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OTAHUHU BUS TRAIN INTERCHANGE, AUCKLAND

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SUMMARY

The Otahuhu Station is a new, fully integrated bus train station that will provide better connectivity between bus and rail networks and more frequent public transport services. The new facility incorporates the existing train platform with two new bus platforms and a terminal building via an elevated concourse.

Two prestressed concrete bridge structures form part of the station construction; a new concourse structure spanning over the bus platforms to the train platform and modification of the existing Titi St Footbridge.

The paper will present the background to the project, design of the concrete structures and challenges and efficiencies encountered throughout construction of the project around live rail.

BACKGROUND

Auckland Transport recently proposed a future public transport network structure to provide a simpler, better connected and more attractive network. The proposal placed more importance on transfers between bus and train in strategic locations. This would be a transformational shift in order to achieve the Auckland Plan’s vision of becoming the world’s most liveable city.

Currently there are limited interchange opportunities around the network, but Auckland Transport has identified Otahuhu as a key interchange location between bus and the rail network in South Auckland. It will be the convergence point for high frequency rail and bus services. The proposed bus train interchange can support a reallocation of bus resources to provide better frequency within the local area, resulting in increases in patronage across the network.

In 2014, Auckland Transport decided to deliver the project using the traditional procurement route, appointing Aurecon and Jasmax to design the new station. The main construction contract was awarded to Downer and commenced in late 2015, with an expected completion date in late 2016.

PROJECT REQUIREMENTS

Site description

The existing Otahuhu Train Station is located on the North Island Main Trunk Line (NIMT), on the west side of Walmsley Road. A site location plan is presented in Figure 1 below.

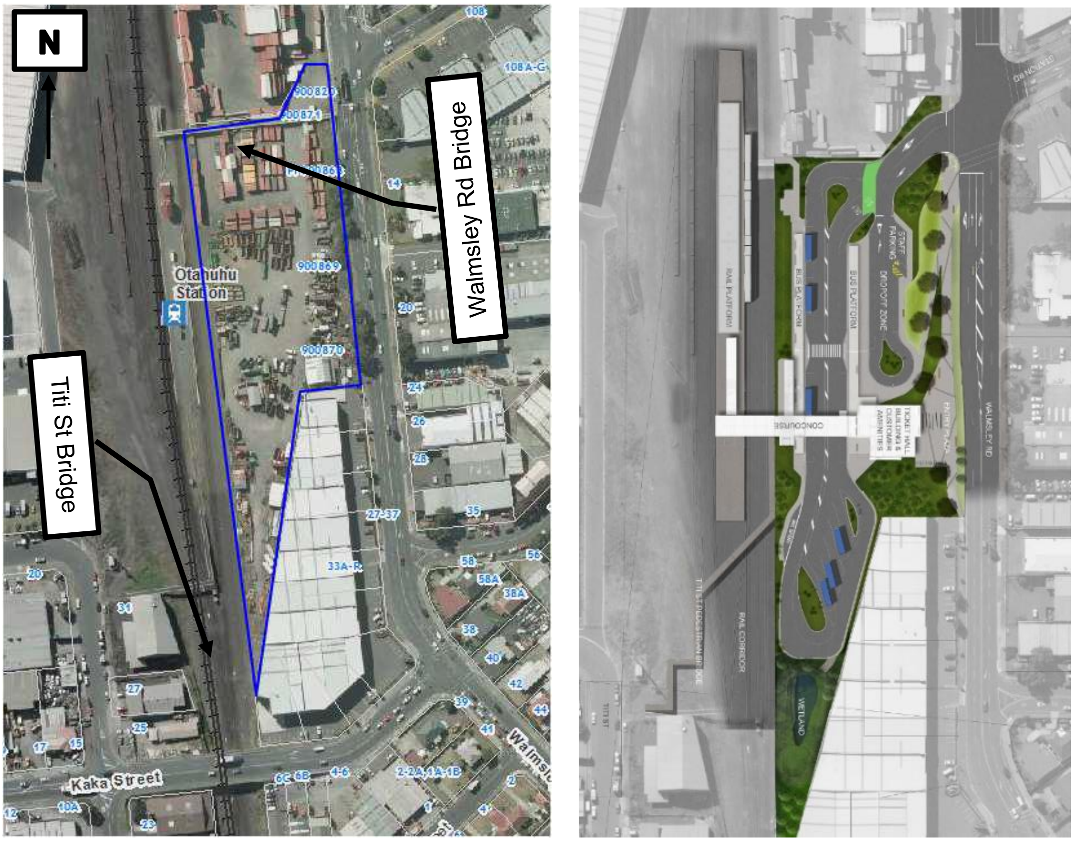
The site for the Project is surrounded by Walmsley Road to the east, Kaka Street to the south, Titi Street to the west and Railway Lane to the north. Westfield Station is further north on the NIMT and Middlemore Station to the south. The site is relatively flat, with the Walmsley Road frontage rising up to road level.

