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Volume 1: Environmental and Social Impact Assessment Report

Chapter 12 Vibration

December 2025

COWI | IPF

Western Balkans Investment Framework (WBIF)

Infrastructure Project Facility Technical Assistance 8 (IPF 8)

Infrastructures: Energy, Environment, Social, Transport and Digital Economy

TA2018148 R0 IPA

Volume 1: Environmental and Social Impact Assessment Report

Chapter 12 Vibration

December 2025

The Infrastructure Project Facility (IPF) is a technical assistance instrument of the Western Balkans Investment Framework (WBIF) which is a joint initiative of the European Union, International Financial Institutions, bilateral donors and the governments of the Western Balkans which supports socio-economic development and EU accession across the Western Balkans through the provision of finance and technical assistance for strategic infrastructure investments. This technical assistance operation is financed with EU funds.
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WB20-BiH-TRA-02	

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7	31/12/2025	ESIA Report – Chapter 12 Vibration	Alexandros Galatas	Irem Silajdžić	Richard Thadani

CONTENTS

List of tables

List of figures

12 Vibration

12.1 Introduction

This chapter reports findings of the assessment of the potential impacts that may arise from the vibrations emitted during the construction phase of the motorway section to nearby dwellings and population (community and workforce). No vibration impacts during operational phase are expected.

The impact from vibration during construction works are assessed considering the environmental and social baseline conditions analysed for the study area, and, where necessary, mitigation measures are suggested.

All the available Project data needed for the calculation of the vibration nuisance have been collected, such as the construction site machinery types for various construction phases, the detailed designs of the foundations of the bridges and the tunnels of the new motorway, the topographical data near the project etc. The area of study includes the nearby housings and settlements along the alignment between km 0+000 (Ovcari Interchange) and km 35+950 (Mostar North Interchange) and the Konjic Bypass alignment.

This chapter should be read in conjunction with the following chapters:

Chapter 1	Introduction
Chapter 2	About the Project
Chapter 3	Detailed Project description
Chapter 4	Policy, legislative and institutional context
Chapter 5	Assessment methodology
Chapter 17	Cumulative impacts
Chapter 18	Residual impacts
Chapter 19	ESMP.

12.2 Baseline Conditions

No substantial vibration source has been identified in the study area. No mining operations or heavy-duty industry facilities were spotted that could be permanent sources of vibration. There is a railway line crossing the alignment at 1+200, which is a source of intermittent vibrations. However, train circulation is very low, and, in that area, there are warehouses and industrial facilities to a distance up to 100m from the alignment, hence there are no sensitive receivers.

For the purpose of vibration modelling, baseline measurements were undertaken at 12 measurement points along the corridor. The measurement survey details are given in the

Table 12-1, while measurement points are shown on Figure 12-1 and Figure 12-2.

Table 12-1: Measurement survey details

Date:	**26.03.2021 - 27.03.2021 and 19.07.2022.**
Sensors:	3-axis geophone type Woelfel model PE-6/U-B (S/N C5HV1) 3-axis geophone type Norsonic model ZEB/GS3T (S/N 653)
Number of sites:	12 sites
N&V experts:	Eng. Alexandros Galatas / Eng. Iris Riga / Eng Georg Pagonakis

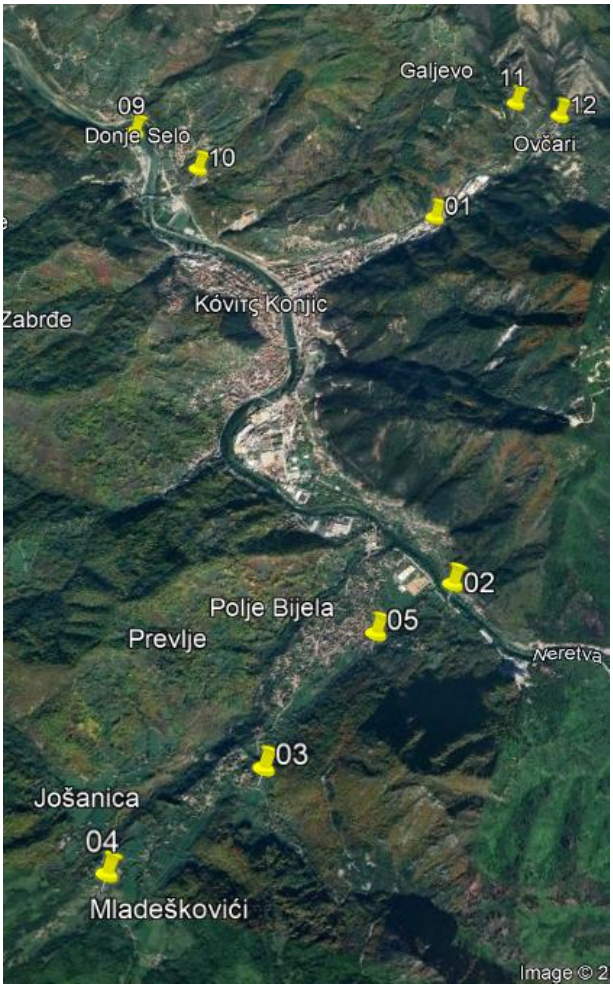


Figure 12-1: Measurements north of Prenj Tunnel and at the Konjic Bypass

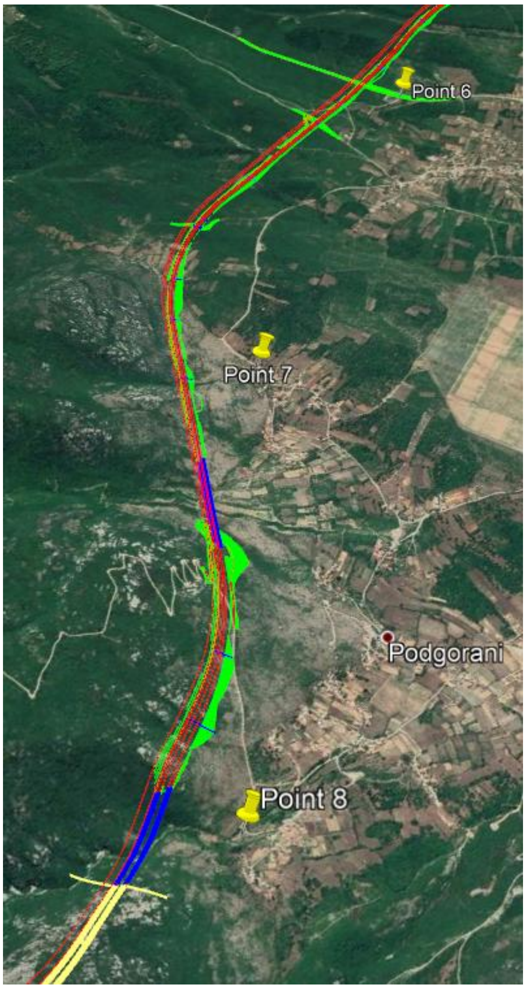


Figure 12-2: Measurements south of Prenj Tunnel

The vibration source used is a special ground vibrator that stimulates ground by a 250kg moving mass (Figure 12-3). The vibration velocity was measured with geophones near the source and to a distance up to 40m away. Characteristics and results of the measurement survey are presented below.

Table 12-2: Measurement points

site	#	X	Y	site	#	X	Y
Site #1	*P100*	6 498 079.36	4 835 112.63	Site #5	*P500*	6 498 449.53	4 832 048.78
	P105	6 498 076.03	4 835 108.89		*P505*	6 498 452.51	4 832 044.77
	P110	6 498 072.71	4 835 105.16		*P510*	6 498 455.49	4 832 040.75
	P120	6 498 066.06	4 835 097.69		*P520*	6 498 461.45	4 832 032.72
	P140	6 498 052.76	4 835 082.75		*P540*	6 498 473.36	4 832 016.65
Site #2	*P200*	6 498 820.65	4 832 473.45	Site #6	*P600*	6 492 996.98	4 810 948.10
	P205	6 498 824.83	4 832 470.71		*P605*	6 492 997.94	4 810 953.01
	P210	6 498 829.02	4 832 467.97		*P610*	6 492 998.91	4 810 957.92
	P220	6 498 837.38	4 832 462.49		*P620*	6 493 000.84	4 810 967.73
	P240	6 498 854.11	4 832 451.53		*P640*	6 493 004.70	4 810 987.35
Site #3	*P300*	6 498 035.87	4 831 093.19	Site #7	*P700*	6 492 581.44	4 812 612.58
	P305	6 498 040.74	4 831 092.09		*P705*	6 492 582.44	4 812 607.68
	P310	6 498 045.62	4 831 090.99		*P710*	6 492 583.44	4 812 602.78
	P320	6 498 055.38	4 831 088.79		*P720*	6 492 585.43	4 812 592.98
	P340	6 498 074.88	4 831 084.38		*P740*	6 492 589.43	4 812 573.39
Site #4	*P400*	6 497 339.11	4 830 335.67	Site #8	*P800*	6 490 945.51	4 813 872.62
	P405	6 497 343.64	4 830 333.57		*P805*	6 490 944.75	4 813 877.56
	P410	6 497 348.18	4 830 331.46		*P810*	6 490 943.99	4 813 882.50
	P420	6 497 357.24	4 830 327.24		*P820*	6 490 942.46	4 813 892.38
	P440	6 497 375.38	4 830 318.82		*P840*	6 490 939.41	4 813 912.15
Site #9	*P900*	6 495 827,47	4 835 454,29	Site #11	*P1100*	6 498 421,59	4 836 152,92
	P905	6 495 831,34	4 835 451,12		*P1105*	6 498 420,74	4 836 157,85
	P910	6 495 835,21	4 835 447,96		*P1110*	6 498 419,89	4 836 162,78
	P920	6 495 842,95	4 835 441,63		*P1120*	6 498418,18	4 836 172,63
	P940	6 495 858,44	4 835 428,97		*P1140*	6 498 414,76	4 836 192,34
Site #10	*P1000*	6 496 370,21	4 835 208,35	Site #12	*P1200*	6 498 744,50	4 836 124,70
	P1005	6 496 365,22	4 835 208,74		*P1205*	6 498 748,70	4 836 121,98
	P1010	6 496 360,24	4 835 209,12		*P1210*	6 498 752,89	4 836 119,26
	P1020	6 496 350,27	4 835 209,90		*P1220*	6 498 761,28	4 836 113,82
	P1040	6 496 330,33	4 835 211,44		*P1240*	6 498 778,06	4 836 102,94

Table 12-3: Soil types and instruments used for measurements

Site	Soil type	Instruments
Site #1	River incoherent coating with gravel and sand, floor is made probably of faulty Middle Triassic dolomites	Norsonic N-150 (S/N 30 multi-channel analyzer Woelfel PE-6/U-B (S/N C5HV1) 3-axis geophone Norsonic ZEB/GS3T (S/N 653) 3-axis geophone
Site #2	Coarse gravel and incoherent sand, floor is consisted of dolomites	Norsonic N-150 (S/N 30 multi-channel analyser Woelfel PE-6/U-B (S/N C5HV1) 3-axis geophone Norsonic ZEB/GS3T (S/N 653) 3-axis geophone
Site #3	Screey and partly alluvial deposition	Norsonic N-150 (S/N 30 multi-channel analyzer Woelfel PE-6/U-B (S/N C5HV1) 3-axis geophone Norsonic ZEB/GS3T (S/N 653) 3-axis geophone
Site #4	Mixed fine-grained and coarse-grained soil	Norsonic N-150 (S/N 30 multi-channel analyzer Woelfel PE-6/U-B (S/N C5HV1) 3-axis geophone Norsonic ZEB/GS3T (S/N 653) 3-axis geophone
Site #5	Soft incoherent soil surface, floor is solid rocks mass - dolomite	Norsonic N-150 (S/N 30 multi-channel analyzer Woelfel PE-6/U-B (S/N C5HV1) 3-axis geophone Norsonic ZEB/GS3T (S/N 653) 3-axis geophone
Site #6	Thick screey and deluvial deposits, incoherent coarse-grained mainly limestone material	Norsonic N-150 (S/N 30 multi-channel analyzer Woelfel PE-6/U-B (S/N C5HV1) 3-axis geophone Norsonic ZEB/GS3T (S/N 653) 3-axis geophone
Site #7	Limestone rock solid masses	Norsonic N-150 (S/N 30 multi-channel analyzer Woelfel PE-6/U-B (S/N C5HV1) 3-axis geophone Norsonic ZEB/GS3T (S/N 653) 3-axis geophone
Site #8	Limestone rock solid masses	Norsonic N-150 (S/N 30 multi-channel analyser

Site	Soil type	Instruments
		Woelfel PE-6/U-B (S/N C5HV1) 3-axis geophone Norsonic ZEB/GS3T (S/N 653) 3-axis geophone
Site #9	Impermeable Miocene sediments	Norsonic N-150 (S/N 30 multi-channel analyser Woelfel PE-6/U-B (S/N C5HV1) 3-axis geophone Norsonic ZEB/GS3T (S/N 653) 3-axis geophone
Site #10	Impermeable Miocene sediments	Norsonic N-150 (S/N 30 multi-channel analyser Woelfel PE-6/U-B (S/N C5HV1) 3-axis geophone Norsonic ZEB/GS3T (S/N 653) 3-axis geophone
Site #11	Impermeable Miocene sediments	Norsonic N-150 (S/N 30 multi-channel analyser Woelfel PE-6/U-B (S/N C5HV1) 3-axis geophone Norsonic ZEB/GS3T (S/N 653) 3-axis geophone
Site #12	Impermeable Miocene sediments	Norsonic N-150 (S/N 30 multi-channel analyser Woelfel PE-6/U-B (S/N C5HV1) 3-axis geophone Norsonic ZEB/GS3T (S/N 653) 3-axis geophone

Table 12-4: Ambient vibrations along the alignment measured during in-situ visit

Location (chainage)	Peek Particle Velocity (mm/s)	Perception level (refer to Table 12-7)
1+400	0.0063	Not perceptible
4+050	0.0674	Not perceptible
4+600	0.0069	Not perceptible
5+650	0.0065	Not perceptible
6+700	0.0054	Not perceptible
24+600	0.0048	Not perceptible
26+550	0.0124	Not perceptible

Location (chainage)	Peek Particle Velocity (mm/s)	Perception level (refer to Table 12-7)
28+400	0.0287	Not perceptible
0+240	0.0057	Not perceptible
kb 0+000	0.0029	Not perceptible
kb 0+800	0.0065	Not perceptible
na 0+200	0.0129	Not perceptible

kb: 'Konjic Bypass' alignment
na: 'east access road to Konjic North I/C' alignment

Figure 12-3: 250 kg Vibration generator

Figure 12-16 to Figure 12-23 demonstrate the resulting transfer vibration velocity vs. frequency to various distances from the source, upon the analysis of the measurements using the special noise & vibration analysis software MEDA.

