CONSTRUCTION METHODS AND ASSOCIATED RISKS FOR RIGID AND FLEXIBLE RETAINING WALLS

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ABSTRACT

This paper describes two types of retaining wall systems, one is a stiff secant piled wall (usually resulting in small wall deflections) the second one is a less rigid and more flexible sheet piling wall (usually having larger allowable wall deformations). Furthermore the water retention capability of both wall types will be discussed as well as the requirement to laterally support the walls with props or anchors.

It is important to design the retaining wall system according to the medium which needs to be retained (usually soil or water); the surrounding ground conditions, the allowable movements of the retained soil behind the wall after excavation and the intended purpose of the retaining structure. Allowable movement is of particular importance to minimize the settlements of adjacent buildings and structures.

The different construction methodologies of the retaining wall types will be described and the main advantages and disadvantages of each system will be highlighted. Furthermore the major construction risks will be discussed.

The paper will also include a case study of a recently completed retaining wall project in NSW. Piling Contractors successfully installed a sheet piling wall for the construction of a cofferdam in the middle of a watercourse. Additionally a hard/hard secant pile retaining wall was installed inside the cofferdam with sockets into high strength rock using 1180 mm and 1300 mm piles. The requirements for both, water tightness and tight vertical wall tolerances of 1:200 were successfully achieved and the paper points out the major construction activities and monitoring techniques of this challenging project.

1 INTRODUCTION

Retaining walls are used for the construction of basement walls as well as earth and water retaining structures. Depending on their use, the geology and the excavation depth/retention height a variety of different wall types can be utilised. These walls can be designed as cantilevered or braced/anchored structures.

Stiff retaining walls usually minimize the wall movement towards the excavation and the soil settlement behind the wall; concrete walls can be integrated in the permanent structure as basement walls if desired. Typical examples for stiff wall types are diaphragm walls, secant pile or contiguous piles walls, which are constructed using cast in place concrete as construction material.

Steel sheet piles on the other hand typically show softer and more flexible displacement behaviour than piled concrete walls. The sheets are commonly made of steel and can be re-used if required. Depending on the sheet thickness and the profile the sheets provide a different degree of stiffness.

The major risks associated for retaining walls in general will be discussed in the next chapter of this paper. The subsequent chapters will highlight the construction methodology of secant pile walls and sheet piling walls separately, as well as particular advantages, disadvantages and associated construction risks. This paper will not discuss any design topics, commercial details or OHS related risks.

2 GENERAL RISKS ASSOCIATED WITH RETAINING WALL CONSTRUCTION

The purpose of retaining structures is to retain soil or water. Regardless of the material the wall properties, materials or the structural systems with anchors, propos or cantilevered systems, the active earth pressure behind the wall will cause wall movements and wall displacement towards the excavation face. The qualitative earth pressure and displacement development is shown in Figure 1 (Bowles 1997).

It can be clearly observed that during each excavation stage wall movement occurs. This movement is caused by a soil wedge behind the wall and the magnitude of the wall movement largely depends on the ground conditions, the lateral support and the stiffness of the wall. Softer systems, like sheet piles, typically show larger displacements than stiffer systems. It should be noted that the movement of the soil wedge "activates" the wall displacement and causes settlements along the slip line and on the surface level behind the wall.

