

Enhancing Steel Structure Erection Efficiency through Mini Modular ‘Cap Structures’ in Gas Processing Projects ¹

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Abstract

This paper presents a constructability approach for the assembly and erection of a Steel-Structure Branch Piperack that extends from the Main Piperack and provide connectivity to associated Vessels and Exchangers. This approach has been studied and implemented in Saudi Aramco’s Fadhili Gas Increment Project (FGIP). The concept introduces a mini-modular strategy of the elevated segment of a branch Piperack, known as the Cap Structure for steel-structure pipe-rack erection, which is pre-assembled separately and lifted as a single modular for final installation in top of the erected stick built steel structure, combining the flexibility of the stick-built method with the efficiency of modularization. This approach significantly reduces work-at-height exposure, allows parallel progress between ground-level and elevated works, and shortens total erection duration by approximately 50% in comparison with conventional methods of installation. The methodology provided improvements in safety and efficiency, offering a replicable model for future projects that are similar in nature.

1 Introduction

Steel structure erection is one of the most critical activities in large industrial and gas-processing projects. Conventional stick-built methods rely on sequential assembly and bolting at height, which exposes workers to elevated hazards and extends the overall execution timeline. In contrast, modular construction offers safer and faster assembly at ground level but is often constrained by transportation limits, crane capacities, and complex interface management.

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To address these limitations, the project team in FGIP developed a hybrid field innovation called the Cap Structure. The method isolates and pre-assembles the uppermost portion of tall steel structures at ground level as a compact mini-module, which is later lifted into place. This strategy bridges the gap between stick-built and modular construction, allowing the project to capitalize on the advantages of both systems.

The main objectives of introducing the Cap Structure were to enhance safety by minimizing work at height, accelerate schedule performance through parallel work execution, and avoid the limitation of maximum height level in manlift.

2 Cap Structure Concept and Design

2.1 Concept Overview

The Cap Structure represents the highest section of a steel structure equipment designed for full ground-level assembly prior to installation. It incorporates all primary and secondary members, platforms, handrails, and access ladders connected through bolted joints to achieve precise alignment. After pre-assembly and quality verification, the completed segment is lifted and installed on top of the lower stick-built frame using a single, well-coordinated crane operation.

The idea emerged during constructability reviews when the team identified that isolating the upper tier could significantly improve safety and progress without changing the overall structural design. By treating this upper segment as a self-contained mini-module, most work traditionally done at elevation was shifted safely to ground level.

2.2 Design Philosophy

The Cap Structure was designed as a stable, liftable steel assembly capable of maintaining dimensional accuracy throughout pre-assembly, lifting, and installation. The design philosophy emphasized structural integrity, lifting safety. Stability was achieved by ensuring adequate rigidity during ground assembly and by defining precise sling locations and center-of-gravity points for balanced load distribution.

Weight verification confirmed that the total mass remained within crane limits while maintaining safety margins. All interface connections were detailed as bolted splices to allow quick alignment and secure fit-up at elevation. A detailed 3D model and sketches were prepared to validate lifting

geometry, clearances, and bolt-hole alignment before fabrication. Ground-level assembly planning also included safe access and working platforms to minimize work at height and facilitate accurate torquing and inspection.

This integrated design approach combined the safety and productivity benefits of modularization with the adaptability of stick-built construction, ensuring controlled execution and efficient installation.

2.3 Key Advantages

The Cap Structure concept delivered clear improvements in construction performance across safety, schedule, and quality dimensions. Ground-level assembly virtually eliminated elevated bolting and inspection activities, greatly reducing exposure to fall hazards. Parallel progress between the lower stick-built frame and ground-level pre-assembly allowed faster overall completion, reducing erection duration from 79 days to 36 days. Controlled conditions improved alignment accuracy and bolting quality, while optimized manpower distribution enhanced productivity.

The successful application of this mini-modular strategy in FGIP demonstrates its potential as a standard approach for similar tall structures in gas-processing and industrial projects, supporting Aramco's wider objectives for innovation and safe project execution.

3 Implementation in FGIP

The Cap Structure Concept was implemented in FGIP through a controlled sequence of ground-level pre-assembly, inspection, lifting, and final bolting. The entire operation was coordinated between Saudi Aramco PMT, contractor team and site safety representatives to ensure that engineering and safety requirements were fully achieved. As shown in Figure 1, the 3D model of the Cap Structure was used to plan the lifting geometry, verify the design, and brief the field team on the execution steps.

