AVOIDING THE PITFALLS IN USING CASCADING MANHOLES

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ABSTRACT

Cascade drop manholes are used (where permitted by the local authority) to avoid crossing services; in an attempt to expend energy within the drainage network; or to reduce pipe grades. Hydraulics through drop manholes is not widely documented, and research such as documented in Granata, de Marinis et al, (2011) indicates that drop manholes can have a significant, unexpected, deleterious effect on the hydraulic capacity of the system.

CFD analysis allows for a cost effective assessment of the hydraulics of structures such as drop manholes without having to construct and monitor scale models or 'take the plunge' and construct and monitor full sized trial systems.

CFD models for a number of manhole geometries (square and circular); inlet geometries (centre cascade, offset cascade and external dropper) and outlet geometries (benched, unbenched, centre outlet and offset outlet) have been modelled. The result of this modelling has been charted for energy loss. The use of this chart will allow the designer to assess the projected energy loss and expected flow regime within the manhole for the purposes of design or 1d modelling.

KEYWORDS

CFD modelling, Drop Manholes, Cascade flow conditions, OpenFOAM

1 INTRODUCTION

Engineers use cascades (for the purposes of this study this is taken to mean a free fall within the manhole as opposed to a vertical dropper, whether internal or external) for a number of reasons:

- To negotiate an obstruction that would make the laying of pipes at grade difficult or impossible
- To bring a shallow, generally service line, down into a deeper, generally trunk, line
- In an effort to reduce the energy in the system
- In an effort to oxygenate wastewater with a depleted oxygen content

In each case the hydraulic requirements are quite different. The designer may want to minimise energy loss or maximise it, or the system energy may not be significant but he may want to maximise turbulence to entrain more oxygen or reduce the turbulence so as to vent air from the system before entering a deep tunnel.

A number of regional authorities in New Zealand allow cascading manholes in stormwater systems and a number of United States utilities will allow cascades of up to 1m (Camino 2011). In each case there does not seem to be any significant guidance on the hydraulics of drop structures.

2 PREVIOUS WORK

The hydraulics of Roman dropshafts has been studied in some detail by Chanson (1999).

There has been some work on the study of the hydraulics of square pits, for example Chanson (1999 and 2004); Camino (2011); Vita et al; O' Loughlin & Stack; Carvalho & Leandro (2012). Circular drop manholes are less well documented with examples being Granata et al (2011, 2010 and 2009); and De Martino et al (2002). The appreciation of the hydraulics of circular manholes is probably the most important for the NZ industry due to their prevalence here.

The use for various techniques for energy dissipation of sewer and hydro dropshafts gives some guidance on the expected hydraulics but at a significantly larger scale than that covered in this paper (Del Giudice et al, 2010; Zhao et al 2006; Anderson, 1961).

The published body on computational fluid dynamics (CFD) studies on dropshafts seems to be very limited with only one reference found (Sousa, 2009).

3 THE HYDRAULICS OF CASCADES

In general the hydraulics of drop structures are dominated by three differing regimes based on the structure geometry and the relationship between the inlet and outlet lines. In the first, the falling nappe falls onto the manhole base and a pool ultimately builds up until it has sufficient head to drive past the orifice formed by the outlet line. In the second, the falling nappe falls on or near the outlet causing the outlet to be gorged and effectively minimising energy loss through the manhole. The third, the nappe falls above the outlet line and cascades down the wall. Depending on the horizontal relationship between the lines this may increase or reduce headloss through the manhole.

