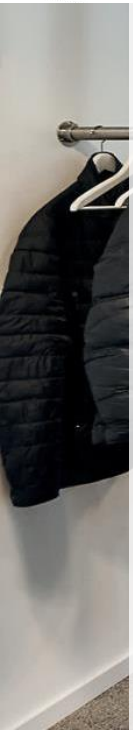
Ground Borne Noise and Vibration Reduction in Urban Areas

6th Railway Talk
5 June 2024, 17:00-18:00 (CET)
Günther Achs FCP . Managing Partner

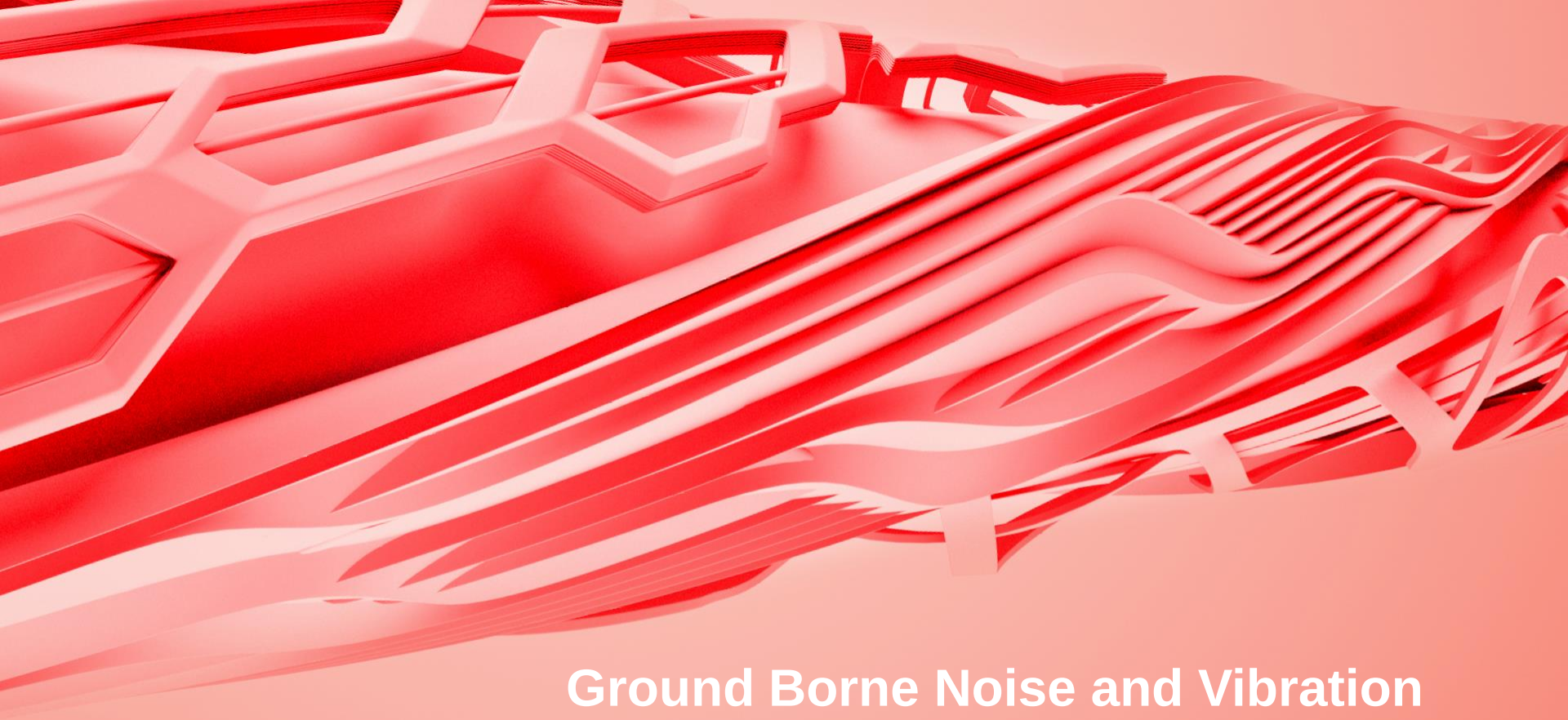
FCP is an internationally active engineering office with more than 350 staff members, its headquarters in Vienna and several branch offices abroad.



Fields of Activity of **FCP**:

- Bridge Engineering
- Structural Design – Buildings
- Industrial & Plant Construction
- Civil Engineering & Tunnelling
- General Consultant & Project Management
- Technical and Financial Control
- Site Supervision
- Health & Safety Engineering
- Traffic Design
- Track Design
- Structural Health Monitoring (BRIMOS®)
- Environmental Sustainability – Carbon Footprint
- LCM Life Cycle Management
- Accredited & Notified Body (BCT)
- CSM Risk Management
- Plant Data Management
- Digital Engineering . BIM
- Noise and Vibration Assessment
- Environmental Protection
- Acoustics
- Research & Development

Company Presentation FCP



Ground Borne Noise and Vibration Prediction Methodology

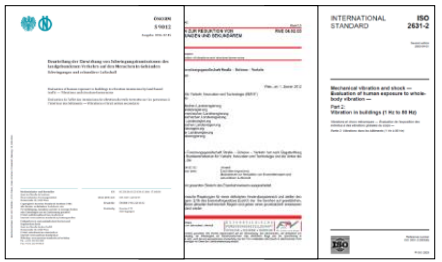
Ground Borne Noise and Vibration Assessment

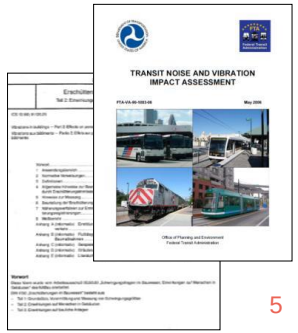
Why?

- Avoid annoyance of residents due to noise & vibration impacts in urban areas
- Protection of sensitive receptors (e.g. sensitive equipment of hospitals, labs, …)
- Protection of cultural heritage and monuments
- Increase the acceptance of public transport, particularly in urban areas

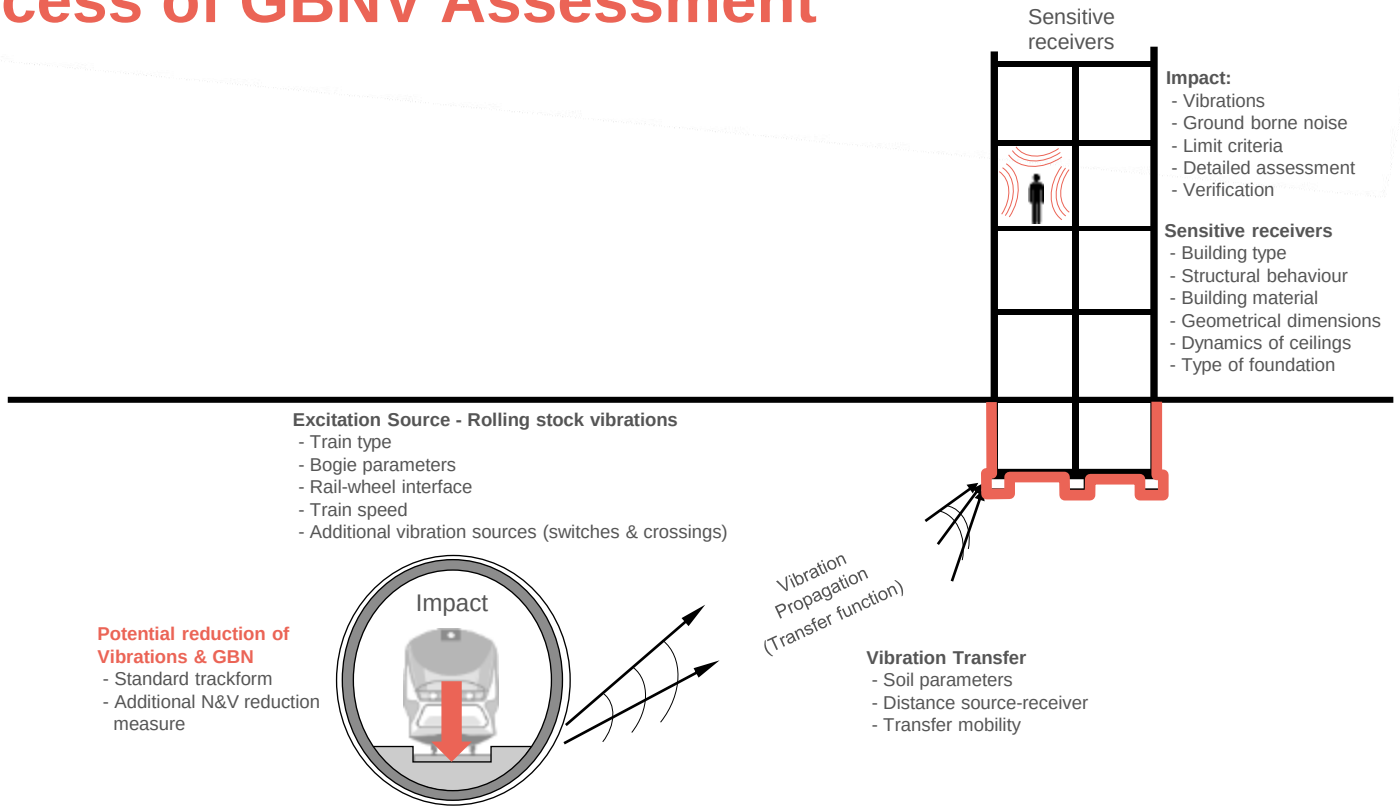
How?