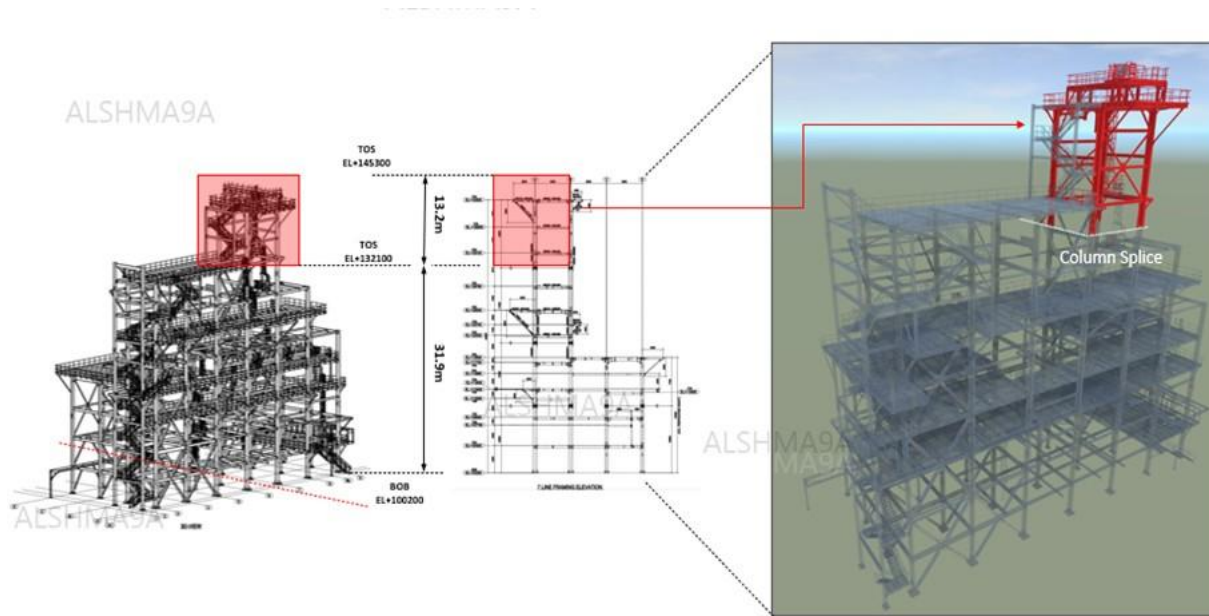


Figure 1: Cap Structure Selection and 3D Representation.

3.1 Pre-Assembly at Ground Level

The Cap Structure components were assembled on a compacted and leveled lay-down area near the main structure. Primary and secondary members were connected using bolted joints to form the complete upper module. Temporary supports were used to maintain correct geometry and alignment during assembly. This approach improved safety and productivity by minimizing work at height and providing full ground-level access for torquing and inspection.

The mini-Modular is implemented in Fadhili Gas Increment Project in Process Area exactly in the steel structure stick built for Acid Gas Enrichment Regeneration (AGE) Column and Acid Gas Removal Regeneration (AGR) Column. The weight of the mini modular for AGE Regeneration Column is 38 tons 14.3m height 7m width and 6m length. The weight of the mini modular for AGR Regeneration Column is 46 tons 9m height 6m width and 11m length.

3.2 Inspection and Readiness for Lifting

After pre-assembly, as shown in figure 2 the structure was inspected for dimensional accuracy, bolt torque, and interface alignment. The lifting plan, rigging configuration and crane selection

were reviewed and approved before the operation. Weather conditions and ground bearing capacity were also checked to confirm readiness. For lifting a 450-ton capacity crawler crane with a 70 m boom height was used.



Figure 2: Mini Modular on ground

3.3 Lifting and Installation

Lifting was executed under a controlled sequence: a trial lift to verify balance and rigging stability, followed by steady hoisting to elevation with tag lines controlling sway and rotation. As shown in figure 3 the structure was aligned to the lower stick-built frame, held under partial crane load while initial bolts were installed, then fully secured before releasing the hook. Four manlifts operated simultaneously for bolting and torquing activities. Complying with Saudi Aramco Standard lifting activities were executed during the night shift due to the lower wind speeds observed at that time.

