

# WALSH BAY WHARVES 6/7 BASEMENT CARPARK CONSTRUCTION

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## INTRODUCTION

In the past 5 years, Sydney Harbour has seen the redevelopment of existing finger wharves for both residential and commercial use. These timber wharves were built in the early 1900's and remain a prominent feature of the harbour heritage. A number of the nine wharves at Walsh Bay have been restored and now function as theatres, restaurants, a hotel and commercial offices. However, as part of the extensive redevelopment, restoration and rejuvenation of Walsh Bay to create a prestige, vibrant, cosmopolitan, precinct, Wharf 6/7 has been completely demolished and is being rebuilt as luxury residential apartments.

To maximise the number of residential floors within the specified height restrictions, the Wharf 6/7 project has incorporated a single level basement carpark built under the deck level in the inter-tidal zone within the harbour. Design and construction of a partially submerged carpark provided a technical challenge and in particular the section of the carpark under the pier required an innovative solution. This paper presents the details of the construction methods used in providing that solution.

The client for the entire Walsh Bay redevelopment is Walsh Bay Partnership, a joint venture between Transfield and Mirvac. The basement structure for Wharf 6/7 has been built by Multiplex Constructions and Waterway Constructions, a design and construct contract valued at \$45m. Robert Bird and Partners have performed the structural design works. Time constraints placed by the client meant that this challenging project of building a submerged basement carpark complete with foundations had to be finished within 14 months.

## THE BASEMENT CARPARK

The basement carpark was constructed in two sections, each part using different construction methods. These sections can be seen in the diagram below, one parallel to the shore under the old shoredsheds and one under the pier extending out into the harbour. At high tide, the bottom of the carpark is 2.5m under water and up to 12m above the seabed for a substantial part of its length. The carpark has an area of more than 13,000m<sup>2</sup>, 5,000 m<sup>2</sup> under the site of the old shoredsheds and 8,000m<sup>2</sup> under the pier.

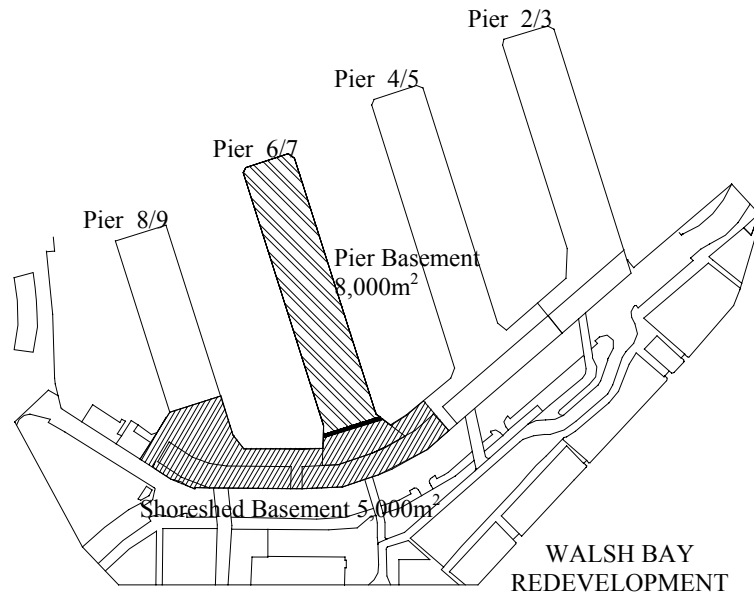


Figure 1: Site Layout

The section under the old shored areas was built behind a 300m long sheet pile wall used to hold the harbour water back whilst the basement was constructed on excavated land. The sheet piles, which were 8m to 23m long, were propped at the top by pairs of 600 mm diameter vertical and raking steel tubes driven to form an A-frame and then stressed into the rock using strand anchors.

To link the two construction areas, a box cofferdam was used to build a 30m long concrete beam supported on 14 raking and vertical piles. This beam, located below the level of the carpark, provided a solid anchor to resist lateral construction loads during pier construction and to assist in waterproofing the joint between the pier and the shored areas.

