

## **Precast Concrete in Reservoir Engineering New Construction Techniques in Water Retaining Design**

R. J. ROBSON, Mott MacDonald Bentley, Leeds.

A. D. BULL, Mott MacDonald Bentley, Leeds.

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**SYNOPSIS.** The use of pre-cast concrete is not new in dam and reservoir engineering. Mott MacDonald Bentley Ltd. (MMB) has promoted a new technique of constructing water retaining elements from pre-cast wall units stitched together with in-situ concrete.

MMB is designing and constructing 14 service reservoirs for Yorkshire Water Services Ltd. (YWS) ranging from 136m<sup>3</sup> up to 16,000m<sup>3</sup>. As part of the productisation of the Service Reservoir design and construction each of these reservoirs all use the same principle pre-cast components. This technique has then been developed for application for reservoir spillway channels using similar components.

This paper provides an overview of the design and construction of the pre-cast service reservoirs and describes the trials carried out on different pre-cast units for spillways. In both applications, the aim has been to provide a modular design which can be re-used, reducing both design and construction time across a programme of reservoir improvement works. This will facilitate MMB to deliver a step change in the improvement of site safety, cost efficiency and assurance in construction quality.

### **INTRODUCTION**

The use of reinforced concrete in reservoir engineering is commonplace and well understood. However, there are some issues on its use requiring a number of trades and high quantities of individual construction materials. MMB across their various work programmes are promoting a product based scheme delivery process. That develops a set of relevant value engineered approved products to efficiently develop a cost effective design.

The new framework agreement between YWS and MMB is construed around the key component of batch working. Batches group similar types of schemes together into a single contract. This facilitates the opportunity for MMB to promote standardised products with both repeatable designs and repeatable projects that give efficiencies across the programme.

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YWS promoted two batch contracts for service reservoirs with fourteen new reservoirs, providing MMB with the commercial confidence to develop the product and identify an appropriate pre-cast concrete supplier and method. On supplier selection, test panels were undertaken at the first site to demonstrate the proposed methodology and practice the techniques required. A similar process was pursued for spillways, though a selection of pre-cast supplier's products were tested through site trials and test panels. For both cases, the site trials allowed the client and also their independent engineers including the All Reservoirs Panel Engineers, to inspect the methods ahead of their actual use. The trials allowed a physical evaluation of both the practicalities of construction and of the completed structure.

This paper describes the design and use of pre-cast reinforced concrete elements in the construction of service reservoir schemes. It then goes on to describe how the pre-cast construction method was trialled and applied for use within overflow spillway construction on impounding reservoir schemes promoted by YWS.

### PRE-CAST SERVICE RESERVOIRS

YWS had a number of service reservoirs requiring replacement. These schemes were grouped into two batches of work and released as concurrent batch contracts. In the main, the schemes have been constructed off-line from the existing assets and brought into service allowing the existing structures to then be decommissioned. While it has been common practice within water engineering to have standard service reservoir designs, the resultant construction projects have often been unique. Pre-cast concrete is a proven technology in many engineering uses. However, because of the difficulty of providing reliable joints it has not been used for clean potable water retaining structures.

Key client design requirements for the reservoirs were monolithic concrete construction and that personnel entry was to be through walk in access secured by watertight doors. MMB invested in the product by developing a 'standard' water retaining design in collaboration with the pre-cast concrete supplier and manufacturer, Carlow Precast. Who; designed, manufactured and supplied the precast component parts that allowed a broad volumetric range of reservoirs to be constructed utilising the same design details.

The selected reservoir product solution comprised a standard precast wall panel acting as a propped cantilever with the roof. The principle element of the reservoir product is the standard wall panel and in-situ concrete joint. The wall units have protruding reinforcement at their base and to either side to engage them with the in-situ concrete base and wall joints providing a continuous, monolithic, reinforced structure. These panels were supplemented by equivalent corner units and also 'T' sections to form the dividing wall partition.

The standard pre-cast wall panels are a 1950mm wide and 4000mm standard internal height and the in-situ wall joints are 450mm long. Pre-cast columns are utilised at a standard spacing carrying precast roof support beams aligned to the spacing of the pre-cast wall panels. The base slab comprised conventional in-situ reinforced concrete fixed to the wall panels.

The walls have a vertical internal face with a sloping and vertical ribbed rear face. The conventional wall units weighed 6.1T with the 'T' pieces to the dividing wall weighing 9.2T.