- Definition of the limit criteria (Human perception in buildings, Historic objects, Sensitive equipment
- Assessment and evaluation of the future noise and vibration impact
- Selection of suitable mitigation measures
- Dynamic design
- Verification of the effectiveness





Process of GBNV Assessment



Basic requirements for reliable N&V Assessment

- Accepted methodology (e.g. international methodology according to FTA)
- Consideration of sensitive receivers, including their structural dynamics, vibration behaviour and building use
- Vibration emission (source) and vibration transfer needs to be determined according to the local conditions (measurements or reliable simulations)
- Noise and Vibration prediction needs to be performed in frequency domain (single value prediction is not sufficient to select mitigation measures properly)
- Mitigation measures to be selected according to the results for each relevant sensitive receiver > section-wise selection of optimized mitigation measures
- Method and each step of prediction needs to be comprehensible

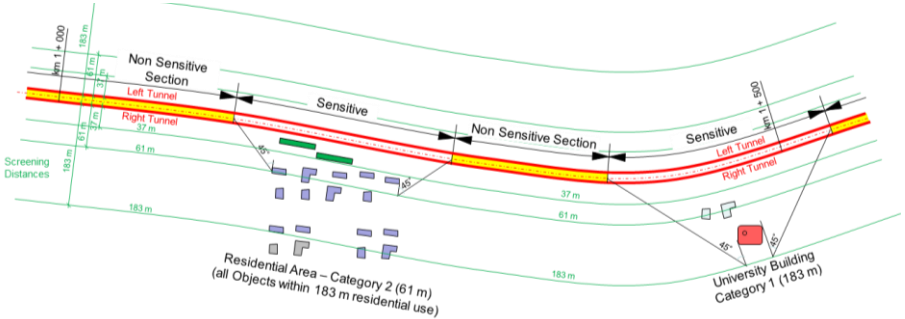
Process of GBNV Assessment

Methodology according to FTA

1. **Early Identification of Sections without mitigation measures**
2. **Determination of Sensitive Receivers**
   - Residential buildings
   - Hospitals, schools, historic monuments
3. **Measurements of vibration emission of the excitation source**
   - Train emission data (Source spectra)
4. **Vibration transmission through track system, tunnel and soil/rock**
   - Clustering / sectioning
   - Evaluation of subsoil parameters
   - Numerical Simulations to assess vibration transfer
5. **Vibration transmission through the buildings along the track**
   - Structural / dynamic parameters of sensitive buildings (Transfer of Vibrations inside buildings)
   - Hospitals, schools, historic monuments
   - Collection of building parameters on site
6. **Prediction and verification of ground borne noise and vibration limits in the buildings**
   - Operational data, track alignment (e.g. turnout locations)
   - Verification of limit criteria for each sensitive receiver
7. **Selection and extent of mitigation measures**
   - Design of mitigation measures (structural & dynamic design, insertion loss)
   - Definition of mitigation lengths
   - Design of transition zones between standard track and upgraded track

Sequences / Process of GBNV Assessment

1. Early Identification of Sections without mitigation measures

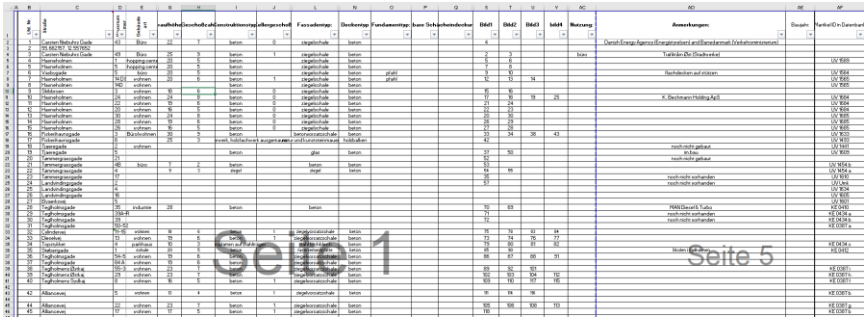


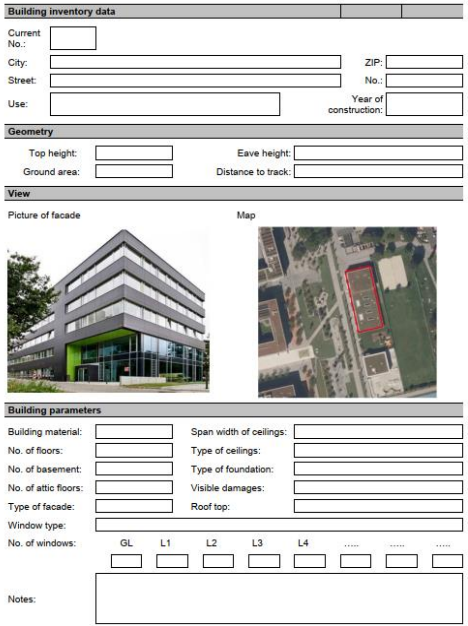
Sequences / Process of GBNV Assessment

2. Determination of sensitive receivers

Building survey

- Structural / dynamic parameters of sensitive buildings (Transfer of Vibrations inside buildings)
- Hospitals, schools, historic monuments
- Collection of building parameters on site
  - Building Material
  - Age of Building
  - Geometrical Dimension
  - Type of Ceilings (Wooden, Reinforce Concrete precast / cast in situ) and geometrical dimension
  - Type of Foundation
  - Number of floors / existence of basement
  - Photos (Façade, Outside, Inside)



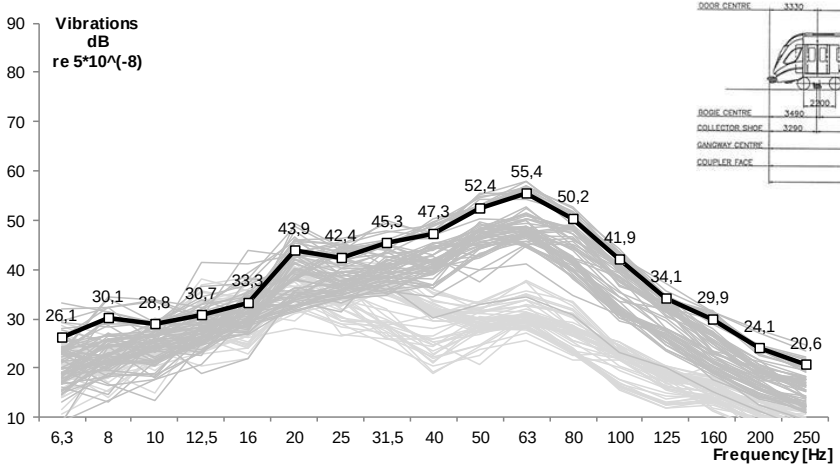


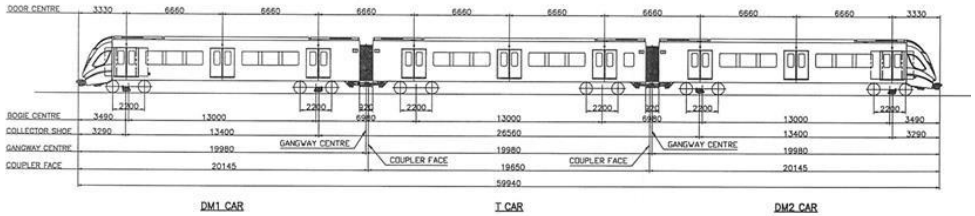
Sequences / Process of GBNV Assessment

3. Measurements of vibration emission of the excitation source

Train Emission Data

- Vibration measurements at real conditions on site – reliable measurements necessary
- Comparable train data including simulations





