Urban Acoustics

Week 6 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 110m 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.

a) Compute the sound power $L_{W,eq,i,m}$ of the highway for the 1/1 octave band range 63-4000 Hz, per vehicle type. Also, compute the total sound power $L_{W,eq,i}$ for the vehicles together.

Cnossos

a) Compute the sound power $L_{W,eq,i,m}$ of the highway for the 1/1 octave band range 63-4000 Hz, per vehicle type. Also, compute the total sound power $L_{W,eq,i}$ for the vehicles together.

<u>Answer</u>:

For both the lightweight vehicles (m=1) and the heavy vehicles (m=3), we first use the next formulae to compute the sound power from rolling noise ($L_{WR,i,m}$) and propulsion noise ($L_{WP,i,m}$) **emitted by one vehicle**, for each octave band:

$$L_{WR,i,m} = A_{R,i.m} + B_{R,i.m} \log_{10}\left(\frac{v_m}{v_{ref}}\right) + \Delta L_{WR,i,m}(v_m)$$

$$L_{WP,i,m} = A_{P,i.m} + B_{P,i.m}\left(\frac{v_m - v_{ref}}{v_{ref}}\right) + \Delta L_{WP,i,m}(v_m)$$

You just have to find the coefficients associated with each vehicle type (for each octave band)

Cnossos

a) Compute the sound power $L_{W,eq,i,m}$ of the highway for the 1/1 octave band range 63-4000 Hz, per vehicle type. Also, compute the total sound power $L_{W,eq,i}$ for the vehicles together.

Answer:

For light vehicles, use v_1 = 120 km/h, v_{ref} = 70 km/h, $\Delta L_{WR,i,1} = 0$

For heavy vehicles, use v_2 = 80 km/h, v_{ref} = 70 km/h, $\Delta L_{WR,i,2} = 0$

Table III.A.1: Coefficients for **category *m*=1** vehicles (passenger cars)

Octave band centre frequency (Hz)	A_R	B_R	A_P	B_P	*a*	*b*
63	79.7	30.0	94.5	-1.3	0	0
125	85.7	41.5	89.2	7.2	0	0
250	84.5	38.9	88.0	7.7	0	0
500	90.2	25.7	85.9	8.0	2.6	-3.1
1000	97.3	32.5	84.2	8.0	2.9	-6.4
2000	93.9	37.2	86.9	8.0	1.5	-14
4000	84.1	39.0	83.3	8.0	2.3	-22.4
8000	74.3	40.0	76.1	8.0	9.2	-11.4

Table III.A.3: Coefficients for **category *m*=3** vehicles (heavy duty vehicles)

Octave band centre frequency (Hz)	A_R	B_R	A_P	B_P
63	87.0	30.0	104.4	0.0
125	91.7	33.5	100.6	3.0
250	94.1	31.3	101.7	4.6
500	100.7	25.4	101.0	5.0
1000	100.8	31.8	100.1	5.0
2000	94.3	37.1	95.9	5.0
4000	87.1	38.6	91.3	5.0
8000	82.5	40.6	85.3	5.0

Cnossos

a) Compute the sound power $L_{W,eq,i,m}$ of the highway for the 1/1 octave band range 63-4000 Hz, per vehicle type. Also, compute the total sound power $L_{W,eq,i}$ for the vehicles together.

<u>Answer</u>:

Once you know the sound power from rolling noise $L_{WR,i,m}$ and propulsion noise $L_{WP,i,m}$ for each octave band and each vehicle type, compute the total sound power **per vehicle** (logarithmic sum):

$$L_{W,i,m} = 10\log_{10}\left(10^{\frac{L_{WR,i,m}}{10}} + 10^{\frac{L_{WP,i,m}}{10}}\right)$$

You can then compute the sound power per meter associated with the flow of type-*m* vehicles as

$$L_{W,eq,i,m} = L_{W,i,m} + 10\log_{10}\left(\frac{Q_m}{1000\,v_m}\right)$$

With Q_1 = 3600 light vehicles per hour

 and Q_3 = 400 heavy vehicles per hour

Cnossos

a) Compute the sound power $L_{w,eq,i,m}$ of the highway for the 1/1 octave band range 63-4000 Hz, per vehicle type. Also, compute the total sound power $L_{w,eq,i}$ for the vehicles together.