An advantage of the pre-cast panel method was considered that it mitigated some of the early age shrinkage problems with long runs of monolithic concrete structures. The main shrinkage has already occurred to the pre-cast panels prior to their installation and the shrinkage experienced by the in-situ concrete joint was anticipated to be nominal given its relatively short length. This was borne out by the constructed walls as no shrinkage cracks were evident.

The in-situ wall joints comprised 'U' bars protruding from the side of each wall panel with vertical reinforcement interlocking them together. Hydrophilic strips were adhered to the in-situ interfaces of the pre-cast panels. The roof design comprises a composite precast soffit slab and in-situ structural screed acting as a structural prop to the walls. The in-situ concrete wall joints had reinforcement lapping into the reinforcement of the roof screed to provide the monolithic roof to wall connection. The roof acted as a structural prop to the walls. The column spacing was set to coincide with alternate wall panels supporting the roof beams.

The original casting method for the standard wall panels utilised a 'clam shell' formwork with the reinforcement fixed into it. The internal shutter was provided with Controlled Permeability Formwork (CPF) to achieve a good quality durable surface to the stored water. While the clam shell technique was successful it was also problematic and a more efficient and economic method was identified. The casting method for the main wall panels was replaced with a flat slab method whereby the wall is cast in the horizontal position against a profiled back shutter. This allowed the top surface to be floated achieving a superior and more consistent finish to the internal face of the reservoir and avoiding the problems encountered with the clam shells.

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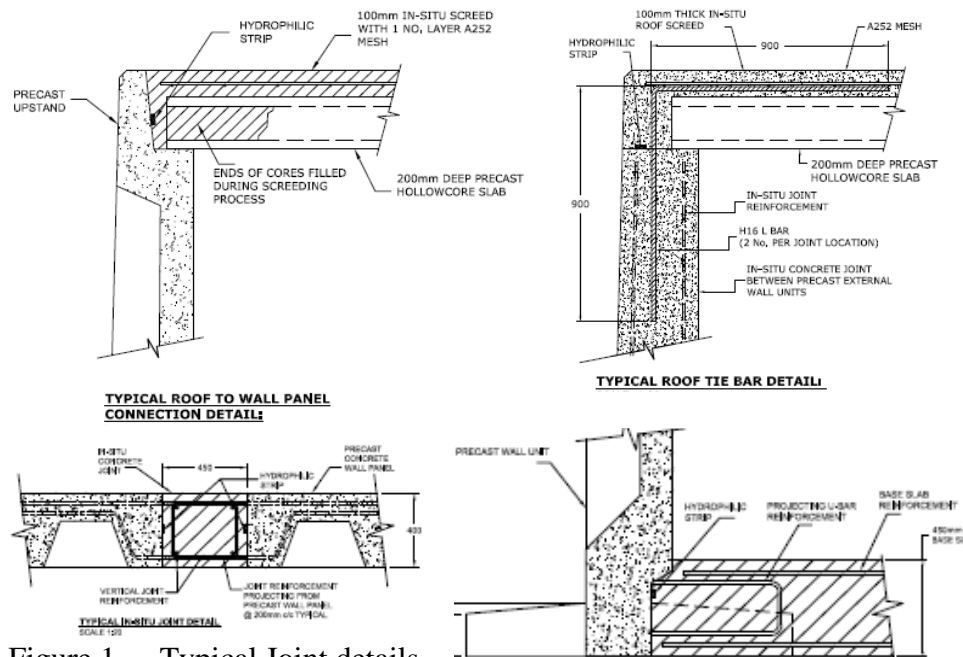


Figure 1. Typical Joint details.

Beyond the individual pre-cast component parts, the product concept encompasses the whole of the project delivery. The batch contract specifies the volumetric storage requirements of each individual reservoir. To ensure that the design of each reservoir met the required volumes and allowed for reductions due to floor slopes and columns a standard sizing model was developed.

The model was adapted to incorporate the dimensions of the precast components following confirmation of the reservoir product components. The model was expanded to also include the main typical calculations; ventilation, overflow sizing and washout sizing. This provided a complete outline design for each reservoir, graphically demonstrating the resultant storage volumes and respective quantities. The output sheets from the model were then used firstly for client design acceptance and then for procurement of the reservoir precast components.

