# תאורת מנהרות בעידן הלדים
# עקרונות מערכות בקרה רציפות

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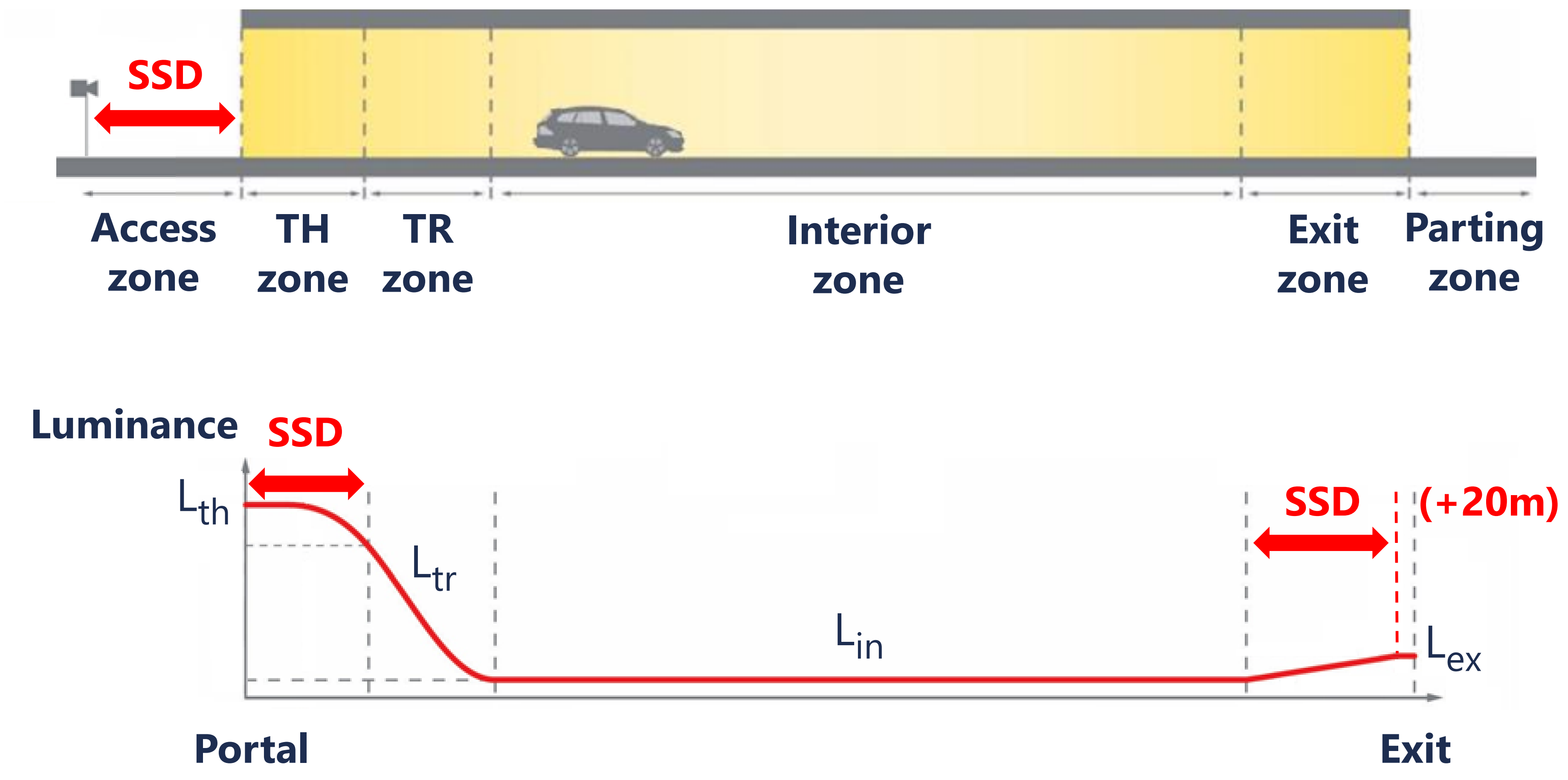
# Spatial adaptation

# Temporal adaptation

**~3500 cd/m$^2$** **~200 cd/m$^2$** **~6 cd/m$^2$**

1500 – 6000 cd/m$^2$ 50 – 500 cd/m$^2$ 2 – 10 cd/m$^2$

# Topology of a one-way tunnel



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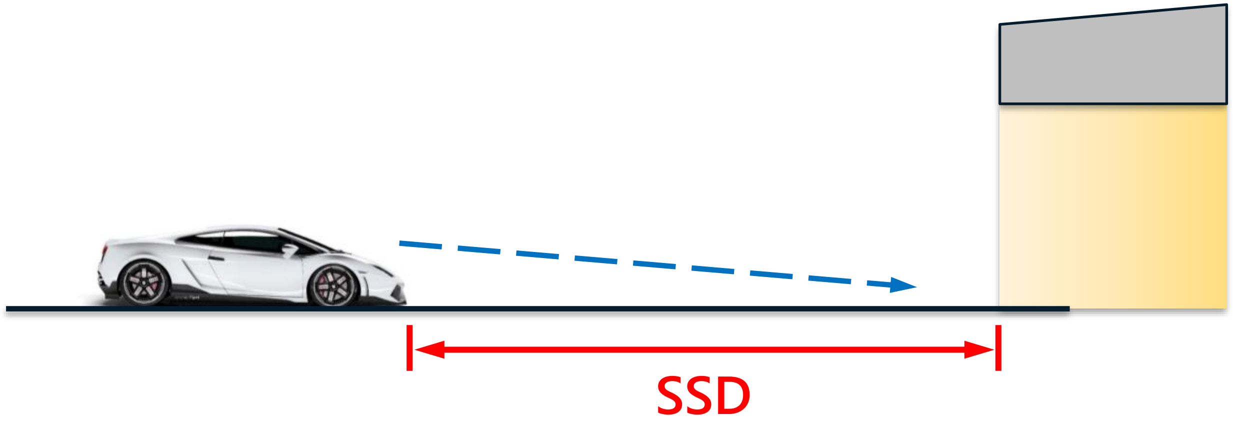
# Safe Stopping Distance (SSD)

## Point of Attention

The driver looks ahead to a point at a distance which is equal to his stopping distance




- *At highest allowed speed*
- *On wet pavement*

$$SSD = \textbf{Distance to react} + \textbf{Distance to brake}$$

# Safe Stopping Distance (SSD)

## Stopping distance

$$SD = u.t_0 + \frac{u^2}{2.g.(f \pm s)}$$

*Reaction + Braking*

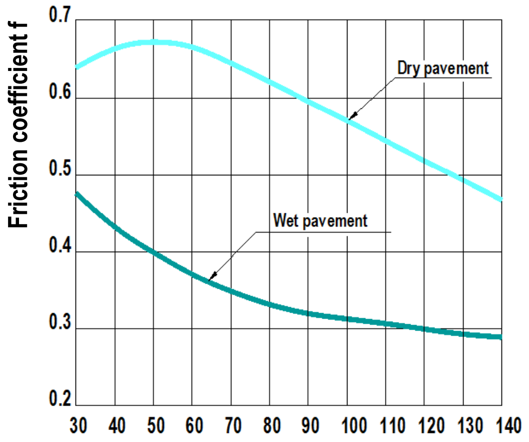
u = traffic speed [m/sec]

$t_o$ = reaction time (by default = 1 sec)

g = gravity acceleration

f = friction coefficient tire-pavement (**wet pavement**)

s = gradient of the road [%]



