

# ENVIRONMENTAL NOISE ANALYSIS AND CONTROL FOR LARGE DATA CENTERS

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Data Centers are located in suburban and exurban areas near residential, educational, medical or other acoustically sensitive facilities. Substantial back-up or standby power capabilities are required to prevent power interruption to critical digital (cloud) storage facilities. Engine-generator equipment produce excess environmental noise crossing property boundaries, which requires containment and/or attenuation to conform to regulatory or “good-neighbor” noise limits for nearby properties. Industrial, commercial, financial and other business sectors rely on cloud computing for program applications and data storage. Escalating demand has led to increasing data center construction in many locations. Acoustical compatibility requirements in various codes, ordinances and regulations vary according to land usage, but generally restrict noise levels at property boundaries to moderate or comfortable levels. Other facility refrigeration or ventilation equipment produces continuous noise that should also be controlled. This paper presents interesting problems and conditions that occur in environmental noise analyses and development of noise mitigation for data center facility designs, with brief case studies to illustrate them, including typical configurations, building and power generation equipment source sound spectrum levels, tonal noise perceptibility, low frequency noise and vibration. Measurement data and calculated predictions contrast ambient versus disturbed conditions. Solutions to example problems are presented with plan drawing or graphic acoustical spectrum chart illustrations. Discussion will include typical conflicts, constraints, limitations and compromises. Concluding remarks will suggest application of appropriate and comprehensive acoustical, noise and vibration criteria and practical approaches to noise mitigation.

Keywords: Noise, Environmental, Attenuation, Mitigation, Directivity

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## 1. Introduction

Large-scale cloud computing and data storage demand is driving proliferation of data facility construction. Mission-critical facility owners seek locations with abundant, reliable electrical power, but to assure 100% continuous power, their electronic equipment require large capacities of ventilation cooling and on-site back-up power generation. Gas and diesel engine-powered generators and air conditioning or ventilation air handlers create significant full-spectrum noise emissions the facilities. Building sites are found in urban central business districts, suburban residential and light commercial neighborhoods and exurban farm lands and isolated rural residencies. With such a variety of geographic loca-

tions, many sensitive receptor occupancies are subject to noise disturbance, including medical, educational, religious, residential, hotel, office, entertainment and commercial properties.

In the site evaluation and design of facilities for data storage, environmental noise must be evaluated for conformance with local noise codes, ordinances and regulations and mitigation of disturbance. Noise propagation influences from loud equipment locations (indoor/outdoor), large reflecting surfaces (data center walls), land topography, atmosphere, distances to receivers and acoustical addition from other environmental noise sources require varying levels of noise attenuation or containment. Three case studies are presented herein to illustrate urban, suburban and exurban facility design analyses.

## 2. Data Center Environmental Noise Sources and Sound Propagation

### 2.1 Equipment Locations and Facility Conditions

The most important parameters are hereinafter described:

- Indoor standby generators (in building enclosure) including: radiated engine noise, engine combustion air and radiator air inlet louvered openings, radiator discharge air outlet louvered openings and engine exhaust stack. Indoor equipment noise is typically more contained.
- Outdoor diesel or gas engine standby electrical generators (in weather and sound enclosures) including the following: cooling radiator air inlet, radiator air outlet, combustion air inlet and exhaust stack, and casing radiated engine noise. Outdoor equipment, even in noise enclosures radiates more noise and is more subject to amplifying reflections from nearby building walls.
- Outdoor building heating, ventilating and air-conditioning (HVAC) on roof or at grade. Air handling units (AHU) casing radiation and inlet/exhaust louvers, exhaust fan discharges and exhaust air outlets, package AHU refrigeration compressors and condenser fans, air-cooled chillers and air compressors.
- Vehicles, including on-site service trucks and employee/client (commuting) vehicles.
- Other sources may include outdoor alarms and/or public-address announcement loudspeakers.

## 3. Conditions That Influence Sound Propagation

Noise emitted from the building or outdoor generator and ventilation equipment is amplified or mitigated by various physical conditions on the site and along the pathways toward sensitive receivers.

