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USING THE HVAC NAMELIST IN FDS FOR TUNNEL BOUNDARY CONDITIONS IN THE TEL AVIV GREEN LINE LRT PROJECT – A CASE STUDY

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ABSTRACT

The Green Line of the Tel Aviv LRT (Light Rail Train) is an ongoing project that will connect 4 municipalities. Though most of the line passes above ground, 4 stations and about 4 km of twin bore tunnels, pass underground. As part of the detailed design of the underground tunnels and stations, CFD analysis is being performed for both tunnels and stations.

One of the most challenging aspects of an underground tunnel or station, are the simulation boundary conditions. To obtain boundary conditions that reflect the changing pressure field, HVAC ducts and nodes were used as a means of coupling 1D calculations to 3D simulations employing what is called the "Multiscale Approach".

After numerous initial setup iterations, a final setup of FDS was used with the multiscale approach obtaining a reactive and rellistic flow field that showed good agreement with 1D simulations for engineering analysis purposes.

INTRODUCTION

Simulations of tunnel flows are a common part of tunnel design. These simulations are used for ventilation design together with other disciplines such as fire Life safety. For this case study, simulations were performed for fire Life safety purposes with FDS (Fire Dynamics Simulator).

Simulations can be performed in 1 dimension, 2 dimension or 3 dimensions. The simulations can yield transient or steady state results based on the needed output. Most widely used are 1D and 3D simulations.

1D simulations are quick and cost effective. When the flow is one-directional, they are the best option for design. Two prominent simulation tools that are used for 1D simulations are SES (Subway Environment Simulation) and IDA Tunnel. In these simulations, tunnels are represented as line segments and nodes.

3D simulations take longer to setup and run. Also, these simulations require considerable computational resources. But for flows that are not one-directional, only these simulations will present the flow field in a realistic manner. In these simulations, the analyzed volume is divided to many small volumes and computed simultaneously for a 3D solution.

Three approaches can be employed for tunnel simulations:

1. 3D simulations of the entire domain – would take too long and require large resources.
2. Using the results of 1D simulations as fixed boundary conditions in a 3D simulation – this use of 1D results has some limitations. First, the results represent steady-state flow and the flow ramp is unknown. Secondly, fixed boundary conditions will not respond with the flow field. And finally, if the flow is not one-directional than the 1D results are not valid.

3. The multiscale approach – having a 1D calculation embedded in a 3D model for representation of tunnels and stations. This approach has the benefit of being practical to run and having a responsive boundary that reacts and changes with the flow field.

Using the HVAC namelist in FDS as a way of employing a multiscale approach is a concept that was previously validated. This use of FDS needed to be adjusted for a real-life project.

LITRATURE REVIEW

In 2010, in his PhD thesis, Collela [1] presented the concept of a multiscale approach for tunnel simulations combining 1D and 3D analysis. In this work, the use of HVAC namelist in FDS was not performed because this option was not released yet.

A series of works done by various authors, from 2014 to 2017 [2][3][4], presented the computational savings by using the HVAC namelist in FDS. These works validated the use of HVAC namelist for tunnel boundary conditions when compared to experimental data.

Pachera et al [5], in 2018, wrote about the capabilities and limitations of multiscale modeling using FDS. He concluded that for cold flows, the results in FDS were promising. He also concluded that for large fires, the pressure oscilations in FDS may interfere with the boundary conditions. It is worth mentioning that this is true close to the fire. For this reason, HVAC boundaries should be far enough from the fire so the pressure field at the boundary will be minimally affected from said oscillations.

PROJECT BACKGROUND

The green line of the Tel Aviv LRT is an ongoing project that will connect 4 municipalities with 39 km of tracks and 62 stops. Most of the line passes on the street level. About 4 km of the line pass underground with 4 underground stations along the tunnels. As part of the detailed design for the project, CFD simulations were performed for all tunnel sections and stations at the underground tunnels.

Figure 1 presents the general ventilation setup in the project. Each underground station is equipped with 4 bidirectional fans with a series of dampers that allows for the use of all 4 fans at one tunnel or as many as needed. When a fire is detected, Smoke management system is operated according to predefined scenario on the smoke management operational regime.

