Experimental campaign about flow transfer between surcharged pipe flow and street level. Discharge coefficient of a sewer grated inlet

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Experimental campaign about flow transfer between surcharged pipe flow and street level. Discharge coefficient of a sewer grated inlet

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Pressure pipe flow conditions appear in sewer systems when flow exceeds the hydraulic capacity of the conduit, causing that some outflow can be produced. In these cases, water exits through manhole and inlets producing surface flooding. Some authors estimate the flow leaving the sewer assuming orifice flow conditions although it requires the use of proper values of the discharge coefficient in order to obtain realistic results. In this paper, an experimental approach to calculate discharge coefficients through an inlet for surcharged pipe conditions is presented. Tests were carried out using a real laboratory platform simulating a road lane. Different surcharged flows through the inlet from 10 to 50 l/s were considered. The range of the obtained discharge coefficient has been between 0.13 and 0.41 for surcharged flow from 10 l/s to 50 l/s. Sensitivity analysis demonstrated that discharge coefficients can be considered constant for any street longitudinal slope.

Keywords: grated inlets; pressure flow; discharge coefficient; full-scale experiments

1. Introduction

Urban floods impacts have been the object of interest of many researchers in last decades (Hammond *et al*., 2018). Moreover, the continuous increase of imperviousness and the potential effects of climate change could exacerbate flooding problems in a short and mid-term horizon (Velasco *et al.*, 2018). During many years, the focus of the pluvial flooding in urban areas was basically oriented in the sewer network performance, assuming that all the runoff produced is introduced to the sewer. Traditionally drainage manuals imposed a security level of the sewer system based on specified return periods associated with the rain event used in the design (Artina *et al*., 2001), while no criteria were used to limit overland flow on the city surfaces during heavy storm events. The first references about manuals and procedures to limit street runoff can be found in USA (DCG, 1969; CCRFCD, 1999; CDOH, 2000) and United Kingdom (BS 6367, 1983; Butler and David, 2004). The behaviour in a city during a rain event is a combination of

the performance of the underground sewer network and the street network, and one of the key points is the flow transfer between surface level and underground level. The proper way to analyse the behaviour of the full drainage system is to consider the join effect of the sewer network (minor system) and the surface level (mayor system) and, consequently, the join effect between surface and overland flow.

The minor system provides a basic level of service by conveying runoff produced by the common (low rainfall intensity) rain events up to storms with a return period equal to the one adopted for the design of the sewer network. So, the major system has to transport the runoff from the more extreme rain events (higher intensity and design return period) that are in excess of what the minor system can deal with.

In the 70's, the city of Denver, Colorado, proposed the first design manual for this city (DCG, 1969), offering the first criteria that describe the connection between major and minor systems. Moreover, in 80's, the so called dual drainage approach, known as DDSWMM (Dual Drainage Storm Water Management Model) was included in many drainage codes of several cities of Canada (Environment Canada and Ontario Ministry of the Environment, 1976).

Notwithstanding these first experiences focused on real implementation of the dual drainage concept, the computational capacity of the computer codes made quite difficult complex 1D/2D simulations in urban areas (Wisner and Kassem, 1982). For this reason, 1D sewer models, assuming that all the runoff enters into the minor system were widely used in the following years (Smith, 2006). 1D models, simple to build up and with less complicated theory were well accepted as common engineering practice and supported by a wide range of software packages. In the 90's Djordjević *et al.* (1991) showed that the flows in the storm sewers are dependent on the excess volumes that are allowed to

flow along the street network or if they are stored in a fictitious sub-basin above the surcharged manhole. Djordjević *et al.* (1999) identified some weak points of the existing models because they provide a "coarse surface descriptions" and a "lack of interaction between surface and underground flow components".

Nasello and Tucciarelli (2005) suggested this approach called Dual Urban Drainage Model as the best to describe what really happens in a city during rain events. The current approach is to consider a 1D model for the sewer network and a 2D model for the street flow networks (Russo *et al.*, 2015) and can be used to analyse the urban flood problems in the sewer networks but, above all, the estimation of surface flood impacts like economic damages (Velasco *et al.*, 2015), and business interruptions.

More recently, Chen *et al.*, (2016) analysed the flow transfers through the manholes neglecting the presence of the cover, although, before the manhole cover is moved during flooding produced by sewer surcharges, overflow occurs through the inlets existing in the urban area. Chang *et al.* 2018 compared numerical simulations of urban flooding considering grated inlets and neglecting them and demonstrated that the effect of inclusion of inlets in dual drainage modelling improves the accuracy of flood modelling. As stated, the definitions of "major system" and "minor system" are referred, respectively, to the surface layer (streets and surface areas) and the ground level below (sewer network). For a reliable modelling a proper representation of the flow transferring between the surface and underground layer is essential. The surface flow must be intercepted by the inlets and introduced in the sewer system. Recent references about inlet efficiency can be found in the technical literature. In most cases, laboratory campaigns have been developed to test the hydraulic efficiency of grated inlets. For instance, tests were developed in United Kingdom, where Highways Agency (HA) commissioned HR Wallingford (HR) in association with the Transport Research Laboratory (TRL) to carry

out a study on the hydraulic performance of gully grating used to collect surface water runoff from roads (May and Todd, 1997). Another scheme of facilities was developed to perform the British Standard in the University of Birmingham (Russam, 1969) and, more recently, the last physical model was done in the laboratory of the University of Sheffield (Djordjević *et al.*, 2013). In Spain, in the hydraulic laboratory of the Technical University of Catalonia, a real scale platform was designed, built and used to test hydraulic efficiency of the most common grates used in Barcelona (Russo, 2010; Gómez and Russo *et al.*, 2011; Russo *et al.*, 2013).

Also in South Korea (Ku and Jun, 2009), and in the United States of America (specifically in the Colorado State University, Urban Drainage and Flood Control District (UDFCD) and Colorado Department of Transportation) other experimental facilities for testing hydraulic capacity of grated inlets were performed (Comport and Thornton, 2012). Another physical model to investigate the hydraulics of intake structures like grate inlets was developed in the University of Wuppertal in Germany by Kemper and Schlenkhoff (2015). In all of these cases, models objective was to estimated how much water can be intercepted by several types of grated inlets and the water that continues downstream.

Some authors have considered the hydraulics of this kind of process similar to an orifice or a weir process (Rubinato *et al.*, 2017). This approach has the advantage that both are included in most of the commercial software available in the market for urban drainage modelling, making easier the application of this concept. If orifice option is adopted in the expression describing its hydraulics, the parameter to estimate the hydraulic of the orifice is the area of the holes, the energy immediately upstream the inlet and a discharge coefficient, different for every type of inlet, and also different for any hydraulic conditions.

Area of the holes is known for every considered inlet and the available energy "*h*" is a function of the flow along the street, depending, essentially, on rainfall and street geometry, while discharge coefficient C_d must be estimated by the user. Unfortunately, inlet providers and manufactures do not provide this information. Some companies like Neenah foundry give a set of abacus to assess the flow captured by the inlets depending on street and curb geometry, but not in the form of a specific discharge coefficient. In the last website version, Neenah foundry suggests to use a discharge coefficient equal to 0.6 (NFCO, 2018), thus it was used as a typical value for orifice coefficient in a tank outlet. So in case of estimating inlet captured flow, discharge coefficient must be estimated. In many cases, practitioners use similar values for inlets discharge coefficients proposed for orifices without considering that their discharge coefficient values depend on geometry and circulating flow. But it is not clear that this value could be used to reflect what really happens in the inlet. Some studies developed in last years (Cárdenas-Quinteros *et al.*, 2017) have shown that discharge coefficients are far from the 0.6 value and, especially for supercritical flow conditions with high Froude numbers, C_d could be close to 0.1 or 0.2 for the flow entrance from the street to the sewer.

