WESTGATE SHOPPING CENTRE SUSPENDED POST-TENSIONED SLAB

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SUMMARY

The Westgate Shopping Centre project is located on a 45,000m2 site between Fred Taylor Drive, Tahi Road and the North Western Motorway in Westgate. The new shopping centre will accommodate approximately 100 specialty stores in 32,000m² of rentable area. Anchored by a Farmers department store and a Countdown supermarket, it will perfectly complement the existing and proposed retail and commercial facilities in the area. The superstructure deck, which will initially act as car parking is an elevated banded-beam-slab post-tensioned in-situ concrete deck. The retail stores are located on grade beneath the superstructure. This paper will focus on the design, construction and the coordination challenges.

INTRODUCTION

The site is situated between Fred Taylor Drive, Tahi Road and the North Western Motorway in Westgate.

The client's desire for clear structural soffit heights, maximum clearance between the ground floor slab and suspended structure, plus a requirement to accommodate future additional levels of retail, made a bonded post tensioned floor slab the obvious solution for the superstructure.

Figure 1: Westgate Shopping Centre

Grouting Services (GSL) was engaged by Dominion Constructors and Fletcher Construction to provide design and construction services for the suspended superstructure.

The post tensioned suspended floor covered a total area of 18,900sq.m and is supported by columns on pad foundations.

The structural solution comprised a series of band beams and 1-way slabs all post-tensioned for economy due to the large spans (typically 8m to 16m).

The high soffit level resulted in Fletcher Construction exploring the use of a permanent soffit formwork system. Comflor was selected as the permanent slab soffit formwork between the beams, a first in New Zealand in combination with post-tensioning and this required great attention and coordination between the design and construction teams.

This innovation was selected to minimise the self-weight and enable the slab formwork to proceed in the most efficient and safe manner.

The slab was constructed in eighteen separate pours divided up over seven discrete seismically separated zones using a total of 5,000m3 of concrete, 110t of post tensioning strand and 400t of reinforcing.

DESIGN SOLUTION

Post-Tensioned Floor Design

Post-tensioned concrete slabs in buildings have many advantages over reinforced concrete slabs and other structural systems.

These include; ability to span larger distances for a given structural depth, reduced level of deflections, early formwork stripping enabling faster construction cycles and quick re-use of formwork, plus, reduced material quantities in concrete and reinforcement.

The most economical and suitable solution was to provide a one-way spanning slab and banded beam. Slabs ranged from 170mm to 235mm in thickness, banded beams ranging from 400mm to 800mm deep and generally 1200mm to 1500mm in width. There were some wider beams up to 7000mm in width which were introduced to deal with eccentric column locations.

Key Design Issues

The design and detailing issues affecting the post-tensioned slab were numerous and resulted in a highly detailed and co-ordinated solution, particularly in relation to the set out of post-tensioning tendons and reinforcement.

The software used to analyze the post tensioned floor system was RAPT and RAM Concept, with several reviews being undertaken to optimise the design for constructability and cost perspectives.

1. <u>Variable Spans</u>

Large slab and beam spans due to column arrangements driven by multiple tenancy requirements. This column arrangement resulted in variable slab and beam spans, with slab spans ranging from 4 to 10m and beams spanning between 8 to 16m.

2. <u>Earthquake and Lateral Considerations</u>

Incorporation of column earthquake moments at each beam-column connection resulted in significant quantities of confinement ligatures. This affected tendon set out, particularly in edge beams where anchors clashed with ligatures.

At each beam-column connection, an allowable design moment of 700kNm was specified by Buller George Turkington and incorporated into the design. A significant amount of effort went into optimising the reinforcing and post-tensioning through these connections for efficient placement.

3. <u>Restricted Tendon Set Out</u>

Incorporation of Comflor into slab design as a permanent soffit formwork resulted in the tendon layout being controlled by the troughs in the Comflor profile in order to achieve cover at low points in the tendon profile. The profile of the Comflor 80 allows for tendon centres in multiples of 300mm and this was the starting point for the longitudinal slab tendon setout – modules of 900mm, 1200mm and 1500mm were adopted.

4. <u>Staged Loading</u>

Staged loading requirements to accommodate future levels of retail provided several complications to the design process. In particular, the impact of this on long term deflections required a detailed study into the time-history load application.

