

Constructability Part IV

CONSTRUCTABILITY DRIVES STRUCTURAL DESIGN AT FORD FIELD

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This article is the fourth in a series on Constructability. In the first three of the series, Constructability was defined and the stages of Constructability outlined. The impact of integrating this philosophy at various stages of design was examined — at the bid stage and during planning and conceptual design (when it can be maximized). This article focuses on the application of Constructability to solve tough challenges that required resolution during the construction of Ford Field, home of the Detroit Lions.

Overview

Constructability adds another dimension to structural design: it induces construction knowledge and experience into the design process; thus enhancing the decision matrix encouraging questions such as “What are the site constraints?”; “Are the foundation construction constraints compatible with the superstructure concept?”; “Is material availability an issue?” and “Is the material of choice the proper material, based on site, schedule and constructability?”.

Designers generally do not consider such conditions when developing the design concept and subsequent design documents. However, such conditions may dramatically impact the schedule and cost of the structure. Loads induced during installation may be significantly larger or opposite in sign from the original code-defined design forces. In fact, the installation forces are real loads, not code-defined. Their magnitude and direction must be considered, and the permanent member sizes and connections must be modified to handle the worst case scenario — even though this condition exists only briefly during construction. In addition, material availability, availability of skilled labor, preferred regional practice and construction sequencing also play a major role in the overall project cost and schedule. All of these elements populate the decision matrix and must be considered to provide an effective, efficient structural solution.

Ruby+Associates has performed a number of Pre-Construction Constructability Reviews on major stadiums and arenas. Smith Group (Ford Field Architect / Engineer of Record) retained Ruby to perform a Constructability review of the 35 percent completion documents (12 months prior to bid). During this review, recommendations were developed that drove the final design and construction of two main elements of Ford Field:

- The SuperColumns
- The roof truss system

Later, Ruby became involved in the development of the strand-jack lift procedure for lifting the roof structure. The following describes the challenges and the solutions that were developed for each of these elements.

The Super Columns

This \$500 million facility sits on 25 acres and includes over 1.8 million square feet of stadium and leased space. As in most covered stadiums, the support of the roof system must be invisible. In this particular case, the existing Hudson warehouse was to be incorporated in the finished facility. The existing ware-

house columns were not capable of supporting any portion of the stadium roof, and the four levels of suites located within the renovated warehouse made a forest of new columns to support the roof unacceptable. The design team decided

to support the roof trusses on eight columns. These column elements consisted of two 18-foot diameter SuperColumns, two 6-foot square JuniorColumns and four 6-foot square columns contained in the structural moment frame at the north end of the building. The Super and Junior columns were located at the southern end of the facility,

Originally, the two SuperColumns supporting the A-trusses were to be 16-foot square steel lattice trussed elements rising approximately 76 feet at the extreme ends of the facility. While this design solution addressed the structural needs for the massive building roof, the two 16-foot square steel lattice columns presented several constructability issues:

- The size of the lattice columns prohibited shop assembly of the lattice trussed elements. The lattice columns would have to be fabricated as individual pieces, shipped and sub-assembled on site.
- The number of members, installation tolerances and the complexity of the connection details would make field assembly very costly and unpredictable.

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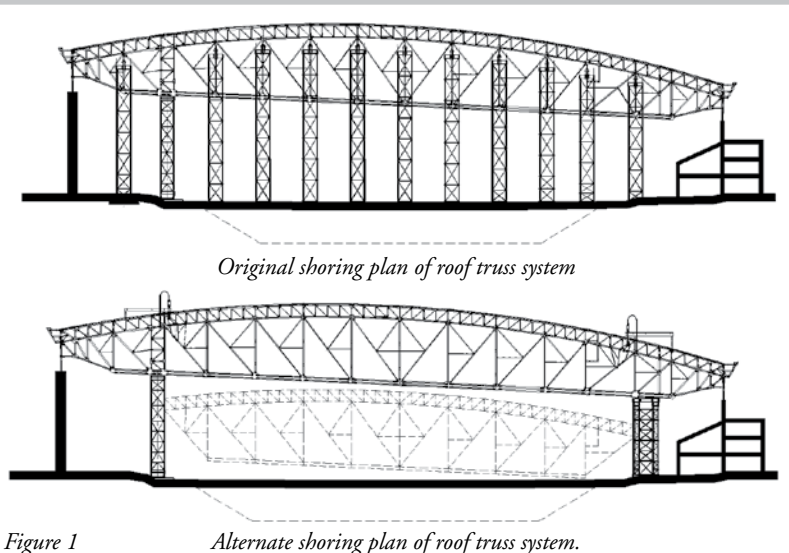


Figure 1

Alternate shoring plan of roof truss system.

