The Auckland War Memorial Museum Underpinned With Modern Technology.

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ABSTRACT

The Auckland War Memorial Museum has undergone a radical transformation and expansion with construction of the “Grand Atrium Building”, a project increasing the museums existing space by over 60%. Working within and beneath the confines of the existing Heritage building, the design/construction team have been forced to think laterally, developing unconventional and innovative solutions to the many challenges presented. A significant challenge was to create a secure undercover truck-dock, beneath the existing four storeys of building. Difficult site and extreme space constraints lead to a jointly developed underpinning solution between Hawkins Construction and the projects structural engineers, Holmes Consulting Group with assistance from Construction Techniques (Contech Ltd). The final solution required four 16.4 metre long x 1.0 metre x 0.5 metre post tensioned beams, supported on permanent steel cased concrete columns and piles constructed underneath and outside the existing building to depths of 16m, allowing excavation beneath the building and construction of the truck-dock. Construction of the beams required unconventional methods for concreting. Through the combined effort of Hawkins Construction and Stevensons Concrete technical staff a feasible solution was found: self-compacting concrete (SCC) technology. The utilisation of SCC technology resulted in easy, fast and safe concreting, producing beams of excellent quality and un-compromised structural properties.

THE PROJECT

The Auckland War Memorial Museum is one of Auckland’s iconic heritage buildings sited prominently within the Auckland Domain on the rim of Auckland’s oldest volcano, Pukekawa. The Museum has occupied the current site since 1929 when the Portland stone building was opened in remembrance to the war dead. 1960 saw the opening of a reinforced concrete semi-circular addition at the rear of the original building, encompassing a war memorial for the over 4000 Aucklanders who lost their lives in World War Two.

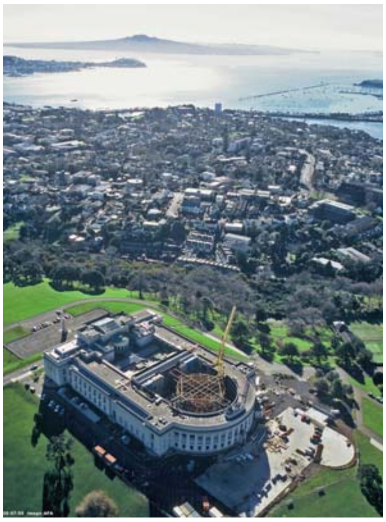

Fig 1. “Auckland War Memorial Museum ”

Construction of the latest phase of Museum development, the “Grand Atrium Building” commenced in 2004 utilising the internal courtyard created with the 1960 addition. Emerging from the central core of this iconic building is seven storeys, two underground, increasing the museums existing space by 60%, containing world-class exhibition halls, educational facilities, collection and retail space, featuring a suspended bowl structure capped off with a copper “wave” dome allowing visitors viewing opportunities from the Museum roof. Also included in the project is a two level under-ground car parking building, located externally to the museum and constructed from concrete.

THE TRUCK-DOCK

One of the most challenging and complex construction activities required on the project was enlarging an access tunnel that was constructed under the building to create permanent undercover truck access to the museum allowing secure processing of goods in a controlled environment. Large scale ground retention and excavation works have been undertaken beneath the constraints of the original building requiring the strengthening and underpinning of the existing building, whilst not affecting operation of the existing galleries above.

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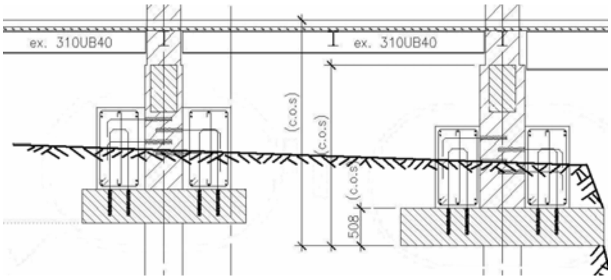

Fig 2. Original Under-Pinning Scheme

Preliminary design schemes developed at the start of the project for the underpinning utilised traditional reinforced insitu concrete beams 1.1m deep by 0.6m wide with temporary columns and piles to allow excavation beneath the existing foundations and subsequent extension of the original building piles (refer to fig 2). The difficult site and space requirements made this solution difficult to construct and would have required substantial hand excavation in confined spaces and involved expensive demolition of temporary works on completion of the underpinning.

