7 Environmental noise

ELEC-E5640 - Noise Control D

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Prediction of sound propagation outdoors

Source type
- Point source
- Cylindrical source (line)
- Surface source

Source operation vs. time
- Hour-based operation or traffic amount

Source emission
- Point sources: SWL
- Point sources: SPL at 10 m

In addition:
- Athmospheric absorption (T, RH)
- Ground absorption
- Topography
- Obstacles between source and receiver (buildings, noise barriers)
- Vegetation zones
- Reflection coefficients of barriers and buildings

Neglegted factors:
- Wind gradient
- Turbulence
- Temperature gradient

Selection of xyz positions:
- Sound source(s)
- Receiver(s) or receiver grid (sound maps)

Selection of prediction method:
- Standardized method, i.e. ISO 9613
- Nordic prediction model
- National practices
- Independent methods

Nearly all regulations are given for L_{Aeq}, therefore, the calculations are done accordingly.

Sound power level, SWL

- SWL, L_W, is determined by:

$$L_W = 10 \lg \frac{\tilde{W}}{W_0} \quad [\text{dB}]$$

W_0=1 pW

- SWL of a finite source is measured by:
  - S [m^2] is the area of measurement surface enveloping the source (excluding the ground where it is mounted)
  - L_I [dB] is the sound intensity level perpendicular to the surface

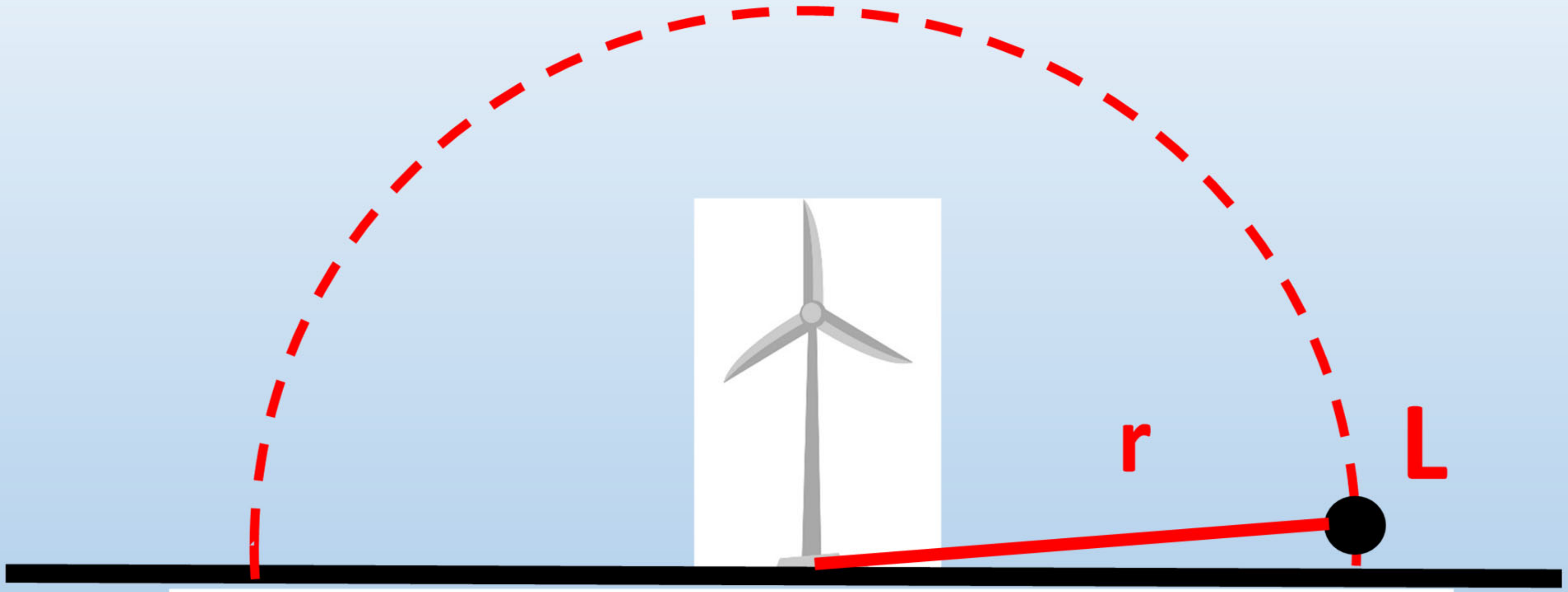
$$L_W = L_I + 10 \log_{10} S$$

$$L_I = 10 \lg \frac{\tilde{I}}{I_0} \quad [\text{dB}]$$

- In free field, L_p=L_I and L_p measurements are used for simplicity.
  - Free field takes place outdoors or in an anechoic chamber

7.1

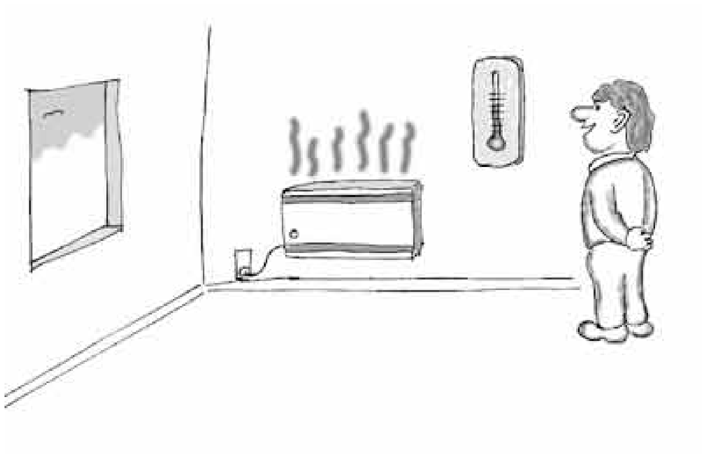
The SWL of e.g. a wind turbine is measured at a distance of approximately r=200 m. SPL is 50 dB. What is sound power level?



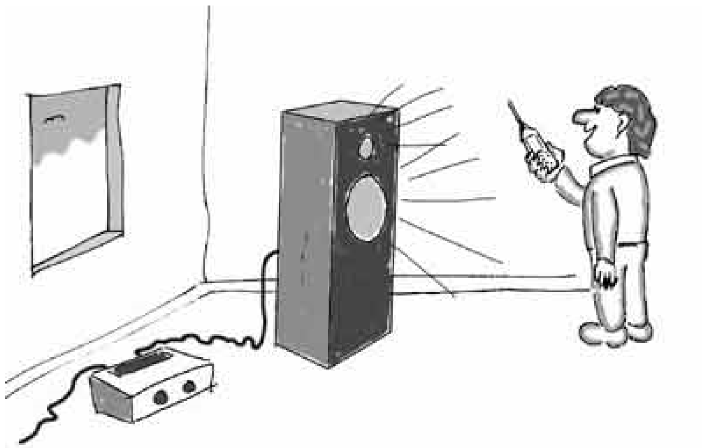
$$L_W = L_p + 10\log_{10} S$$

Analogy between temperature and sound pressure

- **Room temperature [°C]** caused by a radiator in the room depends on
  - the electric power (in Watts) of the radiator
  - the losses of the room (room size, thermal absorption/isolation)
  - the distance to the radiator
  - the location with respect to the thermal flow (directivity) of the radiator



- **Sound pressure [Pa]** caused by a source in the room depends on
  - the sound power (in Watts) of the source
  - the losses of the room (room size, room absorption area, isolation of the room)
  - the distance to the source
  - the location with respect to the directivity pattern



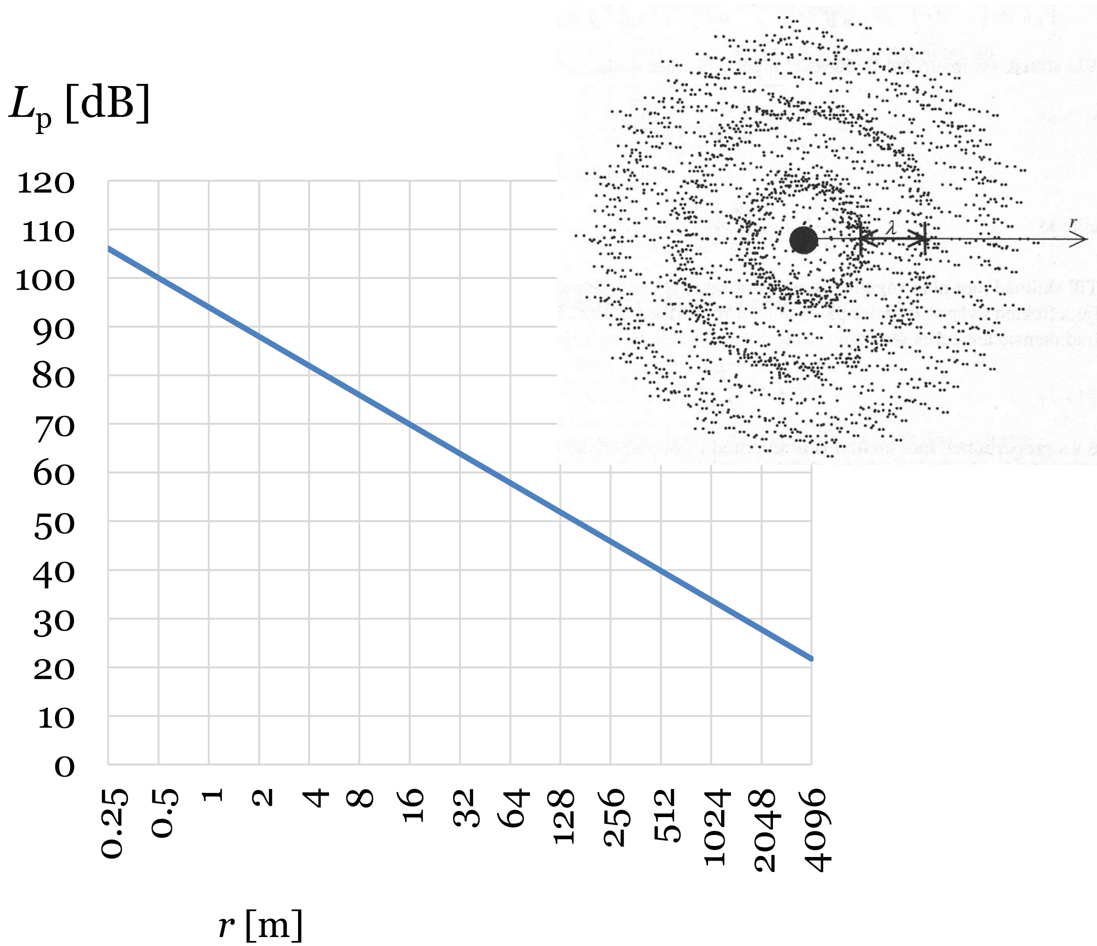
Geometric spatial attenuation

Independent variables:

