Foundation Design for Furnace Building

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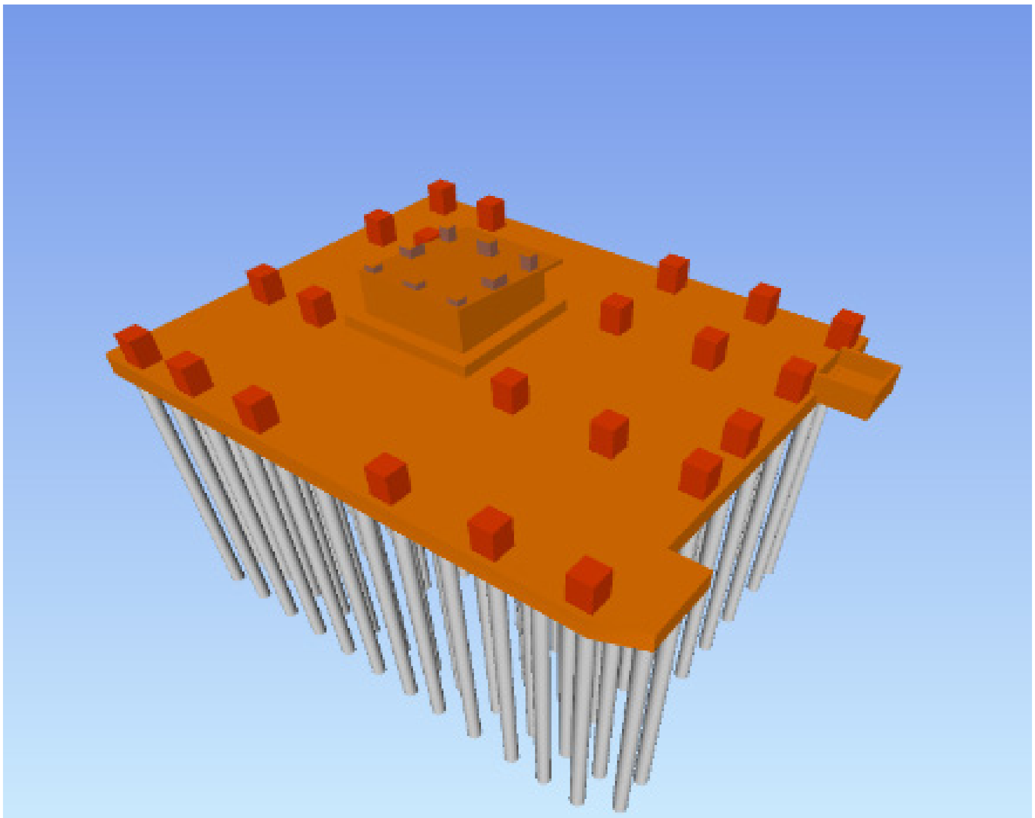
Abstract

This document describes the techniques used to design the deep pile foundation for the oxidation furnace building as part of the Nyrstar Port Pirie lead smelter redevelopment. Due to the soft soil parameters, the foundation consisted of more than 100 closely spaced piles, each reaching a depth of 26m below ground level. On top of the pile group is a 1.6m deep pile cap, with a total volume of 1300m^3; as well as a large pile 'plinth' supporting the 150 tonne lead smelting furnace.

The design consisted of deep piles installed by a continuous flight auger (CFA) piling rig and a reinforced concrete pile cap. When there are a large number of closely spaced piles under a highly loaded structure, load can distribute from one pile to others through the surrounding soil. Various innovative techniques were used in the design to allow for the soil structure interaction, as well as to overcome any uncertainty in soil conditions. Additionally, a non-linear analysis was used to confirm additional overload capacity from the piled raft.

For the pile cap, large prefabricated reinforcing cages were designed with openings for pile starter bars so they could be simply dropped into place; cutting cost of labour and providing an efficient construction process.



1 Overview

The foundation was designed to support the fully clad oxidation furnace building, which was split into 9 modules, and was built offshore in a Chinese fabrication yard. The modules, fitted with a majority of the mechanical equipment and piping, were shipped to site, and lifted into place with a 2000t crane. The completed size of the building has a foot print of 29.5m by 24.2m, and has a total height of approximately 81m. Refer Design of *Modular Process Plant Buildings* blog for more details.

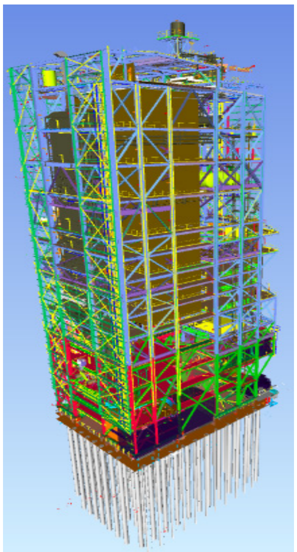


Figure 1 - Furnace Building and Foundation Model

The foundation consists of two major components:

- The plinth in the centre of the foundation. This plinth supports the lead smelting furnace, and consists of approximately 350 cubic metres of concrete.
- The supporting foundation for the main oxidation furnace building. This foundation consists of $1300m^3$ of concrete, and is supported by 89 x 900mm diameter piles. These piles reach a depth of 26m below ground surface.

