Electrical Flood Protection Diving Bell

Wenjing Zheng

Jeremy Leggoe
Department of Chemical Engineering
University of Western Australia

Bruce Barrie & Glen Williams
CEED Client: Water Corporation

Abstract

Following Cyclone Veronica in 2019, a flood risk was identified at the L954 water pump station. If Veronica had made its way to Port Hedland, the predicted flood level would have been 3.5m above the ground of the pump station. The pump station contains electrical switchboards that would take lengthy installation times on replacement at a cost of 1.2 million dollars for the current contingency plan. An extreme cyclone is a low probability, high consequence event, so an alternative contingency plan must be established. This study aims to design and prototype a flood protection structure that can withstand up to 3.5m water head to keep the switchboard dry. Both durability and reliability will be considered for the design. A diving bell structure is proposed because it is easy to install and could stand the required water level. By comparing the design criteria and restraints, two flood protection structures are proposed. One uses a glass reinforced plastics(GRP) bolted sectional panel tank, the other uses PVC tank liner support by stainless steel frame.

1. Introduction

The L954 pump station plays a significant role in the town of Port Hedland. It supplies water to residents and the mining company BHP. BHP relies on the port facilities to export millions of tons of iron ore to other countries and support the Australian economy. The pump station was built in 1968 at an elevation of 4.35m AHD (Australian Height Datum) and has yet to experience a flooding event. Flood modelling for the site indicates that the maximum flood level is 3.65m AHD for a 1 in 500-year event. This will increase to 4.6m AHD and 5.05m AHD in 2060 for a 1 in 100-year and 1 in 500-year event, respectively.

The pump station has not been flooded since it was built 53 years ago. Initial flood assessments did not consider a storm surge from the ocean and hence did not identify a risk of flooding. However, a flood assessment after Cyclone Clare in 2018 modeled a possible storm surge of 7m AHD for Port Hedland at high tide. It is assumed that Cyclone Veronica in 2019 would have had a worst-case storm surge of 7.6m AHD if it had directly passed over Port Hedland at high tide. This would have resulted in the Pump station being submerged by 3.25m of ocean water. Accuracy of datum information has been identified as an issue. As a result it was agreed to design the flood structure for a depth of 3.5m (FM Global, 2008).

In flood-prone areas, flood control methods such as water barriers, dams, and dikes can be adopted. These structural measures would need massive capital input and frequent maintenance and are not feasible at L945 due to space and time constraints. During the investigation of flood protection structures, the client proposed a diving chamber because it is easy to install and could withstand the required water level. A diving bell is a rigid structure that divers use to respire underwater. The air pressure inside of the bell is equal to the ambient water pressure so that water is retained outside the bell (Bevan, 1999).

A site visit was conducted in April to investigate the on-site environment and constraints. Multiple cable trenches cross the floor to the electrical switchboard, passing underneath the switchboard. These trenches are potential inlet paths for water when flooding occurs, which will be considered in the design. The limited clearance between the wall and the end of the switchboard is another factor that needs to be considered. Only a 140 mm clearance is left between the wall and the switchboard, leaving an extremely narrow gap to install the flood protection structure.

Figure 1 Electrical switchboard in water pump station

2. Process

2.1 Problem Identification

It is necessary to understand the problem and diagnose the situation before finding the solution. At the initial stage of the project, the primary task is to define project objectives and design criteria for the structures. By doing a site visit and investigation of the flood level of L954, more details and constraints were brought to the surface. The following design criteria are the important goals that need to be achieved for a successful design:

- The structure should be deployed and stored inside the pump station.
- The structure can be stored in the pump station while not in use.
- The structure is deployable on short notice without specialised skills.
- The structure can withstand up to 3.5m of static water.
- The internal electrical component should remain functional after the flood.
- Any required power will need to be self-supplied, e.g. Genset, battery.

- If a pump is required, it should sit at the lowest ground and avoid installation in a confined space.
- The structure should be reusable.
- The structure should last 10-15 years.
- The structure should not require frequent maintenance.
- Design should be adaptable to different sites.

2.2 Optioneering

The floodwater can potentially enter into the switchboard, so it must either be stopped by high air pressure, or by waterproofing the entire structure. The water level inside an open diving bell will rise as the water depth on the outside increases, due to a rise in hydrostatic pressure. The ideal gas law is:

$$PV = nRT$$

The original pressure in the bell is equal to 101 kPa (1 standard atmospheric pressure), and if the external water level rises to 3.5m the pressure will rise to 135 kPa. Assuming the temperature remains constant, the change in air volume can be calculated:

$$P_1 = 101\ kPa$$

$$P_2 = P_1 + \rho g h = 1000 * 9.81 * 3.5 = 135.335\ kPa$$

$$PV = 101 * V_1 = 135 * V_2$$

$$\frac{V_2}{V_1} = 74.81\%$$

P_1 = Internal pressure of the bell when no water is present.
V_1 = Volume of the gas when no water is present, in (m^3).
P_2 = Internal pressure of the bell when 3.5m water is present.
V_2 = Volume of the gas when 3.5m water is present, in (m^3).
ρ = Density of water in (kg/m^3).
g = Acceleration of gravity, in (m/s^2).
h = Water depth, in (m).

