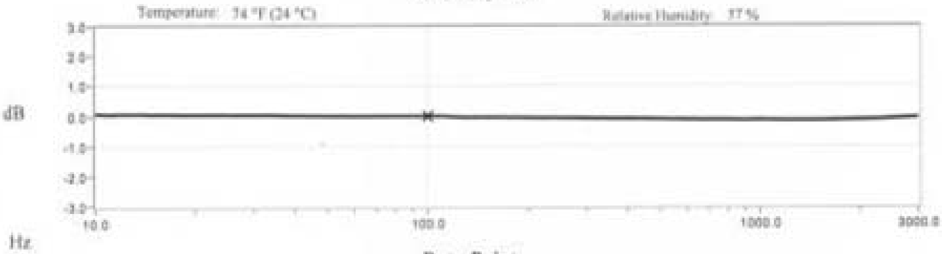
Manufacturer: PCB

Method: Back-to-Back Comparison AT-401-3

Calibration Data

Sensitivity @ 100 Hz	**962 mV/g**	Output Bias	11.4 VDC
	(98.1 mV/m/s²)	Transverse Sensitivity	2.4 %
Discharge Time Constant	1.3 seconds		

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	0.8	300	-0.9
15	0.7	500	-1.3
30	0.5	1000	-1.7
50	0.1	3000	-0.8
REF. FREQ.	0.0		

Condition of Unit

As Found: n/a

As Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 681/280472 and PTB Traceable thru Project 10065.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 9001, ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%.

Technician: Gary Oatis

Date: 6/25/2012

ACCREDITED
CALIBRATION CERT #1862.02

PCB PIEZOTRONICS
VIBRATION DIVISION
Headquarters: 3425 Walden Avenue, Depew, NY 14043
Calibration Performed at: 10869 Highway 903, Halifax, NC 27839
TEL: 888-684-0013 · FAX: 716-685-3886 · www.pcb.com

PAGE 1 of 1

~ *Calibration Certificate* ~

Per ISO 16063-21

Model Number: **356B18**

Serial Number: **LW133898 (z axis)**

Description: ICP® Triaxial Accelerometer

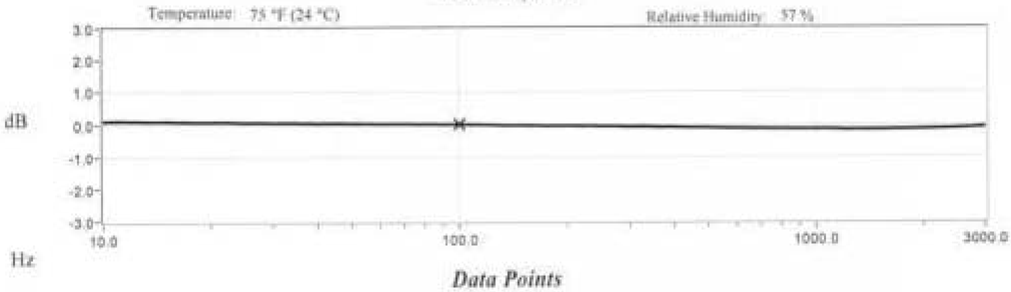
Manufacturer: PCB

Method: Back-to-Back Comparison AT-401-3

Calibration Data

Sensitivity @ 100 Hz	**970 mV/g**	Output Bias	11.4 VDC
	(98.9 mV/m/s²)	Transverse Sensitivity	1.4 %
Discharge Time Constant	1.0 seconds		

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.1	300	-0.9
15	1.0	500	-1.4
30	0.6	1000	-1.9
50	0.2	3000	-1.1
REF. FREQ.	0.0		

Mounting Surface: Beryllium w/Silicone Grease Fastener: 10-32 Female   Fixture Orientation: Vertical
Acceleration Level (pk)*: 1.00 g (9.81 m/s²)
*The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.004 x (freq)²
²The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s²

Condition of Unit

As Found: n/a

As Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 681/280472 and PTB Traceable thru Project 10065.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 9001, ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%.

Technician: Gary Oatis   Date: 6/25/2012

ACCREDITED
CALIBRATION CERT #1862.02
PAGE 1 of 1

PCB PIEZOTRONICS
VIBRATION DIVISION
Headquarters: 3425 Walden Avenue, Depew, NY 14043
Calibration Performed at: 10869 Highway 903, Halifax, NC 27839
TEL: 888-684-0013 · FAX: 716-685-3886 · www.pcb.com

~ *Calibration Certificate* ~

Per ISO 16063-21

Model Number: **356B18**

Serial Number: **LW133898 (x axis)**

Description: ICP® Triaxial Accelerometer

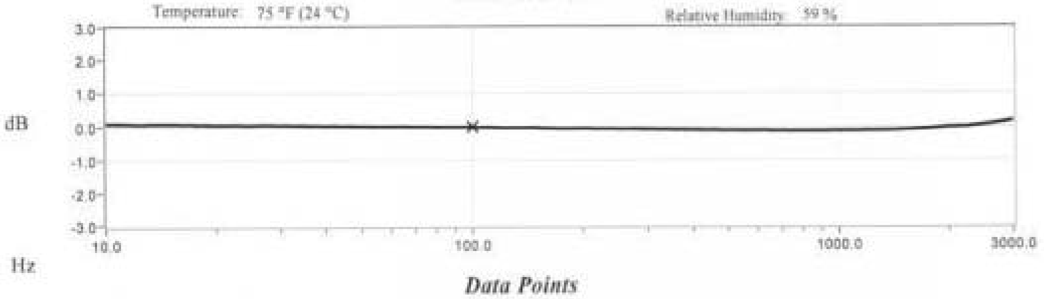
Manufacturer: PCB

Method: Back-to-Back Comparison AT-401-3

Calibration Data

Sensitivity @ 100 Hz	**1013 mV/g**	Output Bias	11.7 VDC
	(103.3 mV/m/s²)	Transverse Sensitivity	0.6 %
Discharge Time Constant	1.0 seconds		

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.1	300	-0.9
15	0.9	500	-1.4
30	0.5	1000	-1.6
50	0.1	3000	2.0
REF. FREQ.	0.0		

Mounting Surface: Beryllium Fastener: Adhesive Fixture Orientation: Inverted Vertical
Acceleration Level (pk)[1]: 1.00 g (9.81 m/s²)
[1]The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.004 x (freq)². [2]The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/a

As Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 681/280472 and PTB Traceable thru Project 10065.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 9001, ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%.

Technician: Gary Oatis

Date: 6/25/2012

ACCREDITED
CALIBRATION CERT #1862.03

PCB PIEZOTRONICS
VIBRATION DIVISION
Headquarters: 3425 Walden Avenue, Depew, NY 14043
Calibration Performed at: 10869 Highway 903, Halifax, NC 27839
TEL: 888-684-0013 · FAX: 716-685-3886 · www.pcb.com

PAGE 1 of 1

Appendix D. Track Inspections

Technical Note No. 44 rev P02

Project:	East-West Rail Phase 1	**To:**	Inan Ekici/David Terry
From:	Julien Green (CEM)	**Cc:**	Mike Ashton, Peter Hampshire, Alan Yeung, Chris Brooks, Stephen Wilson, Ken Lam
Subject:	Permanent Way Inspections at Vibration Monitoring Sites		
Date:	21 November 2013		
Reference:	Document No. 5114534-ATK-GEN-TN-00044 P02		

East-West Rail Phase 1
Permanent Way Condition Inspections at Vibration Monitoring Sites

7. Introduction and Scope

As part of the EWRP1 project, vibration monitoring is being undertaken at sites on the existing Bicester to Oxford line (ELR – OXD) and the Oxford to Anyho Junction line (ELR – DCL). A site which has a similar type of Switch and Crossing (S&C) installed that will be installed on the OXD lines was also monitored for vibration effects, this was at Fenny Compton Junction (ELR – DCL). As part of the vibration monitoring, the existing permanent way, was inspected to determine the following:

a. Component type;

b. Component condition;

c. Overall condition of the permanent way;

d. Identify factors that would unduly impact on the vibration results.

The inspections were Julien Green the project CEM, and a former Permanent Way Maintenance Engineer. The dates and weather conditions during the inspections for each of the sites were as follows:

i. OXD 29m 27.5ch - 9 October 2013. The weather was overcast, slight wind and 16^{o}C;

ii. DCL 65m 23ch - 9 October 2013. The weather was overcast, slight wind and 16^{o}C;

iii. DCL 94m 78ch – 95m 8ch – 20 November 2013. The weather was cold, heavy showers and 4^{o}C.

Due to restrictions of access, the inspection was undertaken from the line side cess and reviewing of the high speed track recording track quality reports.

It should be noted that the dimensions quoted are miles and chains, (however, the dimensions provided in () are those of the project chainage that has been set up for the project on the OXD line. The DCL lines do not interact with the project chainage therefore has not been provided.

8. Oxford to Bicester Line – OXD – 29m 27.5ch

This is a line that runs from Bicester to Oxford and is currently a single line, with a line speed of 30mph and the ELR of the line is OXD, see Figure 1. The area chosen for the vibration monitoring was the Down (southern – left hand side facing Oxford) cess at 29m 27.5chains. This is 4.5chains East (Islip side) of Under bridge OXD50 which crosses the canal. Figure 2, provides a hand drawn sketch of the layout at this location.

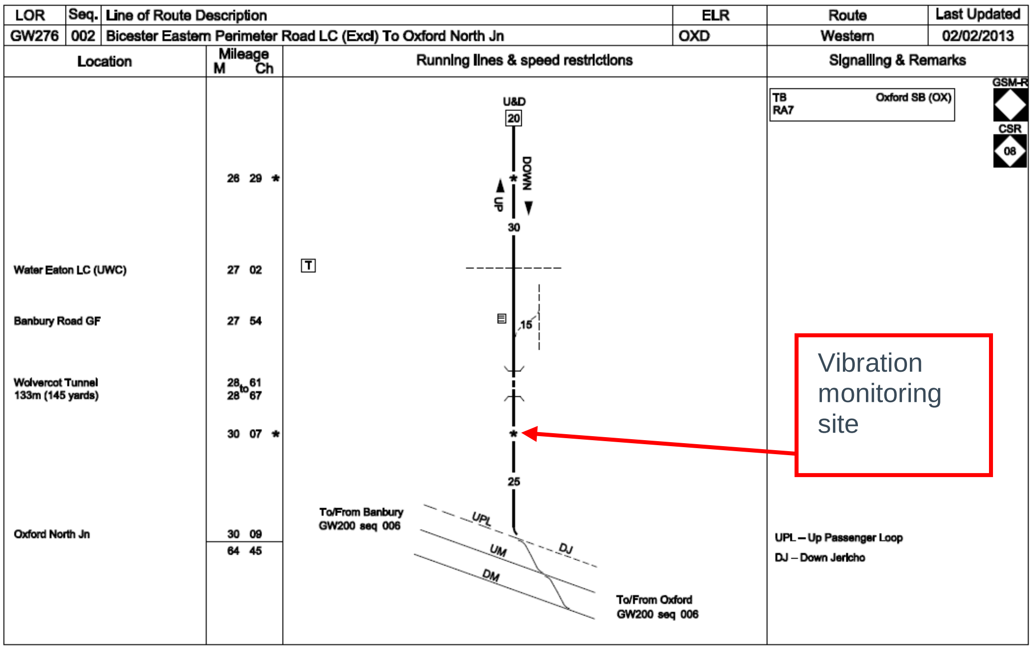


Figure 1: Extract of Sectional Appendix for the OXD Line

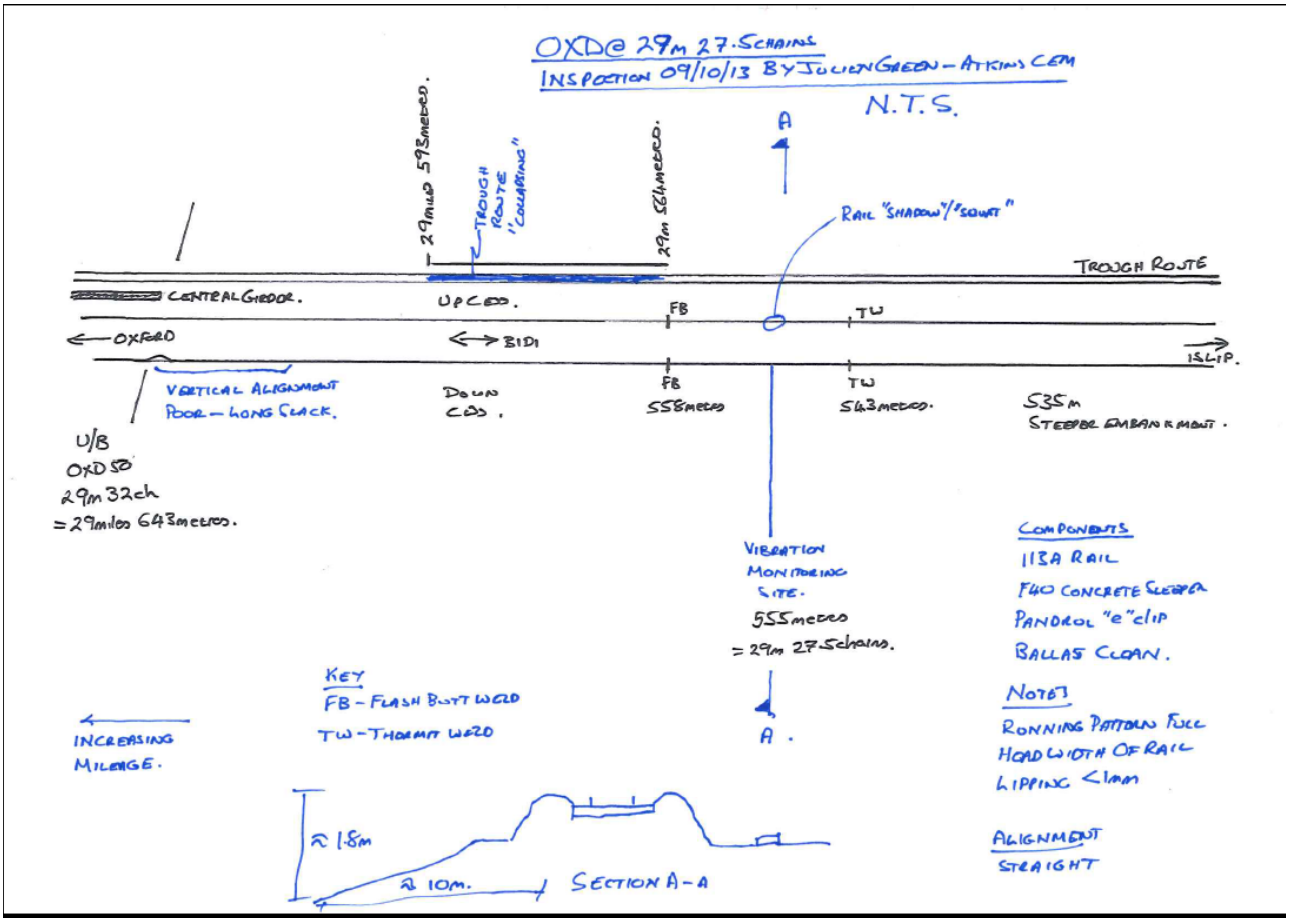


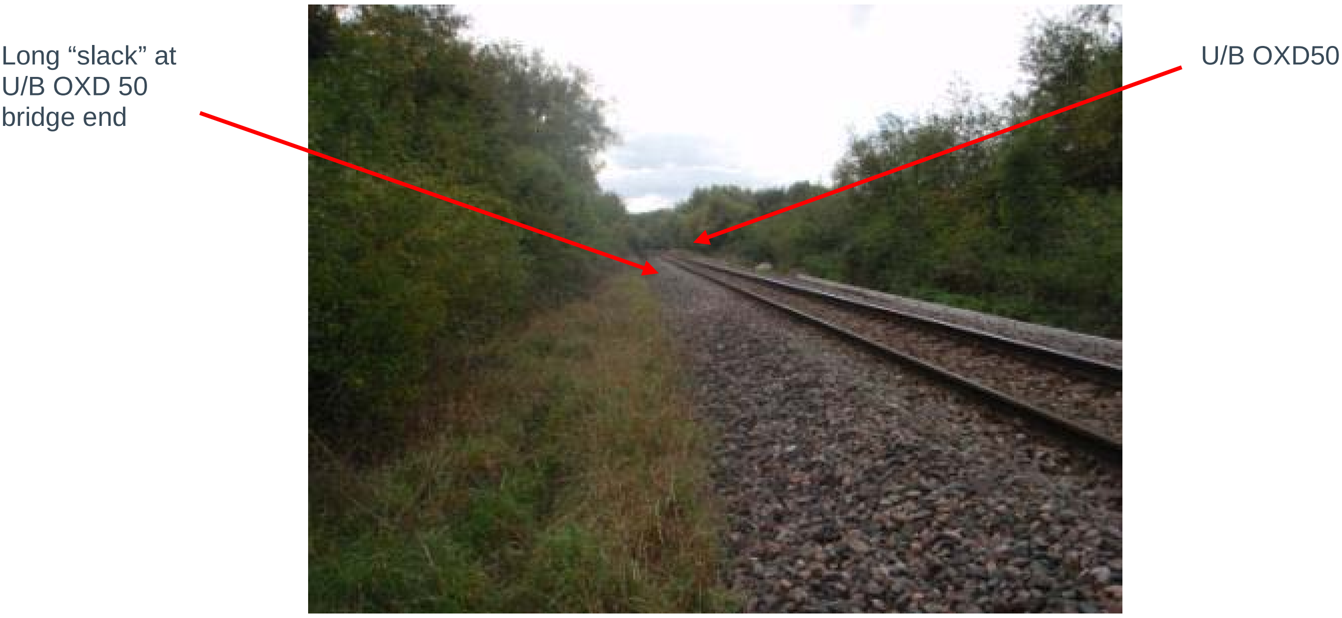
Figure 2: OXD 29m 27.5ch - Site Sketch

8.1. Components

8.1.1. Alignment

At this location, the track is situated on a straight alignment. The horizontal alignment looks satisfactory for the line speed. The vertical alignment at the vibration location is of a satisfactory condition, however at the Islip side of U/B OXD 50, between 29m 30ch and 32chain (the bridge end), there is a long vertical “slack”, see Photograph 2. This is 85m from the vibration monitoring site, however under visual inspection during dynamic loading, no excessive forces were heard or felt over this location.

Photograph 1: OXD Line looking towards Islip (Up direction)



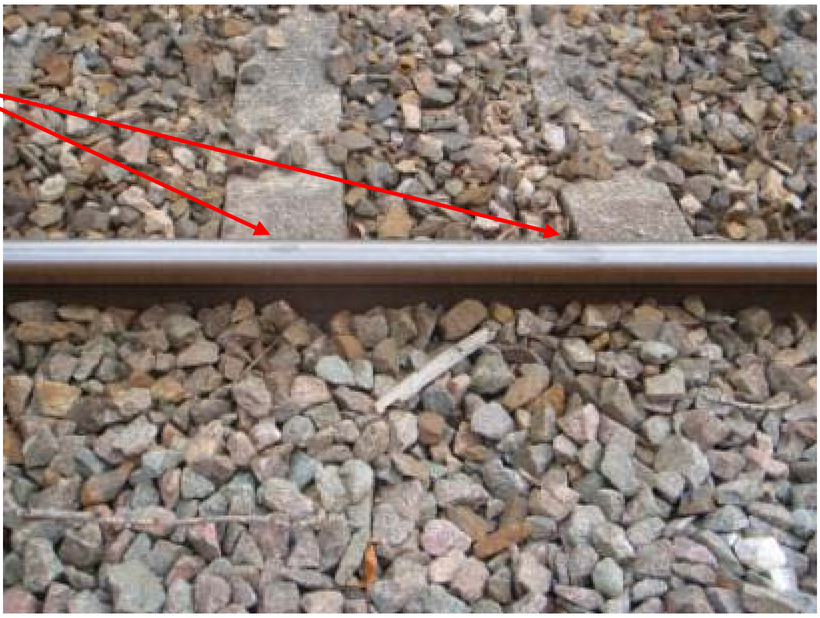
Photograph 2: OXD Line looking towards Oxford (Down Direction)

8.1.2. Rail

The rail is 113A Flat Bottom Workington 1976 rail, on concrete F27 sleepers with pandrol “e” clip” fastenings and rubber pads. Flash butt and thermit welds are located approximately 10m either side of the vibration monitoring site (see figure 2). All the welds looked to be in good condition and no irregularities could be identified, and therefore are assumed to conform to standards.

The Up rail (right hand rail looking towards Oxford) at the vibration monitoring location, showed signs of “shadowing” or a local “squat” developing, see photograph 3. However, no surface “breaking out” had started to occur and when the site was witnessed under dynamic loading, no noticeable change in noise was noted.

“Shadows”/”squat” on the Up rail



Photograph 3: Shadowing on right hand rail facing Oxford

The running pattern on top of the rail, was for the full width of the rail, but appeared smooth in appearance. Minor (<1mm) of lipping was noted on the cess (left hand rail facing Oxford) rail.

8.1.3. Sleepers

The sleepers are concrete F27 sleepers with pandrol “e” clip fastening. All fastenings, pads, insulators were in position and there were none missing.

8.1.4. Ballast

The ballast seems clean, well graded, and free of fines. The cess on both sides is lower than the formation (see photographs 4-7), and as a consequence the ballast shoulder is suitable to resist thermal forces. There is no evidence of any “wet spots” and the track was witnessed under dynamic loading (freight train) and there were no excessive vertical movements.

Photograph 4 and 5: Up Cess (right hand side facing Oxford) looking towards Islip (left) and Oxford (right) ballast shoulder and cess

Photograph 6 and 7: Down Cess (left hand side facing Oxford) looking towards Islip (left) and Oxford (right) ballast shoulder and cess

8.1.5. Topography

The vibration site is on a small shallow embankment (approx 2m height). Between 29miles 564metres to 593metres, the up cess (northern right hand side facing Oxford), a new local ballast retention wall has been installed to stabilise the cable trough route, see photograph 5. The cess in this area, seems to indicate a localised movement in this area. However, the track alignment through here is still consistent at the time of the inspection.

The slopes are heavily vegetated with shrubs and trees.

8.1.6. Track Quality

The latest available track quality data available from the track recording train can be seen in figure 3 below.

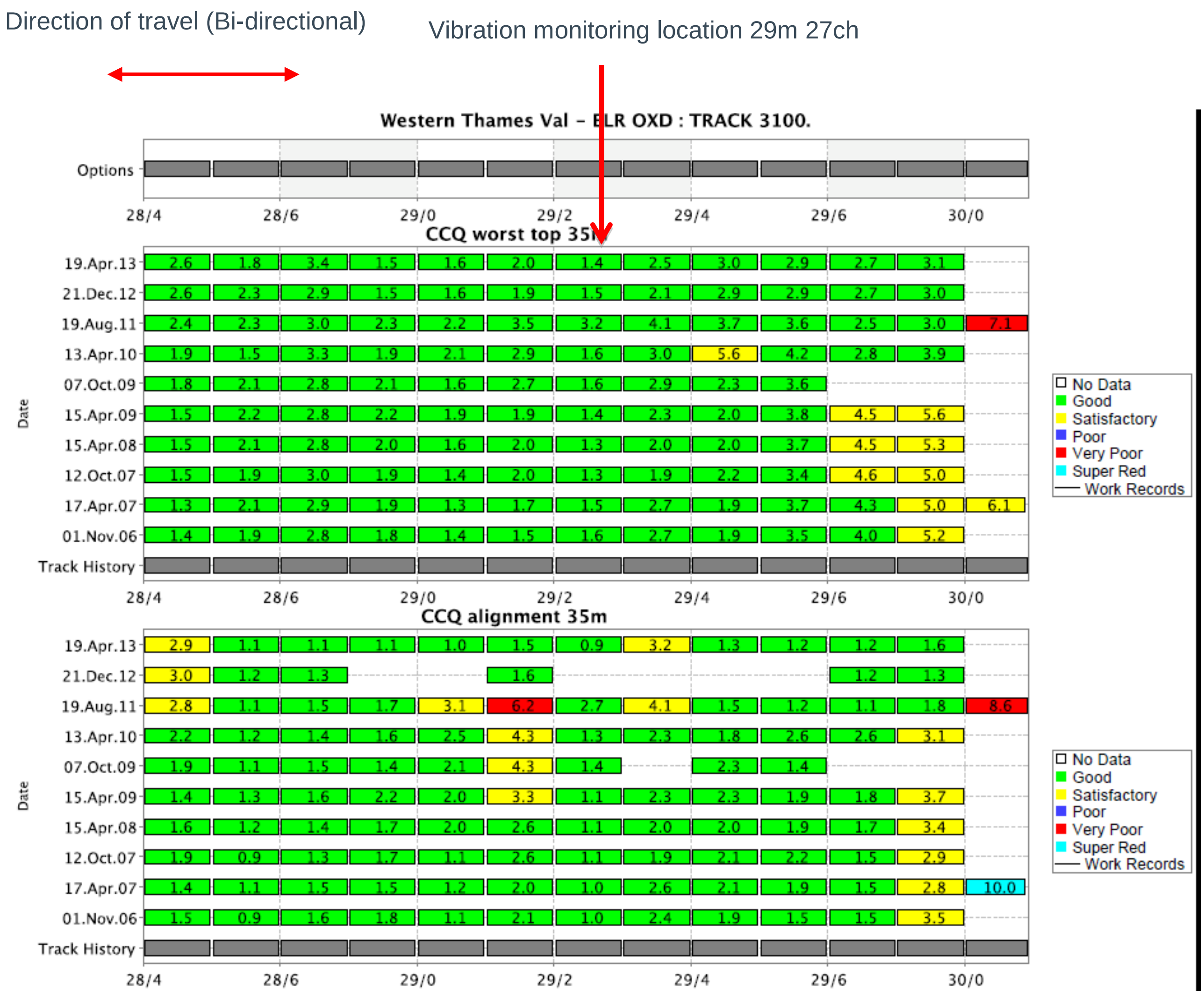


Figure 3: Track Recording Vehicle Track Quality Data

The data clearly shows that for April 2013, that between the 29/2 (29m ¼ milepost = 20chains) and 29/4 (29m ½ milepost = 40chains) that the horizontal alignment is in the good quality band. It can be seen that on the vertical alignment that the 1/8th mile band prior to 29/4 is in the satisfactory band. This is due to the vertical alignment at the under bridge OXD50 bridge ends. As highlighted in photograph 2 and section 2.1.1.

8.2. Conclusion

The track is in a good condition, with no evidence of "track pumping" or other issues that are likely to provide excessive vibration or noise characteristics at this location, and that would be outside of the normal parameters for a well maintained line for the track category currently in service.