1.1 Design Challenges

The project presented a range of design challenges, including:

- Soft soil parameters at the Port Pirie site
- High water table
- Furnace building steelwork at preliminary stages of design
- Large diameter piles closely spaced
- The need to incorporate soil-pile interaction forces

2 Analysis

2.1 Ground Conditions

Extensive geotechnical investigations had been undertaken on the site prior to commencement of the design. The fill material consisted of slag placed in an uncontrolled manner with large boulders of slag present. This produced minimal geotechnical capacity for the first seven metres of soil. Therefore, extensive pile embedment lengths were required to produce the required geotechnical pile capacities.

2.2 Pile Group Soil Interaction

In designing the piled foundation, the methodology aimed to calculate realistic values for design pile loads. One consideration was the pile group soil interaction. It is commonly known that closely spaced, highly loaded piles in a group can be subject to increased axial and lateral forces due to soil pile interaction. Figure 2 graphically shows that the loading from the piles distributes through the soil, with force entering the vicinity of neighbouring piles. Depending upon the analysis method, effects of this can sometimes be ignored.

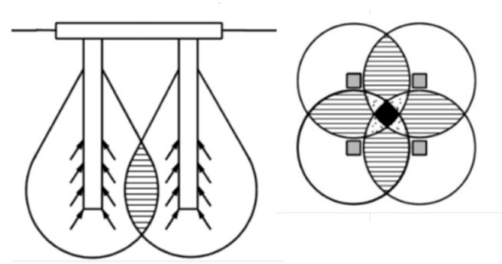


Figure 2 - Soil-Pile Interaction

2.3 Finite Element Analysis

In order to determine the pile axial loads, as well as the pile cap design actions, a finite element analysis (FEA) model was created.

The software, “Piglet” developed by Professor Mark Randolph allows for soil pile interaction. However, Piglet assumes either:

- a rigid pile cap or
- a fully flexible pile cap.

The pile cap considered for this design is somewhere between these two conditions. It is also necessary to calculate the design actions in the pile cap in order to design the reinforcement.

The approach adopted for the analysis was as follows:

- Spring stiffness values at each pile location were calculated with the methodology used in Piglet. This included both the direct stiffness of the pile and the stiffness due to interaction effects.
- Column loads were applied to the model and the analysis carried out to determine design actions in the pile cap, as well as pile loads with realistic stiffnesses for the pile cap.

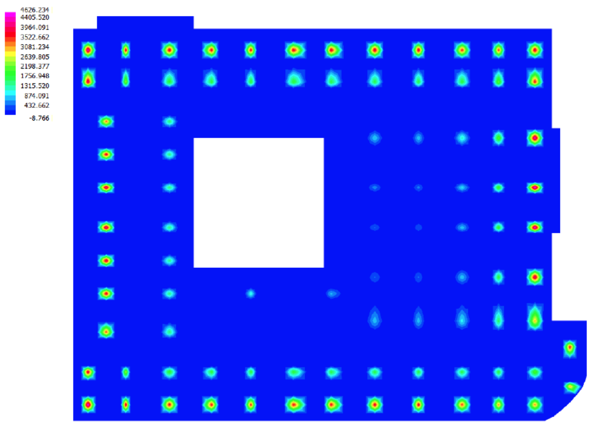


Figure 3 - Pile Envelope Loads

2.4 Non-linear Analysis

As the steelwork building supported on the foundation was at a preliminary design stage, techniques were adopted to allow for the possibility of the pile loads changing somewhat for the final structure.

A non-linear analysis was set up in the FEA model to allow the spread of load from peripheral piles. The pile stubs shown in figure 4 were limited to a specified axial capacity. If this load was exceeded, the model would ignore that pile and distribute the forces to surrounding piles.

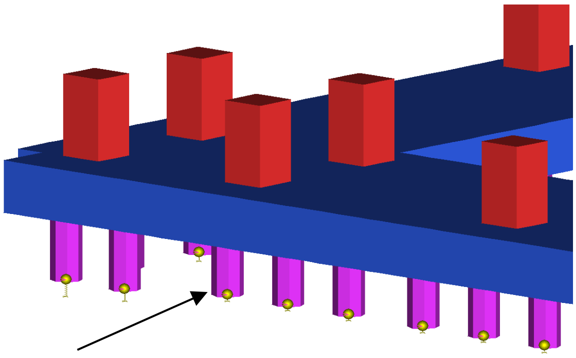


Figure 4 – Finite Element Analysis Model

Analysis was undertaken where the ultimate loads were increased to exceed the current design. The ultimate geotechnical capacity was nominated as the pile member load limit.

