Modified Roof Erection System

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Abstract: Conventional steel roof erection for an industrial building is a hazardous operation. It is also labor-intensive and weather-dependent. With U.S. construction trades facing a skilled-labor shortage, and with constructors pressured to shorten construction schedules, a more efficient roof-erection process is needed. To address this need, a design-build contractor developed the Modified Roof Erection System (MRES). The MRES involves erecting roof modules at a level near the ground, then hoisting them into place. Potential benefits of this process include: (1) Increased safety; (2) higher productivity; (3) less impact from skilled labor shortages; (4) shortened construction schedule; (5) better quality; and (6) reduced cost. Prior to implementing the MRES, the following questions had to be addressed: (1) Do we know how to perform such an operation?; (2) will this technology be acceptable to our customers?; (3) will our subcontractors embrace this type work?; and (4) are we willing to accept the risks involved? This paper discusses development of the MRES process and presents a case study of its initial trial.

INTRODUCTION

Conventional steel-roof erection on an industrial building is a hazardous operation. These roofs are usually constructed in-place, at heights in excess of 7.6 m (25 ft). Traditional methods require considerable skilled labor and heavy, expensive equipment, and they are highly dependent on good weather for productivity and quality.

Typically, the roof of an industrial building is erected by ironworkers aloft. Structural steel members are placed, then metal decking is applied to create a working platform for future rooftop operations. Materials for the roof are handled by a large mobile crane. Beneath the roof, electrical, mechanical, and fire-protection trades install their materials with manlifts. An erection system in which the roof can be built at a low level, then hoisted into place, would greatly reduce safety hazards, allow the use of smaller cranes, and create a more efficient environment for all trades involved.

This paper describes a process, the Modified Roof Erection System (MRES), developed by James N. Gray Construction Company, to address six important areas: (1) Safety; (2) productivity; (3) labor shortage; (4) schedule; (5) quality; and (6) cost.

During the development of the MRES, the company addressed these questions: (1) Do we know how to perform such an operation?; (2) will this technology be acceptable to our customers?; (3) will our subcontractors embrace this type work?; and (4) are we willing to accept the risks involved?

This paper also describes initial use of the MRES on a project.

COMMENT

The company had a contract to erect a steel industrial building of 13,378 m^2 (144,000 sq ft). The erection window between the funding date and the

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required production date occurred during the coldest months of winter. A team was formed consisting of the project manager, structural engineer, project engineer, and superintendent, plus a vice president and a construction engineering consultant (the writers). The team's mission was to devise a plan to minimize the impact of inclement weather on the steel erection. The team established these rules: (1) The process must be safe; (2) the process must allow for reverting to conventional erection if problems jeopardize the schedule; (3) a reasonable increase in cost is acceptable for this prototype process; (4) all increases and decreases in cost and time need to be accounted for; (5) the steel subcontractor must endorse use of the process; and (6) the process will be called the Modified Roof Erection System (MRES).

The two approaches that seemed most promising were to prefabricate roof sections on the ground and then either lift them into place with large cranes or lift them vertically into place with stationary equipment. Because of site restrictions and the expense of renting large cranes, the latter approach was chosen.

Two approaches were considered for lifting the roof sections: screw jacks, such as those used in lift-slabs, and cable hoists. Expense and availability argued for cable hoists.

The team developed a preliminary erection and lifting plan, obtained costs for the necessary equipment, and solicited bids from steel subcontractors. The team then worked with the selected subcontractor to finalize plans for using the MRES on the project.

MRES benefits lay in six important areas: (1) Safety; (2) productivity; (3) labor shortage; (4) schedule; (5) quality; and (6) cost.

Safety problems associated with conventional roof erection come from workers aloft; common incidents include falls and the dropping of tools and materials on workers below. Working at a level near the ground greatly decreases these hazards.

Productivity suffers when workers are working aloft, because they are tied off with safety lines that hamper their efficiency, and because of the time needed to ascend and descend, which in the case of electrical, mechanical, and fire-protection trades often exceeds the time spent actually installing materials, and the time necessary to handle materials with a large crane. The MRES will allow worker access by ladder or stool and permit material handling by small cranes or forklifts, which will also decrease site congestion.

Labor shortages in skilled trades are predicted. The MRES will lessen the impact because of the larger pool of workers willing to work at lower levels.

Schedules will be improved by higher productivity and the ability to work during weather conditions less favorable than those required by the conventional method. Working at a low level with some protection from the existing structure allows work to proceed in wind, rain, and snow conditions that cannot be tolerated aloft. It is even possible for portable, temporary shelter to be used.

