POST TENSION SLAB DESIGN

airey taylor consulting
engineers
scientists

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[HISTORY]

Post-tensioned construction has for many years occupied a very important position, especially in the construction of bridges, storage tanks and buildings. The reason for this lies in its decisive technical and economical advantages.

Although some post-tensioned slab structures had been constructed in Europe quite early on, the real development took place in the USA and Australia. The first post-tensioned slabs were erected in the USA In 1955, already using unbonded post-tensioning. In the succeeding years numerous post-tensioned slabs were designed and constructed in conjunction with the lift slab method. Post-tensioning enabled the lifting weight to be reduced and the deflection and cracking performance to be improved. Attempts were made to improve knowledge by in depth theoretical studies and experiments on post-tensioned plates. Joint efforts by researchers, design engineers and prestressing firms resulted in corresponding standards and recommendations and assisted in promoting the widespread use of this form of construction in the USA and Australia. Use of the lift slab system was discarded because all floors must be in position before fit out can commence.

To date, in the USA alone, more than 50 million m^2 of slabs have been post-tensioned. In Europe, renewed interest in this form of construction was again exhibited in the early seventies. Some constructions were completed at that time in Great Britain, the Netherlands and Switzerland.

The first bonded post tension concrete slabs designed in Perth were designed by the water for the Sheraton (now Pan Pacific) car-park completed in 1973 by Airey Taylor Consulting.

[ADVANTAGES OF POST-TENSIONED BUILDINGS]

Post-tensioned concrete slabs in buildings have many advantages over reinforced concrete slabs and other structural systems for both single and multi-level structures. Some of the main advantages are described below.

1. Longer Spans

Longer spans can be used reducing the number of columns. This results in larger, column free floor areas which greatly increase the flexibility of use for the structure and can result in higher rental returns.

2. Overall Structural Cost

The total cost of materials, labour and formwork required to construct a floor is reduced for spans greater than 7 metres, thereby providing superior economy.

3. Reduced Floor to Floor Height

For the same imposed load, thinner slabs can be used. The reduced section depths allow minimum building height with resultant savings in facade costs. Alternatively, for taller buildings it can allow more floors to be constructed within the original building envelope. As with Longer Spans, for a developer this is a key value adding advantage and may result in a higher component of saleable apartments.

4. Deflection Free Slabs

Undesirable deflections under service loads can be virtually eliminated.

5. Waterproof Slabs

Post-tensioned slabs can be designed to be crack free and therefore waterproof slabs are possible. Achievement of this objective depends upon careful design, detailing and construction. The choice of concrete mix and curing methods along with quality workmanship also play a key role. Post-tensioned slabs are intrinsically waterproof and are in use for basement and roof slabs for this purpose. The post-tensioned concrete should also incorporate a pore blocker. If this option were adopted the slab is permanently impermeable as it is permanently in compression. There is no need for a waterproofing membrane over the roof. Because concrete is in compression there is no need to use waterproofing membrane.

6. Early Formwork Stripping

The earlier stripping of formwork and reduced back-propping requirements enable faster construction cycles and quick re-use of formwork.

7. Materials Handling

The reduced material quantities in concrete and reinforcement greatly benefit on-site craneage requirements. The strength of post-tensioning strand is approximately 4 times that of conventional reinforcement . Therefore the total weight of reinforcing material is greatly reduced.

8. Column and Footing Design

The reduced floor dead loads may be utilised in more economical design of the reinforced concrete columns and footings. In multi-storey buildings, reduced column sizes may increase the floor net lettable area. The latter results in reduced dead load, which also has a beneficial effect upon the columns and foundations and reduces the overall height of buildings or enables additional floors to be incorporated in buildings of a given height.

[SPEED OF CONSTRUCTION]

Economics and construction speed are heavily linked in today's building construction environment. The speed of construction of a multi storey building is foremost in achieving economic building construction.

The key factor in the speed of construction of a post-tensioned framed building is expedient use and re-use of formwork. Post-tensioning allows for the early recovery of formwork by early stressing of tendons.

A typical floor cycle for a multi storey office development is shown below in table 1. This building has a floor area of approximately 1000 m² and is divided into two pours per floor by a construction joint . It is normal to use two full sets of formwork in this type of construction.

