

DESIGN, SIMULATIONS AND IMPLEMENTATION OF VENTILATION SYSTEM FOR METRO LINE 9, AT BARCELONA CITY IN SPAIN

TD&T

Dr. Ana Ruiz Jiménez

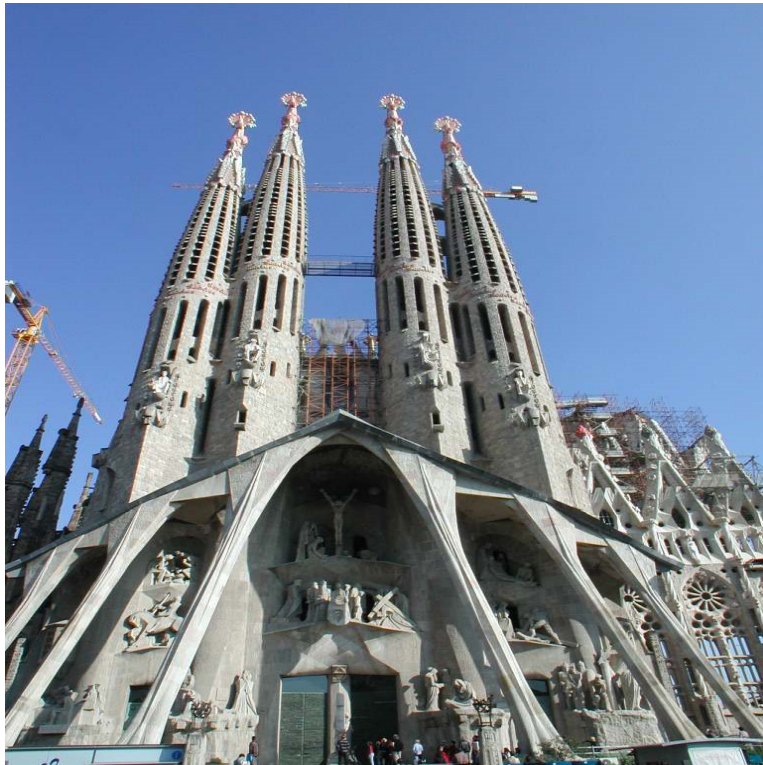


METRO LINE 9, AT BARCELONA CITY IN SPAIN



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INTRODUCTION

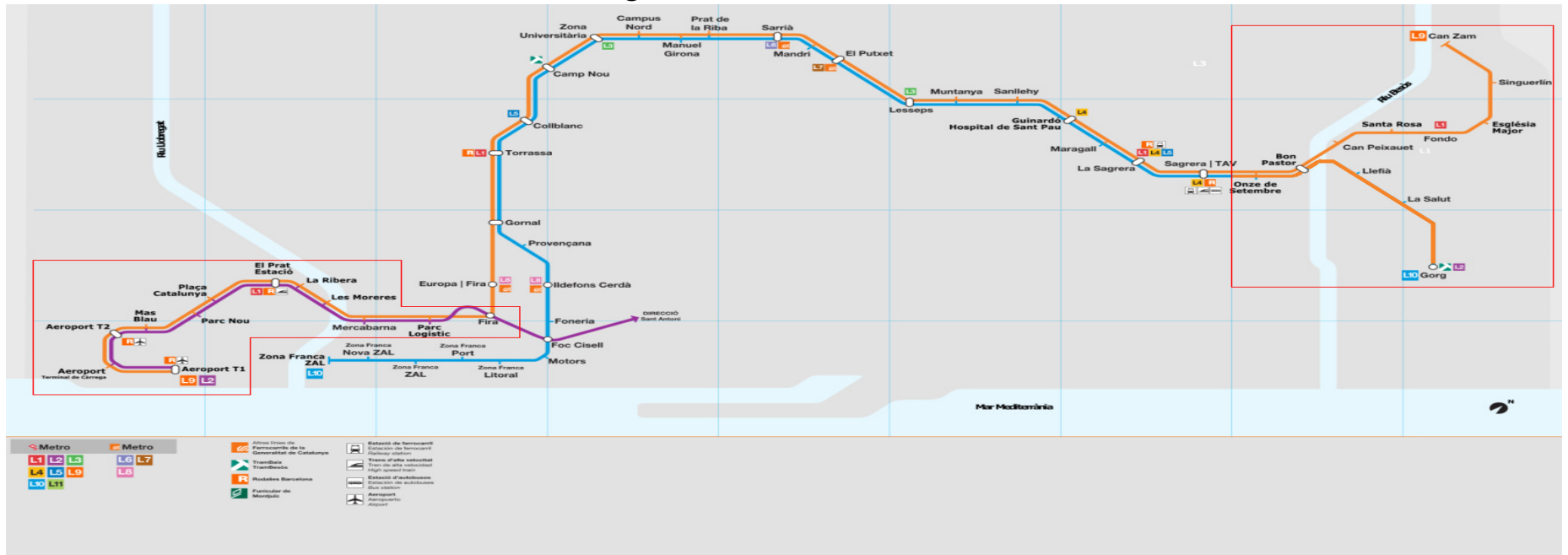


- TD&T has been commanded to design tunnel ventilation system for L9 of Metro de Barcelona.
- Decisions about ventilation strategies have been taken through SES /CFD.
- Line 9 of Metro of Barcelona is a complete line of about 47Km.
- Line 9 (section 4) is in operation.

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INTRODUCTION

- One of the most innovative design oriented metro lines in the world.



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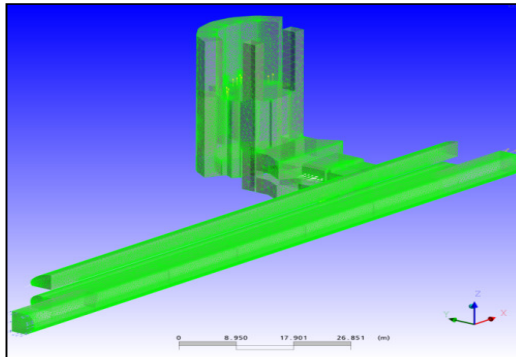
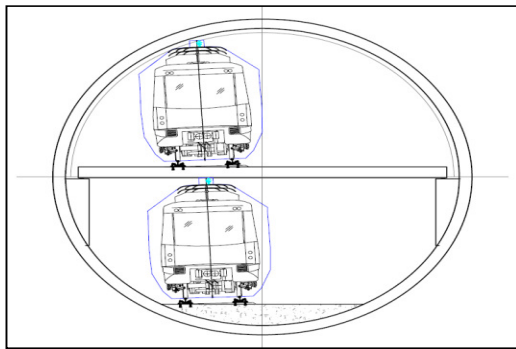
INTRODUCTION

- This present project (Section 4) has been constructed and is currently in operation in Barcelona.



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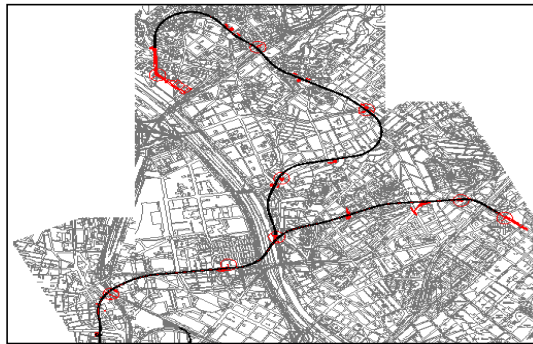
INTRODUCTION



- Line 9 of Metro of Barcelona (Section 4) is a subway line with a very innovative design.
- This tunnel system is a two-level tunnel.
- Ventilation shafts are connected with each tunnel.
- “Shaft” type stations have a special design.

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INFRASTRUCTURE

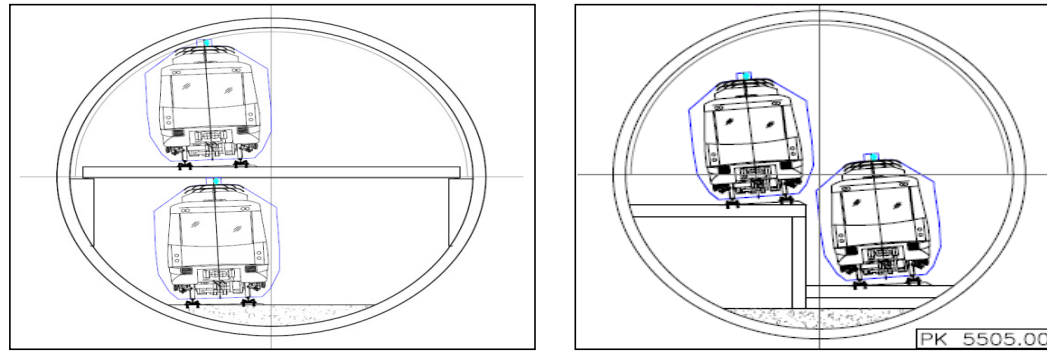


Section Can Zam – Telescopi and Section Gorg –Telescopi, converging at Bon Pastor, up till Sagrera Station.



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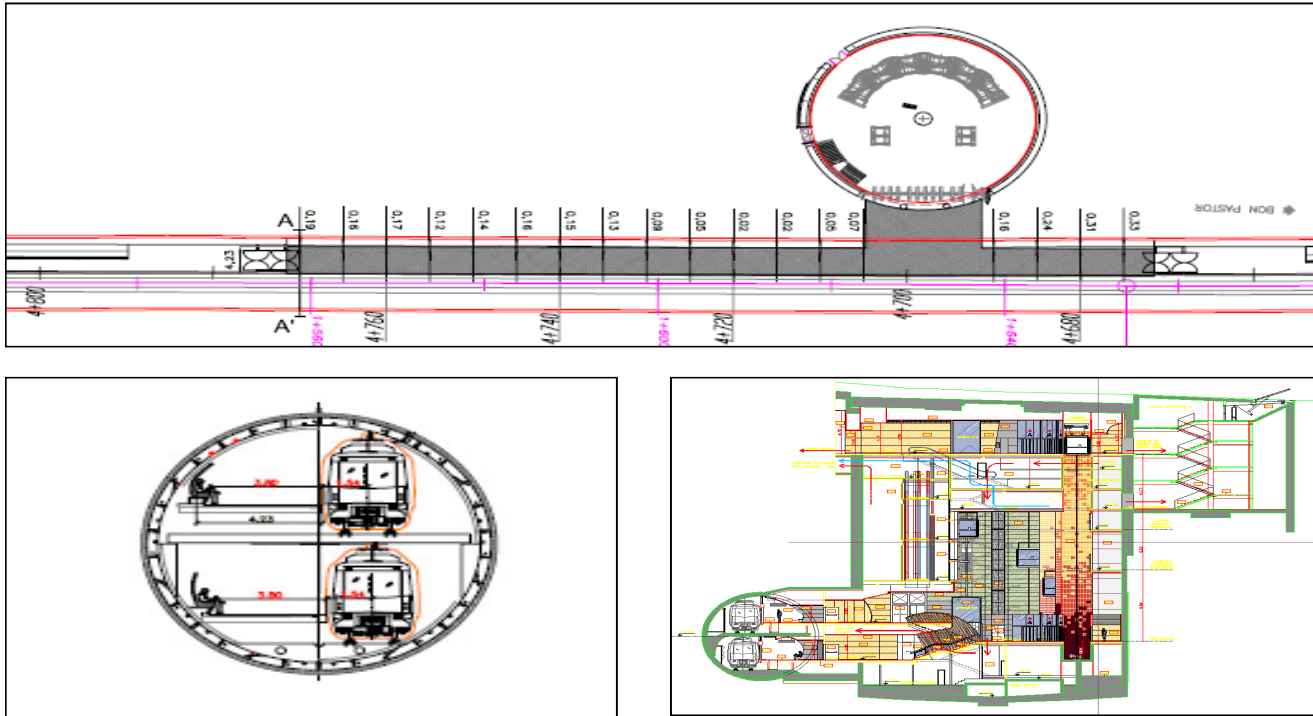
INFRASTRUCTURE



- Bi-level tunnel. These two tunnels are interconnected with ventilation shafts and ramps.
- Ramps for platform exchange are enclosed between
 - Egglesia and Fondo,
 - Fondo and Bon Pastor, and
 - Bon Pastor and Onze de Septembre.
- Cavern type Stations, closed with Platform Screen Doors (PSDs) (only open when train stops in stations). Then, the tunnel is isolated from the stations.

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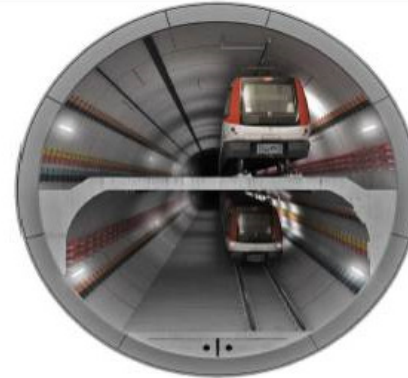
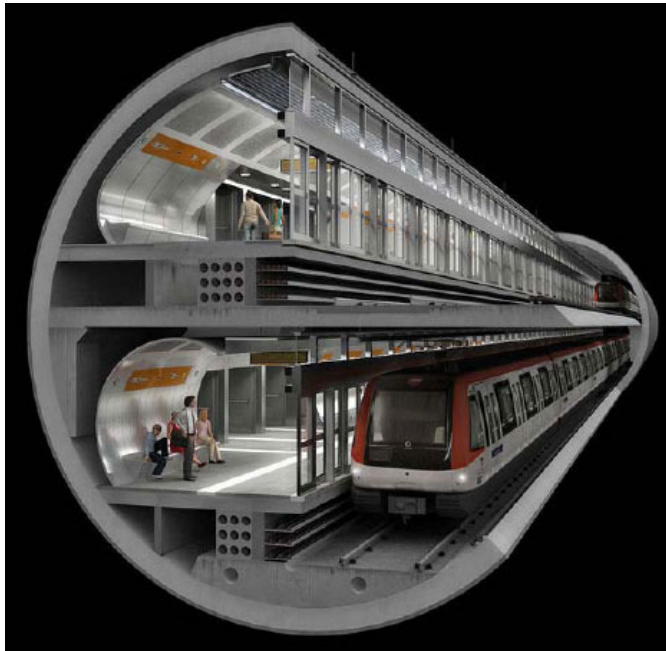
INFRASTRUCTURE



Infrastructure details for tunnels and stations

METRO LINE 9, AT BARCELONA CITY IN SPAIN

INFRASTRUCTURE



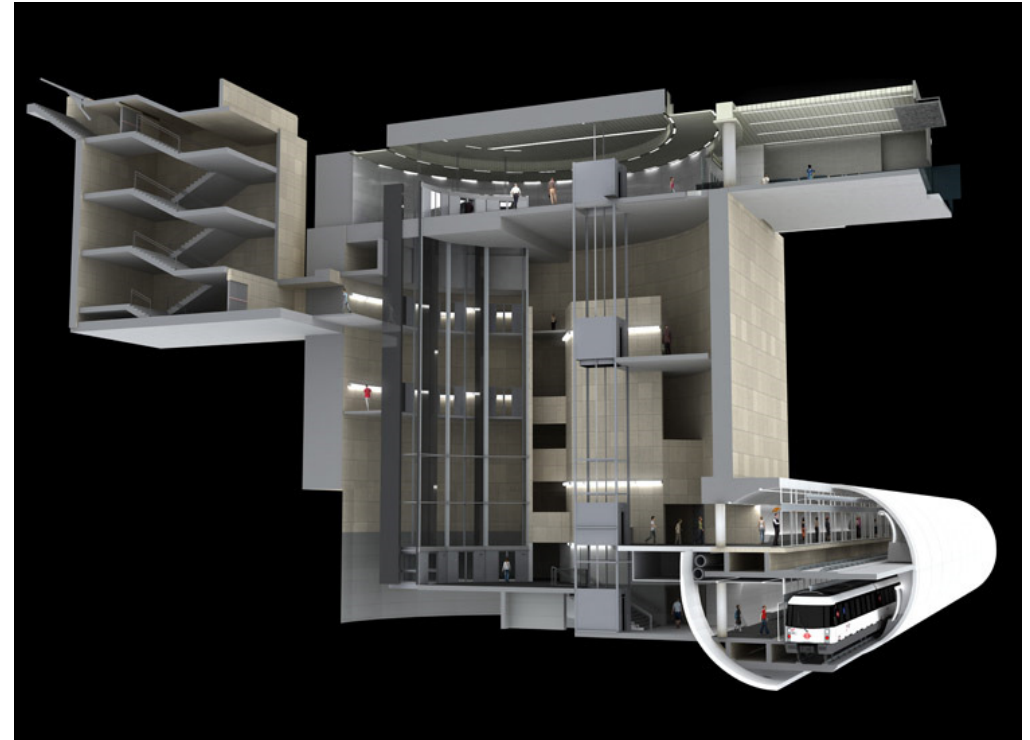
Infrastructure details for tunnels

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INFRASTRUCTURE

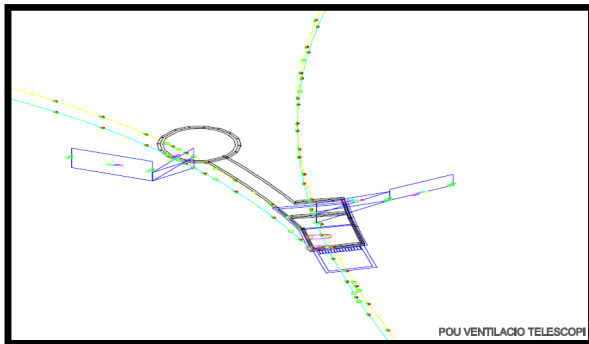
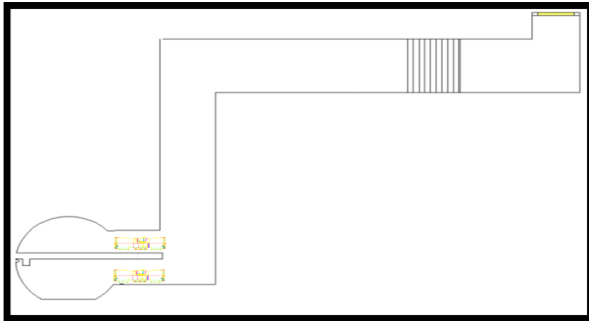


Infrastructure details for stations



METRO LINE 9, AT BARCELONA CITY IN SPAIN

INFRASTRUCTURE



- Interstation shafts include calculated fans:
- Flowrate at confort (at 500 rpm), per fan:
 - $40\text{m}^3/\text{s} = 144.000\text{ m}^3/\text{h}$
 - Total Flowrate: $4 \times 40\text{m}^3/\text{s}$
- Emergency flowrate at (1000 rpm), the two shafts surrounding fire segment, upper and lower tunnels:
 - $70\text{m}^3/\text{s} = 252.000\text{ m}^3/\text{h}$ per fan.

