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Acoustical performance of complex-shaped earth berms

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Earth berms have been used for many years along railways and motorways as noise abatement systems. On one hand their construction is often cheaper than traditional barriers with less negative environmental impacts and better visual integration. On the other hand they need more space to be built and are always proposed with the same global symmetrical, smooth shape. In this work we propose to assess the efficiency of various complex-shaped earth berms dedicated to ground transportation using a 2D Boundary Element Method. For urban roads and tramways innovative low-height berms - no more than 1 m high - are proposed and study. For railways and motorways taller complex-shaped systems up to 4 m high are assessed. The analysis is carried out for 1.5 m high receivers' areas (pedestrians, cyclists) as well as 4 m high ones (buildings). Results are expressed in terms of acoustic gain obtained with the complex-shaped earth berm solution referred to a straight rigid barrier located at the infrastructure's edge.

1 Introduction

The aim of this research is to achieve a parametric study of the acoustic performance of various complex-shaped earth berms as a function of both their geometry and the receivers' location. Different means of ground transportation are addressed here: road traffic in city centers or on motorways, trams, freight and high speed trains.

This work has been achieved in the frame of the European project HOSANNA [1] (Holistic and sustainable abatement of noise by optimized combinations of natural and artificial means) (www.greener-cities.eu).

2 Methodology

2.1 2D-BEM

MICADO, a 2D-BEM code developed at CSTB by Jean and presented elsewhere [2,3], is used here since it is well adapted to complex-shaped impedant geometries situations and as meteorological effects can be neglected for the short propagation. Calculations are performed on the frequency range 100 to 2500 Hz with 20 frequencies per octave band.

2.2 Noise sources description

For **road traffic noise in city centers** only cars are modeled using the *Harmonoise* model [4]. Equivalent point sources for rolling noise and engine noise are located in the middle of each lane at heights of 0.01 and 0.3 m, respectively. The width of the 2-lane infrastructure is 6 m (Figure 1)

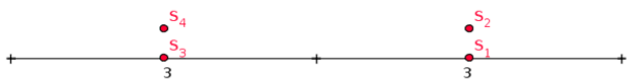


Figure 1: Geometry for the 2-lane city center street

In Figure 2 are shown the power spectra used for rolling noise and engine noise (car driving at 50 km/h).

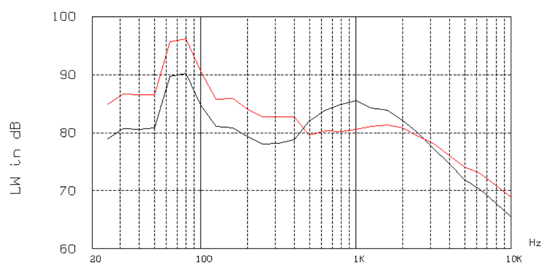


Figure 2: Power spectra for cars driving at 50 km/h. Rolling noise (black) and engine noise (red)

For **tramways** only rolling noise is modeled considering an equivalent source for each wheel at a height of 0.05 m with a distance of 1.50 m from each other, combined with the body of the tram (3.10 m high and 2.40 m wide). Each track is 2.75 m wide (Figure 3).

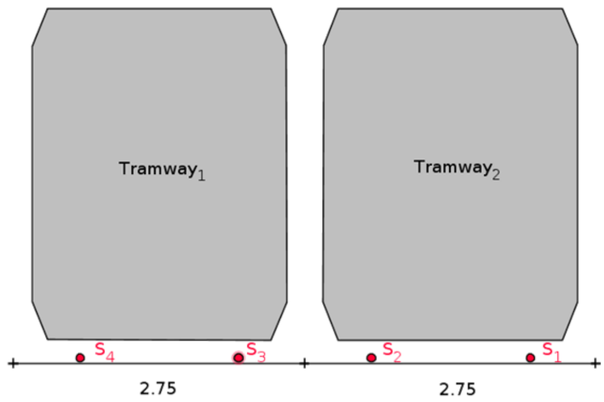


Figure 3: Geometry for the 2-lane tram infrastructure

In Figure 4 is shown the power spectrum used for the tram (running at 30 km/h).