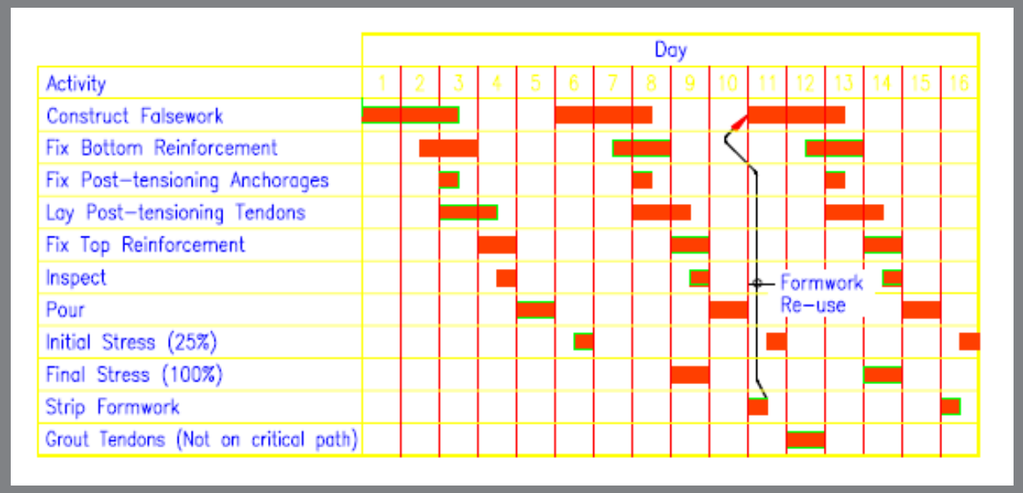


Table 1. Typical 5 day construction cycle. Note that in tower construction it is usual to break the floor into a minimum of two pours. The above cycle is for a half floor with construction of the other half proceeding simultaneously.

[WHEN IS POST-TENSIONING COST EFFECTIVE?]

When considering post-tensioning for a construction project it is important to regard the following advantageous factors:

- By comparison with reinforced concrete, a considerable saving in concrete and steel since, due to the working of the entire concrete cross-section more slender designs are possible.
- Smaller deflections than with steel and reinforced concrete.
- Good crack behaviour and therefore permanent protection of the steel against corrosion.
- Almost unchanged serviceability even after considerable overload, since temporary cracks close again after the overload has disappeared.
- High fatigue strength, since the amplitude of the stress changes in the prestressing steel under alternating loads are quite small.
- Under permanent load, very good behaviour in respect of deflections and cracking.
- Higher punching shear strength obtainable by appropriate layout of tendons
- Considerable reduction In construction time as a result of earlier striking of formwork real slabs.

For the above reasons post-tensioned construction has also come to be used in many situations in buildings.

The graph illustrates two main points. Firstly, how with increasing span the difference in cost between reinforced and post-tensioned concrete flat slabs also increases. Secondly, using an index of one for a 7.0 m span how the cost will vary for other spans. For example, a post-tensioned 10.0 m span will cost approximately 20% more than a post-tensioned 7.0 m span. In general, for spans in excess of 8.0 metres, savings in excess of $10 per square metre should be regularly attained in a direct cost comparison with reinforced concrete slabs.

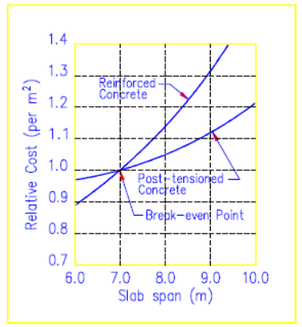


Figure 3: Cost comparison - Reinforced vs Post-tensioned flat slab.

Occupancy of building	Partitions and Other Superimposed Dead Load kPa	Live Load kPa	Load to Balance kPa
Car Parks	Nil	2.5	(0.7-0.85)SW
Shopping Centres	0.0 - 2.0	5.0	(0.85-1.0)SW
Residential (check transfer carefully)	2.0 - 4.0	1.5	SW + 30% of partition load
Office Buildings	0.5 - 1.0	3.0	(0.8-0.95)SW
Storage	Nil	2.4 kPa / m height	SW + 20% LL

Note: SW denotes self weight, LL denotes live load.
Table 1: General level of load to be balanced by post-tensioning tendons to give an economic structure.