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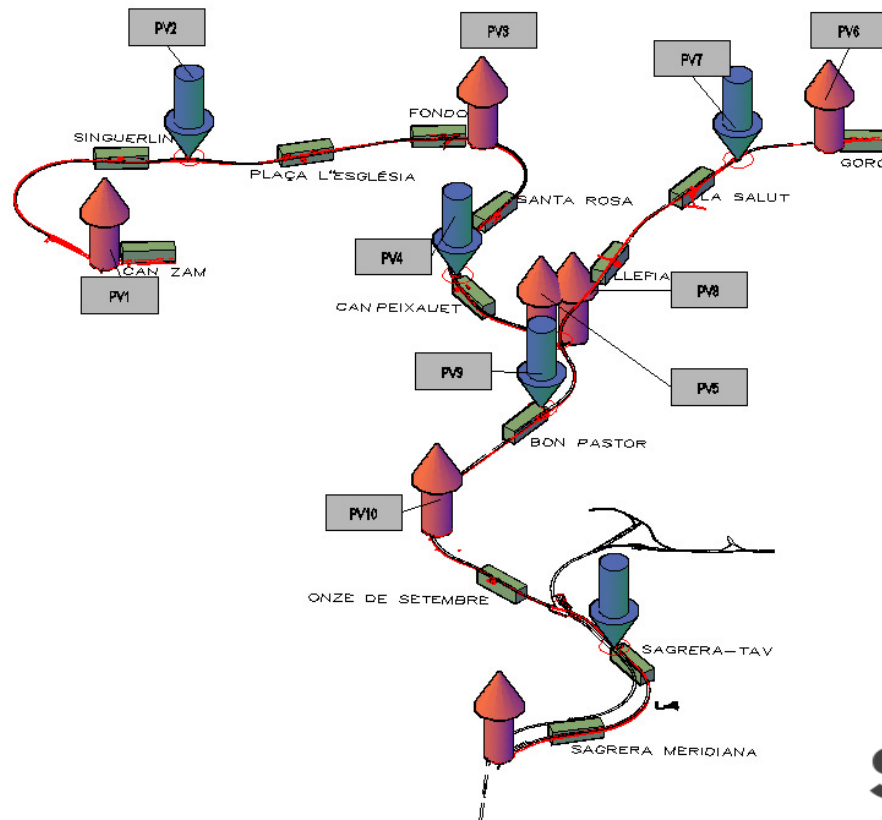
INFRASTRUCTURE

The location of ventilation shafts is as follows:

TVS	Location
PV1	Can Zam
PV2	Between Singuerlin-Egglesia
PV3	Fondo
PV4	Can Peixauet
PV5	Telescopi (I. Can Zam)
PV6	Gorg
PV7	Between La Salut-Gorg
PV8	Telescopi (L. Gorg)
PV9	Bon Pastor
PV10	Between Onze Septembre-Bon Pastor

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INFRASTRUCTURE



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PHASES OF VENTILATION DESIGN

1. Project data
2. Objective: Ventilation Design with SES
3. SES Results Analysis
4. Conclusions: Selection of equipment to be installed

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PHASES OF VENTILATION DESIGN

- Objectives:
 1. Air flow calculation for the right performance of tunnel systems, both for normal operations, and emergency operations.
 2. Specifications for necessary equipment in order to get calculated airflows, IN TUNNELS AND STATION

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Tunnel

SES simulation:

- Each tunnel level has been simulated with SES, interconnected through the ventilation shafts.
- SES program limits have been increased for this long project.
- Every segment is 15 meters long, which is the metro wagon length.

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Tunnel

- **Comfort situation:**

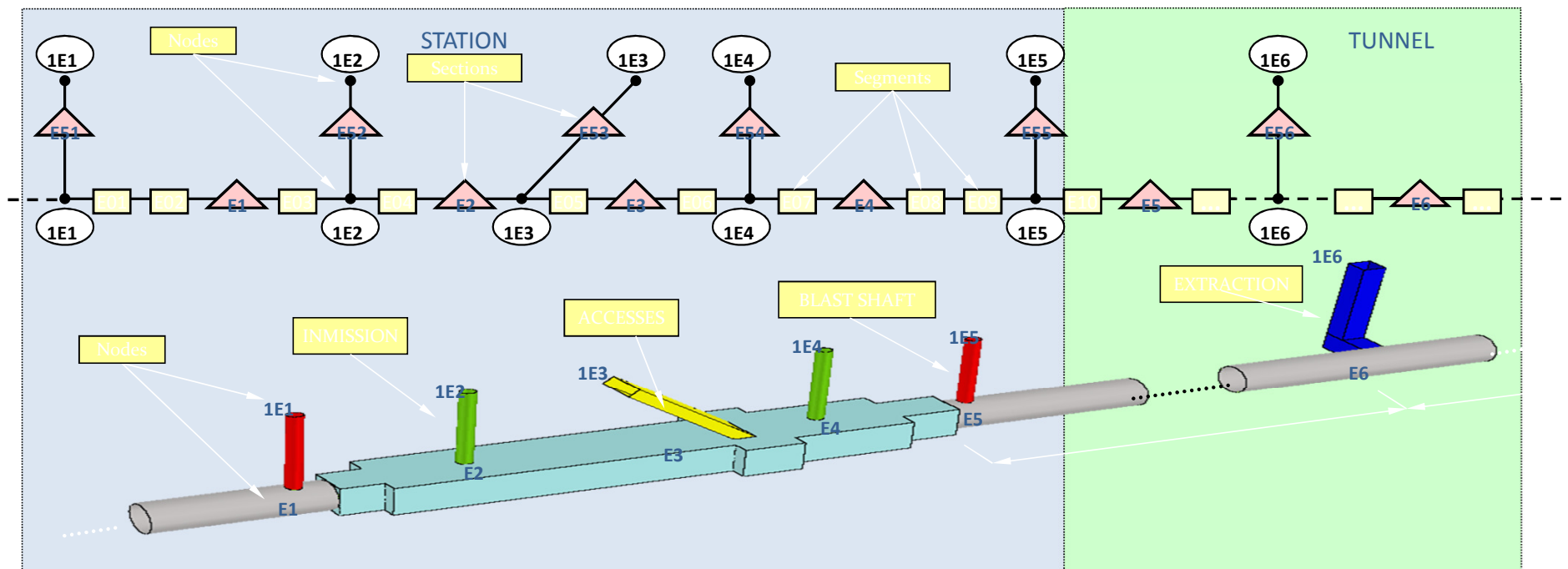
- Air velocity: 0.75 m/s; according to NFPA.

- **Emergency situation:**

- Passenger trains stopped between two shafts.
- Evacuation will assure people arriving to an emergency exit.

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Tunnel (SES)



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Tunnel

Geometrical Model

Development of the tunnel and stations geometrical model with parameters used:

- **Geometrical data:** Introduced, according to the needs of SES programme (nodes, sections, segments, subsegments, etc.):
 - Cross section, perimeter, roughness,
 - Temperature, relative humidity, soil and structure thermal properties.
 - Accumulated height (gradient)
 - Head losses related to geometry changes of the tunnel.

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Tunnel

- Fans data: Initial airflows proposed as fans curves, adjusting these flows into SES.
- Train performance data: physical parameters, friction aerodynamic coefficients, and traction curves.
- Routes data in normal operation, train frequencies and velocities.
- Fires corresponding to trains.

The first step to use SES simulator is to convert all parameters in a one-dimensional model.

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Comfort situation (passenger trains):

The comfort situation has been simulated, and ventilation strategies have been provided.

Trains pass at headways of 3 minutes.

Two different ventilation schemas have been considered:

- Type A: Make-up air in Can Zam + Inmisión en Gorg
- Type B: Exhaust in Can Zam + Make-up air in Gorg

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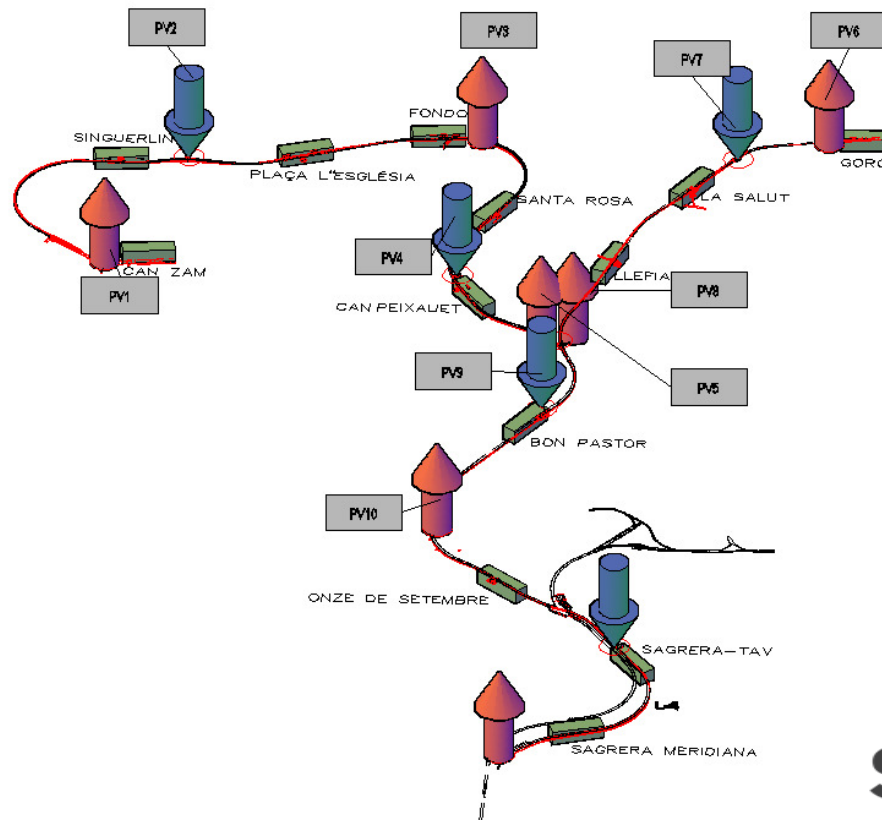
SES SIMULATIONS

Comfort situation (passenger trains):

TVS	Location	Operational mode	
		Type A	Type B
PV1	Can Zam	Intake	Exhaust
PV2	Entre Singuerlin-Egglesia	Exhaust	
PV3	Fondo	Intake	Exhaust
PV4	Can Peixauet	Exhaust	
PV5	Telescopi (I. Can Zam)	Intake	Exhaust
PV6	Gorg	Intake	Exhaust
PV7	Entre La Salut-Gorg	Exhaust	Intake
PV8	Telescopi (L. Gorg)	Intake	Exhaust
PV9	Bon Pastor	Exhaust	Intake
PV10	Entre Onze Septembre-Bon Pastor	Intake	Exhaust

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INFRASTRUCTURE



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SES SIMULATIONS

Comfort situation:

After all simulations, it has been considered **the ventilation Schema B (favours chimney effect)**:

- Exhaust will be done in extremes.
- Intake will be achieved in several low points, (i.e. at shaft between La Salut and Gorg).
- When running these simulations, in normal operation, air velocity is around 1 m/s. Flowrate at confort (at 500 rpm):
 - $40\text{m}^3/\text{s} = 144.000\text{ m}^3/\text{h}$, per fan.

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SES SIMULATIONS

Emergency situation:

After all simulations, it has been considered **the ventilation Schema B:**

- Exhaust will be done in extremes
- Intake will be achieved in several low points,
(i.e. at shaft between La Salut and Gorg)
- When running these simulations, in emergency operation, air velocity should be over critical control velocity.
- Fire simulation strategy has been used as follows:
 - Previous and next Shaft : Flowrate at emergency (upper and lower tunnel at 1000 rpm)
(70m³ /s = 252.000 m³/h, per fan).
 - Rest of Shafts: Flowrate at comfort (40m³ /s = 144.000 m³/h, per fan).

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SES SIMULATIONS

Location of fire segments:

Segment	Tunnel	Between	
		Ventilation Shaft	Ventilation Shaft
494	Lower	PV1 (Can Zam)	PV2
625	Lower	PV2	PV3 (Fondo)
707	Lower	PV3 (Fondo)	PV4 (Can Peixauet)
835	Lower	PV4 (Can Peixauet)	PV5 (Telescopi, Can Zam)
196	Upper	PV2	PV3 (Fondo)
278	Upper	PV3 (Fondo)	PV4 (Can Peixauet)
407	Upper	PV4 (Can Peixauet)	PV5 (Telescopi, Can Zam)
983	Upper	PV6 (Gorg)	PV7

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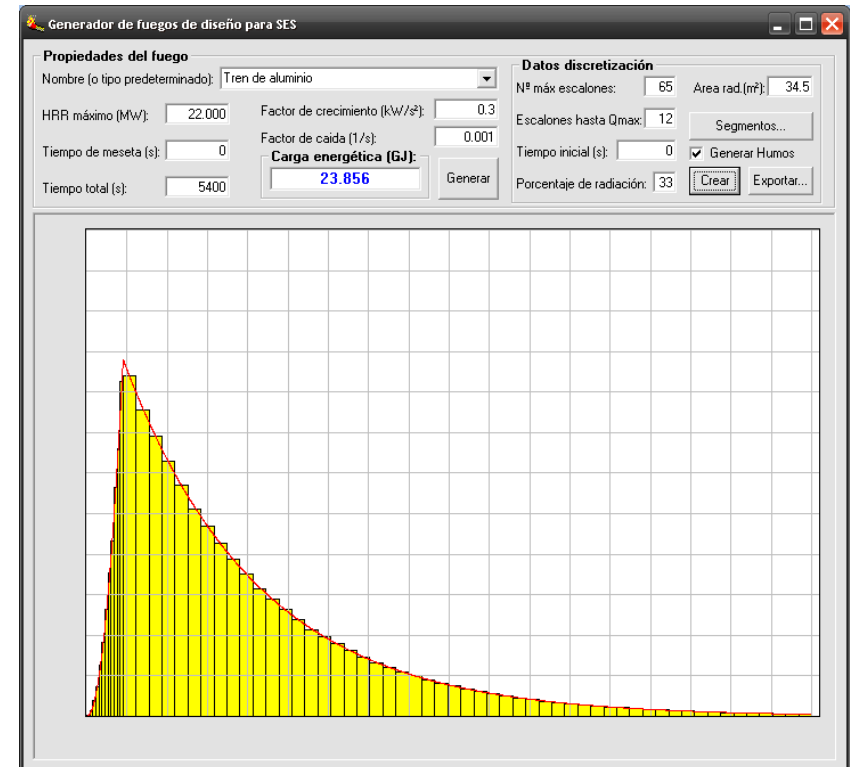
SES RESULTS ANALISYS

- Selection of a segment for detailed analisys (comfort and emergency case):
 - Selection
 - Case Simulation.
 - Some pictures of “***SES TD&T proprietary reader tool***” and explanation.
 - Graphic result and interpretation.

