Locating Grate Inlets to Ensure Effective Drainage of Streets in the Process of Designing Streets and Grading Plans in Bulgaria

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Abstract

This study analyses the existing requirements and standards for determining the locations of grate inlets on streets in Bulgaria. Effective drainage in street design is essential for managing stormwater runoff and preventing urban areas from flooding during heavy rains. To choose optimal locations of grate inlets plays a crucial role in this process. Solving this task is related with designing street slopes in grading plans and designing sewer systems. This article presents an approach, based on successful practices used in the USA and Australia, by proposing a hydraulic based procedure for locating grate inlets in the design process. The technique is adopted to all Bulgarian requirements and standards. As a main criterion it is suggested to use the maximum allowable water spread on the pavement of the traffic lanes. The proposed method considers various factors, such as longitudinal and cross slope, size of grate inlet, design frequency period, intercepted and bypass flow. It starts with determination of the grate inlet locations on continuous grade, then incorporates the specific sag points in vertical curves and intersections. It can be used in the process of designing streets and their grading plans to optimize the drainage efficiency of streets in Bulgaria. It is hydraulic reasoned, very flexible, and easy to apply for different street sections with different features. Implementing this approach can solve the problem of unclarity in locating grate inlets in Bulgaria. Also, the presented procedure could be used as a base to fill gaps in the existing Bulgarian regulations and manuals, related to the drainage of streets in urban areas.

Keywords: grate inlets, effective drainage of streets, designing streets, grading plans, bulgaria

Introduction

The drainage of streets in urban areas is related with placing grate inlets that collect the rain surface water and leads it to the sewer system. In Bulgaria, due to the climate conditions, heavy and intense rainfall events are common, leading to frequent flooding of the street's areas. This situation is a problem for the traffic safety, the strength of the pavement and has a negative impact to the urban areas.

The problem is a consequence of placing grate inlets and their maintenance. There is a lack of legally established principles and methods for determining the locations of grate inlets and no specific criterion in place. Although there are some general requirements, there are no instructions for their implementation. As a result, this leads to ineffective drainage, or in other ways placing more inlets than needed, which is an unnecessary investment.

The design process of streets starts with preparing longitudinal profiles and grading plans in the stage of detailed development plans. The locations of the inlets depend first on the hydraulic parameters and then on the value of the longitudinal slope. For the same hydraulic parameters, a street section with a gentle slope will require significantly smaller distances between the inlets and a greater number of inlets compared to a street section with a steeper longitudinal slope. To select the best locations of the grate inlets in Bulgaria this article presents a common procedure for hydraulic reasoned determination of grate inlet locations, to ensure the effective drainage of streets, which is one of the primary goals of grading plans [1].

Existing requirements and hydraulic calculations in Bulgaria

In Bulgarian professional literature as standards and regulations, student books and manuals, there are several requirements for placing grate inlets. These requirements are based on several factors, including [2, 3, 4]:

- the type and size of the grate inlet;
- the surface slope;
- the street cross slope;
- the characteristics of the street pavement;
- the rainfall intensity;
- considering lowest points, determined by the grading plan;
- according to the locations of pedestrian walkways, subways and public transport stops;
- at street intersections to ensure the drainage of surface water before the pedestrian walkways.

However, there are only general requirements without specific guidelines for their implementation. There are two equations for obtaining distances between inlets $\mathbf{S_p}$ (Equation 1) and their required number $\mathbf{n_{in}}$ (Equation 2) [5, 6, 7].

$$S_p = \frac{1000 q_{in}}{\varphi q \frac{B}{2}} \quad (1)$$

$$n_{in} = \frac{Q}{q_{in}} = \frac{q \varphi A}{q_{in}} \quad (2)$$

where:
q_{in} – inlet flow capacity,
φ - runoff coefficient,
B – street width (including the sidewalk),
q - rainfall intensity,
A – drainage area in ha.

Although, those equations do not consider very important parameters. In these calculations it is assumed that the inlets will operate at their full capacity, which is almost not possible. Furthermore, the results obtained by both equations are going to be identical for streets with different longitudinal and cross slopes, which is not correct, because of the flow velocity.

