Paper 3 Building Vortex Drop Shafts in Dense Urban Areas – A Different Approach

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Abstract
Substantial flooding occurred in Maida Vale in 2007 and 2009. Optimise working with Thames Water investigated the flooding to understand its wider extent with over 200 properties impacted. Part of the solution required flows to drop into a tunnel and storage facility. To achieve this, a vortex type control structure was required to manage the drop of flows. An investigation led to the selection of a tangential vortex drop structure in preference to a scroll type (typically used in the UK). The tangential vortex drop helped to reduce the size of the shaft, saving significant cost and construction time. A physical model helped to verify and optimise the design, giving confidence in its performance.

Flooding in Maida Vale
Managing stormwater in large dense urban conurbations is challenging. Whilst long-term aspirations are moving to a combined grey / green / blue infrastructure approach (Digman et al 2014), providing immediate relief to flooding from the sewer system requires an increase to the capacity of the system, for example: through isolation, conveyance and storage.

The drainage system in London is widely interconnected, often through complex structures, with large trunk sewers running towards the River Thames and west to east. In 2012, Thames Water commissioned Optimise, a joint venture of MWH, Murphys, Barhale and Clancy Docwra to investigate flooding in the Maida Vale area of London and implement a solution by March 2015 with a target price of £17.5M. The investigation included updating the hydraulic sewer model to match flow and depth survey data and more detailed modelling of control structures where flows pass from the local sewers to and between the trunk sewers.

Flood events particularly in 2007 and 2009 highlighted a problem in the local area due to available capacity in the local system and some interaction with the main trunk sewers. Over 100 properties reported flooding at the time with sewage backing up into the basements.

Thames Water believed the number of affected properties to be far higher due to under-reporting. The investigation to flooding in Maida Vale highlighted a key industry challenge to understand which properties previously flooded. Some property owners tend not to report that flooding has occurred for a number of reasons. This can be due to the impact on property value whilst, in some urban areas, rental accommodation is high and tenancy turnover can be very high (e.g. in Westminster 30% turnover per year in rental properties (Rowing, Pers. Comm 2012)). Through a two year investigation with substantial effort of the design and engagement teams, the number of properties identified as flooding in the area and that would be protected through the schemes rose to over 180 (Figure 1).

Solving flooding in Maida Vale
An initial proposed ‘solution’ to prevent the flooding by tunnelling from the Shirland Road area to Formosa Street area would not have solved the flooding. The investigation enabled a greater understanding of the flows and interaction in the network to develop a new two-part solution. One part in the Shirland Road area involved the isolation of the properties, construction of a storage tank and the rearrangement of sewers and connections to the trunk sewers.

The second part of the solution located in Formosa Street involved the construction of a new tunnel, 400 m long, 2.4 m diameter, to take flows to a large storage tank in Westbourne Green and throttle flows upstream (Figure 2). Flows drop into the tunnel when low flows exceed the pass forward flow. The result is a lower top water level in the sewers in the Formosa Street area protecting the basements from flooding in a 1 in 30 year return period storm event.