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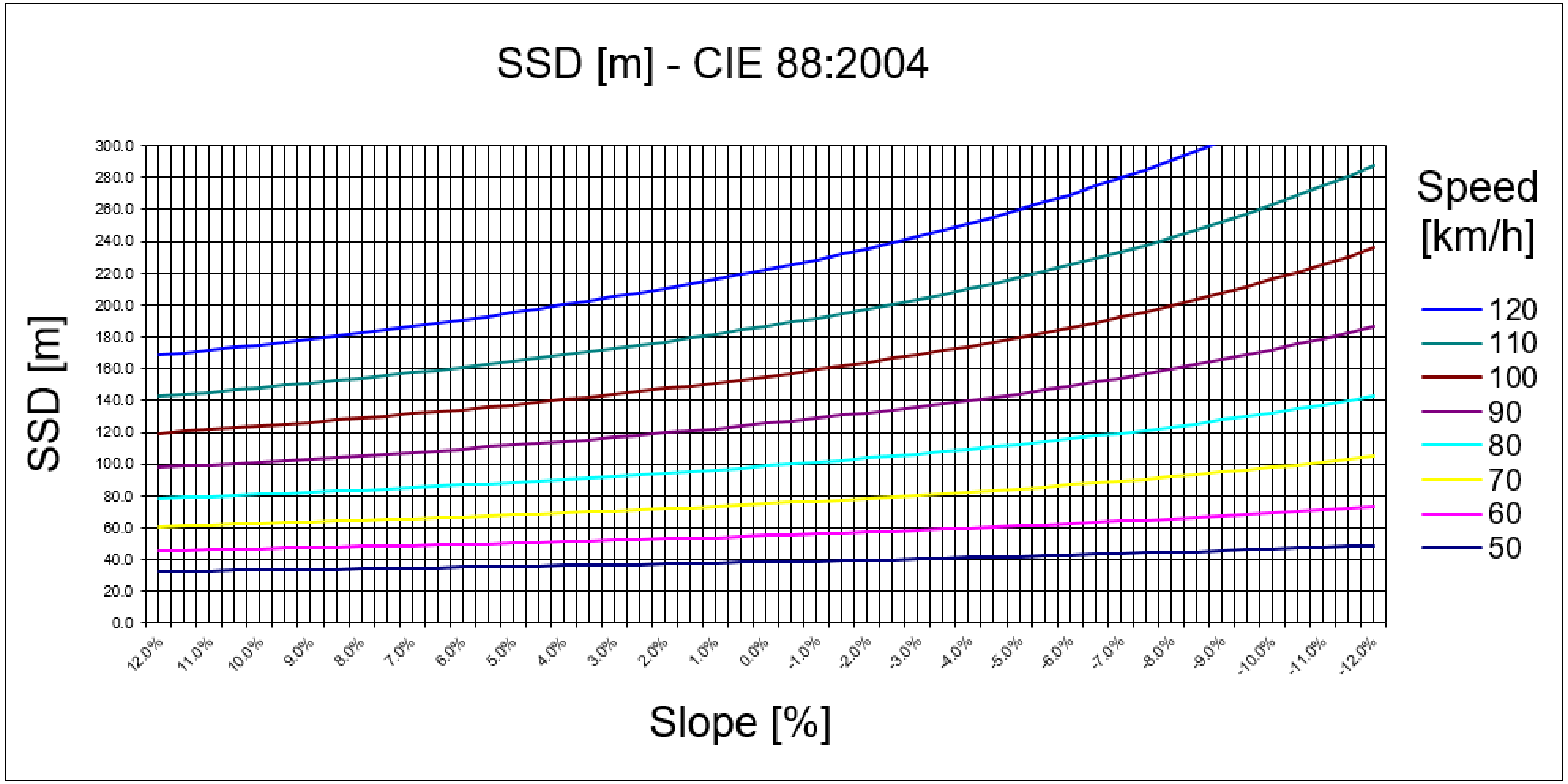
# Safe Stopping Distance (SSD)

## Stopping distance

| SSD<br>Slope 0% | |
|---|---|
| Speed (km/h) | SDD (m) |
| 50 | 38 |
| 60 | 55 |
| 70 | 75 |
| 80 | 99 |
| 90 | 125 |
| 100 | 155 |
| 110 | 187 |
| 120 | 222 |



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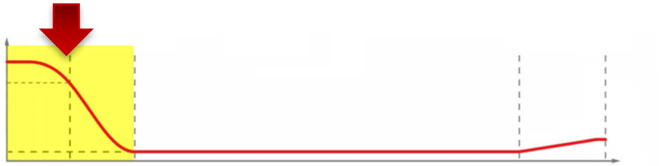
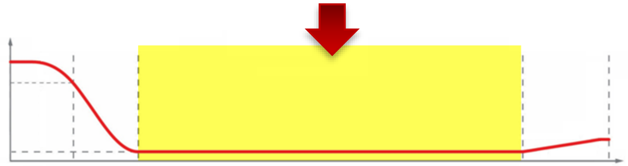
# Threshold and Transition zone



# Interior zone



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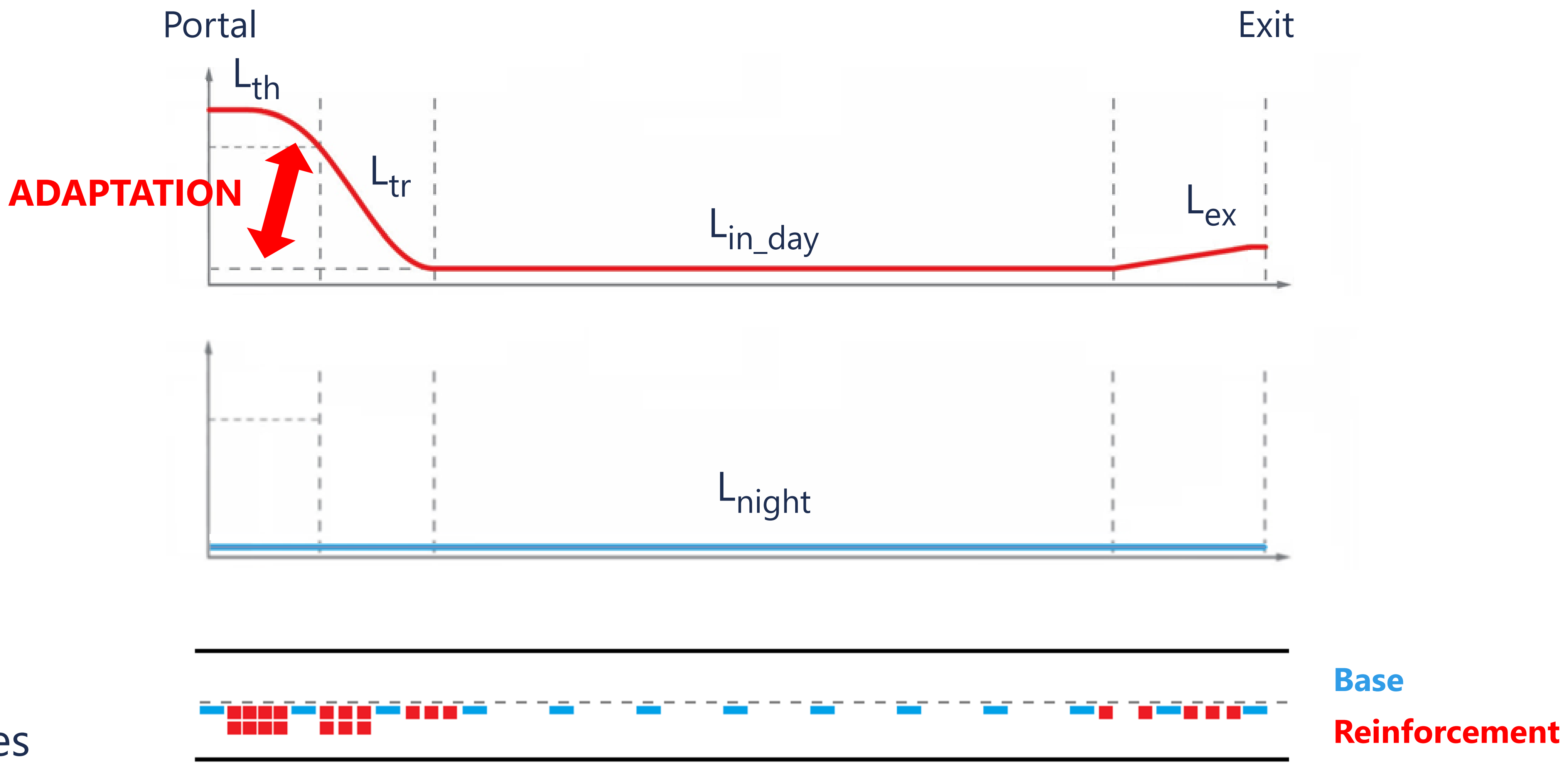
# Exit zone