Successful practices from abroad

In foreign countries (as USA, Great Britain, Australia, and others [8, 9, 10, 11]) they calculate the peak flow **Q** using Rational method (Equation 3). Then they determine the flow in the gutter section **Q'**, which is a modification of Manning`s equation for flow rate in open channels (Equation 4). The modification is needed because the depth of the flow is very shallow and wide. Calculations consider the longitudinal $\mathbf{S_L}$ and cross slope $\mathbf{S_X}$ of the street and also the intercepted $\mathbf{Q_i}$ (Equation 5) and bypass flow $\mathbf{Q_b}$ (Equation 6). For each inlet its efficiency **E** is determined (Equation 7) and, in most cases, it is below 100%.

$$Q = \frac{i \varphi A}{360} \quad (3)$$

$$Q' = \frac{0,376}{n} S_X^{1,67} S_L^{0,5} T^{2,67} \quad (4)$$

$$Q_i = EQ \quad (5)$$

$$Q_b = Q - Q_i \quad (6)$$

$$E = \frac{Q_i}{Q} \quad (7)$$

The main criterion in these calculations is the width of the water spread on the traffic lane **T** which has specific maximum allowable values (Fig. 1). It is calculated by Equation 8, or alternatively, it could be also replaced with the depth of the flow at the curb **d** (Equation 9).

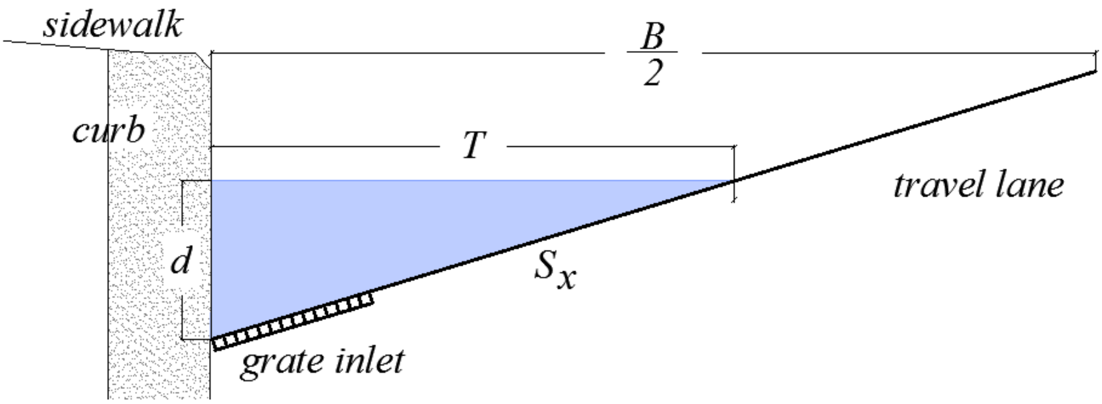

Fig. 1. Maximum Allowable Water Spread.

$$T = \left(\frac{Qn}{0,376 S_X^{1,67} S_L^{0,5}} \right)^{0,375} \quad (8)$$

$$d = T S_X \quad (9)$$

where:
n - Manning's coefficient.

Common Procedure for Locating Grate Inlets on Streets

Based on this research, a common procedure for locating grate inlets on streets has been developed. It is adopted to all Bulgarian requirements and standards. It is hydraulic reasoned, considers the longitudinal and cross slope and it is based on the criterion of maximum allowable water spread. It is very useful for designing grading plans of new streets in urban areas, as well as in street reconstruction projects, with existing pavements and buildings, where the street slopes constantly change, in order to connect the existing structures in elevation.

Advance planning stage

Before beginning with the calculations, there are preliminary steps that involve advance planning. These steps require the selection of design values for various parameters relevant to the calculations and preparing some initial materials.

Design value selection for the participating parameters

1. Design frequency period

Firstly, the value of the design frequency period **P** is determined by referring to the Table 1 extracted from the Bulgarian regulation [3].

Tab. 1. Design frequency period values.

№	Type of urban area	Design Frequency P, year.
1.	Storm sewer	0,5
2.	Cities up to 10 000 population	1 - 2
Cities over 10 000 population		
3.	Residential areas	2 - 3
4.	Industrial areas	1 - 3
5.	Combined central areas, areas for public services in urban areas	2 - 5
6.	Underground road facilities and sag points	10

Based on the determined design frequency period, the corresponding rain intensity is selected from Table 2 [3]. It is important to note that these values can be replaced with more actual and accurate data for the rain intensity in Bulgaria [12].

Tab. 2. Rain intensity values.

