



**FORMER TETROSYL SITE
BEVIS GREEN
WARMERSLEY
BURY**

BURY DROP STRUCTURE MH6

**PHYSICAL AND COMPUTATIONAL HYDRAULIC MODEL TESTING
for
BARRETT HOMES MANCHESTER**

FINAL REPORT

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SUMMARY

This report covers the initial testing undertaken on a physical hydraulic model of the Bury Drop Structure MH6. The physical model was constructed to a scale of 1:7 full size and operated on the basis of Froude law similarity.

Initial testing

The Bury Drop Structure MH6 physical hydraulic model was tested at a number of flow rates representative of the specified flow range. Initial testing was conducted prior to confirmation of the tailwater levels by the Client, as such free discharge conditions were assumed for initial assessment purposes. Initial testing found that the Bury Drop Structure MH6 generally performed satisfactorily for the flow rates investigated, however, minor performance issues were identified that needed to be addressed. A continuous nappe formed at each cascade, which may prevent air from freely venting to atmosphere. Trapping air has the potential to locally pressurise the shaft, which may cause structural damage. The continuous nappes formed at each platform should be disrupted and broken up in order to allow air to be freely vented.

The proposed platform ledges acted to pool water on the platform which dissipated energy at each platform, however, at higher flow rates, a smaller proportion of the receiving flow was intercepted. This resulted in high energy flows cascading onto the platform below. The energy of these nappes formed at each platform of the cascade should be reduced, in so far as can reasonably be achieved.

Development

In order to mitigate the performance issues identified during initial testing, the following modifications to the Bury Drop Structure MH6 arrangement were made:

- At each platform, a flow deflection column was installed at the downstream ledge of each platform, to one side of the shaft, adjacent to the shaft wall. The purpose of the flow deflection columns was to deflect nappe flow away from the shaft wall, creating an air gap through which the entire chamber could be vented to atmosphere. The flow deflection columns were also intended to direct flow away from the shaft man access ladders located at each platform, in so far as was possible. This was proposed in order to reduce potential ragging of solids to the access ladders and to protect them from excessive hydraulic loading.

- The height of each platform ledge was increased by 50 % from 200 mm to 300 mm. The increase in ledge height was intended to intercept a higher proportion of the flow, which will increase the depth of pooled water retained at each platform. The increase in the retained water depth will dissipate a larger proportion of the energy of the receiving flow. It should be noted that, although the increase in ledge height will dissipate more energy, the flows through the drop structure are inherently high energy, especially at the higher flow rates. Therefore, although energy dissipation will be increased, the nappe flows produced at each platform will still exhibit significantly high energy and turbulence.

Final Testing

The modified Bury Drop Structure MH6 physical hydraulic model was tested at a range of flow rates and water levels provided by and agreed upon by the Client. Hydraulic assessment of the Bury Drop Structure MH6 physical hydraulic model found that the drop structure conveyed the flows safely and performed satisfactorily for all flow rates and tailwater levels investigated. Three different general flow conditions occurred within the drop structure, depending on the water level within the shaft:

1. At the higher water levels (100 years + 70% and 1000 year return periods), the drop structure was almost completely surcharged, i.e. up towards the shaft soffit. As flow passed across the shaft soffit at surcharged operation, air was entrained into the flow from the vent provided in the model soffit. This indicates that a vented soffit must also be installed in the prototype drop structure, as failure to do so may result in the chamber becoming depressurised, which could lead to structural damage and possible accelerated failure.
Submerged flow conditions occurred throughout the drop structure at the specified flow range of 100 years + 70% and above. At these conditions, flow paths were dictated by the arrangement of the platforms and the flow was conveyed through the drop structure and into the Outlet Culvert safely.
2. At a return period of 100 years + 35%, the water level within the drop structure was approximately at mid shaft height. In the upper section of the drop structure free-surface flow occurred and the flow cascaded from each platform to the next. This regime was characterised by high levels of air entrainment at each platform. The proposed increase in the height of the platform ledges increased the depth of the retained flow on each platform, which in turn increased energy dissipation. The proposed vertical flow deflection columns at each platform ledge acted to deflect flow away from the wall of the drop structure, allowing air to freely vent to

atmosphere. The flow deflection columns also deflected flow away from the man access ladders somewhat. At the lower depths, submerged flow occurred and the flow patterns were comparable to those at the higher water levels, but with slightly lower velocities and a higher volume of entrained air.

3. At the lower tailwater levels (return periods of 2 years, 20 years and 50 years) the water levels within the drop structure were closer to the invert of the shaft. Under these conditions, flow was also conveyed safely through the drop structure. Free surface cascading flow occurred at each landing level within the drop structure, characterised by high levels of splash, spray and air entrainment. Again, the proposed increased ledge heights increased the depth of retained water on the platforms, increasing energy dissipation, and the flow deflection columns diverted flow away from the wall of the chamber, creating an air gap through which air could be freely vented to atmosphere. The water levels at the base of the drop structure shaft, dictated by the receiving water course tailwater levels, also acted to cushion the flow and increase energy dissipation.

The solids handling of the drop structure was investigated for a range of operating scenarios. Solids were cleared from the drop structure quickly and efficiently at all flow rates investigated. At the higher water levels, solids were held in suspension and transported through the drop structure. Highly buoyant solids, representative of solids such as footballs and plastic bottles, were not drawn through the Inlet Culvert due to the water depth in the drop structure being significantly higher than the soffit of the Inlet Culvert. This is representative of the prototype flow conditions.

At a flow rate of 5670 l/s, the water level was at approximately the mid height of the drop structure. In the upper section of the drop structure free-surface cascade flow was exhibited and solids were either suspended in the flow or tracked along the base of each platform, prior to being transported over the platform ledge to the receiving platform below. In the lower section of the drop structure submerged flow conditions occurred and solids were cleared in a similar manner to those at the higher flow rates and tailwater levels. There was some temporary retention of highly buoyant solids within the submerged flow region within the shaft, however, the highly buoyant solids were cleared from the shaft towards the Outlet Culvert after a short duration of operation.

At the lowest specified flow rate of 1400 l/s, all solids were cleared throughout the drop structure. Cascading free-surface flow occurred throughout the structure and all model solids (floating, suspended and settleable), were transported across each platform, either in suspension, or across the base of the platform to pass over each platform ledge to the successive receiving platform below. Solids were directed towards the central channel formed at the invert of the shaft and out into the outlet culvert within the region of fastest moving flow.

At the lowest specified test flow rate of 1400 l/s, the lowest velocities occurred throughout the drop structure. This indicates that all solids will also be cleared forward to the Outlet Culvert at the higher flow rates of 2800 l/s and 3500 l/s, at which cascading flow also occurred and the flow conditions were comparable.

CFD Modelling of Dry Weather Flow Conditions

Following physical hydraulic modelling of the storm flow conditions, analysis of the dry weather flow conditions (DWF) was conducted. Scaled physical hydraulic modelling of the DWF conditions was not appropriate, as the lower flow rates caused surface tension effects to dominate, preventing accurate analysis to be made. Therefore, Computational Fluid Dynamics (CFD) modelling of the DWF conditions was conducted at full scale. The main purpose of the DWF analysis was to determine whether silts and settleable solids would clear at the lower flow rates.

The arrangement of the drop structure was modified to aid the transport of solids. A number of additional slots were installed in the platform ledges in order to promote flow to spread and transport solids. Primary CFD analysis found that this arrangement resulted in low velocity, recirculation regions, which would be prone to solids accumulation. A revised arrangement was proposed in which a DWF flow channel was installed at Level 1 and benching was installed at Levels 2,3 and 4, in order to promote the transport of solids. CFD analysis of this revised arrangement found that at Level 1, all flow passed through the DWF channel with a high enough velocity to transport silts and settleable solid. At levels 2 - 5, CFD modelling found that temporary stranding of solids would likely occur. This is to be expected and is not detrimental to the performance of the drop structure. The velocities and turbulence throughout Levels 2 – 5 were sufficiently high to prevent long-term accumulation of solids in any one location. It should be noted that, the proposed modifications are small compared to the length scales of the storm flows. Therefore, the findings of the physical hydraulic model study of the storm flow conditions are applicable to the revised proposed DWF arrangement.



This text report is accompanied by a video record in WMV format, which provides video sequences of pertinent details of the model operation.

A handwritten signature in blue ink, appearing to read "Sean MacCarthy".

Sean MacCarthy
Director

1.0 INTRODUCTION

1.1 Description of scheme

A drop structure is proposed on a culverted watercourse to be constructed as part of a development scheme at a former chemical plant in Bury, Greater Manchester. Barratt Homes is to undertake an approved development for 267 residential dwellings at Bevis Green, Warmersley, Bury. The site is a former mill site which, in recent years, has been occupied by Tetrosyl Chemicals. See Location Plan, Figure 1.01.

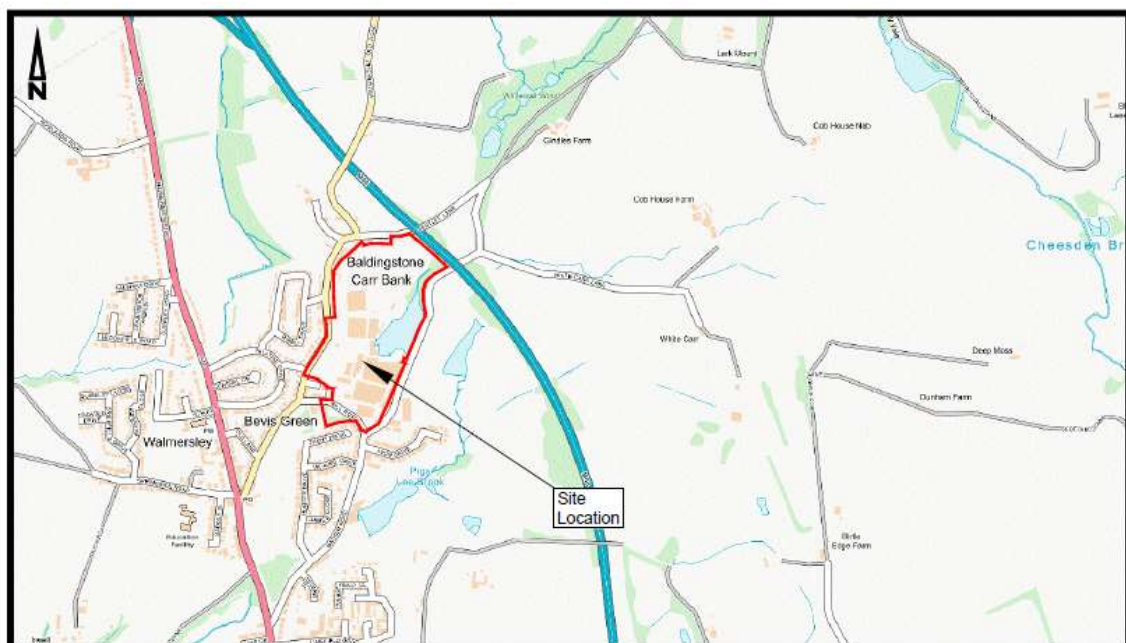


Figure 1.01 – MH6 Drop Structure Development Site Location Plan

A tributary of the Pigs Lee Brook is routed through the site, via the former mill reservoir and then southwards through a stone block culvert of varying size. The culverted watercourse exits the site at the southern boundary and enters a 1200 mm culvert before discharging to open watercourse several hundred metres downstream. As part of the approved works the former mill reservoir will be drained and replaced with a smaller Flood Storage Area (FSA). A new reach of open watercourse (some 300 m long), will be implemented to replace a length of existing culvert (downstream of the reservoir), which will be abandoned as its current alignment takes it below the proposed residential development.

Figures 1.02 and 1.03 show the route of the existing and proposed culverts, plus the diverted watercourse and the proposed location for the MH6 drop structure.

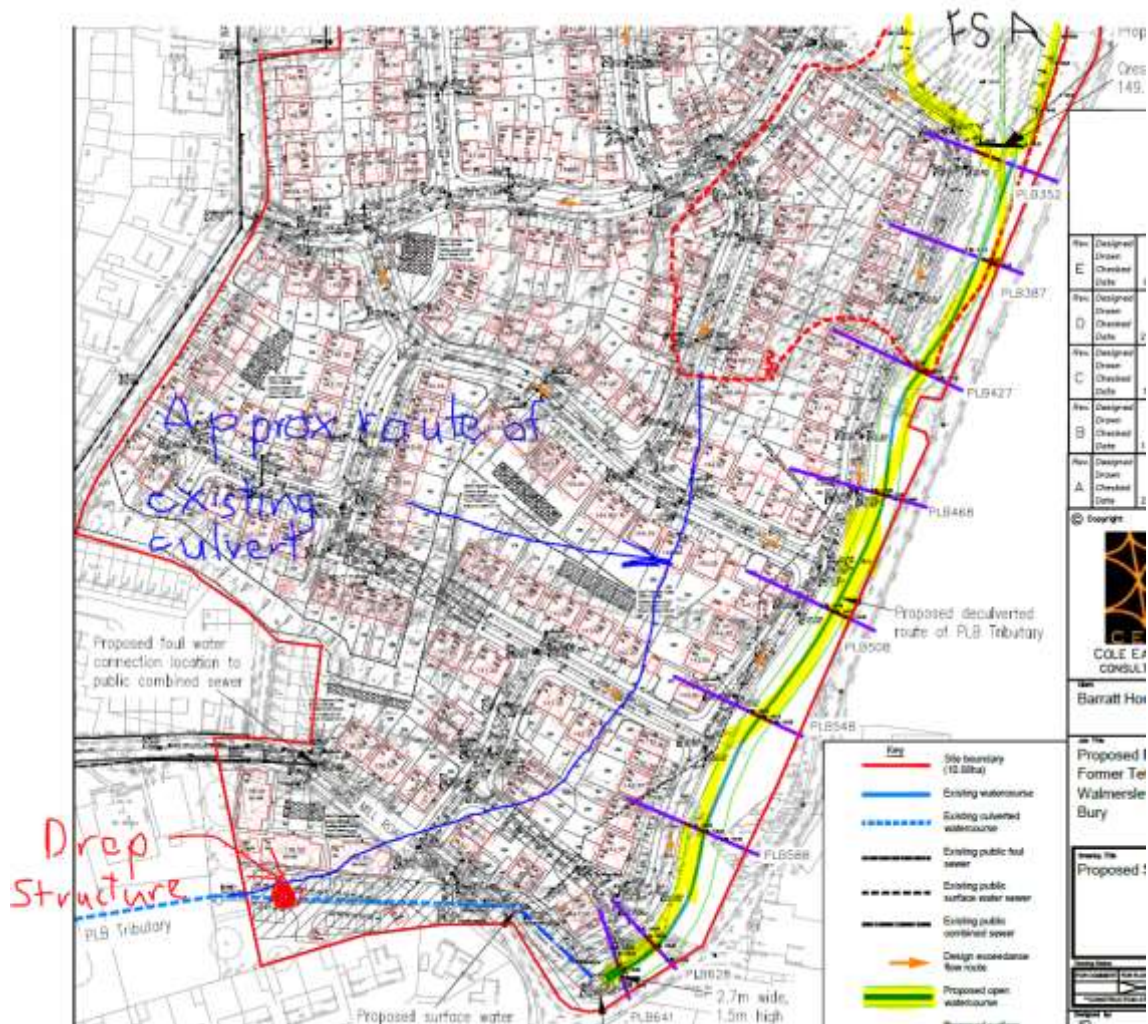


Figure 1.02 – Route of Existing Culvert, Proposed Water Course Diversion & Location of MH6

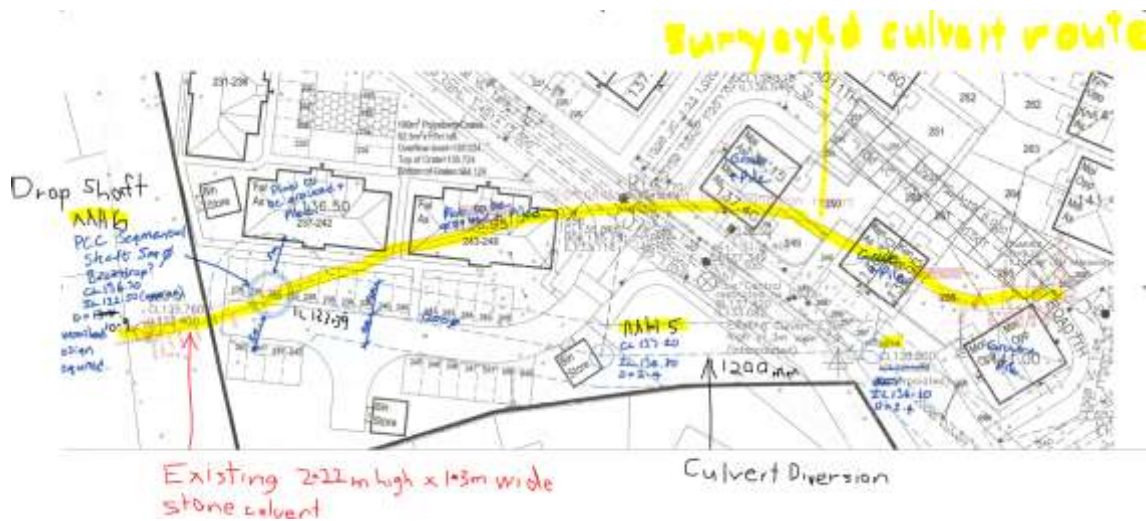


Figure 1.03 – Surveyed Route of Proposed Culvert & Location of MH6

Hydraulic flood modelling and flood risk studies have been undertaken by Cole Easdon Consultants (CEC) in support of the planning application. Detailed design of the proposed watercourse diversion has been undertaken as per the approved Flood Risk Assessment and Hydraulic Modelling Study. The design is to include a PCC segmental drop structure, drop height 10.580 m. The drop structure is to be located at the point where the proposed watercourse diversion culvert joins the existing 2.22 m high x 1.3 m wide stone culvert. Peak flows within the proposed culverted section of the watercourse are provided Table 1.01.

Table 1.01 Pigs Lee Brook – Bury Drop Structure MH6 Storm return periods and predicted flow rates (after Cole Easdon Consultants)	
Return Period (years)	Predicted Flow rate (l/s)
2	1400
5	2000
10	2400
20	2800
30	3100
50	3500
75	3900
100	4200
100 + 35%	5670
100 + 70 %	7140
1000	7500



The design of the sequential drop shaft structure was proposed by Hydrotec Consultants Ltd (HCL) prior to commencement of physical hydraulic modelling. The proposed drop shaft structure consists of a cylindrical chamber with an inlet culvert close to the top of the chamber and an outlet culvert at the base of the chamber. The outlet culvert is orientated at 29° from the inlet culvert. It is proposed to achieve the transition in height from the inlet elevation to the outlet culvert elevation with a cascade type drop shaft.

The primary purpose of a drop structure is to dissipate energy as the flow transitions from a high elevation to a low elevation, to prevent the undesirable effects of high velocity flow and to allow the safe transport of entrained air. Common design options for drop structures include the simple plunge type, the vortex type and the cascade type. The simple plunge type is a poor energy dissipator so was not considered. The vortex drop design is an efficient energy dissipator. However, this design is usually employed for large vertical drops in which the drop height is greater than 5 diameters, which is not the case for the current project. Vortex drop shafts also provide limited access for personnel and equipment. Cascade drop shafts provide efficient energy dissipation and deaeration and also provide access for personnel and equipment. For these reasons, the cascade type drop shaft was chosen for the design of the Bury Drop Structure MH6.

The inlet culvert discharges directly to a platform, Level 1, then onto platform Levels 2, 3 and 4, prior to discharge to the shaft invert and then forward into the outlet culvert. The landings are arranged at incremental orientations to allow a perpendicular inlet connection and a perpendicular orientation of the platform at Level 4 to the Outlet Culvert. Hence at a 29° offset between the Inlet Culvert and the Outlet Culvert, there are 3 incremental orientations of platforms throughout the drop (Level 1 to Level 2, Level 2 to Level 3 and Level 3 to Level 4). The incremental offset of the platforms at each level is, therefore, is $29^\circ/3 \approx 9.7^\circ$.

The landings are identical in plan and occupy slightly more than half of the chamber plan section. Each platform consists of a landing bay, ledge, access ladder and handrail (note that the handrails are not included in the physical hydraulic model, their dimension is too small to be adequately scaled.). The vertical access ladders are fully representative. A footing slab is provided for the access ladder at each landing junction in order to provide a flat, level man access, raised above the landing elevation.



The landing ledge is located at the downstream edge of the platform, this is to produce a retained water to pool behind on the platform to aid in energy dissipation of the free fall jet. The landing ledge does not extend across the full width of the platforms. A 750 mm opening is provided to one side of landing ledge in order to allow drainage during low flow conditions, and also to preferentially direct lower flows away from the access ladders.

Laterally and transversely sloped benching is proposed to form the shaft invert at the base of the cascade structure. This benching is intended to direct flow centrally and promote solids particle tracking towards the shaft centreline and into the outlet culvert within the fastest moving current at the culvert centreline. This is proposed in order to aid self-cleansing characteristics.

The detailed general arrangements of the proposed cascade drop shaft structure for MH6 are shown on Drawings 01 to 04 in Appendix 2. Figure 1.04 details the general terminology used throughout this report.

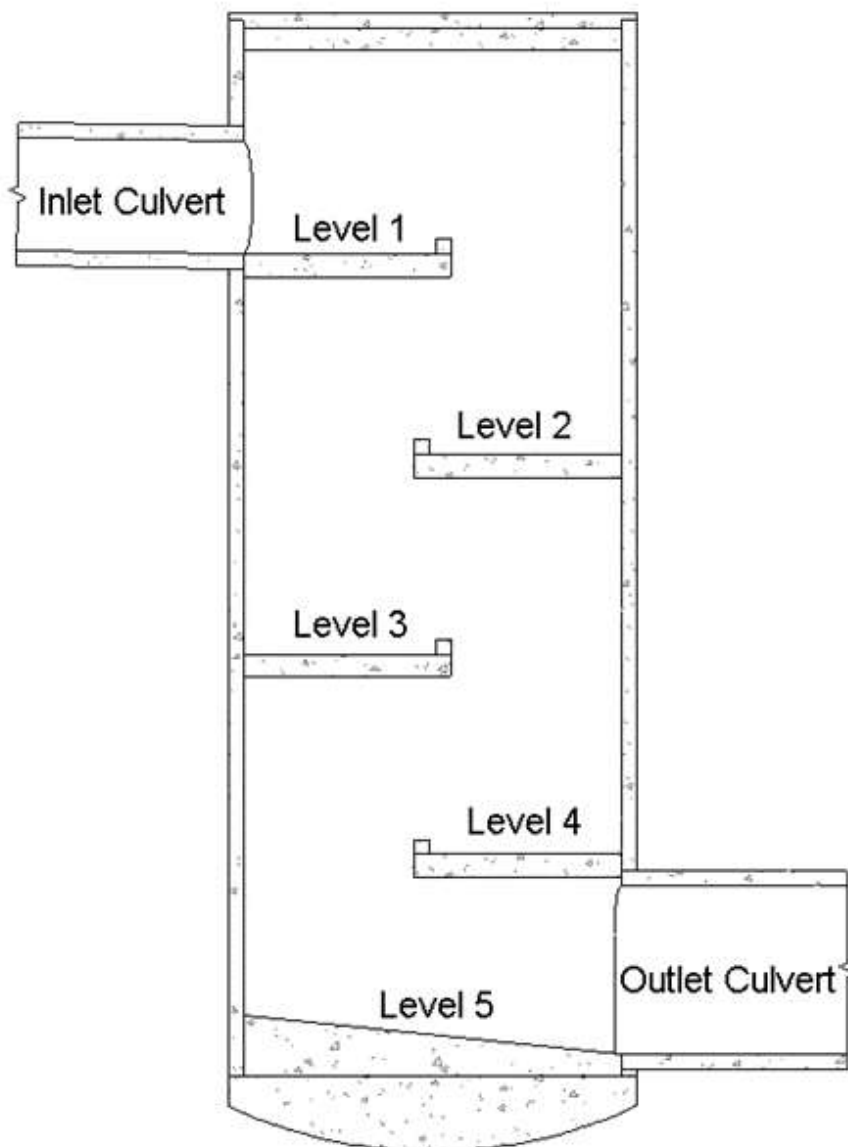


Figure 1.04 – General arrangement of Bury Drop Structure MH6, detailing the terminology used throughout this report

1.2 Purpose of testing

The purpose of the physical hydraulic model test of the MH6 Drop Structure was, as a minimum, to satisfy the following primary objectives: -

- Confirmation of satisfactory hydraulic performance at the Drop Structure for all test case scenarios of inflow and water level.
- Confirmation of satisfactory solids handling and removal from the vicinity of the structure.