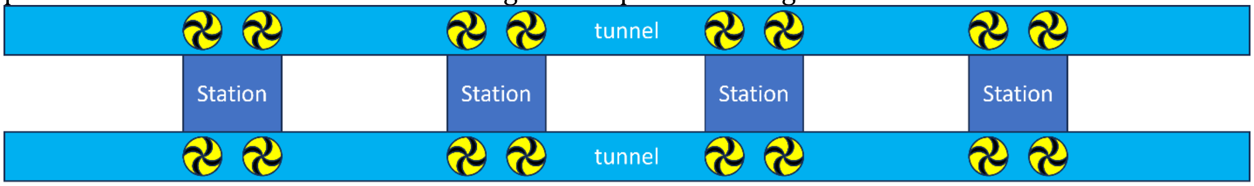

Figure 1: ventilation system schematic

METHODOLOGY

Following the literature review and the information appearing in the FDS user guide [6], it was concluded that the HVAC ducts must be used only for incoming air, must be far enough from any hot gases as the HVAC ducts do not account for heat transfer, and present a strong one directional flow, since the flow is only permitted in one direction in FDS HVAC ducts.

In figure 2, the general layout of the computational domain is presented.

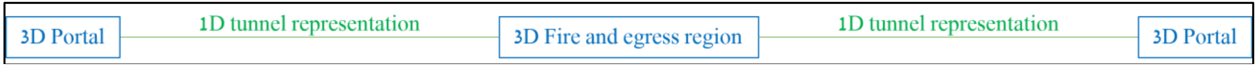

Figure 2: a schematic of the general multiscale layout.

There are 3 regions of 3D simulation, the main region where a fire will be modelled and two portals at the edges of the tunnels. The portals were modelled as 3D regions since a 1D representation of a portal would be unaccurate due to varying geometric section, ceiling vents, beams and partial separating walls. The 3D region are connected with HVAC ducts as a 1D representation of the connecting tunnels.

In the initial runs, the HVAC network in FDS was setup in a similar manner to the way 1D simulations are setup with ducts and nodes representing all tunnel segments, stations, ventilation shafts, cross passages etc. Figure 3 depicts this initial setup.

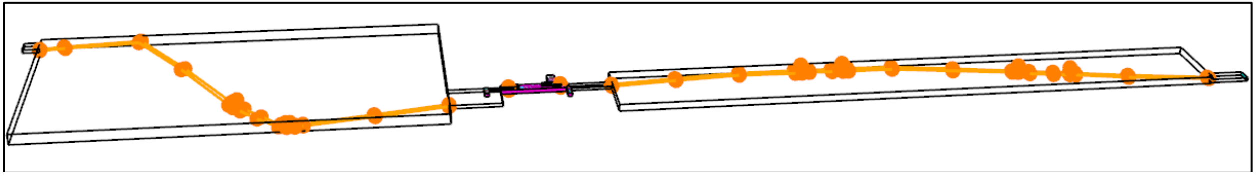

Figure 3: initial HVAC network for tunnel boundary conditions.

Unfortunately, the initial setup did not work due to its intricacy. At first, simulations started and then stopped advancing. Assuming that cross passages were causing the HVAC calculation to enter some kind of calculation loop, all cross passages were discarded from the model. That solved the infinite loop problem suggesting that it was the cause. Next, the simulations encountered access violations. An access violation of a simulation happens when the simulation tries to access more memory than the amount that was allocated for it. After several tries to overcome this problem, It was concluded that the HVAC representation needs to simplified.

While examining how to simplify the HVAC network, it is prudent to analyze the pressure solution and try to make some simplifying assumptions about the setup.

Pressure losses in a tunnels have two main causes. The first, head losses or losses due to transitions in the flow. For example, when air enters a station from a tunnel, the change of the section causes some pressure loss. This is represented as a coefficient. The logical place to define these head losses are at the nodes where transitions occur. So a series of nodes representing transition between different segments would be defined with head losses. For calculation purposes, it does not matter where the head losses are defined if the sum of the losses is the same. Following this logic, multiple nodes could be represented by a single node defined with the sum of the head losses.

