Water jetting for sewer cleansing. First experimental results for efficiency in non-cohesive sediment removal.

Le curage des réseaux par hydrojets: Premiers résultats expérimentaux sur l'efficacité de l'enlèvement des sédiments non-cohésifs.

Francesco Calomino *, Giovanni Gabelli **, Antonio Miglio *

* Dipartimento di Difesa delSuolo – University of Calabria
Ponte Pietro Bucci, Cubo 42b, 87036 Arcavacata di Rende (CS), Italy
E-mail: calomino@dds.unical.it; a.miglio@dds.unical.it

** Nuova ConTec
Via S. Martino, 83, 33086 Montereale Valcellina (PN), Italy
e-mail giovannigabelli@nuovacontec.com.

RÉSUMÉ

L'article reprend les premiers résultats expérimentaux sur l'efficacité des hydrojets utilisés pour l'enlèvement des sédiments non-cohésifs dans les conduits d'écoulement. Les tests ont été effectuées auprès de *nuova ConTec*, à Montereale Valcellina (Italie) utilisant un treillis incliné d'une longueur de 22.00 m auquel a été fixé un conduit en PVC de 24.00 m de long et d'un diamètre de 300 mm. La recherche concerne l'enlèvement d'un dépôt de sable et gravier d'un diamètre moyen de 2 mm et de 2650 kg/m^3 de densité; ce dépôt a une hauteur égale au 15, 30, 50 et 75% du diamètre du tuyau. Sept divers hydrojets ont été testés observant le nombre de cycles et le temps nécessaire pour enlever tout sédiment. Les résultats montrent que l'efficacité est influencée par l'épaisseur du sédiment et par l'inclination des jets.

ABSTRACT

The paper reports the first results on the efficiency of different jetting-heads used for non-cohesive sediment removal in a sewer pipe. The tests were carried out at *nuova ConTec*, Montereale Valcellina (Italy), using an experimental set-up consisting of an inclinable beam 22.00 m long with a 300 mm PVC pipe 24.00 m long fastened to it. The study concerned the removal of a 5 m long bed of sand and gravel of mean 2 mm diameter and 2650 kg/m^3 density; the sediment bed was laid down with depths of 15%, 30%, 50% and 75% of the pipe diameter. Seven jetting-heads were tested, observing the number of cycles and time necessary to remove sediments from the pipe completely. The results show that cleansing efficiency is strongly affected by clogging depth and jet inclination.

KEYWORDS

Sewer cleansing, non-cohesive sediment, high-pressure water jetting, nozzle, sediment removal.

1. INTRODUCTION

Even though sewer design should be oriented to avoid solid deposition (Ackers et al., 1996), the efficiency of a sewer system is often consequent to local conditions (slope, sediment nature and rate, flow regime) so that the flow is affected by solid and sludge deposition.
In these cases, it is necessary to make use of one of the methods for cleaning sewers that are the object of a number of Regulations and Project as EN 14654-1, 2005; EN 752-2, 1998; EN 752-7, 1998.

When planning cleaning operations, one should be aware of the characteristics of the sediment deposit, i.e. type and dimensions of grains, density of the blockage mass. According to Crabtree (1989), the sediments generally found in sewer pipes can be listed as follows:

- Type A - Coarse predominantly granular mineral material found in the invert of pipes.
- Type B - Similar in composition to type A, but concreted by the addition of mineral cements, fats and tars.
- Type C - Mobile, fine grained, largely organic sludges found in quiescent zones.
- Type D - Organic pipe wall slimes and zooloeal films.
- Type E - Fine grained organic and mineral deposits found in storage tanks.

In storm drains, the sediments are mainly made up of granular material of type A and B; indeed, because of the selection consequent to wash-off and transport, about 90% of sediments have grain diameter above 200 mm (Binnie & Partners and Hydraulics Research, 1987). The mean diameter of the sediment, d_{50}, can be assumed as 2,5 mm (May, 1982; Binnie & Partners and Hydraulics Research, 1987; Ackers et al., 1996), the grain density ranging between 2300 and 2700 kg/m^3.

