POST TENSIONED TRIDENT BOWSTRING TRUSSES FOR A 20M HIGH GLAZED WALL

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Abstract

The Trident bowstring wind trusses have been developed for the glazed walls of the atrium space in the new Clear Communications Head Offices in Takapuna, Auckland. The atrium, over 20m in height, connects two six story office blocks and incorporates full height glazed walls on the east and west sides.

The pretensioned trident bowstring truss was selected as the most slender and efficient wind truss solution for the atrium. The trident bowstring truss consists of three tension cables around a central compression strut; no external lateral bracing or end anchorages are required.

The atrium space connects two seismically separated buildings, requiring any support structure to be fixed to one office tower because of expected movements across the atrium. This limits horizontal structure and restraints across the glazed wall. The trident arrangement of tension cables was developed to laterally restrain the compression strut and resist wind face loads using their catenary profile.

The trusses required second order analysis and elastic critical buckling analysis for the final design, with the ultimate wind load case proving critical.
The trusses are detailed to allow fabrication from readily available steel sections. Circular hollow sections and round bars have been used for the central strut and spreaders respectively, with the tension cables fabricated from high tensile steel round bar. The node connections between spreader and tension cables are similarly fabricated from mild steel round bar.

The trusses were assembled and pretensioned whilst horizontal at ground level. Cables were tensioned using the turnbuckles at each end of the truss, with the level of prestress controlled by accurate bar extension measurements and strain gauges.

The wind trusses and transoms supporting the glazed wall loads are all suspended from the atrium roof trusses above. The flexible nature of the roof trusses necessitates provision of vertical adjustment in the glazing support structure, to maintain clearances for thermal and wind movement in future.

Introduction

The new Clear Communications Head Office building in Takapuna, Auckland comprises of two-six storey office towers linked by an atrium space. The whole office development is over 150m long and approximately 21m wide, and is curved in plan over an angle of 135°. (Refer figure 1). The atrium space is in the centre of the development and is over 20m wide by 20m high. The east and west walls of the atrium are glazed full height, whilst the north and south sides of the atrium adjoin the office towers.

Figure 1: Clear Communications Head Office

The atrium space houses the main entrance and reception area for Clear Communications offices, and is an important part of their corporate image. There are suspended walkways passing through the atrium space inter-connecting the two office towers with stairs to each of the office floor levels. (Refer figure 2). These two functions require the atrium space to be elegant and functional.