[CONCLUSION]

In conclusion it is worthy to reinforce a few key points. There is a definite trend towards large spans in buildings due to the fact that there is now more emphasis on providing large uninterrupted floor space which can result in higher rental returns.

Post-tensioning is an economical way of achieving these larger spans. For spans 7.5 metres and over, post-tensioning will certainly be economic and, as the spans increase, so do the savings.

The most significant factor affecting the cost of slab system post-tensioning is the tendon length. Other factors create a scatter of results leading to an upper and lower bound.

Notwithstanding this, it is always advisable to obtain budget prices from a post-tensioning supplier.

The main structural schemes available are the flat plate, flat slab and banded slab, with the latter generally leading to the most cost-efficient structure. However, other factors such as floor to floor heights, services, etc., must be taken into account in the selection of the floor structure.

For high rise construction and highly repetitive floor plates, the use of more specialised structural schemes is appropriate with emphasis on systems formwork.It is not uncommon for post-tensioning to be rejected in certain types of building projects due to a perceived lack of flexibility. However, tendons are usually spaced sufficiently far apart to allow penetrations of reasonable size to be made later, without cutting through the tendons.

Should it be necessary to cut tendons this can easily be achieved using well established methods.

[WHY CHOOSE ATC FOR POST-TENSIONING?]

ATC are the only firm that provides fully detailed tendon drawings specifying the location and profile of post-tensioning. These fully coordinated drawings represent the total upfront requirement for post-tensioning to the developer so the developer can clearly ascertain the cost of the project and therefore is not liable for any unseen costs later down the track or any additional expenses incurred by the requirement of employing a post-tensioning consultant in the construction phase. Detailed drawings with the inclusion of post-tensioning is only provided by other firms that are PT suppliers so that the requirement is that all PT materials must be purchased through this same firm. This does not represent a cost benefit for the client as with ATC drawings, materials can be sourced elsewhere and at a more competitive rate. This is an immensely valuable and unique advantage that ATC can provide to the client, representing a considerable and proven cost saving to ATC's clients.

[POST-TENSIONED CONCRETE IN INDUSTRIAL FLOOR SLABS]

As discussed post-tensioned floor slabs add considerably to construction efficiencies, economy and achievement of performance characteristics in industrial floor applications. Two recent projects using this technology are at an ore processing facility at Cloud-Break mine for the Fortescue Metal Group and the Kerry Stokes Hangar, Perth. Fully post-tensioned floor slabs can provide the seamless finish required for environmental protection against chemical leakage to subsoil's as was done by ATC for the Torpedo Maintenance facility at Garden Island. The case studies discussed highlight design considerations and construction technique.

Parking garage built with post-tensioned slab concrete

[EXPERIENCE IN THE FIELD OF POST-TENSIONING]

ATC have been using the post-tensioning system since the 1970's with very successful results. Below is a sampling of projects where post-tensioned design has been used:

Current Projects:

- **Crown Hotel (all floors), Perth WA. [Current]**

This project comprises extensive podium (9,000 sq.m), one basement and 21 floors of residential accommodation, all post-tensioned cast in place floors.

- **Meaghre Drive, Perry Lakes. [Current]**

One basement, ground and 3 floors of post-tensioning for this apartment project at Perry Lakes designed for top-side down construction.

- **Javelin Lane Apartments, Perry Lakes. [Current]**

Suspended transfer slab post-tensioned and two floors over using precast planks.

- **Apartments at 29 Pearl Street, Scarborough. [Current]**

[INTERNATIONAL PROJECTS]

- Ahmad Abdul Rahim & Ahmad Alttar, Al Raffa, U.A.E. - post-tensioned ground floor slab for commercial and residential building comprising basement + ground + 7 floors
- Bur Juman Centre Extension, Dubai, U.A.E. - Airey Taylor Consulting re-designed and re-documented identified elements of the Bur Juman Shopping Centre, carpark, offices and residential towers.
- Dubai Marina, Dubai, U.A.E. – Value Engineering Study for Arabtec Samsung.
- ADIA Tower, Abu Dhabi, U.A.E. – Value Engineering Study. Alternative Design
- Australian Embassy Staff Apartments, Bangkok: two 7 storied blocks of 57 apartments

[COMPLETED PROJECTS]

- **New Performing Arts Centre, Perth**

This project, adjacent to heritage buildings included precast and post-tensioned concrete design and construction. Structurally this building was considered sufficiently outstanding that it was recipient of the award by Engineers Australia for Best Structure in Australia for 2011.

