



Embracing the Complexities

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When design criteria tightened up on a fast-tracked health care facility project, the early choice to use steel framing allowed the project to stay on track.



▲ View of hospital construction from the central energy plant.

IN A PERFECT WORLD, not one change would occur. However, we don't live in a perfect world and designs evolve. Building geometries are altered, materials are adjusted, and heavily loaded areas are relocated as owners and architects determine the best use of space. Any of these adjustments made to the structural steel following the 100% steel package can have significant cost and schedule impacts that often are not anticipated or understood by the owner and/or contractor.

Impacts can be limited, however, with consistent and diligent coordination up to and beyond the 100% submitted steel package. With staggered design packages, foundation work often is being constructed while structural steel shop drawings are approved and sent for fabrication and the remaining design team is still in design development. The benefit is self-evident: an aggressive and shorter construction schedule allows for earlier occupancy. However, the impacts and costs of additional design need to be recognized to allow this expedited occupancy to occur. Combine these dynamic design challenges with a large scale hospital; Department of Defense (DoD) Anti-Terrorism category IV Progressive Collapse design requirements; four-story open glass atriums, green roofs and an aggressive design package schedule using BIM software and clash detection and you have the new Irwin Army Community Hospital (IACH).

Located in Ft Riley, Kan., this replacement community hospital and clinic is in the early stages of construction. The new Irwin campus includes a 263,000-sq.-ft inpatient

- ◀ The new Irwin Army Community Hospital being constructed in Ft. Riley, Kan., is designed to the highest level of Department of Defense progressive collapse prevention requirements and includes a 263,000-sq.-ft inpatient hospital, 289,000-sq.-ft outpatient clinic, central energy plant, ambulance garage, elevated parking structure, and two pedestrian bridges.
- ▼ One of the corner columns prior to erection showing the W-shape shear lug designed to resist the shear developed by flexural yielding of the column.



- ▲ A square blockout in the mud slab showing the cruciform-shaped void formed in the top of a concrete pile cap designed to accommodate the interior column shear lugs.

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hospital, 289,000-sq.-ft outpatient clinic, central energy plant, ambulance garage, elevated parking structure, and two pedestrian bridges. Considering that this project had to be designed to the most current Unified Facilities Criteria (UFC), 4-023-03: *Design of Buildings to Resist Progressive Collapse*, coupled with the need to create the proper healing environment while under the aggressive umbrella of the multiple design packaged, fast-tracked schedule, all players involved had to maintain the team- and project-first mentality.

Selecting Steel

Initial construction studies varied from cast-in-place concrete with moment frames, to steel with conventional braced frames, to SidePlate moment frames. The cast-in-place concrete system would have required decreased bay sizes and a potentially longer construction schedule, so the ECI (Early Contractor Involvement) team (Balfour Beatty-Walton Joint Venture, BBJV) determined it was not a desirable structural solution. A steel solution with a concrete-filled metal deck floor system posed several advantages, such as larger bays (33 ft by 33 ft) and increased architectural program plan flexibility.

Two lateral-force-resisting systems (braced frames and SidePlate moment frames) were evaluated based on cost, flexibility and impact to foundations while meeting specific Progressive Collapse requirements. Using RAM Structural System software, analysis models were created for both systems. CIS/2 data and pile foundation design information were provided for relative construction cost estimating to the A/E's cost consultant, the ECI team, and four subcontractors solicited by BBJV, for these two options. Based on the cost estimates, the braced frame and SidePlate moment frame systems were cost neutral. The SidePlate Frame system was selected due to its open vertical bays and



▲ Steel columns on site awaiting erection.



▲ SidePlate moment frame tree in the process of being erected.

more efficient means of resisting progressive collapse. This proved to be advantageous when the new UFC was released in July 2009 during design and was implemented into the project requirements, because it requires alternate load path progressive collapse resistance around the entire perimeter of essential facilities. This simply entailed adding more moment frames rather than changing lateral-force-resisting systems as would have been the case had braced frames been selected.

The typical floor geometry throughout the buildings is composite 2-in. metal deck with a 4.5-in. concrete topping. Bay sizes are commonly 33 ft by 33 ft in the hospital, and 33 ft by 26 ft in the clinic. The hospital and clinic are classified as essential facilities, so they warranted the DoD progressive collapse prevention requirements of Occupancy Category IV structures, the most stringent of any building type. Significant detail ramifications occurred with fully developed column base shear lugs, peripheral tie slab reinforcement, and perimeter moment frames. Nonlinear dynamic analysis was used in meeting the alternate load path requirements of the UFC.