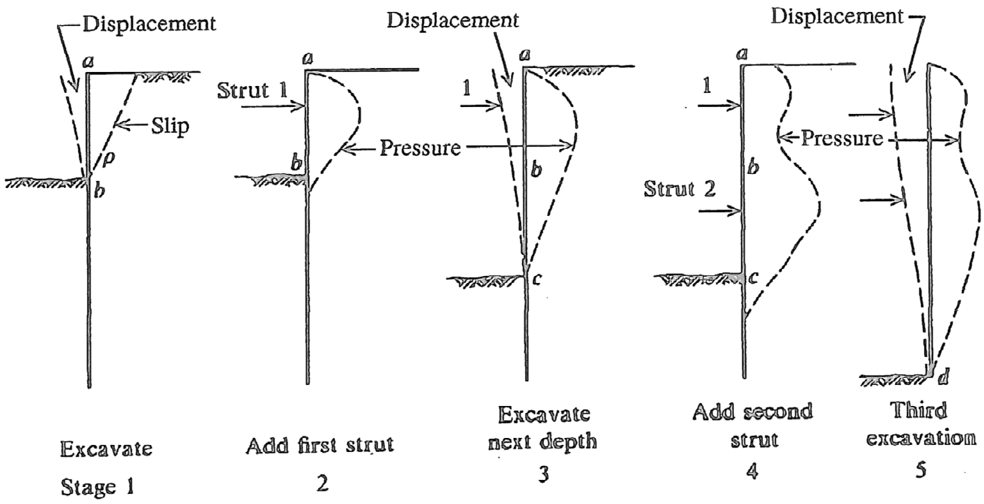

Figure 1: Qualitatively staged earth pressure development behind an excavation after Bowles.

To help with a simple risk management methodology for retaining walls the authors of this paper recommend extending the proposed risks methodology described by Suckling et al (2005) to all types of retaining structures, not only to secant pile walls. Furthermore the authors added a few additional risks which are associated with the construction of retaining walls in general:

<u>Plan tolerance of the piles</u> is important to achieve optimum positional accuracy prior to commencement of the installation process. It is recommended to use a guide wall for concrete piles and walls (Figure 7) and a guide frame for sheet piles or steel piles.

<u>Vertical tolerance</u> of the wall is critical for water tightness and integrity of the wall. AS2159-2009 restrict vertical tolerances of piles installed from land with cut-off levels no more than 2 m below piling platform (typical application for retaining walls) to 4% or 1:25. However, these values are not suitable for most retaining wall applications and need to be increased to 1:75 or 1:100 to ensure wall integrity without gaps. Assuming a secant pile wall constructed from 900 mm concrete pile with a retaining height of 10 m and c/c distances of 0.85 pile diameters (135 mm) between the piles, AS2159-2009 would allow 400 mm of tolerance at the base of the excavation, which would create a gap of 265 mm per pile. In order to avoid any gaps in the wall and considering the adjacent pile could be installed within the same tolerance but opposite rake, the vertical tolerance in this example should be reduced to 65 mm per pile (0.65% or 1:150). With modern piling rigs and suitable installation methods (segmental casings or CSP) such tolerances are achievable.
Pile verticality can be monitored using different devices and typical vertical tolerances for retaining walls are between 1:100 and 1:200. Inclinometers installed in the mast of the piling rigs are usually sufficient for monitoring pile verticality. The case study in section 4.4.3 of this paper describes the vertical monitoring of secant pile wall piles using down hole survey techniques.

<u>Ground conditions</u> and man-made obstructions can have influence on the verticality of the retaining structures. Shallow obstruction can be removed prior to the wall installation. Sheet piling walls are particular sensitive to obstructions which can cause the sheet to refuse or bend and not reaching the proposed design level. Pre-drilling can help to overcome obstructions and the right choice of the overall construction methodology is of great importance.

<u>Corners and curves</u> wall sections need special attention during construction. Sometimes additional unreinforced "soft" piles need to be installed to give corner piles the right guidance and to avoid them to run out of position. For sheet piling walls special corner sheets or profiles are required, these profiles can have different dimensions than the standard sheets.

Adjacent buildings and services should be considered with highest attention. As shown in Figure 1 retaining walls will move and create soil movement behind the walls. More flexible systems like sheet piling walls should be considered carefully for walls close to adjacent buildings as the wall movement might create undesired settlements and resulting damages of neighbouring buildings or underground services. Furthermore driving or vibration impacts have the potential to damage adjacent structures and services. The use of CFA piles for concrete walls should be considered with care as well. If penetration rates can not be kept close to the optimum constant rate, uncontrolled lateral soil excavation around the pile will occur and cause potential settlement of structures and services.