9. Oxford to Anyho Junction – DCL – 65m 23ch

This is a line that runs from Oxford to Anyho junction and is currently 3 lines, the Up Passenger Loop, Up and Down Main. It should be noted that at the time of the inspection, construction work was underway in the Down cess to reinstate the Down Passenger loop.

The line speed for the Up Passenger Loop is 25mph and for the Up and Down Main it is 90mph and the ELR of the line is DCL, see Figure 4. The area chosen for the vibration monitoring was the Up cess (eastern – left hand side facing Oxford) cess at 65m 23chains. Figure 5, provides a hand drawn sketch of the lay out at this location.

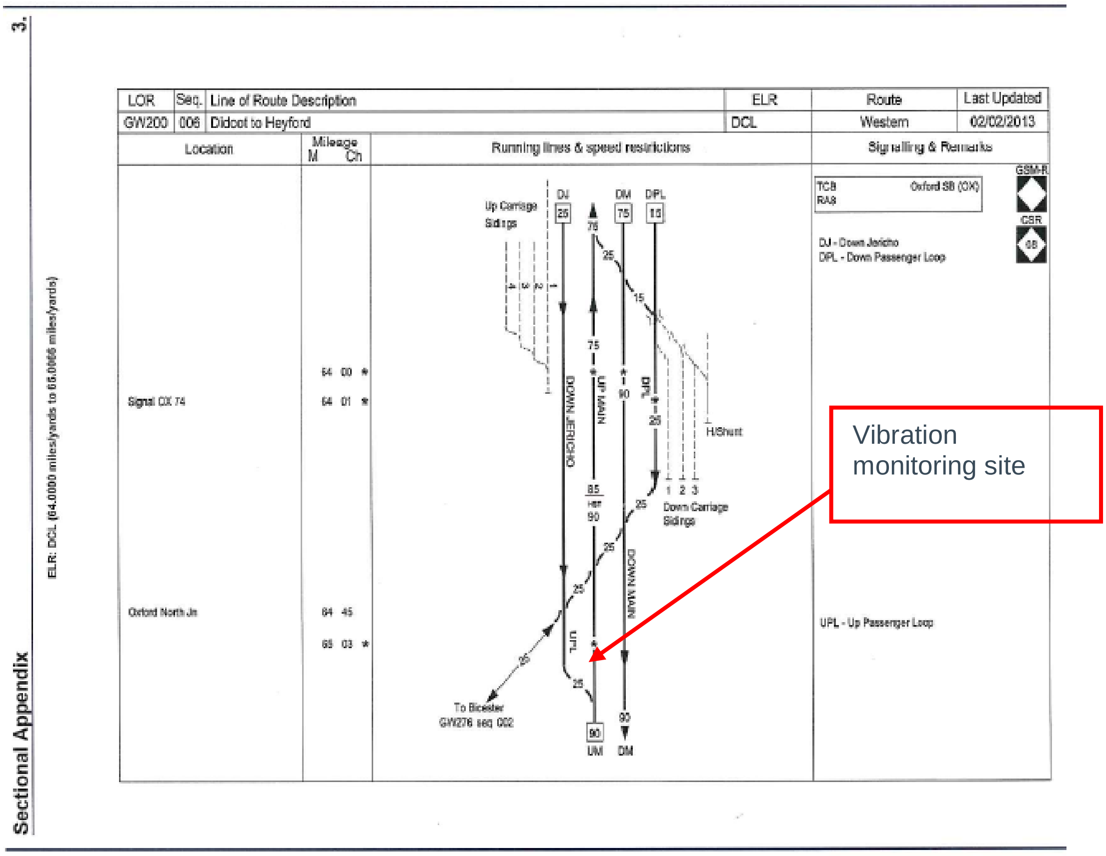


Figure 4: Extract of Sectional Appendix for the DCL Line at 65m 23ch

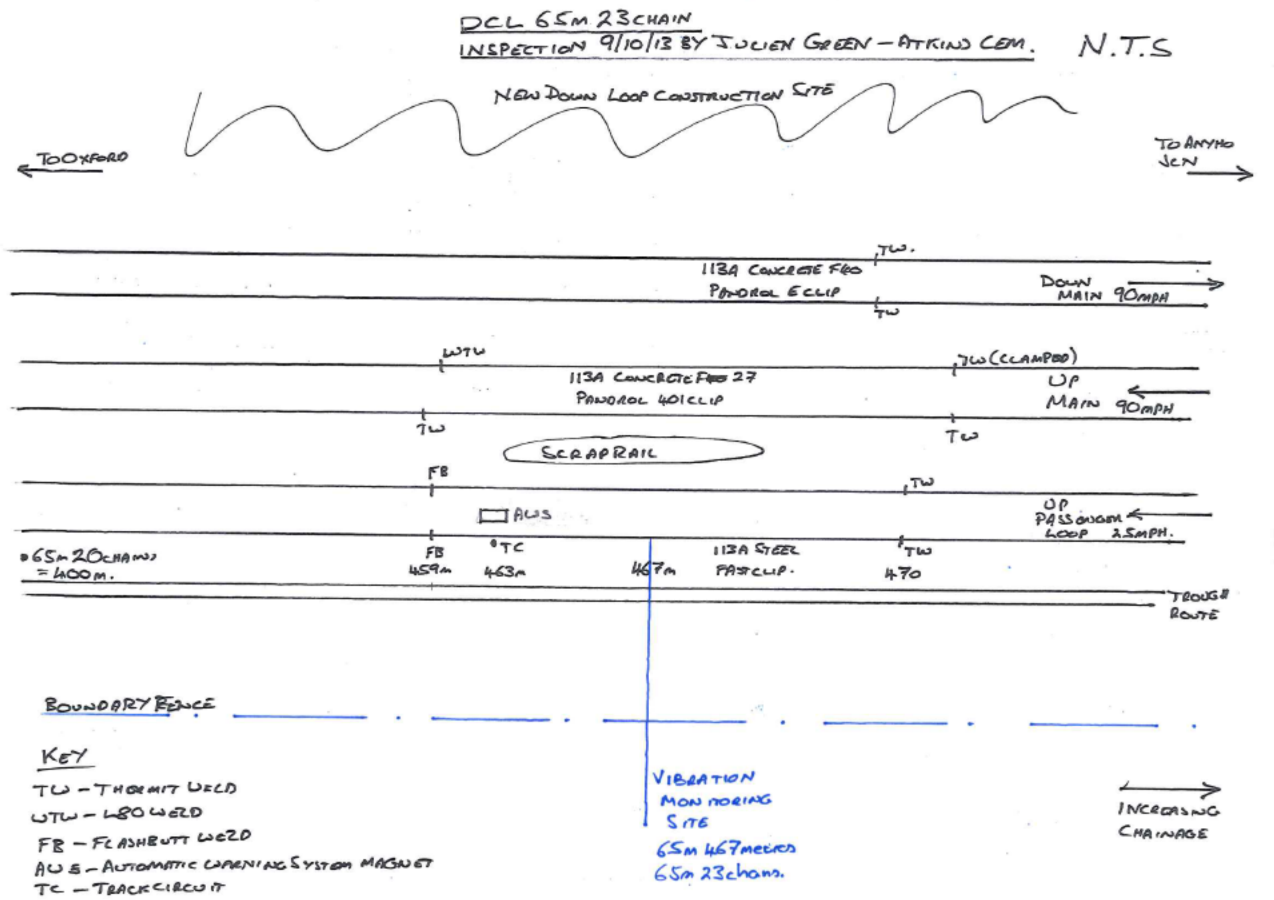


Figure 5: DCL 65m 23chains Site Sketch

9.1. Components

9.1.1. Alignment

At this location, the track is situated on a straight alignment with the alignment going into a transition and right hand curve travelling in the up direction towards Oxford. The horizontal alignment looks satisfactory for the line speed. The vertical alignment at the vibration location is of a good condition. All the lines were witnessed under dynamic loading of freight and passenger trains, and all demonstrated good characteristics with no excessive movement under load.

Photograph 8: DCL Line looking towards Aynho Junction

Photograph 9: DCL Line Looking towards Oxford

9.1.2. Rail

The rail is 113A Flat Bottom rail on all the lines. Table 1 below lists the details for each line. Note that the inspection is only what could be undertaken from lineside.

Table 1: Rail, Sleeper, Fastening types for the DCL lines

Line	Rail	Sleepers	Fastenings	Welds/Joints	Comments
Up Passenger Loop	113A Colivilles 1965 Running pattern, is approximately 50mm and is from the middle to the outside edge of the rail head	Steel	Pandrol fastclips	Thermit welds within 3m of monitoring site to the north and flashbutt welds within 8m to the south	AWS in the 4' within 4m of the monitoring site. (photograph 9)
Up Main	113A The rail head shows evidence of recent rail grinding. The running pattern is approximately 40mm wide in the centre of the rail head.	Concrete F27	Pandrol 401	Thermit welds within 4m to the north. The 6' rail was emergency clamped. (photograph 10) Thermit welds within 8m to the south of the monitoring site. The 6' rail was an "L80" wide gap weld. (photograph 11)	Scrap rail situated in the 10' between the Up Main and Up Passenger Loop. Photograph 9.
Down Main	113A The rail head shows evidence of recent rail grinding. The running pattern is approximately 40mm wide in the centre of the rail head.	Concrete F40	Pandrol "e" clips	Thermit welds within 2m of the monitoring site to the north.	

It was noted that on the Up Main, a thermit weld has been emergency clamped and that there was an L80 wide gap weld installed. There was no evidence of these causing any issues at present and under dynamic loading no excessive track movement or "banging" was noted.

Photograph 10: DCL Line Up Main 6' rail 65m 515yards. Thermit Weld Emergency clamped

Photograph 11: DCL Line Up Main 6' rail 65m 501yards. L80 wide gap weld

9.1.3. Sleepers

The sleepers are as per table 1, all sleepers were in good condition, with all fastenings present and correct.

9.1.4. Ballast

The ballast seems clean, well graded, and free of fines. No evidence of wet beds or "pumping" was identified or witnessed during dynamic loading.

There was some weed growth noted in the 4' and on cess ballast shoulder of the Up Passenger loop however this was well clear of the vibration monitoring site, and no pumping of the track was noted.

9.1.5. Topography

The vibration site is on a steep embankment (approx 3-4m height) on the Up side and at grade on the Down cess side. There is minimal cess on the Up side.

The slopes are heavily vegetated with shrubs and trees.

9.1.6. Track Quality

The latest available track quality data available from the track recording train can be seen in figures 6-7 below.

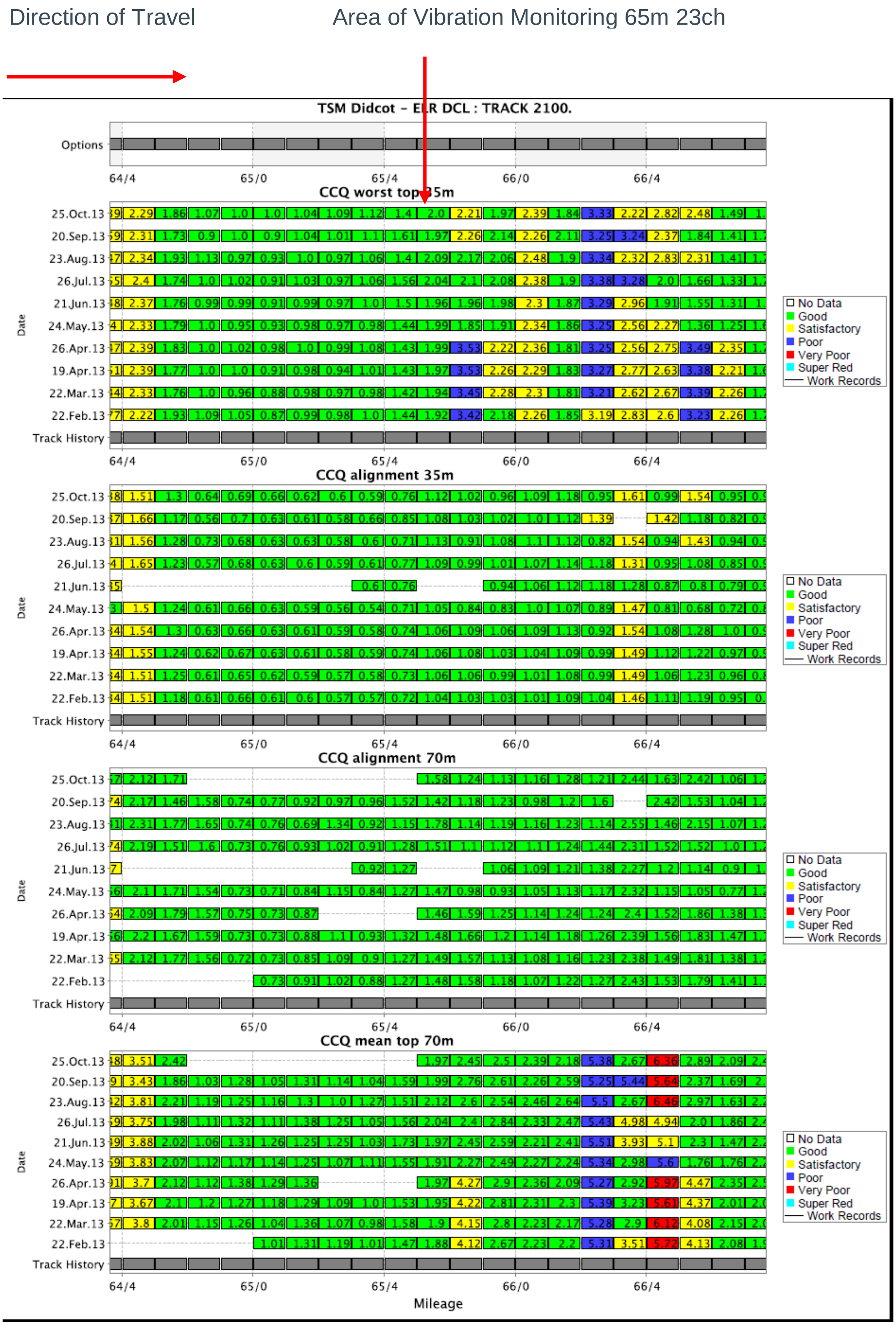


Figure 6: Track Recording Vehicle Track Quality Data (DOWN LINE)

Figure 7: Track Recording Vehicle Track Quality Data (UP LINE)

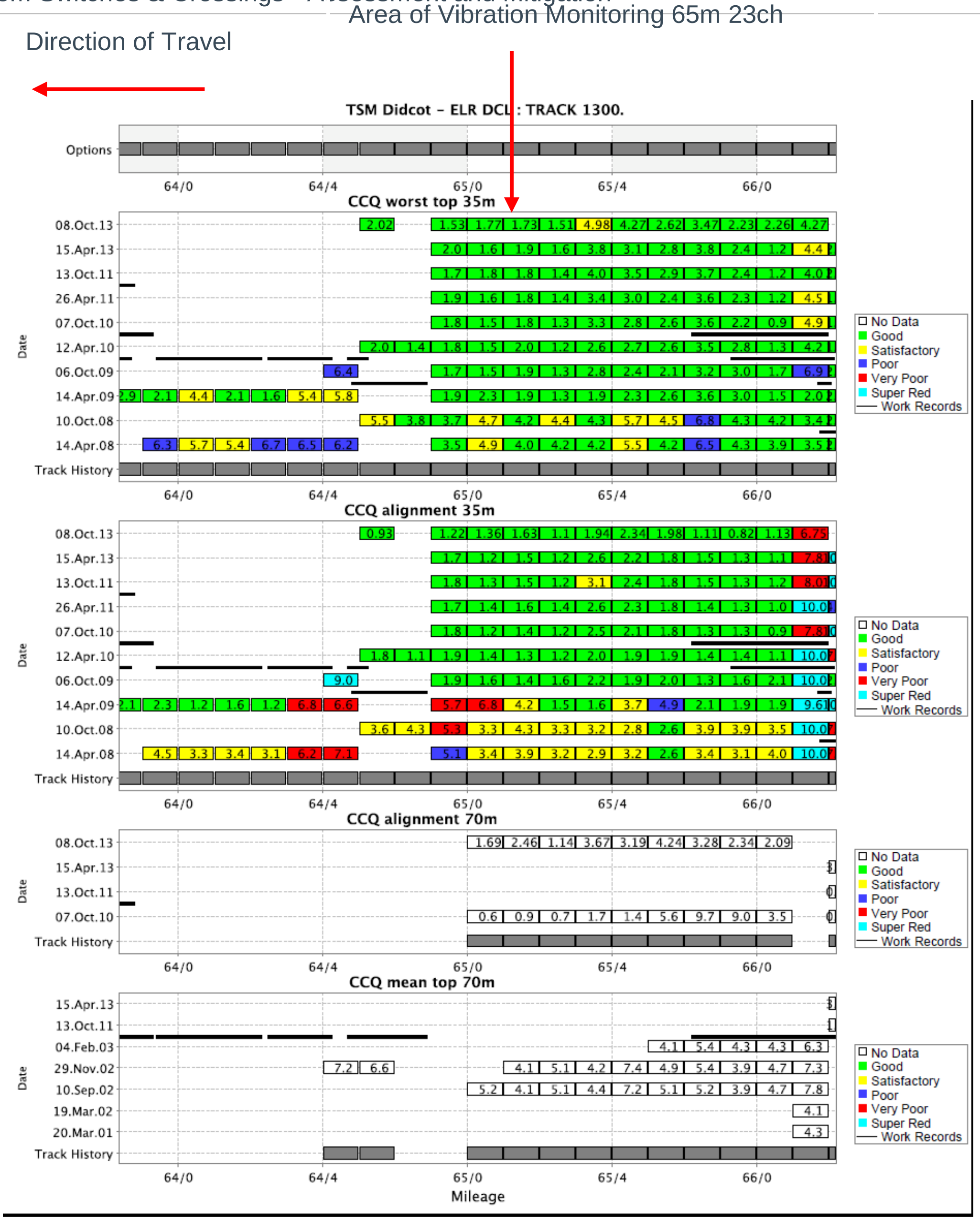


Figure 8: Track Recording Vehicle Track Quality Data (Up Passenger Loop)

The track quality data indicates at the time of the survey, that on all lines and for horizontal and vertical alignment the track was in the "Good" band, this is confirmed from the visual inspections undertaken.

9.2. Conclusion

The track is in a good condition, with no evidence of "track pumping" or other issues that are likely to provide excessive vibration or noise characteristics at this location, and that would be outside of the normal parameters for a well maintained line for the track category currently in service.

10. Banbury to Leamington Spa – DCL – 94m 78ch – 95m 8ch

This is a route that runs from Banbury to Leamington Spa and is currently 3 lines, the Up Goods Loop, Up and Down Main and the location of Fenny Compton Junction, where the STJ1 route (consists of the line to Kineton MOD) merges with the DCL lines. For the vibration monitoring, the inspection was predominantly focused on the S&C crossing (nose) for 160 points (part of 160/161 crossover between the Down and Up Main (see figure 8 and 9).

The line speed for the Up Goods Loop is 15mph and for the Up and Down Main it is 90mph, the ELR of the line is DCL, see Figure 8. The area chosen for the vibration monitoring was the Down cess (western– left hand side facing Leamington Spa) at 95m 1ch (at 160 crossing nose) and at 95m 8ch. Figure 9, provides a hand drawn sketch of the layout at this location.

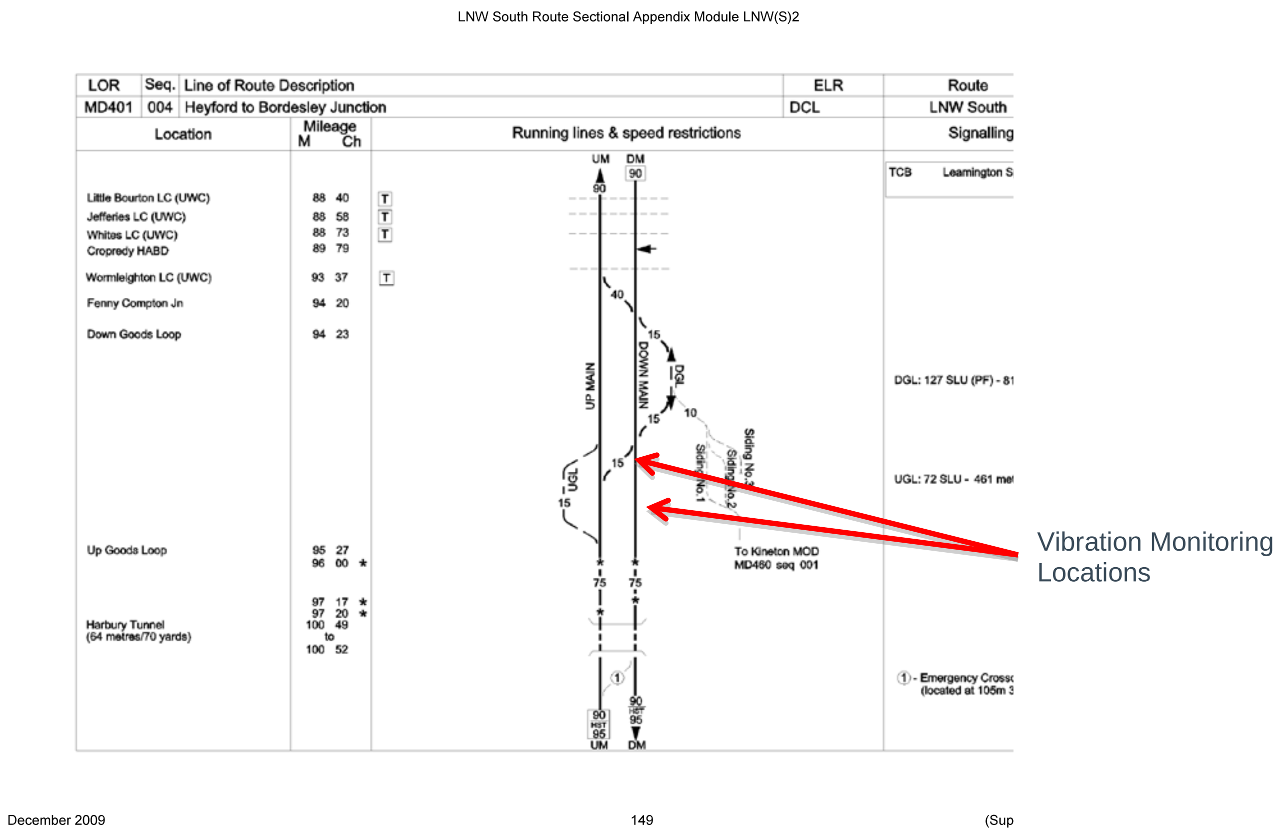


Figure 9: Sectional Appendix for DCL Line at Fenny Compton Junction

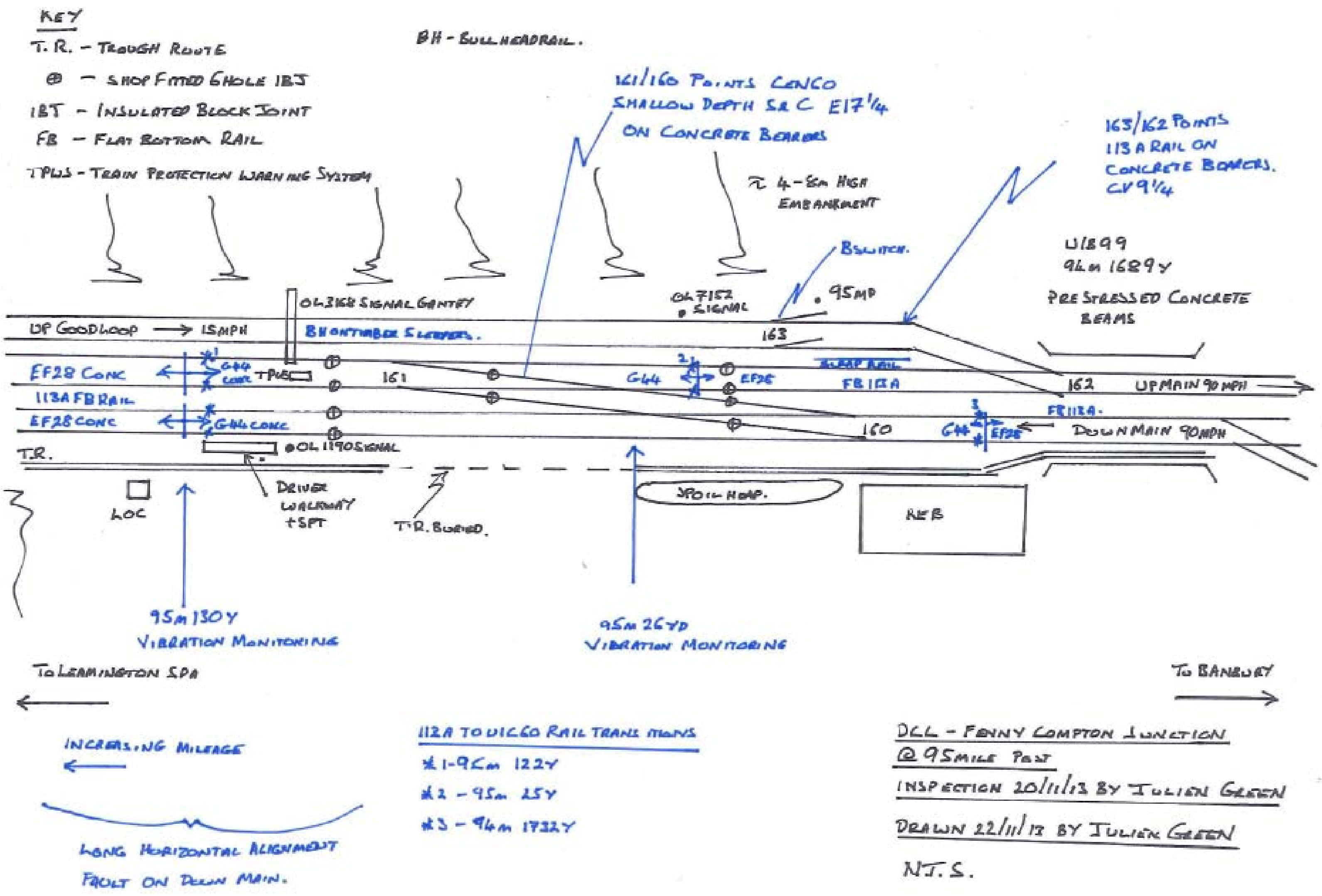

KEY
T.R. - TROUGH ROUTE
⊕ - SHOP FITTED GHOLE IBJ
IBJ - INSULATED BLOCK JOINT
FB - FLAT BOTTOM RAIL
TPWS - TRAIN PROTECTION WARNING SYSTEM
BH - BULLHEADRAIL.
161/160 POINTS CENCO SHALLOW DEPTH S&C E17¼ ON CONCRETE BEARERS
163/162 POINTS 113 A RAIL ON CONCRETE BEARERS. CV9¼
4-5m HIGH EMBANKMENT
B SWITCH.
95MP
UB99 94m 1689Y
PRE STRESSED CONCRETE BEAMS
OL3168 SIGNAL GANTRY
OL7152 SIGNAL
UP GOODLOOP → 15MPH
BH ON TIMBER SLEEPERS.
163
EF28 CONC
113A FB RAIL
EF28 CONC
G44 CONC
TPWS
161
G44
EF56
FB 113A
162
UP MAIN 90 MPH
FB 113A.
160
G44
EF56
DOWN MAIN 90MPH
OL 1190 SIGNAL
T.R.
LOC
DRIVER WALKWAY + SPT
T.R. BURIED.
SPOIL HEAP.
REB
95m 130Y VIBRATION MONITORING
95m 26YD VIBRATION MONITORING
To LEAMINGTON SPA
To BANBURY
INCREASING MILEAGE
LONG HORIZONTAL ALIGNMENT FAULT ON DOWN MAIN.
112A TO UIC60 RAIL TRANSITIONS
*1 - 95m 122Y
*2 - 95m 25Y
*3 - 94m 1732Y
DCL - FENNY COMPTON JUNCTION @ 95MILE POST
INSPECTION 20/11/13 BY JULIEN GREEN
DRAWN 22/11/13 BY JULIEN GREEN
N.T.S.

