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INNOVATIVE DESIGN AND ERECTION SOLUTION FOR PORTAL FRAME INDUSTRIAL STEEL BUILDING ROOFS

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Traditional design and erection of long span steel portal frames for industrial buildings consists of individual column and rafter assemblies, with bolted connections at knee (Column-Beam) and apex joints (ridge). This method ensures expediency for an offsite member fabrication and application of the galvanized coating to individual members, before transportation to the work site followed by assembling and erection at the site. This traditional approach however also inherits safety risks associated with working at heights during member erection, alignment and jointing of individual member connections and during placement and fixing of cladding elements. In view of expediting the onsite construction and to mitigate the risk of working at height during erection, designers worked in tandem with contractors and fabricators to rearrange roof elements so as to allow the whole roof to be pre-fabricated on the ground and be lifted for installation matching with the column alignment. In particular, the portal connection at the column-beam knee joint was relocated and redesigned to suit installation ease. The impact of the proposed solution to the design is investigated herein. A rigorous risk analysis was employed to better understand the modes of failure and frame behavior, which in turn assisted in better identifying the design risks. Furthermore, the benefits achieved in the erection process through increased safety and efficiency are also highlighted.

Keywords: Steel frame erection, Plastic analysis, Working safety risk.

1 INTRODUCTION

MWH was appointed by Origin Energy to provide detailed design services for two water treatment facilities as part of the Australia Pacific LNG (APLNG) project. The detailed design consisted of two 40 mega-liter per day (Ml/d) microfiltration/ion exchange/reverse osmosis water treatment plants in Condabri Central and Reedy Creek, QLD, Australia. Following the successful completion of the detailed design phase, Origin Energy further contracted the MWH design team to support ongoing construction activities, addressing contractors RFI queries, QA/QC inspections through frequent site visits and in some instances, value engineering the contractor proposed design alterations to expedite construction.

In one such instance, structural engineers worked closely with the client, contractor and steelwork fabricators to study, develop and implement an innovative solution for the Membrane Filters/Reverse Osmosis (MF/RO) building. The building was designed as a portal frame structure with a footprint of 26.8 m/45.9 m width and 142.5 m length. This new solution was aimed at accomplishing easier, faster and safer steelwork fabrication/erection and required rearrangement of portal frame connections.

2 TRADITIONAL DESIGN OF MFRO PORTAL FRAME

Traditional portal frame design typically consists of several parallel moment resisting frames across the width and bracing along the length of the structure. The base plate connection is either moment resisting or pinned connection, wherein the latter is more popular amongst the designers. Designers account for transportation constraints in their design, as individual structural elements such as columns, rafters, tie beams, roof/vertical bracings, purlins and girts are usually fabricated off-site, coated and then delivered to the work site. Furthermore, designers also consider the erection constraints at the work site such as crane lifting capacity and assembling logistics. The same general rules were used for the design of the MFRO portal frame building as shown in Figure 1 below.

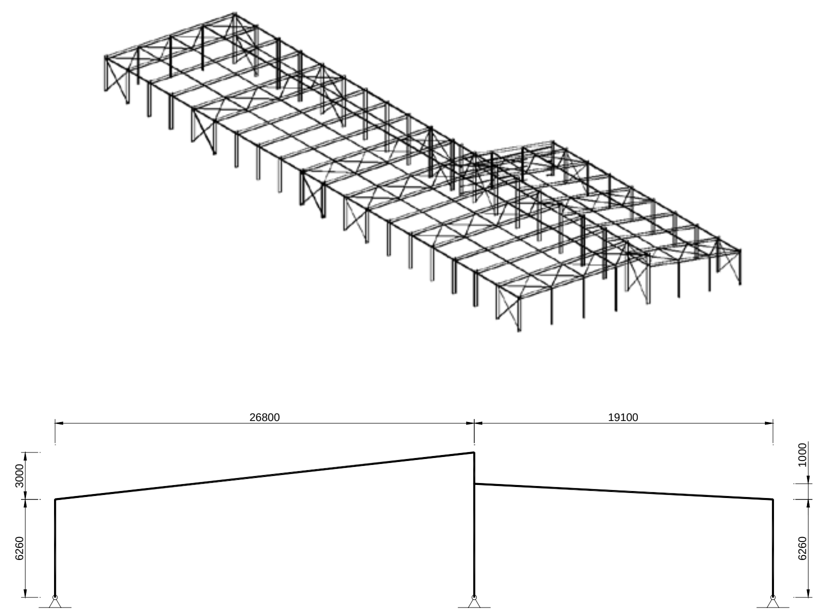

Figure 1. MFRO building structure (dimensions in mm). 3D model of the structure (top) and a typical portal frame (bottom).