High-pressure water-jetting is one of the methods for sewer cleaning. A detailed description of jetting operation is reported by EN 14654-1 (2005). The cleansing machine is carried by a lorry (Figure 1) and consists of a water tank, a high pressure pump and a hose having a nozzle at the extremity. The nozzle is equipped with a number of orifices, before and behind, of varying diameter and inclination (Figure 2). The high power of the pump and the small diameter of the orifices make it possible to use very small water discharges associated to high velocity jets. The jetting head is introduced through a manhole from the downstream end of the sewer pipe where there is the solid deposit to be removed; the rear jets make the nozzle to move upstream along the pipe at a controlled velocity, while their impact with the sediment gradually loose the blockage. After penetrating for a given length, the hose is drawn back, while the high pressure water jets make the loosened sediments to move downstream. The operation is repeated for a number of times (cleansing cycles), until the sewer pipe is completely free of sediments.

The efficiency of operation depends on a wide number of variables, as nature of occlusion (cohesive or non-cohesive material, grain diameter), pipe diameter, pump characteristic curve, nozzle type, number and diameter of orifices, jet inclination.

Usually the operator selects the pump, hose velocity and nozzle on the basis of his experience, since there are not any rules to identify the conditions minimizing cleansing duration or cycle number.

In this paper we report the first results of a study aimed at evaluating the efficiency of a number of commercial nozzles for cleansing of small diameter sewer pipes.
An experimental ad-hoc rig was built, in which the process was carefully simulated. The efficiency was finally evaluated by means of the number of cleansing cycles necessary to remove sediments from the pipe completely.

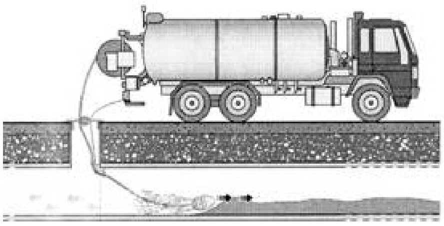

Figure 1 – Cleansing machine

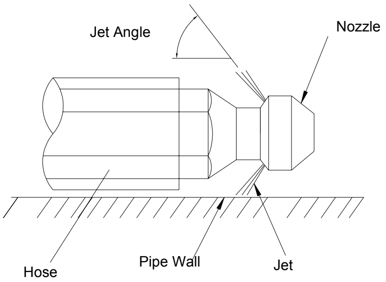

Figure 2 – Sketch of nozzle (Cant and Trew, 1997).

2. SEDIMENT REMOVAL PROCESS

As to the practical aspects, water-jet cleansing is carried out with a number of given conditions as pressure and discharge of the pump, nozzle velocity. As reported by EN14654-1 there are high pressure low volume units (typically 210 bar to 340 bar and 0,5 l/s to 2,5 l/s) and low pressure high volume units (typically 100 bar to 210 bar and 2,0 l/s to 3,0 l/s) and the nozzle velocity and rewind rate should be typically 100 mm to 200 mm per second. The jet velocity varies with the pressure head, and its values are usually between 120 and 350 m/s.

The cleansing cycles are repeated until complete removal of sediments. When the clogging is too long, usually the operator cleans a length of 5 m of pipe, starting from the manhole downstream of the clogging.

When moving upstream, the nozzle, because of the high velocity of the rear jets and the decrease of pressure involved with this, gives rise to air entrainment, so that water and sediments upstream to the nozzle are forced to move downstream.

The nozzle then passes through the sediment mass while the rear jets push downstream the loosened sediments, that take the shape of a dune, having an almost steep front upstream and a gradually sloping back downstream. When the nozzle is withdrawn, an important interaction takes place between the water jets and the dune, with the two following patterns:

1. if the withdrawal velocity is greater than the migration velocity of the dune, the nozzle can pass through the sediment mass; therefore the sediment is only partly removed and a new cycle is required;
2. if the migration velocity is greater than the nozzle velocity, the sediment can be completely removed.

As above said, the water-jetting process is very complex because of the high number of variables to take into consideration, i.e.: type and material of clogging, grain diameter, pipe diameter, pump characteristic curve, nozzle type, number and diameter of orifices, jet inclination.

Moreover, the jet hydrodynamics and the sediment motion is made more difficult to understand because the interference between jets changes their pattern and the interaction between jets and sediments makes the process more and more complicated, taking into account that the sediment motion depends upon the shape of the clogging, that is itself varying with time.

At the moment, there are a few studies in the literature about this process.

An interesting experimental study was carried out at IKT (Institut für Unterirdische Infrastruktur), a Research Institute in Gelsenkirchen, Germany, where the water-jetting was studied in two pipes, the first 300 mm and the second 800 mm of diameter, for a granular sediment with a mean diameter of 2 mm, filling the pipe with a mass 4,2 m long and with depths 15%, 30%, 45 % and 100% of the diameter (Bosseler and Schlüter, 2004). Ten jetting heads were studied, mainly showing that the nozzle velocity giving the best efficiency was 12 m/min. This was more evident for the 800 mm pipe and greater depths of sediment clogging. More information is available on the website www.ikt.de.

