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THE DELIVERY OF THE NEW CHRISTCHURCH BUS INTERCHANGE

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ABSTRACT

The new Christchurch Bus Interchange is the New Zealand Government anchor project 19. Its program, design and delivery were highly focused on creating a place for pedestrians, buses and retail which forms a central terminus of the newly rebuilt central city.

The CERA led anchor project has placed this new facility on the critical path for the city's recovery. From its initial conceptual design in January 2014, to its fast track tender in May 2014, through to its completion in August 2015, the project has exceeded all manner of local and national norms for construction.

The resulting building is an exemplar Civic asset which will enhance Christchurch public transport and it will increase the access and engagement to the new central business district.

Structural steel was the enabler of the structural form needed to create this civic space, while also accomplishing the architectural vision. The author delves into some of the design, detailing decisions and architectural challenges that the use of structural steel helped overcome. This paper outlines the fast track design and documentation process, key decisions and process adopted enroute which contributed to its success. This project provides clients and consultants a clear view of the benefits of industry collaboration and a look into the future of building procurement, highlighting the benefits and challenges overcome in its delivery.

Introduction

Architectus and Aurecon were appointed to design and document the New Christchurch Bus Interchange following the business case feasibility. The site is located in central Christchurch, on the old Christchurch City Council Civic office site, and its design intent is to serve as a central hub to interlink bus movements within the network. The New Christchurch Bus Interchange is designed to accommodate up to 96 bus movements per hour with arrival and departures bays for sixteen buses.

The project was undertaken as a Design and Build contract with the design team novated to Southbase and Theiss Joint Venture (TSB) for the completion of the detailed design and construction.
The design commenced in January 2014 and the design team was novated to the design build contractor TSB in June 2014.

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Table 1: Christchurch Bus Interchange Project Details

Project Value	*Circa $ 53 Million NZD*
End User client	Christchurch City Council (CCC) and Environment Canterbury Regional Council (ECAN)
Tenant	Environment Canterbury Regional Council (ECAN)
Developer	Canterbury Earthquake Recovery Authority (CERA)
Contractor	Southbase & Theiss JV
Project Architect	Architectus (Aurecon's Client)
Engineer	Aurecon all engineering services including Structural
Steel Fabricator	John Jones Steel New Zealand

The project is the first of the Canterbury Earthquake Recovery Authority (CERA) led anchor projects and was completed in August 2015.

Client Brief

Building Brief

The new Christchurch Bus Interchange building is a single storey L shaped building, constructed as two seismically separated buildings, known as Lichfield and Colombo buildings which corresponds to the adjacent streets.

The Lichfield Building is a rectangular shaped building along the Lichfield Street frontage with the potential for a future three storey development over following demolition of the current building.

The Colombo Building is approximately rectangular in shape with a feature architectural roof. The area at the corner of Colombo and Lichfield Streets, the Main Entrance Corner, is a single storey structure with a vaulted cantilever roof to accentuate the building's main entrance.

The buildings are constructed on shallow foundations over competent gravels. The foundations of the Lichfield building were future proofed to allow them to receive a future three storey building.