# Day and night variations

DAY

NIGHT

Types of luminaires



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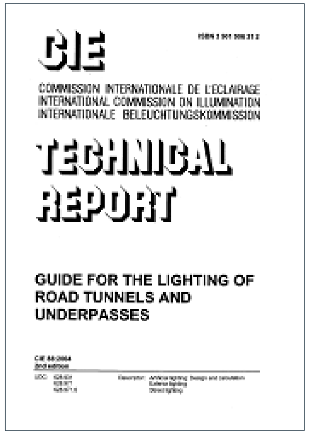
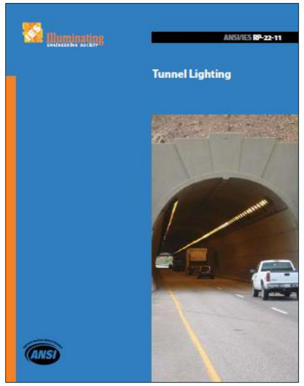
# Tunnel lighting Standards over the world

- **International reference: CIE 88:2004**
  *Guide for the Lighting of Road Tunnels and Underpasses*




- **Europe: CEN/CR 14380:2003 Lighting Applications - Tunnel Lighting**
  *National Standards: NBN, AFNOR, NSVV, BS, DIN, NEN… BS5489-2*


- **USA & Canada: IES RP-8-18 (previously in RP-22-11 Tunnel Lighting)**




- **Australia/New-Zealand: AS/NZS 1158.5:2014**
  *Lighting for roads and public spaces – Part 5: Tunnels and underpasses*

- **Asia: mostly application of CIE 88:2004**

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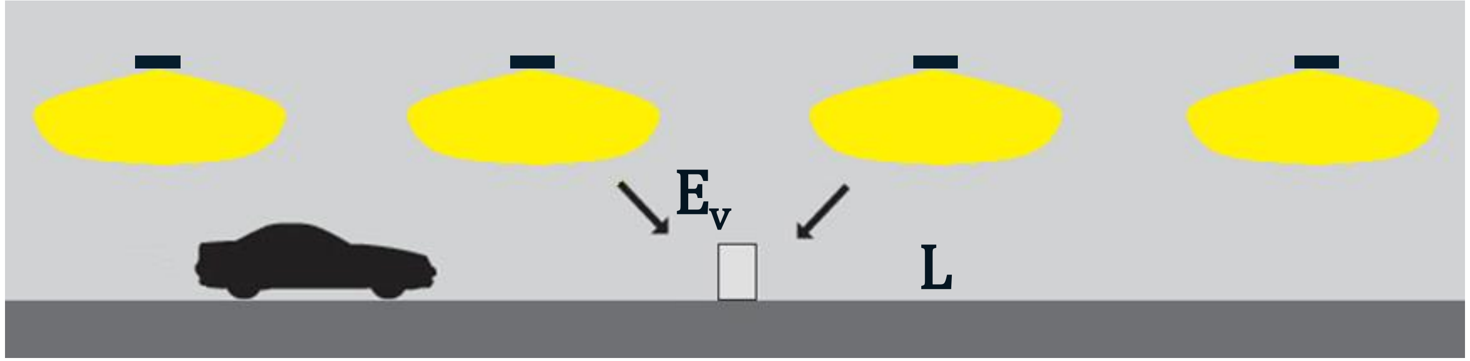
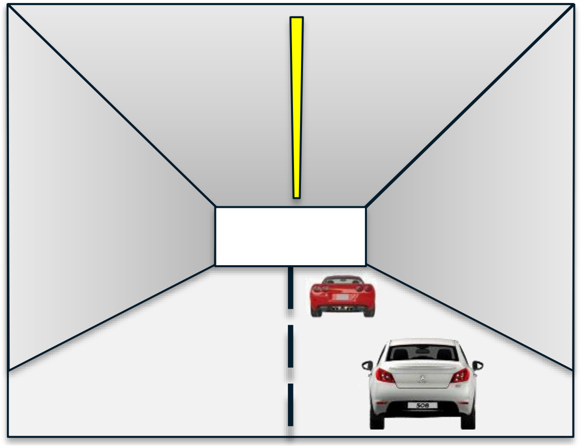
# Symmetrical Lighting (SYM)

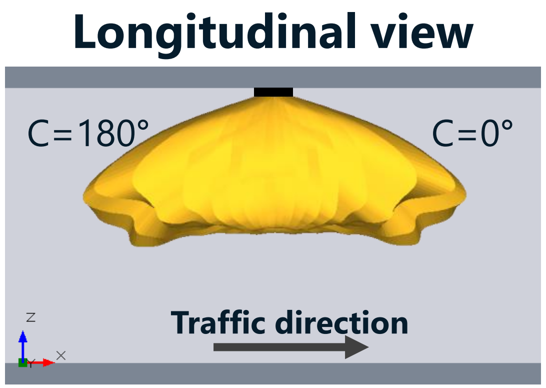
Flux sent symmetrically in backward and forward directions

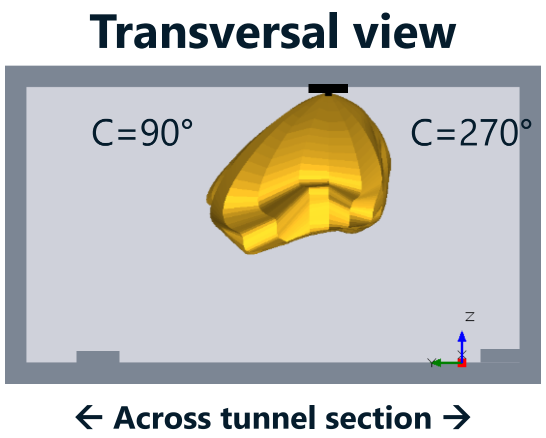


$$\frac{L}{E_v} \leq 0.2$$

# Symmetrical Lighting (SYM)




- Well adapted to high density traffic
- Versatile regarding luminaires location
- Good lighting of walls possible