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SES RESULTS ANALISYS

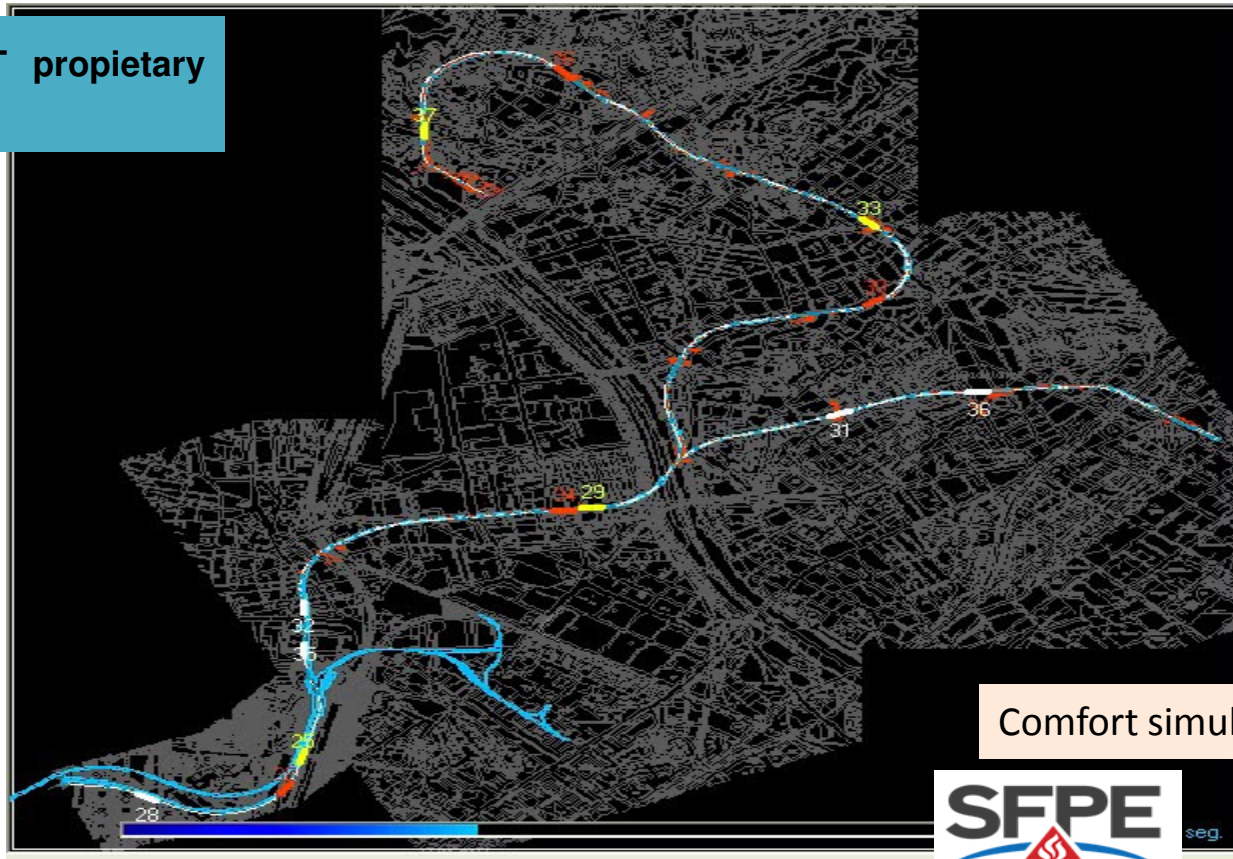
- Conditions:
 - Trains frequency: 4 minutes.
 - Rolling stock: Type Line 9.
 - Fire Size: Aluminium, 22MW.



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SES RESULTS ANALISYS

View of SES TD&T proprietary reader tool.

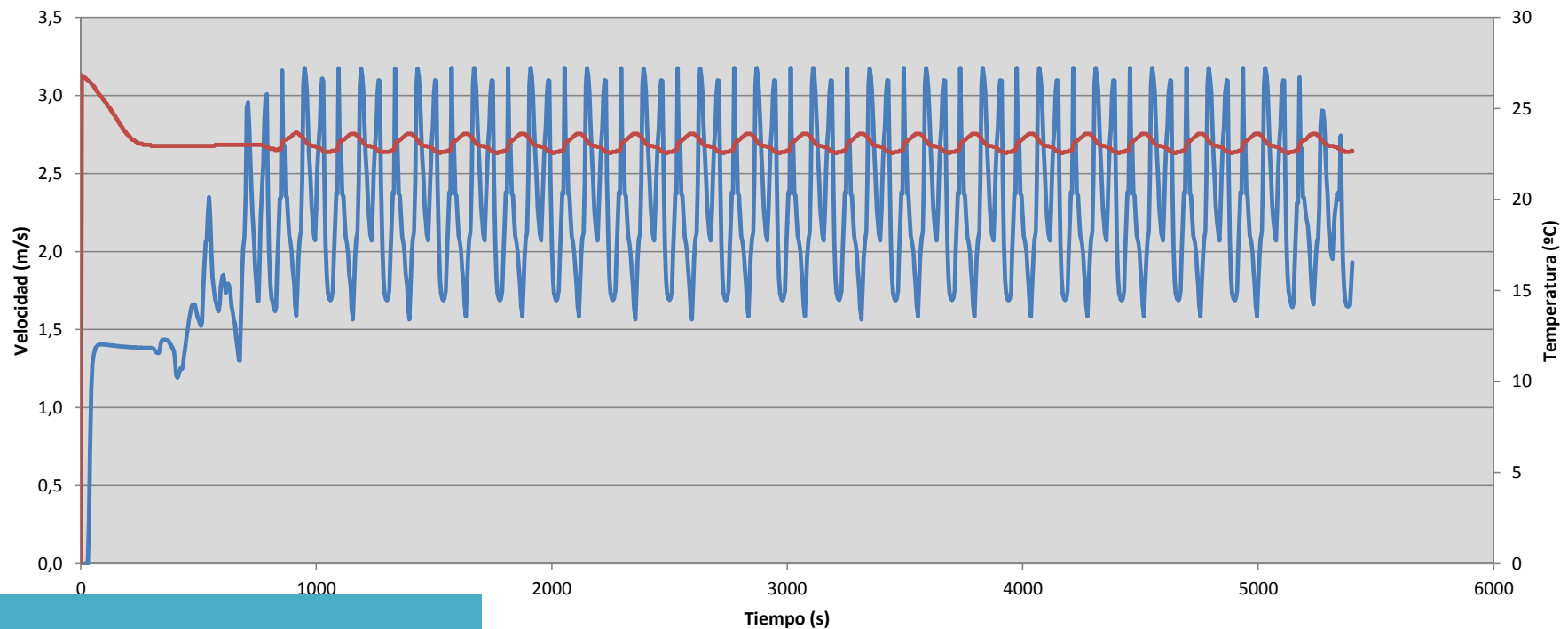


Comfort simulation

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SES RESULTS ANALISYS

Velocidad del aire y Temperatura en el Segmento 0407



Graphic results of **SES TD&T** proprietary tool.

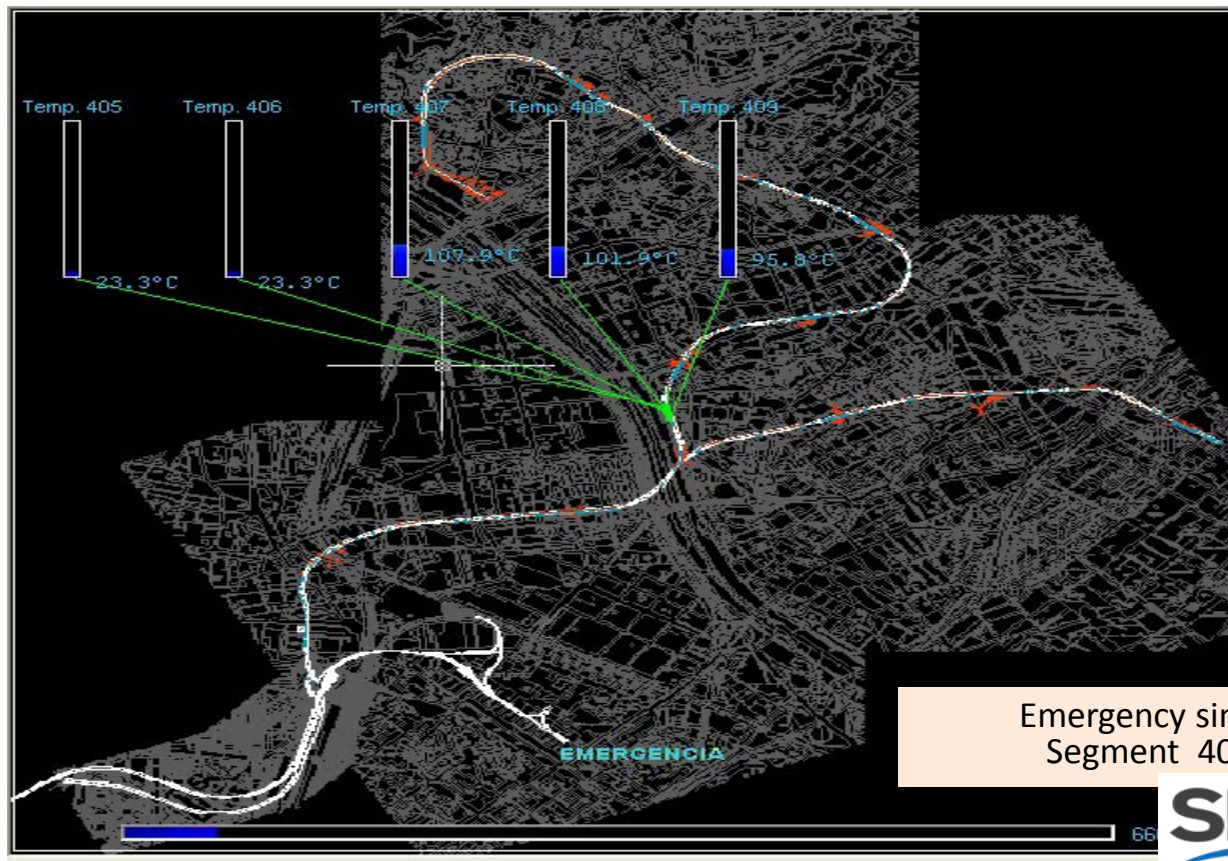
— Velocidad (m/s) — Temperatura (°C)

SFPE
Engineering A Fire Safe World
BENELUX CHAPTER

TD&T
TRANSFER & DEVELOPMENT OF
TECHNOLOGY

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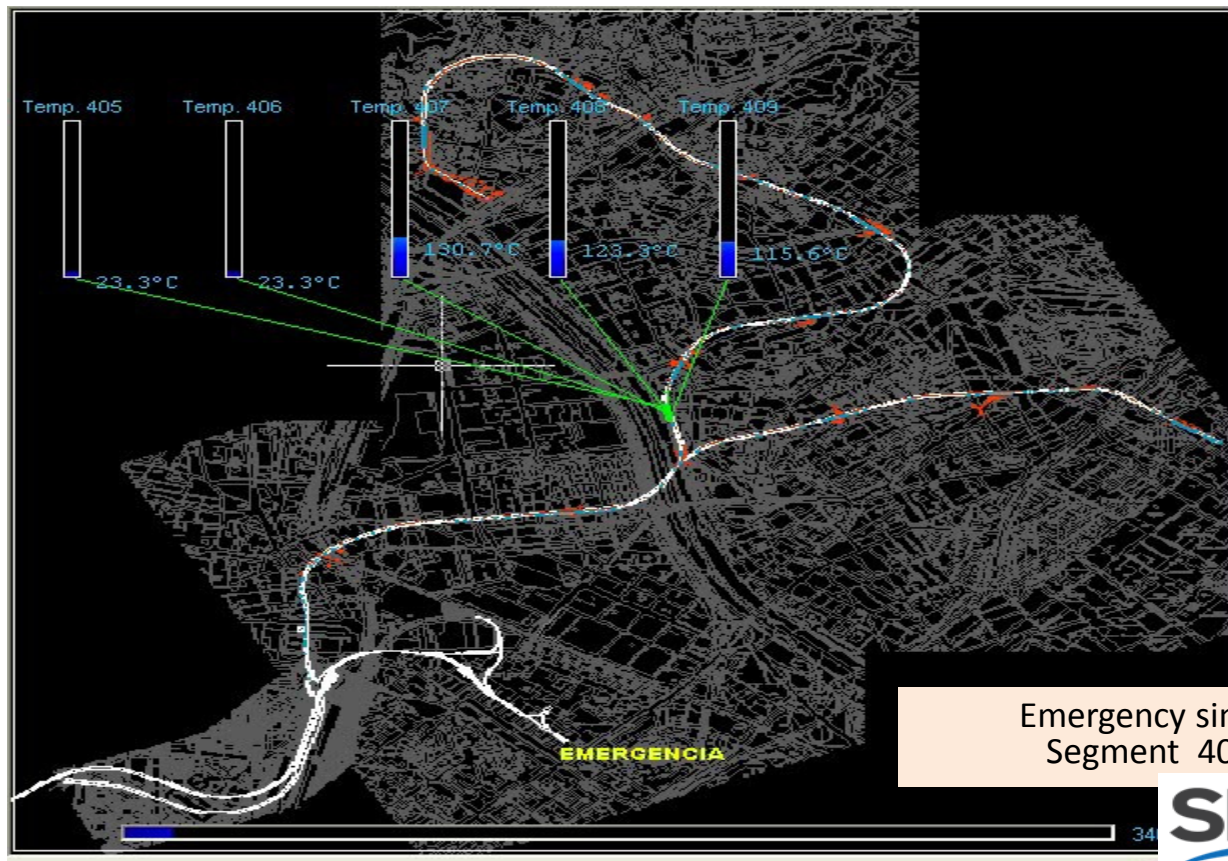
SES RESULTS ANALISYS



Emergency simulation
Segment 407 (G1)

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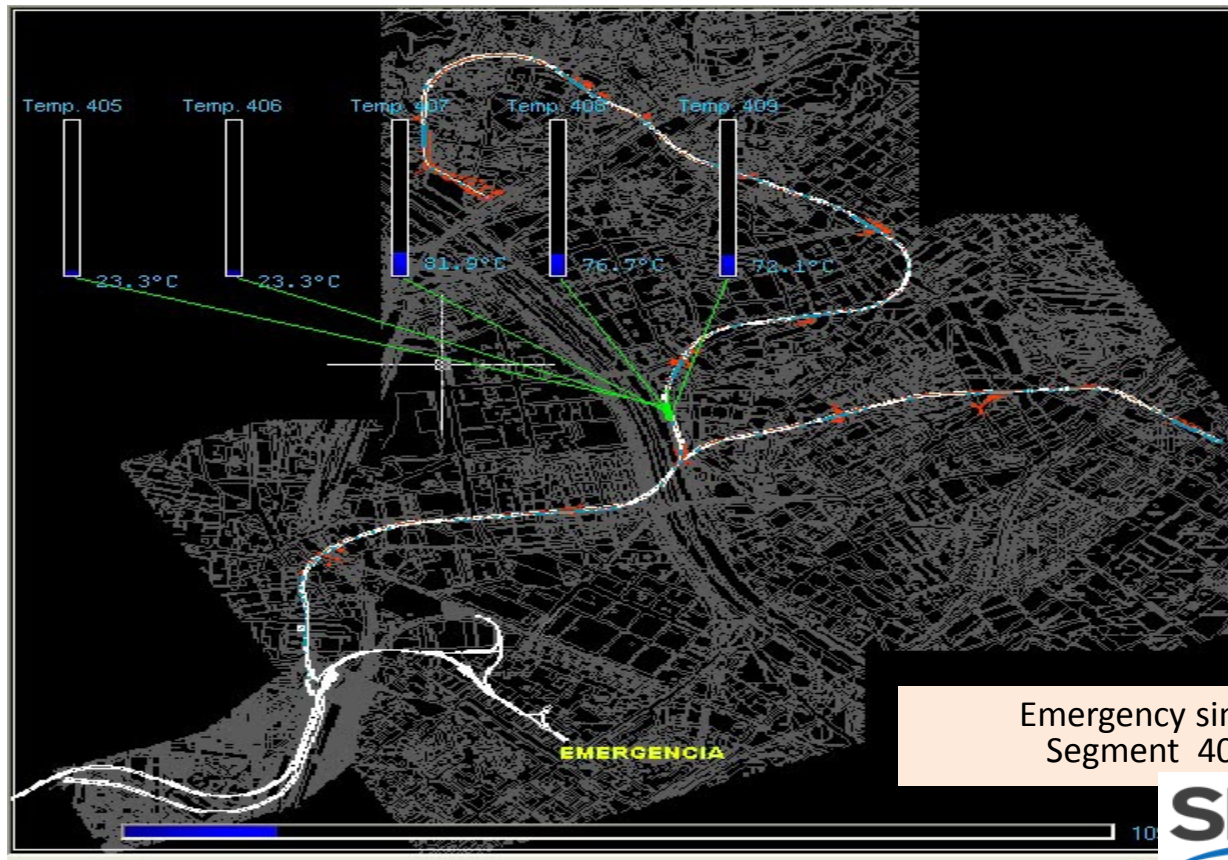
SES RESULTS ANALISYS



Emergency simulation
Segment 407 (G2)

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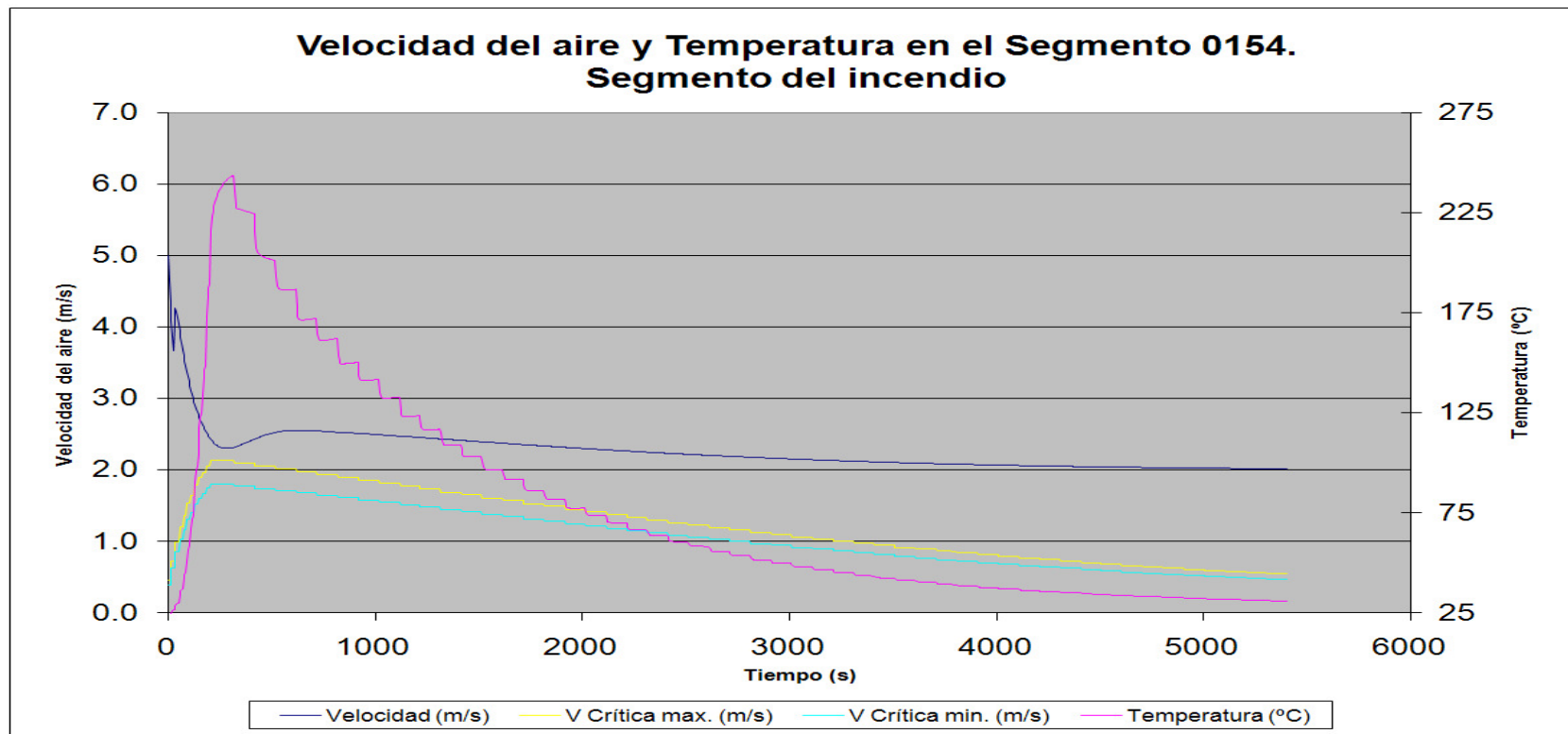
SES RESULTS ANALISYS