- Vibrating surfaces of engine and air handler enclosures radiate sounds in multiple directions, while louvered inlet or discharge air openings emit more directional noise. [1]
- Reflecting surfaces, primarily from large, flat building walls and paved surfaces with dimensions much greater than the individual noise sources, increase noise levels, re: directivity indices (DI, dB) and directivity factors (Q) [Foreman] illustrated by Eq. (1) and Fig. 1.

$$DI = 10 \times \log Q. \tag{1}$$

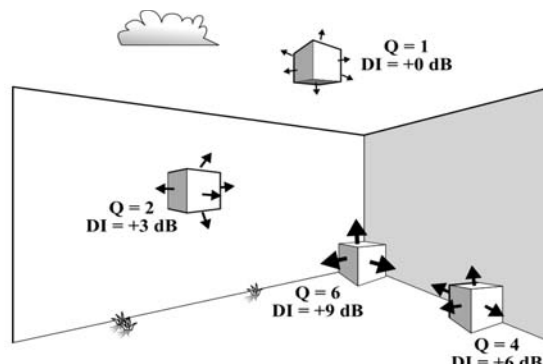


Figure 1: Relationship of Directivity with Large Reflective Surfaces

- “Canyon” effects of sound sources between building walls or building walls and nearby steeply sloped or vertical soil topography cause reverberant build-up of noise between the reflecting surfaces and channeling of sound upward or laterally out the open end(s) of the “canyon.”
- Terrain and Topography: Flat lands permit unobstructed propagation, unless densely forested. Hilly land may provide barriers to sound propagation or cause amplifying reflections. Man-made additions to the terrain, including elevated road or railways, buildings, etc., contribute to barrier and reflector propagation pathway
- Distance loss may be estimated [2] using a sound pressure adjustment shown in Eq. (2),

$$Lp_2 = Lp_1 + 10 \times \log\left(\frac{Q_2}{Q_1}\right) - 20 \times \log\left(\frac{R_2}{R_1}\right) \quad (2)$$

or using a conversion of sound power to sound pressure shown in Eq. (3),

$$Lp = Lw + 10 \times \log(Q) - 20 \times \log(R) - 11 \quad (3)$$

where:  $Lp$  is sound pressure level,  $Lw$  is sound power level,  $R$  is in meters and  $Q$  is the directivity factor given reflecting surfaces.

The corresponding formula in English units where  $R$  is in feet is as follows in Eq. (4):

$$Lp = Lw + 10 \times \log(Q) - 20 \times \log(R) - 0.5 \quad (4)$$

- Atmospheric Conditions: cloud elevations, temperature gradients, wind speed and direction and other weather conditions cause spatial and directional changes to sound propagation.
- Receiver Perceptibility: time of day (day/night), on-off or modulation of sound, tonality or balanced spectrum, transience or continuity vary human receiver perception of sound.

## 4. Ordinances, Codes, Regulations and Environmental Noise Criteria

Local or regional regulation of noise varies between different jurisdictions, although permissible noise limit ranges are similar at property boundaries of typical zoning categories, residential, educational, medical, and commercial, etc. Most, but not all regulations, reduce the permissible nighttime noise. Some apply a penalty for tonal or impulsive sounds. Many ordinances lack a time component, i.e., an instantaneous excess noise level is legally the same as a long-term offending sound. Other ordinances use equivalent level,  $Leq$ , or other time-weighted level as the limit descriptor. The time-of-day, tonality and/or duration factors affect design considerations for outdoor noise-producing equipment.

To limit complaints; permit i) neutral-spectrum noises no more than 10 dB greater, and ii) tonal noises no more than 1-5 dB greater than quiet ambient conditions, depending on tonal frequency.

## 5. Case Study 1 – Urban Industrial District Data Center

### 5.1 Location Description

This data center is in a mid-western U.S. state in urban, industrial location, mostly flat, compared to facility buildings and equipment heights

Distance to nearest receiver property boundaries and describe occupancies: 130 m (425 ft) to nearest sensitive receiver: child care facility, to west, 70 m (555 ft) and 2335 m, (775 ft) to business zoning north and south of the facility, and 110 m (360 ft) to separate owner’s admin. building. An international airport is 4.5 km, (2.8 miles) to the southeast. Multi-lane roadways are on three sides  $\geq$  100 m (330 ft).

The Generator facility is one wing of a building that has occupied office and conference spaces as little as 6 m (20 ft) from the generator rooms’ inlet louvers.

