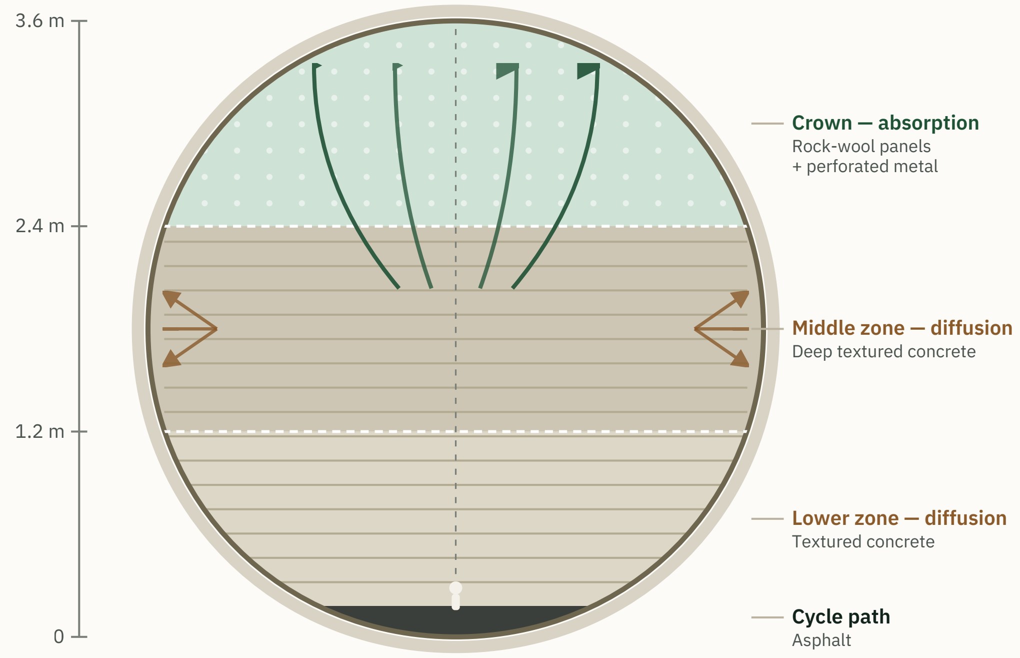
Vélo Tunnel Québec

TECHNICAL BRIEF · ACOUSTICS

TECHNOLOGY · IMPLEMENTATION · COSTS

Acoustics of the cycling tunnel

How to turn a 150 km concrete tube into a controlled, comfortable sound space — bringing reverberation down from 6–8 seconds to under 2 seconds.



TUNNEL CROSS-SECTION — Ø 3.6 m

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1 Executive summary

A bare concrete tunnel behaves like a cathedral: sound bounces around for six to eight seconds. Two complementary technologies, applied continuously over the full 150 km, bring that reverberation below two seconds — the hushed feel of a library — for roughly C$450 million, or C$3 million per kilometre.

REVERBERATION
6–8 s → < 2 s
from "cathedral" to "library"

COST OVER 150 KM
≈ C$450M
C$3.0M/km · ~5% of project

MATERIALS
100% non-combustible
concrete · rock wool · metal

The acoustic challenge in a cycling tunnel is not a comfort detail: a long echo is tiring, drowns out safety announcements, makes any conversation unpleasant, and amplifies ventilation noise to the point of discomfort. The solution rests on two complementary layers. First, **textured concrete** that scatters sound instead of bouncing it back like a mirror — this is *diffusion*. Second, **rock-wool panels faced with perforated metal**, mounted on the crown, which soak up the remaining sound energy like a sponge — this is *absorption*.

This document explains the technology, how to apply it over 150 km, the physics that gets reverberation below two seconds, and a detailed cost breakdown. It also shows why this line item pays off twice over: the same materials that kill the echo make mechanical ventilation bearable and form a fully non-combustible lining — one investment, three problems solved.