All these studies have been considered the entrance of water into the sewer, and not the opposite situation when the sewer is surcharged and flow exits from the sewer reaching the street level.

In the literature, it is possible to highlight studies about surcharged manholes that are located in the centre of the street while the grated inlets are generally located in the lateral curbs. Martins *et al*. 2014 and Lopes *et. al*. 2015 studied the surcharge of a gully box through experimental and numerical analysis. In a more recent experimental and numerical study carried out by Beg *et al*. (2017; 2018) in the Sheffield University, the effects on the surface of surcharge flow on sewer manholes were analysed. In the same

University, Rubinato *et al*. (2018a and 2018b) studied the flow leaving the sewer through manholes, assuming the cover has been removed by the outflow and estimated discharge coefficient considering orifice and weir approaches.

Moreover, concerning lateral grated inlets, Bazin *et al.* (2014) modelled a flow exchange between a street and drainage pipe in comparison with the experimental results obtained in the Ujigawa Open Laboratory in Tokyo, Japan. Finally, the effect of surcharged flow in urban areas was studied by Lee *et al.* (2015) and Bermudez *et al.* (2018).

In this work, an experimental study where an outflow is produced through a grated inlet, reproducing the effect of pressurized sewer for different flows leaving the sewer and different geometric configurations of the platform (different longitudinal slopes). The experiments considered just one grated inlet but the methodology can be extended to any type of inlet.

2. Methodology

2.1 Experimental setup

An existing platform reproducing a street lane in the Flumen laboratory at the Technical University of Catalonia (Barcelona) has been used for this experimental campaign. This platform (Figure 1) was used for previous studies to determine inlets efficiency and their captured flow (Gómez *et al.*, 2005; Gómez *et al.*, 2009; Russo *et al.*, 2013). The platform is 5.5 m long and 3 m wide and longitudinal and transverse slopes can be modified until a maximum of 10% for longitudinal slope and 4% for the transverse slope. The inlet considered for the tests of the study presented in this paper is the so called Barcelona1, the most common grated inlet in Barcelona (Figure 2 and Table 1). Tests were done in real scale to avoid scale effects.

[Figure 1. The platform used in the tests].

[Figure 2. Grated inlet tested, Barcelona1].

Table 1. The geometry of the grate.

Grate	Length (m)	Width (m)	Area of holes (m^2)
Barcelona1	0.74	0.26	0.0852

The platform was modified in such a way the sewer pressurized flow through the inlet and an outflow leaving the conduit through the grate could be correctly reproduced. The exit flows through the grate were from 10 to 50 l/s. The exit flowrate was measured by an electromagnetic flowmeter installed in the tube before the inlet box with an error of 0.5 l/s. Pressurized flow reached the grated inlet through a 200 mm circular pipe. An inlet box of 90 x 30 cm and 50 cm height is located below the grate inlet (Figure 3). The exit flowrate was limited to 50 l/s because after this value the water level exceed the curb of the platform and pressured flow started to generate structural problems in the platform facilities. Water level over the grate inlet was measured manually, with a limnimeter of 1 mm of accuracy. 20 points over the grate were considered for the flow depth measurements and an average value of the 20 measures was considered as representative one (Figure 4). No significant difference among different measurements for each specific geometric and flow condition has been appreciated for this value.

The criterion to select the location of the points of measure of water level over the grate was basically to cover the whole of the grate in order to visualize the effect of slopes in the surcharge flow.

[Figure 3. Inlet box below the grate].

[Figure 4. Location of water level measurements over the grate].

In the figure 5 a scheme of the laboratory installation is shown. In all the tests no flow on

the surface layer was assumed, so the only exchange is from the sewer to the surface street lane represented by the platform. Tests were done in steady flow conditions in all cases (the system needed around 15 min to reach the steady flow conditions). The transverse slope was constant and equal to 2% for the different tests, as required in most of the local urban guidelines for pavement design (Bulletin Official of State No. 55, 2016).

[Figure 5. Scheme of the laboratory installation].

3. Flow description and results

If it is assumed that outflow is described considering an orifice type, outflow Q through the grate can be expressed, assuming that the surface velocity is negligible, as:

$$Q = C_d A_h (2gh_{grate})^{1/2} \qquad (1)$$

where A_h is the area of holes in the grate, h_{grate} is the water level above the grate, difference of the pressure height at the sewer and the atmospheric pressure height over the grate, and C_d is the discharge coefficient including all the effects of energy losses through the grate, effect of approaching velocity, etc. Figure 6 shows the outflow through the grated inlet produced by surcharged pipe conditions. On the same Figure 6 it is possible to observe the differences of water levels over the grate during the tests. Moreover, some oscillations of several millimetres (10 mm as maximum) were observed during the tests, so water level measure takes the average value with time of the water depths.

[Figure 6. Outflow between 10 and 50 l/s for a geometric configuration of the platform with 2% of longitudinal and transverse slopes].

Imposing the outflows, for 10. 20, 30, 40 and 50 l/s, the values in Table 2 as average value of water level over the inlet were obtained, for the case of 0% of longitudinal slope and

2% of transverse slope.

Table 2. Average water level above the inlet grate.

Flow (l/s)	H_{grate} (mm)
10	39
20	56
30	74
40	92
50	105

In all the cases, the grated inlet is covered by water, even with the lowest flow. Reynolds values of the experiments range from 63662 to 318310, (lower value for 10 l/s and greater value for 50 l/s) estimated in the pipe. From the water levels over the grate, it was possible to calculate the following discharge coefficient from the equation 1 (Table 3).

Table 3. Discharge coefficient for the Barcelona grated inlet (transverse slope 2%).

Flow (l/s)	C_d Long. Slope (0%)	C_d Long. Slope (2%)	C_d Long. Slope (4%)	C_d Long. Slope (6%)	C_d Long. Slope (8%)	C_d Long. Slope (10%)
10	0.13	0.14	0.14	0.14	0.15	0.15
20	0.22	0.22	0.22	0.22	0.23	0.23
30	0.29	0.29	0.29	0.29	0.29	0.29
40	0.35	0.35	0.35	0.36	0.36	0.36
50	0.41	0.41	0.41	0.41	0.40	0.40

[Figure 7. Discharge coefficient evolution with the outflow through the grate and related error bars due to flow and flow depth measurements].

So it is possible to observe those discharge coefficients are not the same as used for other

orifice types of flow. Figure 7 shows an evolution with the flow of the discharge coefficients, with an increasing value with the outflow, multiplying for more than 3 the minimum discharge coefficients. For the minimum flow tested, 10 l/s, value of 0.13 was found, while for the maximum flow, 50 l/s, a discharge coefficient of 0.41 was obtained.

As said, these results were obtained with 0% longitudinal slope and 2% of transverse slope and the absence of flow approaching the inlet. In order to carry out a sensitivity analysis regarding longitudinal slope, the same tests were repeated fixing transverse slope to 2% and modifying longitudinal slopes. Specifically, the values of 2, 4, 6, 8 and 10% were tested. In all cases, the same approach was used, considering an average value of the water level over the grate and measuring the water level in 20 points. In this case, for some combinations of flow and slope, especially for high slopes, not all the grate was covered by water, and the outflow was associated to a smaller area. Nevertheless, for those values with no water level above grate, 0 value was considered and they were included too in the average value. Results are presented in the Figure 8 with error bars, considering the error due to the flow measurement (as stated 0.5 l/s) plus the error due to the water level measurement.