- Geometric attenuation term, D_{ge} [dB]
- Sound power level L_W [dB]
- directivity constant k in the direction of interest
- space angle Ω
- distance to the source r [m]

$$L_p = L_W + D_{ge} = L_W + 10\log_{10}\left[\frac{k}{\Omega r^2}\right]$$

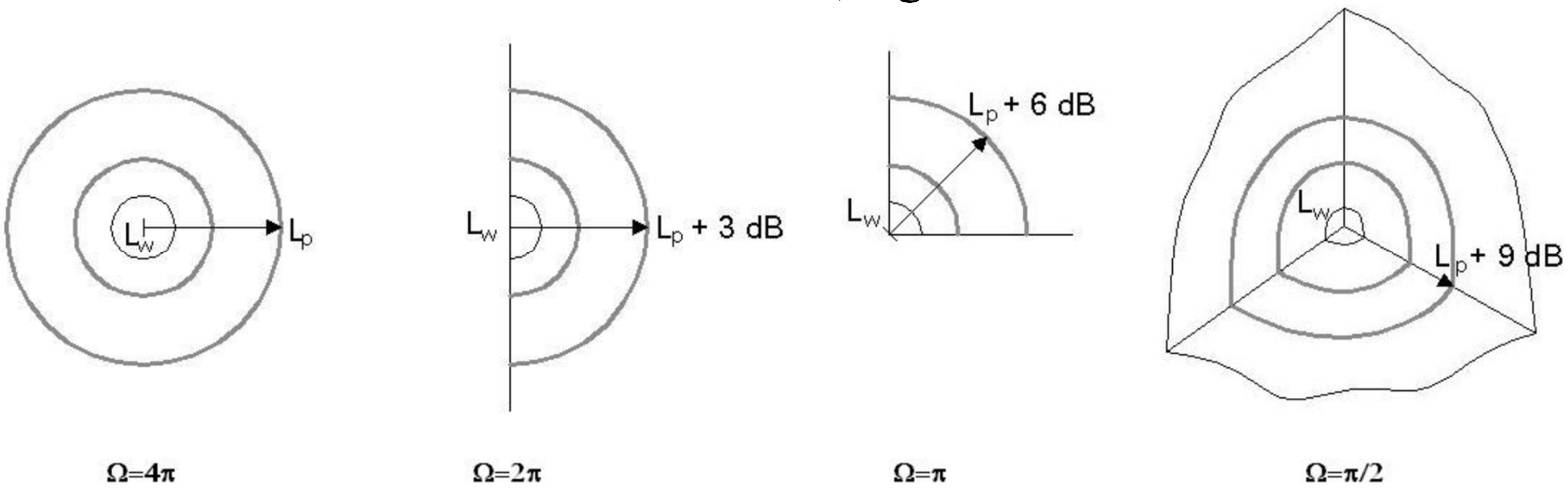
- Figures indicates the SPL produced by a point source with k=1 and Ω=4π. The outcome is a spherical symmetric wave.



Space angle Ω

Suppressed space angle increases the SPL even by 11 dB.

4π	Source is far from surfaces, e.g. wind turbine
2π	Source is near to one surface, e.g. source on the ground
π	Source is near to two surfaces, e.g. washing machine
$\pi/2$	Source is near to three surfaces, e.g. freezer



Directivity constant *k*

- Constant k in the angle θ depends on
  - sound intensity in angle θ, I_θ
  - mean sound intensity in all angles, I_m

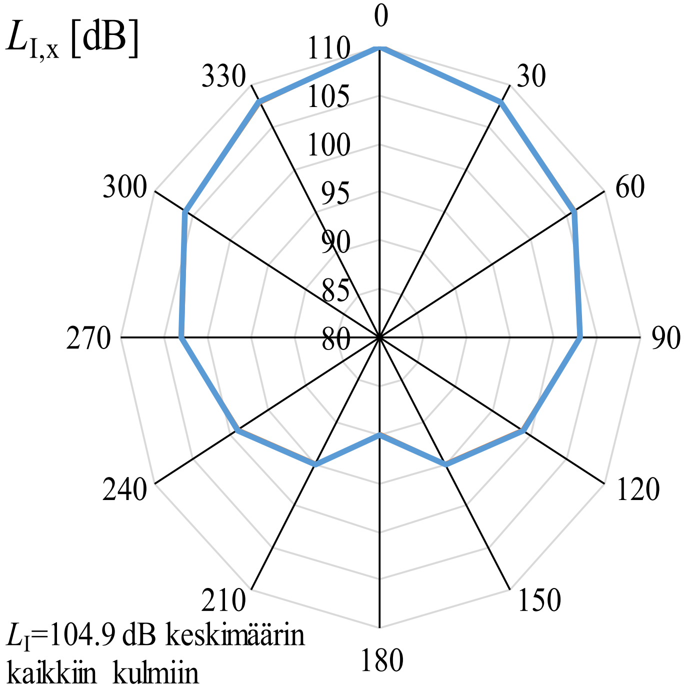
$$k_\theta = \frac{I_\theta}{I_m}$$

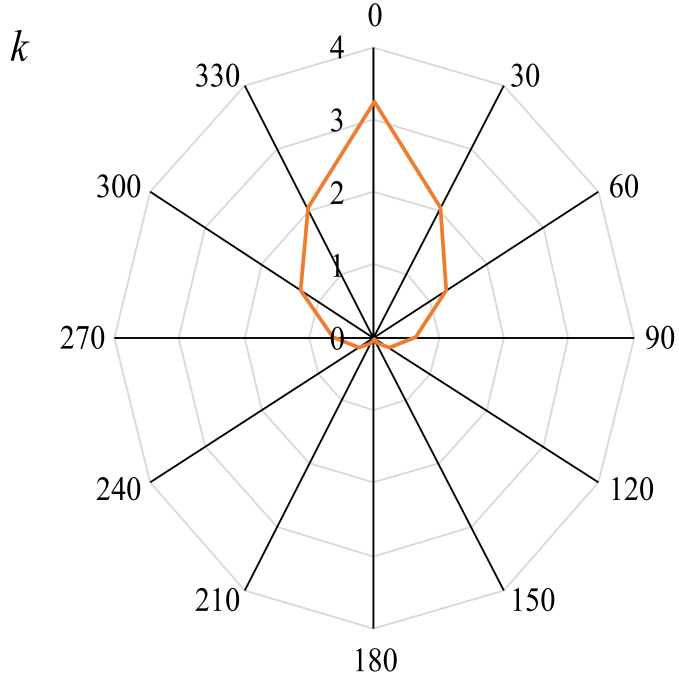
- Directivity index $L_{k,\theta}$ [dB]

$$L_{k,\theta} = 10\log_{10} k_\theta$$

- The propagation equation gets the form:

$$L_p = L_W + L_{k,\theta} + 10\log_{10}\left[\frac{1}{\Omega r^2}\right]$$



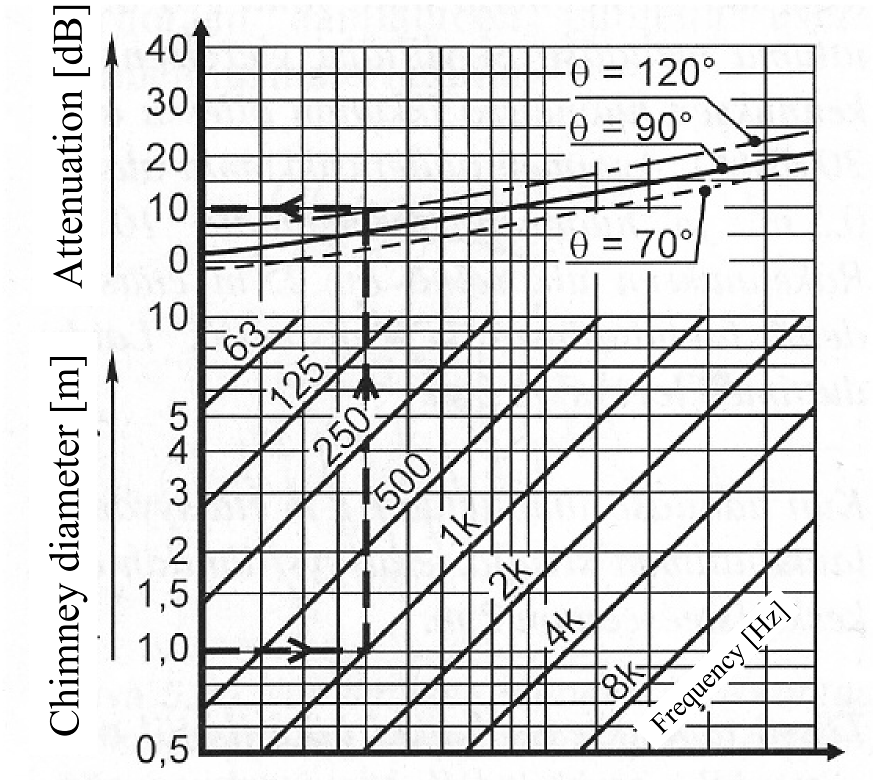


At 0°: k_θ=3.25 and L_k=5.1 dB.

