Urban Acoustics

Week 7 Tutorial
Cnossos model

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Where innovation starts

Cnossos

Problem:

A residential area is located close to a highway. The façade of the closest house is 110 m from the center of the highway. The road has a total vehicle flow of 4000 vehicles per hour which is composed out of 90% lightweight and 10% heavy duty vehicles. The lightweight vehicles have a speed of 120 km/h and the heavy duty vehicles a speed of 80 km/h. For the source, a height of 0 m can be used. The ground between the road and the residential area is of the type compacted lawn and the highway asphalt type ‘very hard and dense’. We consider the highway as a line source and the speed of sound is 340 m/s.

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This exercise is the continuation of the exercise of week 6. The noise level per 1/1 octave band $L_{p,i}$ at 110 m from the highway, at a height of 4 m, is shown in the table below for homogeneous conditions (i.e., without wind) with and without the noise barrier.

F (Hz)	$L_{p,i}$ homogeneous, no barrier (dB)	$L_{p,i}$ homogeneous, barrier (dB)
63	56.6	49.8
125	57.2	48.1
250	56.8	45.3
500	58.0	43.8
1000	63.1	46.0
2000	54.2	40.2
4000	40.1	27.3

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a) There is a plan to construct an open car-parking space of 10 m width just in front of the residential area. Before it could be built, the planners want to check if the parking ground will lead to an increase in sound levels at the nearest façade; if it does increase, they plan to build the parking space on the other side. Compute, without the barrier, the difference in A-weighted sound level $L_{p,A}$.

$$L_{p,i} = L_{W,eq,i} - A_{div} - A_{atm,i} - A_{ground,i}$$

The terms $L_{W,eq,i}$, A_{div} and $A_{atm,i}$ are the same as before (without the barrier). $A_{ground,i}$ will change due to the car-parking space though.

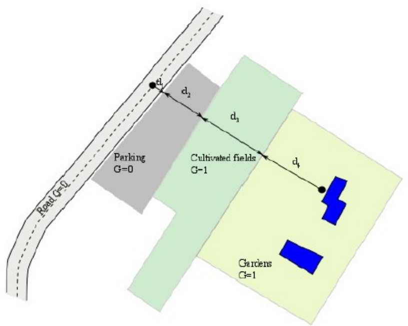
Again, 3 steps to compute the ground attenuation:

- compute G_s and G_{path} based on tabulated values of ground properties
- compute G'_{path} with the formula from the lecture
- estimate $A_{ground,i}$ from the provided figure, for each octave band

Cnossos

a) There is a plan to construct an open car-parking space of 10 m width just in front of the residential area. Before it could be built, the planners want to check if the parking ground will lead to an increase in sound levels at the nearest façade; if it does increase, they plan to build the parking space on the other side. Compute, without the barrier, the difference in A-weighted sound level $L_{p,A}$.

- As before, ground near the source = dense asphalt, so $G_s = 0$
- The ground along the propagation path now consists of 100 m of compacted lawn (G = 0.7) and 10 m of "car park" (G = 0.3)
- You thus need to compute G_{path} as the average G over the propagation path, i.e: $G_{path} = (0.7 \times 100 + 0.3 \times 10) / 110 \approx 0.66$



$$d = d_1 + d_2 + d_3 + d_4$$

$$G_{path} = \left(0 \cdot d_1 + 0 \cdot d_2 + 1 \cdot d_3 + 1 \cdot d_4\right) / d = \left(d_3 + d_4\right) / d$$

Figure VI.7: *Determination of the ground coefficient G_{path} over a propagation path*

Note: you could have included the road near the source for computing G_{path}, although the difference would have been small since the width of the road is small compared with the total path length (and in any case the influence of the ground near the source is somewhat taken into account via G_s).