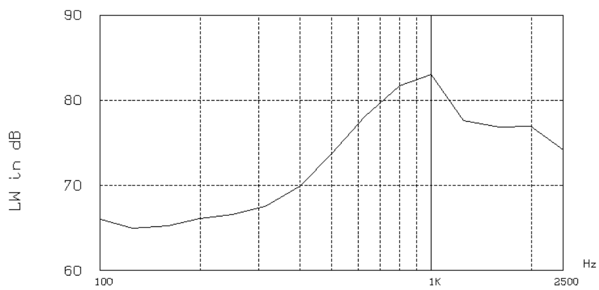


Figure 4: Power spectrum for the tram running at 30 km/h

For **road traffic noise along 4-lane motorways** both cars and lorries are modeled using the *Harmonoise* model [2]. For lorries equivalent point sources for rolling noise and engine noise are located in the middle of each lane at heights of 0.01 and 0.75 m, respectively. Each lane is 3.50 m wide (Figure 5)

Figure 5: Geometry for the 4-lane motorway

Power spectra used for cars (driving at 120 km/h) and lorries (driving at 90 km/h) are given in Figure 6. It is considered that the traffic is composed of 85% of cars and 15% of lorries.

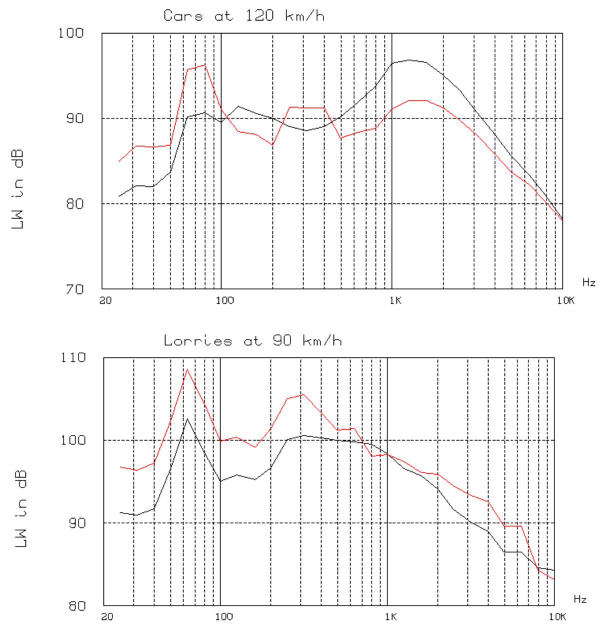


Figure 6: Power spectra for cars driving at 120 km/h (top) and lorries driving at 90 km/h (bottom). Rolling noise (black) and engine noise (red)

For **trains** only the rolling noise is modeled considering an equivalent source for each wheel at a height of 0.05 m above the ballast with a distance of 1.50 m from each other, combined with the body of the train (4 m high). The total width of the 2-track infrastructure is 9.50 with an embankment of 0.70 m above the ground (Figure 7).

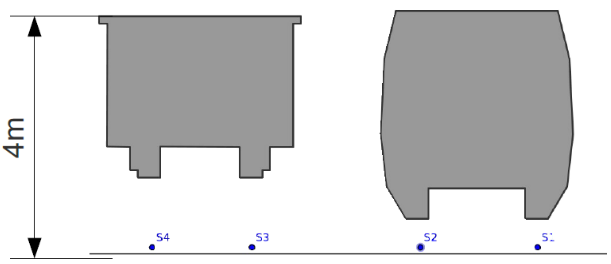
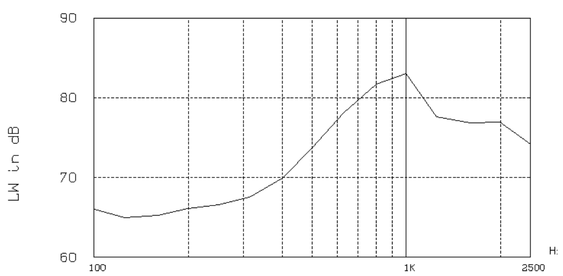


Figure 7: Geometry for the freight train (left) and high speed train (right)

Power spectra used for freight trains (running at 100 km/h) and high speed trains (running at 300 km/h) are given in Figure 8.