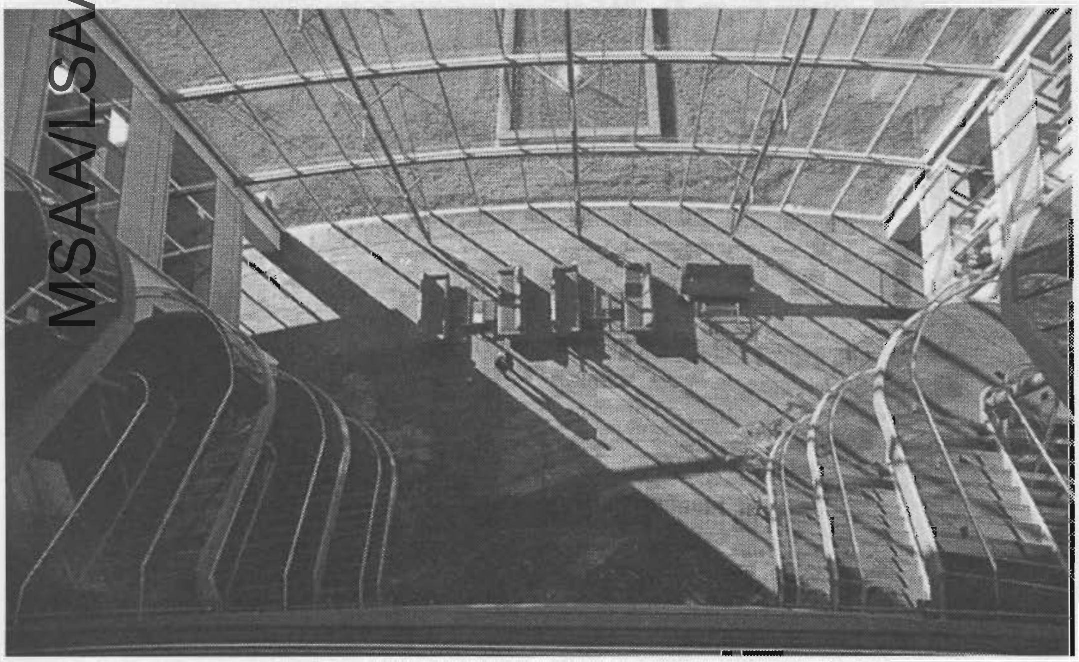

Figure 2: View down Atrium
(Photo by Colleen Tunnicliff, courtesy of Warren & Mahoney Architects)

Concept
The design of the atrium was a joint effort by Architects Warren and Mahoney and Connell Wagner as Engineers. The main criterion for the glazed walls was to use a standard curtain wall glazing system, and to provide a slender and light supporting structure. The slenderness of the wall support structure was viewed as an important

design aspect given the mullions and transoms of the standard curtain wall system already limited the transparency of the glazed wall.

Pretensioned trident bowstring trusses incorporating a central compression strut were developed as the most slender structure for the Atrium wind trusses (refer figure 3). The truss comprises of a central compression strut encircled by three catenary tension cables. Spreader bars connect the cables to the strut at wall transom locations. The innovative arrangement offers the benefits of slender, efficient tension cables to resist face wind loads on the glazing wall, without the requirement to have rigid and strong end anchorages for the cables, or lateral bracing to the central compression strut.

Figure 3. Pretensioned Trident Trusses

Popular planar bowstring trusses consisting of tension cables were not suitable for the wind trusses, because of the strength and flexibility of floor and roof structures limited their ability to provide effective tension cable anchorages. The atrium roof is constructed of steel trusses that span over 20m with a structural depth of less than 1.5m, which restricts the load capacity and ability to act as end anchorage's to the cables. The ground floor slab is suspended and also has a restricted load capacity because of the basement carparks below. These constraints necessitated the use of a compression strut within the wind truss configuration.

The atrium is constructed between two seismically separated office towers that requires all support structure to be fixed to only one building, because of the expected movements between the towers. This eliminates the ability to use slender tension ties across the length of the glazed wall to provide lateral restraint to a compression strut. The trident arrangement of cables was selected as the best alternative to provide effective bracing to the compression strut about both axes, thus enabling the use of a relatively slender compression strut from the reduced buckling lengths. A tension/compression lateral bracing system to the strut, independent of the seismic joint, was not acceptable because of the member sizes.

Analysis

A non-linear analysis was used for design of the full wind structure, considering second order effects (P□□and P□) as well as "tension only" members. An elastic critical buckling analysis was also carried out to calculate the buckling load of the central compression strut and effective length, when restrained by the tensioned cables.

The full wind support structure for each glazing wall was modeled. This included the trident bowstring trusses, spreaders and structural transoms at each floor level. The gravity support structure being independent of the wind trusses were not included in the model. The gravity loads from the glazed walls are supported by the transoms at each level, in turn supported by steel hanger rods from the atrium roof trusses.

The critical load case for design was the ultimate wind load case. This governed the pretension loads of the cables, and the required ultimate breaking load of the cables. The buckling analysis calculated an effective strut length of less than 6m, from a total truss length of 20.5m. This demonstrates the buckling restraint provided by the cables is effective considering that the strut segment length between each transom/spreader level is over 3.5m.

Thermal effects on the wind trusses were not critical for design, as the trident bowstring trusses have vertical movement at their base that allows expansion and contraction from global thermal effects. Thermal effects from differential temperature between the front and back cables are not large enough to be critical in the truss design.

The calculated truss deflections from serviceability wind loads are large and required allowance in design and detailing of the curtain wall.

Fabrication
Readily available materials and fabrication methods were selected to keep costs within a limited budget.

