

Transportation safety in an urban condition

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Abstract. This study explores the problem of cars entry in to subway stations. Cars been driven in to subway stations in many countries including France, Russia, Belarus, Belgium, Italy, etc. Sometimes this results in fatalities or injuries and stoppage of work at the station. In this article, we have systematized statistics on cases of cars entry in to subway stations around the world and suggest a resolution for this problem. The proposed in the study of an anti-ram protective bollard capable of blocking cars driving into stations could serve as such a resolution. Then we develop an method that of determined the optimal location of anti-ram protective bollards. The authors tested the developed methodology on the example of the Prospect Mira station (Kaluzhsko-Rizhskaya line) of the Moscow subway. Equipping territories around subway stations with the developed an bollards will resolve the problem of protecting subway stations against cars entering their territories and will protect people.

1 Introduction

The authors explored the problem of cars entry in to the entrances of subway stations. Investigation showed that such accidents have taken place in different countries of the world including France, Russia, Belarus, Belgium, Italy, etc.

The bus that drove into the entrance of subway station “Slavyansky Boulevard” in Moscow (Russian Federation, 2017) (Fig. 1, 2) caused five death, cars that drove into subway stations “Profsoyuznaya” in Moscow (Russian Federation, 2016) and Chaussee d'Antin La Fayette in Paris (France, 2007) caused the stoppage of work subway stations. The cars that drove into the subway stations “Auch” in Paris (France, 2004) and “Leo Tolstoy Square” in Kiev (Ukraine, 2004) caused wounded people.

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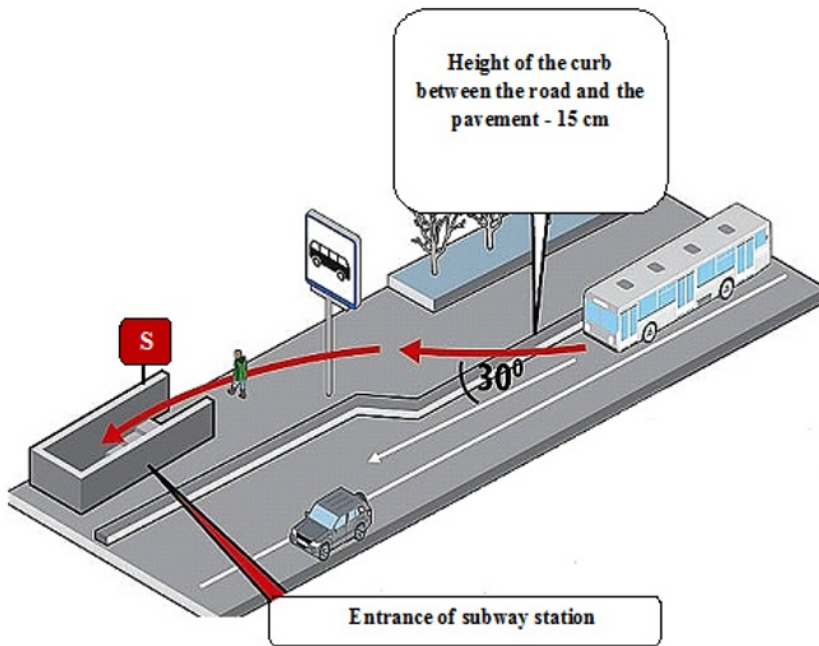


Fig. 1. Scheme entry bus in to the entrance of subway station “Slavyansky Boulevard” (Moscow, 2017), Source: <https://gala-gala15.livejournal.com/478288.html>



Fig. 2. The bus that drove into the entrance of subway station “Slavyansky Boulevard” in Moscow (Russian Federation, 2017), Source: <https://www.dailymail.co.uk/news/article-5211397/At-four-people-killed-bus-Moscow.html>

Statistics on the incidents of cars entry in the subway stations have been systematized in Table 1.

Table 1. Incidents of cars entry in the subway stations.

Year	Subway system	Subway station	Car
2003	Paris	“Balard”	Passenger car
2004	Kiev	“Leo Tolstoy Square”	Passenger car
2004	Paris	“Auch”	Passenger car
2011	Minsk	“Mogilevskaya”	Truck
2012	Paris	“Chaussee d'Antin La Fayette”	Off-road car
2012	Baku	“Gyandzhlik”	Off-road car
2013	Moscow	“Voikivskaya”	Motorbike
2016	Rome	“Magliana”	Passenger car
2016	Brussels	“Clemanso”	Passenger car
2016	Moscow	“Profsoyuznaya”	Passenger car
2017	Moscow	“Slavyansky Boulevard”	Bus

The statistics (Table 1) show that the problem of protecting subway stations against penetration by cars does exist. A cars that drives into a subway station can traumatize or kill people who are at that moment inside the station or can cause a fire at the station in consequence of the explosion of fuel in the car’s tank.