Hence the new air volume trapped inside the bell at 3.5m depth will decrease to 74.8% of the original volume. Water will rise and thus could flood electrical components. Calculation shows that about 25% of the volume (from the bottom) will be filled with water. However, the critical component that must be kept away from the water is at less than 0.5m height (25% of the total height) inside the switchboard. The purpose of the flood protection structure is to reduce the dry-out time (instead of entirely wet, only 25% of the structure is wet). The remaining options can be classified into three main categories:

- Sealed structure (positive pressure): Structure needs to be air-tight. Air pump or any external air intake is required inside the structure to maintain the positive pressure difference. Hence the water is kept away from the electrical components.
- Sealed structure (atmospheric pressure): the structure needs to be air-tight to keep the original atmospheric pressure. No external air intake is required. A water pump is

necessary to ensure the water level inside the structure is lower than the critical electrical components at all times.
- Flood protection structure (allow water to enter the switchboard): The structure itself is air-tight. Water is allowed to enter through the connection between the structure and the concrete ground and only to a certain depth (Piispanen et al., 2016).

The last option is chosen because the flood protection structure (where we allow water to enter the switchboard) can satisfy most of the requirements for the design. Such an option mitigates the concern of a cable duct seal, external power supply for the air pump/water pump. If we allow water into the switchboard, we must ensure all the power is turned off before any cyclone or flooding events. Moreover, a certain dry-out time must be granted after the flooding event is over; all the electrical components inside the switchboard must be dried before resuming the power. Water is an excellent conductor of electricity, and assets could be damaged by short circuits. The objective of such an option would be to reduce the amount of water in the switchboard, hence minimising the time to dry out after any flooding events. The reason for not choosing option 1 and 2 (seal structure with positive pressure or atmosperic pressure) is the complexity. Both of the options need air pump or water pump, which will require power supply, as for perfect seals to be achieved with the ground and in the cable trys.

3. Results and Discussion

Since the flood protection structure (allow water to enter the switchboard) option is selected. The design has been narrowed down to two choices which both allow water to enter the switch board : one is solid material building with GRP bolted section panel tank; the other is flexible material using PVC liner and support by the stainless steel frame.

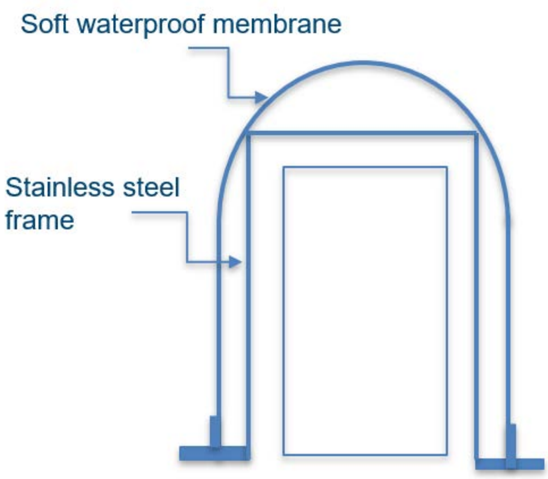

Figure 2 Draft for flexible design (side view)

The flexible design is comprised of two parts: flexible 'skin' made out of PVC liner, and its 'skeleton' - a stainless steel frame. The steel frame will be installed, and bolted to the concrete ground before the potential flooding event. The 'skin' will then be stretched and attached over the steel frame. The PVC liner will come in one piece and must be air-tight to maintain the air pressure inside of the structure. The frame members have been designed to meet AS4100:2020 Steel structures standards, in terms of bending, axial compression, buckling, shear and combination of above loading. The most critical loading comes from the internal pressure of the structure. According to the ideal gas law, the maximum pressure difference reaches 14.7

kPa and distributes non-uniformly along the surface. The PVC cover will be blown up looking like a balloon due to higher pressure inside the cover. Once the flooding event ends, the cover and steel frame can be removed and stored inside the pump station.