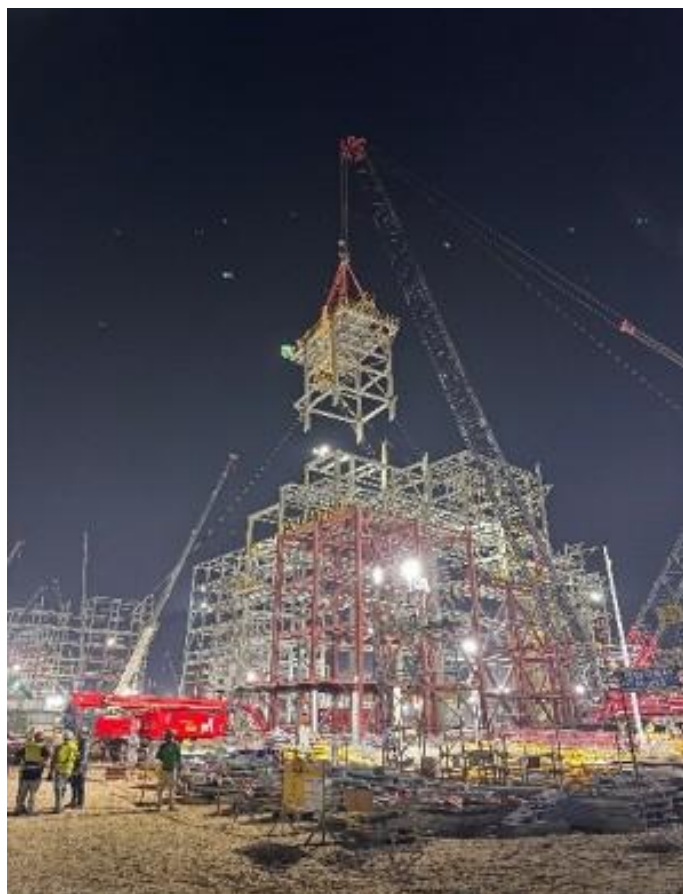


Figure 3: During lifting of the Mini Modular.

3.4 Final Bolting and Verification

Final bolting was completed to secure the structure permanently. Bolts were tightened to the specified minimum bolt values for metric sized high strength bolts shall be determined using an equal percentage of the specified minimum tensile strength as defined for U.S. customary units in the RCSC Specification for Structural Joints, in accordance with ASTM F3125/F3125M Grades A325/A325M and A490/A490M [1], and the crane load was gradually released.

A post-installation inspection confirmed that the structure was level, aligned, and within tolerance as shown in figure 4.

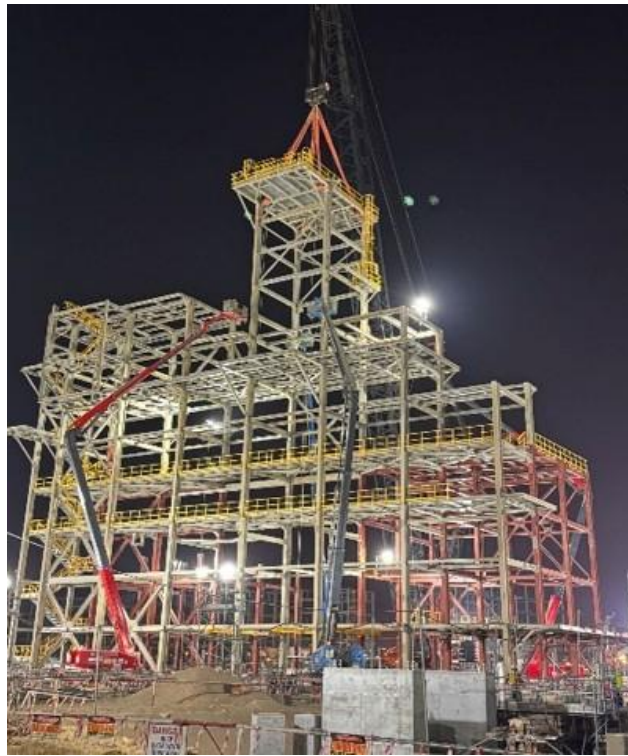


Figure 4: During Erection of the Mini Modular.

3.5 Summary of Implementation

The successful installation validated the Cap Structure as an efficient and safe construction method. Ground-level assembly and controlled lifting minimized high-risk activities and reduced the overall erection time significantly.