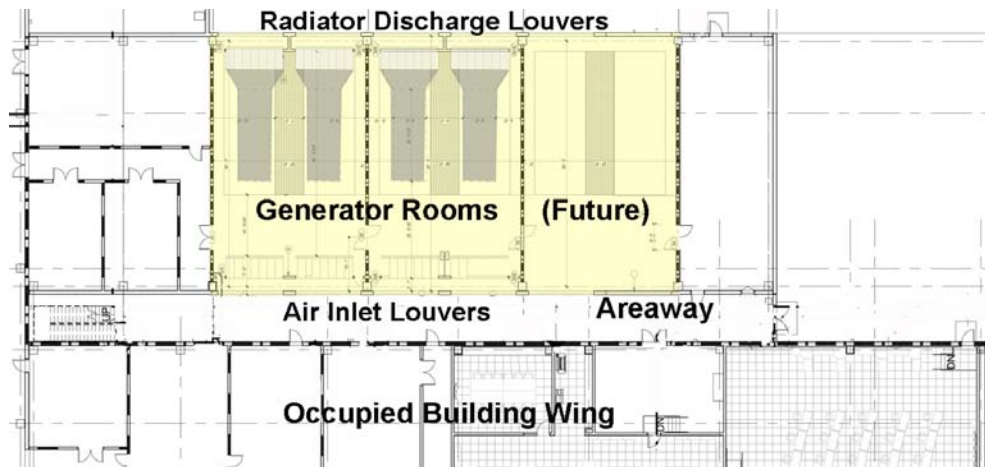


Figure 2: Generator Rooms Across Areaway From Occupied Building Wing

### 5.2 Generator and Building Equipment

This data center has four 3.4MW/1800 rpm generators with turbo inlets per each of two generator rooms plus two future generators in a third room. The generator buildings have inlet louvers in a building areaway (with occupied spaces on other side) and radiator air louvers discharging through opposite ends of rooms. Reverberant noise build-up is anticipated in the areaway, but discharge is to open space with no nearby reflecting surfaces.

Little, if any, additive noise from other building equipment is anticipated, with exception of electrical load banks, 84-90 dBA at 1.5m (5 ft) to be installed in a yard near the generators. A wall enclosure plus some cabinet ventilation attenuation was recommended to reduce level.

Table 1: Ambient Daytime Noise Estimate: Industrial Level with Roadway Traffic

	Overall		Frequency (Hz)							
	dBC	dBA	63	125	250	500	1k	2k	4k	8k
Noise	73	67	70	67	63	62	64	60	52	43
Hourly Leq	LeqC	LeqA								

Based on monitored levels in similar urban industrial area with roadway traffic

### 5.3 Noise Ordinance Limits

The controlling jurisdiction has an ordinance, code and/or regulation limiting generator noise at property boundaries to 55 dBA at night, 72 dBC. Daytime, 65 dBA.

Table 2: Ordinance Limits – Noise From Industrial Activity Crossing Residential or Business Zoning District Property Boundary (summed from A-weighted octave limits).

Limits	Overall		Frequency (Hz)							
	Max dBA	dBA	63	125	250	500	1k	2k	4k	8k
Nighttime 10 pm-8am	71 LmaxA	51 LeqA	66	65	52	46	40	35	35	32
Daytime 8am-10pm	71 LmaxA	56 LeqA	67	66	59	52	46	40	38	38

Excerpt from (undisclosed city) Article XXI, 1-1, Limited Industrial District ordinance, re: Sterling codifiers, Inc. <http://www.sterlingcodifiers.com/codebook/printnow.php>, 3/5/12

### 5.4 Recommendations

Attenuation measures were recommended for environmental noise propagation to adjacent properties of varying occupancy and for mitigation of noise disturbing the adjacent occupied building wing.

Indoor generator rooms: Install sound attenuating inlet air and radiator discharge louvers or attenuator banks behind architectural louvers

Specify high performance, DIL > 45 dBA, three chamber reactive exhaust muffler with body > 3 x inlet diameter and length > 10 x inlet diameter.

Install acoustically absorptive surface finish on one or more walls of areaway between generator room and occupied wing of building. Also install thick or insulated laminated glass in windows.

