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EVACUATION FROM TUNNELS - AN EXAMPLE OF THE STRAŽEVICA TUNNEL

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Abstract:

Tunnels are passageways built for different purposes: road tunnels, railway tunnels, subway tunnels or similar. Their dimensions are becoming more and more considerable, depending on technology improvement. According to the fact that many people and vehicles pass continually through these structures, there was a logical question about a possible evacuation in case of disasters such as fire, explosion or similar. This is a constantly open and actual problem, confirmed by many people who perished in disasters because they could not be evacuated or because an evacuation was delayed for some reasons. This paper has been written to show a possible evacuation situation and to calculate the minimum time for the evacuation in the case of 772 m long Straževica tunnel.

Key words: *evacuation, simulation, tunnels.*

Introduction

Tunnels, generally, present underground objects, with both ends opened, positioned horizontally or with a slight gradient, which serve for railway, road, water ways, or similar, and connect two parts of the road separated by an obstacle that could not be overcome in some other way. The biggest number of tunnels, often the longest of tunnels, was built for railway transport and transport by water, while a smaller part was built on roads and pedestrian crossings. Tunnels, as well as bridges, present the most complicated architectural structures. Their construction demands great knowledge, detailed planning, many different measurements and huge material expenses. Some examples of tunnels are presented in Figure 1.

Figure 1 – Tunnels for traffic in Baltimore (left) and Switzerland (right), figure sources: https://en.m.wikipedia.org/wiki/Cut_and_cover#Cut-and-cover (left), https://www.ethz.ch/en/news-and-events/eth-news/news/2013/11/a-land-of-tunnels.html (right)
Рис. 1 – Автодорожные тоннели в Балтиморе (слева) и Швейцарии (справа), источник фото: https://en.m.wikipedia.org/wiki/Cut_and_cover#Cut-and-cover (слева), https://www.ethz.ch/en/news-and-events/eth-news/news/2013/11/a-land-of-tunnels.html (справа)
Slika 1 – Tuneli za saobraćaj u Baltimoru (levo) i Švajcarskoj (desno), izvor slike: https://en.m.wikipedia.org/wiki/Cut_and_cover#Cut-and-cover (levo), https://www.ethz.ch/en/news-and-events/eth-news/news/2013/11/a-land-of-tunnels.html (desno)

Tunnels can be divided in several ways, depending on different factors. Depending on their position in respect to the ground, tunnels are divided to hill tunnels, underwater tunnels and city tunnels. Depending on their structure, tunnels can be divided to completely constructed tunnels, partly constructed tunnels and no constructed tunnels. As far as the applied construction method is concerned, there are Belgian, Austrian, English, German, Italian and other methods of tunnel construction. There are also many other different divisions of tunnels. From the historical aspect, it was known that tunnels were built in 2500 B.C. under the rivers Tigris and Euphrates. Today, there are many tunnels with different purposes all over the world. Some of the longest tunnels are presented in Table 1.

Table 1 – The longest tunnels in the world
Таблица 1 – Самые длинные тоннели в мире
Tabela 1 – Najduži tuneli na svetu

Name of the tunnel	Location of the tunnel	Length of the tunnel	Purpose	Year
Delaware Aqueduct	New York, USA	137 km	Water supply	1945
Päijänne Water Tunnel	Finland	120 km	Water supply	1982

Name of the tunnel	Location of the tunnel	Length of the tunnel	Purpose	Year
Dahuofang Water Tunnel	Liaoning Province, China	85.32 km	Water supply	2009
Orange–Fish River Tunnel	South Africa	82.8 km	Water supply	1972
Bolmen Water Tunnel	Kronoberg/Scania, Sweden	82 km	Water supply	1987
Tunnel Emisor Oriente	Mexico City, Mexico	62.5 km	Water waste	2012
Guangzhou Metro: Line 3	Guangzhou, China	60.4 km	Metro	2010
Beijing Subway: Line 10	Beijing, China	57.1 km	Metro	2012
Seikan Tunnel	Tsugaru Strait, Japan	53.8 km	Railway Single Tube	1988
Želivka Water Tunnel	Central Bohemian Region, Czech Republic	51.075 km	Water supply	1972