<u>Answer</u>:

Total sound power of light (*m*=1) and heavy duty (*m*=3) vehicles per octave band:

f (Hz)	$L_{WR,i,1}$ (dB)	$L_{WP,i,1}$ (dB)	$L_{W,i,1}$ (dB)	$L_{W,eq,i,1}$ (dB)		$L_{WR,i,3}$ (dB)	$L_{WP,i,3}$ (dB)	$L_{W,i,3}$ (dB)	$L_{W,eq,i,3}$ (dB)
63	86.7	93,6	94,4	79,2		88,7	104,4	104,5	81,5
125	95.4	94,3	97,9	82,7		93,6	101,0	101,8	78,7
250	93.6	93,5	96,6	81,3		95,9	102,4	103,2	80,2
500	96.2	91,6	97,5	82,3		102,2	101,7	105,0	81,9
1000	104.9	89,9	105,0	89,8		102,6	100,8	104,8	81,8
2000	102.6	92,6	103,0	87,8		96,5	96,6	99,5	76,5
4000	93.2	89,0	94,6	79,4		89,3	92,0	93,9	70,9

Cnossos

a) Compute the sound power $L_{w,eq,i,m}$ of the highway for the 1/1 octave band range 63-4000 Hz, per vehicle type. Also, compute the total sound power $L_{w,eq,i}$ for the vehicles together.

<u>Answer</u>:

To get the total sound power $L_{W,eq,i}$ for the vehicles together, compute the logarithmic sum of the sound powers per meter:

f (Hz)	$L_{W,eq,i}$ (dB)
63	83.5
125	84.2
250	83.8
500	85.1
1000	90.5
2000	88.1
4000	80.0

$$L_{W,eq,i} = 10\log_{10}\left(10^{\frac{L_{W,eq,1}}{10}} + 10^{\frac{L_{W,eq,3}}{10}}\right)$$

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b) Compute the noise level per 1/1 octave band $L_{p,i}$ at the closest façade due to the highway, at a height of 4 m. Make use of figure 1 for computing the ground effect and A_{div} = 10log$_{10}$(d)+8.

<u>Answer</u>:

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

$$\text{source-receiver distance } d = \sqrt{4^2 + 110^2} \approx 110.1\,\mathrm{m}$$

- Sound power $L_{W,eq,i}$, we know this as we computed it for last question
- Attenuation due to geometrical spreading; here, for a line source,
  A_{div} = 10log$_{10}$(d)+8 = 28.4 dB (frequency-independent)
- Atmospheric absorption $A_{atm,i} = \alpha_i d/1000$ dB , compute with α_i from table below
- Attenuation due to ground $A_{ground,i}$, see next slides
- Attenuation due to diffraction: $A_{dif,i}$ = 0 dB (no barrier)

Centre Frequency [Hz]	125	250	500	1000	2000	4000
α [dB/km]	0.381	1.13	2.36	4.08	8.75	26.4

Cnossos

b) Compute the noise level per 1/1 octave band $L_{p,i}$ at the closest façade due to the highway, at a height of 4 m. Make use of figure 1 for computing the ground effect and A_{div} = 10log$_{10}$(d)+8.

Answer: $$L_{p,i} = L_{W,eq,i} - A_{\text{div}} - A_{atm,i} - A_{ground,i} - A_{dif,i}$$

Calculation of $A_{ground,i}$:

- Step 1: compute G_s and G_{path} based on tabulated values

Ground near the source = dense asphalt, so G_s = 0

Ground along propagation path = compacted lawn only, so G_{path} = 0.7

Note: if several ground types are present along the propagation path, you need to compute the weighted average of G_{path}.