Emergency simulation
Segment 407 (G3)

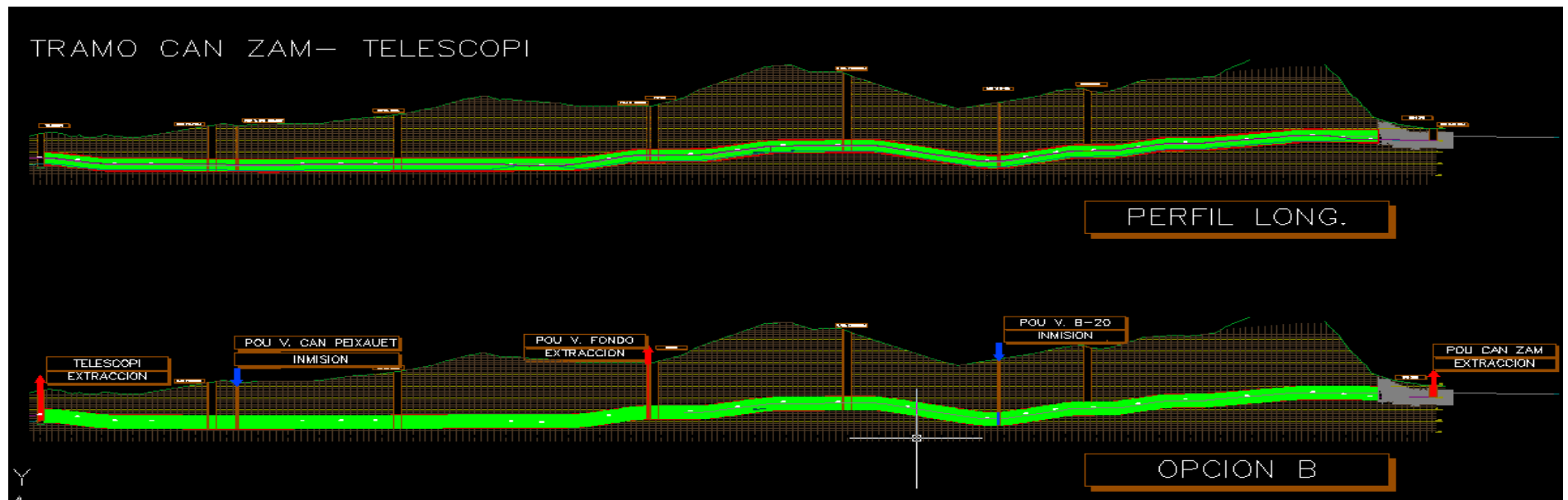
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SES SIMULATIONS



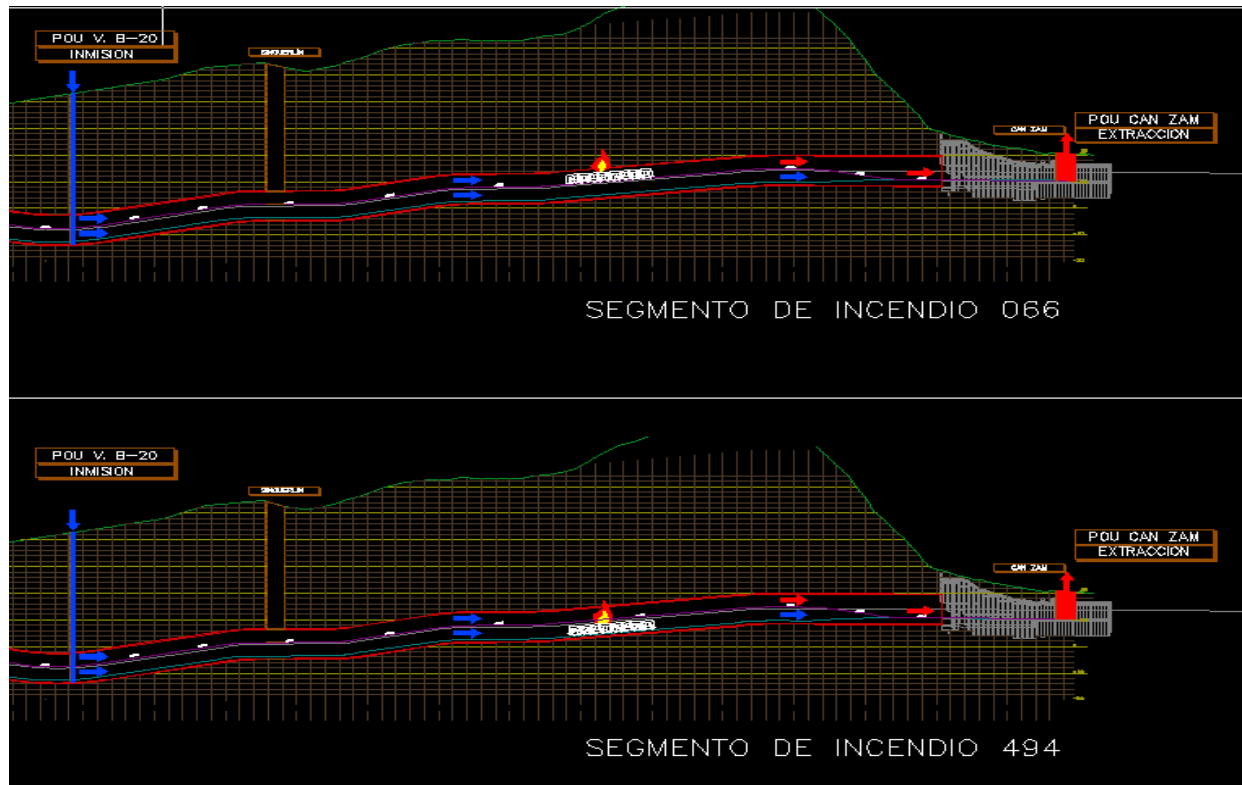
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CONCLUSIONS



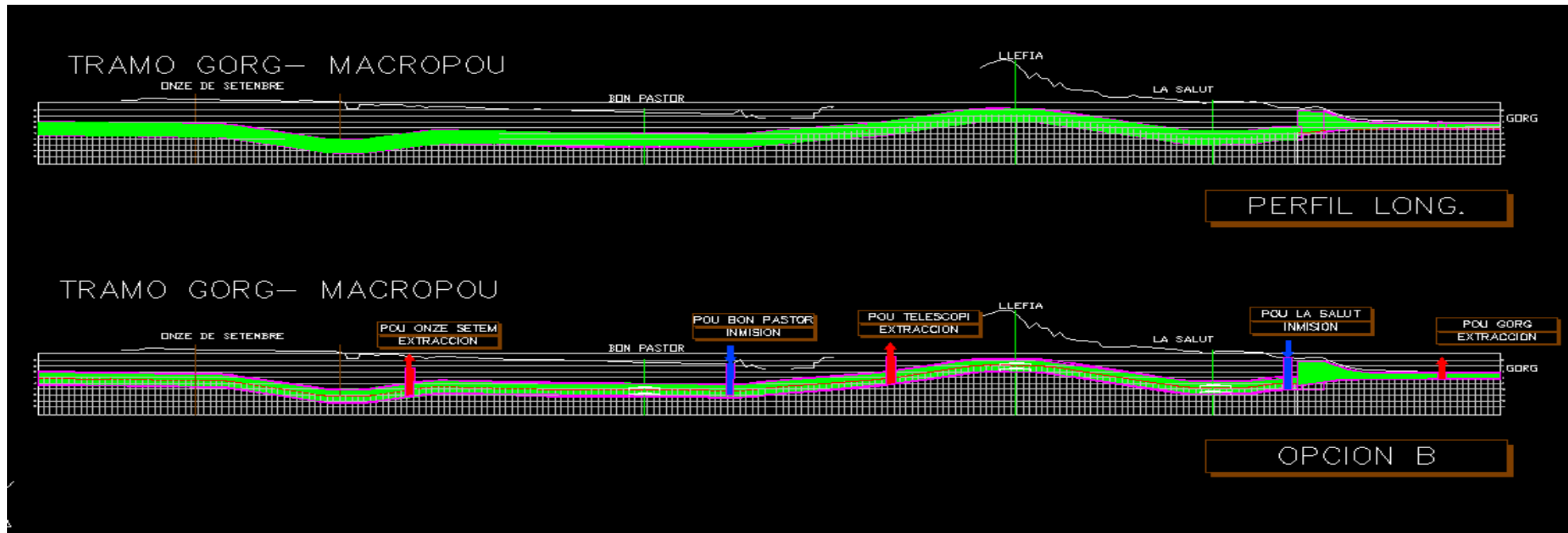
METRO LINE 9, AT BARCELONA CITY IN SPAIN

CONCLUSIONS



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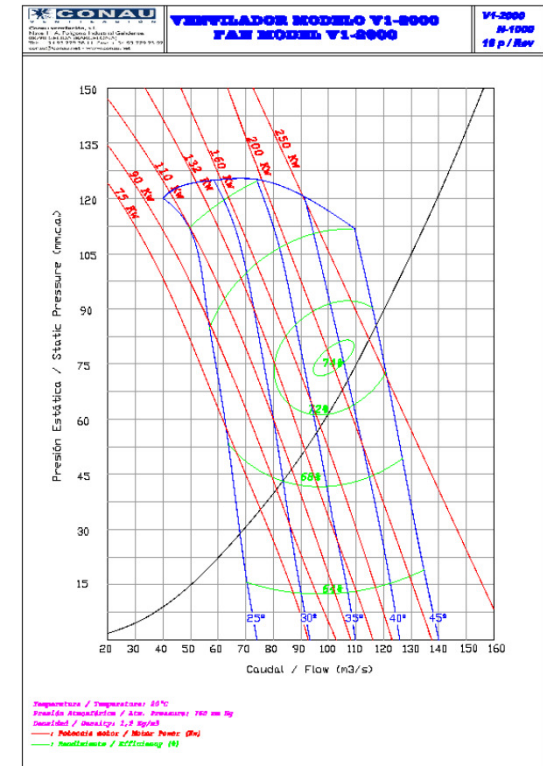
CONCLUSIONS



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CONCLUSIONS: EQUIPMENT

- Option Tipe B: favours chimney effect.
- Equipment:
 - 4 fans per shaft (two fans per level).
 - Flowrate:
 - Comfort: 40 m³/s per fan.
 - Emergency: 70 m³/s per fan.



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CFD TYPICAL STATION

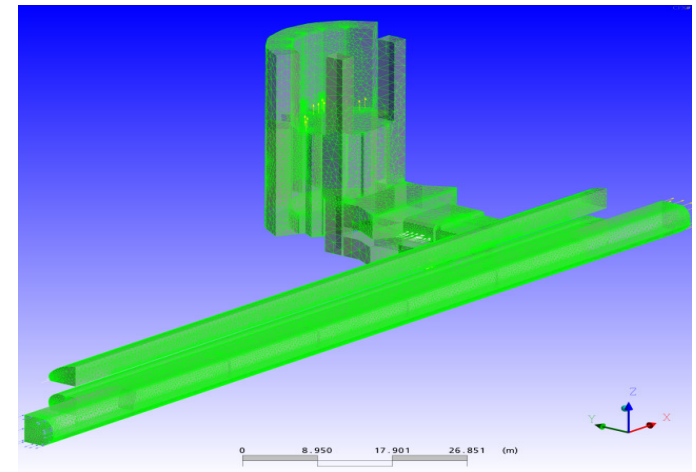
- **CFD fire simulation:**

- Train stopped in mezzanine, at the upper level tunnel, in the station.
- Fire in the mid-wagon.

- **Evacuation study**

- To assure people will arrive to emergency exits.

Ventilation design has been completed for this particular innovative “shaft” type station.



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CFD TYPICAL STATION

The behaviour of a train in fire with open doors, stopped in a platform with PSD open, has been modelled **through CFX simulations**.

It has been reviewed the adequacy of the solution designed by TMB, in this fire situation.

Three CFD simulations have been done:

1. Ventilation solution proposed by TMB.
2. Ventilation design proposed by TD&T.
3. Improvement to OUR TD&T Design, including holes in PSDs 5 m. x 0.75 m, in each extreme of platforms, to be open at 120 s.

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CFD METHODOLOGY

- NFPA-130 Regulations review.
- 3D Modelling of station geometry, ventilation design and fire.
- Mesh creation.
- Selection of physical sub-models.
- Contour conditions at every region.
- Initial conditions.
- Monitoring of iterative solution, controlling parameters for adequate numerical resolution.
- Analysis of results.
- Conclusions.
- Recommendations and improvements.

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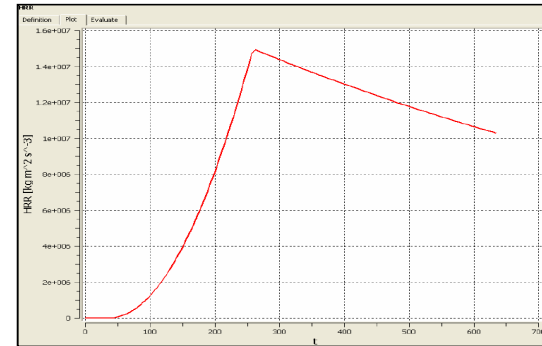
CFD MODEL

FIRE:

Fire evolution according to Eq. (1):

$$HRR = \alpha t^2 \quad (1)$$

$$HRR = HRR_{\max} e^{-\beta(t-t_0)} \quad (2)$$



(“An Overview of Vehicle Fires In Tunnels”, of Haukur Ingasson, presented in the congress “Safety in Rail and Road Tunnels” celebrated en Madrid, ITC 2001)

MULTI- COMPONENT FLUX

Multi-component flux of air, smoke and CO have been modelled, where:

- SOOT COEF = 2.5 g.s⁻¹.MW⁻¹.
- CO COEF = 0.915 g.s⁻¹.MW⁻¹.

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CFD MODELS

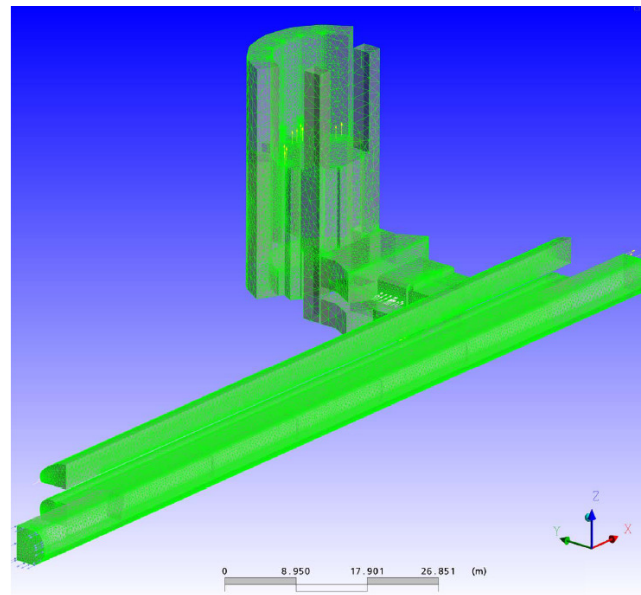
MESH

The dominium of calculus has been generated as 3D solids.

