How to build Raised Intakes or Inlet/Outlet structures in existing bodies of water.

Thought Piece by Brian Darling of Darling Hydro Ltd. This Thought Piece is not intended to be a comprehensive guide to raised intakes or Inlet/Outlet structures, rather it is intended to raise some of the issues and provide a pointer to possible design solutions.

1. Requirement for raised intakes or inlet/outlet structures

There are many reasons why intakes or inlet/outlet structures need to be built within existing bodies of water. My experience is largely related to structures within reservoirs or natural lakes related to hydropower, although there are also many examples of these structures being needed in a marine context (think of the cooling water intakes and outlets for a new coastal nuclear power station such as Hinkley Point in the UK).

An example of new raised intakes are the three new raised intake structures which have/are being constructed within Tarbela Reservoir in Pakistan. Tarbela Dam is situated on the River Indus and is a very large reservoir, which is used to provide irrigation water releases, but it also provides significant hydropower generation (it will have an installed capacity of 6418MW once the 5th Extension Project is completed). Release Tunnel 3 and Tunnel 4 have their new intakes operational, whilst Tunnel 5's new raised intake is currently under construction. These raised intakes have been constructed to address the problem of sedimentation within the reservoir. Since impoundment, the sediment delta has gradually been progressing downstream within the reservoir to a point where it is now encroaching on the dam and the associated low level outlets. Hence, in order to extend the working life of the reservoir, raised intakes are under construction, in order to access the cleaner, less sediment-laden water and thus allow power generation to continue for many years to come.

Raised intake structures for the Tarbela Dam 4th Tunnel (left) and 3rd Tunnel (right) behind a cofferdam formed from natural rock (below) and concrete (above and in the process of demolition), prior to screen fitting.

The new wave of pumped storage hydropower (PSH) projects is also a reason why new Inlet/Outlet structures are being conceived. Many of these projects are using existing bodies of water for either their upper or lower reservoir (usually it's the lower reservoir). In some cases, where the reservoir can be drawn down, it is possible to build these structures in the dry. However, there are many cases where it is not possible to draw the water level down sufficiently, which gives a situation where inlet/outlet structures need to be constructed behind cofferdams or using other techniques.

Borumba Dam impounds an existing reservoir in Queensland, Australia. The proposed PSH project plans to use the existing reservoir as its lower reservoir. However, to give the lower reservoir sufficient storage to provide a volume for the PSH, the plan is to construct a new higher dam below the existing one, thus allowing the reservoir water level to be raised. This means that constructing the new Inlet/Outlet structure is simplified because it will be mainly in the dry, however a cofferdam is still required around the structure to allow the lower levels to be constructed.

A new 385MW PSH project is also planned at the existing Lake Lyell in New South Wales, Australia which plans to use this existing reservoir as the lower reservoir. To create a dry working area for the lower Inlet/Outlet structure, this project intends to bypass a bend in one of the arms of the reservoir by creating a cutting that connects to two sides. Cofferdams can then be constructed either side of the bend, allowing a de-watered area to build the lower Inlet/Outlet structure.

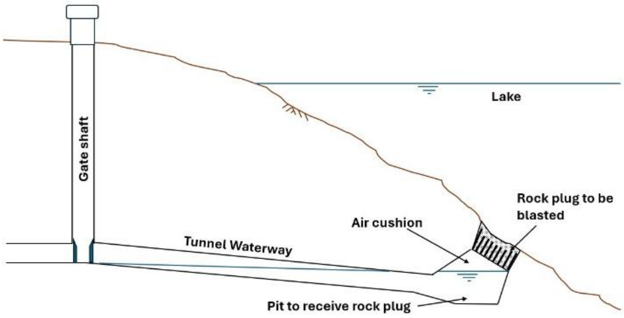
2. Some principles and strategies of raised intake or inlet/outlet construction in existing water bodies:

1) Try where possible to construct the structure in the dry. Like at Tarbela, Borumba and Lake Lyell, designers have sought to be able to construct their raised intake or Inlet/Outlet structure within a dry working area protected by a cofferdam. This allows a safe working environment, reduces risk and makes construction logistics more straight forward.
2) Cofferdams are often vital for allowing construction to be undertaken in dry conditions (this is a whole subject in itself) so it is important to choose the right type and have a strategy for how they will be installed and also removed. Cofferdam types include:
    a. Rock or earth-fill cofferdams with some form of impermeable lining (this can be a clay core, membrane or injection grouted core)
    b. Concrete (either mass concrete, RCC or reinforced concrete)
    c. Concrete caissons can form a cofferdam in appropriate situations. These need to be cast within a dry dock or other assembly area and then are floated into position before being slowly lowered through changing the buoyancy by filling air chambers with water.
    d. Coffer dams can be created using the natural rock – such as by excavating behind what becomes a natural rock dam. This rock often needs grouting, facing concrete and/or anchors to make it workable.
    e. Cellular or double wall cofferdams can be constructed using sheet piles that are placed from a barge. The centre is then filled with earth/clay to improve impermeability.

