Award Winning Constructability

The Lansing Community College, Health & Human Service Career Building project was presented an Outstanding Project Award (New Buildings Under $10 Million) in the National Council of Structural Engineering Associations (NCSEA) 2005 Excellence in Structural Engineering Awards program.

Lansing Community College

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In the June 2006 issue of STRUCTURE®, we introduced the philosophy of Constructability and presented benefits associated with infusing Constructability into the design process. This second article in the series describes the practical application of the principles of Constructability in the redesign of Lansing Community College, Health & Human Service Career Building. Principles discussed in this article are contained in their entirety in the *Constructability Design Guide*, which will be published later this year by the American Institute of Steel Construction (AISC).

What is Constructability?

Constructability has been defined by the Construction Industry Institute as the optimum use of construction knowledge and experience in planning, design, procurement and field operations to achieve overall project objectives. Constructability does not only relate to the ease of construction and/or erection of structural steel; Constructability concepts engage all aspects, materials and elements of construction and therefore can greatly reduce the overall cost of construction as well as the cost of structural steel by facilitating:

- construction friendly designs
- reduction or elimination of special installation conditions
- accurate and cost-effective proposals from fabricators/erectors
- coordination of structural and non-structural items
- trades and related construction activities
- economic material procurement
- timely and inexpensive shop drawing preparation
- standard fabrication processes, and
- architecturally exposed structural steel requirements.

Stages of Constructability

In general, the Constructability process should include the following activities:

- Design team formation
- Data gathering
- Constraints recognition
- Evaluation of constraints
- Program development
- Framing options evaluation
- Preliminary design development
- Testing of options
- Final design process
- Bid package development
- Bidding process
- Fabrication process
- Installation process

To achieve the greatest benefit from Constructability, the Design Team (led by the structural engineer, when appropriate) must understand the interdependent nature and uniqueness of each process, consider each in developing the project program and then integrate each to create a cost-efficient solution for the Owner.

The Lansing Community College (LCC) Project

At LCC, Constructability was introduced at the stage of bidding, fabrication and installation; the project schedule and the architectural envelope had been established at this point. As designed for bidding, the structure was a three-story building with a fourth floor expansion planned in the future, but the three-story building excessed the original budget by approximately $200,000.

Ruby+Associates was presented with the opportunity to partner with Douglas Steel and provide a cost effective redesign in an attempt to deliver the steel structure of the building within budget. Although Ruby+Associates was not involved in the early conceptual stages of the design, the firm was able to apply Constructability principles — the integration of construction knowledge and experience — during the bidding stage and completely redesign the major structural steel components of the building. This redesign saved enough money to enable LCC to procure and Douglas Steel to construct the fourth floor, and still complete the project $100,000 under budget and ahead of schedule!

In the original design, the floor beams were spaced at about 3-feet on center, with a light metal deck and a reasonably thin slab. The lateral-load resisting system consisted of a combination of labor intensive full capacity moment connections, "ornamental" X-bracing and inefficient knee braces throughout the corridors. The framing system also included concrete filled columns. By analyzing several lateral-load resisting systems, the Ruby design eliminated the inefficient bracing, reduced pieces to receive, handle, fabricate and erect, and reduced the field labor required to handle and install the structural steel.

Framing

The initial design decisions made by the Structural Engineer, the choice of construction materials and the determination of the appropriate framing system establish the lower boundary of the economics and the effectiveness that can be realized through Constructability as the design progresses. Structures should be designed to provide sufficient structural capacity to safely resist and sustain all loads and effects of loads that may reasonably be expected, with adequate consideration given to industry standards, ease of fabrication and installation, construction procedures, serviceability and the anticipated service life of the structure.

