REFURBISHMENT OF THE EMERGENCY VENTILATION SYSTEM INCLUDING SACCARDO NOZZLES IN THE NORTH-SOUTH RAILWAY JUNCTION OF BRUSSELS

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ABSTRACT

The North-South railway junction is the main strategic railway link in Belgium which has been recently refurbished to improve its fire safety level. The total length of the underground section is 1.95 km including 3 tunnel sections and 2 intermediate stations. Tunnels have been divided into 3 tubes. This new configuration has increased the complexity of the underground network and the ventilation system has been adapted. In order to control smoke in the 29 new fire zones, the ventilation plenum available at each station extremities have been refurbished with new fire rated fans and a set of Saccardo nozzles. This paper presents the methodology used for the design and specific issues related to the Saccardo system design development. Results of 1D and 3D simulations and comparison with experimental results are presented in the paper.

Keywords: *Rail tunnel, Refurbishment, Saccardo Nozzle, Simulation, Test*

1. INTRODUCTION

The North-South railway junction of Brussels is located between the two stations of "Brusells North" (on the North boundary of the old city) and "Brussels Midi" (located in the South). Most of trains travelling between North and South of Belgium are transiting through this junction. Both stations handle large volumes of commuter, regional and international passengers. They are linked by a 3.8 km railway line which includes an underground section composed of a tunnel around 1.9 km length and two underground stations: Brussels Central and Brussels Congress.

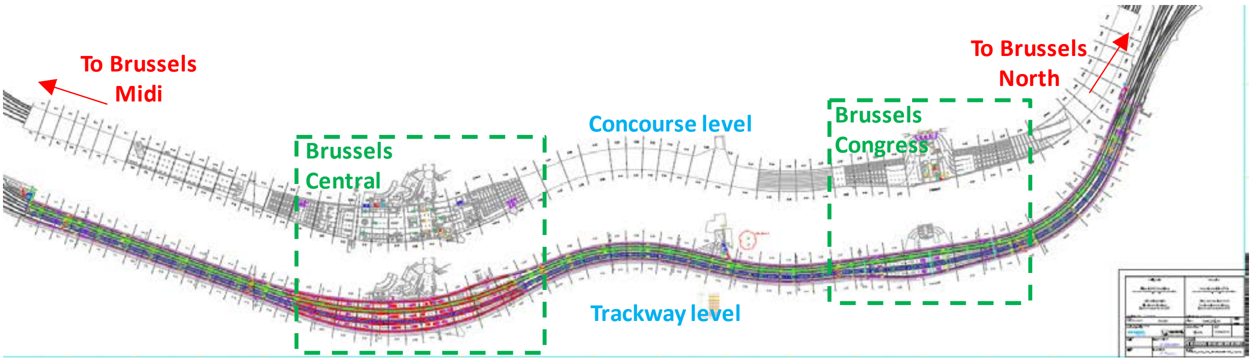

Figure 1: Overall view of the North South railway junction of Brussels

Tunnels and stations include six trackways to absorb the high traffic flow of 1200 trains a day, which makes the junction the busiest railway line in Belgium and the busiest railway tunnel in Europe.

In order to improve the fire safety level, tunnels have been recently divided into three tubes of two trackways as described on the following figure. Sliding doors have been installed between bores and every 50 m to permit quick evacuation of passengers into the adjacent non-incident bore. Those doors are reachable by new walkways. The ventilation system has also been refurbished based on a longitudinal ventilation principle by achieving the critical velocity due to the significant reduction of the cross-section of an incident bore. In addition, the ventilation system provides efficient smoke point extractions at station ends in order to prevent smoke propagation into the adjacent station.