Design loads and load combinations on the building were determined in accordance with AS1170.0, AS1170.1, AS1170.2 and AS1170.4. The structural design was carried out in compliance with the requirements of AS4100. The initial break down of the structure to rafters and columns is shown in Figure 2.

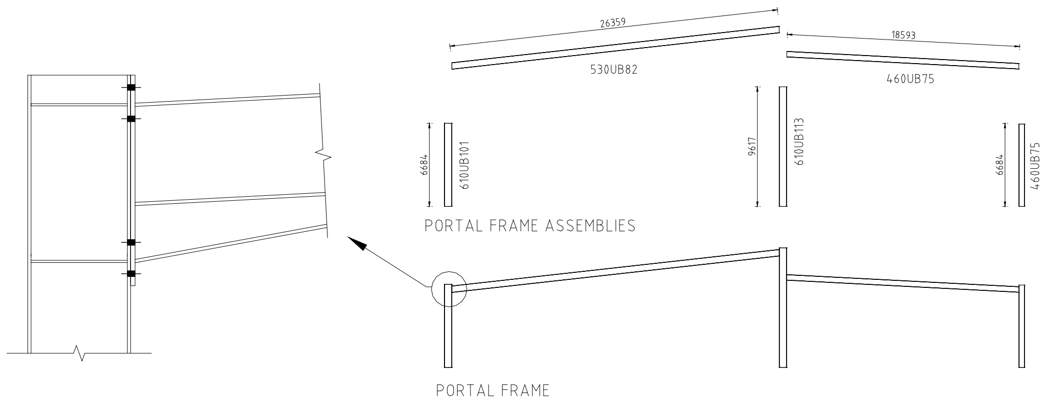

Figure 2. Initial portal frame assemblies.

3 CONSTRUCTABILITY AND SAFETY REVISITED

The MFRO building roof design was revisited and revised following a request from the client to consider an alternative arrangement to assist the contractor with faster and safer roof assembly and erection. The major change to the portal frame design was to move the location of the rafter-column connection from the side to the top of the column (under the rafters, Figure 3). This change allowed the contractor to fabricate a large part of the roof on the ground and lift it to the top of the columns.

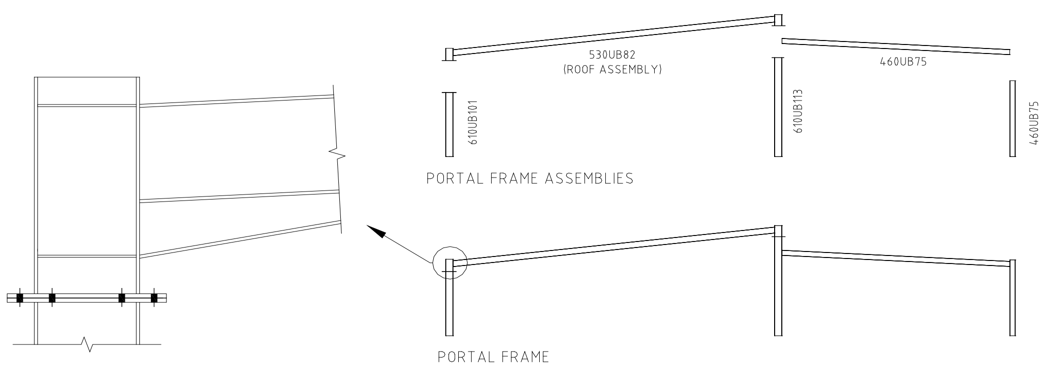

Figure 3. Revisited connection arrangement and assemblies to allow for roof assembly on the ground.