The pier section of the carpark, which projects out from the shore, was built using a unique lowering method described below.

## FINDING THE SOLUTION TO THE CONSTRUCTION OF THE CARPARK UNDER THE PIER

In determining the best construction method for the pier basement, a number of proposals were considered and analysed. These ranged from lifting in large precast units to form the basement to casting the whole unit in one piece at another site and floating it in to place. Eventually, it was decided to cast the basement directly above its final location and lower it down into the harbour on to driven piles. After analysing and reanalysing the bracing requirements for a proposal on this scale, it was decided to cast the level one slab, which formed the carpark roof, directly on top of the yet to be lowered basement. By adopting this construction sequence, the level one slab provided a stiff diaphragm to reduce bracing and had the advantage that the deck could be turned over to the builder of the apartments above at an earlier time. Although the level one slab reduced bracing requirements, a further 1,000t of steel bracing was still required to ensure stability during construction.

To assist in building the basement as economically as possible, the old timber wharf deck was left in place for as long as possible to provide a working deck for piling, column installation and box cofferdam construction. Two hundred and eight new steel tube piles were driven through the old wharf deck. These were used to support the works during construction and remained in place to provide the foundations for the final arrangement. After installing the piles and concreting projecting steel columns inside the piles, the old wharf deck, which had been supported on some 1,500 timber piles was demolished and removed by barge.

The basement floor and walls were cast on the columns above water level. Floor level one, the first apartment level, was cast directly on top of the basement slab. The level one slab was then used as a platform to lower the basement in seven sections down 2.5m to its final location under the water. Once the basement sections were in their final position, the joints were waterproofed and the basement was pumped dry.

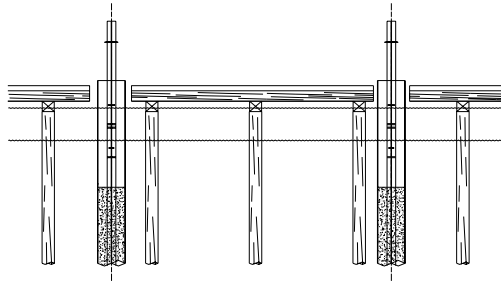
The remainder of the paper describes aspects of the construction method in more detail.

## ASPECTS OF THE CONSTRUCTION METHOD

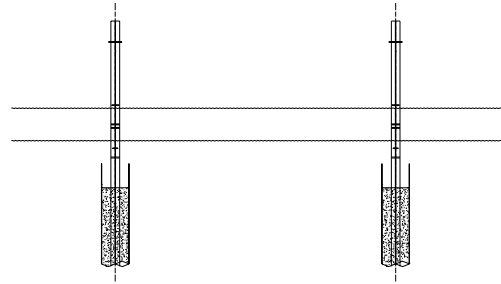
### *Piling*

The piles used to support the pier consist of 600 mm to 1,000 mm diameter steel tubes from 10m to 48m long. They were installed as deeply as possible using a vibrator to minimise noise levels and then by driving with a hydraulic hammer into the sandstone bedrock. The piles were driven to achieve design ultimate capacities up to 12MN per pile in compression and 1MN in tension. To ensure that the required capacities were achieved, 30 dynamic tests and 2 static tests were performed on the 200 pier piles. The net tension loads of up to 600kN per pile are caused by flotation of the completed basement. Further analysis of the tests indicated that for the larger diameter piles, ultimate capacities of more than 20MN were actually achieved for some piles.

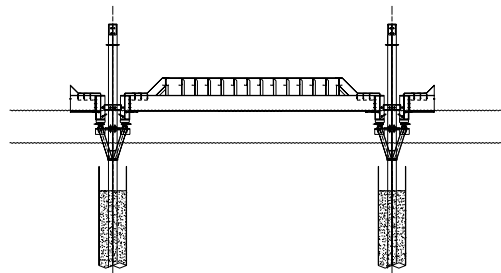
In view of noise level restrictions placed on the site by government authorities, piling noise levels had to be constantly monitored and limited. Insulated hydraulic hammers were used to assist with noise reduction. The sound insulation reduced noise levels by between 10dba and 20dba.