The area over which the Interchange is to be located is more or less rectangular in shape and parallels the NIMT. A triangular portion of the site extends to the south.

Vehicle access is located in the north east corner of the site. An existing pedestrian bridge extends from the NIMT platform to this corner and ramps down to Walmsley Road. Vehicle access continues beneath this bridge.

The existing rail platform is an island configuration serving commuter trains in both north and south directions. Located centrally on the platform is the two storey railway signal box building. A second pedestrian bridge extends from Titi Street in the south west, across the NIMT to the centre of the existing rail platform.

The site is owned by New Zealand Rail Corporation (NZRC). KiwiRail lease the site from NZRC under a “core” lease agreement and the site is tenanted by CSL Containers and used as a container yard.



(a) (b)

Figure 1: (a) Site location (source Auckland Council Maps), (b) Proposed new station layout

The majority of the site is underlain by nominal fill (up to 1 m) overlying alluvium and ash. Basaltic ash/lapilli and alluvium comprising clays and silts were encountered to varying depths up to 3.5m bgl. Shear strengths vary but generally decrease with depth. Below the cohesive alluvium, peat deposits extend to approximately 11 m below ground level, exhibiting very low shear strength typically <15 kPa.

The proposed new station layout, as shown in Fi.1b and Fig.2, involved removing the storage yard making space for a new bus interchange and a terminal building. Due to the high predicted rail patronage, the existing Walmsley footbridge access was no longer adequate and a bigger access was required. An elevated concourse structure would connect the existing train platform with the two new bus platforms and the terminal building. The existing Titi street would be diverted to connect to the new concourse, unifying the entrance into the train platform.

The new station would need allowance for the future CRL line and platform, to be placed next to the existing southbound line and Titi street bridge. This line would be required to reap the full benefit of the CRL project, opening a new commuter service from Henderson to Otahuhu.

Figure 2: Aerial overview of the new station and concourse

<u>Structure requirements and constraints</u>

The concourse was to meet the following requirements and constraints:

- Provide access across the bus interchange and two rail lines (one existing and one future CRL) to the existing train platform
- Incorporate a roof structure
- Vertical clearance for the new double decker buses, and the electrified rail lines.
- Horizontal clearance of the piers to rail lines
- Constructability, difficult access within the electrified rail corridor.
- Rail collision loading onto the pier at train platform.

The realigned Titi bridge was to meet the following requirements and constraints:

- Half of the bridge to be demolished within electrified rail corridor
- Reuse of existing headstock with extensive modification for realignment
- Rail collision load on the new bridge piers.

CONCEPTUAL DESIGN

The key theme of the urban design and architectural was identified as portage between the two bodies of water: Tamaki River and Manukau Harbour. As a result, the concourse concept features striking visual presence of a floating waka, with V shape timber roof truss as shown in Fig 3.

The concourse was to be serviced by sets of escalators on one side and lifts on the other side, at the bus and train platforms. As a logical choice, piers supporting concourse structure were designated at the same positions, resulting in spans of 24m and 26m. The ends of the concourse featured viewing platforms with a lookout to the river and harbour. The viewing platforms created up to 6m cantilevers from the piers location. The concourse width was proposed to be 12m wide, in order to accommodate internal lift shafts and provide enough width to avoid over crowded at peak hours.