## 6. Case Study 2 – Suburban Commercial-Industrial District Data Center

### 6.1 Location Description

This data center was located immediately adjacent to an existing data center belonging to the same owner. It is in a central southern U.S. state in suburban location adjacent to residential and light-industrial land uses. The site and general vicinity are hilly, with elevation changes two to three times height of the data center building. The facility is approximately 6 m (20 ft.) lower ground elevation than the existing facility, which has indoor generators. The new facility will have outdoor generators.

Distance to nearest sensitive receiver property boundaries: approximately 125-130 m (400-425 ft) to residential properties to east and north, respectively, and to business zoned properties; 290 m (950 ft) west to low-rise medical office building, 185 m (600 ft) south to a low-rise bank and office building and 460 m (1500 ft) southwest to hotels.

On-site and vicinity noise monitoring between 10:30 am – 1:30 pm showed weekday ambient environment noise levels varying between 45 dBA/58 dBC and 58 dBA/77 dBC. Continuous noise sources in the environmental noise ambient include outdoor building equipment at nearby commercial /business buildings, a four-lane boulevard roadway to the south and southwest sides of the property and a high-speed multi-lane roadways is 605 m, 1985 ft) to the southwest.

### 6.2 Generator and Outdoor Building Equipment

Twenty 2.0MW and two 1.5 MW generators, each in sound-attenuating weather enclosures, are planned outdoors on ground level in clusters of three, to be distributed around the north, east and west sides of the facility. Adjacent reflective building walls are approximately 1.5 times the height of the genset enclosures. The manufacturer noise data indicates low frequency tonality, i.e., 8 dB sideband differential between 125–250 Hz octaves.

Ninety-eight ventilation/air handlers of similar size and noise level are planned, to be evenly distributed across the facility roof. Although the additive effect of all AHUs operating simultaneously approaches + 20 dB ( $10 \times \log(98) = 19$ ), design analysis indicates potential addition of ventilation noise to operating generator noise is 1-3 dB in 500 Hz octave. Therefore, the generator noise is dominant.

Table 3: Predicted\* Generator + Ventilation Noise at Residential Property Boundaries

	Overall		Frequency (Hz)							
	dBC	dBA	63	125	250	500	1k	2k	4k	8k
Noise Level	64 LeqC	52 LeqA	58	<b>62</b>	54	50	44	40	37	33

\*Based on calculations using manufacturers’ equipment noise radiation data less enclosure manufacturers noise reduction data; summed with acoustical addition of multiple sources, reflections and directionality incorporated.

### 6.3 Noise Ordinance Limits

The municipal noise ordinance permits up to 63 dBA daytime at residential property boundaries. Nighttime levels are 7 dBA lower. Tonal or impulsive sources have a 7 dBA penalty. A tonal sound source at night, therefore, cannot exceed 49 dBA. Example: (Ordinance Limit, dBA = 63 - 7 - 7).