7.2 When are the SWL and the SPL of a point source equal in free field? Check separately the four space angles.

$$L_p = L_W + D_{ge} = L_W + 10\log_{10}\left[\frac{k}{\Omega r^2}\right]$$

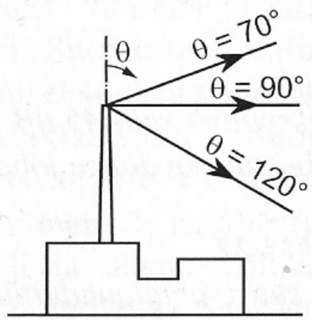
Directivity index of a chimney L_k [dB]



Directivity of sound from a tall chimney. The example with arrows concerns a chimney with a 1.0 m diameter, 1000 Hz and angle θ=120 °, where the attenuation is 10 dB

L_k [dB] for angles 90° and 120° with various chimney diameters *d*.

d, mm	Frequency [Hz] *63*	*125*	*250*	*500*	*1k*	*2k*	*4k*
For Θ=90 degrees							
100	0	0	0	0	0	0	-1
200	0	0	0	0	0	-1	-4
400	0	0	0	0	-1	-4	-7
800	0	0	0	-1	-4	-7	-10
1600	0	0	-1	-4	-7	-10	-13
For Θ=120 degrees							
100	-3	-3	-3	-3	-3	-4	-5
200	-3	-3	-3	-3	-4	-5	-8
400	-3	-3	-3	-4	-5	-8	-11
800	-3	-3	-4	-5	-8	-11	-14
1600	-3	-4	-5	-8	-11	-14	-17



Halme&Seppänen, 2002

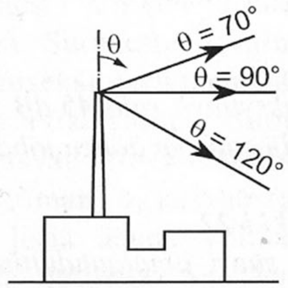
7.3

Chimney is 20 meters high. The diameter is d=1600 mm.
SWL is 115 dB at 63 Hz octave band.
What is the SPL at a yard locating 35 m away?

$$L_p = L_W + D + L_k = L_W + 10\log_{10}\left[\frac{1}{\Omega r^2}\right] + L_k$$

Taulukko 5:13 Suuntaindeksin arvoja 90 ja 120 asteen suuntakulmille oktaavikastoittain.

	Taajuus, Hz						
d, mm	63	125	250	500	1k	2k	4k
	90 asteen kulmalle						
100	0	0	0	0	0	0	-1
200	0	0	0	0	0	-1	-4
400	0	0	0	0	-1	-4	-7
800	0	0	0	-1	-4	-7	-10
1600	0	0	-1	-4	-7	-10	-13
	120 asteen kulmalle						
100	-3	-3	-3	-3	-3	-4	-5
200	-3	-3	-3	-3	-4	-5	-8
400	-3	-3	-3	-4	-5	-8	-11
800	-3	-3	-4	-5	-8	-11	-14
1600	-3	-4	-5	-8	-11	-14	-17

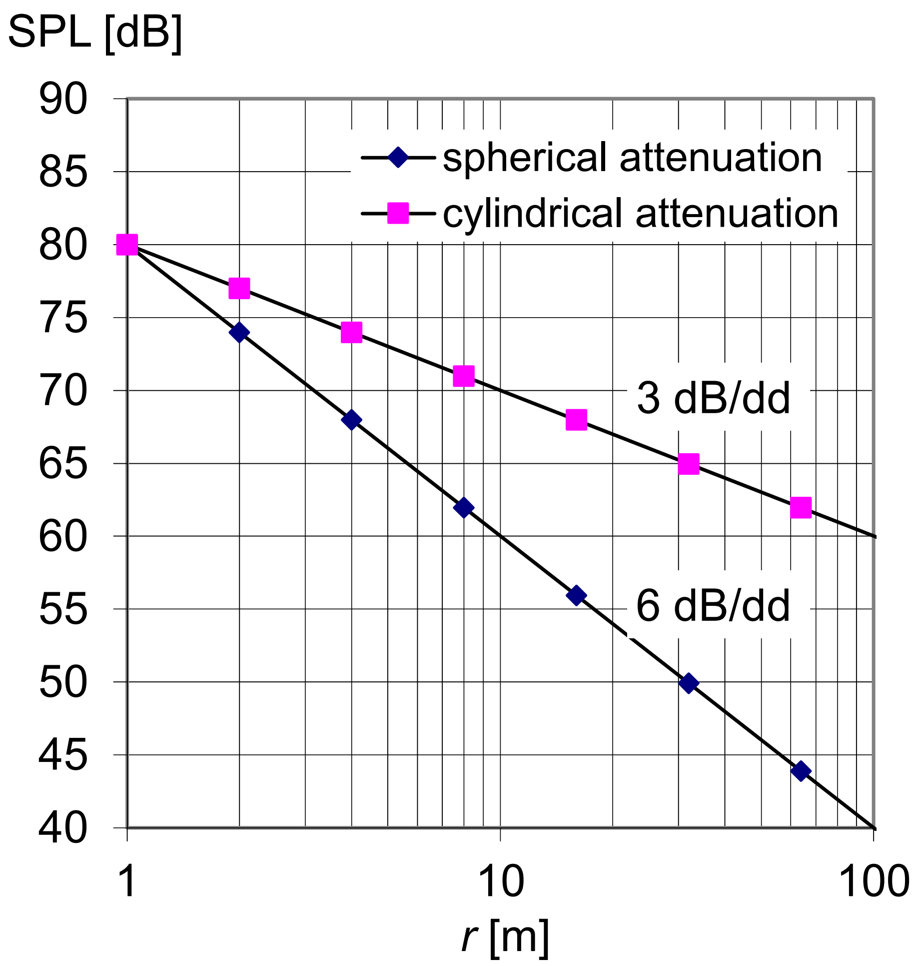


Geometric spatial attenuation D
line source, free field

- Cylinder source
- E.g. a road with constant traffic.
- Usually, line sources are expected to have a symmetric radiation, k=1
- SWL of a line source is not specifically defined because the line length depends on application. $L_{p,1}$ is expressed at a distance r_1 and $L_{p,2}$ at another distance r_2 is determined by

$$L_{p,2} = L_{p,1} - 10 \cdot \log_{10}\left(\frac{r_2}{r_1}\right)$$

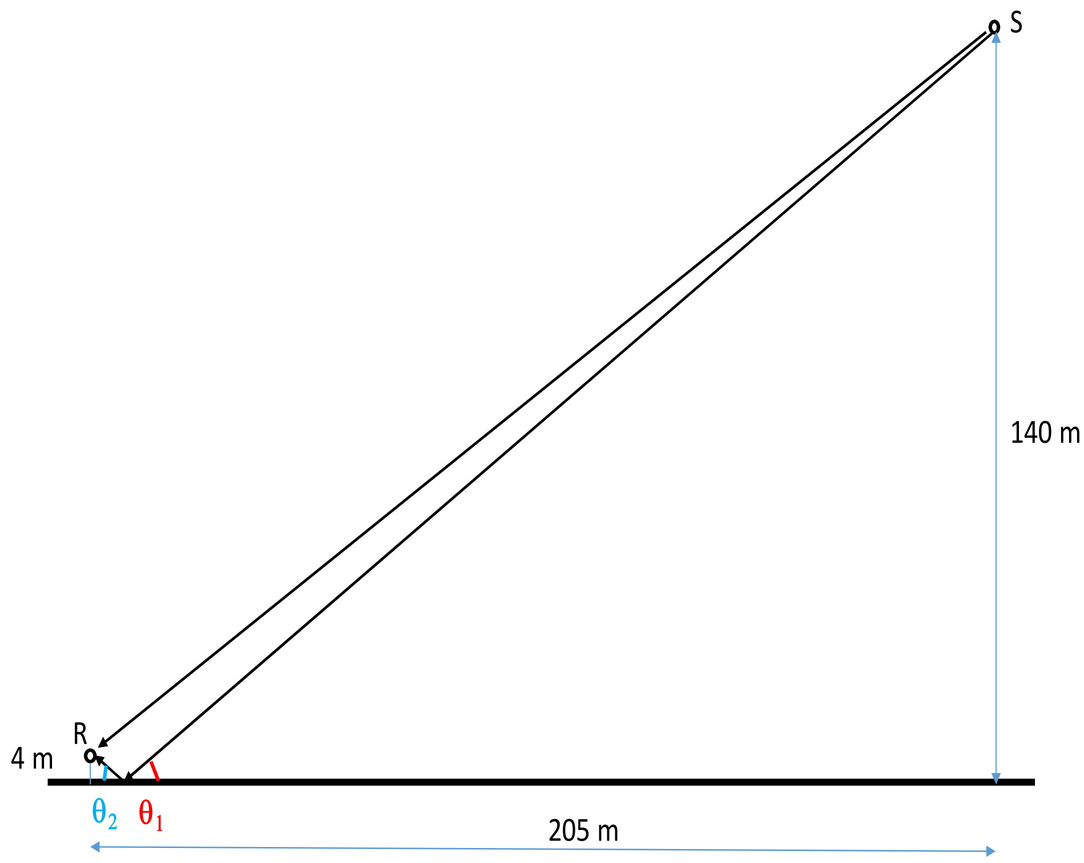
- Comparison of point and line sources when they have equal SPL at 1 m distance.