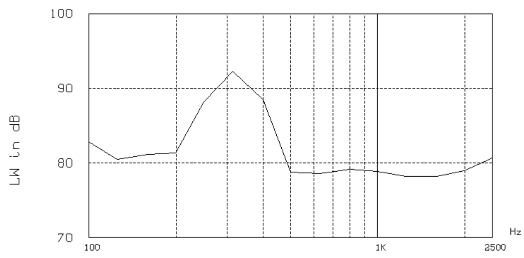


Figure 8: Power spectra for freight trains running at 100 km/h (top) and high speed trains at 300 km/h (bottom)

2.3 Acoustic impedances

The acoustic impedances are calculated using the slit-pore model [5] with the following parameters (σ flow resistivity, *h* porosity and *d* layer depth):

- Asphalt: σ=*70 kPa m s*$^{-2}$*, h=0.2, d=0.04 m*
- Earth: σ=*400 kPa m s*$^{-2}$*, h=0.7, d=*∞
- Train ballast: σ=*1 kPa m s*$^{-2}$*, h=0.2, d=0.3 m*

All other surfaces (trams and trains bodies, reference barrier) are considered to be rigid.

2.4 Definition of IL and ΔIL

The aim is to determine the acoustical efficiency of the studied earth berm by calculating its insertion loss IL referred to the IL of a reference case: a rigid straight barrier (0.10 m wide, same overall height) located at the edge of the transportation infrastructure (Figure 9).

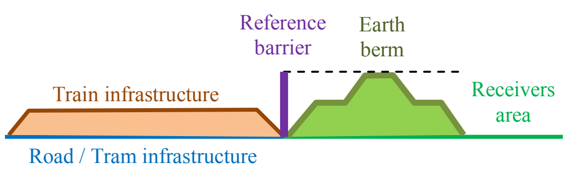


Figure 9: Definition of the reference barrier

For a given 3rd octave-band Δf, the insertion loss $IL(\Delta f)$ is given by:

$$IL(\Delta f) = 10\log_{10}\left|\frac{p_{no}(\Delta f)}{p_{prot}(\Delta f)}\right|^2 \quad (1)$$

where $p_{prot}(\Delta f)$ and $p_{no}(\Delta f)$ are the average acoustical pressures over Δf for the case with a noise protection (berm or reference barrier) and for the case with no noise protection, respectively.

The global insertion loss IL_A expressed in dB(A) is then given by the following equation:

$$IL_A = 10\log_{10}\left(\sum_{\Delta f} 10^{\frac{Lw_A(\Delta f)+EA_{no}(\Delta f)}{10}} \Big/ \sum_{\Delta f} 10^{\frac{Lw_A(\Delta f)+EA_{prot}(\Delta f)}{10}}\right) \quad (2)$$

where $EA_{prot}(\Delta f)$ and $EA_{no}(\Delta f)$ are the average excess attenuations over Δf for the case with a noise protection (berm or reference barrier) and for the case with no protection, respectively, $Lw_A(\Delta f)$ being the traffic noise power level for Δf.

The insertion loss difference ΔIL_A expressed in dB(A) is defined as the difference between the insertion loss obtained with the reference barrier and the one obtained with the studied berm:

$$\Delta IL_A = IL_A(prot = berm) - IL_A(prot = ref\ barrier) \quad (3)$$

It expresses the acoustical gain (positive value in that case) brought by the complex-shaped berm in comparison with a straight rigid barrier.

2.5 Receivers' zones

Four different 20 m long, 1 m high areas of receivers are studied as shown in Figure 10. In each zone, about 50 receivers are considered and all IL results presented hereafter are calculated by averaging over the values obtained for those receivers. Zones 1 and 2 (extending from 1 to 2 m in height) characterise sound levels at heights around 1.50 m above ground (i.e. pedestrian, cyclist or building ground floor) when zones 3 and 4 (extending from 3.50 to 4.50 m in height) characterise sound levels at heights close to 4 m above ground (first floor of buildings).

