Designing for Long Spans

BY JAY RUBY, P.E.

Long-span designs present structural challenges that go beyond spanning longer distances.

DESIGN OF LONG-SPAN SYSTEMS—STRUCTURAL SYSTEMS THAT CROSS LONG DISTANCES WITH LARGE OPEN SPACES—IS CHARACTERIZED BY UNIQUE CHALLENGES. Typically found in arenas, convention centers, and hangars, these structural systems push the envelope of what buildings can do.

Designing long-span structures requires an obsession with stability. Certainly, the structure has to hold up its own weight; just to span the required distance a structure has to support significant dead load. But the complexity of long-span design increases exponentially when snow load, wind load, seismic load, deflection, serviceability, and the dead weight of the floor or roof system are all factored in. Architectural appeal drives the design of such structures, but many factors working simultaneously and in varying degrees must be analyzed in long-span design. The challenge in developing a long-span design is to integrate the architectural concept and appeal with the most efficient, purest structural system. Relevant questions include:

- What are the site constraints?
- Should the pieces be preassembled, or must the structure be "stick built?"
- What type of temporary support is needed?
- What is the nature of the field connections?
- What is the inherent stability of the elements during assembly?
- How will differential deflection impact the structure?
- How can load be transferred from temporary shores to the permanent structure?

Perhaps the greatest challenge is creating a model of the structure that describes how loads change in an as-constructed sequence. Typically, structural models are developed assuming a zero-gravity system—i.e., they assume a 100% constructed structure prior to any load application. In reality, the structure is built one piece or assembly at a time, and the load path for the dead loads may vary significantly from that assumed in the structural design model. In addition, when and how the structure is temporarily braced creates different gravity and lateral load paths.

By addressing the various load paths as the structure is being constructed, the engineer can adjust the design for erection too—not just the final state. By considering the load paths and how the structure responds as it is being constructed, the engineer is able to develop designs that facilitate sequencing of construction and allow efficient use of temporary shoring. Addressing instability issues that occur during construction impacts member size, temporary shoring requirements, and construction sequencing—all of which have a significant impact on overall project cost and schedule. Modeling structures as-constructed, recognizing the various temporary load paths, and designing connections accordingly—while addressing construction sequencing—allow the structural engineer to develop an enhanced decision matrix and lead to design decisions that reduce costs and improve constructability.

Non-Traditional Approach

Long spans frequently occur adjacent to a more conventional column grid system. Oftentimes, this conventional grid system is merely continued to accommodate the long-span requirements, instead of considering the two areas as individual components. While this approach may simplify the decision matrix, it sacrifices the opportunity to reevaluate the unique structural needs of long-span structures.

Investing in a structural analysis to uncover the unique opportunities inherent to long-span structures can positively impact the materials cost and construction schedule; costs associated with the steel structure are a major component of the total construction cost, and structural engineering considerations drive the critical path for completion of design and construction. Because all other trades follow the structural system, it must be constructed as quickly as possible. Investing in structural analysis, framing system evaluation, site analysis, member and element selection, and construction-friendly connections of the long-span elements will go a long way in controlling the constructability and final cost of the facility.

Inserting Constructability

Long-span design demands attention as an independent system. Following the architectural grid of the building may not deliver the most efficient structure. However, structural analysis and framing system evaluation can provide the optimal spacing for the main structural elements to sustain the unique loading criteria, balance the weight of the structure, and support the additional loads of

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Designing Constructability into an Aircraft Hangar

Aircraft hangars can provide powerful examples of how to effectively integrate constructability into long-span design. Structural design of hangars requires the consideration of multiple elements:

- Bay sizes
- Truss depth, framing direction, and specific truss framing concepts
- Sway frame spacing
- Panel points
- Lateral bracing
- Foundations

Even more important is accurately defining the loads that the long-span structure is required to carry. The impact of design load criteria on long-span design is tremendous. For example, the impact of 5 psf of additional assumed dead load in the design of a typical 30-ft by 30-ft grid building generally does not affect the design of beams, columns, or foundations. But in a long-span structure with a supported area of 100,000 sq. ft, 5 psf translates into 500,000 lb of additional load that must be supported. Defining actual load criteria to reflect realistic conditions can significantly impact design.