[Figure 8. Discharge coefficient variation with longitudinal slope].

It is possible to observe that the influence of the longitudinal slope is quite limited, so there is not a serious error to consider constant values. So for any grate inlet, it is possible to define the discharge coefficients and they are approximately constant for any longitudinal slope.

4. Conclusions

An experimental study representing the outflow from surcharged sewer systems through

grated inlets is presented. Full scale 1:1 tests have been carried out for different discharges as outflows from the underground sewer. The discharge coefficient calculated using the orifice expression shows an evident variation with the outflow discharge. Values of this coefficients can increase more than three times depending on the outflow discharge.

Values of the discharge coefficients of grate are not similar to the orifice discharge coefficients used in other cases. So application in case of dual drainage analysis must take into account the real values and not the imported values from other situations.

The flow transfers between the major and minor drainage systems and viceversa become one of the key elements for a good quality of the results. Computer codes available now in the market allow this dual drainage modelling, so, in case of this approach, the accuracy of the results rely on the good estimation of these flow transferring and the right choice of discharge coefficients, in case an orifice type approach, is used to describe the flows through the grate. Moreover, commercial software allows the orifice type to describe the flow transfer between sewer and surface. Grate inlet manufacturers could provide for every grate the specific discharge coefficients so the application to consider dual drainage can be done in a very easy way.

Results of the experimental campaign show a range of values of discharge between 0.13 to 0.41 for a flowrate surcharge between 10 to 50 l/s. Furthermore, is important that the values of C_d estimated were approximately constant for each outflow through the tested grated inlet, whereby the effect of transversal and longitudinal slopes has very poor influence. Tests considered the absence of surface flow approaching the grated inlet. Further analysis could be carried out to analyse the influence of the presence of runoff on the discharge coefficients values of the grate.

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Figure 1. Platform used in the tests

80x88mm (300 x 300 DPI)

Figure 2. Inlet tested, Barcelona1

52x22mm (300 x 300 DPI)

Figure 3. Inlet box below the grate

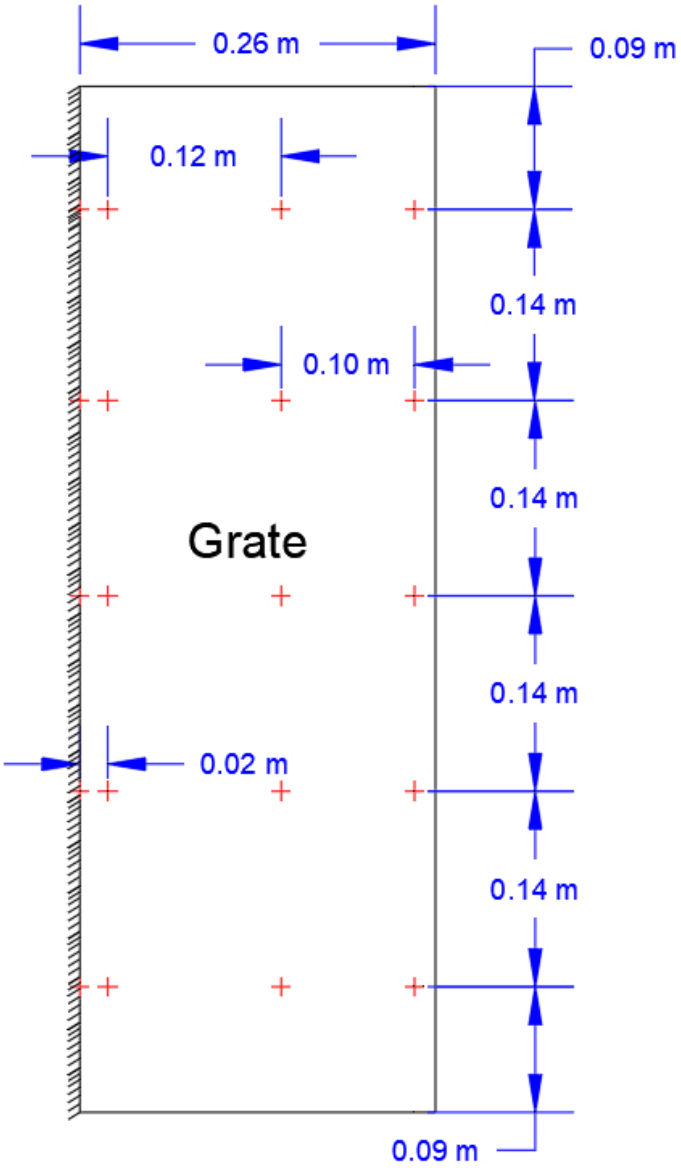

Figure 4. Location of water level measurements over the grate

118x197mm (96 x 96 DPI)

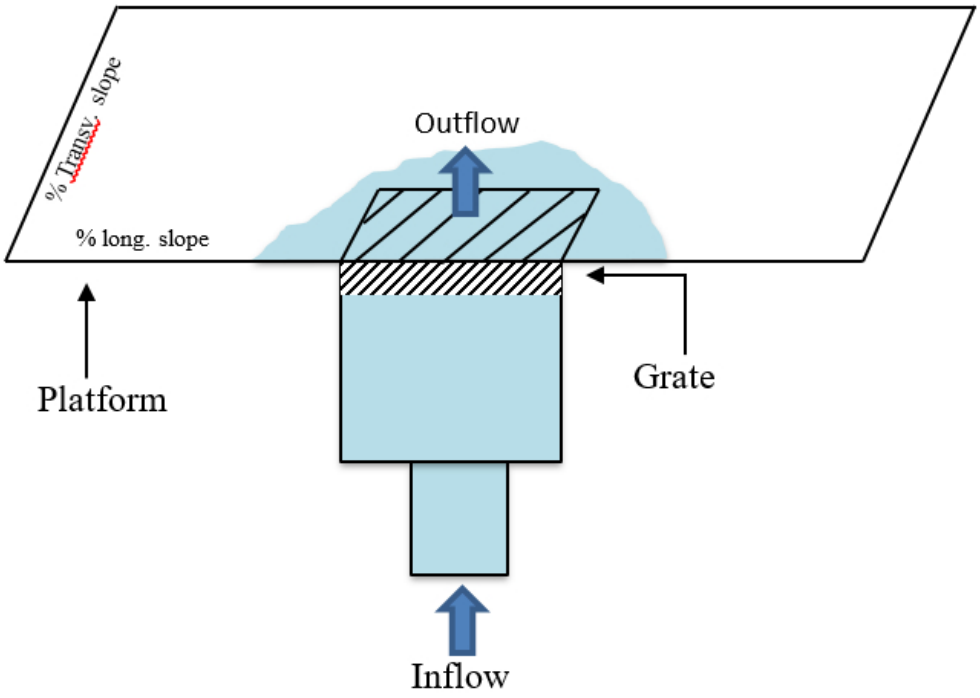

Figure 5. Scheme of the laboratory installation

172x125mm (96 x 96 DPI)