2 The problem: why a tunnel echoes

Sound is a pressure wave that travels through air and bounces off hard surfaces. In an ordinary room — furnished, with carpets, curtains and people — that energy is quickly absorbed. A concrete tunnel is the exact opposite: smooth, dense, parallel walls that reflect almost all the energy they receive. The sound circles round and round before it dies away.

Two phenomena follow. The first is **reverberation**: a long acoustic tail that blurs everything, as in a church or an underground parking garage. The second is **flutter echo**: between two parallel surfaces, sound bounces back and forth at a steady interval, producing that metallic "megaphone" timbre. A simple bell becomes harsh; a voice carried ten metres away comes back as mush.

For a network ridden every day by tens of thousands of cyclists, that is unacceptable. A controlled sound environment is therefore not a luxury: it is a condition of comfort, of safety (hearing an announcement, another user, a service vehicle) and of public acceptance for the project. The engineering target is a number: bring the **reverberation time below two seconds**, the recognised threshold for a large volume to stay intelligible and pleasant.

3 The solution: two complementary layers

The strategy does not rely on a single miracle material, but on the complementarity of two distinct physical mechanisms: scatter what can be scattered, absorb the rest.

3.1 — Diffusion: textured concrete

Rather than casting smooth rings, the lining is moulded with relief patterns — grooves, waves, facets. A flat surface sends sound back in a single direction, just as a mirror reflects light; a textured surface scatters it in every direction. The energy is not *removed*, it is *redistributed* in time and space. The immediate result: flutter echo disappears and the harshness of the timbre softens. Diffusion alone is not enough to shorten the acoustic tail much — it sets the stage for absorption.

3.2 — Absorption: rock-wool panels + perforated metal

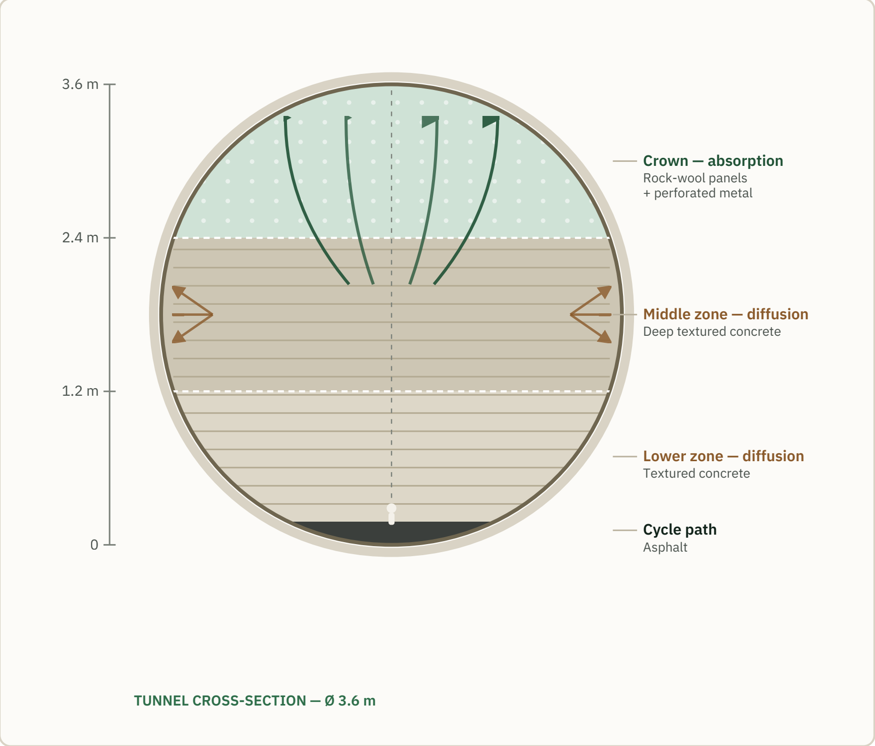
On the upper part of the tunnel, where sound concentrates, absorbing panels are installed. Their construction is precise: a thick layer of **rock wool** (the absorbing material), mounted with an air gap behind a sheet of **perforated metal**. The metal protects the wool, is easy to clean and fire-resistant, while being acoustically "transparent" thanks to its perforations: the wave passes through it and dies in the wool. The depth of the assembly (wool thickness plus air gap) tunes how well it absorbs low frequencies — the hardest to tame.