Spatial attenuation from point source
Ground and athmospheric attenuation included

- Sound power level L_W [dB]
- Directivity constant, k=1
- Space angle Ω
- Distance *r [m]*
- Ground correction D_{gr} [dB]
- Athmospheric attenuation D_{atm} [dB/km]

$$L_p = L_W + 10\log_{10}\left(\frac{k}{\Omega r^2}\right) + D_{gr} - D_{atm}$$



Athmospheric attenuation D_{atm}

- Water molecules absorb sound differently in different temperatures T and relative humidities RH
- Attenuation at distance r [m] is notated by D_{atm}
- D_{atm} is large at large distances and high frequencies
- ”*Low frequencies can be heard farther away*”

$$D_{atm} = \frac{\alpha r}{1000}$$

T	RH	α [dB/km]							
[ºC]	[%]	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
10	70	0.1	0.4	1	1.9	3.7	9.7	32.8	117
20	70	0.1	0.3	1.1	2.8	5	9	22.9	76.6
30	70	0.1	0.3	1	3.1	7.4	12.7	23.1	59.3
15	20	0.3	0.6	1.2	2.7	8.2	28.2	88.8	202
15	50	0.1	0.5	1.2	2.2	4.2	10.8	36.2	129
15	80	0.1	0.3	1.1	2.4	4.1	8.3	23.7	82.8

Table 2 of ISO 9613-2:1996

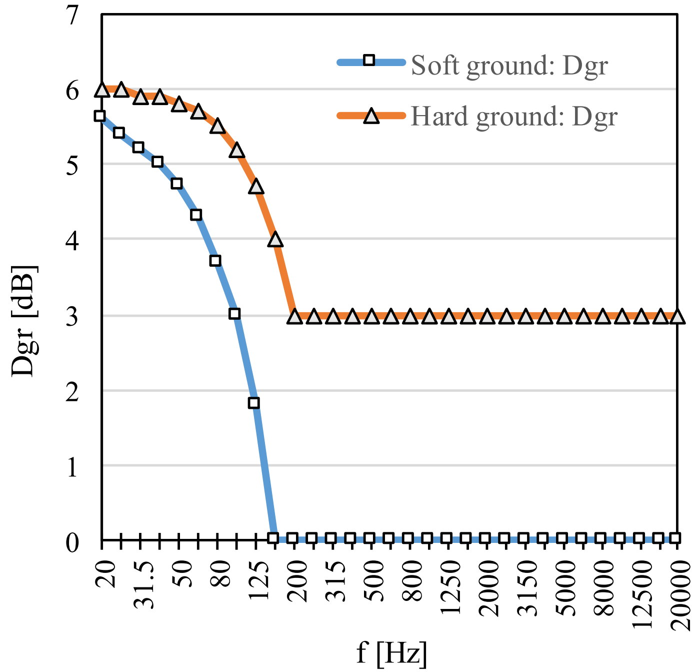
Ground correction D_{gr}

- Ground absorption coefficient α_G:
  - 0.0: hard (asphalt, water)
  - 0.3: mainly hard (sand fields, dense urban areas)
  - 0.7: mainly soft pehmeä (non-dense urban areas)
  - 1.0: soft (natural ground)
- If the ground is hard in the receiver's location, the level increases by 3 dB
  - The correction is valid if the height of the receiver is larger than the wavelength.
- Low-frequency noise deserves a specific attention: if the measurement height is less than $\lambda/4$ from the ground, the sound pressure maximum of the standing wave produces an increment of 6 dB in SPL (same phase of incident and reflected wave).

GENERAL RULES

- Hard ground: +3 dB
  - Water
  - Ice
  - Asphalt
- Soft ground: 0 dB
  - Snow
  - Forest

D_{gr} for wind turbine noise modeling



	***f* [Hz]**	**20**	**25**	**31.5**	**40**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**
Soft ground	D_{gr} [dB]	5.6	5.4	5.2	5	4.7	4.3	3.7	3	1.8	0	0	0	0	0
Hard ground	D_{gr} [dB]	6	6	5.9	5.9	5.8	5.7	5.5	5.2	4.7	4	3	3	3	3

	***f* [Hz]**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10000**
Soft ground	D_{gr} [dB]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard ground	D_{gr} [dB]	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Ympäristöhallinnon ohje, 2/2014
http://www.ym.fi/fi-FI/Ajankohtaista/Julkaisut/OH_22014_Tuulivoimaloiden_melun_mallinta(28436)

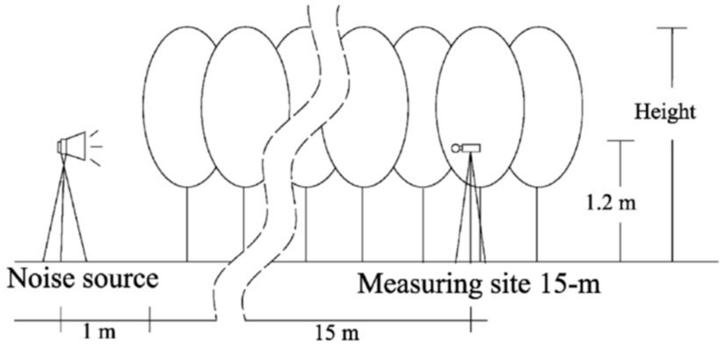
Vegetation attenuation D_{veg}

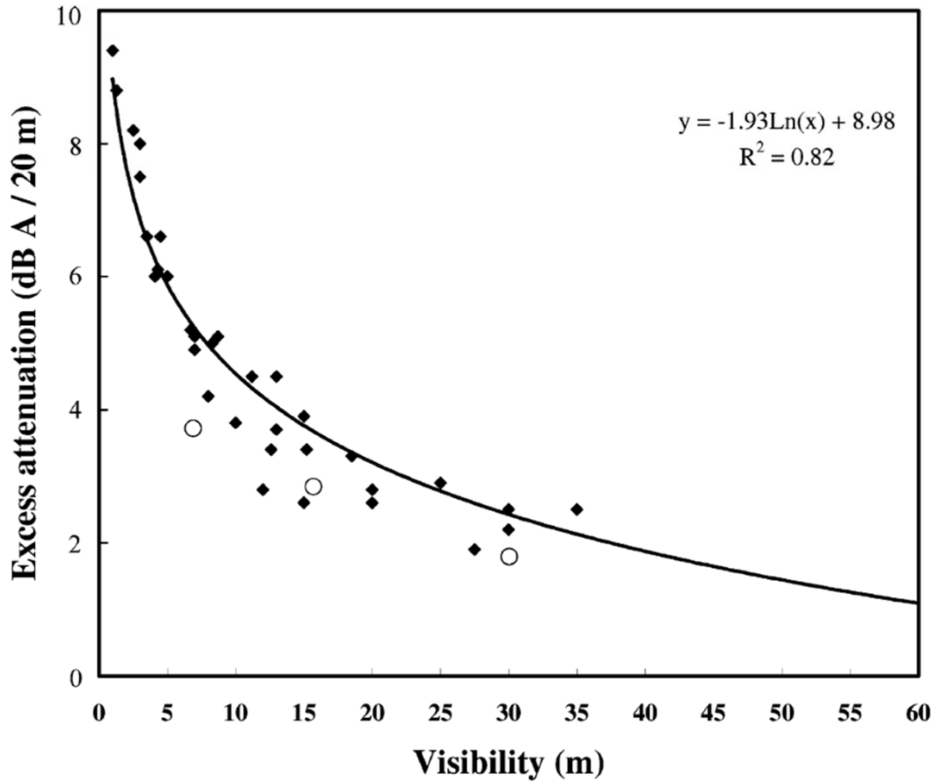
- Fang and Ling (2003) found that the attenuation D_{veg} [dB/20 m] through a vegetative zone is strongly associated with the visibility V_{veg} [m] through the vegetation.

$$D_{veg} = -1.9 \ln\left(V_{veg}\right) + 9$$

- A part of sound bends over the vegetation zones so that there is an upper limit that a vegetative zone can reduce noise in practice.