Figure 3: Artist impression of the concourse concept

A structural form with minimum depth that can be quickly erected over rail corridor, and requires the least maintenance, was desired. A precast prestressed hollowcore bridge girder was considered to fit this criteria. The girders would be placed side by side, and connected together by an insitu slab. They would be made integral with the substructure, eliminating joints and bearings. The rectangular cross section of the girders also fitted well with the proposed escalator.

In order to provide high visibility between bus and train platforms and easier passenger flow, and achieve the illusion of a floating concourse structure, half of the structure width was proposed to be supported on a cantilever headstock and eccentric pier. In addition, the escalators were proposed to span between platforms to the concourse, without intermediate supports, to enhance the openness of the floating structure. The headstock cantilevers were therefore under significant vertical loads, and required a lot of structural depth themselves.

The concept design was later modified significantly with the aim of bringing more value for Auckland Transport, and to meet the revised budget. The lifts were relocated outside of the concourse, reducing the width of the concourse to 8m, just sufficient for the predicted passenger flows. The escalators were also replaced with precast stairs. However, provision for escalators to be fitted in future was still required.

DETAILED DESIGN AND ANALYSIS

Design of the concourse was in accordance with NZS1170, supplemented by the NZTA Bridge Manual. General arrangement drawings for reference are included in the appendix. The key design challenges were:

- Hollowcore girders integral connection
- Concourse cantilever end spans
- Pier headstocks cantilevers and deflection limit
- Rail collision
- Earthquake design with liquefaction potential

<u>Concourse structure</u>

The concourse structure consisted of precast prestressed hollowcore 900mm deep bridge girders, making up an 8m wide deck and total length of 58m. An in situ concrete topping slab connected the girders together and formed the final deck surface. The insitu topping slab was 300mm thick to allow the installation of services ducts to the smart gates on the concourse.

The width of the structure is governed by predicted passenger flows throughout the design life of the structure. Gate line widths and passenger flow rates were used to calculate how many gates would be needed to clear a train’s worth of passengers in suitable time to determine required concourse width. This was then adjusted to suit manufacturing widths of the precast girders to ensure a custom product wasn’t required to save both time and cost.

The precast girders were made integral with the piers allowing the end spans to cantilever over the platforms. The girders were designed to resist selfweight and insitu concrete topping as a simply supported span, but continuous for live loads. Live load analysis considered patch loading over the continuous spans and eccentricity across the deck. A full 5kPa was adopted without applying loaded area reduction factor, due to potential congregation of passengers. Secondary effect due to concrete creep and shrinkage was considered and found could significant influence the design moments in girders.

The integral connection had the additional benefit of distributing collision load and earthquake loads along the concourse. However, these load cases created a significant sagging moment at the girder face where connecting with the integral pier. In order to resist this action, the prestressing strands were detailed to extend from the girder face, to be casted into the pier headstock.