The Straževica tunnel presents a component of Belgrade's detour and it is the largest and the most modern tunnel in Serbia. It presents an integral part of the KORIDOR 10 highway. The tunnel was built in accordance with the latest world standards. The length of the tunnel is 772 m while the complete width is 13 m and the width of the roadway is 11.5 m. It is only the right tunnel tube. The left tunnel tube was realized for only 115 m. The both tunnel tubes should be connected with two pedestrian tunnels with a tunnel cross-section of 25 m^2, intended for evacuation in emergency cases. The tunnel is equipped with complete light and traffic signalization equipment. It also has a very modern system for fire detection, burglary detection, air control, audio and radio system, ventilation system and a system for traffic control. Six lighting systems accommodate the tunnel light to the day light and, in that way, stop the "blindness" of drivers. The complete quantity of dug earth was 70,000 m^3. In order to stop the ground moving, it was necessary to concrete a protective inclined plane of 120 m in length, with 147 tensioned anchors with a length of 9 m. The tunnel excavation was realized by a new Austrian tunnel method. Some of important data for the tunnel are presented in Table 2, while the tunnel is presented in Figure 2 (left and right) (http://www.energoprojekt-ng.rs), (http://www.novosti.rs/vesti/beograd.74.html:378392-Strazevica).

Table 2 – Major data for the Straževica tunnel
Таблица 2 – Главные параметры тоннеля Стражевица
Tabela 2 – Glavni podaci za tunel Straževica

tunnel length	745m +115m
tunnel cross-section	110 m2
tunnel excavation	843,377.00 m3
open-cut excavation	150,390.23 m3
earth fill	79,175.05 m3
gravel fill	80,128.86 m3
concrete lining	18,945.39 m3
concrete MB 30	2,547.61 m3
sprayed concrete MB 30	3,753.08 m

Figure 2 – The entrance at the Straževica tunnel (right) and its inside look (left) (Figure source): http://www.telegraf.rs/vesti/beograd/1083872-obustavljen-saobracaj-kod-tunela-strazevica (left), http://glassrbije.org/sr/ чланак/за-завршетак-тунела-стражевица-обезбеђено-450-милиона (right)
Рис. 2 – Вход в тоннель Стражевица (справа) внутренний вид (слева) (источник фото) http://www.telegraf.rs/vesti/beograd/1083872-obustavljen-saobracaj-kod-tunela-strazevica (слева), http://glassrbije.org/sr/ чланак/за-завршетак-тунела-стражевица-обезбеђено-450-милиона (справа))
Slika 2 – Ulaz u tunel Straževica (desno) i unutrašnji izgled (levo)(izvor slike): http://www.telegraf.rs/vesti/beograd/1083872-obustavljen-saobracaj-kod-tunela-strazevica (levo), http://glassrbije.org/sr/ чланак/за-завршетак-тунела-стражевица-обезбеђено-450-милиона (desno))

Pathfinder 2012 simulation software

Pathfinder presents an agent-based on egress and human movement simulator. There are several different versions of this program. Pathfinder provides a graphical user interface for a simulation design and execution as well as 2D and 3D visualization tools for a result analysis. The movement environment is a 3D triangulated mesh designed to match the real dimensions of a building model. This movement mesh can be entered manually or automatically based on imported data (e.g. FDS geometry). Walls and other impassable areas are represented as gaps in the navigation mesh. The construction of curved walls could be realized as a construction of several straight wall segments. These objects are not actually passed along to the simulator, but are represented implicitly because occupants cannot move in places where no navigation mesh has been created. Doors are represented as special navigation mesh edges. Every door has its own length. In all simulations, doors provide a mechanism for joining rooms and tracking the occupant flow. Depending on the specific selection of simulation options, doors may also be used to explicitly control the occupant flow. Stairways are also represented as special navigation mesh edges and triangles. Stairways can connect different floors and levels. The occupant movement speed is reduced to a factor of their level travel speed based on the incline of the stairway. The occupant speed could be defined for different evacuation scenarios. Each stairway implicitly defines two doors. These doors function just like any other door in the simulator but are controlled via the stairway editor in the user interface to ensure that no geometric errors result from a mismatch between stairways and the connecting doors.