Figure 12-4: Point 1 (near Viaduct 2 and Tunnel T1 east entrance) km 1+400

Figure 12-5: Point 2 (near Viaduct 3 and Tunnel T1 west entrance) km 4+050

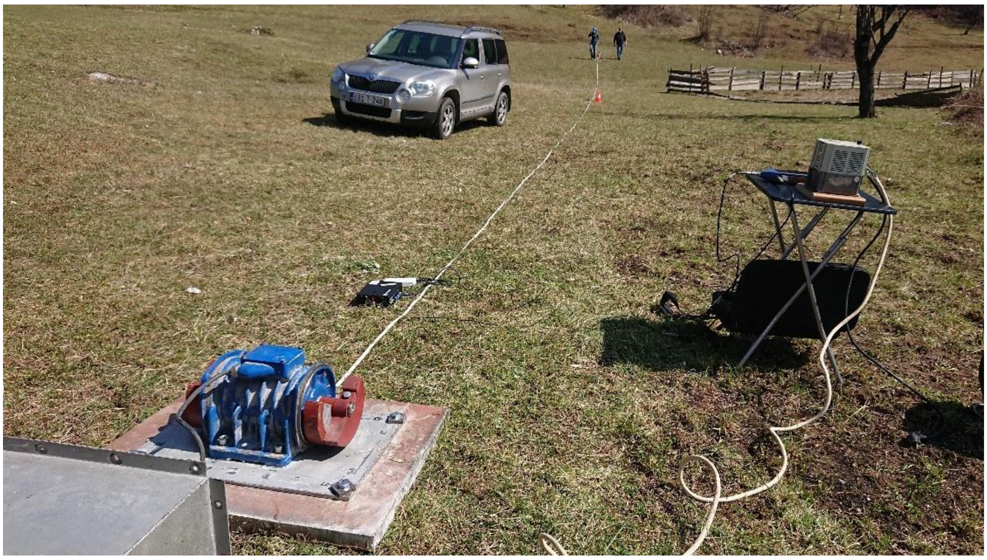


Figure 12-6: Point 3 (near Viaduct 5 footings and Podravac settlement) km 5+650

Figure 12-7: Point 4 (near Viaduct 6 footings, Tunnel T2 and in the Mladeskovici settlement) km 6+700

Figure 12-8: Point 5 (near Viaduct 3 footings and Polje Bijela settlement) km 4+600

Figure 12-9: Point 6, (near Overpass-6) km 28+400

Figure 12-10: Point 7, (near Viaduct 10 footings and Dolac settlement) km 26+550

Figure 12-11: Point 8, (near Viaduct 9 footings and Seliste settlement) km 24+600

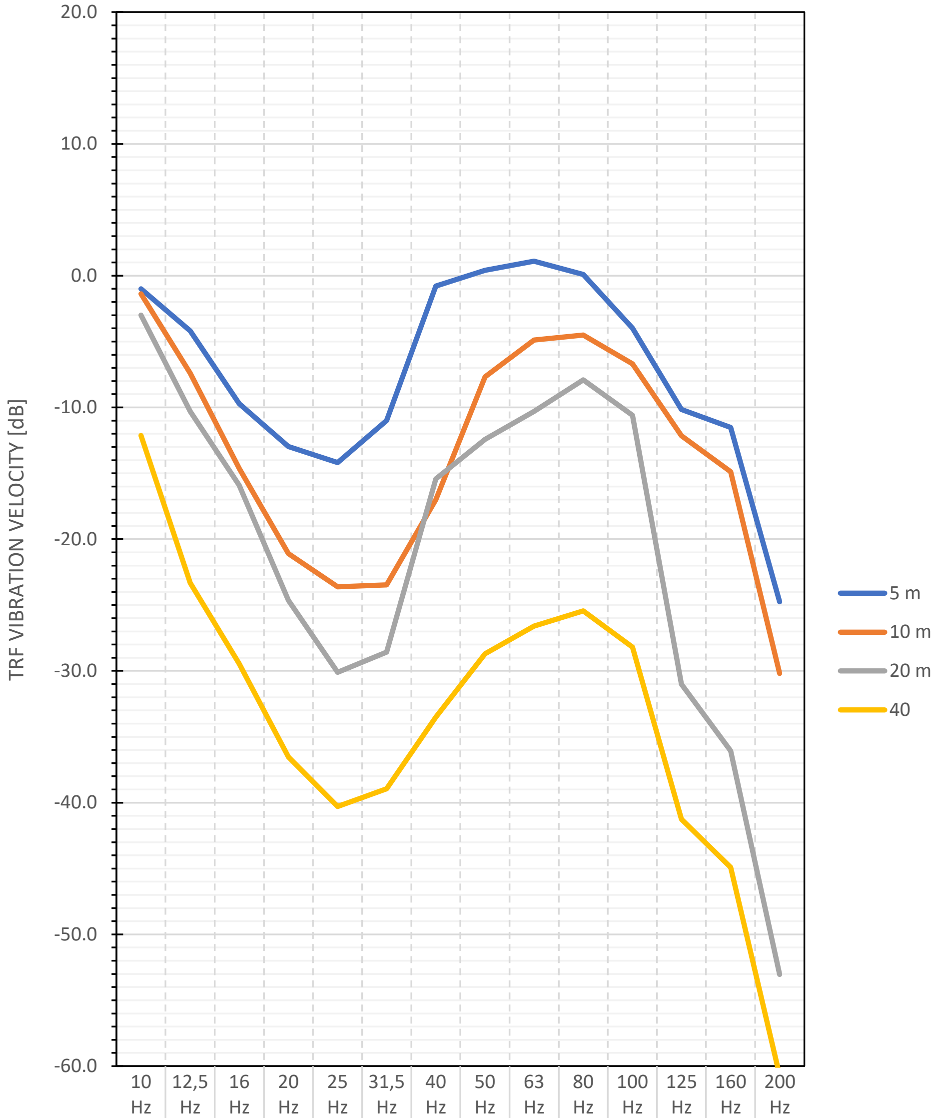
Figure 12-12: Point 9, (near Viaduct and Donje Selo settlement) km 0+420 Konjic Bypass

Figure 12-13: Point 10, (near Viaduct and Donje Selo settlement) km 0+760 Konjic Bypass

Figure 12-14: Point 11, (near start of the alignment) km 0+000

Figure 12-15: Point 12, (near Viaduct and Ovcari settlement) km 0+280

Point 1
BRIDGE M-2
TUNNEL T-1

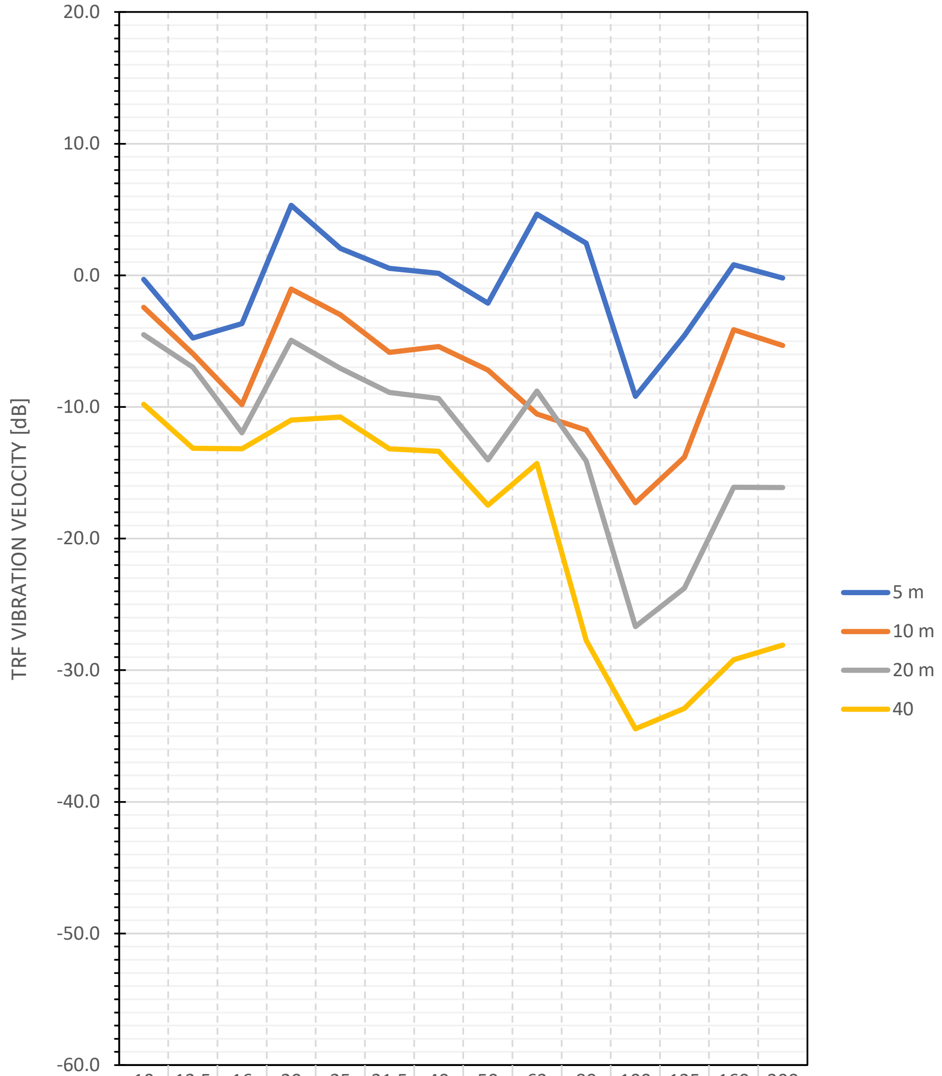


	10 Hz	12,5 Hz	16 Hz	20 Hz	25 Hz	31,5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz
5 m	-1.0	-4.2	-9.7	-13.	-14.	-11.	-0.8	0.4	1.1	0.1	-4.0	-10.	-11.	-24.
10 m	-1.4	-7.4	-14.	-21.	-23.	-23.	-17.	-7.7	-4.9	-4.5	-6.7	-12.	-14.	-30.
20 m	-3.0	-10.	-15.	-24.	-30.	-28.	-15.	-12.	-10.	-7.9	-10.	-31.	-36.	-53.
40	-12.	-23.	-29.	-36.	-40.	-38.	-33.	-28.	-26.	-25.	-28.	-41.	-44.	-60.

1/3-octave band frequency bands [Hz]

Figure 12-16: Transfer function of measurement points at Site #1

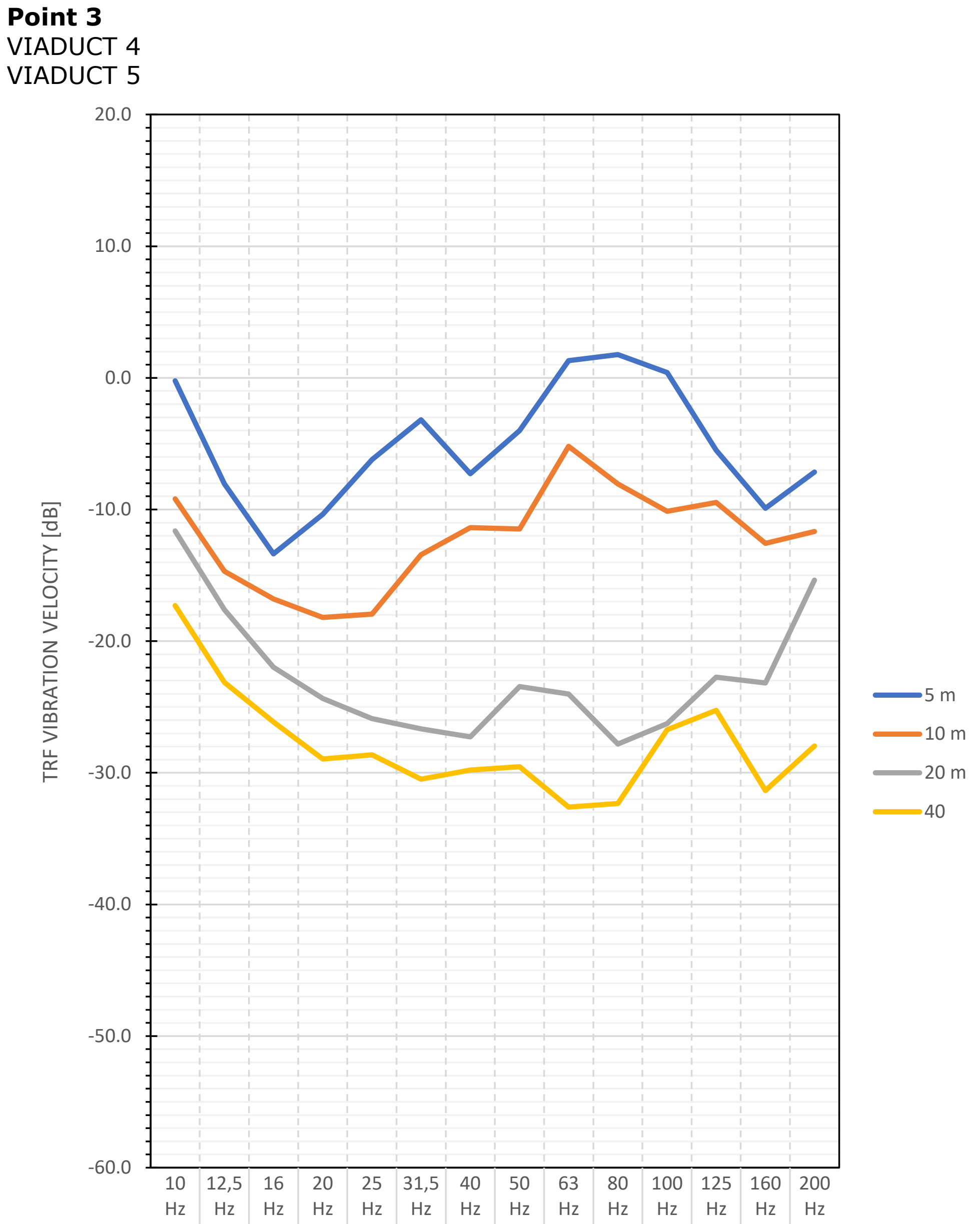
Point 2
TUNNEL T1
VIADUCT 3



	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	200 Hz
5 m	-0.3	-4.8	-3.7	5.3	2.1	0.5	0.1	-2.1	4.6	2.4	-9.2	-4.6	0.8	-0.2
10 m	-2.4	-6.0	-9.8	-1.1	-3.0	-5.9	-5.4	-7.2	-10.	-11.	-17.	-13.	-4.1	-5.3
20 m	-4.5	-7.0	-12.	-4.9	-7.1	-8.9	-9.4	-14.	-8.8	-14.	-26.	-23.	-16.	-16.
40	-9.8	-13.	-13.	-11.	-10.	-13.	-13.	-17.	-14.	-27.	-34.	-32.	-29.	-28.