The construction and maintenance of a certified working platform is critical for the safety of the operations and for achieving specified tolerances and sufficient productivity. The orientation of the piling rig to the wall should be cross carriage in order to apply constant ground pressures along the wall and to allow the rig to move to the next piling location faster. Maintenance of the working platform will be optimized when rotation of the tracks can be reduced.

The lateral support system of the wall is critical for the risk assessment process as well. Anchors or struts need to be installed for most walls; unless the wall is designed cantilevered. As shown in Figure 1 the largest displacements usually occur just prior to the installation of the lateral support system. The specification of the correct anchor lock down load and the strict quality control of the anchor subcontractor is critical for a successful execution. It is also important to carefully manage the interface between the subcontractors on site and select an experienced sheet piling, earthworks and anchoring contractor and to ensure all parties work closely with the designer and follow the excavation plan.

All wall types can be constructed as water retaining structures. However, it is difficult to specify the level or degree of water tightness of a retaining wall and it should be noted that a certain diffusion of moisture can not be completely avoided, regardless if the retaining wall is made of concrete or steel sheets. Nonetheless, running water is not acceptable and must be avoided for any retaining structure which is designed to retain water.

Excavations close to the wall toe (e.g. for footings) should be avoided. The passive resistance of the wall will be removed by the excavation and the wall deflection might increase significantly up to a potential wall collapse.

In summary, an experienced piling subcontractor should be appointed in order to identify and manage the risk associated to the construction of retaining walls in order to get value for the client's investment.

3 SECANT PILE WALLS

Secant pile walls are retaining structures formed by installing overlapping cast in place concrete piles. These piled walls are constructed by first installing a number of primary or "female" piles followed by the installation of secondary or "male" piles within the gaps between the female piles (Figure 2). The difference in pile diameter and pile spacing determines the amount the piles interlock with each other (the secondary pile cuts into the primary pile). Typically the centre to centre distances of the male and female piles are between 0.65 and 0.9 pile diameters to ensure sufficient interlocking between the individual piles, mainly to achieve water tightness.

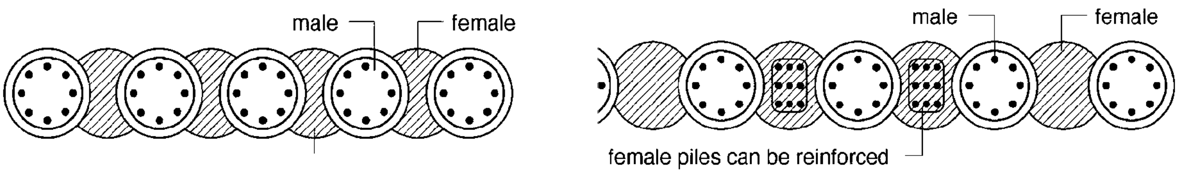

Figure 2: Typical secant pile wall arrangement with "female" (primary) and "male" (secondary) piles forming hard/soft walls (left) and hard/hard walls (right) after Suckling et al. (2005)

Secant pile walls can be constructed using several different drilling methodologies, depending on ground conditions, pile diameters, retaining heights, interlocking requirements and site access. It is important to note that for all Continuous Flight Auger (CFA) techniques computer monitoring of the pile installation process is essential for quality assurance:

- Continuous Flight Auger (CFA) piles for primary and secondary piles
- CFA piles for primary piles and rotary bored piles with thick walled segmental casings for secondary piles
- CFA piles for primary piles and cased CFA (CCFA or CSP) for secondary piles
- Rotary Bored Piles with standard thin walled temporary casing for primary piles and rotary bored piles with thick walled segmental casings for secondary piles

It is critical to select a suitable drilling methodology for the secondary or "male" piles to achieve sufficient interlocking between the piles. Loose joint connecting the CFA auger sections or the drill auger to the Kelly bar could cause lack of rigidity of the drill string resulting in undesired deviations.