Occupants are modeled as upright cylinders on the movement mesh and travel using an agent-based technique called inverse steering. Each occupant calculates movements independently and can be given a unique set of parameters (maximum speed, exit choice, 3D model, etc). Pathfinder supports two movement simulation modes. In "Steering" mode, doors do not act to limit the flow of occupants; instead, occupants use the steering system to maintain a reasonable separation distance. In the SFPE mode, occupants make no attempt to avoid one another and are allowed to interpenetrate, but doors impose a flow limit and velocity is controlled by density. Simulator users can freely switch between the two modes within the Pathfinder user interface and compare answers. The example of occupants' movement in a simulation model of the Straževica tunnel at 385 m from the tunnel exit/entrance is presented in Figure 3.

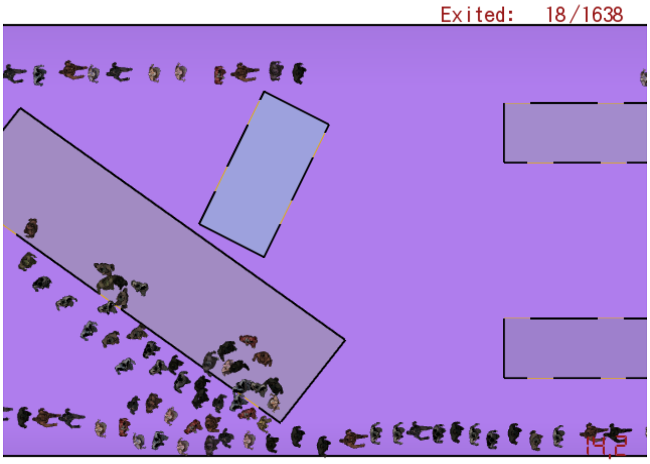

Figure 3 – Modeled occupants in the tunnel simulation model after 14.2 seconds from the start of the simulation
Рис. 3 – Смоделированные пассажиры в симуляционной модели тоннеля спустя 14,2 секунды от начала симуляции
Slika 3 – Modelovani ljudi u simulacionom modelu tunela posle 14,2 sekunde od početka simulacije

A very important software possibility is importing files created in 3D CAD, FDS and PyroSim. These files have their own geometry which can be used in Pathfinder and significantly save time needed to complete the whole evacuation and fire project. The imported geometry is sent as-is to 3D Results, resulting in a clean and fast graphical representation of the data. The used version of Pathfinder for paper results was 2012 version (Thunderhead, 2012, pp.1-4).

Simulation model

The simulation model was realized in Pathfinder 2012 in accordance with its real dimensions. Because of the program possibilities, the curves of the tunnels were not completely realized but that did not influence the simulation results. The similar approximations were used in some earlier published papers (Jevtić, Ničković, 2014, pp.RT6.6.,1-4), (Jevtić, 2014b, pp.537-541), (Jevtić, 2015, pp.545-550).

The simulation was realized for different occupants' speeds (1.25 m/s, 1.5 m/s, 1.75 m/s, 2m/s, 2.5 m/s, 3m/s, 3.5 m/s and 5 m/s) in the case of a collision. The occupants were positioned in their vehicles at the start of the simulation. According to the postulated scenario, the tunnel was full with different vehicles. There were 199 cars, 14 buses and 15 trucks.

Every car had 4 occupants inside, every bus had 58 occupants inside and every truck had 2 occupants inside. The complete number of occupants was 1,638. The dimensions (length, width, height) of every car were 4.2 m x 1.8 m x 1.6 m, the dimensions of every bus were 13 m x 2.65 m x 3.2 m and the dimensions of every truck were 18.75 m x 2.85 m x 3.2 m. Every vehicle had a determined number of doors- cars had 4 exit doors, busses had 3 exit doors and trucks had 2 doors. The distance between every two vehicles was 1m. The vehicles were positioned in two separate roadways. The collision between a bus and a car was in the middle of the tunnel, at 386 m after the entrance/exit of the tunnel. The vehicles in the middle of the tunnel and the collision situation are presented in Figure 4.