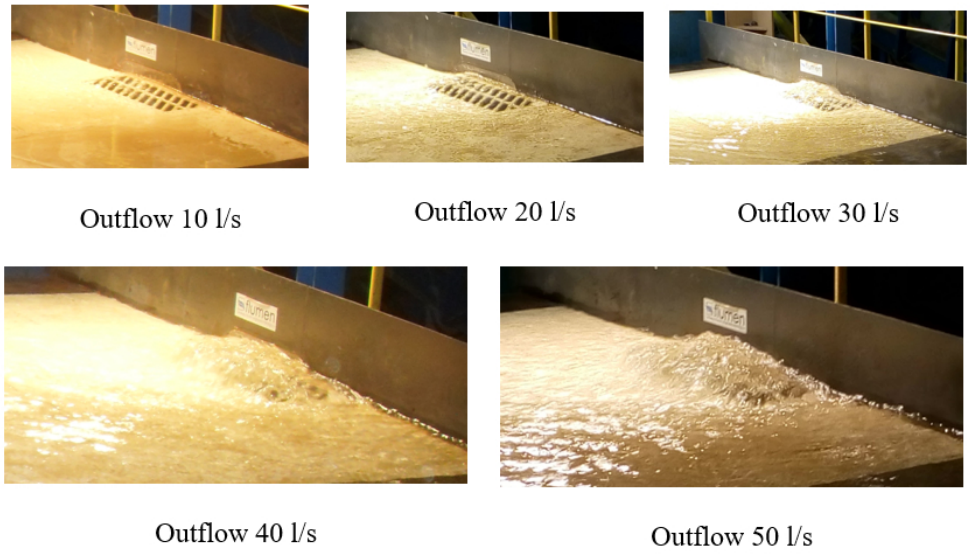

Figure 6. Outflow between 10 and 50 l/s for a geometric configuration of the platform with 2% of longitudinal and transverse slopes

226x128mm (96 x 96 DPI)

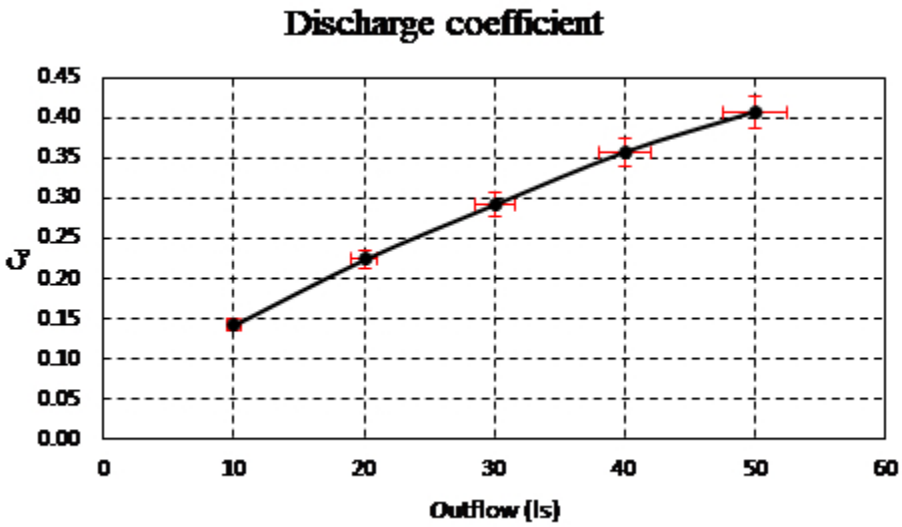

Figure 7. Discharge coefficient evolution with the outflow through the grate and related error bars due to flow and flow depth measurements

127x76mm (96 x 96 DPI)

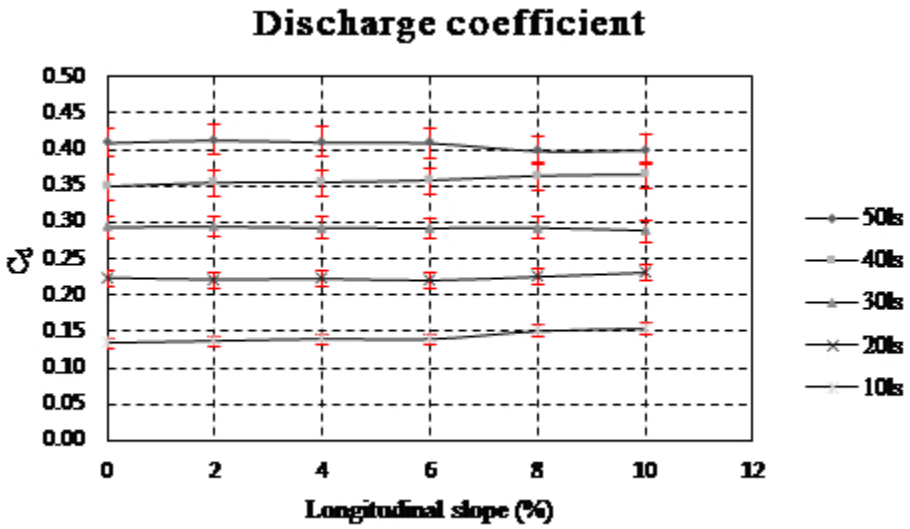

Figure 8. Discharge coefficient variation with longitudinal slope

127x76mm (96 x 96 DPI)

Response to Reviewer(s)' Comments

The authors thank the editor and the reviewers for their positive recommendations and for inviting them to re-submit a revised manuscript, in which they have addressed all the technical issues raised during the revision. In the following text, the authors provide answers to the presented reviews, while quoting and referencing the changes that have been implemented in re-submitted manuscript.

Reviewer(s)' Comments to Author:

Reviewer: 1

Comments to the Author
ABSTRACT
With this sentence "but no references about the proper values of the discharge coefficient to be used are found in the literature" within the abstract, authors either demonstrate that a proper research on previous studies on a similar field has not been conducted, despite also the support of previous literature review suggested with a list of existing papers during revision 1, or wrote the abstract without considering the references they have listed in the introduction of the paper. Values of discharge coefficients are available in literature. The abstract is still unclear and fragmented and some parts should be re-written to be less confusing.

The abstract has been completely re-written and the sentence about the use of proper values of inlet discharge coefficient has been modified.

INTRODUCTION
There are still a lot of sentences not correctly written in English that are very difficult to understand.

The whole manuscript has been checked and several improvements have been provided. Concerning the specific suggestions, they were addressed as following.

i) "Nothing was related to the effects on the city surface."
The sentence was re-written and linked to the previous one:
"Some drainage manuals imposed a security level of the sewer system based on specified return periods associated with the rain event used in the design, while no criteria were used to limit overland flow on the surfaces of our cities during heavy storm events".

ii) "Moreover, in 80's this approach, the so called dual drainage approach, known as DDSWMM (Dual Drainage Storm Water Management Model) was included in many drainage codes for instance in several cities of Canada (Environment Canada, 1976), but, at that time, Wisner and Kassem (1982) suggested that the computer codes existing were not enough good for dual drainage as the codes assumed that all the runoff enters into the minor system (Smith, 2006)."……. too long.
The text has been re-written:
Notwithstanding these first experiences focused on real implementation of the dual drainage concept, the computational capacity of the computer codes made quite difficult complex 1D/2D simulations in urban areas (Wisner and Kassem, 1982). For this reason, 1D sewer models, assuming that all the runoff enters into the minor system were widely used in the following years (Smith, 2006). 1D models, simple to build

up and with less complicated theory were well accepted as common engineering practice and supported by a wide range of software packages.

iii) "More recently, Chen et al., (2016) analyzed the flow transfers assuming that the flow goes through the manhole and that, assuming the cover has been displaced, but this is produced just in case the cover is not in place".