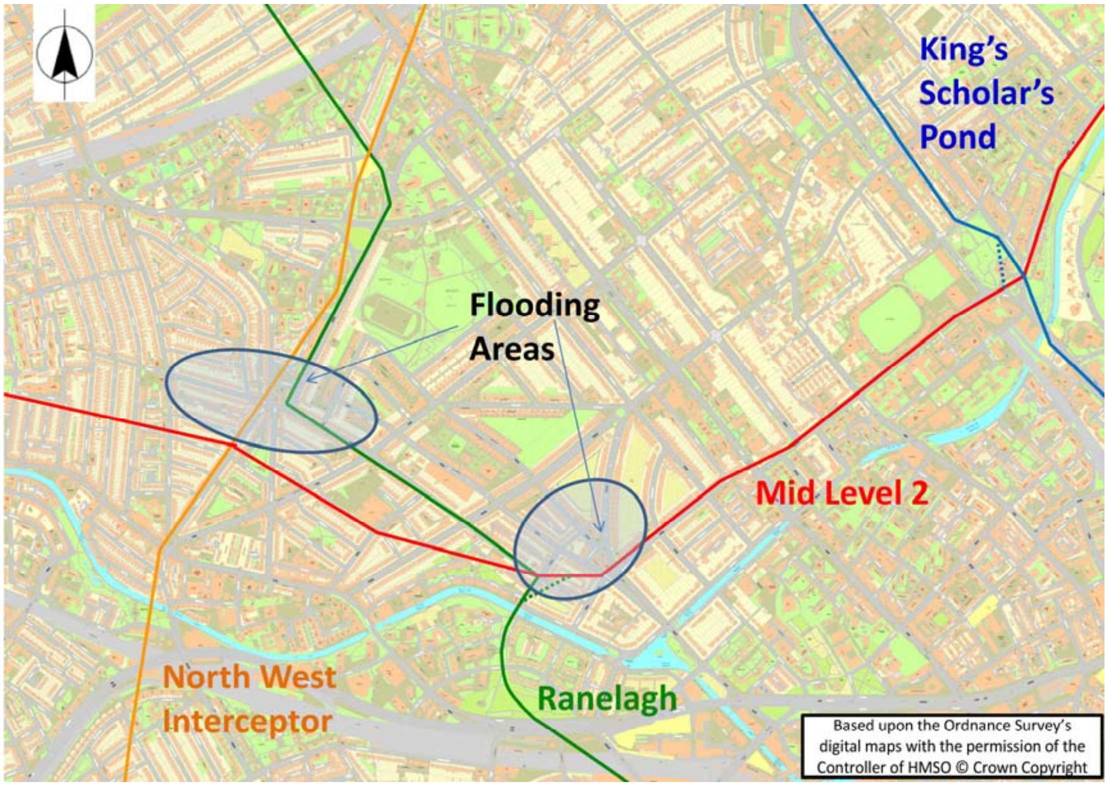

Figure 1 – Location of flooding in the Maida Vale area and trunk sewers.

A key challenge for the works in the Formosa Street area was taking the flows away from the flooding area to a location to store the storm water. This required a vortex drop shaft (Ackers and Crump, 1960) to control flows to the tunnel and the downstream storage (7500 m3 approx.). In total, 15 locations were investigated in the vicinity, but only one was acceptable, and this still required a number of major service diversions with typical drop shaft sizes. The chosen location, which also minimised the amount of disruption in the local area through pipe upsizing etc., is at the junction of Formosa Street and Shirland Road (Figure 3). This site position minimised the length of tunnelling and could be closed for up to 12 months. The typical arrangement often adopted in the UK and a standard approach on recent MWH designs to drop flows to a tunnel uses a scroll type vortex generator (e.g. Dempsey and Dempsey, 2010). This is an open volute-shaped chamber that imposes vortex motion on the flow, which enters the chamber tangentially (Figure 4).

To manage 3.8 m^3/s (of supercritical flow) dropping 13 m required a 7.5m diameter drop shaft. Also, to create subcritical flow, significant pipe upsizing and alterations upstream were required.

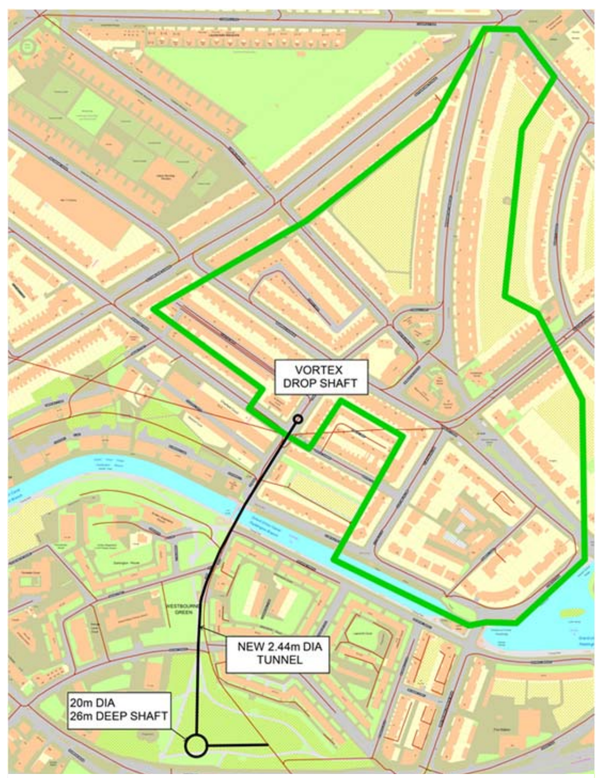

Figure 2 – Overall scheme to solve the Maida Vale flooding

However, the space was not available to build such a structure. This posed a substantial problem that could be solved potentially through a traditional engineering approach or provide an opportunity for the design team to assess the hydraulics and use an alternative drop structure.