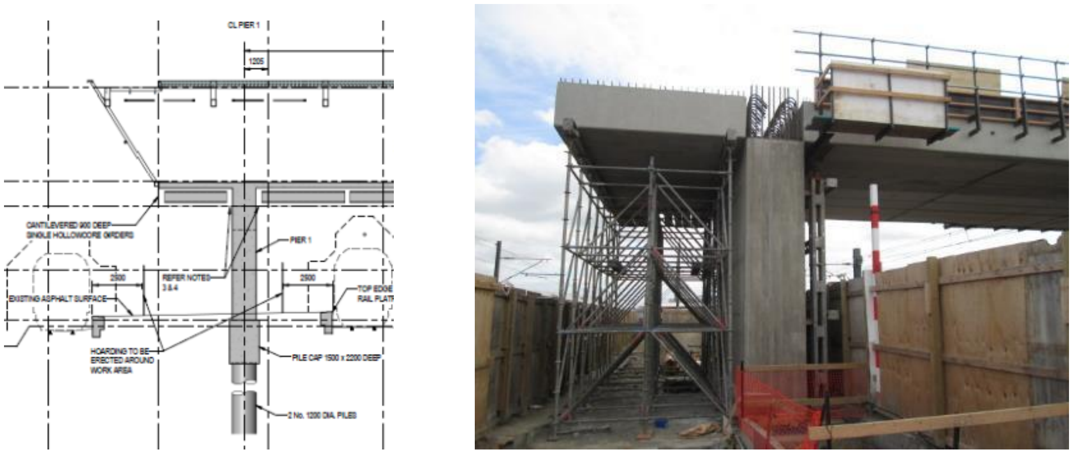


Figure 4: The end pier at train platform, note the tight working area behind hoarding.

The location of the pier on existing train platform was carefully chosen to fit in the construction requirement close to rail line. The pier would have to be offset from the centre of the platform, so that a lift could be placed next to the pier. This requirement, coupled with clearance from the train, leaved not much room to position the pier, as shown in Fig. 4.

The cantilever end spans of the concourse were designed as short segments of the hollowcore girders, temporary supported on falsework until made integral with the pier by constructing the diaphragm and in situ concrete topping, refer Fig.4. The segments were nominally prestressed to resist sagging moment during beam lift temporary support stage. But the final hogging moment is all resisted by the passive reinforcement in the concrete topping.

Making the girders integral with the pier headstock also helped to increase effective structural depth of the cantilevered headstock, reduce reinforcement requirement. Furthermore the increased headstock depth was beneficial with keeping deflection at the tip of the cantilever within allowable limit. The tip of the headstock would be support for the escalator, which had an allowable deflection of 5mm for operational requirement.

The headstock is supported on a blade wall pier 4m wide by 1.2m thick, offset from the centreline of the concourse deck, and supported on pile foundation, due to soft ground. The blade wall at the train platform was designed with allowance for rail collision load to be applied either direction.

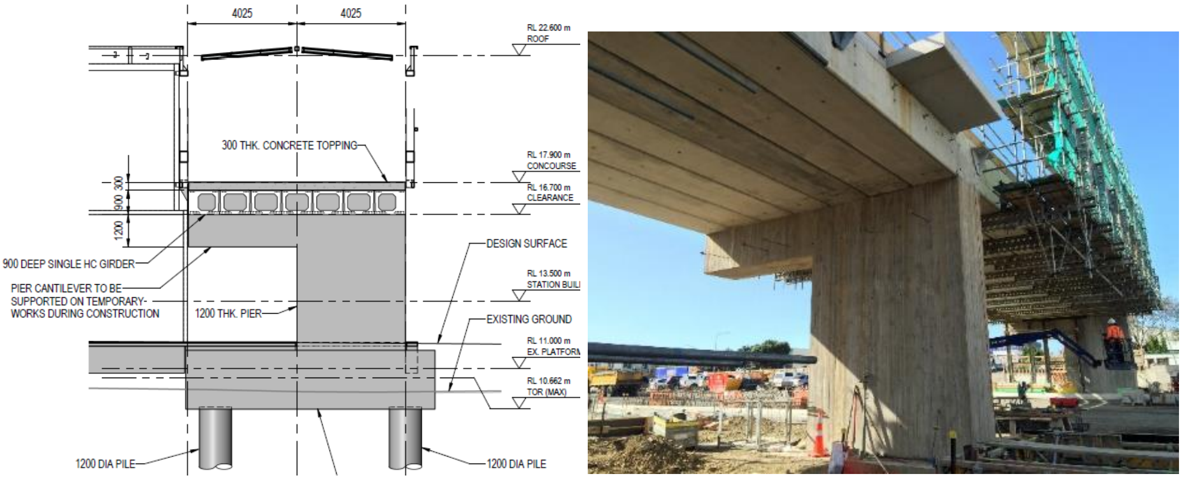


Figure 5: Typical pier arrangment

<u>Movement joints</u>

Adjacent to the concourse is the Ticket Hall/Amenities building, which is a large open space approximately 8m high connecting the concourse with Walmsley Road. It also houses back of house facilities for Auckland Transport and ticketing areas. The building structure comprises steel portal frames on top of a suspended slab which is supported on a network of ground beams and steel driven piles. The vastly different nature of the two adjacent structures required that they were seismically separated.