The studies show that free access to subway stations poses a threat to terrorist attacks with use of cars [1-16].

2 Prevent of cars entry in the subway stations

The problem of protecting subway stations can be resolved by an anti-ram protective bollard (ARPB) which will ensure efficient protection against driving into subway stations of the following cars:

1. passenger cars including jeeps
2. off-road cars;
3. bus;
4. trucks;
5. motorbikes.

This device should be located in areas of possible entrance and blocks cars from penetration into the territory around the station by retractable obstructive posts. A general view of the anti-ram protective device is shown in Figure 3.

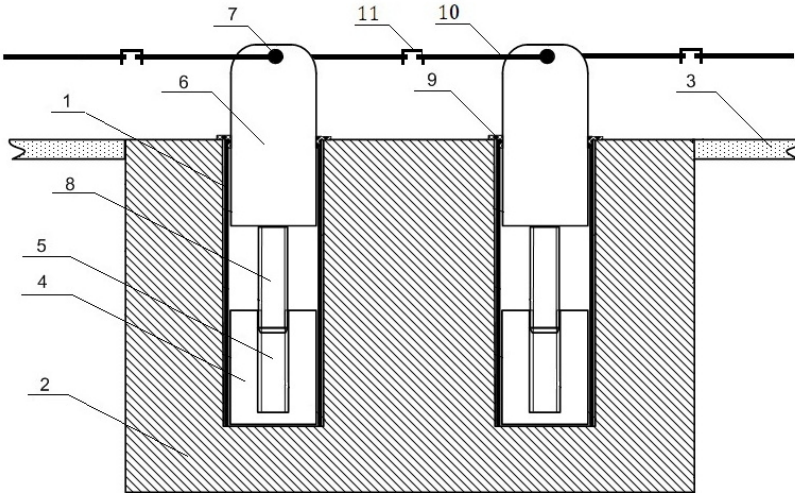


Fig. 3. Two ARPB installed in a joint foundation.

ARPB consists of the following elements: the casing *1*, mounted on a concrete foundation *2* (the concrete foundation is leveled with the asphaltic-concrete pavement *3*); a blocking element consisting of a cylindrical foundation *4*, with a screw hole *5* in its central and barrage post *6* with a mounting hole *7* in its upper part and a screw element *8* in its lower part; a rubber tightening ring *9*; an additional blocking element *10*; and a connection element *11*.

ARPB is of increased resistance against ramming due to the bi-layer casing of the barrage post: the external layer is made of high-strength steel.

ARPB has the function of raising and lowering the barrage post (Figure 4).

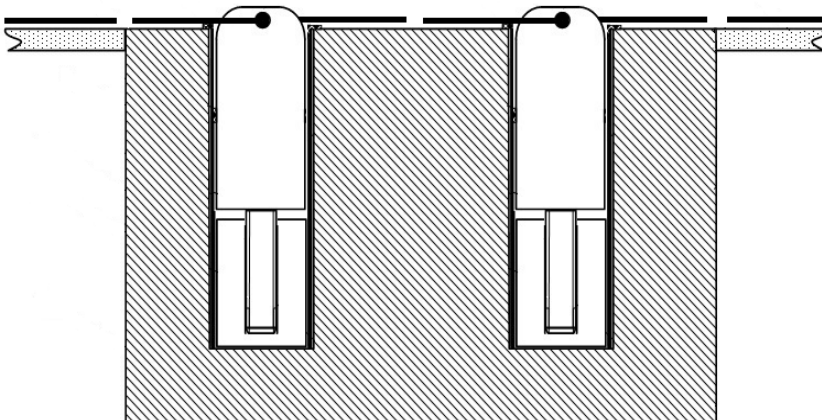


Fig. 4. ARPBs with lowered protective bollards.