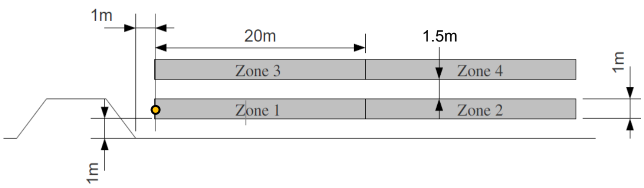


Figure 10: Definition of the 4 receivers' zones and the "pavement" receiver (circle)

We also consider the single receiver located 1.50 m high, 1 m away from the protection ("pavement" hereafter).

3 Configurations and results

In this section we give for each transportation situation the geometry of the studied berms as well as the results obtained in terms of ΔIL_A. We also give results for the case of the reference rigid barrier covered with an absorbing (earth-like) material. A blue (red) figure means gain (loss) compared to a rigid barrier (more than 1 dB(A) difference).

3.1 Cars and trams in city centers

All studied berms (Conf.1 to Conf.6) are 1 m high with an equal surface (in a vertical section) of 1 m^2 (Figure 11)

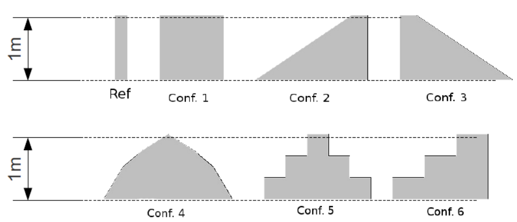


Figure 11: Geometry of low-height berms for city centers

Results for **cars** driving at 50 km/h on a 2-lane street (Fig) are given in Table 1 (IL_A vertical maps in Figure 12).

Table 1: Cars in city center. IL_A (reference barrier) and ΔIL_A (absorbing barrier and studied berms)

CARS CITY	Pavement	Zone1	Zone 2	Zone 3	Zone 4
Ref. barrier	*9.0*	*9.0*	*6.9*	*6.7*	*8.8*
Abs. barrier	0.2	0.1	0.1	0.1	0.1
Conf. 1	-0.5	0.1	-0.1	0.2	-0.1
Conf. 2	-6.1	-2.7	-2.8	-2.1	-2.4
Conf. 3	-0.1	-0.7	-0.2	-0.9	-0.7
Conf. 4	-4.3	-3.0	-2.5	-2.7	-2.7
Conf. 5	-2.1	-1.3	-1.3	-1.3	-1.2
Conf. 6	-3.5	-1.2	-1.6	-1.0	-1.1

From the previous table one can see that within the 4 zones only Conf.1 and Conf.3 give results that do not significantly decrease the protection's performance (when referred to a straight rigid barrier). Conf.2 and Conf.4 show an average loss of performance between 2 and 3 dB(A) and therefore should be avoided.

From the point of view of the receiver on the pavement, Conf.2, Conf.4 and Conf.6 show a sensible loss of performance, up to 6 dB(A) for Conf.2 which is the worst earth berm solution for pedestrians walking along the street. Conf.3 should be preferred.