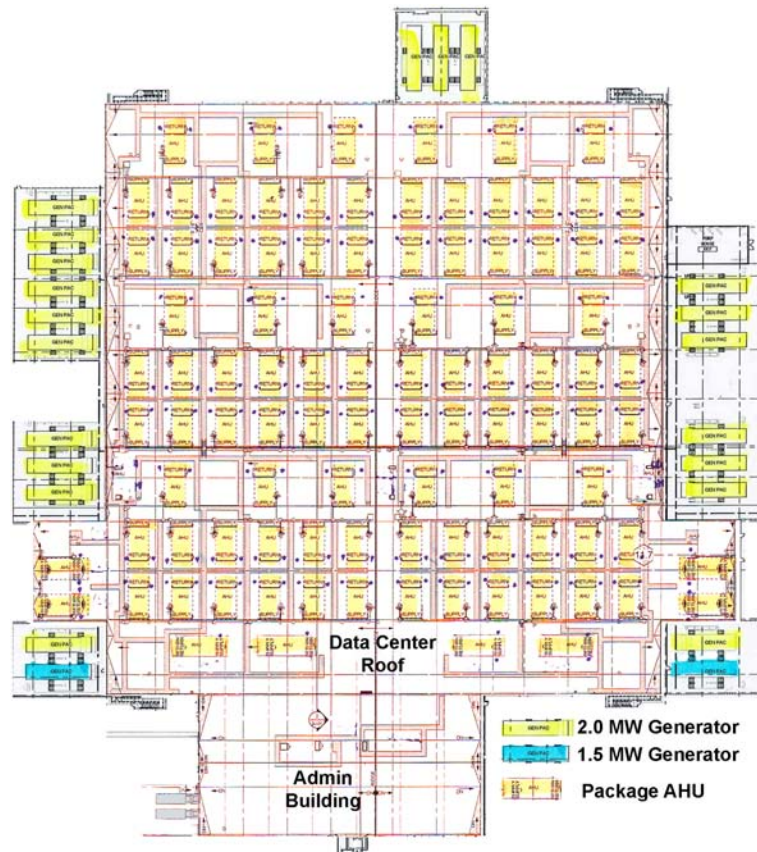


Figure 3: Facility plan with generators' on ground and rooftop AHUs'

## 6.4 Recommendations

Alternate attenuation concepts were recommended for design engineers to select and implement:

Genset enclosures: Consider supplementing or increasing air inlet and radiator discharge attenuators to achieve +3 dB dynamic insertion loss (DIL).

Engine Exhaust Muffler: Upgrade/enlarge muffler to achieve +3 dB performance.

Generator Clusters: consider installing walls around each group of three generators to improvement containment of laterally radiated noise in direction of residential properties.

Facility Walls: apply acoustically absorptive surface finish (environmental durable products) to building walls near generators to reduce reflective noise contribution.

Facility Room: Increase building parapet height or place sound barriers between rooftop air handlers and building edge to reduce laterally radiated noise from AHU inlet and exhaust louvers.

## 7. Case Study 3 – Exurban Location

### 7.1 Location Description

This data center was located in northern U.S. state in an exurban location. The site and vicinity are mostly flat terrain with some hills, having about 3 m (10 ft) elevation change. One nearby area is heavily wooded with dense evergreen growth, which would provide noise mitigation in the east direction. Surrounding vicinity terrains in the other directions are grassy land or farmland, generally flat in comparison with the 6-8 meter (20-25 ft) tall data center building and equipment heights.

Distances to nearest sensitive receivers are: 125 m (410 ft) and 250 m, (820 ft) to nearest residential and farm houses north and east of the facility, 70 m (230 ft) to nearest golf course to the north, with international airport < 2 km (1.24 mile) and two four-lane highways < 400m (13120 ft) nearby.

## 7.2 Generator and Outdoor Building Equipment

The facility has ten existing 2.5MW diesel generators per each of six existing data center buildings, plus one 800kW diesel generator at the existing administrative building, and one 2MW diesel generator per each of four support buildings are extant. A new expansion is planned with twenty 3MW diesel distributed along the north and south faces of the buildings, plus one new 1MW diesel generator in an open area near a new administrative building.

In total, 86 outdoor diesel generators, normally aspirated (no inlet turbochargers), with radiators and air circulating prop fan, are housed inside sound attenuating weather enclosures. The proposed generators are located 4 to 10 m (13 to 33 ft.) from the data center exterior wall (large reflecting surface). Facility ventilation air handling units (see below) are located on the ground between generators and AHUs along each side of the buildings.

