DISCHARGE CAPACITY OF JUNCTION MANHOLES WITH BOTTOM DROPS OR TOP OFFSETS

GAETANO CRISPINO[1], MICHAEL PFISTER[2] & CORRADO GISONNI[3]

[1,3] Department of Civil Engineering, Design, Building and Environment, University of Campania "Luigi Vanvitelli", Aversa (CE), Italy, gaetano.crispino@unina2.it; corrado.gisonni@unina2.it

[2] Civil Engineering Department, Haute Ecole d'Ingénierie et d'Architecture, Fribourg, Switzerland, michael.pfister@hefr.ch

ABSTRACT

An adequate operation of combined sewer systems is related to the efficiency of sewer manholes. Sometimes, sewer manholes are designed to convey safely storm water discharges with a return period shorter than the infrastructure life time. In other cases, the manhole discharge capacity is sufficient but the flow structure established in the manhole leads to unacceptable free-surface flow conditions. This poor performance may easily occur in junction manholes, which merge two or more upstream branches into a single downstream collector. The hydraulic behavior of junction manholes under sub- and supercritical flows has been thoroughly studied in the past, mainly on an experimental basis. However, former studies are all referred to a standard junction manhole layout, with a constant diameter assigned to both up- and downstream branches along with a flat manhole invert. Contrarily, diversified set-ups are usually employed in practical cases. Upstream sewer branches are generally characterized by various cross-section profiles. Moreover, the good design practice recommends settling the concerned branches by aligning the branch tops, in order to avoid backwater effects. Given the above, advancement in design procedures for junction manholes is strongly required, mainly with regard to the discharge capacity of junctions characterized by generalized configurations. The present study considers the results of experimental campaigns performed on different physical models of junction manholes. A communal structure with a junction manhole approached by two circular upstream branches, with variable diameters, is considered. Then, junction angles and upstream branch diameters are varied, resulting in different manhole set-ups with inlet bottom drops or top offsets. Selected overload experimental runs are performed to investigate the hydraulic conditions under which the manhole discharge capacity is exceeded. The analysis of the experimental data allowed in outlining a preliminary comparison of discharge capacity of junctions with generalized layouts.

Keywords: Hydraulic design; sewer manhole; junction manhole; supercritical flow; discharge capacity.

1 INTRODUCTION

Sewer systems operate satisfactorily when the performance of their collectors and manholes is hydraulically adequate. In particular, sewer manholes are crucial elements in urban drainage systems. Each hydraulic or geometrical alteration is located into sewer manholes. Simultaneously, the punctual variation of basic features as cross-section profile, hydraulic roughness, channel slope or discharge frequently can lead to the occurrence of undesired phenomena (shock waves, breakdowns etc.). An accurate design of sewer manholes is thus fundamental. If a sewer manhole does not function as required, then the free-surface conditions across the related collectors are probably unacceptable. Among others, junction manholes are the most frequent structures within urban drainage systems. They combine two or more upstream sewer branches into a single downstream collector, as often occurred into ramified drainage nets. The main component of a junction manhole is the junction chamber, inside of which the free-surface flow irregularities should to be opportunely restrained. The benches of the chamber are required to limit the shock wave maxima, whereas the discharge capacity of the overall structure should be larger than incoming storm water discharges in order to avoid manhole overflow phenomena.

The manhole geometry can be properly selected provided that the hydraulic features of approach flows are exhaustively recognized. In particular, plan outlines of junction manholes approached by subcritical flows should exclude specific appurtenances with sharp-crested geometries. These accessories facilitate the presence of large dead-flow zones originating excessive energy losses across the structure. The computation of the energy loss coefficients for subcritical junction manholes is accomplished by applying the momentum equation based on the similitude between free-surface flows running in the manhole and pressurized flows (Hager, 1987). The recourse of the classical energy head equation helps to predict the subcritical free-surface profiles over the manhole (Gisonni and Hager, 2012), instead.

The flow scenario is completely different for supercritical approach flows. Here, the main intent consists in preventing the interruption of the regular supercritical flow structure into the manhole. If otherwise happens,

 / ISSN 1562-6865 (Online) - ISSN 1063-7710 (Print)

unpleasant events with severe shock waves, breakdown of air-transport in the downstream collector or choking flow in one or both the upstream branches can happen. If the height of the bench walls is safely chosen, then the shock wave maxima, even if significant, should not arise in particular care. According to main literature studies (Del Giudice and Hager, 2001; Gisonni and Hager, 2002; Crispino et al., 2016), the prediction of wave maximum heights is fulfilled by applying empirical relationships validated by physical model data. However, if the total discharge Q exceeds a given value, from here on out named as manhole discharge capacity, then the above-mentioned phenomena may occur resulting in a junction manhole failure.

As for the shock wave heights, the discharge capacity of supercritical junction manholes is estimable through experimental expressions (Del Giudice and Hager, 2001; Gisonni and Hager, 2002; Saldarriaga et al., 2017). This formula depends on the specific junction flow scenario (approach supercritical flows or mixed regimes with sub- and supercritical flows approaching the manhole all at once). In addition, the empirical relationships are all presented for a standard junction manhole set-up, characterized by circular upstream branches and a downstream collector with same diameter D. Moreover, the manhole inlets and outlet were always aligned. Nevertheless, this standardized set-up is a long way to be found in practical wastewater applications, given the enormous variety of geometrical configurations to be considered. Furthermore, a good practical rule commonly employed in the sewer collector design suggests aligning the tops of sewer branches entering and outing from manhole. A such farsightedness might avoid the formation of hydraulic jumps for backwater flows.