CFA piles require constant penetration rates to avoid uncontrolled, lateral spoil removal during the drilling process. Particularly in inner-city projects with adjacent structures and buildings in close proximity to the proposed secant pile wall, uncontrolled spoil excavation by the CFA auger can cause severe settlements and damages on adjacent structures.

It is also important to raise the importance of a suitable concrete mix for the primary or "female" piles for a hard/soft secant pile wall. From a designer's perspective the concrete these softer piles should be as durable as possible, which might cause potential drilling and verticality issues for the piling contractor as the concrete strength develops too rapidly. The contractor would prefer a mix as soft as possible in order to allow sufficient penetration of the soft concrete and no deviations caused by concrete which is "too hard". It is important to carry out a thorough risk assessment with the piling contractor, concrete supplier and the designer prior to commencement of works. Recent developments in concrete technology allow mixes with very low initial strength results in the first ten days after installation.

4 SHEET PILING WALLS

Sheet piles are often used in marine or coastal applications, offering the advantages of quick installation, water-tightness and the ability to be removed with little permanent impact on sensitive environment. Each sheet pile is rolled with a c-shaped "clutch" on each edge, each facing in opposite directions allowing adjacent sheet piles to be interlocked or "clutched". Each clutch has a degree of movement in it and this allows for sheet piled retaining walls to be constructed in any number of orientations, including the gentle arc shape required if required for curved walls (refer to case study in this paper). The installation of sealants into the joints improves the water tightness of sheet piles.

Sheet piles are available in a number of profiles and thicknesses, each offering different stiffness/rigidity and therefore resistance to overturning and failure in a retaining wall capacity.

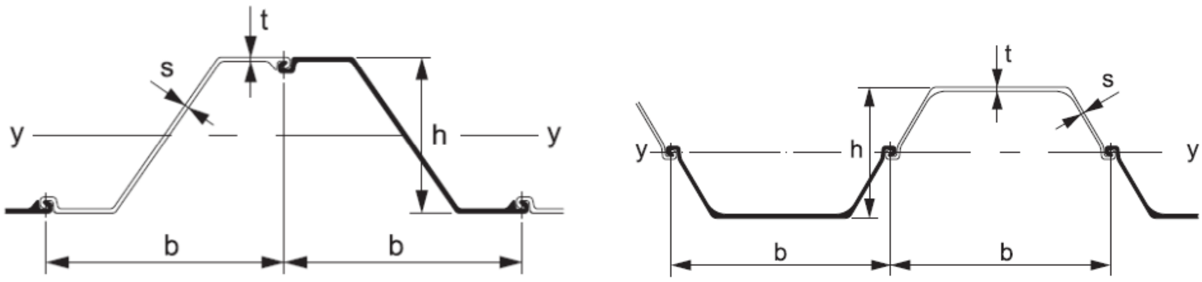

Figure 3: AZ type double sheet pile (left); U type double sheet pile (right)

Sheet piles can be installed up to 35 m in length and used for permanent or temporary applications. The sheets can be installed using vibrators or driving hammers attached to the masts of piling rigs or hanging from cranes.

The use of sheet piles can be an effective solution for small to medium sized basements with limited retaining heights. Sheet piles can be re-used resulting in a cost advantage compared to concrete walls. Furthermore the installation rates are quick, no spoil is generated and the excavation stages can commence straight after the wall installation without curing periods.

4 CASE STUDY

4.1 INTRODUCTION

The Hume Dam is located on the River Murray, approximately 16 km east of Albury-Wodonga on the New South Wales-Victoria Border. The Dam was first constructed during the 1930's and has since undergone enlargement in the 1960's to increase the storage capacity of Lake Hume to just over 3,000,000 Megalitres. The Dam is shown in Figure 4 and serves several purposes, including water supply, irrigation, flood prevention for the Murray Basin and hydro electric power generation from the on-site Hume Power Station.