The use of a 'walk in' access method was first promoted at three service reservoirs by YWS in AMP4. MMB established the general design concept and implemented two of the service reservoirs. Water tight pressure doors are fitted in the side wall of the reservoir and accessed through the valve house providing both secure and safe access eliminating safety hazards normally associated with roof access. This access method is a key part of the YWS AMP5 reservoir standard. The pressure doors (Figure 2) were bulk ordered and delivered direct to Carlow for casting into particular wall panels and subsequently delivered to site



Figure 2. Pressure Door within pre-cast wall panel

For the wall panel installation, setting out strips and pads were constructed to a precise plan and levels. The panels were delivered approximately four to a load and lifted directly into their correct position via a hinged lifting cradle. The cradle is a key component of the installation process, developed by Carlow, ensuring that the panels can be lifted to the vertical without applying point loading to the base of the unit. For a 2,000m<sup>3</sup> reservoir the installation duration for the 46 wall units and 16 columns, lasted 8 days. For a smaller 135m<sup>3</sup> reservoir the installation of the walls took a day. The subsequent steel fixing and base slab pours were of conventional reinforced concrete construction practice and durations. The in-situ wall joints were carried out once the first base slab had been poured and lasted overall for 15 days. See figure 4 for a view of the wall joints prior to casting.



Figure 3. Installation of the precast units



Figure 4. In situ wall joints under construction



Figure 5. Completed Reservoir Structure

The positioning of the roof beams and pre-cast soffit slabs for the 2,000m<sup>3</sup> reservoir took a week and did not require temporary propping. The reservoirs have successfully been flood and drop tested.

The drop tests showed nominal reductions in water depths well within acceptable limits. The flood tests passed satisfactorily demonstrating the roof structure to be adequate to prevent ingress. Figure 8 shows the finished reservoir structure prior to the backfill placement.

#### PRE-CAST SPILLWAY DEVELOPMENT

Confidence was gained following the pre-cast service reservoir works, and previous experience of pre-cast wave walls on reservoir schemes on AMP4, that similar techniques could be applied to impounding reservoir spillway channels. Test trials were proposed and undertaken ahead of new spillway works at a YWS reservoir to investigate the viability of using pre-cast units. Particular objectives of the trials were to assess the practicalities of pre-cast for spillway walls to cope with the different design parameters, including movement joints and the variable site conditions and challenging environment of most IRE sites. Trial constructions were undertaken using panels from three different manufactures to identify the most suitable technique methods.

The trial design parameters were kept deliberately simple to enable the basic construction techniques to be tested on site. These parameters were; working on slopes, lifting, sequence, tolerances, joints, and waterbar details. The three pre-cast unit types and manufacturers chosen for trials were:

- Carlow: Single panels with protruding joint reinforcement and integral support feet.
- Whites: Single panels with protruding joint reinforcement and temporary support feet.
- Oran: Twinwall concrete panels filled with in-situ concrete.

These are shown in Figures 6 to 8 and key details given in Table 1.



Figure 6. Carlow Spillway Trial Panel



Figure 7. Whites Spillway Trial Panel



Figure 8. Oran Spillway Trial Panel

Table 1. Summary of Trial Panels

| Company   | Design  | Features  |
|---|---|---|
| Carlow Precast Ltd,<br>County Carlow,<br>Ireland        | 2m tall x 4m wide x 150mm thick; 2.9T; C50/60 concrete; cast on flat bed with top surface floated.                  | Protruding base steel and side wall U bars; smooth sided panel edges with two fixed integral support feet.  |
| Whites Precast, Dewsbury,<br>West Yorkshire             | 1.5m tall x 4m wide x 200mm thick; 2.9T; C50/60 concrete; cast on flat bed with upper surface floated               | Protruding base steel and side wall bars; smooth sided panel edges with two loose support feet.   |
| Oran Precast Ltd,<br>Oranmore,<br>Co Galway,<br>Ireland | Twinwall; 2m tall x 4m wide x 2 x 75mm thick; 2.9T; 70N concrete; cast on flat bed with both external surfaces cast | Twinwall precast permanent shutters with base starter bars extending into the wall; smooth sided panel edges. Lattice work cross reinforcement tying outer leaves together. |

#### WORKING ON SLOPE

An area of blinding was prepared, comprising a lower section with a slope of 1 in 20 and a sharp break to an upper slope of 1 in 7. These slopes were similar to those of the full size spillway at the actual reservoir, but are not untypical for the Pennine embankments encompassing much of the Yorkshire reservoir stock. The change in gradient also meant the construction of a non-parallel joint could be trialled.

#### LIFTING AND POSITIONING

The Carlow units were provided with two ‘screw in’ inserts cast in to the top edge of the panel. Wire strops were used to lower the unit on to the blinding using a small crane. Due to the high level accuracy of the blinding and the

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relative short panel height, no packing or shimming was required and a good alignment was achieved along the top edge. The integral support feet stabilised the units in their temporary state. However, due to the exposed test site raking props were added to provide additional support against wind loading.