Table VI.1: *G values for different types of ground*

Description	Type	(kPa·s/m²)	*G* value
Very soft (snow or moss-like)	A	12.5	1
Soft forest floor (short, dense heather-like or thick moss)	B	31.5	1
Uncompacted, loose ground (turf, grass, loose soil)	C	80	1
Normal uncompacted ground (forest floors, pasture field)	D	200	1
Compacted field and gravel (compacted lawns, park area)	E	500	0.7
Compacted dense ground (gravel road, car park)	F	2000	0.3
Hard surfaces (most normal asphalt, concrete)	G	20 000	0
Very hard and dense surfaces (dense asphalt, concrete, water)	H	200 000	0

Cnossos

a) There is a plan to construct an open car-parking space of 10 m width just in front of the residential area. Before it could be built, the planners want to check if the parking ground will lead to an increase in sound levels at the nearest façade; if it does increase, they plan to build the parking space on the other side. Compute, without the barrier, the difference in A-weighted sound level $L_{p,A}$.

Now you can compute G'_{path} with the formula

$$G'_{path} = \begin{cases} G_{path} \dfrac{d_p}{30(z_s + z_r)} + G_s \left(1 - \dfrac{d_p}{30(z_s + z_r)}\right) & \text{if } d_p \le 30(z_s + z_r) \\ G_{path} & \text{otherwise} \end{cases}$$

with $d_p = 110$ m, $z_s = 0$ m and $z_r = 4$ m. We find $G'_{path} \approx 0.6$.

From Figure 1, you can finally (roughly) estimate $A_{ground,i}$

Cnossos

a) There is a plan to construct an open car-parking space of 10 m width just in front of the residential area. Before it could be built, the planners want to check if the parking ground will lead to an increase in sound levels at the nearest façade; if it does increase, they plan to build the parking space on the other side. Compute, without the barrier, the difference in A-weighted sound level $L_{p,A}$.

Next, compute the sound level per octave band and apply the A correction

f	$L_{W,eq,i}$	A_{div}	A_{atm}	A_{ground}	A_{dif}	$L_{p,i,old}$	$L_{p,i,new}$
63	83.5	28.4	0.0	-1.7	0.0	56.6	56,8
125	84.2	28.4	0.0	-1.7	0.0	57,2	57,4
250	83.8	28.4	0.1	-1.7	0.0	56.8	57,0
500	85.1	28.4	0.3	-1.7	0.0	58.0	58,2
1000	90.5	28.4	0.4	-1.7	0.0	63.1	63,3
2000	88.1	28.4	1.0	4.3	0.0	54.2	54,4
4000	80.0	28.4	2.9	1.0	0.0	40.1	47.6

$L_{p,A,old}$ = 64.4 dB(A) $L_{p,A,new}$ = 64.7 dB(A)

Slight amplification, but in principle the car park should go to the other side (but you could also consider that the difference is smaller than the uncertainty of the Cnossos model…)

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b) For the receiver position at 110 m from the highway and 4 m height, compute the difference in A-weighted sound level $L_{p,A}$ for **favourable conditions**. Make use of figure 1 for computing the ground effect and make us of A_{div} = 10log$_{10}$(d)+8, with *d* the direct distance between source and receiver.

For favorable conditions, the sound level (for one acoustic path) is expressed as

$$L_{p,F,i} = L_{W,i} - A_{div} - A_{atm,i} - A_{boundary,F,i}$$

$A_{boundary,F,i}$ is either $A_{ground,F,i}$ or $A_{dif,F,i}$. Here, there is no barrier so

$$L_{p,F,i} = L_{W,i} - A_{div} - A_{atm,i} - A_{ground,F,i}$$

<u>Note</u>: since the other terms are the same as for homogeneous conditions, you can consider the sound level difference between the homogeneous $L_{p,H,i}$ and the favorable $L_{p,F,i}$ conditions to avoid recomputing all the terms:

$$L_{p,F,i} = L_{p,H,i} + A_{ground,H,i} - A_{ground,F,i}$$

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b) For the receiver position at 110 m from the highway and 4 m height, compute the difference in A-weighted sound level $L_{p,A}$ for **favourable conditions**. Make use of figure 1 for computing the ground effect and make us of $A_{div} = 10\log_{10}(d)+8$, with d the direct distance between source and receiver.