The second cause for pressure loss is wall friction. Along a series of tunnels and stations, most of the wall friction would come from the tunnels since they are longer and have a smaller section area and perimeter. At the stations, wall friction would be reduced since the section area is larger. This reduction is predicted to be small and together with the short length compared to the tunnels, even smaller. This is assumption will be addressed in comparison to 1D results.

Following this logic, it was assumed that a series of tunnels and stations could be represented by a single HVAC duct. This duct would have the section area, perimeter, and wall roughness of a tunnel. The head losses would be summed up in the nodes.

Figure 4 depicts an example of a boundary condition used for one of the simulations. On the right side, the portal is visible. In the middle, the HVAC vents are colored purple, ducts and nodes are orange. At the left, a short tunnel segment was modeled before entering the station to ensure no hot gasses would come near the boundary vent.

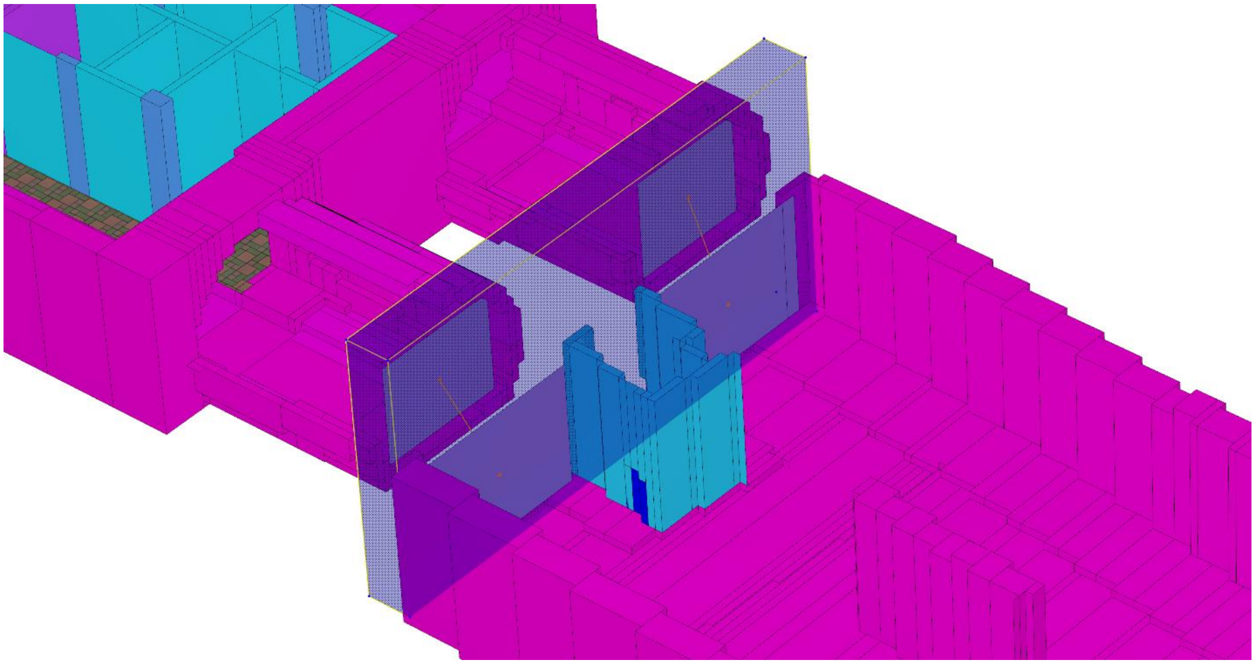

Figure 4: a depicted example of the final setup for HVAC boundary conditions

After simplifying the HVAC boundary conditions, access violation did not occur.
Still, some simulations encountered numerical instabilities due to pressure rises at the very beginning without any discernable reason. This is mentioned It was assumed to relate to the simulation setup. To overcome this, the default FDS pressure iteration number was increased iteratively until reaching an iteration number that allowed the simulation to start. It is worth mentioning that the simulations did not use the pressure iterations to better initialize the pressure field, the problem just vanished once a certain amount of pressure iterations was defined.