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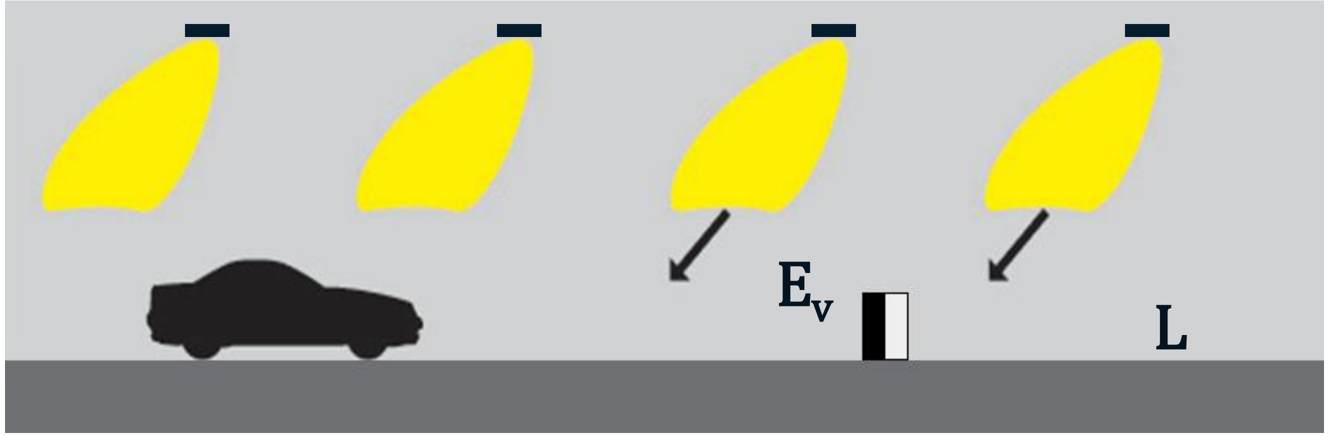
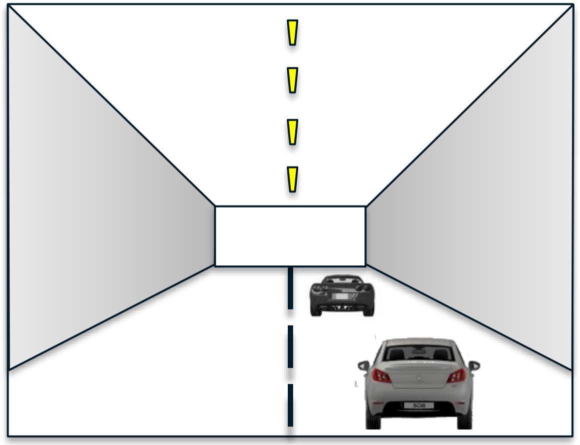
# Symmetrical Lighting (SYM)

# Counter-Beam Lighting (CBL)

Main beam sent in opposite direction to the traffic



Obstacles made visible by negative contrast

$$\frac{L}{E_v} \geq 0.6$$

# $L_{seq}$ example

**CBL:** $$L_{th} = \frac{554}{\frac{1}{(-0.28)}\left(\frac{0.2}{\pi \cdot 0.6} - 1\right) - 1} = 253\ cd/m^2$$

**SYM:** $$L_{th} = \frac{554}{\frac{1}{(-0.28)}\left(\frac{0.2}{\pi \cdot 0.2} - 1\right) - 1} = 386\ cd/m^2$$

$$L_m = (0.8 \cdot 200 + 100 + \underbrace{183}_{L_{seq}})/0.8 \cdot 1 = 554\ cd/m^2$$

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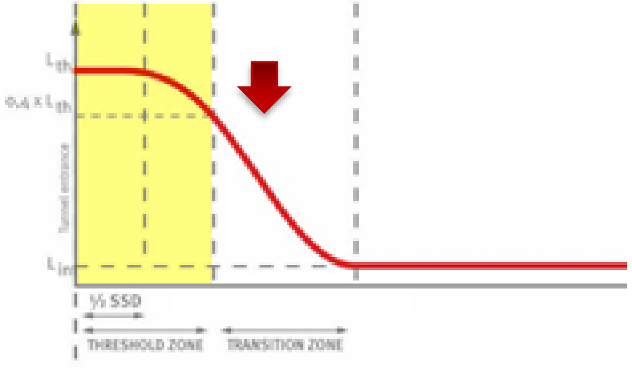
# Entrance: Threshold and Transition zones

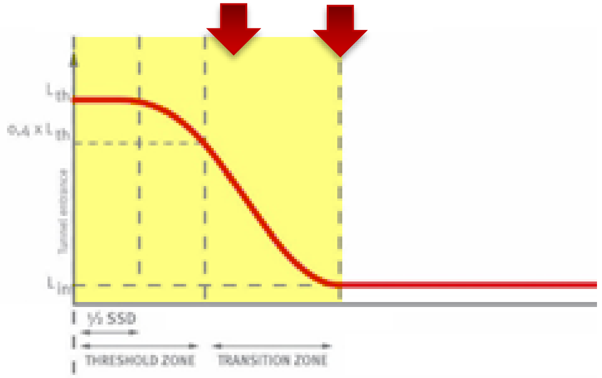
## $L_{th}$ – Visual tasks (given a max speed)

- Obstacles detected at SD from tunnel entrance
- Allow the driver to react in time

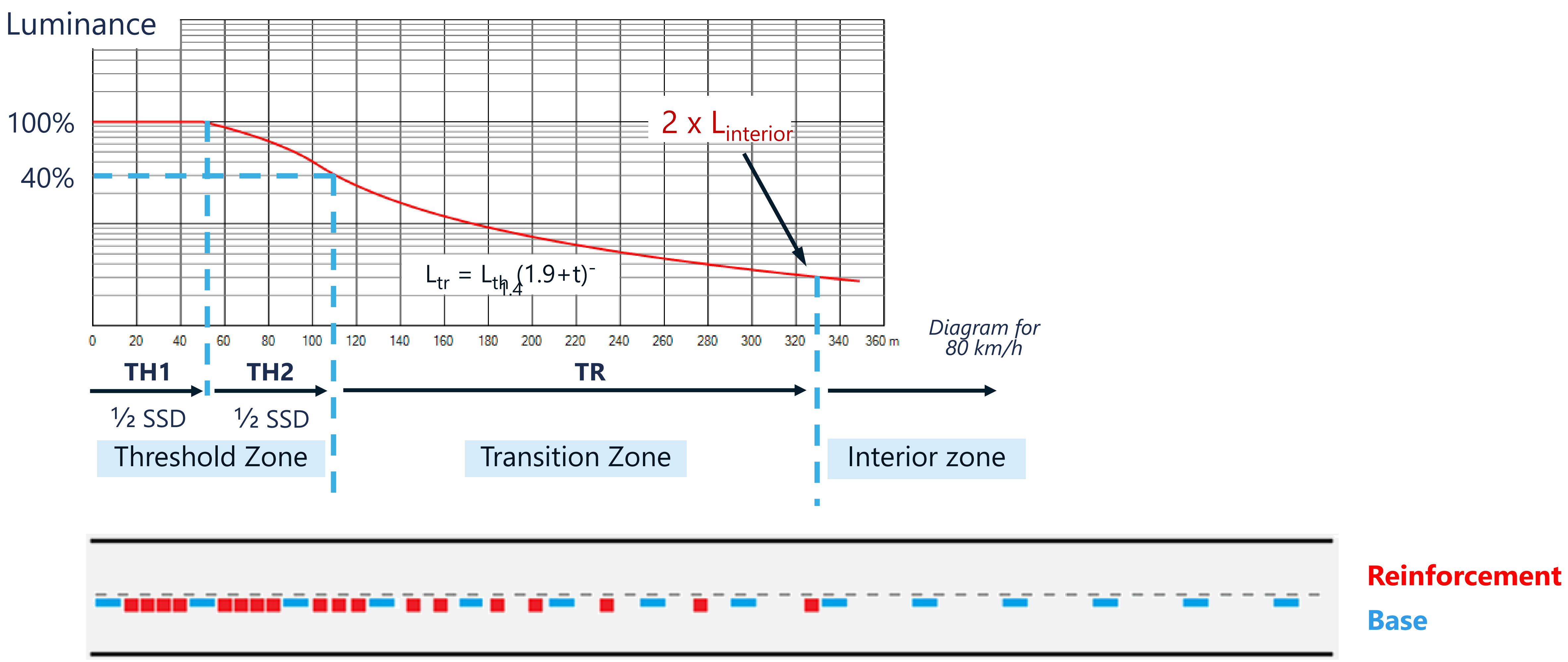



## $L_{th}$ and $L_{tr}$ – Adaptation phenomena

- Spatial adaptation
- Temporal Visual Adaptation (high level → low level)