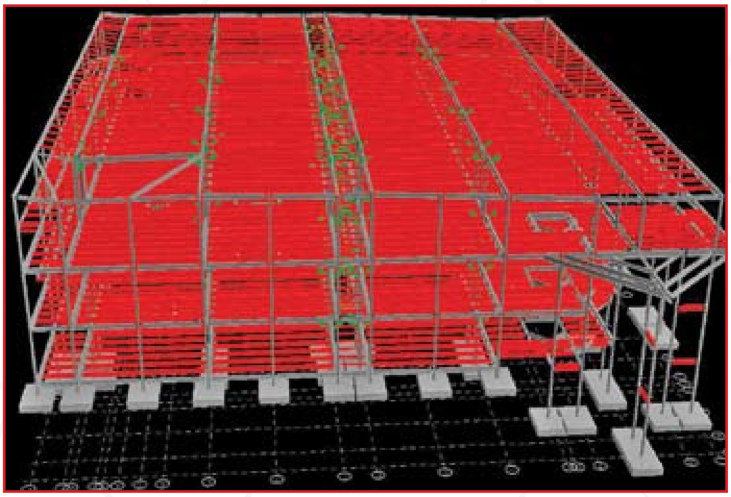
Decisions such as building grid or bay spacing, lateral-load resisting framing options, floor systems and roof systems will impact cost and without Constructability input can be irreversible.

The floor framing follows. The options available to the engineer are numerous. Each, with the variety of elements and materials, magnifies the options and amplifies the importance of inserting construction knowledge into the design process.

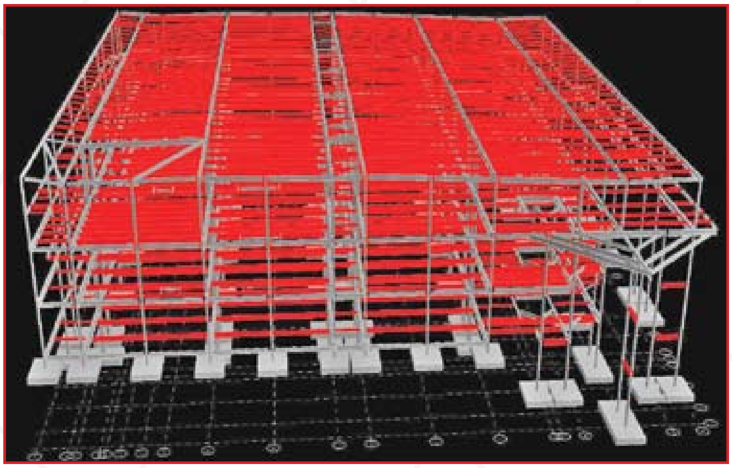
The impact of framing design on the LCC project was huge. The original flooring system for the project was typical for construction of single story structures. In fact, it is commonly used in school construction. However, application of this system for the LCC project was not an economical solution. Ruby increased the 2-inch metal deck to 3-inch, which allowed the floor beam spacing to be increased to 10-feet, reducing the number of floor beams by 78 percent, reducing the shear studs by 11,000 and reducing the steel tonnage by 300 tons.

Further, the original LCC design called for use of "ornamental" X-bracing and knee braces for part of the lateral system. Both the "ornamental" X-braces and knee braces required an additional level of detail preparation, generated many pieces to handle, fabricate and install, were shop labor intensive, were relatively inefficient, provided varying levels of stiffness and were not compatible with the original moment frames. Therefore these braces were disproportionately expensive when viewed as benefits versus cost.

Ruby replaced the inefficient "ornamental" X-braces and knee braces with field-bolted moment frames in both directions. This lateral load-resisting system was developed to suit the structural requirements, while the field bolted moment connections were designed utilizing the actual moments and stiffness required. This concept simplified detailing, reduced beam/girder fabrication to drilling and punching and eliminated pieces which eased erection, shortened the schedule and reduced costs, while providing a lateral-load resisting system that was stiffer than the original with fewer pieces and less field labor.