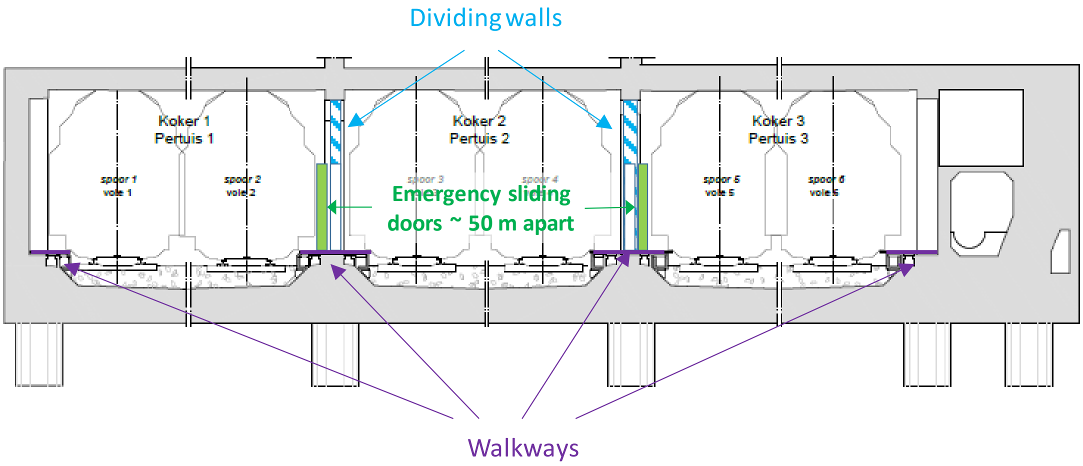

Figure 2: Typical tunnel cross-section after the refurbishment

This new safer configuration leads to increased complexity of the underground network from a ventilation point of view. Drastic objectives to be achieved in case of fire by the new smoke control system were also specified. The ventilation system partly relies on a set of Saccardo nozzles installed in existing ventilation plenums which were originally dedicated for massive extraction of pollution emission from diesel trains. The use of Saccardo is well known in tunnel ventilation in order to develop a longitudinal airflow in case of fire (see [Alston & al.,2013] and [Sturm & al.,2013]. However, the specific project solution relies on the complexity of the underground network and the very restrictive configuration for installing Saccardo nozzles.

For a better understanding of the complexity, this paper firstly presents the refurbishment project including a description of the underground infrastructure and the ventilation network. The solution used for the design of Saccardo systems is then detailed with dedicated discussions on issues specific to this refurbishment project. These include the solution based on multiple nozzles in each bore that has been developed for a more efficient flow management. Risks of Leakages in plenums are also discussed.

The specific design approach used for the project is then developed. 1D simulations including the overall network were used for the design of emergency ventilation scenarios. However, local 3D simulations were performed in order to evaluate the efficiency of the jet fan used to represent the impulse thrust of Saccardo nozzles. Tests results are also provided and compared with theoretical studies.

2. DESCRIPTION OF THE UNDERGROUND INFRASTRUCTURE AND THE VENTILATION SYSTEM

2.1. The underground network

The underground network of the North-South junction is divided into ten sections. Six are dedicated to the three tunnels: two for the south tunnel, two for the central tunnel and two for the north tunnel. The length of each tunnel is respectively 462 m, 650 m and 308 m. Each tunnel contains three bores, noted A, B and C, separated by fire rated full height dividing walls and emergency sliding doors installed every 50 m. The north tunnel has the particularity of including a section with only two bores at the north portal with a length of 120 m.

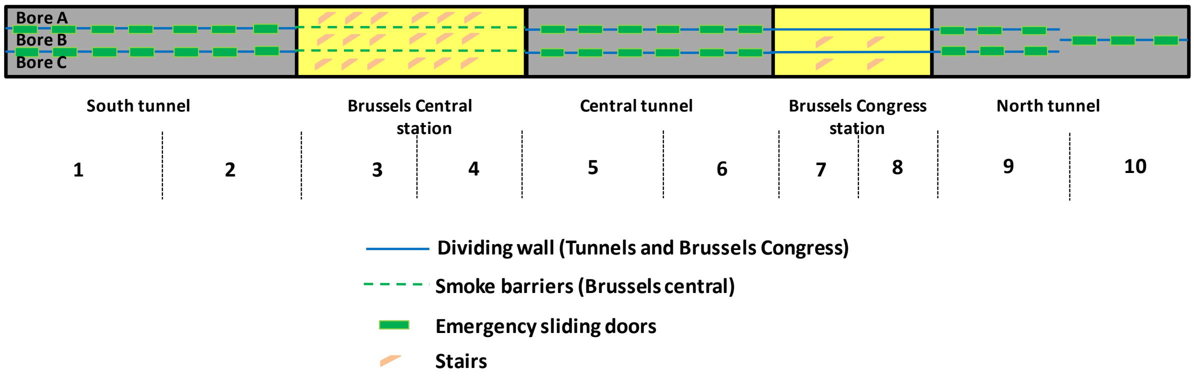

Figure 3: Typical tunnel cross-section after the refurbishment

Brussels Central station contains three central platforms separated by longitudinal concrete smoke barriers as shown in the following figure. Each platform has six stairways in communication with the upper concourse level. Brussels Congress station contains only two central platforms in junction with bores B and C completely separated by full height dividing walls. Each platform has two stairways in communication with the upper concourse level. The bore A does not have any platform in Brussels Congress; it is dedicated to trains which never stop in this station in normal operation.