Figure 9: DCL 94m 78ch – 95m 8ch Site Sketch

10.1. Components

10.1.1. Alignment

At this location, the track is situated on a straight alignment with the alignment straight alignment, transitioning into a left hand curve travelling in the Up direction towards Oxford. The horizontal alignment looks satisfactory for the line speed, however on the Down Main, a “”long alignment” defect was noted. This is satisfactory for the line speed, however correction is recommended, and it is not likely to impact upon the vibration monitoring at this location. The vertical alignment at the vibration locations is in good condition. The Up and Down Main lines were witnessed under dynamic loading of freight and passenger trains, and all demonstrated good characteristics with no excessive movement under load.

Long horizontal alignment fault on the Down main at approx. 95m 5-10ch

Photograph 12: DCL Line at 94m 79chain Looking towards Leamington Spa (direction of travel)

Photograph 13: DCL Down Line (looking towards oncoming trains) at 95m 9chain Looking towards Banbury

10.1.2. Rail

The rail is 113A Flat Bottom rail on all the Up and Down Main lines either side of the main vibration monitoring sites. Through the 160/161 crossover, the rail is CEN60. The Up Goods loop is Bull Head rail. Table 2 below lists the details for each line. Note that the inspection is only what could be undertaken from line side. Note that transition rail (113A to CEN60) are situated on the Up and Down Main lines either side of 160 and 161 points. The vibration monitoring point at 95m 130 yards is only 8 yards from one such transition rail (see Figure 9).

Table 2: Rail, Sleeper, Fastening types for the DCL lines at Fenny Compton Junction

Line	Rail	Sleepers	Fastenings	Welds/Joints	Comments
Up Goods Loop	Bull Head rail into 113A for the 163 trap points and 162 connection to the Up Main Running pattern, not inspected.	Timber	BH	Jointed	
Up Main	113A either side of the mileages below (>95m 6ch and <95m 1ch) CEN60 between 95m6ch to 95m 1ch The rail head shows evidence of recent rail grinding. The running pattern is approximately 40mm wide in the centre of the rail head.	Concrete EF28 Concrete G44	Pandrol 401 Fastclip	Flashbutt and thermit welds throughout the site. No visible evidence of dipped welds. 6 hole shop fitted Insulated Block joints throughout the layout in “standard” signalling locations. All appeared to be in good condition, and no evidence of “pumping” under dynamic load	TPWS loop situated at Signal OL 3168 (toes of 161 points)
Down Main	113A either side of the mileages below (>95m 6ch and <94m 78ch) CEN60 between 95m6ch to 94m 78ch The rail head shows evidence of recent rail grinding. The running pattern is approximately 40mm wide in the centre of the rail head.	Concrete EF28 Concrete G44	Pandrol 401 Fastclip	Flashbutt and thermit welds throughout the site. No visible evidence of dipped welds. 6 hole shop fitted Insulated Block joints throughout the layout in “standard” signalling locations. All appeared to be in good condition, and no evidence of “pumping” under dynamic load	

10.1.3. Sleepers

The sleepers are as per table 2, all sleepers were in good condition, with all fastenings present and correct.

10.1.4. Ballast

The ballast seems clean, well graded, and free of fines. No evidence of wet beds or “pumping” was identified or witnessed during dynamic loading. The Down cess was lower than the ballast shoulder and as such the site should be free draining.

There was some weed growth noted in the 4’ and on cess ballast shoulder of the Up Goods loop however this was well clear of the vibration monitoring site, and no pumping of the track was noted.

10.1.5. S&C

10.1.5.1. 160/161 Points

The S&C is an NR 60 E 17 ¼ layout on concrete bearers, with shallow depth switches, operated by HW point motors and with Edgar Allen cast manganese crossings with weldable legs. The layouts were installed in 2004 according to the NR GEOGIS data reports and are in good condition with all components in place.

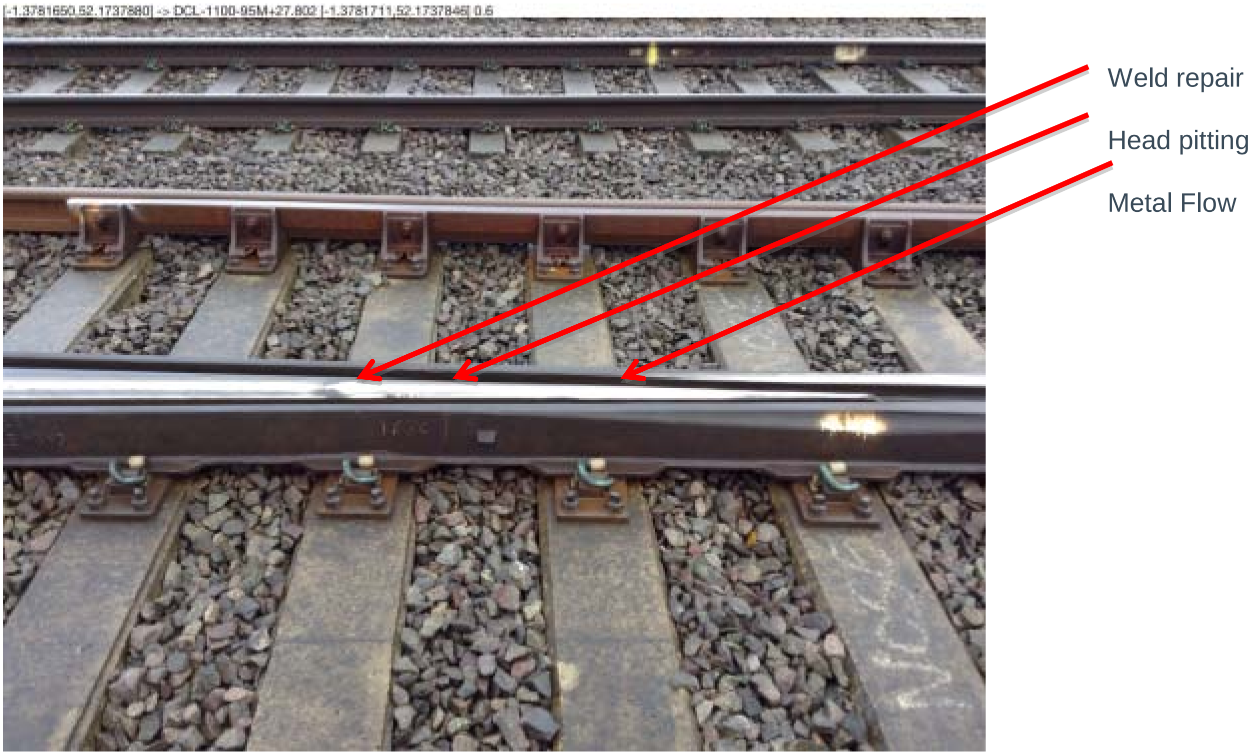
The crossing for 160 points, has several defects noted with its running surface, notably the following (see photograph 14):

i. Metal flow approximately 300mm from the nose;

ii. Pitting of the rail head surface;

iii. Weld repair of the crossing head.

No evidence of “pumping” or excessive “banging” was witnessed under dynamic load, however, it is recommended that the crossing undergo some remedial grinding to restore the correct rail head and frog profile.



Photograph 14: 160 Points, Edgar Allen Cast Manganese Crossing

10.1.5.2. 162 and 163 Trap Points

The S&C is 113A rail on concrete bearers. 163 points is a CV9 ¼ and the 162 trap points is a B switch. Both are in a good condition with no missing components. 163 crossing is a cast manganese with weldable legs, the condition of the crossing could not be assessed from the Down cess.

10.1.6. Topography

The vibration site on the Down cess side is at grade for approximately 40m, this develops into an embankment approximately 4m high at the higher mileage end beyond 95m 8chains.

On the Up Goods Loop cess, the site is on an embankment approximately 4-6m in height.

At the low mileage end of the site at 94m 77chains, the DCL lines cross Underbridge 99.

10.1.7. Under Bridge 99

Under bridge 99, is a precast concrete beam bridge on brick abutments and concrete cill beams. The bridge and abutments seemed to be in reasonable condition, and no major defects were noted as part of the inspection. The eastern elevation can be seen in photograph 15.

Photograph 15: Under Bridge 99, DCL 94m 77ch Western (Down cess) Elevation

10.1.8. Track Quality

The latest available track quality data available from the track recording train can be seen in figures 10-12.

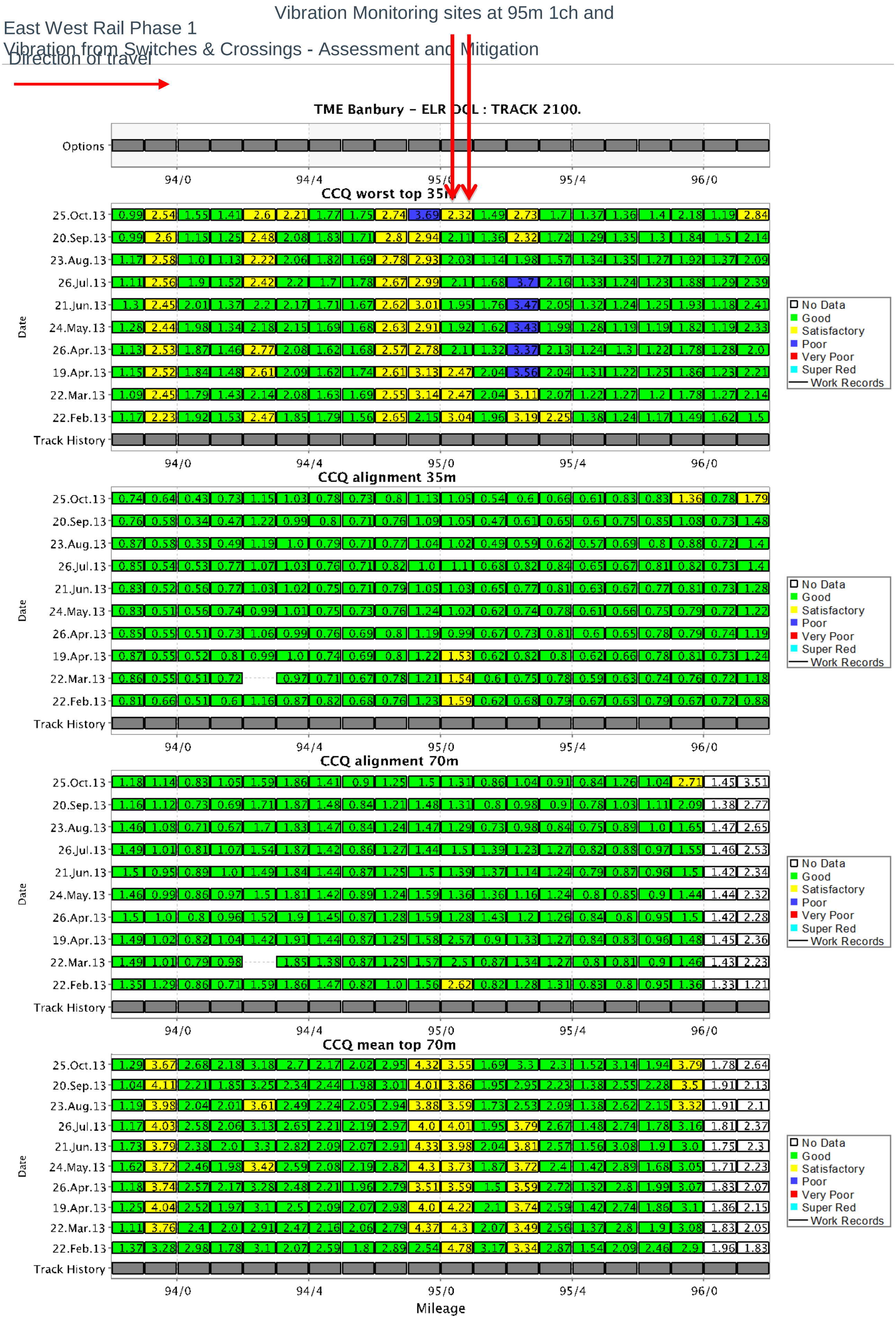


Figure 10: Track Recording Vehicle Track Quality Data (Down Main)

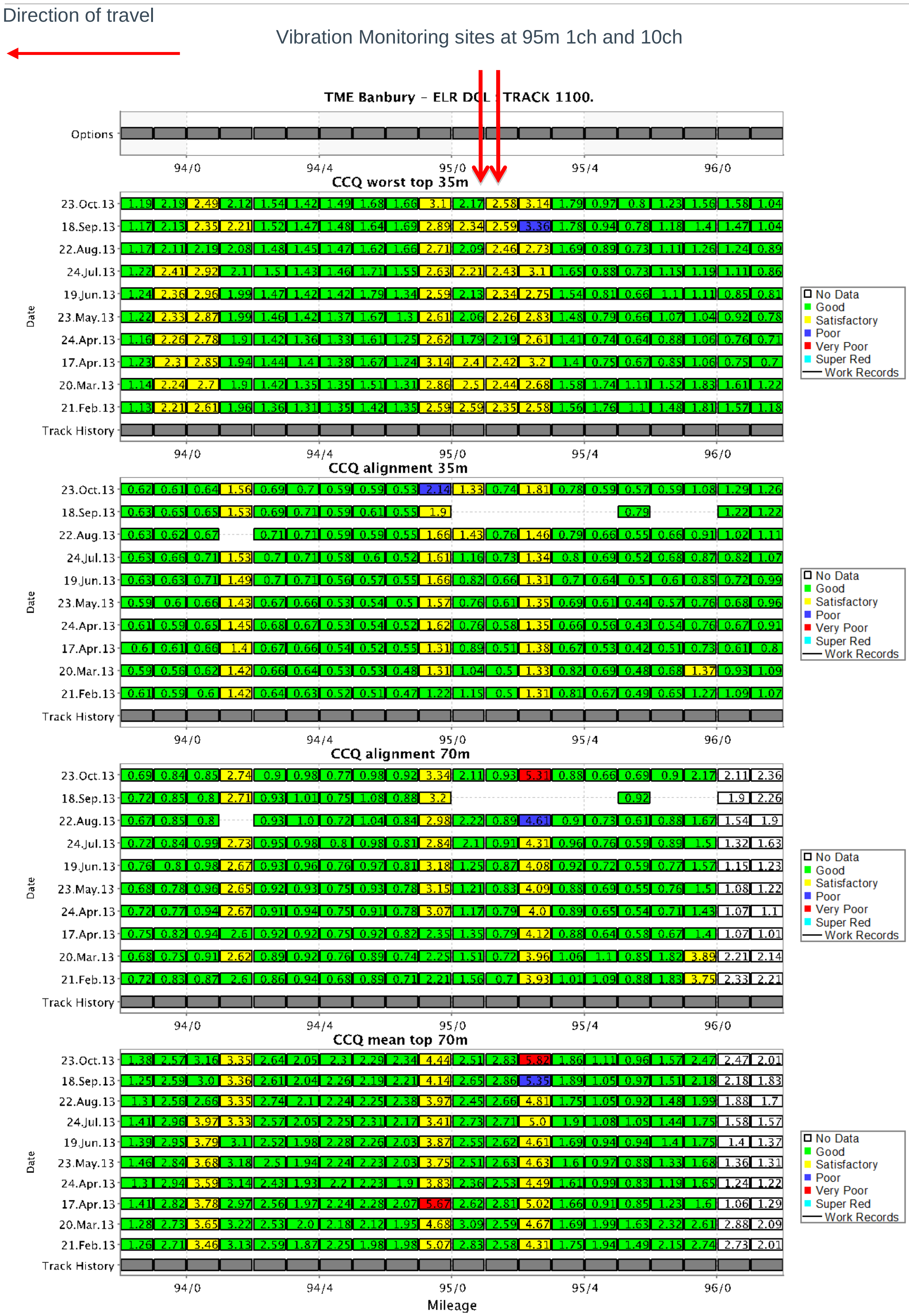


Figure 11: Track Recording Vehicle Track Quality Data (Up Main)

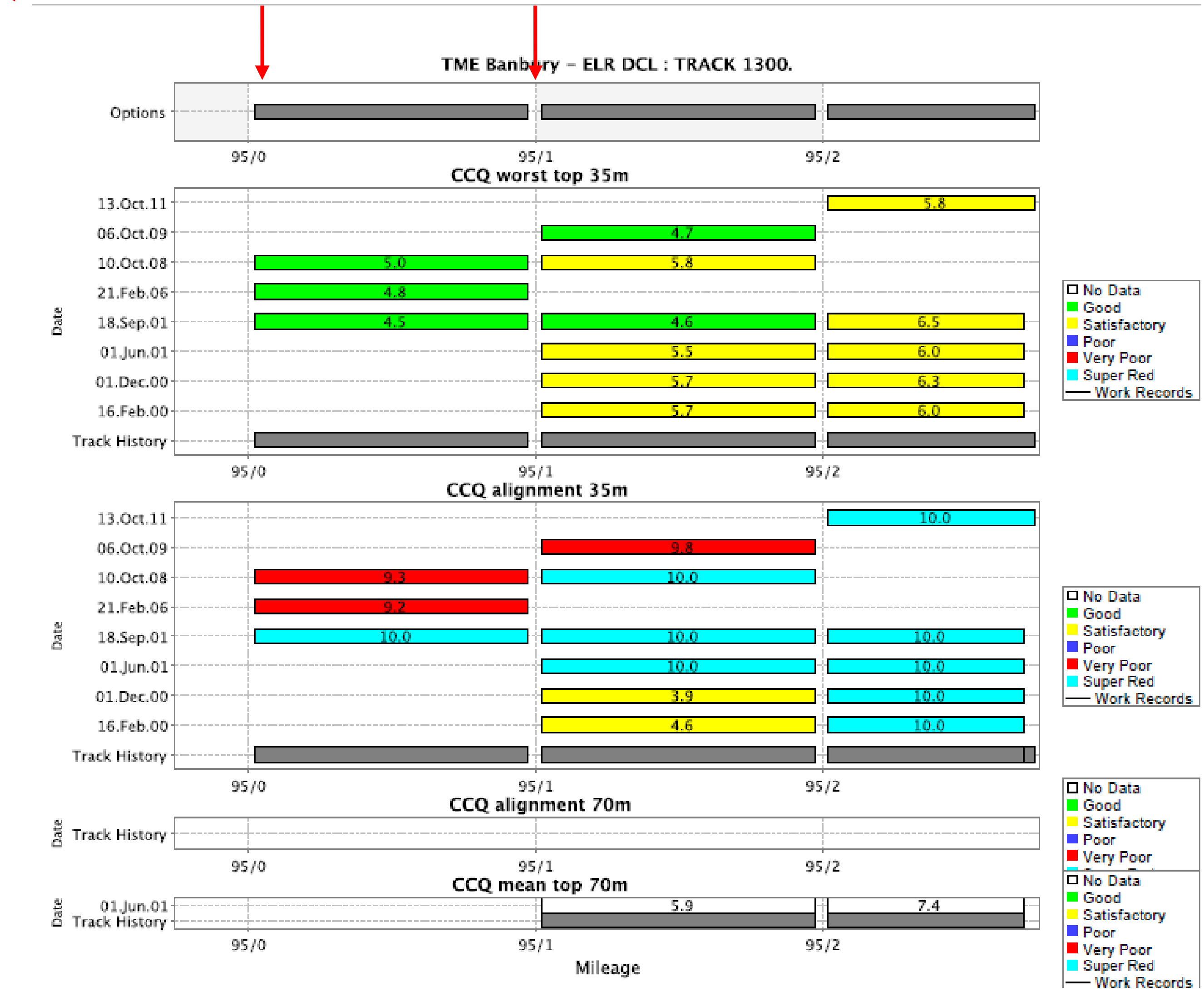


Figure 12: Track Recording Vehicle Track Quality Data (Up Goods Loop)

10.1.8.1. Down Main

As can be seen on Figure 10, the 35m top alignment in the preceding section was classified as poor during the October 2013 inspection. The area of the monitoring was deemed to be satisfactory. Between 94m 70ch and 95m, there is S&C connecting into the Down Goods Loop and under bridge 99. Both of which are likely to have affected the alignment in this area. It is noted that the 35m and 70m alignment are all in the "Good" category and "Satisfactory" for the 70m top.

10.1.8.2. Up Main

As can be seen in Figure 11, the 35m top alignment is "Satisfactory" on the preceding section, and "Good" through the monitoring sites. The 35m alignment is "Satisfactory" through the monitoring site, but "Poor" on the section after the area under consideration. As discussed in 4.1.8.1, this is predominantly due to the under bridge 99.

There are areas of "Poor" top and alignment between 95m 30ch and 20chain, this section is over 200m away from the vibration monitoring site and is not deemed to impact the areas under consideration.

10.1.8.3. Up Goods Loop

As can be seen in Figure 12, no track recording through the areas being monitored has been undertaken since 10 October 2008. The low speed through this area is considered to provide minimal vibration effects compared to that of the Up and Down Main.

10.1.8.4. Maintenance Intervention

It has been confirmed from Network Rail Maintenance that no maintenance activity (except patrolling) has been undertaken in the vicinity of this inspection on any of the Up/Down Main between 23 October 2013 and the date of this visual inspection. (i.e. no tamping has been undertaken).

10.2. Conclusion

The track is in a good condition, with no evidence of “track pumping” or other issues that are likely to provide excessive vibration or noise characteristics at this location, and that would be outside of the normal parameters for a well-maintained line for the track category currently in service. It should be noted that the vibration monitoring point at 95m 130 yards is 8 yards (high mileage side) of a 113A/CEN60 transition rail on the Up and Down Main and a change in concrete sleeper and fastening type (EF28 and pandrol 401 fastening to G44 fastclip fastening).