- **De-sanding plant, Cloud Break mine, Fortescue Metal**

Post-tensioned slab on grade eliminated footings and was designed and constructed in 3 months.

- **Lot 11, 7 Yanana Street, Port Hedland**

Post-tensioned heavy industrial floor for this industrial shed servicing large trucks.

- **Newvest Apartments, East Perth, Transfer Structure**
- **Emirates Airline Building (181 St. George's Tce), Perth**
- **Southshore Offices, Carpark & Retail, South Perth**
- **Pan Pacific Hotel (now Sheraton), Perth Carpark & additions**

Category Winner, Division 2, MBA Excellence in Construction Awards 2000. This award was earned for the recent refurbishment and expansion of the hotel. Airey Taylor Consulting have been continuously commissioned for the structural design of all stages of this building since its inception in 1969.

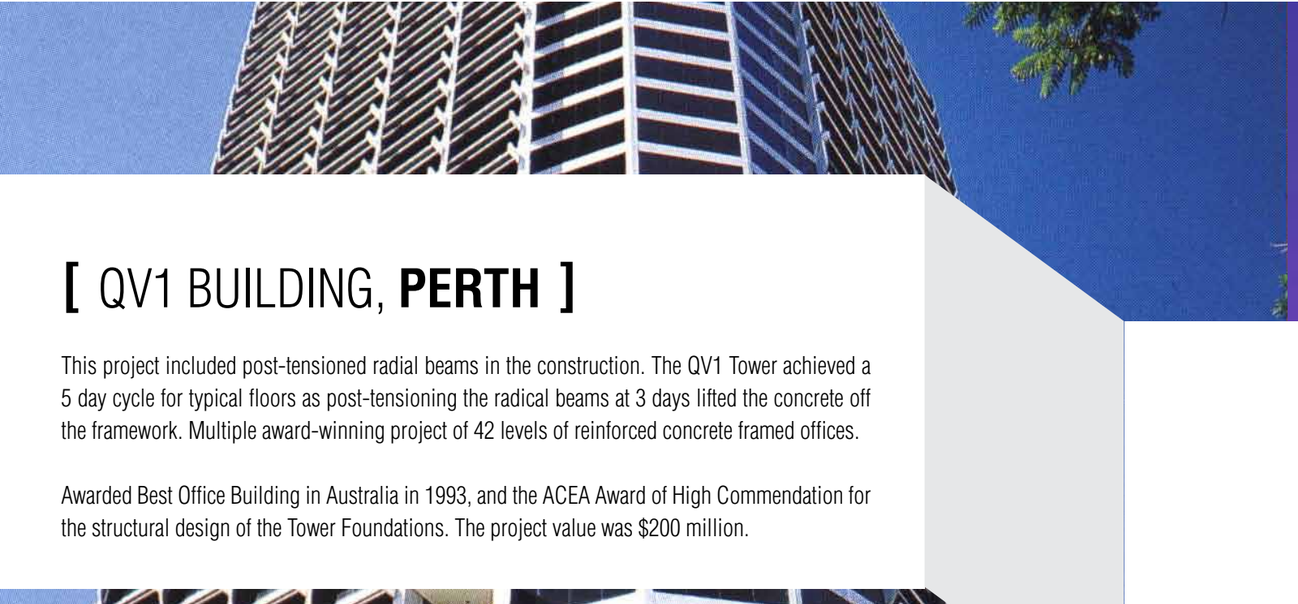
- **Hawker Pacific Hangar, Perth Domestic Airport**