RESULTS

Since the project is ongoing, only part of the results can be displayed at this time. Focusing on the flow field boundary response.

Station flow

The first station that was analyzed using the multiscale approach with HVAC in FDS, had the ventilation systems operating according to 1D analysis recommendations. Reviewing results during the simulation reveled smoke rising from the platform to the concourse. That meant that flow between the platform and the concourse was not one-directional and 1D resuls were not valid. Employing those 1D results as fixed boundary conditions may have not revealed that behavior. Figure 5 shows the flow through the tunnels and the concourse for this simulation.

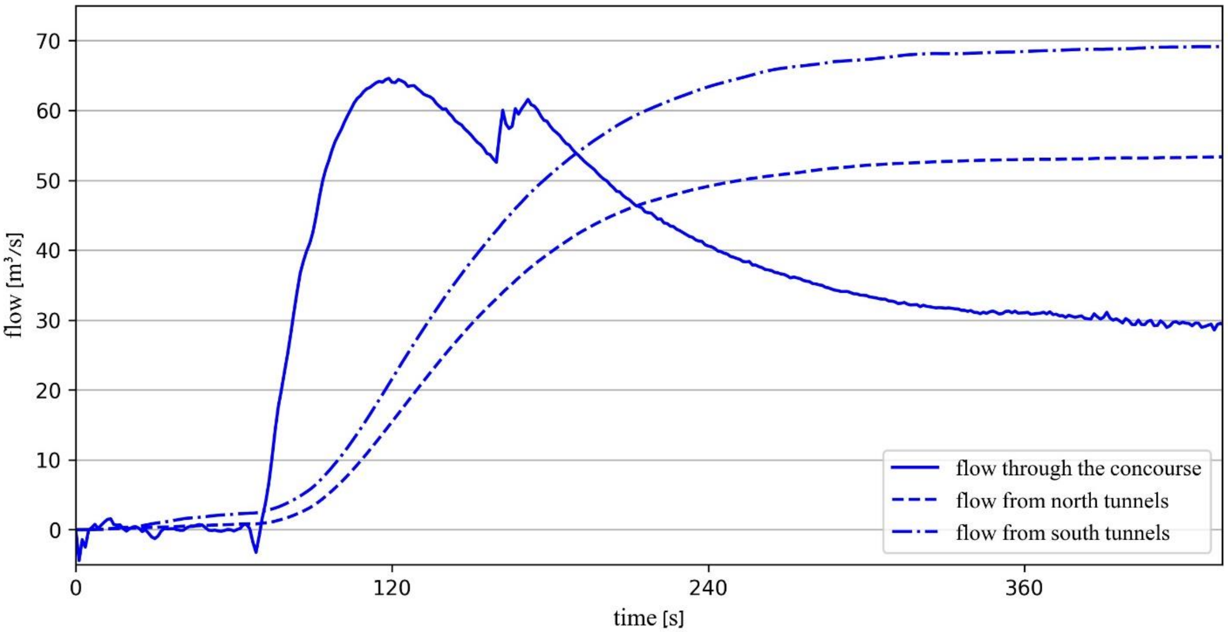

Figure 5: flow through the tunnels and concourse in a station in the initial run

The flow behavior shown in figure 6 exhibits a late response from the tunnels, which is expected due to the pressure losses of the flow. Since air from the concourse is closer, the flow response is almost immediate. When flow starts coming in through the tunnels, the flow from the concourse starts diminishing. A spike in the concourse flow is visible at about 180 seconds. That occurs because the platform edge doors on the other side of the platform close in the simulation when passengers are done alighting the train and air flow from the adjacent tunnel through those doors stops.

This is a good example of how the multiscale approach can help in the design with a better representation of the flow field.

SES Result Comparison

To validate the results some basic SES simulations were performed. The comparison was performed for the event tunnel in steady state flow. In the SES model tunnel and station segments were defined differently while head loses and wall roughness were the same. This allowed to examine the assumption of employing a single HVAC duct to represent a series of tunnels and stations

In figure 6, the flow at the boundary of a tunnel segment is compared with the flow that was obtained from SES and fitted to a curve as was used in former projects. The difference in the steady state flow is less than 7%.