Appendix E. Description of Pass-By Events

Event Ref	Specific Track	Type	Operator	Class	Number of Cars / Wagons	Car / Wagon Data	Bogie / Suspension Comments	Train Length (m)	Speed Estimate (mph)
1	Down	Passenger	Chiltern Trains	DVT + 6 Mk3 Coaches + Class 67 Loco	8	Loco hauled Mk3 coaches with Driving Van Trailer (DVT). Loco 67010 / DVT unknown.	Class 66 has 3 driving wheelsets per bogie. Suspension is coil sprung. Mk3 coaches have coil spring primary and air bag secondary suspension. The DTV has the same type of bogie as the coaches.	176.6	84
2	Up	Passenger	Cross Country	Class 221	5 car	Diesel Electric Multiple Unit - each vehicle powered but sometimes operated with engines cut-out	The Class 221 this has a tilting bogie (which does not tilt anymore) which is heavier. It is an outside frame bogie with primary suspension springs and Air Bag secondary suspension.	116.16	89
3	Up	Freight	Freightliner	Class 66	1 loco + 27 wagons	Loco (66503) + 6 FTA/FSA type + 13 Low floor (FLA) and 6 "Pocket" Wagons (KTA)	coil spring bogies on primary/secondary.	564.84	70
4	Down	Passenger	Cross Country	Class 220	4 Car	Diesel Electric Multiple Unit - each vehicle powered but sometimes operated with engines cut-out	The Class 220 has Rubber Cheveron primary and the Air Bag secondary. The bogies are inside frames.	93.34	88
5	Down	Freight	DB Schenker (EWS)	Class 66	1 loco + 14 wagons	Loco 66037 + 4 x Network Balast Wagons (type JNA) + 10 x (type IOA)	coil spring bogies on primary/secondary.	228.7	61
6	Down	Passenger	Chiltern Trains	DVT + 6 Mk3 Coaches + Class 67 Loco	8	Loco 67017/ DVT 82304 - other details as event 1.	As event 1	176.6	87
7	Up	Passenger	Chiltern Trains	Class 168	4	"Turbostar" Diesel Multiple Unit - each vehicle is powered, with one powered and one unpowered bogie per vehicle.	Both bogie types have: Primary Suspension of rubber cheveron and the Secondary is Air Bag.	94.48	80
8	Up	Freight	Freightliner	Class 66	1 loco + 26 Wagons	Loco (66558) + 26 FSA/FSA type	coil spring bogies on primary/secondary.	554.4	58
9	Down	Passenger	Cross Country	Class 221	5 car	As Event 5	As Event 5	116.16	81
10A	Down	Freight	Freightliner	Class 66	1 loco + 24 wagons	Loco 66955 + 24 Container Wagons (1st pair is a FWA) the remaining are the longer variety (Probably FTA/FSA).	coil spring bogies on primary/secondary.	671.123	20
10B	Up	Passenger	Cross Country	Class 221	5 car	As Event 5	As Event 5	116.16	81
11	Down	Freight	Colas	Track Tamper	2	73923+73923 08-4X4/4S-T Tamper 2 vehicle Unit		40	77
12	Down	Passenger	Chiltern Trains	DVT + 6 Mk3 Coaches + Class 67 Loco	8	Loco 67014/ DVT 82301 - other details as event 1	As event 1	176.6	90
13	Down	Passenger	Cross Country	Class 221	5 car	As Event 5	As Event 5	116.16	87
14	Up	Passenger	Cross Country	Class 220	4 Car	As Event 4	As Event 4	93.34	84
15	Up	Passenger	Chiltern Trains	Class 168	3 or 4	As event 7	As event 7	47.24	79
16	Down	Passenger	Cross Country	Class 221	5 car	As Event 5	As Event 5	116.16	83
17	Down	Passenger	Chiltern Trains	Class 168	3	As event 7	As event 7	70.86	86
18	Down	Freight	Freightliner	Class 66	1 loco + 26 wagons	Loco 66534 + 26 container wagons -FSA/FTA type	coil spring bogies on primary/secondary.	542.83	15
19	N/A	Background	N/A	N/A	N/A	N/A	N/A	N/A	N/A
20	Up	Passenger	Cross Country	Class 221	5 car	As Event 5	As Event 5	116.16	87
21		Passenger							
22	Down	Passenger	Cross Country	Class 220	4 Car	Unit No. 220011	As Event 4	93.34	89
23	Up	Passenger	Cross Country	Class 220	4 Car	As Event 4	As Event 4	93.34	85

Event Ref	Specific Track	Type	Operator	Class	Number of Cars / Wagons	Car / Wagon Data	Bogie / Suspension Comments	Train Length (m)	Speed Estimate (mph)
24A	Up	Freight	DB Schenker (EWS)	Class 66	1 loco + 26 Wagons	Loco (66194) + 10 FTA/FSA type + 12 FKA +4 FYA	coil spring bogies on primary/secondary.	527.72	54
24B	Down	Freight	DRS	Class 66	2 locos	47???+47813	coil spring bogies on primary/secondary.	38.76	79
25	Down	Passenger							
26A	Down	Passenger							
26B	Up	Passenger	Chiltern Trains	DVT + 6 Mk3 Coaches + Class 67 Loco	8	Loco 66017/ DVT 82304? - other details as event 1	As event 1	176.6	80
27	Down	Passenger	Cross Country	Class 220	4 Car	As Event 4	As Event 4	93.34	88
28	Down	Freight	Colas	Class 66	1 loco + 21 Wagons	Loc 66849? + 20 Ballast Wagons (MLA) + 1 Flat (rail carrier)	coil spring bogies on primary/secondary.	378.4	52
29	Down	Passenger	Chiltern Trains	Class 168	3	As event 7	As event 7	70.86	90
30A	Up	Passenger	Chiltern Trains	DVT + 6 Mk3 Coaches + Class 67 Loco	8	Loco ?/ DVT ? - other details as event 1	As event 1	176.6	76
30B	Down	Passenger	Cross Country	Class 220	4 Car	As Event 4	As Event 4	93.34	91
31	Up	Passenger	Cross Country	Class 220	4 Car	As Event 4	As Event 4	93.34	85
32	Up	Passenger	Cross Country	Class 220	4 Car	As Event 4	As Event 4	93.34	87
33	Down	Freight	DB Schenker (EWS)	Class 66	1 loco + 36 Wagons	Loc 66020+ 36 Car Carriers	The wagons have four wheels i.e. no bogies.	497.32	59
34	Down	Passenger	Cross Country	Class 220	4 Car	As Event 4	As Event 4	93.34	86
35	Up	Passenger	Chiltern Trains	Class 168	3	As event 7	As event 7	70.86	81
36	Down	Freight	Freightliner	Class 66	1 loco + 18 Wagons	Loc 66547+18 Network Rail Balast Wagons (IOA)	coil spring bogies on primary/secondary.	325.6	72
37	Up	Passenger	Cross Country	Class 220	4 Car	As Event 4	As Event 4	93.34	84
38	Down	Passenger	Chiltern Trains	Class 168	4	As event 7. Unit 168003	As event 7	94.48	91
39	Up	Passenger	Chiltern Trains	Class 168	3	As event 7	As event 7	70.86	82
40	Up	Freight	Freightliner	Class 66	1 loco + 23 Wagons	Loco (665?7) + 23 FTA/FSA type	coil spring bogies on primary/secondary.	492.9	62
41	Up	Passenger	Cross Country	Class 221	5 car	As Event 5	As Event 5	116.16	85
42	Up	Passenger	Chiltern Trains	Class 172	2	Latest version of BOmbardier Diesel Multiple Unit - each vehicle is powered, with one powered and one unpowered bogie per vehicle.	Inside framed bogie (FLEXX-ECO). Both bogie types have: Primary Suspension of rubber cheveron and the Secondary is Air Bag.	47.24	83
43	Down	Passenger	Chiltern Trains	Class 168	3	As event 7. Unit 168214	As event 7	70.86	85
44	Up	Freight	DB Schenker (EWS)	Class 66	1 loco + 26 Wagons	Loco (66067) + 36 Car Carriers	The wagons have four wheels i.e. no bogies.	497.32	52
45	Down	Freight	Freightliner	Class 66	1 loco + 33 Wagons	Loc 66591+30 FWA (shortlinner flats) + 3 longer wagons (Probably FTA/FSA).	coil spring bogies on primary/secondary.	501.835	70
46	N/A	Background	N/A	N/A	N/A	N/A	N/A	N/A	N/A
47	Down	Freight	DB Schenker (EWS)	Class 66	1 loco + 36 Wagons	Loc 66127 + 36 Car Carriers	The wagons have four wheels i.e. no bogies.	497.32	60
48	Up	Freight	Freightliner	Class 66	1 loco + 30 Wagons	Loco (665?7) + 30 FTA/FSA type	coil spring bogies on primary/secondary.	636.4	58
49	Up	Passenger	Cross Country	Class 220	4 Car	As Event 4	As Event 4	93.34	87
50	Down	Passenger	Chiltern Trains	Class 168	3 + 4	As event 7	As event 7	165.34	90
51	Up	Freight	Freightliner	Class 66	1 loco + 24 Wagons	Loco (66564) + 1st 6 (FWA) + 16 FTA/FSA type	coil spring bogies on primary/secondary.	426.334	60
52	Up	Passenger	Chiltern	Class 168	3	As event 7	As event 7	70.86	47

Event Ref	Specific Track	Type	Operator	Class	Number of Cars / Wagons	Car / Wagon Data	Bogie / Suspension Comments	Train Length (m)	Speed Estimate (mph)
			Trains						
53A	Down	Passenger	Cross Country	Class 220	4 Car	As Event 4	As Event 4	93.34	88
53B	Up	Passenger	Chiltern Trains	Class 168	3	As event 7	As event 7	70.86	74
54		Passenger	Chiltern Trains	DVT + 6 Mk3 Coaches + Class 67 Loco	8	Loco 66013/ DVT 82303 - other details as event 1	As event 1	176.6	87
55	Down	Passenger	Cross Country	Class 221	5 car	As Event 5	As Event 5	116.16	85
56	Up	Passenger	Chiltern Trains	Class 168	4	As event 7	As event 7	93.34	68
57	Up	Passenger	Cross Country	Class 221	5 car	As Event 5	As Event 5	116.16	90
58	Down	Passenger		Class 165	2	"Networker Turbo" Diesel Multiple Unit - each vehicle is powered, with one powered and one unpowered bogie per vehicle.	Bogie Type: P3-17 (power), T3-17 (trailer). Primary Suspension is rubber cheveron and the Secondary is Air Bag.	45.82	72
59	Up	Passenger	Cross Country	Class 220	4 Car	As Event 4	As Event 4	93.34	86
60	Up	Passenger	Chiltern Trains	Class 168	3	As event 7	As event 7	70.86	88
61	Down	Passenger	Chiltern Trains	Class 168	4	As event 7	As event 7	94.48	82
62	Up	Passenger	Chiltern Trains	Class 168	4	As event 7	As event 7	94.48	91
63	Down	Passenger	Cross Country	Class 220	4 car	As Event 4	As Event 4		0
64	Down	Passenger	Chiltern Trains	Class 168	3	As event 7	As event 7	70.86	91
65	Down	Passenger	Chiltern Trains	Class 168	4	As event 7	As event 7	94.48	75
66	Up	Passenger	Cross Country	Class 221	5 car	As Event 5	As Event 5	116.16	80
67	Up	Passenger	Cross Country	Class 220	4 car	As Event 4	As Event 4	93.34	79
68	Down	Passenger	Chiltern Trains	DVT + 6 Mk3 Coaches + Class 67 Loco	8	Loco 66017/ DVT 82304 - other details as event 1	As event 1	176.6	86
69	Down	Passenger	Chiltern Trains	DVT + 6 Mk3 Coaches + Class 67 Loco	8	Loco 66013/ DVT 82303 - other details as event 1	As event 1	176.6	76
70	Up	Passenger	Cross Country	Class 220	4 Car	As Event 4	As Event 4	93.34	86
71	Down	Freight							

Appendix F. Measured Vibration Levels

Table 7. Derived VDV ($ms^{-1.75}$)

Event	Line	Window Time(s)	Type	Speed	VDV								EVDV							
					A				B				A				B			
					Distance 3.2	5.1	7.1	9.1	Distance 3.2	5.1	7.1	9.1	Distance 3.2	5.1	7.1	9.1	Distance 3.2	5.1	7.1	9.1
1	1	5.8	Passenger	84	0.34702	0.41196	0.3666	0.22609	0.13599	0.09719	0.06818	0.05516	0.30694	0.39029	0.33095	0.20261	0.13547	0.09939	0.07031	0.05604
2	2		Passenger	89																
3	2		Freight	70																
4	1	5.4	Passenger	88	0.15244	0.22834	0.13993	0.12809	0.12346	0.08636	0.06991	0.05573	0.12038	0.19072	0.11843	0.10498	0.10946	0.08252	0.06473	0.05128
5	1	9	Freight	61	0.1948	0.25062	0.17912	0.12581	0.12286	0.09211	0.06466	0.05071	0.17489	0.22297	0.17885	0.11578	0.11742	0.09181	0.06778	0.0534
6	1	5.5	Passenger	87	0.48143	0.43842	0.36582	0.23367	0.15282	0.10396	0.07166	0.05794	0.42775	0.43046	0.34217	0.21444	0.15012	0.10766	0.07348	0.0574
7	2		Passenger	80																
8	2		Freight	58																
9	1	5.3	Passenger	81	0.33851	0.40211	0.32677	0.19665	0.14825	0.1025	0.06976	0.0532	0.29714	0.34251	0.26507	0.16606	0.14216	0.09617	0.06963	0.05217
10A	1	75.8	Freight	20	0.18819	0.16119	0.10364	0.06814	0.09426	0.06282	0.04916	0.04092	0.1389	0.12398	0.08007	0.05499	0.06374	0.04377	0.03584	0.03098
10B	2		Freight	81																
11	1	5.3	Freight	77	0.17482	0.10346	0.0839	0.0572	0.0852	0.05502	0.04491	0.03377	0.1163	0.07889	0.05936	0.04248	0.06782	0.04812	0.03813	0.02958
12	1	5.3	Passenger	90	0.4888	0.44544	0.33806	0.22669	0.15926	0.10413	0.07157	0.06196	0.43264	0.43989	0.32724	0.21165	0.15107	0.10716	0.07459	0.06243
13	1	5.3	Passenger	87	0.3851	0.40286	0.34405	0.2291	0.15559	0.10755	0.07129	0.05765	0.33833	0.35269	0.28675	0.18398	0.15021	0.10262	0.06826	0.05488
14	2		Passenger	84																
15	2		Passenger	79																
16	1	5.3	Passenger	83	0.36458	0.39289	0.3469	0.21202	0.15028	0.09531	0.06698	0.04955	0.15025	0.15963	0.13377	0.08249	0.06897	0.04293	0.03173	0.02312
17	1	5.3	Passenger	86	0.24609	0.26097	0.1957	0.10892	0.11446	0.08876	0.06345	0.04495	0.19458	0.20509	0.1473	0.08265	0.09325	0.07361	0.0548	0.04092
18	1	88.1	Freight	15	0.18159	0.16525	0.10469	0.0684	0.08132	0.05467	0.04534	0.03745	0.13358	0.12414	0.07975	0.05486	0.05277	0.0371	0.03161	0.02785
20	2		Passenger	87																
21	1	5.3	Passenger		0.19659	0.24179	0.15068	0.11391	0.10711	0.07083	0.05048	0.03971	0.15862	0.1879	0.11993	0.09071	0.09085	0.06358	0.04611	0.03587
22	1	5.3	Passenger	89	0.26297	0.23586	0.13171	0.12583	0.12876	0.08433	0.06711	0.05256	0.21744	0.19445	0.11468	0.10195	0.10821	0.0727	0.05681	0.04499
23	2		Passenger	85																
24A	2		Freight	54																
24B	1	5.3	Freight	79	0.43988	0.51234	0.2769	0.21506	0.19383	0.12716	0.09171	0.07555	0.13454	0.18357	0.10178	0.07694	0.07058	0.04662	0.03361	0.02858
25	1	5.3	Passenger		0.25092	0.27618	0.19576	0.11364	0.11462	0.08524	0.06441	0.04919	0.21288	0.23076	0.1614	0.09331	0.10197	0.07889	0.06167	0.04658
26A	1	5.3	Passenger		0.25851	0.21525	0.12618	0.10258	0.10365	0.07407	0.04917	0.04049	0.18301	0.15225	0.09454	0.07405	0.07514	0.05674	0.04085	0.03356
26B	2		Passenger	80																
27	1	5.5	Passenger	88	0.26248	0.23478	0.13719	0.13047	0.10859	0.07344	0.05112	0.0415	0.21206	0.19204	0.11442	0.10434	0.09368	0.06602	0.04556	0.03614
28	1	17.4	Freight	52	0.30707	0.23867	0.18452	0.13976	0.18433	0.13424	0.10367	0.0854	0.29405	0.23624	0.1812	0.14235	0.18677	0.13826	0.10954	0.09203
29	1	5.3	Passenger	90	0.24611	0.27417	0.1881	0.11276	0.12237	0.10647	0.06714	0.04831	0.19056	0.21525	0.14158	0.08708	0.0984	0.07813	0.05635	0.04316
30A				76																
30B	2		Passenger	91																
31	2		Passenger	85																
32	2		Passenger	87																
33	1	19.8	Freight	59	0.32476	0.23892	0.17643	0.12325	0.12751	0.08533	0.06725	0.05596	0.27986	0.21454	0.15702	0.11025	0.1083	0.079	0.06591	0.05364
34	1	5.3	Passenger	86	0.23943	0.2244	0.14843	0.12989	0.10538	0.0716	0.0518	0.0403	0.20494	0.18677	0.12309	0.10402	0.09463	0.06652	0.04653	0.03696
35	2		Passenger	81																
36	1	11.2	Freight	72	0.31198	0.21951	0.16844	0.11582	0.12234	0.09547	0.07121	0.05262	0.30272	0.21111	0.16806	0.11411	0.11993	0.09343	0.07381	0.05388
37	2		Passenger	84																
38	1	5.3	Passenger	91	0.27985	0.26963	0.19476	0.109	0.11481	0.08321	0.06332	0.04619	0.22898	0.22588	0.15692	0.0894	0.10218	0.07558	0.05735	0.04365
39	2		Passenger	82																
40	2		Freight	62																
41	2		Passenger	85																
42	2		Passenger	83																
43	1	5.3	Passenger	85	0.27122	0.26365	0.17142	0.11107	0.10729	0.07448	0.05237	0.0402	0.20756	0.20653	0.13352	0.08561	0.0898	0.06608	0.04839	0.0359
44	2		Freight	52																
45	1	17	Freight	70	0.35314	0.34347	0.23743	0.15625	0.17193	0.10993	0.07965	0.06741	0.34436	0.3507	0.23945	0.15399	0.16969	0.11325	0.08373	0.07036
47	1	19.1	Freight	60	0.11833	0.21832	0.15536	0.10564	0.13019	0.08799	0.05401	0.04603	0.10714	0.20133	0.14689	0.10332	0.11726	0.0832	0.05429	0.04647
48	2		Freight	58																
49	2		Passenger	87																
50	1	5.3	Passenger	90	0.12079	0.26661	0.18535	0.10429	0.13166	0.09561	0.0735	0.0554	0.11579	0.26481	0.17857	0.10571	0.09605	0.07577	0.0582	0.13111
51	2		Freight	60																
52	2		Passenger	47																
53A	2		Passenger	88																
53B	1	5.3	Passenger	74	0.0854	0.21111	0.12365	0.11116	0.10126	0.0689	0.05078	0.03373	0.07379	0.17327	0.10498	0.09187	0.0902	0.06363	0.04711	0.03171
54	2		Passenger	87																
55	2		Passenger	85																
56	2		Passenger	68																
57	1	5.3	Passenger	90	0.13313	0.36273	0.26787	0.19614	0.16258	0.1061	0.07099	0.06056	0.12206	0.32441	0.22769	0.15864	0.1545	0.10285	0.06975	0.05736
58	2		Passenger	72																
59	2		Passenger	86																
60	1	5.3	Passenger	88	0.09801	0.22222	0.13663	0.10281	0.10587	0.0771	0.05948	0.04461	0.07935	0.17945	0.11148	0.08466	0.08831	0.06618	0.05269	0.03923
61	2		Passenger	82																
62	1	5.3	Passenger	91	0.10766	0.23164	0.16811	0.09682	0.10921	0.08296	0.064	0.04571	0.09016	0.19795	0.14013	0.0815	0.09539	0.07447	0.05958	0.04369
63	1	5.3	Passenger	0	0.0855	0.21233	0.13974	0.12022	0.10592	0.07212	0.0556	0.04571	0.07592	0.17843	0.11589	0.09908	0.09492	0.06621	0.04946	0.0405
64	1	5.3	Passenger	91	0.09522	0.23386	0.1534	0.0993	0.11342	0.07962	0.05886	0.04291	0.07627	0.19146	0.12238	0.07959	0.09406	0.06833	0.05206	0.03897
65	2		Passenger	75																
66	2		Passenger	80																
67	1	5.3	Passenger	79	0.08862	0.18652	0.15084	0.10072	0.10028	0.05995	0.04826	0.03974	0.07799	0.15859	0.1281	0.08856	0.08727	0.05604	0.04593	0.03719
68	1	5.8	Passenger	86	0.13686	0.38632	0.32135	0.20136	0.14469	0.09842	0.07003	0.05385	0.13021	0.37705	0.29942	0.18269	0.08727	0.09997	0.07034	0.05323
69	2		Passenger	76																
70	1	5.3	Passenger	86	0.07907	0.20824	0.12512	0.1115	0.11047	0.07279	0.05433	0.04398	0.0692	0.17349	0.10681	0.09446	0.09774	0.0672	0.04814	0.03941
71	1	36.7	Freight		0.06414	0.14847	0.08856	0.05783	0.11345	0.06679	0.05463	0.04592	0.04909	0.11662	0.07213	0.04926	0.06915	0.04632	0.03883	0.03438

