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ALSO THE 4TH DIMENSION OF THE TOWN – ITS UNDERGROUND STRUCTURES – HAS ITS RISKS

The article is devoted to risk assessment of underground structures from the point of view of their existence, operation and human failure (of users and/or operators). Two likely instances of their abuse for disseminating poisonous substances in an urban agglomeration are described. Both possibilities have been scrutinized using either physical simulation or an in-situ experiment. The distribution of agent depending on chosen parameters (agent's imitation, meteorological conditions, etc.) was verified on Prague's Old Town Square model in an aerodynamic tunnel. The in situ experiment with surrogates was performed at underground subway changing station. The parameters, results of the experiments and conclusions are discussed in detail.

1. Introduction

Apart from air pollution caused by exhalations and emissions from chemical, metallurgical and power generating industries, the biggest negative impact on the environment is the gradual occupation of land and free area by various construction development projects. The phenomenon has become extremely important particularly in connection with the fast development or expansion of urban agglomerations.

The space under the ground level (apart from extraction of raw materials) can be used for activities which are difficult to place and operate on the surface. The reasons may be e.g. technical, environmental or economic. Underground facilities are often situated in locations with adverse effects of the natural environment (aggressive underground water, distorted formations, pressures), and they are affected by operations in the underground facility and the time factor.

The processes require regular monitoring and diagnosing of defects of the underground structures, planning of maintenance and refurbishments and timely implementation of the planned measures (cement injections, waterproofing, anchoring, shot-concreting, safety elements etc.).

Poor maintenance increases risks associated with the operation of underground structures, such as traffic accident, fire, explosion etc.

Meanwhile, underground structures are very sensitive to technology failure as a result of sabotage or terrorist attack with the potential consequences – endangered lives and health of big numbers of people and disruption of municipal infrastructure. Underground structures, particularly line projects, may be for example abused for distribution (spreading) of dangerous chemical and biological

substances on a large territory of the city. Also an explosion in a collector may have synergic effects, e.g. derailing of a subway train etc.

The above-mentioned facts have led us to identification of risks and we also clearly recognized opportunities of potential abuse of some underground structures for spreading of poisonous agents in the urban agglomeration or direct application of such substances e.g. in an underground traffic structure.

For this reason we have performed some experiments using physical modeling and “in-situ” experiments with substitute chemical agents.

2. Determination of risks in underground structures

After the analysis we divided the risks based on association with:

- a) the *existence* of underground structures,
- b) the *operation* of underground structures,
- c) the *human failure* of users or operators of underground structures.

a) *Risks associated with the existence of underground structures*
The risks are caving and sinking. The factors listed below increase the mentioned risks:

- effect of underground water (its chemical properties, temperature, flow rate, its effect on the rock, i.e. leaching, water bearing, swelling; its aggressiveness, i.e. acidity, content of mineral elements, sulphates, sulphanes, free carbonic acid etc.),
- the dead weight of lining,
- confining pressure (vertical, lateral, pressure on the stope bottom, lengthwise),

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- loading with buildings and construction objects on the surface,
- long-term technological loading of underground structures,
- loading generated by operations on the surface,
- seismic effects,
- underground gases,
- underground temperature.

b) *Risks associated with the operation of underground structures*

- b1) traffic line underground structures imply the following risks
- defect on one car or a railway set,
 - traffic accidents with a property damage,
 - traffic accident with an injury,
 - traffic accident with a fatality,
 - local fire,
 - large fire,
 - poisoning of persons with smoke and toxic products,
 - explosion (explosive fire, detonation),
 - destruction of building structures (structure collapse),
 - burying and caving,
 - suffocation of trapped persons,
 - injury caused by electric power,
 - scalding and burning,
 - flooding,
 - environment pollution,
 - release of toxic substances.

b2) water management line underground structures imply the following risks

- pollution, contamination, poisoning of the medium,
- breakdown of the line and release of the medium in the environment, infection, epidemic,
- drowning.