1.3 Determination of model scale

In order to ensure efficient and reliable operation of the proposed drop structure, it was essential that the physical model testing was undertaken at a suitably large scale in order to ensure dynamic similarity at all pertinent flow cases.

In selecting the optimum scale for a model, consideration must be given to a range of factors both practical and theoretical. Practical considerations such as the circulating pump capacity, depth of model, the floor space utilised and ultimately cost, place limits on the maximum size of a model. Theoretical considerations regarding the correct representation of flow conditions places limits on the minimum size of a model.

The correct representation of flow conditions principally requires the Reynolds Number to be above a critical value within the model to ensure that, where fully turbulent conditions are present in the prototype, similar turbulent conditions exist within the model. If the model is too small this condition will not be met.

In mixed closed conduit and free surface models, such as drop shaft type applications, it is necessary to ensure that the Reynolds Number (Re) at surcharged locations exceeds 30,000 with a factor of safety of 2.0, hence a value of not less than 60,000, and that the Reynolds Number at free surface regions exceeds 5,000. This is to ensure that viscous scale effects are minimised and to ensure that, where fully turbulent conditions exist on the prototype, they are similarly represented on the model.

The drop shaft was modelled at a scale of 1:7. Table 1.02 shows the prototype and model Reynolds numbers at the specified minimum and maximum flows. The Reynolds numbers were calculated at the Outlet Culvert, assuming full depth. This is standard practice as it results in a conservative calculation, as if the Outlet Culvert ran at a lower flow depth for a particular flow rate, the Reynold number would be greater. As shown, the minimum Reynolds number is above the limiting value of 60,000, hence all model flows were in fully turbulent regime.

Table 1.02 Bury Drop Structure MH6 Reynolds numbers			
Return Period (years)	Prototype Flow Rate (l/s)	Reynolds Number	
		Prototype	Model
2	1400	1,148,983	61,336
1000	7500	6,155,268	330,758

1.4 Flow rates and operating philosophy

Upon agreement with the Client, the physical hydraulic model was tested at the flow rates and tailwater levels shown in Table 1.03. This provided a representative range of operating scenarios to investigate the flow conditions within the drop shaft. The tailwater levels for each flow rate were provided by the Client and calculated by CEC through numerical hydraulic modelling.

Table 1.03 Bury Drop Structure MH6 Model test flow rates and tailwater levels		
Return Period (years)	Flow rate (l/s)	Tailwater level (mAD)
2	1400	123.391
20	2800	123.771
50	3500	123.910
100 + 35%	5670	129.326
100 + 70 %	7140	136.016
1000	7500	136.140

Note: Tail water level is defined here as the water depth a (hydraulically) short distance downstream of the entrance to the outlet culvert.

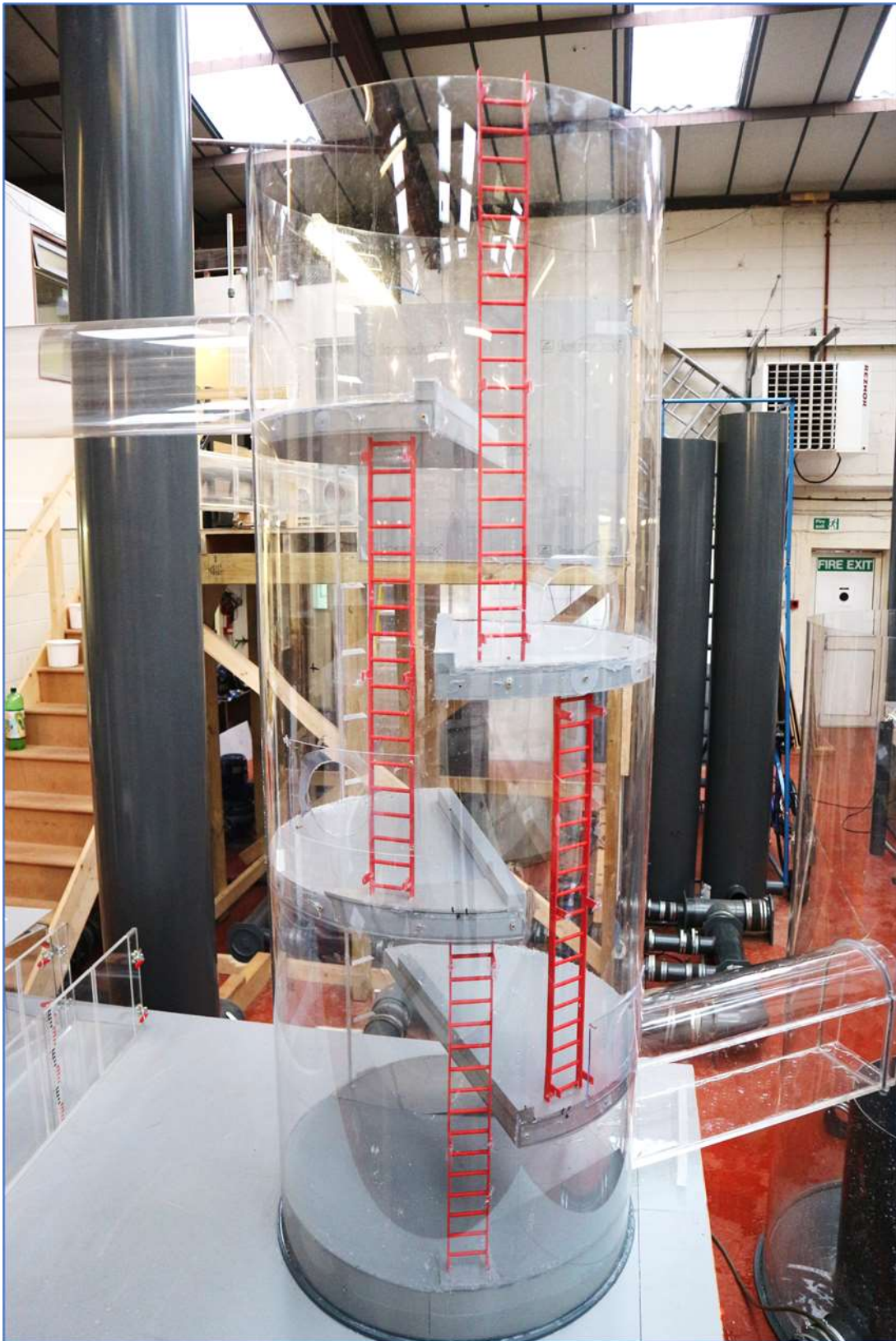
1.5 Description of model

The model of Drop Structure MH6 includes sufficient length of the proposed inlet culvert in order to allow a representative flow path to be produced on approach to MH6. The full proposed initial arrangement of MH6 was physically modelled and included all necessary benching, ledges, walls, and all relevant internal details. Sufficient length of the existing 2.22m high x 1.3m wide stone outlet culvert was provided, in order to allow a representative flow path to be produced at the exit from to MH6, hence not hydraulically short.

The model was constructed at 1/7th scale, and operated to undertake base-line tests, development and confirmatory tests for all pertinent flow and water level cases. Provision was made to allow representation of the full range of inflows from the diverted water course and the full range of tailwater levels within the receiving culvert.

The model was designed in accordance with detail extracted from the Client's general arrangement drawings, as provided, and the approved initial concept arrangement drawings. The model inlet boundary comprises a vertical plane within the proposed inlet culvert at not less than 8 x diameters upstream of MH6. Flow training measures were installed at the inlet and outlet boundaries to ensure minimum disturbances from model recirculation tanks and pipework.

General views of the initially proposed Drop Structure MH6 arrangement, prior to any development or modifications, are provided in Images 1.01 to 1.04.



**Image 1.01 – General overview of the Drop Structure MH6
physical hydraulic model**



Image 1.02 – Inlet Culvert and Level 1 platform



Image 1.03 – Platforms at Levels 2 and 3



Image 1.04 – Level 4 platform and the base of the drop shaft at Level 5

1.6 Measurement of model recirculation flows

The physical hydraulic model was equipped with external recirculating pumps, control valves and orifice plate flow meters, to enable adjustment and accurate setting of the individual flows. Sufficient model pumping capacity was provided to achieve the specified maximum design inflow of 7500 l/s at 1/7th scale.

All model recirculation flows can be set and continuously monitored using orifice plate flow meters, which were installed on each model pump recirculation line. The orifice plate sizes were determined as a function of flow and model scale and where possible, we would always attempt to run the orifice plate within the central region of its curve, to provide maximum accuracy. The model was equipped with three 150 mm pipe diameter orifice plate flow meters.

Each of the orifice plate flow meters were calibrated internally by in-house volume displacement testing and measured in line with BS EN ISO 5167-1: 2003. An orifice plate of each size was then re-calibrated via the use of an externally calibrated ultrasonic flow meter. Prior to installation on the test rig, the orifice plates were first checked visually for damage. An accurate K value was previously determined for each individual orifice plate and this value was used to produce flow data that could accurately determine the passing flow for variations in recorded deflection, measured on the model manometers. As such, a range of model flows could be set that accurately represented the full range of prototype flows, at the given scale.

The maximum required flow rate through the Drop Shaft is defined by CEC as 7500 l/s (1 in 1000 year). Based on a model scale of 1:7 the equivalent flow rate at scale is 57.7 l/s. The orifice plates were sufficiently sized for the defined flow rates and provided a suitable deflection within the central region of the orifice plate range.

The orifice plates used on the Bury drop structure MH6 model are detailed in Table 1.04.

Table 1.04 Bury drop structure MH6 Orifice plate designations		
Flow line designation	OP reference number	OP Pipe diameter
Pump 1	150/16	150 mm
Pump 2	150/23	150 mm
Pump 3	150/24	150 mm

Figure 1.05 shows a typical calibration curve for a 150 mm orifice plate utilised on the Bury Drop Structure MH6 model test rig.

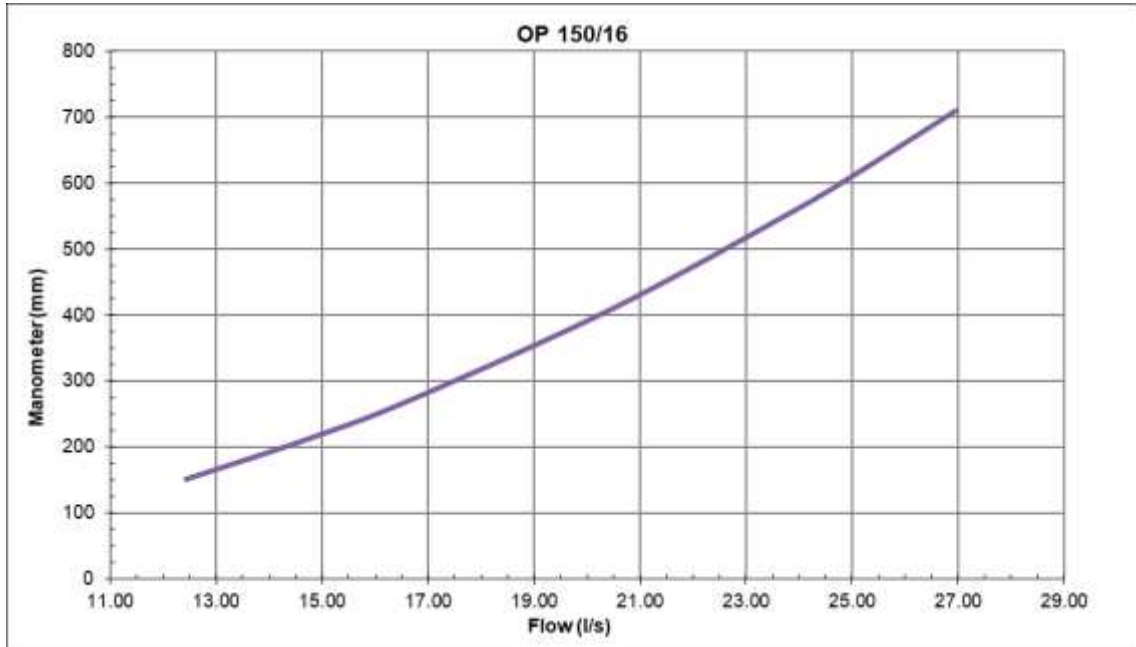


Figure 1.05 – Orifice plate calibration curve for OP Reference 150/16

1.7 Representation of solids

It is important that the Bury Drop Structure MH6 is relatively self-cleansing. To study the behaviour of grits and solids on a physical model, grit particles of varying settling velocity, sawdust and plastic particles were introduced into the model. Sawdust acts as an emulsion and also a binding agent to provide a good indicator of composite grease and gross solid type material. In addition, fibrous material including cloth, sponge and gauze is also added to ensure the full anticipated range of particles are assessed. The solids ranged from positive to negative buoyancy, the scale considerations in the modelling of the grit and floating material are discussed in Appendix A1 of this document.

It is important to represent the solids fraction of surface water and storm water in order to highlight potential problems of grit settlement and accumulation. Various methods of representing grit particles may be employed, in HCL experience grit transport and settlement can be successfully simulated using graded samples of plastic particles. Care must be taken to ensure the particles are of uniform density and free from air (hence, there must be an absence of any air voids within the particles). It is not possible to linearly scale a grit particle within a reduced scale model as this would result in particles that are too small. This can be overcome by using plastic particles with a lower settling velocity (SG) than the full scale grit particles and by determining the equivalent particle size on the basis of settling velocity.

The equivalent full scale size of the model grit particles is determined on the basis of the settling velocity of a typical sewage sample. In accordance with Froude Law affinity, the model particle settling velocity is multiplied by the square root of the model scale to determine the full scale settling velocity and hence, the equivalent particle size. Figure 1.06 demonstrates the settlement curve and equivalent particle size for the model debris at a scale of 1/7.

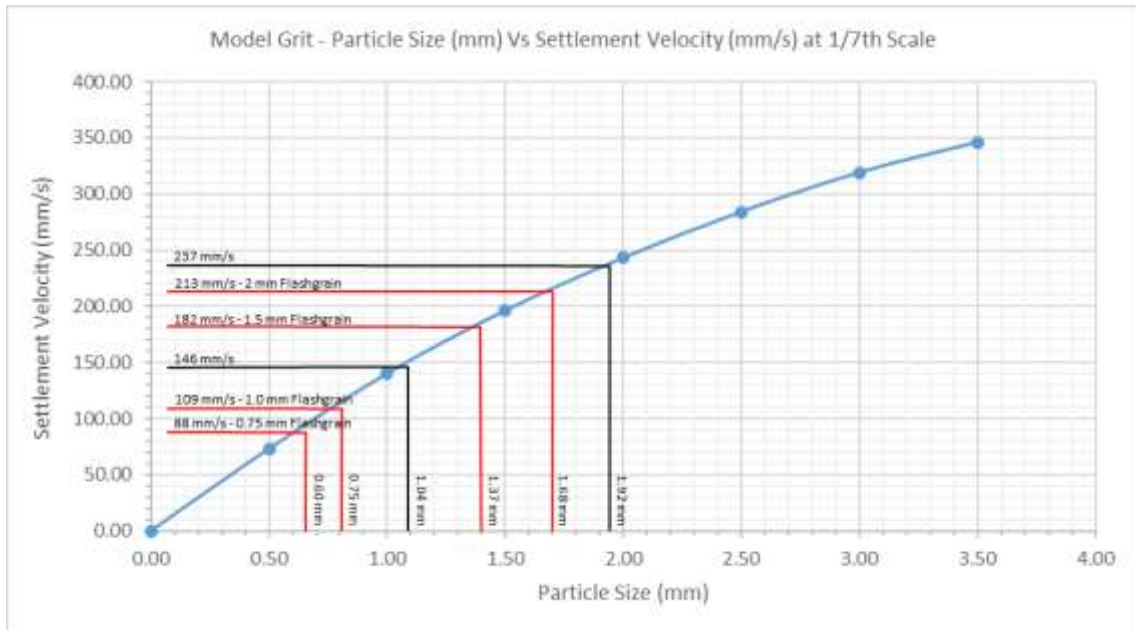


Figure 1.06 - Grit settlement curve for 1/7 scale model grit particles.

In terms of neutral and positive buoyancy debris, representing fibrous material, fat, oil and grease (FOG) is more difficult to accurately simulate, given the cohesive nature of the solids. Indicative sampling is utilised on the model using varying grades of plastic shavings, saw dust (which acts as an agglomerate to bind the debris together), varying types of cut rag type material, sponge, and shredded plastic film. When well mixed, this sample has proved effective in simulating the accumulation and transportation of a full scale floating and neutrally buoyant debris sample, with accuracy. As the volume of this type of sample is unspecified, a large volume was assumed for the purposes of the modelling exercise and was delivered into the model via the dedicated upstream inlet pipe.

Image 1.05 illustrates the range of solids samples utilised for testing, inclusive of both settling solids and floating debris.



Image 1.05 - Typical representation of modelled solids introduced into the Bury drop structure MH6 model

2.0 INITIAL ASSESSMENT

2.1 Introduction

Prior to confirmation of the tailwater levels from the Client, the physical hydraulic model of the Bury Drop structure MH6 was initially tested at a range of flow rates with a free-discharge maintained at the downstream end of the model. Hydraulic assessment of the drop structure investigated the ability of the structure to pass the required flows, together with an assessment of the flow conditions within the drop structure.

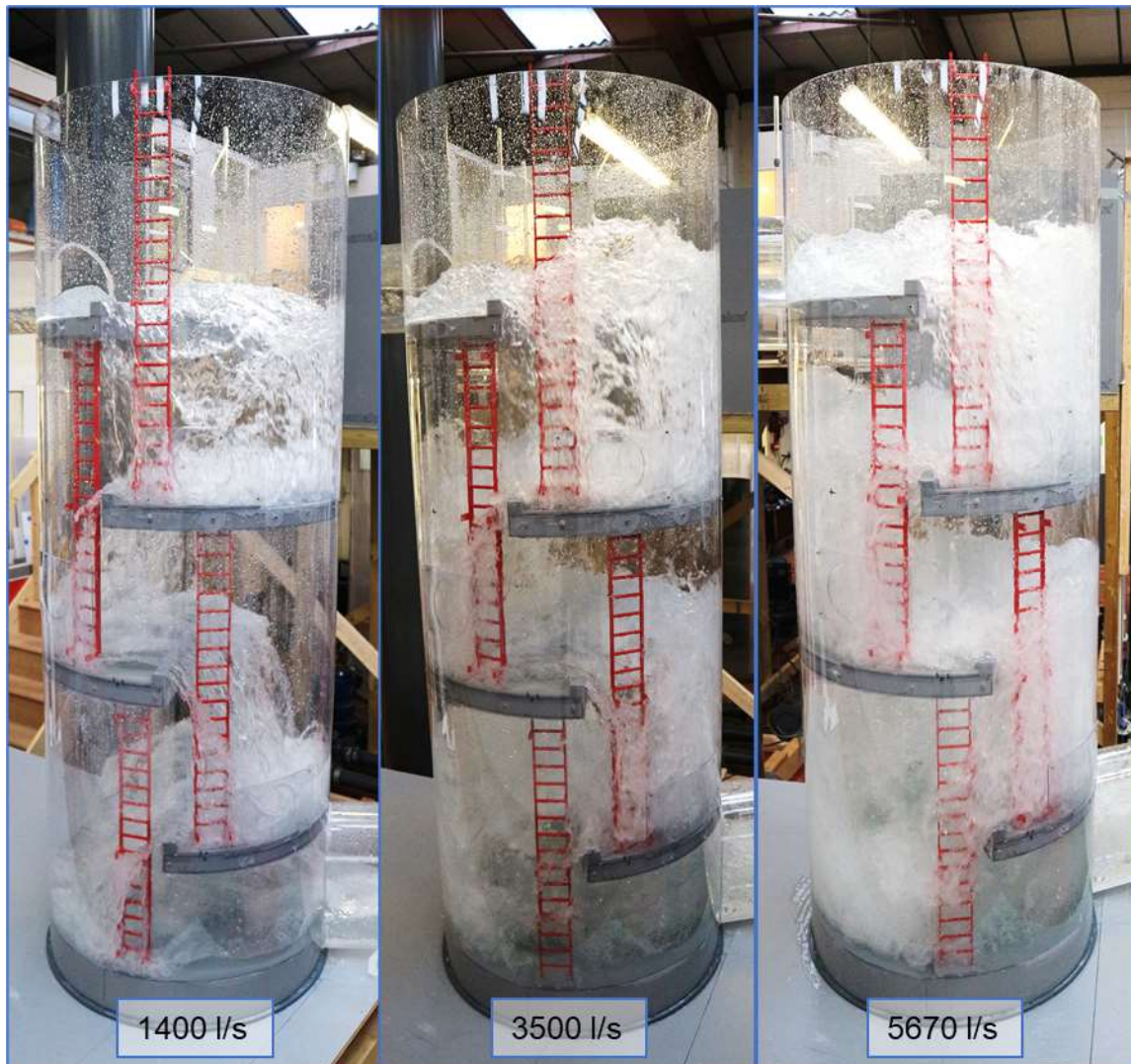
The drop structure was initially tested at flow rates of 1400 l/s, 3500 l/s and 5670 l/s (i.e. return periods of 2 years, 50 years and 100 years + 35% respectively), in order to provide a broad assessment of flow conditions for the initially proposed drop structure arrangement. During this testing minor performance issues were identified. Therefore, modifications were made to the proposed drop structure in order to improve performance prior to further, more detailed testing. The findings of this initial assessment of the Bury Drop Structure MH6 are detailed in this section.

2.2 Hydraulic Assessment

Image 2.01 shows the initially proposed arrangement of the drop structure operating at the three flow rates of 1400 l/s, 3500 l/s and 5670 l/s, which were investigated for the initial assessment.

Flow exiting the inlet culvert traversed the inlet platform (Level 1) and cascaded off the platform edge to form a free falling jet. The free fall jet impinged on the receiving surface of each intermediate platform and then discharged off the platform edge with a free fall jet before reaching the base of the shaft and exiting through the outlet culvert. Significant volumes of air were entrained into the flow, with more air entrainment occurring at the higher flow rates. This air entrainment is to be expected in cascades and is a feature and function of the cascade design, it does not pose any problems to the performance of the drop structure.

As the flow rate increased, the velocity and turbulence of the flow increased significantly, however, under operation up to the peak flow rate of 5670 l/s the drop structure was able to safely convey flow forward to the outlet culvert at the specified height of drop.



**Image 2.01 – Flow conditions within the Bury Drop Structure MH6,
Initial review flow rates of 1400 l/s, 3500 l/s and 5670 l/s**

Image 2.02 shows the Level 1 platform at each of the flow rates investigated. In each case, flow enters the drop structure via the inlet culvert and pools behind the platform ledge, before cascading onto the platform below. At the higher flow rates, the incoming flow is deeper, so the platform ledge intercepts a smaller proportion of the flow. As the flow cascades onto the ledge below, it impacts on the far wall of the chamber. At an inflow of 1400 l/s, only a small proportion of the flow impacts the opposing wall of the shaft. As the flow rate increases, the entire cascade jet impacts the opposing wall of the shaft at a high velocity.



Image 2.02 – Flow conditions at Level 1 platform at a range of flow rates

Image 2.03 shows the flow conditions at Level 3 for the three flow rates investigated. For all flow rates, the conditions at Level 3 were similar to those at Levels 2 and 4. Flow cascaded onto the Level 3 platform, where it pooled behind the platform ledge and cascades onto the platform below. Similarly to Level 1, at the higher flow rates, the ledge intercepted less of the flow. This resulted in high energy flow cascading onto the receiving platform below. As the flow rate increased, the volume of water increased, as did air entrainment. This resulted in the flow utilising a larger volume of the cascade structure at each level, as the flow rate increased.

At an inflow of 1400 l/s, the cascade free fall jet from Level 2 to Level 3 did not impinge on the far wall of the shaft, which is dissimilar to Level 1. This is because the flow had a lower horizontal velocity component than at Level 1, due to the cascade platform offset causing the flow to change direction. At the higher flow rates, the free fall jet impinged against the opposing internal wall of the shaft.