Historically there had been questions about the stability of the Dam, prompting upgrade works to commence to ensure the Dam and its earth embankments were able to withstand extreme flood and earthquake events. An area of particular focus was the Southern Training Wall (STW) which was firstly strengthened with anchors and then more recently subjected to a more substantial $60m engineering solution, funded by State Government and the Murray Darling Basin Authority.

The scope of the upgrade works included installation of improved drainage and filter systems and the construction of a mass concrete buttress to add additional support to the STW and southern earth embankment. Piling Contractors were engaged by McConnell Dowel for the construction of the retaining wall and piling solutions, namely a sheet piled cofferdam to and a hard-hard secant piled wall.

Figure 4: Aerial view of Hume Dam and Southern Embankment

4.2 LOCAL GEOLOGY

The local geology of the area comprises igneous formations of gneisses and schists of the Ordovician period, which were later intersected by granitic intrusions associated with major faulting in the area. Geotechnical investigations and boreholes taken in the area to be piled showed alluvial sediments (silts, sands and gravels) overlying extremely weathered to highly weathered low strength granite, progressing through to slightly weathered and fresh very high strength granite, granodiorite and gneiss.

Table 1 shows a typical profile of the project geology.

Table 1: Typical profile of the project geology (secant pile wall)

Elevation	Material	Description
RL +150 m to RL +147 m	Fill/Recent Sediments	Silty sand, Sandy gravel, sand, gravel and cobbles. Density of the material ranges from loose to medium dense.
RL +147 m to RL +137 m	Extremely weathered to highly weathered rock	Granite rock (granite, granodiorite and gneiss). Extremely to highly weathered. Extremely low to very low strength.
RL +137 m to RL +131 m	Highly to moderately weathered rock	Granite rock (granite, granodiorite and gneiss). Highly to moderately weathered with steeply inclined fault and alteration of brecciated and/or extremely weathered rock. Medium to high strength with steeply inclined zones of very low to low strength.
Below RL +131 m	Slightly weathered to fresh rock	Granite rock (granite, granodiorite and gneiss). Slightly weathered and fresh. Very high strength.

4.3 STAGE 1: COFFERDAM CONSTRUCTION

4.3.1 PURPOSE

In order to access the Southern Training Wall of the Dam, an area of the Murray River needed to be cut off and dewatered to facilitate excavation into the river sediments and construction of a working platform (Figure 5). A cofferdam constructed from sheet piles was selected for this purpose as this provided both the ability to prevent water ingress into the excavation and also allowed for low long term impact and easy removal on completion of the works to allow the Murray River to return to its natural state.

