Chevron braces cut costs

Economical Health Care Design in Seismic Zone 4

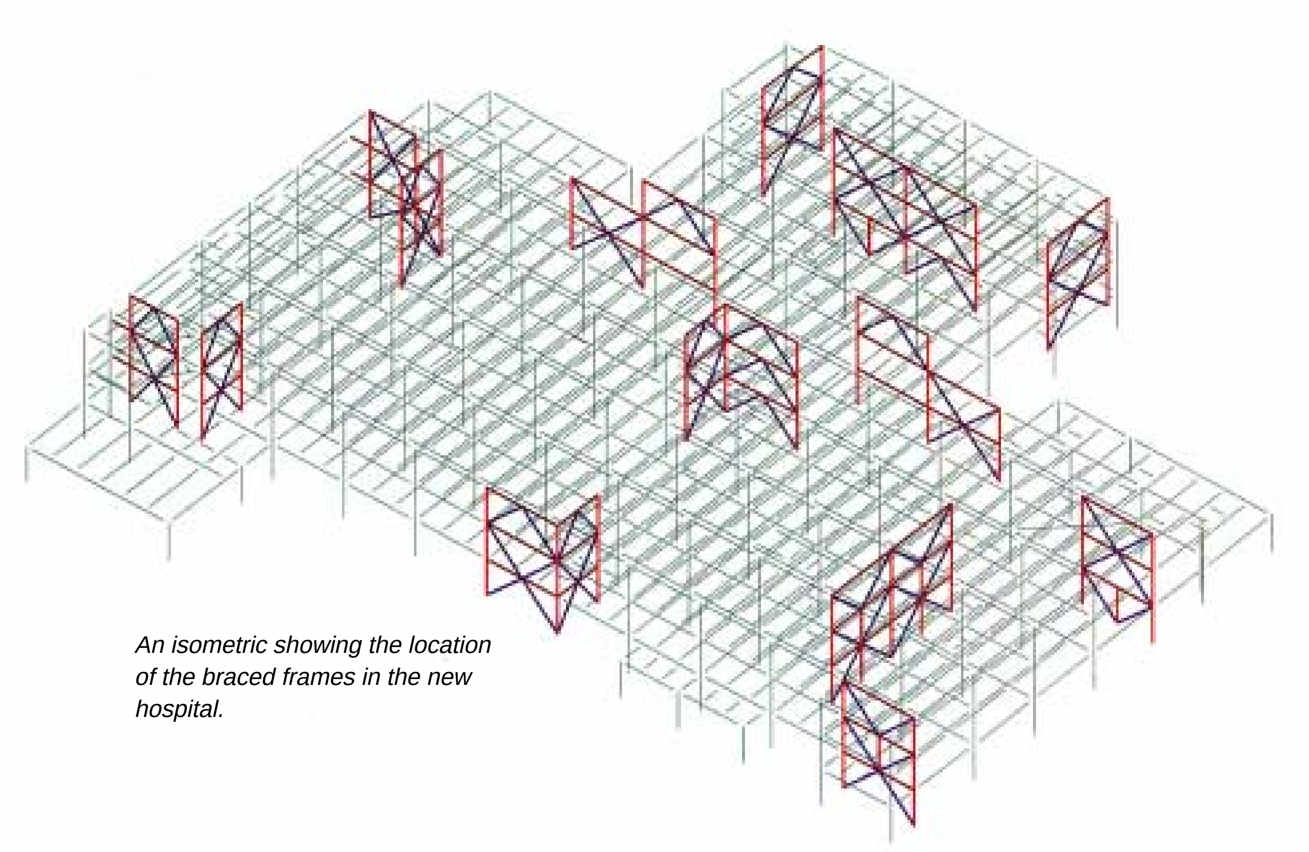
(Top) An artist's rendering of the soon-to-be-complete Three Rivers Community Hospital in Grants Pass, OR.

(Above) A braced frame during erection.

By J. John Walsh, S.E.

Cost control is one issue that never seems to go away on building projects. When the entire project team, including the owner, general contractor, architect and structural, mechanical, electrical and civil engineers assembled in Portland, OR, to begin the design process for the new Three Rivers Community Hospital, discussions centered on establishing conceptual designs for each building system and on cost saving opportunities.