# Entrance: Threshold and Transition zones



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# Interior zone – Long tunnels

## Luminance in function of traffic flow and stopping distance


| Luminance in long tunnels (cd/m²) | | |
|---|---|---|
| SSD (m) | Low traffic flow | Heavy traffic flow |
| 160 m | 6 | 10 |
| 60 m | 3 | 6 |

| Traffic flow * | One way traffic | Two way traffic |
|---|---|---|
| High | > 1500 | > 400 |
| Low | < 500 | < 100 |

** peak hour traffic, vehicles/hour/lane*

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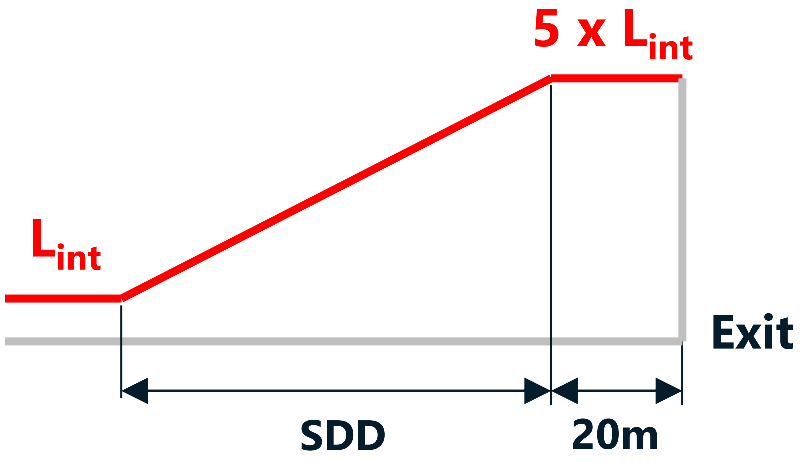
# Exit zone

## Increase of luminance in function of interior luminance level and stopping distance


The daytime luminance in the exit zone:

- increases over a length equal to the SDD
- from the level of the interior zone to 5 times that level
- 20 m from the exit portal



# Luminance uniformity and glare restriction

## Uniformity on road surface

- Overall uniformity: **$U_o \geq 0.4$** (whole carriageway)
- Longitudinal uniformity: **$Ul \geq 0.6$** (axis of each lane)


## Uniformity on walls

- Overall uniformity: **$U_o \geq 0.4$**

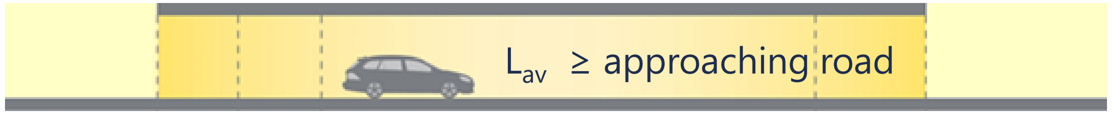
## Disability glare restriction

- Threshold increment: **TI ≤ 15 %**

  In all zones (except Exit)

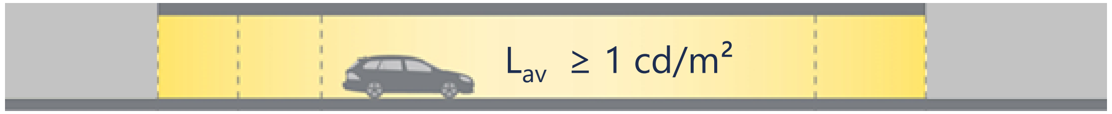

# Night Lighting

- **Tunnel part of an illuminated road:**




Continuity: Luminance in tunnel ≥ Luminance of approaching road

- **Tunnel part of an unilluminated road:**




Minimum: Luminance in tunnel ≥ 1 cd/m², with $U_o$ ≥ 40% and Ul ≥ 60%

# Zones and types of lighting

| Type | Entrance lighting | Base lighting | Exit lighting |
|---|---|---|---|
| SYM | V | V | V |
| CBL | V | X | V |

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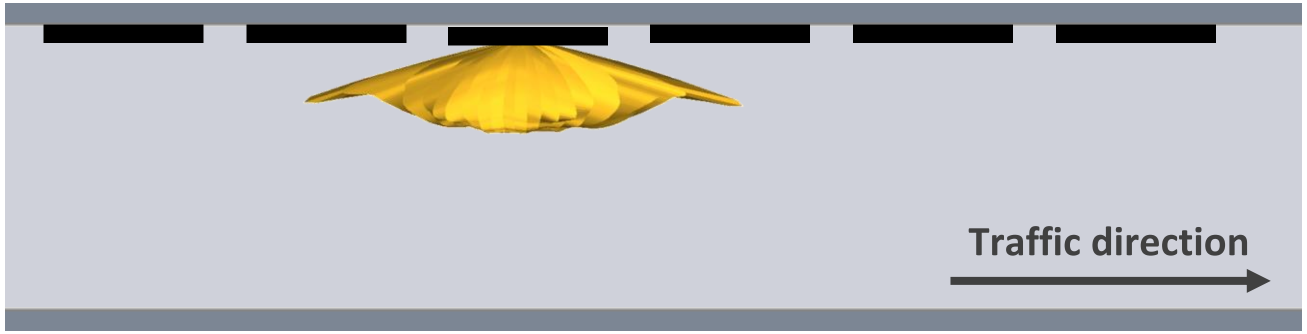
# Base lighting – Extensive symmetrical

- Higher spacing, optimum lumen package
  → Lower quantity of luminaires
- Lower visual comfort and guidance

- Flicker restriction: Avoid 4 Hz < f < 11 Hz
  Negligible if f < 2.5 Hz or if f > 15 Hz

# Base lighting – Continuous line symmetrical

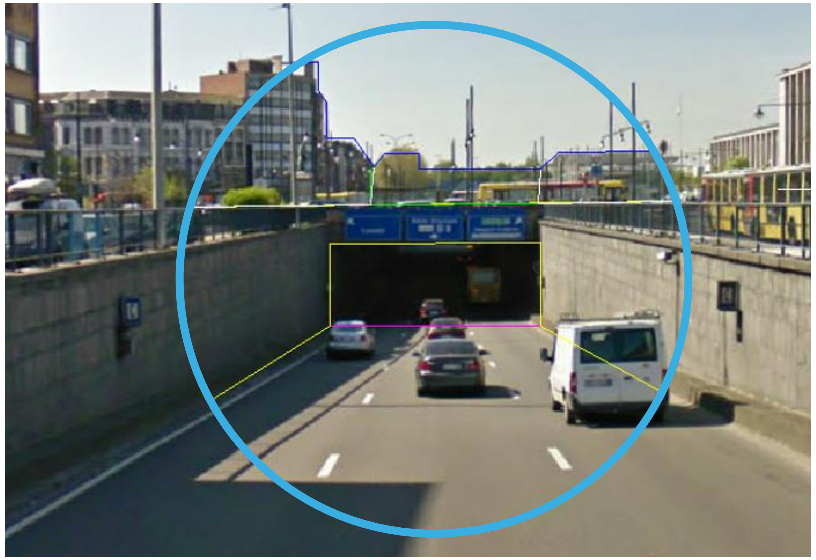
- Low Luminance and long light source
  → Comfortable solution
- Continuous or nearly continuous row of luminaires
  → Excellent visual guidance
- Higher quantities of luminaires