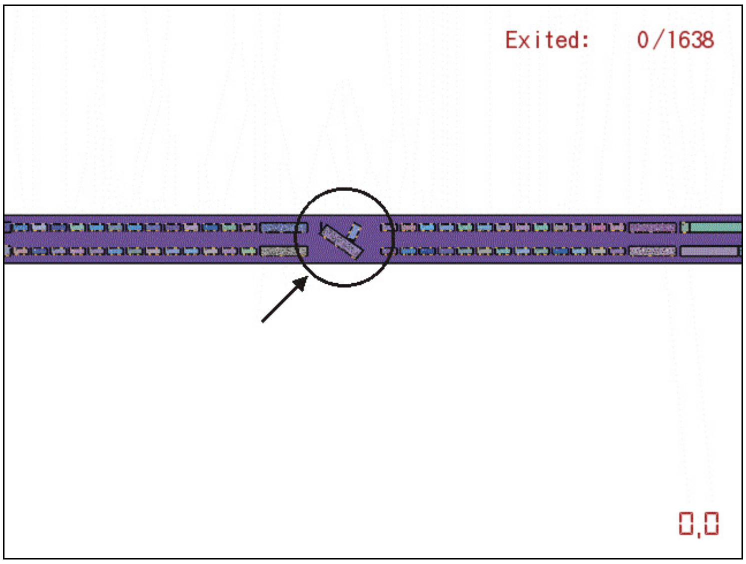

Figure 4 – The simulation example for the second scenario with the noted location of crash at the start of the simulation
Рис. 4 – Симуляционный пример по второму сценарию с обозначенным местоположением аварии в начале симуляции
Slika 4 – Simulacioni primer drugog scenarija sa obeleženom lokacijom sudara na početku simulacije

Simulation results

Some scenes from the case where the occupants' speed was 1.5 m/s are presented in Figures from 5 to 12, while the complete simulation results were presented in Figure 13.

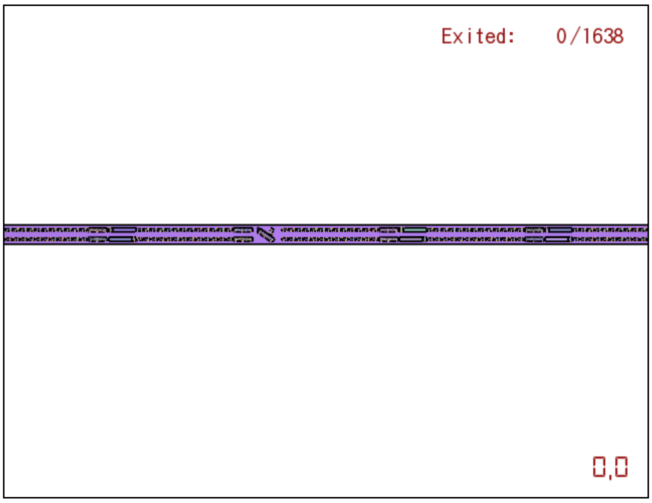

Figure 5 – The simulation example for the noted case with the noted location of crash at the start of the simulation
Рис. 5 – Симуляционный пример приведенного случая с обозначенным местоположением аварии в начале симуляции
Slika 5 – Simulacioni primer za pomenuti slučaj sa obeleženom lokacijom sudara na početku simulacije