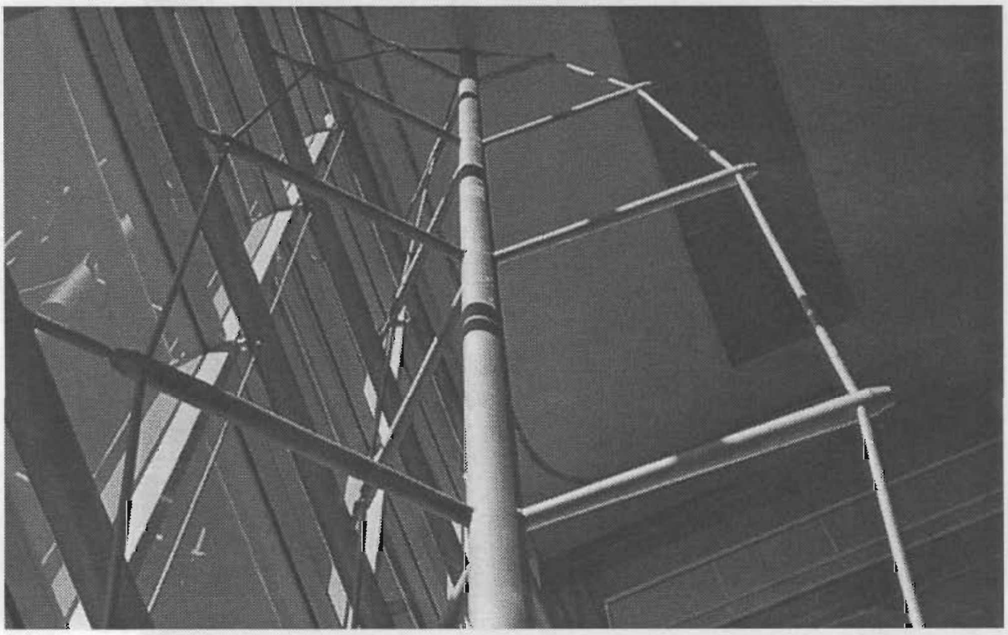

Figure 5: The Truss Shape
(Photo by Colleen Tunnicliff, courtesy of Warren & Mahoney Architects)

The central compression strut was fabricated from steel hollow sections and round solid steel bars. The spreader members, nodes and turnbuckles were fabricated from solid steel bar. High tensile steel round bar was selected for the catenary cables. All the connections including the nodes and turnbuckles were detailed to be relatively simple and repetitive so they could be easily machined. No cast fittings have been used for the wind trusses. A general steelwork fabricator was able to fabricate all the trusses because of the relative simplicity of the design and material selection.

Erection
The trusses were assembled and pretensioned whilst horizontally supported at ground level. The truss is self-bracing (an internally stable system), therefore no external supports or restraints are required to pretension the truss. This simplified construction and reduced erection costs.

The truss cables were tensioned using turnbuckles located at each end of the truss, with the level of prestress controlled by accurate measurement of the cable extensions at each turnbuckle. The total tension force in all three cables was checked by strain gauges located at quarter points around the circumference of the central compression strut. The turnbuckles were developed and tested prior to assembly of the trusses to ensure the required tension in the cables could be achieved. The use of end jacking to tension the cables was aesthetically unacceptable, because of the constraints this imposed on the connection details at either end of the trusses. The use of in-line jacks to tension the cables was considered, but the cost of this method of jacking was expensive, with the equipment and personnel available only from Australia. The tensioning turnbuckles provided a cost effective and aesthetically desirable solution.