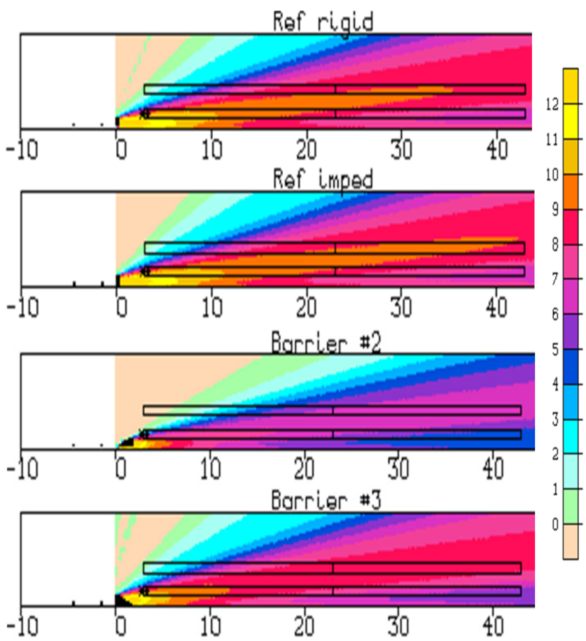


Figure 12: Cars in city center. Vertical maps of IL_A
From top to bottom: ref. and abs. barrier, Conf.2, Conf.3

For the case of **tramways** running at 30 km/h results are given in Table 2 for the case when the tram is close to the barrier, and in Table 3 when it is running on the opposite track (with meaningful IL_A vertical maps in Figure 13).

Table 2: Tram (track close to the protection). IL_A (reference barrier) and ΔIL_A (absorbing barrier and studied berms)

TRAM CLOSE	Pavement	Zone1	Zone 2	Zone 3	Zone 4
Ref. barrier	*7.9*	*8.3*	*8.5*	*6.3*	*6.9*
Abs. barrier	5.3	4.9	4.9	4.5	5.2
Conf. 1	5.1	5.1	4.6	4.8	5.4
Conf. 2	0.5	3.5	1.4	3.9	4.2
Conf. 3	6.0	4.1	4.6	3.6	4.5
Conf. 4	-0.3	1.6	-0.4	2.5	2.3
Conf. 5	1.6	2.7	1.2	3.2	2.8
Conf. 6	1.4	3.4	1.1	4.2	3.5

From the previous table one can see that when the tram runs close to the protection all tested geometries show equivalent or (often) higher noise abatement than the reference barrier's one. Looking at the results in the 4 zones, one can remark that Conf.1 give the best performance (about 5 dB(A)) when the less efficient one is Conf.4.

From the point of view of the receiver on the pavement, Conf.1 and Conf.3 give the best performances, up to 6 dB(A) for Conf.3 (the worst geometry being Conf. 4).

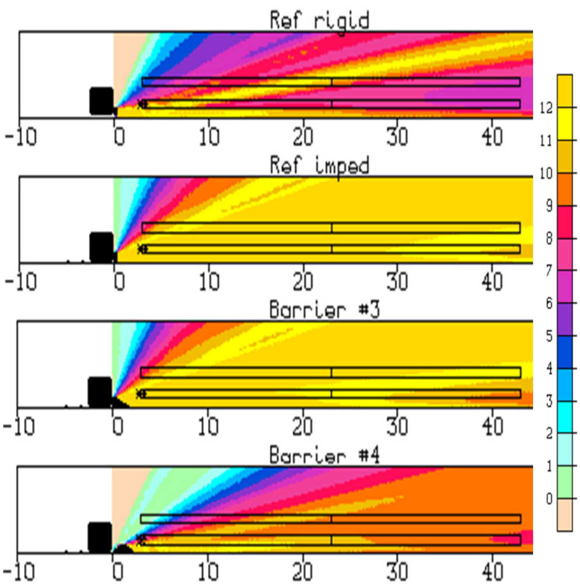


Figure 13: Tram (close track). Vertical maps of IL_A From top to bottom: ref. and abs. barrier, Conf.3, Conf.4

When the tram runs on the opposite track (see Table 3 and Figure 14) there is often a gain of a couple of dB(A) brought by the low-height earth berm. Considering an average on the 4 zones Conf.2 and Conf.6 show the best improvement.

However from the point of view of the receiver on the pavement Conf.2 gives a loss of about 2 dB(A) and therefore should not be recommended for such situations; on the other hand all other berm geometries show a very limited improvement for this "pavement" receiver.