Computation of $A_{ground,F,i}$:

The procedure is exactly the same as for the homogeneous case:

- compute G_{path} and G_s
- apply the correction G'_{path} with the same formula

$$G'_{path} = \begin{cases} G_{path}\dfrac{d_p}{30(z_s+z_r)} + G_s\left(1-\dfrac{d_p}{30(z_s+z_r)}\right) & \text{if } d_p \le 30(z_s+z_r) \\ G_{path} & \text{otherwise} \end{cases}$$

- then use the provided figure to estimate $A_{ground,F,i}$

(the figure is of course not the same as for the homogeneous case)

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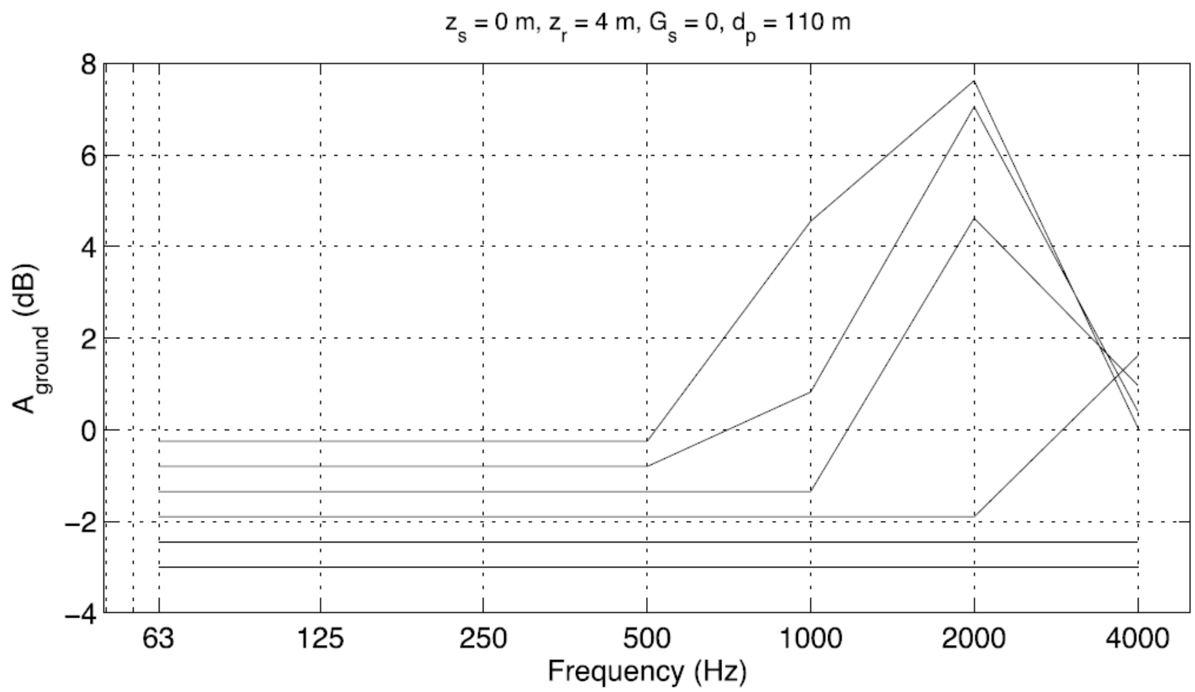

A_{ground} for various values of G'_{path} for favourable conditions. Lines for G'_{path} = 0 (lowermost line) to G'_{path} = 1 (upper line). Other lines with increment of G'_{path} = 0.2.

Here, $G'_{path} \approx 0.64$ (without the parking from question a)).

You can then estimate $A_{ground,F,i}$ and compute the sound level with favorable conditions.

