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THE DELIVERY OF THE NEW CHRISTCHURCH BUS INTERCHANGE

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Abstract

The Christchurch Bus Interchange (CBI) was the first government Anchor Project to be completed as part of the rebuild programme following the damage caused by the Canterbury Earthquake Sequence. The CBI consists of a single storey L-shaped building, constructed as two seismically independent structures, known as the Lichfield and the Colombo buildings.

Aurecon New Zealand Ltd (Aurecon) was appointed to design and document the structure under a tight delivery schedule. The structural system for both buildings is achieved by two-way Seismic Moment Resisting Frames (SMRFs), which allow for the architectural roof shape and deliver the large open areas within the interchange building required for passenger movement. Several 3-Dimensional models using computer packages ETABS, SAP2000 and SAFE were developed to overcome the various design challenges and ensure a robust and economical design was achieved.

A number of related steps were taken early in the design process to achieve the required programme. Steel procurement became part of the critical path as the circular hollow sections (CHS) which formed an integral part of the SMRF's were not readily available in New Zealand and were ordered from China. To ensure the certification and the quality of the structural steel met the New Zealand Standards, Aurecon prepared a material requirement specification for overseas uncertified structural steel and inspected the steel mill during material testing and prior to shipping. A collaborative culture was developed between architects, contractors, engineers and steel fabricators from the conceptual design phase to assist in development of the architectural and structural form. The series of workshops organised between all parties allowed for the discussion of concepts, agreement of a cost- and time-effective approach to design, delivering speed and accuracy in the material fabrication and simplifying the construction process. The CBI opened in May 2015 and is considered an important and attractive civic asset that increased the access to and engagement with the newly re-built Central Business District.

Keywords: post-disaster recovery, seismic design, steel procurement, collaboration

1. Introduction

On the 22nd of February 2011 magnitude 6.3 earthquakes struck Christchurch's Central Business District (CBD), New Zealand, reaching peak ground accelerations of 1.8g horizontally and 2.2g vertically. The earthquake, part of the Canterbury Earthquake Sequence, resulted in 185 fatalities and caused extensive damage to the building stock.

In March 2012, The Canterbury Earthquake Response Authority (CERA) estimated that the total cost of demolition was around $1.5 billion. Information contained in the Treasury Fiscal and Economic Update released in 2011 estimated that the total cost of rebuild would be approximately $30 billion, including the damage estimates plus additional costs such as business interruption, inflation and reconstruction to new standards [1]. Although the majority of the fatalities occurred in two buildings, the Pyne Gould Building and the CTV building, which suffered catastrophic types of failure, the damage was widespread around the city of Christchurch. In particular, many old unreinforced masonry buildings were damaged beyond repair.

When using traditional design practice, buildings are typically designed to respond inelastically to seismic ground motions without reaching collapse, preserving life safety during and immediately after a major earthquake. This performance criteria was achieved for the majority of the buildings in Christchurch's CBD, except for the two previously identified buildings. Nevertheless, the high reconstruction costs associated with the Canterbury Earthquake Sequence and those costs related to business interruption have demonstrated the importance of a building's rapid reoccupation after a significant earthquake. These events have significantly changed public perceptions.

Aurecon New Zealand Ltd was appointed in November 2013 to design and document the new Christchurch Bus Interchange (CBI) located in central Christchurch, New Zealand. The CBI was the first government anchor project following the Canterbury Earthquake Sequence. As a result of the aforementioned change in public perception it was designed to sustain minimal damage during a design level seismic event. From an operational point of view, the Bus Interchange is to serve as the central hub for interlink bus movements within the transport network.

The following figure 1, left image, illustrates the central location of the CBI in Christchurch's CBD and it establishes the architectural design intent of the CBI with the large open spaces and gothic shaped ceiling space, right image.