Appendix G. Frequency Analysis of S&C Amplifications

G.1. S&C Amplification from Passenger Trains, dB

Figure 21. Passenger Train, 6.3Hz

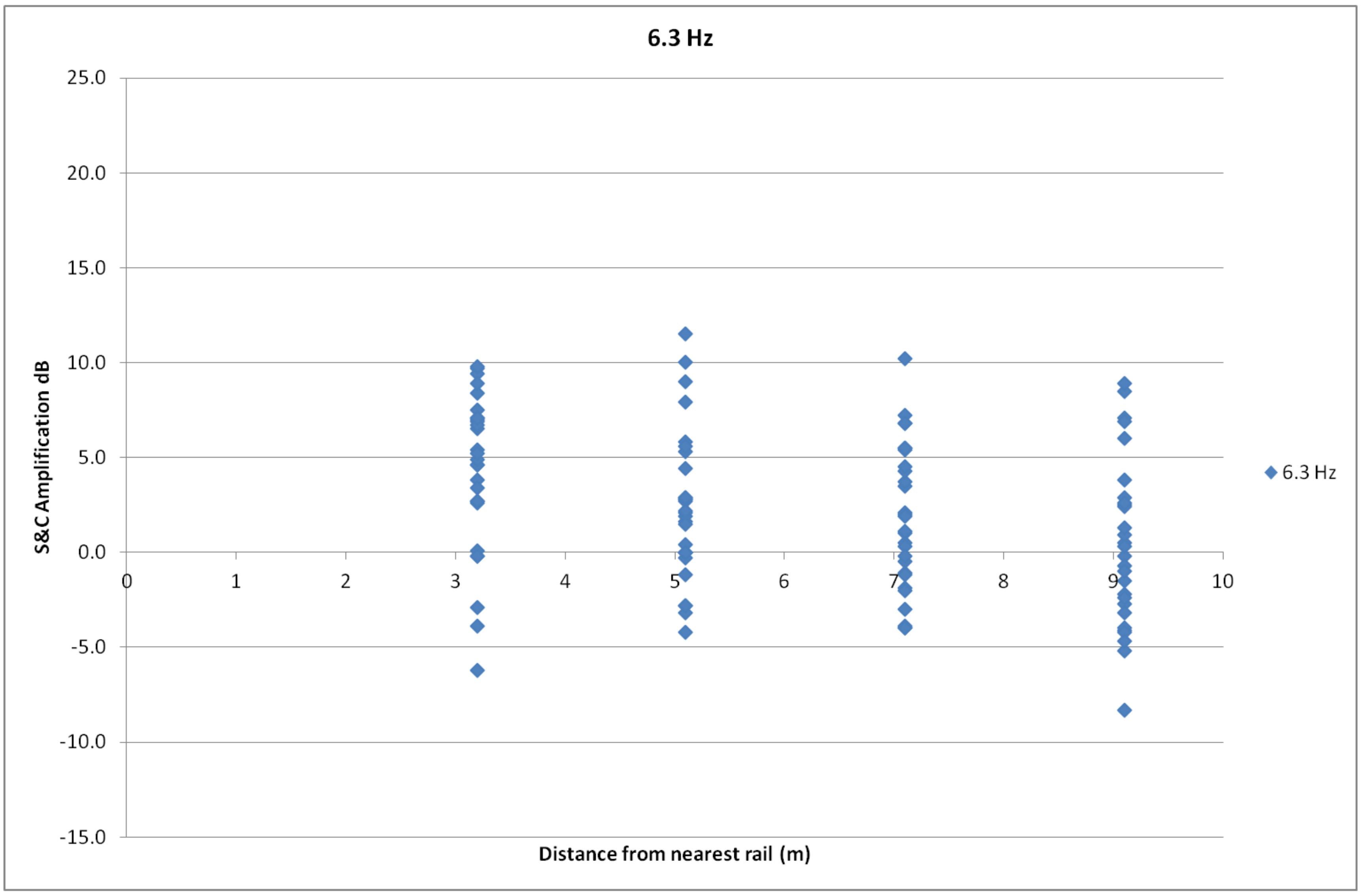


Figure 22. Passenger Train, 8Hz

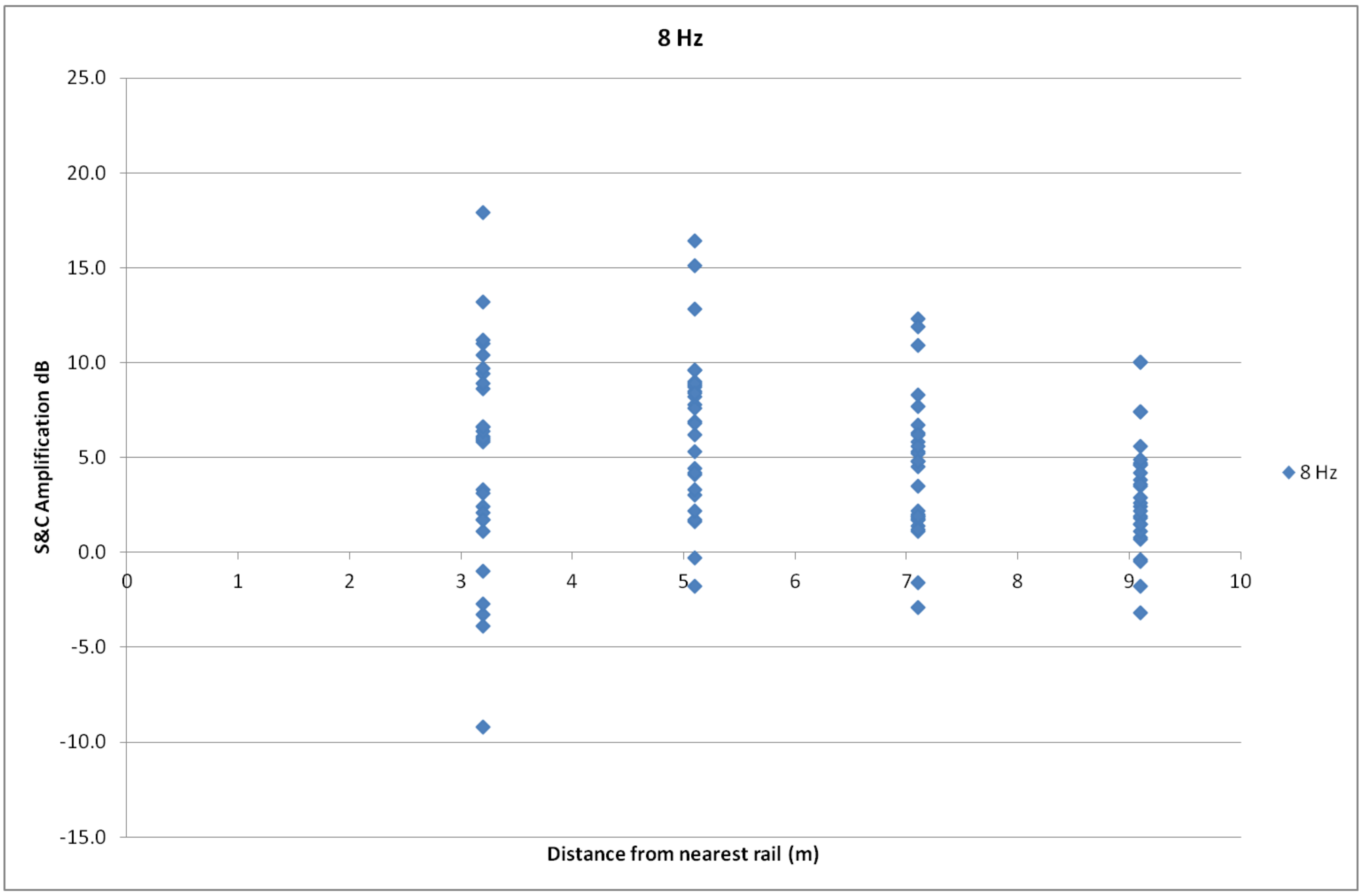


Figure 23. Passenger Train, 10Hz

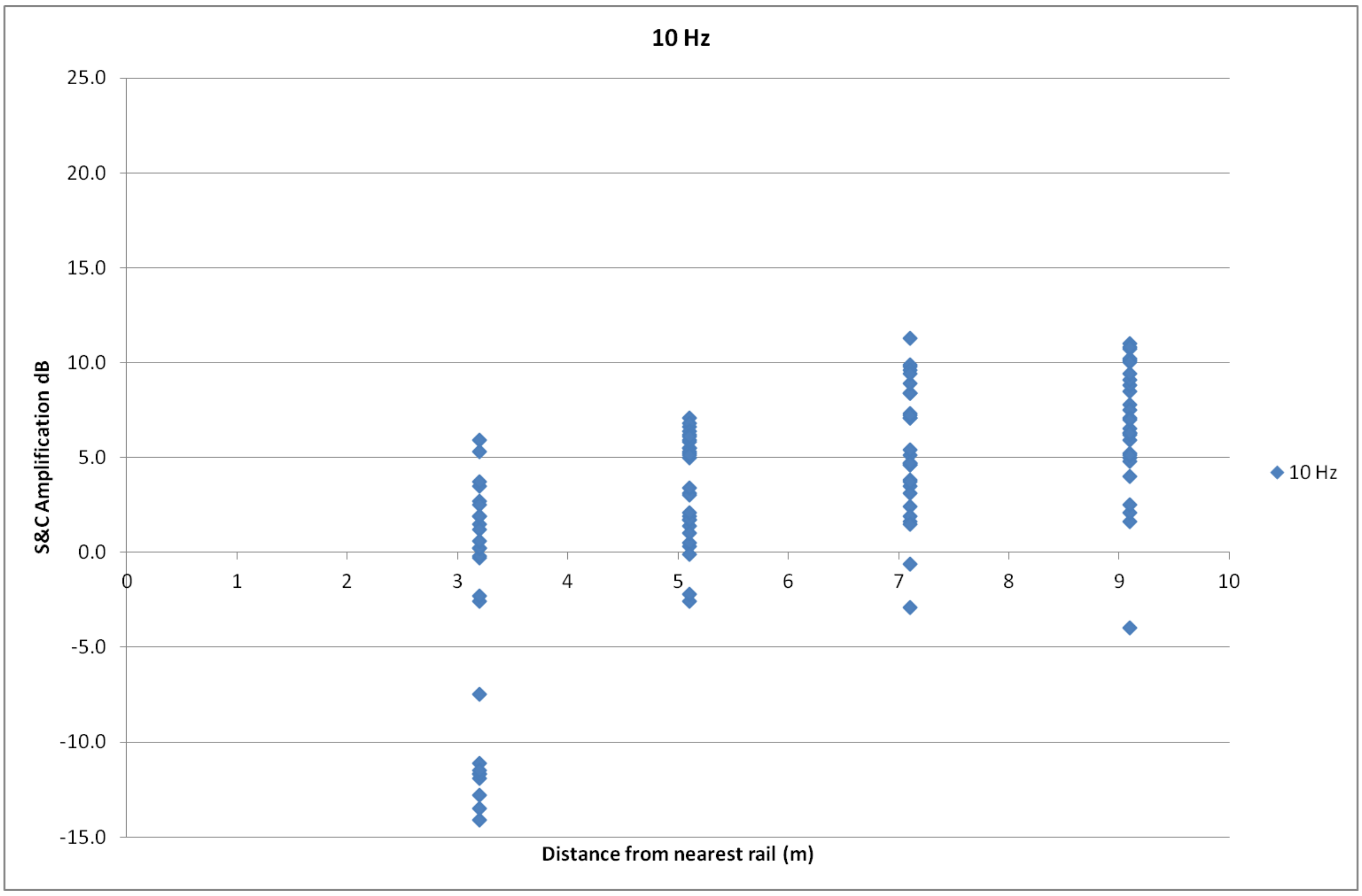


Figure 24. Passenger Train, 12.5Hz

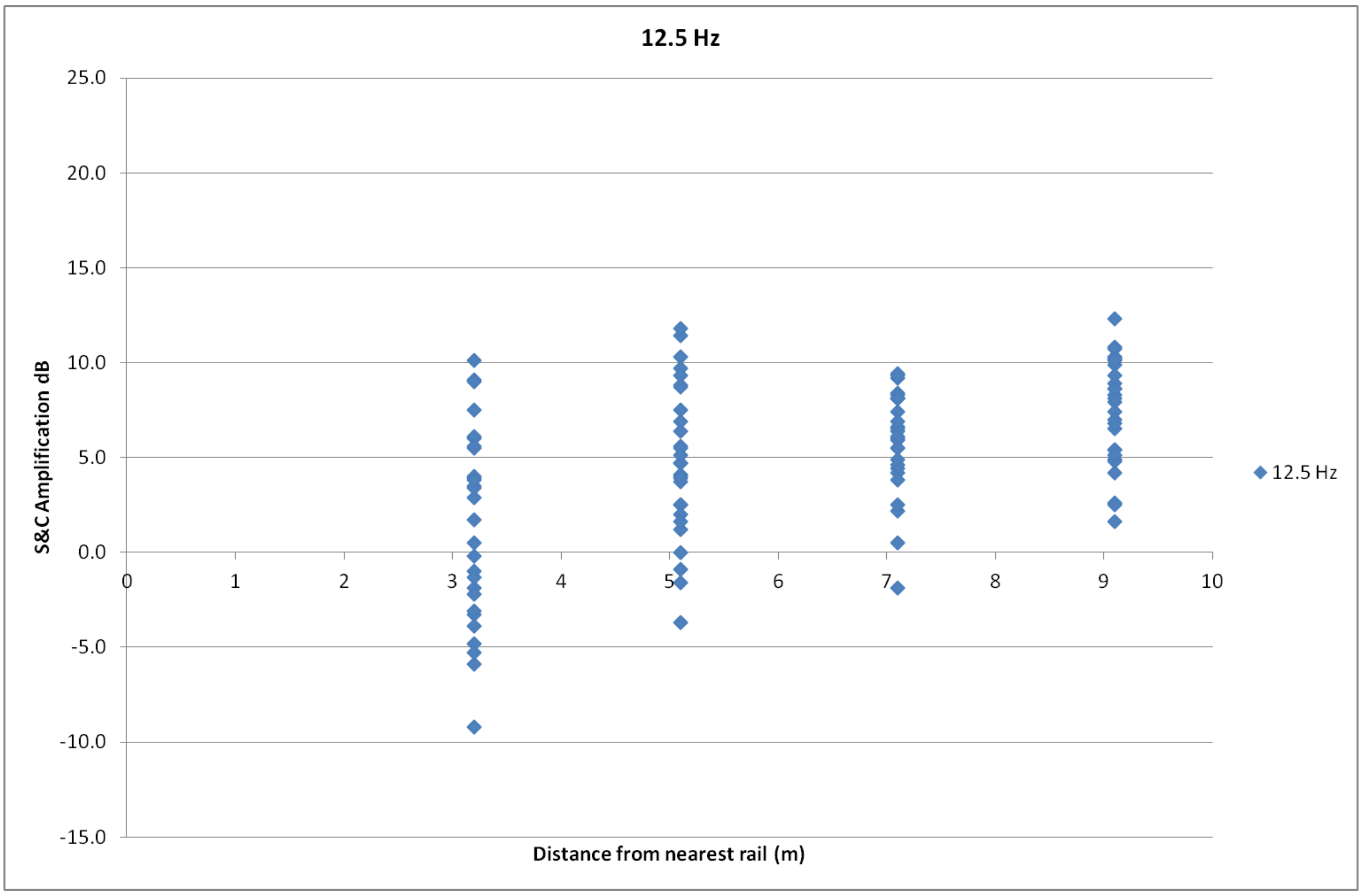


Figure 25. Passenger Train, 16Hz

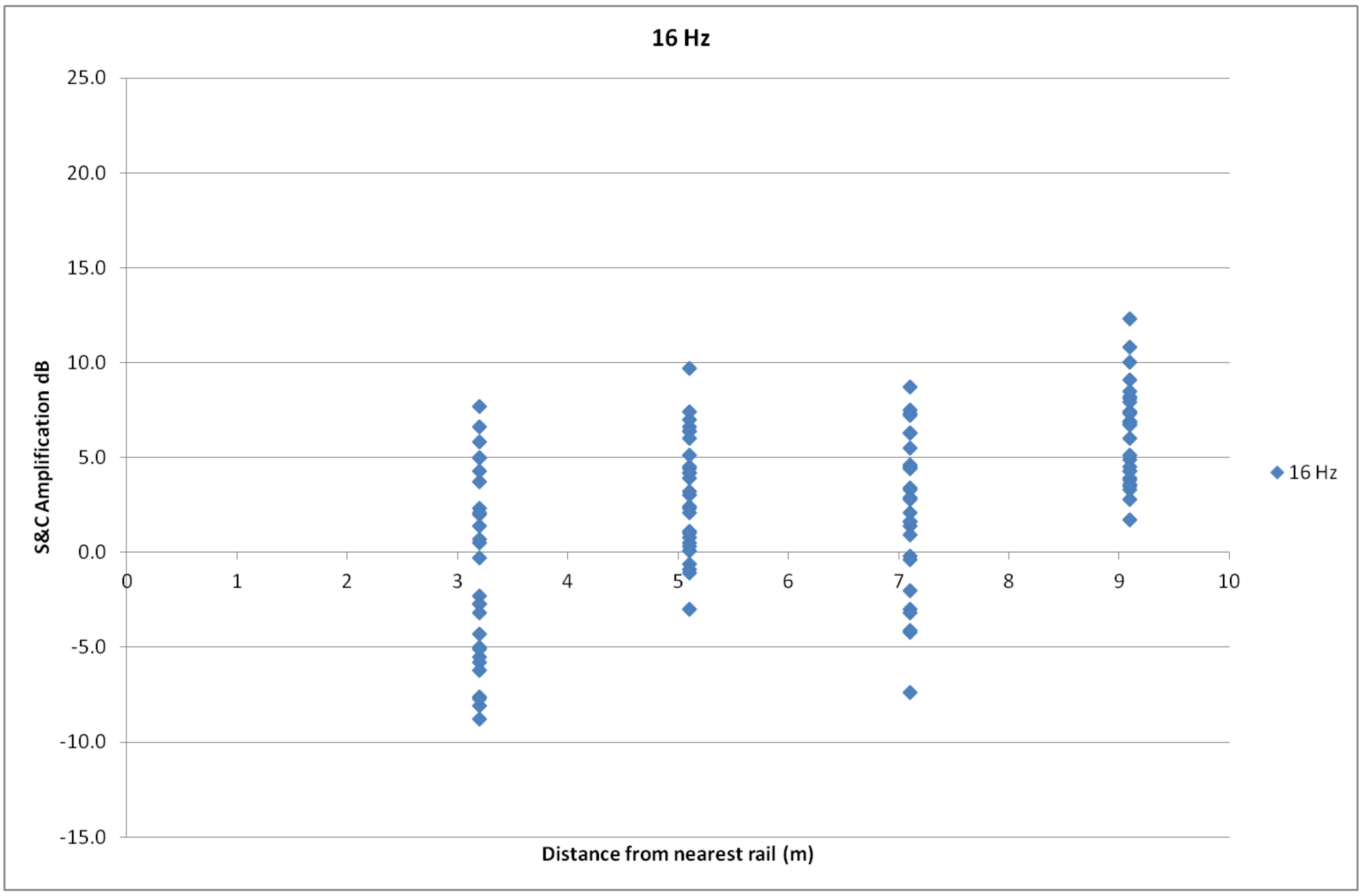


Figure 26. Passenger Train, 20Hz

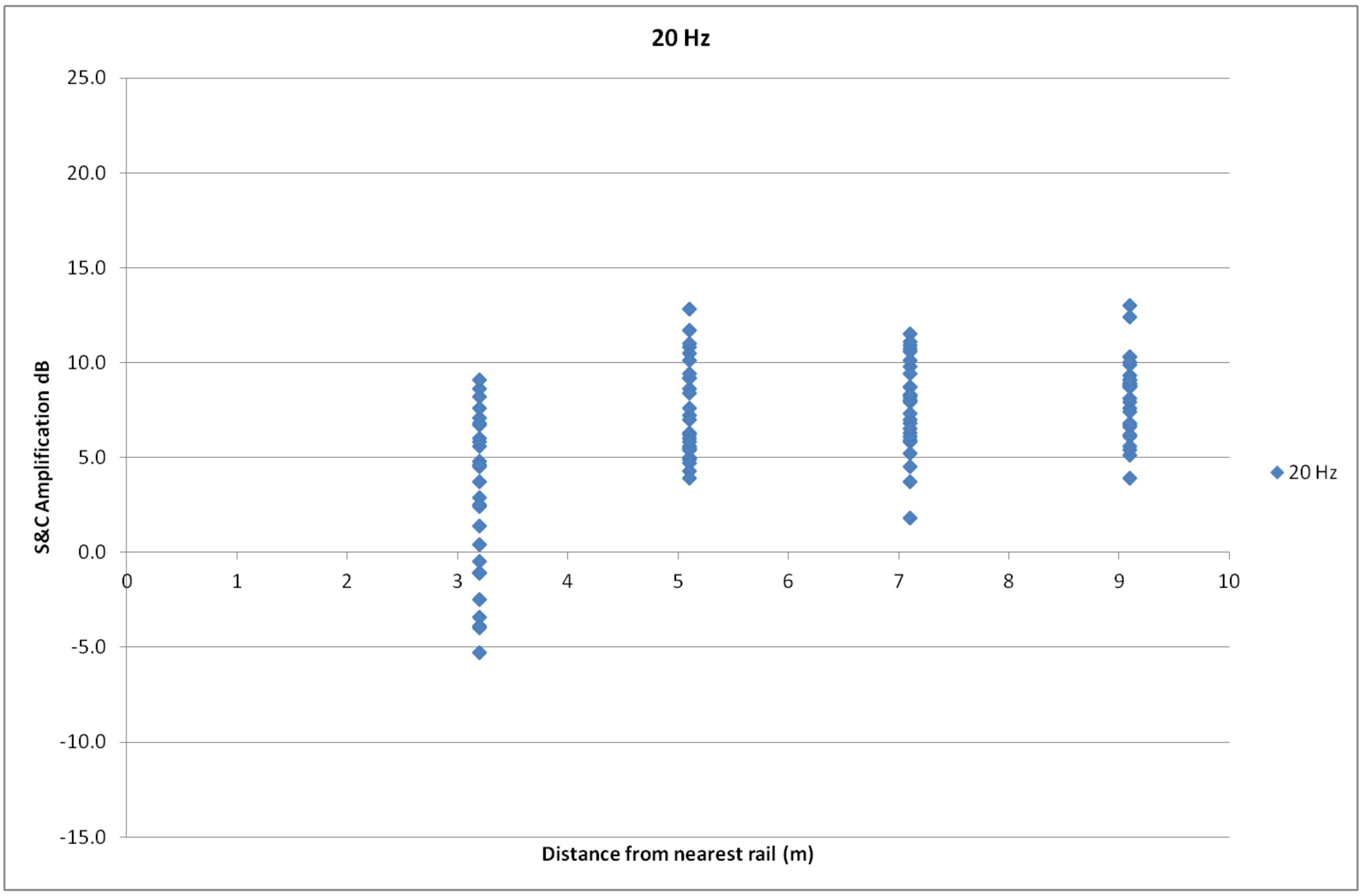


Figure 27. Passenger Train, 25Hz