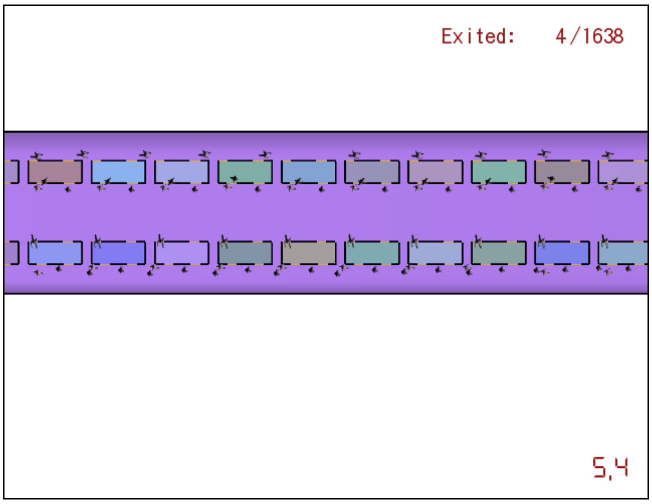

Figure 6 – The simulation example for the noted case after 5.4 seconds from the start of the simulation
Рис. 6 – Симуляционный пример приведенного случая спустя 5.4 секунды от начала симуляции
Slika 6 – Simulacioni primer za pomenuti slučaj posle 5,4 sekunde od početka simulacije

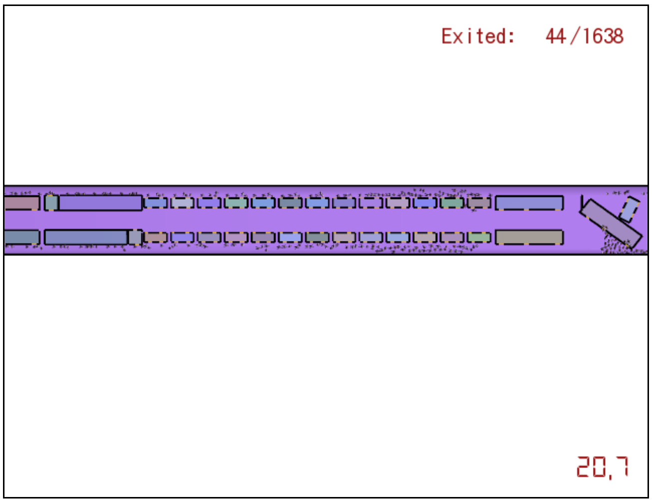

Figure 7 – The simulation example for the noted case after 20.7 seconds from the start of the simulation

Рис. 7 – Симуляционный пример приведенного случая спустя 20.7 секунд от начала симуляции

Slika 7 – Simulacioni primer za pomenuti slučaj posle 20,7 sekundi od početka simulacije

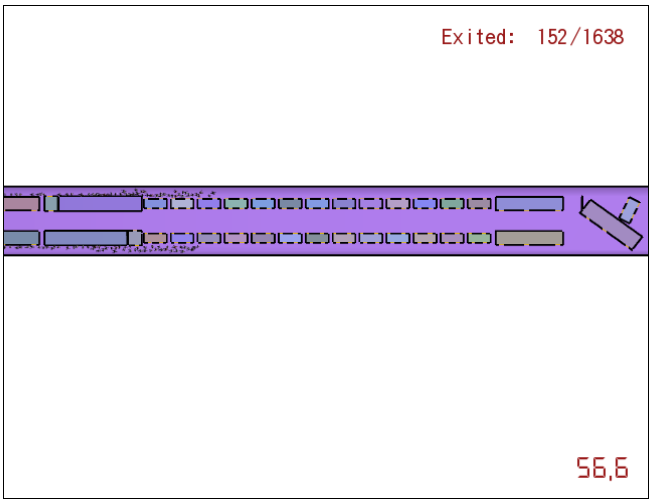

Figure 8 – The simulation example for the noted case after 56.6 seconds from the start of the simulation

Рис. 8 – Симуляционный пример приведенного случая спустя 56.6 секунд от начала симуляции

Slika 8 – Simulacioni primer za pomenuti slučaj posle 56,6 sekundi od početka simulacije