The Whites units were also provided with two 'screw in' inserts cast in to the top edge of the panel, and were positioned as per the Carlow units on to the blinding. The separate feet of these units had to be positioned first and the panels lowered on top. Positioning of both the wall and the feet jointly was difficult to ensure accuracy. In addition, to ensure stability of the panels in their temporary state to prevent toppling raking props were an essential requirement.

The Oran units were provided with two 20mm bars cast between the panels near the top edge of the unit. Lifting strops were used to manoeuvre them in to position. These panels sat directly on to the base reinforcement with discreet downstands providing temporary vertical support off the blinding. The main difference is that the base steel and wall starter bars had to be in place prior to the units being positioned. Conceptually this was not considered a problem. However, in practice the starter bars clashed with the lattice steelwork fixing the double wall panels together. The starters had to be adjusted numerous times before the panel could be finally lowered on to the blinding. Like the Whites units, these panels also had to be secured with raking props to prevent toppling throughout the temporary state.

### CONSTRUCTION JOINTS

Both the Carlow and Whites units used a similar jointing method to ensure structural continuity between each panel and the base. The Carlow and Whites units had protruding steel at the panel base to engage the reinforcement mat of the base. The units had protruding steel into the wall joints with a system of reinforcement installed locking the units together. Figure 12 shows the joint detail devised for the Carlow units and is similar to that of the service reservoir precast panels.

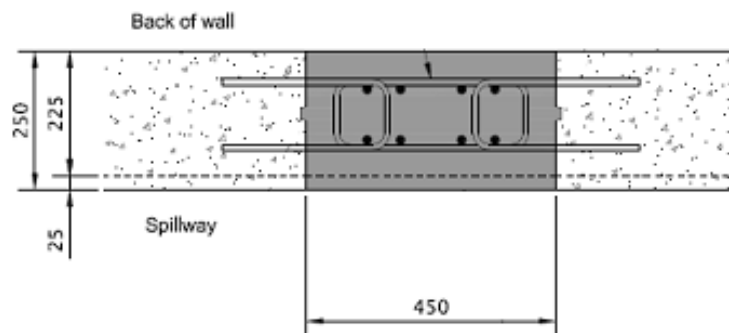


Figure 9. Typical Carlow pre-cast Spillway Construction Joint, with additional 25mm wall thickness to accept surface finish.



To provide a ‘water tight’ joint there was much debate over whether or not to use a hydrophilic strip or just scabble of the concrete faces (or both). The design on the service reservoirs with the thicker walls was to use hydrophilic strips only. Both scabbling and hydrophilic strips were adopted.

The Oran panels use a different concept, providing permanent shutters abutted to each other providing a flush joint. In situ concrete is placed internally providing continuity of structure across the wall panels. This provides a very neat joint as the panels do not require an external infill piece.

### SEQUENCE OF CONSTRUCTION

With both the Carlow and Whites units the construction sequence was similar; blinding, followed by positioning of the wall units. The base slab was fixed and cast followed by construction of the wall in-situ joints. A trial was also undertaken to cast the in-situ wall joints before the base slab. This proved more successful than anticipated and concealed the kicker joint.

The installation sequence of the Oran units started with the blinding concrete then fixing of the base reinforcement and wall starter bars. The wall units are then positioned over the reinforcement. The base slab was then cast followed by the wall infill pours.

### MOVEMENT JOINTS AND WATERBAR DETAILS

Movement joints are typically positioned every 15 to 30m, with 4 to 8 units provided between joints. To allow the movement joints to incorporate a water bar detail, the spacing between both the Carlow and Whites units was extended. In addition, the thinner Carlow unit was thickened locally to accommodate both dowels and a centre-bulb water bar detail.