2.2. A ventilation system based on specific sets of Saccardo nozzles

The location of a fire is identified by the section and the bore in which the fire occurs. 29 fire zones are identified, 17 of which are in tunnel sections.

In case of a fire in a tunnel, the following objectives have been set by safety studies for the emergency ventilation system considering a design fire of 35 MW:

- To prevent backlayering by achieving a longitudinal velocity of 2.95 m/s in the bore where the fire occurs, when two trains are blocked in the incident bore (the train on fire and an additional following train).
- To prevent smoke propagation into the adjacent section downstream the fire, which requires massive point extraction at each station end in order to extract the flow of smoke generated by the longitudinal ventilation in the section under fire. In addition, a contra-fresh air flow velocity of 1 m/s has also been set to guaranty the confinement of smoke at the massive extraction point.
- To reduce the smoke propagation in the adjacent bore by considering seven emergency sliding doors opened simultaneously (4 doors upstream the fire and 3 doors downstream the fire). The goal is to keep an overpressure in the adjacent non-incident bore as far as possible, which is challenging for this project with seven open doors. For that reason, a minimum longitudinal velocity of 1 m/s in the adjacent safe bore has also been retained for permitting dilution of smoke that would propagate in this bore.

The above objectives can be summarized in the following figure, as an example in case of a fire in the section 5 – Bore A.

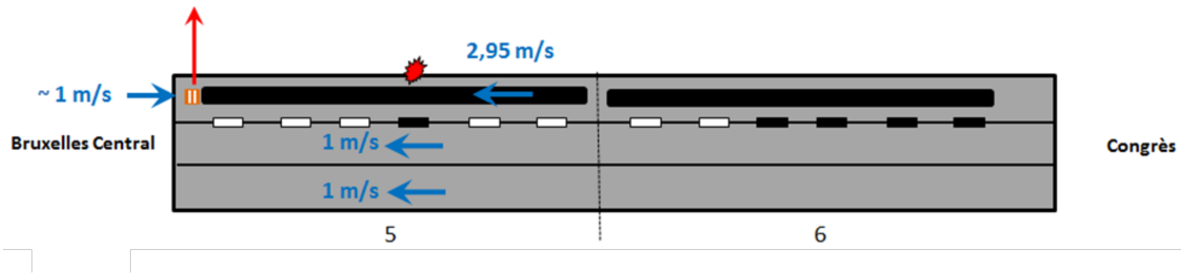

Figure 4: Objectives of tunnel emergency ventilation

The synopsis of the ventilation system is shown in the following figure. Jet fans are installed closed to portals, but the system mainly relies on three ventilation plants. Two plants (A1 and A2) are located at Brussels Central station. The A1 plant is located at the South extremity of the station whereas A2 is located at the North extremity. The third plant A3 is located at Brussels Congress station. Each plant has been refurbished with 3 new fire rated tunnel ventilation fans (2+1 in redundancy) named L1, L2 and L3. They are all equipped with isolation dampers. The flow rate capacity of each fan is 150 m3/s in extraction mode and around 125 m3/s in supply mode. L1, L2 and L3 fans of each plant are connected to ventilation plenums located above trackways at station extremities. Each ventilation plenum includes a set of dampers (10 above each bore) for massive extraction / supply and Saccardo nozzles for impulse injection. For A1 and A2 ventilation plants, two additional fans (1+1 in redundancy) named T4 and T5 equipped with isolation dampers are also installed. With a flow rate capacity of 45 m3/s each, they are dedicated to the transverse ventilation of Brussels Central station.