In the short term, the suspended slab was to be used as a car park and this required sloping slabs to facilitate water run-off and collection. In these areas of sloping slab, the beams and slab thicknesses were maintained by having the soffit mimicking the sloped shape. The stage 1 loading parameters were 1.5kPa DL and 2.5kPa LL. The stage 2 loading parameters were 4.5kPa DL and 4.0kPa LL.

5. <u>Corbel and Seismic Joint Requirements</u>

Complex supporting column geometries required supporting corbels to be incorporated into the design to pick up adjoining slabs and beams across seismic joints. The seismic joints were required to be 250mm wide. This also required a waterproofing detail with significant flexibility with respect to movement of the joint.

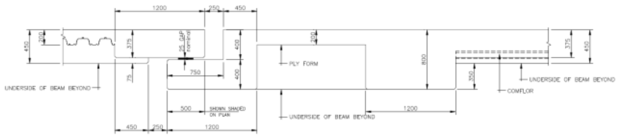

Figure 2: Load Bearing Corbel & Seismic Joint

A flexible waterproofing system (mastic asphalt) was to be installed on top of the post-tensioned slab after a suitable drying period had elapsed. A de-bonding membrane was laid down prior to application of the mastic asphalt.

6. <u>Construction Joints</u>

Casting sequence also meant that construction joints were required in several locations and these were effected with conventional reinforcement across the joint. A proprietary water stop was incorporated to ensure water tightness.

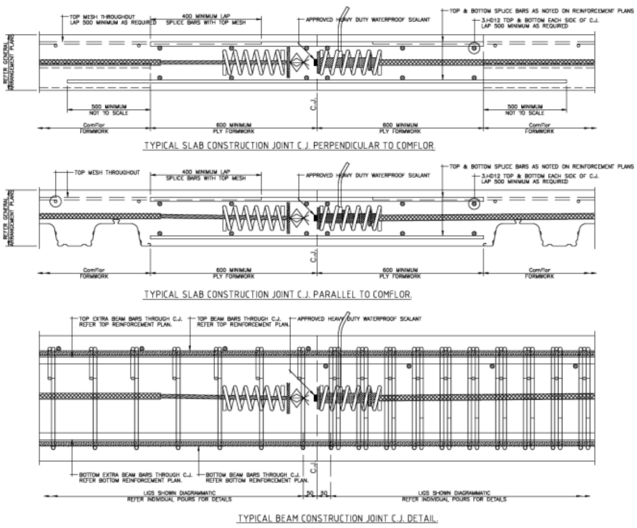

Figure 3: Typical Construction Joint

7. Detailing Issues

Anchorage set out for tendons and cast-in fixings for perimeter steelwork required specific detailing of ligatures in the perimeter beams. In a number of locations, tendon spacings were adjusted to avoid beam / column connections.

8. Crack Control

The level of post-tensioning in the beams and in the spanning direction of the slabs, provides a high level of crack control.

In addition, the fact that the Comflor sheet has been used as soffit formwork, also provides a high level of crack control for the slab soffits.

The transverse post-tensioning was used in the slabs to provide a minimum pre-compression of 0.8MPa in the non-spanning directions.

Minimum slab thicknesses of 170mm were governed by the Comflor profile and the placement of the transverse tendons.

9. Detailed Analysis

The floor system was analysed using both 2-D and 3-D finite element methods. In most cases the finite modelling was used to study deflection sensitive locations in detail.

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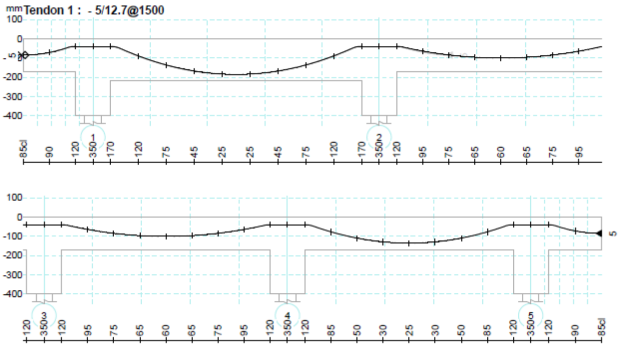