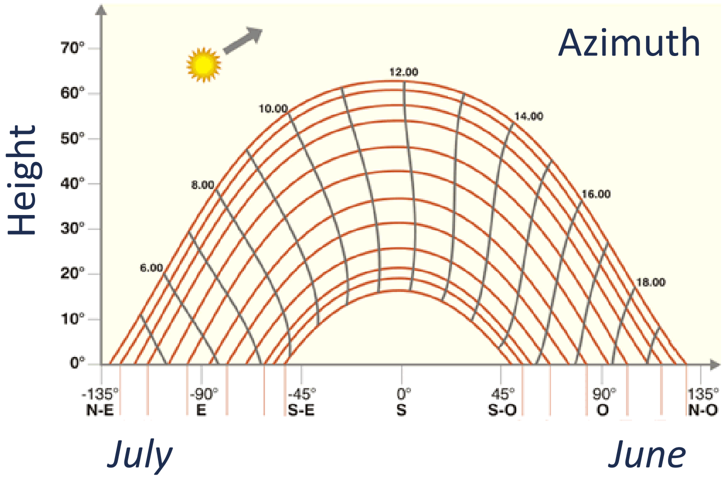


# Lighting Control

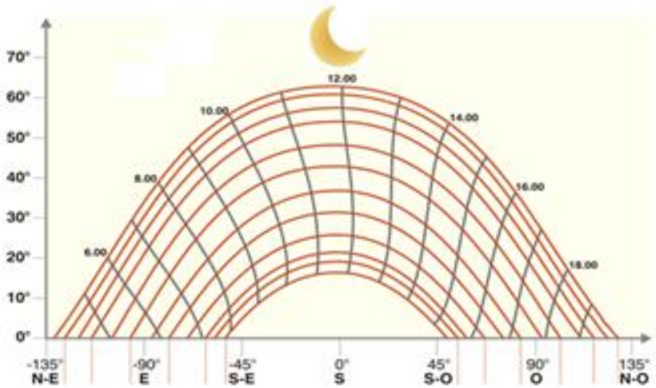
To follow changes of adaptation luminance (daylight conditions in access zone)

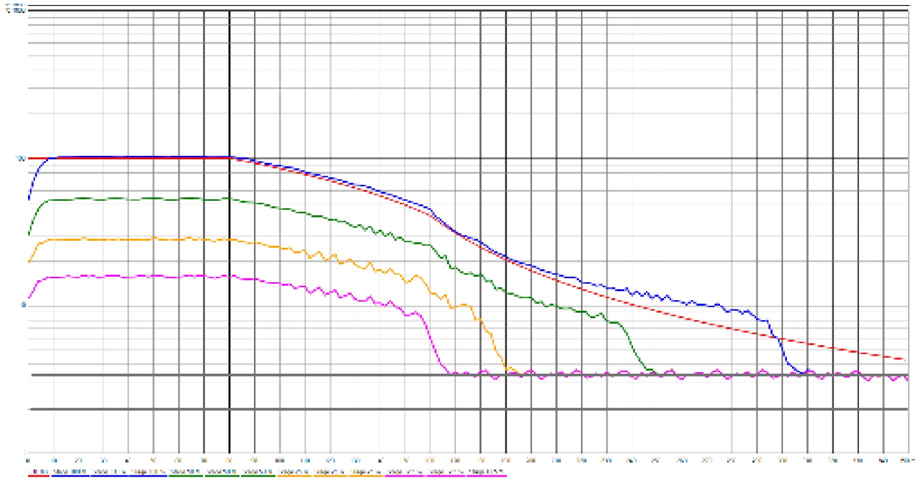
- Weather conditions: clear, overcast…
- Position of the sun
- Daily, seasonal…





# Lighting Control



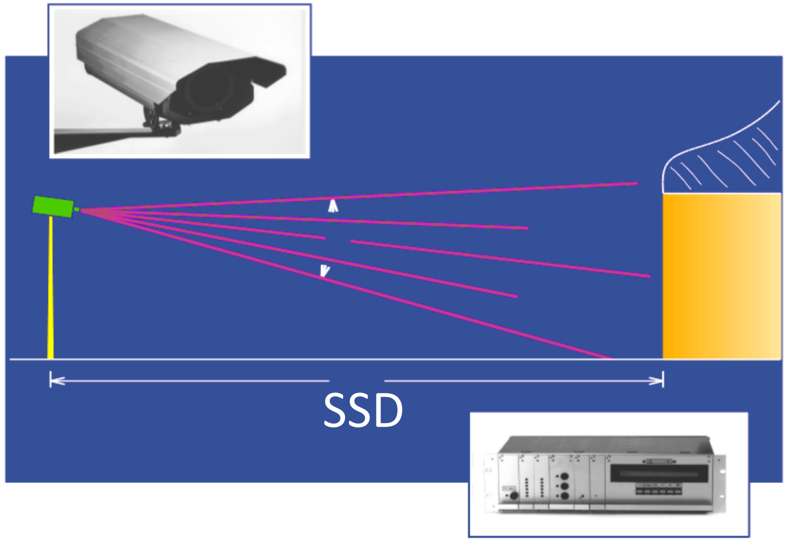
# Lighting Control

Continuous monitoring of luminance in access zone

- Adaptation of reinforcement lighting to the actual value of access luminance
  - by switching ON/OFF (simple control)
  - by continuous dimming (advanced control)

- Keep $L_{th}/L_{20} > k$

- Luminancemeter at SSD before tunnel portal



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# Classical control: Switching Steps

## Typically 3 to 5 reinforcement stages + Day + Night

| | Stage | Reinforcement | Interior lighting |
|---|---|---|---|
| | Stage 1 | 100% | 100% |
| | Stage 2 | 75% | 100% |
| | Stage 3 | 50% | 100% |
| | Stage 4 | 25% | 100% |
| | Day | 0% | 100% |
| | Night | 0% | 50%-25% |

**Technology limitations**

- “Classical” switching ON/OFF (HID)
- Bi-power control gear (50% flux)
- Ignition and extinction waiting time
- Only group luminaires management

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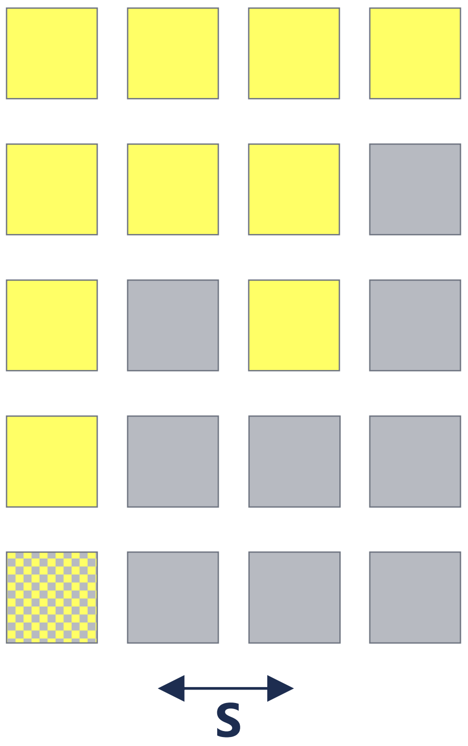
# Classical control: Switching Steps