P [years]	1	2	3	4	5	10	20	25	50	100
Zone 1 [mm/h]	92	114	128	137	145	167	190	197	220	243
Zone 2 [mm/h]	81	101	113	121	127	148	168	174	194	214

2. Runoff coefficient and Manning's coefficient

Subsequently, the runoff coefficient **φ** and the Manning's coefficient **n** are selected based on the type of pavement. In Table 3 are the values, related with different surface type that are used in Bulgaria [3] and in Table 4 are the values of the Manning's coefficient [9, 10].

Tab. 3. Runoff coefficient values.

№	Surface type	φ
1.	Roofs - all kinds	0,90 - 0,95
2.	Solid pavements - asphalt, paving without gaps, sidewalks	0,85 - 0,90
3.	Paving with gaps	0,50 - 0,70
4.	Cobblestones	0,35 - 0,50
5.	Gravel surfaces	0,30 – 0,40
6.	Yards without pavement, station, warehouse and sport facilities	0,15 – 0,30
7.	Lawns, parks and gardens, including paths in them	0,10 – 0,20
8.	Cultivated lands	0,10

Tab. 4. Manning's coefficient values.

Pavement	n	Type of Pavement	n
Concrete – average condition	0,013	Concrete pavement	0,014 - 0,016
Concrete – poor condition	0,016		
Asphalt – average condition	0,017	Asphalt pavement - smooth texture	0,013
Asphalt – poor condition	0,021	Asphalt pavement - rough texture	0,016

Determining the main criterion

One of the crucial steps that follows is the selection of the primary criterion, which is the maximum allowable water spread. An adoption of the limited values of the maximum allowable water spread has been made based to the Bulgarian street classification (Table 5), following an analysis of various options used internationally.

Tab. 5. Maximum Allowable Water Spread.

Classification	Street functional type	V [km/h]	Maximum Allowable Water Spread T [m]
I class	High speed urban highways	80	1 m or shoulder
II class	Urban highways	60/70	1 m
III class	Regional roads	50	1,5 m
IV class	Main streets	50	1,5 m
V A class	Collection streets	30	1,5 m
VI class	Service streets	30	1,5 m
	Service streets - type shared	20	1,5 m
Intersections, bus stops			0,50 m

Certainly, taking into account the potential existence of exceptions or specific factors, different values may be suggested if necessary.

Determination of the width of the drainage area

This step involves determination of the width of the drainage area **W_e** (Fig. 2) which usually includes half of the street width and the width of the adjacent sidewalk. In case of narrow streets, we can have one side cross slope. In such situations the with will include the whole street width and the width of both adjacent sidewalks.

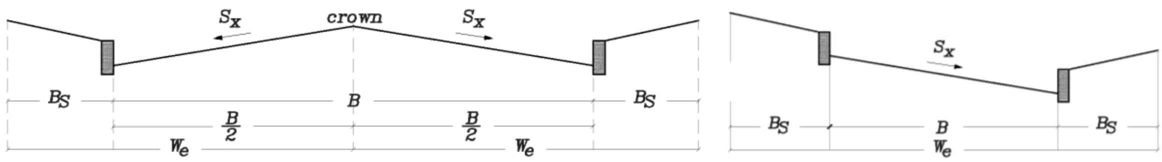

Fig. 2. Determination of the width of the drainage area for streets with two side or one side cross slope.

Then, it is necessary to gather all the initial materials and data, including longitudinal sections, drawings, and other relevant information. Next step involves selecting the type and size of the inlets, considering the various available options. Subsequently, a required grate inlets are placed at specific locations, such as:

- before pedestrian walkways;
- before and after bridges;
- before public transport stops.

Calculating stage

Afterward, we can proceed with the calculation part, where there are three main steps (Fig. 3).

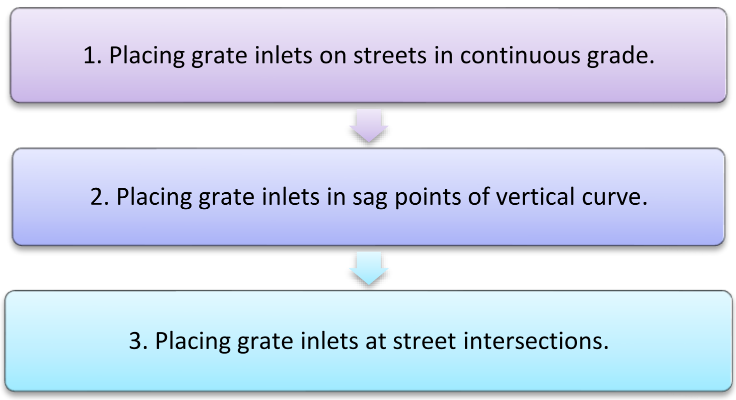

Fig. 3. Calculating stage – main steps.