At each platform level, and for all flow rates, the flow cascaded from each platform with a continuous nappe formation, which sprung along the full length of the platform ledge. The continuous nappe formation prevented the free venting of air through each landing level, which may act to pressurise the shaft at a particular level and cause structural damage to the shaft. In order to prevent this condition, the continuous nappe formation should be broken up and dispersed at each platform level so that air is allowed to freely vent to atmosphere within the shaft.

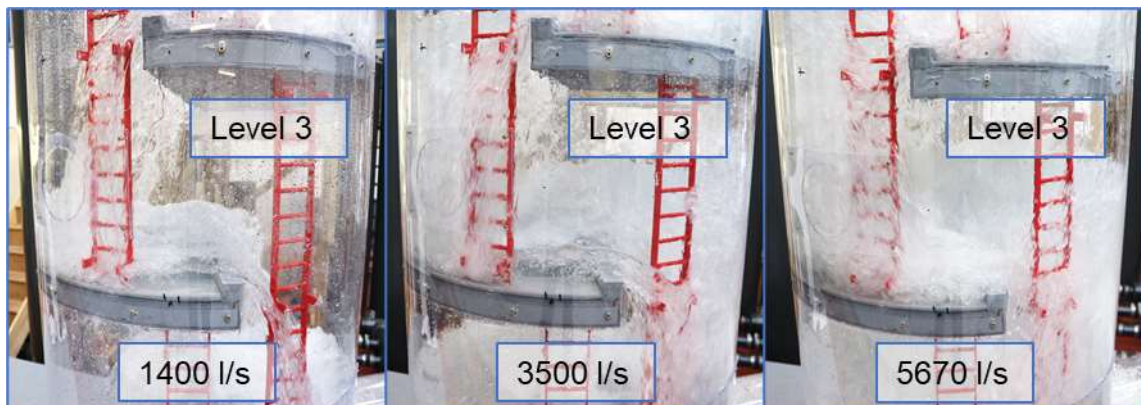


Image 2.03 – Flow conditions at Level 3 at a range of flow rates

2.3 Conclusions from Initial Testing

Initial testing found that the Bury Drop Structure MH6 generally performed satisfactorily for the flow rates investigated, however, minor performance issues were identified which should be addressed. A continuous nappe formed at each cascade, which may prevent air from freely venting to atmosphere within the shaft. Trapping air has the potential to locally pressurise the shaft, which may cause structural damage. The continuous nappe formation should be broken up and dispersed at each platform level so that air is allowed to freely vent to atmosphere within the shaft.

The proposed platform ledges acted to pool water on the platform which dissipated energy at each platform, however, at higher flow rates, a smaller proportion of the receiving flow was intercepted. This resulted in high energy flows cascading onto the platform below. The energy of these nappes formed at each platform of the cascade should be reduced, in so far as can reasonably be achieved.

The next Section of this report describes the modifications which are proposed to the Bury Drop Structure MH6 in order to address the performance issues identified by this phase of initial assessment.

3.0 DEVELOPMENT

3.1 Introduction

Following completion of the initial testing programme on the Bury Drop Structure MH6 arrangement, a number of adverse hydraulic features were highlighted, which could compromise performance, these comprised:

- A continuous nappe formed at each cascade, which prevented air from venting within the shaft. This may act to locally pressurise the chamber, which can cause structural damage.
- The platform ledges, which act to pool water and dissipate energy, intercept a smaller proportion of the flow at higher flow rates, which reduces the energy dissipation at each platform.

A programme of modifications was proposed, which were intended to mitigate these performance concerns.

3.2 Modifications

Flow deflection columns – At each platform, a flow deflection column was installed at the downstream ledge of each platform, to one side of the shaft, adjacent to the shaft wall. The purpose of the flow deflection columns was to deflect nappe flow away from the shaft wall, creating an air gap through which the entire chamber could be vented to atmosphere. The flow deflection columns were also intended to direct high velocity flow away from the shaft man access ladders located at each platform, in so far as was possible.

Platform ledge height – The height of each platform ledge was increased by 50 % from 200 mm to 300 mm. The increase in ledge height was intended to intercept more of the flow, which will increase the depth of pooled water retained at each platform. The increase in the retained water depth will dissipate a larger proportion of the energy of the receiving flow. It should be noted that, although the increase in ledge height will dissipate more energy, the flows through the drop structure are inherently high energy, especially at the higher flow rates. Therefore, although energy dissipation will be increased, the flows will still exhibit significantly high energy and turbulence.

Figures 3.01 and 3.02 provide details of the proposed modifications, full details are provided in Drawings 05 and 06 in Appendix 2.0.

Image 3.01 show a view of the proposed modifications installed at one of the platforms within the physical hydraulic model. Note that the installation is identical at each platform.



Figure 3.01 – Proposed modifications to Bury drop structure MH6 – Sections

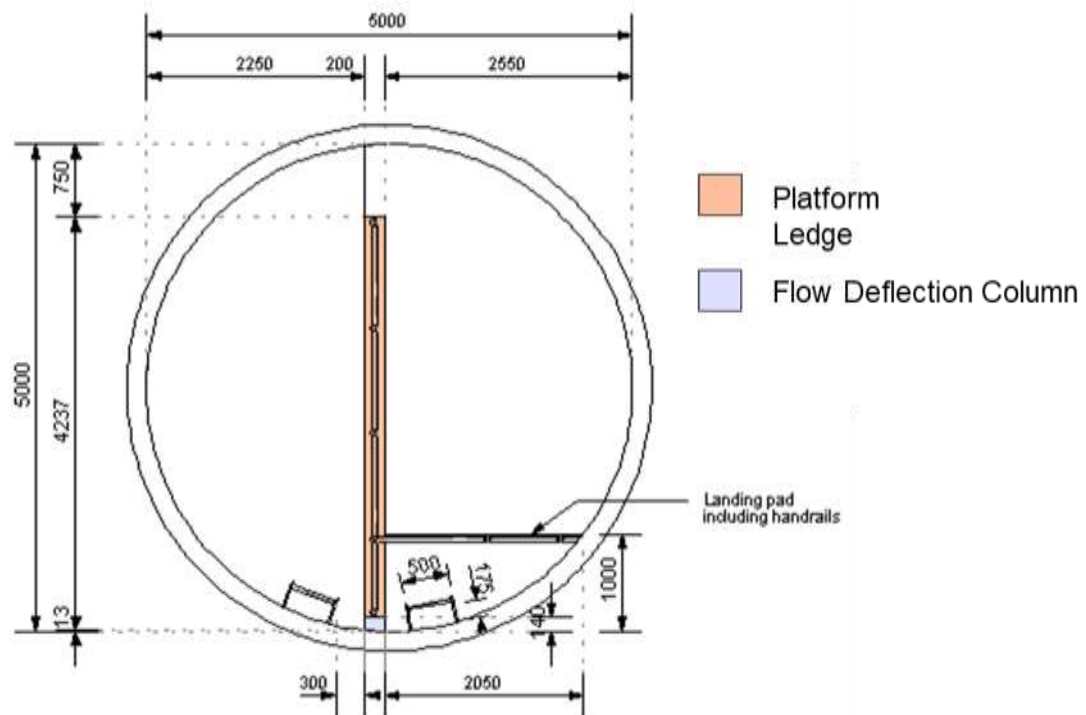


Figure 3.02 – Proposed modifications to the drop structure, plan of generic platform



Image 3.01 – Proposed modifications installed in the physical hydraulic model

4.0 FINAL TESTING

4.1 Introduction

The modified Bury Drop Structure MH6 arrangement was investigated at the flow rates and tailwater levels listed in Table 1.03. As detailed in initial testing, three distinct flow conditions were observed, depending on the tailwater level within the shaft, however, the drop structure was found to perform satisfactorily for all operating conditions investigated. Solids assessment found that solids were cleared from the drop structure for the investigated operating conditions. The findings of this investigation are described in the following sections of this report.

4.2 Hydraulic Assessment

The Bury Drop Structure MH6 was first tested at specified flow rates of 7140 l/s and 7500 l/s, with tailwater levels of 136.016 mAD and 136.140 mAD, representing return periods of 100 years + 70% and 1000 years, respectively. The flow conditions were appreciably similar in each case, due to the similar flow rates and water levels, as can be seen in Image 4.01. In each case the shaft was almost completely full of water, due to the high tailwater levels.

Flow entered the drop structure via the Inlet Culvert and was conveyed down the full height of the cascade following interception and re-direction by each of the successive platforms before exiting the shaft via the Outlet Culvert. The flow direction was altered at each successive platform level, causing recirculation regions and turbulence, which aided in energy dissipation. The flow velocities were generally high, due to the high flow rates, however, the drop structure was able to convey the flows safely.

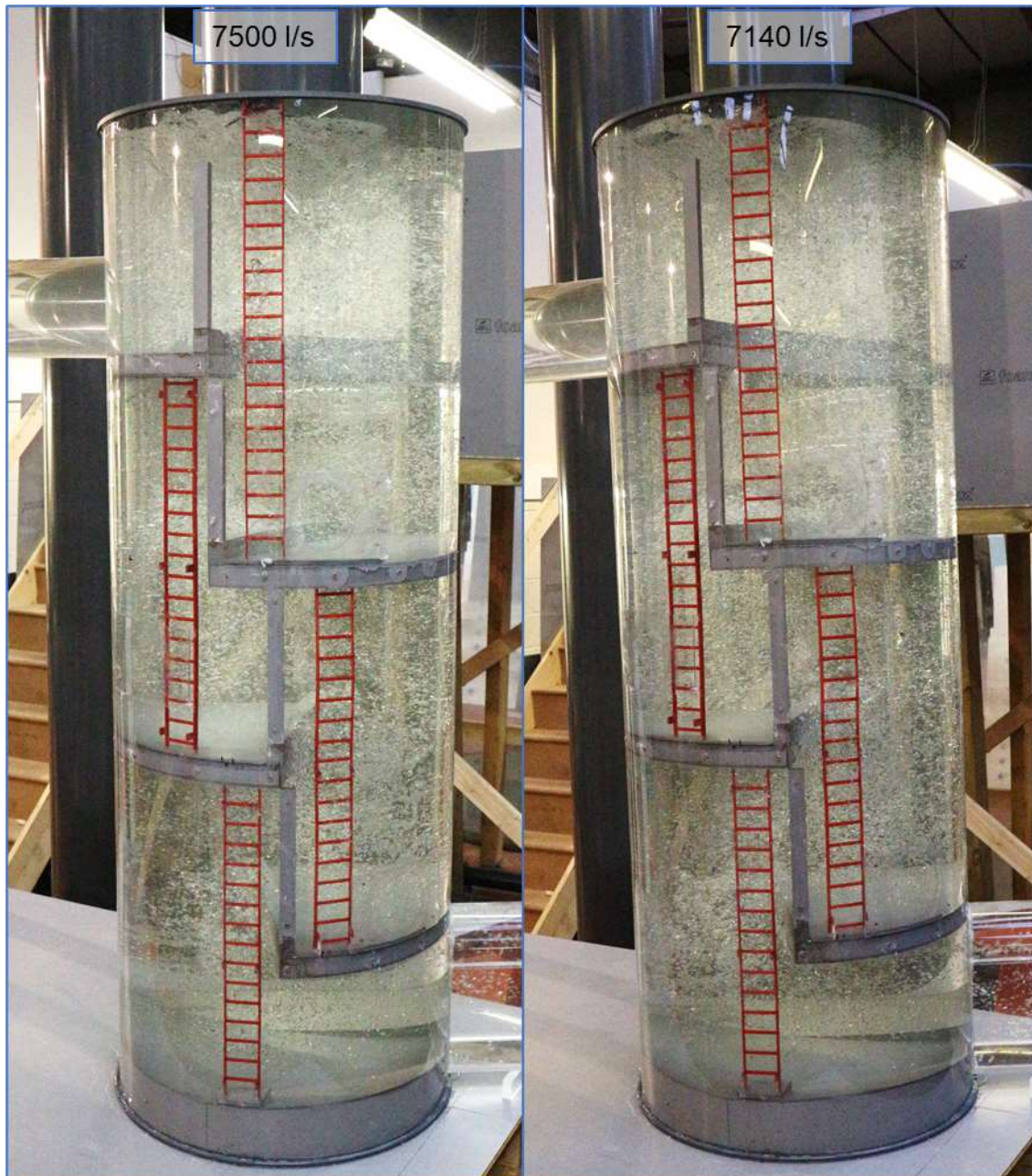


Image 4.01 – Flow conditions within the Bury Drop Structure MH6 at flow rates of 7500 l/s and 7140 l/s

Image 4.02 shows the flow conditions at platform Level 1, at a flow rate of 7500 l/s, with the flow paths indicated in the image. Note that the flow paths indicated were comparable to those at 7140 l/s. Flow entered the drop structure via the Inlet Culvert and travelled across the chamber, where it was deflected by the far wall. A certain proportion of the flow was deflected upwards towards the soffit of the chamber. This instigated a recirculation region close to the top of the chamber. As flow passed across the soffit, air was entrained into the flow from the vent located in the model soffit plate. This indicates that a vented soffit must also be installed in the full scale Bury Drop Structure MH6, as failure to do so could result in the chamber becoming depressurised, which may lead to structural damage or failure. The recirculation path resulted in a slightly higher water level at the side of the chamber opposing the inlet. Entrained air was conveyed through the drop structure and into the Outlet Culvert.

Flow passing along the invert of the platform was deflected upwards slightly, by the platform ledge, before re-orientation downwards towards the lower platform levels. At the downstream side of the platform ledge, a low velocity region occurred. This allowed some air bubbles to rise in this region. These air bubbles were then intercepted by the higher velocity flow and transported down towards the lower platform levels.

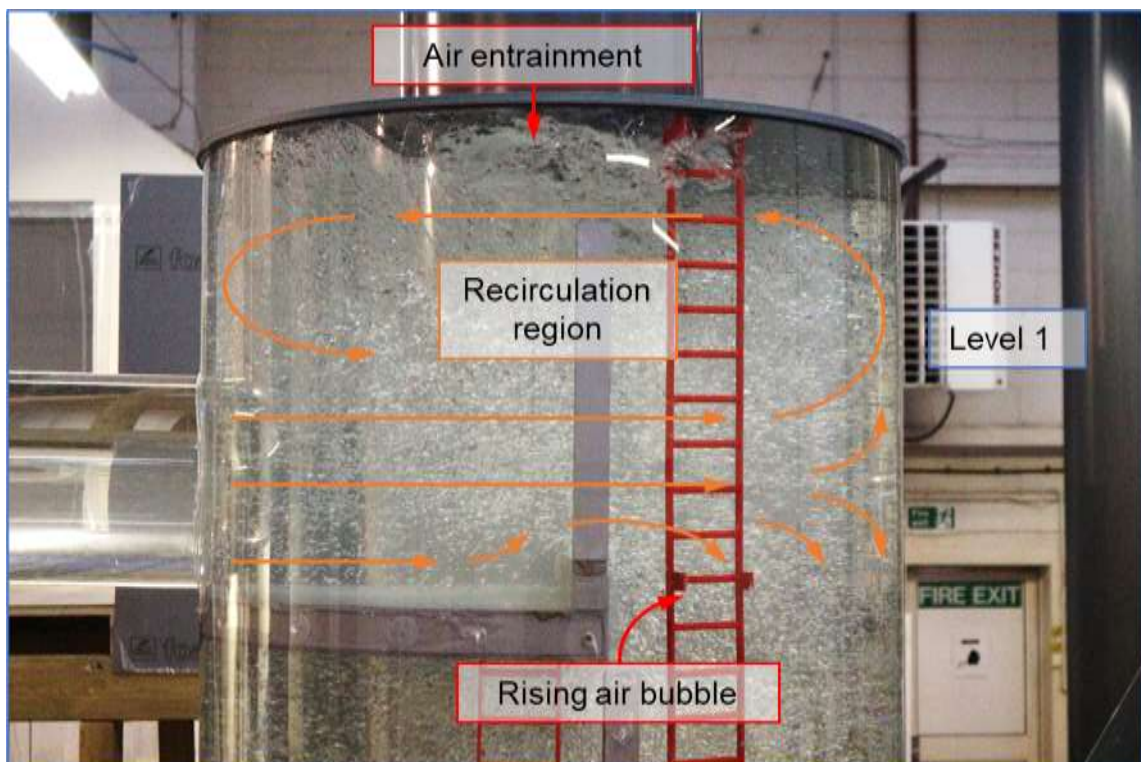


Image 4.02 – Flow conditions at Level 1 at a flow rate of 7500 l/s

Image 4.03 shows the flow conditions at Levels 2 and 3 at a flow rate of 7500 l/s. Again, the flow conditions are comparable to an inflow of 7140 l/s. Flow from Level 1 travelled down until it was intercepted by the platform at Level 2, where it was deflected towards the centre of the chamber. Flow was deflected over the platform ledge and travelled across the chamber in a relatively high velocity, narrow concentrated jet. Upon impacting the far wall of the shaft, the jet was deflected both upwards and downwards, forming two recirculation regions, which circulated in opposite directions to one another. In the topmost region of Level 2, beneath the Level 1 platform, a recirculation region occurred which occupied a relatively large depth. Opposite to the platform at Level 2, a smaller recirculation region occurred, which occupied a smaller depth. A certain proportion of the flow was deflected down, towards Level 3. At Levels 3 and 4, the flow conditions were similar to those at Level 2.

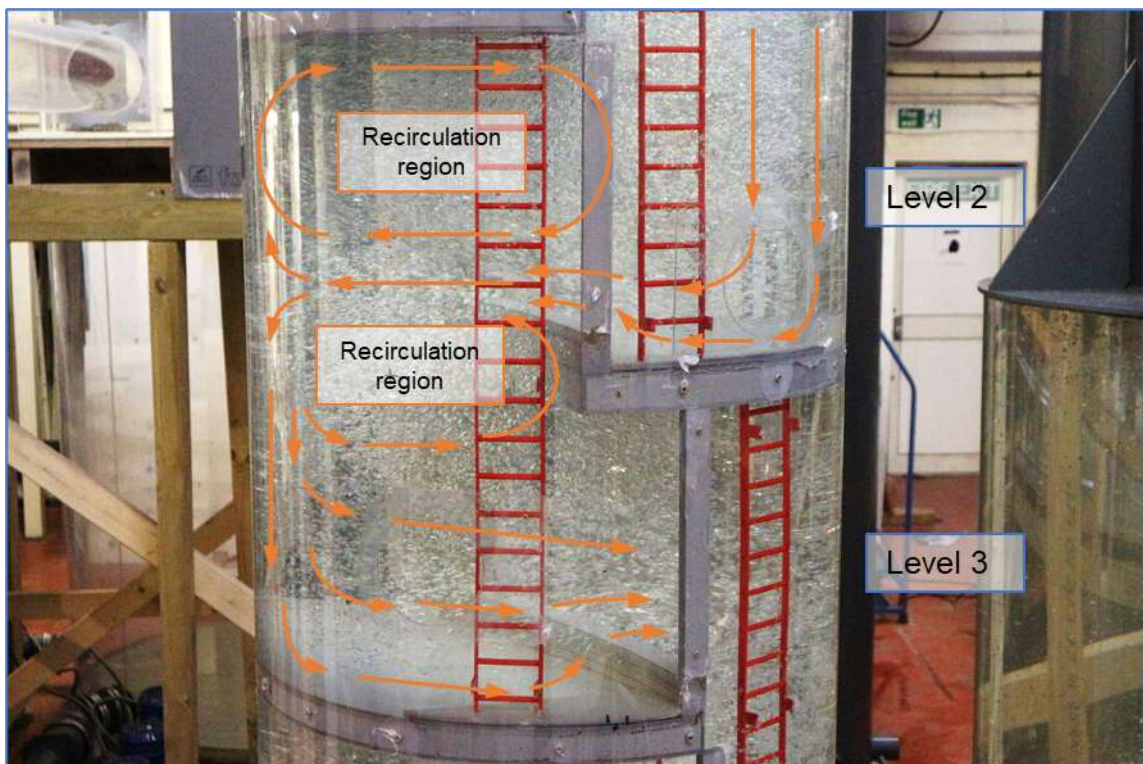


Image 4.03 – Flow conditions at Levels 2 and 3 at a flow rate of 7500 l/s

Image 4.04 shows the flow conditions at Level 5 at a flow rate of 7500 l/s. Similarly to conditions at the higher levels, a recirculation region occurred opposite to the platform at Levels 4 and 5. Flow travelled down from the Level above and was drawn towards the Outlet Culvert, utilising the majority of the flow depth at Level 5. Image 4.06 shows the truncated Outlet Culvert at a flow rate of 7500 l/s. The flow utilised the entire depth of the Outlet Culvert, with air bubbles distributed reasonably evenly through the flow depth.

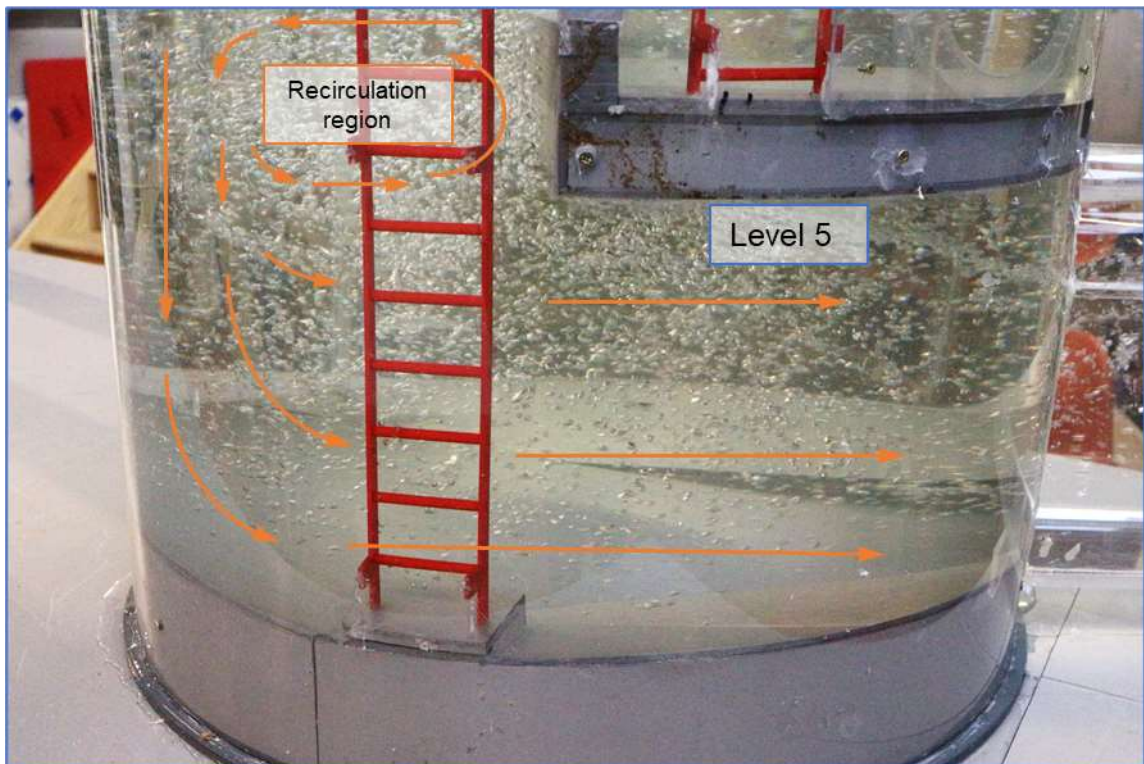


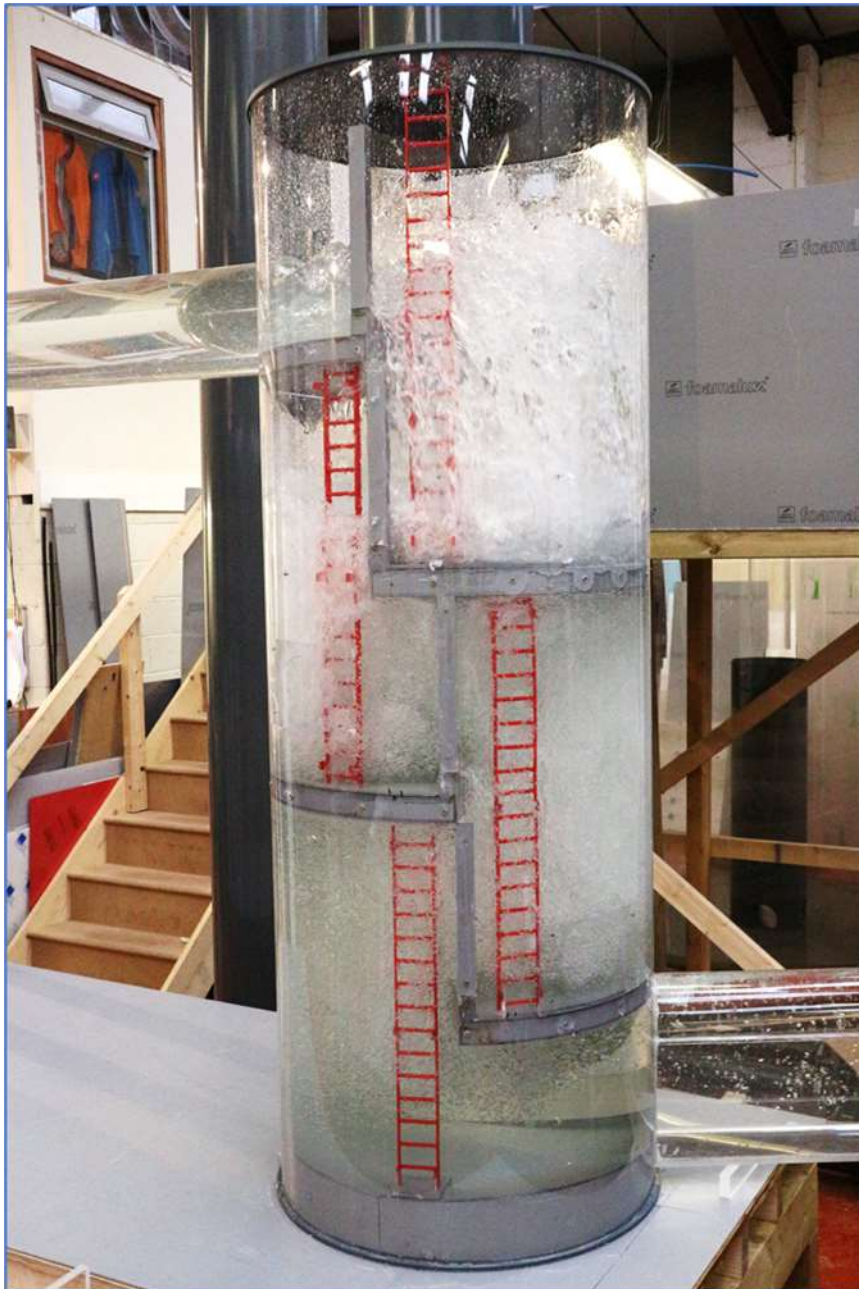
Image 4.05 – Flow conditions at Level 5 at a flow rate of 7500 l/s



Image 4.06 – Flow conditions within the truncated outlet Culvert at 7500 l/s

The Bury Drop Structure MH6 was next tested at a specified flow rate of 5670 l/s, with a tailwater level of 129.326 mAD, representing a return period of 100 years + 35%. The main difference between the flow conditions in this operating scenario and those discussed previously is that the water level was at approximately the mid depth of the shaft. This resulted in free-surface flow conditions in the upper section of the drop structure and submerged flow conditions in the lower section of the drop structure, as shown in Image 4.07. The free-surface flow conditions in the upper section of the drop structure caused significantly more air entrainment to occur than was observed at the higher tailwater levels.