1/3-octave band frequency bands [Hz]

Figure 12-17: Transfer function of measurement points at Site #2

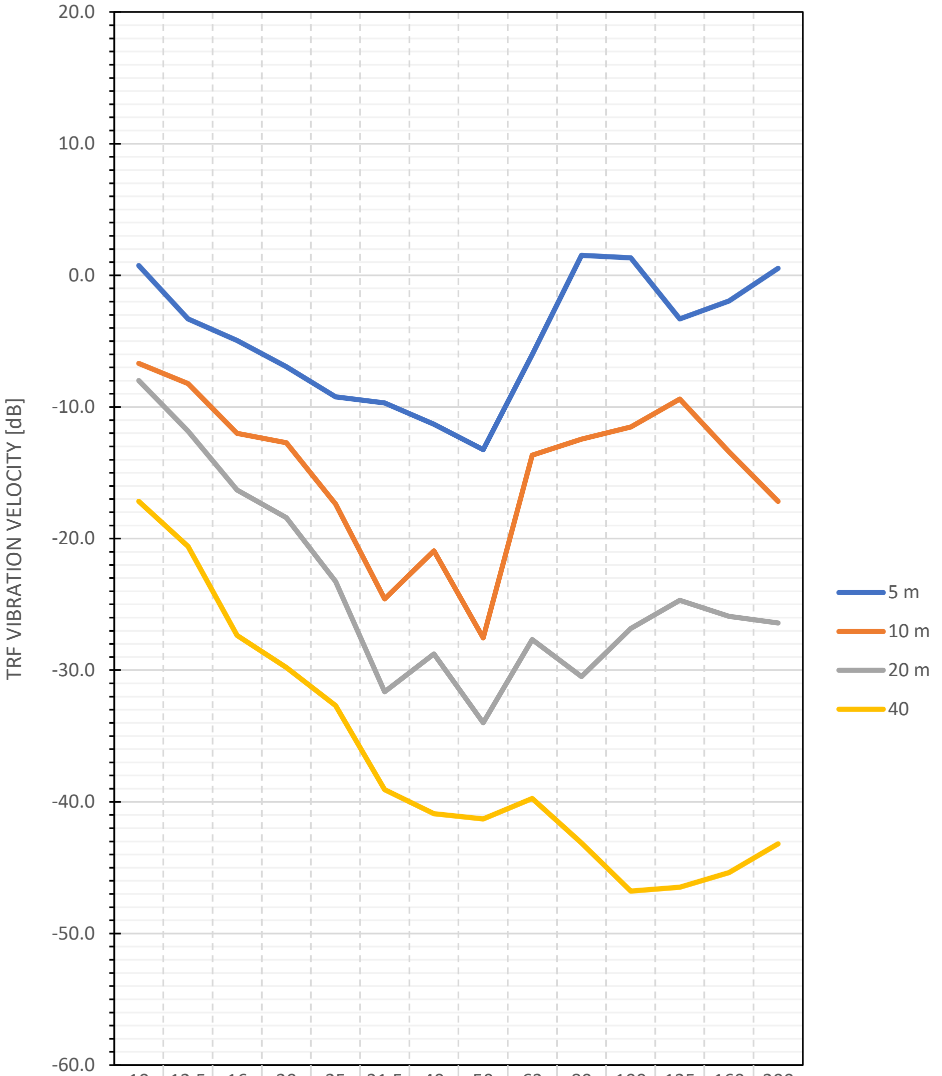


	10 Hz	12,5 Hz	16 Hz	20 Hz	25 Hz	31,5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz
5 m	-0.2	-8.1	-13.	-10.	-6.2	-3.2	-7.3	-4.0	1.3	1.8	0.4	-5.5	-9.9	-7.2
10 m	-9.2	-14.	-16.	-18.	-18.	-13.	-11.	-11.	-5.2	-8.1	-10.	-9.5	-12.	-11.
20 m	-11.	-17.	-22.	-24.	-25.	-26.	-27.	-23.	-24.	-27.	-26.	-22.	-23.	-15.
40	-17.	-23.	-26.	-29.	-28.	-30.	-29.	-29.	-32.	-32.	-26.	-25.	-31.	-28.

1/3-octave band frequency bands [Hz]

Figure 12-18: Transfer function of measurement points at Site #3

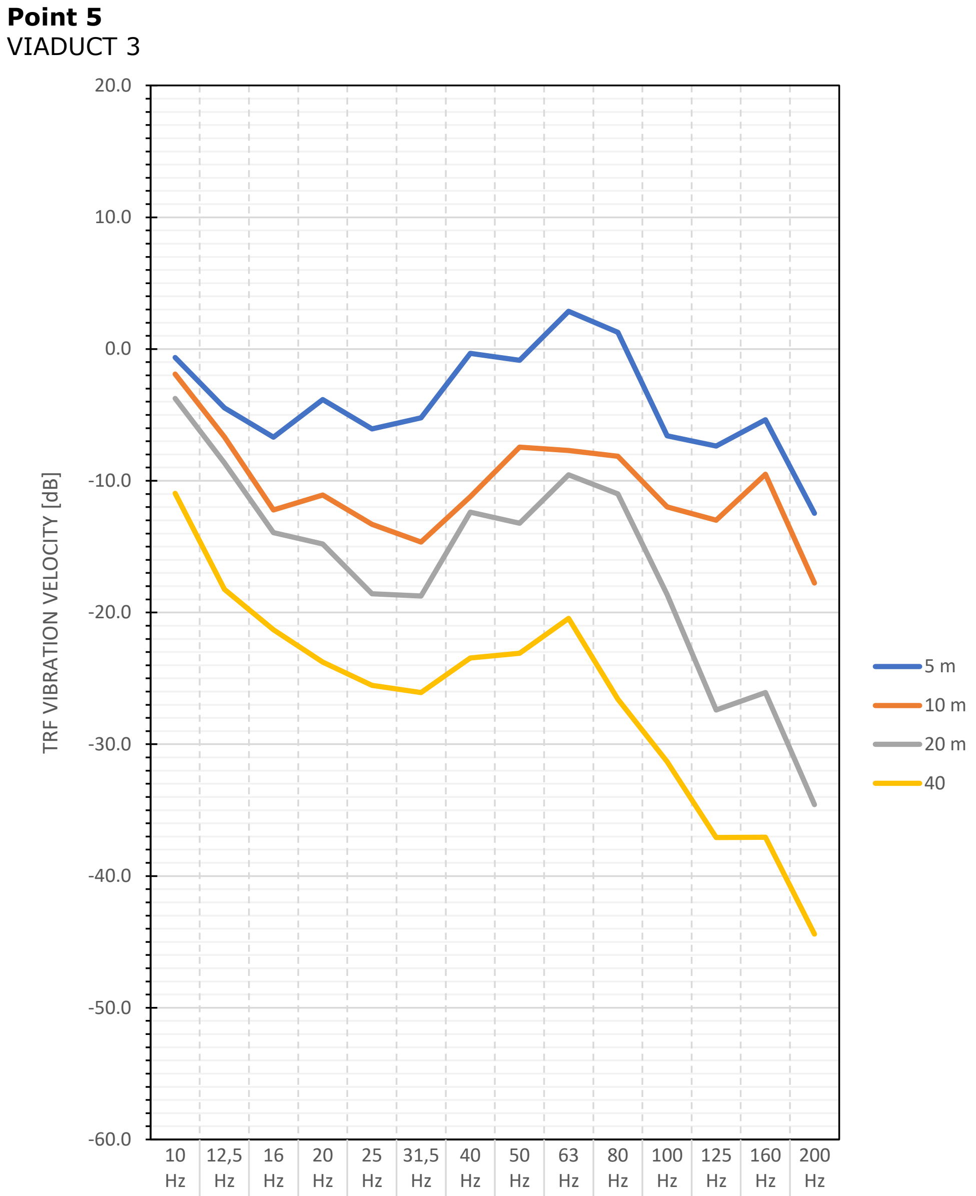
Point 4
VIADUCT 6
TUNNEL T-2



	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	200 Hz
5 m	0.8	-3.3	-4.9	-7.0	-9.2	-9.7	-11.	-13.	-6.0	1.5	1.3	-3.3	-1.9	0.5
10 m	-6.7	-8.2	-12.	-12.	-17.	-24.	-20.	-27.	-13.	-12.	-11.	-9.4	-13.	-17.
20 m	-8.0	-11.	-16.	-18.	-23.	-31.	-28.	-34.	-27.	-30.	-26.	-24.	-25.	-26.
40	-17.	-20.	-27.	-29.	-32.	-39.	-40.	-41.	-39.	-43.	-46.	-46.	-45.	-43.

1/3-octave band frequency bands [Hz]

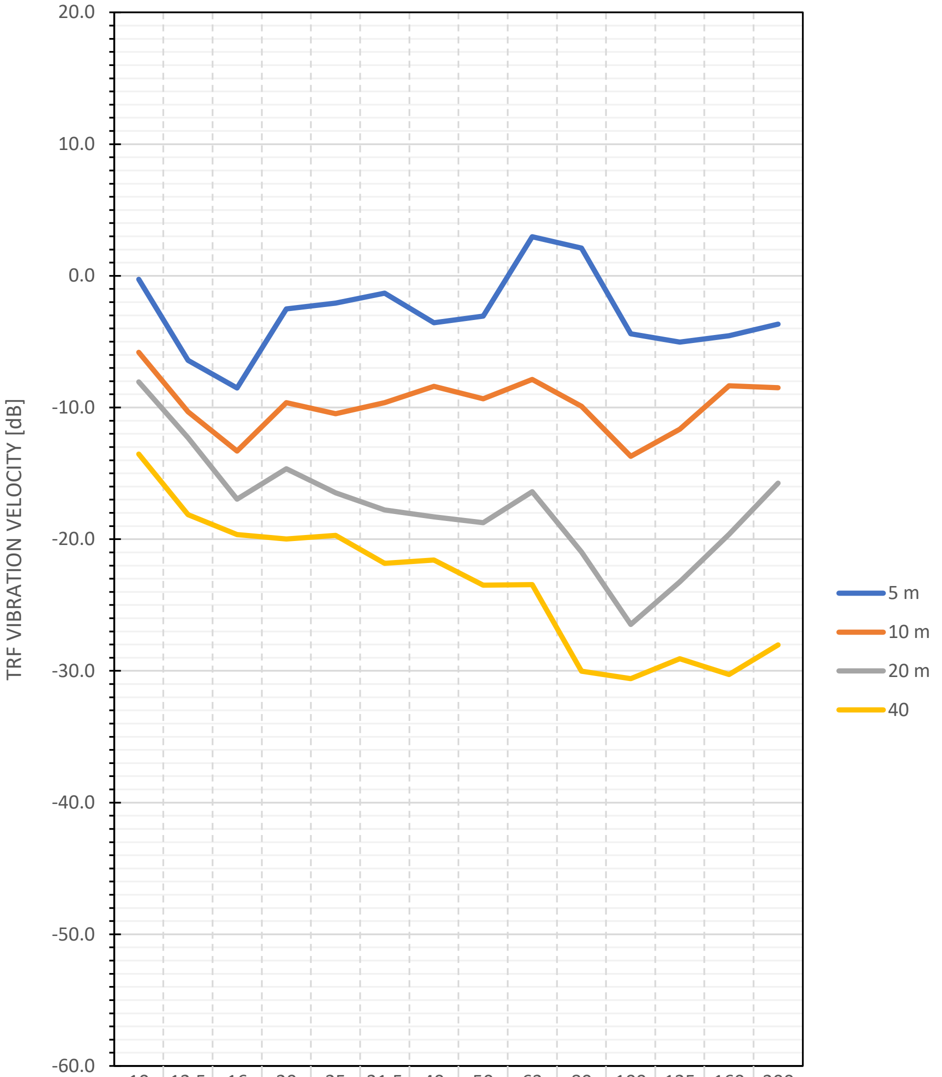
Figure 12-19: Transfer function of measurement points at Site #4



	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	200 Hz
5 m	-0.7	-4.5	-6.7	-3.8	-6.1	-5.2	-0.3	-0.9	2.9	1.3	-6.6	-7.4	-5.4	-12.
10 m	-1.9	-6.7	-12.	-11.	-13.	-14.	-11.	-7.4	-7.7	-8.1	-12.	-13.	-9.5	-17.
20 m	-3.8	-8.6	-13.	-14.	-18.	-18.	-12.	-13.	-9.5	-11.	-18.	-27.	-26.	-34.
40	-11.	-18.	-21.	-23.	-25.	-26.	-23.	-23.	-20.	-26.	-31.	-37.	-37.	-44.