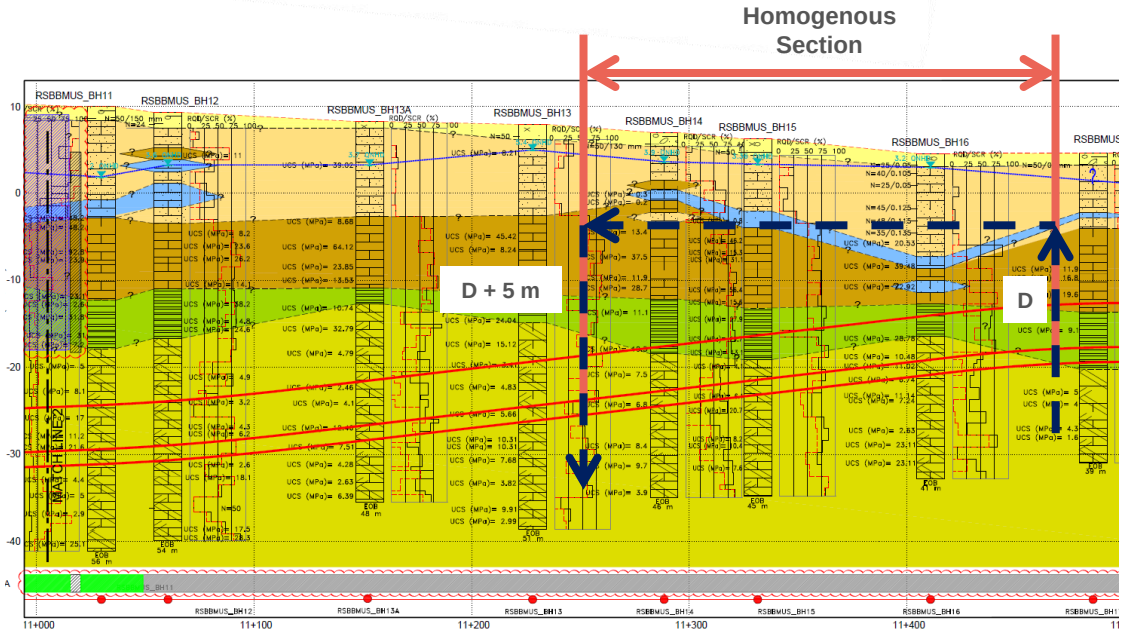
Variation of vibrations at tunnel wall for train pass by (95 % fractile)

Sequences / Process of GBNV Assessment

4. Geotechnical Assessment

Geotechnical clustering

- Soil layering
- Vertical alignment of tunnel sections
- Homogenous soil parameters

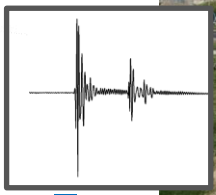


Sequences / Process of GBNV Assessment

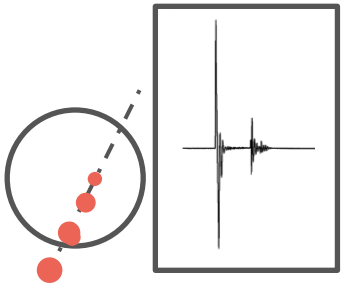
4. Vibration transfer through soil

Vibration transfer - Measurements

- Impacts in tunnel or on viaduct
- Simultaneous measurements of impact force and vibration response
- Transfer of impact points to a line source (acc. to rolling stock)



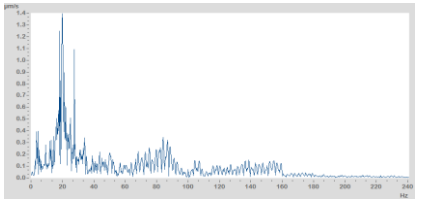
5 Receiver positions on surface perpendicular to tunnel axis



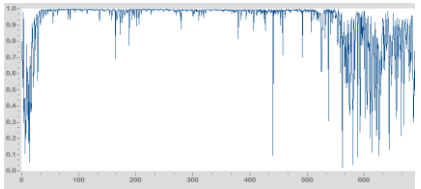
11 Impact positions along tunnel axis

Transfer Function

Point source transfer function (narrow band)