C.-F. Fang, D.-L. Ling / Landscape and Urban Planning 63 (2003) 187–195



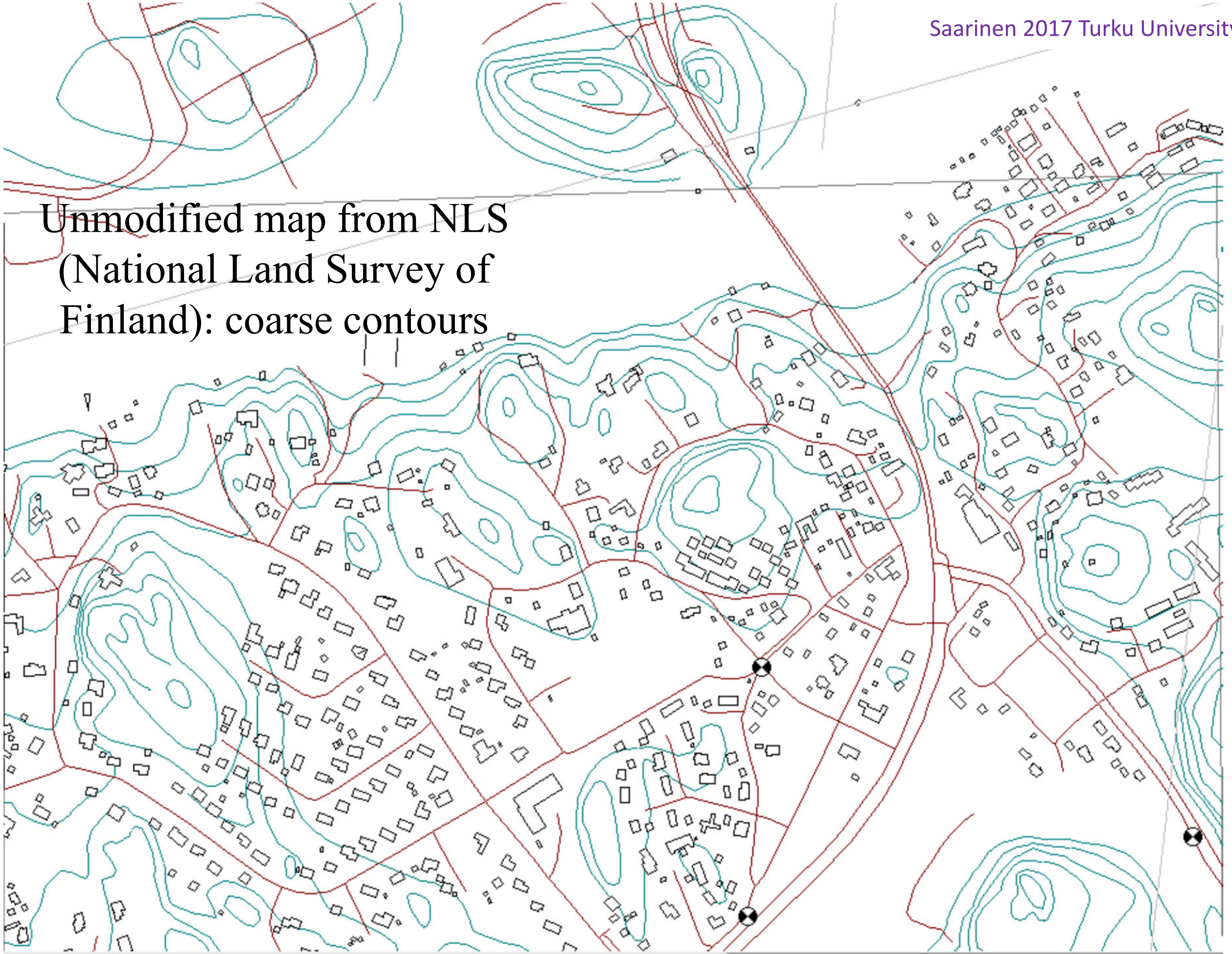


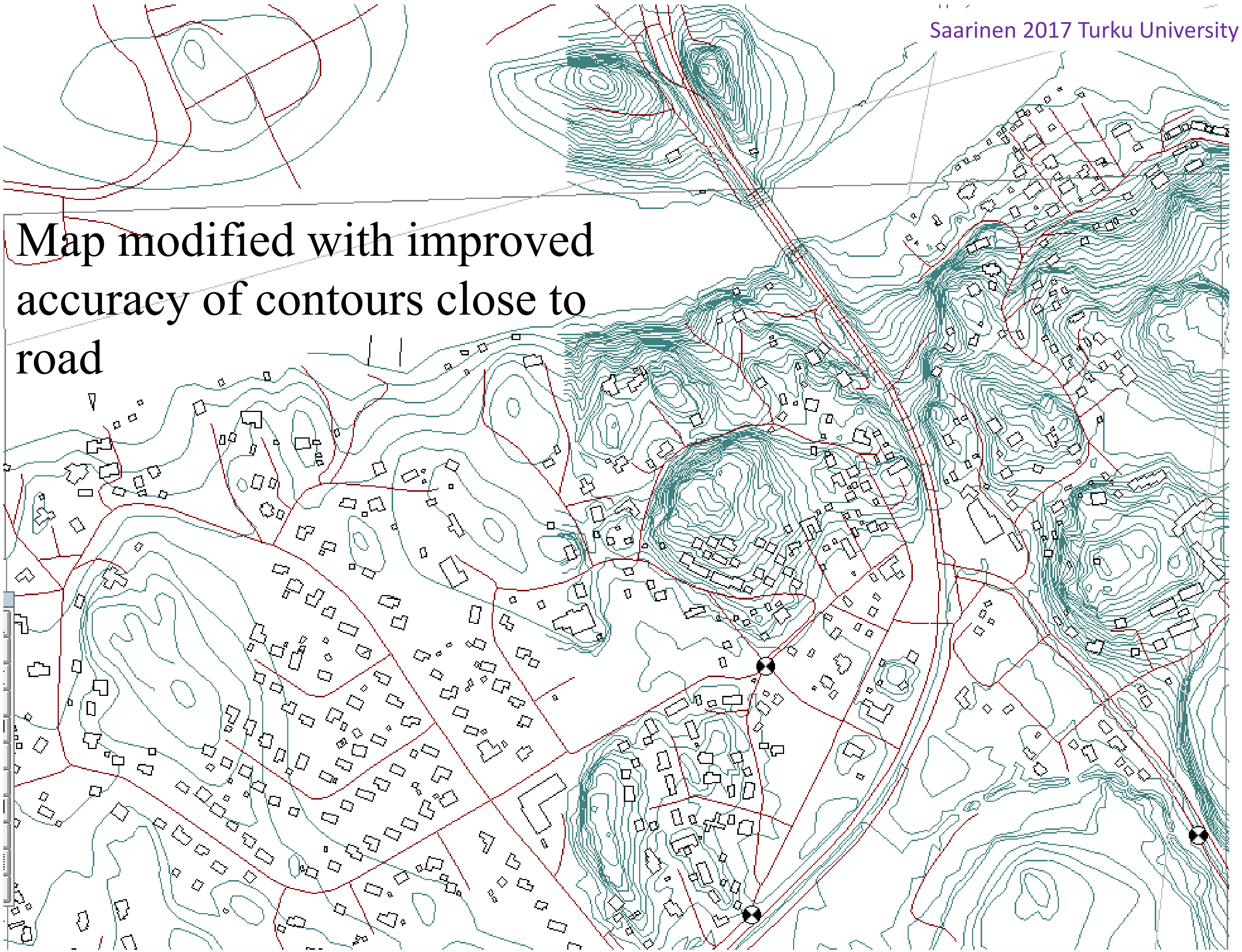
Topography

- Important for sound sources located close to ground
- Topography is downloaded from map service
- Maps give height contours with 5 m density
- Near the sound source, the accuracy may need to be improved by hand