Volume: 9.593 m³

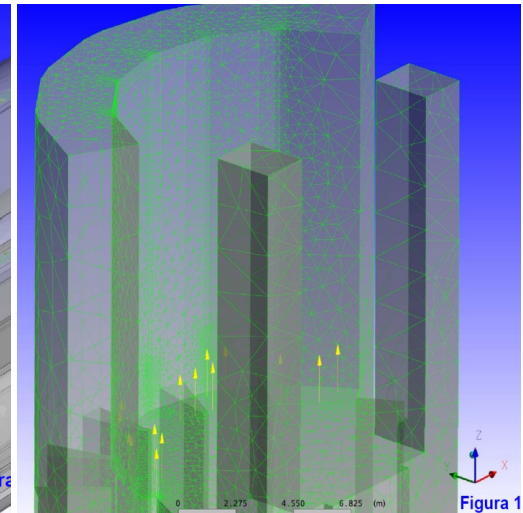
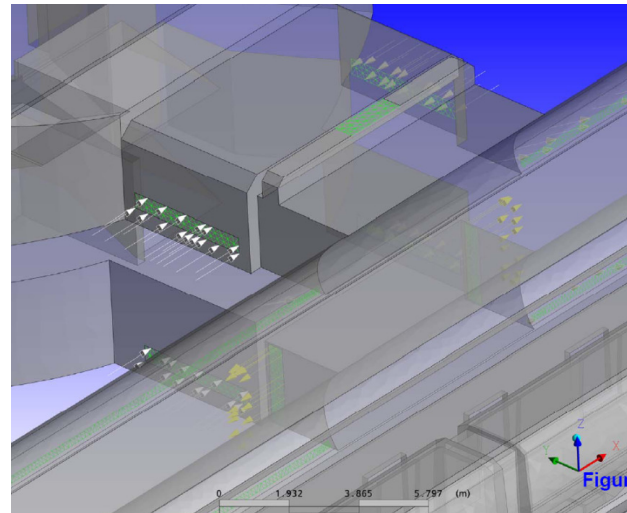
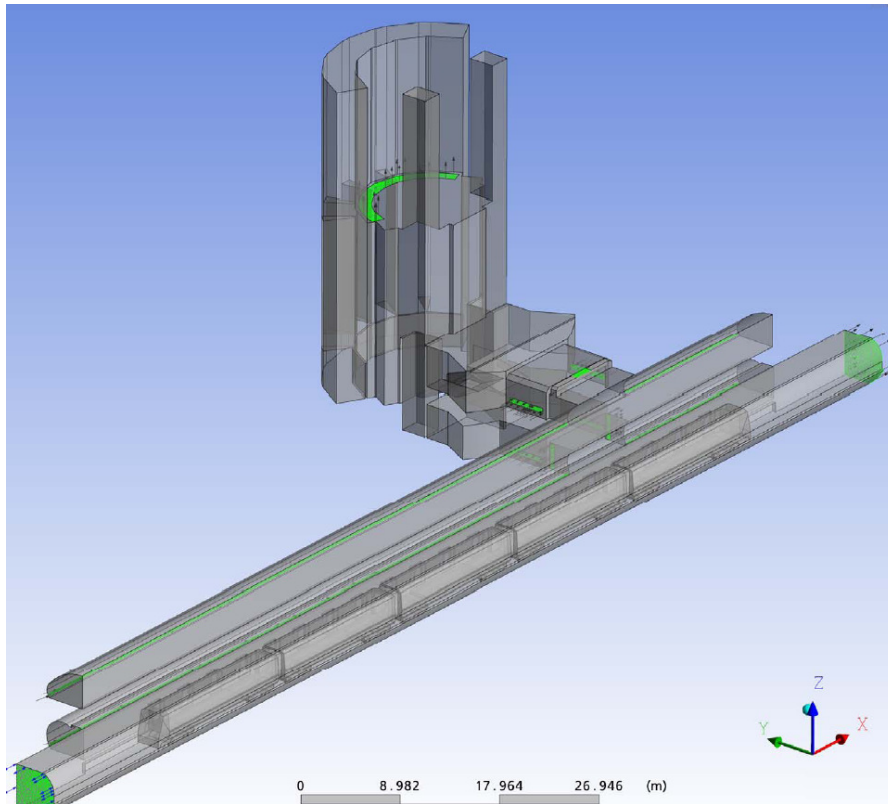
N. tetrahedra: 6.037.489

N. nodes: 1.117.256



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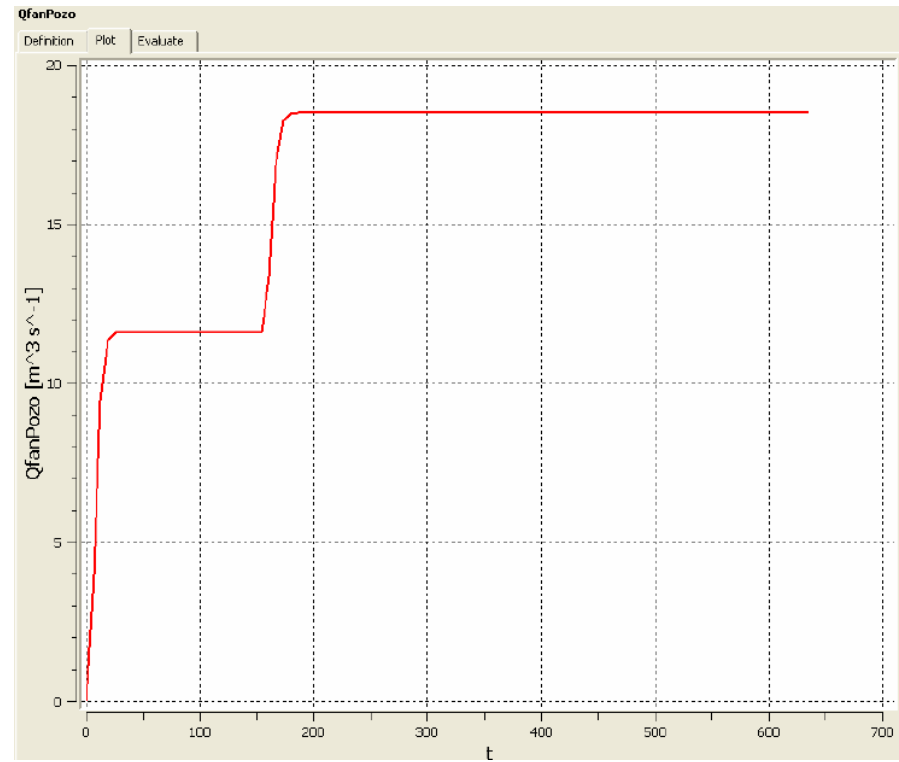
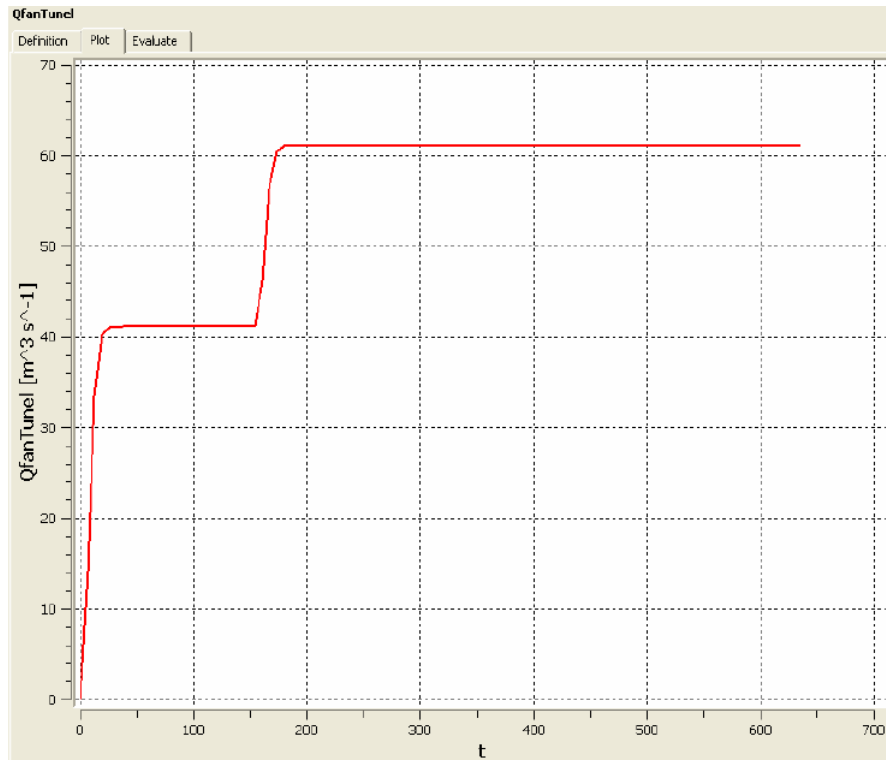
CFD MODEL SIMULATION 1



Contour conditions are shown according to TMB design.

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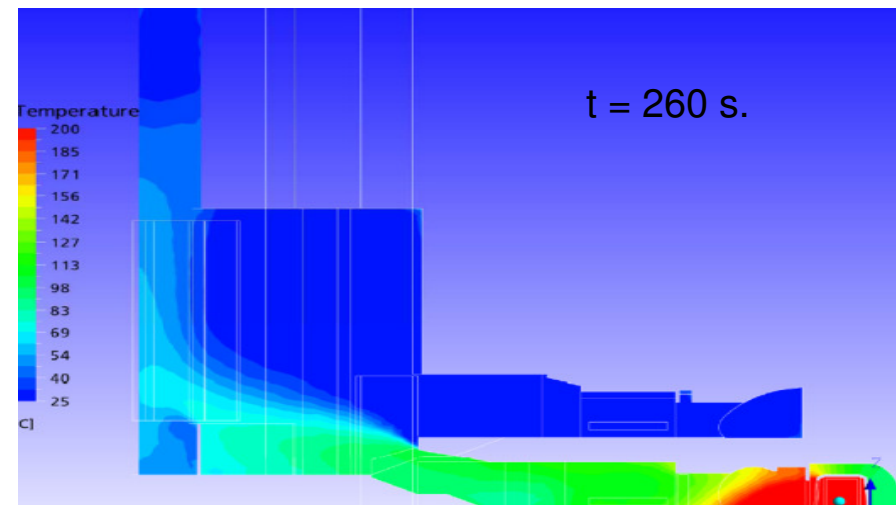
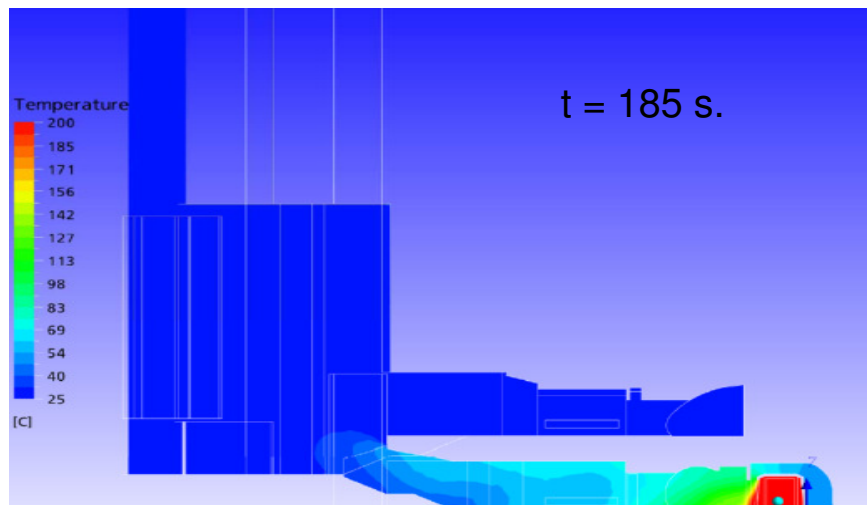
CFD MODEL SIMULATION 1



METRO LINE 9, AT BARCELONA CITY IN SPAIN

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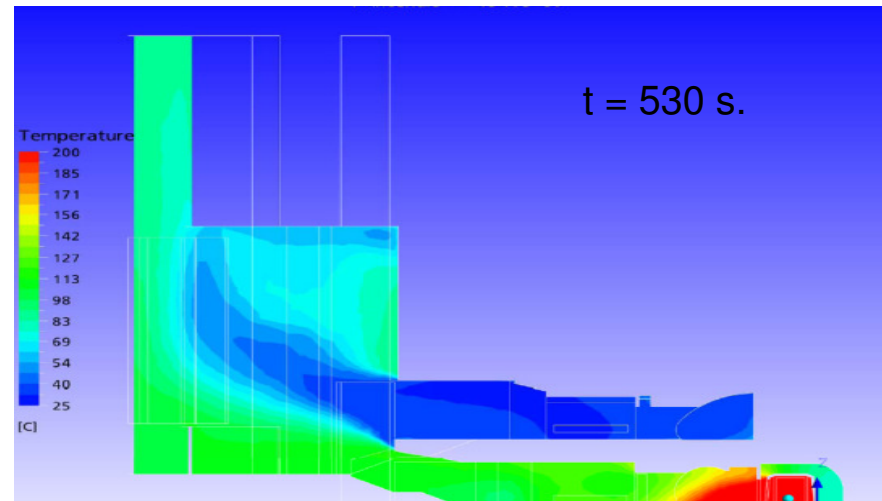
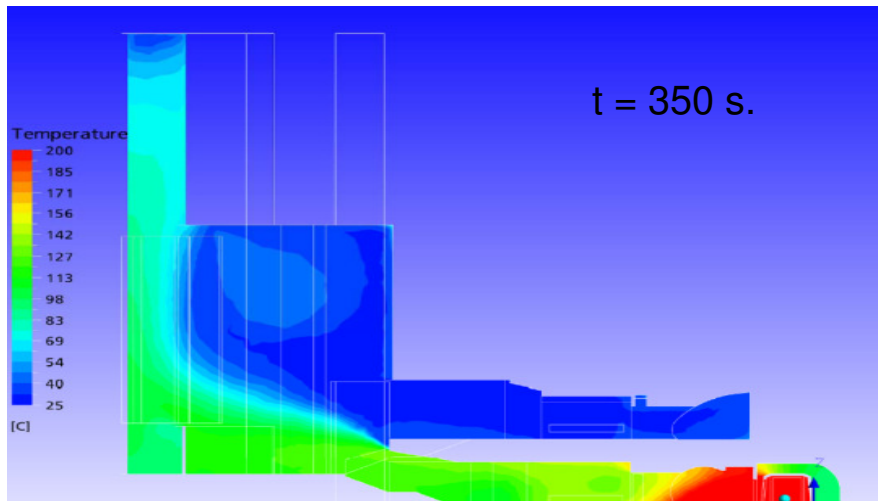
Fire progresses: Temperature rises from fire at platform, well above 60 °C.



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CFD MODEL SIMULATION 1

- Temperatures above 1000 °C close to the surface where the fire is set.
- Temperatures at platform exceed 60 °C (sustainability conditions).

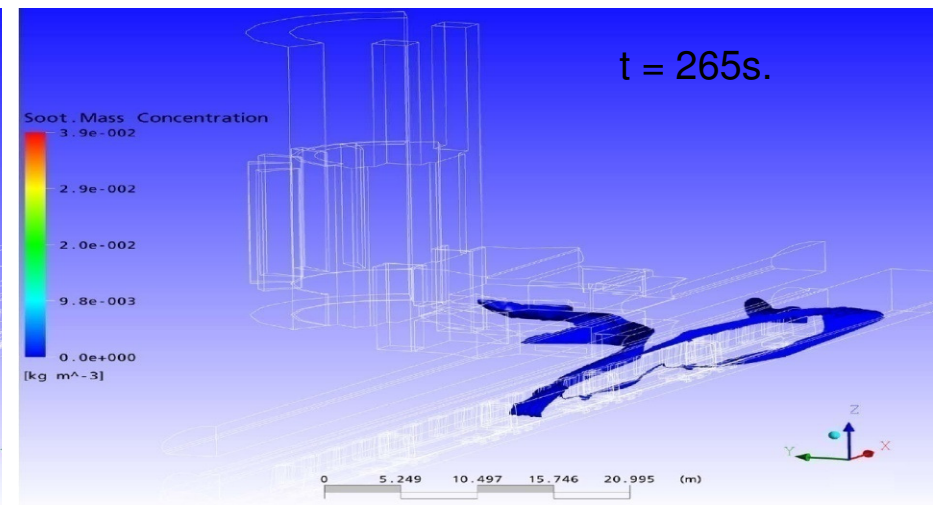
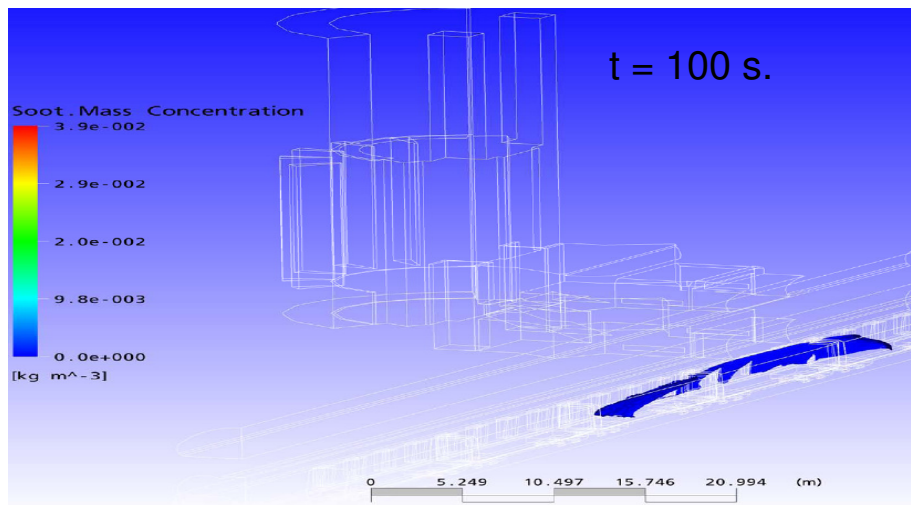


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CFD MODEL SIMULATION 1

Soot mass concentration $6 \cdot 10^{-5} \text{ kg/m}^3$.

- Smoke goes into the station.
- Ventilation design is not correct.