Point source coherence function



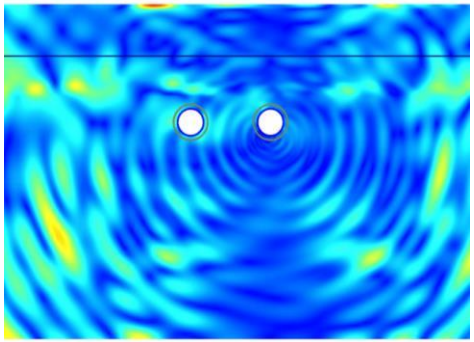
Sequences / Process of GBNV Assessment

4. Vibration transfer through soil

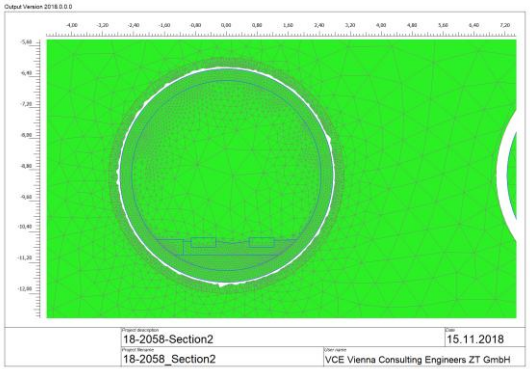
Vibration Transfer

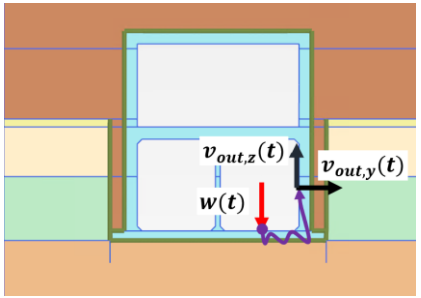
Numerical simulations

- Numerical simulations for every location to be investigated



$TF_{numerical\ simulation}$



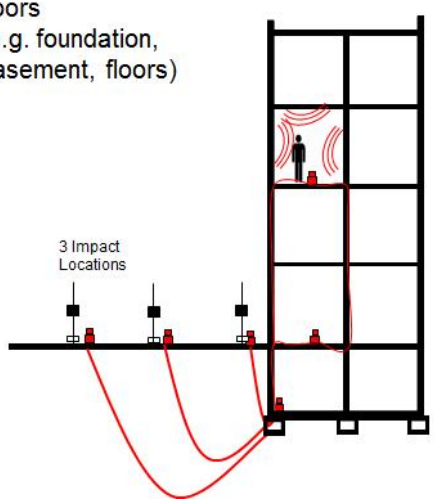


Sequences / Process of GBNV Assessment

5. Vibration transfer through buildings

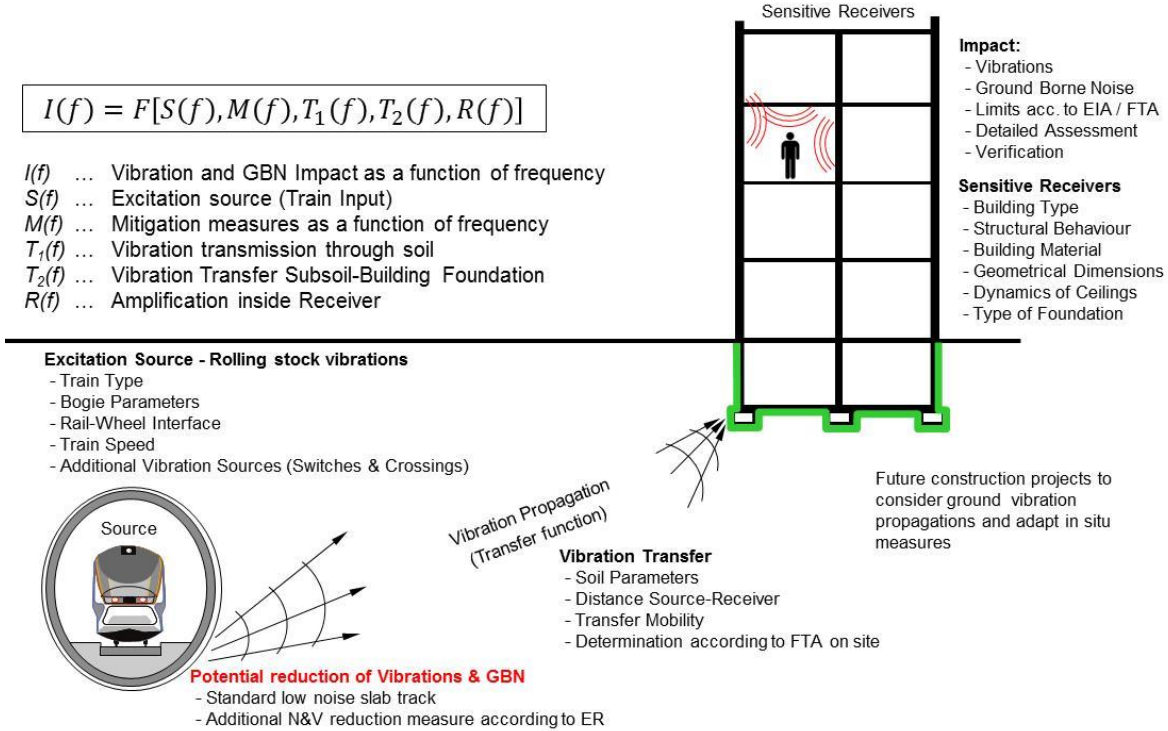
Structural / dynamic parameters of sensitive buildings
(Transfer of vibrations inside buildings)

- 7 categories representing most of the building types
- Buildings within influence zone of metro lines
- Impacts set outside the building
- Receivers next to the building and on floors
  (e.g. foundation, basement, floors)



Sequences / Process of GBNV Assessment

6. Prediction and verification of GBNV limits in the buildings



Sequences / Process of GBNV Assessment

6. Prediction and verification of GBNV limits in the buildings

Verification of every sensitive object (noise and vibration limit criteria)

RED LINE — Left Track — Sensitive Receiver (SR)

No	Section	Geological Section Type	Bottom Tunnel Depth [m]	Ch. Start	Ch. End	Section Length [m]	SR-ID	Use	Horizontal Distance SR to track [m]	Tunnel depth at SR [m]	Slant Distance to SR [m]	Building Category	Land Use Category	Switch	Distance-Level Reduction [dB re 5x10^(-8)]	Limit Lv [dB re 5x10^(-8)]	Limit LA [dBA]
1	No HMSS			-12-842	-12-289	553											
2	RS-AP-TO			-12-289	-12-084	205		no building						yes			
3	No HMSS			-12-084	-6-981	5103											
4	RS-00-TO	SL	19	-6-981	-6-927	54	RS-00-a	Commercial	100	20.4	102	CAT C	Cat 3	yes	16.1	69.1	40.0
5	No HMSS			-6-927	-5-813	1114											
6	RS-01 TO	SL	21	-5-813	-5-663	150	RS-01-a	Commercial	94	18.7	96	CAT C	Cat 3	yes	16.1	69.1	40.0
7	RS-01	SL	21	-5-663	-5-548	115	RS-01-b	Commercial	0	21.4	21	CAT A	Cat 3		0.0	69.1	40.0
8	RS-02	SL_MS	26	-5-548	-5-250	298		no building									
9	RS-03	MS_RUS	29	-5-250	-4-255	995	RS-03	Office	0	28.7	29	CAT A	Cat 3		0.0	69.1	40.0
10	RS-03	MS_RUS	29	-5-250	-4-255	995	RS-04	Commercial	1	26.6	27	CAT F	Cat 3		0.0	69.1	40.0
11	RS-04	SL_MS	25	-4-255	-4-124	131	RS-04	Commercial	0	26.6	27	CAT F	Cat 3		0.0	69.1	40.0
12	No HMSS			-4-124	-3-668	456											
13	RS-05	MS_RUS	30	-3-668	-3-455	213	RS-05	Commercial	0	28.4	28	CAT D	Cat 3		0.0	69.1	40.0
14	RS-06	SL_MS	22	-3-455	-3-069	386	RS-06	Residential	0	22.1	22	CAT C	Cat 2		0.0	66.0	35.0
15	No HMSS			-3-069	-2-876	193											
16	RS-07-TO	SL	18	-2-876	-2-726	150	RS-07-a	Commercial	116	17.1	117	CAT D	Cat 3	yes	21.4	69.1	40.0
17	No HMSS			-2-726	-2-530	196											
18	RS-07	SL	19	-2-530	-1-691	839	RS-07-b	Commercial	32	19.7	38	CAT E	Cat 3		0.0	69.1	40.0
19	RS-07	SL	22	-2-530	-1-691	839	RS-07-c	Commercial	12	22	25	CAT E	Cat 3		0.0	69.1	40.0
20	RS-08	MS_RUS	23	-1-691	-1-345	346	RS-08	Residential	0	22.9	23	CAT C	Cat 2		0.0	66.0	35.0
21	RS-09	MS_RUS	26	-1-345	-1-005	340	RS-09-a	Residential	0	25.9	26	CAT C	Cat 2		0.0	66.0	35.0
22	RS-09	MS_RUS	26	-1-345	-1-005	340	RS-09-b	Institutional	6	32.3	33	CAT G	Cat 3		0.0	69.1	40.0
23	RS-10	MS_RUS	27	-1-005	-0-076	929	RS-10	Residential	20	29.1	35	CAT C	Cat 2		0.0	66.0	35.0
24	Msheireb			-0-076	0+218	294											
25	RN-01	MS_RUS	29	0+218	0+466	248	RN-01	Residential	0	27.2	27	CAT D	Cat 2		0.0	66.0	35.0
26	RN-02	MS_RUS	32	0+466	1+161	695	RN-02-a	Residential	0	32.6	33	CAT D	Cat 2		0.0	66.0	35.0
27	RN-02	MS_RUS	32	0+466	1+161	695	RN-02-b	Residential	60	26.9	66	CAT A	Cat 2		3.5	66.0	35.0
28	RN-02-TO	MS_RUS	31	1+161	1+313	152	RN-02-b	Residential	142	26.9	145	CAT A	Cat 2	yes	17.6	66.0	35.0
29	RN-02	MS_RUS	32	1+313	1+465	152		no building									
31	RN-03		31	1+465	1+597	132		no building									
32	No HMSS			1+597	2+210	613				30.2	30						
33	RN-04	MS_RUS	25	2+210	2+331	121	RN-04	Institutional	15	25.3	29	CAT G	Cat 3		0.0	69.1	40.0
34	No HMSS			2+331	2+597	266											
35	RN-05	SL	22	2+597	2+918	321	RN-05-a	Institutional	72	22.2	75	CAT F	Cat 3		10.8	69.1	40.0
36	RN-05	SL	22	2+597	2+918	321	RN-05-b	Institutional	37	22.2	43	CAT F	Cat 3		0.0	69.1	40.0
37	RN-05-TO	SL	17	2+918	3+070	152	RN-05-b	Institutional	128	22.2	130	CAT F	Cat 3	yes	24.0	69.1	40.0
38	No HMSS			3+070	3+281	211									0.0		
39	RN-06	SL_MS	28	3+281	3+466	185	RN-06	Commercial	103	30.6	107	CAT F	Cat 3		8.7	69.1	40.0
40	RN-07	MS_RUS	30	3+466	3+680	214	RN-06	Commercial	131	30.6	135	CAT F	Cat 3		15.8	69.1	40.0
41	No HMSS			3+680	3+748	68											
42	RN-08	SL	21	3+748	4+140	392	RN-08	Institutional	29	29.3	41	CAT E	Cat 3		0.0	69.1	40.0
43	RN-09	MS_RUS	31	4+140	4+649	509	RN-09	Office	20	28.2	35	CAT D	Cat 3		0.0	69.1	40.0
44	RN-10	SL_MS	26	4+649	5+024	375	RN-10	Office	30	27	40	CAT E	Cat 3		0.0	69.1	40.0
45	RN-11	SL	22	5+024	6+200	1176	RN-11-a	Office	40	19.4	44	CAT E	Cat 3		0.0	69.1	40.0
46	RN-11	SL	22	5+024	6+200	1176	RN-11-b	Residential	35	22.2	41	CAT E	Cat 2		0.0	66.0	35.0
47	RN-11	SL	24	5+024	6+200	1176	RN-11-c	Office	82	23	85	CAT E	Cat 3		13.5	69.1	40.0
48	RN-11	SL	24	5+024	6+200	1176	RN-12-a	Residential	23	23.8	33	CAT B	Cat 2		0.0	66.0	35.0
49	RN-12	SL_MS	24	6+200	6+630	430	RN-12-a	Residential	23	23.8	33	CAT B	Cat 2		0.0	66.0	35.0
50	RN-12	SL_MS	24	6+200	6+630	430	RN-12-b	Residential	120	24.7	123	CAT B	Cat 2		9.9	66.0	35.0
51	RN-12	SL_MS	24	6+200	6+630	430	RN-12-c	Residential	49	24	55	CAT B	Cat 2		2.6	66.0	35.0
52	No HMSS			6+630	6+996	366									0.0		
53	RN-13	SL_MS	23	6+996	7+839	843	RN-13	Residential	112	22.7	114	CAT B	Cat 2		8.7	66.0	35.0
54	No HMSS			7+839	8+420	581											
55	RN-14-TO	SL	18	8+420	8+572	152	RN-14	Office	88	16.7	90	CAT F	Cat 3	yes	13.5	69.1	40.0
56	No HMSS			8+572	11+599	3027											
57	RN-15	RUS	42	11+599	11+965	366	RN-15-a	Institutional	75	39.2	85	CAT G	Cat 3		8.3	69.1	40.0
58	RN-15	RUS	42	11+599	11+965	366	RN-15-b	Residential	38	41	56	CAT B	Cat 2		0.0	66.0	35.0
59	No HMSS			11+965	12+095	130											
60	RN-16	RUS	35	12+095	12+708	613	RN-16	Residential	0	35.5	36	CAT B	Cat 2		0.0	66.0	35.0
61	No HMSS			12+708	13+699	991											
	Total assessed track length (left track) [m]					26247											