Saarinen 2017 Turku University of Applied Sciences

Unmodified map from NLS (National Land Survey of Finland): coarse contours

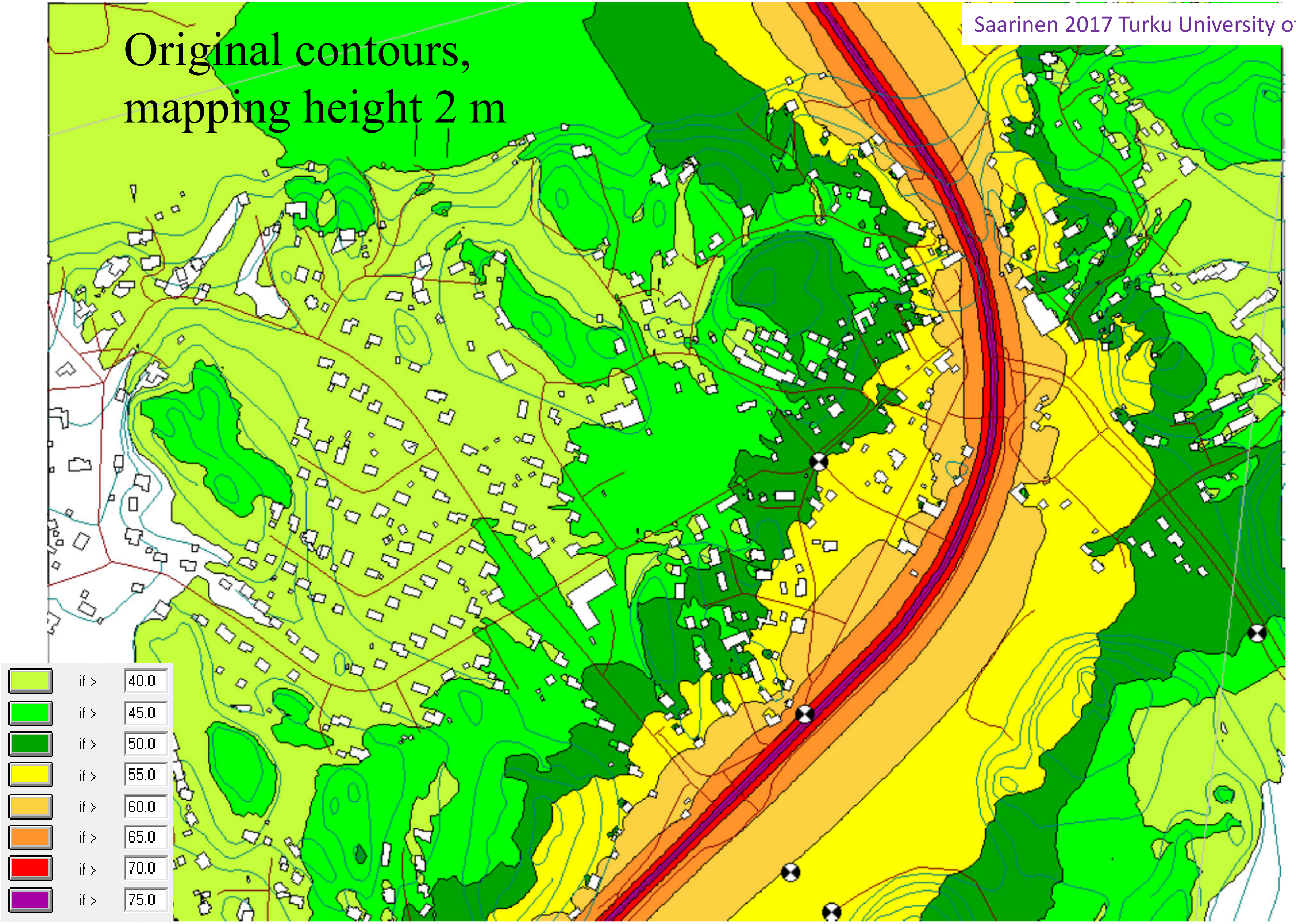




Saarinen 2017 Turku University of Applied Sciences

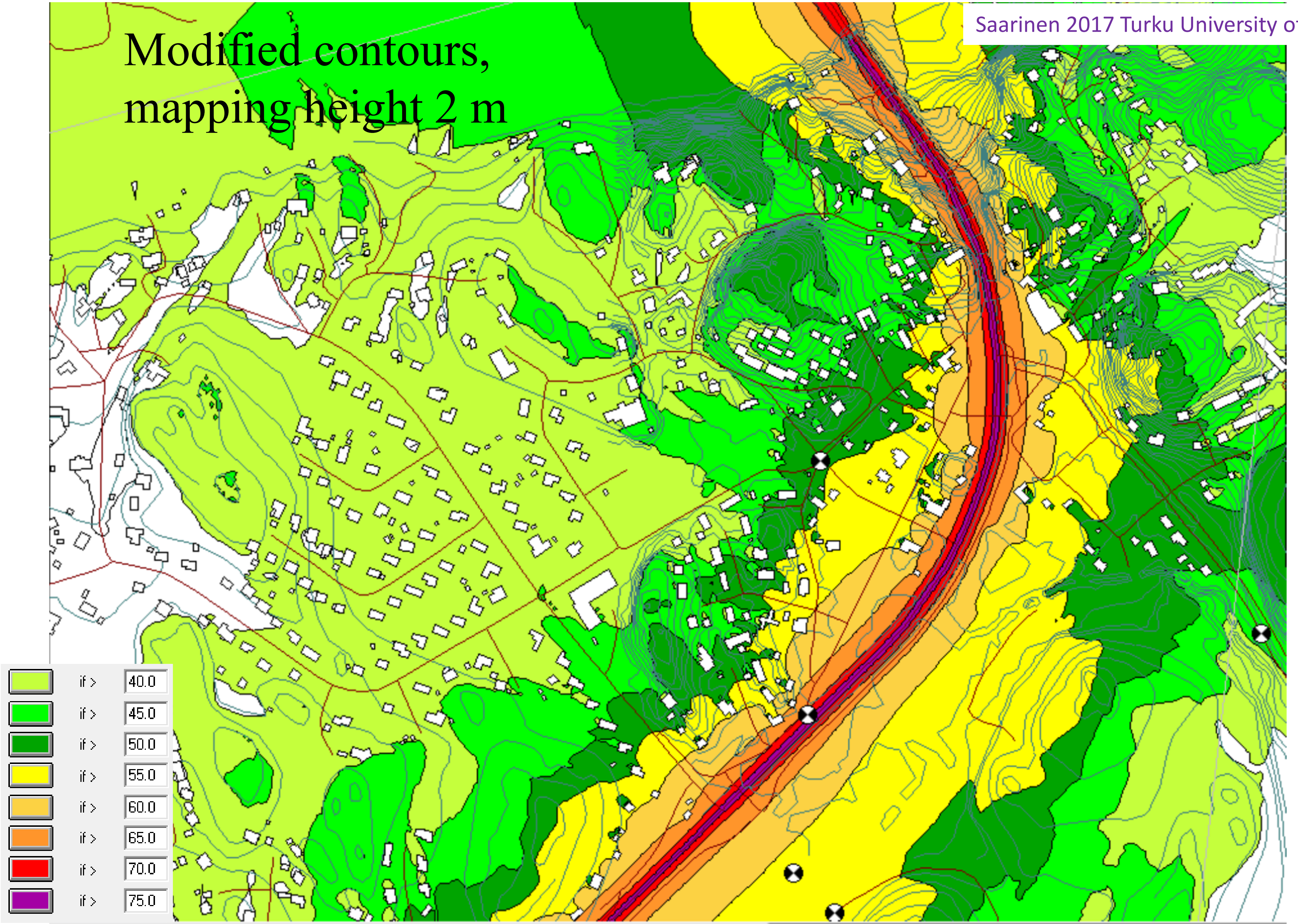
Original contours, mapping height 2 m

Saarinen 2017 Turku University of Applied Sciences



Modified contours, mapping height 2 m

Saarinen 2017 Turku University of Applied Sciences



Noise barriers

hansarakenne.fi

kuhmonbetoni.fi

a1highways.com.au/noise-barriers

sepa.fi

boscoitalia.it

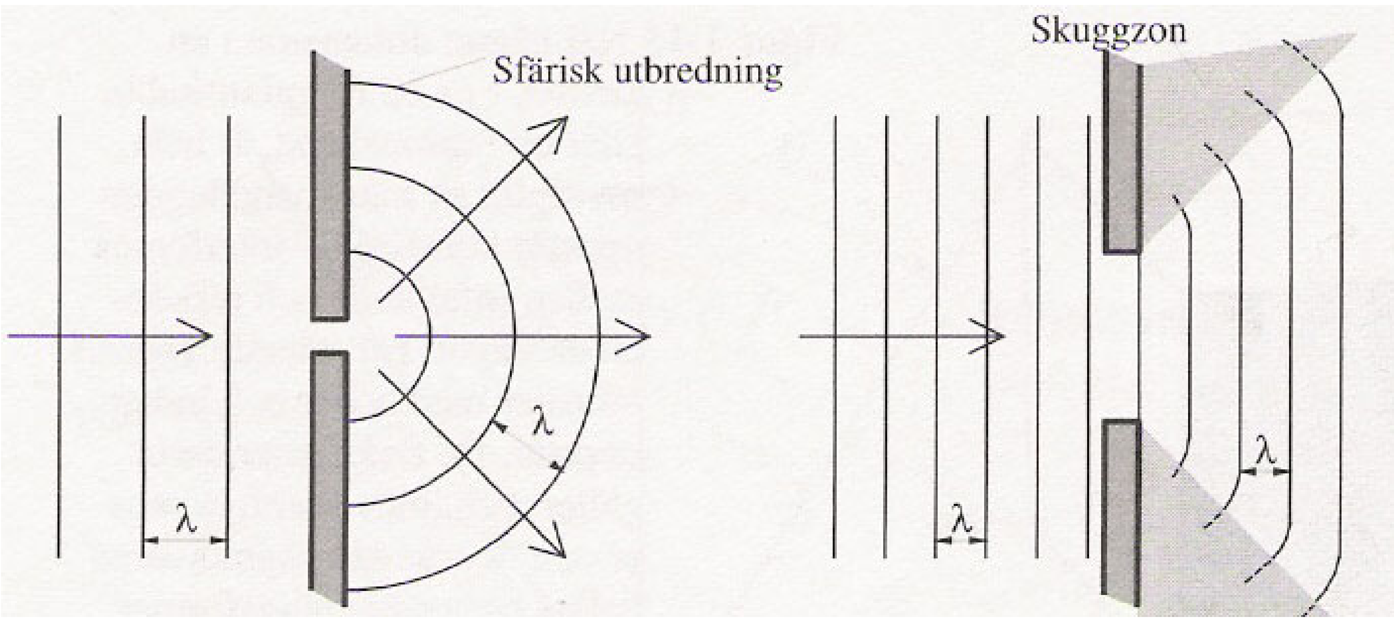
Diffraction in a hole

Strong and perfect diffraction: hole << λ:

- Phase is constant within the hole
- The hole acts as a perfect new point source
- Energy is equally transmitted in all directions behind the hole