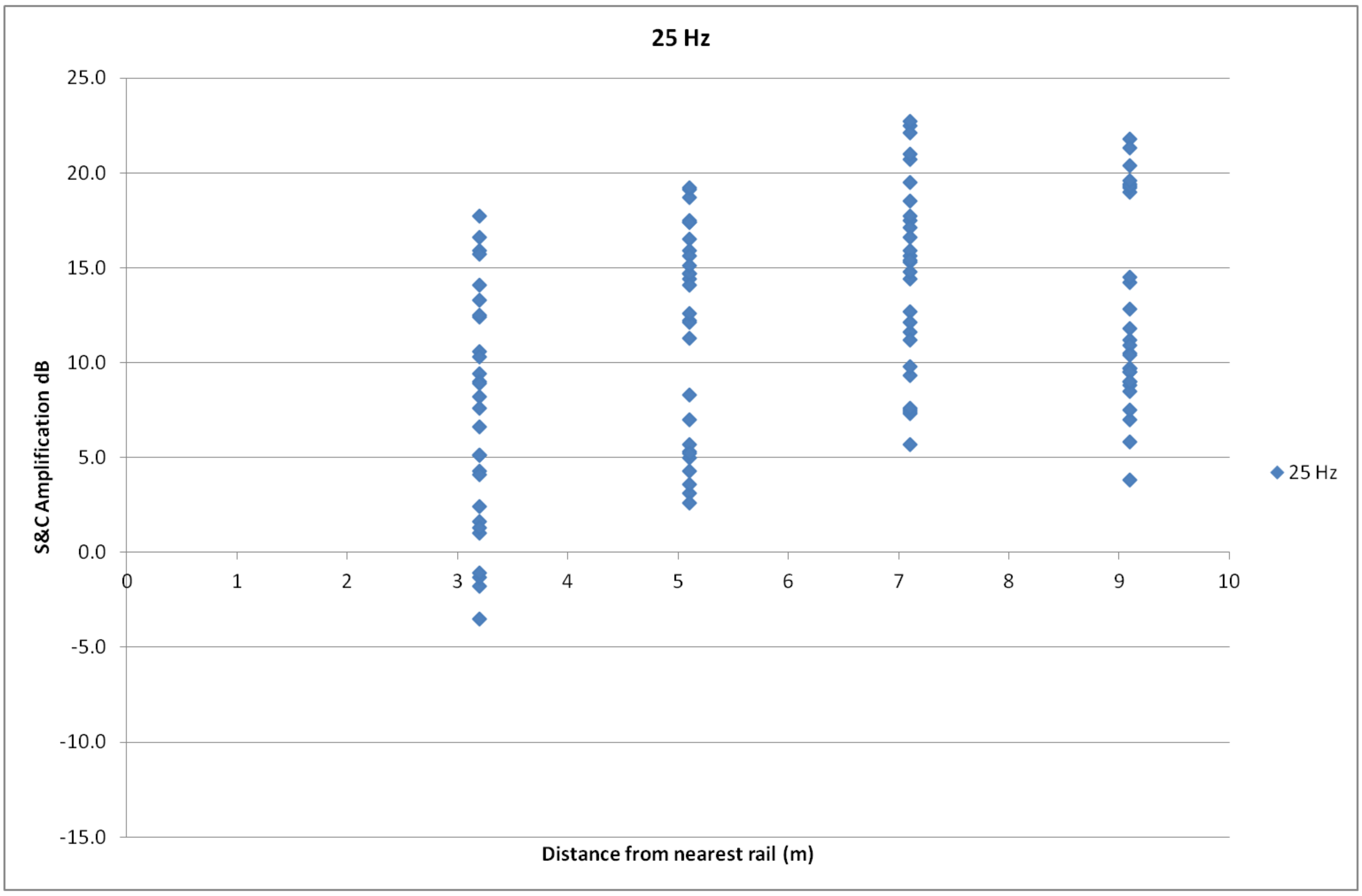


Figure 28. Passenger Train, 31.5Hz

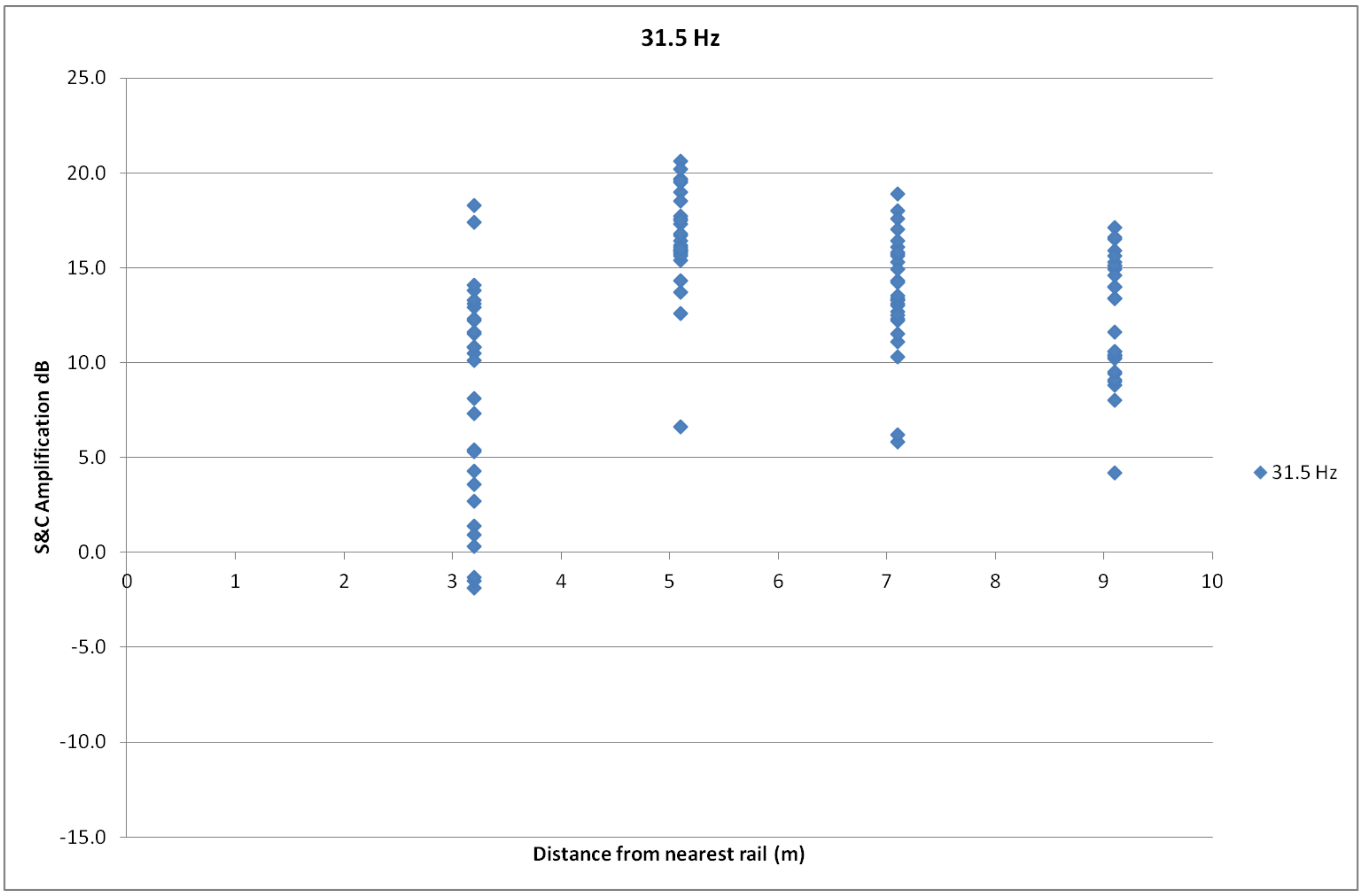


Figure 29. Passenger Train, 40Hz

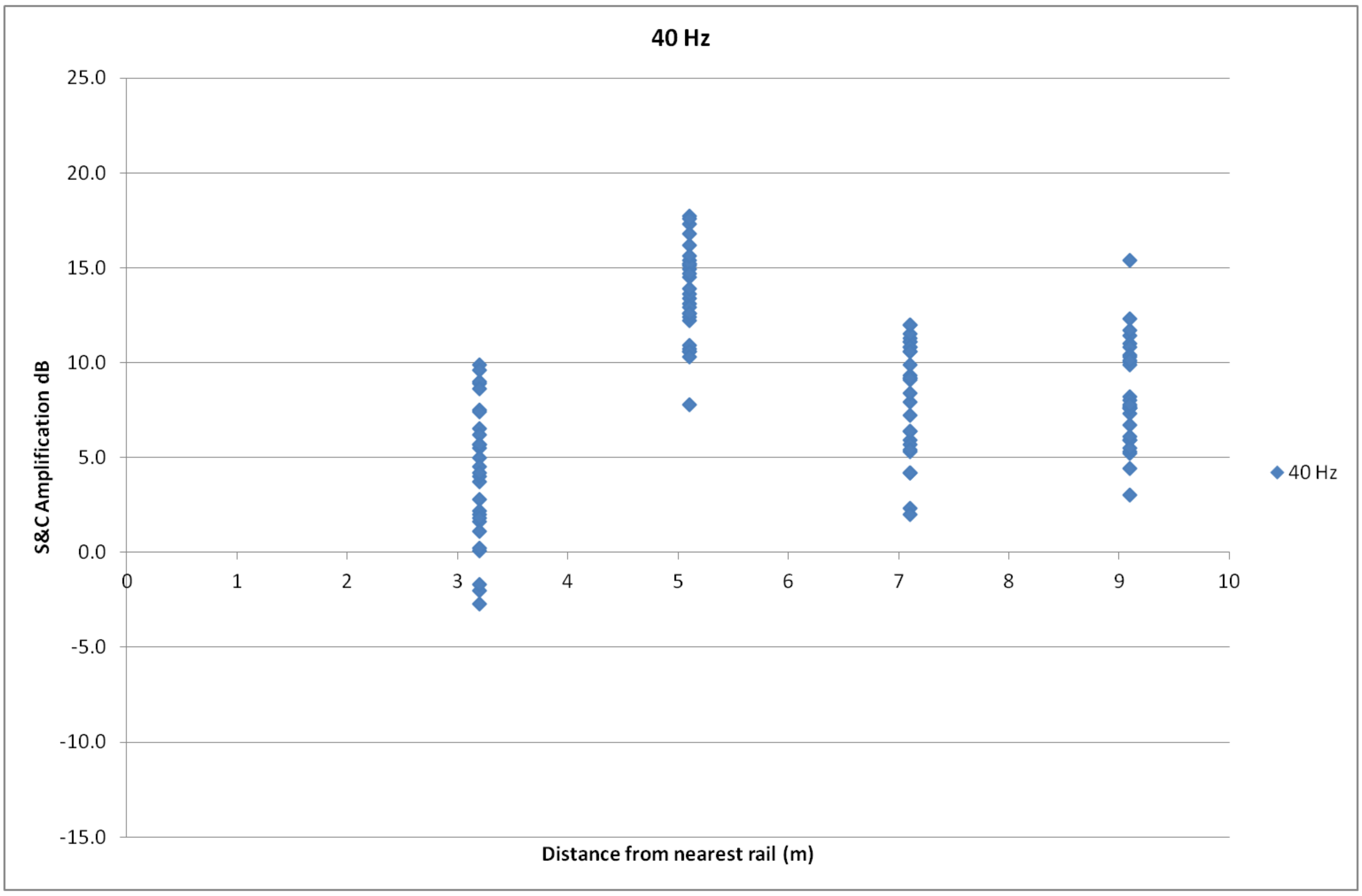


Figure 30. Passenger Train, 50Hz

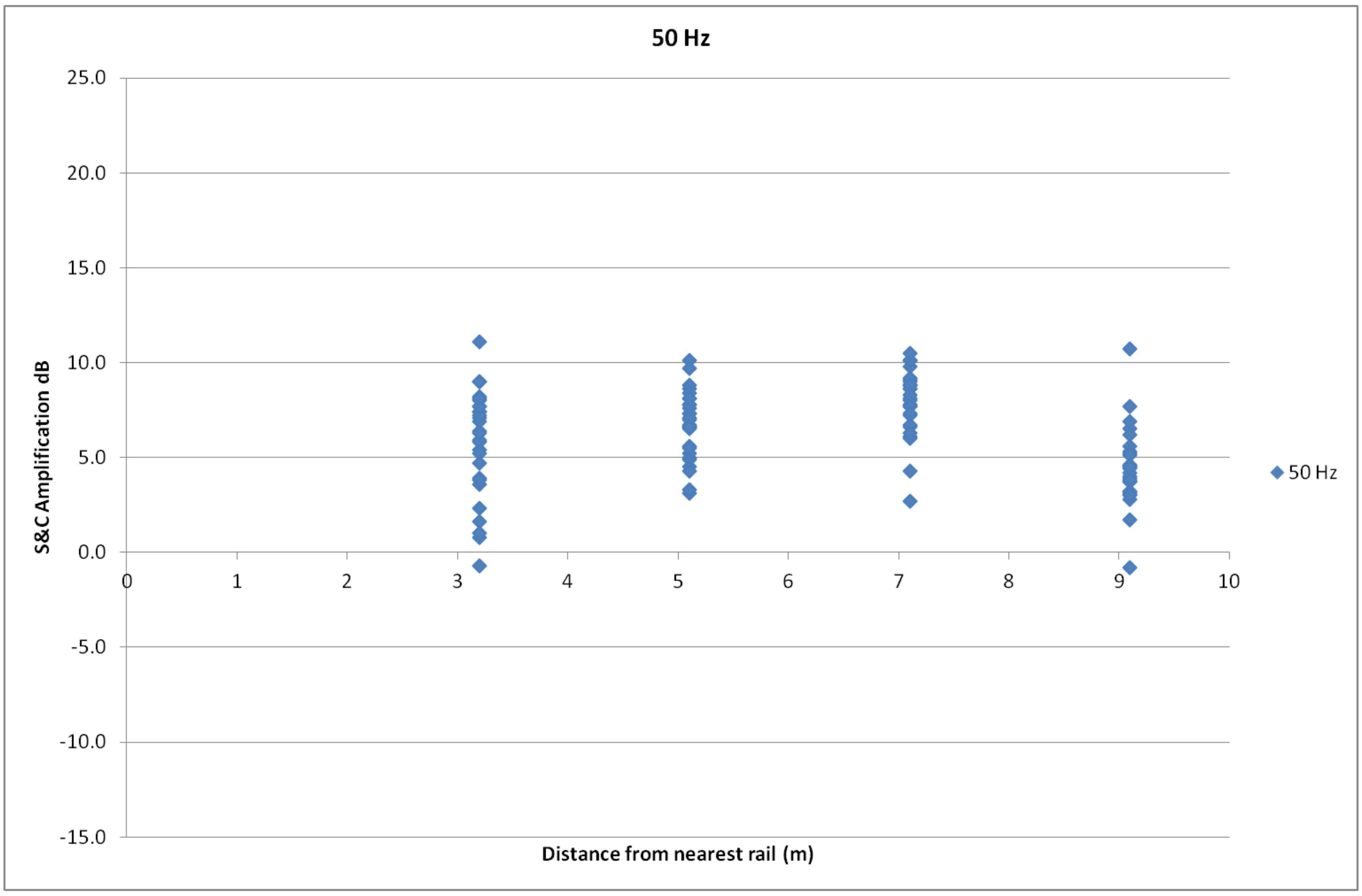


Figure 31. Passenger Train, 63Hz

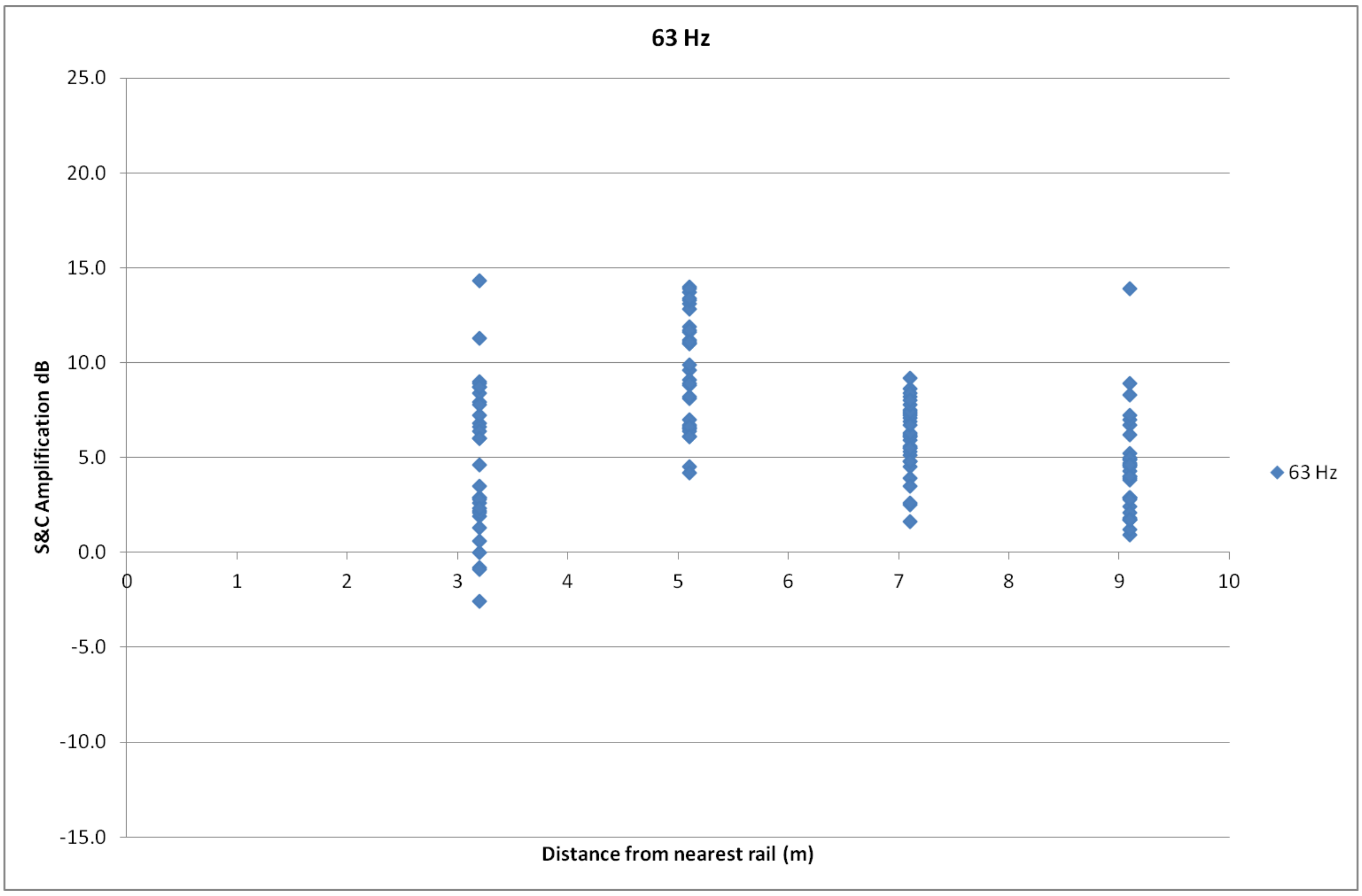


Figure 32. Passenger Train, 80Hz

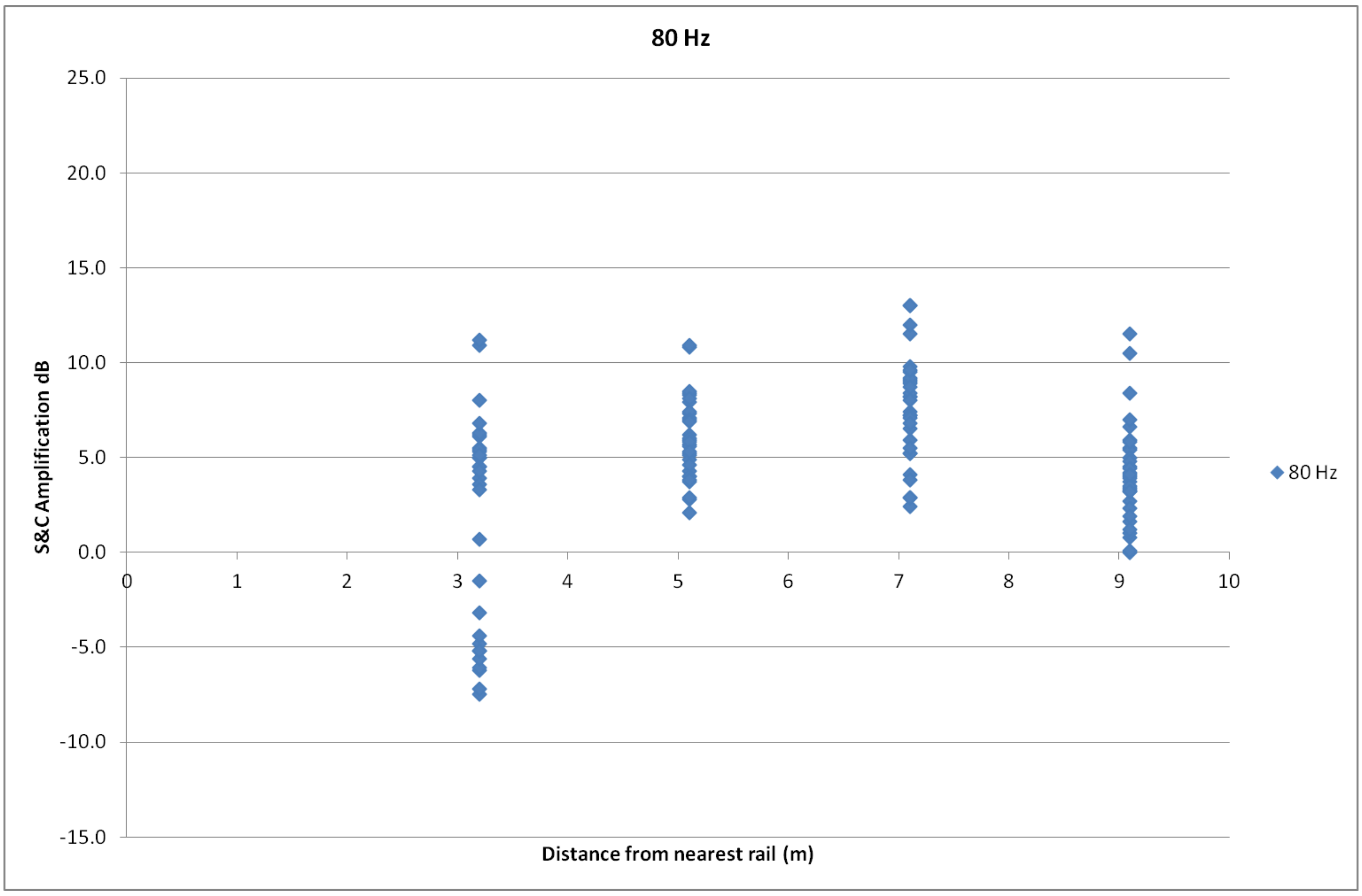


Figure 33. Passenger Train, 100Hz

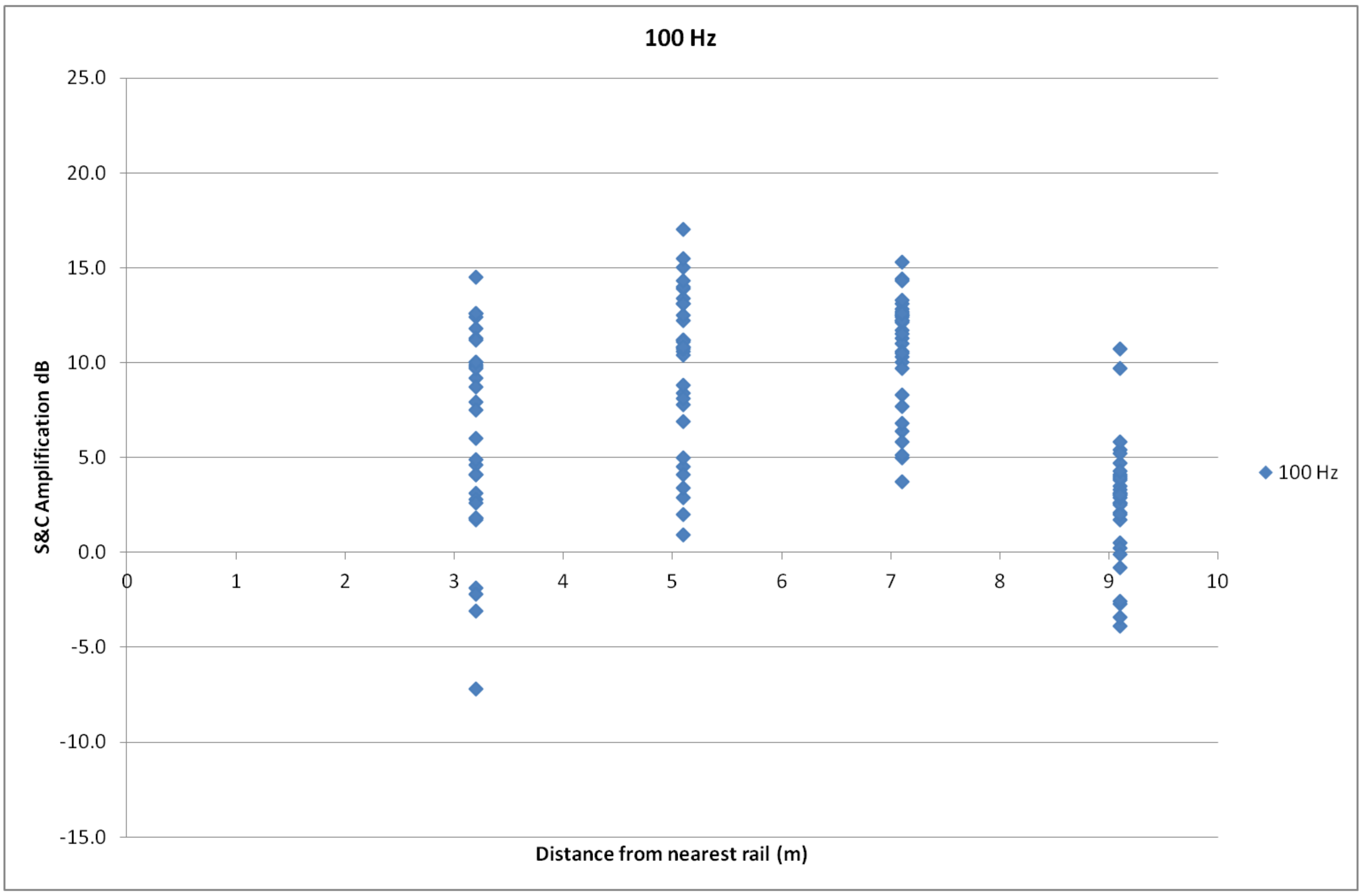


Figure 34. Passenger Train, 125Hz

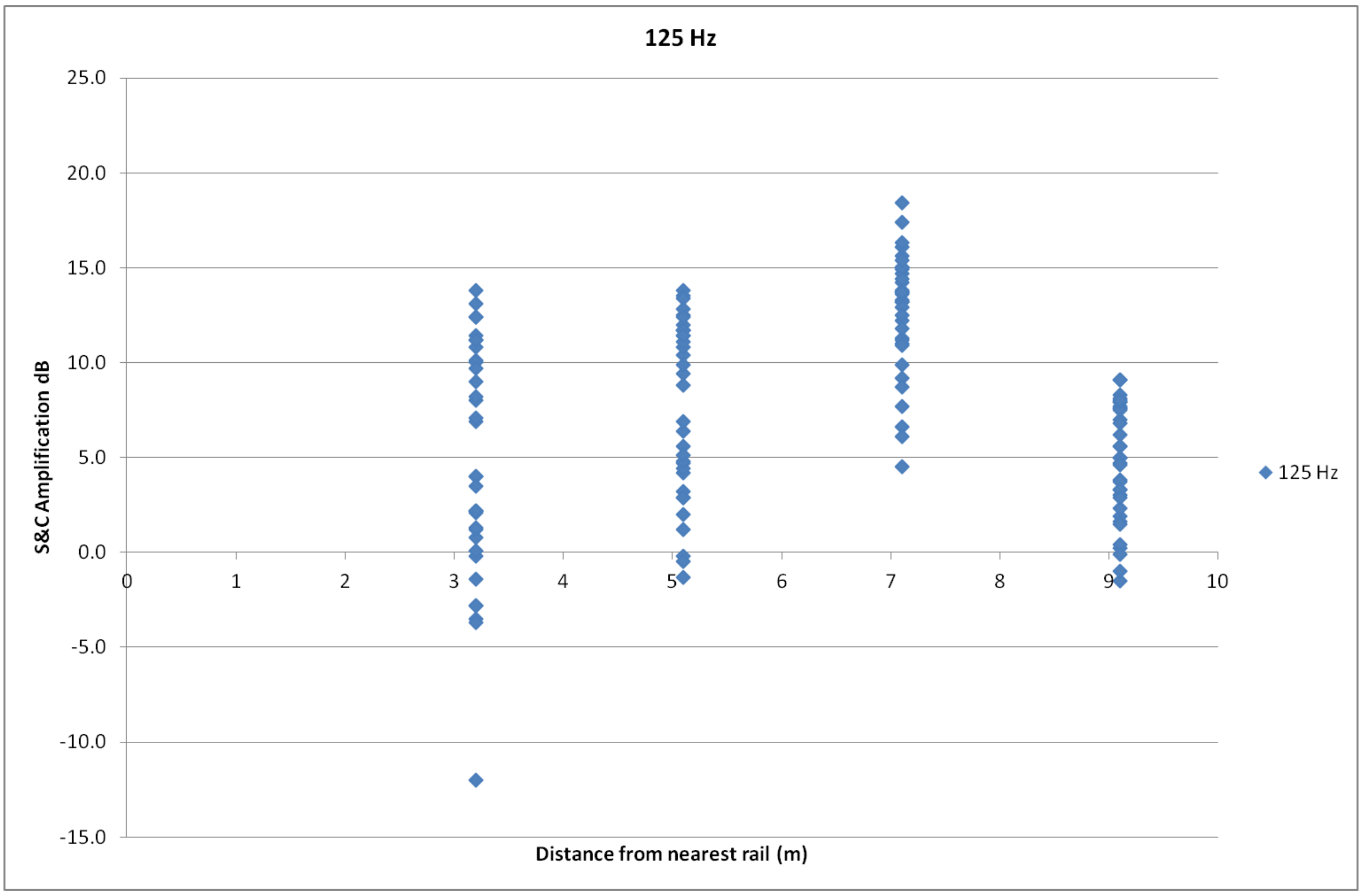
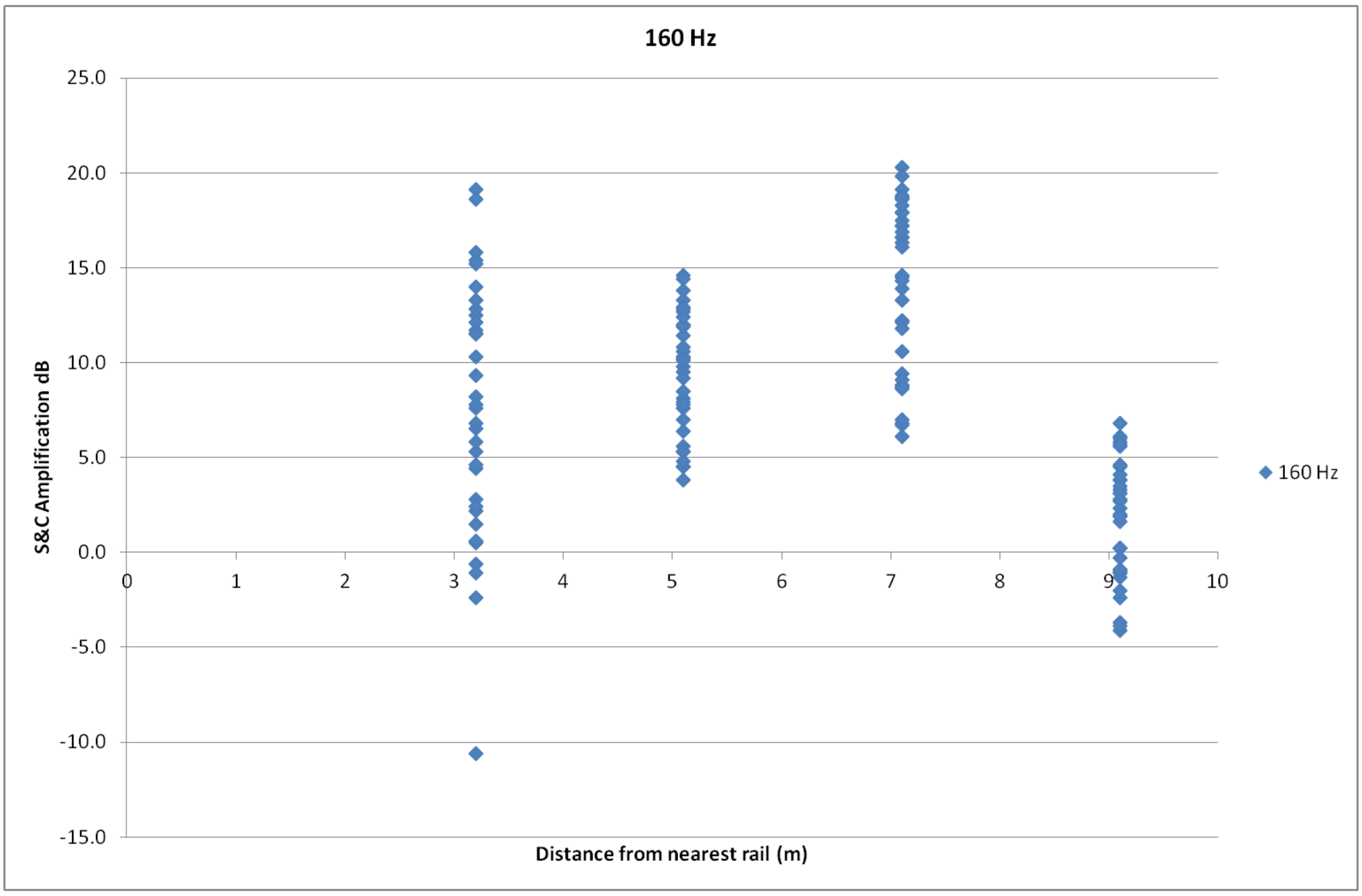