3.3 — The three zones

Treatment varies by height, because not every surface plays the same acoustic role. The lower and middle zones, at ear and handlebar height, receive increasingly deep textured concrete; the crown, where energy accumulates, receives the absorbing panels.

THE THREE ACOUSTIC TREATMENT ZONES

Zone	Height	Treatment	Role
Lower zone	0 – 1,200 mm	Textured concrete	Diffusion at wheel height
Middle zone	1,200 – 2,400 mm	Deep textured concrete	Diffusion at ear height
Crown (upper zone)	2,400 mm → ceiling	Rock-wool panels + perforated metal	Absorption of residual energy
Floor	—	Asphalt cycle path	None (running surface)



Tunnel cross-section. Lower and middle zones carry textured concrete (diffusion); the crown carries rock-wool panels faced with perforated metal (absorption). Green arrows show sound energy absorbed at the crown; brown arrows show energy scattered by the textured walls.

4 The science: how we reach under 2 seconds

The acoustic performance of a large volume is measured by its **reverberation time**, written RT_{60}: the time it takes a sound to decay by 60 decibels — that is, to become a thousand times quieter — in practice, the time it "takes to die". The shorter it is, the more intelligible the space.

4.1 — The Sabine equation

The reference calculation is the Sabine equation, which links reverberation time to the volume of the space and its total absorption:

$$RT_{60} = 0.161 \times \frac{V}{A}$$

where **V** is the volume (in m³) and **A** the total absorption (in m² sabins). That absorption A is found by adding, for each surface, its area times its **absorption coefficient α** — a number between 0 (reflects everything, a perfect mirror) and 1 (absorbs everything, an open window). Smooth concrete has an α of about 0.02; good rock wool exceeds 0.85.

4.2 — The bare tunnel: the calculation

Let us reason over one metre of tunnel, which repeats identically along the whole length. The geometry is set by the 3.6 m internal diameter.

TUNNEL GEOMETRY (PER LINEAR METRE)

Quantity	Value
Internal diameter	3.6 m
Radius	1.8 m
Internal perimeter	11.3 m
Cross-sectional area	10.2 m²
Volume per metre (V)	10.2 m³

The surfaces are then split across the three zones and assigned their absorption coefficient, first bare (all smooth concrete), then treated.

SURFACES AND ABSORPTION COEFFICIENTS (AT 500 HZ)

Surface	Area (m²/m)	α bare	α treated
Floor (asphalt)	3.0	0.03	0.03
Lower + middle walls (textured concrete)	3.3	0.02	0.07
Crown (absorbing panels)	4.4	0.02	0.85
Total	**10.7**	—	—

Bare, the total absorption per metre is A = (3.0 × 0.03) + (7.7 × 0.02) ≈ **0.24 sabin**. Applying Sabine:

$$RT_{60} = 0.161 \times \frac{10.2}{0.24} \approx 6.7\ \text{s}$$

This lands exactly on the stated range: **6 to 8 seconds**. A raw concrete tunnel really is an acoustic cathedral.