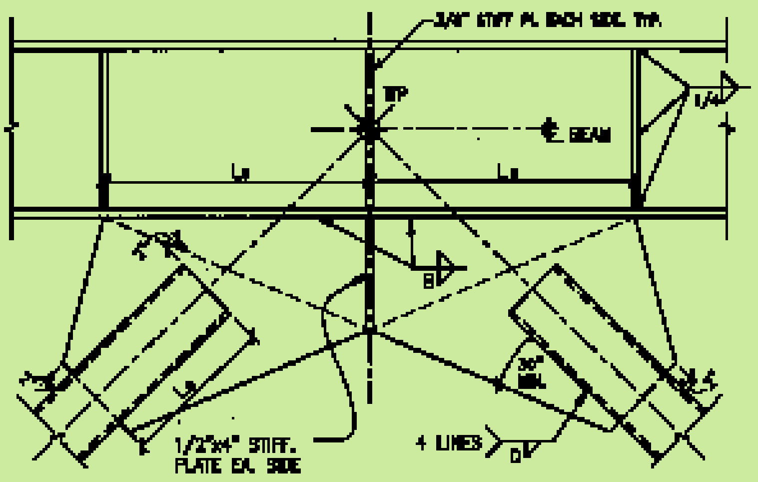
Given the building's seismic zone 4 location, the structural engineer's first order of business was selecting the lateral load resisting system. Past experience on similar projects indicated that significant cost savings could be realized if a braced frame system was incorporated into the architectural planning, rather the more common moment resisting frame system. This is not a simple exercise, however, and requires early and active collaboration between the structural engineer, architect and owner. On many projects, braced frames systems are considered too late in the planning process and modifications such as moving openings or increasing wall thickness to conceal braces (thereby reducing room sizes or moving corridors) becomes impossible without a wholesale redesign. Fortunately, on Three Rivers Community Hospital, the project's structural engineer, Structural Affiliates International, Inc., was involved from the beginning when the team was receptive to the tradeoffs presented.



An isometric showing the location of the braced frames in the new hospital.

New Beginnings

In 1994, Asante Health System acquired two Grants Pass, OR, hospitals and merged them into a single entity called Three Rivers Community Hospital and Health Center. A strategic plan was adopted with a goal of ultimately combining all operations at a single site, but neither existing hospital could economically accommodate the consolidation completely due to age, condition, obsolescence and site limitations. After extensive evaluation, the Asante Board of Directors voted in 1997 to purchase property for the construction of replacement hospital facilities on a new 44-acre site in south Grants Pass.



Chevron Brace Connection Detail.

The new Three Rivers Community Hospital is envisioned as a health care center for the 21st century, with emphasis on:

- Ambulatory care and educational services.
- Patient privacy in all areas, from patient registration to discharge.
- Expansion capability to accommodate future growth.
- A "system" facility with selected support services provided from a central, off-site location that serves all Asante facilities.
- Creation of a physical environment promoting health. Site design for proximity of the hospital to future medical office buildings and health-related organizations.

The new facility is three-stories

tall, and includes a 182,000-sq.-ft. hospital, an 11,500-sq.-ft. central plant, and a 3,000-sq.-ft. link for a total of 196,500 sq. ft.. Construction cost is $32,000,000. The project is conceptually designed as a health-care mall with a central circulation atrium. Diagnostic and treatment areas are located to the west of the atrium and the administrative and support functions to the east. Services are provided through centralized ancillary functions to both inpatients and outpatients, though separate accesses are maintained for each. Inpatient access to the nursing units above occurs from the service elevators, while outpatient functions are accessed directly from the central atrium, including imaging, cardiopulmonary, fast-track, gift shop, patient registration and a resource center. Large portions of the atrium will also be used for public functions, including outpatient waiting, some dining, and public vendors in order to make efficient use of the inherent circulation space of mall-type designs.

The exterior walls are an Exterior Insulation and Finish System (EIFS), selected for it's light weight, visual appearance and economy.

Structural Design Objectives

Once the decision was made to proceed with the project, time became a major concern. Andersen Construction developed a fast-track construction schedule that included separate bid packages for site work, foundations, steel mill order, and structural steel. Knowing that structural design would be complete approximately 6 months ahead of architectural, mechanical, and electrical, the structural system had to be capable of efficiently accommodating the ongoing design revisions associated with a fast-track project. It was also apparent that superstructure construction would take place during the rainy Oregon winter.

The structural engineer was charged with accommodating sometimes conflicting design requirements:

- Minimize construction cost.
- Use materials that are easily adapted for future modifications. Since this is a fast-track project, some modifications may actually take place during the construction period.
- Use greater bay sizes to minimize column interference.
- Minimize weight of structure to reduce earthquake forces.
- Maintain hospital functions after a major seismic event.
- Use systems that are less dependent on weather conditions during construction.
- Enclose the building as quickly as possible.