3. EXPERIMENTAL SET-UP

The experiments making the object of this paper were carried out at *nuova ConTec* (Montereale Valcellina, ITALY), an Italian nozzle producer, using an experimental installation consisting of a steel beam 22 m long, with a PVC pipe 24 m long with an internal diameter of 300 mm fastened to it.

Thirteen windows of 0,80 x 0,15 m were cut into the upper part of the pipe, with the aim of introducing the sediment and shaping it into a regular bed 5 m long, at a distance of 13 m from the downstream extremity, were a tank collected the washed-off sediment. The windows allowed observation of the clogging removal efficiency every ½ cleansing cycle (one nozzle pass). The installation is shown in Figure 3. The experiments were carried out with depths of the sediment bed equal to 15%, 30, 50% and 75% of the diameter. The sediment was a mix of sand and gravel, having mean diameter d_{50} = 2,0 mm and grain density of 2650 kg/m^3 and it was laid down without compaction, so that the deposit density was 1850 kg/m^3, a value in good agreement with those found in the literature (Goodison and Ashley, 1990).

Seven different jetting heads were tested, whose main features are listed in Table 1. The front orifices of nozzle N_1 and N_4 were plugged up during the tests.

The pump pressure and flow were continuously recorded by a data logger and the information was stored into a computer.

Tab. 2 shows the values of flow (Q), pump pressure (p_p), pressure measured upstream of the nozzle (p_N) and estimated jet velocity (V).

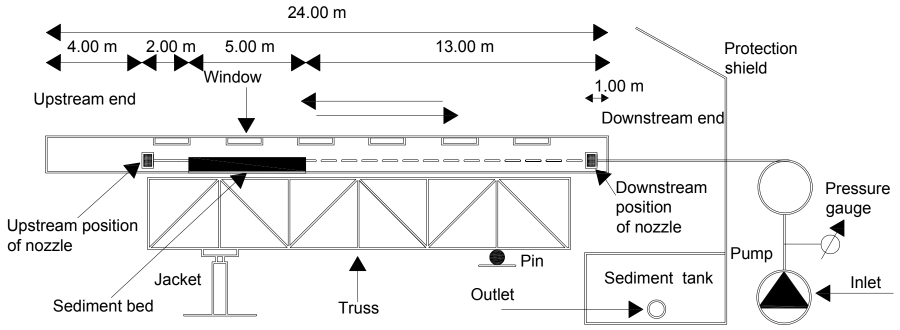

Figure 3 – Experimental set-up

Table 1 – Jetting heads tested

Nozzle	Weight (daN)	Number of orifices	Diameter of orifices (mm)	Jet angle (°)
N1	0,270	1 front jet 6 rear jets	2.00	1 front jet=0° 6 rear jets=35°
N2	2,300	1 front jet 8 rear jets	4 da 1.20 4 da 1.50	8 rear jets = 30°
N3	10,600	12 rear jets	9 da 1.20 3 da 1.00	3 rear jets=30° for d=1.00 mm 3 rear jets=30° for d=1.20 mm 6 rear jets=20° for d=1.20 mm
N4	3,760	1 front jet 8 rear jets	1.40	1 front jet = 0° 8 rear jets=15°
N5	10,000	4 rear jets	2.00	4 rear jets=15°
N6	5,210	8 rear jets	1.40	4 rear jets=5° 4 rear jets=10°
N7	2,220	6 rear jets	1.40	3 rear jets=6° 3 rear jets=12°

Table 2 – Pressures, flow and velocity

Nozzle	**p_P (MPa)**	**p_N (MPa)**	**Q (l/min)**	**V (m/s)**
N1	18.5	16.8	115	183
N2	18.5	17.1	107	185
N3	18.5	16.3	125	185
N4	18.5	16.5	125	181
N5	18.5	16.3	125	181
N6	18.5	16.8	121	181
N7	18.5	17.3	95	182

4. EXPERIMENTAL RESULTS

During the experiments, the pipe slope was 0,3 %, the pressure head was 18,5 Pa and the flow was ranging between 95 and 125 l/s according to the jetting head to be tested.

For each nozzle, the number of cleansing cycles and the time for complete removal of sediments were observed. Since the nozzle was started at a distance of 1 m from the downstream end and stopped at 4 m from the upstream end, the length travelled by the nozzle for each pass was 19 m, while the duration of 1 pass was about 95 s.