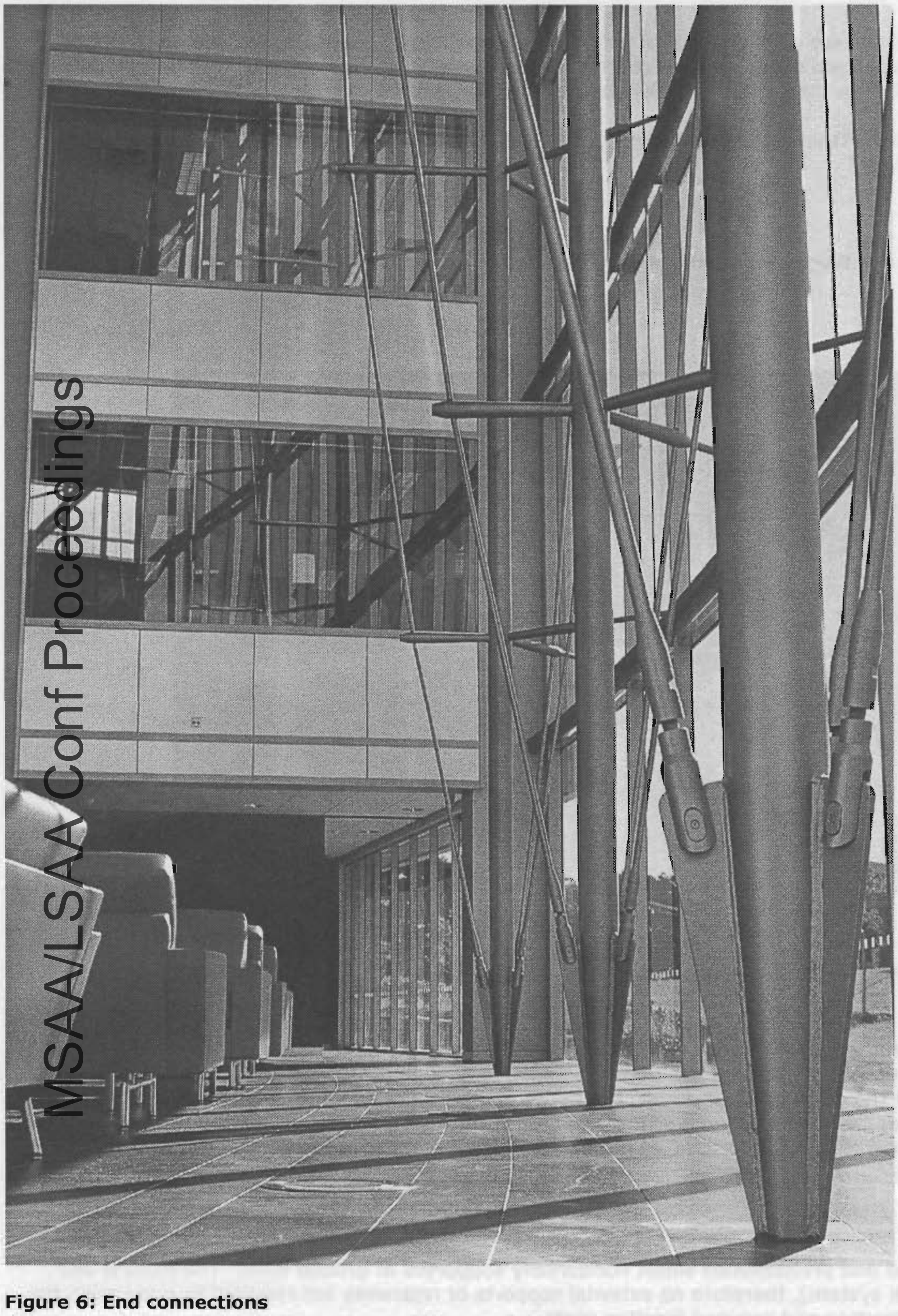

Figure 6: End connections
(Photo by Colleen Tunnicliff, courtesy of Warren & Mahoney Architects

One of the difficulties with the tension cables bracing the central compression strut is the relative movement that occurs during pre-tensioning. The elongation of the cables and shortening of the strut cause movement at each end of the spreader, this required special details to allow the spreader bars to rotate during tensioning, whilst keeping the cable-located.

The design and construction methodology allowed for relative and absolute movement of the curtain wall and atrium trusses. The curtain wall and trusses are both suspended off the atrium steel roof trusses, which deflected considerably during the construction of the curtain wall. This required both the glazed wall suspension structure/rods and wind trusses to be capable of vertical adjustment, to keep clearances for thermal and wind load vertical movement, ensuring the glazing does not become load bearing.

Another benefit of this wind truss system is that general steelwork erectors assembled the trusses because of the simple componentry, and detailed but straightforward construction methodology provided in the design. This provides savings to the client by eliminating the requirement for a specialist subcontractor for the prestressing and assembly of the trusses.

Conclusion

The pretensioned trident bowstring trusses are slender and efficient trusses. The truss does not require external lateral restraints or end anchorages for pretensioning. Tensioning is a simple procedure using turnbuckles at each end of the truss and can be carried out at ground level. The innovative assembly has a light and minimalist form in keeping with the City of Sails