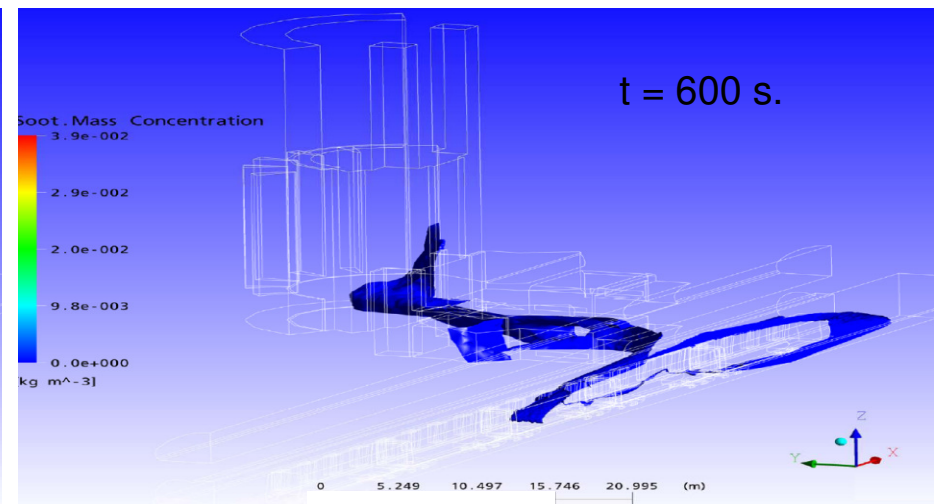
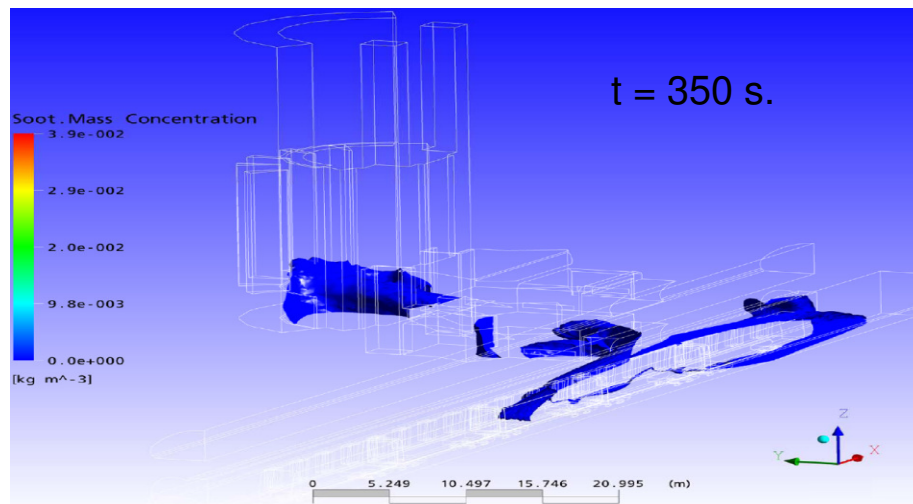


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CFD MODEL SIMULATION 1

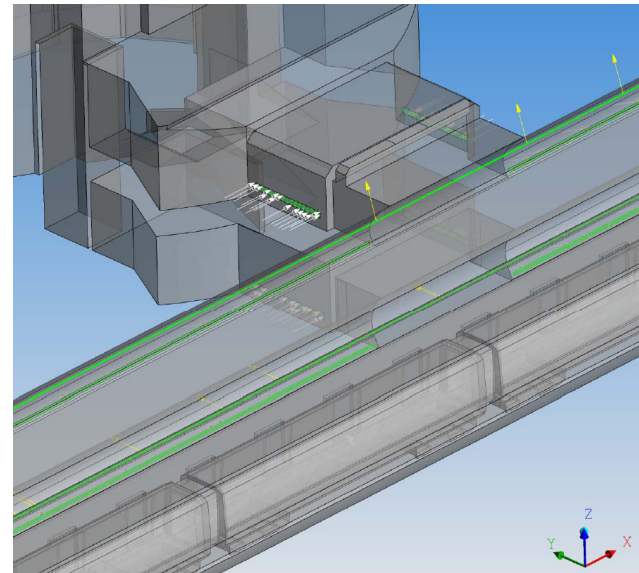
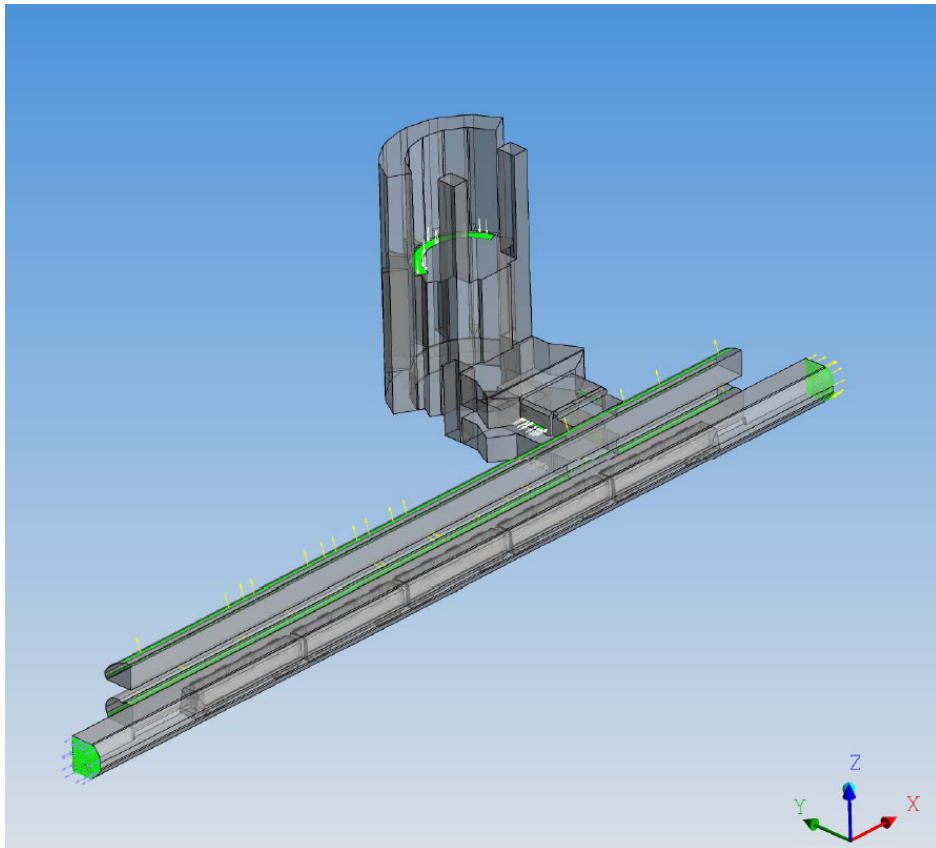
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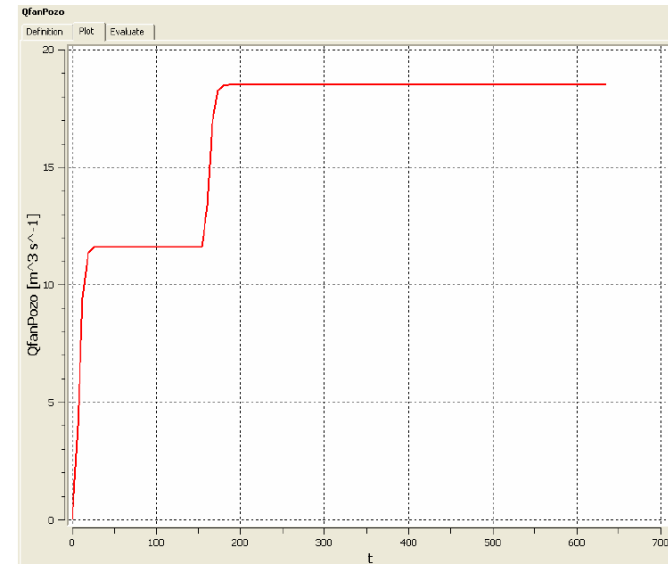
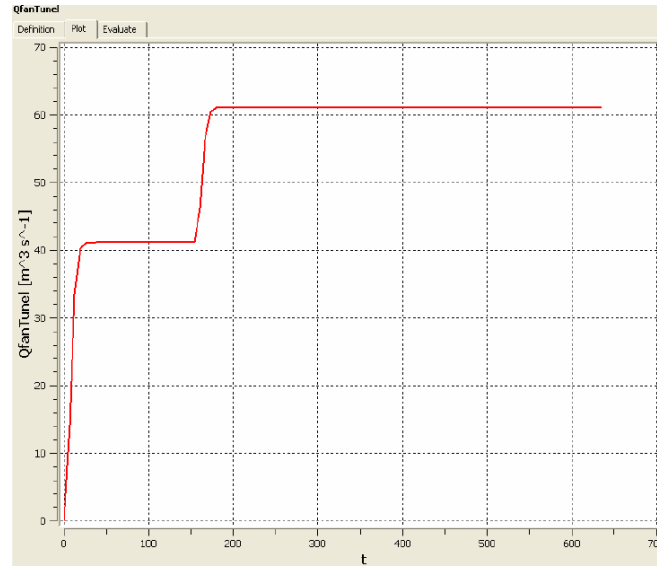
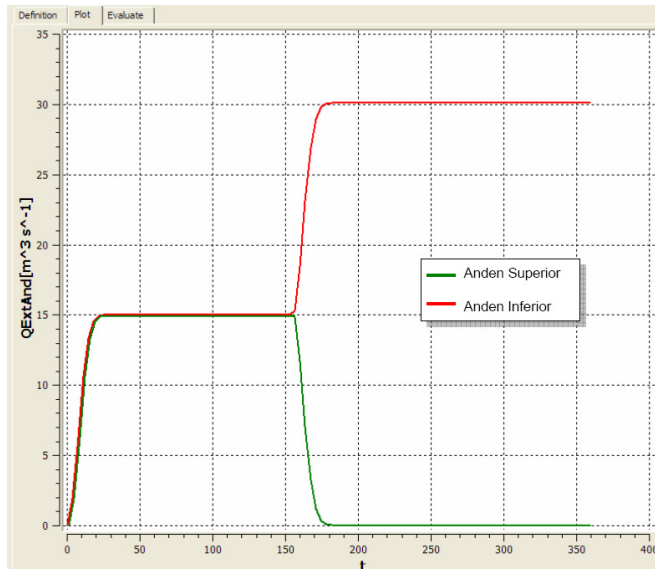
CFD MODEL SIMULATION 2



Contour conditions are shown according to TD&T design.

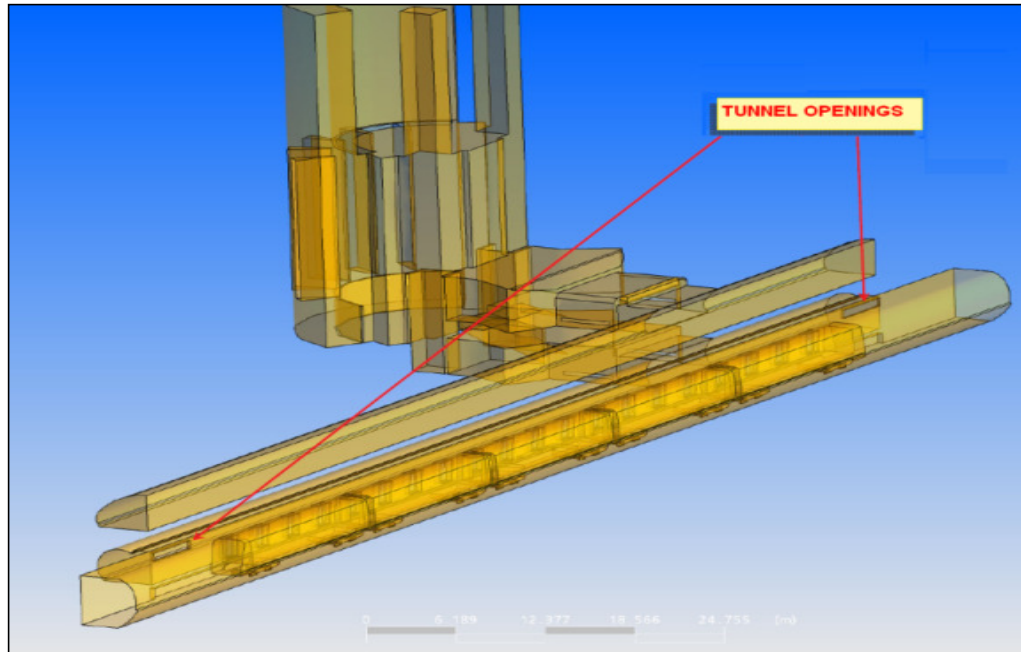
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CFD MODEL SIMULATION 2

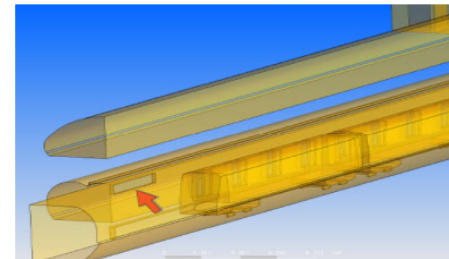
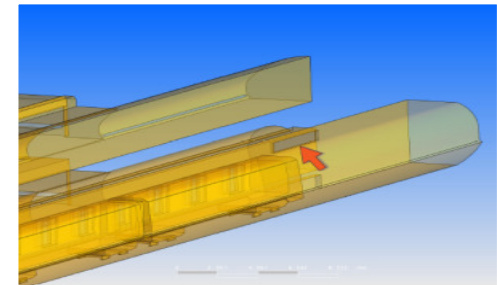


METRO LINE 9, AT BARCELONA CITY IN SPAIN

CFD MODEL SIMULATION 3



Simulation 3 includes openings in platforms.

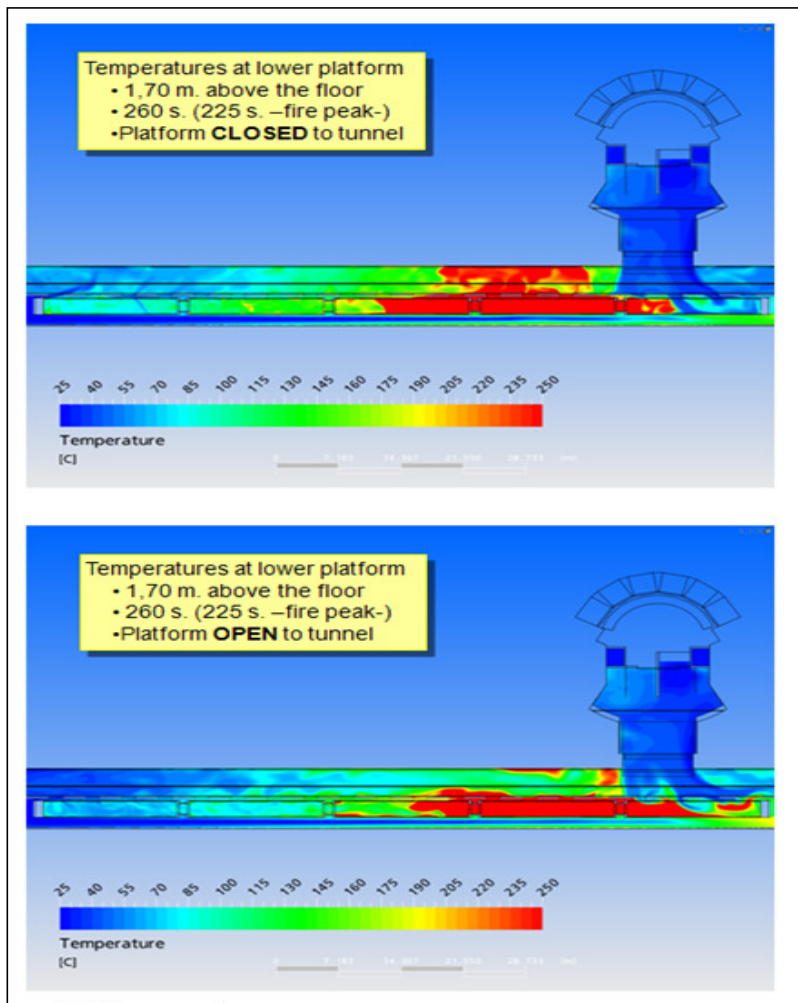


Contour conditions are shown according to TD&T design (simulation 2).

METRO LINE 9, AT BARCELONA CITY IN SPAIN

CFD SIMULATIONS

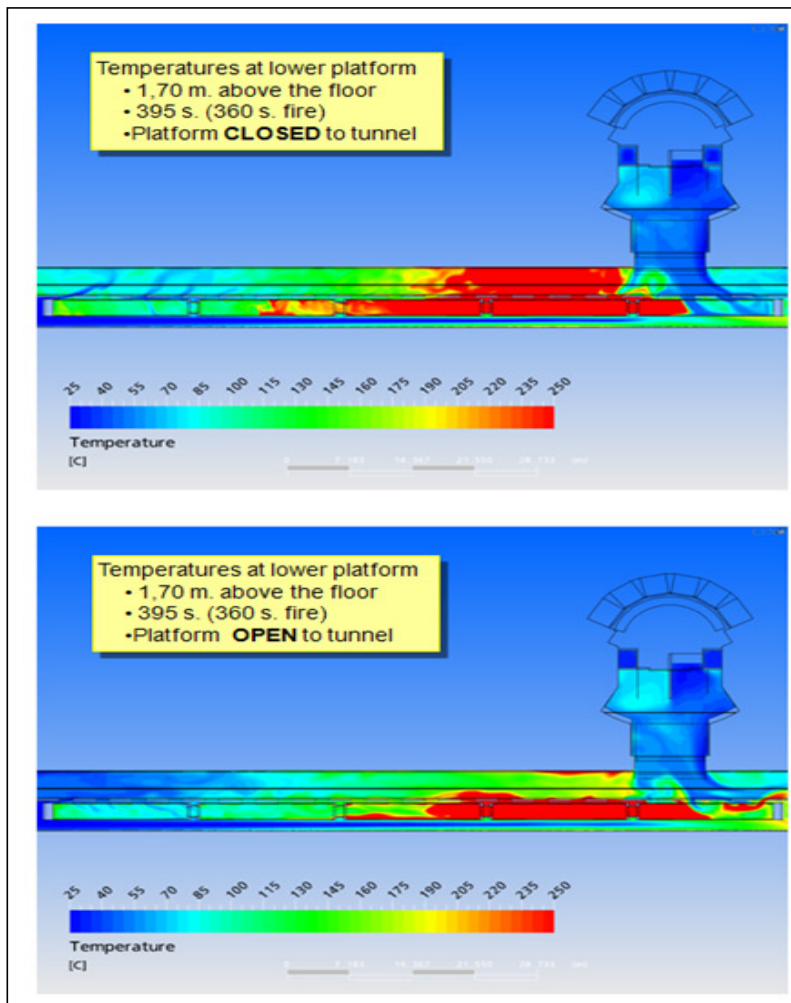
Comparative of temperatures at 260 seconds.