Figure 12-20: Transfer function of measurement points at Site #5

Point 6
VIADUCT 9

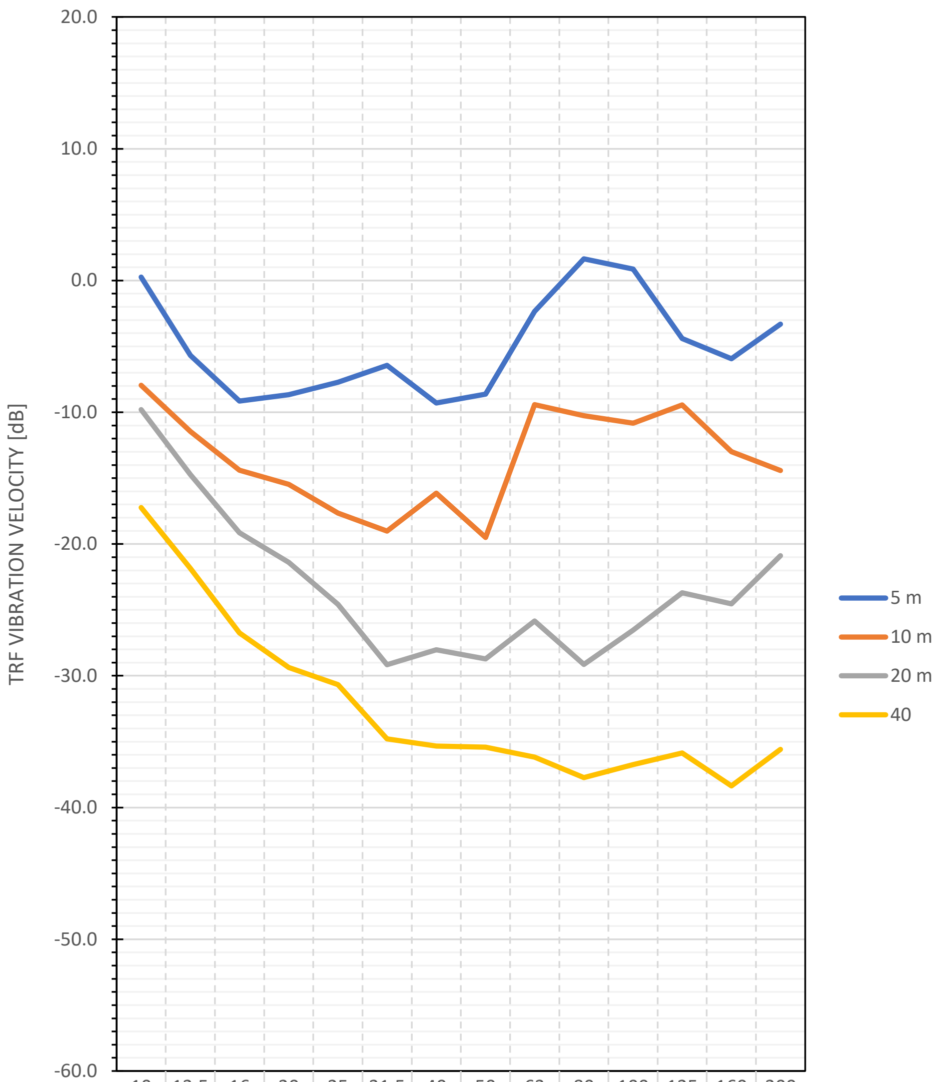


	10 Hz	12,5 Hz	16 Hz	20 Hz	25 Hz	31,5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz
5 m	-0.3	-6.4	-8.5	-2.5	-2.1	-1.3	-3.6	-3.1	3.0	2.1	-4.4	-5.0	-4.6	-3.7
10 m	-5.8	-10.	-13.	-9.6	-10.	-9.6	-8.4	-9.3	-7.9	-9.9	-13.	-11.	-8.3	-8.5
20 m	-8.1	-12.	-17.	-14.	-16.	-17.	-18.	-18.	-16.	-21.	-26.	-23.	-19.	-15.
40	-13.	-18.	-19.	-20.	-19.	-21.	-21.	-23.	-23.	-30.	-30.	-29.	-30.	-28.

1/3-octave band frequency bands [Hz]

Figure 12-21: Transfer function of measurement points at Site #6

Point 7
VIADUCT 10

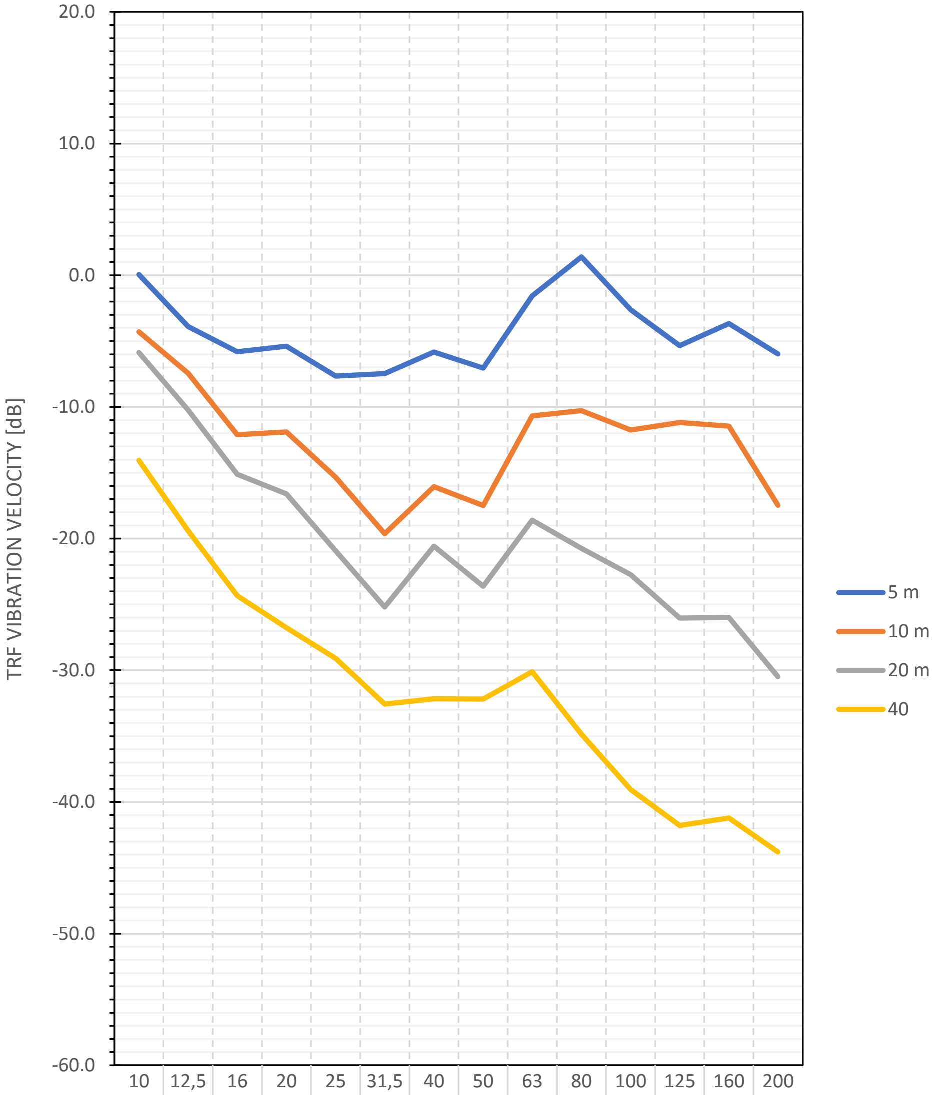


	10 Hz	12,5 Hz	16 Hz	20 Hz	25 Hz	31,5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz
5 m	0.3	-5.7	-9.2	-8.7	-7.7	-6.4	-9.3	-8.6	-2.4	1.6	0.9	-4.4	-5.9	-3.3
10 m	-8.0	-11.	-14.	-15.	-17.	-19.	-16.	-19.	-9.4	-10.	-10.	-9.4	-13.	-14.
20 m	-9.8	-14.	-19.	-21.	-24.	-29.	-28.	-28.	-25.	-29.	-26.	-23.	-24.	-20.
40	-17.	-21.	-26.	-29.	-30.	-34.	-35.	-35.	-36.	-37.	-36.	-35.	-38.	-35.

1/3-octave band frequency bands [Hz]

Figure 12-22: Transfer function of measurement points at Site #7

Point 8
VIADUCT 10
TUNNEL T5

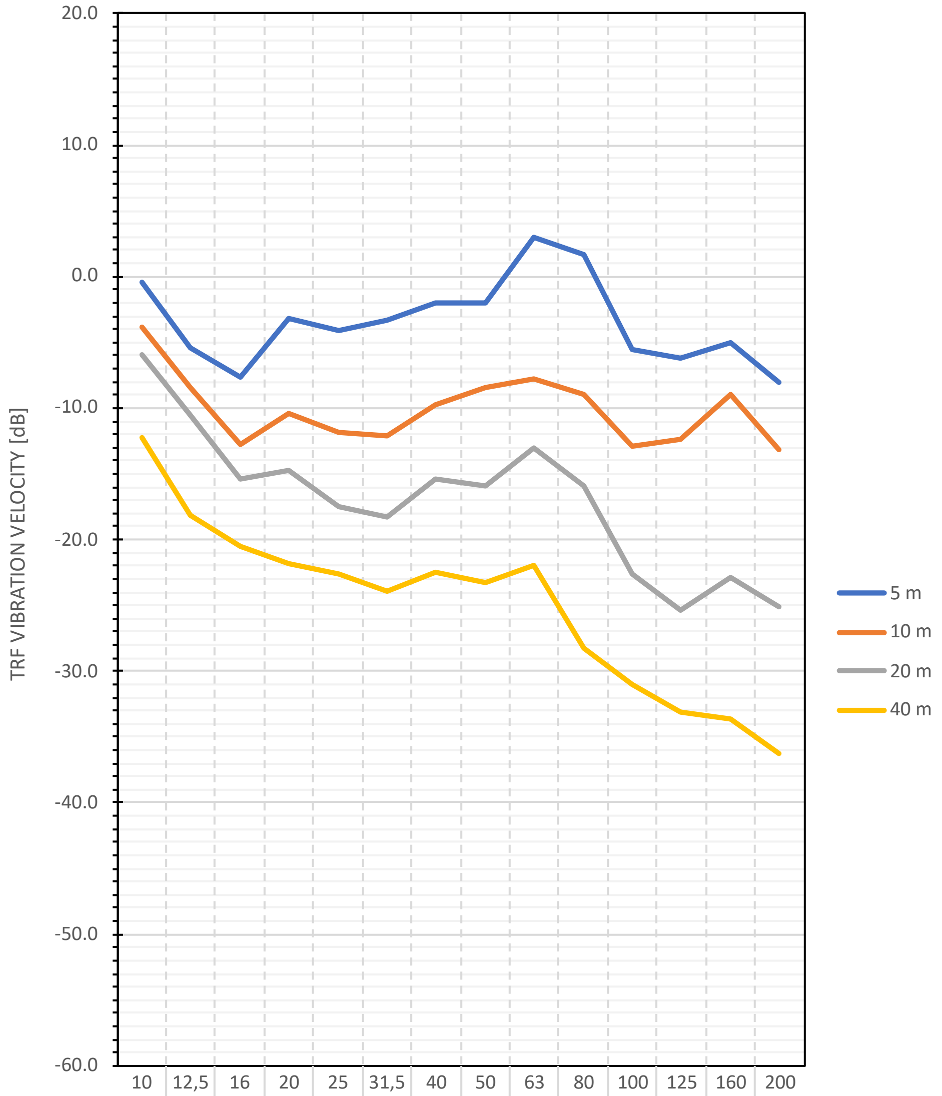


	10 Hz	12,5 Hz	16 Hz	20 Hz	25 Hz	31,5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz
5 m	0.1	-3.9	-5.8	-5.4	-7.6	-7.5	-5.8	-7.1	-1.6	1.4	-2.6	-5.3	-3.7	-6.0
10 m	-4.3	-7.4	-12.	-11.	-15.	-19.	-16.	-17.	-10.	-10.	-11.	-11.	-11.	-17.
20 m	-5.9	-10.	-15.	-16.	-20.	-25.	-20.	-23.	-18.	-20.	-22.	-26.	-26.	-30.
40	-14.	-19.	-24.	-26.	-29.	-32.	-32.	-32.	-30.	-34.	-39.	-41.	-41.	-43.