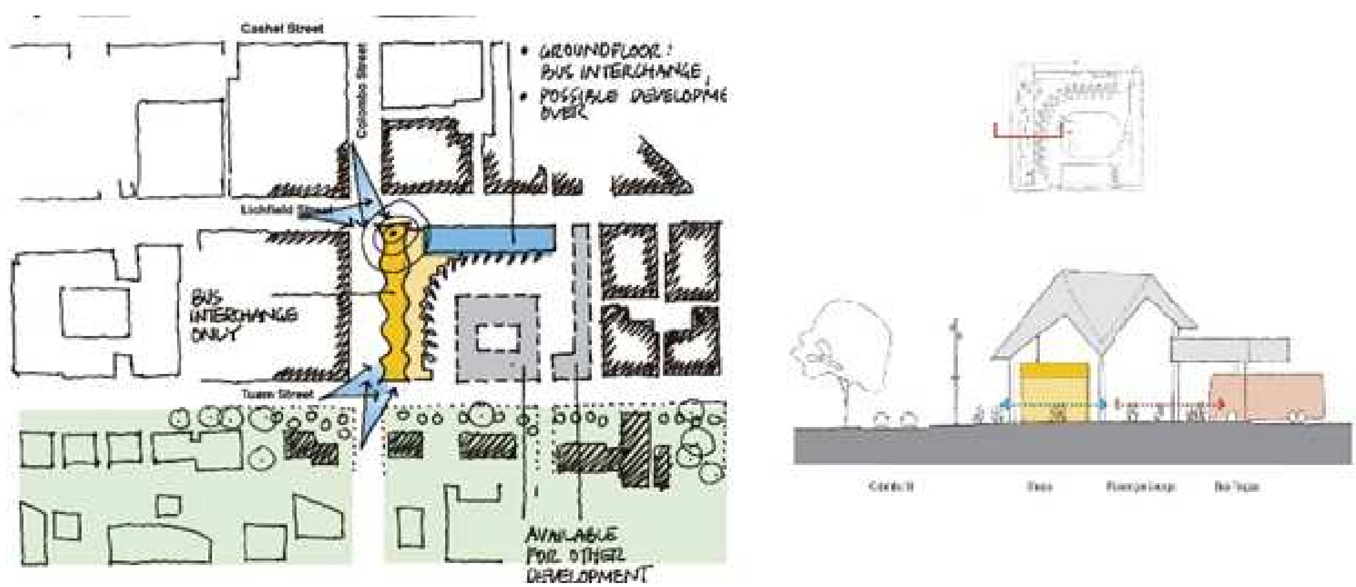


Fig. 1- Site Strategy Summary, left image, and Architectural Concept showing a section through the Colombo Building, right image, (Images courtesy of Architectus).

Structural steel was the enabler of the structural form needed to create this civic space, while also accomplishing the architectural vision. This paper outlines some of the challenges and solutions regarding the architectural and structural design, steel procurement and fabrication, as well as the benefits of industry collaboration. It also details the fast track design and documentation process, key decisions and process adopted en route which contributed to its success.

2. Building Description

The CBI is a single storey L-shaped building, constructed as two seismically independent structures, known as the Lichfield and the Colombo buildings.

The Lichfield building has a rectangular form and consists of steel moment resisting portal frames in both primary directions supported on a concrete raft foundation. The foundation system was designed to provide vertical support for a potential future multi-storey building comprising three suspended levels for office and commercial use.

The Colombo Building comprises a complex three dimensional roof formed by moment resisting portal frames. The roof is shaped as a vaulted ‘M’ and has a 17 m long cantilever at the north end. The cantilever is located above the main entrance and its architectural design intent is to provide a sense of space and civic amenity, as well as a direct access to the nearby retail precinct.

The vaulted M-shaped roof is inspired by Christchurch’s gothic architectural heritage and offers a sense of volume and power. The CBI also provides a number of retail spaces in the form of self-bracing retail pods which are supported on shallow foundations.

Fig. 2- Architect’s impression of the CBI Colombo and Lichfield Buildings, left and right images respectively (Images courtesy of Architectus).

The previous image, figure 2, illustrates the architectural design intent of the CBI, highlighting the main corner entrance of the building as a point for people to meet and to get direct access to the retail predict. The images above also captures the open space nature of the facility with the high ceiling spaces and large glazing areas providing plenty of natural light.

3. Structural System Design Philosophy

3.1 General Design Approach

After initially investigating the potential use of several resilient structural design options, such as rocking columns with replaceable fuses, we adopted a more traditional system without any requirement for diagonal braces interfering with views or use. The structural system for both buildings is achieved by two-way Steel Moment Resisting Frames (SMRFs) which deliver the architectural roof shape and large open areas within the interchange building, and provide minimal disruption to passenger movement.

The building's structural frames typically consist of circular hollow section (CHS) steel columns, hot rolled and custom welded steel beams which form the two-way SMRFs. The exception is the main entrance of the Colombo Building which exists under a seventeen metre long cantilevered roof which is supported by a custom welded steel portal frame..