Figure 4: Typical RAPT Tendon Layout

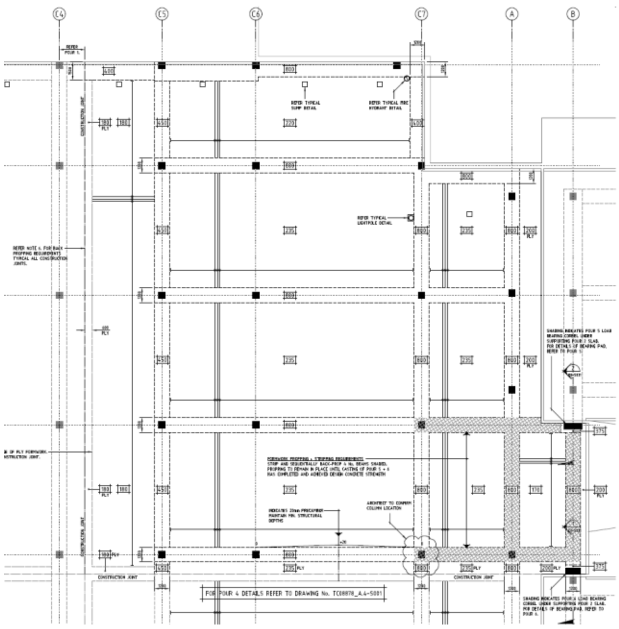

Figure 5: Typical Post-tensioned Floor

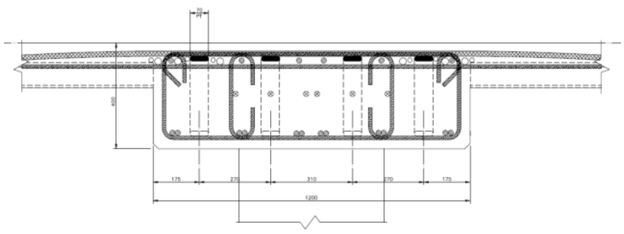

Figure 6: Banded Beam Cross Section

10. <u>Deflections</u>

Deflection control and serviceability was a key requirement and these were to be limited to Span/600.

Modelling was undertaken on a time / history comparison as some of the heavier loadings were not to be applied until sometime in the future after the bulk of the creep shrinkage had taken place.

A finite element analysis on RAM Concept software was carried out to analyse these deflections and in some areas it was identified that deflection control would govern the design. These areas were optimised by introducing local pre-camber into the formwork.

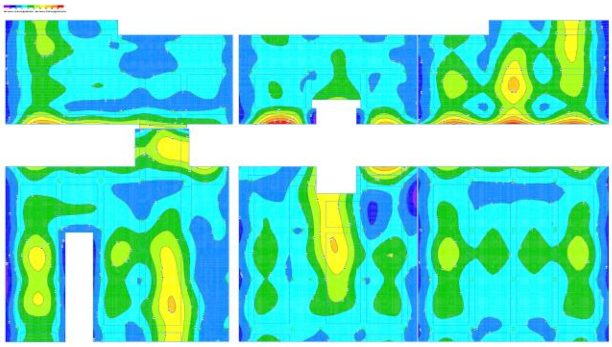

Figure 7: Typical Deflection Plan

11. <u>Restraint</u>

The floor slab system was designed as a bonded post-tensioned floor design. A maximum drying shrinkage of 650microstrain at 56days was specified.

Movement joints were provided at regular intervals by Buller George Turkington and earthquake separation was allowed for at these connections.

Restraint issues play a large role in the detailing of a post tensioned slabs, as the slab needs to be able to elastically shorten during tensioning and creep and shrink after post-tensioning.

This need for the slab to be able to move is at odds with the need for the slab to be laterally restrained. However failure to resolve these problems will result in significant forces occurring at restraint locations and will result in cracking within the slab and overloading the restraining structure.

For this slab the potential restraints came from the supporting in-situ concrete columns, and horizontal interface at concrete corbel connections.

The column restraint was accounted for in the design. To resolve the restraint at the concrete corbel connections, teflon bearing strips were introduced to effectively provide a sliding joint.

CONSTRUCTION

Fletcher Construction was appointed the main contractor.

The principal subcontractors engaged on the job were Dominion Constructors (Constructor), Acrow (Propping and Doka Formwork) Grouting Services (post-tensioning), Steel and Tube (reinforcement) and Russell Gordon Concrete (concrete placing).

Firth concrete was used to supply the concrete while Aotea Pumps and Ian Howe Concrete Pumps were engaged to carry out the concrete pumping.

Figure 8: Doka Formwork System

Formwork

The post-tensioned slab was broken up into eighteen separate pours.