Original design



Alternate design

Member Selection

Member selection includes columns, beams, horizontal bracing, vertical bracing, trusses and sway frames. Often, structural engineering decisions for member selections are driven by computer-based analyses that do not contain critical or realistic parameters:

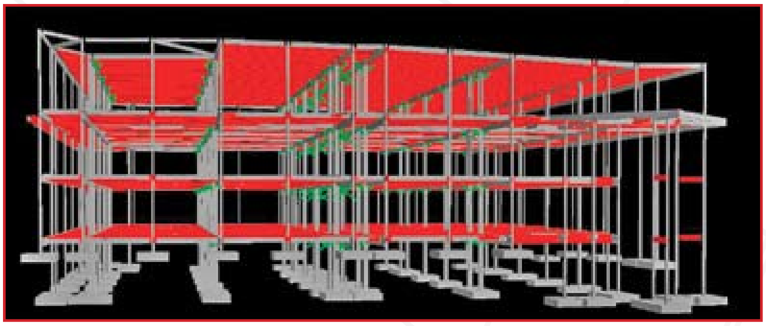
- What architectural constraints exist? Are there options?
- What is the cost or schedule impact?
- What is the relationship of each member to the others?
- What is the availability of the member or material?
- What opportunities exist to increase uniformity of shapes and sizes?
- How will the members impact the ease of construction?
- Were the members needed? Were there options?

During the redesign of LCC, the Ruby/Douglas team considered these and other Constructability issues as they developed alternatives for the cantilevered framing along the perimeter of the structure, the "ornamental" X-bracing, the inefficient knee bracing, the concrete-filled columns, the original column orientation, the cantilever girder/columns details, the floor system design and the inability to insert vertical bracing within the building due to schedule and architectural constraints.

Connection Development

Connections are a major contributor to the final cost of the structure. Initial structural design decisions directly impact the difficulty of the connections in structures. An understanding of the mechanics of connectors and the process of fabrication and erection constraints builds a unique understanding of the Constructability concept. An initial effort to plan, conceive and design an efficient framing system pays big dividends when developing the connections. Designing connections that perform and are constructible delivers a structure that is simpler to detail, fabricate and erect. Initial framing considerations and the subsequent connection developments are the keys to providing contractor-friendly structures, without sacrificing the integrity of the structure.

When the lateral load-resisting system was redesigned on the LCC project, connection design was an important design aspect to re-evaluate as well. The original beam to beam connections were to be double angles designed to support 75 percent of the beams uniform load capacity. Lateral-load resisting connections were required to develop the beam's full moment capacity, and (as noted previously) the knee braces and the "ornamental" X-braces were detail intensive



Orginal design

and inefficient. The Ruby/Douglas team developed completely field-bolted moment connections using the actual moments and stiffness required, eliminated the bracing elements and utilized single plate shear connections, thus simplifying shop fabrication and installation and subsequently reducing shop and field labor.

Fabrication Process

Partnered with Douglas Steel, Ruby pursued economies in the fabrication process in every aspect of the structural design for the LCC project. The fabrication of structural steel requires custom detailing, cutting, punching, drilling, welding, grinding and painting of structural shapes of various sizes, weights and material grades. The concept of standard, off the shelf details is a myth. Therefore, the designer must consider if the degree of difficulty of the structural system proposed is warranted for the project structure. Degree of difficulty can refer to number of pieces, field welding requirements, length of span, exaggerated connection forces, inappropriate framing requirements, excessive bracing details or requirements, column web stiffeners or web doubler plates, and inappropriate use of material or shapes, among other factors.

The Ruby/Douglas team reviewed each aspect of the structural framing system and related detail requirements, changed the floor system which reduced the number of floor beams, eliminated the doubled angles and substituted single plate shear connections, modified the concrete-filled columns, eliminated the time consuming "ornamental" and knee bracing details and designed the moment connections for the actual forces.

Construction Process

By understanding the nuances inherent to the construction industry, the structural engineer can simplify the overall construction process by understanding the various construction industry standards, by utilizing this knowledge during the design process and by accommodating the standards within the project construction plan; thus reducing costs, improving schedules, and minimizing conflict between the design and construction teams.

To do this, several key construction considerations should drive structural design decisions. The essential five S's are as follows:

- Site – Constraints such as access, staging areas, operating area and storage space?
- Season – What regulations or weather conditions must be accommodated?
- Sequence – Is the project to be sequenced? How can material handling be minimized? How can "comeback work" be avoided?
- Scheduling – When should various materials arrive? How will the structural steel be integrated with the other trades? When will the lateral-load resisting system non-structural steel elements arrive at the site?
- Stability – The erector is responsible for stability of the structure during installation. This task has a cost associated with it that is closely tied to the need for temporary bracing and the impact of non-structural steel elements in the lateral load system. How can this be simplified?