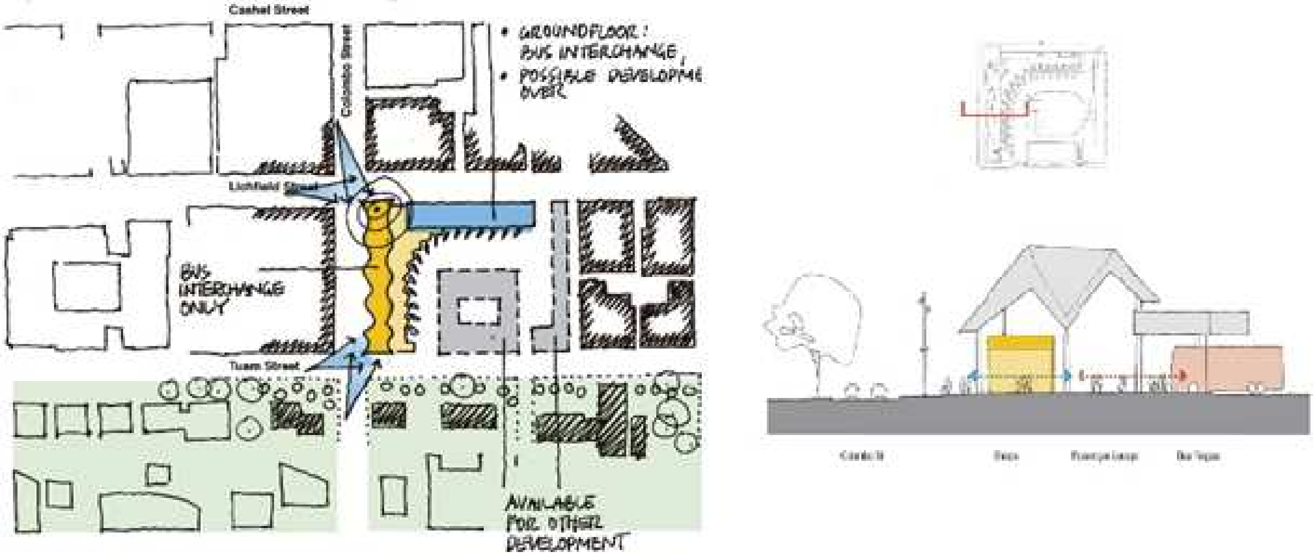

Figure 1: Site Strategy Summary, left image, and Architectural Concept showing a section through the Colombo Building, right image (images courtesy of Architectus)

The Colombo Building consists of a complex 3 dimensional structural steel roof frame that provides a front entry which cantilevers in excess of 17m, providing an overwhelming sense of height and space, and civic amenity. The columns range in length from 5 to 11m all of which typically deliver frame action. After initially exploring resilient structural design options, the client adopted a more cost effective steel moment frame of traditional design without diagonal braces interfering with views or use.

The complex roof structure incorporates a 3 dimensional seismic bracing frame set within the confined architectural envelope. A vaulted inverted M roof shape is adopted to provide volume and space, whilst also providing support for the upper roof substrate.

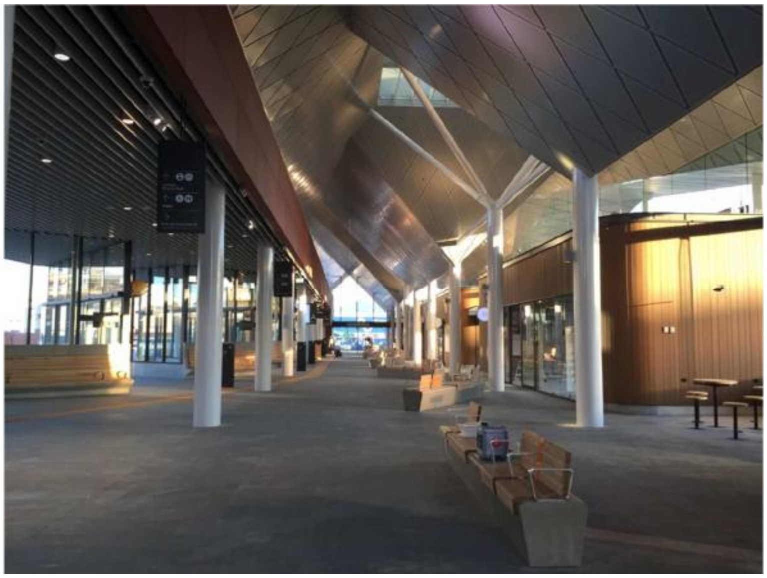

Figure 2: Image showing the Colombo building soffit which consists of folded aluminum panels on a secondary steel grillage (image courtesy of Architectus)

For the Lichfield building one of the client requirements was the provision of a foundation system that would provide vertical support to a potential future multi-storey building. For the development of this new multi-storey building, the current Lichfield building superstructure would need to be demolished and replaced. The column base plate detail allows for the removal and replacement of the existing steel columns. The new columns will need to project up to support and brace the floors above while maintaining their current plan locations within the building envelope.