Table 3: Tram (track opposite to protection). IL_A (reference barrier) and ΔIL_A (absorbing barrier and studied berms)

TRAM AWAY	Pavement	Zone1	Zone 2	Zone 3	Zone 4
Ref. barrier	*4.5*	*4.9*	*2.3*	*2.9*	*3.5*
Abs. barrier	1.2	1.2	1.0	1.2	1.3
Conf. 1	0.6	1.1	0.9	1.2	1.2
Conf. 2	-1.7	2.1	2.1	3.0	3.4
Conf. 3	1.2	0.9	0.9	0.9	1.0
Conf. 4	-0.2	1.9	2.3	2.6	3.2
Conf. 5	0.6	2.1	2.1	2.3	2.7
Conf. 6	-0.3	2.2	1.9	2.6	2.8

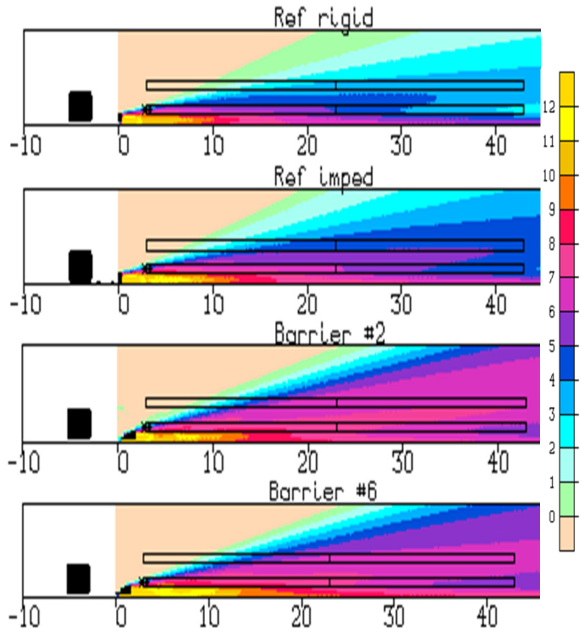


Figure 14: Tram (opposite track). Vertical maps of IL_A From top to bottom: ref. and abs. barrier, Conf.2, Conf.6

3.2 Motorways

For the motorway situation, all studied berms (Conf.1 to Conf.8) are 4 m high with a width ranges from 4 to 16 m (Figure 15)

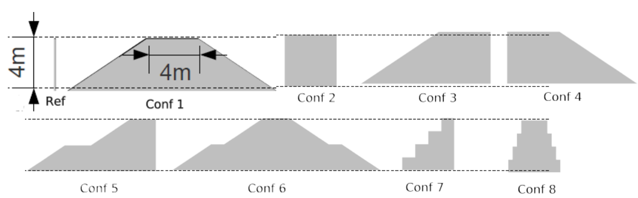


Figure 15: Geometry of berms along motorways

Results for **cars and lorries** driving respect. at 120 km/h and 90 km/h on a 4-lane motorway are given in Table 4 with meaningful IL_A vertical maps in Figure 16.

Table 4: Motorway (cars and lorries). IL_A (reference barrier) and ΔIL_A (studied berms)

MOTORWAY	Pavement	Zone1	Zone 2	Zone 3	Zone 4
Ref. barrier	*21.1*	*17.5*	*15.0*	*15.7*	*15.4*
Conf. 1	-3.1	-2.3	-1.8	-2.5	-2.4
Conf. 2	6.3	3.3	1.4	1.5	0.8
Conf. 3	1.8	0.1	-1.9	-1.4	-1.9
Conf. 4	0.5	0.6	1.4	0.4	0.2
Conf. 5	0.3	-0.9	-2.7	-1.7	-2.5
Conf. 6	-4.7	-3.2	-2.3	-3.3	-2.8
Conf. 7	3.0	0.9	-0.6	-0.1	-0.4
Conf. 8	4.3	-2.7	0.6	0.5	0.2

In a wide range of receivers, one can see from the previous table that in the case of a motorway the less efficient berms have a geometry close to those usually built along roads and railways, i.e. Conf. 1 and Conf.6. The noise abatement is between 2 and 3 dB(A) less than the reference barrier's one. The best solutions are obtained when the first diffraction edge gets closer to the sources, that is Conf.2 and Conf.4 with an improvement between 0,5 and 3 dB(A). This is partly due to the presence of creeping waves above an absorbing surface sufficiently close to the sources.

