Focusing ENERGY

BY PAT FORTNEY, S.E., P.E., P.ENG., PH.D., ADAM FRIEDMAN, S.E., P.E., AND CRAIG PETERSON

Pat Fortney is president of Cives Engineering Corporation and chief engineer with Cives Steel Company, **Craig Peterson** is vice president of Peterson Beckner Industries and **Adam Friedman** is an associate with Computerized Structural Design.

Images courtesy of Cardno Haynes Whaley or Cives except where noted as otherwise

A cantilevering cube serves as the focal and entrance point of ExxonMobil's new campus in Houston.


Courtesy of ExxonMobil

▲ The Cube supported by the Bars.

ONE OF THE WORLD'S LARGEST energy companies is concentrating the energy of its personnel in a new facility.

In 2011, ExxonMobil began construction on a new campus in Houston that will consolidate several EM divisions. The campus will serve 10,000+ employees and is being built on a 385-acre site that includes multiple office buildings, a laboratory, a wellness center, a child development center and dining and retail space.

The focal point and main entrance of the campus is the Energy Center, a steel-framed training and meeting facility made up of multiple components: underground tunnels that provide access for deliveries, utilities and maintenance for the campus; a "Town Hall" that serves as a gathering location for large meetings; two six-story "Bar" buildings that include meeting space and offices; and the three-level "Cube" structure in the middle.

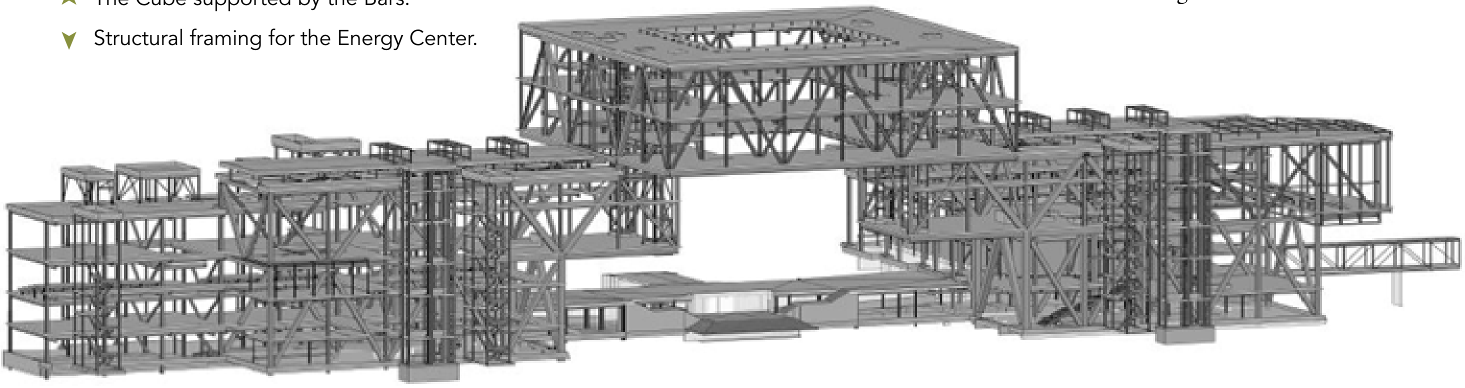
The building's framing system—9,000 tons of structural steel in all—is primarily a braced frame, with columns, beams and braces being a mix of large built-up box shapes, wide-flange shapes and HSS. The built-up shapes are made of 4-in.- to 6-in.-thick plates forming box shapes ranging from 24-in. to 36-in. squares to 24-in. by 48-in. rectangles. The Cube sits upon eight pot bearings positioned at the top of the two cantilevered portions of the two perimeter frames of the North and South Bars—two pot bearing locations at each frame line—and cantilevers 60 ft in both the east and west directions, appearing to hover above the entire structure.

The joints that form the vertical frames are complex; several locations have as many as 11 members faming to a single joint, and mill-to-bear joints were assumed in the design of the connections to transfer the large compression and bending loads required for these designs. The plates that make up the box members framing to some of the larger joints were as thick as 6 in. For these connections, complete joint penetration (CJP) welds would have been costly and time-consuming and required continuous laying in most cases, and the fabricator, Cives, was concerned with the amount of continuity, stiffener and diaphragm plates that would have been needed.

To minimize the amount of hardware used in these connections, the design team chose to form built-up nodes by using cheek plates aligned with the face-to-view in elevation plates of the box members. All axial loads, out-of-plane bending and in-plane shear were taken through the interface of the box member plates and cheek plates. The out-of-plane shear and in-plane bending were transferred from the box members to diaphragm plates welded between the two cheek plates, and the cheek plates and diaphragm plates were made ½ in. thicker than the box member plate material to account for fabrication and erection tolerances.