METRO LINE 9, AT BARCELONA CITY IN SPAIN

CFD SIMULATIONS

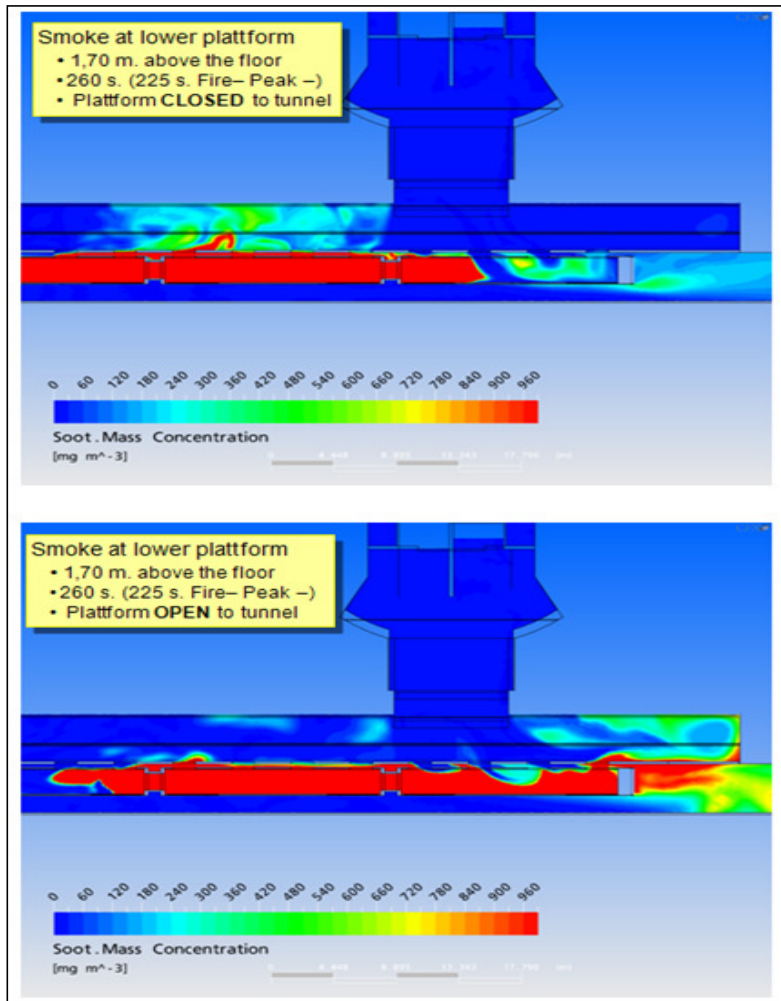
Comparative of temperatures at 395 seconds.



METRO LINE 9, AT BARCELONA CITY IN SPAIN

CFD SIMULATIONS

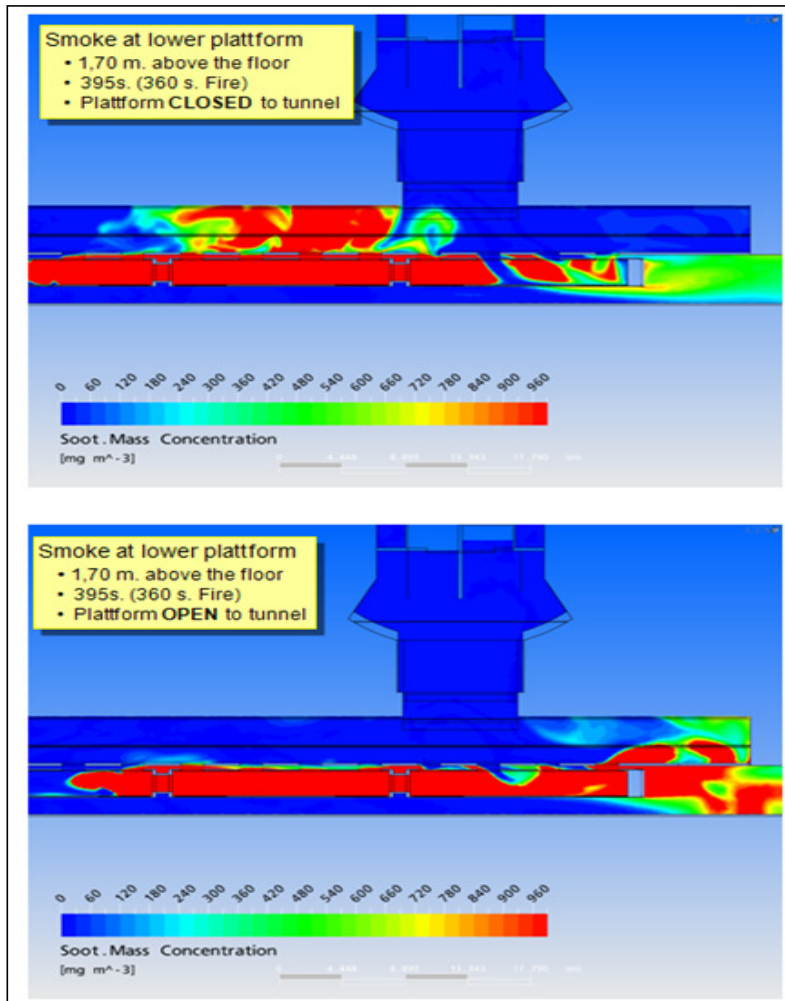
Comparative of soot mass concentration at 260 seconds.



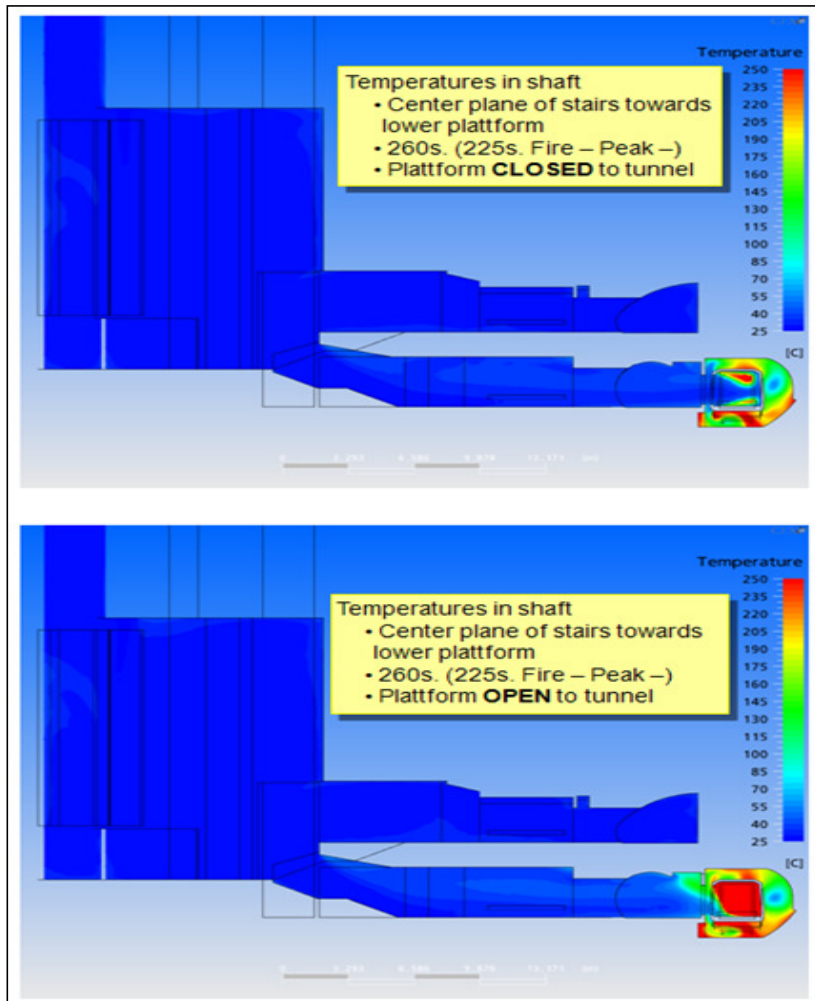
METRO LINE 9, AT BARCELONA CITY IN SPAIN

CFD SIMULATIONS

Comparative of soot mass concentration at 395 seconds.



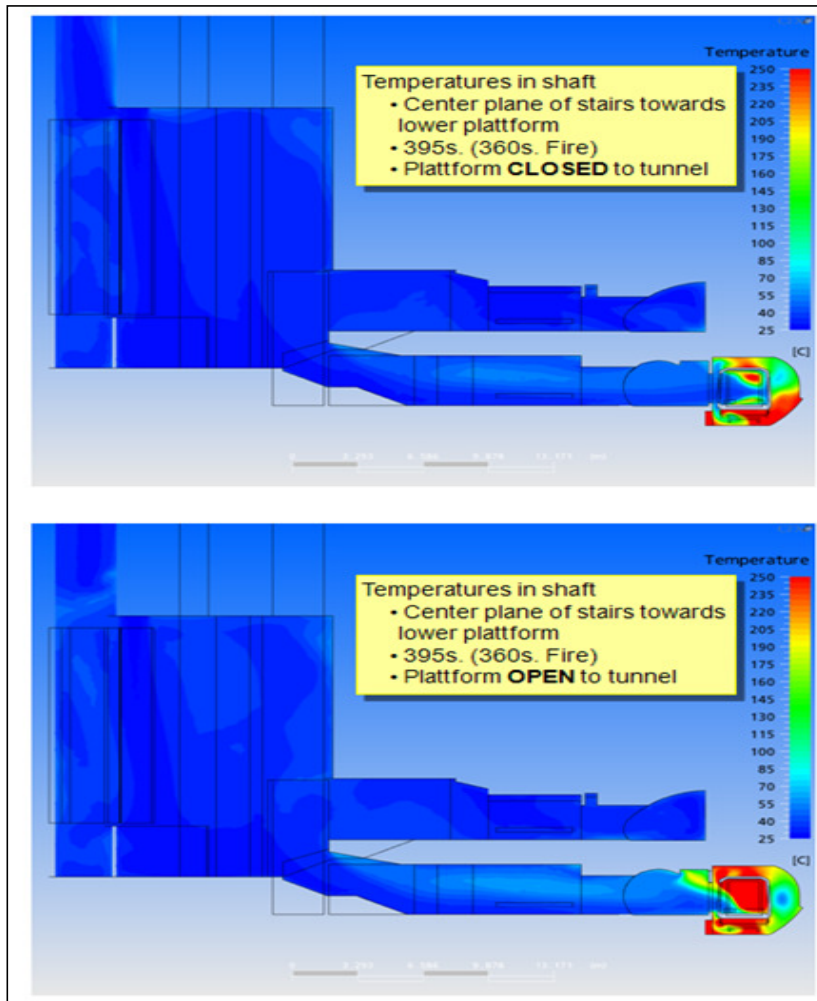
METRO LINE 9, AT BARCELONA CITY IN SPAIN



CFD SIMULATIONS

Comparative of shaft temperatures at 260 seconds.

METRO LINE 9, AT BARCELONA CITY IN SPAIN



CFD SIMULATIONS

Comparative of shaft temperatures at 365 seconds.

METRO LINE 9, AT BARCELONA CITY IN SPAIN

TD&T METHODOLOGY

- Preprocessor input
- Segments Generator
- Route Generator
- Postprocessor of output data
- Fans Editor
- Plug-in AutoCad for ventilation sections
- Graphical Postprocessor
- Saccardo shafts Implementation

METRO LINE 9, AT BARCELONA CITY IN SPAIN

TD&T METHODOLOGY

Replanteos [Sin_nombre]

Archivo Generar

Opciones generales Trazado en planta Trazado en alzado Puntos singulares Resultados

Datos generales

Título:

Observaciones:

Datos iniciales

P.K. Inicial (m.): 0 X Inicial: 0

Azimut Inicial (Grad): 0 Y Inicial: 0

Z Inicial: 0

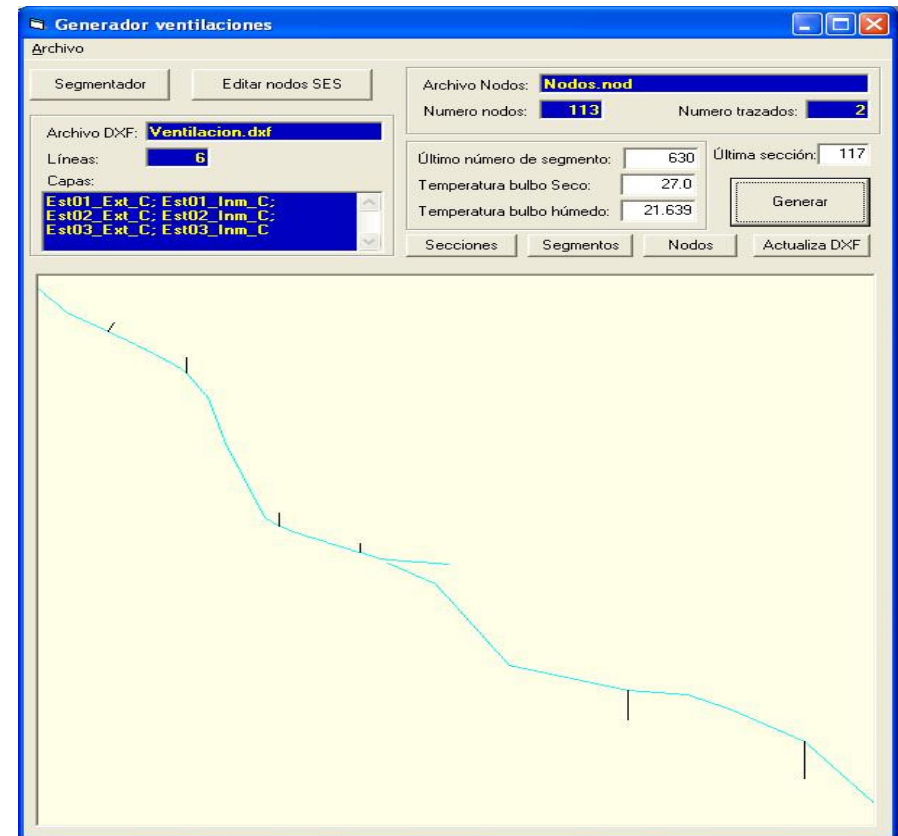
Datos generación

☒ Toda su longitud

☐ P.K. Inicio (m.): 0

P.K. Fin (m.): 0

Paso en la generación (m.): 1



METRO LINE 9, AT BARCELONA CITY IN SPAIN

TD&T METHODOLOGY

Editor Nodos SES

Filtrar
Tipo aero.: [dropdown] Tipo termo.: Combo1 [dropdown]

Nodos(0): [list box]

Tipo aerodinámico: 0 Tipo termodinámico: 1

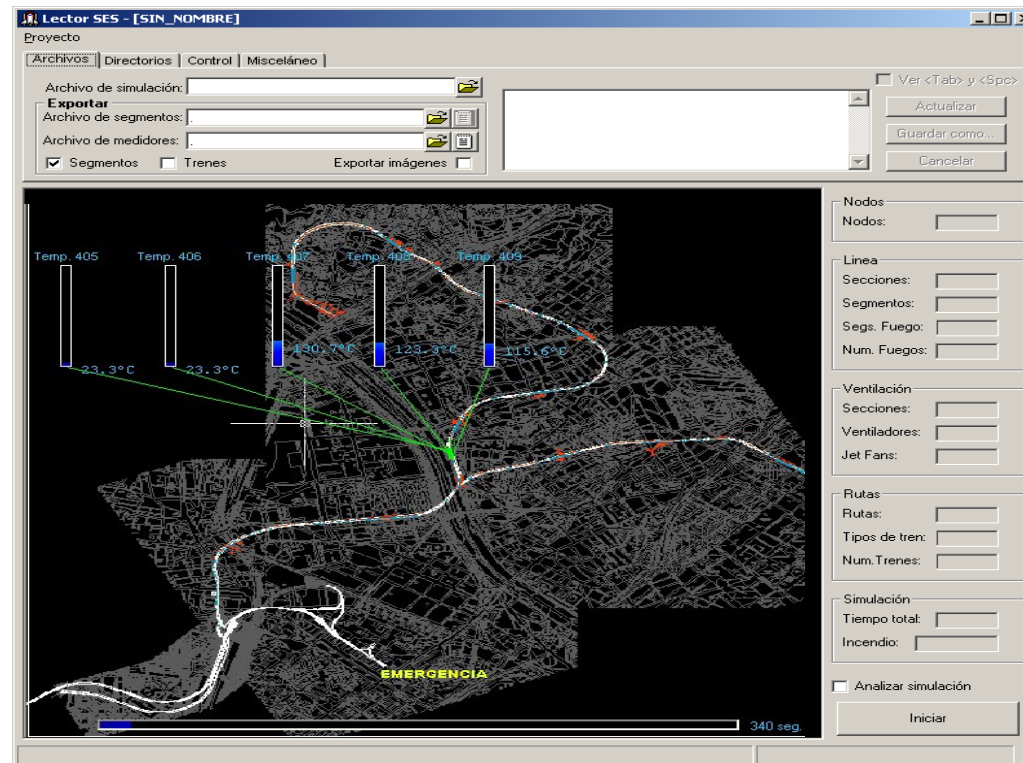
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C. I. P.: [input]