Figure 35. Passenger Train, 160Hz



G.2. S&C Amplification from Freight Trains, dB

Figure 36. Freight Train, 6.3Hz

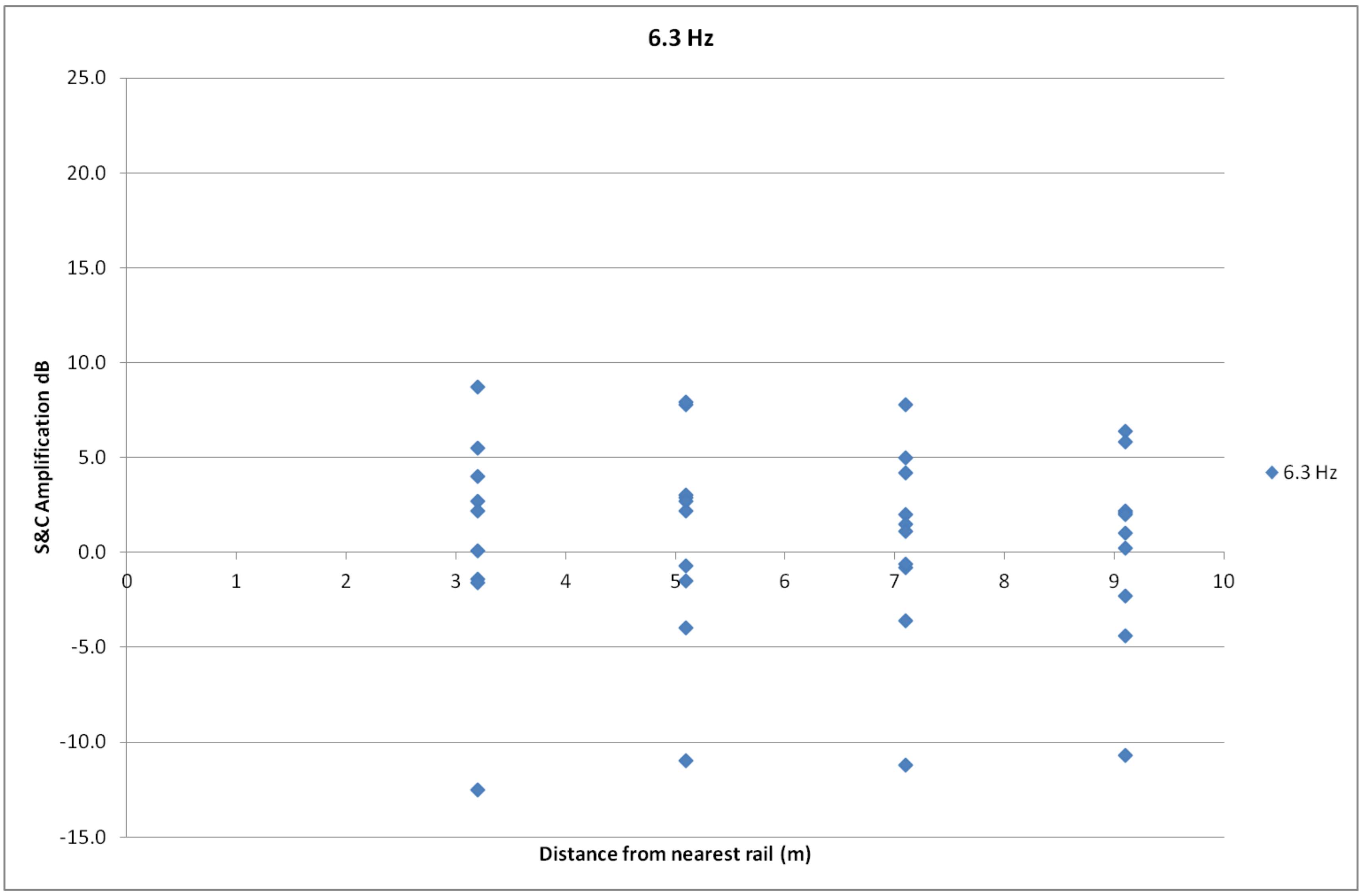


Figure 37. Freight Train, 8Hz

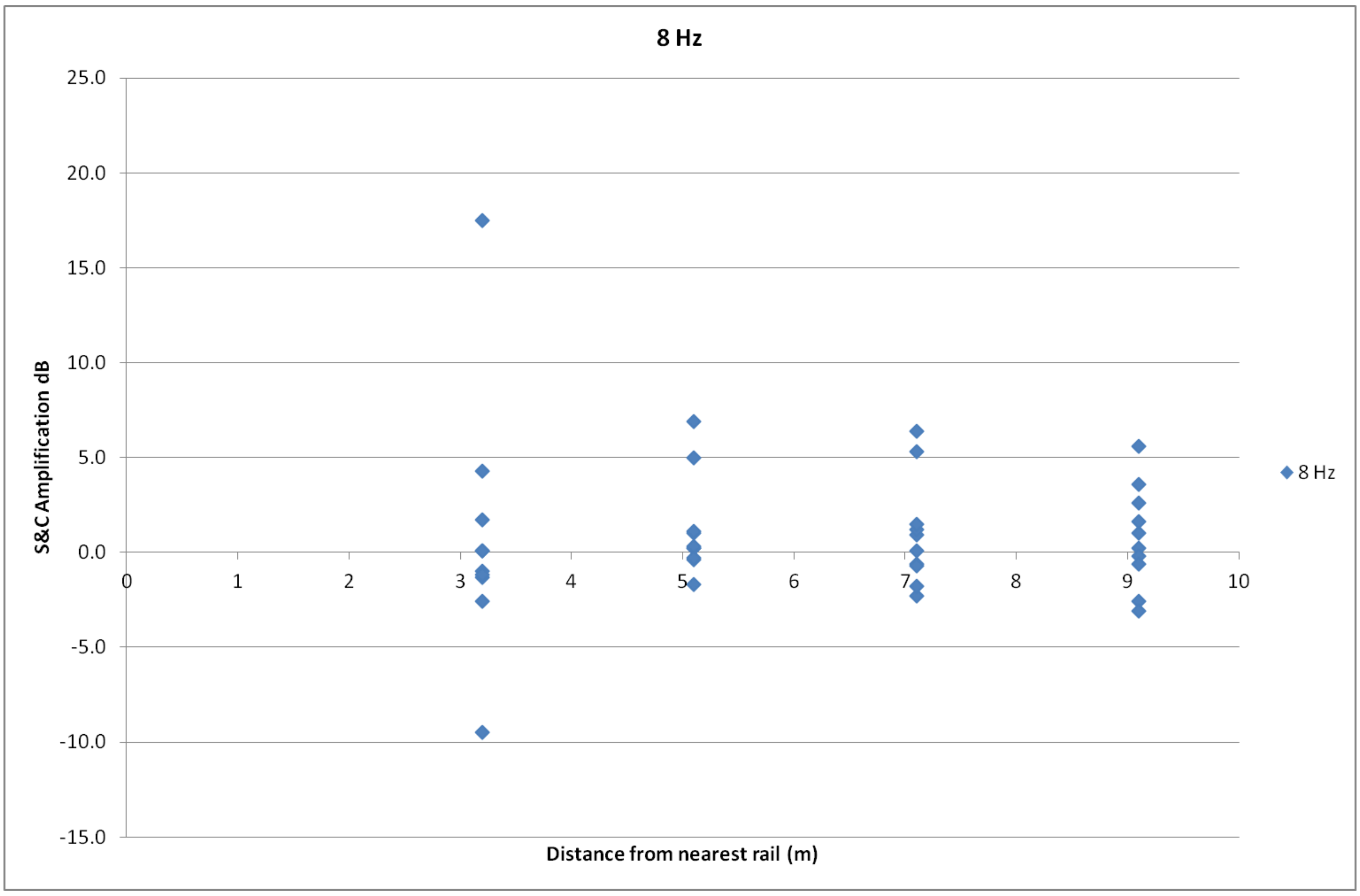


Figure 38. Freight Train, 10Hz

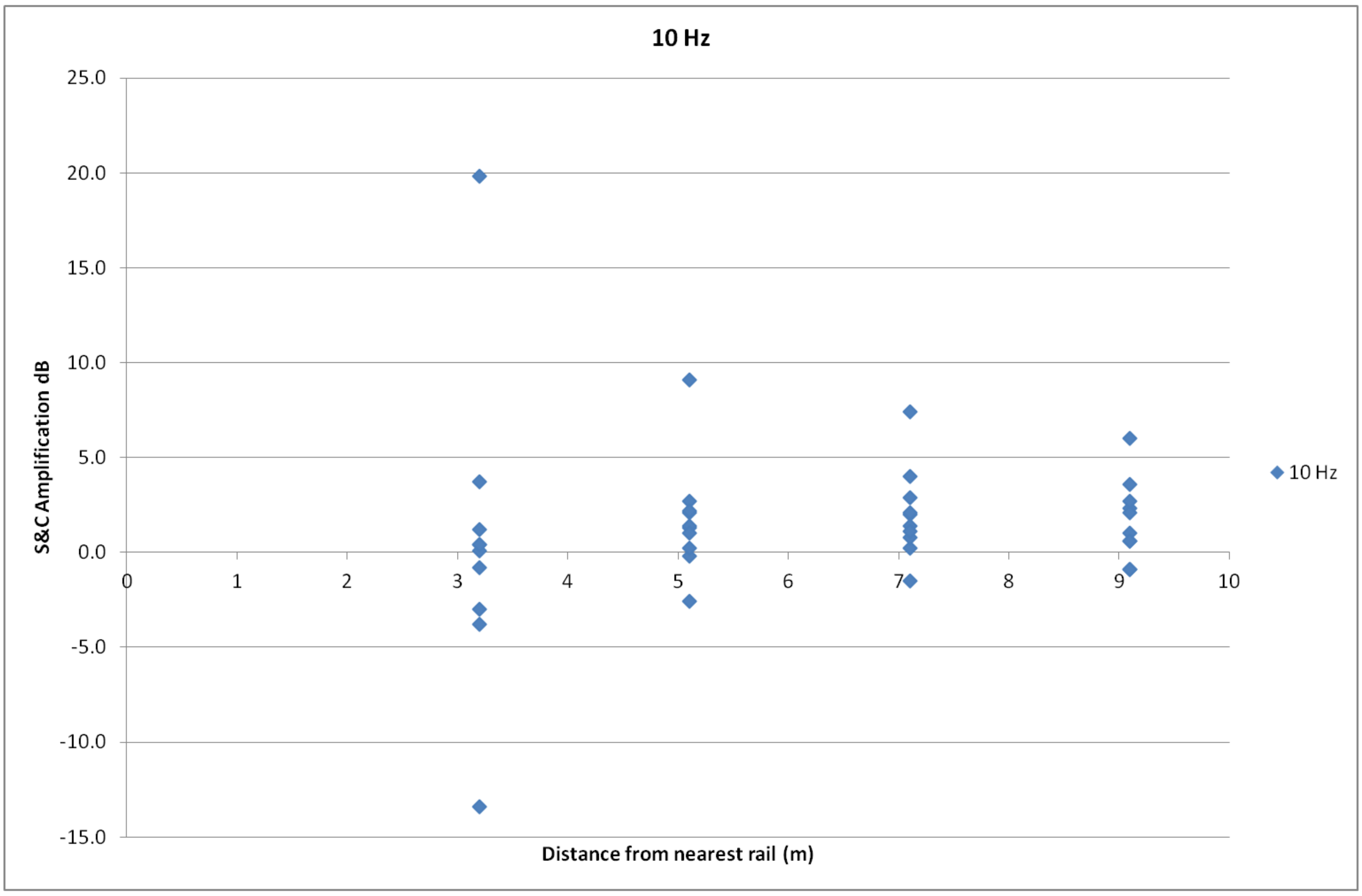


Figure 39. Freight Train, 12.5Hz

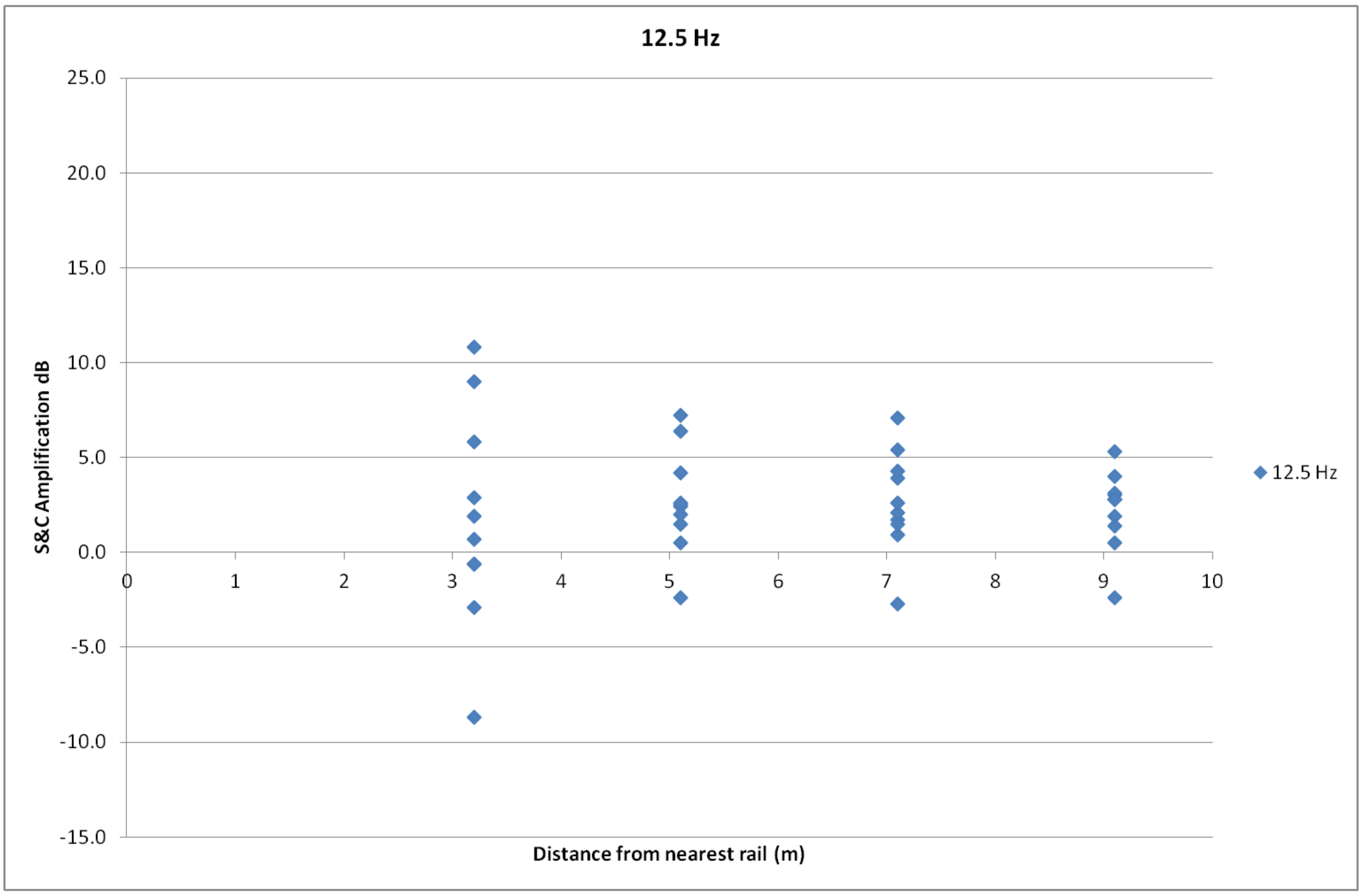


Figure 40. Freight Train, 16Hz

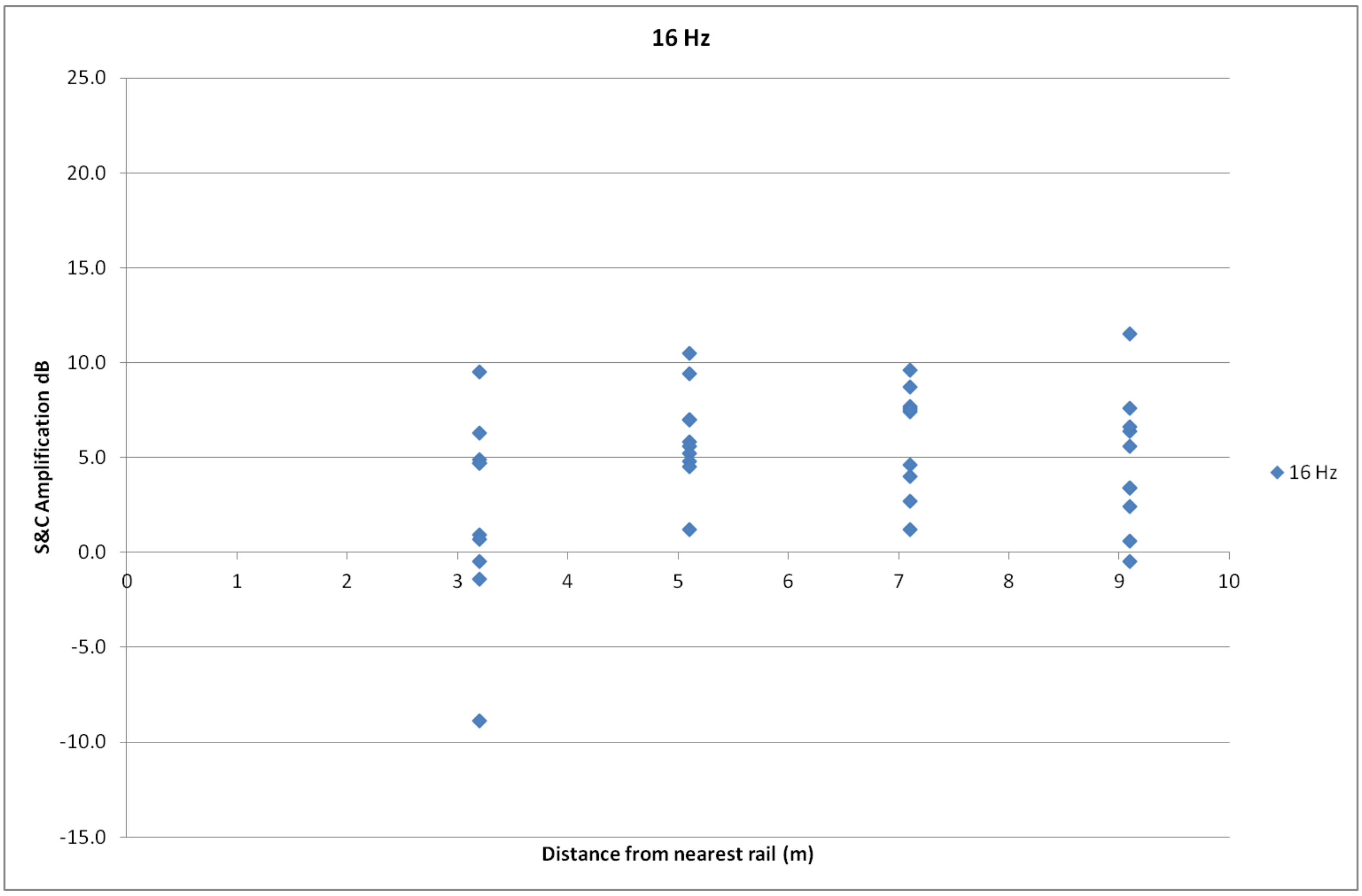


Figure 41. Freight Train, 20Hz

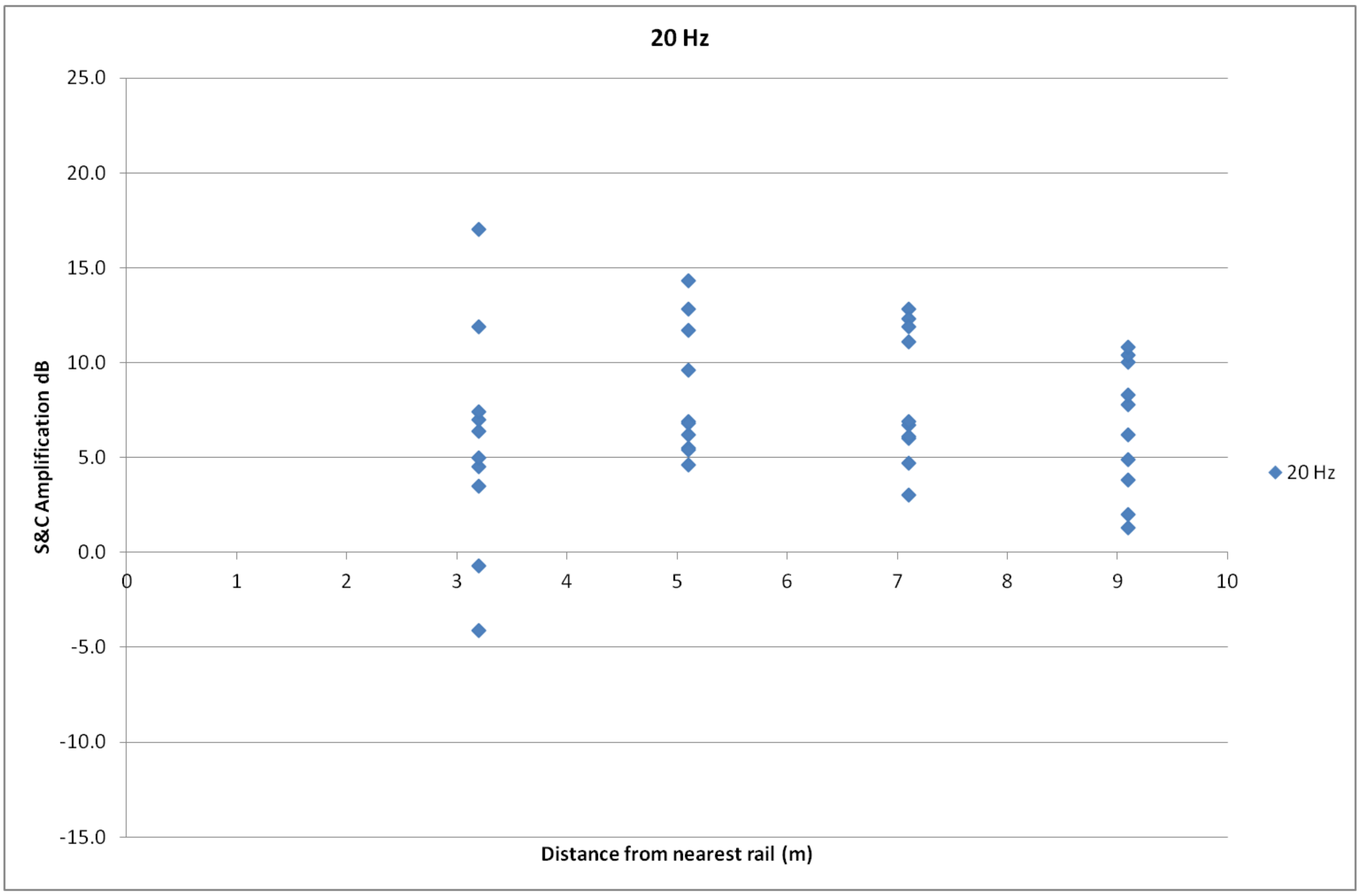


Figure 42. Freight Train, 25Hz

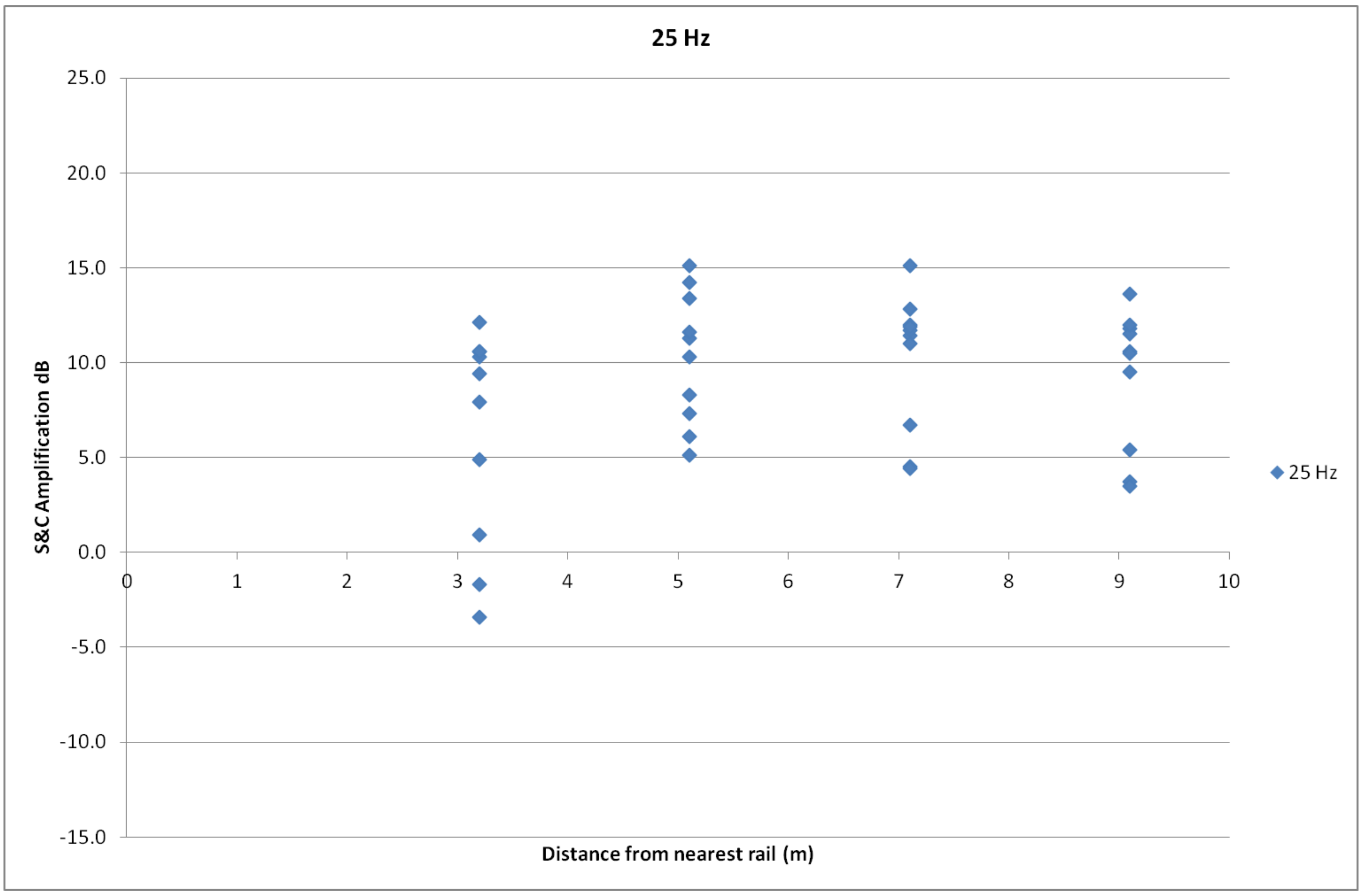


Figure 43. Freight Train, 31.5Hz

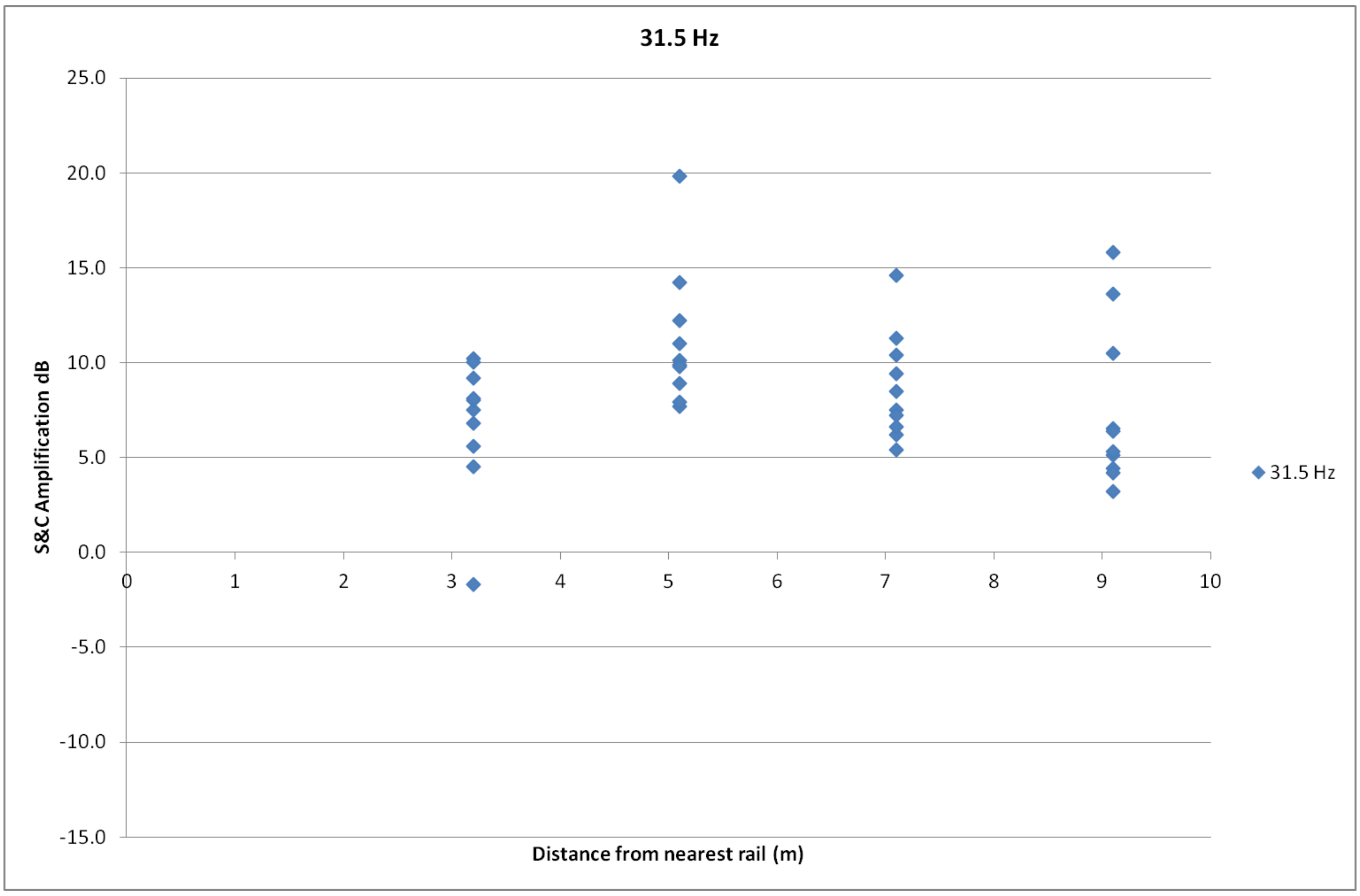