Image 4.08 shows the flow conditions at Level 1. Due to the relatively high flow rate, the Inlet Culvert was full surcharged and operated at full depth. As flow entered the chamber, the flow depth decreased slightly, as the flow spread across the width of the platform. A proportion of air was entrained into the flow in this region due to turbulence at the free-surface. The increased height of the ledge at this level acted to intercept more of the flow, as would be expected, creating a deeper pool of retained water behind the ledge, which increased energy dissipation of the flow at this Level. Flow deflected over the ledge, where it cascaded into Level 2, below. The cascade was highly turbulent, resulting in significant air entrainment. The high turbulence of the flow also caused the cascade to break up, allowing air to be freely vented to atmosphere. The flow deflection column also deflected flow away from the shaft wall, allowing air to freely vent to atmosphere.



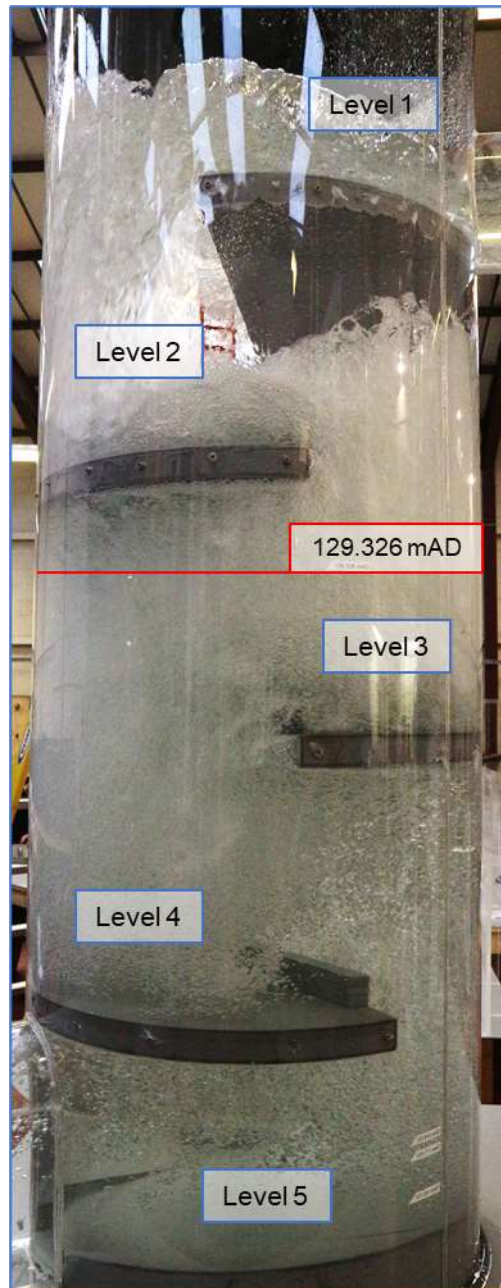
**Image 4.07 – Flow conditions within the Bury Drop Structure MH6
at a flow rates of 5670 l/s**



Image 4.08 – Flow conditions at Level 1 at a flow rate of 5670 l/s

Image 4.09 shows the flow conditions throughout the drop structure. As flow cascaded from Level 1, it impacted the Level 2 platform with high levels of energy and turbulence, entraining a significant volume of air into the flow. Again, the increased height of the platform ledge acted to pool a larger depth of retained water, which cushioned the impact of the cascading flow onto the receiving platform and increased energy dissipation.

The tailwater level of 129.326 mAD was between the Level 2 and 3 platforms, as indicated in Image 4.09. However, due to the high flow rate, the water level within the drop structure was effectively directly beneath the Level 2 platform. Flow at Level 2 was deflected over the platform ledge to Level 3. As Level 3 was submerged, the cascading flow from Level 2 was cushioned, dissipating energy. At Levels 3, 4 and 5, the flow patterns were comparable to the higher tailwater levels, as submerged flow occurred. The only significant differences in the flow conditions to those observed previously was a significantly increase in air entrainment, due to the free-surface flow conditions produced in the upper section of the drop structure. Flow velocities throughout the shaft were also slightly lower, due to the lower inflow rate.



**Image 4.09 – Flow conditions throughout the Bury Drop Structure MH6
at a flow rate 5670 l/s**

Image 4.10 shows the truncated model section of the Outlet Culvert under operation at a flow rate of 5670 l/s. The flow conditions within the Outlet Culvert were slightly different to those observed at the higher flow rates. Significantly more air was entrained into the flow at 5670 l/s and the lower flow velocity allowed more of the entrained air bubbles to rise to the topmost region of Level 5 (beneath the Level 4 platform), prior to exiting the drop structure via the Outlet Culvert. This circulation mechanism resulted in the forward transport of air within an air pocket located at the soffit of the Outlet Culvert, as well as entrained air bubble transport through the cross section of the culvert.

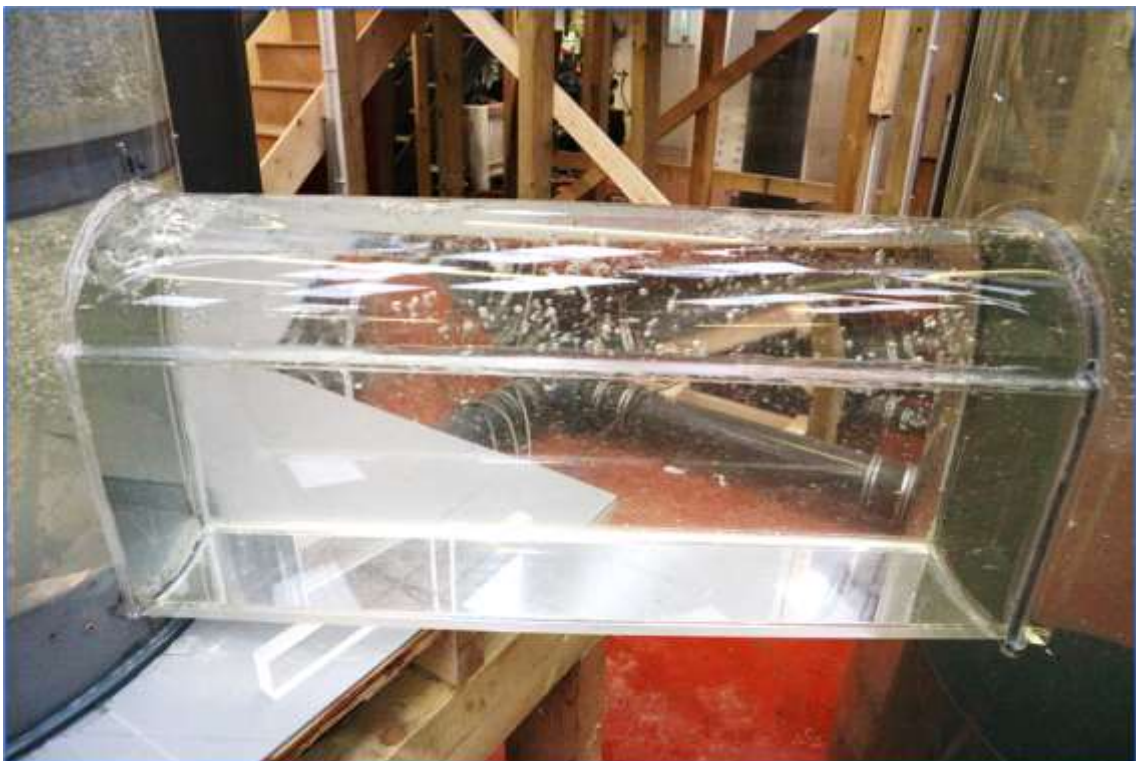


Image 4.10 – Flow conditions and air bubble transport within the Outlet Culvert at a flow rate of 5670 l/s

A continuous forward passage of entrained air was observed within the model outlet culvert. The air bubble formation at the Outlet Culvert soffit was maintained as an elongated string/narrow pocket type form and did not exhibit any appreciable growth over time due to continuous scour and passage forward within the main body of flow through the culvert.

The Bury Drop Structure MH6 was next tested at the three lowest flow rates of 1400 l/s, 2800 l/s and 3500 l/s, with tailwater levels of 123.391 mAD, 123.771 mAD and 123.910 mAD, representing return periods of 2 years, 20 years and 50 years respectively. The flow conditions at each of these operating scenarios were similar to those previously reported, in that the tailwater levels were close to the base of the drop structure, as such free-surface, cascading flow conditions were present at each platform level, as can be seen in Image 4.11.

Image 4.12 shows the flow conditions present within the shaft at Level 1 for each flow rate. Similarly to at a flow rate of 5670 l/s, flow entered the drop structure via the Inlet Culvert and pooled behind the platform ledge. Contrary to operation at 5670 l/s, however, the Inlet Culvert did not run full, due to the lower flow rates, so the incoming flow was at a lower depth and had a lower inlet velocity. Again, the proposed increase in the platform ledge height acted to pool a larger depth of retained water, increasing energy dissipation.

Flow entered the drop structure via the Inlet Culvert and was conveyed down the full height of the cascade following interception and re-direction by each of the successive platforms before exiting the shaft via the Outlet Culvert. Flow passed across each of the platforms and cascaded over the ledge onto the platform with a defined jet formation. At 1400 l/s, the cascading jet did not impinge on the opposing curved internal wall of the shaft. At 2800 l/s and 3500 l/s, however, the flow velocities were higher, so the cascading jet did impinge on the opposing wall.

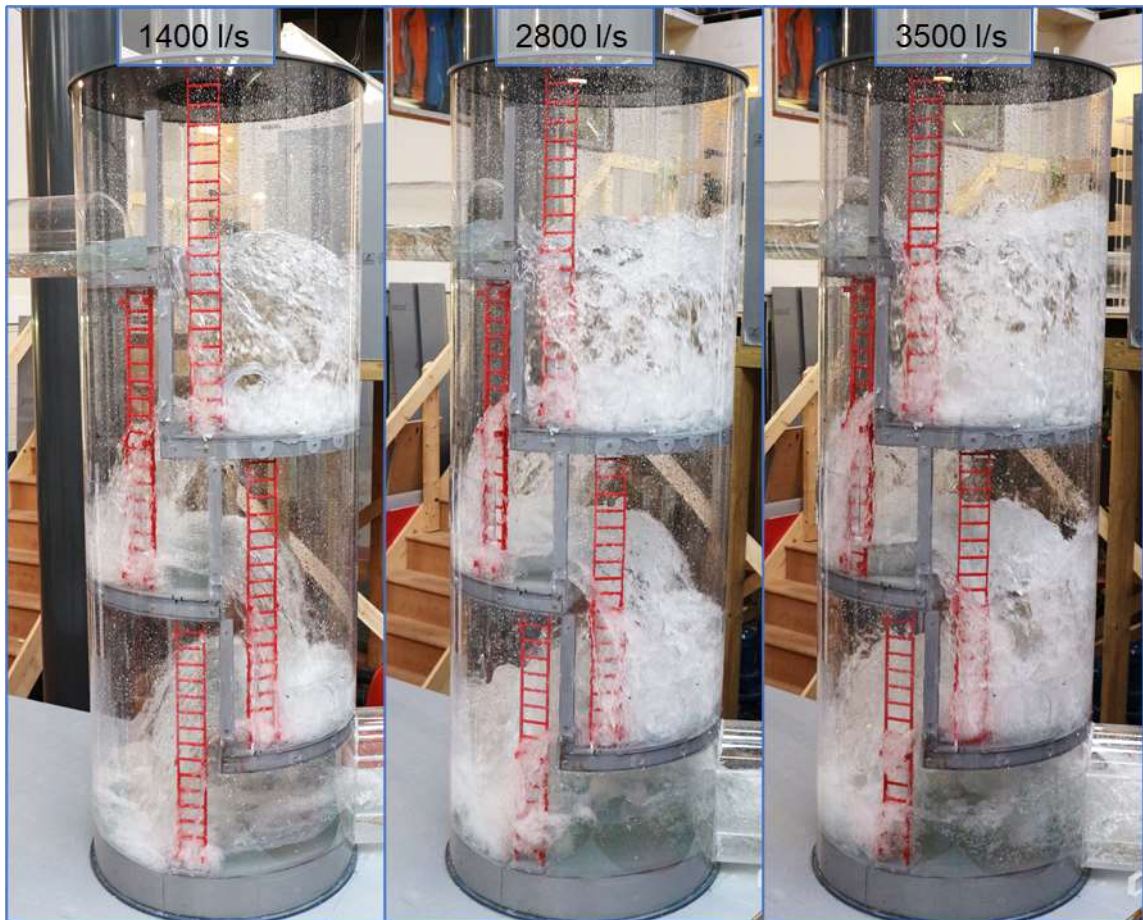


Image 4.11 – Flow conditions within the Bury Drop Structure MH6 at flow rates of 1400 l/s, 2800 l/s and 3500 l/s



Image 4.12 – Flow conditions at Level 1 of Bury Drop Structure MH6 at flow rates of 1400 l/s, 2800 l/s and 3500 l/s

Image 4.13 shows the flow conditions at Levels 2 and 3. As the cascading flow impacted on the receiving platform below, significant air entrainment occurred. Again, the flow pooled behind the platform ledge. The increased ledge height increased the depth of retained flow on each platform, increasing the energy dissipation at each platform. The flow then cascaded over the ledge, onto the platform below. These flow conditions were comparable at Levels 2, 3 and 4 at each flow rate.

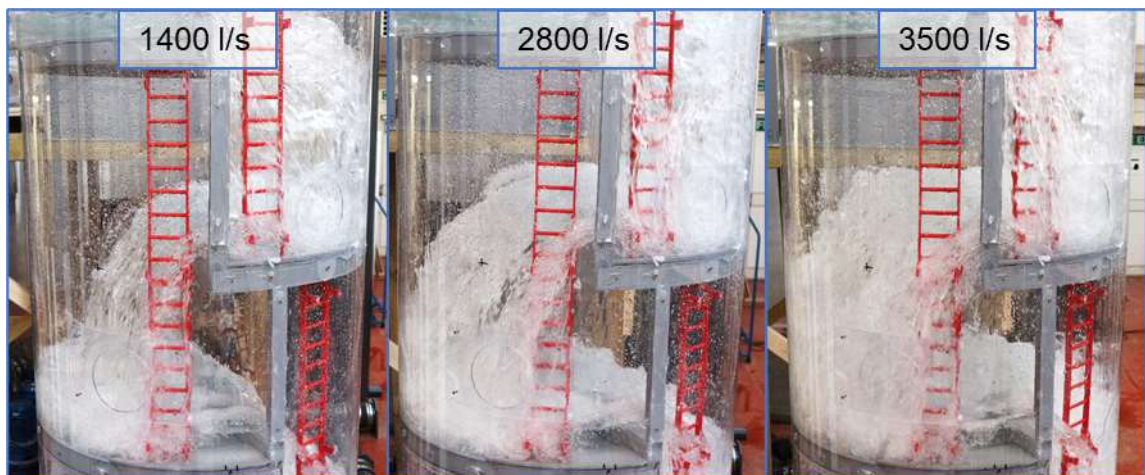


Image 4.13 – Flow conditions at Levels 2 and 3 of Bury Drop Structure MH6 at flow rates of 1400 l/s, 2800 l/s and 3500 l/s

Image 4.14 shows the influence of the flow deflection column at Level 3 at a flow rate of 1400 l/s. It can be seen that the column deflected the flow away from the shaft wall, creating an air gap between the wall and the cascading nappe. This air gap was sufficient to allow air to freely vent to atmosphere within the shaft. The flow deflection columns also directed higher velocity components of flow away from the shaft man access ladders, which were located to one side of each platform. This should reduce potential ragging of solids to the access ladders and protect them from excessive hydraulic loading.

The effect of the flow deflection columns on the flow path produced at the discharge from each platform ledge was comparable for all intermediate platforms within the shaft at flow rates at which cascading free-surface flow was present.



Image 4.14 – Flow deflection column effects at Level 3 at a flow rate of 1400 l/s

Image 4.15 shows conditions within the shaft at platform Level 5 at each of the three flow rates tested. As shown, the tailwater levels within the shaft are slightly higher than the base of the drop structure for each flow rate displayed in the image and the tailwater levels increased incrementally with flow rate. The tailwater levels at these flow rates create a pool of water at Level 5, which cushioned the cascading jet produced from Level 4 and dissipated the jet energy. Flow was then re-directed towards the Outlet Culvert, with a proportion of the entrained air vented to the free surface within the shaft prior to entry to the Outlet Culvert.



Image 4.15 – Flow conditions at Level 5 at flow rates of 1400 l/s, 2800 l/s and 3500 l/s

Image 4.16 shows the flow conditions within the truncated Outlet Culvert at 1400 l/s, 2800 l/s and 3500 l/s. In all cases, a free-surface existed within the culvert. At 1400 l/s any entrained air was evacuated from the flow at the free-surface over a relatively short distance. At 2800 l/s and 3500 l/s, entrained air bubbles remained in the flow over the length of the truncated Outlet Culvert. In the prototype culvert, these entrained air bubbles would be evacuated from the flow a short distance downstream of the downstream extent of the physical hydraulic model.



Image 4.16 – Flow conditions within the Outlet Culvert at flow rates of 1400 l/s, 2800 l/s and 3500 l/s

Conclusions from Hydraulic Assessment

Hydraulic assessment of the Bury Drop Structure MH6 physical hydraulic model determined that the proposed drop structure conveyed the flows safely and performed satisfactorily for all flow rates and tailwater levels investigated. Three different general flow conditions occurred within the drop structure, depending on the water level:

1. At the higher water levels (100 years + 70% and 1000 year return periods), the drop structure was almost completely surcharged, i.e. up towards the shaft soffit. As flow passed across the shaft soffit at surcharged operation, air was entrained into the flow from the vent provided in the model soffit. This indicates that a vented soffit must also be installed in the prototype drop structure, as failure to do so may result in the chamber becoming depressurised, which could lead to structural damage and possible accelerated failure.
Submerged flow conditions occurred throughout the drop structure at the specified flow range of 100 years + 70% and above. At these conditions, flow paths were dictated by the arrangement of the platforms and the flow was conveyed through the drop structure and into the Outlet Culvert safely.
2. At a return period of 100 years + 35%, the water level within the drop structure was approximately at mid shaft height. In the upper section of the drop structure free-surface flow occurred and the flow cascaded from each platform to the next. This regime was characterised by high levels of air entrainment at each platform. The proposed increase in the height of the platform ledges increased the depth of the retained flow on each platform, which in turn increased energy dissipation. The proposed vertical flow deflection columns at each platform ledge acted to deflect flow away from the wall of the drop structure, allowing air to freely vent to atmosphere. The flow deflection columns also deflected flow away from the man access ladders somewhat. At the lower depths, submerged flow occurred and the flow patterns were comparable to those at the higher water levels, but with slightly lower velocities and a higher volume of entrained air.
3. At the lower tailwater levels (return periods of 2 years, 20 years and 50 years) the water levels within the drop structure were closer to the invert of the shaft. Under these conditions, flow was also conveyed safely through the drop structure. Free surface cascading flow occurred at each landing level within the drop structure, characterised by high levels of splash, spray and air entrainment.

Again, the proposed increased ledge heights increased the depth of retained water on the platforms, increasing energy dissipation, and the flow deflection columns diverted flow away from the wall of the chamber, creating an air gap through which air could be freely vented to atmosphere. The water levels at the base of the drop structure shaft, dictated by the receiving water course tailwater levels, also acted to cushion the flow and increase energy dissipation.

The detailed characteristics of operation of the proposed arrangement of Bury Drop Structure MH6 may be more readily observed within the video record accompanying this text report. Video record is provided of the flow conditions within the Bury Drop Structure MH6 for each operating scenario investigated.

4.3 Solids Assessment

Solids assessment of the proposed Bury Drop Structure MH6 was initially conducted at inflow rates of 7140 l/s and 7500 l/s. As with the hydraulic assessment, the solids handling at these two inflow rates were comparable, due to the similar flow rates and water levels. In these two operating scenarios, the Inlet Culvert was surcharged as the water level exceeded the soffit level of the Inlet Culvert. Hence model solids representing highly buoyant objects, such as footballs and plastic bottles, were not drawn through the Inlet Culvert into the drop structure. This is representative of the full scale structure as at inlet water levels significantly higher than the Inlet Culvert, highly buoyant materials would not be expected to be drawn into the drop structure.

In both inflow cases tested for the initial solids assessment all other solids were cleared from the drop structure relatively quickly. FOG, rag type material and settleable solids were all held in suspension and transported through the drop structure without deposition or build-up.

The detailed characteristics of solids transport within the proposed arrangement of Bury Drop Structure MH6 may be more readily observed within the video record accompanying this text report.

Images 4.17 – 4.19 demonstrate solids suspension and transport at various positions within the drop structure under operation at an inflow of 7500 l/s, which is also representative of 7140 l/s. It can be seen that all solids are in suspension and there is no deposition or build-up of any solids.