Structural Brief

The structural design of the Bus Interchange Building supports the client's project requirements by providing larges open areas with glazed facades and roof skylights enabling a greater exposure to the natural light. The double height vaulted Colombo building roof space allows natural light to penetrate the space and its shape has been inspired by Christchurch's gothic heritage.

The structural system for both buildings is achieved by two-way steel moment resisting frames (SMRF's) which, allows for the architectural roof shape and to maintain the open areas required within the interchange building for passenger movements.

Figure 3: Architect's impression of the Christchurch Bus Interchange (images courtesy of Architectus)

The building is likely to contain people gathered in crowds or groups while in transit, and the structural design reflects the importance level 3 factors for the facility (SANZ, 2002). The new bus interchange has not been designed for a specific post-disaster function.

Figure 4: Architect’s impression of the Christchurch Bus Interchange: Main Entrance Corner Cantilever and photograph of Bus interchange under construction, right image (image courtesy of Architectus)

Structural Design Philosophy

The building frame typically consists of circular hollow section (CHS) steel columns, hot rolled steel I section beams and custom welded steel I section beams. The main entrance (corner portion) of the building is created by utilizing the custom welded beams (CWB’s) and custom welded columns (CWS’s) in a portal frame configuration. The architectural roof form at the main entrance, is formed by an extensive 17m long cantilever, via shaped CWB’s that cantilever and are folded on plan projecting outward from the entry portal. The transfer of lateral loads through the roof diaphragm is achieved by utilizing steel cross bracing that follows the undulating roof plans and transfers the induced lateral loads to the SMRF’s.

The SMRF’s have been designed in accordance with NZS1170.5:2004 (SNZ, 2004) and NZS3404:1997 (SNZ, 1997) for both a serviceability limit state (SLS) earthquake and an ultimate limit state (ULS) earthquake. The SLS represents an event with a 50 year return period and the ULS represents an event with a 1000 year return period (SANZ, 2002).

A design ductility of $\mu=1.25$ and a structural performance factor of $S_p=0.925$ have been used for the ULS design actions to determine the inertial effects and deformations under an ULS level event. Based on this design approach the beams and columns are expected to remain mostly undamaged following a design level earthquake.

The maximum acceptable ULS design drift limit has been defined as 2.5% in accordance with NZS1170.5:2004 (SNZ, 2004). The calculated expected elastic drift levels are typically around 1.5%, when subjected to ULS loading criteria. This lower level of drift enables a more efficient integration with the facades and secondary non-structural elements.

The Colombo building foundation system is a grillage of reinforced concrete two-way beams which, are founded on 400 mm of compacted backfill. The north corner of the building, is the exception to this as it relies on an extensive concrete pad to resist the high overturning loads generated from the main entry cantilever roof support system.

The columns base plate connections and foundations have been designed for the seismic overstrength actions.

The Lichfield building foundation system is a reinforced concrete raft, designed for the future development of three suspended concrete floors above the current good floor level. The design of this future multi-storey building was taken to a preliminary stage, and was based on having a structural system consisting of two-way SMRF’s.

Design Challenges

Program

The structural and architectural design began in early 2014 and the design team had approximately 3 months to deliver preliminary documentation suitable for tender, with the foundation consent deadline due in April 2014.

Architect and engineer started a series of regular workshops to develop the architectural and structural form. The main entrance corner was a key design focus of the early sessions since, it constitutes the main access to the Bus Interchange and provides direct access to the Retail Precinct.

The early and continuous collaboration between engineer and architect was crucial to meet the tight project deadlines. The engineer and architect agreed on a design program with issue dates for frozen architectural envelope drawings and, with those frozen backgrounds the structural team worked towards ensuring that the structural members sizes, connections and positioning fit within the architectural constraints.

Aurecon engineers produced specific connection design intent details for the steel fabricator to review for buildability and, once agreed upon those connections were then modelled in 3D Revit. Later on in the design process, during the steel fabrication phase, Aurecon engineers held weekly meetings with the steel fabricators to support the TSB's delivery program.