4.3 — The treated tunnel: the calculation

With treatment, the crown's absorption leaps. A = (3.0 × 0.03) + (3.3 × 0.07) + (4.4 × 0.85) ≈ **4.06 sabins** — nearly seventeen times more. The same calculation now gives:

$$RT_{60} = 0.161 \times \frac{10.2}{4.06} \approx 0.40\ \text{s}$$

CALCULATED REVERBERATION TIME (SABINE)

Scenario	A (sabins/m)	RT_{60}	Ambience
Bare tunnel (smooth concrete)	0.24	6.7 s	Cathedral — megaphone effect
Treated tunnel (crown covered)	4.06	0.40 s	Theoretical — very dead
Adopted design target	**0.82**	**< 2 s**	**Library — comfortable**

4.4 — Why target under 2 seconds, not 0.4 second

The Sabine calculation gives 0.4 second — well *below* the target. Two reasons explain why a more conservative goal, "under 2 seconds", is adopted instead, and this is where the real engineering lies.

A tunnel is not a room. The Sabine equation assumes a "diffuse field": sound bouncing equally in all directions within a compact volume. But a 150 km tube is the exact opposite — an extremely elongated geometry. Sound launched along the tunnel axis travels long distances before meeting the absorbing walls; its decay *along* the tube is therefore slower than room theory predicts. The reverberation a cyclist actually perceives is longer than the idealised 0.4 s. The two effects — strong absorption pulling down, elongated geometry pushing up — meet in a comfortable range, under two seconds.

We do not want a "dead" tunnel. An over-absorbing space sounds muffled, oppressive, unnatural. A little liveliness is pleasant — and cheaper. The two-second target leaves a deliberate margin. To put numbers on it: if the tunnel behaved like an ordinary room, covering just **about 13% of the crown** with high-performance panels would be enough to reach two seconds. We specify far more — near-continuous coverage — not as overkill, but precisely because a 150 km tube *is not* an ordinary room: its axial dimension demands continuous absorption, and that continuity also provides a substantial safety margin.

4.5 — The matter of low frequencies

Not all sounds absorb equally well. High frequencies are easy; **low frequencies** — the background rumble — are the most stubborn, because their waves are long. That is exactly the purpose of the air gap behind the perforated metal: increasing the effective thickness of the assembly pushes absorption down toward the low end of the spectrum. Final sizing means tuning wool thickness and air-gap depth to cover the whole useful range, from the low rumble of ventilation to the high tones of bells.

Scope of this calculation. The figures above are preliminary design estimates, meant to demonstrate feasibility and order of magnitude. A real project requires detailed acoustic modelling (ray tracing, finite elements), full-scale prototypes, and in-situ acceptance measurements — items included in the budget in Section 6.

5 Implementation: applying it over 150 km

The strength of this approach is that it industrialises. Both layers fit into processes already proven by The Boring Company, repeated identically across 150,000 metres.

5.1 — Textured concrete: at the plant, not on site

The tunnel lining is made of precast concrete rings, placed by the boring machine as it advances. The texture is not added afterward: it is moulded **at the precast plant**, by engraving the relief pattern directly into the steel moulds of the segments. The ring therefore arrives already textured, with no extra step in the tunnel. The added cost is limited to mould design, slightly slower demoulding, and tighter quality control — not the price of the concrete itself.

5.2 — The panels: modular and accessible

The crown panels are installed after the lining, on a light sub-frame anchored to the ring. They come as **modular cassettes**, which speeds installation and allows later access for maintenance. The space behind the panels also houses cabling, conduits and lighting — the acoustic lining doubles as a service plenum.

5.3 — Continuity: the central requirement

The golden rule is **continuity over the whole length**. A break in the treatment creates a hard reflecting spot — an acoustic "hot spot" that ruins performance locally. It is precisely the combination of plant-textured segments and repeated cassettes that makes this continuity realistic: a single set of parts, duplicated one hundred and fifty thousand times, with no improvisation in the field.

5.4 — A 100% non-combustible lining

All three materials — concrete, rock wool (mineral, melting above 1,000 °C) and metal — are completely non-combustible. The acoustic lining **adds no fuel load**. In a tunnel where the worst credible fire is a lithium-battery thermal runaway, that is a major asset: treating the sound also treats the fire.