1/3-octave band frequency bands [Hz]

Figure 12-23: Transfer function of measurement points at Site #8

Point 9
BRIDGE @0+420
KONJIC BYPASS

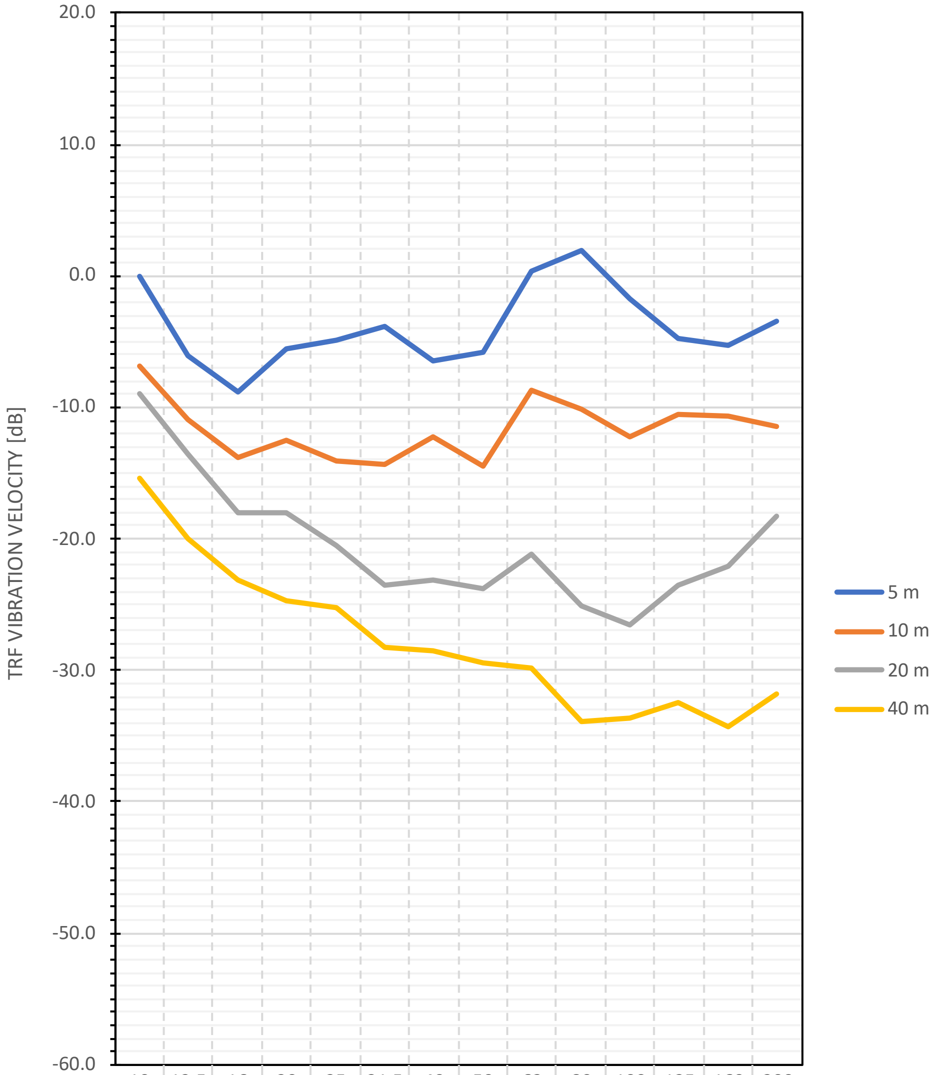


	10 Hz	12,5 Hz	16 Hz	20 Hz	25 Hz	31,5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz
5 m	-0.5	-5.4	-7.6	-3.2	-4.1	-3.3	-1.9	-2.0	2.9	1.7	-5.5	-6.2	-5.0	-8.1
10 m	-3.9	-8.5	-12.	-10.	-11.	-12.	-9.8	-8.4	-7.8	-9.0	-12.	-12.	-8.9	-13.
20 m	-5.9	-10.	-15.	-14.	-17.	-18.	-15.	-16.	-13.	-16.	-22.	-25.	-22.	-25.
40 m	-12.	-18.	-20.	-21.	-22.	-24.	-22.	-23.	-21.	-28.	-31.	-33.	-33.	-36.

1/3-octave band frequency bands [Hz]

Figure 12-24: Transfer function of measurement points at Site #9

Point 10
BRIDGE @0+760
KONJIC BYPASS

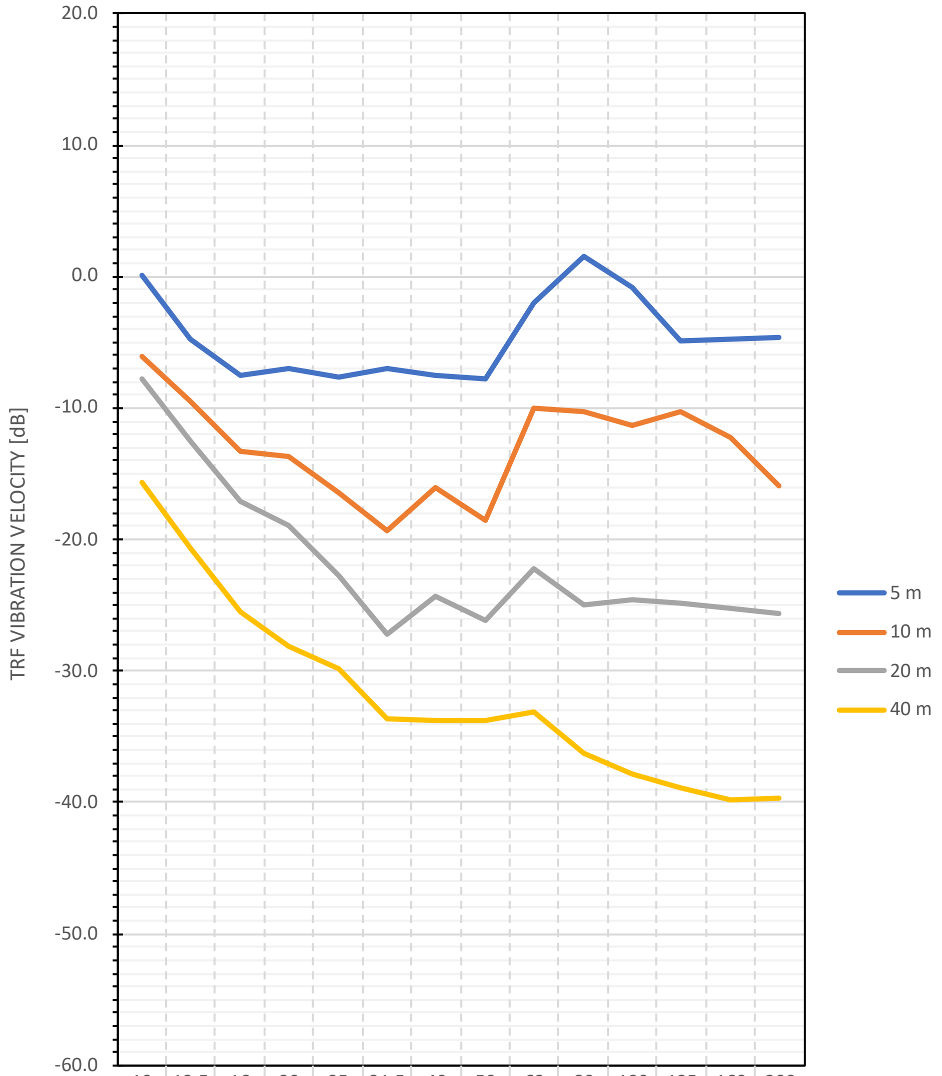


	10 Hz	12,5 Hz	16 Hz	20 Hz	25 Hz	31,5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz
5 m	0.0	-6.0	-8.8	-5.6	-4.9	-3.9	-6.4	-5.8	0.3	1.9	-1.8	-4.7	-5.2	-3.5
10 m	-6.9	-10.	-13.	-12.	-14.	-14.	-12.	-14.	-8.6	-10.	-12.	-10.	-10.	-11.
20 m	-8.9	-13.	-18.	-18.	-20.	-23.	-23.	-23.	-21.	-25.	-26.	-23.	-22.	-18.
40 m	-15.	-20.	-23.	-24.	-25.	-28.	-28.	-29.	-29.	-33.	-33.	-32.	-34.	-31.

1/3-octave band frequency bands [Hz]

Figure 12-25: Transfer function of measurement points at Site #10

Point 11
EXIT OF TUNNEL @0+000

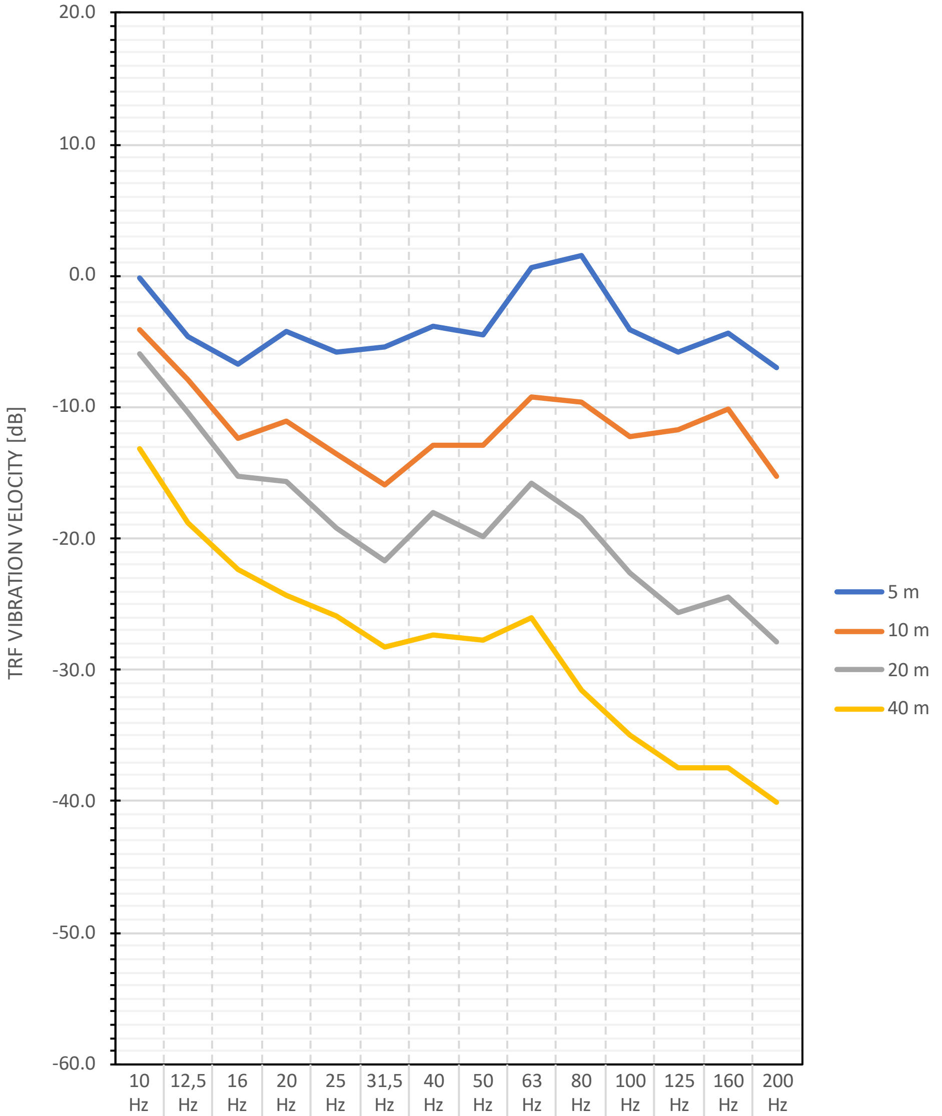


	10 Hz	12,5 Hz	16 Hz	20 Hz	25 Hz	31,5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz
5 m	0.2	-4.8	-7.5	-7.0	-7.7	-7.0	-7.6	-7.8	-2.0	1.5	-0.9	-4.9	-4.8	-4.6
10 m	-6.1	-9.5	-13.	-13.	-16.	-19.	-16.	-18.	-10.	-10.	-11.	-10.	-12.	-15.
20 m	-7.8	-12.	-17.	-19.	-22.	-27.	-24.	-26.	-22.	-24.	-24.	-24.	-25.	-25.
40 m	-15.	-20.	-25.	-28.	-29.	-33.	-33.	-33.	-33.	-36.	-37.	-38.	-39.	-39.

1/3-octave band frequency bands [Hz]

Figure 12-26: Transfer function of measurement points at Site #11

Point 12
KONJIC NORTH I/C
BRIDGE



	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	200 Hz
5 m	-0.2	-4.7	-6.7	-4.3	-5.9	-5.4	-3.9	-4.5	0.7	1.5	-4.1	-5.8	-4.3	-7.0
10 m	-4.1	-8.0	-12.	-11.	-13.	-15.	-12.	-12.	-9.2	-9.7	-12.	-11.	-10.	-15.
20 m	-5.9	-10.	-15.	-15.	-19.	-21.	-18.	-19.	-15.	-18.	-22.	-25.	-24.	-27.
40 m	-13.	-18.	-22.	-24.	-25.	-28.	-27.	-27.	-26.	-31.	-35.	-37.	-37.	-40.

1/3-octave band frequency bands [Hz]

Figure 12-27: Transfer function of measurement points at Site #12

12.3 Assessment of Potential Impacts

12.3.1 Overview of Potential Impacts

Vibrations and ground-borne noise are present in most environments, but most of the times the levels that reach the receivers are usually bellow the perceived limits. Sources that can produce a perceptible level of vibration and ground-borne noise are: transport systems (rail and road under certain circumstances), mining operations (including explosions), construction sites, demolitions, industry and some activities in the housing environment and entertainment.

Ground-borne vibration is the oscillatory motion of the ground in relation to a static equilibrium position. Vibration is transmitted through soil in different wave types: body waves (longitudinal and transverse) and surface waves (Rayleigh, Love, etc.). Each type (Figure 12-28) has a different transmission speed and different reduction rate related to the distance from the source (Figure 12-29).

The impact of vibration ranges from annoyance when levels are somewhat above perception, to cosmetic damage to buildings, up to structures' collapsing and health issues (vibration white fingers, etc.) when exposed to very high vibration magnitudes (handheld or blasts).