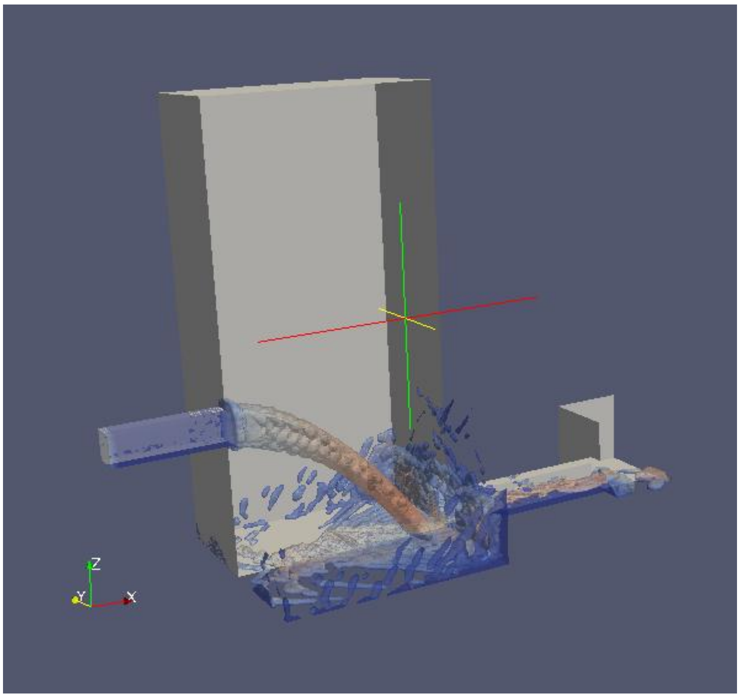


Figure 1: Access chamber with nappe falling below the outlet line

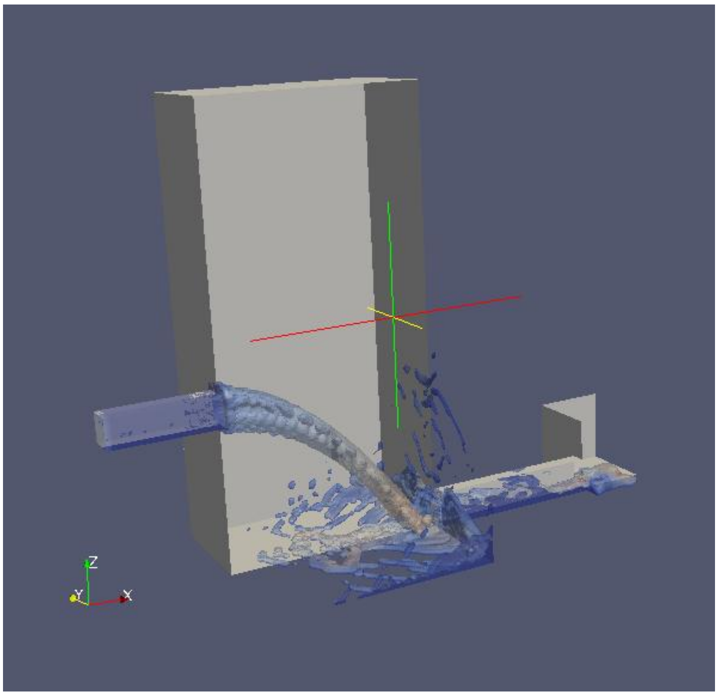


Figure 2: Access chamber with nappe falling on the outlet line

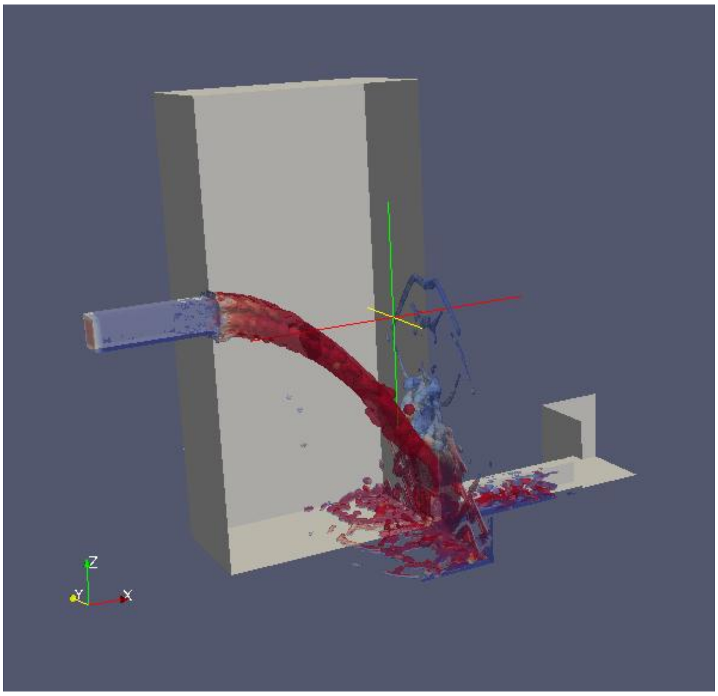


Figure 3: Access chamber with nappe falling above the outlet line

The classical mechanics equation for the falling nappe is:

$$x = tV_b \qquad \text{Equation (1)}$$

for the displacement in the x direction and;

$$z = H + \frac{d_b}{2} - \frac{1}{2}gt^2 \qquad \text{Equation (2)}$$

in the z (vertical) direction, where:
H = the height of the fall
d_b = the flow depth at the inlet to the manhole
V_b = the flow velocity at the inlet to the manhole
t = time
g = gravitational acceleration.
(Chanson 1999)

In larger installations a vortex dropshaft may be employed in order to encourage headloss, aeration and a smooth transition from high to low levels. These have the disadvantage of relatively large footprints, design costs and installation costs (Anderson, 1961).

The vortex encourages headloss through friction against the sidewall. The thin, fast moving sheet of water encourages aeration which may have a positive effect in depleted wastewater.

4 CFD MODELLING

As mentioned above the vast majority of the published work seems to have been undertaken using scaled physical models. This paper considers the hydraulic models of four general structure types using CFD techniques:

- A straight cascade manhole
- A cascading manhole with an offset inlet line
- A cascading manhole with an offset inlet and outlet line
- An external dropper manhole.

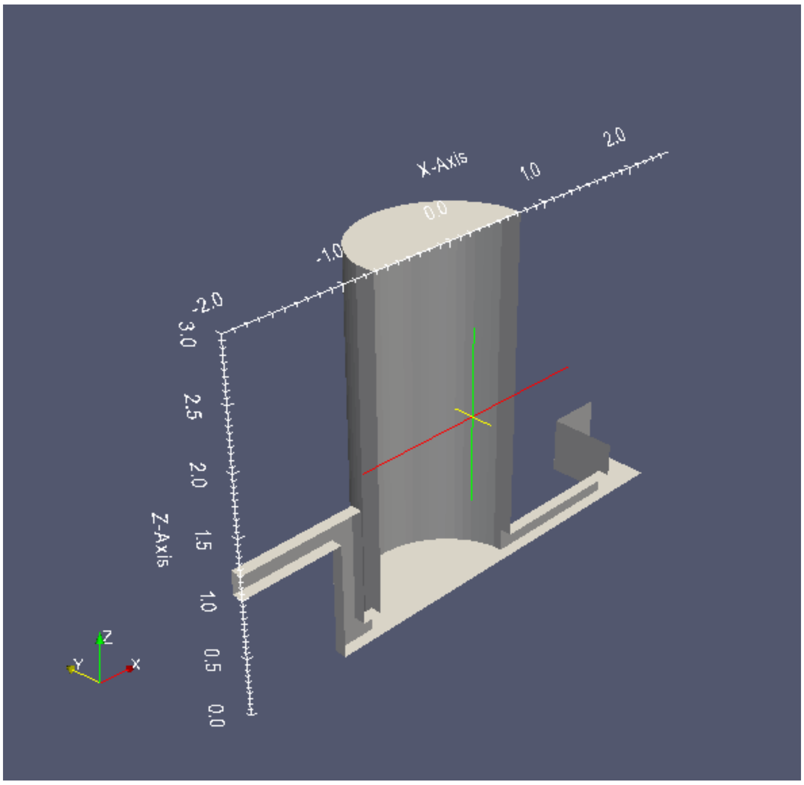


Figure 4: Typical external dropper model

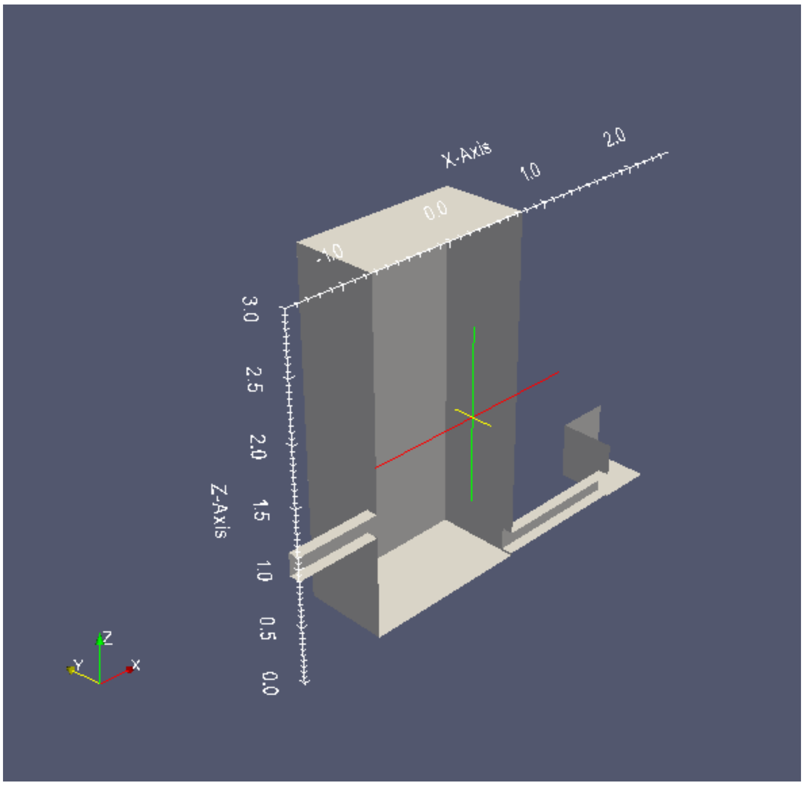