Given the above, existing equations valid for predicting the junction, manhole discharge capacity need to be validated, or modified if necessary, by considering generalized manhole set-ups. At this aim, the present paper provides first results derived by a set of experimental studies on 45° and 90° junction manholes, which were characterized by upstream branch diameters different from the downstream one and, above all, by the presence of small drops or top offsets at the manhole inlets.

2 PHYSICAL MODEL INVESTIGATION

Experiments were conducted at the Laboratory of Hydraulic Structures of the École Polytechnique Fédérale de Lausanne, Switzerland. Two physical models of junction manholes characterized by conventional dimensions were utilized, with a junction angle δ equal to 45° and 90°, respectively. As visible in Figure 1, the physical models were made out of PVC, with transparent conduits and manhole bench walls to facilitate the free-surface flow observations. Both 45° and 90° junction manholes were approached by two circular upstream branches, the straight (subscript o) and the lateral (subscript L) one. A downstream collector (subscript d), with a circular cross-section profile too, outed from the junction chamber. The diameter of the downstream collector was constant (D_d = 0.240m). Conversely, the upstream branches were characterized by variable diameters D_o and D_L, alternatively equal to $0.51 \cdot D_d$, $0.79 \cdot D_d$ and 1.00·Dd. Nine set-up combinations resulted from the variation of the upstream branch diameters, as illustrated in Table 1. Set-up I was characterized by equal up- downstream diameters, corresponding to the standardized junction manhole layout.

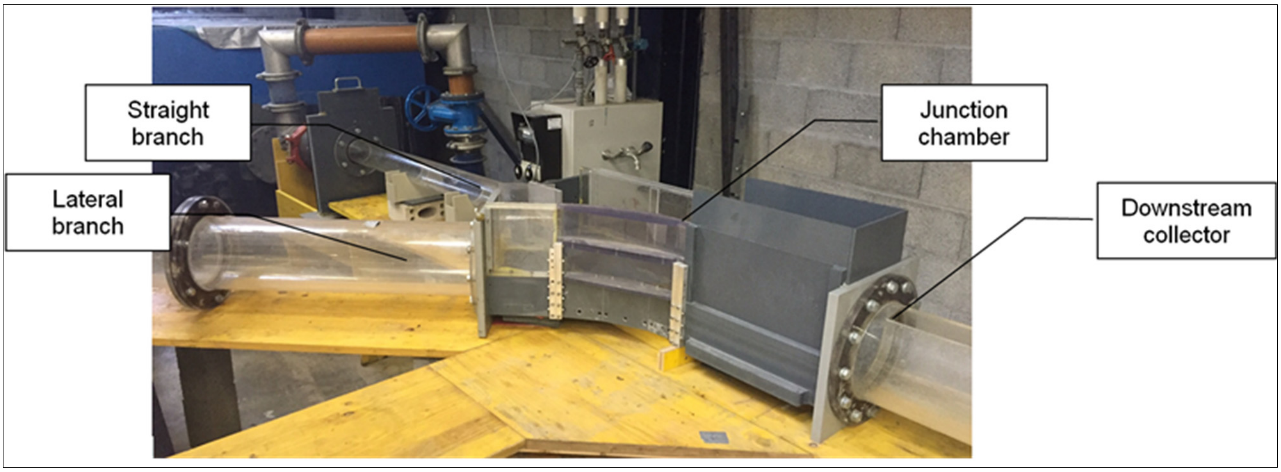

Figure 1. Physical model of 45° junction manhole installed at the LCH/EPFL.

Junction chamber and downstream collector inverts were always aligned. Bottom drops or top offsets (Figure 2) were thus present at the straight and/or at the lateral manhole inlet if the corresponding upstream branch diameter differed from the downstream one. In particular, the 45° junction manhole model was tested for both set-ups with bottom drops and top offsets, whereas the manhole inlets of the 90° junction manhole were only characterized by top offsets. The geometrical features of remaining components (lateral branch curvature, bench heights and junction chamber length) followed from the basic recommendations derived by Del Giudice and Hager (2001) and Gisonni and Hager (2002).

Table 1. Junction manhole set-ups tested by varying the upstream branch diameters (D_d = 0.240m).

Set-up	D_o [m]	D_o/D_d [-]	D_L [m]	D_L/D_d [-]
A	0.123	0.51	0.123	0.51
B	0.123	0.51	0.190	0.79
C	0.123	0.51	0.240	1.00
D	0.190	0.79	0.123	0.51
E	0.190	0.79	0.190	0.79
F	0.190	0.79	0.240	1.00
G	0.240	1.00	0.123	0.51
H	0.240	1.00	0.190	0.79
I	0.240	1.00	0.240	1.00

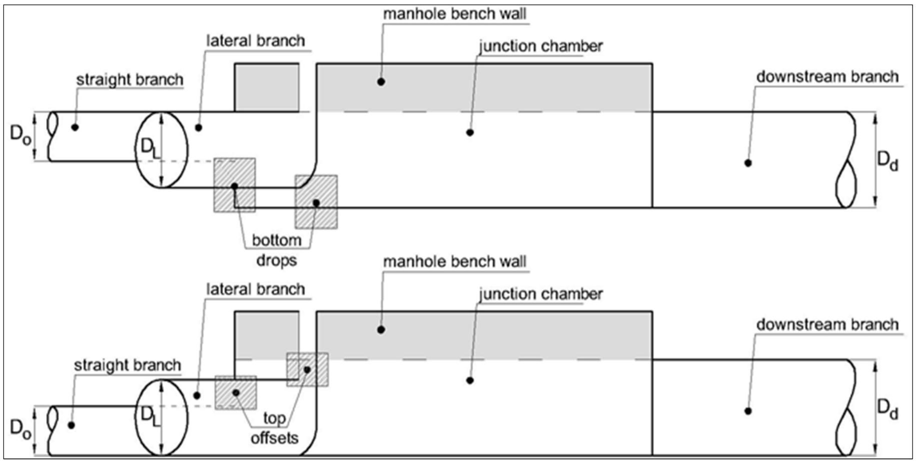

Figure 2. Sketch of the junction manhole with bottom drops (top) or top offsets (bottom).