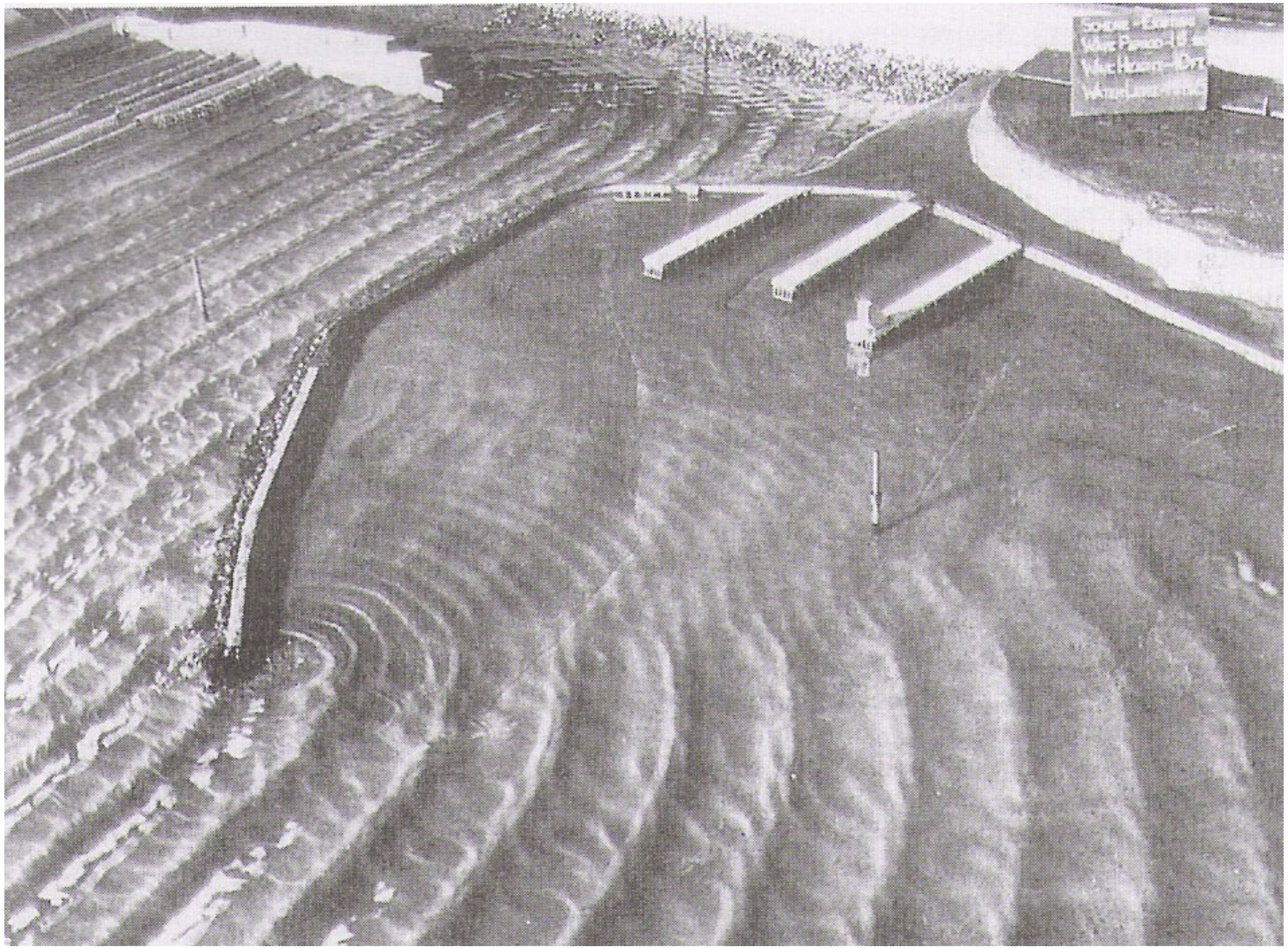
Weak diffraction: hole >> λ

- Phase is not constant within the hole
- Middle part of sound wave transmits the hole without any disturbance
- Only the sound waves closer than λ/2 to the edge ”perceive” full diffraction



Weak diffraction: hole >> λ

- Barrier can be considered as a one-sided infinite hole



Insertion loss of a barrier in free field for a point source

- *Insertion loss*: reduction of SPL in a specific point as consequence of a noise barrier, $D_{nb,tot}$
- Factors affecting insertion loss are diffraction (bending) over the barrier, D_{nb} and transmitted sound through the barrier (airborne sound reduction index, R)
- If R= ∞, barrier's insertion loss D_{diff} [dB] due to diffraction for a point source in free field follows Maekawa's law:
  - L_{p1} without barrier
  - L_{p2} with barrier
  - z is the distance difference [m]

$$D_{nb,tot} = L_{p,1} - L_{p,2}$$

$$D_{nb,tot} = -10 \cdot \log_{10}\left(10^{-R/10} + 10^{-D_{diff}/10}\right)$$

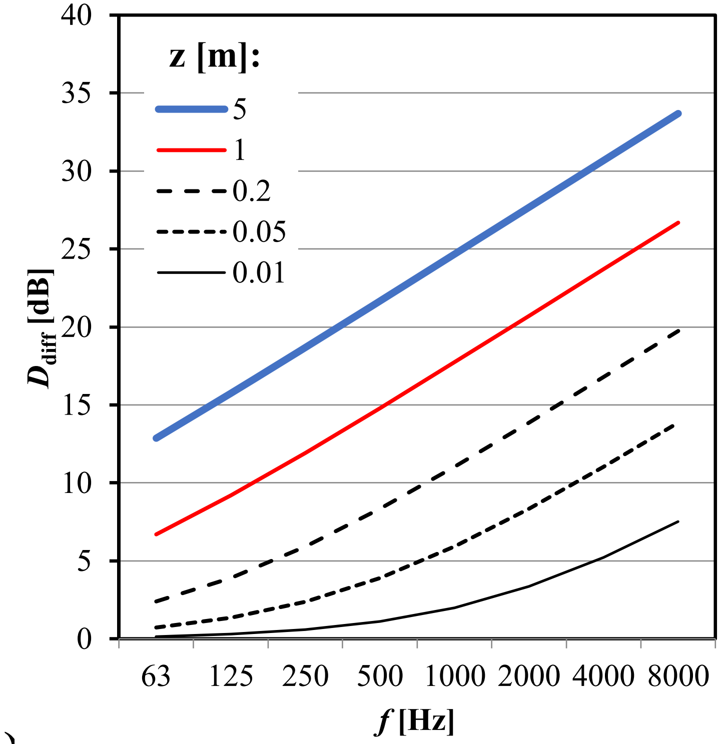
Maekawa's Law

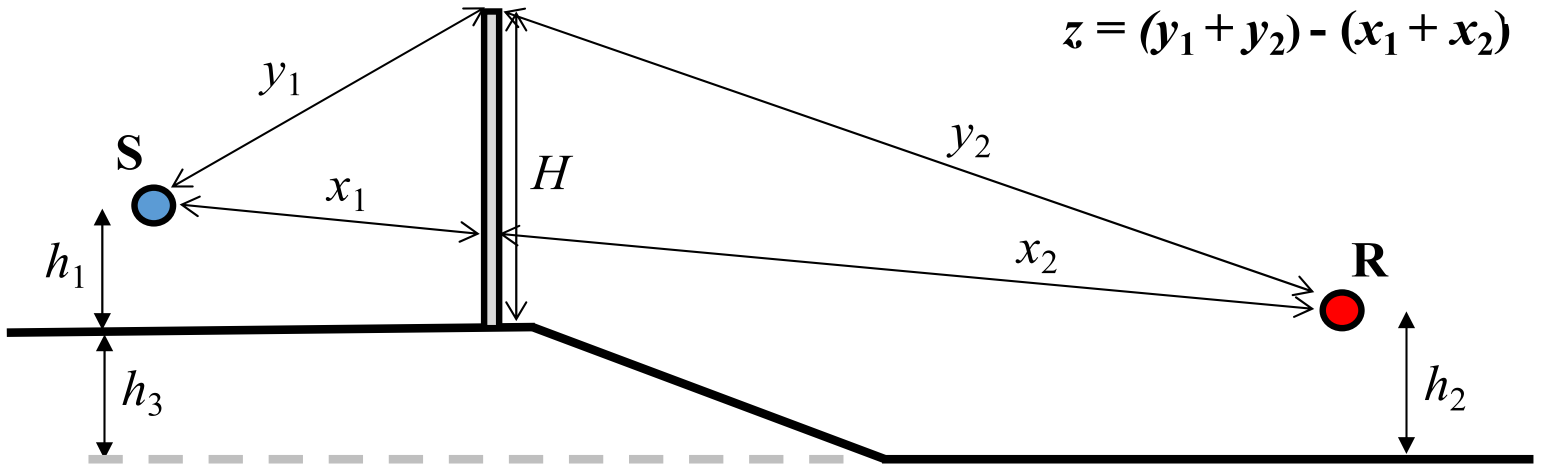
$$D_{diff} = 10\log_{10}\left(1 + 20\frac{z}{\lambda}\right)$$

Distance difference z

- z increases by setting source and receiver close to the barrier
- Maximum value of z is 2H.