Figure 5: Image of the Christchurch Bus Interchange South Elevation under construction (image courtesy of Architectus)

To meet the program target delivery dates one of the implemented solutions was to separate the primary and secondary steel packages to allow for the fabrication of primary steel to begin, while the secondary steel was still being designed. This assisted in shortening the delivery program in terms of shop drawings commencement and in the procurement of non-standard steel sections. Despite the separation in the delivery of the steel packages, there was an element of overlap between those packages with respect to the detailing.

Roof Geometry

The complex geometrical roof shape of the Colombo building also presented some design and detailing challenges. The majority of the moment connections are different from one another and required specific design and detailing.
In addition to the complex 3D Revit model, Aurecon produced detailed design intent sketches of the moment connections, gathered feedback from both the structural steel fabricator and the contractor, and worked collaboratively towards the delivery of cost-effective and structurally robust connections.

Steel procurement

The circular hollow steel sections (CHS) forming part of the SMRF's required for the project were not readily available in New Zealand, hence they were ordered by the New Zealand Government, as client supply items, direct from China. Since the steel delivery from China requires a 14 week lead time, the steel procurement became part of the critical path.

Aurecon prepared a material requirements specification for the CHS sections procurement to assure compliance with the New Zealand Standards. This included manufacturing tolerances, welding specification, mechanical and chemical properties as outlined in EN 10219:2006 (EN, 2006). Material testing requirements were also outlined, as well as the steel supplier responsibilities, such as to provide appropriate third party New Zealand certifications. Asian based Aurecon structural engineers also visited the steel mill prior to the shipping of the steel to New Zealand to carry out a visual inspection.

Analysis

Aurecon developed 3D models of the Colombo and Lichfield Buildings using the finite element software ETABS Nonlinear V9.7.4 (CSI, 2014). These models were used to design the building structure for gravity and seismic actions which, utilized the modal response spectrum method, as defined by the loading code NZS1170.5:2004 (SNZ, 2004).

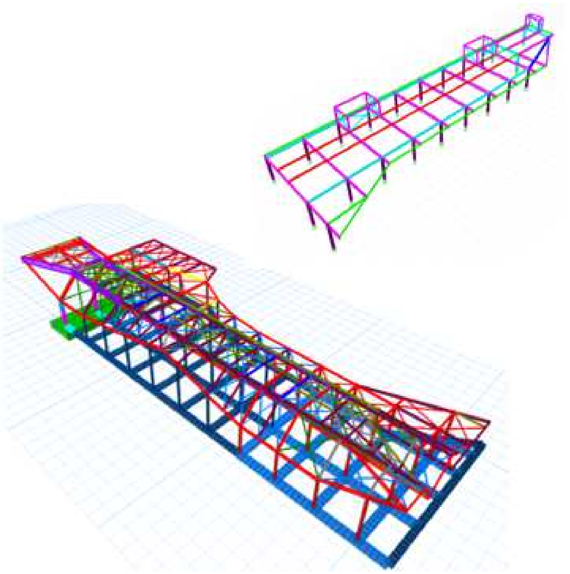

Figure 6: 3D ETABS models of Colombo and Lichfield Buildings, left and right respectively

Raft Slab Analysis by the Finite Element Method "SAFE" (CSI, 2014) was used to model and analyse the concrete raft foundation and to design the flexural and shear reinforcement.
Three sets of subgrade soil spring stiffness's were provided by the geotechnical engineer for each building foundation design. The first set of spring stiffness's was used to analyse the structural behavior of the foundation under gravity actions, at both the serviceability limit state (SLS) and the ultimate limit state (ULS). The second set of spring stiffness's was used to analyse the structural response of the foundation under seismic actions. For post-earthquake reconsolidation settlements a final set of spring stiffness's was adopted in the design.