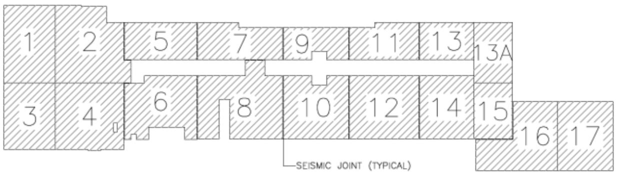

Figure 9: Pour Layout

The high floor to ceiling depth of 5m dictated that a proprietary formwork system for the beams would be a suitable method of supporting the suspended beams and the Dokamatic Table Formwork System was selected.

The integration of the permanent slab soffit metal formwork (Comflor) worked well with the Doka System and minimised on site labour and propping requirements.

A total of 3,500sq.m of Doka formwork was used which was enough to set up work on 3 pours at once. Additional formwork resource was provided in the form of conventional formply on shore load. The complexity of working 5m above the ground platform was reflected in the time frame to prepare each slab which ranged between 2 and 3 weeks.

Seismic bracing was incorporated into the formwork system and uplift was restrained with the use of mechanical anchors.

Figure 10: Multiple Work Faces

Accurate placement of the Comflor sheets was critical to ensure post-tensioning strands could be installed in the Comflor troughs in their design locations and this required detailed shop drawing preparation and review.

Pour sequencing was optimised to ensure full access to slab edges was available and an 800mm access strip was supplied around the slab perimeter to facilitate the strand installation and stressing operations. Pour sizes ranged from 650sq.m to 1450sq.m.

A working crew of up to 40 men per slab was used to carry out the formwork and reinforcing operations.

Figure 11: Comflor Permanent Soffit Formwork

The advantage of having a post-tensioned solution meant early and easy stripping (due to balancing of concrete self-weight) and limited back propping.

Post-tensioning & Conventional Reinforcement

The order in which the post-tensioning strand and reinforcement is installed is critical due to the profiled alignments of the post-tensioned tendons and the phrase “PT takes priority” was adopted by the site team to ensure a reasonable continuity was maintained between respective trades.

Once the formwork was erected and edge boards installed with pre-formed slots for the strand, the post-tensioning anchorages were bolted in place. The reinforcing steel installation commenced at the same time with a primary focus being the bottom mat to the beams and slab.

It was imperative that stock material placement on the formed deck was well planned and co-ordinated to ensure the duct installation could proceed in both directions. After the duct was placed and taped, the strand for the beam tendons were installed and this was followed by the strand for the slab tendons.


Figure 12: Post-tensioning & Reinforcement

Once the strand had been installed, the top mat of reinforcing steel was placed, and, during this time, the grout tubes, sealing of the ducts and final tendon profiling was undertaken.

Where access to the perimeter of the slab was not possible, pans were used within the body of the slab to enable the stressing operations to take place.

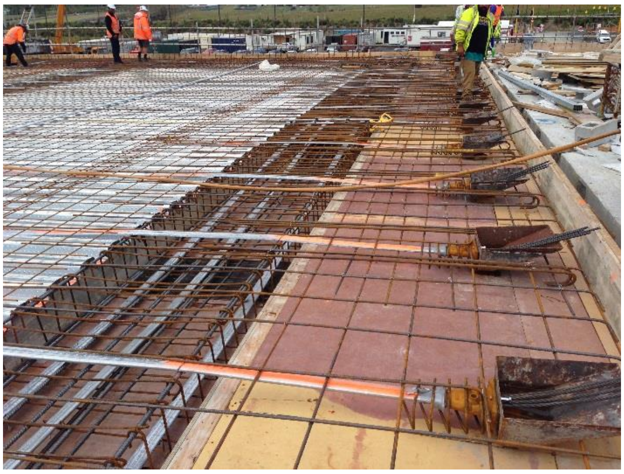
Figure 13: Stressing Pans

The installation cycle of the slab was governed by the formwork with the installation of the reinforcement and post-tensioning for each pour was completed over a 1.5 week period for each slab with a combined workforce of 20 men (6 from the post-tensioning crew and 14 from the reinforcing crew).


Figure 14: Post-tensioning & Reinforcement

Concrete

The post-tensioned slab was broken up into eighteen separate pours, with pour sizes ranging from 150m3 to 500m3.

The scale of the project and large volume of each pour presented a challenge for the concrete supplier and placer.


Figure 15: Corbel & Seismic Joint

The concrete was generally dispatched from the local Henderson Plant and trucks were occasionally drawn from the Albany Plant to ensure consistent delivery.