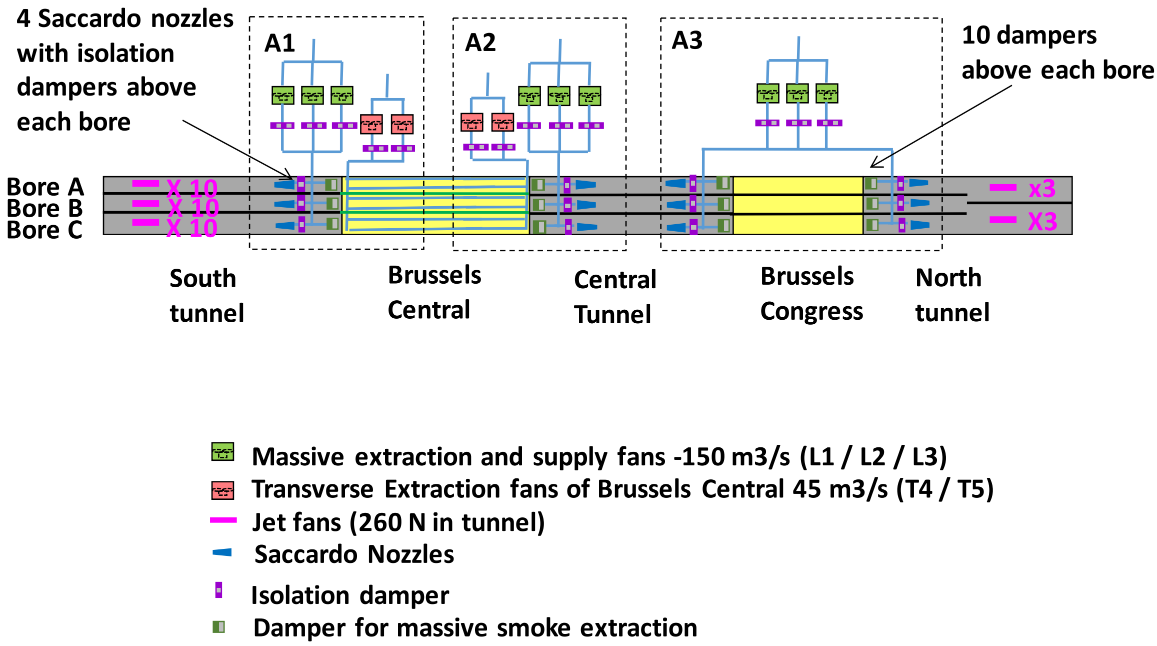

Figure 5: Synopsis of the ventilation system after refurbishment

3. SPECIFIC TOPICS RELATED TO THE DESIGN OF SACCARDO SYSTEMS

3.1. A nozzle distribution like an organ

Saccardo nozzles have already been frequently installed in tunnels to supply fresh air and to create a longitudinal thrust upstream the fire, in order to achieve the critical velocity in the incident bore. However, in the case of the North-South railway junction of Brussels, tunnels include three bores with common ventilation plenums and common fans (L1, L2, L3). The flow rate provided by fans is first released in the common ventilation plenums and then through

Saccardo nozzles. Consequently, attention must be paid to adequately supply the flow rate and produce the desired thrust in appropriate incident bores to achieve the ventilation objectives. Moreover, even if a large amount of the flow rate delivered by supply fans should be dedicated to the incident bore, a part of it remains necessary for the non-incident adjacent bore in order to limit the risk of smoke propagation into it. As already mentioned above, the Saccardo solution proposed was based on the installation in each ventilation plenum of a set of 4 reduced size Saccardo nozzles with an ejection area of 1.08 m² above each bore. Each nozzle is equipped with a two positions isolation damper to fully close or open the nozzle. This solution has been preferred over the client reference design configuration, that relied on one single nozzle above each track with multi-position dampers. With the new proposed solution, it is possible to adjust the flow rate distribution between each bore by fully open or fully closed 0, 1, 2, 3, or 4 nozzles in the dedicated bore. The flow rate provided by the fans is adjusted proportionally to the total number of Saccardo nozzles opened for the three bores. The flow rate injected in each bore is then directly proportional to the number of Saccardo nozzles opened in the dedicated bore. With the reference design configuration, the control of airflow distribution between bores would have been more complex and unreliable. Indeed, it would have been necessary to determine by dedicated inaccurate flow measurements inside of the nozzles the appropriate damper position for each flow distribution configuration. Another advantage of the proposed solution is the ability to keep the same ejection velocity whatever the flow rate injected in a bore as the ratio between the injected flow rate and the total injection area of opened Saccardo nozzles is kept constant. The nominal thrust developed in a bore remains consequently proportional to the injected flow rate. With this, it is still possible to develop a significant thrust in a bore, even when a limited flow rate is injected. This can be particularly relevant to improve the overpressure in the non-incident adjacent bore. With the reference configuration, the nominal thrust would have been proportional to the square of the injected flow rate as the injection area would have been constant. For instance, with half of the flow rate, the thrust would have been divided by 4 whereas it is only divided by two with the proposed solution.