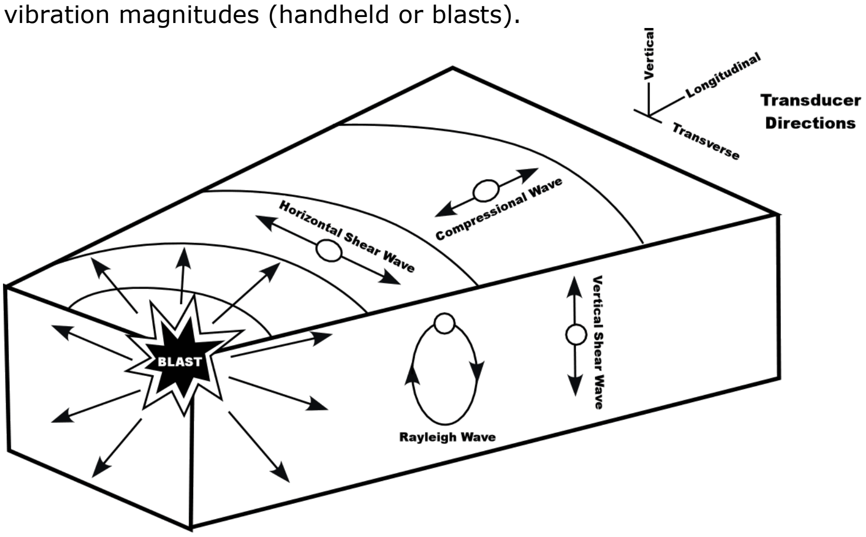


Figure 12-28: Particle motion associated with the different wave types

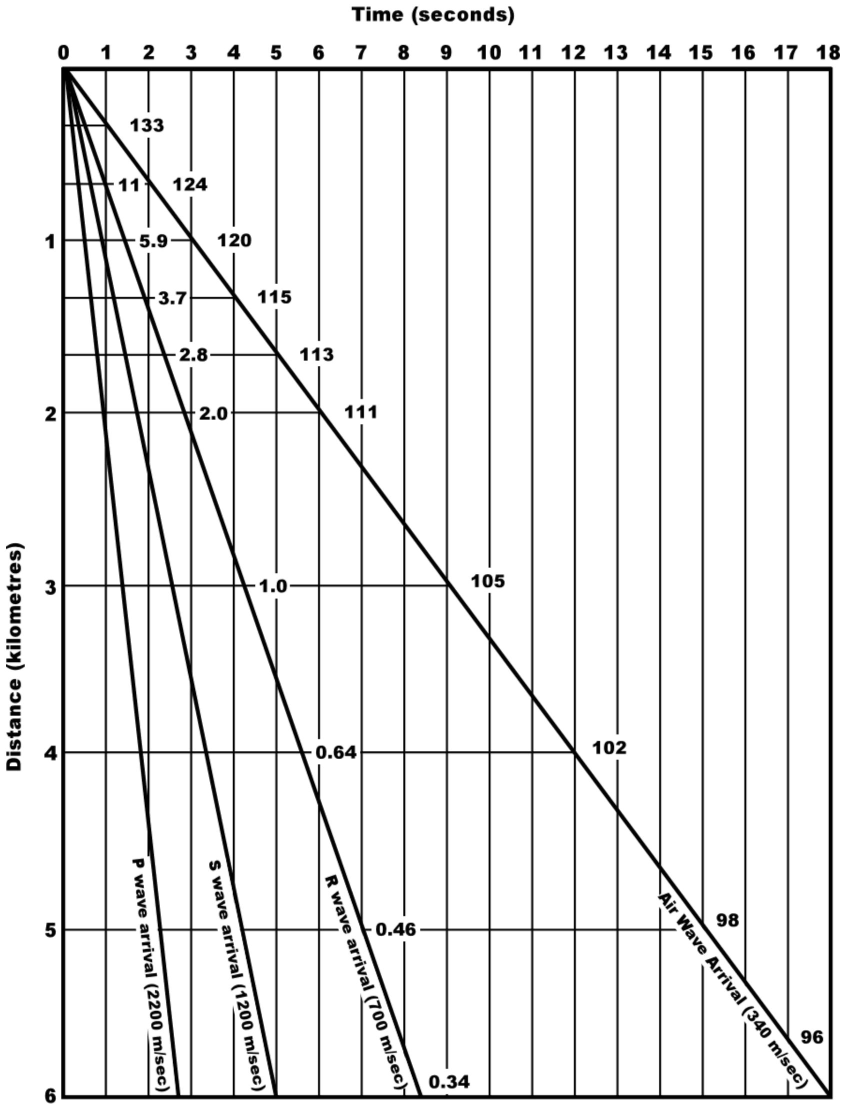


Figure 12-29: Time delay associated with the different wave types

12.3.2 Assessment Methodology

12.3.2.1 Regulatory Framework

The impact of vibrations in humans depends on the level of exposure. There is no provision in the national or European legislation, in order to assess the effect of vibrations on humans, with regards to discomfort in everyday life (and not for prolonged exposure to environments with severe vibrations where there is a risk of health effects).

According to DIN 4150-3:2016: "Structural vibration Part 3: Effects of vibration on structures"[1], to protect the environment from causing a high level of vibrations from explosions that can cause nuisance or damage to nearby

[1] DIN 4150-3: "Structural vibration Part 3: Effects of vibration on structures", 2016

structures, the maximum permitted peak particle velocity must not exceed the following values, for different types of buildings and buried pipework.

Table 12-5: DIN 4150-3 ppv guideline values for evaluating the effects of short-term vibration on structures

Line	Type of structure	Guideline values for velocity, v_i, in mm/s			
		Vibration at the foundation at a frequency of			Vibration at horizontal plane of highest floor
		1 Hz to 10 Hz	10 Hz to 50 Hz	50 Hz to 100 Hz*)	at all frequencies
1	Buildings used for commercial purposes, industrial buildings, and buildings of similar design	20	20 to 40	40 to 50	40
2	Dwellings and buildings of similar design and/or occupancy	5	5 to 15	15 to 20	15
3	Structures that, because of their particular sensitivity to vibration, cannot be classified under lines 1 and 2 and are of great intrinsic value (e.g. listed buildings under preservation order)	3	3 to 8	8 to 10	8
*) At frequencies above 100 Hz, the values given in this column may be used as minimum values.					

Table 12-6: DIN 4150-3 ppv guideline values for evaluating the effects of short-term vibration on buried pipework

Line	Pipe material	Guideline values for velocity measured on the pipe, v_i, in mm/s
1	Steel (including welded pipes)	100
2	Clay, concrete, reinforced concrete, pre-stressed concrete, metal (with or without flange)	80
3	Masonry, plastic	50

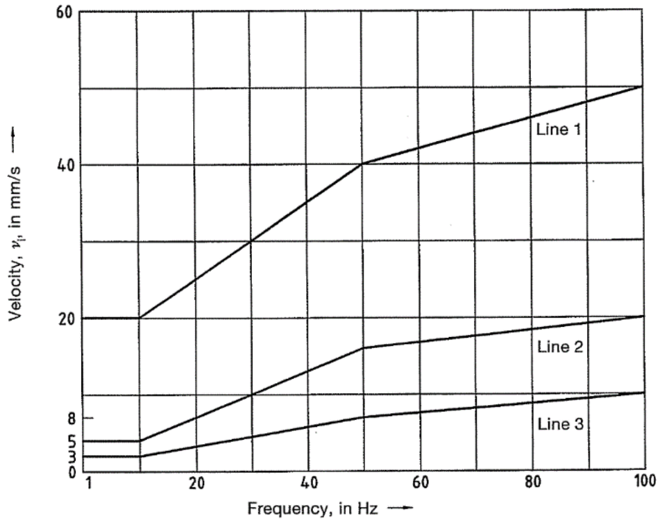
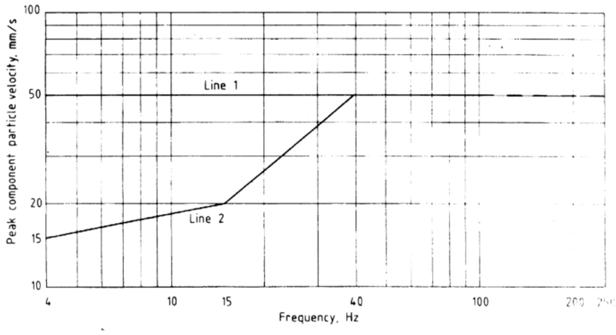


Figure 12-30: Curves of DIN 4150-3 ppv guideline values given in Table 12-5

Usually there is no major damage impacts on structures from ground vibration except from high magnitude explosions and earthquakes. Nevertheless, sometimes damages can occur at cosmetic parts of nearby buildings. Based on the British standards BS 7385-2:1993 "Evaluation and measurement for vibration in buildings. Guide to damage levels from ground-borne vibration"[2] and BS 5228-2:2009+Amnd1:2014 "Code of practice for noise and vibration control on construction and open sites – Part 2: Vibration"[3], the maximum permitted values of peak particle velocity for not causing damage to different types of buildings are given in Figure 12-31, which suggests lest 'strict' values than DIN 4150.



Line (see Figure 1)	Type of building	Peak component particle velocity in frequency range of predominant pulse	
		4 Hz to 15 Hz	15 Hz and above
1	Reinforced or framed structures Industrial and heavy commercial buildings	50 mm/s at 4 Hz and above	
2	Unreinforced or light framed structures Residential or light commerical type buildings	15 mm/s at 4 Hz increasing to 20 mm/s at 15 Hz	20 mm/s at 15 Hz increasing to 50 mm/s at 40 Hz and above
NOTE 1 Values referred to are at the base of the building (see **6.3**).			
NOTE 2 For line 2, at frequencies below 4 Hz, a maximum displacement of 0.6 mm (zero to peak) should not be exceeded.			

Figure 12-31: Transient vibration guide values for cosmetic damage according to BS 7385-2

[2] British standard BS 7385-2 "Evaluation and measurement for vibration in buildings. Guide to damage levels from groundborne vibration", 1993
[3] British standard BS 5228-2 "Code of practice for noise and vibration control on construction and open sites – Part 2: Vibration ", 2014

According to internationally accepted guidelines (standards BS 6472:1992, ISO 2631), the limits where vibrations are felt are much lower as shown in the following table.

Table 12-7: Limits of perceptuality and disturbance from exposure to vibrations

Peek Particle Velocity (mm/s)	RMS weighted acceleration (m/s^2)	Perception level[4]
0,10	< 0,01	Not perceptible
0,15	0,015	Threshold of perception
0,35	0,015 - 0,02	Barely perceptible
1,0	0,02 - 0,08	Easily perceptible
2,2	0,08 -0,315	Strongly perceptible
6,0	> 0,315	Extremely perceptible

Ground excitation frequency from construction machinery usually lies in the range from 30 to 200 Hz, hence the limit ppv ≤ 10 mm/s inside nearby sensitive receivers is considered for this assessment. The limit is well above the structural damage magnitudes, although vibration during certain works will be perceived. However, due to the short-term and the intermittent nature of the Project, it is not expected to generate broad annoyance.

12.3.2.2 Vibration Sources During Construction

Construction activities involve certain machinery that produce remarkable vibrations. US Federal Transit Administration provides a catalogue of vibration levels caused by the construction machinery which is shown in the following table[5].

Table 12-8: Vibration emissions from construction machinery

Equipment	ppv at 5m, [mm/s]	
Pile Driver (impact)	upper range	38.557
	typical	16.358
Pile Driver (Sonic)	upper range	18.644
	typical	4.318
Clam shovel drop (slurry wall)		5.131
Hydromill (slurry wall)	in soil	0.203
	in rock	0.432
Vibratory Roller		5.334

[4] The degree of perceptibility (on building floors) refers to vibrations with a frequency content between 8 Hz and 80 Hz.
[5] U.S. Department of Transportation, "Federal Transit Administration. FTA-VA-90-1003-06 'Transit Noise and Vibration Impact Assessment.'", 2020

Equipment	ppv at 5m, [mm/s]	
Hoe Ram		2.261
Large bulldozer		2.261
Caisson drilling		2.261
Loaded trucks		1.930
Jackhammer		0.889
Small bulldozer		0.076

Another major source of vibration that can be apparent in special cases during tunnel construction is the use of explosives. During the explosion, the ground vibration radiates out from the borehole with decreasing intensity and reduces to levels below of perception with distance. However, wavefront reinforcement of ground vibration can occur depending on the soil underlayers, the rock structures as well as the drilling and delay pattern.

A number of researchers have investigated the problem of ground vibration prediction and have proposed various formulae. While not an extensive catalogue, the following formulae demonstrates the different approaches used:

> Langefors Formula (Langefors and Kihlstrom, 1973)

$$v = k\sqrt{\frac{Q}{D^{1.5}}}$$

> Square root scaled distance (United States Bureau of Mines (USBM), 1980; ICI, 1990; Australian Standard (AS) 2187.2, 1993):

$$v = k\left(\frac{D}{\sqrt{Q}}\right)^{-e}$$

> Cube root scaled distance (Ambraseys/Hendron, 1968; Hendron/Oriand, 1972):

$$v = k\left(\frac{D}{\sqrt[3]{Q}}\right)^{-e}$$

where:

v: peak particle velocity (mm/s)

$Q \geq 0$: instantaneous charge mass (kg)

$D > 0$: distance (m)

$k \geq 0$: site constant / rock transmission factor for Langefors Formula

$e > 0$: site exponent

12.3.2.3 Definition, Properties and Measuring Units of Vibration/Indicators for the Assessment of Environmental Vibrations

Mechanical vibrations appear when a force is applied to a solid body which gains kinetic and potential energy. Thus, vibration can be measured from the result of this power transmission, characterised by the displacement of the equilibrium point (displacement d in m), the vibration velocity (velocity v in m/sec) and the vibration acceleration (acceleration a in m/s²). Displacement is measured along a defined axis, while the other two vector quantities are measured in a specified reference system (x, y, z). All three quantities are time variant, and they are characterised by their instantaneous value, their maximum value (peak) and their root-mean-square (rms) value.