4 Results and Benefits

4.1 Safety Improvement

The Cap Structure approach reduced work at height by shifting bolting, torquing, and inspection to ground level, which lowered exposure to fall hazards and reduced dependence on manlift. Lifting was executed with lower wind speeds condition, improving stability and control of the suspended load. The activity was completed without recorded safety incidents.

4.2 Schedule Acceleration

4.2.1 Acid Gas Enrichment Regeneration (AGE) Column:

Compared with the Typical erection method 47 days with production rate of 1 ton per day for each crane, the Cap Structure execution finished in 25 days, achieving a 22 days reduction (47% faster) as shown in figure 5. The gain was driven by parallel execution of lower stick-built portion proceeded while the upper “Cap” module was assembled.

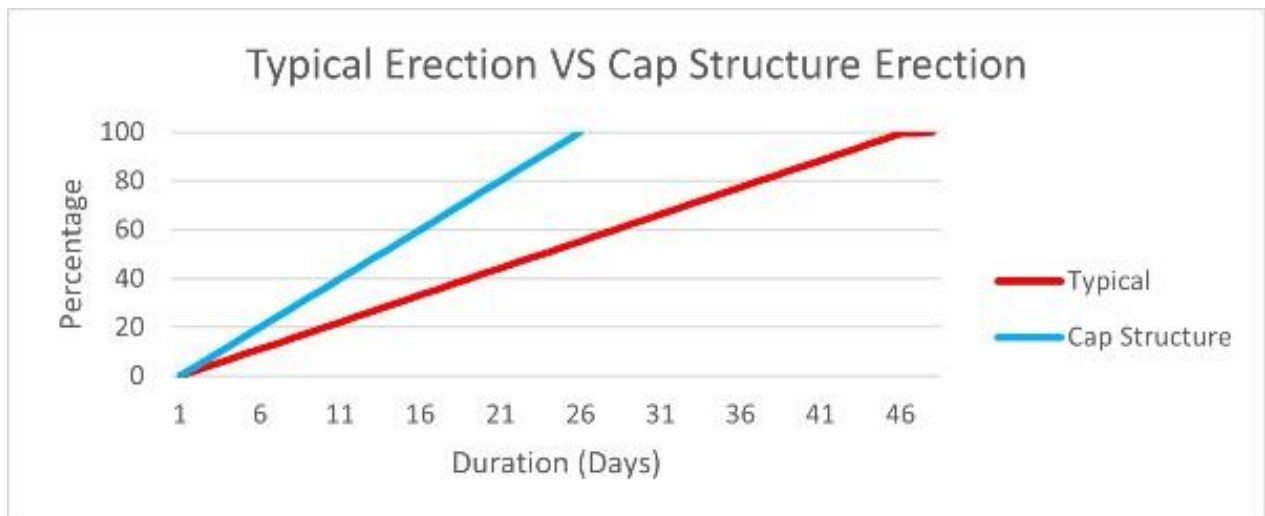


Figure 5. Erection schedule comparison Typical method: 47 days vs Cap Structure: 25 days (22 days earlier).

4.2.2 Acid Gas Removal Regeneration (AGR) Column

Compared with the Typical erection method 79 days with production rate of 1 ton per day for each crane, the Cap Structure execution finished in 36 days, achieving a 43 days reduction (55% faster) as shown in figure 6. The gain was driven by parallel execution of lower stick-built portion proceeded while the upper “Cap” module was assembled at ground level.