Compression loads that were a combination of main member axial compression and couples of the design moments were taken through bearing at the cheek-diaphragm plate-to-box member interfaces. At these locations, interfaces were designed and fabricated to be mill-to-bear surfaces, and axial tension and shears were transferred through the welds.

▼ Structural framing for the Energy Center.



The design team chose to form built-up nodes by using cheek plates aligned with the face-to-view in elevation plates of the box members. All axial loads, out-of-plane bending and in-plane shear were taken through the interface of the box member plates and cheek plates.

Bar to Cube

In a project full of complex connections, one of the most complex areas involved the union of the Cube to the Bar buildings (again, eight pot bearings were used to transfer load from the Cube to the Bars). The cheek plates of the nodal connections at these eight locations are 4 in. thick, and the top and bottom walls are 4½ in. thick. To facilitate erection concerns, the Cube was built on top of temporary jacking assemblies, and permanently resting the Cube on the pot bearings occurred after substantial completion of its erection.

The main load transfer is carried by the 36-in. by 36-in. by 3½-in. built-up box brace, which carries 10,800 kips of compression force. Furthermore, structural engineer Cardno Haynes Whaley (CHW) required that the erection engineer, Computerized Structural Design (CSD), apply a concurrent biaxial lateral force of 500 kips acting at the top of jacking assembly. These lateral forces were applied to account for friction and wind and, due to geometry, act at an eccentricity of approximately 42 in. relative to the top of the pot bearing. The jacking assembly and the nodal plates would be required to carry the design loads from the full weight of the completed Cube to provide for the unlikely event that a pot bearing would need to be replaced.

To transfer the pot bearing loads to the joint below, a steel bearing plate was used, straddling the two 4-in.-thick cheek plates used as part of the nodal connection. This arrangement allowed the entire load to be transferred directly to the cheek plates such that no load was delivered to the face of the top wall of the node. To ensure this behavior, the bearing plate was made sufficiently strong and stiff enough such that the bearing plate would not come into contact with the top wall of the node. A 6-in. bearing plate was used and similar considerations were required for the 8-in.-thick plates located beneath the jacking assembly.

Extreme Forces

Construction began with the Bar buildings, which incorporated heavy braced frames that ran parallel to the overall length of the structure. The extreme forces in the braced frames required a variety of end connections (both tension and compression) ranging from milled to bear end connections with partial penetration welds to complete penetration demand-critical welds—all of which needed heavy erection aids to keep members in place before final welding could be completed. With many separate large members framing into single heavy nodes at different elevations and angles—and with many of the individual connections being milled to bear—the challenge was to work nodes and members such that all bearing surfaces were within tolerance. As such, the team designed erection aids that provided adjustability to achieve proper bearing while maintaining stability after the member was released from the crane hook. These aids incorporated hydraulic jacks that could be used to adjust the box braces inside a "cradle" that could then be shimmed to stabilize the braces. This type of erection aid was used in several locations, both at lower levels and upper levels, to ensure that connection nodes mated properly with the box braces.

Another issue presented itself at the 60-ft-long cantilevered portions of the Bar building structures. Large tension braces that were part of the cantilevered portions of the trusses could not be installed without additional support. Due to the size and weight of the tributary framing, the erection team determined that shoring towers at each frame line would be required to support and stabilize the framing. These towers would allow for easy vertical adjustment of the framing to again help ensure that the milled to bear surfaces at end connections were properly seated so that field welds could meet AWS D1.1 requirements. A subsequent issue was how and when to remove the towers. Since these cantilevers would eventually support the

Fabricating the nodal connections.

To facilitate erection concerns, the Cube was built on top of temporary jacking assemblies, and permanently resting the Cube on the pot bearings occurred after substantial completion of its erection.