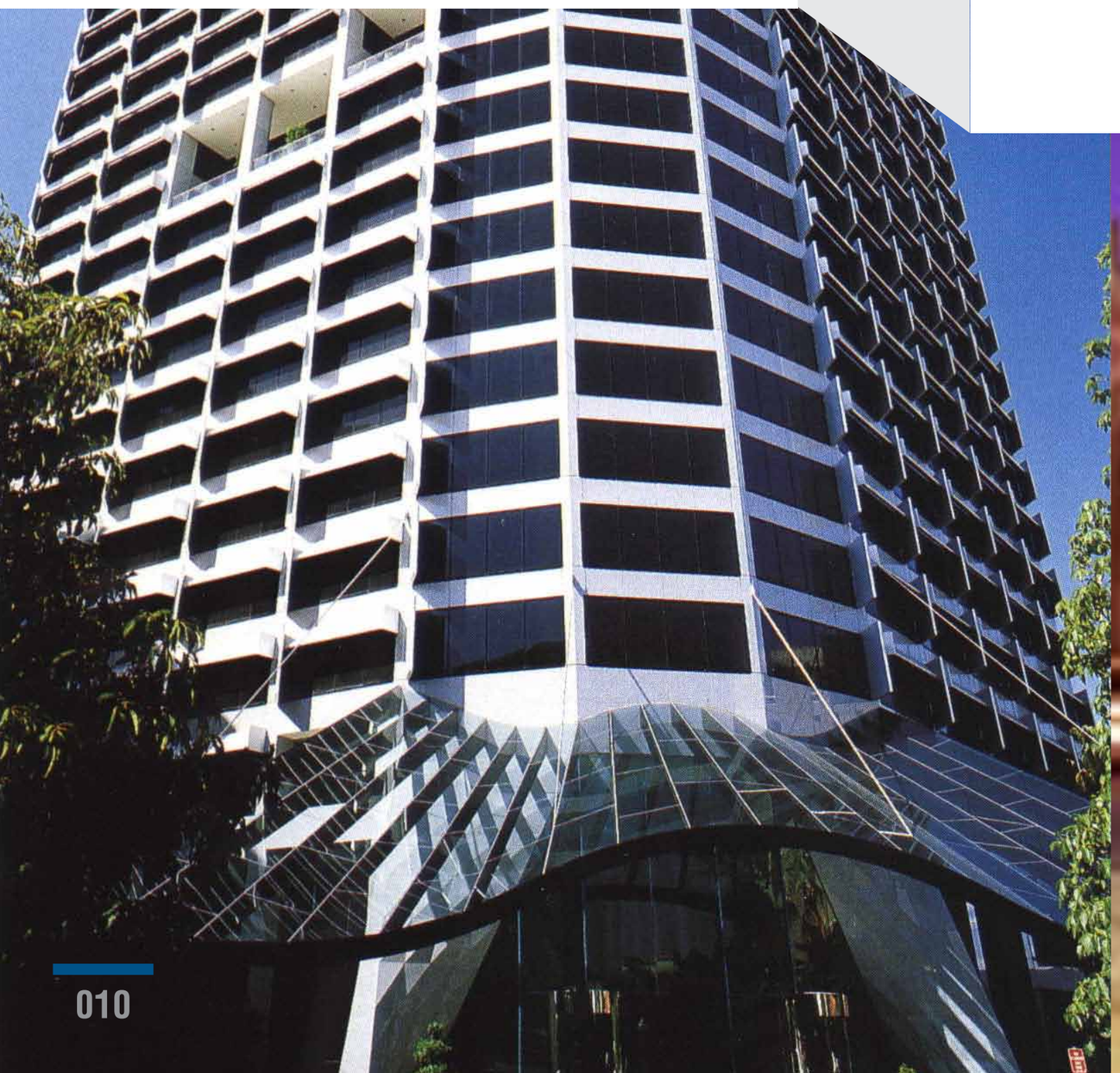
Airey Taylor Consulting won the Master Builders Award for Excellence for 2010 for best Industrial Building under $10 million.

[QV1 BUILDING, **PERTH**]

This project included post-tensioned radial beams in the construction. The QV1 Tower achieved a 5 day cycle for typical floors as post-tensioning the radical beams at 3 days lifted the concrete off the framework. Multiple award-winning project of 42 levels of reinforced concrete framed offices.

Awarded Best Office Building in Australia in 1993, and the ACEA Award of High Commendation for the structural design of the Tower Foundations. The project value was $200 million.





[T.V.W. TELETHON INSTITUTE OF CHILD HEALTH RESEARCH, **SUBIACO**]

ATC designed the structure of this complex building to resolve the structural challenges inherent in the multi-functioning accommodation of administrative, medical, clinical and research elements. The post-tensioned design solution provided great synergies for reticulation of high levels of services, leading to a project that was $1 M under budget (estimate $14.3 million). This building was the recipient for the Master Builders Association award for Best Building in WA Division 4 for 2000.