## ON/OFF switching cycles for reinforcement lighting stages



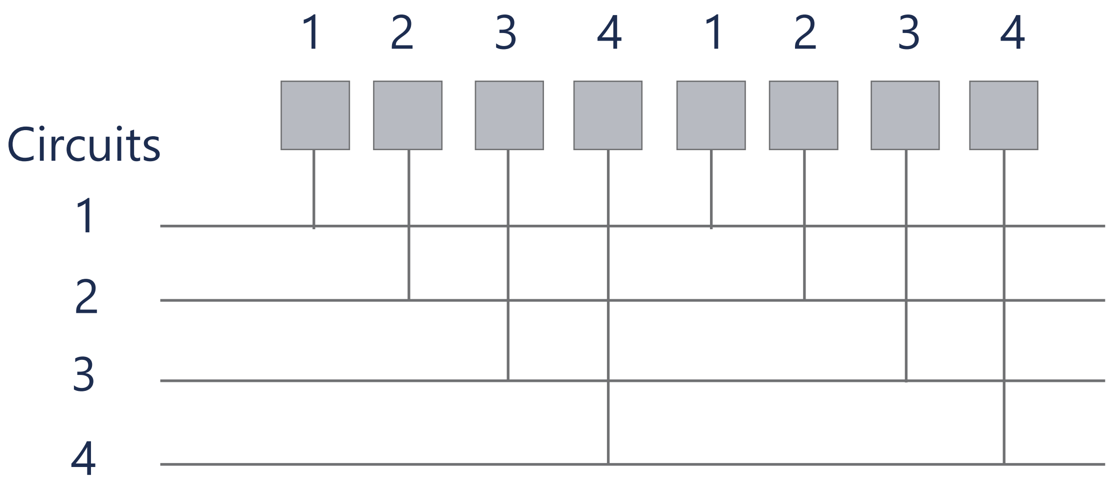

Stage 1 100%

Stage 2 75%

Stage 3 50%

Stage 4 25%

Stage 5 12.5%



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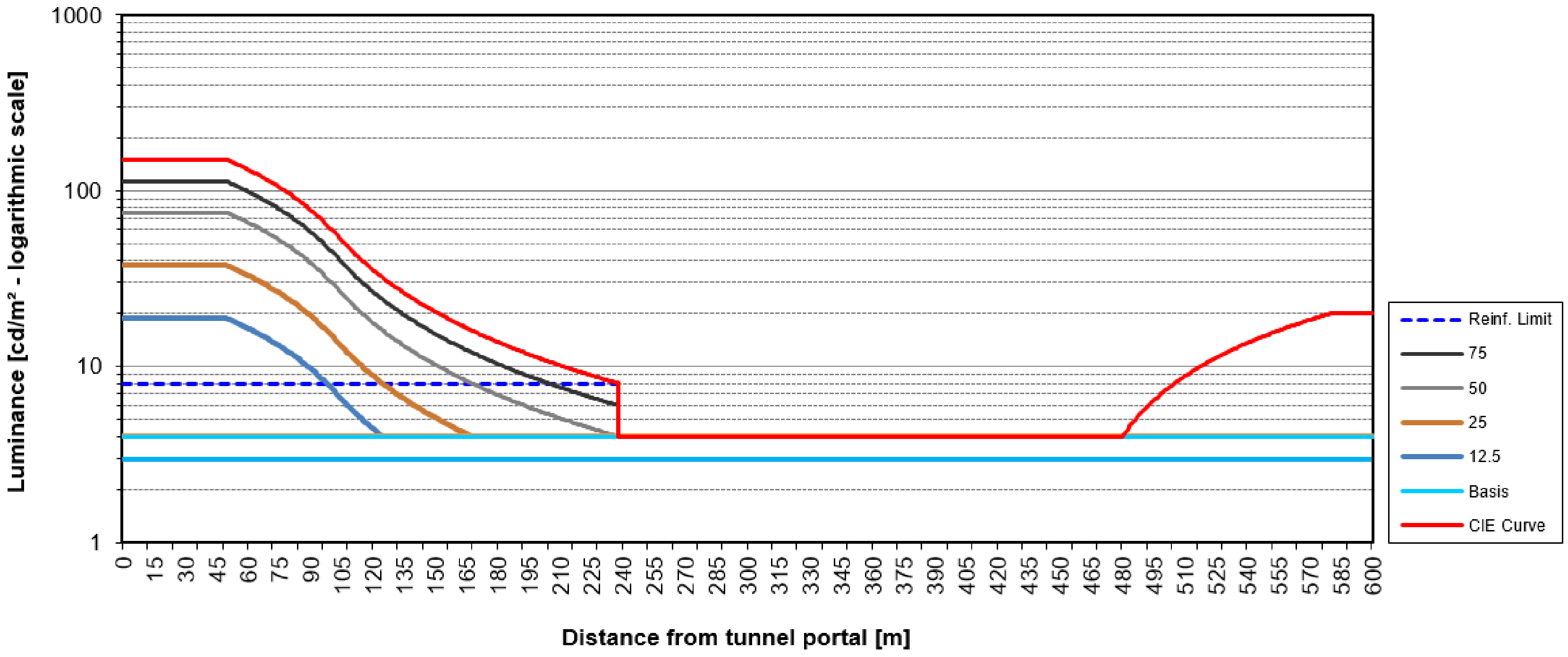
# Classical control: Switching Steps

## Whole tunnel view



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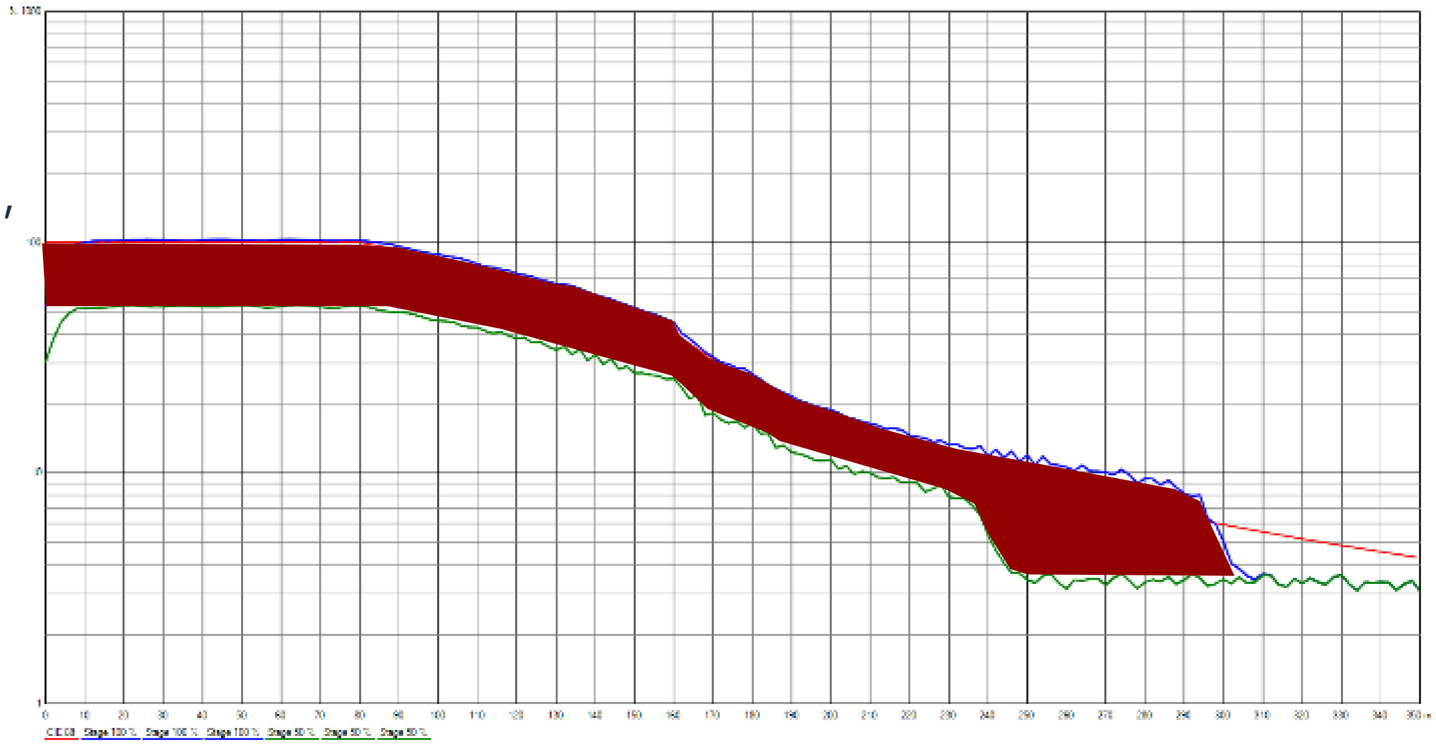
# Classical control: Switching Steps