VIBRATIONS — One third octave bands [Hz]

No	10	12	16	20	25	32	40	50	63	80	100	125	160	SUM Lv [dB re 5x10^(-8)]	Lv limit exceeded [dB re 5x10^(-8)]
4	50.5	54.7	55.9	44.8	33.7	26.5	23.0	17.6	25.5	24.5	18.4	20.5	16.0	59	-10
6	50.5	54.7	55.9	44.8	33.7	26.5	23.0	17.6	25.5	24.5	18.4	20.5	16.0	59	-10
7	46.7	53.8	53.6	50.0	45.7	41.3	37.6	38.8	31.0	24.1	26.2	28.0	18.9	58	-11
9	43.3	44.6	47.3	48.1	38.9	28.1	27.4	26.3	19.5	23.6	21.5	15.6	5.8	53	-17
10	49.6	54.8	61.4	61.4	48.8	31.6	33.2	33.7	23.8	19.9	16.1	8.4	-4.5	65	-4
11	55.2	65.9	72.0	67.1	52.5	38.4	39.6	41.9	36.2	26.1	34.9	28.8	13.5	74	5
13	48.5	48.3	56.6	68.0	55.7	41.0	32.5	21.1	19.2	25.2	21.4	15.6	10.0	69	0
14	59.9	64.3	67.6	55.5	38.0	31.5	27.5	23.9	34.2	38.0	36.6	34.7	26.1	70	4
16	41.3	46.4	50.2	56.9	47.7	38.8	27.3	18.2	15.3	11.1	10.8	12.6	7.8	59	-11
18	53.7	57.7	55.6	54.1	52.4	49.5	39.0	37.5	32.9	32.5	25.5	20.1	11.7	62	-7
19	53.7	57.7	55.6	54.1	52.4	54.1	45.0	38.7	35.6	32.5	26.8	21.2	14.7	63	-6
20	51.8	50.2	54.1	48.6	36.5	23.4	23.0	14.9	23.2	25.9	15.6	16.2	13.0	58	-8
21	52.3	51.2	55.9	49.9	36.5	23.4	23.0	15.2	23.3	26.5	17.7	18.2	13.0	59	-7
22	47.7	46.5	45.5	52.3	35.5	39.6	45.8	26.2	21.8	22.3	20.4	2.2	-9.9	56	-14
23	52.3	51.3	57.1	50.7	34.2	19.6	20.0	13.3	24.1	33.3	23.8	16.7	9.4	60	-6
25	48.5	48.3	56.6	68.0	55.7	41.0	32.5	21.1	19.2	25.2	21.4	15.6	10.0	69	3
26	48.5	48.3	56.6	68.0	55.7	41.0	32.5	21.1	19.2	25.2	21.4	15.6	10.0	69	3
27	39.8	41.0	43.8	44.6	35.4	24.6	23.9	22.8	16.0	20.1	17.9	12.0	2.2	49	-17
28	31.7	33.0	35.7	36.6	27.3	16.5	15.8	14.7	7.9	12.0	9.9	4.0	-5.8	41	-25
33	47.7	46.4	44.4	51.5	37.7	43.5	48.8	28.0	21.0	15.5	14.3	3.8	-6.3	56	-13
35	47.1	57.4	59.6	54.8	45.4	34.0	32.6	35.3	24.5	10.4	10.1	10.0	-2.2	63	-6
36	57.9	68.3	70.4	65.7	56.2	44.8	43.4	46.2	35.3	21.2	20.9	20.8	8.6	74	4
37	39.9	50.3	52.4	47.7	38.2	26.8	25.4	28.1	17.3	3.2	2.9	2.8	-9.4	56	-14
39	48.4	59.0	63.2	58.4	43.7	30.9	30.9	33.6	27.5	17.4	26.1	20.1	4.7	66	-3
40	33.8	39.0	45.6	45.5	33.0	15.8	17.4	17.8	8.0	4.0	0.3	-7.4	-20.3	49	-20
42	53.7	57.7	55.6	54.1	52.4	49.5	39.0	37.5	32.9	32.5	25.5	20.1	11.7	62	-7
43	48.5	48.3	56.6	68.0	55.7	41.0	32.5	21.1	19.2	25.2	21.4	15.6	10.0	69	0
44	51.0	55.4	57.1	55.5	48.6	47.7	41.2	34.5	36.5	37.4	40.8	29.2	19.5	62	-7
45	53.7	57.7	55.5	54.1	52.4	54.1	45.0	38.7	35.6	32.5	26.8	21.2	14.6	63	-6
46	53.7	57.7	55.6	54.1	52.4	49.5	36.9	34.5	31.4	32.5	25.5	20.1	11.7	62	-4
47	40.2	44.2	42.1	40.6	38.9	40.6	31.5	25.3	22.1	19.0	13.3	7.7	1.2	49	-20
48	59.6	64.7	63.1	61.6	53.5	41.1	32.4	40.4	32.1	20.8	11.8	19.4	-6.4	69	3
49	54.7	60.1	62.6	63.1	49.7	39.1	36.6	40.4	37.1	25.7	27.1	28.5	1.3	67	1
50	48.9	54.3	54.7	53.1	39.8	30.6	26.7	30.9	27.2	15.8	17.2	18.6	-8.6	59	-7
51	56.3	61.6	62.0	60.5	47.1	38.0	34.1	38.3	34.6	23.1	24.6	25.9	-1.3	67	1
53	50.1	55.5	55.9	54.3	41.0	31.8	27.9	32.1	28.4	17.0	18.4	19.7	-7.4	61	-5
55	50.4	60.8	62.9	58.2	48.7	37.3	35.9	38.7	27.8	13.7	13.4	13.3	1.1	66	-3
57	23.4	23.2	17.4	24.6	10.1	19.7	25.7	9.3	6.0	1.3	3.3	-6.6	-14.5	31	-38
58	29.9	30.2	32.2	37.9	26.8	17.0	14.8	18.4	13.5	2.4	-2.4	5.9	-17.0	40	-26
60	32.0	33.3	34.2	37.9	26.8	17.0	15.4	21.6	17.3	6.7	-0.4	5.9	-16.6	41	-25

