Constructability Specialists: Great Synthesizers

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This article is the last in a series on Constructability. Previous articles defined Constructability, established its role in the project planning and design process, described its foundation in construction knowledge and experience, and provided case studies that demonstrated the positive impact of Constructability on total project cost. While Constructability delivers immediate value to a project, this design philosophy has a much broader appeal: Constructability positions the engineering profession to remain a relevant asset to clients in the future. The following thoughts describe why and how.

In his book, *The World is Flat*, Thomas Friedman suggests that the key to thriving in today's (and tomorrow's) globalized world, where globalization reaches beyond countries and companies to individuals, is delivering "untouchable" services. He provides a "Help Wanted" list to define what service providers (including engineers) must become to survive and flourish.

Below are those services that align most closely with what structural engineering professionals in the future must be:

- Great collaborators and orchestrators – able to operate in, mobilize, inspire and manage a multidimensional and multicultural workforce.
- Great synthesizers – able to bring together all of the parts from others and place them in front of the client.

Constructability experts are positioned to be the "Great Synthesizers", delivering comprehensive coordination to the project team throughout planning, design and construction. Consider the coordination that typically occurs during the design of a project – mechanical, electrical, plumbing, egress, architectural, civil, landscaping, fire protection, security and more – all of which require contact with manufacturers, suppliers and installers:

- Beam penetrations are provided for duct work and piping;
- Slab edges are designed and detailed to accept the fascia;
- Floor openings are coordinated with the stairs and elevators;
- Openings are provided for mechanical shafts; and
- Floor to floor height is developed considering building usage, utility and ceiling requirements.

The typical design approach requires significant coordination among the design professionals related to the various trades to develop the design concept. This coordination delivers great benefit to the Owner (savings in cost and schedule), assists the individual trade contractors in simplification of their installation, and is an expected service of the design team.

Yet, coordination with the construction contractor on the structural elements necessary for successful construction of the building skeleton is somewhat rare, usually limited to a review of the documents just prior to issuance for bids, and this coordination gap presents an opportunity for structural engineers to fill Friedman's "Help Wanted" list of the future. If coordination with trades was extended to include coordination with the building frame contractor, the positive impact of this Constructability design philosophy would be immediate, improving delivery, reducing risk and enhancing financial performance.

The following sections discuss key areas where coordination between the building's design and detail requirements and the building frame contractor greatly enhance the quality of the finished product, and provide a means for the Owner to benefit from reduced cost and/or schedule. This enlarged concept of coordination can be performed throughout the design process, from concept to final design, developing a constructability dialogue between the design professional and the building frame contractor or construction specialist.

Structural Design Considerations That Are Not A Function Of The Analysis

Constructability is about coordination. Project Coordination! Complete coordination of all aspects of the project from the foundations to the final pane of glass. Complete project coordination is a necessary element for any successful project, and is most effective when performed early and most certainly prior to assigning contracts. Methods to accommodate distortion, construction loads and weld shrinkage, as well as erection aids and stability, can be addressed and planned through project coordination. All members of the construction team are affected by the depth of coordination performed by the design team. The design team's ability to address these and similar construction related issues, during the initial project stages and continuing through the preparation of the design documents, goes a long way towards enhancing overall constructability and improving the quality of the final product.

Structural Steel

Design of the major structural systems demands consideration and coordination of issues that are not typically part of the computer analysis performed during the design of the structure. These issues must be addressed by a "great synthesizer" – someone who can address overall project coordination issues at very early stages of the project: the Structural Engineer. Introducing constructability and coordination to construction and design teams, the process of reviewing constructability issues and the related coordination, allows the design team to include this and other relevant information within the final design documents, eliminating the unknowns and allowing for a fair and competitive bidding process.