Quality will be improved because of increased supervision possible when crews and work are easily observable. Most of the structural members and connections can be observed, and many even touched, from positions on the ground, and topside work is only a stepladder away.

Cost will decrease using the MRES because of the factors mentioned earlier. It is expected that as the MRES roof modules get larger, it will become increasingly cost effective for electrical, mechanical, and fire-pro-

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tection trades to install their materials at the low level and have only to install connectors aloft. This method should lead to lower subcontract prices. However, small cost increases are expected during the first few projects until the process is accepted by all involved.

To determine the MRES feasibility the team asked these questions: (1) Do we know how to perform such an operation?; (2) will this technology be acceptable to our customers?; (3) will our subcontractors embrace this technology?; and (4) are we willing to accept the risks involved?

Do we know how to perform this operation? The answer is a qualified "yes." Yes, we can safely construct a roof module on the ground and raise it to its permanent position. But we are not yet sufficiently confident to perform this operation for a complete roof. Therefore, the prudent approach is to construct and raise the roof in small modules, always using technologies and materials that will allow for expanding the operation to larger modules.

Will our customers accept this technology? Although we can't be sure, it is reasonable to expect that there will no objection if cost, quality, and schedule requirements are the same as on conventionally constructed buildings. As development proceeds it will be important to look for selling points. The fact that the company is engaged in research and development, while many of our competitors are complacent, should be one such point.

Will our subcontractors embrace this technology? Again, we can't be sure, but we can assume the subcontractors will continue to bid. Motivation should come from the fact that if they know we are committed, they will want to be a continuing "partner" in the technology. Also, increased team training should encourage participation.

Are we willing to accept the risks involved? Our anticipated primary risks lie in two areas: increased costs due to additional labor, materials, time, etc., and the risk of physical damage during the lifting operation. Secondary areas of risk lie in possibly creating bad will with equipment suppliers and union labor. In addition to the cost of hoisting equipment, increased resource costs are inevitable during the initial development stages. And although personnel hazards can be minimized, safety of the roof modules may be an initial problem.

TECHNICAL DESCRIPTION

The following is a description of the MRES as it would be used on a typical, small industrial building. The discussion is limited to the building structural components that will be affected by the MRES. First, the construction sequence will be shown, followed by the necessary design changes.

Construction Sequence

Columns are placed in the usual manner. Starting with girders and bar joists, a roof module is then constructed at a low level (Fig. 1).

Next, under-roof materials (electrical, mechanical, and fire protection), decking, and deck-top units are added, and lifting gear is attached (Fig. 2).

One by one roof modules are then raised to their permanent positions (Fig. 3).

Design Changes

These are design changes required from conventional roof erection.

- Moveable seats to support girders at the lower level, and an intermediate level, if needed (Fig. 4).