Water depths, at fixed points along the conduits and the manhole, and shock wave heights, where waves occurred, were measured by the utilization of a conventional point gauge. The approach discharges Qo and QL were measured singularly by inductive flowmeters with a full scale (FS) accuracy of ±0.5%. Selected test-runs were carried out by varying the main hydraulic independent parameters for each upstream branch, including: the approach filling ratio $Y = h/D$, where h is the water depth, and the approach flow Froude number $F = Q/(gY^4h^5)^{0.5}$ (Pfister and Gisonni, 2014), where Q is the discharge and g is the gravitational acceleration. The approach filling ratios varied between 0.20 and 0.65, because for supercritical flows in circular conduits the free surface flow breaks down whenever the filling ratio is larger than 70% (Hager and Gisonni, 2005). Different junction flow scenarios, with approach flows simultaneously supercritical or subcritical or under mixed flow conditions, were replicated in the physical model. However, transcritical flows with Froude numbers ranging between 0.80 and 1.20 (Gisonni and Hager, 2012) were avoided, so that only fully sub- or supercritical flows entered the junction manhole.

3 JUNCTION MANHOLE DISCHARGE CAPACITY

As specified by Del Giudice and Hager (2001), the discharge capacity (subscript C) of a junction manhole can be exceeded due to the occurrence of two possible troubling phenomena:

- choking flow in the downstream collector, occurred due to the formation of a relevant swell up to occlude the manhole outlet cross-section. If the approach flows are both supercritical, then they break down with an abrupt transition from free-surface to pressurized air – water flow;
  choking of one or both the approach flows over the upstream branches, which may potentially happen when the upstream flows are so perturbed to break the free-surface flow regime or for an approach flow significantly dominant on the other one. In both cases, a hydraulic jump occurs with a possible backwater effect. The pressurization of an upstream branch may successively cause the breakdown condition in the junction manhole.

The junction discharge capacity is usually represented by means the capacity Froude number $F_C = Q_C/(g \cdot D^5)^{0.5}$ (Del Giudice and Hager, 2001). A set of experimental relationships was suggested by Del Giudice and Hager (2001) and Gisonni and Hager (2002) to predict the capacity discharge of standard 45° ad 90° junction manholes, depending on the specific flow scenario. These relationships are summarized in Table 2. As reported, the capacity Froude number is fixed as a function of the approach filling ratio Y_o and Y_L. According to the concerned formula, the straight filling ratio Y_o has a more significant effect. Furthermore, for junction flow scenarios (III) (δ =45°) and (I) (δ =90°), the straight Froude number F_o was also included among the affecting parameters.

Table 2. Experimental relationships used for predicting F_C in 45° or 90° junction manholes under a standard set-up (Del Giudice and Hager, 2001; Gisonni and Hager, 2002).

		Junction flow scenario	Experimental relationship
45° junction manhole	(I)	both supercritical flows	$F_C = 5.5 \cdot Y_o \cdot Y_L^{0.5}$
	(II)	subcritical straight flow and supercritical lateral flow	$F_C = 0.7 \cdot (Y_o \cdot Y_L^{0.5})^{1/3}$
	(III)	supercritical straight flow and subcritical lateral flow	$F_C = 0.6 \cdot Y_o \cdot F_o$
90° junction manhole	(I)	both supercritical flows	$F_C = 0.6 \cdot F_o \cdot Y_o^{1.2} \cdot Y_L^{-0.2}$

3.1 45° junction manholes

The experimental campaign conducted on the 45° junction manhole with inlet top offsets (Niedermann, 2013) was characterized by particular tests during of which the capacity of the structure was clearly overtaken. A choking flow was observed in the junction chamber, and it was essentially induced by the formation of limit flow conditions over the upstream branches. The pressurization of one or both upstream branches provoked the occurrence of a hydraulic jump in the manhole or just upstream from the junction chamber. An increase of the water level up to the crest of the manhole bench walls was thus observed. Contrarily, the choking flow in downstream collector was hardly reproducible experimentally, because the large downstream collector diameter (D_d = 0.240m) compared with the smaller upstream branch diameters would have required significant tailwater levels to produce the transition from free-surface to pressurized flow. However, these water levels were difficult to be obtained by installing small upstream branch diameters.

For 45° junction manholes equipped with bottom drops (Crispino, 2016), the discharge capacity was again exceeded due to the abrupt pressurization of the upstream branches. Figure 3 shows the alarming overflow condition observed in the junction chamber during a specific test-run. Approach flows were both supercritical, with Froude numbers equal to F_o = 1.49 and F_L = 3.96, and the corresponding filling ratios were forced to be Y_o = 0.60 and Y_L = 0.40. The development of unstable free-surface flow conditions over the lateral branch generated, firstly, the transition to a pressurized flow along the pipe and, at a later time, the propagation of the choking flow in the junction chamber and along the straight branch. The bottom drop at the straight inlet did not thus inhibit the backwater effect into the straight branch. As a result, the water level in the junction chamber touched lightly the crest of the bench walls, as visible in Figure 3. The outlet cross-section was thus completely submerged, and a gated flow occurred at the entrance of the downstream collector.