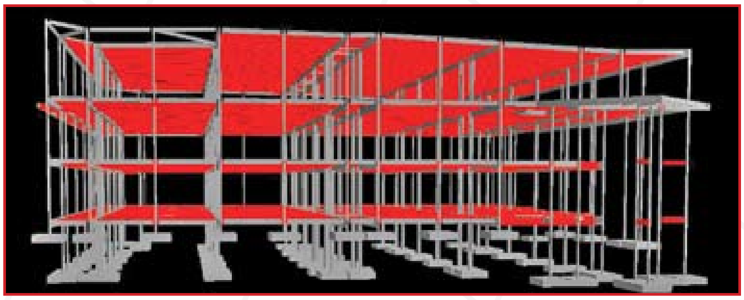
The impact of construction process decisions was first illustrated on the LCC project by the concrete-filled column for the structure. These columns were a construction concern due to site constraints, temporary heating or blankets during curing, sequencing of trades, schedule delays due to the cure time and, finally, stability after concrete placement. While these Constructability items are of concern and would impact the project schedule, several other factors made their use impractical on this project.

First, the concrete-filled columns were among the heaviest construction components on the project, increasing the crane capacity requirement and/or decreasing the operating radius necessary for the crane's operation. Secondly, due to the limited number of such columns, the cost associated with their procurement and installation was a premium. Finally, the columns could cause major scheduling issues. If the columns were installed as hollow HSS members, then filled with concrete in the field, the required concrete curing time could limit flexibility and the out of sequence concrete placement would disrupt the installation of the remaining structural steel. Further, connection options to these columns were limited due to AESS constraints and concrete-fill requirements.

The Ruby redesign eliminated the concrete-fill from these HSS columns in several ways:

- utilizing higher strength material,
- utilizing a thicker HSS shape,
- modifying the connections details and in the extreme case, and
- designing a built-up column shaft. The built-up shaft consisted of a 10-inch HSS shape inserted into a 12-inch HSS shape column, detailing the base and cap plates in a doughnut configuration to allow each of the HSS members to be adequately attached to the supporting elements.

These alternatives reduced the cost of the materials, simplified fabrication, expedited the construction schedule, eliminated the impact on the size of the crane required and simplified the design of connections to these columns.



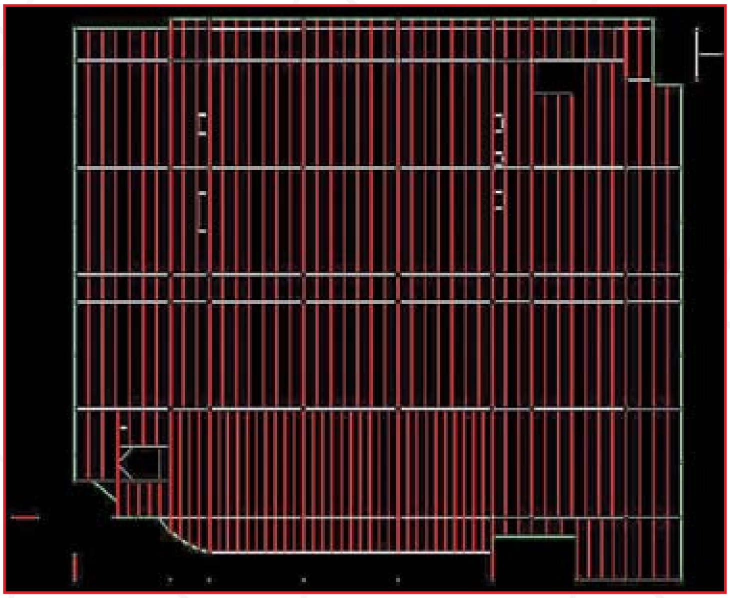
Alternate design

The original floor system, as previously noted, consisted of floor beams at 3-feet on center. The number of beams and related field-installed shear studs demanded an excessive amount of field hours to install. Ruby revised the floor system with floor beams at 10-foot spacing. This reduced the number of floor beams by about 360 pieces and eliminated 11,000 shear studs.