Figure 5: Typical square chamber model

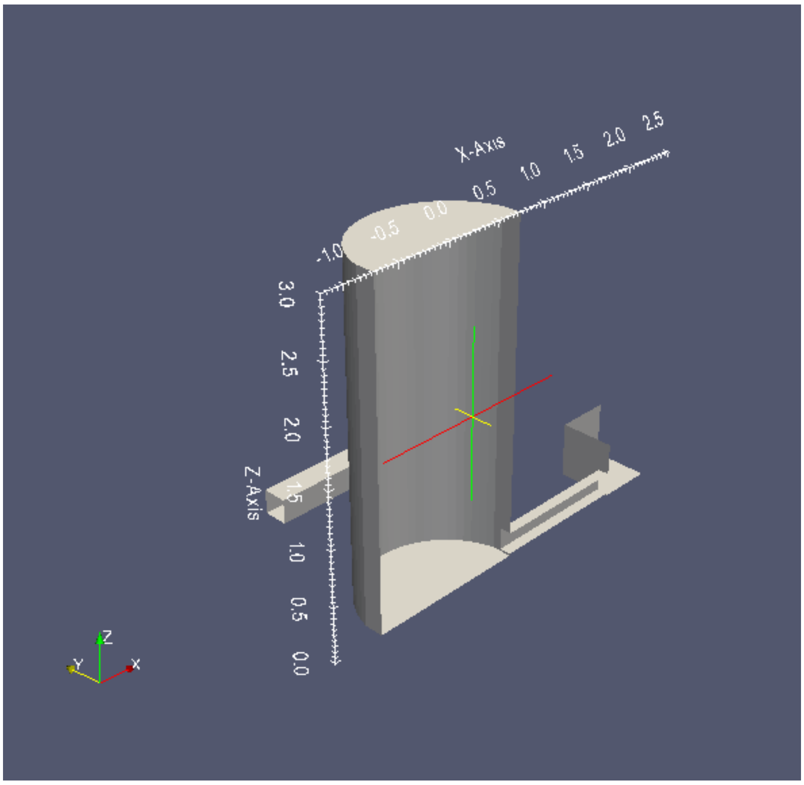


Figure 6: Typical manhole with offset inlet model

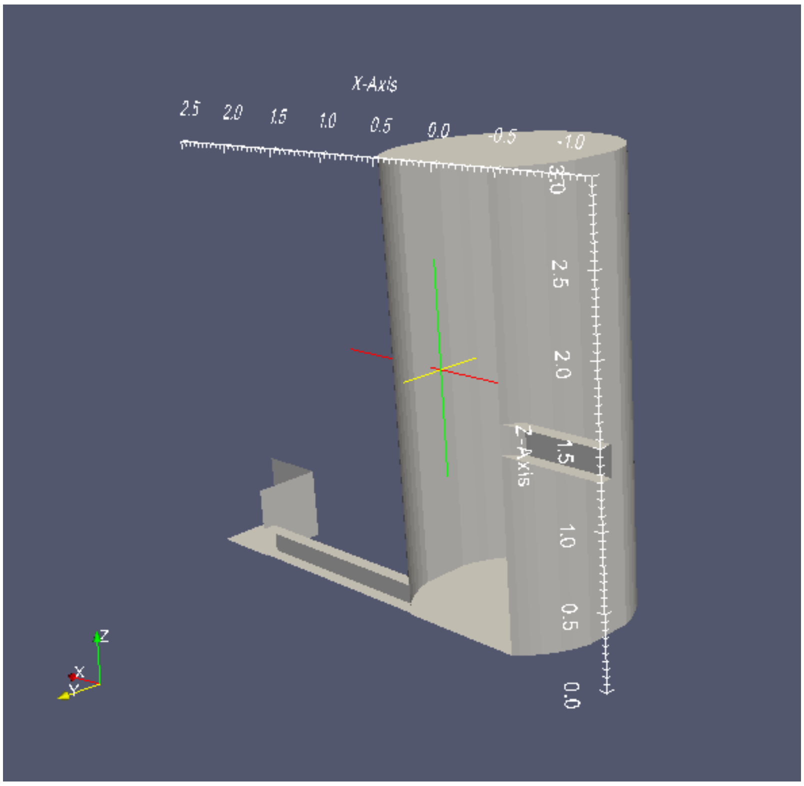


Figure 7: Typical manhole with offset inlet and outlet model

In each case the ‘pipes’ were modelled as 200mm x 200mm square conduits. This simplified the modelling of the inlet and outlet lines for offset applications and made for a better structured mesh.

Where a circular manhole has been modelled, this has been a 1.5m diameter manhole. Where a square chamber has been modelled, this has been 1.5 x 1.5m plan area. In all cases the manhole riser is 3m total height and sealed. The inlet water velocity has been modelled as 3 m/s or 120 l/s.

The modelling was undertaken using the OpenFOAM CFD modelling package developed by OpenCFD Ltd at the ESI group and distributed by the OpenFOAM foundation. The model meshing was done using the built in blockMesh utility. This produced a hexahedral mesh which is a requirement for dual fluid applications in OpenFoam. Automatic mesh refinement was used to allow the software to increase the model resolution in the area of the water surface.

The interFoam volume of fluid algorithm was used for the fluid modeling; this uses the PISO technique for turbulence modeling.

Timesteps were calculated at runtime, using a target Courant number of 0.8. This allowed the software to adjust the timestep to match the refining grid. Results were recorded at 0.05 second intervals.

Fall heights between 0.9 and 1.6m were modeled for the differing geometries.

Benching was included in selected models but this, at the flowrates modeled, did not have any significant (positive or negative) effect on the manhole hydraulics.

Headloss was calculated by taking a section through the inlet and outlet lines, taking using the velocity to calculate the v2/2g and averaging the values. The pressure head was divided by 1000 x g to equate to metres of head and the average of the flow area was taken to be the geodetic head. The sum of the three gave the total head at the section location. The difference between the inlet and outlet was taken to be the headloss.

5 QUALITATIVE HYDRAULIC AND TURBULENCE DISCUSSION

5.1 SQUARE CHAMBER

The direct fall from a square chamber manhole provided the most turbulent hydraulic conditions. While this does result in modest headloss there are very high near wall velocities resulting in high wall shear stresses. This can result in the erosion of the manhole structure over the life of the asset.

5.2 EXTERNAL DROPPER

The external dropper provided a slight improvement in the hydraulics, the relatively high velocities in the system made for a turbulent regime within the manhole, similar to that of the direct drop.