4 switching stages (100% - 50% - 25% - 12.5%)

Example: stage 100% operating between 100% and 51%



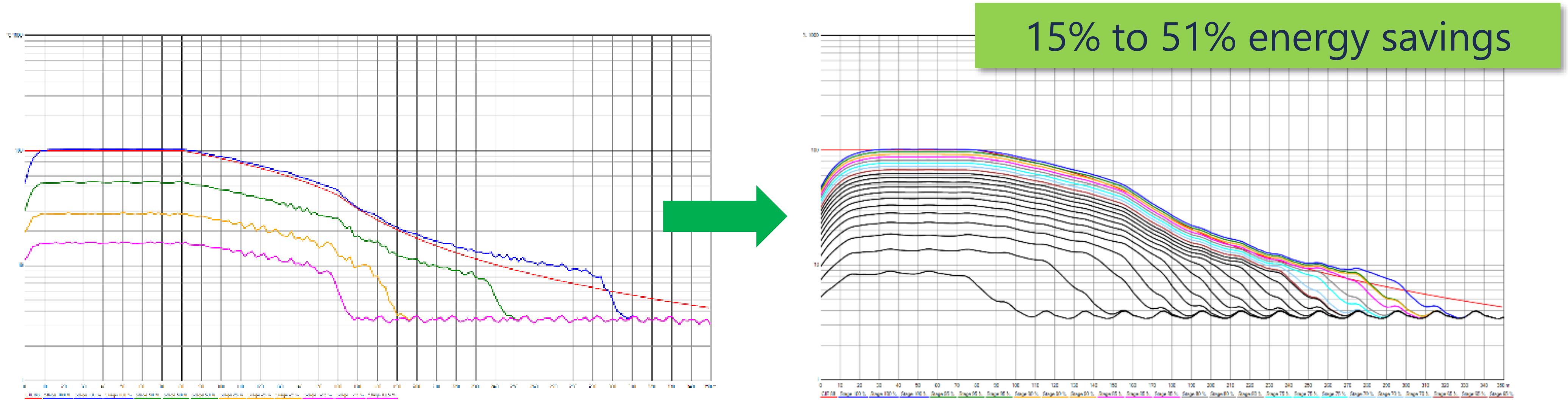
When 60% required, stage 100% is used

→ Overlighting

# Optimizing Lighting Management

**Continuous dimming removes overlighting**

When 60% required → 60% of $L_{th}$ is provided



# Optimizing Lighting Management

**Example: short tunnel (80 m), $L_{th}$ = 80 cd/m² (OMNIstar, ContiLED)**

**HID** 4 stages (100%, 50%, 25%, 12.5%): 36459 kWh

-16%

**LED** 4 stages (100%, 50%, 25%, 12.5%): 30501 kWh

-30%

8 stages: 25306 kWh

-32%

10 stages (each 10%): 24631 kWh

-37%

20 stages (each 5%): 22862 kWh

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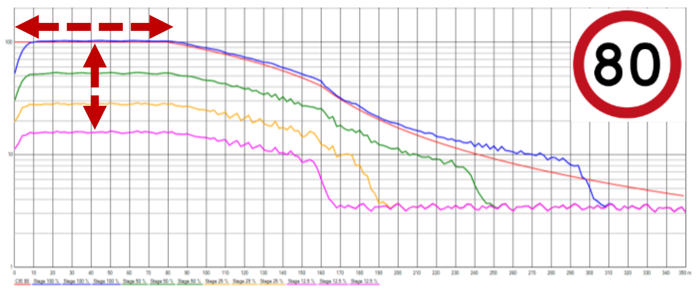
# Using new potential

## Traffic speed management

$L_{th}$ varies with traffic speed → dynamic adaptation possible

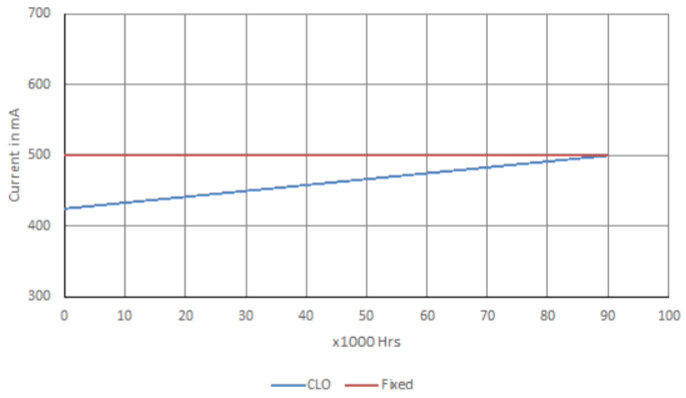
- Dynamic speed limitation
- Traffic jam…




Possible energy savings **from 10% to 30%** on reinforcement lighting

## Maintenance management

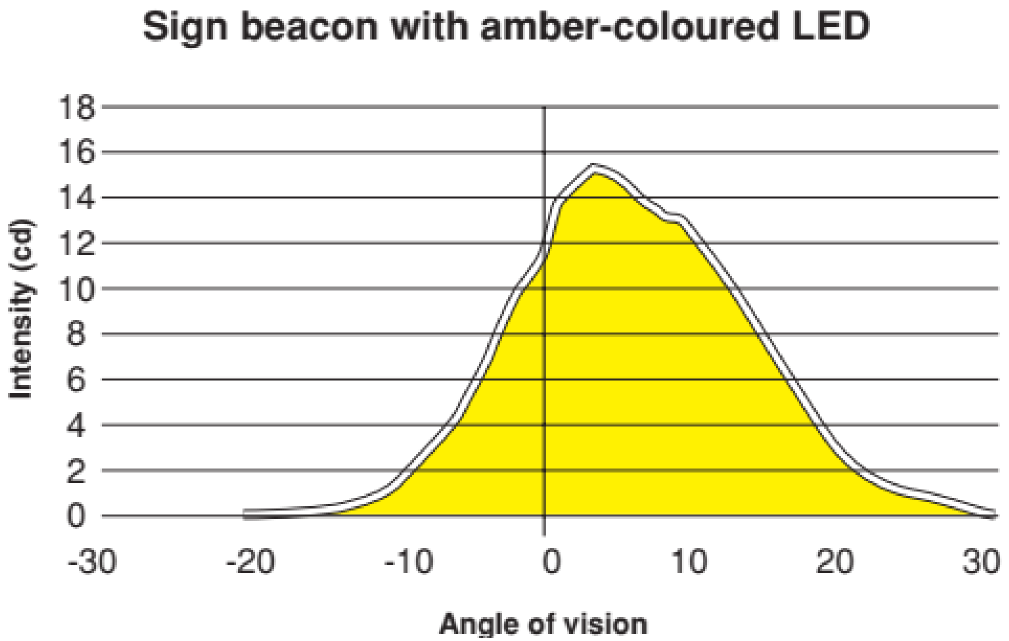
- CLO
- Operating time
- Power consumption monitoring



# Tunnel lighting
# LED guidance beacon

Thanks to its 12 LEDs on either side, the BJ guidance beacon acts as a visual guide both in normal conditions and when there is smoke due to a fire.
A direct 230 V power supply is also possible – in which case a transformer is integrated.

# PHOTOMETRY




This table shows that the maximum intensity is reached in a 4° angle of vision, which corresponds to the position of motorists in normal traffic conditions, or of pedestrians who are heading towards emergency exits.

CIE193:2010

# שאלות ? ☺