$$D_{diff} = 10\log_{10}\left(1 + 20\frac{z}{\lambda}\right)$$

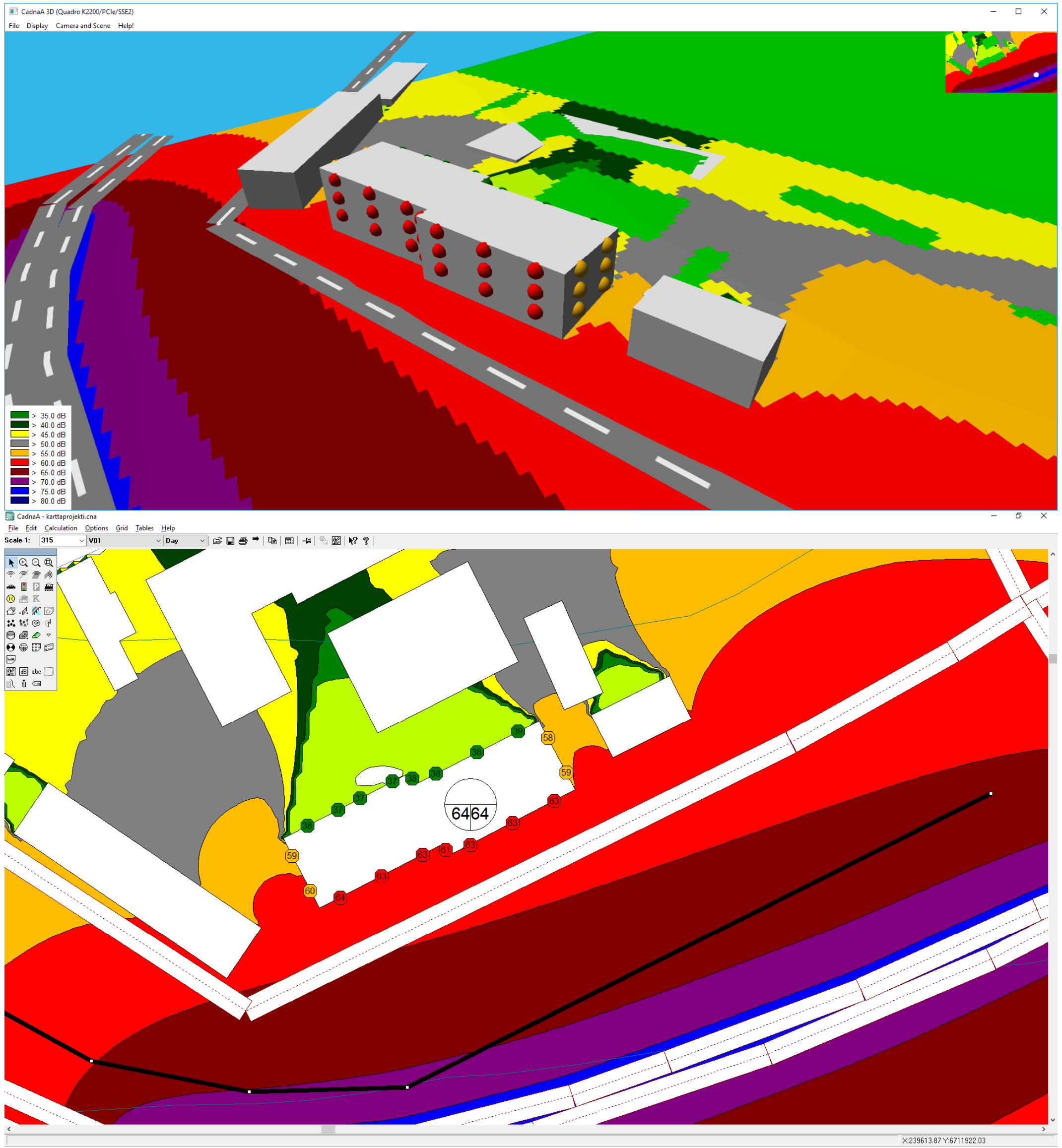




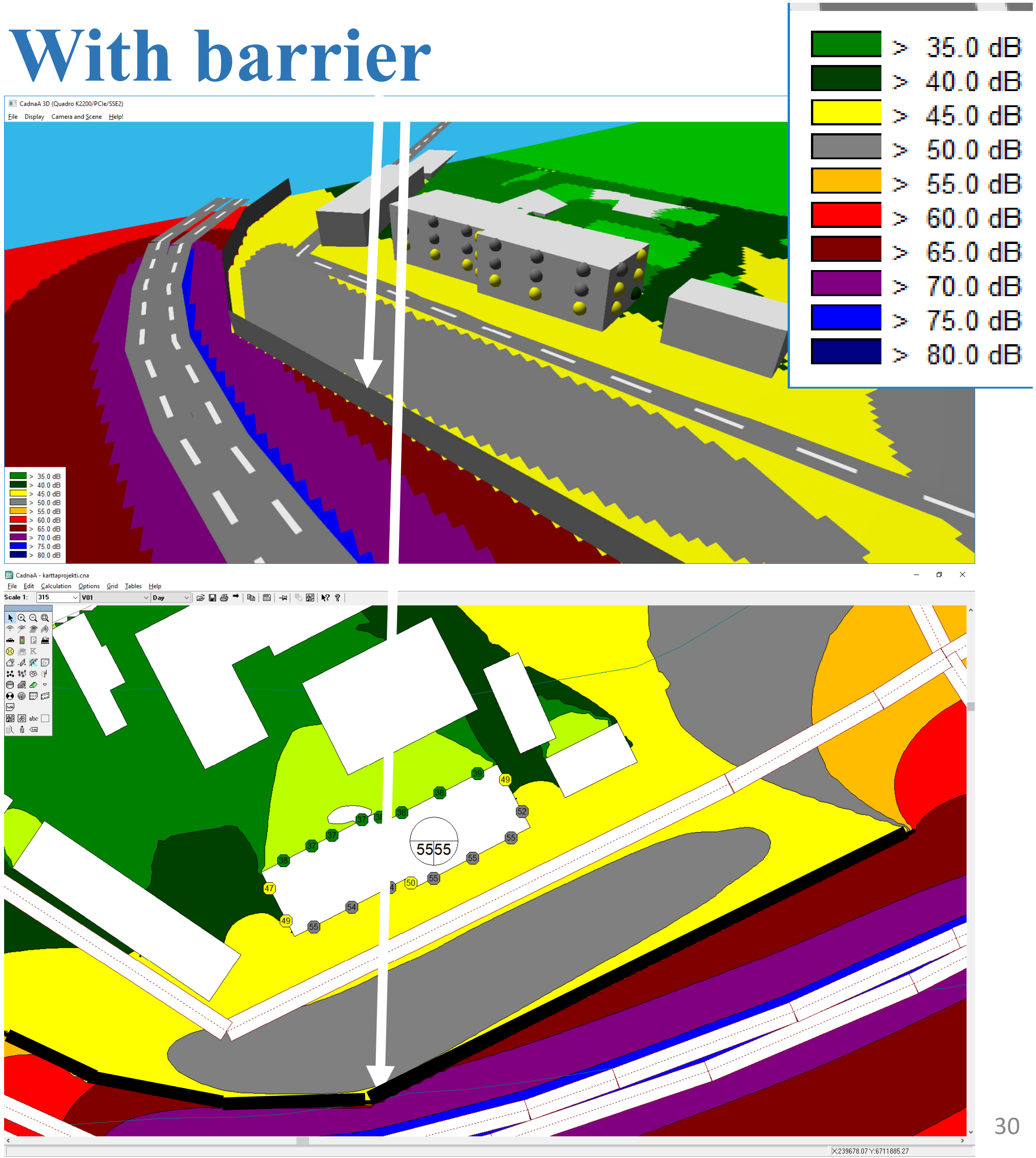
Cadna A. Screen height 4.0 m. 1000 vehicles per hour. 20% heavy vehicles. 50 km/h. Nordic prediction method. Ground absorption 0.4. House height 9 m. Maanmittauslaitoksen karttapohja. Purpose was to study the impact of screen on the facade of the three storey building. The maximum value on the facade reduced from 64 to 55 dB LAeq. The reduction was larger on the lowest floor.

Barrier
Martinsillan Grilli Oy
Subwa
Paratiisintie
Köydenpunojankaari
Köydenpunojankaari
Virusmäenramppi
Yrjänänkatu
2D
Kartta
Google
Kuvat ©2018 Google,Karttatiedot ©2018 Google Suomi Ehdot Lähetä palautetta 10 m

Without barrier



With barrier



L_{den} and L_{dn}

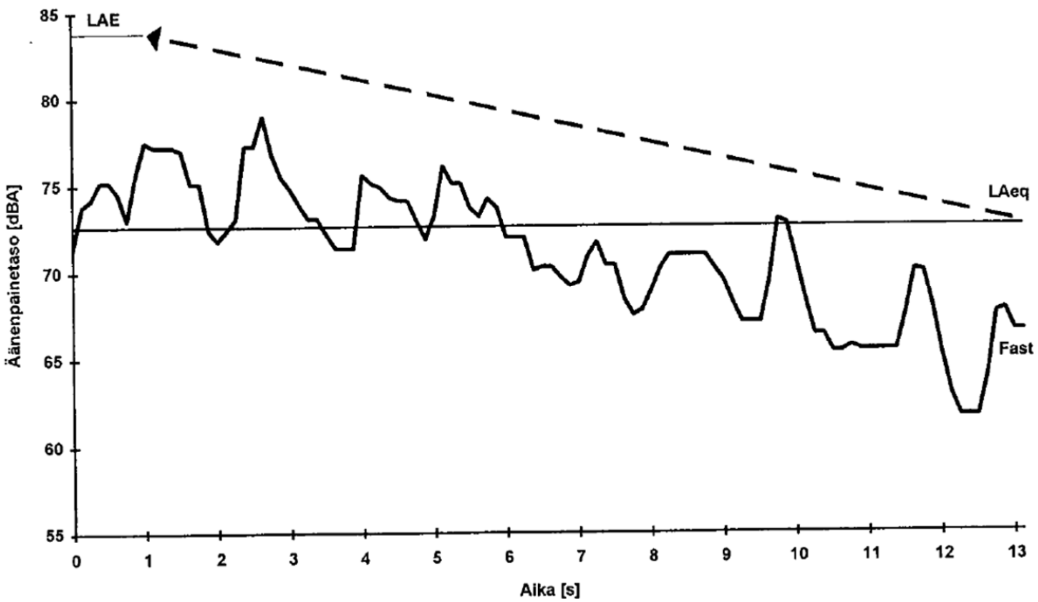
- L_{den} (DENL, day-evening-night level) describes the noise exposure using a single number.
- It has been found to explain well the health effects of environmental noise instead of using separate values for night, evening and day.
- L_{den} involves **penalty for different times of day:**
  - day 07-19: penalty **0 dB**
  - evening 19-23: penalty **5 dB**
  - night 23-07: penalty **10 dB**
- Some documents also use L_{dn}:
  - day 07-23: penalty **0 dB**
  - night 23-07: penalty **10 dB**

$$L_{den} = 10log_{10}\left[\frac{1}{24}\left(12\cdot 10^{(L_{Aeq,07-19}+0)/10} + 4\cdot 10^{(L_{Aeq,19-23}+\mathbf{5})/10} + 8\cdot 10^{(L_{Aeq,23-07}+\mathbf{10})/10}\right)\right]$$

Sound Exposure level L_{AE}

- L_{AE} (*SEL, sound exposure level*) expresses the energy of sound occurrence
- Used for sounds which consist of single occurrences:
  - Train
  - airplane
- L_{AE} means that the whole energy of the occurrences is normalized to 1-second-long occurrence so that different occurrences become comparable. (t_0=1 s).

$$L_{AE} = L_{Aeq,T} + 10\lg\left(\frac{T}{t_0}\right)$$



Kuva 6. Äänialtistustaso (L_{AE}) on tapahtuman keskiäänitaso (L_{Aeq}) normalisoituna yhteen sekuntiin.

Tiihinen & Hänninen, 1997