The text has been re-written:

More recently, Chen et al., (2016) analysed the flow transfers through the manholes neglecting the presence of the cover, although, before the manhole cover is moved during flooding produced by sewer surcharges, overflow occurs through the inlets existing in the urban area.

iv) "compared flooding numerical simulation of local flooding"….
v) "The authors demonstrated could drainage approach improves the accuracy in flood modelling"……

The sentences have been re-written as following:

More recently, Chen et al., (2016) analysed the flow transfers through the manholes neglecting the presence of the cover, although, before the manhole cover is moved during flooding produced by sewer surcharges, overflow occurs through the inlets existing in the urban area. Chang et al. 2018 compared numerical simulations of urban flooding considering grated inlets and neglecting them and demonstrated that the effect of inclusion of inlets in dual drainage modelling improves the accuracy of flood modelling.

vi) "to guarantee the exit flowrate was with an electromagnetic flowmeter"….
vii) "Outflow is measured using an electromagnetic flow meter"… it repeats what should be the sentence vii

This part of the manuscript has been re-written as following avoiding repetitions:

The exit flows through the grate were from 10 to 50 l/s. The exit flowrate was measured by an electromagnetic flowmeter installed in the tube before the inlet box with an error of 0.5 l/s. Pressurized flow reached the grated inlet through a 200 mm circular pipe. An inlet box of 90 x 30 cm and 50 cm height is located below the grate inlet (Figure 3). The exit flowrate was limited to 50 l/s because after this value the water level exceed the curb of the platform and pressured flow started to generate structural problems in the platform facilities.

Literature is very vague at the beginning.

The sentences have been modified and specific references have been provided.

For example:

i) "Urban floods have been the object of interest of many researchers in last decades."….. which researchers? Any specific reference?

The sentence has been modified and a specific reference about the state of the art concerning flooding impacts has been added as following:

Urban floods impacts have been the object of interest of many researchers in last decades (Hammond et al., 2018).

ii) "Some drainage manual imposed a security level based on specified return periods associated with the rain event used in the design."…… which manual? Are you referring to? Any specific reference?

The sentences have been modified and some reference about the state of the art concerning flooding impacts have been added as following:

Traditionally drainage manuals imposed a security level of the sewer system based on specified return periods associated with the rain event used in the design (Artina et al., 2001), while no criteria were used to limit overland flow on the city surfaces during heavy storm events. The first references about manuals and procedures to limit street runoff can be found in USA (DCG, 1969; FCD, 1999; CDOH, 2000) and United Kingdom (BS 6367, 1983; Butler and David, 2004). The behaviour in a city during a rain event is a combination of the performance of the underground sewer network and the street network, and one of the key points is the flow transfer between surface level and underground level.

After the first two paragraphs, the literature review includes many details and a consistent description of previous works, which is full of facts. Nevertheless, it is not properly written and does not follow a specific scheme or a clear structure.
For example, towards the end of the introduction, the authors refer to the fact that previous studies generally locate the manhole in the centre of the street referring to existing studies that are correct (Martins et al. 2014, Lopes et al. 2015, Beg et al. (2017, 2018), and Rubinato et al. (2018a, 2018b)). However, at the same time, they also include Bazin's study, that modelled gullies on the side of the street, and this is in contradiction with the context mentioned.
The literature review has been restructured and the references have been reordered as following:
In the literature, it is possible to highlight studies about surcharged manholes that are located in the centre of the street while the grated inlets are generally located in the lateral curbs. Martins et al. 2014 and Lopes et. al. 2015 studied the surcharge of a gully box through experimental and numerical analysis. In a more recent experimental and numerical study carried out by Beg et al. (2017; 2018) in the Sheffield University, the effects on the surface of surcharge flow on sewer manholes were analysed. In the same University, Rubinato et al. (2018a and 2018b) studied the flow leaving the sewer through manholes, assuming the cover has been removed by the outflow and estimated discharge coefficient considering orifice and weir approaches.
Moreover, concerning lateral grated inlets, Bazin et al. (2014) modelled a flow exchange between a street and drainage pipe in comparison with the experimental results obtained in the Ujigawa Open Laboratory in Tokyo, Japan. Finally, the effect of surcharged flow in urban areas was studied by Lee et al. (2015) and Bermudez et al. (2018).
In this work, an experimental study where an outflow is produced through a grated inlet, reproducing the effect of pressurized sewer for different flows leaving the sewer and different geometric configurations of the platform (different longitudinal slopes). The experiments considered just one grated inlet but the methodology can be extended to any type of inlet.

METHODOLOGY

In Review 1 one of the comments was: "There is no discussion about the uncertainty, repeatability, reproducibility, justness and trueness of the measurements. Only the accuracy is stated".

In Revision 2 the authors have addressed the uncertainty, justness and trueness of the measurements but not the repeatability, reproducibility. How many times each test was repeated? How were the hydraulic parameters varying by replicating the same conditions multiple times? None of this is mentioned in the methodology.

For each geometric configuration and each pressurized flow, flow depths were measured once steady flow conditions were reached. Flow depths in 20 points were measured manually and a mean flow depth was estimated with no significant differences among different measurements for each specific geometric and flow conditions. The following sentence has been introduced:

No significant difference among different measurements for each specific geometric and flow condition has been appreciated for this value.

In all the tests no flow on the surface layer was assumed, so the only exchange is from the sewer to the surface street lane represented by the platform.

Yes you are right. Flow interchanges from street flow to sewer flow have been treated by the authors in other works.

Authors mentioned that the water level over the grate was measured manually, with a limn meter of 0.1 mm accuracy but later on, in section 3, they also mention that oscillations of several millimetres (10 mm as maximum) were observed. Considering that the flow escaping the manhole in these conditions is highly unsteady (Figure 6) and this measurement has to be taken manually, how can they confirm the accuracy of 0.1 mm for each instant and then completing an average? Furthermore, if the accuracy is 0.1 mm, why are the measurements of H in Table 2 including two decimal values???

The gage used for the flow depth measurements has an accuracy of 1 mm (the text has been corrected), although oscillations in some flow conditions reached the height of 10 mm. For this reason, average values of the mean water level measured during a short interval in 20 locations was considered. The two decimals are due to the ratio of the available data. In the current version of the manuscript, it has been decided to avoid the use of decimals for consistence.

RESULTS

Discussion of the results is basically a repetition of what is either presented in Table 3 or displayed in figures 7 and 8.

How do these results compare with existing studies found on similar recent studies? In review 1 there was only one comparison with a paper that was submitted for publication and not published yet (Cosco et al., 2018) but now even that one was deleted.

There is not critical assessment of the results obtained especially mentioning the existing limitations of the study (e.g. additional water level on the street especially under flooding conditions or unsteady conditions typical of heavy rainfall events causing flooding).

The authors have been deleted the reference Cosco et al., (2018) because they are involved in further improvements of this manuscript. Specific statements about the absence of approaching flow on the platform have been added in the section of results and conclusions.

Reviewer: 2

Comments to the Author
The Authors are to be congratulated for the substantial revision of their manuscript. Thank you for having incorporated the changes and the improvements suggested in the preceding round of the revision process. I do believe that the manuscript was greatly improved in terms of readability and scientific soundness. Overall, I found the manuscript to be much improved. I still have few minor comments specially regarding the references.

P4L28: The authors demonstrated could drainage approach improves the accuracy in flood modelling - check English
The full manuscript has been checked improving some sections according to reviewers' suggestions.