The project team worked in a collaborative manner on all aspects of the project and during the initial phases of construction design review meetings were held on a regular basis. It was during this forum that the team reviewed the proposed underpinning option for the truck dock and sought to optimise the design solution. It was at this stage that the option of utilising post-tensioning technology was first mooted. The initial concept design of a post-tensioned beam solution developed between Hawkins Construction, Holmes Consulting Group and Contech, was proven to be feasible.

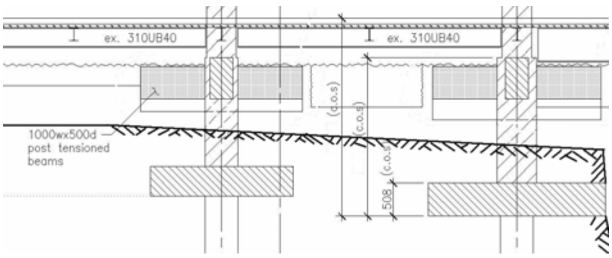

Fig 3. Developed Post Tensioned Beam Solution

Comprehensive and extensive consultation and design development took place to refine and optimise the post-tensioned beam solution. It was during this process that a drop-down portion was required at the ends of the beams where they protruded through the Museum's façade. Heritage constraints required that the beams were not to be visible from the exterior of the Museum, in order to achieve this requirement the beam-ends were dropped to a lower level that would be hidden within the new structure being constructed. On completion of the structure the Heritage façade will be restored above the drop down portion of the beams.

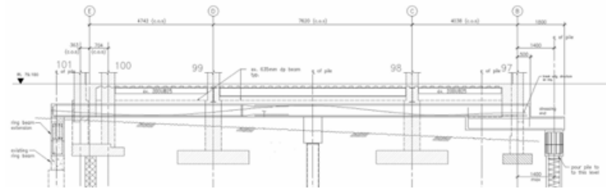

Fig 4. Elevation of Beam & Drop-Down Portion

The final developed solution utilised four large post tensioned beams, with drop-down ends protruding through the heritage facade, supported on permanent steel cased concrete columns and piles constructed underneath and outside the existing building to depths of 16 metres (refer to fig 5). Construction of the post-tensioned beams allows 4,000m^3 of volcanic material to be excavated from beneath the building and construction of the truck-dock structure to be completed.

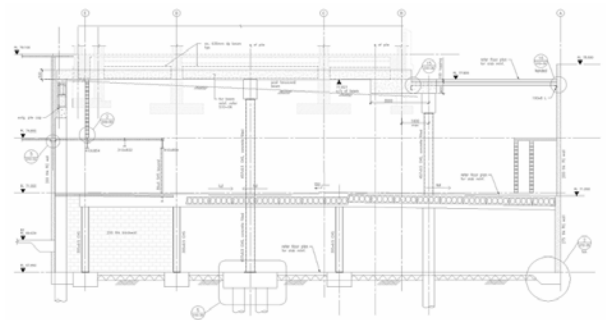

Fig 5. Cross Section of Truck Dock Structure

THE CHALLENGE OF UNDERPINNING

Stevensons Concrete technical team had been working very closely with Hawkins Construction on this project providing technical support and concrete solutions. Confronted with construction of the concrete post-tensioned beams at the top of future truck-dock area, the Stevensons Concrete technical team was called in to discuss and assist with developing the solution at very early stage, even before final drawings started to arrive. The challenge was to construct four 16.4m long by 1.0m wide and 0.5m deep beams directly underneath the existing concrete floor slab in extremely constrained space with clearances between the existing slab above and the ground less than a metre.