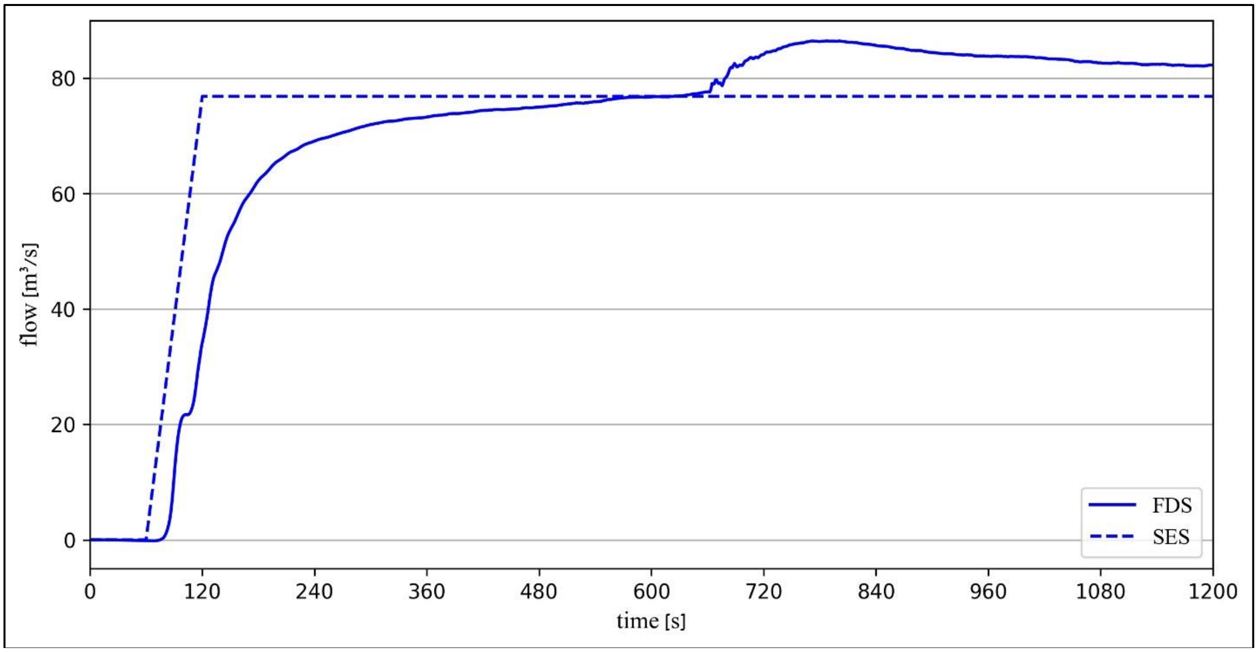

Figure 6: flow at a boundary in FDS compared to SES result at that point for the southern tunnel segment

As expected, the flow response from the tunnel boundary is delayed. Two changes in the flow are visible at about 90 seconds and 640 seconds. At these times, a cross passage door is opened for egress and closed after all passengers have passed to the adjacent tunnel. While the cross passage is open, air from the adjacent over-pressurized tunnel flows into the event tunnel thus reducing flow from the boundary. When the cross passage closes more air comes in from the boundary to compensate.

Figure 7 compares FDS and SES in the same manner as figure 6, but for the boundary of a different tunnel. Here, steady state flow difference is less then 2%.