3.2. Advantages and drawbacks of big size ventilation plenums of the junction

Another particular issue for the North-South railway junction of Brussels is the geometrical characteristic of ventilation plenums. Ventilation plenums were originally designed for axial fans manufactured in the 50’s which were not able to generate high total pressures. Plenums have consequently large sizes in order to minimize the pressure losses. The following drawings represent the A3 South ventilation plenum which a width of 50 m and a height of 2 m. The main advantage of this geometrical configuration is that a low velocity less than 1.5 m/s can be kept in plenums for the expected flow rates supplied by fans. The pressure losses in the plenum can then be limited and an almost constant static pressure inside the plenum volume can be established at the desired over-pressure of around 900 Pa, that is necessary to compensate the pressure loss through nozzles. This constant pressure allows providing homogeneous flow rates and thrusts between opened Saccardo nozzles.

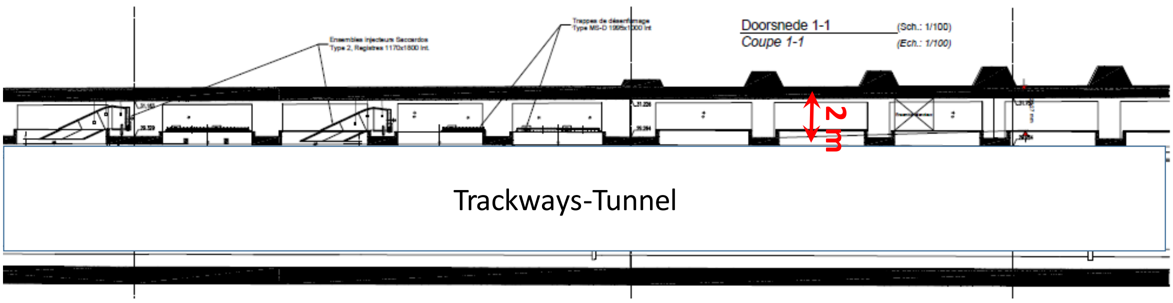

Figure 6: Ventilation plenum of A3 South –Elevated view

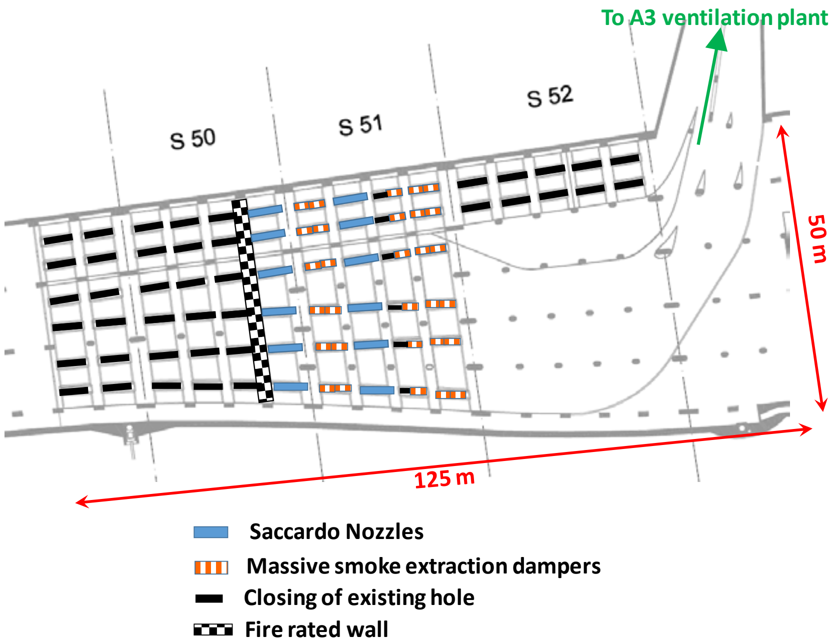

Figure 7: Ventilation plenum of A3 South – Plan view

Nevertheless, the risk of leakages is significantly higher in such a case. It should be noted that the static pressure level requested in ventilation plenums for supplying Saccardo nozzles at the expected flow rate and ejection speed is generally very high (as a reminder, around 900 Pa for this project). The following figure shows the loss of performance on the longitudinal thrust provided by Saccardo nozzles following the total area of leakages. The plenum size is subject to a lot of civil works, which interface with other areas that require particular attention to the sealing procedures. This risk of leakages is also reinforced by the fact that ventilation plenums are also used for cabling and contain lot of holes for cables crossing. Existing holes were spotted during an inspection of plenums. For that reason, a campaign was made for sealing all visible holes and large cracks.