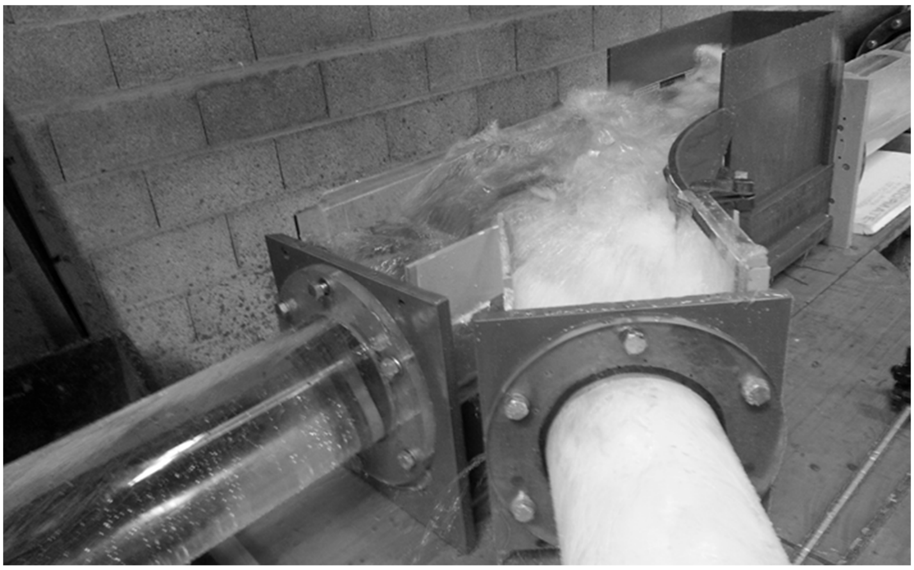

Figure 3. Choking of the junction manhole due to the abrupt pressurization of upstream branches, as observed in 45° junction manhole with bottom drops under set-up E (see Table 1).

As previously observed by Del Giudice and Hager (2001) for standardized 45° junctions, the experimental discharge capacity F_c can be plotted against $Y_o \cdot (Y_L)^{0.5}$, for flow scenarios (I) and (II), and against $Y_o \cdot F_o$, when the hydraulic behavior of the junction manhole is dominated by the straight supercritical flow (flow scenario (III)). However, the experimental data collected for 45° junction manholes under generalized set-ups did not follow the recommended equations, as represented in Figure 4a. The variation of the upstream branch diameters had to be thus accounted for because it made the experimental relationships suggested by Del Giudice and Hager (2001) ineffective. Given that the downstream collector diameter D_d was unchanged passing from standardized to generalized junction manholes, it is convenient to introduce the diameter ratio $\beta = D_i/D_d$ (i = o, L) to consider the variability of the upstream branch diameters. Figure 4b shows the experimental capacity Froude numbers F_C as a function of $\beta_o Y_o \cdot (\beta_L Y_L)^{0.5}$. For upstream branch diameters equal to the downstream one, the diameter ratio coefficients β_o and β_L are equal to 1.0 giving again the parameter suggested by Del Giudice and Hager (2001). Conversely, if the upstream branch diameters differ from the downstream one, then the conventional equation can be modified as:

$$F_C = 5.5 \cdot \left[\beta_o Y_o \cdot \left(\beta_L Y_L \right)^{0.5} \right] \quad [1]$$

As visible, Eq. [1] overestimates the discharge capacity exhibited by 45° junctions with bottom drops or top offsets, especially when the lateral diameter is $D_L = 0.51 \cdot D_d$ (set-ups (A) and D)). No evident differences between junction manholes equipped with bottom drops or top offsets are recognized, instead. It is noteworthy that the experimental data corresponding to the set-up (I), that is the standard junction set-up, are well predicted by Eq. [1].