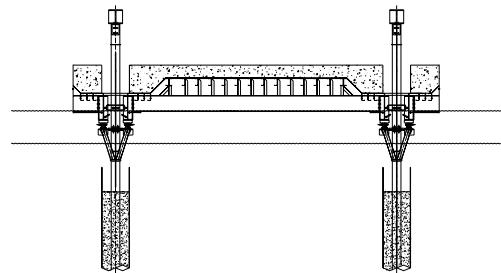
Drive piles and cut off to RL 1.35  
 Install structural steel columns  
 Fill pile with concrete



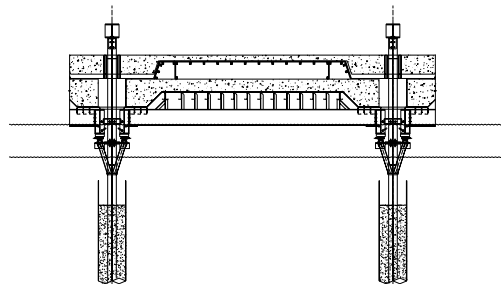
Demolish existing wharf  
 Cut off piles to RL-1.05



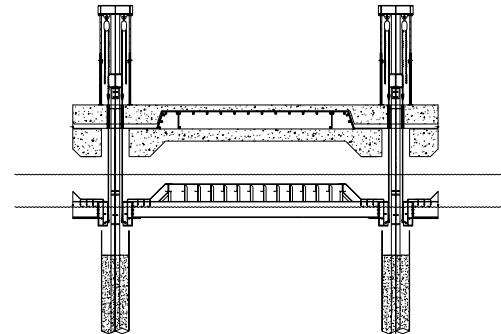
Install lower headstocks and jacks  
 Install soffit forms  
 Place temporary bracing and infill formwork



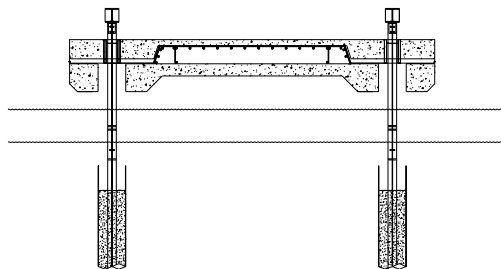
Install jacking rods and upper headstocks  
 Form, reinforce, pour & stress basement slab & walls



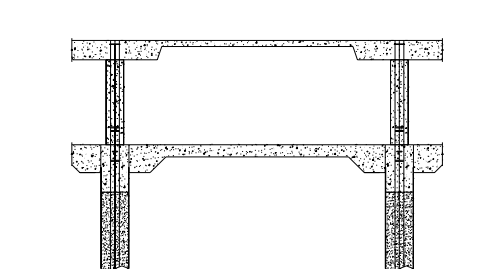
Install stitch bracing and level 1 formwork  
 Reinforce, pour and stress Level 1 slab



Take up basement load with jacks  
 Set up pontoon lowering frames  
 Remove formwork jacks, lower headstocks & forms



Remove pontoon lowering frames  
 Install waterproofing collars to piles



Lower basement and install lateral bracing  
 Waterproof basement and remove bracing  
 Form, reinforce & pour concrete basement columns

Figure 2: Construction Procedure

### *Building Columns*

Because of space limitations within the carpark, large diameter piles could not be continued up to form building columns between the basement floor and the level one slab. Consequently, after installation of the piles, heavy steel columns were concreted into the piles. The construction method adopted eliminated the need for external pile caps, which would have been difficult to construct under water. It was difficult to obtain compact columns which would carry ultimate design loads up to 5,000kN and still fit inside the piles. We considered heavy wall tubes and even solid steel billets. Eventually, especially fabricated H sections with 40mm thick flanges and webs were used.

The columns, which projected out of the piles to above the level one slab, became a critical part of the construction method. Fabrication within the column sections included supports for the formwork headstocks as well as shear keys for the future basement and level one slab locations.