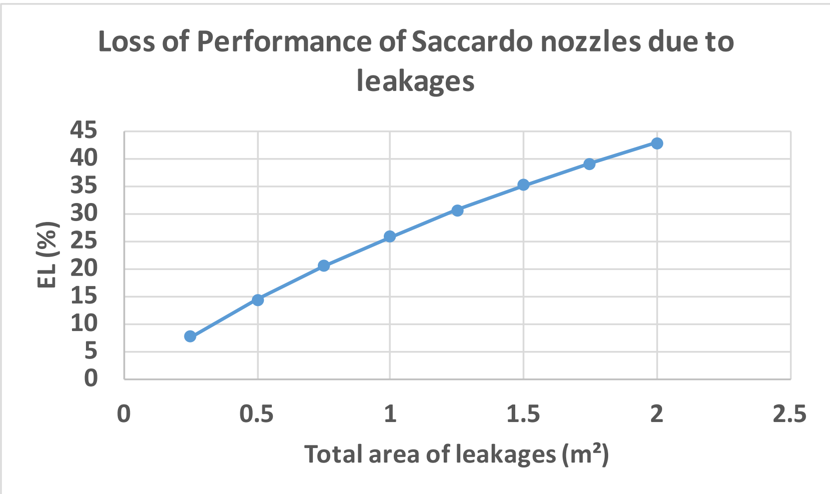

Figure 8: Loss of efficiency of Saccardo nozzles due to leakages

4. DESIGN AND TESTING

4.1. Design approach and results

The design approach is based on 1D simulations for the overall design of ventilation scenarios. In the 1D model, Saccardo nozzles are represented by supply shafts and jet fans in order to simulate the thrust. In a 1D model, the thrust developed by a jet fan is expressed as follows:

$$T = \frac{\rho}{\rho_0} T_0 \left(1 - \frac{u_2}{u_{ejJF}}\right) . \xi = (p_2 - p_1) . A_T + FL$$

With T_0, the nominal thrust of the jet fan for the reference density ρ_0, u_{ejJF} the ejection velocity of the jet fan and ξ the efficiency including aerodynamic losses. *FL* are the linear tunnel friction losses. *p_1 and p_2* are the static pressures upstream and downstream the Saccardo (Pa). u_2 is the longitudinal flow velocity upstream and downstream the Saccardo (m/s) and A_T is the tunnel area (m^2)

This can be compared with the following momentum equation, in the case of the velocity upstream the Saccardo is very low and negligible, and were Q_{ej}, V_{ej} and θ are respectively the volume flow rate, the ejection speed and the ejection angle of the Saccardo.

$$(p_2 - p_1) . A_T + FL = \rho . Q_{ej} . u_{ej} . cos\theta . \xi \left(1 - \frac{u_2}{u_{ej} . cos\theta . \xi}\right)$$

It can be assumed that the jet fan which can be used for the 1D model has the following characteristics in term of nominal thrust and ejection velocity:

$$T_0 = \rho_0 . Q_{ej} . u_{ej} . cos\theta \qquad u_{ejJF} = u_{ej} . cos\theta$$

The parameter which remains to be defined for the implementation of the Saccardo system into the 1D modelling is the efficiency ξ, which is in fact the efficiency of the Saccardo (see also [Tabarra & al.,2013] and [Tarada & al.,2013]). Studies based on 3D simulations have been performed to evaluate this parameter. The simulation was done with a geometry including the four Saccardo nozzles of the project as shown in the following figure.