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

Description	Type	(kPa·s/m^2)	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

b) Compute the noise level per 1/1 octave band $L_{p,i}$ at the closest façade due to the highway, at a height of 4 m. Make use of figure 1 for computing the ground effect and A_{div} = 10log$_{10}$(d)+8.

<u>Answer</u>:

- <u>Step 2</u>: compute G'_{path} with the formula

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

Here, d_p = 110 m, z_s = 0 m and z_r = 4 m, so the condition $d_p \le 30(z_s + z_r)$ is true.

We find $G'_{path} \approx 0.6$

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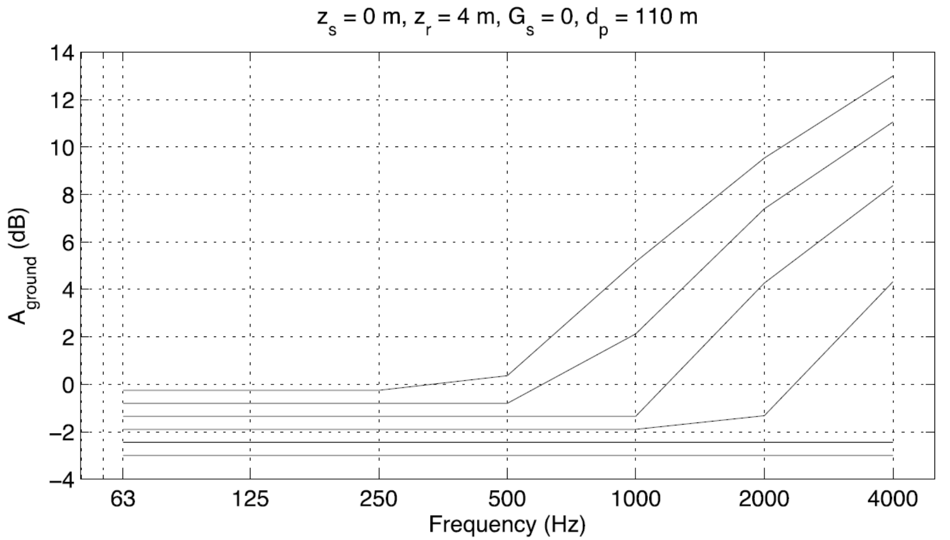
b) Compute the noise level per 1/1 octave band $L_{p,i}$ at the closest façade due to the highway, at a height of 4 m. Make use of figure 1 for computing the ground effect and A_{div} = 10log$_{10}$(d)+8.

Answer:

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

- Step 3: from the computed value of G'_{path} , you can estimate $A_{ground,i}$ from the provided figure, for each octave band:

f	$A_{ground,i}$
(Hz)	(dB)
63	-1.5
125	-1.5
250	-1.5
500	-1.5
1000	-1.5
2000	4.5
4000	8.5



Cnossos

b) Compute the noise level per 1/1 octave band $L_{p,i}$ at the closest façade due to the highway, at a height of 4 m. Make use of figure 1 for computing the ground effect and A_{div} = $10log_{10}(d)+8$.

<u>Answer</u>:

You can now compute the noise level per octave band:

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

f	$L_{W,eq,i}$	A_{div}	A_{atm}	A_{grnd}	A_{dif}	$L_{p,i}$
(Hz)	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)
63	83,5	28.4	0,0	-1.5	0.0	56,6
125	84,2	28.4	0,0	-1.5	0.0	57,2
250	83,8	28.4	0,1	-1.5	0.0	56,8
500	85,1	28.4	0,3	-1.5	0.0	58,0
1000	90,5	28.4	0,4	-1.5	0.0	63,1
2000	88,1	28.4	1,0	4.5	0.0	54,2
4000	80,0	28.4	2,9	8.5	0.0	40,1

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c) For the same receiver point as b), compute the A-weighted sound level $L_{p,A}$.