5.5 — Synergy with ventilation

A raw tunnel fan puts out 85 to 95 dB(A) at one metre — unbearable for anyone passing beneath. The same absorption that kills the echo brings that noise down to a soft, continuous background of **60 to 65 dB(A)**, a pleasant white-noise "hum" that even masks stray sounds. The acoustic line item therefore does more than remove the echo: it makes mechanical ventilation bearable.

6 Costs in detail

The "Acoustics" line of the construction budget comes to roughly **C$450 million over 150 km**, filed under technical systems. Here is its breakdown, built up from treated area and unit rate.

DETAILED ACOUSTIC COST BREAKDOWN — 150 KM NETWORK

Item	Basis	Amount (C$M)
Acoustic panels (rock wool + perforated metal, sub-frame, install)	660,000 m² × ~$300/m²	198
Textured concrete — premium over smooth lining (relief moulds, casting, QC)	495,000 m² × ~$180/m²	89
Point treatments (stations, tunnel crossings, smoke locks, junctions)	lump sum	40
Acoustic engineering, modelling, full-scale prototypes, testing and acceptance	lump sum	35
Subtotal		**362**
Technical contingency (20%)	risks, unknowns	72
Total — "Acoustics" item	**≈ C$3.0M/km**	**≈ 434**

This total of about C$434M is carried at **C$450M** in the master budget, a prudent rounding that adds a cushion. Per unit, that works out to:

- **C$3.0 million per kilometre** of tunnel;
- **C$3,000 per metre** of length;
- about **$300 per m²** of treated internal surface;
- about **5%** of the network's total construction cost (≈ C$8.9 billion).

The nuance that works in the project's favour. A good share of the "textured concrete" is not a truly *new* cost: the lining rings are already cast and already paid for in the "tunnels" line (C$1.9 billion). Texturing them only changes the mould. The only genuinely additional material item is the crown panels. The strictly *incremental* cost of acoustics is therefore lower — on the order of C$250–350M — and keeping C$450M in the budget provides a welcome margin of credibility against any challenge.

On the operating side, acoustics is almost free: concrete, rock wool and metal require **no major maintenance for 30 years or more**. No dedicated line appears in the annual budget; occasional cleaning of the panels is already included in routine tunnel maintenance.

7 Co-benefits

Beyond removing the echo, this line item stacks up advantages rarely found together:

- **Fire safety** — a fully non-combustible lining, with no added fuel load.
- **Bearable ventilation** — fan noise brought down from 85–95 to 60–65 dB(A).
- **Durability** — no major maintenance for decades; stable, inert materials.
- **Aesthetics** — the concrete relief and the panels create, under LED lighting, plays of light and shadow that give the tunnel its own architectural signature.
- **Intelligibility and comfort** — a conversation stays clear at three metres, a shout does not hurt the ears, safety announcements are audible.

8 Conclusion and limits

Turning 150 km of concrete tube into a controlled, comfortable sound space is a well-bounded engineering problem with a proven solution: diffuse with textured concrete, absorb with rock-wool and perforated-metal panels, all applied continuously. The physics confirms feasibility: reverberation drops from 6–8 seconds to a target under two seconds, with a comfortable margin. The cost, about C$450M or C$3M/km, is barely 5% of the project — and its strictly new cost is lower still.

The figures presented here are preliminary design estimates. Moving to a real project means three steps: **detailed acoustic modelling** of the tube and its junctions, **full-scale prototypes** measured in the lab, then **in-situ acceptance measurements** on the first sections. Two requirements must be written explicitly into the tender: **silenced fans** (without which noise exceeds 85 dB) and a **continuous acoustic lining** with no gaps. On those conditions, the goal of reverberation under two seconds across the whole network is entirely achievable.

Vélo Tunnel Québec — a citizen project for a 150 km underground cycling network in the greater Québec City region, using The Boring Company's tunnelling technology.
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