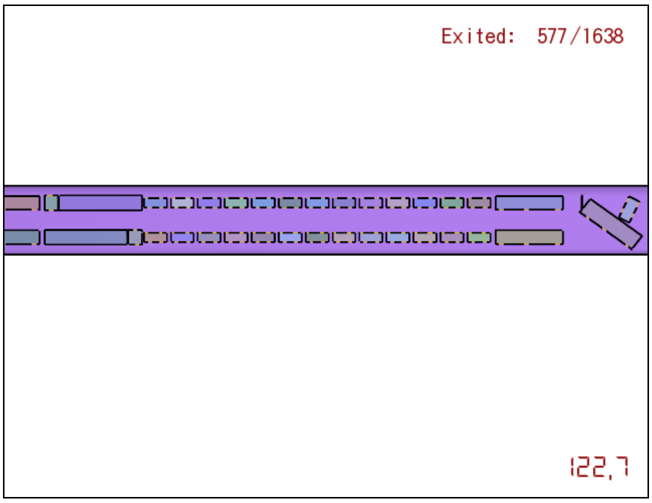

Figure 9 – The simulation example for the noted case after 122.7 seconds from the start of the simulation
Рис. 9 – Симуляционный пример приведенного случая спустя 122.7 секунд от начала симуляции
Slika 9 – Simulacioni primer za pomenuti slučaj posle 122,7 sekundi od početka simulacije

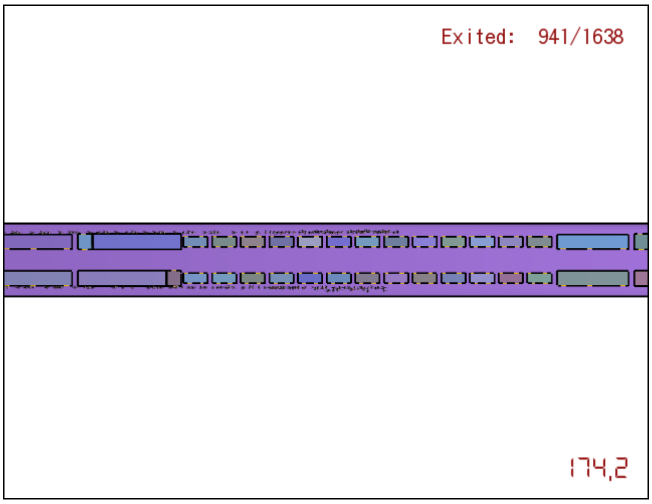

Figure 10 – The simulation example for the noted case after 174.2 seconds from the start of the simulation
Рис. 10 – Симуляционный пример приведенного случая спустя 174.2 секунды от начала симуляции
Slika 10 – Simulacioni primer za pomenuti slučaj posle 174,2 sekunde od početka simulacije

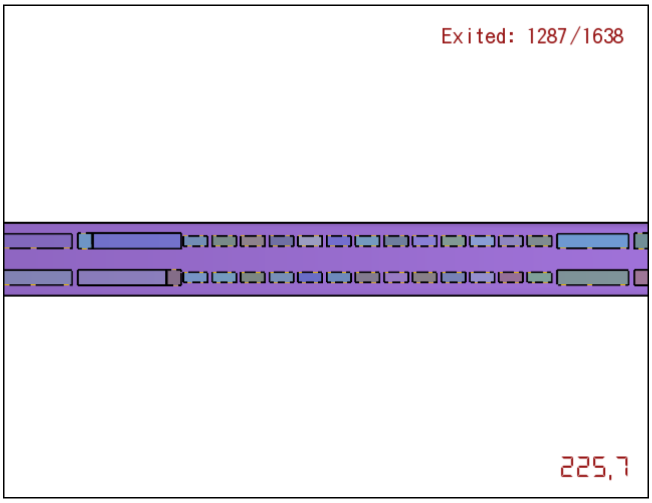

Figure 11 – The simulation example for the noted case after 225.7 seconds from the start of the simulation
Рис. 11 – Симуляционный пример приведенного случая спустя 225.7 секунд от начала симуляции
Slika 11 – Simulacioni primer za pomenuti slučaj posle 225,7 sekundi od početka simulacije