These three physical quantities (acceleration - velocity - displacement) are unambiguously connected at each frequency, and therefore the measurement of any one of them can provide the maximum or rms values of the other two[6]. However, the relationship between these descriptors can vary greatly in different situations, depending on the frequency content of the vibration energy. The overall vibration is the total unfiltered vibration over the entire spectrum.
The response of humans, buildings, and equipment to vibration is usually described in terms of velocity or acceleration. Since human sensitivity to vibration typically corresponds to a constant level of vibration velocity amplitude, as a function of frequency within the frequency range that is of most concern for environmental vibration produced by rail transit systems (i.e., roughly 8 to 100 Hertz [Hz]), vibration velocity is used in this analysis as the primary measure to evaluate the impacts of vibration.

The peak particle velocity (ppv) is the most accepted and used indicator of vibration levels. Most regulations and standards prescribe vibrations thresholds in terms of the ppv. For each recorded waveform, the maximum particle velocity over the total recorded time is regarded as the peak particle velocity (Figure 12-32). This type of particle velocity must not be confused with the velocity with which the wave propagates through the medium (i.e., information of interest in seismic exploration).

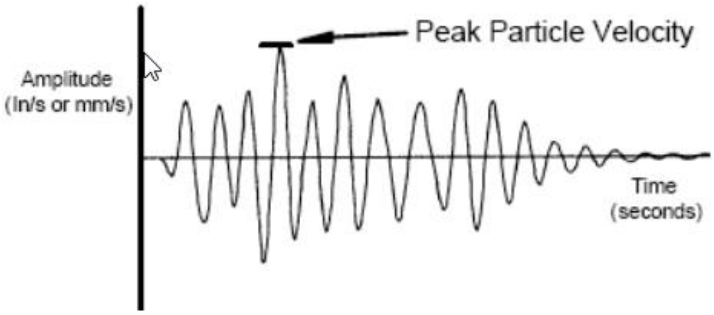


Figure 12-32: Typical vibration recording

The measurement of vibration can be expressed on a logarithmic scale with a unit of measurement in decibel (dB) as follows:

The level of rms vibration acceleration: The level of rms vibration velocity:

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[6] Given that: $a(t) = \frac{dv(t)}{dt}$, the acceleration is associated with the velocity when it is evaluated in frequency bands (such as octave bands or 1/3-octave bands), using the formula $a = 2\pi f\, v$, where f is the centre frequency of the band.

$$L_a = 20\log\frac{a_{rms}}{a_{ref}} = 10\log\frac{\sqrt{\int_0^T a(t)^2dt}}{a_{ref}^2} \qquad L_v = 20\log\frac{v_{rms}}{v_{ref}} = 10\log\frac{\sqrt{\int_0^T v(t)^2dt}}{v_{ref}^2}$$

In contrast to sound, where the reference value of acoustic pressure is worldwide defined as $p_{ref} = 20 \times 10^{-6}\ Pa$ (threshold of perceptible sound), there is no consistent reference unit for vibrations. Common values are:

a_{ref} = 10^{-6} m/sec^2 and v_{ref} = 10^{-9} mm/sec [ISO 1683:2008].

12.3.2.4 Analysis of Calculations and Transfer Functions

Ground-borne vibration is influenced by factors regarding source (its emissions in the frequency domain), transmission path (soil characteristics) and receivers (soil-structure interaction and building structure designs).

The resonant frequency range for ground propagation is in the range of 0-10 Hz for cohesive soils, and higher frequencies for soils of friction material[7]. To assess the vibration impact to sensitive receivers near the source, computational methods are used, which allows us to predict the level of the vibration that will reach the receivers.

The source parameters are given from databases of vibration emissions for various machinery. The propagation parameters are the propagation through soil/rock and through the foundations of the building to the building itself.
The procedure is based on using vibration velocity transfer function. The transfer function completely defines the composite vibration propagation characteristics between two points.

The formula that calculates the vibration level in the buildings is:

$$L_v = L_F + TF + C_{build},$$

where L_v is the peak or rms vibration velocity level at the receiver (in dB), L_F is the vibration velocity level at the source (in dB), TF is the vibration velocity transfer function and C_{build} is the adjustment factor to account for soil-structure interaction and vibration amplification from building components (slabs etc).

The calculated estimate of the vibration level at the receiver is then compared to the vibration limits applicable to the area under study. If there are areas where the level is over the limits, mitigation measures must be designed.

- Vibration velocity at 5m from source (L_F) is given in Table 12-8.
- Vibration velocity transfer function (TF) is measured insitu (see Chapter 12.2) at the hot-spots identified (see Chapter 12.3.2.5, paragraph *Areas investigated-Sensitive Receivers*). The measurement of the transfer functions and all the calculations are made with the following software: MEDA vibration acquisition and analysis software, license number S087/604. Calculations involve assessment of impact to 10m, 20m and 40m from

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[7] Natasha Zamani & Usama El Shamy, "Analysis of wave propagation in dry granular soils using DEM simulations", 2011

source, based on measurements 5m from source, where source emission is known.

> The adjustment factor C_{build} is estimated from bibliography. In general, there is a positive insertion loss from the transition of the vibration waves from the ground to the stiff concrete foundations and there is amplification from the foundations to the upper floors due to structural resonances (Table 12-9). For this study, a conservative -3 dB scenario is assumed for SSI (due to the unknown condition and type of the nearby buildings) and for floor-to-floor attenuation and amplification due to resonances of floors, walls and ceilings, a +6 dB amplification is considered (Table 12-9).

Table 12-9: Various factors that affect vibration level in buildings

Receiver factor	Adjustment to propagation curve		Comment
Coupling to building foundation	Wood Frame Houses	-5dB	**The general rule is the heavier the building construction, the greater the coupling loss.**
	1-2 Story Masonry	-7dB	
	3-4 Story Masonry	-10dB	
	Large Masonry on Piles	-10dB	
	Large Masonry on Spread Footings	-13dB	
	Foundation in Rock	0dB	
Floor-to-floor attenuation	1-5 floors from grade	-2dB/floor	**This factor accounts for dispersion and attenuation of the vibration energy as it propagates through a building.**
	5-10 floors from grade	-1dB/floor	
Amplification due to resonances of floors, walls and ceilings		**+6dB**	**The actual amplification will vary greatly depending on the type of construction. The amplification is lower near the wall/floor and wall/ceiling intersections.**

12.3.2.5 Input Parameters

Identification of vibration sources

Construction vibration, similar to noise, is highly dependent on the specific equipment and operation methods employed. Construction vibration can cause a variety of potential effects, including interference with vibration-sensitive equipment, low rumbling or ground-borne noise, vibrations perceptible to humans at moderate levels, and cosmetic damage to buildings at the highest levels for very specific operations during construction period. Most construction processes do not generate high enough vibration levels to approach the threshold for cracking damage; moreover, structural damage is highly unlikely for construction vibration.

Because construction is a short-term, temporary impact, construction vibration was assessed at locations where prolonged annoyance or building cosmetic damage might occur; namely, at the receptors within the vicinity of the bridges and tunnels for the project. Another considerable source, depending on the methods and the machinery used, is the vibration rollers during soil compaction. Reviewing the geometry of the proposed Project, as taken from the design documents, the length of the section considered for this assignment is approximately 36 km[8] and the project includes 5 tunnels and 10 bridges-viaducts, which are considered as hot-spots for the vibration impact during construction due to the machinery used for drilling tunnels and foundation piles of bridges.

Table 12-10: Locations of tunnels and bridges along the main alignment

Structure	Chainage	Description
bridge	~1+250	maximum length 484 m
tunnel	~2+600	maximum length 2,200 m
bridge	~3+950	maximum length 657 m
bridge	~5+750	maximum length 55 m
tunnel	Prenj Tunnel	total length 10 km
bridge	~23+000	maximum length 360 m
tunnel	~23+600	maximum length 857 m
bridge	~24+250	maximum length 334 m
bridge	~25+700	maximum length 430 m
tunnel	~32+850	maximum length 2,250 m

Table 12-11: Locations of bridges along 'east access road to Konjic North I/C' alignment

Structure	Chainage	Description
bridge	~0+280	length 150m

Table 12-12: Locations of tunnels and bridges along 'Konjic Bypass' alignment

Structure	Chainage	Description
tunnel	~2+260	length 800m
bridge	~0+760	length 40m
bridge	~0+420	length 331m

Soil types

Based on the Environmental Impact Study of the project[9], the soil types encountered throughout the alignment is as described below.

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[8] The route enters the canyon of Konjic Bijela and gradually climbs towards the tunnel Prenj which is an underground crossing the main mountain. Upon exiting the tunnel, route Prenj develops north of the area above the settlements of Dubrava above Selista and Zelanika and gradually descends into the area of Bijelo Polje

[9] "ZAGREBINSPEKT" Ltd. MOSTAR, "MOTORWAY ON CORRIDOR Vc - ENVIRONMENTAL IMPACT STUDY Section: Konjic (Ovcari Interchange) – Mostar north", 2016

From the start of the route section of this part of the motorway up to stationing value of km 1+200, consists of middle Triassic dolomites which are exposed to weathering along the major fissures and faults. Surface layer consists of incoherent fine-grained soil with modification of thickness, ranging from 1 to 3 m. Dolomites as basic rocks belong to solid rocks, and according to OTU classification the belong to category "A". Numerical designation on IG map is 2.

From station value of km 1+200 up to 1+450 km, the valley of the river Tresanica covered with gravel and sand incoherent coating has thickness to a maximum of 4 m. The floor of this incoherent soil is made probably of faulty Middle Triassic dolomites. It is going to be bypassed by a bridge and supporting pillars should be based on dolomite.

At stationing value of km 1+450 to 3+800 km, route lies within dolomite. The massif is passed through by a tunnel under the elevation point Mejit and Orlovac and runs in the dolomites along its entire length. Dolomites belong to the solid rock masses and, according to OTU classification belong to category "A", with numerical value of 2. A major fault that occurs at km 2+500 up to 2+600 km probably caused a considerable degradation of the rock mass and it is expected to detect medium-solid rock mass, i.e., category "B" according to the classification OTU.

From km 3+800 up to 4+500 km the Neretva River is bypassed. The riverbed is filled with coarse gravel and incoherent sand with a maximum thickness of 7 m. The numeric designation is 15. The floor is consisted of dolomites (2).

From 4+500 up to 5+450 km the terrain is made of solid rocks mass - dolomite covered with 1 to 3 m thick surface soft incoherent soil. Floor layer of dolomite belongs to solid rock mass (2).

From 5+450 km up to 5+800 km, screey and partly alluvial deposition, which belongs to the coarse grain incoherent soil with maximum thickness of 6 m (14) are registered.

From km 5+800 up to 6+050 km, terrain consists of shaly lower Triassic sediment shales, sandy limestone and sandstone covered with up to 3 m thick fine-grained non-coherent soil. Floor screes belong to semi-solid bedrock and category "B" according to the classification OTU. Numerical designation on IG map is 12.

From km 6+050 up to 6+800 km, terrain is built of mixed fine-grained and coarse-grained soil (14) with the maximum thickness of up to 7 m.

From km 7+600 and further until north portal of tunnel Prenj (T3), terrain is built from lower Triassic schist (12). All up to the north portal of tunnel Prenj, the terrain is built on an area of thick layers of coarse-grained incoherent soil, mostly with screey and glacial origin (14). The thickness of these layers is very large and (near the entrance portal) thickness over 90 m is determined by drilling.

From south portal of tunnel Prenj (T3) up to stationing km 23+250, terrain is made of coarse incoherent soil of glacial and screey origin and (14) is mainly bypassed. The thickness of this incoherent soil is probably greater than 10 m.

From 23+250 up to km 26+800, the motorway route passes through limestone rock solid masses (1), category "A" according to OTU. Tunnel Gradina at km 23+250 to 24+050 km along its entire length passes through the solid rock. At km 24+130 to 24+250 and 25+500 to 25+750 km to, two rock screes of long-grained non-cohesive soils, mostly of limestone composition, are bypassed.

From km 26+800 up to km 31+500 km, route passes through thick screey and deluvial deposits of Bijelo Polje, an incoherent coarse-grained mainly limestone material. Assessment is, according to the results of local drilling, that the thickness of these layers of the route range is greater than 50 m.

From km 31+350 up to 35+950 km, route passes through the solid rock limestone massif (1:03). On this part of the route, the tunnel Orlov Kuk is passing through the solid rock mass, which is planned to being built near the water source Bosnjaci-Potoci.

Areas investigated – sensitive receptors

Combining the locations where extensive vibration emissions are expected during construction (Table 12-10) with the location of sensitive receivers, the following 8 hot-spots, shown in Figure 12-33-Figure 12-40, have been identified for further investigation.