Single plate shear connections were substituted for the originally specified double angle connections. This substitute reduced field labor and eliminated the common bolts through the girder beams webs (a potential erection safety issue).

Lost Opportunities

The traditional design begins with the prime design professional presenting the concept in a graphic form, which generally establishes the building grid and basic architectural constraints. The structural engineer takes the building grid, reviews the architectural constraints, digests the code and project requirements, develops possible lateral load-resisting systems and selects the framing and lateral-load resisting system to suit the prime design professional's concept.



Original design 2nd floor

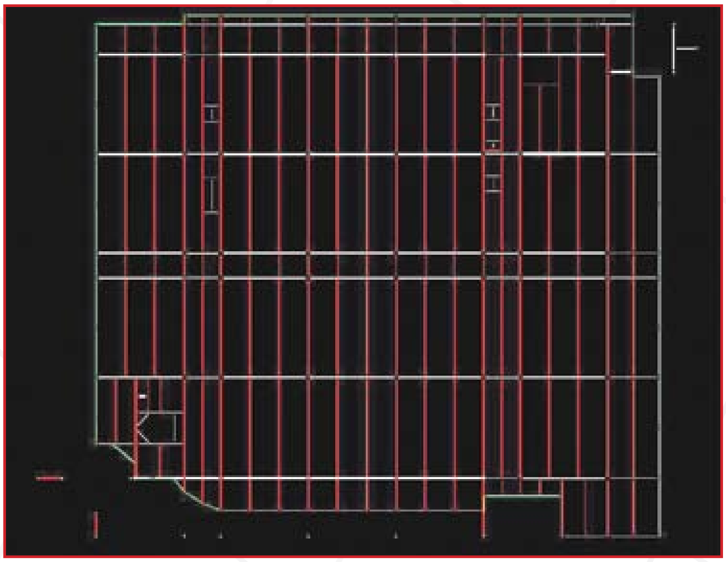
The Constructability design begins with the design team reviewing the owner's program and the prime design professional's concept, brain-storming options and alternatives, jointly establishing the building's requirements, allocating space for the lateral-load resisting, recognizing any code restrictions and preparing the project requirements accordingly. The design then proceeds with all of the team members understanding the concept, the focus and the constraints.

The Ruby redesign at LCC eliminated over 700 members, beams and braces, as well as 11,000 shear studs from the floor system, eliminated cantilever perimeter framing, substituted steel columns for concrete-filled columns and moved to a completely field bolted structure. The resulting floor system (including a thicker slab) added minimal dead load to the structure, but increased the strength of the composite floor system. This redesigned structure was easier to build, stiffer and much more economical — over 300 tons of structural steel were eliminated!

However, the impact of the redesign was limited because Constructability was inserted during the bidding stage instead of at the planning stage. The foundations for the structure were already in place, and they were designed to accommodate the building's original lateral-load resisting system. If Constructability had been inserted during the initial concept stage of the project, the opportunity existed to eliminate the moment frame requirements in favor of a more economical chevron or full story X-bracing scheme. The AESS perimeter columns could have been more economical as 12- or 14-inch HSS shapes in lieu of the original 8- and 12-inch HSS. The redesign was the most cost-effective solution based on the architectural constraints and the project schedule constraints that *existed at the time of bidding.*

As stated earlier, Constructability is not just related to installation, but engages all aspects, material and elements of construction to provide maximum benefit to the owner. The best solution for the facility may not be the least cost structure. Each project has a personality and each personality demands a unique solution.