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$$L_{p,F,i} = L_{p,H,i} + A_{ground,H,i} - A_{ground,F,i}$$

f (Hz)	$L_{p,H,i}$ (dB)	$A_{ground,H,i}$ (dB)	$A_{ground,F,i}$ (dB)	$L_{p,F,i}$ (dB)
63	56.6	-1,5	-1	56,1
125	57,2	-1,5	-1	56,7
250	56,8	-1,5	-1	56,3
500	58,0	-1,5	-1	57,5
1000	63,1	-1,5	-1	62,6
2000	54,2	4,5	5	53,7
4000	40,1	8,5	0.5	48,1

A-weighted sound level is now $L_{p,F,A}$ = 64.1 dB(A) (for homogeneous case, it was $L_{p,H,A}$ = 64.4 dB(A))
This is counter intuitive because one would expect an amplification with favorable conditions:
this is because a favorable wind emphasizes the ground effects

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c) To reduce the noise level, a thin 4 m tall barrier was proposed at 10 m from the road. For homogeneous conditions, the values of $L_{p,H,i}$ at the receiver point of a) per 1/1 octave band are shown in Table 1. For the same position, compute the difference in A-weighted sound level $L_{p,F,A}$ for **favourable conditions** using figure 2.

$$L_{p,F,i}=L_{W,i}-A_{div}-A_{atm,i}-A_{boundary,F,i}$$

Answer:

In favorable conditions with a barrier, we can use the formula

$$L_{p,F,i}=L_{W,i}-A_{div,n}-A_{atm,i}-A_{dif,F,i}$$

As for the previous question, we can also more conveniently compute the difference with the homogeneous case, i.e.,

$$L_{p,F,i}=L_{p,H,i}+A_{dif,H,i}-A_{dif,F,i}$$

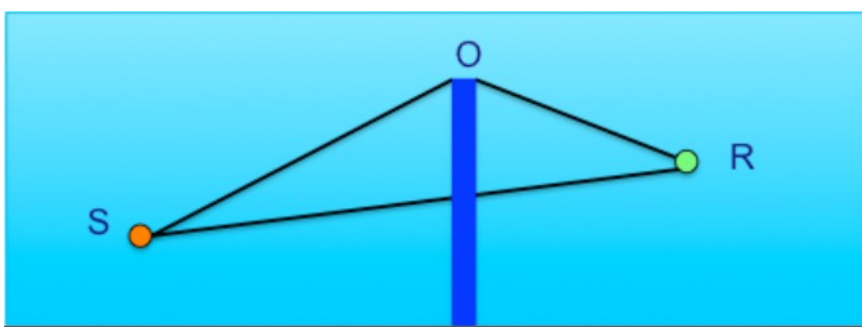
To compute $A_{dif,F,i}$ use the following formulae

Cnossos

c) To reduce the noise level, a thin 4 m tall barrier was proposed at 10 m from the road. For homogeneous conditions, the values of $L_{p,H,i}$ at the receiver point of a) per 1/1 octave band are shown in Table 1. For the same position, compute the difference in A-weighted sound level $L_{p,F,A}$ for **favourable conditions** using figure 2.

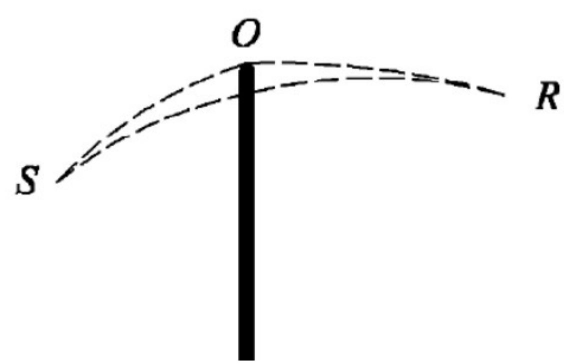
<u>With homogeneous conditions</u>:

$$A_{dif,H,i} = \Delta_{dif,SR,i} + \Delta_{ground,SO,i} + \Delta_{ground,OR,i}$$