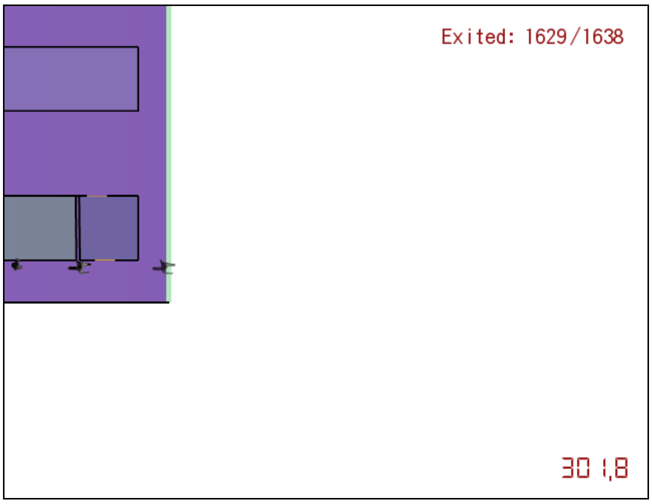

Figure 12 – The simulation example for the noted case at the exit/entrance of the tunnel after 301.8 seconds from the start of the simulation
Рис. 12 – Симуляционный пример приведенного случая спустя 301.8 секунд от начала симуляции
Slika 12 – Simulacioni primer za pomenuti slučaj posle 301,8 sekundi od početka simulacije

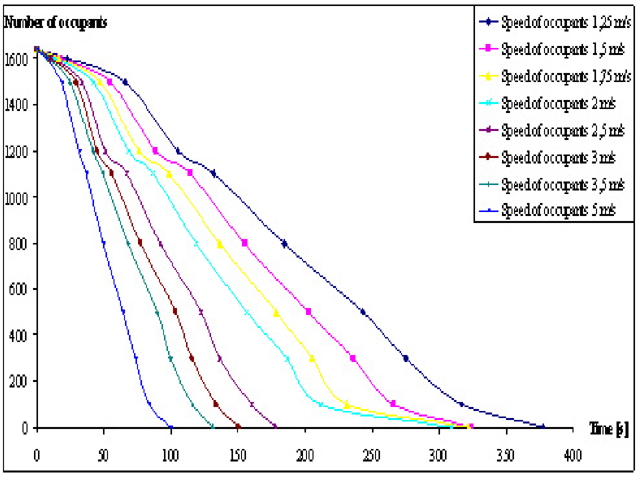

Figure 13 – Simulation results for realized cases
Рис. 13 – Результаты моделерования симуляционных событий
Slika 13 – Rezultati sumulacije za realizovane slučajeve

Analysis of the results

The simulations were realized on a laptop Lenovo IdeaPad G50-80 80E502F3YA, with the Intel Core i5-5200U processor (2 cores, 2.20GHz, 3MB cache), DDR3L memory controller (up to 1600MHz), Intel Turbo Boost 2.0 (2.70GHz) and 8GB of DDR3 RAM. The realized simulations for the presumed cases showed mostly expected results. The simulations presumed a collision in the tunnel that barricaded the tunnel, without human victims. Lower occupants' speeds (1.25 m/s and 1.5 m/s) implied calm occupants, while higher occupants' speeds could imply occupants in panic (3.5 m/s, 5 m/s). The realized results showed that, for the chosen occupants' speeds, the evacuation time would be shorter for higher occupants' speeds; however, it does not mean that a very high occupant speed would imply very short evacuation time; on the contrary, in that case, the possibilities for unpredicted situations rapidly increase and evacuation time rapidly increases (Helbing, et al, 2000, pp.487-490).

Also, in the case of some collision with victims or some other consequences, such as fire, explosion, gas leakage or similar, speeds of occupants would be much different and their behavior would be chaotic and pretty unpredictable. That would imply different situations, such as panic, jams, injuries and similar. For example, it is very hard to leave a bus with jammed doors, since it is necessary to break the glass on the windows to leave the bus. Also, it is very hard to leave the tunnel with injured occupants that often have to be carried, which implies higher possibilities for jams and slower evacuation.

Conclusion

An analysis of evacuation times and evacuation routes using proper software presents a very helpful tool in evacuation realization because it gives a good presentation how the available evacuation routes could be used for different accidents (fire, earthquake, etc)(Jevtić, 2014a, pp.153-158). It is also possible to locate new evacuation routes that could be used in accidents (pedestrian tunnels) for successful evacuation. Testing these factors for different occupants' speeds and behaviors gives a good real presentation of a potential evacuation scenario inside the object and it offers great advantages in projecting and installing complete protection systems, such as fire protection systems, smoke protection systems, and similar (Netcu, et al, 2011, p.277). The application of this program for different objects puts it in the line with necessary engineer's tools for calculating and projecting safety evacuation systems for any type of evacuation causes (Serban, et al, 2014, pp.48-52).