The CBI was designed as an Importance Level 3 (IL3) structure. An IL3 building is described as a structure that as a whole may contain people in crowds or items of high value to the community or pose risks to people or crowds [2]. The design of the two-way SMRFs was developed as a Category 3 structure, corresponding to a nominally ductile system [3]. The columns were designed for the beam's flexural over-strength, thus forming a beam side-sway mechanism. Based on this design approach the beams and columns are expected to withstand a design level earthquake with minimal damage, which for an IL3 structure is equivalent to a 1000 year return period [3, 4].

The roof diaphragm of both buildings is designed as a semi-rigid diaphragm comprising of tension only steel cross-braces. The seismically induced lateral loads are transferred through the roof diaphragm, which follows the undulating roof pitches, to the SMRFs, and downwards to the foundations.

The Colombo Building is founded on a two-way grillage of reinforced concrete ground beams. The northern corner of the building is the exception relying on a massive concrete pad to resist the high overturning loads generated by the main entry cantilever roof. The following photo, figure 3, shows the main entry cantilever roof in the final stages of construction, with the Lichfield building to the left and the independent retail pods to the right.

Fig. 3- CBI Main Entrance Corner Cantilever under construction (Site photograph courtesy of Aurecon New Zealand).

The foundation system of the Lichfield Building comprises a 900 mm deep reinforced concrete raft, designed for the future development of three suspended concrete floors above the current ground floor level.

The design of this future multi-storey building was taken to a preliminary stage, and was based on a similar structural system (two-way SMRFs). The column base plate connections were designed and detailed to allow for the non-destructive removal of the current Lichfield building superstructure and the columns for the future multi-storey building to be affixed in the same locations. The column base plate connections and foundations were designed for seismic over-strength actions of the future superstructure.

The custom welded portal frame supporting the cantilever roof and respective foundation were detailed to take into account buildability and temporary works during construction. These columns were partially cast into the foundation pad as stubs with a column splice was provided at mid-height. This allowed direct shear and tension load transfer to the foundations. An alternative foundation option with tension piles was considered, however it was rejected to avoid the introduction of an additional construction trade on site.

3.2 Structural Analysis Methodology

3-Dimensional computer models using the finite element software ETABS Nonlinear V9.7.4 [5] were developed for both buildings to determine the seismic load distribution into the structural elements and establish the overall response of each building seismic loading. The seismic demands on the elements have been derived from the modal response spectrum method in accordance to with the relevant New Zealand loading standard NZS1170.5:2004 [3]. The tension only roof cross-bracing was designed by applying a non-linear static load case to the structures until the full design load was reached. The lateral demands due to wind loads were also considered in accordance with AS/NZS1170.2:2011 [6].

The following image displays the Colombo building ETABS model, including the foundations beams and the roof cantilever beams both modelled as linear frame elements.