Gravity Load System Selection

A 30'-by-30' structural bay was used throughout the facility, with a 15' floor-to-floor height. The selected structural system is the result of studies of several options.

Structural steel was the obvious choice for the project as coming close to meeting all the criteria. Cast-in-place concrete systems were eliminated primarily due to weather-sensitive construction over a lengthy period, but also due to the difficulty in making modifications as the design evolved.

ASTM Grade A992 was used for beams and columns and ASTM A36 for plates and other shapes. Cambering the floor beams and girders was determined to be a lower cost option than designing uncambered members to support the additional concrete weight that occurs as the beams deflect. A comparison of lightweight versus normal weight concrete was undertaken by analyzing the floor system for 3-1/4" of lightweight concrete over 2" metal deck and 4-1/2" of normal weight concrete over 3" metal deck, both spanning 10 feet to composite beams and girders. The additional mass of the normal weight concrete also increased seismic forces, resulting in an increase of 35 tons of steel in the lateral load resisting system. Even though lightweight aggregate had to be transported more than 200 miles, the cost comparison provided by Andersen Construction indicated that the lightweight concrete was more cost effective than normal weight for the floors.

Lateral Load Resisting System Selection

A major seismic event is likely during the lifetime of this building. The design must therefore incorporate sound earthquake engineering principles, while optimizing construction economy, structural integrity and functional flexibility. Limiting interstory drift is also important for minimizing non-structural damage to walls, ceilings, utilities, and contents.

The governing 1998 Oregon Structural Specialty Code (OSSC) is based on the 1997 Uniform Building Code (UBC). The UBC places Grants Pass in seismic zone 3, but the OSSC modifies the UBC to extend seismic zone 4 into the southwest corner of the state, based on data from the National Earthquake Hazards Reduction Program (NEHRP) maps. In September 1999, the Oregon Seismic Safety Policy Advisory Commission passed a resolution further expanding zone 4 to all of the west coast of Oregon. Although Grants Pass still would remain in seismic zone 3, it would lie within 30 miles of the boundary with zone 4. With the uncertainties inherent in seismic zonation, the design team and owner decided in the interest of increased seismic safety, and as a margin against future code revisions, that the design would be based on OSSC seismic zone 4 requirements for an essential facility. The design of steel members and connections followed the 1997 AISC Seismic Provisions for Structural Steel Buildings.

Lateral load resisting systems studied included concrete shear walls, steel special moment-resisting frames (SMRF) using Reduced Beam Section (dog bone) beams, steel eccentric braced frames (EBF), and steel special concentric braced frames (SCBF). The structural engineer used RAM Frame from RAM Analysis for most of the analysis. However, for connection design internally developed spreadsheets were used. Also, portions of the design needed to be checked by hand because the current version of RAM Frame doesn't include the 1997 AISC Special Seismic Provisions or the 1997 UBC Provisions (though the next release is anticipated to include both).

A concrete shear wall system was eliminated early in the design due to the obstructions the walls create in planning and future remodeling, as well as the disadvantages of concrete construction mentioned previously.

A SMRF is a common system in low-rise hospitals primarily because it is very desirable from a planning flexibility standpoint and can easily accommodate future modifications. Disadvantages of this system include high cost, a tendency for increased non-structural earthquake damage, slower erection due to extensive field welding, and some weather-dependency due again to extensive field welding. The code requires that exterior panels be capable of accommodating the Maximum Inelastic Response Displacement, which is approximately 3.5 inches for a SMRF on this project. Compliance would result in visually undesirable increased joint sizes and window frame widths.

Structural Affiliates International, Inc. met with Moon-Mayoras early in Schematic Design to study the possibility of implementing a braced frame solution. Our initial effort was to minimize the impact on functional planning and future building modifications by locating the braces at stair and elevator shafts. With that accomplished, additional braced bays were added to maintain the seismic Redundancy Factor at 1.0. The 1997 UBC Redundancy Factor applies to Zones 3 and 4 and increases reliability by encouraging multiple paths of resistance to earthquake forces. That is, providing multiple smaller braced frames rather than a few large ones. Non-redundant systems are subject to a penalty of up to 1.5 times the design load.

Braced frame prior to erection.

Integrating the additional braces into the floor plan on all three levels required some compromises in the planning (both now and in the future) that were accepted by the architect and owner. Adjustments were also made to the structure to achieve an acceptable solution. For example, typical structural bays are 30 feet by 30 feet, and with the brace and fire protection an 8 foot corridor can only fit at the center of the bay. By adding a column to divide the 30 foot bay into a 20 foot braced bay and a 10 foot unbraced bay, the corridor was accommodated with little additional structural cost. Also, by moving the braces from the perimeter to the first interior bay and cantilevering the diaphragm, exterior fenestration and articulation of the wall systems was unaffected. Braced systems were thus determined to be a feasible alternative.