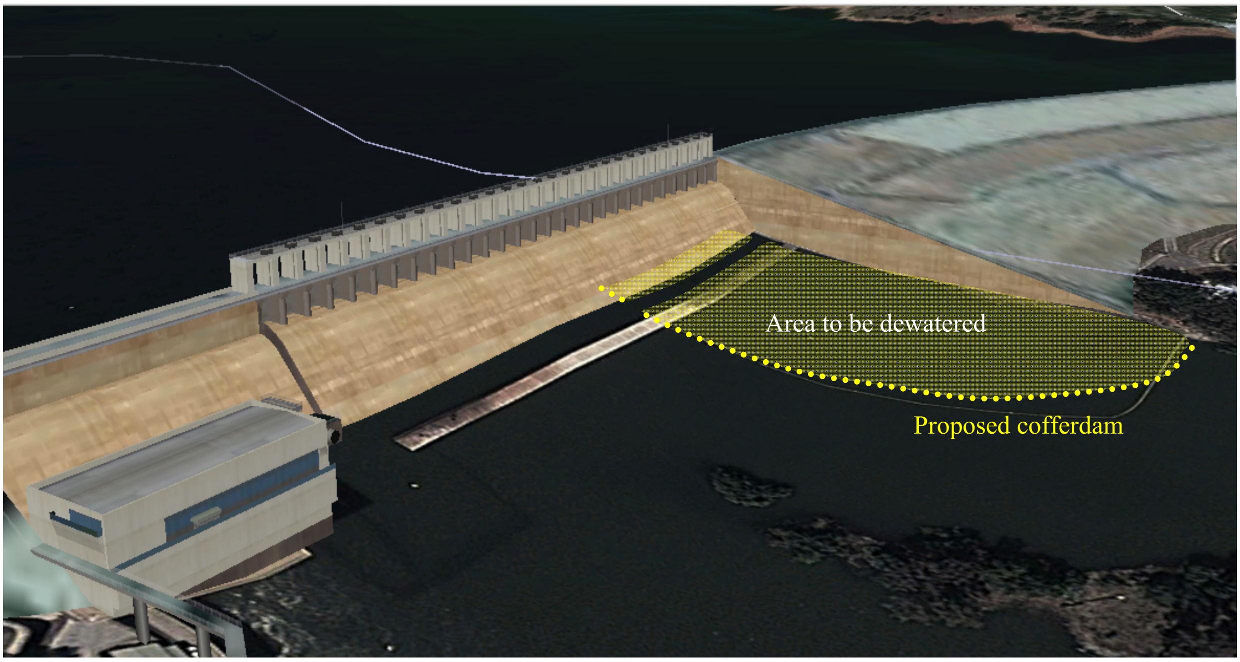

Figure 5: Sketch of cofferdam area

4.3.2 EARTHWORKS

An earth embankment was progressively constructed out from the southern riverbank, moving out in an arc to meet up with the existing concrete energy dissipater structure at the foot of the dam. A team of divers were used to install two pre-fabricated steel bulkheads shaped to fit specifically around the u-shaped dissipater, the downstream one of the pair being fitted with a connection which would permit the first sheet pile to be clutched into place and provide continuity of water resistance.

Figure 6: Sheet pile installation along earth embankment

4.3.3 PILE TYPE

The sheet piles selected for the Hume Dam cofferdam were a mixture of Z-profiles and U-profiles and were about 13 m in length to allow them to penetrate through the riverbed alluvium and embed into the weathered granite. The tight fitting clutches on the sheet piles, although not completely waterproof, offered an acceptable level of water resistance for the purpose and duration of the project without requiring any additional sealants.

4.3.4 CONSTRUCTION

Following certification by a geotechnical engineer to confirm the platform would be suitable for a piling rig to operate upon, a track mounted piling rig with a telescopic mast and vibratory hammer was walked onto the embankment. With lifting holes cut into the top of each sheet pile, the piling rig was able to work in isolation by lifting, gripping and driving each pile to depth. Once the sheet pile is lifted to its vertical position, the vibratory hammer is placed over the sheet, the hydraulic jaws closed and the sheet lifted and clutched into the last driven sheet. Once activated, the eccentric vibratory effect of the hammer helps to mobilise the ground around the sheet pile as the downward crowd force of the rig pushes the sheet pile into the ground (Figure 6).

4.4 STAGE 2: SECANT PILE WALL CONSTRUCTION

4.4.1 PURPOSE

Once the cofferdam had been installed, the area had to be dewatered and prepared for the construction of the mass concrete buttress alongside the Southern Training Wall (Figure 8). Mass concrete footings were required as foundations for the buttress so a piled retaining wall solution was necessary to permit excavation below riverbed level for backfilling with concrete.