b3) power engineering line underground structures imply the following risks

- fire,
- fire with explosion,
- loss of information and communication systems,
- leakage of media from the damaged distribution system,
- destruction of structures (collapse),
- burying and caving,
- injury caused by electric power,
- scalding and burning,
- flooding,
- contamination of air from ventilation shafts.

b4) hall-type underground structures imply the following risks

- fire,
- large scale fire,
- explosion,
- destruction of structures (collapse),
- burying and caving,
- suffocation of trapped persons,
- poisoning of persons with smoke and toxic products
- contamination of the environment.

c) *Risks associated with human failure*

Human failure, including accidental or deliberate actions, criminal acts or terrorist attacks imply the following risks

- violation of occupational safety rules, technical regulations, operating rules,
- violation of acts,
- civil unrest, occupation of portals, loss of access to the entries,
- theft, assault, murder,
- planting of an explosive, activation, explosion,
- application of an explosive with a contaminant,
- sabotage in the system,
- application of chemical and biological weapons.

Moreover, we used additional approaches available, i.e. selection of threats and their classification into those which endanger underground structures as a whole, those which have no effect on their safety and those which only affect a specific type of structure (e.g. an epidemic may endanger the subway operation).

Another potential approach was identification of the so-called TOP (main, key) events and initiations events (internal and external).

The analytic combination of the selected risks and threats and the identification and evaluation of initiation events allow to perform a very fast basic safety analysis for underground structures.

Subsequently, we provided examples of a potential abuse of underground structures and experiments we conducted to mitigate such threats and their impact.

3. Example of an Underground Structure abuse for Spreading of a Poisonous Substance in an Urban Agglomeration

As mentioned above, line underground structures may be abused for spreading of dangerous poisonous substances in urban agglomerations.

a) *selection of the poisonous substance and location for the abuse*

The selected substance for model abuse was sarin, i.e. nerve agent, classified as a chemical weapon. These agents are generally organic compounds of phosphorus featuring high toxicity for mammals, fast commencement of effects and penetration into organism through all portals of entry.

The reasons to select sarin included:

- its relatively simple preparation from available materials (CH_3Cl , AlCl_3 , PCl_3 , NaF , SbF_3 , 2-propanol),
- its higher vapor pressure compared to other nerve agents (385.7 Pa, 25°),
- its slight odor,
- its latent effect.

We also considered the location for sarin abuse and when and which method to use to release sarin into the atmosphere. We

selected the Old Town square (Staroměstské náměstí) during the striking time of the Astronomical Clock and the method was spilling or by abuse of outlets of the underground structures under the square surface. For additional tests in an aerodynamic tunnel and for the “in-situ” method it was necessary to find an agent meeting at least partly the following criteria:

- similar physical and chemical properties,
- easy detection (including subjective response to smell or odor by the experimenting persons),
- acceptable toxicity and labor safety while working with the agent,
- availability (delivery, price).

Based on a comparison of basic physical properties (boiling point, vapor pressure) with sarin we opted for pentyl-acetate as a substituent. However, the published dependences of kinematic and dynamic viscosities and diffusion coefficient on temperature were not completely identical and therefore we had to use a graphical correlation comparison [1].

b) physical modeling of spreading of hazardous materials (sarin substituent, propane, aerosol) in the Old Town Square and its surroundings

Most human activities (including negative ones) are performed on the Earth surface surrounded with the so-called atmospheric boundary layer (ABL). Above ABL there is free atmosphere and bottom part of ABL is called the surface sublayer. The methods for description of flow patterns in ABL and thus also the spreading of hazardous agents are:

- mathematical modeling,
- physical modeling,
- direct measurement in the field (“in-situ”).

Mathematical modeling consists in numerical solution of motion equations (non-linear partial differential equations).

The method is still used particularly in cases with simple geometry – planar or slightly undulated ground.

The physical modeling is for more complex cases, e.g. for territories with a high density of structures (town centers). The method uses an analogy between flow patterns near the Earth surface and flow patterns near a wall in a special aerodynamic tunnel. The model requires development of a suitable geometrically similar model which forms a tunnel wall.