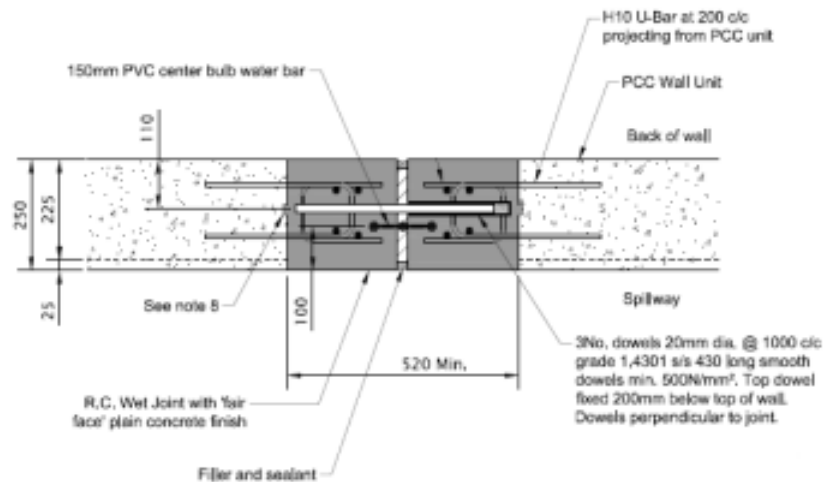


Figure 10. Typical Spillway Movement Joint Carlow / Whites panels

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In comparison, the movement joint on the Oran unit was very simple to construct as it could be installed conventionally between the external wall panels to engage with the in-situ infill concrete. This provided the neatest joint finish.

### TRIAL SUMMARY

The trials demonstrated that despite working on a gradient on a very exposed site, it was possible to position all of the pre-cast units and produce a system of good wall joints and base slabs. The trial identified the best features of each unit that could be incorporated into the final design. The pre-cast unit closest to MMB's requirements was that manufactured by Carlow. The Whites units were a close second. The Oran unit provided many advantages with regards to the finished product and was the most attractive option on initial review of the design. However, it was the most difficult to install and required operatives to be in a high risk position to guide the unit over the starter bars.

The units provided by Carlow were able to be placed with minimal physical interaction and were stable in their temporary state. The methodology had been previously applied to the service reservoir programme and was well understood. The Carlow units provided the most viable system to achieve a pre-cast spillway panel. The site trials were witnessed by both the client and their independent technical consultant MWH.

The process concluded with development of the detail design and confirmation of the product costs. To provide a complete component product, standard design spreadsheets were developed. The final design was agreed with the client during Spring 2011 and the site of the reservoir trial was confirmed as being suitable for the first installation.

### PRECAST SPILLWAY APPLICATION

The reservoir trial site was chosen for the first full installation because the spillway is almost straight with minor changes in gradient, relatively small PMF 40m<sup>3</sup>/s and a small channel size. Main channel panel manufacture commenced in April 2011 at the Carlow factory. Site works commenced in June 2011.

The spillway was excavated on two fronts, both above and below the midway bridge. A temporary channel was created to provide flood protection in the event of an overflow and provide a level base from which to place the spillway wall sections. The channel was constructed trapezoidal working in short lengths and blinding the same day to base and sides.

Once the site attendant facilities and blinding were set up and a delivery sequence established, the positioning of the units was undertaken at approximately 6 No. units per day equivalent to 9.3 linear metres of channel.



Figure 11. First reservoir precast spillway installation.

#### FURTHER DEVELOPMENTS

During the trials and installation work further features were identified for potential inclusion on future projects.

- Screw jack feet
- Water bar joints
- Copings
- Lifting arrangements
- Patterned finish



Figure 12. In situ wall joint to base level

The next spillway project to be undertaken with precast units was for a much larger channel where the design was developed further. The precast

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walls were higher and thicker with a total 100m pre-cast channel length. A stone effect surface finish and copings were a requirement of the planning permission. The overall wall thickness was increased by 25mm to accept the stone effect patterned formliner finish. The in-situ concrete joints were finished with a complementary formliner to provide a consistent appearance between the two construction types. Site feedback has led to simplification of the joint details and provision of jacking points in the support feet to enable safer alignment operations, (Figure 12).

### CONCLUSIONS

In summary we have found that the use of pre-cast concrete in reservoir engineering offers the following advantages:

- Quality
- Simple and safe construction, reducing operations
- Flexible to suit differing applications
- Patterned finishes available
- Standard design spreadsheets
- Programme and cost efficiencies
- Repeatability
- In situ

Jointed precast panels are a new method for spillways and potable water reservoirs. These projects and trials have shown that pre-cast can be successfully implemented for both potable water storage and reservoir spillway designs. The method provides repeatable designs that improve construction safety and the overall project delivery.

### ACKNOWLEDGMENTS

The authors would like to express their gratitude for the assistance provided by the following people and organisations in the development of the works described and the writing of this paper. Yorkshire Water Services Ltd. who have promoted these works. Oran Precast and Whites for the provision of pre-cast panels. Carlow Precast for their continued assistance in the provision of design and pre-cast products. J N Bentley Ltd and their construction teams for their ongoing support and scheme delivery. Ian Carter, AR Panel Engineer, QCE for both spillway schemes and also one of the larger precast service reservoirs. MWH Ltd, YWS's independent technical consultant.

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