The flexible material design can reduce the installation time, which is especially important as we are normally not given much notice ofcyclone/flooding events. Another perk is the material weight. PVC cover is lighter than a solid rigid structure which is typically composed of heavy material and will require more labour to install. In terms of storage, soft and flexible material is easier to store because it can be folded and put in a bag without taking much space. Despite the advantages of flexible material, it may not be as strong as solid material if punctures and tears occur during manual handling or the flooding event.

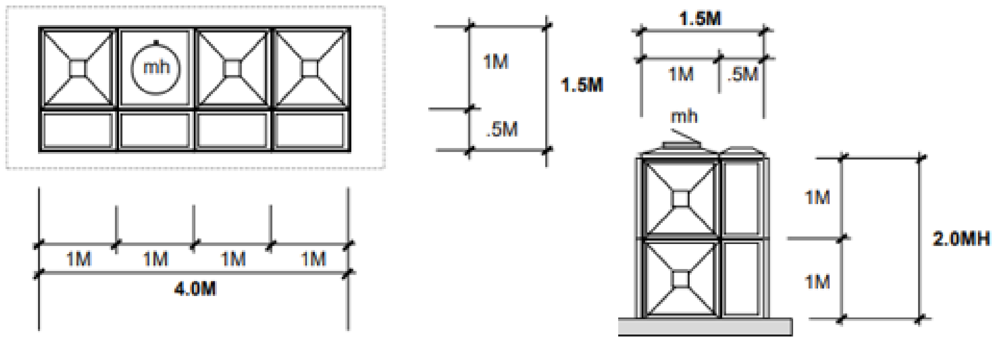

Figure 3 Draft for solid design

The solid design used GRP bolted sectional panels to build up the tank. Each panel is a 1m x 1m square section. When the panels are bolted together with gaskets in between, they can form a large area inside the pump station, suitable for storing liquid up to 1 mega litre. The fibreglass reinforced polyester (FRP) tank is very vigorously designed to withstand 3.5m of hydrostatic water pressure. In our case, we will use the reversed modular tanks, to resist the water coming into the switchboard and maintain the air pressure in the structure.

Compared to the design with flexible material, the panel tank is more robust and has already been used to store water. This will make prototyping simpler, with products in the existing market. The downside of this design is that since the modular panel tanks are built for keeping water in but not keeping water out, lab testing is mandatory to verify if the tank works the other way around. The panel tanks also take a longer time to install, with much more connections needing to be sealed. Usually, in an emergency event, personnel on site have to complete a significant amont of work in a timely manner. To install the panels up to a 2m height could be challenging. Technicians would need the assistance of scaffolding or a platform.

4. Conclusions and Future Work

Concept for the flood protection structure have been developed to help preserve the millions of dollars worth of electrical switchboard from soaking in flood water. The design could also be deployed on other assets adjacent to flood-prone areas by adjusting its sizes and connections to the ground. The two proposed designs need to be prototyped and lab tested before being able to be applied on site.

Future lab testing is essential to properly prove the water-tightness and the design function compared to the theory. It is essential to know how much water in actual fact enters the switchboard, which will determine the contingency plan and time required to dry out the switchboard. The length of time that the structure can resist the hydrostatic pressure for also affects the contingency plan in the case of an extreme flooding event. Only after successful lab testing, will a full-scale model be able to be deployed.

5. Acknowledgements

I would like to express my sincere gratitude toward people who have given me assisstance, support and guidance throughout the final year thesis project. The University of Western Australia who gave me this opportunity to study Engineering and work on my Master of Professional Engineering thesis project. The Co-Operative Education for Enterprise Development program offered research project, this project links industry with prospective graduates and the cutting-edge research program. To my supervisor Jeremy Leggoe, who constantly challenged each design iteration and encouraged myself to improve it every time.
Glen Williams for providing industrial advice and practical insights of the project. Bruce Barrie for initiating the project and organising the site visit. Eirene Conocono for guidance on electrical engineering knowledge.

6. References

Barbero, E. J., Sosa, E. M., & Thompson, G. J. (2013). Testing of full-scale confined inflatable for the protection of tunnels. In *Textiles composites and inflatable structures VI: proceedings of the VI International Conference on Textile Composites and Inflatable Structures, Barcelona, Spain. 9-11 October*, *2013* (pp. 431-442). CIMNE.

Bevan, J. (1999). Diving bells through the centuries.

FM Global.(2008) FM Global Report for Lot 954. Perth: FM Global.

Piispanen, A. R., Lombardi, M. R., & Burleson, W. Variable Depth Capability for Portable Inflatable Habitats.

Standards Australia. (2020). AS/NZS 4100:2020 Steel Structure Standards Australia, Standards New Zealand.

Water Corporation. (2019). Port and South Hedland Flood Mapping. Perth: Water Corporation