ROOF FOR MANUFACTURING PLANT, GUANGZHOU, CHINA

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Introduction

Scott Wilson Irwin Johnston were invited by Craig Fyall Consulting to assist with the structural design for a new tile adhesive factory to be built in the Economic Technology Development Zone in Conghua approximately two hours north of Guangzhou, Peoples Republic of China (PRC).

The client's brief was for an innovative high tech structure which could adequately project a similar image for their company which was involved in state of the art production of tile adhesive.

The geometry had to offer a dramatic shape with visual impact, while at the same time house a 18m high manufacturing plant and mezzanine offices. Other considerations were ease of erection, low maintenance and low cost.

Cyclonic wind loading presented considerable challenge together with the chosen structural material consisting of aluminium.

Through innovation and team effort an elegant solution was found.

The System: Expanded Structural Aluminium Beams

The building system is based on light weight expanded aluminium beam bolted together to form the framework for a structure. The light extrusions minimise the need for structures to have to bear the burden of excess dead weight. These sections give an excellent strength to weight ratios. The short member lengths and their lightweight nature (heaviest single part is approximately 50kg), enable the majority of structures to be constructed on the ground and lifted into positions without the requirement for heavy lifting gear.

The system lends itself readily to arch form buildings and to remote areas, where transport and erection facilities may be problematic. In addition since all parts are jig drilled and interchangeable, where required, the structures can be easily dismantled and moved to new locations.

The members selected for the project were 475mm and 200mm deep sections, with a maximum length of 5 metres. These sections are I-beam shaped and weight 12.5kg and 2.5kg per metre, respectively.

The beams are expanded extrusions of the structural aluminium alloy 6063-T6. Laboratory testing of the sections was carried out to formulate safe load tables and an acceptable design procedure. These tests were verified by computer simulation of the models, by the Sydney office of Scott Wilson Irwin Johnston, which found that the sections would perform adequately and equally would comply with AS/NZS 1664: Aluminium Structures.

Design of the Superstructure

Building Description

The building was required by the client to manufacture tile adhesive for the Chinese market. An open plan, column free floor area, of approximately 1300 square metres, was specified, along with a clear height requirement of 18m to allow for the installation of a gravity fed tile adhesive machine, which would occupy approximately 30% of the floor area.

The client wanted a structure that could project a high tech and innovative image for the company. A statement amongst the relatively ordinary surrounding buildings.

The building envelope designed by the Architect, Bosco Seeto, consisted of three half-arched structures, placed in line, each approximately 15 metres wide with an arch span of 25 metres. The height of the arches to these segments are 12 metres, 13 metres and 18 metres high respectively.

The cladding to the building consists of 0.7m aluminium sheeting, incorporating translucent sheeting, with low level windows and a glazed, aluminium framed entrance foyer. Enclosed mezzanine offices were provided.

The substructure of the building consists of a in-situ concrete suspended slab, supported on concrete piles through fill material into the underlying natural ground. Scott Wilson Irwin Johnston provided the column loads and the slab and piles were designed by a local Chinese consultant.

The structure to each segment consist of half-arch frames generally at 4.5m centres, spanning from ground level to the top of Ampliform columns, varying in height from 12m to 18m. The Arch structures and columns were formed by bolting together 4 metre lengths of 475mm deep sections, using a combination of proprietary and specially designed full depth connectors. To support the roof sheeting, 200mm deep sections, generally at 2m centres were utilised as purlins. For the vertical wall sheeting, 200mm deep sections at 2.25m centres were used as girts.

The glazed entrance foyer was designed as a two pin braced structure, supported at ground level and at a horizontal truss at roof level.

Design Loading

The dead and live loadings for the structure were derived from AS 1170: Minimum Design Load on Structures; Dead and Live loading and load combinations. The structure was checked against AS1170-4 Earthquake loads as a Type I structure and as a Design Category A building, it was not required to be analysed for earthquake forces.

The aluminium structure itself was designed to AS/NZS 1664: Aluminium Structures, and this code was used as the basis for confirming the capabilities of the system.

From the building configuration and site location it was obvious from the outset that the critical loading cases would be those incorporating windloads.

The local Design Institute required that the structure be designed in accordance with the PRC wind code, which specified that the site was located within a cyclonic wind loading area.

From the PRC wind code, a characteristic value for external wind loading, normal to building surface was obtained. However, we were unable to determine from the code, the appropriate internal pressure and suction values. A further consideration to be resolved was that the PRC code is based on a maximum mean wind velocity, with a return period of 30 years, where as AS1170.2: Wind Loads is based on peak gust windspeeds with a return period of 50 years.

Through Scott Wilsons' extensive experience in the design of structures within PRC and through consultation with our Melbourne and Jiangsu offices, a method of converting the PRC code wind velocity to an equivalent Australian wind velocity was derived. With this equivalent wind velocity, a detailed static analysis was carried out to enable an accurate assessment of the wind loading to be applied to the structure.