Placing grate inlets on streets in continuous grade

The initial step includes successively determination of distances between inlets, starting from the crest and continuing down the grade. The calculations for each street are independent of one another, so the order is not significant. Firstly, the distance **S_{p1}** for the first inlet from the crest is determined, followed by calculating the subsequent distances **S_p** down the grade (Fig. 4).

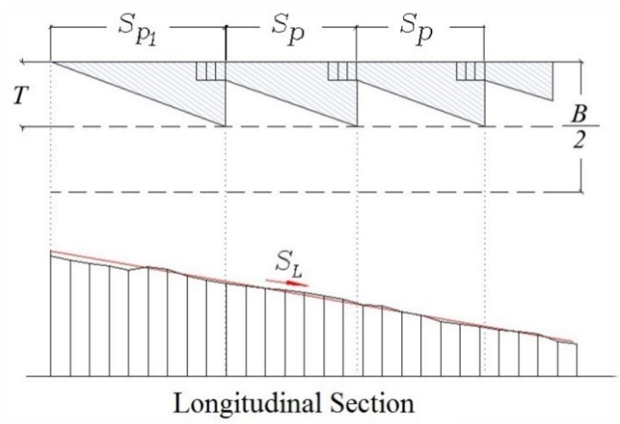

Fig. 4. Distances between grate inlets on continuous grade.

These distances remain equal, until a specific parameter in the calculation changes. These calculations are performed according to the accepted value of the main criterion **T**. The distances are calculated using Equation 10 and 11, which have been converted to SI units from the corresponding equations used in the USA and proposed in imperial units [8].

$$S^1{}_p = 3593700 \frac{Q^1}{\varphi i W_e} \tag{10}$$

$$S^n{}_p = 3593700 \frac{\left(Q^n - Q^{n-1}{}_b\right)}{\varphi i W_e} \tag{11}$$

where:
Q^1 – flow in the gutter section for the first inlet (Equation 4),

Q^n – flow in the gutter section for the current inlet (Equation 4),

$Q_b{}^{n-1}$ – bypass flow for the previous inlet (Equation 6).

All calculations can be filled in a calculation sheet [9], where all the red values represent the given parameters, which were chosen in the advance planning stage (Fig. 5). The calculations for each longitudinal section are made in different stages, as shown on Fig. 6, starting always from the crest and going down the grade.

street name				
from		km		
to		km	P=	5
right			T=	1
left			n=	0.016

№	km.	S_p /m/	W_e /m/	φ	t /min/	i /mm/h/	Q /m³/s/	S_L	S_x	d /m/	W /m/	T /m/	W/T	L /m/	E_0	V /m/s/	Rf	Rs	Q_i /m³/s/	Q_b /m³/s/	E %	№
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	0	23.65																				
inlet 1	24	20.62	9	0.9	5	114	0.0061	0.015	0.025	0.03	0.5	1	0.5	0.5	0.84	0.49	1	0.18	0.0053	0.0008	87	inlet 1
inlet 2	44	20.62	9	0.9	5	114	0.0061	0.015	0.025	0.03	0.5	1	0.5	0.5	0.84	0.49	1	0.18	0.0053	0.0008	87	inlet 2
inlet 3	65	20.62	9	0.9	5	114	0.0061	0.015	0.025	0.03	0.5	1	0.5	0.5	0.84	0.49	1	0.18	0.0053	0.0008	87	inlet 3

Fig. 5. Calculation sheet.

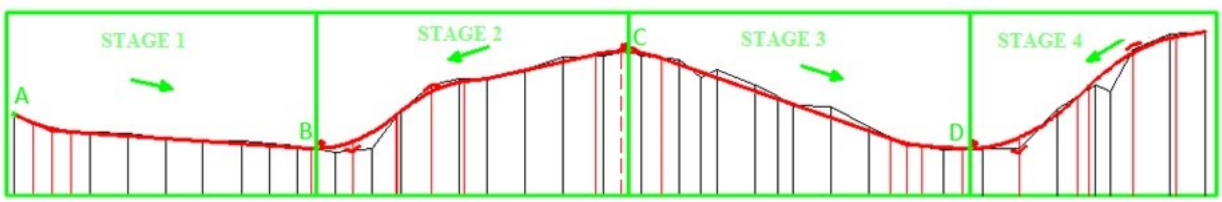

Fig. 6. Different longitudinal sections.