5.3 OFFSET INLET LINE

Vortex droppers, discussed briefly above are widely used for the drop shafts for high volume, high depth wastewater dropshafts. These large units tend to occupy a large plan area as well as being comparatively expensive to provide. In an effort to provide a similar (if less well controlled) effect, a circular manhole was modeled, with the inlet line offset to as close to a tangent as was considered practicable. The outlet line was retained in the normal central position. This resulted in the expected vortex fluid movement with the water 'orbiting' around the manhole centre at 4.8m/s (offset inlet with a 1.4m drop). The circular motion, however, meant that the flowline out of the manhole was sub-optimal with the flow lines needing to turn a 90 degree bend in order to exit. The streamlines in figure 4 show that the majority of the water leaving the manhole is directly from the falling nappe with only a minor component from the volume within the manhole.

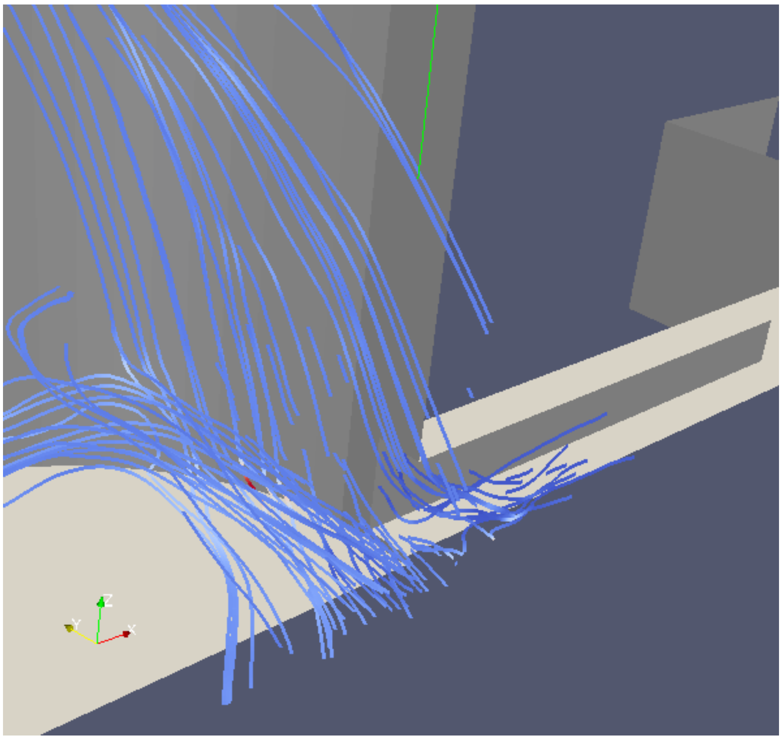


Figure 8: Flowlines at central outlet line

5.4 OFFSET INLET AND OUTLET LINE

With the obvious limitations with the option above, a manhole was modelled with the inlet and outlet line in a line, but the manhole offset (so as to have both inlet and outlet tangential to the manhole). This resulted in significantly better flowlines than that shown above, especially at the outlet. While there is some turbulent constriction of the flowlines, the majority of the falling nappe falls over the outlet line, thus creating a more constructive circulation at the base of the manhole.