Our model of the Old Town Square was based on 45 first line core buildings and palaces. They were detailed replicas as shown in Fig. 1, of hardened polypropylene with a coat of façade paint. The used scale was 1:160. The total model was subsequently placed in an aerodynamic tunnel in the Institute of Thermomechanics of the Academy of Science of the Czech Republic in Nový Knín.

We modeled spreading of the sarin substituent – pentyl-acetate, “inert” propane and CO₂ aerosol + glycerin.

We selected the following four points in the Old Town Square as model source points from which the substituent (inert agent, aerosol) was released into do ABL:

- in front of the town hall tower (Town Hall),
- in Male namesti in front of the U Princů restaurant,
- at the end of Parizska street on the Old Town Square,
- next to the statue of J. Hus.

The point source – was an opening with the diameter of 0.4 cm at the surface level of the model for propane and aerosol, for pentyl-acetate we used an evaporation micro-bowl (1.5 x 1.5 cm).

Based on meteorological data about prevailing flow patterns in Prague 1 we selected the following wind directions:

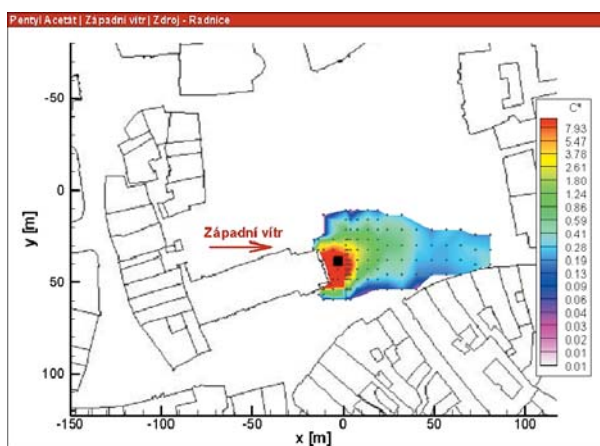


Fig. 1: Model of the Old Town Square in the aerodynamic tunnel [Source: own]

- north-west,
- west-north-west,
- west,
- south-west.

An example of results of physical modeling of distribution of horizontal concentrations of pentyl-acetate and propane in the west wind from one of the selected points (sources) in the Old Town is shown in Figure 2.

A comparison of sizes of concentration fields for pentyl-acetate and propane shows a significant difference. One of the main reasons is that pentyl-acetate is the so-called active admixture, it is adsorbed on the model bottom surface and particularly on the walls of buildings (see the vertical profile or visualization of flow patterns [2]). Unlike pentyl-acetate, propane is the so-called passive admixture. Based on dimensionless concentrations the measurement results with propane have been identified as the worst potential variant of spreading of a hazardous material in the given location.



by abuse of poisonous war gases as a result of a criminal or terrorist act. For this reason the Ministry of Interior – General Directorate of Fire Rescue Service of the Czech Republic (GR HZS CR) strongly focused on this issue. The State Office for Nuclear Safety focused on one partial problem, i.e. on contamination of the subway premises and spreading of the contaminant in its premises.

For this purpose we used an “in-situ” experiment, i.e. we released substituent of the poisonous sarin (pentyl-acetate) in the area of the subway station “Muzeum”, which is a junction of the C and A subway lines.

The agent was released on the platform of the “Muzeum” C station during the operation of subway trains and without operation of subway trains with winter ventilation (air intake into the space between stations, air extraction from the station via an exhaust shaft).