Design Concept

When Scott Wilson were appointed as consultant for the structural design of the factory, some preliminary design schemes were already being considered.

One scheme involved tall reinforced concrete columns to provide horizontal restraint to the arched sections. The scheme was not ideal and resulted in large diameter columns. Concern was also raised with regard to the quality of the local concrete available. Furthermore the design looked ungainly and was a fundamental departure from the initial scheme of a full aluminum structure.

An alternative design proposed, consisted of a large steel spine truss spanning longitudinally at the position of the intersecting arches. This truss was to be supported on columns at each gable end of the building. Due to the relatively long span of the building (48m) the proposed truss depth began to intrude on the clear height requirements of the gravity feed tile-grout machine. The truss option also had to be dismissed on the basis of a lack of elegance and too high a cost.

To achieve the 25m clear span, with a 475mm deep section, would have been ambitious using traditional steel members. The added complexity of using the structural aluminium system, in a way that had not been attempted before, was challenging. Due to the free boundary conditions on the aluminium system, the arch to act more like a beam than a typical arch structure. Consequently such a structure would have been significantly unacceptably flexible. A structural system which would reduce deflections and transfer the lateral loads on the arched members was required.

After several brainstorming sessions, Scott Wilson devised an intricate wind frame system, utilising the two external and two internal gable walls as rigid wind walls. Strategically placed wind trusses were located within the roof plane to transfer the horizontal component of these loads to the gable walls.

To accurately assess the complex interaction between the members and the bracing system, an elaborate, three-dimensional model was developed using a Microstran analysis package. Once the structure had been modeled and analysed, the position of the roof bracing was adjusted to keep deflections within the allowable span/250 limit.

The gable walls were critical in transferring the wind load from roof to the ground. Consequently, it was essential for the walls to act as rigid diaphragms. With the external gable walls the lack of significant openings meant that a straightforward braced structure was adopted. However, the internal gable walls had to be open below the arch intersection. To achieve the rigidity in these walls 200mm deep members were placed between the two adjacent arches and cross-bracing was strategically placed between the adjacent arches to form a rigid truss.

Each half-arch segment contains cross bracing at both the top and bottom of the arch. This bracing, by stiffening the top and bottom of the arch, helped in reducing the arch span. To further reduce deflections, additional rows of cross-bracing were placed, generally at the centre of the arch, spanning between the wind frames. Where the wind load was critical the orientation of the cross-bracing effectively formed a two dimensional truss, acting in both vertical and horizontal planes, enabling a rigid spine to be created along the length of the building.

With the introduction of the bracing system, high tensile loads of up to 110kN were induced within the cables. The relatively low bearing capability of aluminium meant that special galvanised connectors had to be fabricated to transfer these loads to the Ampliform members. These connectors were isolated from the aluminium, by the use of a backing tape to minimise the risk of electro-chemical corrosion between the dissimilar materials.

Connection Design

Due to the building location in a cyclonic zone, high uplift wind loadings were induced within the purlin members. The combination of this uplift force and the length of the span required that intermediate purlins be added in the end spans, of the two external segmental arched sections.

To verify that the bearing strength could be achieved in the alluminium, small scale testing was carried out on the purlin end connections. A simple testing platform, utilising a prestressing jack to induce the uplift wind load, was set up and deformations noted as the load was gradually increased. The test results, backed up extensive detailed analysis, showed that while generally the standard M10 bolts were sufficient, in a number of purlins on the larger spans, M12 bolts were required in lieu of the standard M10 bolts.

Construction, Fabrication, Erection and Maintenance

The beams are manufactured much the same as expanded aluminium as used in door screens. The beams are extruded before being punched with slotted holes. The flanges are then gripped and pulled apart with hydraulic jacks to form the required depth of beam.

The slotting procedure is critical. Fine tolerances are required in order to ensure the accuracy of the slotting, which could affect deformation and twisting of the web and flanges of the beams in the untempered state. The completed beams are than artificially aged to T6 properties.

The three arched sections of the structure were constructed at low level with the use of A-frames and pulleys using a simple repetitive procedure. When the arches were complete, the column members were pinned to the ends on the underside of the arches. The ends of the arches were then raised by crane into their final positions with the column members rotating into position. The bottom ends of the column members were furnished with temporary wheels.

The required maintenance is regarded as negligible due to the structure being constructed predominantly of aluminium.

Conclusion

This presentation can only give a flavour of this unique project which required painstaking work from everybody concerned. The project presented a major design and construction challenge to Scott Wilson and Craig Fyall Consulting and involved extensive interfacing whilst the structure was being assembled and erected. The programme and cost restraints were onerous and were only achieved through excellent teamwork and co-ordination.

The project demonstrated that through the use of innovative methods of design, aluminium systems, can be used to develop structures with significant spans, which are both aesthetically pleasing, light-weight and relatively cost-effective to construct