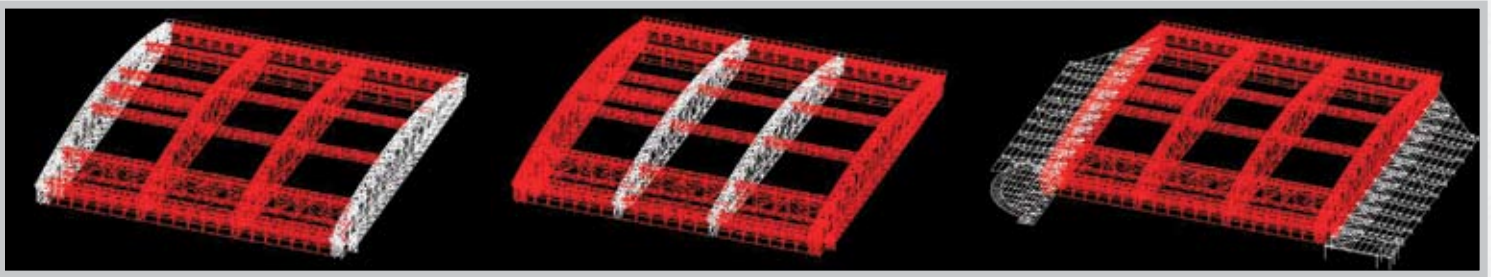


Figure 2: Truss sub-assemblies - left to right - A trusses, B Trusses, Bridging Trusses

- The stability of a 16-foot square lattice column during the months of construction and subsequent jacking of the roof truss was a concern.
- Temporary bracing for the 16-foot square lattice column would limit access and crane movement within the construction site.
- Foundation installation, project schedule constraints and site access would likely delay the installation of the 16-foot square lattice columns until the foundation installation was completed.

Given these challenges, Ruby+Associates recommended that the SuperColumns be redesigned using cast-in-place concrete construction. Concrete could be placed in concert with the deep foundation installation, and the resulting SuperColumns would be stiffer and better suited to accommodate the construction of the remaining structural components of the stadium roof.

Roof Truss System Design

The roof truss system presented a set of challenges:

- Could the roof system be designed to allow a cost effective solution from the shop through installation?
- How could the transport costs to the site be minimized?
- Would site staging requirements influence the design?
- What impact does final installation have on the design?

Originally, the roof box truss top and bottom chord assemblies ranged from 15 to 16 feet square, wider than most elements can be shipped economically; therefore costly field assembly would be required. In addition, limited site assembly area would negatively impact the field assembly cost. Ruby recommended reducing the truss chord assemblies to approximately 14 feet, which would allow shop sub-assembly of chords, greatly reducing shipping costs and eliminating the need for complete field assembly of the truss box chord. This solution reduced field man-hours requirements and simplified the final installation scheme.

While the original plan was to ship the 12.5 x 12.5 foot box trusses in assemblies down the St. Lawrence Seaway, the project schedule dictated that 90 percent of the major steel erection occur October thru February, when the seaway was frozen. The steel was therefore shipped via truck. Because Highway 401 could not accommodate the wheel loading required for the assemblies, the truss elements had to be broken down before they were shipped.

Construction of the Roof Truss System

How should the massive roof truss system be constructed to balance fabrication/erection efficiency, minimize temporary shoring, optimize the sub-assembly and final assembly process, and maximize job-site safety?

Erection of the roof truss system was a massive undertaking. The original design concept was based on the roof being built on 76, 10- to 12-foot square shoring towers, up to 125 feet tall (Figure 1, page 29). Each shoring tower would be guyed for stability and would require a jacking head to simultaneously lower the roof system upon completion.

Each shoring tower also would require an independent foundation and deadmen for the temporary guys. Access for the iron workers would require transporting them to their work stations four times each day. The 90 foot deep roof system, supported by the shoring towers, also would require guy wires for stabilization while construction proceeded. Additionally, the playing field elevation was to be 35 feet below grade; removal of the temporary shoring foundations and deadmen, as well as the field excavation, would have to be delayed until after the roof trusses were complete and the shoring towers were removed.

Given the site constraints, project schedule and construction sequencing, this approach was very complicated, near impossible and definitely too costly. Ruby+Associates developed two alternate installation schemes during the proposal stages and worked with the successful steel contractor, Steelcon/SCI of Kalamazoo, Michigan, in preparing the concepts:

- 1st Alternative: Horizontal ground assembly – tip up to vertical – lift. Under this alternative, the tail sections of the roof trusses would be installed using permanent framing and temporary shoring at the final elevation. The main sections of the roof trusses would be assembled on the ground, in the horizontal position (14 feet tall), then rotated to vertical (90 feet tall). Lateral framing, roof joists and one-third of the metal roof deck would be installed. Then, the 2,700 ton roof structure would be lifted into place and connected to the tail sections.
- 2nd Alternative: Vertical ground assembly – lift. The second alternative (the concept used) followed the above procedure, except the ground assembly of the roof trusses was performed in the vertical position on low temporary shores. Although the erection had to accommodate the 90 foot tall truss, this alternative was more desirable because it reduced the amount of space required to construct the roof lift assembly, and it eliminated the need to tip the completed framed truss.