The form of the overall structure from an architectural point of view did not provide a straightforward place to accommodate a movement joint so the joint is split at various levels. The ideal movement joint location to suit the architectural form was where the cantilever hollowcore girders meets the pier. This obviously could not be done, so the roof structure over the concourse is supported on brackets fixed to the concourse which allow horizontal movement in all directions.

At ground level, the slab is suspended as a risk mitigation factor to design for the predicted settlements of the site over the 100 year design life. This slab again has a complex movement joint whereby one side is tied to the Ticket Hall structure and the other is allowed to slide to avoid any of the Ticket Hall building load being transferred to the concourse piles and vice versa.

Titi street footbridge

The existing Titi St Footbridge connection was to be partially demolished and realigned to connect to the new concourse. The modifications to the bridge consisted of a new span over the existing rail and future City Rail Link tracks. The new span of precast prestressed I-girders was adopted, similar to the existing main span.

For the spans next to the concourse, the same hollowcore girders with topping slab was adopted. To avoid putting a bridge pier too closed to the concourse, the last span was designed as a cantilever, similar to the concourse structure.

The new pier would be within 5m from the future CRL tracks, so collision load had to be considered. All of the hollowcore spans were made integral with the pier, and would distribute the load along the bridge instead of a single pier.

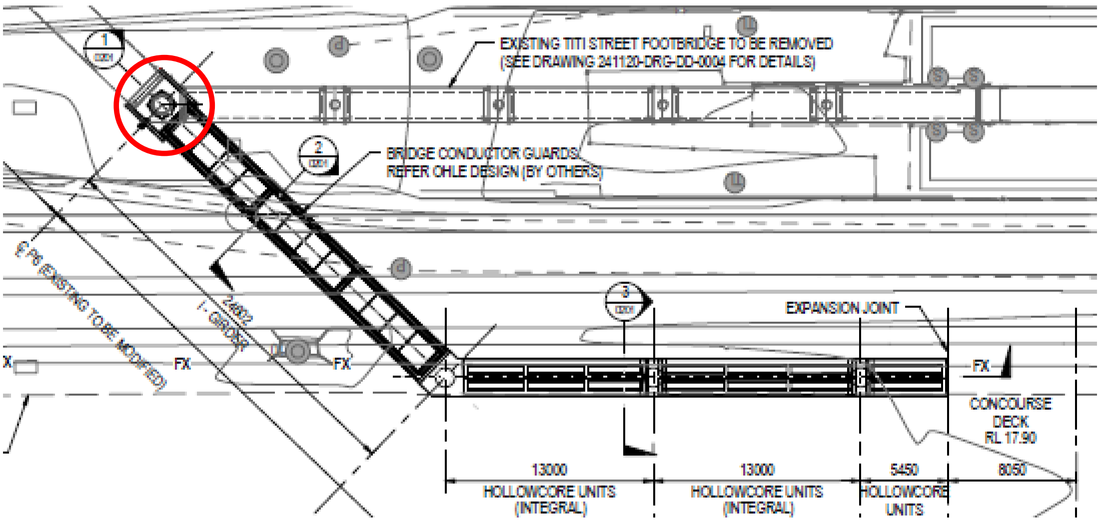


Figure 6: Titi St bridge plan, note the existing pier circled in red to be modified.

The existing angled pier head was to be straightened. This required partial demolition to expose reinforcement, and coupled with new reinforcement to form a new shape. Ancon MBT couplers, a type of lockshear bolts coupler, was adopted, to avoid welding of reinforcement on site.