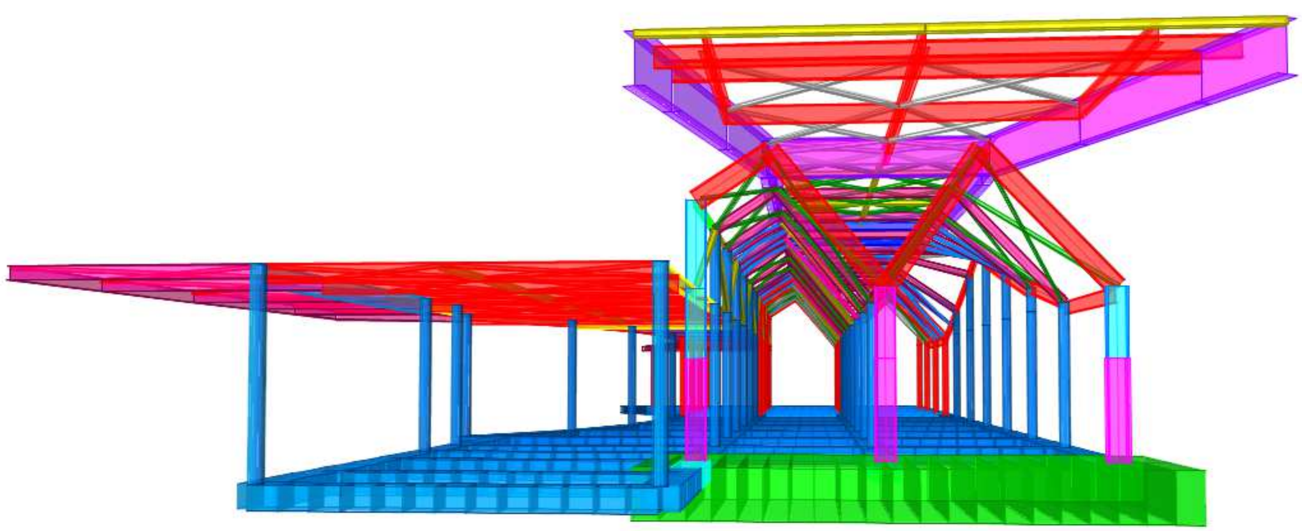


Fig. 4- Three dimensional ETABS model of the Colombo Building – North Elevation (ETABS model print screen courtesy of Aurecon New Zealand).

Due to the more complex structural shape of the Colombo Building and the requirement to design the cantilever roof for vertical seismic and wind accelerations, a separate analysis was performed using the finite element software SAP2000 [7]. Soil-structure interaction was included in the analysis and modelled using a series of Winkler elastic springs of uniform stiffness under the pad foundation. The pad foundation was designed and detailed using the strut and tie theory from the derived over-strength demands of the main structural supporting frame.

For the Lichfield Building, A 3-Dimensional computer model using the engineering software package SAFE [9] was developed to design the raft foundation. The natural ground conditions were modelled using three sets of soils stiffness's and iteratively analysing the raft until convergence was achieved. The first spring stiffness value was used to analyse the structural behaviour of the foundation under gravity actions, at both the serviceability limit state (SLS) and the ultimate limit state (ULS). The second spring stiffness was used to examine the structural response of the foundation under seismic actions. The third spring stiffness value was adopted to simulate post-earthquake reconsolidation settlements.

The left image of Figure 5 below shows the deformed shape of the three dimensional SAP2000 model of one of the typical base plates and the right image illustrates a typical base plate under construction.

Fig. 5- Three dimensional SAP2000 model [7] of the column base connection showing bolts in tension, left image, and a site photograph with the base plate and HD bolts in place , right image (SAP2000 base plate model and site photograph courtesy of Aurecon New Zealand).

The typical column base plates were also modelled with the finite element software SAP2000 [7]. A series of non-linear static analyses were undertaken to measure the distribution between stresses in the baseplate, bearing stresses in the concrete foundation and tension force in the bolts. The intent of these analyses was to optimize the base plate thicknesses and the number of bolts. The loads considered in the design included the overstrength moment of the columns combined with tension and compression actions. The results of the finite element analyses were validated by empirical methods provided in the paper “Circular Base Plates with Large Eccentric Loads” [8].

4. Steel Procurement

The steel circular hollow section (CHS) columns which form an intrinsic part of the SMRFs required for the project were not readily available in New Zealand. Consequently these were ordered by the New Zealand Government, as client supply items, directly from China. Since the steel delivery from China requires a fourteen week lead time, the steel procurement became part of the critical path.

The supply and use of Chinese steel, while increasing the range of available section sizes, brought with it issues with the certification and quality assurance of the structural steel. To mitigate this issue, Aurecon prepared a material requirements specification for overseas uncertified structural steel to ensure compliance with the New Zealand Standards, or an alternative internationally recognised standard if the relevant sections fell outside the scope of the New Zealand Standards. This included manufacturing tolerances, welding specification, and mechanical and chemical properties as outlined in EN10219:2006 [11]. The following testing requirements were specified to ensure appropriate third-party New Zealand certification:

- Steel Material Property Tests: Tensile and Charpy tests to confirm yield strength, ultimate strength and elongation. A minimum of three were columns randomly selected from the different batches and taken out of shipping for testing. The testing was conducted by an accredited CNAS laboratory and an accreditation certificate was submitted to the engineer for review and approval. All tests were conducted according the reference standards as specified in EN10219 [11].
- Weld Related Tests: to ensure welding satisfied the requirements of EN10219-1:2006 (E) Section 9.4[11].

- Dimensional Checks: to ensure all dimensions (sizes, thickness and corner radii) are compliant with EN10219 [11].

Several of Aurecon's Asia-based structural engineers visited the steel mill during material testing and carried out a visual inspection prior to the shipping of the steel to New Zealand.