<u>Answer</u>:

Apply the *A* correction to each octave band, then compute the logarithmic sum of the noise levels:

$$L_{p,A} = 10\log_{10}\left(\sum_i 10^{\frac{L_{p,i}+W_i}{10}}\right)$$

F (Hz)	63	125	250	500	1KHz	2KHz	4KHz
A-weighting correction factor (dB)	-26.2	-16.1	-8.6	-3.2	0	1.2	1

We find $L_{p,A}$ = 64.4 dB(A)

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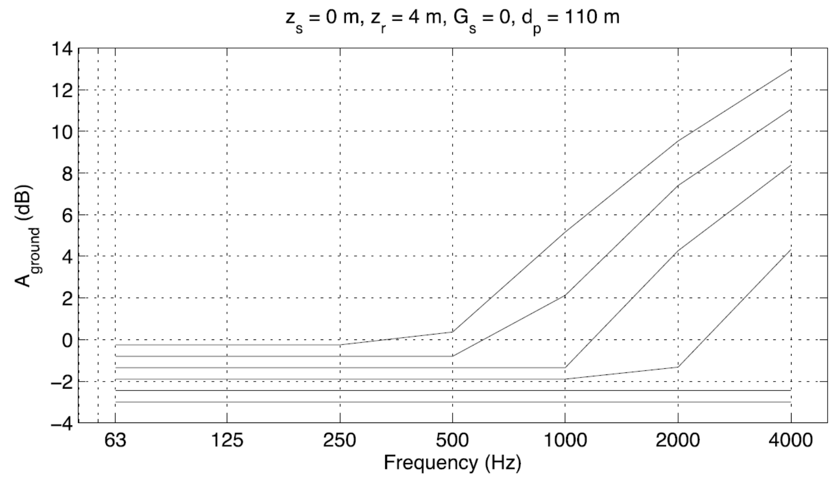
d) In winter time, the ground between the residential area and the road is occasionally covered by snow. How much does the A-weighted sound level $L_{p,A}$ change due to this?

<u>Answer</u>:

With snow the ground absorption will change, so you need to recompute $A_{ground,i}$:

Now, G_{path}=1, leading to G'_{path} = 0.9

You can thus estimate $A_{ground,i}$ from the figure.



Following the same procedure as before, we find $L_{p,A}$ = 60.0 dB(A), i.e., a reduction of 4.3 dB(A).

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e) To reduce the noise level, a thin 4 m tall barrier is erected at 10 m from the road. At the receiver point of b), compute the reduction in A-weighted sound level $L_{p,A}$ due to the barrier. Make use of figure 2 for this purpose.

<u>Answer</u>:

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

Now, absorption due to diffraction: $A_{dif,i} = \Delta_{dif,SR,i} + \Delta_{ground,SO,i} + \Delta_{ground,OR,i}$

Here, $A_{ground,i}$ = 0 since the ground effect is already included in $A_{dif,i}$. Otherwise, the other terms are the same as before.

Let's now compute the different terms appearing in the definition of $A_{dif,i}$, accounting for diffraction and the ground effects on both sides of the barrier, respectively.

Cnossos

e) To reduce the noise level, a thin 4 m tall barrier is erected at 10 m from the road. At the receiver point of b), compute the reduction in A-weighted sound level $L_{p,A}$ due to the barrier. Make use of figure 2 for this purpose.

<u>Answer</u>:

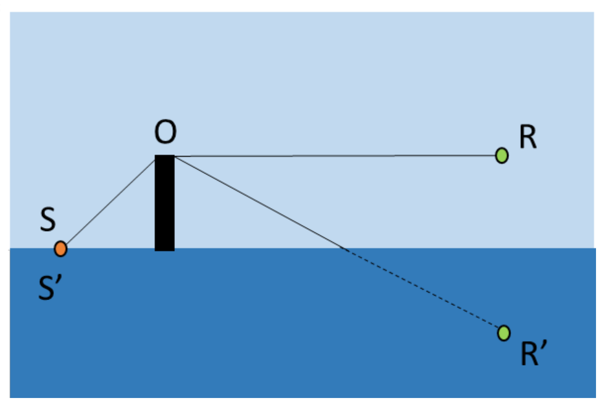
$$\Delta_{dif,SR} = \begin{cases} C_h 10 \log_{10}\left(3 + \dfrac{40\delta}{\lambda}\right) & \text{if } \dfrac{40\delta}{\lambda} \geq -2 \\ 0 & \text{otherwise} \end{cases}$$