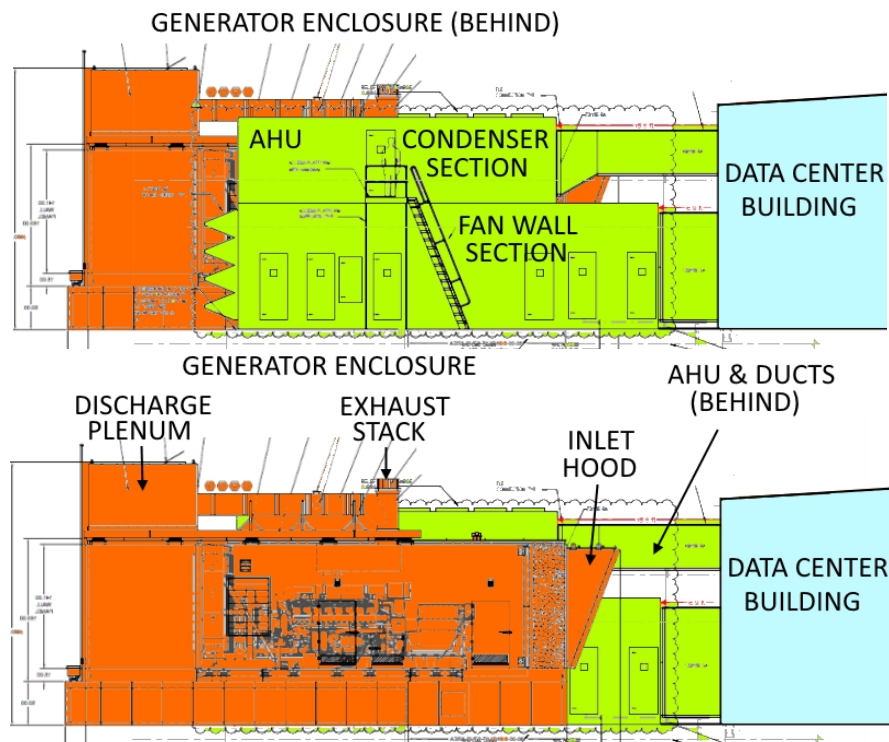


Figure 4 a, b: Generators' and AHUs' relationship to Data Center Exterior Walls

New outdoor package air-handling ventilation units with plenum fan-walls and compressor/condenser sections were proposed. Existing building equipment includes rooftop package air handling units with compressor/condenser sections, indoor fan-wall air handling units, indoor wall-mounted ventilating prop fans, and indoor fluid cooled computer room air conditioners with scroll compressor noise. New and existing building equipment were estimated to produce noise levels at adjacent properties generally in conformance with ordinance limits. Noise from all non-generator equipment was at least 9 dB quieter in all octave bands, and therefore not anticipated to acoustically add to generator noise.

Environmental ambient noise (estimated, based on existing conditions, distances and roadways).

Table 4: Ambient Daytime Noise Level Estimates for Residential Areas

	Overall		Frequency (Hz)							
	dBC	dBA	63	125	250	500	1k	2k	4k	8k
Noise Level, Hourly Leq	66 LeqC	59 LeqA	60	61	59	56	55	51	42	31

### 7.3 Noise Ordinance Limits

The controlling jurisdiction has an ordinance, code and/or regulation limiting generator noise at property boundaries to: L5 percentile, 55 dBA at night, 72 dBC. Daytime, 65 dBA, 76 dBC.

(Undisclosed city and extraterritorial jurisdiction) Noise Ordinance, Chapter 7 “Noise Control,” Sec. 4-7-6 thru 4-7-7.

Table 5: Ordinance Limits - Noise Received on Residential Zoned Property

	Daytime 7AM-7PM	Evening 7PM-10PM	Nighttime 10PM-7AM
Basic Levels (L5A)	65 dBA	60 dBA	55 dBA

Table 6: Ordinance Limits - Noise Received on Business Zoned Property

	Daytime 7AM-7PM	Evening 7PM-10PM	Nighttime 10PM-7AM
Basic Levels (L5A)	65 dBA	65 dBA	65 dBA

### 7.4 Recommendations

Attenuation measures were recommended for the generator noise-control weather enclosures: [3, 4]

- Mineral wool insulated 900 mm (36") deep intake sound baffles
- Insulated sound directional exhaust plenum
- 100 mm (4") thick mineral wool insulation with perforated liner
- Protective hood with fixed vane louvers over air inlet
- Heavy duty spring isolators
- Interior mounted critical grade silencer
- Side mounted intake relief openings with fixed vane sound louvers
- Genset enclosure noise was estimated using spreadsheet calculations and SoundPLAN 3D noise modeling [5] to just achieve the prescribed nighttime operation limits of the ordinance.

Noise barrier walls evaluated for optimum confidence, but were eliminated in “value engineering.”

**Final Result:** Indications by owner that existing neighbour has not complained with respect to day-time equipment exercise.

## 8. Conclusions

Data center construction has proliferated across the country in urban, suburban and exurban areas. The mission critical operational requirements of the facilities make large cooling ventilation and high capacities of backup power absolutely necessary. The resulting environmental noise, continuous and broadband for ventilation and sporadic and tonal low-frequency dominant for generators, should be limited to avoid undesirable disturbance to sensitive receiver neighbors and to conform to regulations. Sound quality and volume, propagation influences, distances and nature of sensitive receptors must be considered in analyses. There are many physical and parametrical differences between different sited, but each project requires careful analysis and implementation of noise mitigating measures.

## REFERENCES

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