Figure 44. Freight Train, 40Hz

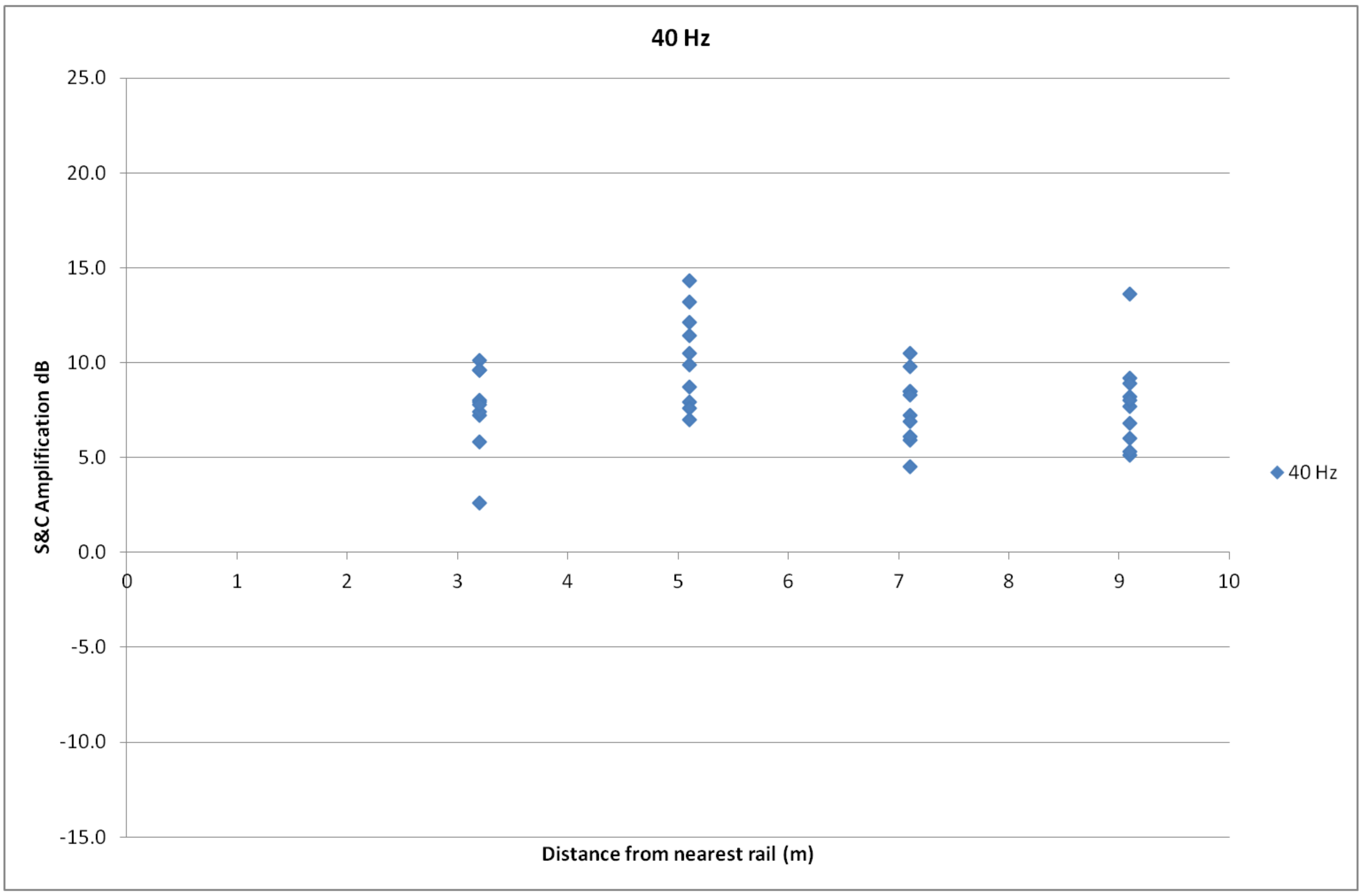


Figure 45. Freight Train, 50Hz

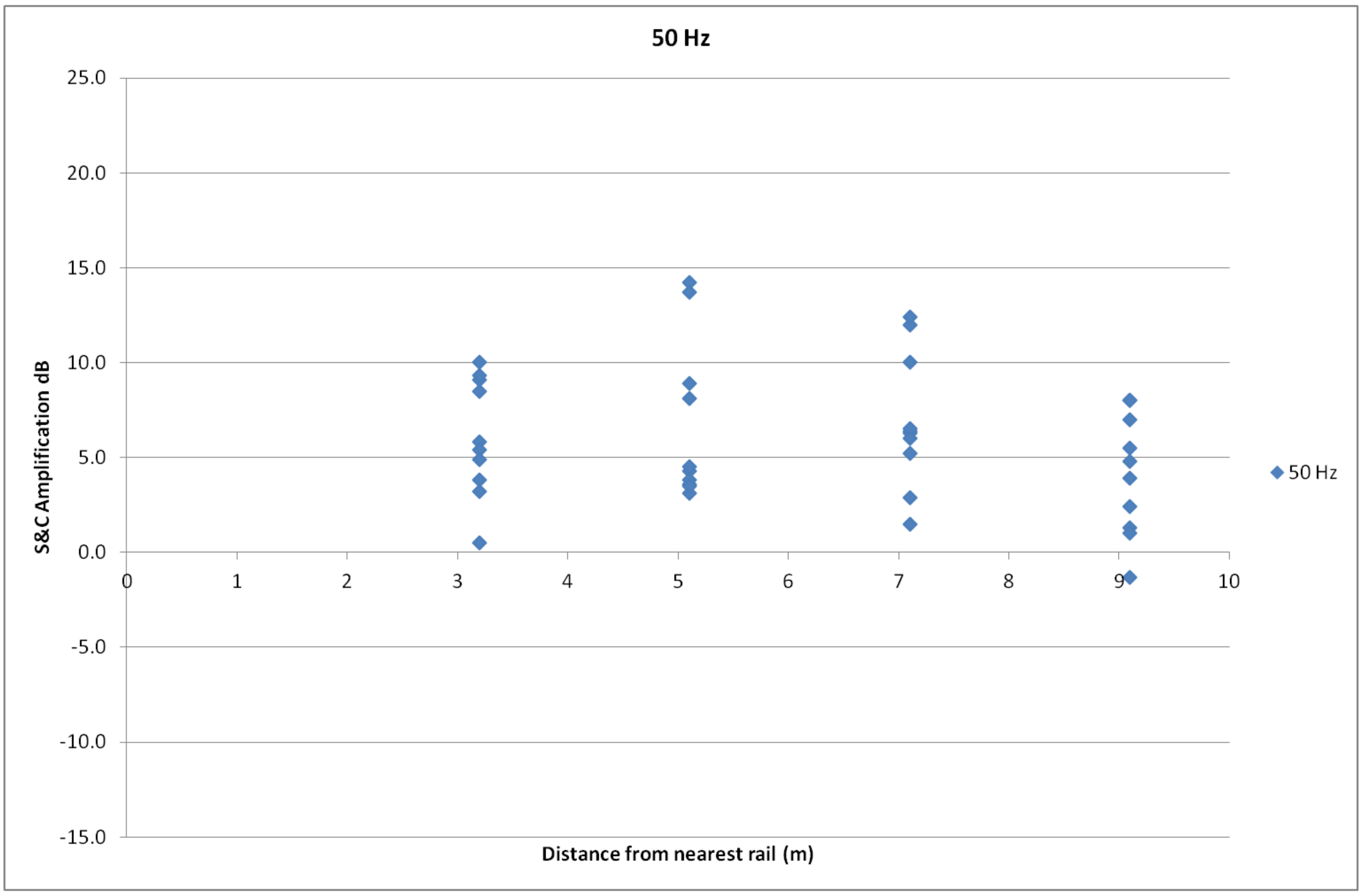


Figure 46. Freight Train, 63Hz

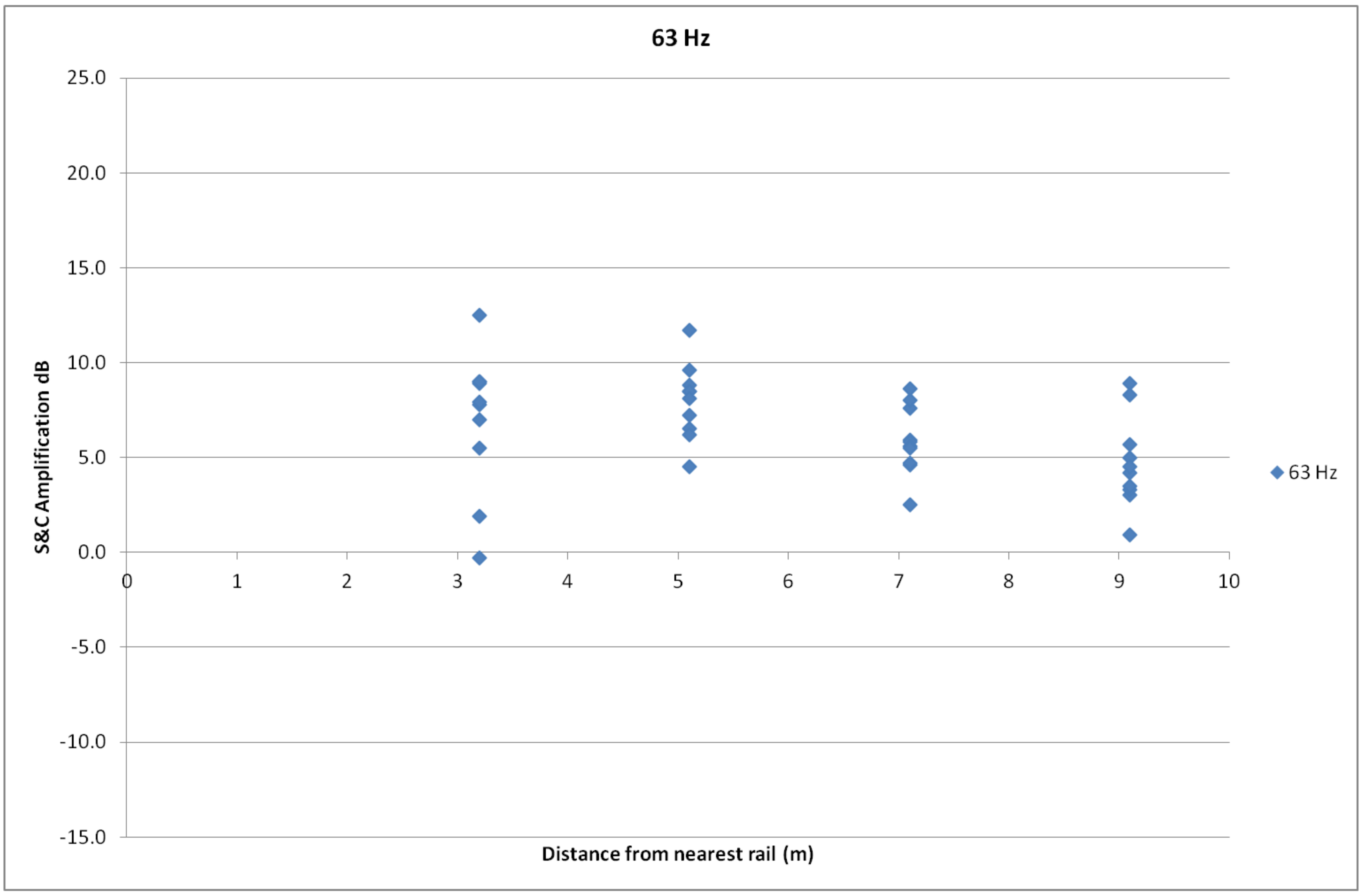


Figure 47. Freight Train, 80Hz

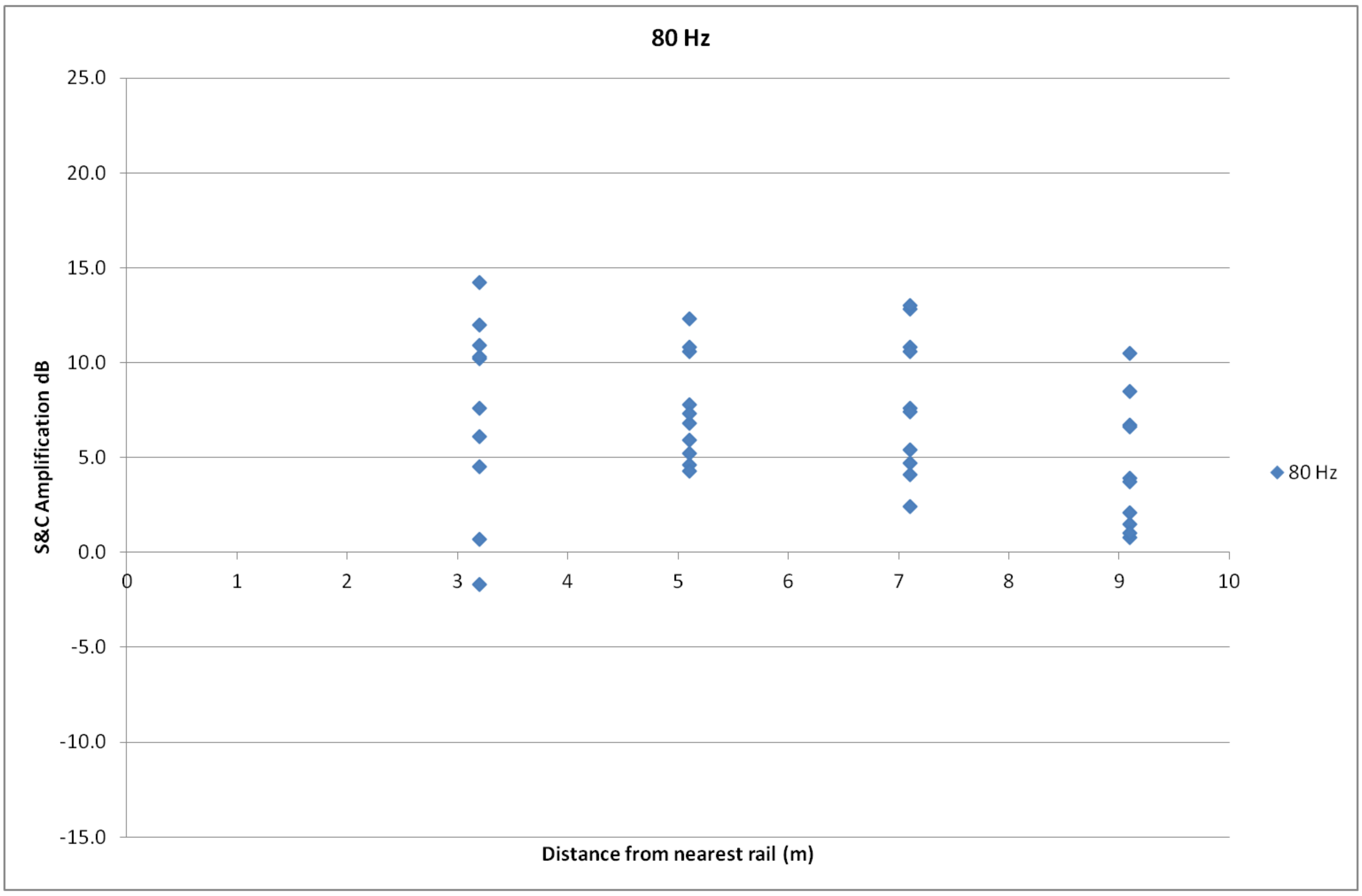


Figure 48. Freight Train, 100Hz

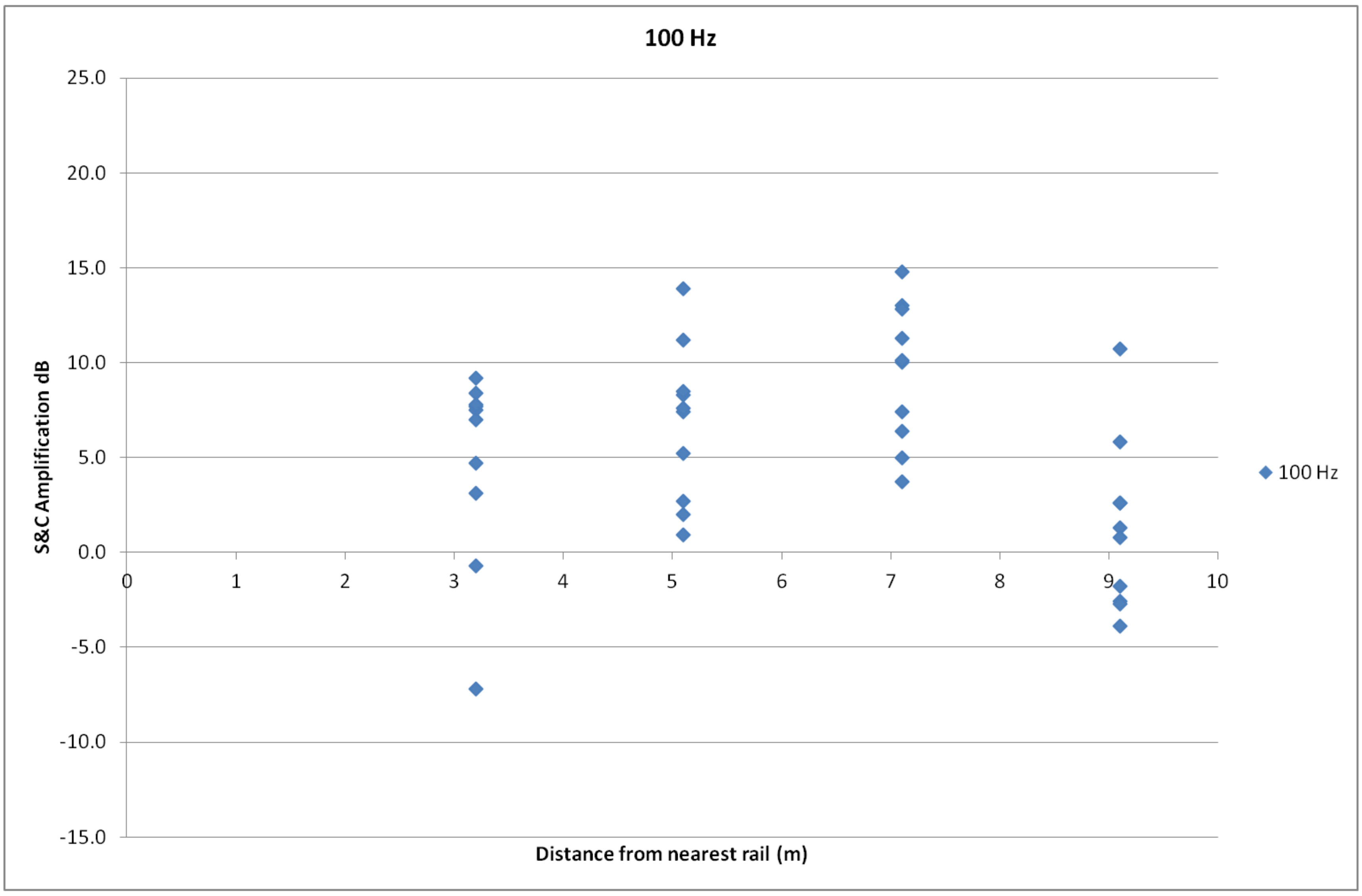


Figure 49. Freight Train, 125Hz

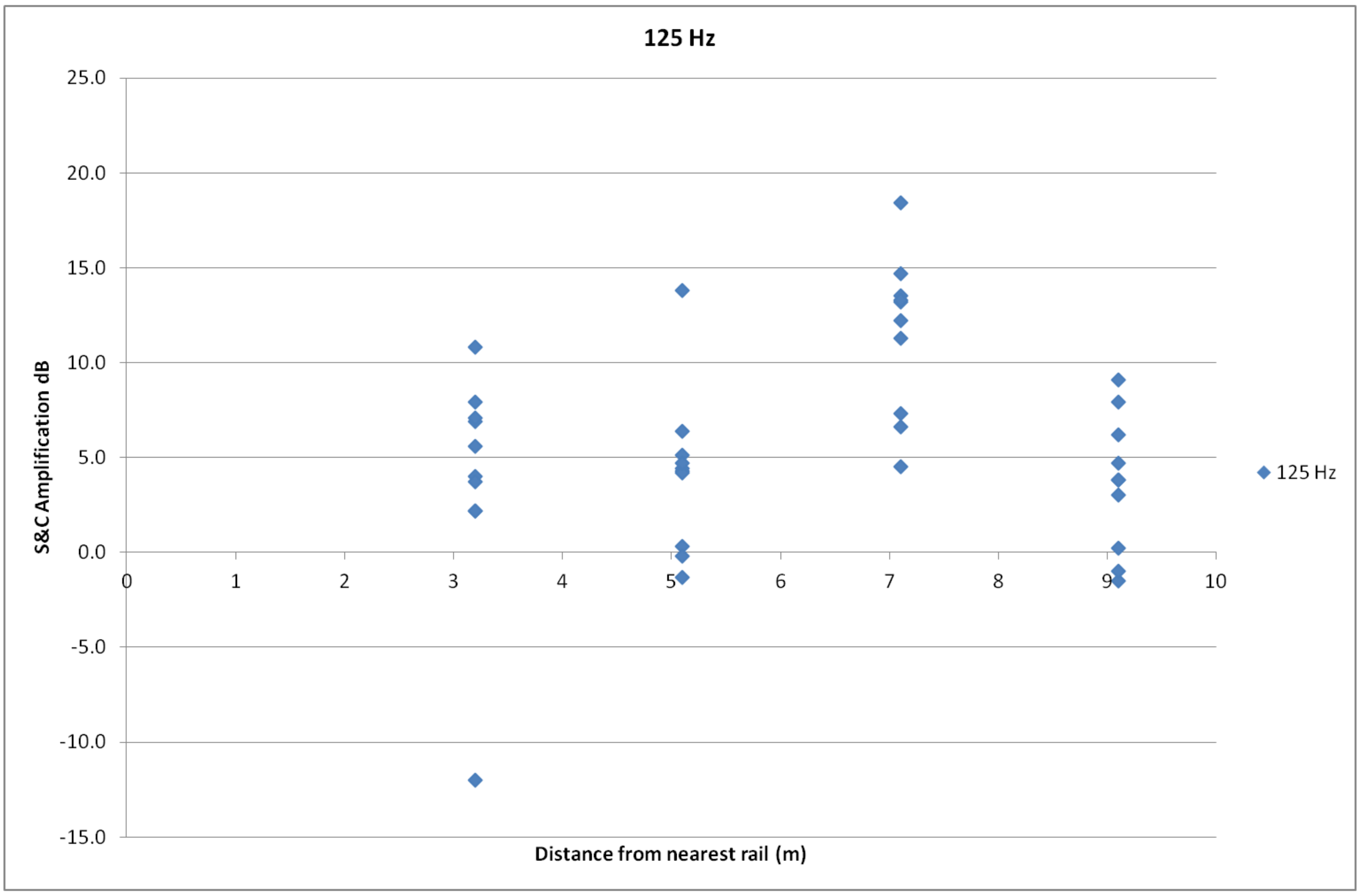
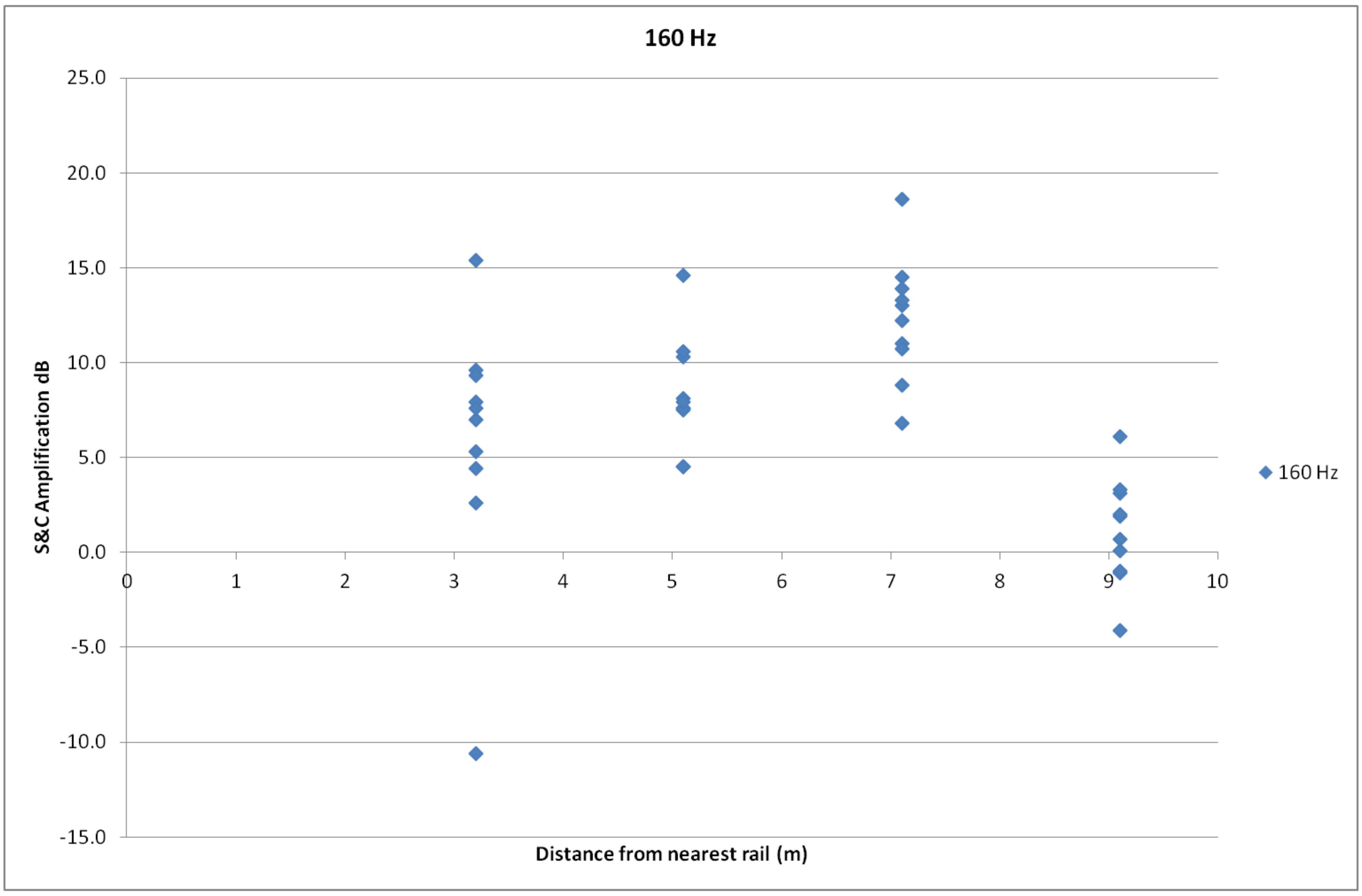


Figure 50. Freight Train, 160Hz



Peter Hampshire
Atkins The Axis
10 Holliday Street
Birmingham
B1 1TF

peter.hampshire@atkinsglobal.com
+44 7803 25 8604