<u>With favorable conditions</u>:

$$A_{dif,F,i} = \Delta_{dif,\widehat{SR},i} + \Delta_{ground,\widehat{SO},i} + \Delta_{ground,\widehat{OR},i}$$



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$$\Delta_{dif,\widehat{SR}} = \begin{cases} C_h 10\log_{10}\left(3+\dfrac{40\delta_F}{\lambda}\right) & \text{if } \dfrac{40\delta_F}{\lambda} \geq -2 \\ 0 & \text{otherwise} \end{cases}$$

$$C_h = \min\left(\frac{f_m h_0}{250}, 1\right)$$

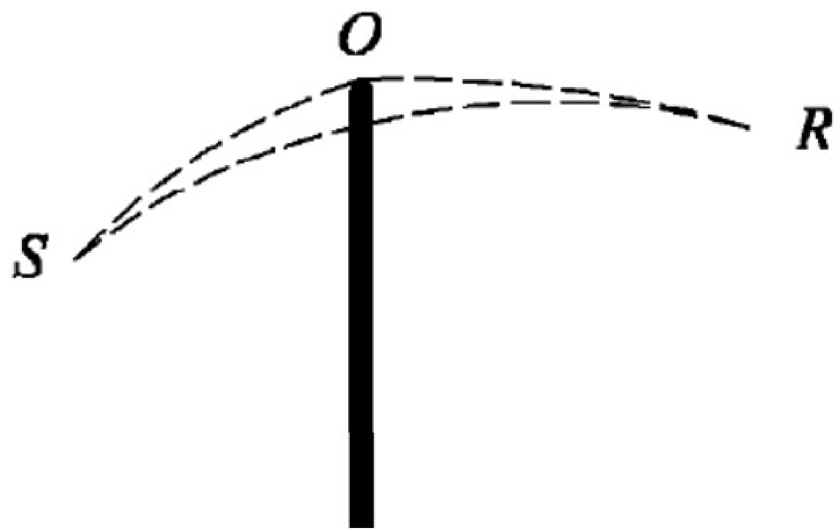
$$\delta_F = \widehat{SO} + \widehat{OR} - \widehat{SR}$$

$$\widehat{SO} = 2\Gamma \arcsin\left(\frac{SO}{2\Gamma}\right)$$

$$\widehat{OR} = 2\Gamma \arcsin\left(\frac{OR}{2\Gamma}\right)$$

$$\widehat{SR} = 2\Gamma \arcsin\left(\frac{SR}{2\Gamma}\right)$$

$$\Gamma = \max(1000, SR)$$



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$$\Delta_{ground,\hat{S}O} = -20\log_{10}\left(1+\left(10^{\frac{-Aground(\hat{S}O)}{20}}-1\right)10^{\frac{-\left(\Delta_{dif,\hat{S}'R}-\Delta_{dif,\hat{S}R}\right)}{20}}\right)$$

$$\Delta_{ground,\hat{O}R} = -20\log_{10}\left(1+\left(10^{\frac{-Aground(\hat{O}R)}{20}}-1\right)10^{\frac{-\left(\Delta_{dif,\hat{S}R'}-\Delta_{dif,\hat{S}R}\right)}{20}}\right)$$

Check out the provided Matlab script for the details of the computations!

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$$L_{p,F,i} = L_{p,H,i} + A_{dif,H,i} - A_{dif,F,i}$$