### *Formwork/Falsework System*

The piles and columns are on an eight metre grid in both directions to suit the spacings required for car parking and the apartments above. The combined formwork and falsework system was designed for the weight of the basement slab, basement walls and the level one slab, a total of 1800kN vertical load per span, as well as lateral loads due to wind, wave and potential impact of 430kN per span. To maintain program, an arrangement had to be adopted which allowed for rapid stripping of the soffit formwork.

To satisfy these requirements, formwork units 8m to 18m long and 7.4m wide were fabricated from a grid of 700mm deep welded beams and other steel sections. The largest formwork units weighed just over 20 tonnes. These could be lifted into place but due to limited access, stripping was difficult. The best solution was to fill them with polystyrene and float them out. It provided an unusual spectacle to see 4,000 square metres of steel formwork weighing a total of 600 tonnes floating around Sydney Harbour.

As well as the strength considerations and the capacity of the formwork to float, there were concerns about deflections during concreting. The forms deflected 25mm whilst casting the basement slab. This stored significant elastic energy in the formwork beams that had to be released in a controlled manner. To facilitate this, the forms were mounted on a series of special 50t and 100t capacity formwork jacks which were imported from Germany.

### *Basement Concreting*

The design of the basement makes no provision for leakage during service. Consequently, the concrete has to be waterproof. A special 60MPa mix was developed by the CSIRO for use in the basement concrete. The concrete section has been designed for a maximum crack width of 0.2mm during construction and in service.

The size of the pours were governed by the desire to have as few joints as possible consistent with programming and formwork requirements and the numbers of jacks to be used for lowering which could reasonably be synchronised. It was decided to divide the basement into seven major pours each 40m wide and 24m or 32m long and one small pour at the joint between the pier and the shoresheds. To facilitate lowering, a series of Macalloy bars, extending from basement level to several metres above level one, were cast into the basement pours at each column.

### *Lowering the Basement*

After both the basement and level one slabs were cast and cured, the basement load was transferred from the formwork system to the level one slab and upper headstocks. This was achieved by jacking the Macalloy stress bars that had been cast into the basement slab. After transfer of the basement load to level one and removal of the soffit formwork, the basement was lowered to its final position.

Each U shaped basement section which was lowered, weighed 17,000kN or 22,000kN and employed either 36 or 48 number 50 tonne jacks working in pairs at each column. Because the load in each jack varied from column to column, the jack ram displacements were synchronised. Differential deflections across the slab had to be limited to a maximum of 6mm to ensure that cracking of the concrete did not occur during

lowering. To cater for the possible failure of a jack, a novel air operated turning system for the Macalloy nuts was developed by the jacking contractor, Austress Freyssinet. This system ensured that the nuts were maintained at a constant 6mm above the deck at all times. In addition to the Macalloy bars used for jacking, extra “lazy” bars were cast in the slabs to ensure that the design factor of safety was maintained in the event of a failure of one or more of the main jacking bars.

### *Stability*

Each combined basement plus level one slab pour weighed up to 30,000kN. The units being lowered weighed up to 22,000kN and had to be designed for lateral loads of up to 1,800kN. These loads were supported on top of piles cantilevering some 14m above the seabed. Consequently, stability was a major issue throughout the casting and lowering process. It was decided that an alternative redundant load path would be maintained for vertical loads, a longitudinal load path would be maintained back to the anchor block near the shore and raking piles would be mobilised for lateral loads at all times during the construction works.

The primary load path for vertical loads during casting was through the soffit forms and their connections to the columns. A secondary load path was provided by setting up headstocks on top of the columns which were connected to Macalloy bars in the basement. During the lowering operation, the secondary load path was provided through additional “lazy” Macalloy bars. All these bars remained in place after lowering until the basement was finally concreted into the piles.

A longitudinal load path was provided through the structure of the steel beam formwork units which were tied together with steel struts and braces. After casting and before the forms were removed, the load path was transferred to the level one slab. This was achieved using a series of braces installed in the previously lowered basement around the lift pit area in each pour. When the level one slab was poured, gaps were left at 32m to 48m intervals for 60 days to allow for shrinkage of the slab. At these locations, the columns on each side of the strip were connected by steel longitudinal and cross bracing to ensure continuity of the load path.