From the point of view of the receiver on the pavement ("pavement" corresponding here to a cycle or pedestrian path), Conf.2 and Conf.8 give the best performances, up to 6 dB(A) for Conf.2 (the worst geometry being Conf. 6).

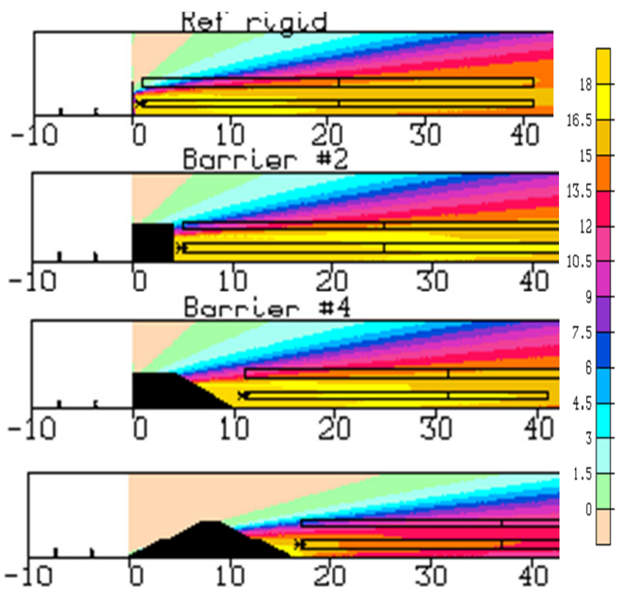


Figure 16: Motorway. Vertical maps of IL_A
(From top to bottom: ref. barrier, Conf.2, Conf.4, Conf.6)

3.3 Trains

For the railway situations, all studied berms (Conf.1 to Conf.4, 7 and 8) are 4 m high and have a width ranging from 4 to 16 m (same as those studied for the motorway and defined in Figure 15).

Results for **freight trains** going at 100 km/h are recapped in Table 5 with significant IL_A vertical maps given in Figure 17.

Table 5: Freight train. IL_A (reference barrier) and ΔIL_A (absorbing barrier and studied berms)

FREIGHT TRAIN	Pavement	Zone1	Zone 2	Zone 3	Zone 4
Ref. barrier	*24.3*	*15.3*	*13.4*	*10.3*	*12.4*
Abs. barrier	3.8	3.1	3.4	3.3	3.5
Conf. 1	-3.1	2.0	2.9	3.2	3.0
Conf. 2	7.7	7.0	5.0	5.7	4.6
Conf. 3	3.7	4.9	2.9	4.6	3.3
Conf. 4	-0.5	3.5	4.6	4.3	4.1
Conf. 7	2.6	3.0	2.0	2.9	2.0
Conf. 8	2.6	3.0	2.0	2.9	2.0

In the receivers' zones, one can observe that in the case of freight trains all studied berms show a better performance than the reference barrier, this being mainly due to a partial cancellation of the barrier-body effect (multiple sound reflections between facing surfaces). The best geometry is Conf.2 (between 5 and 7 dB(A) gained) when the less efficient is the conventional berm Conf.1.

The conclusions are the same for the receiver on the pavement ("pavement" corresponding here to a cycle or pedestrian path) except for Conf.1 where the performance is less by 3 dB(A). Hence Conf.1 is not adapted to such paths.