Seismic design

The lateral load resisting system of the structures is provided by the diaphragm action of the in-situ slab to transfer lateral loading of the concourse deck and roof structure to the blade piers. Cantilevered actions of the pier transfer moments, shears and axial loading into the piles which are resisted by deformation of the soil. In addition, the eccentricity from the centre the concourse deck to the centre of the blade piers creates torsion and additional moments and shear loading into the piles.

For this type of structural arrangement the NZTA BM allows plastic hinges to form in the piles with a maximum ductility factor of $\mu = 3$. In this case a more robust solution was adopted and the structure designed to be nominally ductile with $\mu = 1.25$. Although the structure will essentially remain elastic under the design seismic event it was considered prudent to meet the design provisions and detailing requirements for a ductile structure to prevent collapse under MCE. Capacity design principles were adopted, the blade piers and the superstructure were designed for the over-strength capacity of the piles.

A 3D dynamic model of the concourse structure was created in which the stiffness and mass distribution was modelled to accurately represent the structural system. Modal analysis was conducted in the principal longitudinal and transverse directions of the concourse structure. The number of modes included in the analysis was selected to achieve a minimum 90% mass participation in both orthogonal directions. The individual modal analyses were combined using the 100% and 30% orthogonal contribution. Accidental eccentricity was added to the results of the modal analysis.

Liquefaction analysis of the soil layers were conducted using the CPT data obtained from the ground investigation and it was considered there is potential for liquefaction to occur up to 14m below ground during a design seismic event.

Cases considered in the seismic analysis were:

- Cyclic analysis without liquefaction – structure inertial loads that would occur without liquefaction,
- Cyclic liquefaction analysis – structure inertial loads that would occur accounting for stiffness and strength degradation of the soil. In addition, inertia loads of the top non-liquefiable crust were applied concurrently.

While the piles were detailed to form a hinge in the assumed liquefaction case, they were overdesigned in the case of no liquefaction, and as a result, the overstrength factor was higher than 1.5, i.e. more than MCE actions. The smaller of the overstrength factor or 1.5 was adopted for designing of the structure.

CONSTRUCTION

There were several challenges which were encountered during construction.

One of the piers had to be constructed in a live rail corridor which meant sequencing of works became very important. The piling for the pier had to be done at a Christmas/New Year block of line where there was 2 weeks of unrestricted access to the rail corridor. The piling rigs would have bene too closed to live electrified lines, and works were allowed only during this block of line period when the lines were turned off.

Figure 7: Piling during enable work, note the proximity to the overhead electrified lines.

The complex issue came that these piles needed to be installed before the design of the concourse was complete as the Building Consent was not able to be submitted until the following June. The piles were designed for some excess capacity due to the concourse and remaining structures on site only being at a preliminary design phase when the piles were installed. As it turned out, one of the lift shafts had to be tied to the piles and that excess capacity quickly got became utilised.

Due to timing of the works, delivery and installation of the girders became a headache. The governing factor was the transportation limitations around transporting oversized loads during the summer holiday period. As such, all girders required on site by February needed to be on site before Christmas. With the contract being signed in late October that did not leave much time. Shop drawings were fast tracked with turn-around from Aurecon within 24 hours in some circumstances, all so that the girders could meet programme. They were steam cured at the HEB precast yard in Mt Maunganui to again ensure tight timeframes were met. Several inspections were constructed at the precast yard, however the fast tracked construction had not had a detrimental effect on the quality.

The girders were delivered on time and were able to be installed during the available block of lines, being craned in place as one large span over the rail corridor. At approximately 26 tonnes per girder, consideration had to be given to where the crane could be stationed. Soft underlying soil limited crane size, so it had to be fairly close to the location of the concourse.

The cantilever girders created a challenge due to the large amount of reinforcing steel required in the topping. With stairs needing to tie into this landing, it took quite an effort to get everything to fit in together. To mitigate against any risk of voids, a smaller aggregate was used in the topping slab than initially specified (13mm as opposed to the initially specified 19mm). The careful curing and close analysis of the mix design ensured there were no adverse effects of this change both structurally and architecturally.