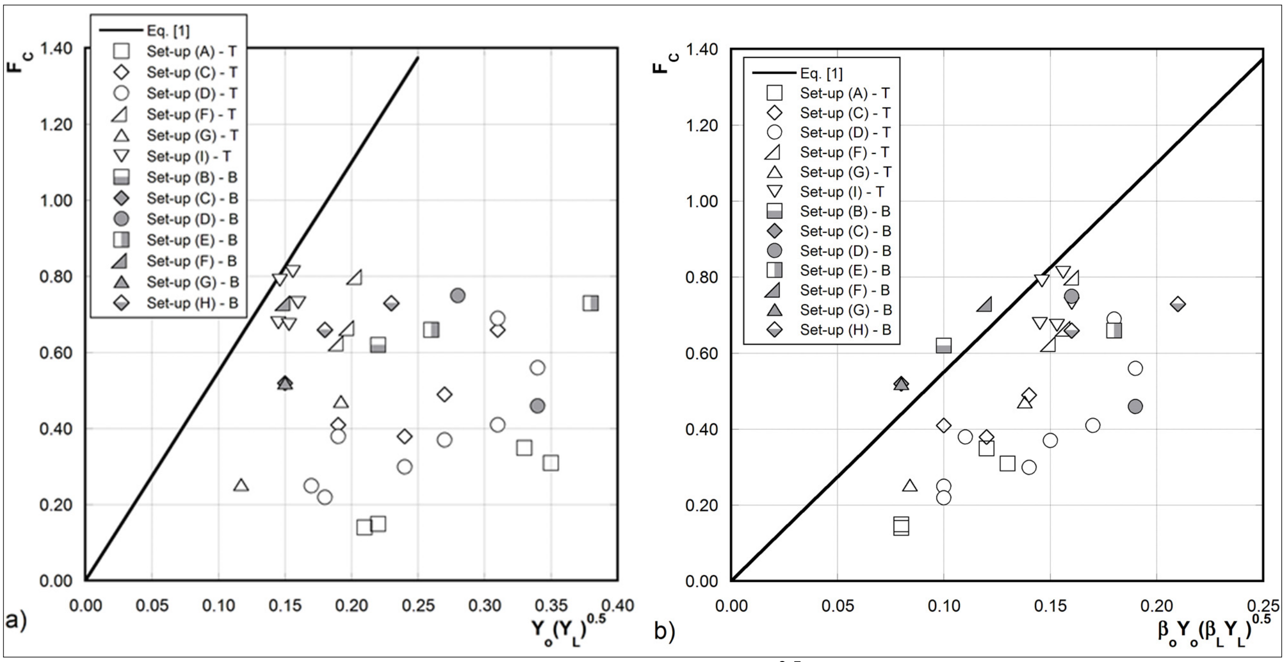

Figure 4. Capacity Froude Number F_c as a function of $\beta_o Y_o \cdot (\beta_L Y_L)^{0.5}$ for 45° junction manholes equipped with bottom drops (B) or top offsets (T) under junction flow scenario (I).

For subcritical flows issued by the straight or the lateral branch (junction flow scenarios (II) and (III)), the capacity Froude number of 45° junction manholes can be plotted against $[\beta_o Y_o \cdot (\beta_L Y_L)^{0.5}]^{1/3}$ and $(\beta_o Y_o F_o)$ (Figures 5a, b), respectively, according to following equations:

$$F_C = 0.7 \cdot \left[\beta_o Y_o \cdot \left(\beta_L Y_L \right)^{0.5} \right]^{1/3} \quad [2]$$

$$F_C = 0.6 \cdot \left(\beta_o Y_o F_o \right) \quad [3]$$

Here, only experimental data referred to the junction manhole equipped with top offsets are available. Physical observations confirm previous statements derived by Del Giudice and Hager (2001). The discharge capacity of 45° junction manholes under junction flow scenario (III) is larger than under flow scenario (II), even if generalized set-ups with variable upstream branch diameters are considered. As illustrated in Figures 5a, b, the relationships suggested by Del Giudice and Hager (2001), even if modified by introducing the diameter ratio, don't allow to estimate accurately the discharge capacity of 45° junction manholes with top offsets at manhole inlets. The discrepancies are more evident when junction flow scenario (II) is considered (Figure 5a). In this case, the effect related to the reduction of the lateral branch diameter is again significant, as recognized for the flow scenario (I). Infact, the differences between observed and predicted data are larger than for other set-ups. If junction flow scenario (III) is considered (Figure 5b), then the reliability of the expression suggested for standard junction manholes increases. This evidence might prove that larger deviations between the experimental data collected for generalized junction manholes and the relationships recommended by Del Giudice and Hager (2001) for standard junctions are derived when supercritical flows are issued by the lateral branch.

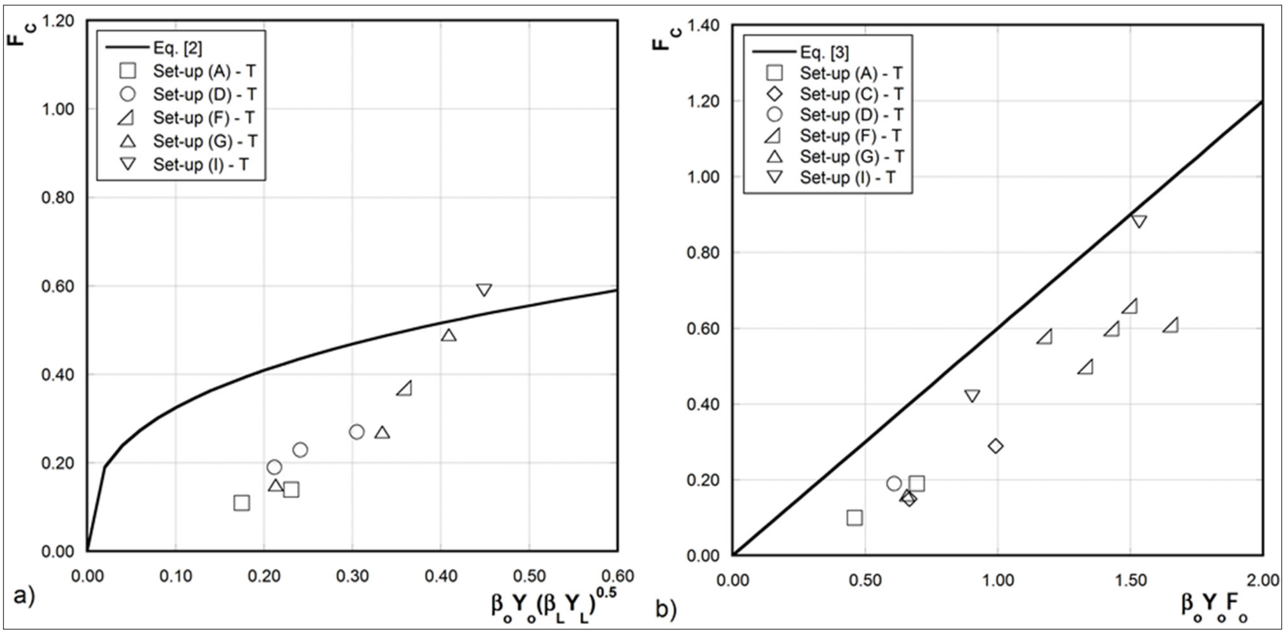

Figure 5. Capacity Froude Number F_c as a function of: a) $\beta_o Y_o(\beta_L Y_L)^{0.5}$ (junction flow scenario II) and b) $\beta_o Y_o F_o$ (junction flow scenario III) for 45° junction manholes equipped with top offsets.