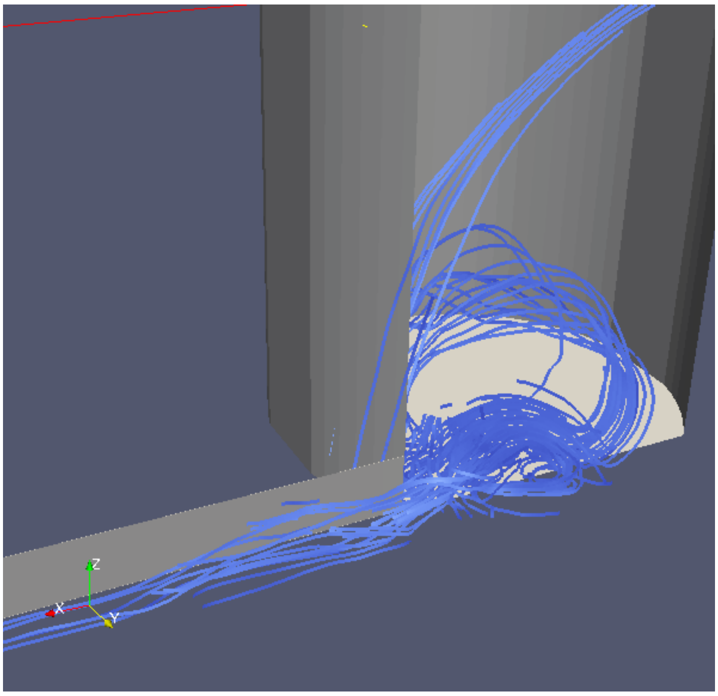
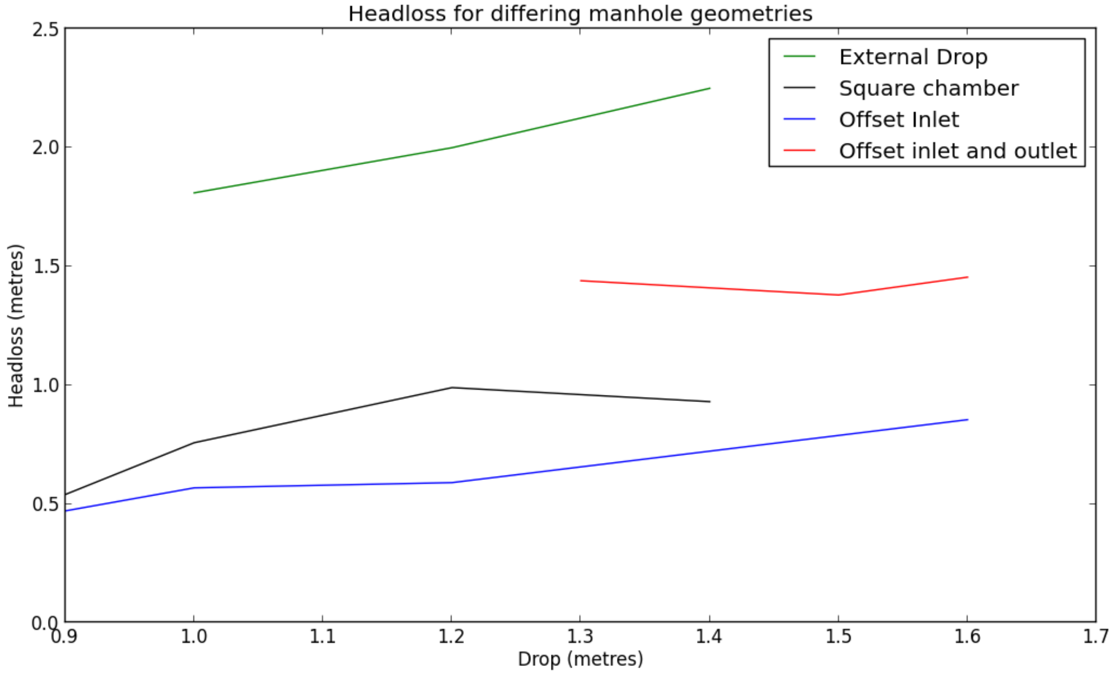


Figure 9: Flowlines at offset outlet line

6 MEASURED HEADLOSS

The headloss was calculated as outlined in section 4, above. This data was then tabulated against the height of the fall for each manhole type.



6.1 EXTERNAL DROP

Headloss for the external drop manhole was shown as being the highest for the calculated manhole geometries. This is hypothesized to be because of one or more of the following factors:

- The added friction loss due to the longer length of piped network
- The losses induced by the two right angled turns in the external dropper geometry
- The exit loss induced by the water discharging within the pool at the invert of the manhole

6.2 SQUARE CHAMBER

Chanson (2004) indicates that there is an expected reduction of headloss in a cascading manhole where the nappe falls directly onto the outlet line orifice. This is not apparent in the modeling undertaken in this study; however it may be more apparent with differing model geometries and / or differing inlet flows.

6.3 OFFSET INLET AND OFFSET INLET AND OUTLET

The modest headloss shown by the offset inlet only scenario is surprising to the author, given the complicated flow paths at the manhole exit. With this in mind the relatively substantial headloss shown in the offset inlet and outlet model is likewise surprising – the smoother exit lines would tend to suggest that the headloss would be less.