Figure 3 (left) – location showing the challenges of building the vortex drop shaft within the existing site constraints minimising expensive utility diversions and being as far away as possible to neighbouring tall properties

Developing the vortex drop shaft within the difficult site constraints

With a clear need to reduce the footprint of the drop shaft at Formosa Street to avoid costly and time-consuming service diversions, a literature review investigated the potential alternate drop shaft intake options. The review focused on options with a smaller footprint than the scroll-type vortex generator. The review identified a number of alternatives such as plunge and helicoidal types (Williamson, 2001) and the preferred option, the tangential vortex generator (Jain and Kennedy, 1983;Jain, 1984; Williamson, 2001). This was a compact design that directs flow to the drop pipe tangentially to induce a vortex.

Figure 4 – Example of the scroll type vortex

A good understanding was available for the scroll vortex generator's depth-discharge characteristics across a range of scales and geometries. In comparison, there was far less knowledge of the characteristics and examples available of the tangential vortex generator in the UK, with it previously being used in the US and sometimes referred to as the Milwaukee intake (Del Giudice and Gisonni, 2010).

In the tangential vortex, the flow determines the hydraulic control point. The approach channel or pipe controls the water depth when the flows are low and the flow within the vortex generator are supercritical. For larger flow, the slot at the point where the intake meets the drop pipe controls the water depth. Flow stability is crucial to the operation of the structure and depends on the geometry of the vortex generator.

Building on papers by Jain (1984) and Williamson (2001), and in discussion with Hydrotec Ltd, a methodology developed by Yu and Lee (2009) was used help create the conceptual design of the tangential vortex drop shaft. This outlined a number of geometry and flow conditions to ensure stability of the hydraulic operation of the vortex. An outline design was developed following these conditions.

Verifying the tangential intake vortex drop through physical modelling

The review identified a lack of industry examples of the tangential vortex drop shaft in the UK. The specific conditions found at Formosa Street, including supercritical approach flow, a shorter and steeper taper (than recommended) and limited available space, led to the commissioning of a physical scale model. Optimise appointed Hydrotec Consultants Ltd to test, verify and optimise the design. The aim was to demonstrate that the top water levels in the upstream system were below flood levels, the vortex drop shaft operated as designed and air was expelled back up the shaft from the de-aeration chamber and tunnel outlet. Hydrotec built a 1/5th scale model of the upstream pipework and manhole, tangential drop shaft, de-aeration chamber and outgoing tunnel (Figure 5).

Initial testing ran the equivalent 1 in 30 year return period flow through the network (3.8m^3/s). This indicated that the height of the tangential vortex walls had to be increased to prevent overtopping (Figure 6). Initial observations showed significant entry head losses to the pipe leading to the vortex in the upstream manhole. Here a new 800mm dia pipe to be built in parallel with an existing brick egg sewer upstream joined the manhole. The losses resulted in higher than acceptable water levels upstream of the manhole, leaving properties at risk of flooding (Figure 7).