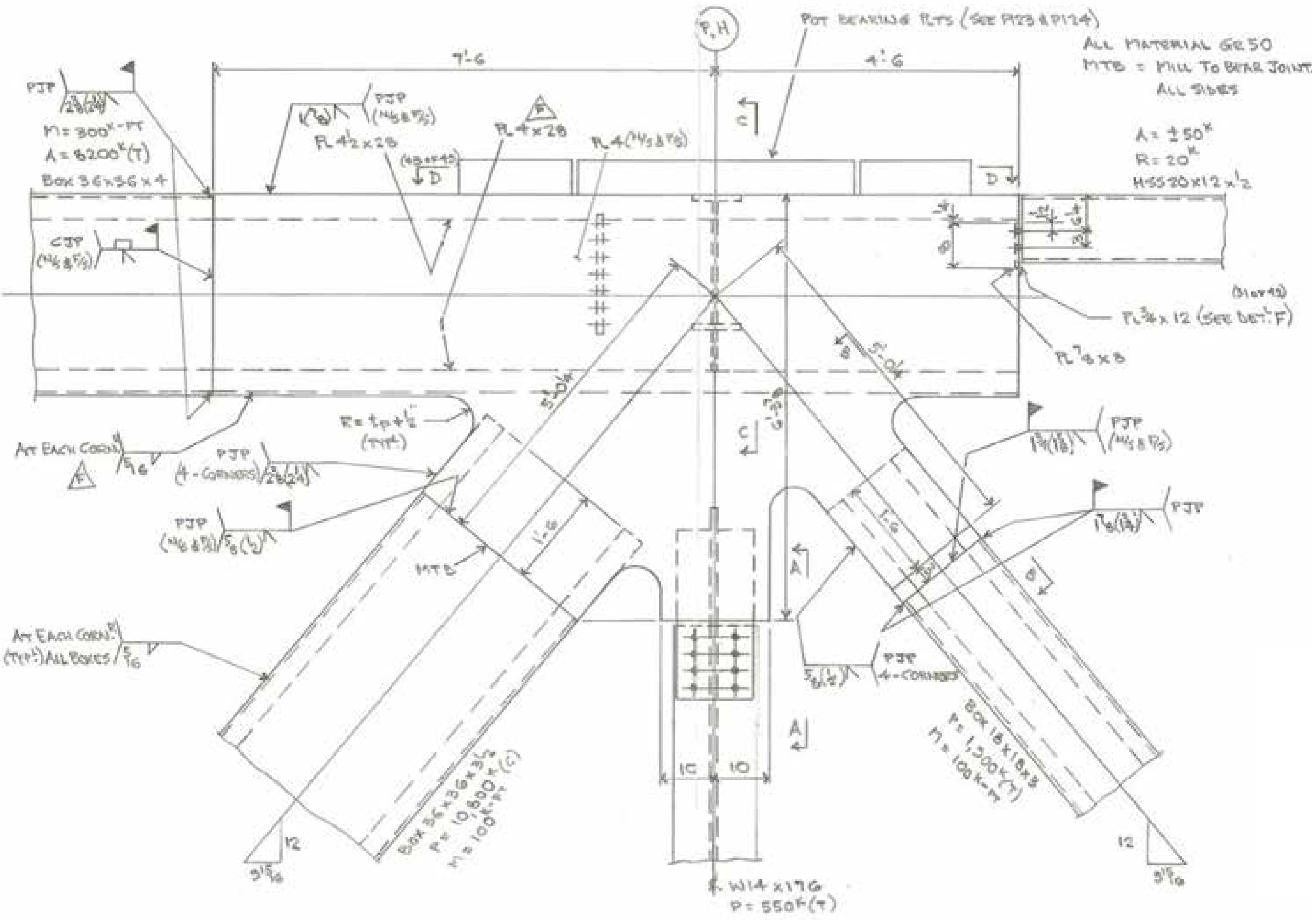
1,400-ton Cube structure, they were extremely stiff. It would be very difficult to lift this structure to remove shims and disassemble the shoring tower, so the team came up with a solution of using sand pots to de-center the loads from the shoring towers. Each sand pot consisted of a section of pipe, with top and bottom bearing plates, filled with sand and equipped with a "valve" that could be opened to remove sand, thus lowering its overall height. This type of unit works extremely well for de-centering compression loads, and its use allowed the erector, Peterson Beckner Industries (PBI), to remove the shoring towers without lifting the cantilevered structure.

When it came to erecting the Cube, temporary support of the transverse "collector" trusses at each Bar building was needed until the two sides of the Cube were joined, as the Cube would take weeks to build. Due to its size, the Cube was designed to be supported on pot bearings; one side used fixed bearings and one side used guided sliders. The guided pot bearing sliders presented an issue since they could not be fixed, but were required as part of the vertical load path during erection. Additionally, the Cube would eventually need to be lifted to adjust the pot bearings into final position. To overcome this issue, a series of haunches and support frames were used to bypass the pot bearings during erection; at the completion of erection, these haunches could also be used to support jacks to lift the cube. This system worked perfectly, providing stability during erection and, due to careful planning and foresight, the haunches were used to lift the Cube for final adjustments.