[THE COLONNADE, **SUBIACO**]

An outstanding example of engineering expertise working in tandem with architectural sensitivity to create an effective retail and commercial resolution within a prevailing architectural ethos. The structure originally designed by others was redesigned and re-documented by Airey Taylor Consulting to achieve outstanding economies using banded Pre-stressed slab construction, an overall saving of $1 million in a budget of $13 million.

This project won Airey Taylor Consulting the Master Builders Award for Best Building in the State in 1996 as well as a Certificate of Commendation.

[ST QUENTIN'S, **CLAREMONT**]

This project comprised of one basement (constructed using top-side down construction), post-tensioned extensions to ground floor including podium and five floors of apartments using AFS walls and pre-cast, pre-stressed planks over this. Airey Taylor were the given a high commendation for this project in the 2011 Awards for Excellence in Concrete by the Concrete Association of Australia for this project.

This building is a showcase of integrated state-of-the-art concrete construction techniques. A challenge for the site was achieving maximum usage of the plot ratio whilst fronting onto one of the major traffic snarls in Perth at a corner of Stirling Highway near two private schools without need for road closure for delivery and operation of construction equipment and materials.

This was addressed by use of top-down construction technique where the post-tensioned ground floor slab is first cast with capability of supporting building loads and truck traffic.

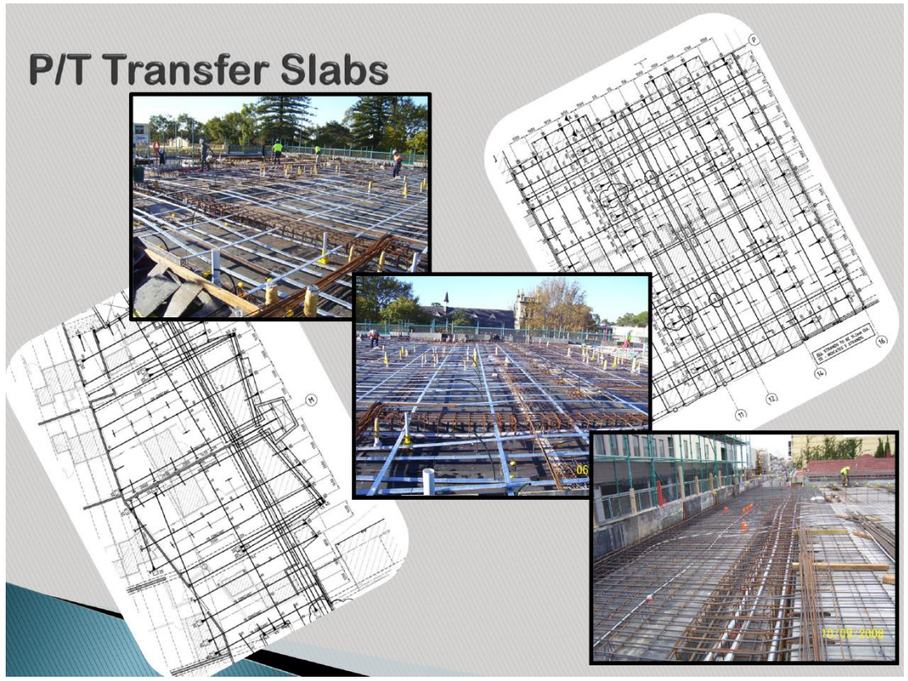
At maximum plot ratio the slab also keeps the site free of dirt and dust and provides the clean surface on which to store building materials. The basement levels are then excavated from around cast in-situ "belpiles" that form the columns of the carpark, whilst at the same time construction of the upper part of the building can commence, saving several months and $500,000 for the client.

The design strategy permitted recourse to use of mobile craneage only obviating the need for on-site tower craneage. Walls were constructed using a proprietary sandwich panel that is composed of a compressed fibre-cement composite panel frame filled with concrete in situ. The process is very clean and results in excellent acoustic and thermal properties for the residents near a busy highway, with a high loadbearing capacity. These panels were extensively used as shear walls and as transfer beams.