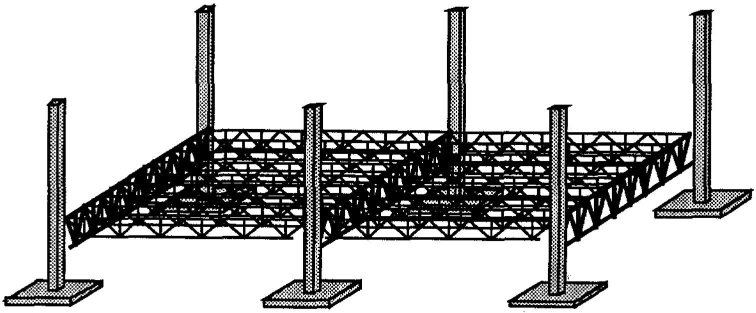

FIG. 1. Roof Module's Structural Components

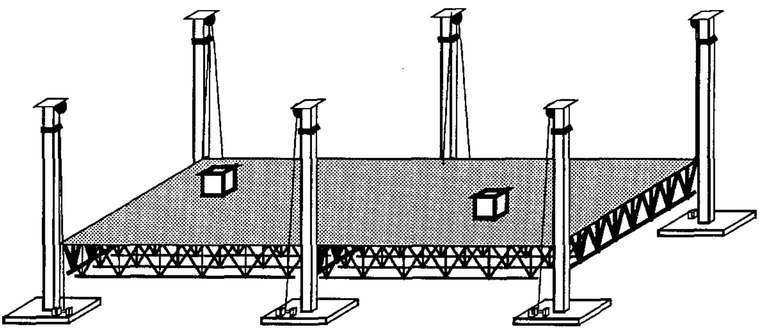

FIG. 2. Roof Module Complete and Ready to Lift

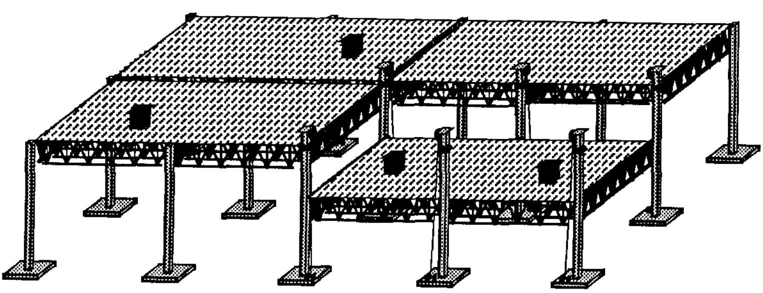

FIG. 3. Roof Modules Being Raised to Permanent Position

- A girder on each end of a module for hoisting (Fig. 5).
- A make-up piece to span the decking between positioned modules (Fig. 6).
- A lifting eye on girder ends to facilitate hoisting (Fig. 7).
- A column extension to locate the lifting mechanism higher than the column top (Fig. 8).
- A stable foundation on which to mount the hoisting motor (Fig. 9).

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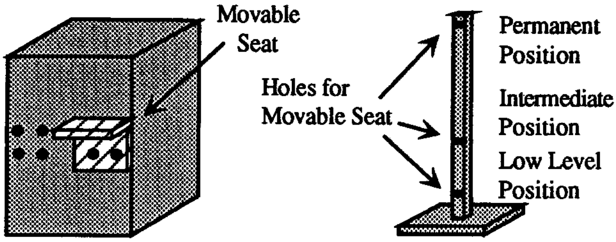

FIG. 4. Moveable Seat

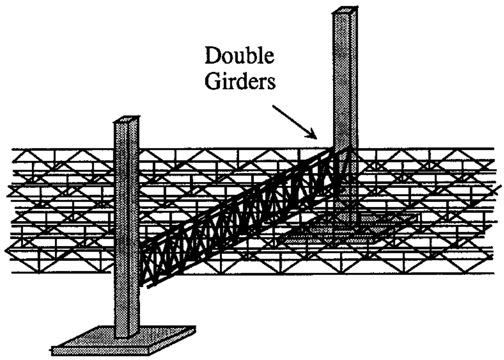

FIG. 5. Lifting Girders

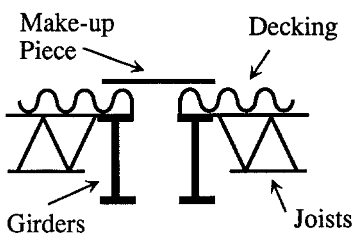

FIG. 6. Makeup Piece

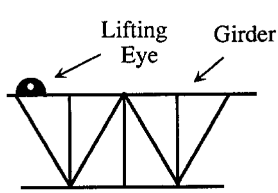

FIG. 7. Lifting Eyes

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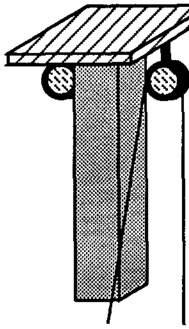

FIG. 8. Column Extension

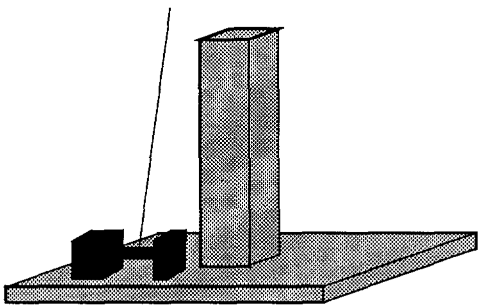

FIG. 9. Hoisting Motor

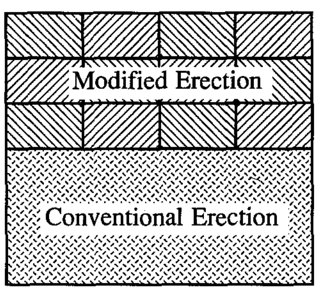

FIG. 10. Roof-Erection Plan

CASE STUDY

Project Description

The initial trial of the MRES was on an industrial building with a plant area of 13,378 m^2 (144,000 sq ft), a ceiling clear height of 7.3 m (24 ft), and 24 bays measuring 15.2 x 18.3 m (50 x 60 ft). Half of the plant was conventionally erected and the other erected with the MRES. The MRES half was erected in 12 two-bay modules (Fig. 10).