P7L1:"Specifically, an experimental campaign was developed in the University of Coimbra developing several comparisons between experimental and numerical simulation results in terms of surcharged flow by manholes (Martins et al. 2014, Lopes et al. 2015, Beg et al. (2017, 2018), and Rubinato et al. (2018a, 2018b)).
"Rubinato et al. (2018a, 2018b) is research done at the University of Sheffield Beg et al. (2018) relates to flow inside a Manhole and is also research done at the University of Sheffield Beg et al. (2017) relates to the surcharge in a gully Martins et al. 2014 studied the drainage inside a gully Lopes et. al. 2015 studied the surcharge of a gully

The final part of the introduction and the bibliography review has been re-written as following:
In the literature, it is possible to highlight studies about surcharged manholes that are located in the centre of the street while the grated inlets are generally located in the lateral curbs. Martins et al. 2014 and Lopes et. al. 2015 studied the surcharge of a gully box through experimental and numerical analysis. In a more recent experimental and numerical study carried out by Beg et al. (2017; 2018) in the Sheffield University, the effects on the surface of surcharge flow on sewer manholes were analysed. In the same University, Rubinato et al. (2018a and 2018b) studied the flow leaving the sewer through manholes, assuming the cover has been removed by the outflow and estimated discharge coefficient considering orifice and weir approaches.
Moreover, concerning lateral grated inlets, Bazin et al. (2014) modelled a flow exchange between a street and drainage pipe in comparison with the experimental results obtained in the Ujigawa Open Laboratory in Tokyo, Japan. Finally, the effect of surcharged flow in urban areas was studied by Lee et al. (2015) and Bermudez et al. (2018).
In this work, an experimental study where an outflow is produced through a grated inlet, reproducing the effect of pressurized sewer for different flows leaving the sewer and different geometric configurations of the platform (different longitudinal slopes). The

experiments considered just one grated inlet but the methodology can be extended to any type of inlet.

Experimental campaign about flow transfer between surcharged pipe flow and street level. Discharge coefficient of a sewer grated inlet

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Experimental campaign about flow transfer between surcharged pipe flow and street level. Discharge coefficient of a sewer grated inlet

Pressure pipe flow conditions appear in sewer systems when flow exceeds the hydraulic capacity of the conduit, causing that some outflow can be ~~is~~ produced. In these cases, w~~W~~ater exits through manhole and ~~the~~ inlets producing surface flooding~~, in case they are directly connected with no flap gate~~. Some authors ~~In this case, the flow~~ estimate the flow leaving the sewer ~~can be simulated~~ assuming orifice flow conditions although it requires the use ~~,~~ of ~~but no references about the~~ proper values of the discharge coefficient in order to obtain realistic results. In this paper, a~~to be used are found in the literature.~~n experimental approach to calculate discharge coefficients through an inlet for surcharged pipe conditions is presented. Tests were carried out using a real laboratory platform simulating a road lane. Different surcharged flows through the inlet from 10 to 50 l/s were considered. The range of the obtained discharge coefficient has been between 0.13 and 0.41 for surcharged flow from 10 l/s to 50 l/s.

~~An experimental approach is presented, where, from real scale tests in a laboratory platform, different flows from 10 to 50 l/s are tested representing the outflow to the streets through one grate. In every test, water levels are measured manually over the grate, and an orifice equation is used to calculate the discharge coefficient. Values show a dependence of the discharge, increasing the value with the outflow. The range of the obtained discharge coefficient is between 0.13 and 0.41 for surcharge flow from 10 l/s to 50 l/s.~~ Sensitivity analysis demonstrated that ~~of the longitudinal slope is presented where no effects are observed, so~~ discharge coefficients can be considered constant for any ~~could be considered constant with the~~ street longitudinal slope.

Keywords: grated inlets; pressure flow; discharge coefficient; full-scale experiments

1. Introduction

Urban floods impacts have been the object of interest of many researchers in last decades (Hammond *et al*., 2018). Moreover, the continuous increase of imperviousness and the potential effects of climate change could exacerbate flooding problems in a short and mid-term horizon (Velasco ~~*et al.*~~*et al.*, 2018). During many years, the focus of the pluvial

flooding in urban areas was basically oriented in the sewer network performance, assuming that all the runoff produced is introduced to the sewer. ~~Some~~ Traditionally drainage manuals imposed a security level of the sewer system based on specified return periods associated with the rain event used in the design (Artina *et al.*, 2001), while no criteria were used to limit overland flow on the city surfaces during heavy storm events. The first references about manuals and procedures to limit street runoff can be found in USA (DCG, 1969; CCRFCD, 1999; CDOH, 2000) and United Kingdom (BS 6367, 1983; Butler and David, 2004)~~. Nothing was related to the effects on the city surface~~. ~~But more and more, people are aware that t~~The behaviour in a city during a rain event is a combination of the performance of the underground sewer network and the street network, and one of the key points is the flow transfer between surface level and underground level. The proper way to ~~analyze~~analyse the behaviour of the full drainage system is to consider the join effect of the sewer network (minor system) and the surface level (mayor system) and, consequently, the join effect between surface and overland flow.

The minor system provides a basic level of service by conveying runoff produced by the common (low rainfall intensity) rain events up to storms with a return period equal to the one adopted for the design of the sewer network. So, the major system has ~~is able~~ to transport the runoff from the more extreme ~~(high intensity and design return period events)~~ rain events (higher intensity and design return period) that are in excess of what the minor system can deal with.

In the 70's, the city of Denver, Colorado, proposed the first design manual for this city (DCG~~enver~~, 1969), offering the first criteria that describe the connection between major and minor systems. Moreover, in 80's, ~~this approach,~~ the so called dual drainage approach, known as DDSWMM (Dual Drainage Storm Water Management Model) was

included in many drainage codes of several ~~for instance in several~~ cities of Canada (Environment Canada and Ontario Ministry of Environment, 1976).~~,~~

Notwithstanding these first experiences focused on real implementation of the dual drainage concept, ~~but, at that time, Wisner and Kassem (1982) suggested that~~ the ~~the~~ computational capacity of the computer codes ~~existing we~~made quite difficult complex 1D/2D simulations in urban areas (~~re not enough good for dual drainage~~ Wisner and Kassem, 1982). For this reason, 1D sewer models, assuming that all the runoff enters into the minor system were widely used in the following years (Smith, 2006). 1D models, simple to build up and with less complicated theory were well accepted as common engineering practice and supported by a wide range of software packages. ~~as the codes assumed that all the runoff enters into the minor system (Smith, 2006).~~ In the 90's Djordjević ~~*et al.*~~*et al.* (1991) showed that the flows in the storm sewers are dependent on the excess volumes that are allowed to flow along the street network or if they are stored in a fictitious sub-basin above the surcharged manhole. Djordjević ~~*et al.*~~*et al.* (1999) identified some weak points of the existing models because they provide a "coarse surface descriptions" and a "lack of interaction between surface and underground flow components".

Nasello and Tucciarelli (2005) suggested this approach called Dual Urban Drainage Model as the best to describe what really happens in a city during rain events. The current approach is to consider a 1D model for the sewer network and a 2D model for the street flow networks (Russo ~~et al.~~*et al.*, 2015) and can be used to analyse the urban flood problems in the sewer networks but, above all, the estimation of surface flood impacts like economic damages (Velasco ~~et al.~~*et al.*, 2015), and business interruptions.