4.4.2 PROJECT REQUIREMENTS

The piles were required to penetrate through the alluvium and weathered rock and socket into high strength rock and also needed to be as close to watertight as possible due to the high groundwater level and significant head pressures associated with the upstream levels of the Dam. The piles would also have to deal with the large forces which could be exerted by the southern embankment. Tolerances on pile verticality were extremely stringent (1:200 – equating to 80 mm over a 16 m pile) to ensure that the design was satisfied.

The wall was to be constructed in a repeated u-shape so that 5 "cells" would be created for the buttress foundations to be built from (Figure 9). Furthermore, the piles in the sections of the piled wall adjacent to the STW were required to be drilled into the existing concrete wall which stepped into the buttress foundations at depth. A method which could deal with piling in soft alluvial sediments, high strength rock and reinforced concrete had to be adopted.

4.4.3 SOLUTION & CONSTRUCTION

The final solution was a hard-hard large diameter secant piled wall, in which all the piles had reinforcement. Male and female piles in the wall were alternate diameters (1180 mm diameter male piles were cut into 1300 mm diameter female piles) to ensure that sufficient overlap was achieved.

To ensure that the piles were installed exactly in the correct location, a guide wall was installed consisting of a polystyrene drill guide set into concrete at the pile cut off level. The layout of the piles on the project meant that the piling rig would frequently be tracking over the guide wall to access other piles, so design work was undertaken to ensure the guide wall would be durable enough to resist this without damage or deflection.

Figure 7: Installation of the guide wall

Two tracked Bauer BG V-series piling rigs were mobilised to site to for the works and were set up to install the piles using segmental casings. The segmental casing technique allowed the borehole to be supported through the alluvial deposits as the material within the casing was progressively removed. The casing was drilled to rock and then a socket drilled into the high strength rock beyond using rock drilling and coring tools. This technique was applied to both piles into rock and piles into the reinforced concrete of the STW.

Throughout the drilling process, piles were checked the position and verticality, using both manual techniques and the on-board rig telemetry which is accurate to 0.1°.

To further ensure piles were constructed within the tight tolerances, down hole survey tools were used to do a final check on the pile. This process involved a 3-legged gyroscopic sensor which was first calibrated at the surface in a level position and was then inserted into the pile casing, with the 3 legs ensuring the sensor was central within the borehole (Figure 9). Measurements were taken at 1m increments along the length of the pile both as the sensor was lowered to the toe and raised to the surface and data was transmitted back to a surface based laptop via a Bluetooth connection.

The readings generated by the system provided a plus or minus measurement in the up/down and east/north direction and when used in conjunction with surveyed coordinates of the top of the casing, the toe of the pile could be very accurately plotted.

Figure 8: Pile installation within the dewatered cofferdam

4.5 SUMMARY CASE STUDY

The Hume Dam project presented several technical challenges and required a combination of retaining wall techniques to achieve the design requirements. With a critical attention to detail and a wide range of equipment to draw upon, Piling Contractors were able to successfully fulfil the Client's entire requirement and construct the piles within tolerance and without any quality issues.

Figure 9: Down hole survey to check verticality (left); cells 1, 3 and 5 complete and excavated (right)

5 CONCLUSIONS AND RECOMMENDATIONS

Retaining walls can be constructed using different methodologies and techniques. Each technique from a soft wall to a stiff wall has its particular advantages, disadvantages and risks. It is important for clients to carry out a thorough risk assessment prior to commencement of the design process to evaluate potential construction risks which are associated with certain wall types.

The paper provides a simplified overview about the most common construction risks associated with retaining walls in general and introduces sheet piled walls (soft walls) and secant piled walls (rigid walls) as examples providing a case study where both systems were successfully used on a landmark project.

It is important to highlight that besides the construction risks highlighted in this document, various other project specific risks, design risks, contractual risks, geotechnical risks and other risks must be considered carefully before and during the planning and execution stage of a retaining wall project. It is important to choose an experienced team of sub-contractors, designers, consultants and suppliers and to successfully manage the project and to clearly specify the technical and commercial project requirements.

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