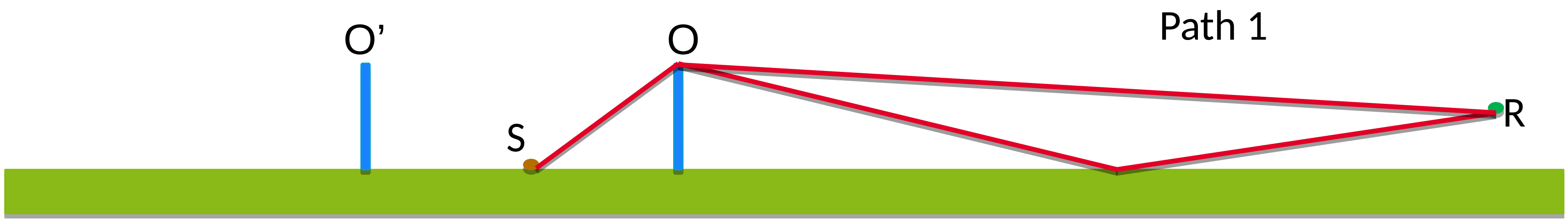
f (Hz)	$L_{p,H,i}$ (dB)	$A_{dif,H,i}$ (dB)	$A_{dif,F,i}$ (dB)	$L_{p,F,i}$ (dB)
63	49,8	5,3	5,2	49,9
125	48,1	7,6	7,5	48,2
250	45,3	9.9	9,8	45,5
500	43,8	12,7	12,5	43,9
1000	46,0	15,5	15,4	46,2
2000	40,2	18,5	18,3	40.4
4000	27,3	21,1	21.2	27,4

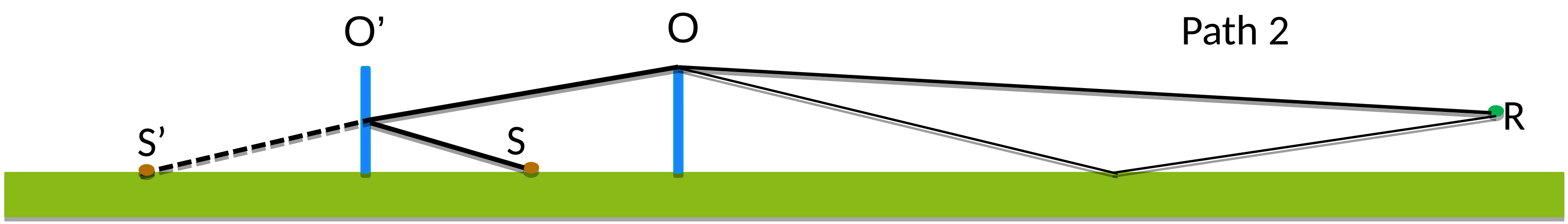
A-weighted sound level is a bit larger and is now $L_{p,F,A}$ = 48.8 dB(A)

for homogeneous case, it was $L_{p,H,A}$ = 48.6 dB(A)

Here, the difference is small because the source is very close to the barrier.
So the barrier is effective even in favorable conditions.

d) A barrier is also located at the other side of the road, see figure 3. Draw the sound rays in figure 3 that determine the sound level at receiver position R due to source position S. Neglect multiple (more than 1) reflections from the noise barrier.





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Cnossos

e) Compute the A-weighted sound level $L_{p,A}$ at the receiver position in the situation of figure 3, that means with the two barriers in homogeneous conditions. Assume the absorption coefficient $\alpha_{r,i}$ from the barrier is equal to 0. Make use of Figure 4.

To compute $L_{p,A}$, we need to compute the sound levels associated with each path, $L_{p,n=1,i}$ and $L_{p,n=2,i}$. We already know the level associated with path 1 thanks to the exercises of week 6, so we only need to compute $L_{p,n=2,i}$, with

$$L_{p,2,i} = L_{W',i} - A_{div,2}(S'R) - A_{atm,2,i}(S'R) - A_{boundary,2,i}$$

Because of the reflection on the second barrier, we consider the image-source *S'* as the source for path 2

This means that we "remove" the second barrier, so we just have to consider the diffraction on the first barrier. The problem thus becomes very similar to the exercise of week 6.

Cnossos

e) Compute the A-weighted sound level $L_{p,A}$ at the receiver position in the situation of figure 3, that means with the two barriers in homogeneous conditions. Assume the absorption coefficient $\alpha_{r,i}$ from the barrier is equal to 0. Make use of Figure 4.