5. Collaboration - Construction Documentation

The project was undertaken as a design-and-build contract with the design team novated to the contractor for the completion of the detailed design. The design commenced in January 2014 and the CBI opened in May 2015. To meet the programme deadlines, architects and engineers worked closely from the conceptual design phase to the jointly develop the architectural and structural form. The main entrance corner of the CBI, where the cantilever roof is located, was a key design focus of the early sessions. The complex geometry of the Colombo building roof also presented design and detailing challenges. The majority of the moment resisting connections are unique and thus required specific design and detailing.

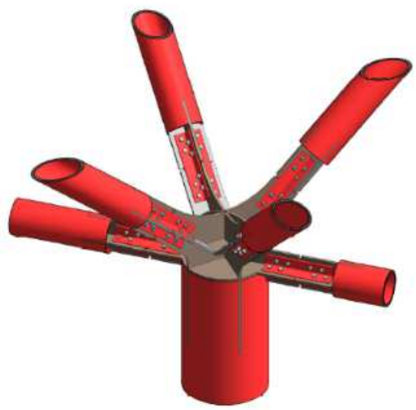
The roof geometrical complexity can be observed from the site photograph below, figure 6. The photograph is taken from the south elevation of the Colombo building during Aurecon's site observations and it displays the vaulted shaped portal frames and the undulating shape of the roof.

Fig. 6- Image of the Christchurch Bus Interchange South Elevation under construction (Site photograph courtesy of Aurecon New Zealand).

The engineers and architects agreed on a design program with issue dates for frozen architectural envelope drawings. Aurecon's engineers produced a package of conceptual sketches of the roof moment connections for the contractor and the steel fabricator to review and provide input on the buildability. A series of workshops discussed these concepts and agreed the most cost- and time effective approach to design and construct these details. A 3-Dimensional Revit model was developed and the steel detailing discussed in a collaborative forum between architects, contractors, engineers and steel fabricators with the aim of providing speed and accuracy of fabrication.

This successful collaboration process was evident 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 utilise readily available equal angles sections as gussets and load transfer mechanisms. The main drivers for the connection detailing were structural performance, cost-effectiveness and minimising erection times.

The images below demonstrate some of the stages of the tree columns design process, from the 3D REVIT modelling, left image, to the finished product, right image.



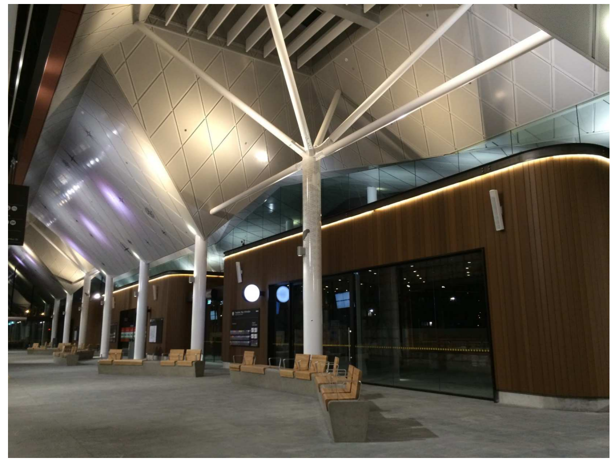


Fig. 7- Tree column details from REVIT and as built, left and right images respectively (REVIT 3D modelling detail and site photograph courtesy of Aurecon New Zealand).

To meet the program 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, prior to completion of the secondary steel design. This assisted in shortening the delivery program in terms of shop drawings commencement and procurement of non-standard steel sections.

6. Conclusions and Lessons Learnt

New Zealand Government placed this anchor project 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 May 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's public transport system and increase the access to and engagement with the newly rebuilt central city.

Collaboration between architect, engineer and steel fabricator was vital to meet the programme dates. To enable this, Aurecon's 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 fabrication process Aurecon engineers held weekly meetings with the steel fabricators to help support the contractor's delivery program.

The procurement of unfabricated plain steel sections from China allowed the engineers to utilise section sizes not commonly available in the New Zealand market, which when carefully integrated into the construction program lead to important programme benefits. This option provided more choices outside of the New Zealand and Australian markets, however the lengthy lead times needed to be taken into account in the programme. Consultants, contractors and owners should be aware of the extensive certification and quality assurance process needed when utilizing overseas uncertified 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.

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.

7. Acknowledgements

I would like to acknowledge Aurecon New Zealand for their support throughout this project and Architectus for all collaboration during the project.

8. Copyrights

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