Termodinámico
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Subnodo B: [input]
Subnodo C: [input]
Condiciones de contorno
Temperatura de bulbo seco: [input]
Temperatura de bulbo húmedo: [input]

Aceptar Cancelar

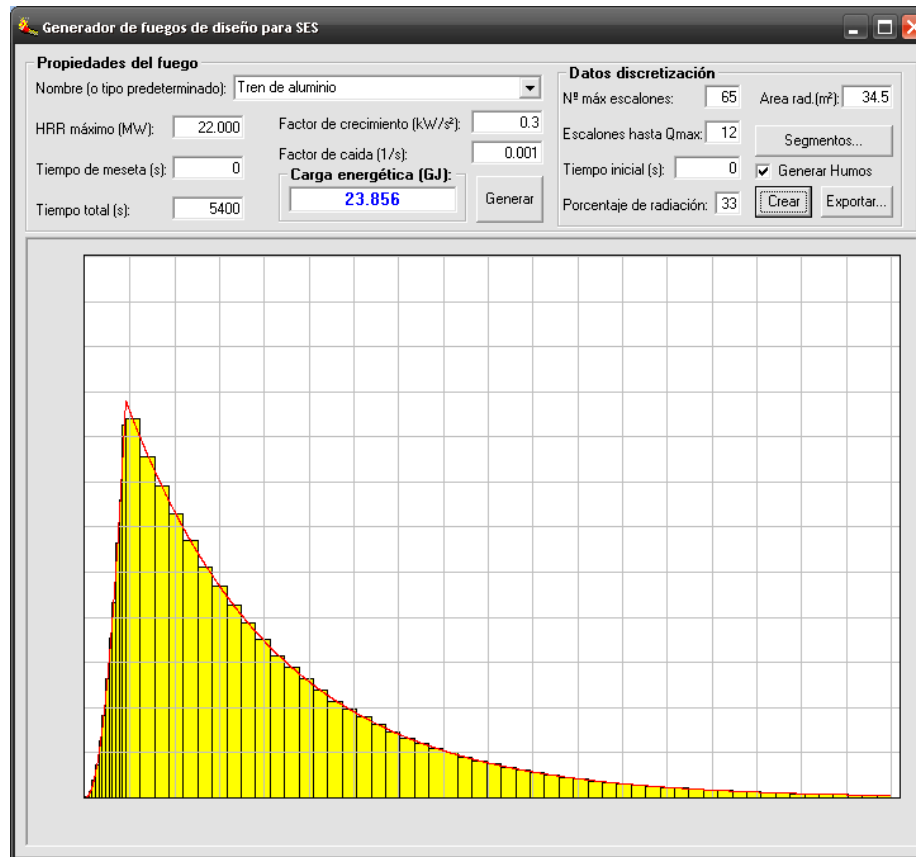
METRO LINE 9, AT BARCELONA CITY IN SPAIN

TD&T METHODOLOGY



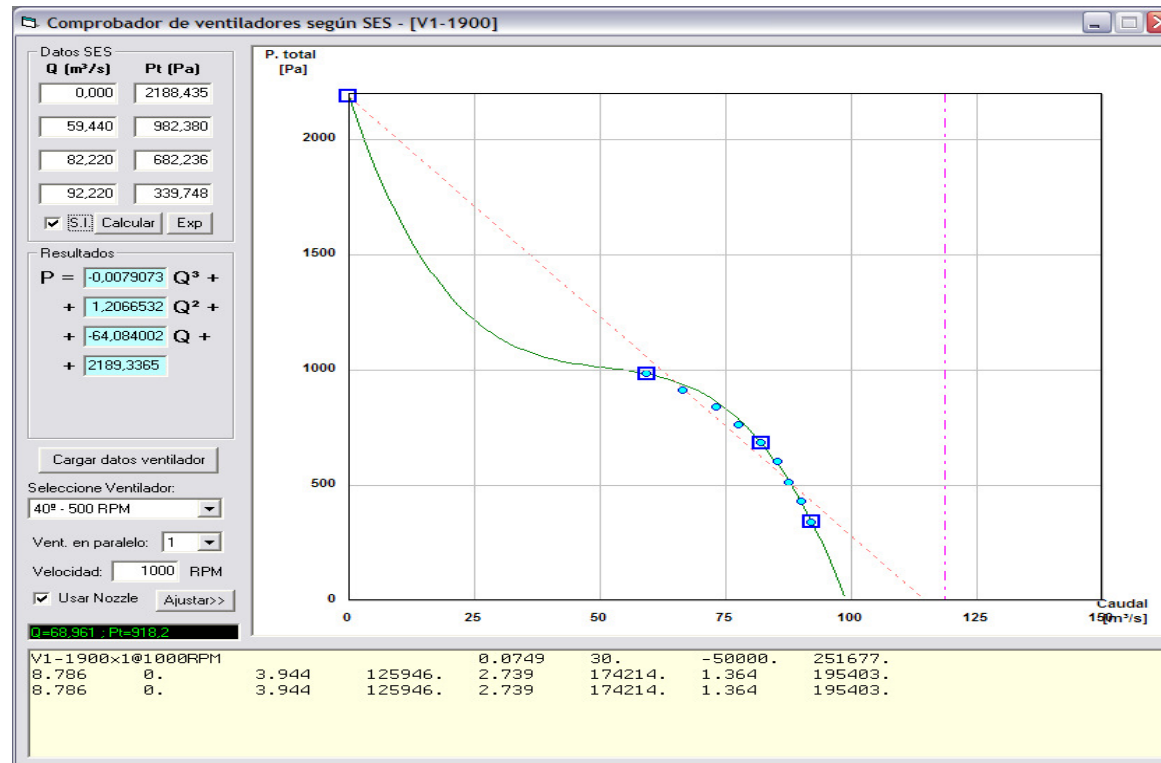
METRO LINE 9, AT BARCELONA CITY IN SPAIN

TD&T METHODOLOGY



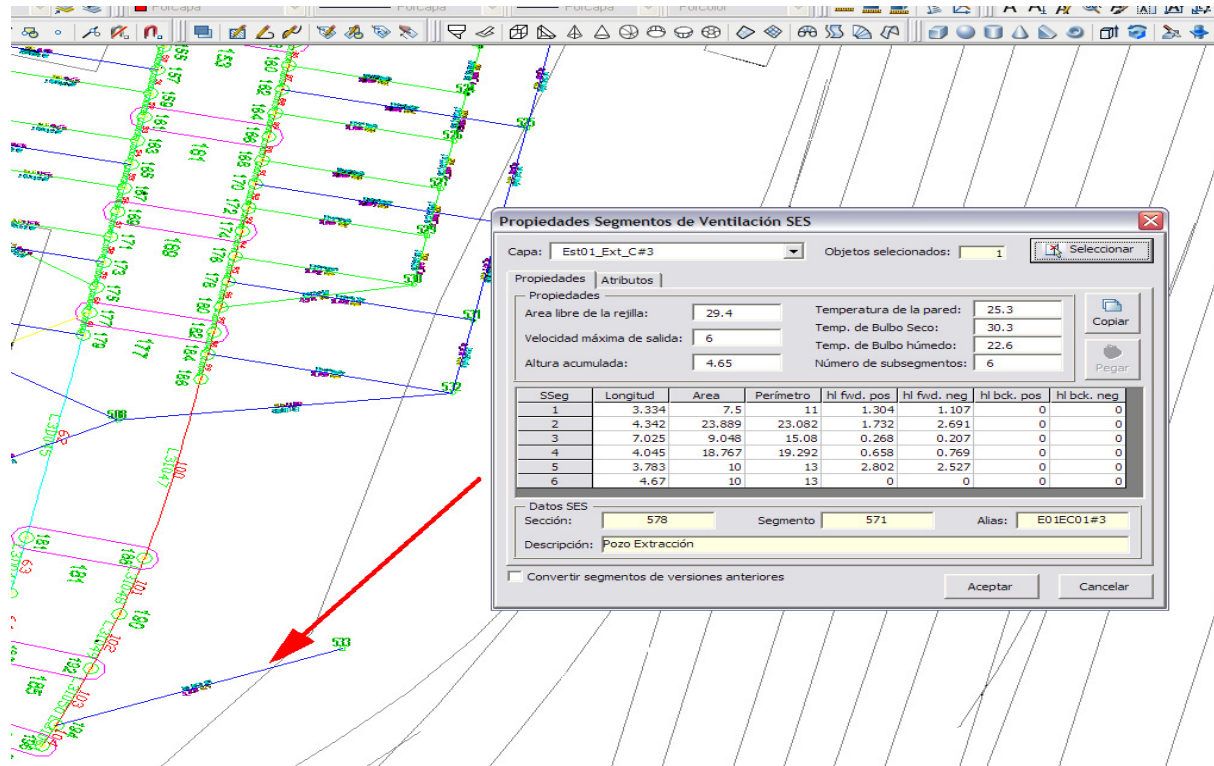
METRO LINE 9, AT BARCELONA CITY IN SPAIN

TD&T METHODOLOGY



METRO LINE 9, AT BARCELONA CITY IN SPAIN

TD&T METHODOLOGY



METRO LINE 9, AT BARCELONA CITY IN SPAIN

TD&T METHODOLOGY

Segmentation of tunnel

The first part of the discretization of tunnels/stations system, will consist in defining the segments which the tunnel system will be divided into.

Tunnels and stations will correspond to sections and line segments.

Plant and profile

For execution of simulations of the model, the plant and profile of the tunnel are reproduced exactly as provided in the project.

METRO LINE 9, AT BARCELONA CITY IN SPAIN

TD&T METHODOLOGY

Location of Nodes / Sections

Next task, after reproducing plant and profile of tunnel and stations area, is situating nodes.

Criteria to set up nodes are:

- Changes of grade
- Connection between tunnels
- Connection of ventilation shafts
- Connection with atmosphere (portals)

METRO LINE 9, AT BARCELONA CITY IN SPAIN

TD&T METHODOLOGY

Division of sections / Segments

Line sections have been divided into segments with an objective length of 15m (car length), with a tolerance of $\pm 5\%$. Where this has not been possible, the most uniform division of segments has been intended.

Characterization of segments

Line segments generated, as described in last paragraph, are described by

- Free area (cross section minus rails section, and any element).
- Perimeter.
- Absolute rugosity of section.
- Accumulated height.
- Length.
- Head losses coefficients affecting circulating flows.
- Initial dry and wet bulb temperatures.

METRO LINE 9, AT BARCELONA CITY IN SPAIN

TD&T METHODOLOGY

Line Sections/ Ventilation Segments

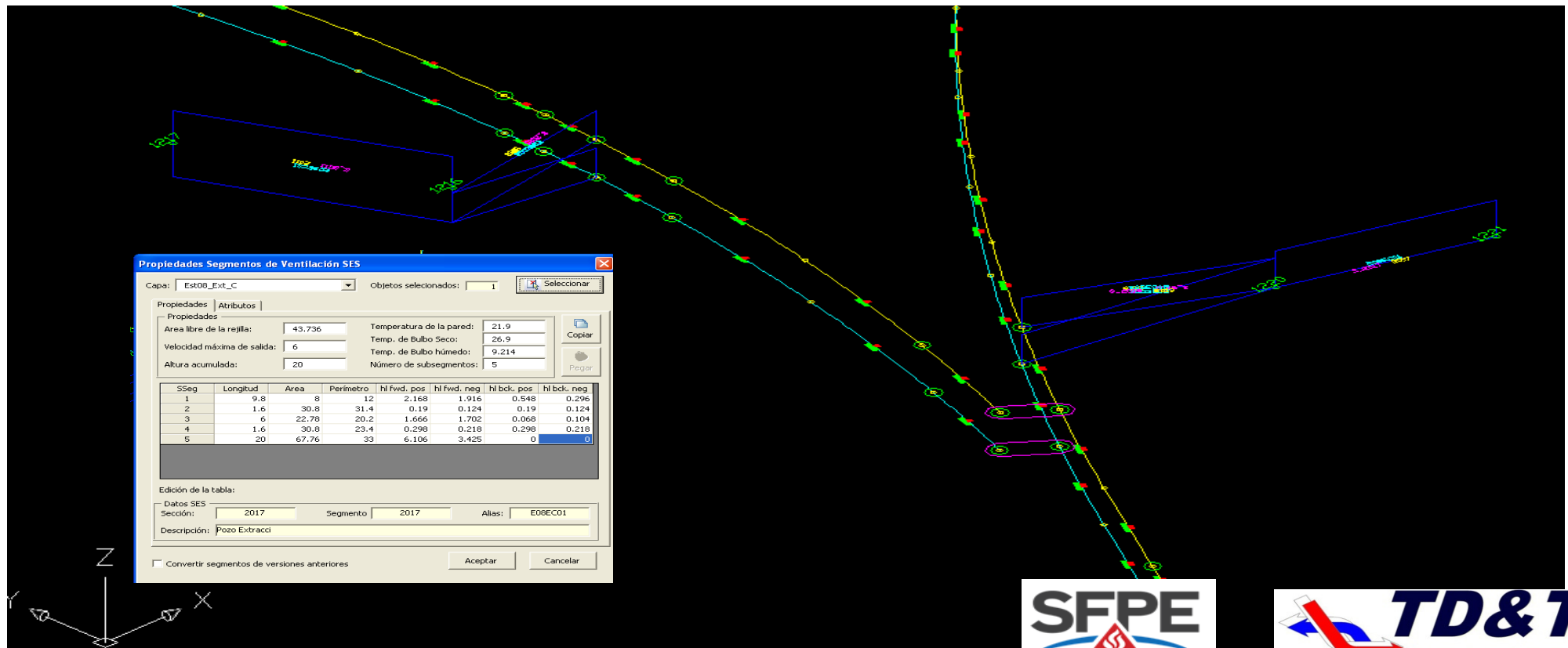
Other than regular segment characterization, ventilation shafts should show other parameters as

Shafts and ducts

All ventilation shafts have been modeled, for tunnels and stations, using our AutoCAD plug-in tool.

METRO LINE 9, AT BARCELONA CITY IN SPAIN

TD&T METHODOLOGY



METRO LINE 9, AT BARCELONA CITY IN SPAIN

TD&T PROJECTS

Metro Systems

- Riyadh Metro Line 3 (Saudi Arabia)
- Chennai Metro Rail Project Corridors 1 and 2
- Jaipur Metro Line 1 (India)
- Metro Santiago de Chile Lines 3 and 6 (Chile)
- Line 12 of Metro of México (Mexico)
- Athenas Metro ,Kalamaria Extension (Greece)
- North Line at Metro of Dublin (Ireland)
- New metro line to Torrejón de Ardoz, Madrid. (Spain)
- Line 2 of Metro of Barcelona. (Spain)
- Metro Sur. Madrid. (Spain)
- Metro lines 1 and 2 of Metro of Málaga. (Spain)
- Line 9 of Metro of Barcelona. (Spain).
- Line 10 (Metro Norte) of Metro of Madrid. (Spain)
- Metro lines 1, 3 and 5 of Metro of Valencia. (Spain)
- Stations with/without HVAC at metro of Xi'an (China)".
- Blue Line of Metropolitano of Lisbon. (Portugal)
- Line1 of Metro of Seville. (Spain)

METRO LINE 9, AT BARCELONA CITY IN SPAIN

TD&T PROJECTS

Railway Projects (HSR and conventional)

- HSR Tunnel Quejigares (Spain)
- HSR Tunnel Santa Marina (Spain)
- 150N Riverside Overbuild at Chicago Union Station AMTRAK (USA)
- Chicago Union Station Platforms (USA)
- Pajares HSR tunnel (25 km length). (Spain)
- HSR Tenerife Island South Train (Spain).
- Commuter line FGC to Terrassa. (Barcelona, Spain)
- Railway lines of Basurto and Elejabarri. Bilbao (Spain).
- HSR Santa Justa St.- Airport of San Pablo". Seville (Spain).
- HSR tunnel under Barcelona City. (Spain).
- Guadarrama Tunnel, HSR line. (Spain).
- REVS (belt parkway) for Madrid Township. (Spain).

Road Tunnels

- Brisbane Road Tunnel Belt. (Australia).
- Churriana Road Tunnel, Málaga. (Spain)
- Tunnel under channel in port of Valencia. (Spain)
- Bracons Tunnel. (Spain)
- North-West Arch of Madrid tunnels. (Spain)
- Urban tunnels. Madrid Township. (Spain)



METRO LINE 9, AT BARCELONA CITY IN SPAIN

TD&T PROJECTS

CFD (Computational Fluid Dynamics)

- Chicago Union Station Platforms (USA)
- Griffith Station of North Line, Dublin Metro. (Ireland)
- FGC line to Terrassa (Barcelona Spain) :
- Terrassa Tunnels. Branch: Rambla-Can Roca (Barcelona Spain). Rambla-Egara, Upc Vallaparadis, Renfe and Can Roca”(Spain).
- Station of Can Peixauet , Line 9 of Metro of Barcelona”(Spain).
- Pavillions 12 and 14 of IFEMA (Feria de Madrid, Spain).
- Chennai Rail Metro Project (Chennai Central, Washermanpet, Saidapet, tunnels).
- Ernest Lluch Station (Barcelona, Spain).
- Plaza de Cataluña.Station (Barcelona, Spain).
- Pajares Tunnel (Spain).
- Añaza-Santa Maria del Mar Station (Spain)
- Costa Adeje Station (Tenerife, Spain).
- Santa Cruz de Tenerife Station(Spain).
- Girona HSR Station (Spain).



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