Engineering Erection and Lift Plan

The Ford Field roof structure consists of four main north/south long span roof trusses, connected by east/west bridging trusses and super long-span joists. This framing encompasses an area approximately 630-feet long by 540-feet wide which covers the playing field, the lower seating bowl, the north/south upper seating areas and the luxury boxes.

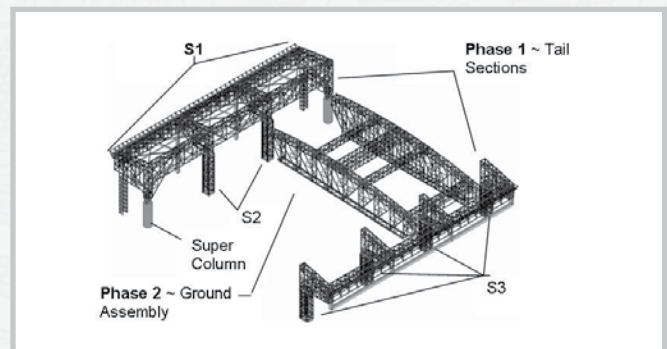


Figure 3: Alternate lift plan for roof truss system

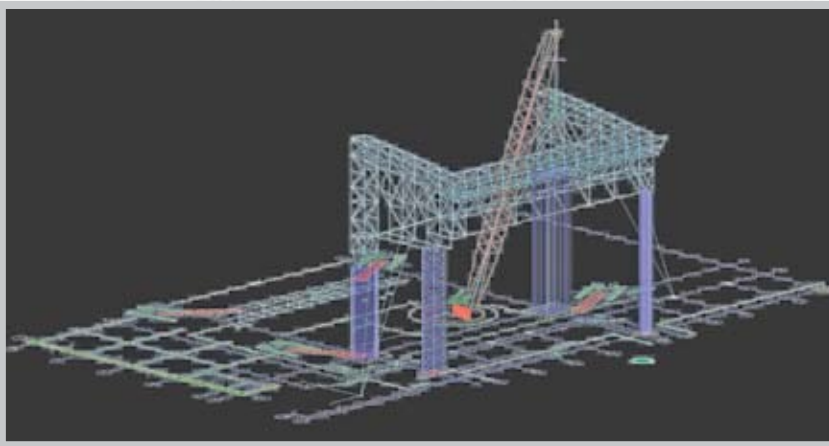


Figure 4: Erection simulations – Phase 1

The Engineered Erection and Lift Plan for the eight-acre roof structure was divided into two phases:

- Phase 1: conventional steel erection: planning and engineering, site logistics, shoring design, rigging design, multi-stage truss sub-assembly and tip-up analysis, crane positioning and individual member, sub-assembly and partial truss stability analysis.
- Phase 2: heavy lift engineering: truss lift and stability analysis, reinforcing or modification of members and/or connections, shoring tower design (Figure 3 - S1, S2 and S3), overturning analysis, jacking platform design, jacking sequences, sub-assembly and strand lift hitch designs and inspection of all temporary works: reinforcing, modifications and connections.

The Structural Steel Project team combined conventional steel erection of truss sub-assemblies with Strand Jack Heavy Lift Technology to deliver the two largest steel assembly lifts in North American history (at that time) and to meet the 26-month construction schedule.


Truss sub-assemblies

Truss sub-assemblies are illustrated in Figure 2. The A and B Trusses are constructed with boxed truss top and bottom chords connected with plane frame vertical and diagonal web members. The A Truss is supported by a set of pot bearings located on top of an 18-foot diameter by 76-foot tall SuperColumn at the south, and a slide bearing assembly fixed to the concrete frame at the north end. The B Truss is seated on a pot bearing on a 6-foot square concrete Junior column at the south end and a slide bearing assembly on the north.

Phase 1 of the erection/lift plan involved the assembly and erection of the north and south ends (tail sections) of each A and B Truss and their connecting Bridging Trusses (Figure 3 –Truss A south tail is supported by the SuperColumn and S1; Truss B south tail is supported by the Junior column and S2; while the north tail of both trusses is supported by S3 and the permanent slide bearing). The tip-up concept often used by pre-cast concrete erectors was combined with heavy rigging expertise during this sub-assembly construction. Truss assemblies weighing up to 300 tons were built horizontally to limit the work elevations to 18-feet above grade. A total of 17 truss sections were ground assembled in the horizontal position and rotated to their vertical orientation.