A module the size of two bays—18.3 x 30.5 m (50 x 60 ft)—was lifted with air driven hoists. The first half of the building was erected by the conventional method and the second half by the MRES, for three reasons:

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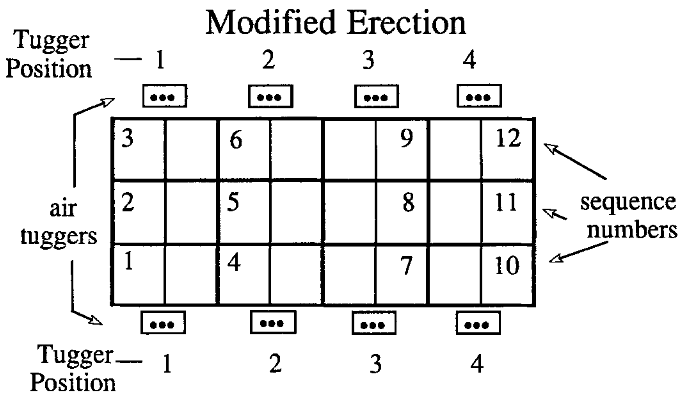

FIG. 11. MRES Sequencing and Hoist Plan

(1) To have a structure that the trades could work on while details of the MRES were worked out; (2) to provide a stable mass to tie the MRES module into (this stability eliminated having to provide column bracing for the initial lifts); and (3) to provide a benchmark for comparing the MRES.

MRES Methodology

A low-level roof height of 2.7 m (9 ft) was chosen. Air hoists (tuggers) were mounted in clusters of three on concrete masses (Fig. 11).

Modules 1–6 were fabricated at the low level. The six tuggers were placed in tugger position 1 and used to lift modules 1, 2, and 3. Next, modules 7–9 were fabricated while the tuggers were moved to tugger position 2 to lift modules 3, 4, and 5. This sequencing continued until all 12 modules were in place.

The erector controlled the MRES, but electrical, mechanical, and fire-protection trades were encouraged to take advantage of the low-level modules to install their materials.

Construction Observations

The MRES exceeded expectations; there were no major problems. Observations related to the six expected benefits were as follows.

Safety was possibly enhanced by reducing man-hours expended aloft. There were no personnel injuries and only minor and easily repairable damage to material—no more than could be expected using the conventional erection method.

Productivity was probably improved for the erector because personnel continued work during inclement weather that would have precluded working aloft. The erector kept a 64 x 10^3 kg (70 ton) crane on site, so the productivity increase expected from use of a smaller crane was not observed. The mechanical subcontractor installed pipe hangers from a ground position.

Labor shortage was not an issue, because the erector used the same crew for both the conventional and modified erection.

Schedule was maintained during the most severe winter weather because steel workers could be productive at the low level. The entire project was completed two months early—a consequence partly attributable to MRES success in inclement weather.