References

Helbing, D., Farkas, I., Viscsek T., 2000. *Simulating dinammical features of escape panic*, Nature, Vol. 40, pp.487-490,

http://www.energoprojekt-ng.rs/en/references/underground-structures/putni-tunel-strazevica-srbija,

http://www.novosti.rs/vesti/beograd.74.html:378392-Strazevica-Svetlo-posle-20-godina,

Jevtić, R.B., 2014a, *The importance of fire simulation in fire prediction*, *Tehnika Elektrotehnika*, Vol 1., pp.153-158, ISSN 0040-2176, Beograd.

Jevtić, R.B., 2014b, *Simulation of the shopping centre Zona I evacuation*, *Tehnika Elektrotehnika*, Vol 3., pp.537-541, ISSN 0040-2176, Beograd.

Jevtić, R.B., 2015, *The simulation of sanitary objects evacuation-an example of hotel Radon in Niška Banja*, *Tehnika Elektrotehnika*, Vol 3., pp.545-550, ISSN 0040-2176, Beograd.

Jevtić, R.B., Ničković, T.J., 2014, *Object evacuation for different speeds of occupants*, 58th ETRAN conference, pp.RT6.6.,1-4, Vrnjačka Banja.

Netcu, C., Panaitescu, V., Popa, C. and Anghel, I. 2011. *3D simulation of a subway station fire*. Bucharest: Police Academy. p.277.

Serban, M., Codescu, S. and Ionel-Alin, M. 2014. *Computational simulation of road tunnel fire protection by sprinklers*, European Journal of Environmental and Safety Sciences, Vol. 2., pp.48-52.

Thunderhead, 2012. *Pathfinder Exmple Guide*, USA.

ЭВАКУАЦИЯ ИЗ ТОННЕЛЯ – НА ПРИМЕРЕ ТОННЕЛЯ СТРАЖЕВИЦА

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ОБЛАСТЬ: пути сообщения
ВИД СТАТЬИ: оригинальная научная статья
ЯЗЫК СТАТЬИ: английский

Резюме:

Тоннели представляют собой подземные сооружения различных типов назначения: железнодорожные, автодорожные, тоннели для метрополитенов и др. Благодаря технологическому развитию размеры тоннелей с каждым днем увеличиваются. Учитывая тот факт, что большой поток пассажиров и транспортных средств непрерывно проезжает через данные объекты, возникает естественный вопрос об их эвакуации в случае чрезвычайных ситуаций, таких как: пожар, взрыв и пр. Вопрос об эвакуации более чем актуален, так как подобные риски несут за собой большое количество человеческих жертв, если своевременно не предпринять меры по эвакуации.

В работе представлены возможные эвакуационные ситуации и минимальный расчет времени для эвакуационных мероприятий на примере тоннеля Стражевица 772 м.

Ключевые слова: *эвакуация, моделирование, тоннели.*

EVAKUACIJA IZ TUNELA – PRIMER TUNELA STRAŽEVICA

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OBLAST: saobraćaj
VRSTA ČLANKA: originalni naučni članak
JEZIK ČLANKA: engleski

Sažetak:

Tuneli su objekti sagrađeni za različite svrhe. Mogu biti putnički, železnički, tuneli za podzemne železnice i služiti za slične namene. Njihove dimenzije postaju sve veće zahvaljujući tehnološkim poboljšanjima. Uzimajući u obzir činjenicu da mnogo ljudi i vozila kontinualno prolazi kroz ove objekte, postavilo se pitanje o mogućoj *evakuaciji u slučaju katastrofa, kao što su požar ili eksplozija. Iskustva govore da je mnogo ljudi izgubilo život jer nisu mogli biti evakuisani ili je evakuacija zbog nekog razloga kasnila. U ovom radu opisuje se moguća evakuaciona situacija i izračunava minimalno vreme potrebno za evakuaciju u tunelu Straževica koji je dugačak 772 m.*

Ključne reči: *evakuacija, simulacija, tuneli.*

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