It is nevertheless suggested, however, that if moderate headloss is a requirement of the system design that the offset inlet and outlet manhole would present a good option to expend energy without the flow being overly turbulent within the manhole.

7 CONCLUSIONS

A number of manhole configurations have been assessed. The headloss for the various configurations have been graphed against the drop height. This shows that the maximum headloss can be achieved with an external drop configuration, however an offset inlet and outlet line, creating a vortex flow results in a significantly cleaner flow regime.

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REFERENCES

Anderson, S. H. (1961). *Model Studies of Storm-Sewer Drop Shafts*. St. Anthony Falls Hydraulic Laboratory, University of Minnesota.

Camino, G. A., Zhu, D. Z., Rajaratnam, N., & Shome, M. (2009). Use of a stacked drop manhole for energy dissipation: a case study in Edmonton, Alberta. *Canadian Journal of Civil Engineering*, *36*(6), 1037-1050.

Camino, G. A., Zhu, D. Z., & Rajaratnam, N. (2010). Hydraulics of Stacked Drop Manholes. *Journal of Irrigation and Drainage Engineering*, *137*(8), 537-552.

Carvalho, R. F., & Leandro, J. (2011). Hydraulic Characteristics of a Drop Square Manhole with a Downstream Control Gate. *Journal of Irrigation and Drainage Engineering*, *138*(6), 569-576.

Chanson, H. (1996). Energy loss at drops – discussion *Journal of hydraulic research*, IAHR, Vol 34 No. 2 pp 273 - 278.

Chanson, H. (1999, January). Energy dissipation and drop structures in ancient times: the Roman dropshafts. In *Water 99 Joint Congress, 25th Hydrology & Water Resources Symposium and 2nd International Conference on Water Resources & Environmental Research* (Vol. 2, pp. 987-992).

Chanson, H. (2004). Hydraulics of rectangular dropshafts. *Journal of irrigation and drainage engineering*, *130*(6), 523-529.

Del Giudice, G., Gisonni, C., & Rasulo, G. (2010). Design of a scroll vortex inlet for supercritical approach flow. *Journal of Hydraulic Engineering*, *136*(10), 837-841.

De Martino, F., Gisonni, C., & Hager, W. H. (2002). Drop in combined sewer manhole for supercritical flow. *Journal of irrigation and drainage engineering*, *128*(6), 397-400.

Granata, F., de Marinis, G., Gargano, R., & Hager, W. H. (2010). Hydraulics of circular drop manholes. *Journal of Irrigation and Drainage Engineering*, *137*(2), 102-111.

Granata, F., Gargano, R., de Marinis, G., & Hager, W. H. (2010). Choking features of drop manholes in sewer systems. In *Proc., 1st IAHR European Division Congress (CD-ROM), International Association for Hydro-Environment Engineering and Research*.

Granata, F., de Marinis, G., Gargano, R., & Hager, W. H. (2009). Energy loss in circular drop manholes. In *33rd IAHR Congress*.

Granata, F., de Marinis, G., Gargano, R., & Hager, W. H. (2011). Performance of Circular Drop Manholes in Ventilation Absence. In *Proceedings of the 34th World Congress of the International Association for Hydro-Environment Research and Engineering: 33rd Hydrology and Water Resources Symposium and 10th Conference on Hydraulics in Water Engineering* (p. 2444). Engineers Australia.

O'Loughlin, G., & Stack, B. (2002, September). Algorithms for pit pressure changes and head losses in stormwater drainage systems. In *Global Solutions for Urban Drainage, Proc. of the Ninth Int. Conf. on Urban Drainage, Sept 8-13 2002, Portland, OR*.

Sousa, V., Bombardelli, F. A., & Chanson, H. (2009). Numerical simulation of rectangular dropshafts using a volume-of-fluid (VoF) technique. In *33rd IAHR Biennial Congress* (pp. 7009-7016). IAHR.

Zhao, C. H., Zhu, D. Z., Sun, S. K., & Liu, Z. P. (2006). Experimental study of flow in a vortex drop shaft. *Journal of Hydraulic Engineering*, *132*(1), 61-68.