ARPB specifics:

- ARPB has the function of lowering and raising of the protective bollard;
- ARPB has a mechanical activator for moving the bollard which is independent of any External Systems. The bollard is lowered by twisting into the steel base. The twisting-insertion is performed through the physical effort of a human being revolving it clockwise with the additional protective element (10 in Fig. 3) which serves as a lever. The bollard has a screw element in its lower part; this element fits into the hole in the case of the

foundation. This hole has a thread for twisting the screw element in to lower the bollard; when rotated in reverse (unscrewed), the bollard raises;

- the structure of ARPB is maximally simplified and allows anyone without special training to lower bollards in 1-1.5 min. which ensures Emergency Services cars thoroughfare when they arrive;

- ARPB the diameter of the bollard is 375 mm;

- ARPB has the special shape of a bollard rounded in its upper part and has no sharp corners or projecting parts.

ARBP meets all the specific features of subway systems and therefore it can be applied to protect subway stations against cars driving into the entrances of stations.

3 Method of Location Anti-ram Protective Bollards at Subway Stations

The use of a methodology for choosing the location of ARPBs at subway stations is a prerequisite for ensuring effective protection of subway stations. This condition can be justified by the fact that almost all subway stations are built according to individual projects and, as a rule, are located in conditions of dense urban development. On the pedestrian paths adjacent to the stations, a large number of pedestrians moves. On adjacent roads there is a dense stream of transport. The situation becomes especially serious at peak times. Placing ARPBs in such conditions without scientifically grounded guidelines creates risks that the protection of stations will not be sufficiently effective. The optimal location of the ARPB should be determined specifically for each station based on the use of the method of placement of ARPBs developed by the author and described below.

Placement of anti-ram barriers on the territory adjacent to the subway station can be divided into two stages:

- Stage 1 - the choice of location;

- Stage 2 - determination of the density of placement of ARPBs.

3.1 Stage 1 - Choosing a location

One of the conceptual issues affecting the performance of ARPB when blocking the intrusion of an intruder using a motor car is the correct choice of the location of ARPBs on the territory adjacent to the subway station.

The reasons for the need to correctly calculate the location of ARPB:

- efficiency of application - the correct placement will ensure guaranteed blocking of the passage of cars;

- the cost of equipping the facility ARPB - proper placement will avoid the additional costs associated with the installation of unnecessary protective devices.

The territory near the subway station, on which the passage of cars must be blocked, is a pedestrian zone adjacent to the entrance to the subway station, since it is the entrance to the station and the congestion of people entering / leaving the station.

The boundaries of the pedestrian zone adjacent to the entrance to the subway station must be determined individually for each station - they are defined as the boundaries of the territory at the entrance to the subway station, where people gather in / out of the subway station during rush hours.

For example, according to statistics, rush hours in the Moscow subway are: 8.00-9.00 in the morning and 18.00-19.00 in the evening, while the maximum traffic is observed on days of the week on Thursday and Friday [17].

If it is technically possible for cars to enter a pedestrian zone not only from the side of the roadway, but, for example, along a sidewalk or other non-carriageway territory, the boundary of these territories and the pedestrian zone adjacent to the station entrance is also equipped with ARPB.

3.2 Stage 2 - determination of the density of placement of ARPB

To prevent small cars from driving between ARPB installed near subway stations, we need to correctly calculate the spacing between ARPB. Firstly, we need to calculate the maximum distance apart for the arrangement of ARPB.

To calculate the maximum permissible distance between ARPBs that will ensure guaranteed blocking of the passage of small cars we need to know the minimum dimension parameters of existing cars. For this purpose we have analyzed standard cars with minimum dimension parameters (Table 2).

Table 2. Cars parameters.

<i>Cars</i>	<i>Length, mm</i>	<i>Width, mm</i>	<i>Height, mm</i>
Mercedes SMART ForTwo	2700	1560	1540
Suzuki Twin	2735	1475	1450
Fiat Seicento	3319	1508	1440
Citroen C1	3430	1630	1460
Toyota iQ	2985	1680	1500
Aston Martin Cygnet	3078	1680	1500
Autobianchi Transformabile	2985	1340	1320

Following the analysis we have obtained data on the minimal width of a car which is 1340 mm. In order to resolve the problem of guaranteed blocking of cars we must introduce the reliability index (constricting the maximum distance between ARPB), which is adopted as 10 % of the established minimal width of a car. This is determined by a theoretical probability of driving cars into a station that either have not been considered during our research or are non-standard, i.e. those with less width.

The maximum distance between the ARPBs R_{max} is calculated according to the formula

$$R_{max} = X_{vh} - (X_{vh} \cdot X_{br}) - X_{pp}, \tag{1}$$

where X_{vh} is the width of the car, mm;

X_{br} is the car blocking reliability index;

X_{pp} is the diameter of the protective post, mm.