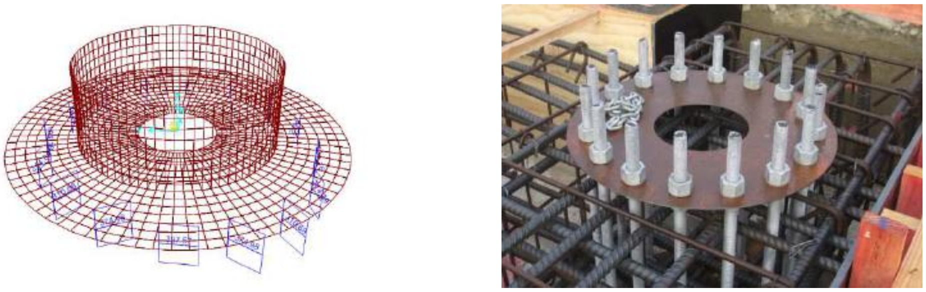

Figure 7: 3D SAP2000 model (CSI, 2014) of column base connection showing bolts in tension (left image) and a site photograph with the base plate and HD bolts in place (right image)

To verify and optimize plate thicknesses, the column base plates were modeled with the finite element package SAP2000 (CSI, 2014) and a series of non-linear analyses were undertaken to measure the stresses that developed in the plate, the bearing stresses in the concrete foundation and the distribution of tension force in the bolts.

The loads considered in the design include the overstrength moment of the columns combined with tension and compression actions. The design of the connections were based on the SAP2000 (CSI, 2014) models and on the paper “Circular Base Plates with Large Eccentric Loads” (Liu, D., 2004).

Design

Superstructure Design

The design of the two-way SMRF’s was undertaken in accordance to NZS3404:1997 (SNZ, 1997) for a category 3 steel moment resisting frame with the columns being designed for the beam’s flexural strength overcapacity.

The main entrance corner roof cantilever structure is supported on the welded portal frames which transfer the gravity and seismic loads to the mass concrete pad. The large overturning actions produced by 17 m long cantilever are resisted by the mass concrete pad. To provide direct shear and tension load transfer to the foundations, the CWC’s are partially cast into the foundation pad, as stubs, and a column splice is provided at mid-height.

The portal frame and foundation detailing was also carried out to take into account buildability and the temporary support of the CWC’s.

An alternative foundation option considered was to use tension piles, as opposed to the foundation pad, but this was value engineering out to avoid the introduction of an additional construction trade on site and to fast-track the construction process.

Foundation Design

The main entrance corner foundation was designed and detailed using beam theory and the strut and tie theory for the derived overstrength capacities of the CWC’s under the nominally ductile loads. To determine the system’s flexibility the soil-structure interaction was modeled in SAP2000 (CSI, 2014).

The Lichfield building raft foundation was designed considering the natural ground conditions taking into account three sets of soils stiffness’s which were provided by the geotechnical engineer. The stiffness’s values were modelled in the SAFE (CSI, 2014) program and iteratively analysed until convergence was achieved.

Safety in Design

Safety in design has been a central part of the design process, given the space utilization and the client requirements. An example of safety in design are in the precast wall design criteria. The precast walls shown in figure 8 form the waiting passenger’s seats behind the bus fingers, and have been designed to accommodate the horizontal impact load of a bus in accordance to AS/NZS 1170.1 Supplement 1:2002 (SNZ, 2002).

Figure 8: Image showing the Bus Interchange Bus fingers (arrival bay) with concrete precast seat for awaiting passengers (image courtesy of Architectus)

Detailing

The team's approach to detailing, in particular to the complex connections in the Colombo Building, was to produce a series of concept sketches for the contractor and steel fabricator to review for buildability. A design team workshop was then organized to discuss ideas and to agree the most cost and time effective approach following fabricator and contractor feedback, Aurecon completed the steel detailing and Revit modelling.