Image 4.17 – Solids in suspension at Level 1 at a flow rate of 7500 l/s



Image 4.18 – Solids in suspension at Level 4 at a flow rate of 7500 l/s



Image 4.19 – Solids in suspension at Level 5 at a flow rate of 7500 l/s

Solids handling was next assessed at a flow rate of 5670 l/s, at which the water level was at approximately the mid depth of the shaft. At this condition, the water level was sufficiently low for highly buoyant solids to also be drawn through the Inlet Culvert into the drop structure. All solids were cleared from the drop structure. In the upper section of the drop structure, cascading free-surface flow occurred. Under these conditions, solids were either suspended in the pooled water depth retained at each platform or tracked rapidly across the base of the platform, prior to being transported over the platform ledge to the receiving platform below. This can be seen in Image 4.20.

At the lower, surcharged, platforms within the shaft the solids were transported in a similar manner to those at the higher flow rates and tailwater levels and were rapidly transported through the drop structure, see Image 4.21. Some rag type material accumulated around the ladder positions, however, this was not deemed to be excessive and is unavoidable. The highly buoyant solids, behaved slightly differently to the other solids in the submerged flow region, as depicted in Image 4.22. Due to their high buoyancy, a proportion of these solids rose within the drop structure until they met the underside of a platform. They remained there temporarily until the highly turbulent, recirculating flow transported them back into the main flow path. All these highly buoyant solids were cleared from drop structure after a short duration of operation.



Image 4.20 – Absence of solids at Level 1 at a flow rate of 5670 l/s



Image 4.21 – Solids suspension at Level 5 at a flow rate of 5670 l/s



Image 4.22 – Highly buoyant solids at Level 2 at a flow rate of 5670 l/s

Finally, solids handling was assessed at a flow rate of 1400 l/s, the lowest representative flow rate investigated within the model. At this inflow the tail water level within the shaft was close to the shaft invert and cascading free-surface flow occurred throughout the drop structure. All model solids were regularly transported and cleared through the drop structure at this flow rate. This demonstrated that all solids would be cleared from the drop structure at under all cascading flow conditions, as the lowest flow rate produces the lowest flow velocities.

Images 4.23 and 4.22 show solids at Levels 1 and 5 respectively at a flow rate of 1400 l/s. At this flow rate, fewer solids were in suspension and more solids tracked along the floor of each the platforms, due to the lower velocities. At Level 1, a small recirculation region occurred to the right of the Inlet Culvert, as viewed from upstream to downstream, in which a small number of settleable solids remained temporarily. These settleable solids were regularly agitated and cleared from the platform after a short duration of operation. Similarly to the upper section of the drop structure at 5670 l/s, solids were transported across the intermediated platforms and over the platform ledges. At Level 5, all solids were readily transported forward to the Outlet Culvert.



Image 4.23– Absence of settleable solids at Level 1 at a flow rate of 1400 l/s



Image 4.23– Absence of solids at Level 5 at a flow rate of 1400 l/s

Conclusions from Solids Assessment

Solids were readily transported and cleared through the full drop structure at all flow rates investigated. At the high inflow and high shaft water levels, solids were maintained in suspension and readily transported through the drop structure. Highly buoyant solids, such as footballs and plastic bottles, were not drawn into through the Inlet Culvert due to the water depth in the drop structure exceeding the soffit of the Inlet Culvert. This is representative of full scale flow conditions.

At a flow rate of 5670 l/s, the water level was at approximately the mid depth of the drop structure. In the upper section of the drop structure free-surface cascade flow occurred and solids were either suspended in the flow, or tracked along the base of each platform, prior to being transported over the platform ledge to the receiving platform below. In the lower section of the drop structure submerged flow conditions occurred and solids were cleared in a similar manner to those at the higher flow rates and tailwater levels. There was some temporary retention of highly buoyant solids within the submerged flow region, however, the highly buoyant solids were regularly cleared forward after a short duration of operation.

At the lowest flow rate of 1400 l/s, the lowest representative flow rate investigated within the model, all solids entering the Inlet Culvert were transported through and cleared from the drop structure. Cascading free-surface flow occurred throughout the model and solids were transported across each platform, either in suspension or across the base of the platform, prior to passing over the platform ledge to the receiving platform below. This indicates that all solids will also be cleared through the drop structure at the higher flow rates of 2800 l/s and 3500 l/s, at which cascading flow also occurred and the flow conditions were comparable.

5.0 CFD MODELLING OF DRY WEATHER FLOW CONDITIONS

5.1 Introduction

Physical hydraulic modelling of the Bury Drop Structure MH6 was conducted for the flow rates indicated in Table 1.03, which represent storm flow conditions. There is also value in understanding the performance of the drop structure under normal operation, such as dry weather flows and the average design flow. However, the initial scope of the physical hydraulic model study was to investigate significantly higher flows than those which will occur during these conditions of operation and the geometric scale of the model was chosen accordingly. This dictated a model scale of 1:7, physical hydraulic modelling of flows of less than 1400 l/s was not possible on this model apparatus due to limitations in scale. At inflows of less than 1400 l/s flow within the model was non turbulent, i.e. viscous and surface tension effects dominate, which is unrepresentative of full scale prototype flow. Therefore, any analysis of the flow conditions at the low flow rates would be not be representative or reliable.

Hydraulically, it is not expected that there are any potential risks to the integrity of the drop shaft at lower inflow rates. However, it was considered that there may be the potential for the accumulation of fine sands and silts on each of the platforms, which may not be adequately cleared to the outlet culvert at lower flow rates. The potential for persistent siltation may therefore arise on the cascade platforms. Model testing has shown that these solids will be cleared at the 2 year return period and above, however, this frequency of solids clearing may not be considered acceptable.

It is not possible to determine how solids would be deposited within the cascade at flow rates of less than 1400 l/s, or what additional loading may arise from any potential solids accumulation. To adequately model the drop structure at the lower, normal operation flow rates, a reduced model scale, such as 1:2, would be required. Construction of such a model would be impractically large and costly and is not a viable option. Therefore, computational fluid dynamics (CFD) modelling of the drop structure is a more practical modelling Approach. As such, a CFD modelling study of the Bury Drop MH6 was conducted at DWF conditions. All CFD modelling was conducted at the Q50 flow rate of 27 l/s, representing the peak flow which is exceeded 50% of the time, with a free-discharge condition at the downstream outlet boundary.

5.2 Primary CFD Modelling

Figures 5.01 and 5.02 provide details of the initially proposed revisions to the Bury Drop Structure MH6 arrangement to mitigate against potential solids accumulation at inflows of less than 1400 l/s. At each platform ledge, four slots of 150 mm width were proposed, in addition to the 750 mm gap from the end of the ledge to the shaft wall. The 750 mm gap was retained as physical hydraulic model testing showed that the drop structure performed satisfactorily at the tested return periods with this gap in place. The 150 mm slots were intended to promote spread of flow across the width of each platform to promote solids scour and transport and prevent excessive shoaling of lighter solids and silts. The addition of these 150 mm slots to the platform ledges is not expected to have any appreciable effect on the hydraulic performance of the drop structure at return periods of 2 years and above, i.e. as physically model tested.

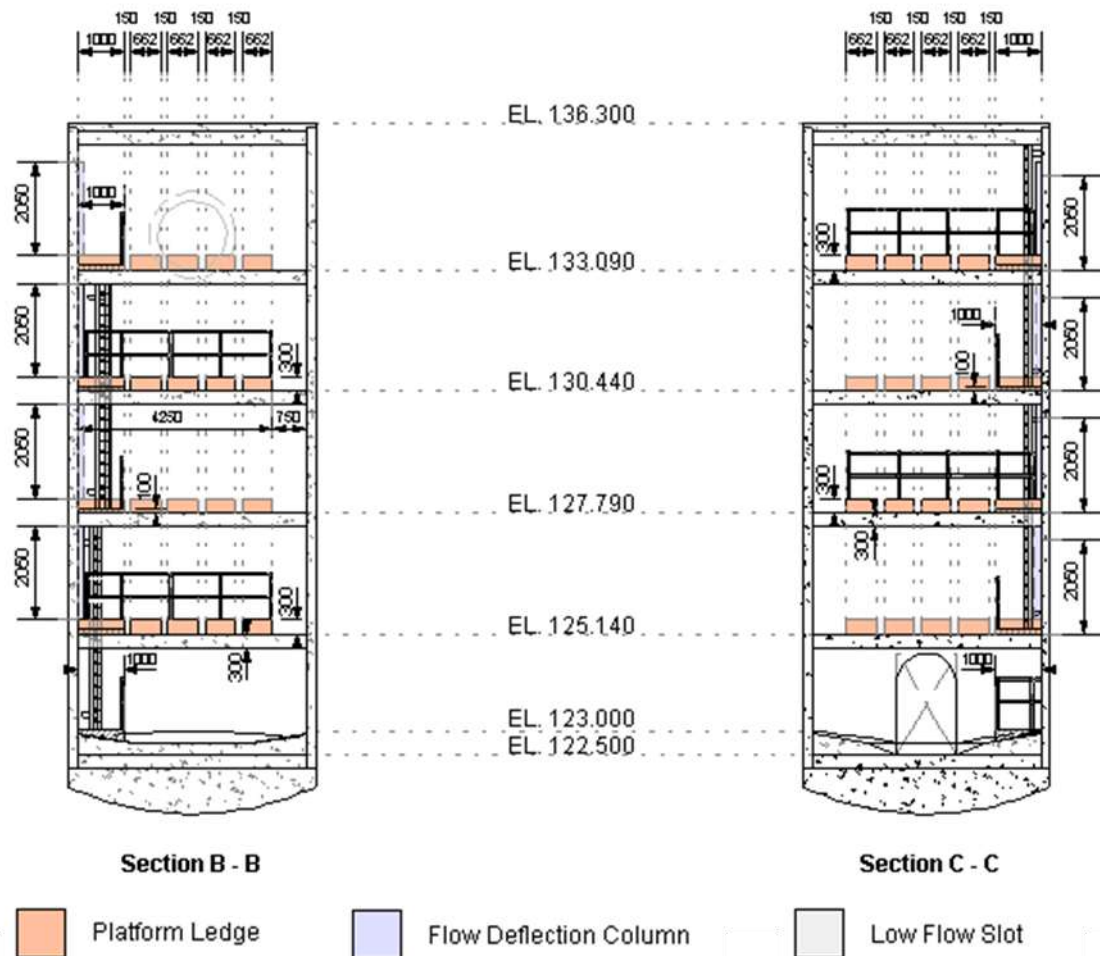


Figure 5.01 – Initially proposed low flow modifications – Sections

From Figures 5.01 and 5.02, a 3D model was generated. The 3D model was meshed into individual cells, over which the Navier-Stokes equations were solved numerically. The CFD modelling conducted in this study specifically utilised the Realisable $k-\epsilon$ turbulence model. The modelling was conducted utilising the commercial ANSYS Fluent solver.

Bury Drop structure MH6 – Physical Hydraulic Modelling

Figure 5.03 shows an image of the computational mesh used for the CFD analysis of the tank. The mesh architecture was arranged such that the zones having more pronounced velocity gradients, and thus requiring the greatest scrutiny, have finer grid pattern. Whereas, zones of less interest and impact on general flow patterns have coarser cells.

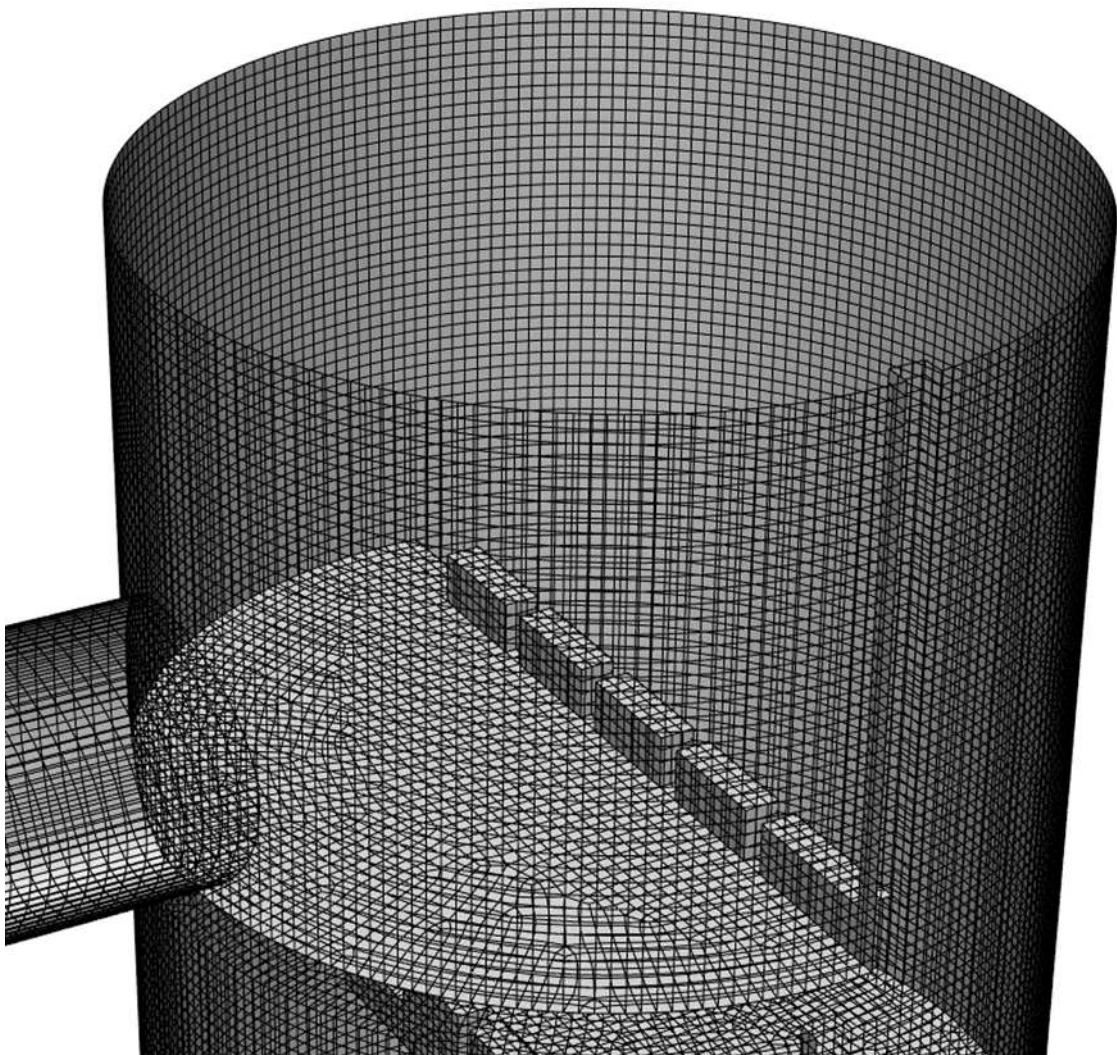


Figure 5.03 – Computational mesh used for primary CFD modelling

Figures 5.04 and 5.05 show the flow streaklines at the water surface, coloured by velocity, at the platforms of Levels 1 and 2. In both cases, large low velocity and recirculation regions occurred. This was due to the fact that the DWF velocities were too low to promote effective spreading of the flow, as was intended by the inclusion of the low flow slots. The low velocity recirculation regions would be prone to an accumulation of light solids and silt. Therefore, the proposed arrangement of the primary CFD analysis is not suitable for solids clearance at DWF conditions.

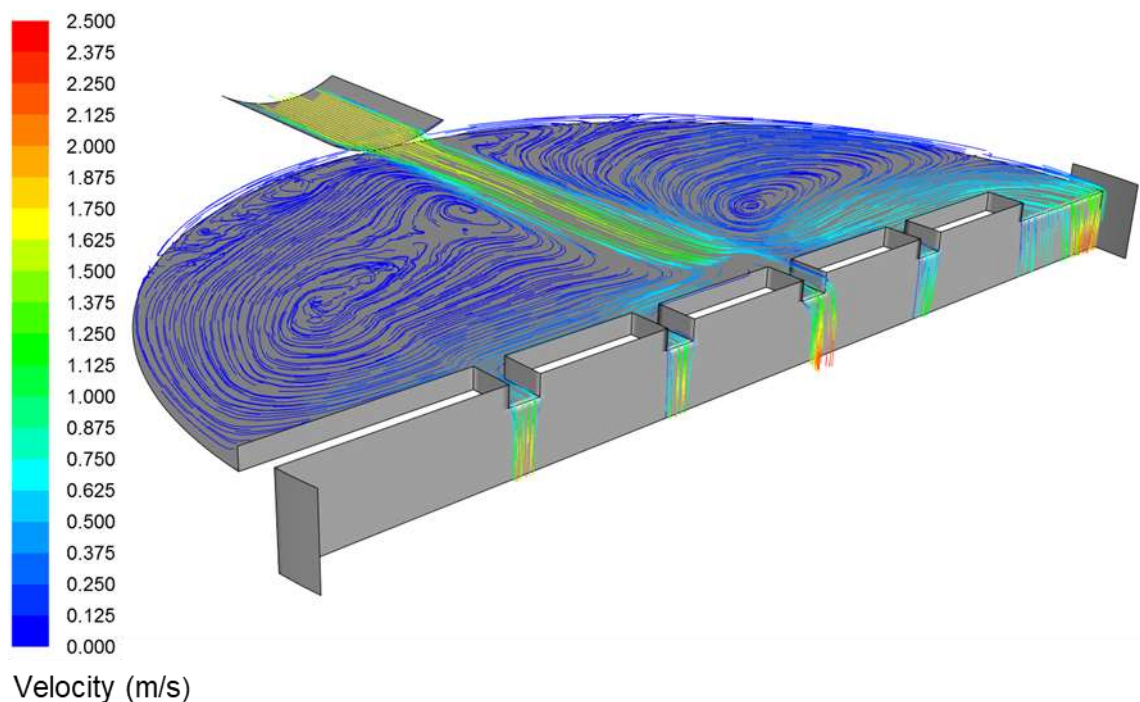


Figure 5.04 – Flow streaklines coloured by velocity at Level 1 – Initially proposed low flow arrangement

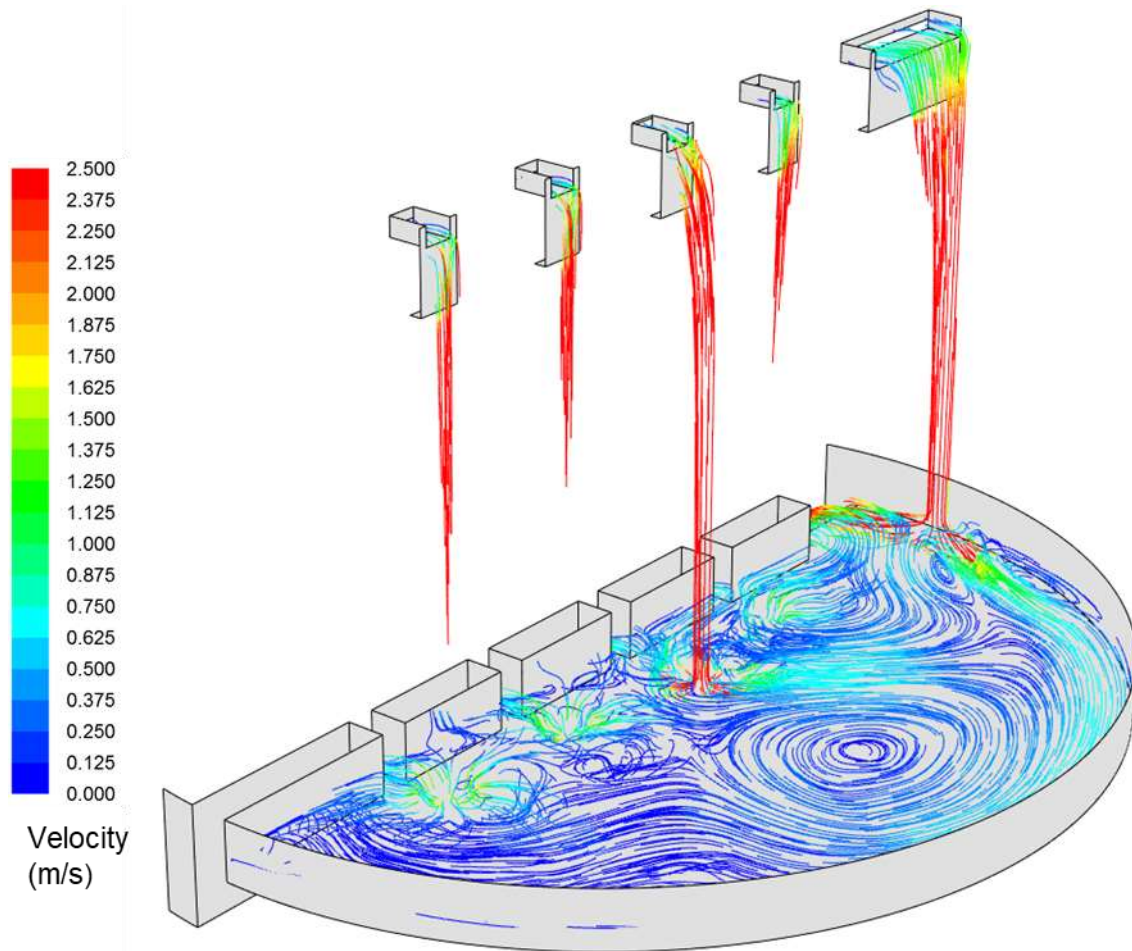


Figure 5.05 – Flow streamlines coloured by velocity at Level 2 – Initially proposed low flow arrangement

5.3 Secondary CFD Modelling

In order to further promote the clearance of solids, a secondary DWF arrangement was proposed. A DWF channel was proposed at the Level 1 platform, which runs directly from the inlet pipe to the 750 mm gap in the ledge, which was relocated to the centre of the ledge. Low gradient sloped benching was proposed across the remaining surface of the platform, to promote the transport of water and solids towards the DWF channel and the central 750 mm gap in the ledge. The low flow slots were retained at either side of the 750 mm ledge gap, as these will promote solids clearance at intermediate flows and would not impact either the DWF flow or storm flow conditions.

The proposed arrangement of the platforms at Levels 2, 3 and 4 were identical. Similarly to Level 1, the 750 mm ledge gap was relocated to the centre of the ledge. Sloped benching was proposed across the entire platform surface which would act to direct low flows and solids towards the 750 mm central gap in the ledge. The steepest part of the benching, adjacent to the 750 mm gap, is located so as to intercept the majority of the DWF from the platform above. Again, the low flow slots were retained at either side of the ledge, for the same reasons as at Level 1. The arrangement of Level 5 was identical to that of the physical modelling study. These modifications in geometry will promote solids clearance at DWF conditions, however, would have a negligible effect on the storm flow conditions. Therefore, the findings of the physical hydraulic modelling of storm flow conditions are applicable to this proposed arrangement.

These proposed modifications are shown in Figures 5.06 and 07. Full details of the proposed modifications are included in Appendix 2. The computational mesh was constructed with the same approach as that of the previous CFD modelling. The mesh at Level 2 is shown in Figure 5.08.