The major supporting elements of the Cube structure were six 50-ft-tall trusses incorporating three levels. Two of the trusses acted as "collector trusses" spanning 180 ft in the east-west direction, one at each bar building. Then four infill or "tie-in" trusses spanned 180 ft in the north-south direction to connect between the collector trusses; the six trusses were then further tied together with additional bracing and floor/roof framing. Due to the long spans and extremely heavy assemblies, some weighing as much as 240 tons, PBI decided against setting trusses in full lengths and instead opted to pre-assemble selected components into smaller assemblies, which were then erected individually.

As part of the erection of each collector truss, one of the diagonal members had to be set in place beneath the top chord of the partially erected truss and its lower connection made before it could be connected at its upper end. This again required a specialized rigging plan and creative erection aids. The first step required hoisting the heavy braces, weighing 23 tons, into position under the top chord and installing an adequate number of bolts in the lower connection. It was then held in place at the upper end with wire rope and a stability frame. This kept the brace in place but did not fix it in its final position. At the meeting point of the top chord and diagonal, a connection node with milled to bear ends needed to be installed and welded. This particular connection node was part of a larger assembly that included a vertical member, diagonal member and a portion of bottom chord. The erection engineer provided an adjustable erection aid and frame, which allowed PBI to install both the diagonal box brace and node assembly without any issues.

The next phase of the Cube's construction required bridging the gap between the collector trusses, a span of approximately 180 ft. Due to site and crane limitations, the tie-in trusses used to span this gap would need to be erected as two separate assemblies. PBI determined the best way to move forward with construction would be to set the majority of these trusses in two segments using shoring towers. The shoring towers, which were used on previous projects, would be modified by adding additional height and head sections, and tie-in trusses were also slightly modified for the new loading condition. PBI, CSD and Cives worked together to modify member sizes, connection details and framing to ensure proper fit-up, and PBI used two heavy-lift cranes to



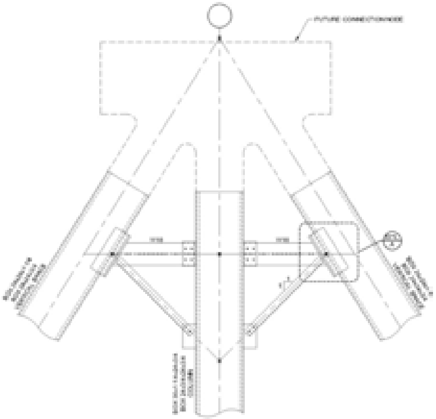
An engineering sketch of one of the (eight) joints representative of the nodal plate concept.

erect the first segment of the first tie-in truss (approximately two thirds of the truss), which connected to a collector truss on one end and perched on top of a shoring tower at the other end. PBI then erected the corresponding portion of the adjacent tie-in truss and floor framing in between before spanning the gaps and erecting the final sections of each tie-in truss; the second pair of tie-in trusses was erected in similar fashion.

After completion of the Cube, the final major challenge was to de-center the erected Cube structure off of temporary supports onto the permanent pot bearing supports. During the erection process, the eight pot bearings that support the Cube had been locked in place to prevent movement and rotation during construction. As the Cube was de-centering, the final locations of the pot bearings were adjusted and released to allow for rotation and guided movement as the structure moves due to changes in temperature and environmental loads. CSD and PBI worked to create a decentering procedure that used the previously designed and fabricated jacking haunches. It was critical that the pot bearings be protected and that damage to them be avoided during the process as they would be impossible to replace on any acceptable timetable at this point in the process. CHW worked with CSD and PBI to determine the correct final locations for each pot bearing and, with this information in hand, PBI jacked the Cube up at each set of pot bearings, made the final bearing location adjustments and then lowered the Cube onto the pot bearing supports. Loads at the main pot bearings were approximately 220 kips and loads at the smaller pot bearings were 130 kips. This put the total cube weight at approximately 1,400 kips for the structural steel framing.

The Energy Center, and the new ExxonMobil campus as a whole, is scheduled to open this summer. ■

The authors would like to thank ***Roy Loftus****, P.E.,* ***Dave Rasmussen*** *and* ***William Thornton****, P.E., Ph.D., of Cives Engineering Corporation,* ***Conrad Hernandez*** *and* ***Larry Peterson*** *of Peterson Beckner Industries and* ***Thomas Getschman****, P.E., of Computerized Structural Design for their assistance with this article.*



Node erection detail on paper...

...and actual erection in the field.

Owner
ExxonMobil

Architect of Record
Gensler

Design Architect
Pickard Chilton

Structural Engineer
Cardno Haynes Whaley

Erection Engineer
Computerized Structural Design, S.C.

Steel Team

- **Fabricator**
  Cives Steel Co.,
  Mid-South Division
- **Erector**
  Peterson Beckner
  Industries, Inc.
- **Detailer**
  Cives Engineering Corporation