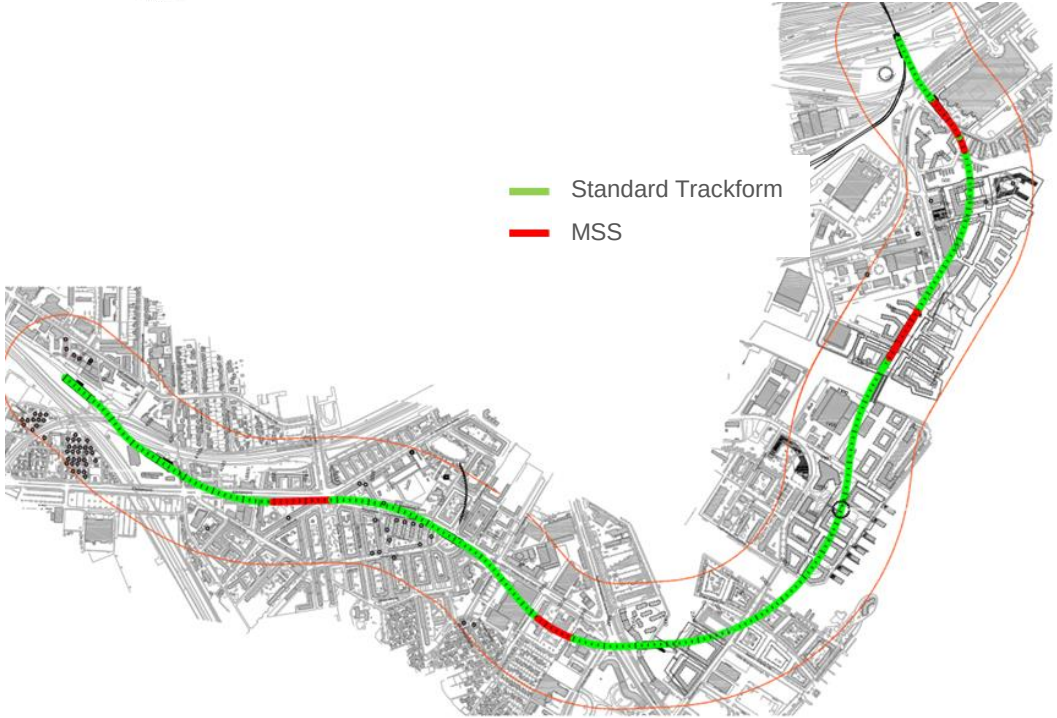
GROUND BORNE NOISE — One third octave bands [Hz]

No	10	12	16	20	25	32	40	50	63	80	100	125	160	SUM LA [dBA]	LA limit exceeded [dBA]	Length of sections with required measures [m]
4	-14.0	-4.1	5.5	0.4	-5.1	-6.7	-5.5	-6.7	5.3	8.1	5.3	10.3	8.7	16	-24	
6	-14.0	-4.1	5.5	0.4	-5.1	-6.7	-5.5	-6.7	5.3	8.1	5.3	10.3	8.7	16	-24	
7	-17.8	-5.0	3.2	5.6	6.8	8.1	9.1	14.5	10.8	7.7	13.1	17.8	11.7	22	-18	
9	-21.1	-14.3	-3.1	3.8	0.1	-5.1	-1.1	2.0	-0.7	7.2	8.3	5.4	-1.5	14	-26	
10	-14.8	-4.0	11.0	17.0	10.0	-1.6	4.7	9.4	3.6	3.5	3.0	-1.8	-11.7	20	-20	
11	-9.2	7.1	21.6	22.7	13.6	5.2	11.1	17.6	16.0	9.7	21.7	18.7	6.2	28	-12	131
13	-16.0	-10.5	6.2	23.6	16.9	7.8	4.0	-3.2	-1.0	8.8	8.3	5.4	2.8	25	-15	
14	-4.5	5.5	17.2	11.1	-0.8	-1.7	-1.1	-0.3	13.9	21.6	23.5	24.5	18.8	29	-6	386
16	-23.1	-12.4	-0.2	12.5	8.9	5.6	-1.2	-6.1	-4.9	-5.3	-2.4	2.4	0.5	15	-25	
18	-10.8	-1.1	5.1	9.7	13.6	16.3	10.4	13.3	12.7	16.1	12.3	10.0	4.5	23	-17	
19	-10.8	-1.1	5.1	9.7	13.6	20.9	16.4	14.5	15.4	16.1	13.7	11.0	7.4	25	-15	
20	-12.7	-8.6	3.7	4.2	-2.3	-9.7	-5.6	-9.4	2.9	9.5	2.4	6.0	5.7	14	-21	
21	-12.1	-7.6	5.5	5.5	-2.3	-9.7	-5.6	-9.1	3.1	10.1	4.6	8.1	5.7	15	-20	
22	-16.7	-12.3	-4.9	7.9	-3.3	6.4	17.3	1.9	1.6	5.9	7.2	-7.9	-17.1	19	-21	
23	-12.1	-7.5	6.6	6.3	-4.6	-13.6	-8.5	-10.9	3.9	16.9	10.6	6.5	2.2	19	-16	
25	-16.0	-10.5	6.2	23.6	16.9	7.8	4.0	-3.2	-1.0	8.8	8.3	5.4	2.8	25	-10	248
26	-16.0	-10.5	6.2	23.6	16.9	7.8	4.0	-3.2	-1.0	8.8	8.3	5.4	2.8	25	-10	695
27	-24.6	-17.8	-6.6	0.2	-3.5	-8.6	-4.7	-1.5	-4.3	3.7	4.8	1.8	-5.0	10	-25	
28	-32.7	-25.8	-14.7	-7.8	-11.5	-16.7	-12.7	-9.6	-12.3	-4.4	-3.3	-6.2	-13.1	2	-33	
33	-16.7	-12.5	-6.0	7.1	-1.1	10.3	20.3	3.8	0.8	-0.9	1.2	-6.4	-13.6	21	-19	
35	-17.4	-1.4	9.2	10.5	6.6	0.8	4.0	11.1	4.3	-6.0	-3.1	-0.2	-9.4	17	-23	
36	-6.6	9.5	20.0	21.3	17.4	11.6	14.9	21.9	15.1	4.8	7.8	10.6	1.4	27	-13	321
37	-24.6	-8.6	2.0	3.3	-0.6	-6.4	-3.2	3.9	-2.9	-13.2	-10.2	-7.4	-16.6	9	-31	
39	-16.0	0.2	12.8	14.0	4.9	-2.3	2.3	9.3	7.2	1.0	13.0	9.9	-2.5	20	-20	
40	-30.7	-19.9	-4.8	1.1	-5.8	-17.4	-11.2	-6.5	-12.2	-12.4	-12.8	-17.6	-27.6	4	-36	
42	-10.8	-1.1	5.1	9.7	13.6	16.3	10.4	13.3	12.7	16.1	12.3	10.0	4.5	23	-17	
43	-16.0	-10.5	6.2	23.6	16.9	7.8	4.0	-3.2	-1.0	8.8	8.3	5.4	2.8	25	-15	
44	-13.4	-3.4	6.7	11.1	9.8	14.5	12.6	10.2	16.2	21.0	27.6	19.0	12.2	30	-10	
45	-10.8	-1.1	5.1	9.7	13.6	20.9	16.4	14.5	15.4	16.1	13.7	11.0	7.4	25	-15	
46	-10.8	-1.1	5.1	9.7	13.6	16.3	8.4	10.3	11.2	16.1	12.3	10.0	4.5	23	-12	
47	-24.3	-14.6	-8.4	-3.8	0.1	7.4	2.9	1.0	1.9	2.6	0.2	-2.5	-6.1	12	-28	
48	-4.8	5.9	12.6	17.2	14.7	7.9	3.8	16.2	11.9	4.4	-1.3	9.2	-13.7	23	-12	1176
49	-9.7	1.3	12.1	18.7	10.9	5.9	8.1	16.1	16.9	9.3	14.0	18.3	-5.9	25	-10	430
50	-15.5	-4.5	4.3	8.7	1.0	-2.6	-1.8	6.6	7.0	-0.6	4.1	8.4	-15.9	15	-20	
51	-8.2	2.8	11.6	16.1	8.3	4.8	5.5	14.0	14.3	6.7	11.4	15.7	-8.5	23	-12	430
53	-14.3	-3.3	5.4	9.9	2.2	-1.4	-0.6	7.8	8.2	0.6	5.3	9.6	-14.7	16	-19	
55	-14.0	2.0	12.5	13.8	9.9	4.1	7.4	14.4	7.6	-2.7	0.3	3.1	-6.1	20	-20	
57	-41.1	-35.6	-33.0	-19.8	-28.7	-13.5	-2.9	-15.0	-14.2	-15.1	-9.9	-16.8	-21.7	-1	-41	
58	-34.5	-28.6	-18.2	-6.5	-12.0	-16.2	-13.7	-5.9	-6.7	-14.0	-15.5	-4.2	-24.2	1	-34	
60	-32.4	-25.5	-16.2	-6.5	-12.0	-16.2	-13.2	-2.6	-2.9	-9.7	-13.6	-4.2	-23.8	3	-32	
	Total length of sections with required measures (left track) [m]															3387