Quality was likely improved because the erector's superintendent and the

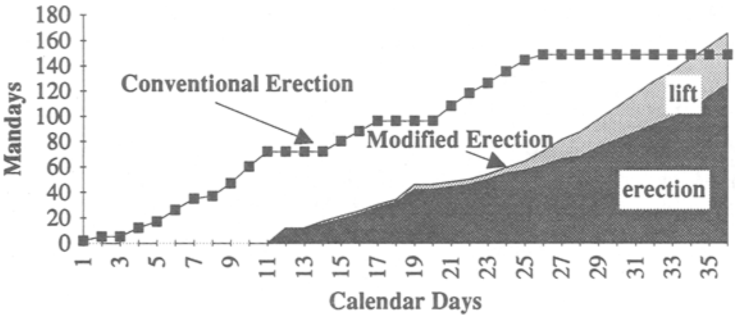

FIG. 12. Labor Utilization

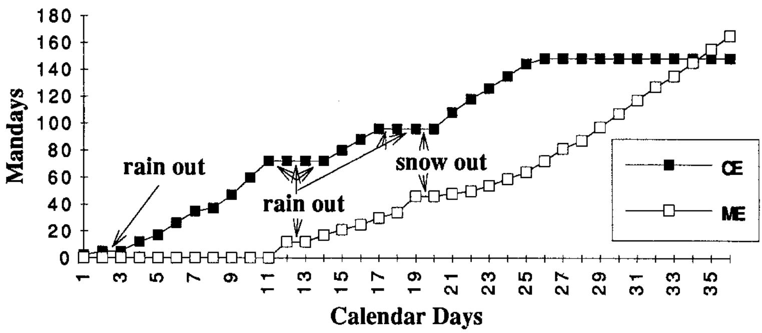

FIG. 13. Conventional versus Modified Erection Schedules

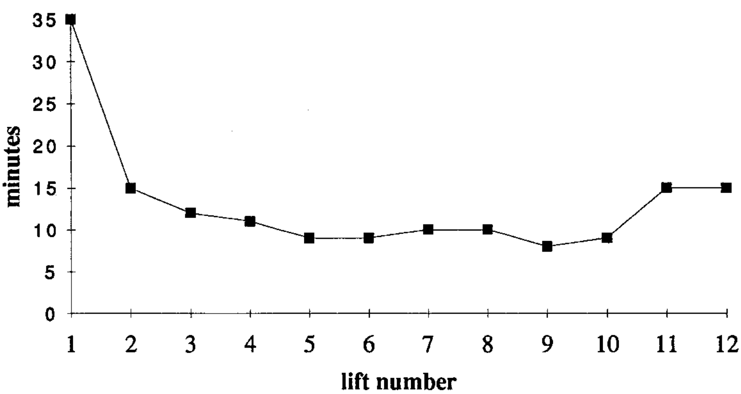

FIG. 14. Lift Times

company's superintendent inspected the work more frequently than they would have if the erection had been performed aloft, and because steel workers were in a more comfortable position.

Cost was slightly higher than would have been expected using the conventional method, primarily because of extra material. However, it isn't possible to tell whether or not the roof could have been erected safely and on time using conventional methods. Also, lessons learned on this site are expected to result in cost reductions on future projects.

COST AND SCHEDULE ANALYSIS

Material and Equipment

Additional cost for the MRES was minimal, due primarily to the cost of lifting equipment. The extra girder on each module and the column extensions created additional cost.

Labor

Total labor utilization for the MRES was slightly higher because of handling the lifting equipment. Labor required for steel erection of the roof section using the MRES was only 85% of that required for conventional erection. Conventional versus MRES labor hours requirements are shown in Fig. 12.

Increased erector man-hours for the MRES were mostly attributable to moving tuggers, rerigging modules, constructing deadmen, installing deck transition plates, welding stabilizing bars to columns, and lifting modules.

Schedule

As shown in Fig. 13, inclement weather affected the conventional erection much more than the modified erection. During the period when both were under way, the modified erection was stopped only 2 days, and the conventional erection was stopped 6 days. It cannot be said for certain that conventional erection could not have proceeded on these inclement weather days, but it is certain that the erector preferred to work on the modified erection close to the ground, either through necessity or by choice.

The labor required for lifting should be able to be reduced significantly on future jobs because of larger module size (i.e. fewer lifts) and additional experience. The steel erection sequence is essentially the same for conventional and modified erection, but the lifting is a new operation.

Workers involved in the lifting operations, rigging, and hoisting, became more productive on successive modules. Lifts times for the 12 modules are shown in Fig. 14. Cable twisting was experienced on the final two lifts, 11 and 12, causing the lift times to increase slightly. Even so, the actual lifting time is very small in comparison with the rigging time.

CONCLUSIONS AND RECOMMENDATIONS

Erection of steel roofs on industrial buildings are common in the construction industry. Conventional erection methods, erecting the roof in place, are fraught with problems. In-place erection is unsafe in the best of conditions and extremely hazardous in inclement weather. Workers aloft must be concerned about their stability and deal with tie-off lines, which detract from their work. Quality is also an issue. Inspectors having to venture aloft don't inspect as closely as they would for erection at ground level.

The MRES has been shown to be technically feasible and shows promise of eventually being economically feasible. It offers potential benefits in six important areas: safety, productivity, labor shortage, schedule, quality, and cost.

The MRES was a success, not only did it accomplish its goal, to provide a safe, economical method for erecting a steel roof in inclement weather, it also showed that teamwork and constructability studies can effectively meet new challenges.

As was expected the MRES prototype provided many lessons. First, it showed that careful planning paid off in the successful completion of the trial run. Second, it identified numerous areas where improvement can be made for future projects.

Future efforts should address the following:

- Improved lifting mechanism that allows for better elevation control and shorter rigging time
- Mounting of lifting mechanism that utilizes existing foundations
- Optimum low level elevation(s) to facilitate work of subcontractors
- Wagon to transport materials under roof module at low level
- Alternative designs that take advantage of the MRES, improving constructability
- Coordination among designer, erector, and field managers to optimize low level fabrication
- Ways to facilitate low level installation of electrical, mechanical, and fire-protection systems

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