The cleansing process was carried out as above said in par. 2, the nozzle velocity being 12 m/min, as suggested by Bosseler and Schlüter (2004). For each jetting head 4 tests were carried out, one for each clogging depth (15%, 30%, 50% and 75%). The reproducibility of the process was observed by repeating each test 3 times, so that in total 84 tests were carried out. Only once, when the nozzle was stopped by the sediment mass, the total time was not the same in all the 3 runs.

For each test we observed the evolution of the sediment deposit at each pass; the analysis of data showed that for clogging depths = 15%, the sediment dune evolution was the same, independent of the nozzle; while for clogging depths > 15% the evolution changed along with the jet inclination. In particular, for jet inclination > 15 °, that is for nozzles N1, N2, N3 and N4, the migration velocity of the dune was small and its shape did not change; on the contrary, for jet inclination ≤ 15° the dune evolved rapidly and took different shapes. Figure 4 shows an example of the sediment deposit evolution, concerning nozzle N6 (the most efficient one) for clogging depth = 75%. One should note the rapid removal of sediments, so that after 4 passes the pipe was completely free; one can also note that the dune shape changed between the 1st (steep front upstream) and second pass (steep front downstream).

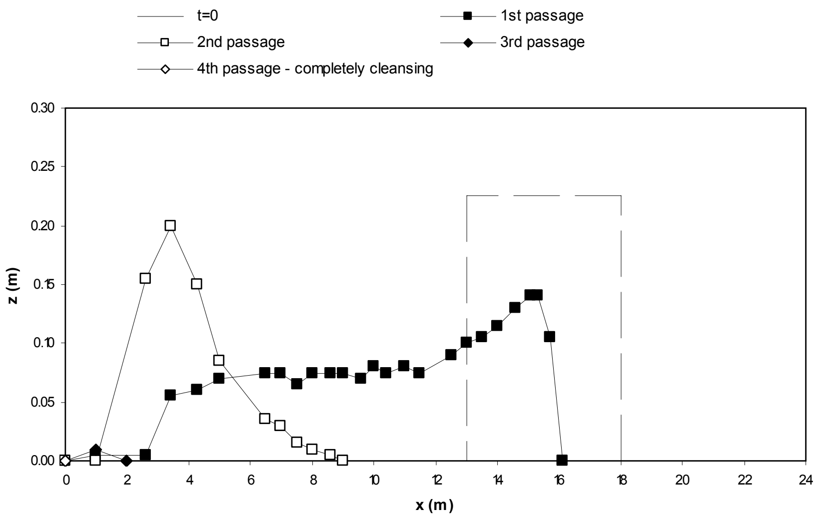

Figure 4 – Evolution of sediment deposit – Nozzle N6 , clogging depth 75% .

Finally, we could observe that the dune migration velocity was smaller than the velocity of nozzle for clogging depths >15%.

The number of cleansing cycles and the time for complete removal of sediments for the 28 cases tested are shown in Figure 5.

One can easily observe that:

- the jetting head performance, that is the number of cleansing cycles necessary for complete removal of sediments, is greatly affected by clogging depth;
- the performance of different jetting heads is always the same for clogging depths equal to 15%.
- the duration of cleansing ranges between 4 min and 20 min depending on the clogging depths and the nozzles tested.

Figure 6 shows that the nozzle performance is considerably affected by jet inclination; it should be noted that for clogging depths of 15% and 30%, the performance decreases when the jet inclination is greater than 20°; on the contrary the performance does not increase for jet inclination smaller than 15°.