Concreting started at mid-night on each pour and a working crew of 20 men was employed in the concrete placing/finishing and post-tensioning/supervision operations.

Dominion engaged Aotea Pumps and Ian Howe Concrete Pumps for concrete pumping and this ensured adequate backup pumps were available on site.

Consistent delivery of concrete to the face is critical and thanks to a great team effort, a respectable delivery / placement rate of over 75m3 per hour was consistently achieved.

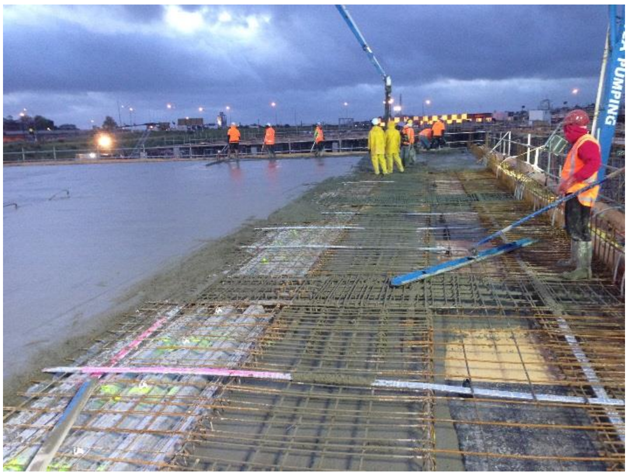

Figure 16: Concrete Pumping & Placing

Once each floor was poured, an initial stress was applied when the concrete strength reached 7MPa. The floor was fully stressed once the concrete reached 22MPa.

Back propping was required at both construction joint and concrete corbel locations.

Grouting of the post-tensioned duct was completed after approvals had been obtained for the site measured extensions recorded during tensioning.

A grout mix design was developed that provided 0% bleed and a compressive strength of 70MPa at 7days.

The slab surface achieved an FM2 finish by way of free screeding.

After completion of the post-tensioned slabs, the precast concrete exterior panels were installed followed by the structural steel erection.


Figure 17: Stripped Floor Soffit

Lessons Learned

The success of the post-tensioned concrete slab at Westgate was very much the result of a team effort from all those involved.

As with all projects there are things that do not go according to plan. Fortunately in this project there were only a few due to a high level of pre-planning and coordination between designers, detailers and the various site based subcontractors, and these were;

Significant effort and extra time required to install reinforcement and post-tensioning duct and strand into deep beams (deeper than 500mm).

Possible future solution – prefabrication of reinforcement cages with ducting installed (even pre-casting of edges).

Managing the congestion at beam-column joints. Possible better solution – less column frame requirement and less generic requirement.

Managing access at height for under-soffit stressing operations. Possible better solution – more use of stressing pans.

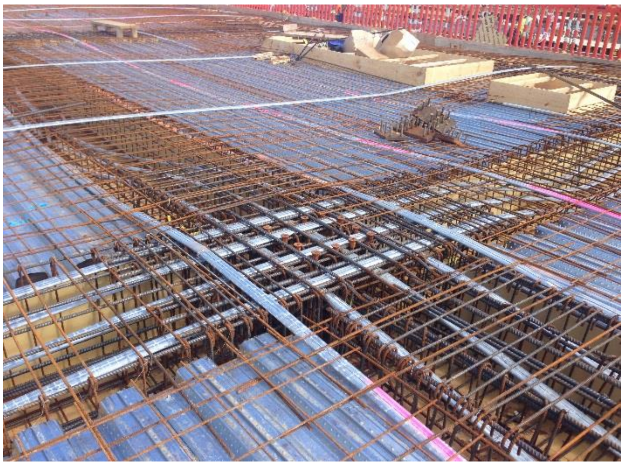

Figure 18: Beam-column Joint Congestion

SUMMARY

The project is due for handover in late 2015 and has kick started the transformation of the northwest region of Auckland.

The suspended post-tensioned concrete structure is economical when compared to its composite reinforced and precast equivalents. The New Zealand construction market is embracing this method of in-situ construction with several recent buildings and suspended car-parks being completed in a similar manner. The success of this project also shows that where conventional sacrificial soffit formwork is expensive or impractical then post-tensioning can be used with deep profiled composite floor decking systems.

REFERENCES

[1] www.edgece.com
[2] www.groutingservices.co.nz

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