MFRO building steelwork elements were independently fabricated, hot dipped galvanized and then transported to the work site. The building columns were erected first and restrained using a temporary bracing system as shown in Figure 4.

The building roof was segmented into smaller panels with the sizes restricted by crane lifting capacity. Roof panels were then set out and assembled on leveled ground beside the building site. Each roof panel consisted of a part column, rafters, purlins, bracing, insulation and cladding.

On the ground, assembling allowed for easy access to the roof elements and greatly minimized the safety risks associated with working at heights despite the fact that the number of end plate connections was unchanged. This new arrangement also allowed for easier bolt fastening when the roof was lifted and placed in its final position.

Figure 4. Roof panels assembled on the ground.

Each one of the roof panels was then lifted using a 4 point lifting auxiliary frame suspended from a 200 Ton lifting crane. Roof fixers were simultaneously lifted and positioned at each of the column-rafter joints using elevated work platforms (cherry pickers). The panel was then perfectly aligned on the respective column location and then fixed in its final position as shown in Figure 5.

4 DESIGN CONSIDERATIONS

A series of plastic analyses were undertaken to better understand the impact of the revised connection arrangement and to assess the stability of the frame under vertical and lateral design load combinations. For lateral wind loading, various internal pressure scenarios combined with external wind loading were considered and the most critical one was identified. Based on the design sections and loading combinations, collapse mechanisms were determined as shown in Figure 6 using a nonlinear finite element analysis assuming elasto-perfect plastic material for steel.

Figure 5. Lifting and fixing of the pre-assembled roof panels.

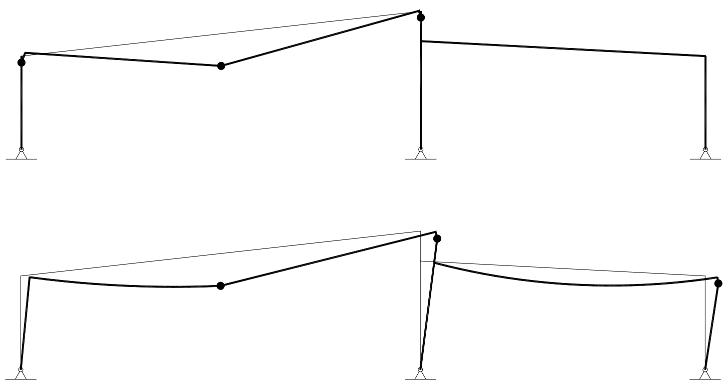

Figure 6. Collapse mechanism for vertical (top) and lateral (bottom) load.

It was observed that the vertical load mechanism was a local mechanism for the long span rafter, and the local haunch of the rafter caused the plastic hinge to be shifted to the uppermost section of the column where the section was weaker and an axial force-bending moment combination was more onerous. Similar behavior was seen for the lateral wind loading where plastic hinges were created at the highest point of the middle and end column (Figure 6).

This put the plastic hinges at the location of the new proposed connection which resulted in about a 17% lower ultimate frame capacity for the lateral wind loading (the end plate connections were not designed to develop full member strength). Furthermore, the frame ductility was reduced about 7% for lateral wind loading, measured with respect to the original design (Figure 2).

If a more ductile behavior was demanded the columns and beams could have been resized to ensure the plastic hinges were created at the rafter ends (which is a more favorable condition for the overall stability of the frame). For the MF/RO portal frame building, the reduced ductility was deemed to be acceptable in view of meeting design and performance requirements; hence member sizes were not revised.

5 CONCLUSION AND RECOMMENDATIONS

MFRO building portal frame design was revisited on the client's/contractor's request in view of expediting construction and reducing risks associated with working at heights. Rearranging the end plate connection from the rafter end to the top of the column enabled the contractor to assemble the whole roof in smaller panels and lift it to its final location. This reduced the duration of working at heights particularly that required for the installation of purlins, tie members and roof cladding.

Additionally, this process allowed a number of activities to be executed in parallel and reduced construction time to meet the project targets. Although maintaining the same design sections reduced ultimate frame capacity and ductility, it was considered acceptable given the performance requirement of the structure.

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