To provide transverse stability, the raking piles were temporarily welded to the vertical columns. During the lowering process, a number of additional columns and struts prevented sideways movement of the basement. These became more important as the works progressed out into the rougher more exposed waters at the outer end of the pier. After lowering each basement section, the additional columns and struts were removed and after concreting the pile penetrations through the basement, the temporary raker connections were cut out.

The adopted approach to bracing and stability was formulated after many meetings and much discussion. As a result, the vertical and lateral stability was provided by 600t of structural soffit formwork plus an additional 350t of other steelwork, a total of almost 1,000t of steelwork. The cost of maintaining stability using this amount of steelwork was substantial.

### *Waterproofing*

During the lowering process, water was allowed to flow into the basement through the open end, the pile holes, and the joints between concrete pours. These had to be closed before the water could be pumped out. Temporary bulkhead walls were installed across the 40m wide opening of each section in turn so that the basement could be waterproofed in stages. Temporary seals were installed at the gaps between sections and at each pile location so that the water could be pumped out to allow the final concrete plugs to be poured.

To determine the best way to seal the pile penetrations, various arrangements of collars and waterproofing foams were tested in a rig built for the purpose. Some of the plastic materials failed immediately while other materials held the required three metre head of water for some time and then failed. Many of the plastic materials relaxed after being compressed for one to two days and then completely lost their capacity to hold back a substantial water head. We eventually abandoned the use of plastic foams for other than formwork and changed to a flexible epoxy to provide the temporary waterproofing. This revised arrangement worked remarkably well. It could withstand substantial water heads up to four metres so alternative waterproofing planned for the deeper lift pit support piles was not necessary.

At the pour joints between sections, a rubber gasket with steel backing was bolted across the joint to temporarily seal the basement. This system required detailed preparation of the bearing surface with epoxies.

Once all the holes were sealed, the basement could be pumped out. At this point, it became buoyant with around 10,000kN of net uplift per pour. We had installed an arrangement of propping and antifloat brackets to resist this uplift. Much to our surprise the basement continued to move up and down about 8mm as the tide rose and fell. Some rapid investigation proved that it was not the net uplift that was significant but the total change in load from low tide to high tide. This was about 1,400kN per column or 28,000kN per basement section. To be effective, the props had to be tightened at a very low tide (which occurs infrequently) and the number of props had to be doubled. Movement was reduced to 1.5mm over a king tide cycle and 0.7mm on a neap tide. When performing construction works within the water, one is continually reminded of the very large loads imposed by water and the tides. As a result of the basement movement, the permanent concreting of the basement holes had to be performed with regard to the tides using a special concrete mix. After concreting was completed, all discernible relative movement between the basement and the columns ceased.

To ensure that the basement carpark remains waterproof, all concreted joints included three levels of permanent waterproofing including hydrophilic seals and Fuko re-injectable hoses. These re-injectable hoses allow for resealing throughout the design life.

### *Finishes*

On completion of waterproofing, finishing works included the installation of reinforced concrete columns around the steel columns to provide additional compression capacity for the seven stories of building above and the extension of the level one slab past the basement wall on the western side. A timber boardwalk 600m long was built around the perimeter of the structure. With the boardwalk in place, the wharf presents as a timber construction similar to the other Walsh Bay wharves and the submerged basement is effectively out of sight.

### CONCLUSION

The redevelopment of Walsh Bay 6/7 wharves as luxury residential apartments over the water required the construction of a large basement carpark in the intertidal zone. A number of alternative constructions methods were discussed and analysed. The chosen method involved casting the basement above water level then lowering into its final position using jacks and Macalloy bars. As far as we know, construction of this type and on this scale has not been performed elsewhere in the world.

The combination of the unique methods used and time constraints imposed presented a range of engineering challenges which required a high level of cooperation between the designers and contractors. Despite the scale of the project and the technical innovation required, the whole project was completed in 14 months and finished on the scheduled date.

5 December 2001