Understanding the anatomy of Constructability, and inserting it into a project *during* the initial concept stage is similar to the value of preventative medicine: problems are avoided and risks are reduced. The true value of introducing the philosophy of Constructability into a project can be measured in what does not happen: time is not lost, money is not wasted, claims are not made and budgets are not exceeded.▪



Alternate design 2nd floor

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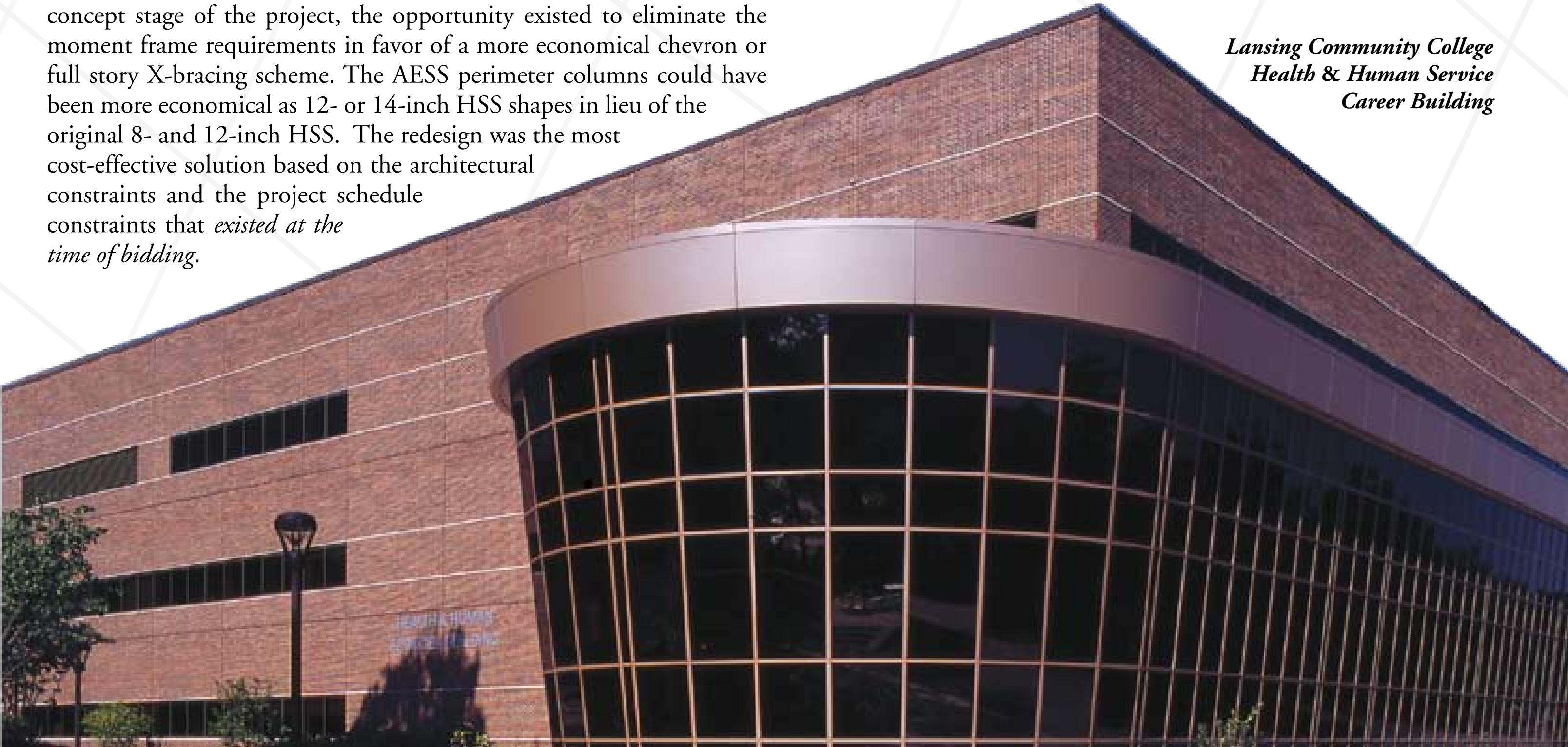
For *Constructability Part 1* visit STRUCTURE's on-line archives at **www.structuremag.org**, June 2006



Lansing Community College Health & Human Service Career Building