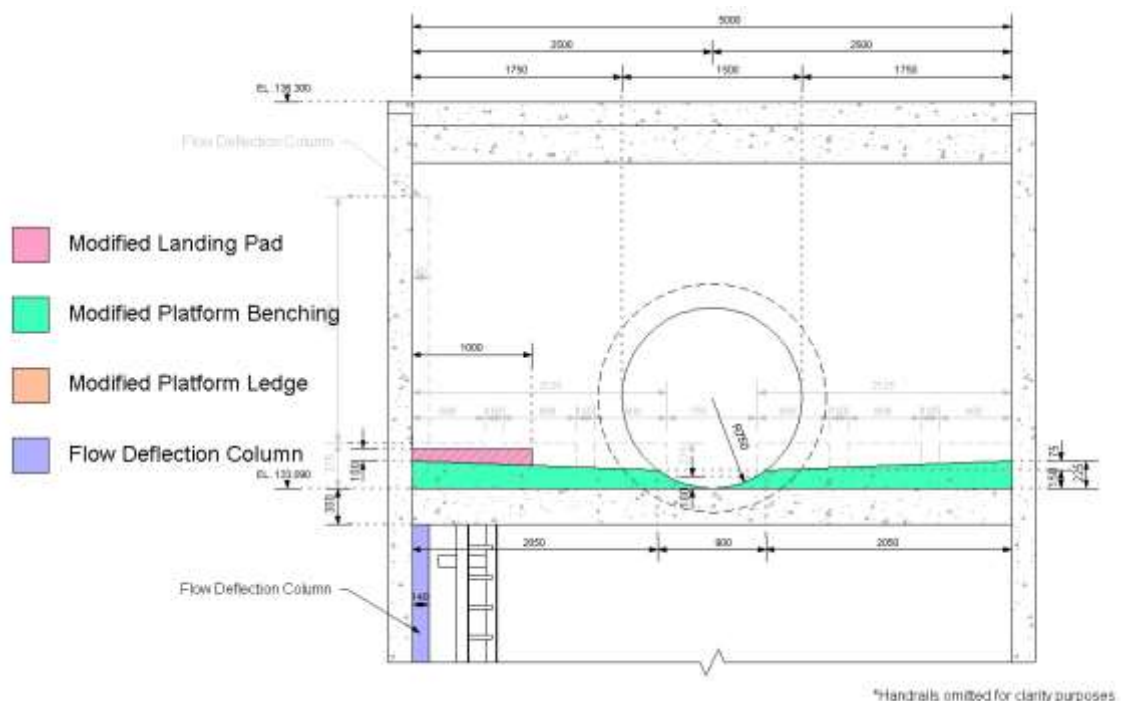


Figure 5.06 – Revised DWF modifications at Level 1

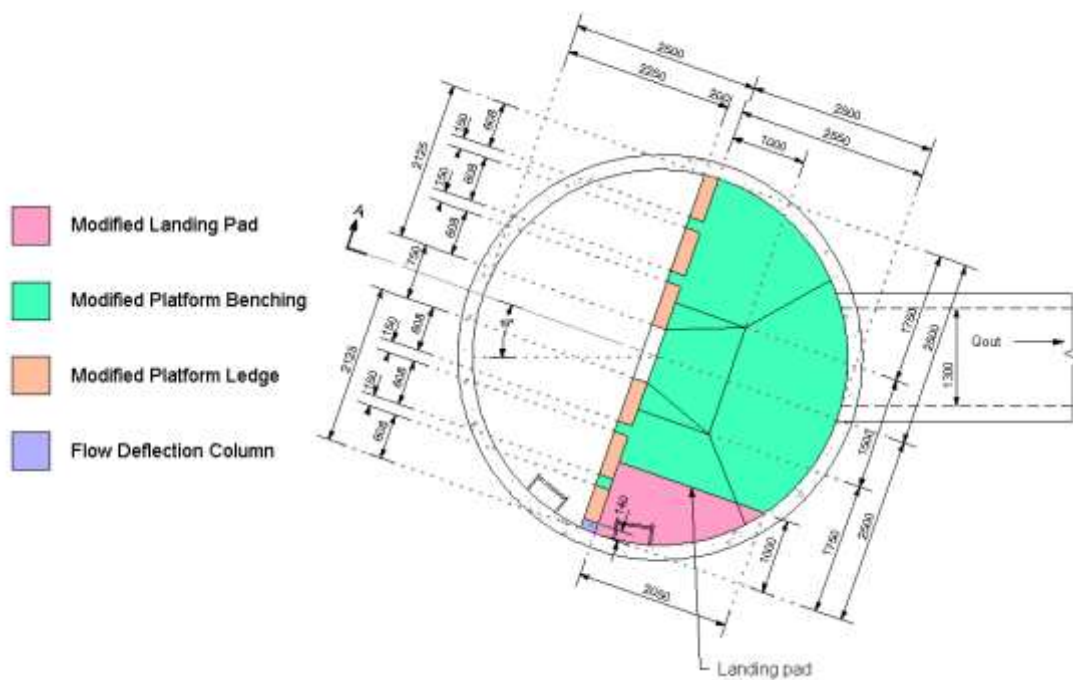


Figure 5.07 – Revised DWF modifications at Levels 2, 3 and 4

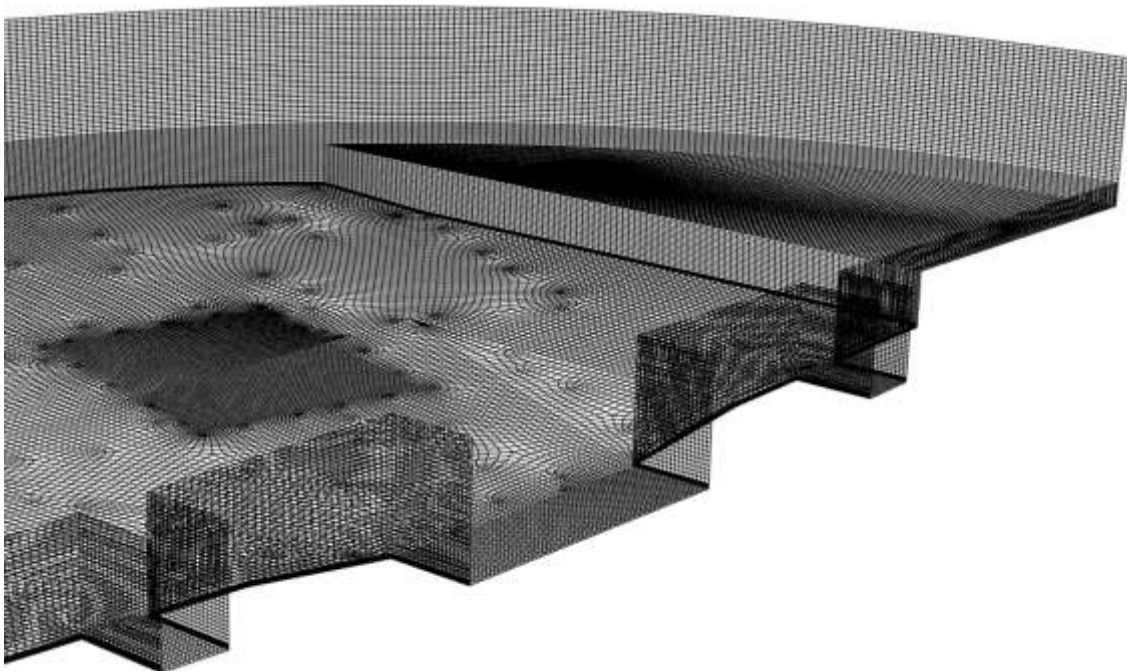


Figure 5.08 – Computational mesh at Level 2

Figure 5.09 shows an isosurface coloured by velocity of flow through the DWF channel of the platform at Level 1 at the Q50 flow rate of 27 l/s. The depth of the DWF channel was sufficient to contain all of the flow at Q50. Note that, for this reason, only the DWF channel was modelled in order to reduce computational time. All of the flow remained within the DWF channel and the velocities were sufficient to promote the clearance of silts and settleable solids through the channel. At intermediate inflow rates, the water level may increase so that not all of the flow would be contained within the DWF channel. The sloped benching outside of the DWF channel will promote the transport of solids towards the channel.

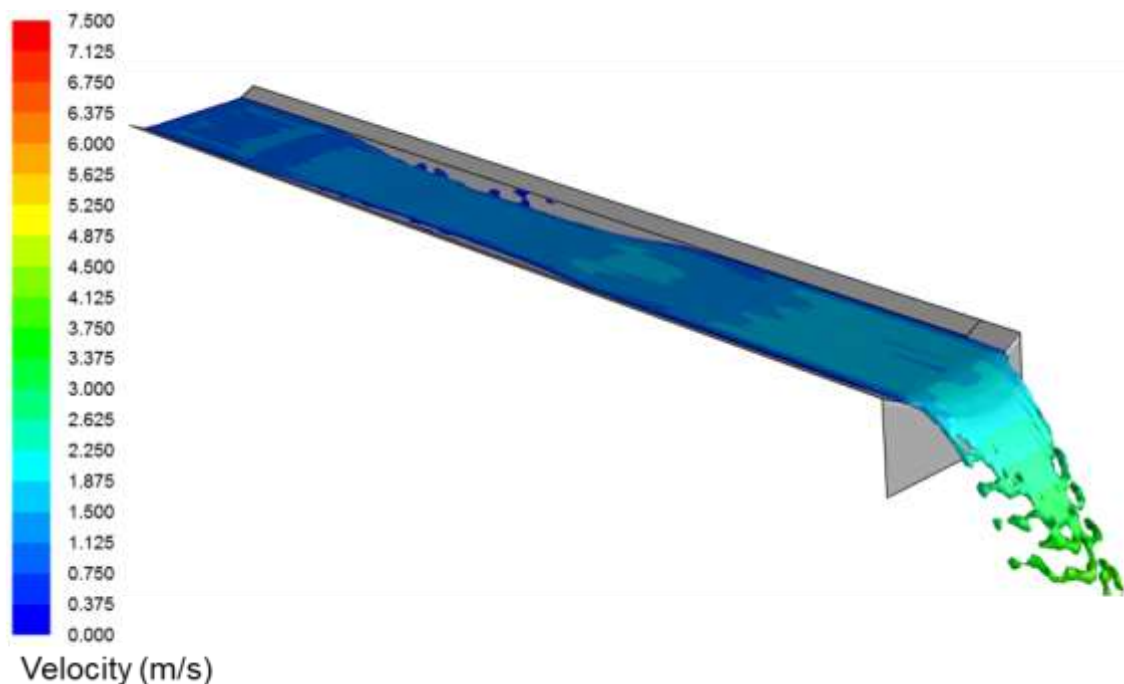


Figure 5.09 – Isosurface coloured by velocity of flow through the DWF channel of the platform at Level 1

Figure 5.10 shows flow streaklines at the water surface, coloured by velocity, of flow plunging from Level 1 and impacting on the Level 2 platform. Figure 5.11 shows flow streaklines adjacent to the surface of the platform. Flow impacted on the platform at a high velocity and spread radially across the platform, as would be expected. No recirculation regions occurred, which will prevent the accumulation of silts and settleable solids in any one location. As the inflow rate reduces and the water drains from the platform, stranding of a small number of solids will likely occur. This is to be expected and is not problematic for the performance of the drop structure. The highly turbulent nature of the flow will prevent a large accumulation of solids in any one location. CFD analysis found that almost all of the flow passed through the larger, central gap in the platform ledge, with only a small volume of flow passing through the smaller gaps in the ledge.

Figure 5.10 shows that some water overtops the man access ledge and spreads over a small region of the landing pad. The flow on the platform is transient and the flow onto the landing pad represents an intermittent wave. Only a small volume of solids would be transported onto the landing pad and the intermittent wave would aid in the clearance of any solids which were transported onto the landing pad. Therefore, it is not expected that there will be an issue with solids accumulation on the landing pad. Note that Figure 5.10 shows flow streaklines at only a small area of the landing pad, whereas Figure 5.11 shows streaklines across the entire ledge. This is because Figure 5.11 shows streaklines adjacent to the platform surface. In areas not occupied by water, such as on the landing pad, the streaklines represent the flow paths of the air within the model.

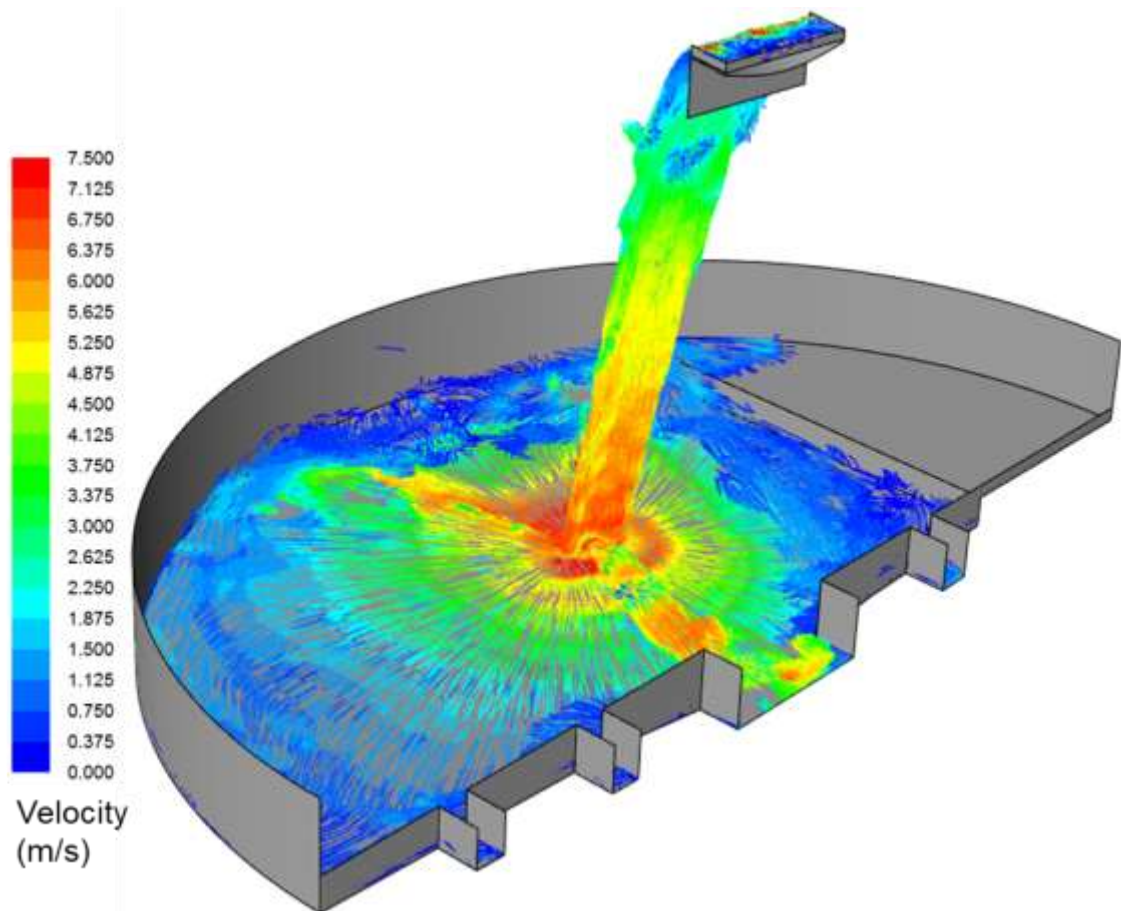


Figure 5.10 Flow streamlines at the water surface, coloured by velocity, at the Level 2 platform

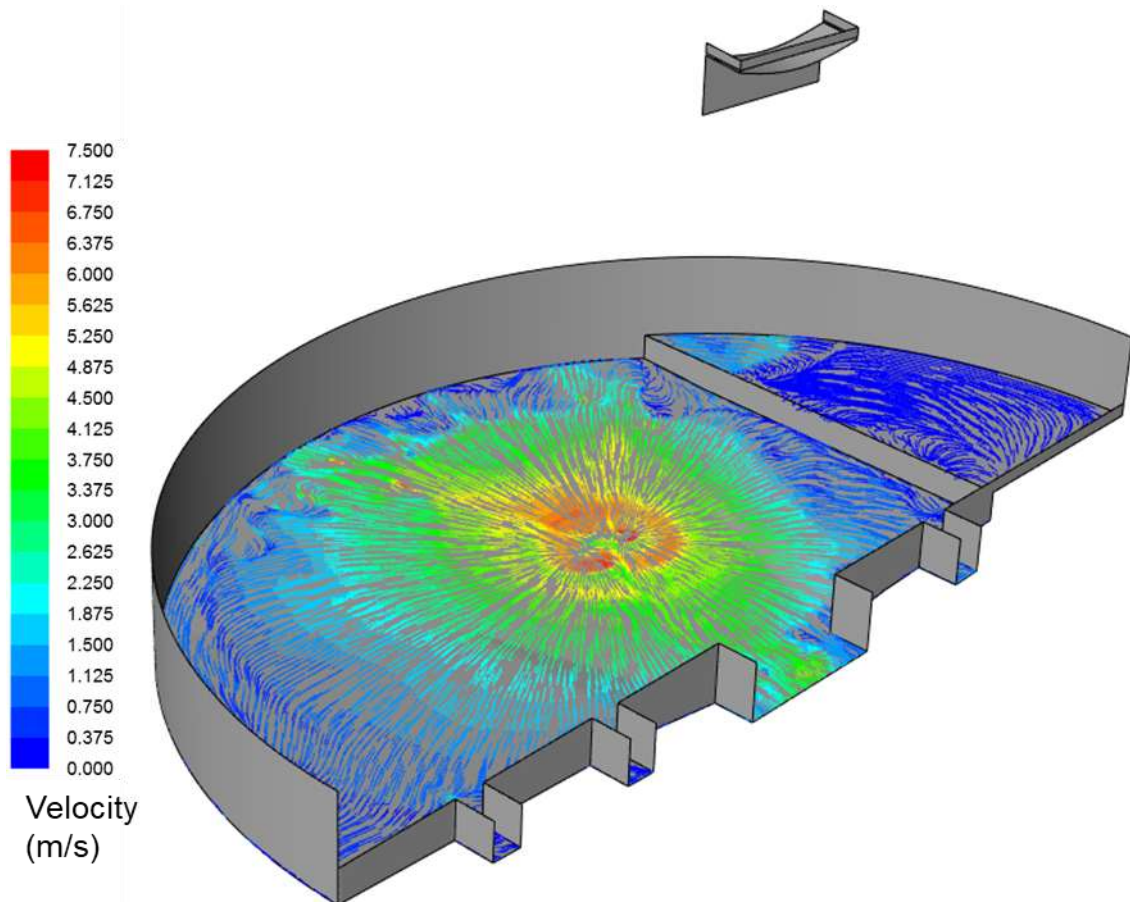


Figure 5.11 Flow streamlines at the platform surface, coloured by velocity, at the Level 2 platform

The proposed arrangements of the platforms at Levels 3 and 4 are identical to that of the platform at Level 2, so it is expected that the flow conditions at Levels 3 and 4 would be comparable to those at Level 2. Therefore, the platforms at Levels 3 and 4 were not modelled, as CFD modelling of these platforms would have been prohibitively time consuming and expensive and would have delayed the results significantly, only to produce findings which are comparable to those of Level 2. The outlet flow conditions at Level 2 were applied as the inlet conditions at Level 5.

Figure 5.12 shows streaklines at the water surface, coloured by velocity, at Level 5. As water from the platform above impacted the base of the drop structure and spread radially, with supercritical flow occurring. As the flow approached the opposing wall from the outlet channel, a hydraulic jump formed and flow was deflected laterally. The flow was transported around the supercritical flow region beneath the incoming jet, towards the outlet channel. A small volume of fluid was transported over the benching at the sides of the outlet channel, where the slope of the benching would aid the transport of flow and solids towards the outlet channel.

Figure 5.13 shows streaklines adjacent to the invert, also coloured by velocity, at Level 5. As at Level 2, streaklines are displayed across the entire surface of the invert, whereas in Figure 5.12, no streaklines are visible across parts of the benching. This is again due to the fact that, adjacent to the solid surface, streaklines are displayed for both air and water, however, in Figure 5.12, streaklines are shown at the water surface only. Figure 5.13 also shows that flow spread radially from the impact from the platform above, with higher velocity, supercritical flow occurring. The flow then deflected from the rear wall of the shaft, and was transported around the supercritical flow region, towards the outlet channel.

The velocities within the supercritical flow region were sufficient to scour silt and settleable solids from the invert. In the lower velocity regions, the gradient of the benching will promote the transport of solids towards the outlet channel. Similarly to at Level 2, stranding of solids will likely occur as the flow rate through the drop structure reduces. However, the velocities and turbulence at Level 5 are sufficiently high to prevent a permanent accumulation of solids in any one location. A small number of temporary stranded solids is to be expected, this would not be detrimental to the performance of the drop structure. The velocities through the outlet channel were also sufficiently high to clear silts and settleable solids. Therefore, CFD analysis has shown that this proposed arrangement would prevent the accumulation of silts and settleable solids at DWF conditions.

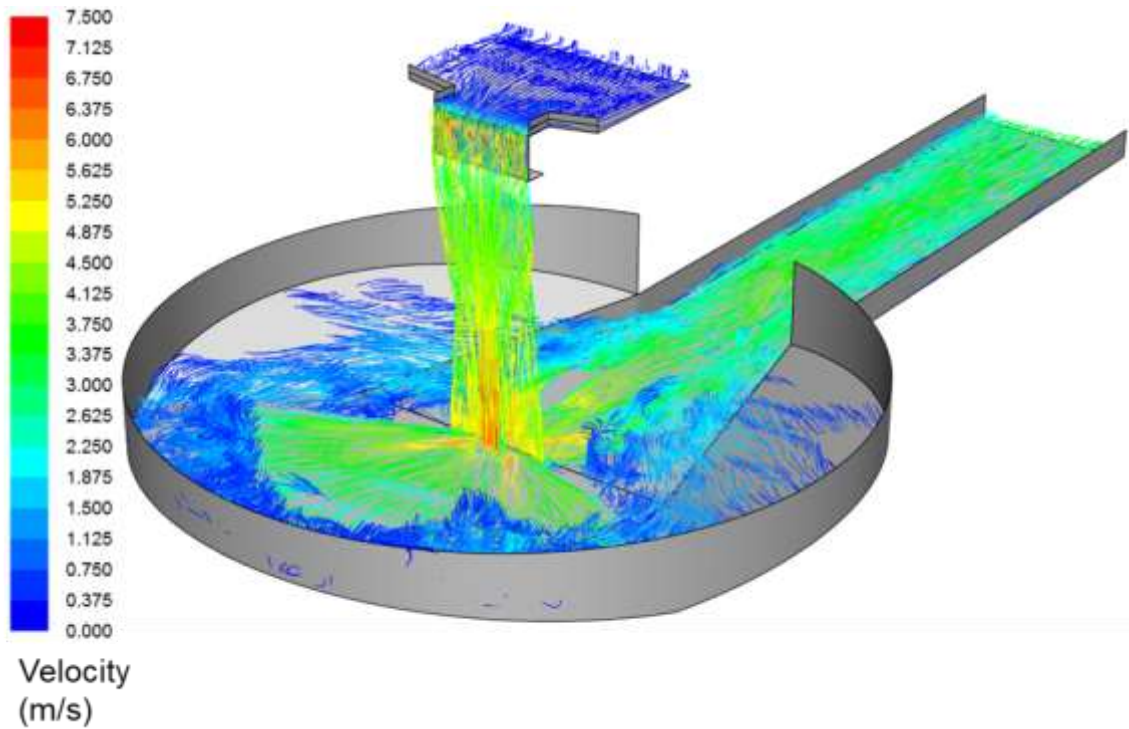


Figure 5.12 Flow streamlines at the water surface, coloured by velocity, at Level 5

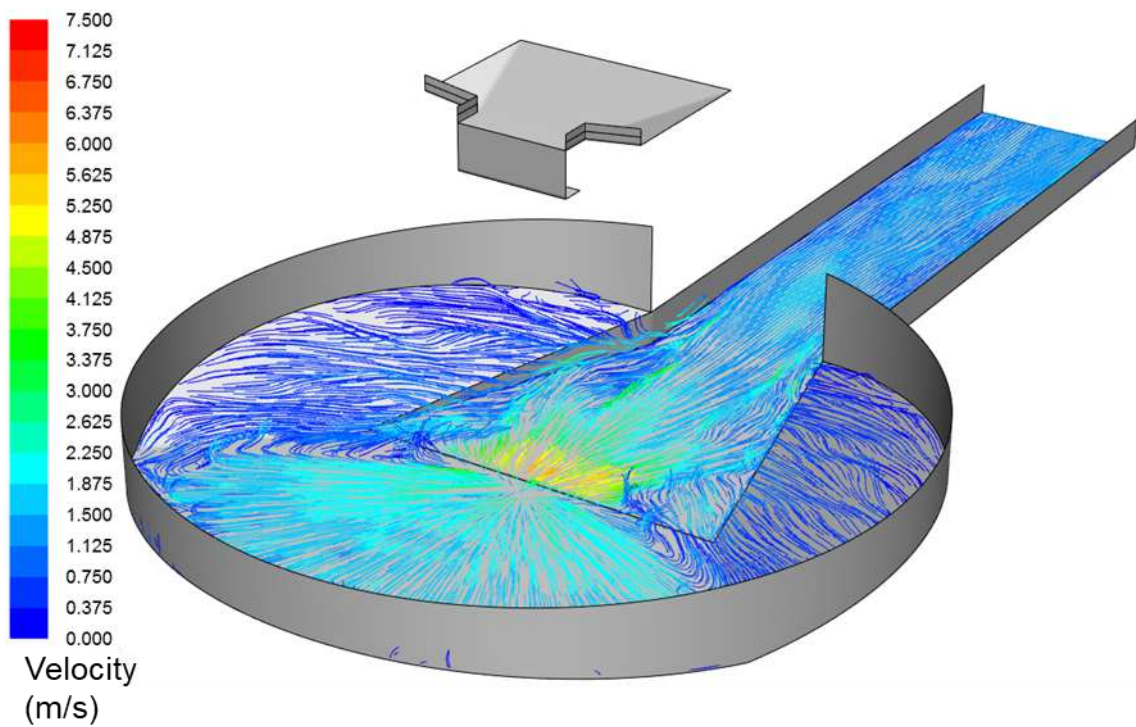


Figure 5.13 Flow streamlines at drop structure invert, coloured by velocity, at Level 5

5.4 Conclusions from CFD Modelling of Dry Weather Flow Conditions

Following physical hydraulic modelling of the storm flow conditions, analysis of the dry weather flow conditions (DWF) was conducted. Scaled physical hydraulic modelling of the DWF conditions was not appropriate, as the lower flow rates caused surface tension effects to dominate, preventing accurate analysis to be made. Therefore, Computational Fluid Dynamics (CFD) modelling of the DWF conditions was conducted at full scale. The main purpose of the DWF analysis was to determine whether silts and settleable solids would clear at the lower flow rates.