CONCLUSION

Otahuhu station is a new integrated bus train interchange that will provide better frequency within the local area, resulting in increases in patronage across the network. The elevated concourse structure, featuring cantilever end spans and headstocks, is a robust solution with extensive use of precast girders made integral.

APPENDIX

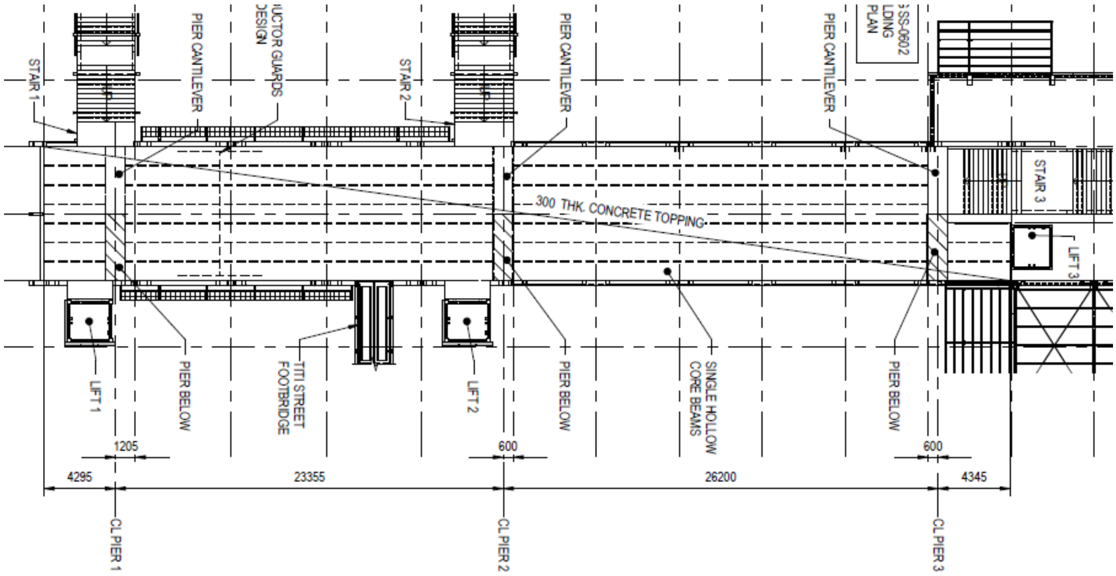


Figure 8: Concourse - Plan

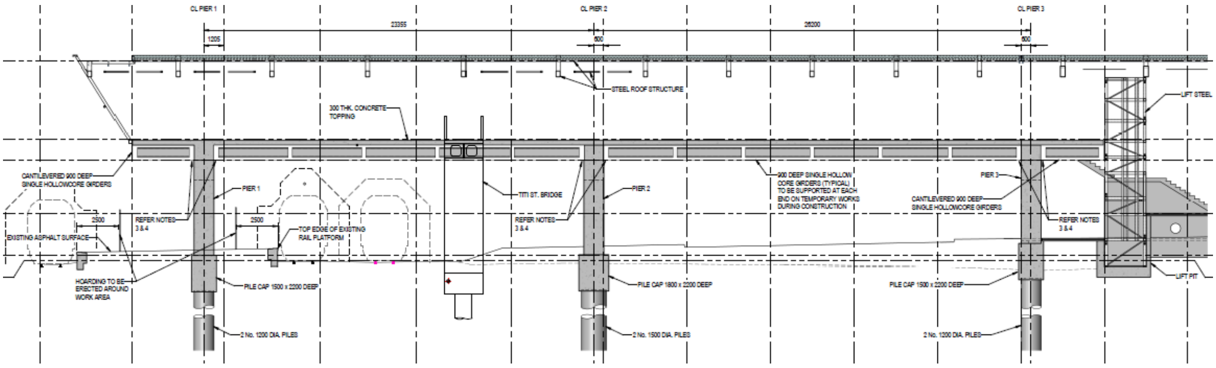


Figure 9: Concourse – Long section