3.2 90° junction manholes

Gisonni and Hager (2002) experienced the discharge capacity excess of 90° junction manholes because of the formation of a relevant swell height. The swell gave origin to the occurrence of the choking of the downstream collector. More rarely, the junction discharge capacity was overtaken due to the flow blockage in the upstream branches. Gökok (2013) investigated the discharge capacity of 90° junction manholes equipped with inlet top offsets originated by upstream branch diameters different from the downstream one. As for Niedermann (2013), the overflow condition in the junction chamber was mainly due to the pressurization of one or both the upstream branches. The choking of the downstream collector induced by the formation of a relevant swell at the manhole outlet was not frequent because of the reduced upstream branch diameters which inhibited the achievement of significant tail water depths.

For 90° junctions under junction flow type (I), Gisonni and Hager (2002) concluded that the capacity Froude number F_c depended on the dynamic momentum of the straight flow F_oY_o multiplied for the ratio Y_o/Y_L (see Table 2). However, as for 45° junction manholes, the reduction of the upstream branch diameters affected the experimental capacity Froude numbers observed by Gökok (2013). Contrarily, if the diameter ratios β_o and β_L are again adopted, then the following equation can be used:

$$F_C = 0.6 \cdot \left[F_o \cdot \left(\beta_o Y_o / \beta_L Y_L \right)^{0.2} \right] \quad [4]$$

The experimental data collected for 90° junction manholes with inlet top offsets result to be nearby located around the line expressed by Eq. [4], as represented in Figure 6. Again, more relevant deviations between observed and predicted capacity Froude numbers are mostly obtained for the smallest lateral branch diameter D_z/D_d = 0.51. Moreover, similarly to 45° junction manholes the employment of the empirical formula adopted for the standard junction manhole continues to give overstimated discharge capacity values.

Differently from Gisonni and Hager (2002), Gökok (2013) tested the capacity of the physical model of 90° junction manhole also under subcritical approach flows (junction flow scenarios (II) and (III)). Figures 7a, b shows the corresponding results. For such junction flow types, the capacity Froude numbers are hereby estimated by using Eq. [2] and [3] according to the recommendations for 45° junction manholes. The discharge capacity of the 90° junction manhole approched by a supercritical straight flow and a subscritical lateral flow results to larger than in the reverse junction flow type, as identified previously for 45° junction manholes.

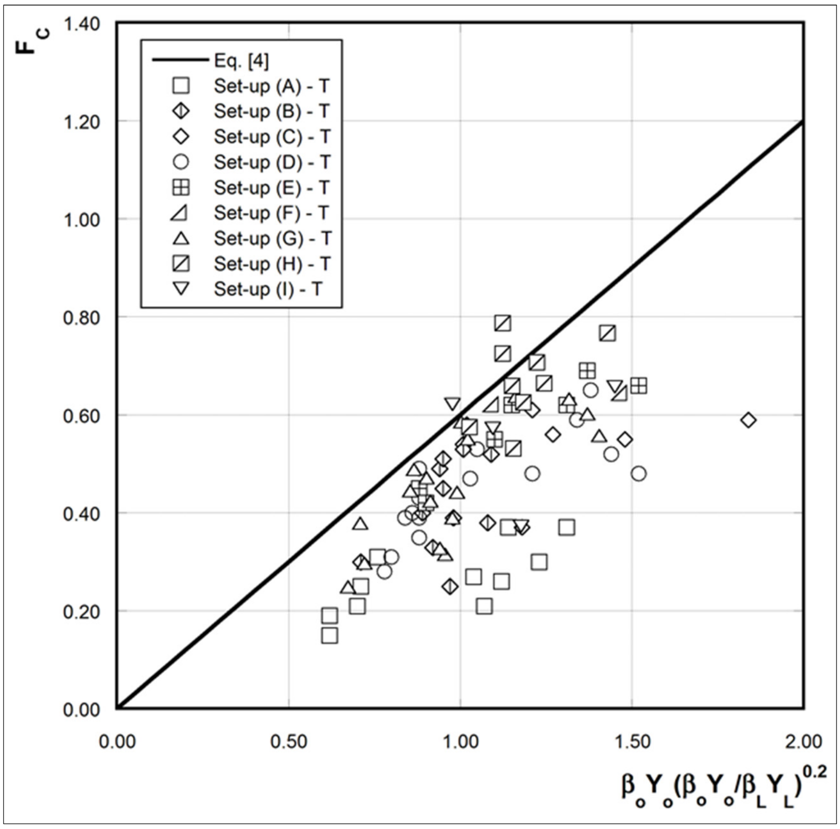

Figure 6. Capacity Froude Number F_c as a function of $\beta_o Y_o(\beta_o Y_o/\beta_L Y_L)^{0.2}$ for 90° junction manholes equipped with top offsets (T) under junction flow scenario (I).