One pair of self-aligning lift hitches was designed to suit eight different truss configurations. The truss tail sections and bridging trusses were erected on a combination of permanent concrete construction and high capacity temporary shoring towers. The completion of Phase 1 involved assembly and erection of in-fill Joist Modules between the A and B truss tail sections.

Phase 2 involved the ground assembly of the re-remaining 450-foot long sections of the A and B Trusses in a vertical orientation, infill of the bridging trusses, and installation of the roof joists and modification of the top chord gusset plate to accept the strand jack lift fixture. Ten 445-ton capacity strand jacks, connected to four lift fixtures, were used to lift the 2,700-ton roof assemblies 75 feet. The duration of the west lift was 4.5 hours, while the east lift was completed in 1.5 hours. Ironworker crews immediately started making the final connections at the four interface locations. These connections, which established the full truss spans for the first time, allowed the strand jack, lift plate and shoring tower removal operations to begin. The removal





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operations were a carefully choreographed sequence of events engineered to safely and permanently transfer the 2,700-ton roof truss panel loads from the strand jack/shoring tower support system to the long span roof truss structure.

Erection Simulation

Ruby prepared several 3-D models to simulate the installation of the initial tail sections and gutter trusses. These models were used by the contractor to establish crane positioning, determine boom length, minimize crane movement, verify lift clearances and develop the proper rigging dimensions. *Figure 4* (page 31) depicts the setting of the first gutter truss between truss A and B tail sections. The crane, a Manitowoc 888 ringer with a 250-foot boom and 1.4 million pounds of counterweight, was installed on a double layer of 12-inch thick crane mats over 12 to 24 inches of compacted stone in order to distribute the 3 million pounds of crane and counterweight. It should be easy to understand why minimizing the movement of the 888 ringer was a top priority. To minimize the required operating positions for the 888 ringer, Ruby performed swing studies, clearance and capacity verification, site constraint evaluation and usage evaluation.

Strand Jack Heavy Lift Technology

This lift technology, supplied by John Gibson Projects of Middlesbrough, England, typically is used in offshore and bridge construction overseas, but has limited use in the United States. The engineered lift plan took advantage of the lifting capacity of the strand jacks by allowing the erector to ground assemble two roof assemblies, covering nearly two acres each. By lifting this 2,700 ton roof assembly, the team reduced the number of shoring towers required to construct the roof from 76 to 8. Eight high capacity shoring towers were designed with provisions



Tip up of truss assemblies

for vertical and horizontal position adjustment to accommodate fabrication and erection tolerances and thermal effects during installation of the structure. The tail sections of the trusses, along with the shoring towers, served as the supporting structure for the strand jack equipment. The erected Phase 1 steel was in essence used as the lift platform support for the Phase 2 heavy-lift operation (*Figure 5*). Safely moving 2,700 tons of steel from ground elevation to final position in 1½ hours is a testament to the technology and the suitability of this application.

Touchdown!

Construction and erection of this modern stadium (incorporating a historic structure) was a complete success. The roof lift was the largest lift done in North America at the time. Of course, the devil was in the details. To demonstrate that the erected structure would function in a manner consistent with the original design approach, Ruby+Associates performed a six-stage, 3-D computer study of the truss behavior using superposition to sum the effects of each stage of construction. The team then shifted focus to the actions required to safely sustain the forces induced during the erection process. This required an in-depth review of specific truss member forces for each stage to evaluate stress reversals and/or overstress conditions. Through this engineering effort, 76 members were revised, reinforced or braced to carry forces associated with the lift procedure. This is one of the primary benefits of Constructability –

the philosophy demands that design consider forces that will impact the structure during its entire lifetime – even while it is being built. ■

Design/Build Team

Erection Engineer – *Ruby + Associates, P.C.*

General Contractor – *Hunt/Jenkins*

Architect / Engineer of Record – *Smith Group*

Structural Engineer of Record – *Thornton-Tomasetti*

Steel Erector – *SCI/Steelcon*

Steel Fabricator – *ADF Group*

Lift Equipment/Operation – *John Gibson Projects*



Figure 5: Strand Jack Heavy Lift Technology.

David I. Ruby, P.E., S.E., SECB, FASCE, is a Principal with Ruby + Associates PC, in Farmington Hills, Michigan. Mr. Ruby specializes in steel designs that speed and ease constructability. David can be reached via email at druby@rubyusa.com.

Brian M. Volpe, P.E., S.E., has over ten years of experience in structural steel detailing and structural engineering. Currently, he is leading the development of erection procedures for aviation facilities in Florida and Tennessee. Mr. Volpe has contributed to several signature projects for Ruby, providing lift engineering support for the Ford Field roof lift, the largest lift in North America at that time. Brian can be reached via email at bvolpe@rubyusa.com.