Figure 12-33: Vibration hot-spot #1 – Viaduct 2 and north portal of tunnel T1

Figure 12-34: Vibration hot-spot #2 – Viaduct 3 and south portal of tunnel T1

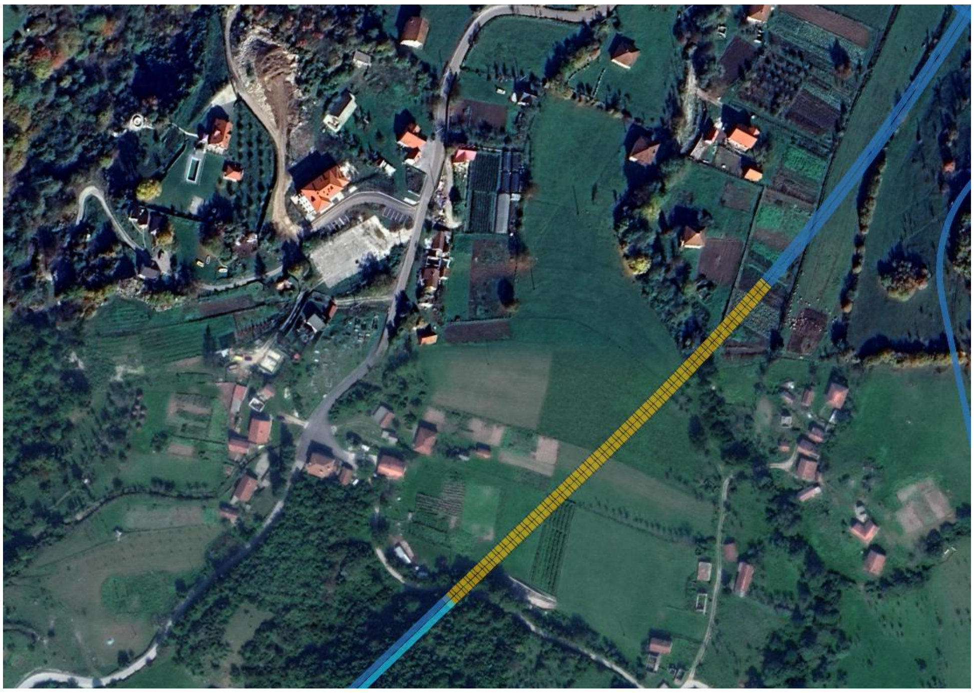

Figure 12-35: Vibration hot-spot #3 – Viaduct south of Konjic South I/C

Figure 12-36: Vibration hot-spot #5 – Viaduct ~ 23+600

Figure 12-37: Vibration hot-spot #6 – Viaduct ~ 24+250

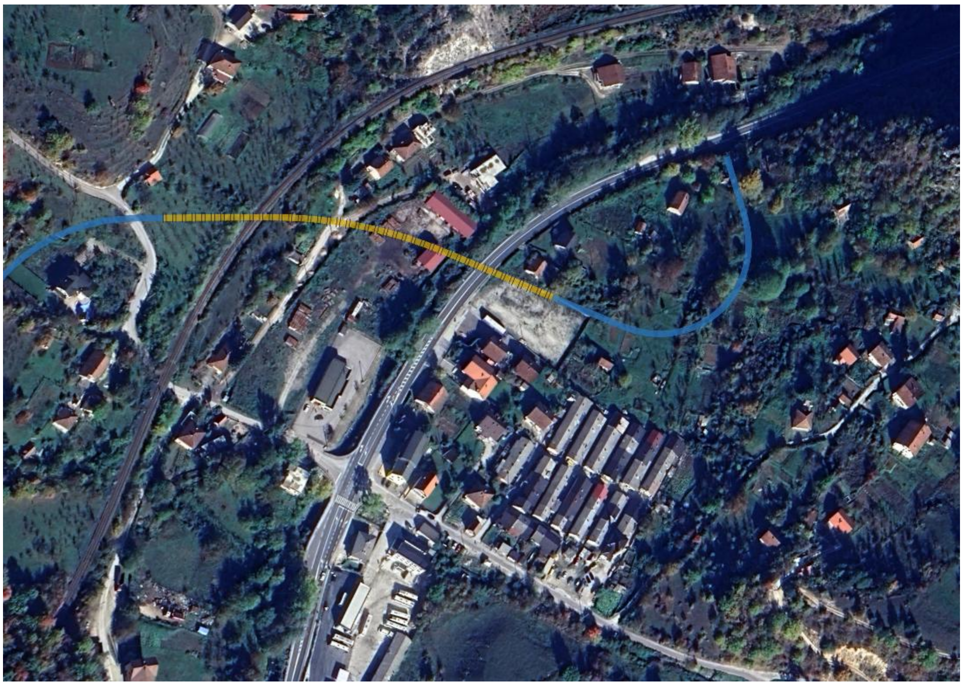

Figure 12-38: Vibration hot-spot #7 – Viaduct on 'east access road to Konjic North I/C'

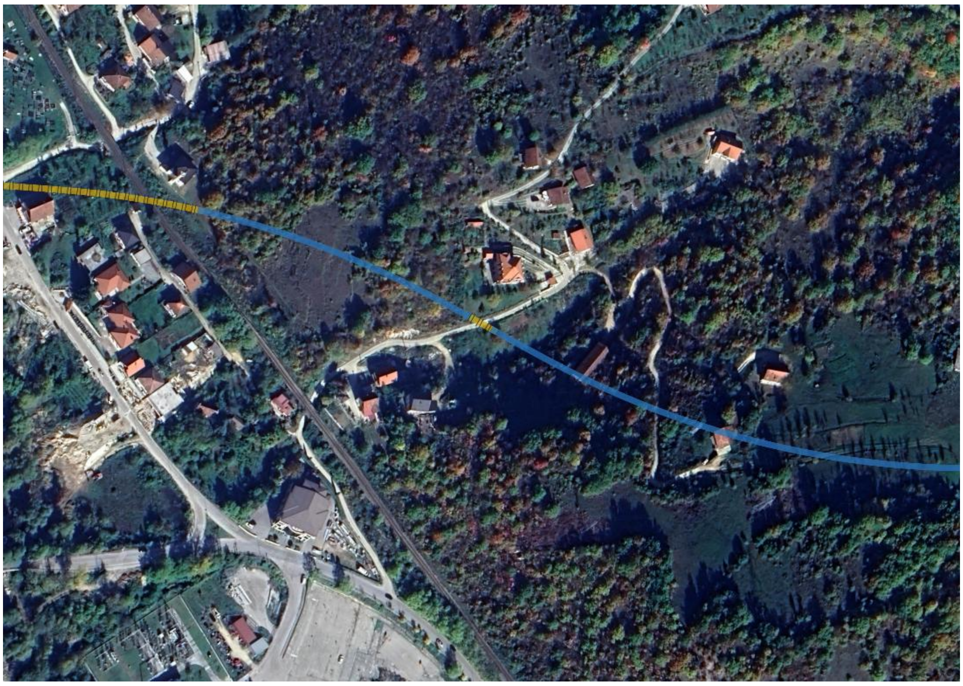

Figure 12-39: Vibration hot-spot #8 – Viaduct in 'Konjic Bypass' ~0+760

Figure 12-40: Vibration hot-spot #9 – bridge in 'Konjic Bypass' ~0+420

12.3.3 Assessment of Vibration Impacts

The methodology for assessing vibrations in nearby dwellings and other sensitive buildings during construction works was analysed in Chapter 12.3.2 and it is the outcome of the formula $L_v = L_f + TF + C_{build}$. The input data in the formula derive from the machinery vibration emissions (Chapter 12.3.2.2), from the in situ vibration measurements of ground response (Chapter 12.2) and from the soil-structure-interaction (SSI) and the vibration damping inside buildings (Chapter 12.3.2.4). The results are summarised below, compared to the 10 mm/s limit[10].

Table 12-13: Estimates of vibration levels inside buildings for the 8 measurement sites

Pos	Machinery	ppv at 5m [mm/s]	ppv at 10m [mm/s]	ppv at 20m [mm/s]	ppv at 40m [mm/s]
VB1	pile driving	54.2982	29.9081	13.5814	2.0865
	drilling, etc.	26.0597	15.9781	7.0347	1.0288
VB2	pile driving	54.2982	24.2951	12.0265	6.7905
	drilling, etc.	26.0597	11.1951	4.5859	2.2911
VB3	pile driving	54.2982	27.7777	9.0140	3.5910
	drilling, etc.	26.0597	13.5771	4.7475	1.7532
VB4	pile driving	54.2982	16.0527	4.4029	1.2647
	drilling, etc.	26.0597	7.8650	1.7665	0.4690

[10] the ppv ≤ 10 mm/s limit is a conservative value for structural damages although vibration inside buildings during certain works will be perceived. However, do to the short-term and the intermittent nature of the project, it is not expected to generate broad annoyance.

Pos	Machinery	ppv at 5m [mm/s]	ppv at 10m [mm/s]	ppv at 20m [mm/s]	ppv at 40m [mm/s]
VB5	pile driving	54.2982	24.6917	11.0140	3.2404
	drilling, etc.	26.0597	12.6539	5.0611	1.3338
VB6	pile driving	54.2982	25.1679	8.4106	4.0751
	drilling, etc.	26.0597	11.9604	3.9294	1.5852
VB7	pile driving	54.2982	20.2966	5.1334	1.7296
	drilling, etc.	26.0597	9.8680	2.4206	0.6873
VB8	pile driving	54.2982	18.6524	6.5257	1.9467
	drilling, etc.	26.0597	9.3248	2.7507	0.7425
VB9	pile driving	54.2982	24.4838	8.6820	3.5221
	drilling, etc.	26.0597	12.1968	3.8482	1.3950
VB10	pile driving	54.2982	21.9790	6.5232	2.6444
	drilling, etc.	26.0597	10.4977	3.0606	1.0387
VB11	pile driving	54.2982	19.3101	5.4565	1.7918
	drilling, etc.	26.0597	9.5429	2.3872	0.6883
VB12	pile driving	54.2982	21.0030	7.4652	2.5842
	drilling, etc.	26.0597	10.4531	3.2217	0.9950

Based on the above results, Table 12-14 presents the recommending safety distances for tunnel drilling and bridge foundations in the identified vibration hot-spots.

Table 12-14: Recommended safety distances for nearby buildings and structures

Location	Recommended safety distances for nearby buildings and structures
Viaduct 2	Pile-driving ≥ 29m Drilling and other construction activities ≥ 17m
Tunnel 1	Pile-driving ≥ 29m Drilling and other construction activities ≥ 17m
Viaduct 3	Pile-driving ≥ 28m Drilling and other construction activities ≥ 14m
Bridge south of Konjic South I/C	Pile-driving ≥ 20m Drilling and other construction activities ≥ 15m
Viaduct 9	Pile-driving ≥ 28m Drilling and other construction activities ≥ 17m
Viaduct 10	Pile-driving ≥ 23m Drilling and other construction activities ≥ 16m

Location	Recommended safety distances for nearby buildings and structures
Bridge at east access road to Konjic North I/C	Pile-driving ≥ 16m Drilling and other construction activities ≥ 10m
Bridge in Konjic Bypass at 0+420	Pile-driving ≥ 22m Drilling and other construction activities ≥ 15m
Bridge in Konjic Bypass at 0+760	Pile-driving ≥ 22m Drilling and other construction activities ≥ 15m

Finally, regarding the phase of soil compaction, which will take place in all places of the project, it is suggested that no heavy-duty vibrator rollers are used in a distance closer than 17 m from any sensitive receiver. For these regions other soil compacting methods must be used.

Note: Existing vibration levels, mainly road traffic, has negligible impact on vibrations. Hence a cumulative vibration model from traffic on the road network and/or other activities is not considered.

Table 12-15 below provides a summary of vibration impacts and assessment of their significance.

Table 12-15: Summary of potential vibration impacts and assessment of their significance before mitigation

Phase	Type of potential impact	Adverse/ Beneficial	Magnitude	Sensitivity	Impact evaluation	Significance (before mitigation)
Vibration						
Pre-construction	No impacts	-	-	-	-	-
Construction	Structural damage from vibration caused by equipment and operation methods employed including use of explosives	Adverse	Moderate	Medium	**Moderate**	**Significant**
Operation	No impacts	-	-	-	-	-

12.4 Mitigation and Enhancement Measures

In the previous chapter, the assessment of the expected vibration levels during construction was analysed for various phases and locations of the project. There are three operations that have been identified to be candidates for increased vibrations above the specified limits, leading to broad annoyance and complaints of the local community: pile-driving works, drilling and excavation works and usage of heavy vibrator rollers for soil compaction.

Recommended safety distances are between 16m and 29m for pile-driving, between 10m to 17m for drilling and 17m for operation of heavy-duty vibrator rollers. Detailed safety distances are given in Table 12-14.

If sensitive receivers are acknowledged within the safety zone buffers, then other methods of construction should be used, such as low vibration sonic pile-drivers or pre-digging holes for piles, less powerful excavation machinery, compacting rollers without vibration, etc.

In case of usage of explosives for the tunnel mining, the same limit of 10 mm/s peak particle velocity applies to nearby sensitive receivers. The tunnels that do have sensitive receivers in close range are: T1, T2 and T5. The contractor shall deliver, prior to construction, a detailed study that accounts for the soil in each area of interest and the explosive charges he is planning to use. Controlled explosions should also take place prior to construction, as a test to validate the study's forecasts for the vibration levels to the receivers.

In any case, continuous vibration monitoring during construction works involving the above operations is highly recommended, as well as a detailed pre- and post-construction condition assessment and crack survey for any existing structures in a distance up to 40m from the relevant works.

It is also very important, in order to avoid complaints, to communicate properly with those affected. Before carrying out any inevitable activities that produce vibrations near receivers that are sensitive to noise and vibration, they should be informed in advance of the tasks to be performed, and of the expected duration.

All machinery and equipment must be maintained at high levels of optimum operation. Machinery and operational equipment (including excavators, crushers, loading/unloading, generators, concrete plants, etc.) will be placed as far away from noise and vibration-sensitive areas as possible.

At the same time, activity planning will be designed to avoid the effects, e.g., avoiding the simultaneous use/operation of equipment that produces vibrations and not using it during quiet hours.

The choice of equipment will consider the vibration level. Where possible, electrical equipment will be used instead of diesel or petrol engine equipment and must comply with European Directive 2000/14/EC on project machinery noise. Regular maintenance of equipment and vehicles is recommended in accordance with manufacturers' recommendations. Any broken parts should be replaced immediately.

In the event of any complaint, the source of the excessive vibration will be identified and measures such as the location of the equipment and the operating hours will be assessed.

It goes without saying that there will be a regular check that all installations, machinery, and vehicles are operated efficiently and according to the specifications of manufacturers, by trained and qualified operators. In addition to increased safety, this process also affects the proper maintenance and as quiet operation of the machinery as possible.

In case the safety buffers are kept, the vibrations emitted during the construction stage will not cause permanent nuisance conditions. The conditions that will be created will be short-term and reversible.