I.e., if $X_{vh} = 1340$ mm (data from Table 2), X_{br} is 10 % of X_{vh} , $X_{pp} = 375$ mm, so $R_{max} = 831.0$ mm.

The density of spacing anti-ram bollards R_{pl} is determined by the formula

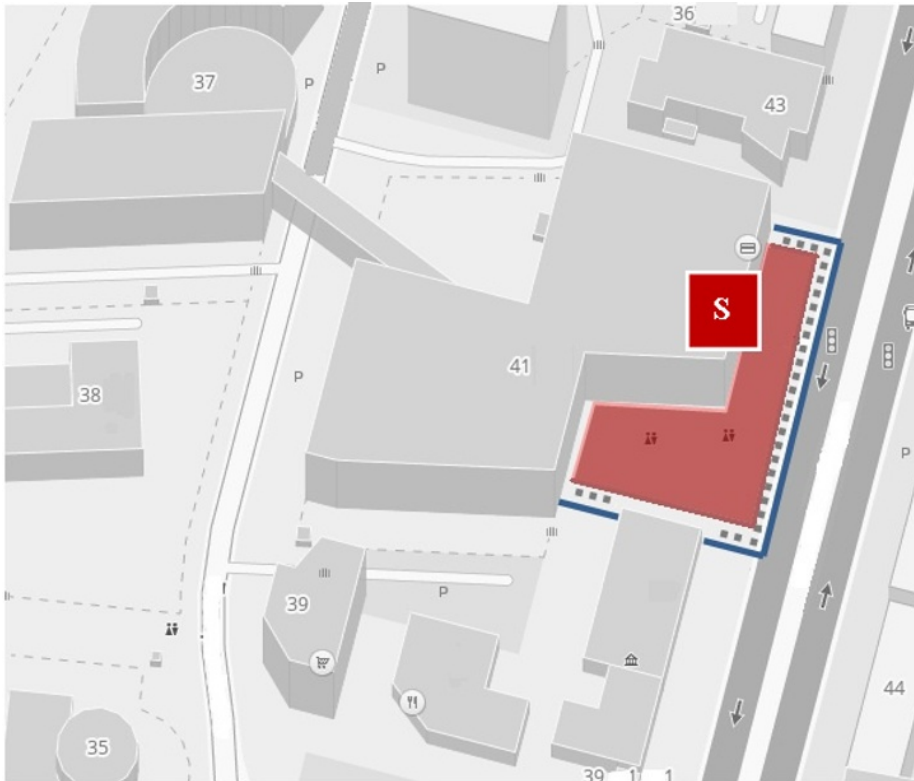
$$R_{pl} = R_{max} + X_{pp}. \tag{2}$$

Thus, if $R_{max} = 831.0$ mm, $X_{pp} = 375$ mm, the spacing density of ARPBs calculated according to formula (2) is one device per 1206.0 mm.

The author tested the developed methodology on the example of the Prospect Mira station (Kaluzhsko-Rizhskaya line) of the Moscow subway.

The boundaries of the pedestrian zone adjacent to the entrance to the subway station and the possible entry points of cars to the pedestrian zone, including along the pedestrian paths, were determined. Taking into account the factors affecting the choice of location of anti-

ram barriers, the ARPB placement line was determined, which allows you to completely block unauthorized entry of cars to the pedestrian zone adjacent to the station entrance and at the same time spend the minimum amount of ARPB. The resulting layout of ARPB is shown in Figure 5.



Key:





-  - Entrance of subway station "Prospect Mira";
-  - Pedestrian zone adjacent to the station entrance;
-  - Line placement ARPB;
-  - Possible places of entry of cars to the pedestrian zone adjacent to the entrance to the station.

Fig. 5. Location of ARPBs on the territory near the station "Prospect Mira" ("Kaluzhsko-Rizhskaya" line of the Moscow Subway) *Source:* © of Map: 2GIS

4 Conclusions

The research we conducted ascertained the existence of the problem of protecting against of cars entry in to the entrances of subway stations. This can become the reason for stoppage of work and, what is much worse, can kill people who are present at that moment in the station. The drove of a bus into the entrance of subway station "Slavyansky Boulevard" in

Moscow (Russian Federation, 2017) which caused five death and interrupted the work of the station can serve as an illustration.

We proposed a anti-ram protective bollard and developed a method for placing it at subway stations. Equipping subway stations with such devices will resolve the problem of protecting against of cars entry in to the entrances of subway stations.

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