Example of cellular cofferdam construction within the Ghazi Barotha headpond to provide a dry working area for the construction of the 4th Hydropower Extension powerhouse at Tarbela

    f. Other forms of cofferdam – including stacked filled bags, sheet piles, inflatable barriers, water-filled barriers or bespoke cofferdam systems
    g. A combination of more than one type – eg a natural rock dam below with a concrete dam above – as is the case at Tarbela.
3) Fabricating intake or Inlet/Outlet structures offsite and floating them into position (like a caisson) can also be a workable solution. The lowering process is highly technical, often requiring divers and associated barges with cranes and means of anchoring. Depending on the size of the structure, some form of dry-dock may be required to facilitate construction, but this then requires developing other site compounds outside of the main project construction areas – with associated environmental implications.

4) Although less common, Underwater Tunnel Piercing or Lake Tap is another technique that can be used to connect a new waterway to an existing body of water – usually where the connection point is located in very good quality rock. It involves tunnelling the new waterway close to the reservoir edge at the required depth. A short distance from the reservoir, a chamber/pit is created. The final intermediate plug of rock is then drilled and explosives set. The waterway is then evacuated, gates are closed and the tunnel is flooded. The following explosion blasts the final plug thus connecting the two bodies of water, with the rock fragments from the plug being retained within the chamber/pit. Due to the irregular nature of the mouth in the blast zone, fitting a control structure to house screens or gates can be problematic (although not impossible).



Underwater Tunnel Piercing or Lake Tap schematic

5) Dredging and excavation underwater is often necessary to prepare areas either for cofferdams or for siting structures that have been fabricated offsite. Also removing cofferdams once they have fulfilled their purpose. Where materials are loose and can be excavated by a dredger or barge mounted excavator, then this can be undertaken in a relatively straightforward way (assuming careful environmental controls etc). Excavating rock underwater can be much more challenging – particularly if there are restrictions in underwater blasting.
6) At early planning stage, allowing sufficient space for intake or Inlet/Outlet structure construction is very important. There are many variables that need to be confirmed that will impact the structure size and siting. Allowing for sufficient submergence is one critical aspect impacting the depth of the structure. The detailed modelling using CFD or physical models is not usually undertaken until later in the design process – so a change to the submergence assumption can have a significant unwelcome design impact in later stages. Assumptions regarding the boundaries and quality of the geology can also have significant repercussions. Starting with over optimistic design assumptions regarding steepness and support requirements for excavated slopes can lead to insufficient space being available for an excavation. Construction access into and out of the working area can also be a critical parameter for the construction costs and timeframes.
7) Having a diving crew for underwater work is sometimes needed for the construction of these structures. Experience has shown that provision of these services is expensive and also takes significant amounts of time, with consequences if the project has to wait for the right conditions for the divers.
8) Means of water filling at commissioning or after maintenance (stoplogs often need to be removed in balanced water conditions) needs to be considered along with the necessary means of venting air from the structure.
9) Instrumentation for commissioning and monitoring is often forgotten in the design process for these kinds of structures. Based on the fact that these structures are likely to be submerged over their lifetime, having means of monitoring them is something that should be carefully considered.

3. Other factors to be considered

Intake and Inlet/Outlet structures will often have slots for screens. Design of screens should not be taken for granted. In a recent project, even when vibration calculations had been undertaken, the project found cracks appearing in multiple steel bars caused by fatigue failure from vibration that have ended up in the complete screen replacement. Screen design for Inlet/Outlet structures is further complicated by the fact that design needs to account for flow in both directions.

It is common for projects to assume trash screen cleaning machines will not be required initially, but many will expect a design where an automated trash screen cleaner can be retrofitted at a later date should trash build up become problematic. A sufficiently advanced trash screen cleaning design is needed to ensure that, if retrofitting is required, this can be achieved with minimal disturbance to the project.

Sometimes, intakes and Inlet/Outlet structures house the gates and bulkheads required for isolation and maintenance. Also, access points to the waterway may be necessary – particularly lowering points and hatches for Remote Operated

Vehicles (ROV). In other cases, these facilities are set back within separate shafts away from the intake structure itself. In whatever case, the connection between the structure and the associated waterway should be carefully considered. Often there is need for transitions from circular section to rectangular section or various types of flow splitting (bifurcation, trifurcations, baffles etc) that all require sufficient length and space from a hydraulic and construction perspective.

4. Conclusion

There are many inter-relating facets to producing a workable design for raised intakes or Inlet/Outlet structures constructed within existing water bodies. Particularly important is the consideration of how these structures are going to be constructed in association with the temporary works and access. Every situation tends to be different, often requiring bespoke solutions and innovative engineering problem solving. Environmental and social constraints also play their part in developing a workable long-lasting solution.