Constructability issues associated with major structural steel components are identified and discussed below:

Trusses

- Truss geometry must suite the projected usage of the facility; considering such constraints as utilities, security, piping and suspended loading.
- Depth of trusses must accommodate suspended HVAC units and other process related equipment.
- Maximum shipping depth varies based on shop location and site location, local ordinance, over-the-road clearances, trucking availability, shop capacity or size restrictions.
- Maximum shipping length varies based on trucking availability, local ordinance, shop crane capacity, shop size restrictions, site laydown area, installation crane capacity, and handling and lateral stability requirements.
- Chord size, shape and orientation may vary based on shop practice, material availability, lateral stability and splice location.
- Web member size and shape may vary based on shop practice and material availability.
- Maximum weight of shipping piece varies based on trucking availability, local ordinance, shop crane capacity and installation crane capacity.

Columns

- Column size and shape may vary based on material and shape availability.
- Columns can be sized to minimize web and flange stiffeners.
- Column length may vary based on local ordinance, union work rules, trucking availability, shop crane capacity and installation crane capacity.
- Maximum weight of a shipping piece varies based on trucking availability, local ordinance, shop crane capacity and installation crane capacity.
- Layout of column anchor bolts coordinated with the foundation reinforcing provides the basis for accurate initial construction.

Bracing

- Bracing geometry should suite the usage of the facility, considering openings, and other penetrations and circulation requirements in the final facility.
- The member size and shape may vary based on material and shape availability and bracing configuration.
- Bracing member efficiency may vary based on slenderness, supplemental gravity supports, or tension system vs. a tension-compression system.
- The benefit of X-bracing versus Diamond bracing versus Chevron bracing should be determined.
- Bracing geometry impacts installation costs.

Connections

- Column splice requirements are determined by analysis or noted as 125 percent of maximum tensile capacity.
- Gravity column splice requirements are AISC standard splices.
- Connection detail layouts, if not fully designed, depict the required connection geometry, the design criteria and generally communicate the Structural Engineer of Record's (SER's) connection expectations.

Cantilevers and other elements that require elevation control

- Elevations must be coordinated with the final usage of the facility or finished elevation requirements.
- Elevations shown on the design documents are those required prior to dead load deflection.
- Shoring requirements, special erection needs, design assumptions and SER's expectations are very helpful additions to the design documents.
- Cambered geometry for trusses are developed by the fabricator/detailer based on the camber information noted on the design documents.
- Prior to considering camber, read AISC *Code of Standard Practice* Section 6, AISC Design Guide #3 and David T. Ricker's article *Cambering Steel Beams* in AISC Engineering Journal 4th Quarter 1989.
- Camber of beams is an imprecise procedure and is not an acceptable means to establish elevation in the field; the elevation (not a camber) and related dead load should be noted on the design documents. i.e., El + 1.5" (dead wt of beam only)
- Camber shall be measured in the shop and is not guaranteed upon arrival in the field.
- Camber required in the field after installation must be noted as such on the design documents.

Welding versus Bolting

- Shop bolting versus shop welding is generally a fabricator preference and is not necessarily a cost factor or a function of the structure itself.

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- Bolted construction generally is easier to install and does not require the skills associated with field welding.
- Field welding generally requires temperature control before, during and after weld completion.
- Weld shrinkage and subsequent distortion can be addressed with proper weld sequencing, thus eliminating the concern for the quality of the finished product or the fear of introducing a new idea.
- Welding galvanized steel or stainless steel to low carbon steel or to stainless can be done by using the proper technique and electrode.
- Joint development will often provide an insight into the fabrication and connectivity issues that will impact the constructability and final cost of the structure. This joint development is better for the Owner when it is performed and reviewed with a building frame contractor prior to the issuance of the bid documents.
- For both welding and bolting issues, the proper source for up-to-date information is through industry.

Lateral stability

- The lateral stability of the structure is a function of the initial design assumptions, the erection sequence and the erector-installed temporary bracing.

Regardless of the nature of the structure, the erector is responsible for the lateral stability as it is installed. The erector's temporary bracing must therefore sustain the forces imposed on the structure during the installation process. For the erector to accomplish this, the SER should identify the lateral-load-resisting system and connecting diaphragm elements that provide for lateral strength and stability in the completed structure; and any special erection conditions or other considerations that are required by the design concept, such as the use of shores, jacks or loads that must be adjusted as erection progresses to set or maintain camber, position within specified tolerances or prestress (COSP Section 7.10.1).