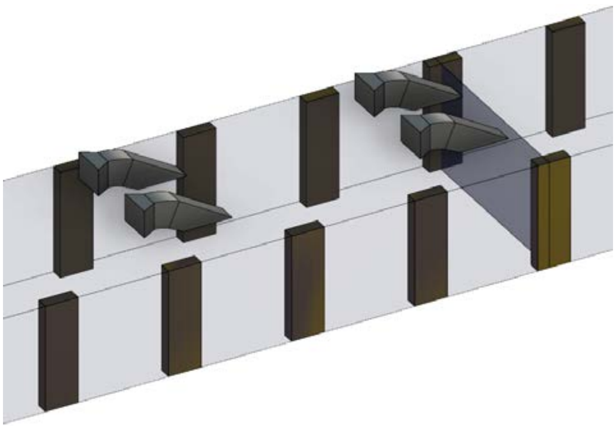

Figure 9: Saccardo nozzles and typical tunnel section of the North South Brussels junction

As shown by [Sturm & al.,2013], the efficiency ξ may vary depending on the velocity upstream the Saccardo. For that reason, simulations have been done for a specific flow distribution that has to be achieved by the design of ventilation scenarios. A total volume flow rate of 125 m^3/s is provided by the Saccardo system (31.25 m^3/s in each nozzle) inside a typical tunnel section of the North-South junction of Brussels. The ejection speed for this flow rate is 28.9 m/s for an ejection angle of 27°. A static pressure has been fixed at entry portal at -35 Pa which leads to a longitudinal velocity of 3.7 m/s downstream the Saccardo system. A second simulation was performed with a vertical shaft of huge size with the same injection flow rate. Contrary to the configuration with Saccardo nozzles, this shaft does not bring any longitudinal momentum in the tunnel. In order to achieve the same velocity as the one obtained in the first simulation and balance the linear friction losses, the longitudinal momentum provided by the Saccardo is compensated in this second simulation by an additional static pressure *DP* at entry portal. The following figure illustrates calculation conditions for both configurations.

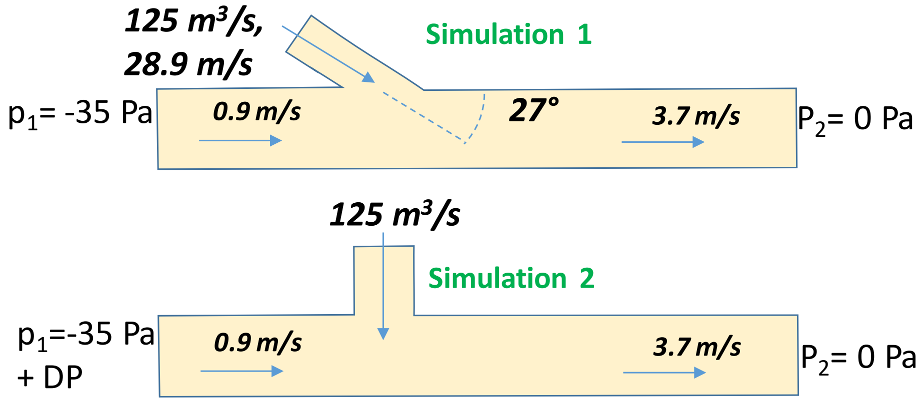

Figure 10: 3D Calculation conditions with Saccardo nozzles and with a vertical shaft

By writing the momentum equation for the second simulation configuration and by comparison with the one for the first configuration expressed in the previous page, the following formula can be deduced:

$$DP.A_T = \rho.Q_{ej}.u_{ej}.cos\theta.\xi\left(1 - \frac{u_2}{u_{ej}.cos\theta}\right)$$

A value of + 60 Pa has been established from this study for *DP*. The corresponding efficiency is 0.83.

4.2. Comparison between theoretical results and measurements

Tests were performed for each emergency ventilation scenarios after installation works. Those tests rely on measurements of the longitudinal flow velocity in tunnel cross-sections with a log-Tchebycheff methodology based on 25 points in the cross-section as prescribed by ISO 5802 standard. Measurements are then compared to the results provided by cold smoke 1D simulations of the corresponding ventilation scenario under the same conditions as those established during the test (no fire and no train). For this paper, the comparison is done for the case of a fire in the bore C of section 5. The corresponding ventilation scenario is presented in the following figure. Saccardo nozzles of the plenum A3 South are used in that case with 3 nozzles open in the incident bore and 2 nozzles open in each adjacent non-incident bore.