Engineering Challenges

Per the UFC, column bases have to be designed to resist the shear developed by flexural yielding of the columns in order to provide a ductile, inelastic response. With a typical story height in a new hospital, and a column designed with Alternate Path analysis to resist progressive collapse, these shear forces can be hundreds of kips in magnitude. This force has to be transferred into the support, which in this case was a concrete pilaster.

To resist these enormous loads, several options were investigated, including 1) encasing the column in concrete, 2) shear lugs, and 3) transferring the load horizontally through a diaphragm via braces. Due to phasing concerns expressed by the ECI team, option 1 was eliminated. Because there was no room for braces below the diaphragm, option 3 was eliminated. Thus W-shape shear lugs (e.g., W14x257), not plates, were used to transfer the column base shear into the pilaster. The lugs were designed as cantilevered beams and required complete-joint-penetration groove welds to the underside of the base plate to transfer the shear. Corner columns required the shear lugs to be loaded biaxially for substantial loads in each direction because both strong- and weak-axis flexural strength had to be developed. Columns not continuous to the ground were analyzed using the Alternate Path procedure in accordance with Section 3-1.6 of UFC 4-023-03. In some cases, the adjacent supporting columns also were supported by beams, resulting in special shear connection details for the transfer beams.

The east face of the clinic consists of a 240-ft-long curved, open four-story atrium, a key architectural component of both the interior and exterior elements. Three-dimensional space trusses consisting of 2-in.-diameter Architecturally Exposed Structural Steel (AESS) HSS are provided at each floor level to absorb lat-

eral loading (blast, wind and seismic) spanning between W24 steel columns. The space trusses met the strict, visually-pleasing welded connection requirements of AESS to marry the strength requirements of blast-resistant design and the elegance required by the atrium space. The lateral loads and weight of the curtain wall are supported at the second and third levels with vertical mullions attached to the truss webs. Supporting the curtain wall at each level independently prevented the trusses from requiring intumescent paint, a significant construction cost savings, as they met the exception in the code for non-rated members.

Landscaped low roofs on the fourth level of both the hospital and clinic provide occupants a connection with nature. The loads used in the design of these spaces included an additional dead load coordinated with the landscape designer to provide an adequate soil depth and substrate for the vegetation. With fully saturated soils, self weight of the deck and slab, and MEP loads from the ceiling below, the dead loads pushed upwards of 150 psf. Meanwhile the tie force requirements to resist progressive collapse still had to be met even with abrupt jumps in slab elevations. Typically, peripheral ties were placed around these changes in slab elevations.

Design Packages/ECI

Multiple design packages are commonly a structural engineer's worst nightmare. Issuing 100% foundation packages and/or 90% structural steel documents while the remaining design (outside of civil) is in its very early stages is unnerving. Ultimately, a proficient structural engineer can provide the contractor an early start of construction while accommodating architectural adjustments and not being overly conservative. Ideally, communication and the expectation of potential changes, coupled with their effects on erection, sequencing and scheduling, must be set early with all players involved: contractor, owner and the design team.

With the early foundation package on this project, the number, layout, and elevation of piles at each cap were requested by the contractor. At that point in time, the building extents, heavily loaded areas, number of stories and exposures were determined to be adequate for pile design to proceed with only a slight bit of caution. At the next design package, structural steel for the superstructure (including slab edges) was issued while the architectural team was approaching 65% completion. This is typically the time when the team's emotions and composites are truly tested.

The most critical aspect of this package to the structural engineering team was the coordination and verification of all dead load and extreme live load variations in both the hospital and clinic. Bays with increased loading resulted in heavier members, shorter center-to-center beam spacing, and higher shear stud counts often reaching fully-composite behavior. Through early studies, it was determined that conservatively designing the entire building for the heaviest live load



▲ Columns not continuous to the ground were analyzed using the UFC Alternate Path procedure.

(225 psf vs. 100 psf) would add more than \$4 million in construction cost. Instead, the design team coordinated with the Corps of Engineers Kansas City District to selectively categorize live load areas and optimize bays.

As programming changed with significant impacts on the associated live loads and vibration criteria, the structural design had to be modified quickly to minimize or avoid cost increases and delays. This procedure also applied to changes in the skin as the envelope design progressed. Accommodating high-density storage units with 350 psf live loads, critical vibration requirements for bays supporting medical imaging technology, fully grouted floor-to-floor CMU partitions for security, and unprocured elevator equipment meant the engineer, architect, and owner had to coordinate at an aggressive and efficient pace. In the end, a relatively small percentage of the structure had to be modified due to the diligence and engagement of the structural engineering team after the 100% steel package was issued.

The Irwin community facility is expected to be completed in 2014. Leo A Daly's partnership with the Corps of Engineers throughout the design process has materialized a facility that will serve our nation's finest for many years to come. **MSC**

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