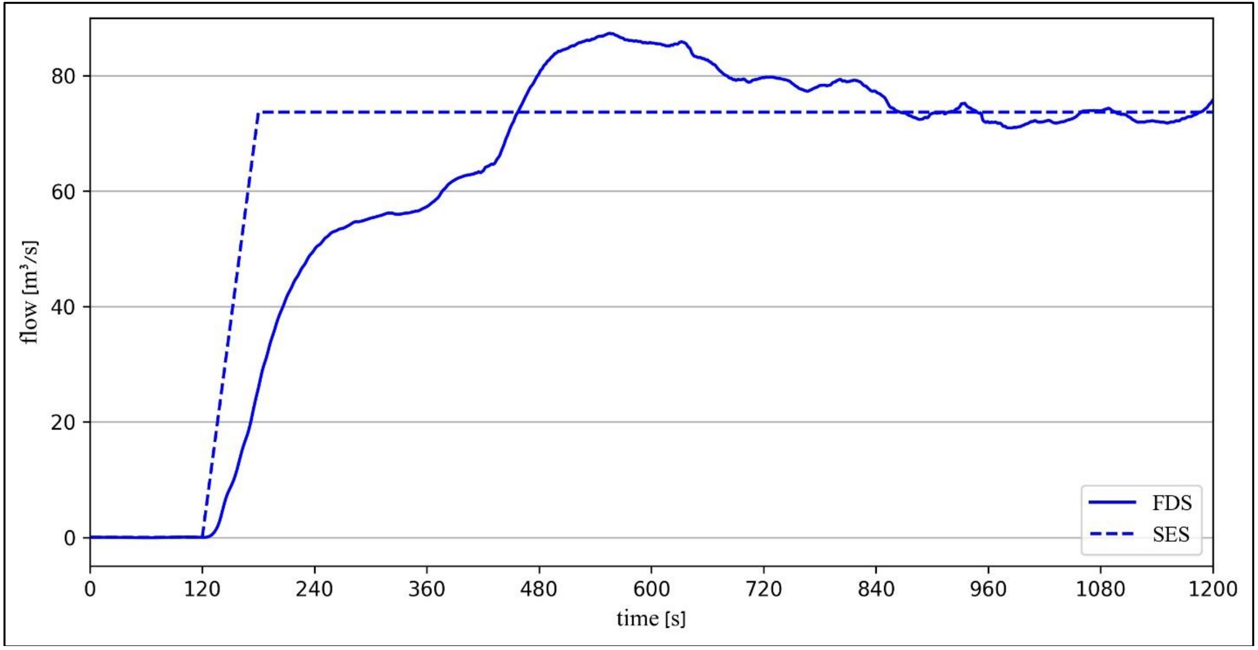

Figure 7: flow at a boundary in FDS compared to SES result at that point for the northern tunnel segmnet

DISSCUSSION

3 Dimensional CFD vs. 1 dimensional analysis

1 dimensional analysis is simple, cost-effective and quick compared to a full 3 dimensional or multiscale approach. For this reason, in cases with a one-directional flow field, 1D analysis should suffice. When flow is not one-directional, 3D analysis should be employed to ensure a correct solution of the flow field.

FDS HVAC vs SES

As presented with the results, there is a good agreement between the SES and FDS steady-state flow for engineering analysis purposes. In table 1 a basic comparison is presented between the HVAC namelist in FDS and the SES parameters.

Table 1: FDS and SES comparison of some parameters.

parameter	**HVAC namelist in FDS**	**SES**
Flow direction	1D	1D
Segment representation	Line segment	Line segment
Transition representation	nodes	nodes
Section geometry	Area and perimeter	Area and perimeter
Wall friction	Roughness	Roughness
Head loss	Loss coefficient	Loss coefficient
Heat transfer calculation	no	yes
Fire representation	no	yes
Transient flow field	yes	no

As the table shows, HVAC namelist and SES are defined and calculated the same for the most part. The main differences are that HVAC namelist does not calculate heat transfer and should only be used for cold flow, and SES does not calculate the transient flow field in a fire scenario.

FDS Model setup

Head loss and wall roughness are parameters that should be applied carefully in order to obtain realistic flow at the boundary. The values used were the same as the ones in the 1D analysis for this project. These values are assumed, and the sensitivity of the results to these assumptions are beyond the scope of this work.

Initial struggles with the pressure field and pressure zones would suggest that these simulations are sensitive to the pressure solver. it is unclear if these are due to HVAC boundaries.

CONCLUSION

The use of the HVAC namelist as a means of the multiscale approach in FDS showed good agreement with 1D results for engineering analysis purposes.

The flow field in the simulations reacted to changes in the flow field and displayed a realistic behavior in flow response from the boundaries.

Other scenarios in this project will be examined in the same manner upon completion for further insights.

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