Challenging a building's layout parameters can also deliver significant savings. For instance, increasing bay spacing in a structural framing system from a grid of 30 ft to 40 ft can deliver the following results:

Trusses	30% fewer pieces
	26% fewer connections
	27% fewer trusses
Top chord framing	27% fewer joists
Bottom chord bracing	53% fewer pieces
	53% fewer connections
Vertical lateral bracing	28% fewer pieces
	28% fewer connections
Foundations	27% fewer foundations

Figures 1 through 3 illustrate the impact of altering this basic design parameter on the truss system, columns, connections, and bracing. As these figures show, the structural elements are reduced tremendously moving from a grid of 30 ft to a grid of 40 ft—and structural needs are still met.

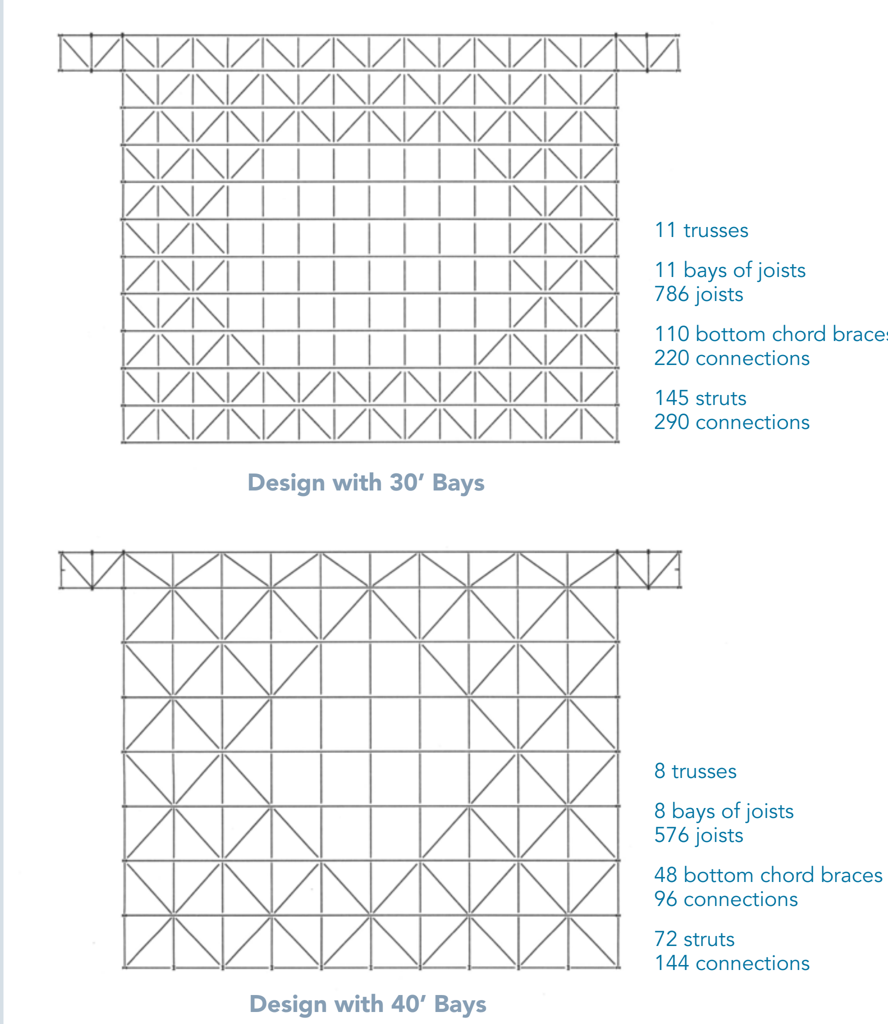

Figure 1.