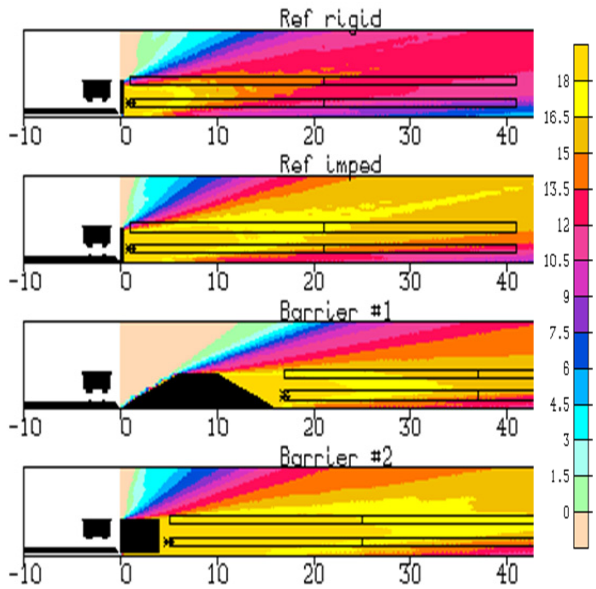


Figure 17: Freight train. Vertical maps of IL_A
From top to bottom: ref. and abs. barrier, Conf.1, Conf.2

Results for **high speed trains** going at 300 km/h are recapped in Table 6 with significant IL_A vertical maps in Figure 18.

Table 6: High speed trains. IL_A (reference barrier) and ΔIL_A (absorbing barrier and studied berms)

H SPEED TRAIN	Pavement	Zone1	Zone 2	Zone 3	Zone 4
Ref. barrier	*18.8*	*13.4*	*11.5*	*15.3*	*10.4*
Abs. barrier	2.5	2.3	2.3	2.3	2.2
Conf. 1	-1.7	1.4	-0.1	1.1	1.0
Conf. 2	3.5	5.1	2.9	3.6	3.2
Conf. 3	2.3	3.2	-0.3	1.8	1.8
Conf. 4	-0.4	3.5	1.8	2.9	2.6
Conf. 7	2.9	3.7	2.3	3.0	3.3
Conf. 8	5.5	5.0	3.4	3.0	4.7

In the receivers' zones, one can observe that in the case of high speed trains all studied berms show an equivalent or better performance than the reference barrier. The best geometries are Conf.2 and Conf.8 (between 3 and 5 dB(A) gained) when the less efficient is the conventional berm Conf.1.

The conclusions are the same for the receiver on the pavement ("pavement" corresponding here to a cycle or pedestrian path) where Conf.1 show a loss in performance of 2 dB(A). Again Conf.1 is not adapted to such paths.

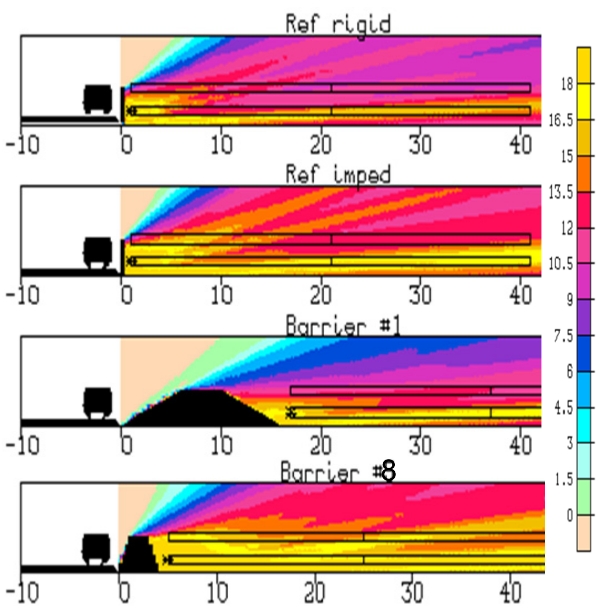


Figure 18: High speed train. Vertical maps of IL_A
From top to bottom: ref. and abs. barrier, Conf.1, Conf.8

4 Conclusion

As recommendations, the best and worst tested earth berms solutions depending on the type of transportation infrastructure and the receivers' location are recapped in Table 7.

Table 7: Best and worst tested solutions for earth berms as a function of transportation case and receiver area

		Pavement / cycle & ped. path		4 zones	
Case	Berm height	Highest performance	Lowest perf.	Highest performance	Lowest perf.
Cars in city	1 m				
Tramway	1 m				---
Motorway	4 m				
Freight train	4 m				---
H. Spd train	4 m				---

Acknowledgments

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