It was established that the use of conventional vibrated concrete would have required enormous effort and expense and there were concerns about the quality that would have been achieved. Self-compacting concrete (SCC) technology was the obvious alternative that the Stevensons Concrete technical team offered to the design and construction team. Stevensons Concrete had successfully supplied SCC to a number of projects and was very confident that this project could utilise the product and achieve the required quality with success.

CONSTRUCTION USING SELF-COMPACTING CONCRETE

A requirement in the use of self-compacting concrete is that the formwork is constructed to be "water-tight" so as to prevent any leakage and the risk of bursting. Due to the space constraints it was decided to use conventional timber formwork as it could be assembled from small, relatively lightweight components and altered to fit around the existing structure as required. The formwork was designed on the basis of the general design requirements for formwork outlined in the two part article "Formwork" presented in New Zealand Concrete Construction (March and April 1989). The assumption was made to treat the concrete pressure, Pmax, on the formwork as fully hydrostatic where Pmax = Dh where D = Weight Density (taken as 25KN/m^3) and h = height of lift. Each stage of the formwork construction was carefully checked and all joints were sealed with silicone to prevent concrete leakage.

The post-tensioned beam layout required four beams that were bundled into two pairs either side of the existing structures floor beams. The beams within each pair were connected to each other via a thickening (0.2m deep by 1.0m wide) at the base of the beam, and surrounding the original stub columns and footings.

Fig 6. Construction of the Beam Formwork

Typically the formwork constructed for the beams was hard up against the bottom of the existing floor above resulting in the concrete being encased on all four sides. For the team to monitor the SCC filling of the beam formwork and ensure quality a series of Ø50–Ø100mm holes located at approximately 1m centers were drilled through the existing floor above, along the length of the beams. The idea being that as the beam formwork was filled and the SCC flowed up through each of the holes progressively as it filled the length of the formwork, the holes were plugged with timber chocks.

Fig 7. Quality Control Inspection Holes in Action

To effectively execute the installation of SCC it was decided to install two valves (connection points for the concrete pump) on the outer side of the northern beam approximately 4m from each side of the beam. The idea was to pump as much as possible SCC through the initial connection point (starting valve) and use the other valve to complete filling if needed to be.

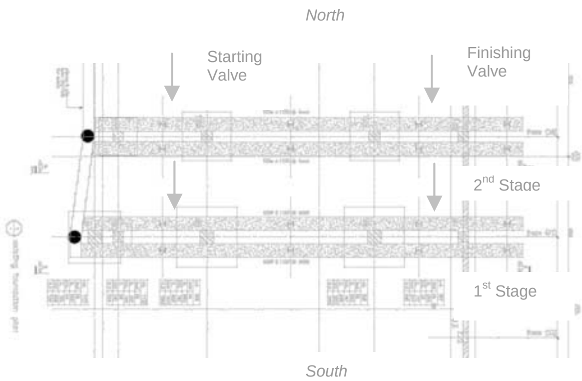

Fig 8. Post Tensioned Beam Layout

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The pump operator (Ian Howe Concrete Pumps) supplied and installed the pumping valves. A medium size squeeze type of pump was used.

Fig 9. Pumping Valve in Position

SELF-COMPACTING CONCRETE REQUIREMENTS

The requirements for SCC were quite simple. It should freely flow through steel reinforcement and around the tendon ducts, completely fill the formwork and maintain stability. Specified compressive strength was 50MPa. The quality parameters for SCC were set out to be as the following:

- slump flow 700 ± 20mm to be maintained during the full discharge from delivery truck,
- T_{500} to be within the range of 2.0 and 2.5 sec for fast flow.

On the construction site the quality of SCC was checked and verified by performing a slump flow test. The target slump flow before SCC discharge from a delivery truck was 720mm. If the slump flow was below the required parameter it was adjusted with the addition of super-plasticiser just before SCC discharge.

TRIALING OF SELF-COMPACTING CONCRETE ON SITE

Before commencing the concreting of long beams, the team decided to try SCC and evaluate it's performance on the short segment of drop-down beam of similar cross section and reinforcement congestion, which protruded through the building façade (refer to fig 10).