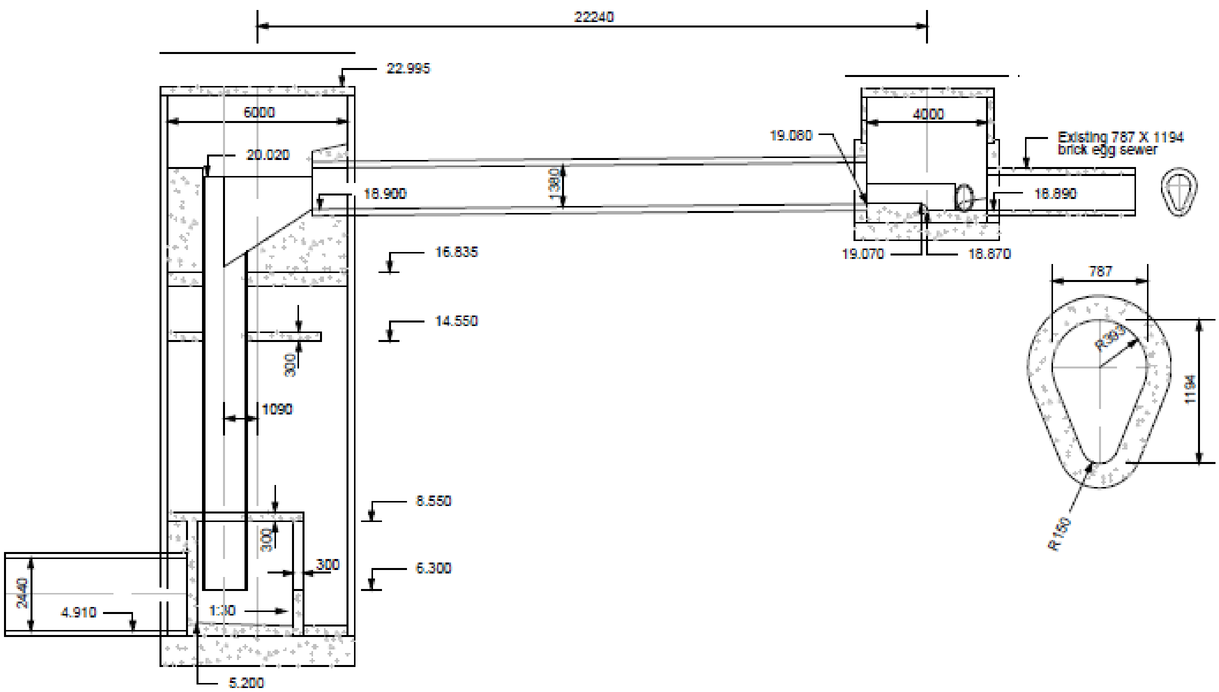

Figure 5 – Drawing showing the section of the drop shaft and upstream manhole

A change in the benching height and shape reduced flow separation at the entry point and improved the transition of flow. Despite the changes, a noticeable separation zone was apparent and required an alternative upstream arrangement. This resulted in replacing the egg shaped sewer online rather than duplicating it. This significantly improved the transition of flows, reducing the inlet head losses substantially and reducing air entrainment in the connecting sewer.

Testing demonstrated there was stability in the vortex generator with air transport and the associated turbulence acceptable. In the receiving shaft, air was released to the free surface in the outlet tunnel and back to the shaft when the water level was below tunnel soffit. Two cases of air entrainment occurred during full pipe submergence. Air migrated to the soffit (Figure 8), accumulated and travelled back to the shaft. Under a range of flow conditions, the de-aeration chamber promoted significant energy dissipation.

Figure 6 – Testing of the tangential intake vortex drop (1), flow entering the vortex drop under critical conditions

Figure 7 – Testing of the tangential intake vortex drop (2), control point for the flow upstream and substantial head losses

Figure 8 – Testing of the tangential intake vortex drop (3), de-aeration chamber for the 1 in 30 year return period flow with tunnel full. Note the bubble track rapidly directs air to the soffit

Extreme testing of the vortex drop shaft demonstrated its operation for higher flows. As flows reached the equivalent of 4.2 m^3/s, conditions became considerably more turbulent local to the vortex generator, with out of channel flow at the vortex.

The learning and amendments from the design were used to amend the hydraulic sewer model. One of the outputs from the physical model process was a measured level vs discharge curve for the upstream chamber. The primary controlling factor for this flow was an orifice effect caused by flow in the outgoing pipe connecting the chamber to the drop shaft at high (design) flows. The level vs discharge curve was used to define an equivalent orifice for the hydraulic sewer model to represent the flow entering the drop shaft. It was not possible to import the measured curve directly into the model because the relationship only applied when the drop shaft was not surcharged. Representing the drop shaft in its surcharged state was outside the scope of the physical model.

The benefits of adopting the tangential approach for vortex drop shafts

The Formosa Street tangential vortex generator is currently under construction with the drop pipe being installed within a 6 m diameter drop shaft with a 1.4 m diameter concrete approach pipe. Selecting and building the tangential vortex drop shaft at Formosa Street resulted in a number of specific benefits to the project. Table 1 outlines these specific project benefits. This innovation resulted in cost savings in excess of £600,000 and a reduction in programme of at least six weeks.

A broader review comparing the tangential and scroll vortex type drop shaft identified three key aspects:

- **Smaller footprint -** The tangential vortex generator is less than half the width of a scroll vortex generator. It is easier to construct and support within the shaft due to the reduced size of the generator. The drop pipe could be constructed as a steel special and lowered in one piece rather than casting in-situ. This reduces the cost and makes it safer to construct whilst providing good visibility and space for safe access to the bottom of the shaft.