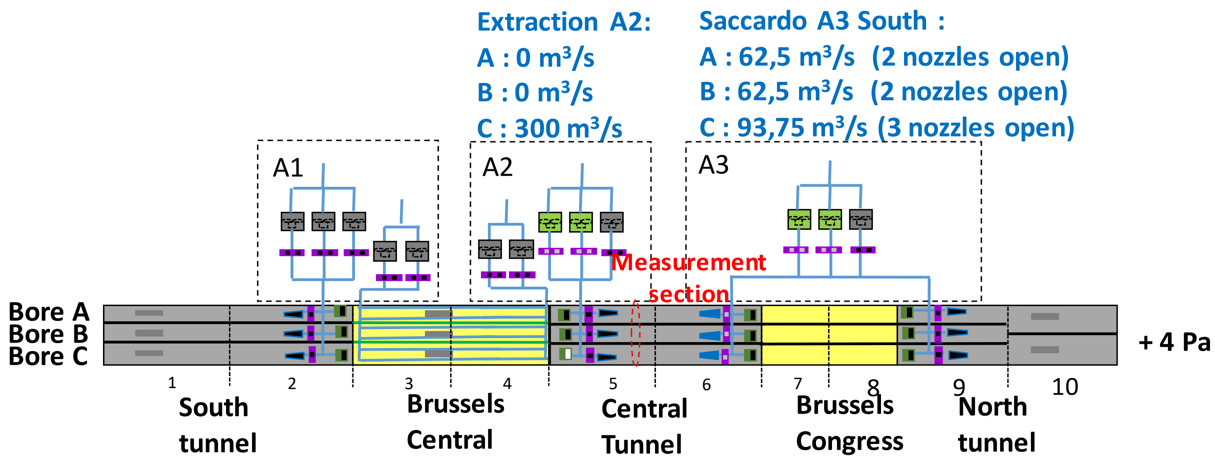

Figure 11: Ventilation scenario for a fire in section 5 – Bore C

It should be noted that A3 south Saccardo nozzles are installed in an enlarged cross-section of 76 m² in comparison to the typical tunnel cross section of 46 m² considered in the 1D geometry. The nominal pressure rise provided by the jet fan simulation Saccardo nozzles in the 1D model is consequently reduced by a factor of 1.65 (76/46). The following results show that the results match between the measurements and the simulation when an efficiency of 0.81 is implemented in the model. This value is very close to the efficiency of 0.83 estimated by theoretical studies (2.4% difference). The design methodology can consequently be considered as validated.

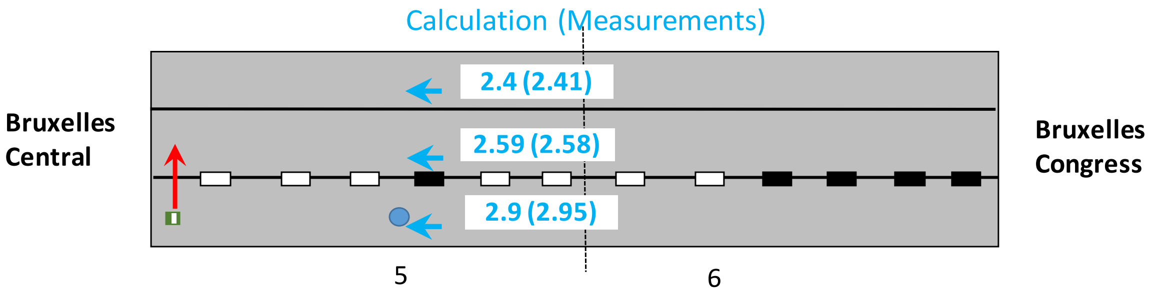

Figure 12: Comparison between measurements and cold smoke simulation with an efficiency of 0.81

5. SUMMARY AND CONCLUSIONS

The refurbishment of the ventilation system on the North South railway junction in Brussels was faced to several constraints in terms of design objectives to be achieved but also due to the particularity of the civil infrastructure. A specific concept was proposed for Saccardo systems based on a multiple nozzles configuration in each plenum and each bore. This configuration was proposed for a better control of flow in each bore. Particular care was required regarding the risk of leakages in big ventilation plenums with a campaign for resealing existing hole. The design methodology based on combination of 1D and 3D modelling was successfully validated by testing.

6. REFERENCES

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