The implementation of this design technique provided the following advantages:

- Pile loads could be redistributed if building design forces exceeded original assumptions.
- Pile cap design actions could be updated if building loads increased and pile loads redistributed.
- Progressive checking of the foundation design could be carried out during the steelwork detailed design phase to understand how it would perform.
- The contractor could start construction prior to completion of detailed design of the building steelwork.

3 Constructability

3.1 Piling

3.1.1 Piling Overview

Due to the water table sitting approximately one metre below the ground level, sheet piling was installed to allow excavation for the pile cap.

Continuous flight auger piling (CFA) was used for the foundation construction. The CFA piling rig is made up of a large auger, and a central hollow channel through the centre of the auger. A concrete pump gets attached to the top of the auger, and once it reaches the specified depth, pumps concrete as the auger retracts, filling the bore hole.

This piling technique was chosen for the following reasons:

- Effective in locations where soft ground conditions are present.
- Considered to be the most effective for minimising cross aquifer contamination.
- Suitable for installing the piles to the required 26m below ground surface.

Figure 5 – CFA Piling Rig

3.1.2 Piling Construction Sequence

One of the constraints for the pile installation was the uncontrolled nature of the fill material at the site. Normally predrilling would occur through the slag layer before the CFA rig could be used. However, it was decided to excavate all of the slag material to base of pile cap to facilitate efficient installation of piles, without the need for predrilling.

The following outlines the steps of the construction sequence used:

1. Install sheet piling to prevent water ingress for the excavation and prevent cross-aquifer contamination.
2. Excavate slag/fill to the bottom of pile cap level. Pour a cement stabilised fill.
3. Backfill the foundation with a structural fill and compact to engineering specifications. This structural fill acted as a suitable working platform and was designed to withstand the bearing capacity of the piling rig.
4. Drill through the structural fill, cement stabilised fill, and the natural ground until the pile reached the specified depth of 26m.
5. Following the completion of the piles, the fill was removed, leaving the top stubs of the piles exposed. As the structural fill depth was the same as the pile starter bar length, the contractor was left with simply removing of the top of the concrete pile stubs, resulting in the correct pile starter bar length.

Figure 6 – Post Piling Excavation

3.2 Pile-Cap

When the reinforcement was sized it was found that top and bottom reinforcement in each direction was significant and that shear reinforcement was also required. However, there were a lot of inefficiencies and costs involved in fixing the reinforcement insitu as workers had to wear extensive protective clothing and respirators, and work was to be carried out during the summer months.

Efficient constructability solutions were developed for the foundation, such as:

- Prefabricated reinforcement cages minimised the amount of labour work on site and allowed for simple installation of the pile cap reinforcement. Cut outs were created for the pile locations, and loose bars placed across the openings in situ.

Figure 7 – Reinforcement Cage

- Any loose reinforcement bars were sized for lengths that were manageable by one or two workers.
- Easier loose bar installation by reducing the amount of pile starter bars.
- Reinforcement bar spacing was chosen so that it was small enough for labourers to walk on if necessary, but also large enough for the concrete vibrator to fit between the gaps. This allowed the top reinforcement to be installed efficiently by the labourers.

All of these considerations aided in the efficiency of the construction of the pile cap, and decreased the time required on site to build the pile cap.

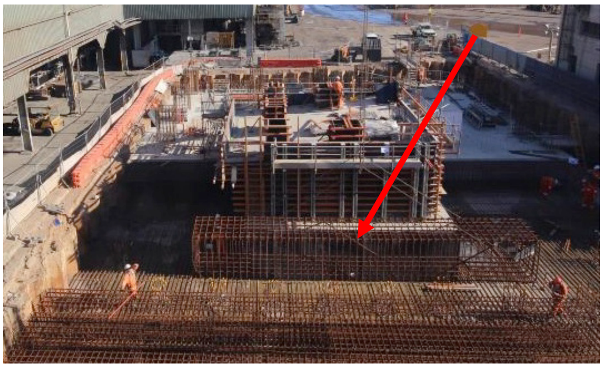


Figure 8 - Reinforcement Cage Lifted into Place

4 Conclusion

In summary, the design of the pile cap considered the possibility of increased loading events. As the building loads were only at the preliminary stage, it was essential that the design be future proofed. The use of non-linear analysis allowed the redistribution of pile loads with sufficient reinforcement in the pile cap to accommodate this.

The design for the piles had to consider soil-pile interaction. With large diameter, closely spaced piles, the total load on the piles can be underestimated if this is ignored.

An efficient construction process was critical. Due to weather conditions and a demanding work environment, it was essential that the construction process of the foundation was efficient. The use of pre-fabricated cages, as well as a range of other design considerations, all contributed to meet a tight time schedule in an economical way.

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