The speed and concentration gradient was determined in 7 measuring points (platform, escalator, corridors, lobby), and the

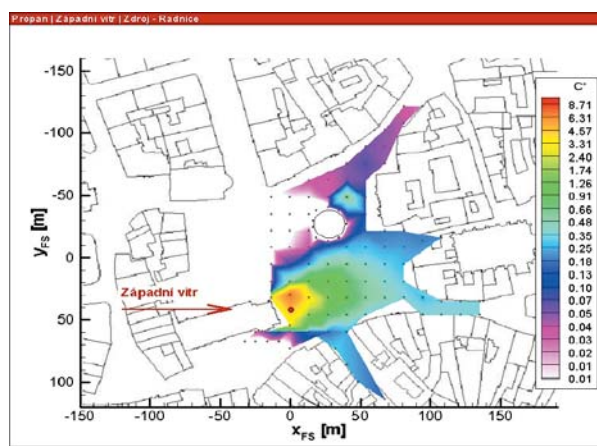


Fig. 2: Horizontal distribution of concentrations of pentyl-acetate and propane, with the source location in front of the town hall tower

We used modeling to select a place for the contaminant release within the square and the wind direction resulting in contamination of the entire Old Town Square.

Also capillary action of the agent was demonstrated at higher levels in the buildings compared to the square center (vertical concentration profile2). Experimental results from the aerodynamic tunnel were transformed into the MS Excel format compatible with geographic information systems (GIS) and they were provided to the Ministry of Interior of the Czech Republic and to the City Council of the Capital of Prague.

4. Example of abuse of Traffic line Underground Structures (Prague Subway) for spreading of Poisonous Agents

The Prague subway is a major traffic junction with a high concentration of persons and it may be a place potentially endangered

concentrations were also measured at the exhaust shaft and in the trains. The spreading results were processed but they are subject to special confidentiality regulations.

Apart from results of the experiments the report also contains a description of systems in the Prague subway (e.g. method of ventilation, station dimensions, types of trains, passenger turnover, time intervals of passenger movement etc.) and a list of factors affecting the real effects of the poisonous agent:

- spatial layout of the station,
- passability of exits from the stations,
- intensity and direction of flows in the station,
- intensity and direction of air intake from ventilation shafts,
- type of subway trains,
- operating schedule of subway trains,
- quantity of spread poisonous agent,
- toxicity of the poisonous agent,

- method of spreading (evaporation - aerosol, pressure - explosion),
- location from which the poisonous agent is spread,
- chemical and physical properties of the poisonous agent,
- adsorption and condensation of the poisonous agent on construction lining materials in the station (marble, eloxal coated aluminum),
- adsorption of the poisonous agent on clothes and hair of passengers and reverse desorption,
- chemical stability of the poisonous agent,
- temperature, pressure, air humidity inside and outside the station,
- concentration (density, turnover) of passengers in the station premises,
- demographic distribution of passengers in the station premises,
- physical parameters of passengers (body weight, height) in the station premises,
- psychological parameters of passengers - ability to respond to the event,
- mob frenzy - suggestion, panic,
- time of problem identification in the station,
- professional approach by the station dispatcher and Integrated Rescue System elements,
- response time to call help and hand over of qualified information (identification of the poisonous agent),
- relative delay of evacuation, decontamination, medical first aid for the afflicted passengers.

Each factor was analyzed and discussed. In some cases the analysis was supported with our own experiments, e.g. for adsorption and desorption of the poisonous agent on the subway station lining we measured the actual evaporation speed of sarin, depending on the air flow speed, we measured adsorption on different types of clothes etc.

References

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5. Conclusion

Without the use of underground premises it is impossible to address some transport and infrastructural needs in many urban agglomerations.

However, the underground structures shall be resistant to negative effects of the natural environment, they are influenced by the operation, they represent a weak point for technology failure, sabotage or terrorist attack.

We determined risks to which the underground structures are exposed, selected threats and identified internal and external initiation events.

The purpose of the performed experiment on the Old Town Square model in the aerodynamic tunnel was to demonstrate the importance of physical modeling in urban agglomerations. The results obtained from this exposed location may contribute to better orientation of rescue service elements in case of an extraordinary event.

The "in-situ" experiments in the junction station of the Prague subway were very demanding in terms of organization. The spreading of the substituent of poisonous agent proved to be dramatically different with passing trains in the station and without the trains. One of the findings critical for safety was that if the trains are stopped from passing the deeper station premises will not be endangered by contamination (release of agent in the upper station).