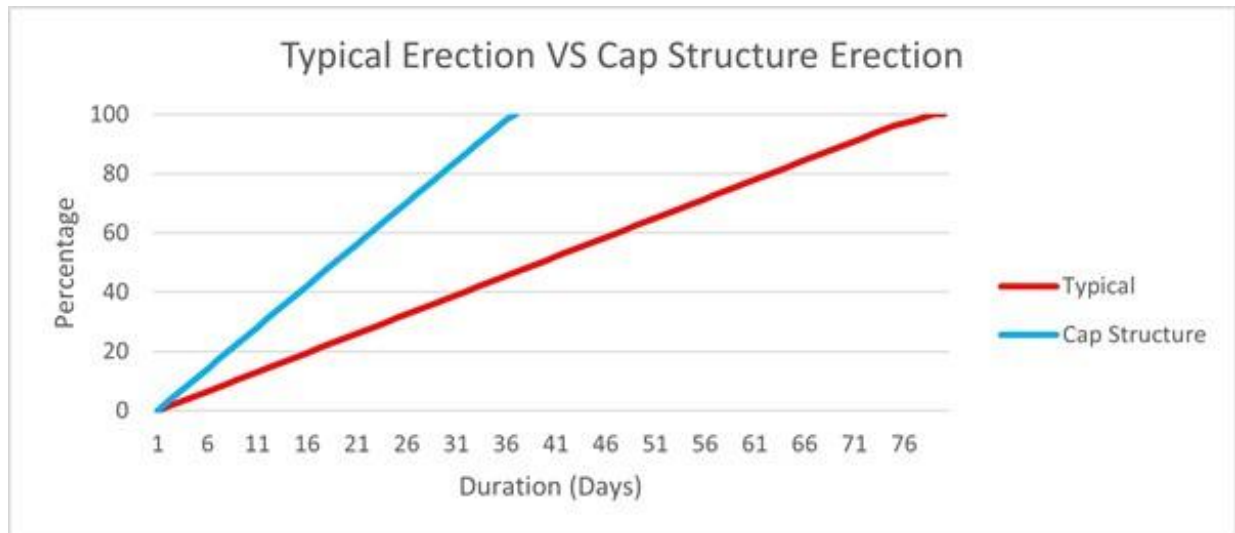


Figure 6. Erection schedule comparison Typical method: 79 days vs Cap Structure 36 days (43 days earlier).

4.3 Quality and Productivity

Ground-level pre-assembly improved fit-up and alignment prior to lifting, enabling cleaner final connections and less rework at elevation. Performing bolting and torque verification at grade provided better tool access and more reliable inspection. In parallel, field resources were utilized more efficiently: crews advanced concurrently on separate fronts, and crane utilization was focused into a short, high-value operation rather than long sequence of individual lifts.

5 Conclusion

The Cap Structure mini-modular approach delivered its intended outcomes in FGIP. By pre-assembling the upper segment at ground level and installing it in a single lift, the method reduced work at height, concentrated crane time, and enabled true parallel execution. The result was a safer workflow, cleaner fit-up at elevation, and a substantial schedule improvement from 79 to 36 days. Successful application on the AGE and AGR Regeneration Column structures confirms that the concept is practical, achievable, and compatible with standard bolted steel erection practices and site safety controls.

5.1 Lessons Learned

- Ground-level pre-assembly improved alignment control and reduced rework
- Verifying module weight and confirming center of gravity were critical to stable lifting
- Sling locations and load distribution must be defined early in the lift study
- Coordinated briefings between the crane crew, manlift operators, and the elevation team minimized delays during final fit-up
- Preparation for lifting one day in advance and remove any obstacle material for the lifting such as gratings and miscellaneous

5.2. Items for Consideration

- Required qualified Rigger I
- Lifting shall be carried out with Heavy load crane
- Limited working space since it requires to suspend nearby activities: To mitigate risks in constrained spaces, the contractor must ensure site preparation per 12-SAMSS-008, including verifying soil compaction standards, removing underground utility hazards [2].

6 References

- [1] RCSC. 2020. Specification for Structural Joints Using High-Strength Bolts. ASTM International. 2016.
- [2] Saudi Aramco. 2021. Erection of Structural and Miscellaneous Steel (12-SAMSS-008).
- [3] Steel Structure Schedule Acceleration in Fadhili Gas Increment Project. Saudi Aramco Internal Report.

About the Authors



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Abdulrahman Shukri is a certified Lead Auditor for Quality Management Systems (ISO 9001:2015) and a Project Management Professional with six years of experience in engineering and executing large-scale oil and gas projects. He currently serves as a Project Engineer on the Fadhili Gas Increment Project at Saudi Aramco, leading Steel Structure activities. His work focuses on project engineering practices, structural systems, and quality management in industrial environments. He holds a Bachelor's degree in Chemical Engineering from Yanbu Industrial College, Saudi Arabia. Mr. Shukri can be contacted at shukri1414@gmail.com



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Abdulaziz Alsoufi is a mechanical engineer with over 8 years of experience at Saudi Aramco, where he has played a key role in critical energy projects and operating facilities. Currently contributing to the Fadhili Gas Increment Project, Abdulaziz brings a robust technical background and hands-on expertise to the design, implementation, and optimization of mechanical equipment. He earned his Bachelor's degree in Mechanical Engineering from King Abdulaziz University, and throughout his career, he has demonstrated a commitment to operational excellence and engineering innovation within the oil and gas industry.



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