An EBF system has an R-factor of 7 versus 6.4 for a SCBF, for a 10 percent reduction in base shear. This reduction, even when combined with a further reduction in base shear due to the longer period of an EBF, was not sufficient to offset the additional costs of increased beam sizes, web stiffeners and beam-column connections.

The Special Concentric Braced Frame was selected for its low cost, speed of erection, minimized field welding and the ability to successfully integrate the braced bays into the architectural design. The system's special requirements contained in the AISC Seismic Provisions are expected to provide performance levels comparable to SMRF and EBF systems with the added benefit of limiting non-structural damage by reduced drift. The SCBF system resulted in a steel savings of approximately 200 tons over the SMRF system.

Design Implementation

Once the lateral load resisting system was selected, compatibility of the brace geometry with the architectural, mechanical and electrical systems was reconfirmed. Structural Affiliates International prepared a 1/16-inch scale isometric drawing of the braces, beams and columns for use as a visual tool for design team's coordination and to immortalize our decisions. As the architectural design evolves on a fast-track project, revisions that affect the structural system are almost inevitable. These were kept to a minimum through the acceptance of the braced bays as virtually "untouchable" and, ironically, by the fact that it was a fast-track project. Changes in the structural design are progressively more difficult and expensive to implement as structural drawings are issued, bids are accepted, shop drawings are prepared, steel is fabricated, and steel is erected. Thus options for architectural design revisions diminish as construction progresses.

The basic building block for the braced bays consists of a chevron brace at the first floor, V-brace at the second (thus forming a two-story X), and a chevron brace at the third floor. This pattern was developed to allow an 8' corridor to be placed in the middle of the chevron and a 4' door to be placed against the outer columns on the V-brace. One of the critical requirements for a Special Concentric Braced Frame system is to prevent plastic hinge formation in the chevron beams under unbalanced brace buckling and yielding forces. The beam must support the full tensile capacity of one brace simultaneously with 30% of the compression capacity of the other brace. The impact on the beams is significant – on this project the chevron beams would increase from W24x55 to W36x150. In the two-story X configuration this issue is resolved by the braces taking the forces rather than the beams. Where a two-story X was not possible, a zipper column was added to resist the unbalanced forces. At the roof level, life-safety consequences of excessive beam deformations are not considered as severe as at floors, so the chevron beam is not required to meet that load combination.

Welded HSS tube braces were preferred from the beginning since more economical sizes are available and the connections are simpler than wide-flange braces. This preference worked in concert with the desire to keep the Redundancy Factor at 1.0. Multiple, distributed braced bays carrying lower forces would be implemented rather than fewer highly-loaded bays. Columns were generally oriented with the strong axis parallel to the braces, but a few locations required that a single column form the end of two intersecting braced bays. In these cases, the columns were designed for 100 percent of the seismic force in one direction combined with 30 percent of the seismic force in the other direction.

It is imperative that the design forces are properly delivered to the individual vertical load-resisting elements (braced frames) by a reliable system of drags and collector elements. The code now specifies special load combinations for these elements that require them to transfer the maximum earthquake force that can be developed in the structure. On this structure that means designing collector members and their connections for 2.8 times the calculated seismic force.

Construction

Shortly after the structural package was completed, shop drawings submittals began. These were prepared and reviewed in small packages to correspond with the planned erection sequence. Braced bays were laid out and welded flat on the first floor slab-on-grade and lifted into place as a unit three stories tall and 30 feet wide. With these elements forming points of fixity, erection of the balance of the steel beams and columns progressed rapidly to completion in 8 weeks.

Conclusion

Three Rivers Community Hospital serves as an example of how a team of professionals from all disciplines can work together to explore all options and arrive at the most appropriate solution for the project.

Through early, continuous involvement of the structural engineer; a positive, determined attitude on the part of the architect; rapid cost comparisons by the contractor; and a supportive owner, it is possible to realize the cost savings inherent in implementing a braced frame solution on a hospital project.

(For more information on the project, see www.asante.org, where an onsite web camera has been set up to view construction progress.)

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Project Information

Structural Engineer: Structural Affiliates International, Inc., San Diego, CA

Architect: Moon Mayoras Architects, Inc., San Diego, CA

Owner: Asante Health System, Medford, OR

General Contractor: Andersen Construction Company, Inc., Portland, OR