- **Improving the hydraulics -** The geometry of the tangential vortex generator ensures the velocity (and kinetic energy) of the incoming flow is high. This is efficiently transferred into a vortex motion at the slot at the downstream end of the vortex generator. By contrast, the scroll vortex generator is relatively low velocity and is typically used with a sub-critical approach flow. The upstream water depth required to induce vortex flow is therefore greater. A reduction in flow depth upstream of the vortex reduced the size and depth of the approach pipe or channel, hence minimising the costs to build the structure.
- **Accommodating a range of approach flows -** The approach flow to a tangential vortex generator can be either supercritical or subcritical. This flexibility means that a tangential vortex generator can be easily adapted to incoming sewers that are relatively steep..

Table 1: Comparison of tangential and scroll vortex generators

Aspect	Tangential Vortex Generator	Scroll Vortex Generator
Approximate vortex generator dimensions	Width = 1.4m Length = 3.6m	Width = 4.2m Length = 3.5m
Diameter of shaft required to contain vortex structure	6m	7.5m*
Size of approach pipe/channel**	1.4m diameter pipe	1.4m wide x 2.4m high culvert with 1m cascade at upstream end in a new structure
Depth of approach pipe/channel	4.5m to invert	5.5m to invert
Utility service diversions	2 No. HV cables	2 No. HV cables 2 No. LP gas mains 1 No. 180mm water main with lateral connections
Management of wastewater and stormwater during construction	0.9m diameter concrete bypass pipe	Over-pumping up to 1.5m^3/s
Streetworks reinstatement	Carriageway	Carriageway and footpath
Operation and maintenance	Higher energy (supercritical) intake. Reduced likelihood of solids deposition and odour issues.	Typically lower energy (subcritical) intake. Increased likelihood of solids deposition and odour issues.

** Although the scroll vortex generator could physically fit within the 6m shaft, it was not possible to provide safe operator access to the shaft base without an increased shaft size. A 7.5m shaft is the next commercially available size but would of course incur greater cost and procurement timescales.*
*** Required length of pipe/channel is 20m in both cases.*

Since developing this approach and completing the physical testing, the learning has been applied to other Optimise contracts with the construction of another tangential drop shaft with a revised taper. The reduced footprint meant the drop pipe could be constructed within a smaller shaft within woods, minimising the disruption and environmental impact.

Conclusions

The need to drop substantial flows to a tunnel and storage in a dense urban area resulted in an investigation into appropriate vortex drop structures. The reduced space and requirement to ensure the top water level entering the vortex and upstream were kept low to prevent flooding combined with minimising construction costs and time, led to the selection of the tangential vortex type structure. A physical model helped to verify and optimise the design, including amending the vortex walls and upstream chamber and pipe design to minimise head losses. The physical model demonstrated the successful expulsion of air from the bottom of the shaft under the 1 in 30 year return period conditions. This tangential vortex drop shaft can be applied in other situations to enable construction in locations where space is a premium and help reduce costs.

Acknowledgement

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References

Ackers, P. and Crump, E.S. (1960) The Vortex Drop, ICE Proceedings, Volume 16, Issue 4, 01 August 1960 , pages 433 –442

Dempsey, T and Dempsey S (2010) Preston UID Scheme, Spring WaPUG, Coventry

Digman C.J., Ashley, R.M., Hargreaves, P. and Gill, E. (2014a) Managing urban flooding from heavy rainfall - Encouraging the uptake of designing for exceedance – Summary Report. C738a

Del Giudice, G. and Gisonni, C. (2010) Vortex dropshafts: history and current applications to the sewer system of Naples (Italy), First IAHR European Congress – May 2010

Jain, S. C., and Kennedy, J. F. _1983_. "Vortex-flow drop structures for the Milwaukee metropolitan sewerage district inline storage system." Rep. No. IIHR Rep. No. 264, Iowa Institute of Hydraulic Research, The Univ. of Iowa, Iowa City, Iowa.

Jain, S.C. (1984) Tangential Vortex-Inlet, Journal of Hydraulic Engineering, 110:1693-1699

Williamson, S (2001) Drop Structure Design for Wastewater and Stormwater Collection Systems, 1998 William Barclay Parsons Fellowship, Parsons Brinckerhoff Monograph 14.

Yu, D. and Lee, J.H.W. (2009) Hydraulics of Tangential Vortex Intake for Urban Drainage, Journal of Hydraulic Engineering, Volume 135, pp 164-174.