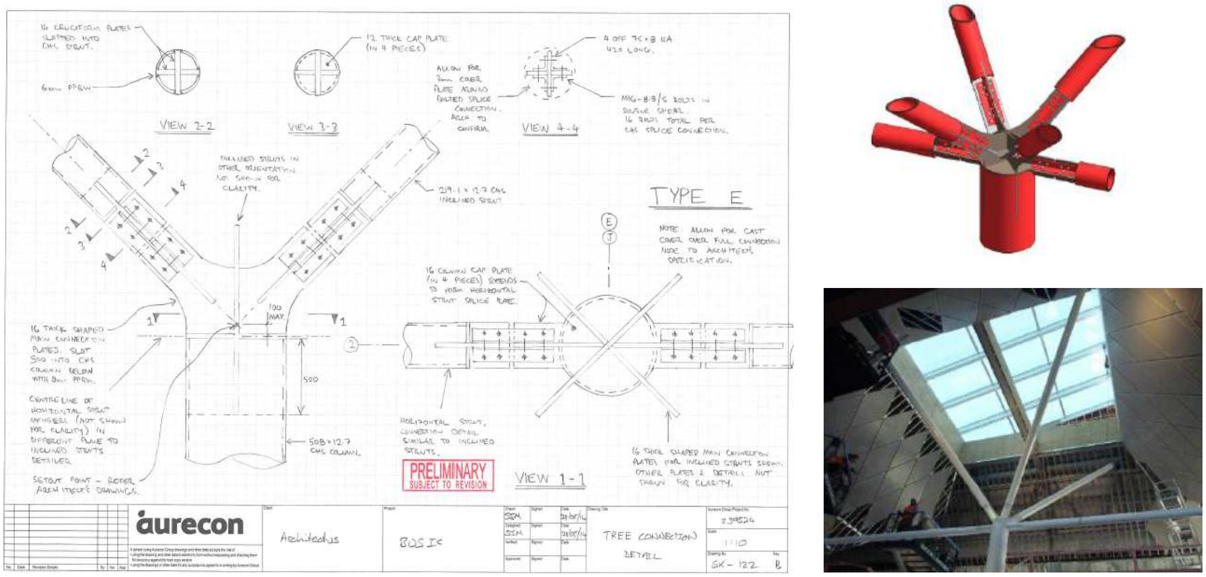

Figure 9: Tree column details from conception, left image, to completion. Top right image, illustrates the 3D Revit modelling of the connection, whilst the bottom right image shows the finished column detail

A good example, of this collaboration process are in the design of the "tree columns". The "tree columns" were conceived as a cost effective solution for supporting skylights and the roof protrusions. These connections employ bolts in double shear and utilizes readily available equal angles sections as gussets and load transfer mechanisms. The main drivers for the connection detailing were structural performance, cost-effectiveness and to minimize erection times.

The new Bus Interchange building also provides a retail space in the form of self-bracing retail pod buildings which, are supported on shallow foundations. The façade integration between the pod structures and the main Bus Interchange roof structure was detailed to accommodate the seismic drifts under the (ULS) load criteria.

Figure 10: Internal view of the Bus Interchange showing the internal concept of the Colombo building, left image, and a view from the south-west corner of the Colombo building, right image, showing the self-bracing pads (images courtesy of Architectus)

Other secondary non-structural elements such as the partitions, ceilings and soffits have been detailed to allow for the seismic induced drifts, with the intent of limiting damage at the serviceability limit state (SLS) earthquake.

Conclusions and Lessons Learnt

Collaboration between architect, engineer and steel fabricator was vital to meet the contractor’s program and to deliver the steelwork on time.

Aurecon engineers produced specific connection design intent details for the steel fabricator to review for buildability. The subsequent use of 3D Revit modelling allowed for speed and accuracy in the steel shop drawing stage. To streamline the RFI process, Aurecon engineers held weekly meetings with the steel fabricators to help support the TSB’s delivery program.

The steel procurement of un-fabricated plain steel sections from China allows the engineer to access sections sizes not commonly available in the New Zealand market, which when carefully integrated into the construction program can lead to important program benefits. It provides more options outside of the New Zealand and Australia markets, but the lengthy lead in times needs to be accounted for in the program. Consultants, contractors and owners should be aware of the extensive certification and quality assurance process needed when utilizing overseas un-certified structural steel.

Consultants also should be made aware that design and build contracts require extensive engineering design and drafting resources, in particular to achieve the objectives of complex and fast track projects.

Finally, the use of structural steel was crucial for the successful delivery of the new Christchurch Bus Interchange. It enabled the design intent and client requirements to be accomplished with speed and accuracy. The adoption of structural steel supported the architectural vision of *“larges open areas, column free spaces with a vaulted cantilever roof to accentuate the building’s main entrance”* while delivering a fast track design and documentation process.

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