The arrangement of the drop structure was modified to aid the transport of solids. A number of additional slots were installed in the platform ledges in order to promote flow to spread and transport solids. Primary CFD analysis found that this arrangement resulted in low velocity, recirculation regions, which would be prone to solids accumulation. A revised arrangement was proposed in which a DWF flow channel was installed at Level 1 and benching was installed at Levels 2,3 and 4, in order to promote the transport of solids. CFD analysis of this revised arrangement found that at Level 1, all flow passed through the DWF channel with a high enough velocity to transport silts and settleable solid. At levels 2 - 5, CFD modelling found that temporary stranding of solids would likely occur. This is to be expected and is not detrimental to the performance of the drop structure. The velocities and turbulence throughout Levels 2 – 5 were sufficiently high to prevent long-term accumulation of solids in any one location. It should be noted that, the proposed modifications are small compared to the length scales of the storm flows. Therefore, the findings of the physical hydraulic model study of the storm flow conditions are applicable to the revised proposed DWF arrangement.

5.0 CONCLUSIONS

Initial testing

The Bury Drop Structure MH6 physical hydraulic model was tested at a number of flow rates representative of the specified flow range. Initial testing was conducted prior to confirmation of the tailwater levels by the Client, as such free discharge conditions were assumed for initial assessment purposes. Initial testing found that the Bury Drop Structure MH6 generally performed satisfactorily for the flow rates investigated, however, minor performance issues were identified that needed to be addressed. A continuous nappe formed at each cascade, which may prevent air from freely venting to atmosphere. Trapping air has the potential to locally pressurise the shaft, which may cause structural damage. The continuous nappes formed at each platform should be disrupted and broken up in order to allow air to be freely vented.

The proposed platform ledges acted to pool water on the platform which dissipated energy at each platform, however, at higher flow rates, a smaller proportion of the receiving flow was intercepted. This resulted in high energy flows cascading onto the platform below. The energy of these nappes formed at each platform of the cascade should be reduced, in so far as can reasonably be achieved.

Development

In order to mitigate the performance issues identified during initial testing, the following modifications to the Bury Drop Structure MH6 arrangement were made:

- At each platform, a flow deflection column was installed at the downstream ledge of each platform, to one side of the shaft, adjacent to the shaft wall. The purpose of the flow deflection columns was to deflect nappe flow away from the shaft wall, creating an air gap through which the entire chamber could be vented to atmosphere. The flow deflection columns were also intended to direct flow away from the shaft man access ladders located at each platform, in so far as was possible. This was proposed in order to reduce potential ragging of solids to the access ladders and to protect them from excessive hydraulic loading.

- The height of each platform ledge was increased by 50 % from 200 mm to 300 mm. The increase in ledge height was intended to intercept a higher proportion of the flow, which will increase the depth of pooled water retained at each platform. The increase in the retained water depth will dissipate a larger proportion of the energy of the receiving flow. It should be noted that, although the increase in ledge height will dissipate more energy, the flows through the drop structure are inherently high energy, especially at the higher flow rates. Therefore, although energy dissipation will be increased, the nappe flows produced at each platform will still exhibit significantly high energy and turbulence.

Final Testing

The modified Bury Drop Structure MH6 physical hydraulic model was tested at a range of flow rates and water levels provided by and agreed upon by the Client. Hydraulic assessment of the Bury Drop Structure MH6 physical hydraulic model found that the drop structure conveyed the flows safely and performed satisfactorily for all flow rates and tailwater levels investigated. Three different general flow conditions occurred within the drop structure, depending on the water level within the shaft:

1. At the higher water levels (100 years + 70% and 1000 year return periods), the drop structure was almost completely surcharged, i.e. up towards the shaft soffit. As flow passed across the shaft soffit at surcharged operation, air was entrained into the flow from the vent provided in the model soffit. This indicates that a vented soffit must also be installed in the prototype drop structure, as failure to do so may result in the chamber becoming depressurised, which could lead to structural damage and possible accelerated failure.
Submerged flow conditions occurred throughout the drop structure at the specified flow range of 100 years + 70% and above. At these conditions, flow paths were dictated by the arrangement of the platforms and the flow was conveyed through the drop structure and into the Outlet Culvert safely.
2. At a return period of 100 years + 35%, the water level within the drop structure was approximately at mid shaft height. In the upper section of the drop structure free-surface flow occurred and the flow cascaded from each platform to the next. This regime was characterised by high levels of air entrainment at each platform. The proposed increase in the height of the platform ledges increased the depth of the retained flow on each platform, which in turn increased energy dissipation.

The proposed vertical flow deflection columns at each platform ledge acted to deflect flow away from the wall of the drop structure, allowing air to freely vent to atmosphere. The flow deflection columns also deflected flow away from the man access ladders somewhat. At the lower depths, submerged flow occurred and the flow patterns were comparable to those at the higher water levels, but with slightly lower velocities and a higher volume of entrained air.

3. At the lower tailwater levels (return periods of 2 years, 20 years and 50 years) the water levels within the drop structure were closer to the invert of the shaft. Under these conditions, flow was also conveyed safely through the drop structure. Free surface cascading flow occurred at each landing level within the drop structure, characterised by high levels of splash, spray and air entrainment. Again, the proposed increased ledge heights increased the depth of retained water on the platforms, increasing energy dissipation, and the flow deflection columns diverted flow away from the wall of the chamber, creating an air gap through which air could be freely vented to atmosphere. The water levels at the base of the drop structure shaft, dictated by the receiving water course tailwater levels, also acted to cushion the flow and increase energy dissipation.

The solids handling of the drop structure was investigated for a range of operating scenarios. Solids were cleared from the drop structure quickly and efficiently at all flow rates investigated. At the higher water levels, solids were held in suspension and transported through the drop structure. Highly buoyant solids, representative of solids such as footballs and plastic bottles, were not drawn through the Inlet Culvert due to the water depth in the drop structure being significantly higher than the soffit of the Inlet Culvert. This is representative of the prototype flow conditions.

At a flow rate of 5670 l/s, the water level was at approximately the mid height of the drop structure. In the upper section of the drop structure free-surface cascade flow was exhibited and solids were either suspended in the flow or tracked along the base of each platform, prior to being transported over the platform ledge to the receiving platform below. In the lower section of the drop structure submerged flow conditions occurred and solids were cleared in a similar manner to those at the higher flow rates and tailwater levels. There was some temporary retention of highly buoyant solids within the submerged flow region within the shaft, however, the highly buoyant solids were cleared from the shaft towards the Outlet Culvert after a short duration of operation.

At the lowest specified flow rate of 1400 l/s, all solids were cleared throughout the drop structure. Cascading free-surface flow occurred throughout the structure and all model solids (floating, suspended and settleable), were transported across each platform, either in suspension, or across the base of the platform to pass over each platform ledge to the successive receiving platform below. Solids were directed towards the central channel formed at the invert of the shaft and out into the outlet culvert within the region of fastest moving flow.

At the lowest specified test flow rate of 1400 l/s, the lowest velocities occurred throughout the drop structure. This indicates that all solids will also be cleared forward to the Outlet Culvert at the higher flow rates of 2800 l/s and 3500 l/s, at which cascading flow also occurred and the flow conditions were comparable.

CFD Modelling of Dry Weather Flow Conditions

Following physical hydraulic modelling of the storm flow conditions, analysis of the dry weather flow conditions (DWF) was conducted. Scaled physical hydraulic modelling of the DWF conditions was not appropriate, as the lower flow rates caused surface tension effects to dominate, preventing accurate analysis to be made. Therefore, Computational Fluid Dynamics (CFD) modelling of the DWF conditions was conducted at full scale. The main purpose of the DWF analysis was to determine whether silts and settleable solids would clear at the lower flow rates.

The arrangement of the drop structure was modified to aid the transport of solids. A number of additional slots were installed in the platform ledges in order to promote flow to spread and transport solids. Primary CFD analysis found that this arrangement resulted in low velocity, recirculation regions, which would be prone to solids accumulation. A revised arrangement was proposed in which a DWF flow channel was installed at Level 1 and benching was installed at Levels 2,3 and 4, in order to promote the transport of solids. CFD analysis of this revised arrangement found that at Level 1, all flow passed through the DWF channel with a high enough velocity to transport silts and settleable solid. At levels 2 - 5, CFD modelling found that temporary stranding of solids would likely occur. This is to be expected and is not detrimental to the performance of the drop structure. The velocities and turbulence throughout Levels 2 – 5 were sufficiently high to prevent long-term accumulation of solids in any one location. It should be noted that, the proposed modifications are small compared to the length scales of the storm flows. Therefore, the findings of the physical hydraulic model study of the storm flow conditions are applicable to the revised proposed DWF arrangement.

APPENDIX 1 MODEL SIMILARITY

A1.1 Model Scale

The fundamental scale for any hydraulic model is the geometric scale, that is the ratio of a given length in the model to a given length in the full scale application. Practical considerations such as the circulating pump capacity, depth of model, the floor space utilised and ultimately cost, place limits on the maximum size of a model. Theoretical considerations regarding the correct representation of flow conditions places limits on the minimum size of a model.

The correct representation of flow conditions principally requires that the Reynolds Number to be above a critical value within the model to ensure that, where fully turbulent conditions are present in the prototype, similar turbulent conditions exist within the model. If the model is too small this condition will not be met.

Much has been written concerning the problem of scaling results from a physical model to predict full-size prototype performance. It is apparent that a scaling law for one arrangement may not be appropriate for another and thus no definitive, universally applicable law exists. In open channel studies it is generally accepted that the Reynolds Number should be at least 2,500 to ensure fully turbulent conditions are present. In studies where vortex formation may occur it is necessary to ensure that the Reynolds Number, at the outlet culvert, assuming full flow depth, has a value of at least 30 000 to 40 000 to eliminate viscous effects.

In this instance, at a nominal minimum flow of 1400 l/s the full scale Reynolds Number at the outlet culvert will be approximately 1148983. From practical considerations the model was constructed to a scale of 1/7 full size which will result in a Reynolds Number at the plane of the model outlet culvert of approximately 61336. This is in excess of quoted minimum values, and will ensure similarity between model and prototype at all flow rates investigated.

Following the selection of an appropriate geometric scale, the dynamic scale of for example, velocity and discharge, will be determined according to scaling criteria dictated by a particular model law. For free surface flows the governing forces are gravity and inertia, these forces are related by the Froude Scaling Law, which may be stated as:

Froude Number similarity will be achieved if the Froude Number in the prototype (F_p) and model (F_m) are equal, i.e. :

$$F_p = \frac{V_p}{\sqrt{g \cdot L_p}} = F_m = \frac{V_m}{\sqrt{g \cdot L_m}} \quad 1.1$$

Where V_p and V_m are the velocities in the prototype and model, L_p and L_m are characteristic lengths in the prototype and model and g is the gravitational constant. This will ensure dynamic similarity for flow regimes governed primarily by gravity. Rearrangement of equation 1.1 gives the velocity scale :

$$V_m = V_p \frac{\sqrt{g \cdot L_m}}{\sqrt{g \cdot L_p}} \quad 1.2$$

For a geometrically similar model the model scale factor may be defined by $S = L_m / L_p$ and the gravitational constant g will be equal, hence

$$V_m = V_p S^{1/2} \quad 1.3$$

The flow scale may be derived by continuity, whereby

$$Q \propto L^2 V \quad 1.4$$

Substitution into equation 1.2 gives

$$Q_m = Q_p S^{5/2} \quad 1.5$$

Similarly, transformation to take account of time is made using

$$V \propto L/T \quad 1.6$$

so that

$$T_m = T_p S^{1/2} \quad 1.7$$

Force scales are based on the ratio of measured force to inertial force and provided these are maintained in equal ratio model similarity of forces will also be achieved:

$$\frac{F_p}{\rho L_p^2 V_p^2} = \frac{F_m}{\rho L_m^2 V_m^2} \quad 1.8$$

so that assuming the model and full scale application are operated with the same fluid, substitution into equation 1.3 gives

$$F_m = F_p S^3$$

1.9

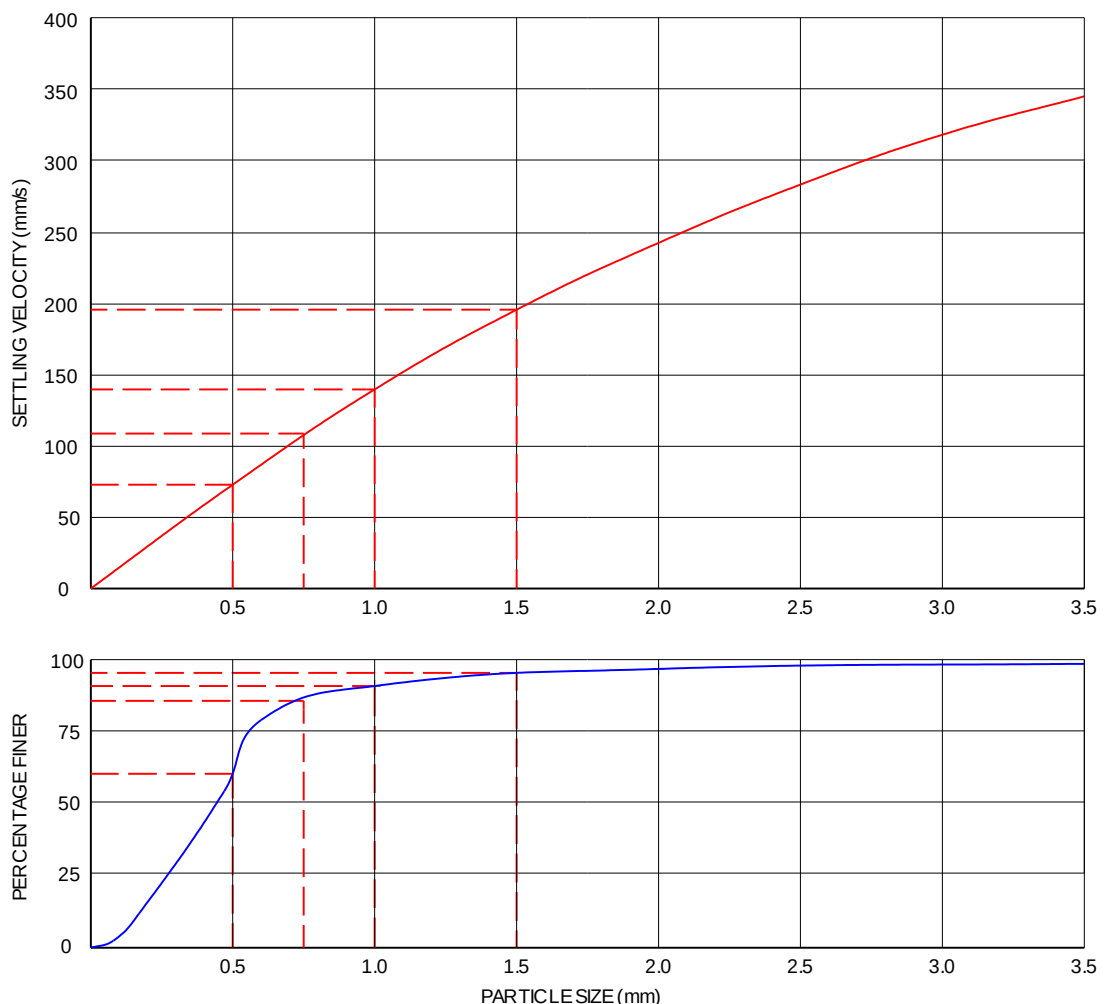
For the application in question a geometric scale of 1 to 7 was selected, hence the appropriate dynamic scales may be calculated as follows

Property	Scale Relationship	Model Value
Geometric	$S = L_m / L_p$	1/7
Velocity	$V_m = V_p S^{1/2}$	1/2.65
Flow	$Q_m = Q_p S^{5/2}$	1/130
Time	$T_m = T_p S^{1/2}$	1/2.65
Force	$F_m = F_p S^3$	1/343

A1.2 Modelling grit

It is important to represent the solid fraction of storm water and surface water in order to highlight potential problems of grit settlement and accumulation. Various methods of representing grit particles may be employed, in our experience grit transport and settlement can be successfully simulated using graded samples of plastic particles. Care must be taken to ensure the particles are of uniform density and free from air.

In accordance with scaling principles the plastic particles are selected on the basis of a settling velocity equal to the square root of the full scale particle settling velocity. The characteristic particle size distribution and settling velocity of a typical sewage sample are presented below.



The characteristic particle size distribution and settling velocity of a typical sewage sample

Interpretation of the model grit characteristics must be carried out as it is not possible to represent the cohesive or organic binding properties of the sewage solids. Also, value judgements have to be made with respect to disregarding particles in the sample which fail to become adequately wetted or to which air bubbles have attached. These techniques have however been shown in practice to be accurate in predicting grit transport and deposition.

A1.3 Grease

The definition of 'grease' usually refers to agglomerated particulate matter which is derived from a complex mixture of both the organic and inorganic constituents of sewage. The constituents are derived primarily from food sources and domestic and industrial oils, grease generally enters sewers in an emulsified form. De-emulsification of these source materials due to cooling results in separation of the solid constituents and an agglomeration with other non-greasy particulate matter. If left to accumulate, grease may create significant maintenance problems. Agglomeration with inorganic constituents such as rags may result in matting and, under extreme conditions, bridging to form a solid impenetrable barrier. Balling of grease and rags may also lead to maintenance problems further downstream.

The accurate representation of 'grease' properties within a physical model is not possible due to difficulties associated with scale similarity of the agglomeration process. However, indicative behaviour may be simulated using positive and neutral buoyancy solids such as chopped sponge, polystyrene and sawdust. Sawdust acts as an emulsion and also as a binding agent, to provide a good indicator of composite grease type properties.

A1.4 Scale effects

Scale errors occur whereby the laws of dimensional similarity cannot be satisfied simultaneously within a model operating on the basis of one particular law of affinity. This model was operated on the basis of Froude Number similarity, this effectively exaggerates the viscous influence defined by the Reynolds number (for non-turbulent conditions) and also exaggerates surface tensile forces defined by the Weber number. This condition is termed a 'scale effect'.

Under this model application, air was entrained in the flow at the cascade drops or at the soffit of the drop structure. Due to surface tension effects, air bubbles generated within a model exhibit the same absolute size as those generated within the prototype. As a result, air bubbles apparent in the model will be disproportionately large compared to their boundary scale.

The prototype, which operates at a higher Reynolds Number and therefore higher shear rate, will exhibit a larger number of proportionately smaller bubbles.

As a result of this condition, model bubbles will be more buoyant than their prototype full scale counterparts and will therefore exhibit a higher rise velocity. This results in model bubbles approaching the water surface quicker than their prototype counterparts, which will travel further. Hence the rise trajectory of model bubbles will be steeper.

It can be shown that within a Froude scale model, the depth of air bubble penetration is dictated by gravitational and inertial forces, provided flow is fully turbulent. Hence this characteristic will be correctly represented within the model provided the model is operated in excess of the Critical Reynolds Number (Re_c of approximately 2000), which will ensure that the flow regime is fully turbulent. Therefore, where prototype operation is critical in relation to the depth of air bubble penetration, conditions will be correctly represented within the model, provided the geometric scale is selected to satisfy Reynolds Number constraints.

The depth of air bubble penetration and subsequent rise trajectory is of importance where the full scale installation has a bearing on the passage of air to say, a pump or transfer pipe, whereby more air may enter the pump or pipe within the prototype than within the model. Hence, where considered critical, an assessment of the relative characteristics of the prototype bubble flow paths and model bubble flow paths must be made. The deviation in bubble rise trajectory cannot be eliminated within a small scale Froude model, however the effect is reduced as the model scale is reduced.