~~-~~More recently, Chen ~~*et al.*~~*et al.*, (2016) ~~analyzed~~analysed the flow transfers ~~assuming~~

~~that the flow goes~~ through the manhole~~s and that,~~ neglecting the presence of ~~assuming~~ the cover ~~has been displaced, but this is produced just in case the cover is not in place~~, although, ~~. B~~before the manhole cover is moved during flooding produced by sewer surcharges, overf~~f~~low occurs~~leaves~~ through the inlets existing in the urban area. ~~Another interesting paper (~~Chang ~~*et al.*~~*et al.* 2018~~)~~ compared ~~flooding~~ numerical simulations of urban~~local~~ flooding ~~of areas with and~~ considering ~~without sewer~~ grated inlets and~~s~~ neglecting them~~gullies~~ and~~. The authors~~ demonstrated that~~could~~ the effect of inclusion of inlets in dual drainage modelling ~~drainage approach~~ improves the accuracy of~~in~~ flood modelling. ~~modelling.~~

As stated, the definitions of "major system" and "minor system" are referred, respectively, to the surface layer (streets and surface areas) and the ground level below (sewer network). For a reliable modelling a proper representation of the flow transferring between the surface and underground layer is essential. The surface flow must be intercepted by the inlets and introduced in the sewer system. Recent references about~~of~~ ~~the~~ inlet efficiency can be found in the technical literature. In most cases, laboratory campaigns have been developed to test the hydraulic efficiency of grated inlets. For instance, tests were developed in United Kingdom, where Highways Agency (HA) commissioned HR Wallingford (HR) in association with the Transport Research Laboratory (TRL) to carry out a study on the hydraulic performance of gully grating used to collect surface water runoff from roads (May and Todd, 1997). Another scheme of facilities was developed to perform the British Standard in the University of Birmingham (Russam, 1969) and, more recently, the last physical model was done in the laboratory of the University of Sheffield (Djordjević ~~*et al.*~~*et al.*, 2013). In Spain, in the hydraulic laboratory of the Technical University of Catalonia, a real scale platform was designed, built and used to test hydraulic efficiency of the most common grates used in Barcelona

(Russo, 2010; Gómez and Russo ~~*et al.*~~*et al.*~~,~~, 2011; Russo ~~*et al.*~~*et al.*, 2013).

Also in South Korea (Ku and Jun, 2009), and in the United States of America (s~~S~~pecifically in the Colorado State University, Urban Drainage and Flood Control District (UDFCD) and Colorado Department of Transportation) other experimental facilities for testing hydraulic capacity of grated inlets were performed (Comport and Thornton, 2012). Another physical model to investigate the hydraulics of intake structures like grate inlets was developed in the University of Wuppertal in Germany by Kemper and Schlenkhoff (2015). In all of these cases, models objective was to estimated how much water can be intercepted by several types of grated inlets and the water that continues downstream.

Some authors have considered the hydraulics of this kind of process similar to an orifice or a weir process (Rubinato ~~*et al*~~*et al.*, 2017). This approach has the advantage that both are included in most of the commercial software available in the market for urban drainage modelling, making easier the application of this concept. If orifice option is adopted in the expression describing ~~the~~ its hydraulics ~~of the orifice~~, the parameter to estimate the hydraulic of the orifice is the area of the holes, the energy immediately upstream the inlet and a discharge coefficient, different for every type of inlet, and also different for any hydraulic conditions.

Area of the holes is known for every ~~inlet~~ considered inlet~~,~~ and the available energy "*h*" is a function of the flow along the street, depending, essentially, on rainfall and street geometry, while discharge coefficient C_d must be estimated by the user. Unfortunately, inlet providers and manufactures do not provide this information. Some companies like Neenah foundry give a set of abacus to assess the flow captured by the inlets depending on street and curb geometry, but not in the form of a specific discharge coefficient. ~~But~~

~~i~~In the last website version~~s~~, Neenah foundry~~they~~ suggests to use a discharge coefficient equal to 0.6 (NFCO~~eenah foundry~~, 2018), thus it was used as a typical value for orifice coefficient in a tank outlet. So in case of estimating inlet captured flow, discharge coefficient must be estimated. In many cases, practitioners use similar values for inlets discharge coefficients proposed for orifices without considering that their discharge coefficient values depend on geometry and circulating flow. But it is not clear that this value could be used to reflect what really happens in the inlet. Some studies developed in last years (Cárdenas-Quinteros ~~*et al.*~~*et al.*, 2017) have shown that discharge coefficients are far from the 0.6 value and, especially for supercritical flow conditions~~,~~ with high Froude numbers, ~~and~~ C_d could be close to 0.1 or 0.2 for the flow entrance from the street to the sewer.

All these studies have been considered the entrance of water into the sewer, and not the opposite situation when the sewer is surcharged and flow exits from the sewer reaching~~into~~ the street level. ~~A recent study focused on the flow leaving the sewer but through manholes, assuming the cover has been removed by the flow (Rubinato *et al.*, 2018a). But before this is produced, flow exit is more usual through inlets.~~

~~In this work, an experimental study where an outflow is produced through the grate inlet is presented, reproducing the effect of pressurized sewer for different flows leaving the sewer and geometries (longitudinal slopes) in the platform. The experiments considered just one grated inlet but the methodology can be extended to any type of inlet.~~

In the literature, it is possible to highlight studies about surcharged manholes that are located in the centre of the street while the grated inlets are generally located in the lateral curbs. Martins *et al.* 2014 and Lopes *et. al.* 2015 studied the surcharge of a gully box through experimental and numerical analysis. –In a more recent experimental and

numerical study carried out by Beg *et al*. (2017; 2018) in the Sheffield University, the effects on the surface of surcharge flow on sewer manholes were analysed. In the same University, Rubinato *et al*. (2018a and 2018b) studied the flow leaving the sewer through manholes, assuming the cover has been removed by the outflow and estimated discharge coefficient considering orifice and weir approaches. ~~Specifically, an experimental campaign was developed in the University of Coimbra developing several comparisons between experimental and numerical simulation results in terms of surcharged flow by manholes (Martins *et al*. 2014, Lopes 2015, Beg (2017, 2018), and Rubinato (2018a, 2018b)).~~

Moreover, concerning lateral grated inlets, Bazin ~~et al.~~*et al.* (2014) modelled a flow exchange between a street and drainage pipe in comparison with the experimental results obtained in the Ujigawa Open Laboratory in Tokyo, Japan. Finally, the effect of surcharged flow in urban areas was studied by Lee *et al.* (2015) and Bermudez *et al.* (2018).

In this work, an experimental study where an outflow is produced through a grated inlet, reproducing the effect of pressurized sewer for different flows leaving the sewer and different geometric configurations of the platform (different longitudinal slopes). The experiments considered just one grated inlet but the methodology can be extended to any type of inlet.

2. Methodology

2.1 Experimental setup

An existing platform reproducing a street lane in the Flumen laboratory at the Technical

University of Catalonia (Barcelona) has been used for this experimental campaign. This platform (Figure 1) was used for previous studies to determine ~~the~~ inlets efficiency and theirits captured flow (Gómez ~~et al.~~*et al.*, 2005; Gómez ~~et al.~~*et al.*, 2009; Russo ~~et al.~~*et al.*, 2013). The platform is 5.5 m long and 3 m wid~~th~~ and longitudinal and transverse slopes can be modified until a maximum of 10% for longitudinal slope and 4% for the transverse slope. The inlet considered for the tests of the study presented in this paper is the so called Barcelona1, the most common grated inlet in Barcelona (Figure 2 and Table 1). Tests were done in real scale to avoid scale effects.

[Figure 1. The platform used in the tests].

[Figure 2. Grated i~~I~~nlet tested, Barcelona1].

Table 1. The geometry of the grate.