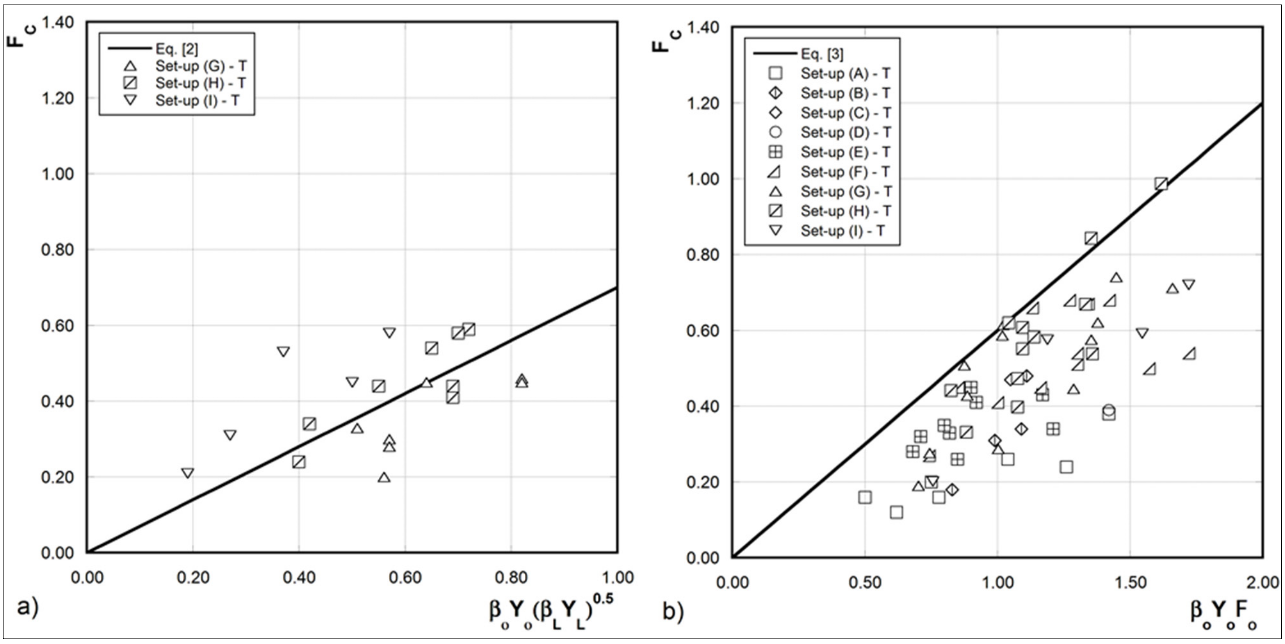

Figure 7. Capacity Froude Number F_c as a function of: a) $\beta_o Y_o \cdot (\beta_L Y_L)^{0.5}$ (junction flow scenario II) and b) $\beta_o Y_o F_o$ (junction flow scenario III) for 90° junction manholes equipped with top offsets.

4 FILLING RATIO IN THE DOWNSTREAM COLLECTOR

As described above, the overload condition resulting in the excess of the discharge capacity of the 45° and 90° junction manholes were initiated by the instable free-surface flow conditions in the upstream branches. A hydraulic jump thus occurred in the junction chamber, and the water level increased significantly up to crest of the manhole bench walls in the worst-case scenario. As a consequence, the junction flow generated a wall shock wave which impinged abruptly on the manhole end wall as represented in Figure 8.

The outlet cross-section resulted to be occluded and, in most cases, a gated flow entered the downstream collector.

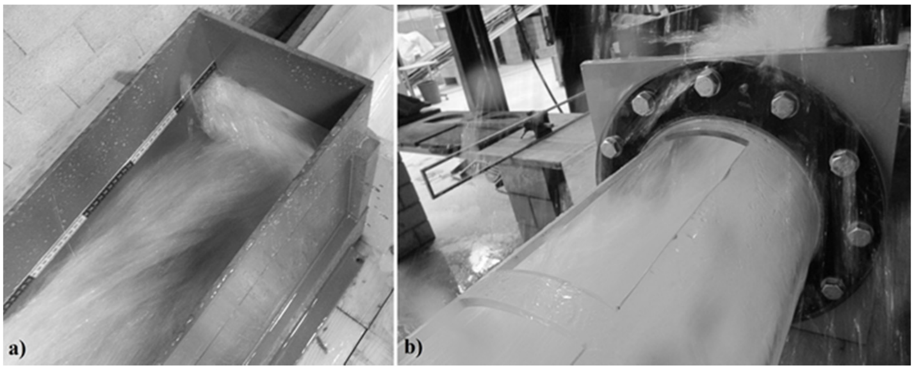

Figure 8. Top a) and downstream b) view of the flow impact against the manhole endwall, as observed during the physical model tests on the 45° junction manhole with bottom drops.

The free-surface flow running along the downstream collector was relevantly shocked (Figure 9a), and it resulted to be transcritical ($F_d < 1.20$) or, sometimes, weakly supercritical ($1.20 < F_d < 2.00$). The experimental filling ratio Y_d ranged between about 0.25 and 0.75, depending on the severity of the overflow phenomenon occurred in the junction chamber. Figure 9b reports the downstream Froude numbers, as a function of the total discharge $Q = Q_o + Q_L$, against the downstream filling ratios, and it compares the present results with the observations collected by Saldarriaga et al. (2017) on a physical model of supercritical junction manhole approached by three upstream branches. As can be seen, downstream Froude numbers obtained by Saldarriaga et al. (2017) (grey circles in Figure 9b) were always less than 1.0 (subcritical flows) whereas the outflow observed in the present investigation was supercritical.