Concrete

Design of concrete framed facilities also requires a similar understanding of the construction process and coordination of the entire project to maximize efficiencies. Variables such as those listed below are examples of such considerations:

- Reinforcing steel sizes may vary based on availability and local practice.
- Grade and type of concrete may have limited availability or local practice knowledge.
- Shoring and re-shoring requirements.
- Loading and support of concrete.
- Form deflection limits.
- Concrete finish requirements.
- Mass concrete procedures.
- Joint location and details in slabs on grade and walls.
- Precast vs. poured-in-place - local practice and availability.
- Precast shipping restrictions or trucking availability.
- Cold or hot weather concreting procedures noted within the design documents.
- Layout of column anchor bolts including the foundation reinforcing provides the basis for accurate initial construction.

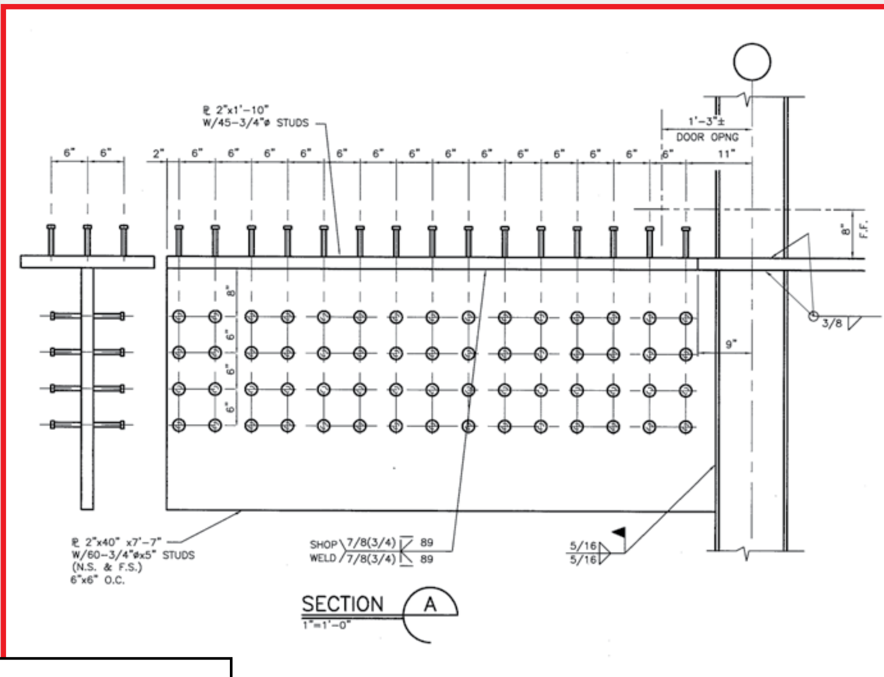
Conclusion

Factors that impact the quality, schedule and cost of the constructed product are regularly addressed within the concept of Constructability. The fundamentals of Constructability – coordination, conceptualization, creativity and BIM - cannot be **automated**, **digitized**, or **out-sourced**. This is our profession's future! Constructability enables the design professional to develop creative solutions and to bring enhanced value to the client. Constructability is the path that will return the civil/structural engineering professional to the role formerly played – a role that was and will again become integral in the development, design and construction of buildings and other structures.▪