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

f_m= central frequency of frequency band
h_0= height of the barrier

$$\delta = SO + OR - SR$$

$$\lambda = c / f_m$$

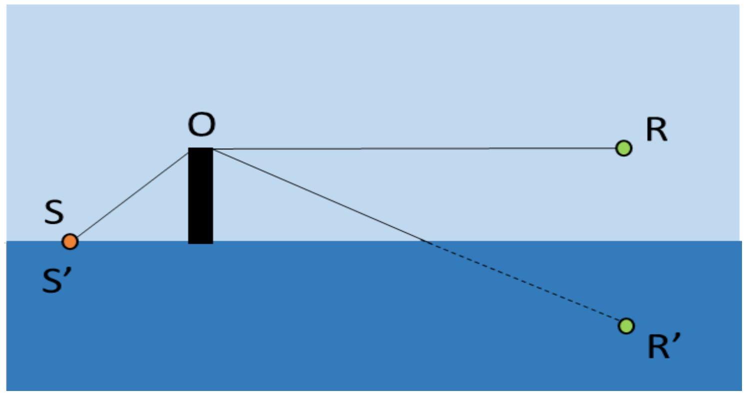


Cnossos

e) To reduce the noise level, a thin 4 m tall barrier is erected at 10 m from the road. At the receiver point of b), compute the reduction in A-weighted sound level $L_{p,A}$ due to the barrier. Make use of figure 2 for this purpose.

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

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



See the Matlab script for more details on how to compute these two terms

Cnossos

e) To reduce the noise level, a thin 4 m tall barrier is erected at 10 m from the road. At the receiver point of b), compute the reduction in A-weighted sound level $L_{p,A}$ due to the barrier. Make use of figure 2 for this purpose.

<u>Answer</u>:

f	$L_{W,eq,i}$	A_{div}	A_{atm}	A_{ground}	A_{dif}	$L_{p,i}$
(Hz)	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)
63	84,1	28.4	0,0	0	5,3	49,8
125	84,2	28.4	0,0	0	7,6	48,1
250	83,8	28.4	0,1	0	9,9	45,3
500	85,1	28.4	0,3	0	12,7	43,8
1000	90,5	28.4	0,4	0	15,5	46,0
2000	88,1	28.4	1,0	0	18,5	40,2
4000	80,0	28.4	2,9	0	21,3	27,3

Once you know the new A_{dif}, recompute the A-weighted sound level:

$$L_{p,A} = 10\log_{10}\left(\sum_i 10^{\frac{L_{p,i}+W_i}{10}}\right)$$

$L_{p,A} = 48.6\ dB(A)$

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f) To even further reduce the noise level, it has been suggested to reduce the speed limit to 100 km/h for the lightweight vehicles. How much would the A-weighted sound level $L_{p,A}$ reduce due to this measure?

<u>Answer</u>: Reducing the speed reduces the sound power level $L_{W,eq,i,m}$ for the lightweight vehicles. Re-calculate the sound power, then as before compute the sound level $L_{p,i}$, then compute the A-weighted sound level.

	without speed limit	with speed limit
no snow, no barrier	64.4	63.0
snow, no barrier	60.0	58.7
no snow, barrier	48.6	47.3

<u>A-weighted sound levels (in dB(A)) for the different configurations, with and without the speed limit</u>

Here, reducing the speed limit decreases the noise by more than 1 dB(A), although the decrease is rather small compared to the barrier.

Questions?

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(last chance!)