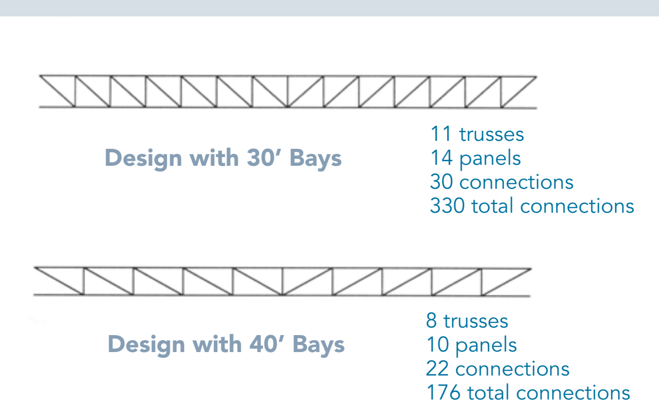

Figure 2.

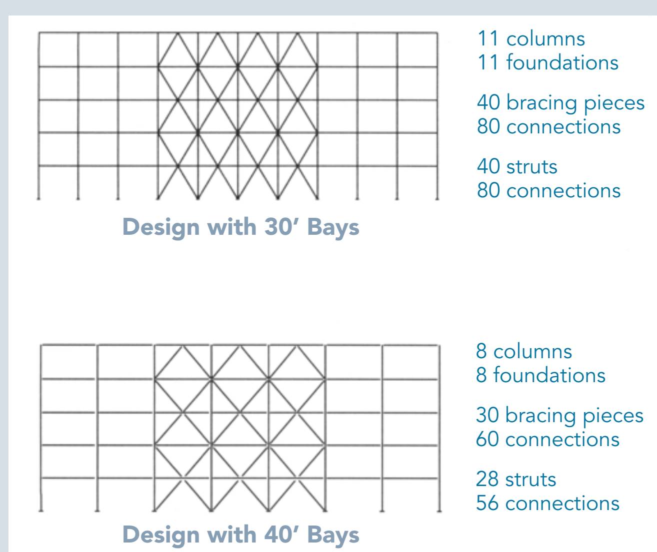

Figure 3.

the roof or floor system. This approach considers:

Structural framing. What is the load path? How can each structural element's efficiency—from the deck/slab to the supporting beams and joists to the trusses—be maximized? Efficiency in size, span, constructability, number of pieces, etc. must all be considered.

Bracing. Bracing established by architectural considerations alone may be insufficient, unbalanced, difficult to install, or very inefficient. First, establish a minimum bracing requirement to accommodate structural demands. Then, determine how this bracing requirement can be made efficient and integrated within the architectural grid.

Fabrication. Can shop fabrication be maximized to reduce pieces, improve quality, and minimize field costs? Should the trusses be built to facilitate shipping? If field subassembly is necessary, can connections and member elements be minimized?

Erection. Provide a suggested sequence of construction, not just final building design. How should construction be sequenced to minimize temporary shoring and maximize the efficiency of member sizes? Where should temporary bracing be located? How do load paths change as the structure is being built? Who better to direct how the structure should be built safely than the structural engineer who designed the structure?

Design of the trusses provides an excellent example of balancing material, fabrication, and erection costs. As the depth of the truss increases, material costs decrease. However, fabrication and shipping costs may increase or decrease based on the fabrication shop's capabilities and design requirements. Field time is minimized since deeper trusses carry more load, allowing framing optimization and element reductions. Ultimately, constructability integrates the design decision matrix with construction considerations and drives the lowest total cost alternative.

Optimal Design

Integrating constructability into long-span delivers the optimal structural design. The structural engineer can help the fabricator/erector perform better by guiding construction sequencing based on structural considerations—and without getting into means and methods of construction. With a focus on constructability, the engineer can produce the owner's ultimate goal: an economical, serviceable long-span structure. MSC