Placing grate inlets in sag points of vertical curve

Following that, it is necessary to place inlets in all low points within the sag vertical curves. Here, specific additional requirements must be fulfilled to ensure effective drainage, which is very troubled in these places. All calculations must be performed with a minimum design frequency period of 10 years, according to the Bulgarian standards. However, considering global trends, examples, and climate change, it is recommended to consider larger values to guarantee a satisfactory performance. At the lowest point of the sag curve, an obligatory inlet, known as the low point inlet, is required, along with two flanking inlets to support its functionality (Fig. 7) [9].

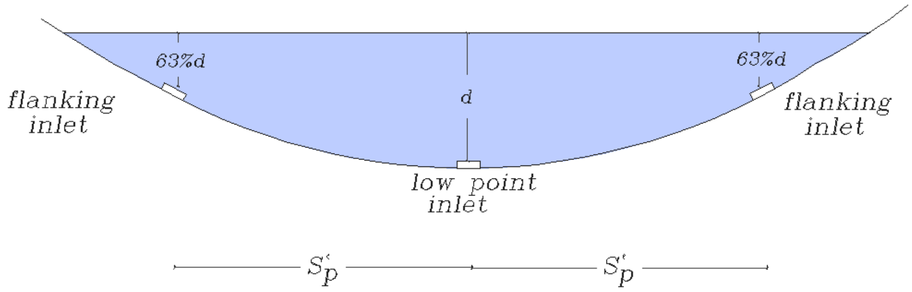

Fig. 7. Low point inlet and flanking inlets at sag vertical curve.

They are placed at a distance from the lowest point **Sp`** (Equation 12), determined based on the type of the curve and the criterion of the maximum allowable spread (Equation 13 and 14).

$$S_p^{'}\left(200K\left(d_{low}-d_{fl}\right)\right)^{0,5} \tag{12}$$

$$d_{fl}=0,63\%d_{low} \tag{13}$$

$$K=\frac{L^{curve}}{S_L^2-S_L^1} \tag{14}$$

where:
d_{fl} – the depth of the flow at the curb for the flanking inlet,
d_{low} – the depth of the flow at the curb at the lowest point,
L^{curve} – length of the vertical curve,
S_L^1 and S_L^2 – longitudinal slopes before and after the vertical curve.

Depending on the length of the vertical curve, additional grate inlets may need to be placed before reaching the inlets located in the continuous grade section, if the water spread width exceeds the allowable limit set by the criterion (Fig. 8). All calculations are made considering longitudinal slope changes in the curve section (Equation 15).

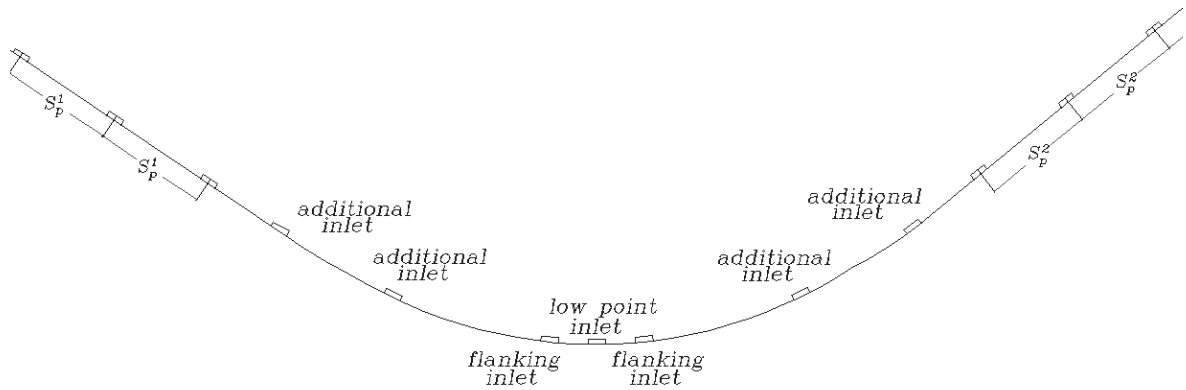

Fig. 8. Additional inlets at sag vertical curve.

$$S_L^{curve}=\frac{x}{R^{curve}} \tag{15}$$

where:
x – distance from the lowest point,
R_{curve} – the radios of the vertical curve.