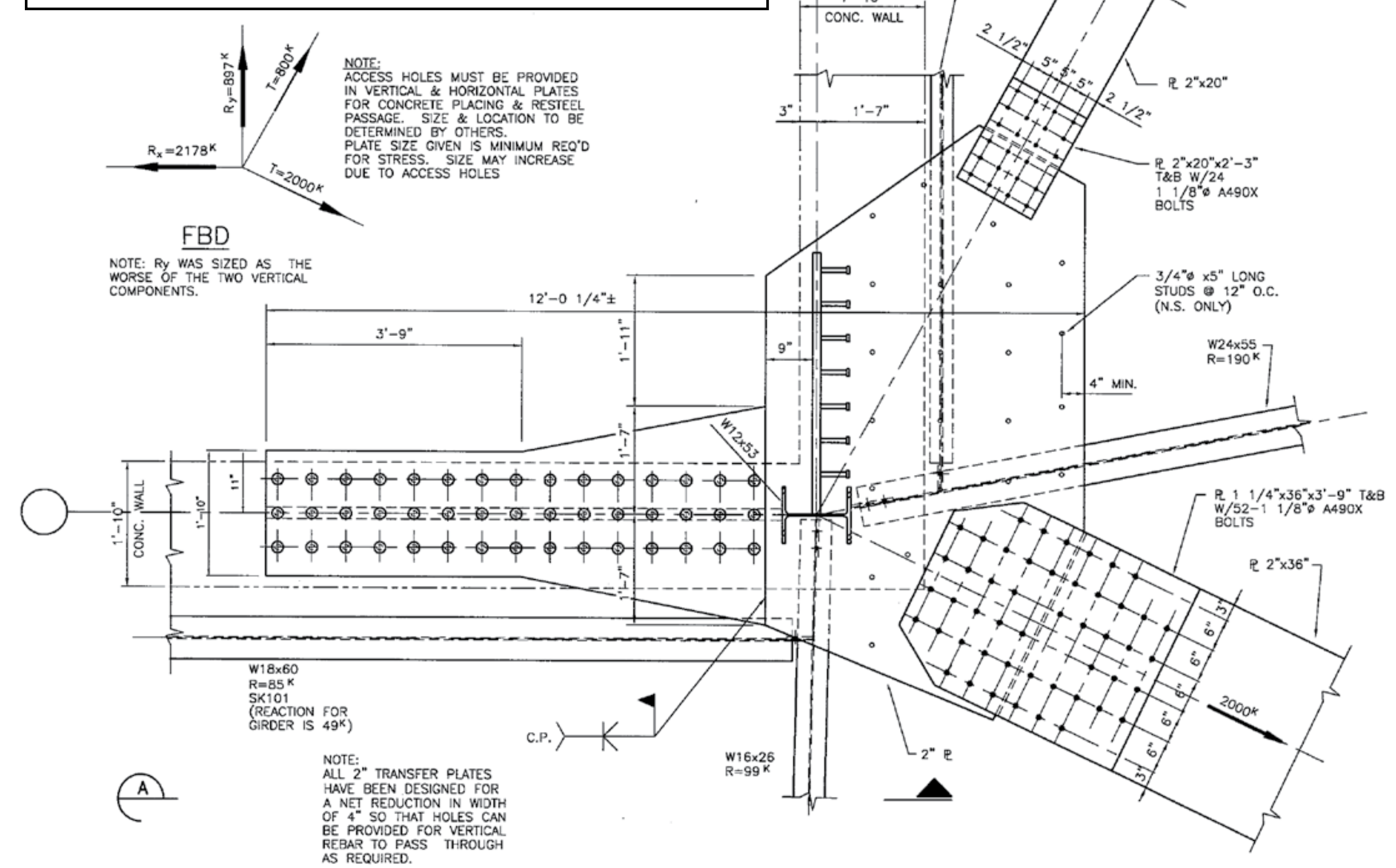
Example 1:
Coordination/Constructability Considerations

Original floor bracing plan – no detail layout of joint or design criteria. This detail requires coordination between materials and trade contractors; structural steel, concrete and elevator. Several elements essential to the successful construction of this facility were not addressed on the plan:

- Will the structural steel, connections and reinforcing fit in the wall?
- Compatibility of structural steel connections and anchorage issues.
- Definition of the shear transfer mechanism.
- Shear wall reinforcing coordinated with the structural steel.
- Internal force transfer between the steel and concrete.
- Limitation of shear wall geometry and elevator requirements.



The solution, developed during the steel shop drawing process, did not fit within the original concrete shear walls. Elevator access opening and shaft conflicts existed as well as concrete shear wall reinforcing placing issues. Early constructability and coordination would have eliminated such issues and provided coordinated design documents.



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