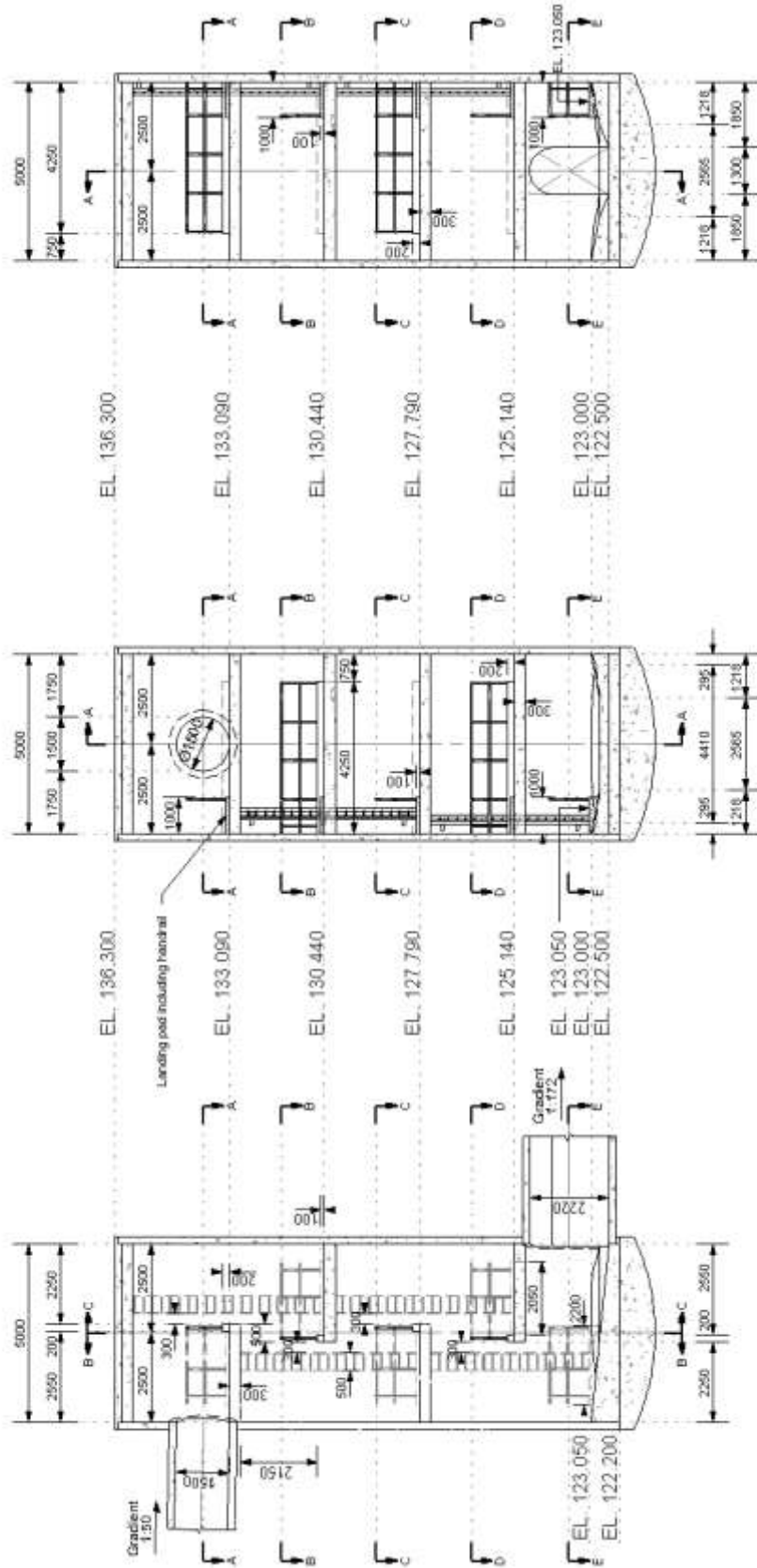
APPENDIX 2 DRAWINGS

The following drawings form part of this report:-

<i>Title</i>	<i>Drawing No.</i>
General Arrangement Drawings	
Drop Shaft Design – Former Tetrosyl Site, Bevis Green, Bury Sections A-A, B-B and C-C	01
Drop Shaft Design – Former Tetrosyl Site, Bevis Green, Bury Plans A-A and B-B	02
Drop Shaft Design – Former Tetrosyl Site, Bevis Green, Bury Plans C-C and D-D	03
Drop Shaft Design – Former Tetrosyl Site, Bevis Green, Bury Plan E-E	04
Details of Modifications	
Bury Drop Shaft - Details of Modifications - Plan at A-A	05
Bury Drop Shaft - Details of Modifications - Plan at B-B	06
Bury Drop Shaft - Details of Modifications - Plan at C-C	07
Bury Drop Shaft - Details of Modifications - Section A-A (of Plan at A-A)	08
Bury Drop Shaft - Details of Modifications - Section A-A (of Plan at B-B)	09
Bury Drop Shaft - Details of Modifications - Section A-A (of Plan at C-C)	10
Bury Drop Shaft - Details of Modifications - Section B-B (of Plan at A-A)	11
Bury Drop Shaft - Details of Modifications - Section B-B (of Plan at B-B)	12
Bury Drop Shaft - Details of Modifications - Section B-B (of Plan at C-C)	13

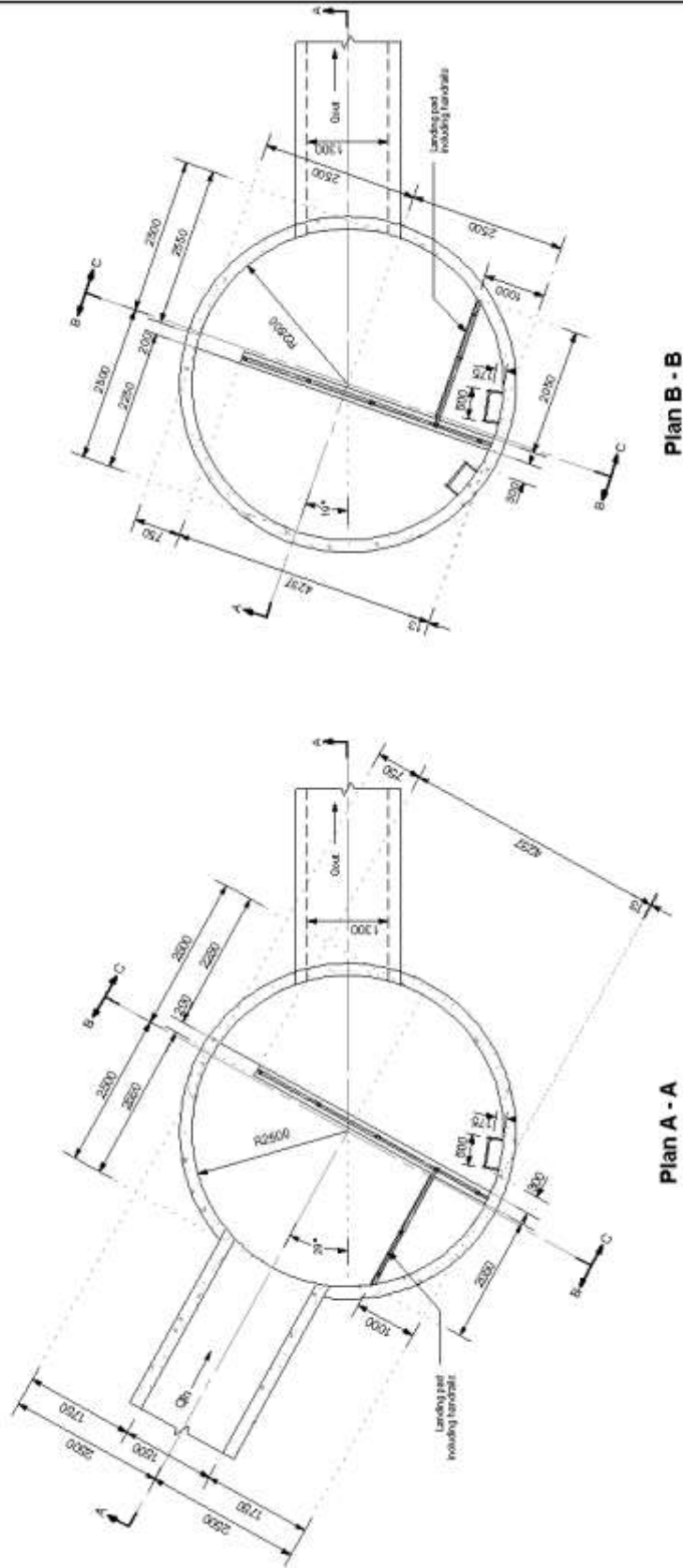
Bury Drop Shaft - Details of Modifications - Section C-C (of Plan at A-A)	14
Bury Drop Shaft - Details of Modifications - Section C-C (of Plan at B-B)	15
Bury Drop Shaft - Details of Modifications - Section C-C (of Plan at C-C)	16

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Drop Shaft Design - Former Tetrosyl Site, Bevis Green, Bury
Sections A - A, B - B and C - C

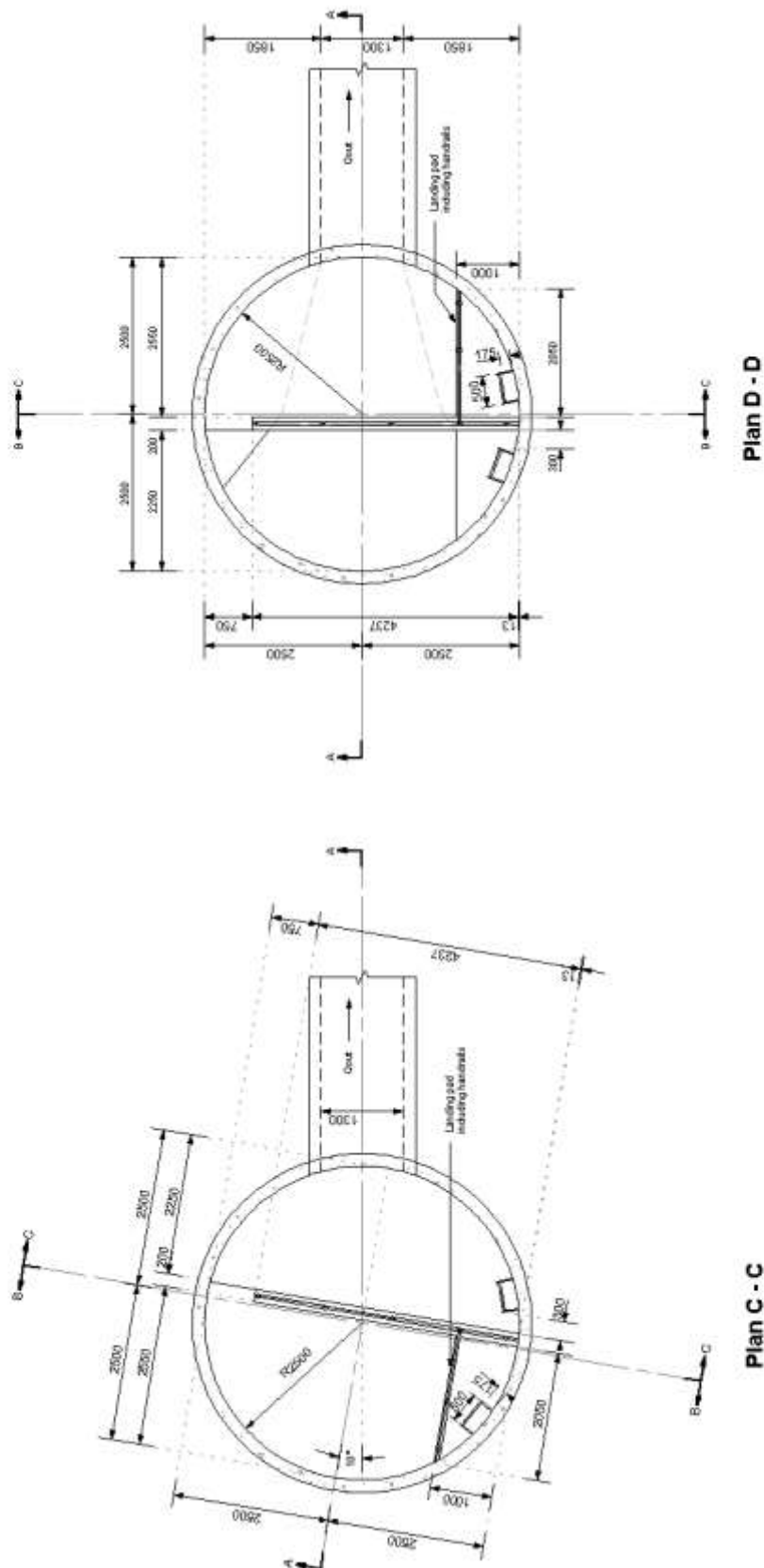
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Drop Shaft Design - Former Tetrosyl Site, Bevis Green, Bury
Plans A - A and B - B

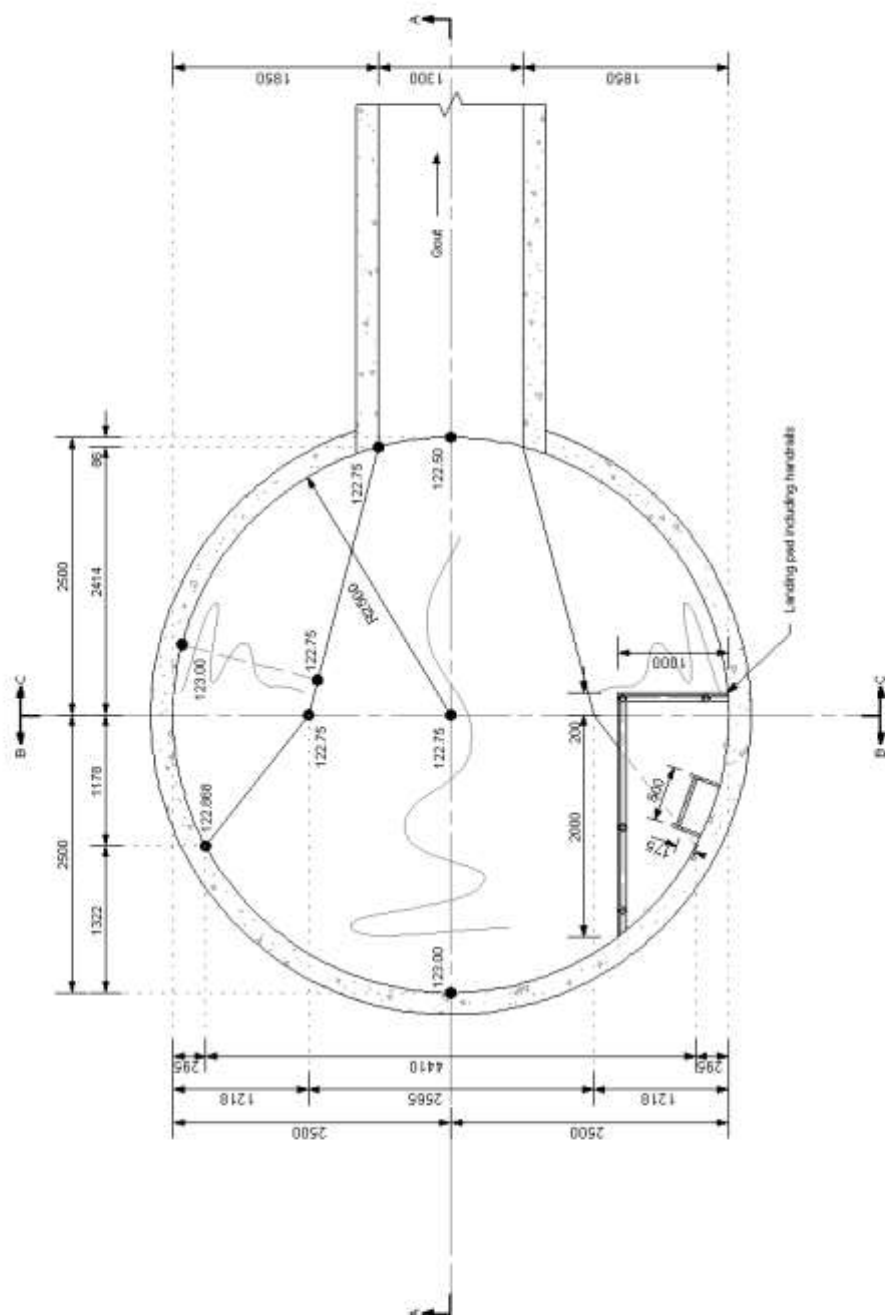
Drawing 02

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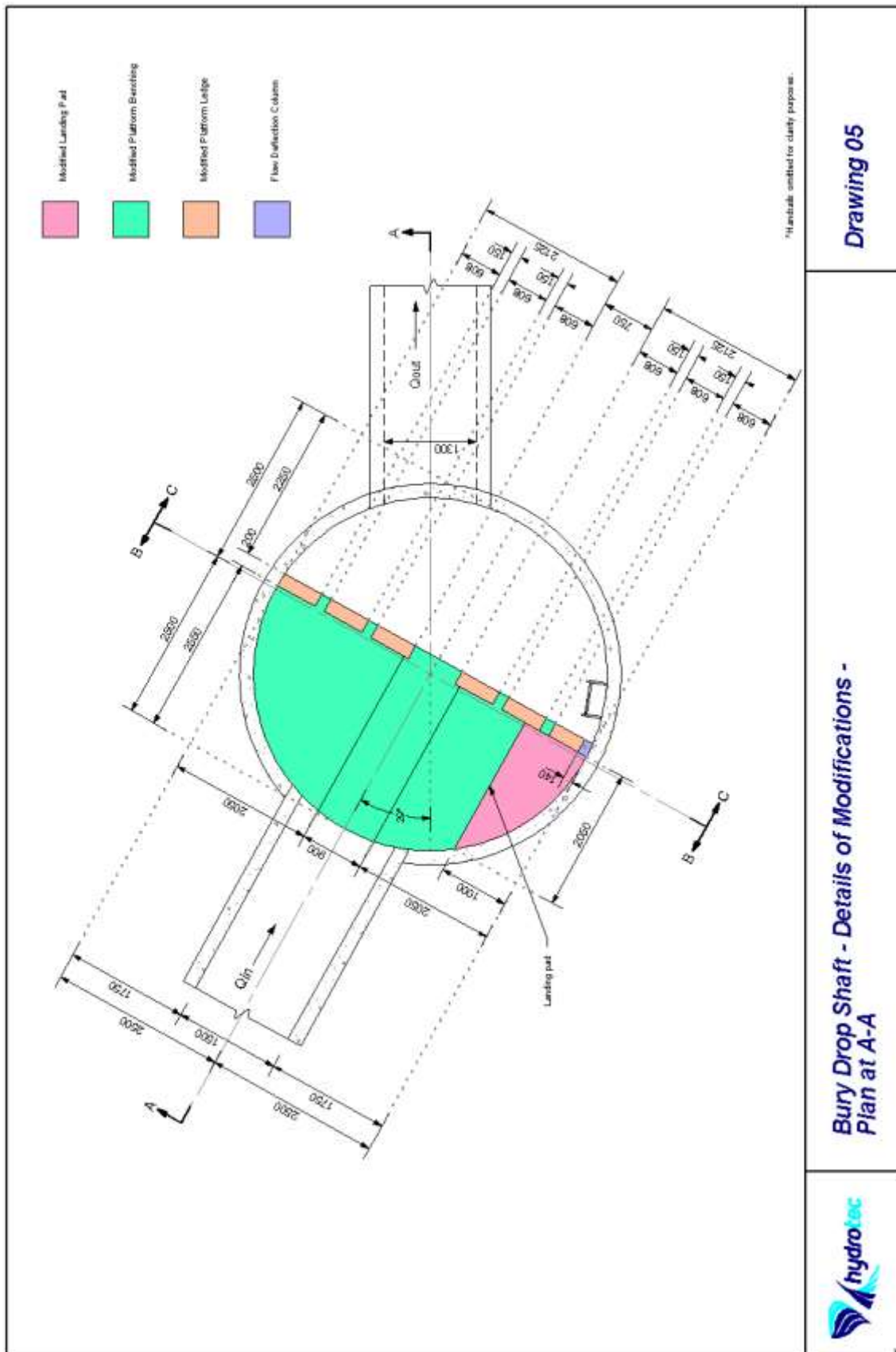
Drop Shaft Design - Former Tetrosyl Site, Bevis Green, Bury
Plans C - C and D - D

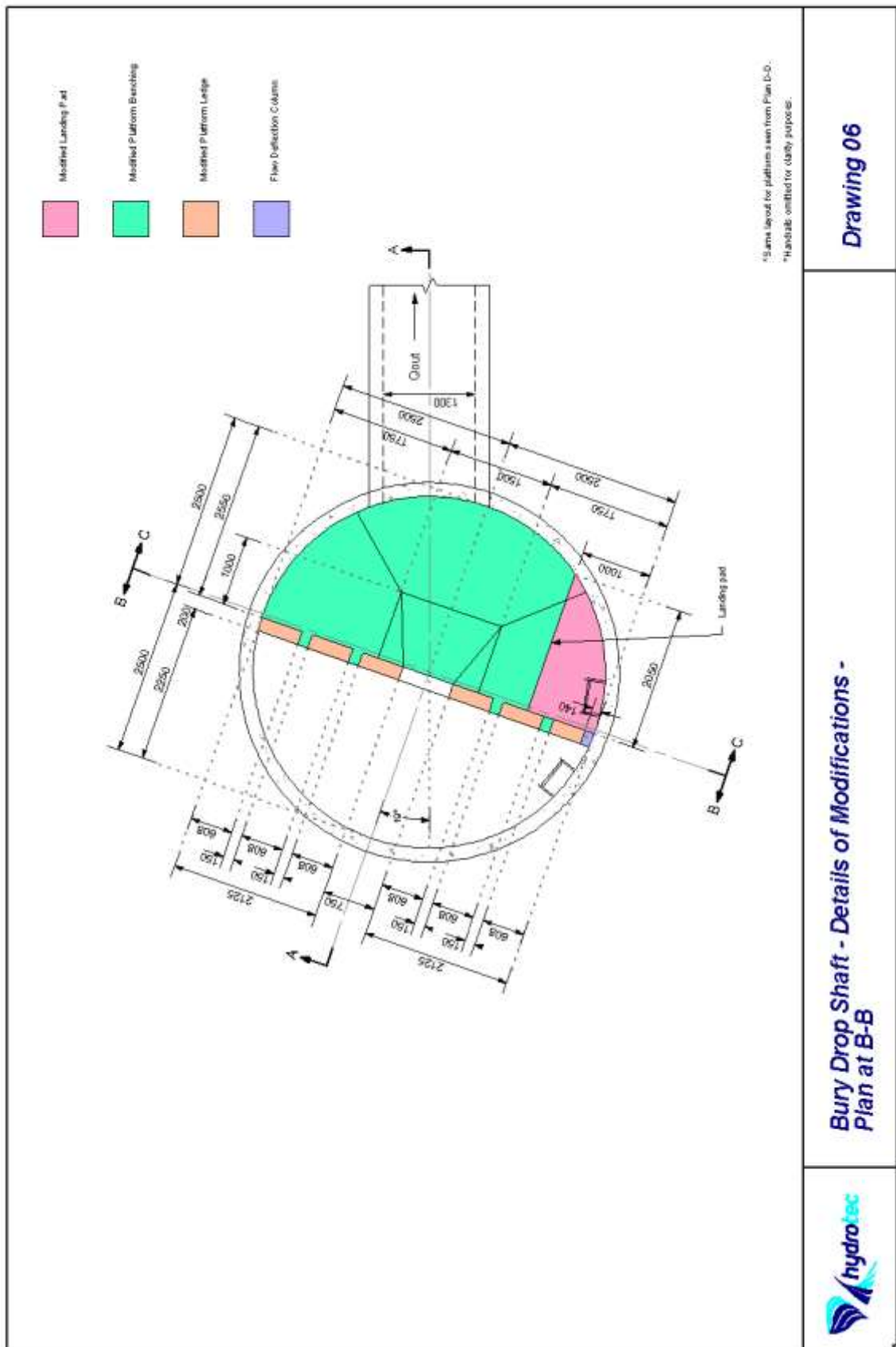
Drawing 03

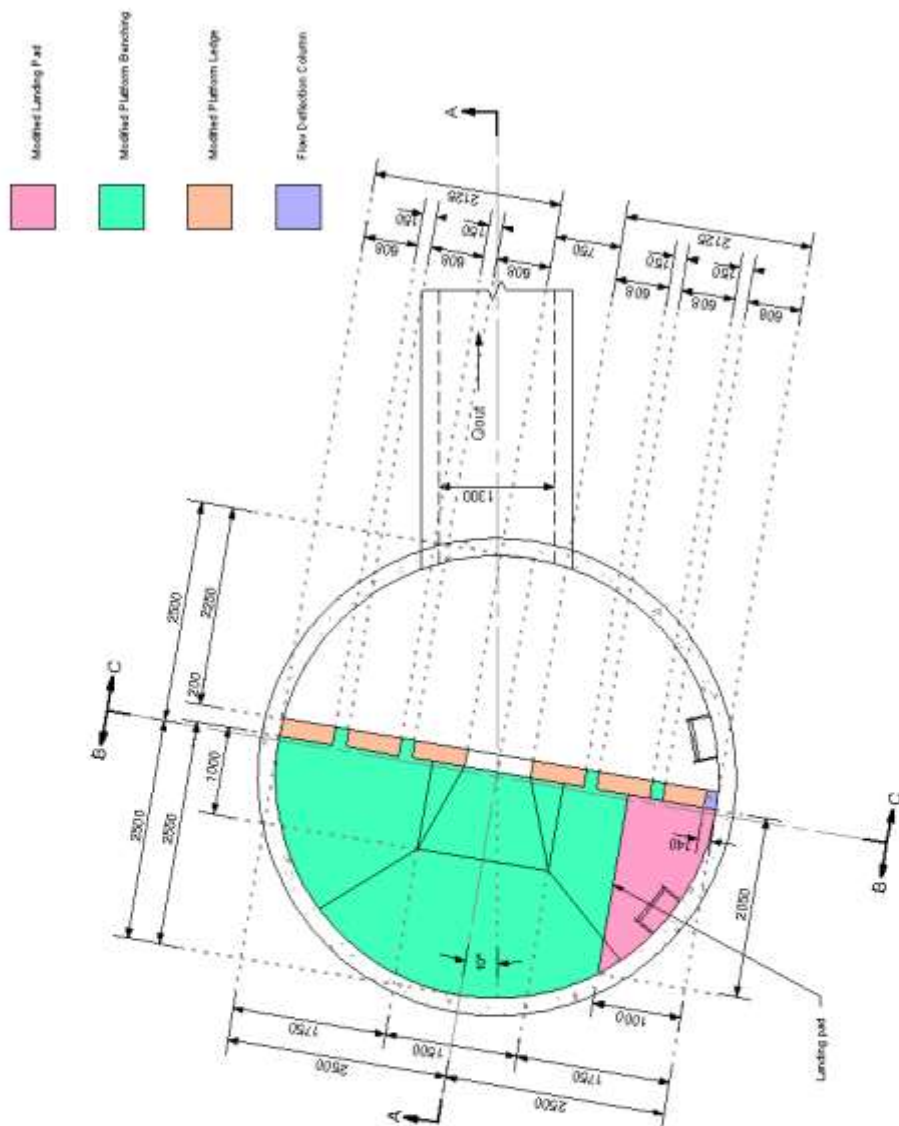


**Drop Shaft Design - Former Tetrosyl Site, Bevis Green, Bury
Plan E - E**

Drawing 04







*Handrails omitted for clarity purposes.