Grate inlets in sag places have a high potential of clogging, so it is recommended to consider a clogging factor, because the presence of debris and trash can significantly reduce the capture capacity of the inlet [13, 14].

Placing grate inlets at street intersections

Intersections are places where separate streets with their stormwater runoff meet and pedestrian, bicycle and automobile traffic take place simultaneously. To ensure a secure and convenient passage, it is necessary to implement special measures for their drainage. This includes accounting the total gutter flow for each street and reducing the maximum allowable water spread, because of the intensive traffic. The grate inlet locations are chosen providing the criterion for maximum allowable water spread of 0,50 m, also considering the locations of the pedestrian walkways and the changes of cross slopes at the intersection according to the grading plan [15].

The type and placement of the pedestrian walkways hold significant importance – if they are on the street pavement, are there reduced curd heights or they are organized as a speed hump. Also, there are intersections that are designed as a plateau or raised intersection at the height of the adjacent sidewalks [16, 17]. In those cases, the free drainage of surface water in the traffic lane becomes impossible, when the longitudinal slope of the street is falling towards the raised part (Fig. 9). These places are specific in terms of drainage and the rainwater must necessarily be directed to grate inlets located in suitable places.

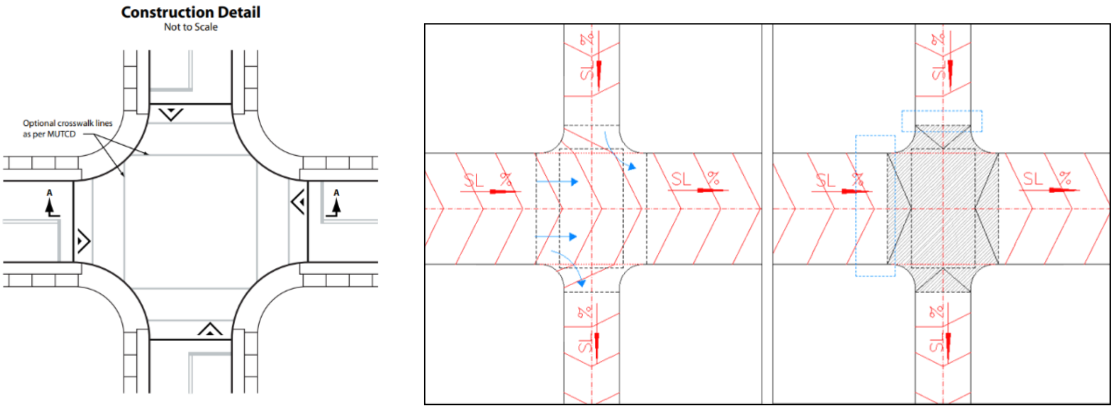

Fig. 9. Plateau or raised intersection.

Taking into consideration all factors and elements, the places of the grate inlets are determined according to the maximum allowable water spread, avoiding risk of ponding the pedestrian walkways or flooding adjacent sidewalks.

General requirements and recommendations

Additionally, there are some general requirements that help to assure the effective drainage:

- minimum inlet efficiency - 60%;
- for streets with a steep longitudinal slope (more than 8%) it is recommended to use a slotted drain inlet along the entire width of the street,
- for low point inlet and the flanking inlets in sag vertical curve, a clogging factor of at least 50% should be provided.

Conclusion

The primary objective of this study is to establish a common procedure for hydraulic reasoned determination of grate inlet locations on streets. It provides a main criterion of the maximum allowable water spread on the traffic lane and considers both the longitudinal and cross slope of the street. The approach includes determination of the grate inlet locations on continuous grade, in sag points of vertical curves and at street intersections. The procedure is very flexible and easy to apply to different street sections with different features. It can be used in designing grading plans of streets in Bulgaria and serve as a base to fill gaps in the existing Bulgarian regulations and manuals, related to the drainage of streets in urban areas. By achieving this goal, the study contributes to one of the key objectives of grading plans - effective and reliable drainage of the areas.

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