*) Section of Red Line beside Msheireb station. Information about policy for future developments outstanding

Sequences / Process of GBNV Assessment

7. Selection and extent of mitigation measures



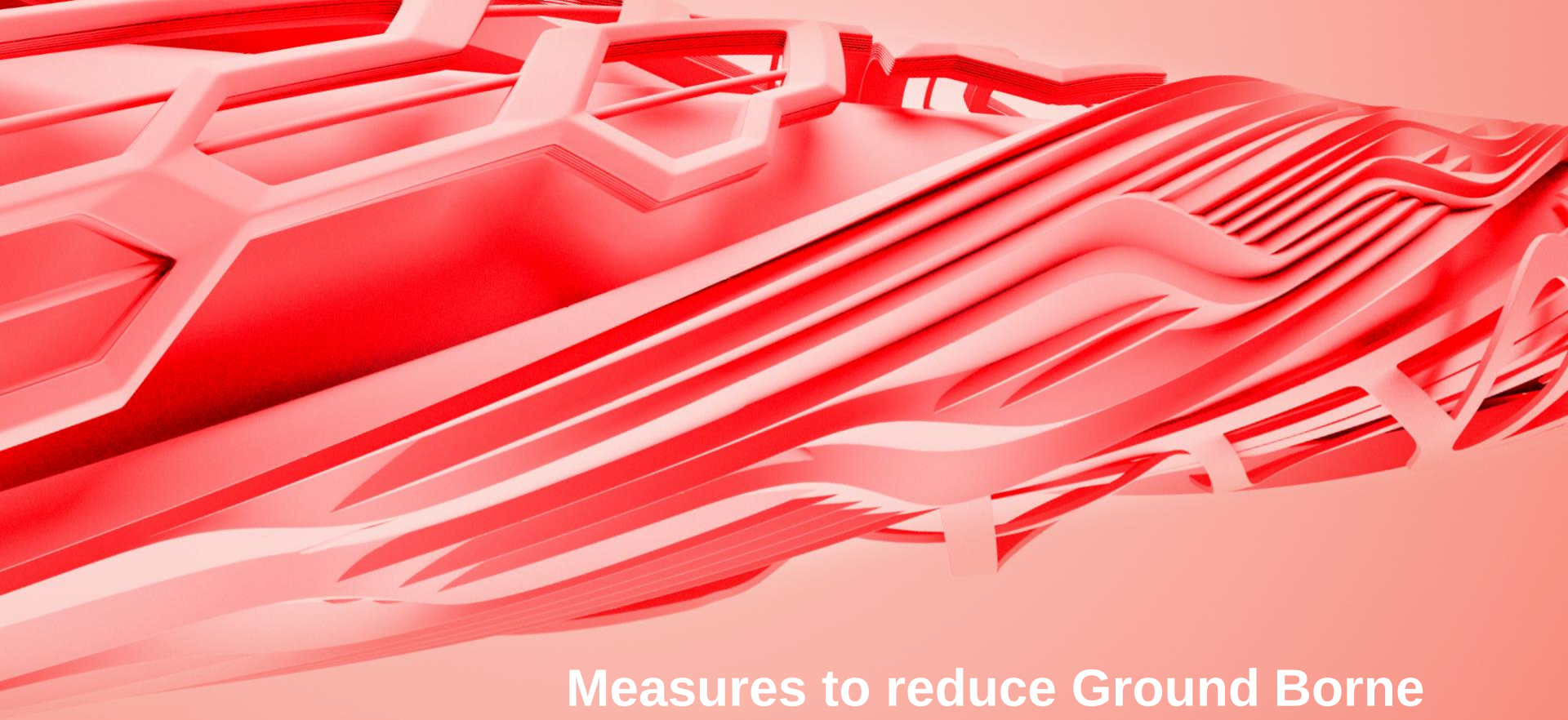
Sequences / Process of GBNV Assessment

Summary

Train emission	• **Measured data on comparable rolling stock** • Alternative: Adaption of existing data from comparable trains
+	
Insertion loss	• 2D 6DOF numerical model for theoretical determination (design assumption) • Verification with measurement-based determination on mock-ups
+	
Vibration transfer	• **Impact measurements according to FTA** • Alternative: Numerical simulations using FEM
+	
Coupling	• **Building measurements** • Validation with literature, data bases and previous projects
+	
Amplification	• **Building measurements** • Validation with literature, data bases and previous projects
+	
Safety factor	• Safety factor, tailored according to quality of input data