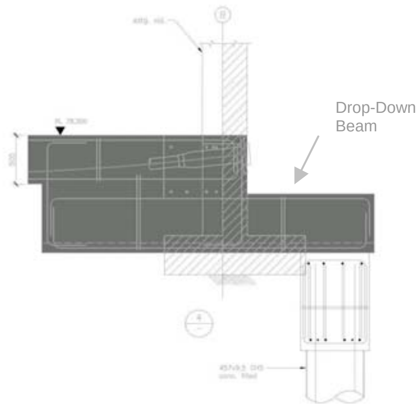

Fig 10. Cross-Section of the Drop-Down Beam

The trial SCC pour of the drop-down beams went very well with the SCC flowing easily, quickly filling the formwork.

Fig 11. SCC Concreting of the Drop-Down Beams

CONCRETING OF THE POST TENSIONED BEAMS

Keeping in mind the extreme space constraint it was decided to split the concreting into two stages and cast each pair of beams separately, starting with the Southern pair.

The outer beam of the Southern pair (refer to fig 8) had the top opened, which allowed the team to monitor how well SCC filled the beam formwork. The outer formwork of the Southern beam was constructed some 50mm higher to prevent an overflow of SCC. The on-site construction quality control procedure assumed to monitor the filling of the outer beam. This was sufficient enough, as complete filling of the outer beam with a slightly higher level of SCC would mean that the inner beam (concealed and hard up under the existing floor) was completely filled too.

The pour started early in the morning before traffic build-up could delay delivery to site. The concrete pump and hose were set up the night before the pour. Working within the extremely confined space constraints required a great effort to get a pump hose underneath the formwork and connect it to the “starting” valve. In a few moments SCC flowed through a connection channel to the outer beam and started filling the formwork. More than 90% of the total volume of SCC was pumped through the “starting” valve. To complete the pour the pump hose was disconnected and re-connected to the other valve to complete the pour (refer to fig 8). The main requirement for the use of the second pumping valve was to prevent an overflow of the SCC through the open top ends at the western end of beams and to reduce the pump pressure on the formwork.

In total 24m^3 of SCC was continuously pumped into the beams through the two valves. Exceptional flowability and filling characteristics of SCC made it possible to execute the concreting effortlessly and to accomplish the necessary quality control measures. The result was a structure of excellent quality.

The concreting process for the Northern beam pair was as per the Southern pair with the only exception being that the top of both beams were hard against the existing concrete floor, thus requiring the series of holes drilled through the floor to monitor the concrete filling the beams and ensure the required quality was achieved. The concreting of the beams went exactly as planned without any problems. The quality control holes worked very well (refer to fig 7) and provided excellent visual confirmation that the SCC had completely filled the formwork. The only unexpected problem was the speed that the SCC was flowing up through the control holes as the formwork was filled, so blocking the holes proved to be quite a mission for some (refer to fig 12).

Fig 12. Blocking the Inspection Holes

As it was with the Southern beam pair, the majority of SCC was pumped through the “starting” valve with the reminder of the 24m^3 required to be pumped through the second valve.

Test cylinders were used to monitor the compressive strength development of the SCC in the beams. A series of testing cylinders were cured alongside the beams to provide closest curing conditions. Testing of the compressive strength started 7 days after the SCC was poured. One testing cylinder was crushed daily until the specified compressive strength of 50MPa was achieved, and then confirmed by crushing an additional cylinder.

Fig 13. Completed Beam and Column Cap

SUMMARY

Successful execution of the project could not have been achieved without the thorough design, planning, cooperation and collaboration between Hawkins Construction, Stevenson Concrete, Holmes Consulting Group, Contech and Ian Howe Concrete Pumps. The details of the time of the pour, pump and pump line arrangements, concrete delivery schedule, amount of workers required and their responsibilities during the pour were meticulously thought through, agreed and implemented.

The experience gained from this project has prompted further use of SCC on site by Hawkins in further beams, columns and on difficult shaped and curved architectural elements requiring a high specification F5 finish.