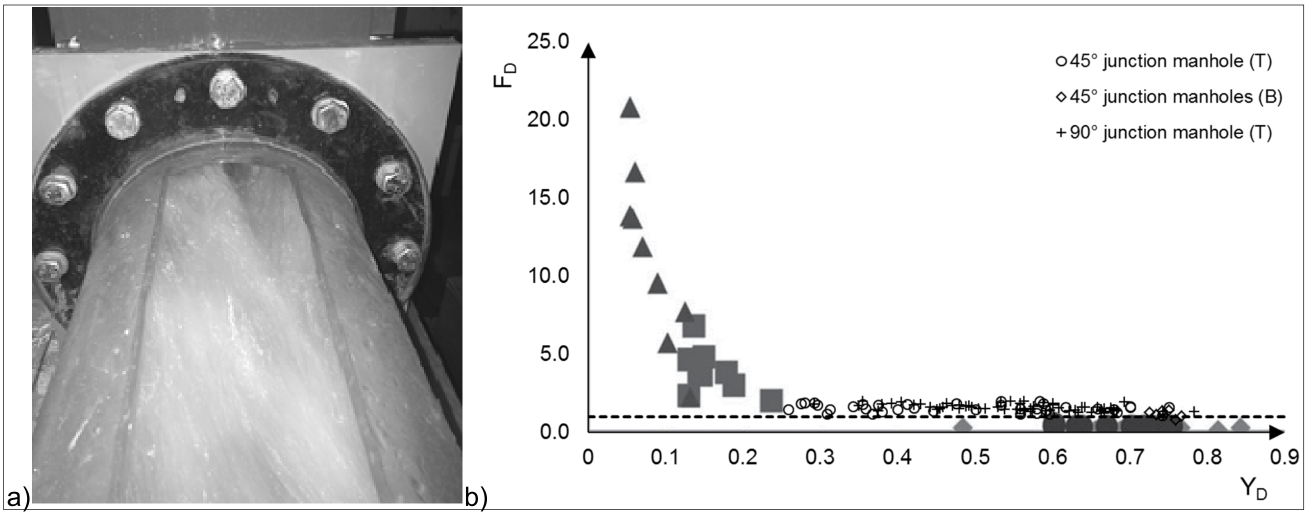

Figure 9. a): Downstream view of the outflow during an overload test on the 45° junction manhole with bottom drops and b) Froude numbers F_d as a function the downstream filling ratio Y_d (grey triangles and squares correspond to the upstream filling ratios observed by Saldarriaga et al., 2017).

5 CONCLUSIONS

The computation of the discharge capacity of junction manholes is a basic phase in the design of such hydraulic structures, especially when approach supercritical flows are expected. The main equations suggested in literature are all referred to a standard junction manhole set-up. However, this reference geometry is often in unconformity with the real junction configurations. The present study aimed thus to verify the reliability of concerned relationships for generalized junction layouts characterized by variable upstream branch diameters and, above all, by the alignment of the branch tops.

Preliminary results derived by the overload test on 45° and 90° junction manholes equipped with bottom drops or top offsets showed that the conventional equations used for predicting the capacity Froude number under various junction flow types are not reliable. Contrarily, it was necessary to introduce the diameter ratio in these empirical equations accounting for the variation of the upstream branch diameters. As modified, the new relationships are characterized by a larger accuracy, even if they overestimated the experimental data.

No significant difference between the discharge capacity of junction manholes with bottom drops or top offsets emerged according to the present observations.

The excess of the discharge capacity of both 45° and 90° junction was due to the occurrence of choking flow in the upstream branches. In most cases, the overflow of the junction chamber happened, and a gated flow entered the downstream collector. Despite the shock effects, the free-surface flow along the downstream collector was transcritical or, sometimes, supercritical, differently from Saldarriaga et al. (2017).

REFERENCES

Crispino, G., Pfister, M. & Gisonni, C. (2016). Shock Wave Patterns in Supercritical Junction Manholes with Inlet Bottom Offsets, *Proceedings of the 4th IAHR Europe Congress*, Liege, Belgium, 27-29 July, 563-570.

Del Giudice, G. and Hager, W.H. (2001). Supercritical Flow in 45° Junction Manhole. *Journal of Irrigation Drainage Engineering*, 127(2), 100-108.

Gisonni, C. & Hager, W.H. (2002). Supercritical Flow in the 90° Junction Manhole. *Urban Water,* 4(4), 363-372.

Gisonni, C. & Hager, W.H. (2012). *Idraulica dei Sistemi Fognari – Dalla Teoria alla Pratica*, Springer-Verlag, 625.

Gökok, T. (2013). Physical Model Investigation of Supercritical Flow in Junction Manholes, *MSc. Thesis.* Laboratory of Hydraulic Constructions (LCH), Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland.

Hager, W.H. (1987). Discussion to Separation Zone at Open-Channel Junctions. *Journal of Hydraulic Engineering*, 113(4), 539-543.

Hager; W.H. & Gisonni, C. (2005). Supercritical Flow in Sewer Manholes. *J. Hydraul. Res.*, 43(6), 660-667.

Niedermann, E. (2013). Physical Model Investigation of Supercritical Flow in 45° junction manholes, *MSc. Thesis*. Laboratory of Hydraulic Constructions (LCH), Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland.

Pfister, M. & Gisonni, C. (2014). Head Losses in Junction Manholes for Free Surface Flows in Circular Conduits. *Journal of Hydraulic Engineering*, 140(9).

Saldarriaga, J., Rincon, G., Moscote, G. & Trujillo, M. (2017). Symmetric Junction Manholes under Supercritical Flow Conditions. *Journal of Hydraulic Research*, 55(1), 135-142.