=

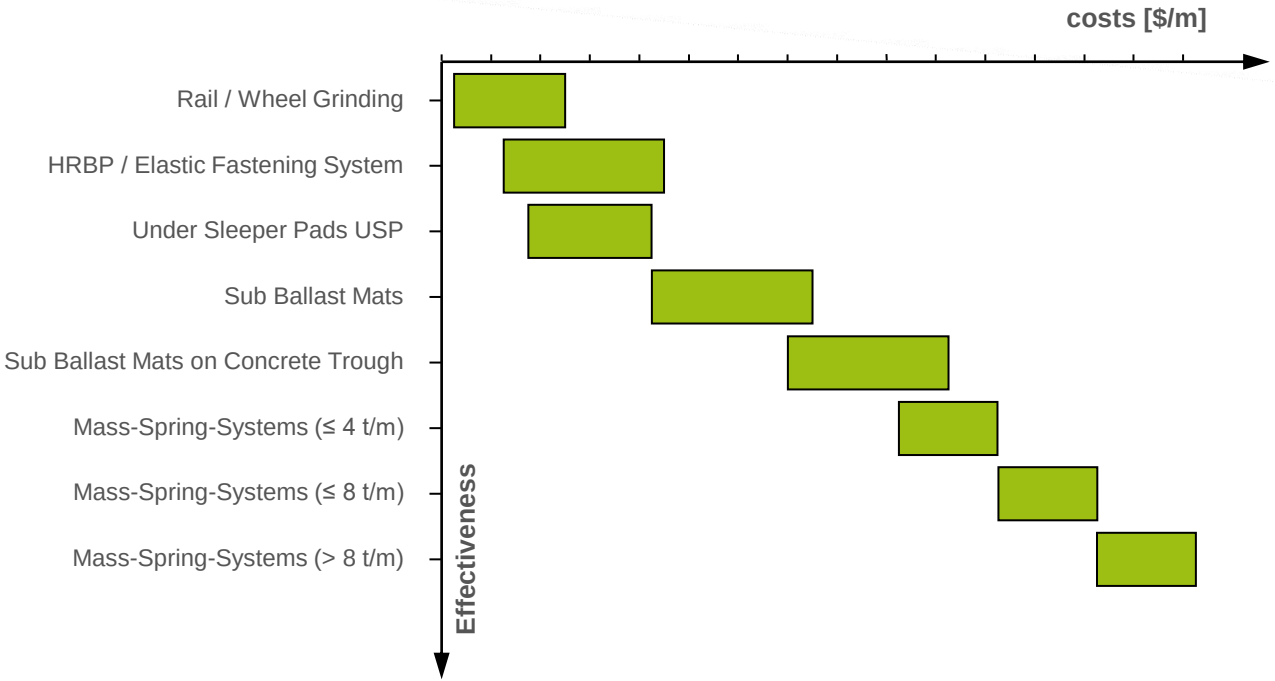
Ground-borne noise and vibration impact



Measures to reduce Ground Borne Noise and Vibration Impacts

Design of Vibration Mitigation Measures

Variety of mitigation systems



Design of Vibration Mitigation Measures

Dynamic and Structural Design Principles

Dynamic Design - Definition Insertion Loss

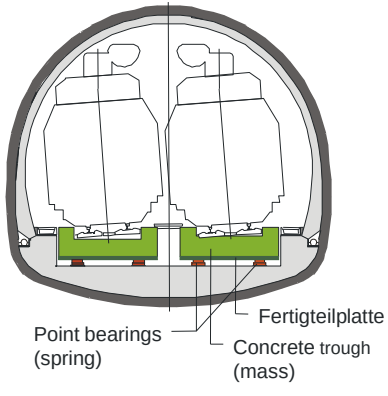
- **Definition of the necessary vibration reduction (“insertion loss”)**
  - Rolling stock, train speed, operation schedule
  - Track quality, safety margin
- **Design of a system to fulfil the requirements of the insertion loss (mass, spring, damper)**
- **Selection of a suitable elastic element**
- **Coordination with the structural design**

Structural Design

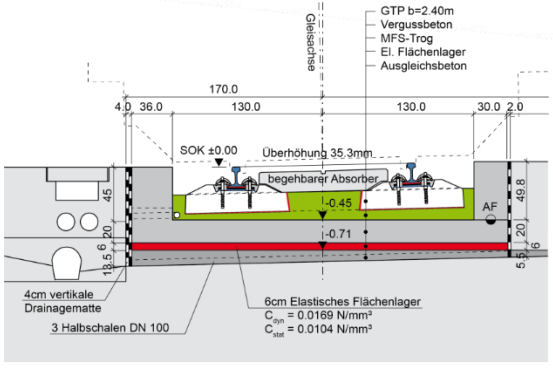
- **Available / required space**
  - Possible height of construction
  - Maintenance issues
- **Loads**
  - Vertical, Lateral, Temperature, etc.
- **Maximum tolerable deflections**
- **Vehicle dynamics**
  - Relative displacements
  - Transition zones
- **Subgrade**

Design Principles of Mass-Spring Systems (MSS)

MSS with Point Bearings

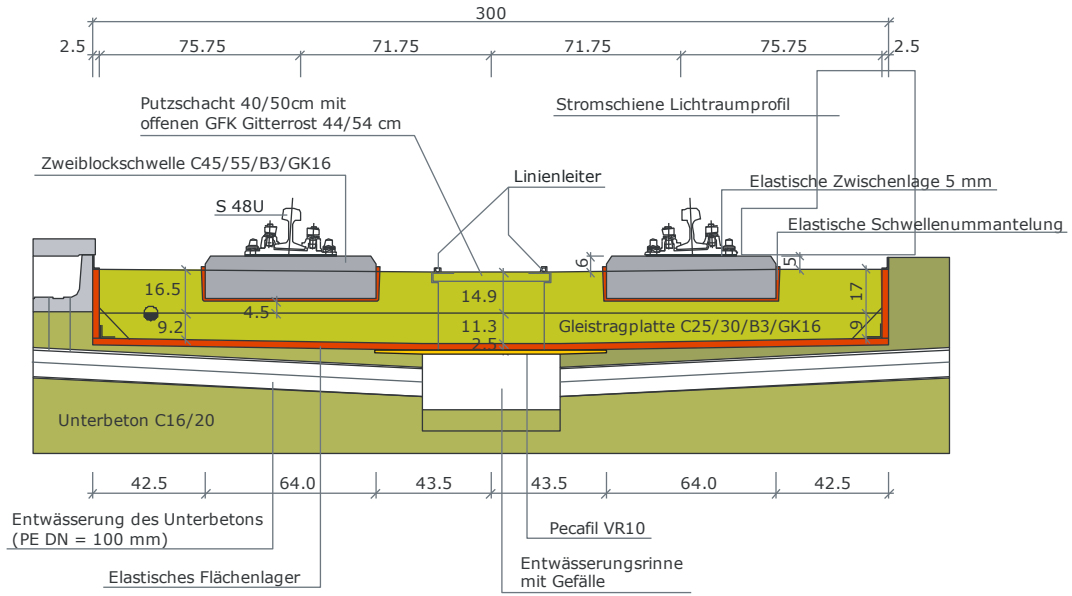


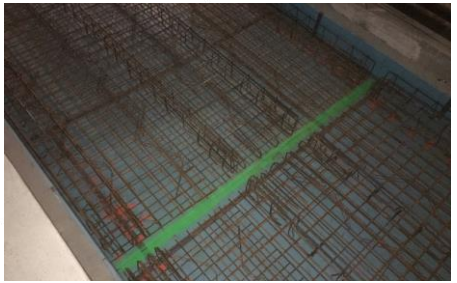
MSS with Full Surface Bearings

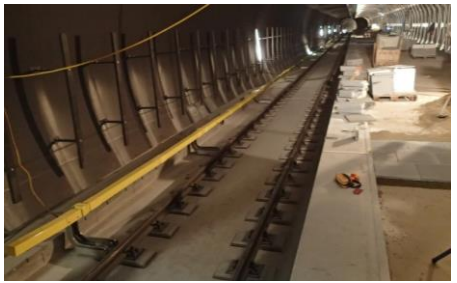


Vienna Urban Transport System / Metro

Mass-Spring-System with Full Surface Bearing f_0 = 21.0 Hz

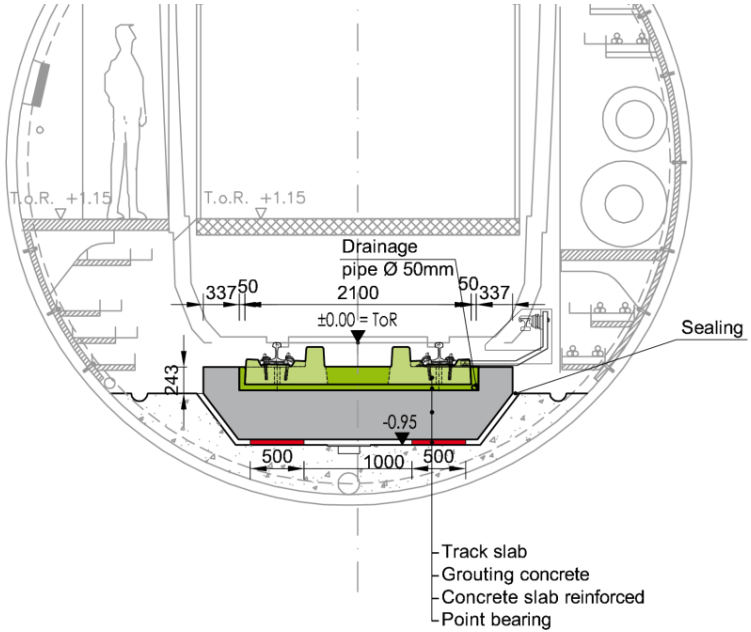


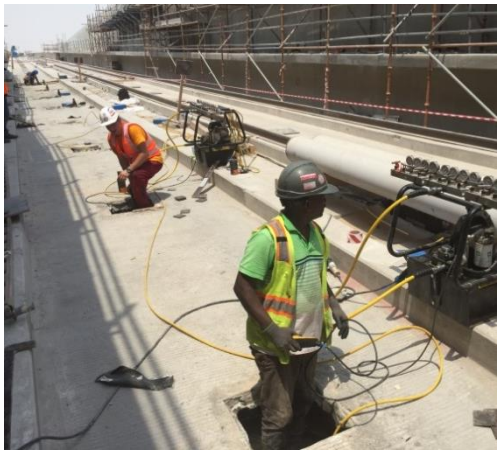




Metro Doha / Qatar

Mass-Spring-System with Point Bearings f_0 = 6.0 Hz





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Mass Spring Systems with Full Surface Bearing

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