The upper floors utilised pre-stressed precast hollow core planks for regular shaped areas and post-tensioned cast in situ concrete for areas with irregular shapes and where load transfer due to misalignment of walls occurs.

[CHRIST CHURCH GRAMMAR SCHOOL COLLABORATIVE LEARNING CENTRE]

As part of the continuous improvement of their campus, the school decided to replace the existing dated facilities at the North West Corner of the campus with a new facility management and extra class rooms at the ground floor with a covered multi-purpose assembly area/ sports courtyard on the first floor. The design by architects Donaldson + Warn called for a suspended weatherproof concrete deck covered with a framed long span steel roof. This was achieved by designing a and fully detailing a band beam post-tensioned floor with a steel deck post-tensioned concrete composite slab. The choice of using permanent steel deck sheeting offered a reduction in construction cost with ease of attachment of mechanical fixtures to the underside of the post-tensioned slab through proprietary groove fixing without the need for drilling through the post-tensioned slab. The project was delivered on time, and below budget, further cementing the relationship between Airey Taylor Consulting and Christ Church Grammar School.



[PANORAMA APARTMENTS CARPARK ROOF, **PERTH**]

This prestigious Perth landmark utilises precast walls & floors for the tower section with a reinforced concrete transfer floor over the car parking level. The car parking floors are post-tensioned insitu concrete and the tower has piled spread footings beneath low rise walk up units.
The structural design conceived and developed by Airey Taylor Consulting (formerly Airey Ryan & Hill) has allowed outstanding rapidity of construction with benefits to the builder and client. Turn-around time per floor by builders Multiplex was 7 days. This represents substantial project cost benefits overall and exemplifies designed constructability offered by ATC in multilevel structures.

The Singaporean Government sponsored a study group to study buildings of excellence in Australia. ATC won the “Golden Chopsticks” award for this project.

[181 ST GEORGE’S TERRACE OFFICE BUILDING WITH CAR PARKING FOR **CAPE BOUVARD**]

Airey Taylor Consulting were commissioned to design the structure for this project by Entact Clough Pty Ltd. This project was originally designed by another engineering practice and re-designed by Airey Taylor Consulting to achieve economies by upgrading the technical response. The overall saving in building cost was 10% due to project synergies achieved by better design. The alternative design provided by ATC saved the value of the neighbouring structure.
Designed by others this was redesigned by ATC to save 10% of global costs.

[12 BELLEVUE TERRACE, **PERTH**]

This 8 storied residential apartment building utilised reinforced concrete slabs on concrete columns and load bearing brickwork above Level 3. The transfer floor at Level 3 was constructed of post-tensioned band beams and reinforced concrete slabs on columns spaced to suit the car park at Level 2. Parts of Levels 1 & 2 are on grade with a section of reinforced concrete suspended slab.

The lift and stair cores have been utilised to provide lateral stability to the building. The building features sloping stone-clad columns front and back and feature balconies. The rear of the building is founded on piles to provide support in the metastable zone of Kings Park escarpment.

Due to the fragile nature of the adjoining Tudor House, precautions were taken to limit the amount of distress to the building including cement grouting under-pinning Tudor House adjacent to the boundary and use of contiguous piling.

[MR SUWAIDI'S APARTMENTS, **UNITED ARAB EMIRATES**]

Airey Taylor Consulting and BW Gulf, Consulting Engineers in Association, designed the structure of a 4 basement, ground, plus office, plus 43 typical floors of apartments, one service floor and two penthouse floors and recreation centre floors for Mr Khalfan Suwaidi of Sharjah, United Arab Emirates.

The superstructure for the building was designed and documented in Sharjah and the substructure comprising ground level and four basements was designed in Perth.

The interaction of the structure and soil was modelled using Finite Element Analysis, which modelled the various load conditions which included lateral loads generated by seismic shock with an acceleration coefficient of 0.15. The site had a high water table and sand soils of increasing stiffness with depth.

The structural design of the ground floor and below was prepared to permit top side down techniques to be used.

The construction technique proposed and the method of analysis used is not common so that a PowerPoint presentation was prepared for presentation to the Sharjah Municipality as part of the approvals process. It is proposed that if acceptable as a paper, the presentation would be augmented. It is suggested that a member of the organising committee may wish to view the presentation and advise whether the subject is considered suitable for inclusion in the conference proceedings.

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