Grate	Length (m)	Width (m)	Area of holes (m^2)
Barcelona1	0.74	0.26	0.0852

The platform was modified in such a way the sewer pressurizede flow through the inlet ~~could be reproduced with the aim of representing the pressure flow in the sewer~~ and an outflow leaving the conduit through the grate could be correctly reproduced. The e~~E~~xit flows ~~considered~~ through the grate were from 10 to 50 l/s. ~~To guarantee t~~The exit flowrate was measured by ~~with~~ an electromagnetic flowmeter installed in the tube before the inlet box with an error of 0.5 l/s. Pressurized f~~F~~low ~~arrived~~reached ~~to~~ the grated inlet through a 200 mm circular pipe. An inlet box of 90 x 30 cm and 50 cm height is located below the grate inlet (Figure 34). ~~, where the limitation of T~~the exit flowrate was limited to~~in~~ 50 l/s because after this value ~~flowrate~~ the water level exceed the curb of the platform and ~~our~~ pressured flow ~~installation~~ started to generate structural ~~have~~ problems in the platform facilities ~~of pressure~~. ~~The~~ W~~w~~ater level over the grate inlet was measured manually, with

a limnimeter of ~~0.~~1 mm of accuracy. 20 points over the grate were considered for the flow depth measurements ~~over the grate,~~ and an average value of the 20 measures was considered as representative one (Figure 4). No significant difference among different measurements for each specific geometric and flow condition has been appreciated for this value.

The criterion to select the location of the points of measure of water level over the grate was basically to cover the whole of the grate in order to visualize the effect of slopes in the surcharge flow.

[Figure 34. Inlet box below the grate].

[Figure 43. Location of water level measurements over the grate].

~~Flow arrived to the inlet through a 200 mm circular pipe. An inlet box of 90 x 30 cm and 50 cm height is located below the grate inlet (Figure 4).~~

~~Outflow is measured using an electromagnetic flow meter, with an error of 0.5 l/s.~~

~~[Figure 5. Scheme of the laboratory installation].~~

In the figure 5 a scheme of the laboratory installation is shown. In all the tests no flow on the surface layer was assumed, so the only exchange is from the sewer to the surface street lane represented by the platform. Tests were done in steady flow conditions in all cases ~~,~~ (the system needed around 15 min to reach the steady flow conditions). The transverse slope was constant and equal to 2% for the different tests, as required in most of the local urban guidelines for pavement design (Bulletin Official of State No. 55, 2016).

[Figure 5. Scheme of the laboratory installation].

3. Flow description and results

If it is assumed that outflow is described considering an orifice type, outflow Q through the grate can be expressed, assuming that the surface velocity is negligible, as:

$$Q = C_d A_h (2gh_{grate})^{1/2} \qquad (1)$$

where A_h is the area of holes in the grate, h_{grate} is the water level above the grate, difference of the pressure height at the sewer and the atmospheric pressure height over the grate, and C_d is the discharge coefficient including all the effects of energy losses through the grate, effect of approaching velocity, etc. Figure 6 shows the outflow through the grated inlet produced by surcharged pipe conditions. On the same Figure 6 it is possible to observe the differences of water levels over the grate during the tests. Moreover, some oscillations of several millimetres (10 mm as maximum) were observed during the tests, so water level measure takes the average value with time of the water depths.

[Figure 6. Outflow between 10 and 50 l/s for a geometric configuration of the platform with 2% of longitudinal and transverse slopes].

Imposing the outflows, for 10. 20, 30, 40 and 50 l/s, the values in Table 2 as average value of water level over the inlet were obtained, for the case of 0% of longitudinal slope and 2% of transverse slope.

Table 2. Average water level above the inlet grate.

Flow (l/s)	**H $_{grate}$ (mm)**
10	39~~.10~~

20	56~~.15~~
30	74~~3.65~~
40	92~~.45~~
50	105~~4.55~~

In all the cases, the grated inlet is covered by water, even with the lowest flow. Reynolds values of the experiments range from 63662 to 318310, (lower value for 10 l/s and greater value for 50 l/s) estimated in the pipe. From the water levels over the grate, it was possible to calculate the following discharge coefficient from the equation 1 (Table 3).

Table 3. Discharge coefficient for the Barcelona ~~inlet~~ grated inlet (transverse slope 2%).

Flow (l/s)	**C_d Long. Slope (0%)**	**C_d Long. Slope (2%)**	**C_d Long. Slope (4%)**	**C_d Long. Slope (6%)**	**C_d Long. Slope (8%)**	**C_d Long. Slope (10%)**
10	0.13	0.14	0.14	0.14	0.15	0.15
20	0.22	0.22	0.22	0.22	0.23	0.23
30	0.29	0.29	0.29	0.29	0.29	0.29
40	0.35	0.35	0.35	0.36	0.36	0.36
50	0.41	0.41	0.41	0.41	0.40	0.40

[Figure 7. Discharge coefficient evolution with the outflow through the grate and related error bars due to flow and flow depth measurements].

So it is possible to observe those discharge coefficients are not the same as used for other orifice types of flow. Figure 7 shows an evolution with the flow of the discharge coefficients, with an increasing value with the outflow, multiplying for more than 3 the minimum discharge coefficients. For the minimum flow tested, 10 l/s, value of 0.13 was

found, while for the maximum flow, 50 l/s, a discharge coefficient of 0.41 was obtained.

As said, these results were obtained with 0% longitudinal slope and 2% of transverse slope and the absence of flow approaching the inlet. In order to carry out a sensitivity analysis regarding longitudinal slope, the same tests were repeated fixing transverse slope to 2% and modifying longitudinal slopes. Specifically, the values of 2, 4, 6, 8 and 10% were tested. In all cases, the same approach was used, considering an average value of the water level over the grate and measuring the water level in 20 points. In this case, for some combinations of flow and slope, especially for high slopes, not all the grate was covered by water, and the outflow was associated to a smaller area. Nevertheless, for those values with no water level above grate, 0 value was considered and they were included too in the average value. Results are presented in the Figure 8 with error bars, considering the error due to the flow measurement (as stated 0.5 l/s) plus the error due to the water level measurement ~~(as stated 0.1 mm)~~.

[Figure 8. Discharge coefficient variation with longitudinal slope].

It is possible to observe that the influence of the longitudinal slope is quite limited, so there is not a serious error to consider constant values. So for any grate inlet, it is possible to define the discharge coefficients and they are approximately constant for any longitudinal slope.

4. Conclusions

An experimental study representing the outflow from surcharged sewer systems through grated inlets is presented. Full scale 1:1 tests have been carried out for different discharges

as outflows from the underground sewer. The discharge coefficient calculated using the orifice expression shows an evident variation with the outflow discharge. Values of this coefficients can increase more than three times depending on the outflow discharge.

Values of the discharge coefficients of grate are not similar to the orifice discharge coefficients used in other cases. So application in case of dual drainage analysis must take into account the real values and not the imported values from other situations.

The flow transfers between the major and minor drainage systems and viceversa become one of the key elements for a good quality of the results. Computer codes available now in the market allow this dual drainage modelling, so, in case of this approach, the accuracy of the results rely on the good estimation of these flow transferring and the right choice of discharge coefficients, in case an orifice type approach, is used to describe the flows through the grate. Moreover, commercial software allows the orifice type to describe the flow transfer between sewer and surface. Grate inlet manufacturers could provide for every grate the specific discharge coefficients so the application to consider dual drainage can be done in a very easy way.

Results of the experimental campaign show a range of values of discharge between 0.13 to 0.41 for a flowrate surcharge between 10 to 50 l/s. Furthermore, is important that the values of C_d estimated were approximately constant for each outflow through the tested grated inlet, whereby the effect of transversal and longitudinal slopes has very poor influence. Tests considered the absence of surface flow approaching the grated inlet. Further analysis could be carried out to analyse the influence of the presence of runoff on the discharge coefficients values of the grate.

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