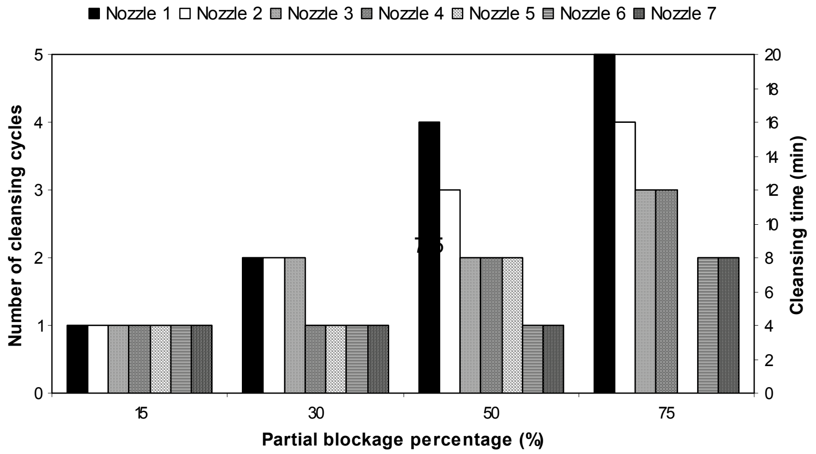

Figure 5 – Cleansing cycles and time for complete removal of sediments

In conclusion, for a 300 mm sewer pipe with a 5 m long deposit of granular non-cohesive sediment with d_{50} =2,0 mm, having clogging depths of 15%, 30%, 50% and 75 % of the pipe diameter, the graph in Figure 5 provides information for selecting the nozzle giving the best performance, for nozzle velocity of 12 m/min, confirming the results obtained by Bosseler and Schlüter (2004). The figure also shows that the jetting-head performance depends on the clogging depth only above 15% of the diameter.

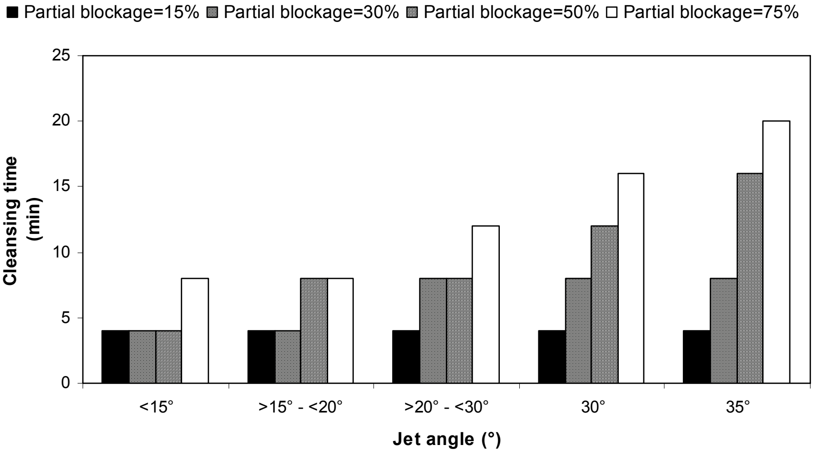

Figure 6 – Cleaning time versus jet inclination

The graph in Figure 6 suggests that the nozzles with jet inclination smaller than 15° when the clogging depth is above 50 % should be selected.

5. CONCLUSIONS

The paper reports the first experimental results about the efficiency of seven commercial jetting-heads for the removal of non-cohesive sediments in a sewer pipe. Obviously, the results here obtained do not allow the conception of a general model to represent the cleansing process. Anyway, since the experimental installation can simulate very well the main features of sewer cleansing operation, we obtained some interesting information about how two variables affect it, that is jet inclination and clogging depths.

The flexibility of our experimental installation will allow us to carry out in the future more complete observations aimed at giving a wider understanding of such a complicated process.

REFERENCES

Ackers, J.C., Butler, D., and May, R.W.P. (1996). *Design of sewers to control sediment problems*, CIRIA, Report 141, London, UK.

Binnie and Partners and Hydraulics Research (1987). *Sediment movement in combined sewerage and storm-water drainage systems*, CIRIA, RP 366, Phase I Project Report, London, UK.

Bosseler, B., and Schlüter, M. (2004). *Kanalreinigung – Düsen, Drücke, Hockdruckstrahlen*, Report IKT, Gelsenkirchen, Germany.

Cant, J., Trew, J. (1997). *Sewer Jetting Code of Practice*, WRc, 1st Edition, April 1997.

Crabtree, R.W. (1989). Sediment in sewers, *Journal IWEM*, Vol. 3 (No. 6), pp 569-578.

EN 14654-1: 2005. *Management and control of cleaning operations in drains and sewers. Sewer cleaning*.

EN 752-2: 1998. *Drain and Sewer Systems Outside Buildings - Part 2: Performance requirements*.

EN 752-7: 1998. *Drain and Sewer Systems Outside Buildings – Part 7 Maintenance and operations*.

Goodison, M.J. and Ashley, R.M. (1990). Sediment movement in combined sewers in Dundee, *Wat. Sci. and Tech., Vol. 22*, (No. 10/11), pp 586-602.

May, R.W.P. (1982). *Sediment transport in sewers*, Hydraulics Research Station, Report IT 222, Wallingford, UK.