$L_{W',2,i}$ is the sound power of the virtual source *S'*, defined as

$$L_{W',i} = L_{W,i} + 10\log_{10}(1-\alpha_{r,i}) - \Delta_{retrodif,i}$$

This corresponds to the sound power of the original source $L_{W,2,i}$, with a correction factor to account for the absorption of the barrier $\alpha_{r,i}$, and a correction factor to account for retrodiffraction:

$$\Delta_{retrodif,i} = \begin{cases} C_h 10\log_{10}\left(3+\dfrac{40\delta'}{\lambda}\right) & \text{if } \dfrac{40\delta'}{\lambda} \geq -2 \\ 0 & \text{otherwise} \end{cases} \qquad C_h = \min\left(\frac{f h_0}{250}, 1\right)$$

with $\delta' = S'O - SO' - OO'$.

<u>Note</u>: here, there is also a diffraction due to the first barrier, so you must consider the path between the image-source *S'* and the diffraction point *O*, at the top of the first barrier (see previous figure), and not the actual receiver *R*, to compute δ' (see Cnossos report, page 98).

[redacted]

Cnossos

e) Compute the A-weighted sound level $L_{p,A}$ at the receiver position in the situation of figure 3, that means with the two barriers in homogeneous conditions. Assume the absorption coefficient $\alpha_{r,i}$ from the barrier is equal to 0. Make use of Figure 4.

Computing $A_{div,2}$ and $A_{atm,2,i}$ is the same as before, except that you need to consider the path length $S'R$ instead of SR:

$A_{div,2}$ = 10 $\log_{10}(S'R)$+8 (because the road is considered as a line source)

$A_{atm,2,i} = \alpha_i \, S'R/1000$ dB (the coefficients α_i are tabulated, see previous tutorials)

Cnossos

e) Compute the A-weighted sound level $L_{p,A}$ at the receiver position in the situation of figure 3, that means with the two barriers in homogeneous conditions. Assume the absorption coefficient $\alpha_{r,i}$ from the barrier is equal to 0. Make use of Figure 4.

To compute $A_{boundary,2,i}$, use the same procedure as in tutorial of week 6 with the barrier, except that the source position is now *S'*:

$$A_{boundary,2,i} = A_{dif,H,i} = \Delta_{dif,S'R,i} + \Delta_{ground,S'O,i} + \Delta_{ground,OR,i}$$

Again, this formula accounts for the diffraction by the rightmost barrier and for the ground effects on both sides of the barrier.

See the Matlab script for the details of the computations.

Cnossos

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Again, this formula accounts for the diffraction by the rightmost barrier and for the ground effects on both sides of the barrier.

See the Matlab script for the details of the computations.

Cnossos

e) Compute the A-weighted sound level $L_{p,A}$ at the receiver position in the situation of figure 3, that means with the two barriers in homogeneous conditions. Assume the absorption coefficient $\alpha_{r,i}$ from the barrier is equal to 0. Make use of Figure 4.

You can now compute $L_{p,n=2,i}$

The total sound level (per octave band) is then the logarithmic sum of all paths:

$$L_{p,i} = 10\log_{10}\left(\sum_{n} 10^{\frac{L_{p,n,i}}{10}}\right)$$

And, finally, you need to apply the A correction.

The total sound level is now 54.0 dB(A); with only one barrier, the level was 48.6 dB(A) !

This is because the sound from the road reflects on the second barrier, which creates a new sound path, which is not good for the quietness of the residential area on the right of the road.

Cnossos

f) How much is $L_{p,A}$ reduced when the faces of the barriers have an absorption coefficient $\alpha = 0.9$ for all frequencies?

With this absorption coefficient, the sound power of the image source is reduced by 10 dB. The sound level associated with path 2 then needs to be recalculated, and the new A-weighted total sound level is found to be 49.6 dB(A), corresponding to a reduction of about 5 dB(A) in the residential area (which is good, although the level is still higher than without the second barrier).

Bottom line: a noise barrier redirects the sound but does not absorb it. It can decrease the noise in an area while increasing the noise somewhere else. Using absorbing materials on or next to the barriers can help with sound absorption.