OPTIMIZED DESIGN ELIMINATES ANCHOR BOLTS

Early cooperation between the owner, designer and contractors helped optimize this steel design

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TOO OFTEN, BUILDING TEAM MEMBERS ARE WILLING TO PAY HOMAGE to all the current buzzwords such as partnering without paying attention to the actions that would make them meaningful. However, the design and construction of a new processing facility in Casa Grande, AZ, could not have been successfully completed without close cooperation and teamwork between the owner, engineer and fabricator.

Preliminary design on the Abbott Laboratories Inc. Ross Products Division Processing facility started in-house with the owner in January 1993 and with select structural and geotechnical consultants in February of that year. The owner's schedule required that the facility be functional by December 1995: To meet that schedule, the owner decided to design and release the foundations for construction prior to completing the final structural design of the building. This strategy required that a geotechnical engineering evaluation and subsurface exploration be undertaken at the same time as the final foundation design. It also required that steel design be completed prior to the commencement of the traditional contract document stage. Additional fast track activities included contractor prequalification by the owner and phased bidding of the foundations and structural steel. The phased bidding allowed for advancement of the schedule and opened a window of opportunity during the construction for design review and innovation by all team members.

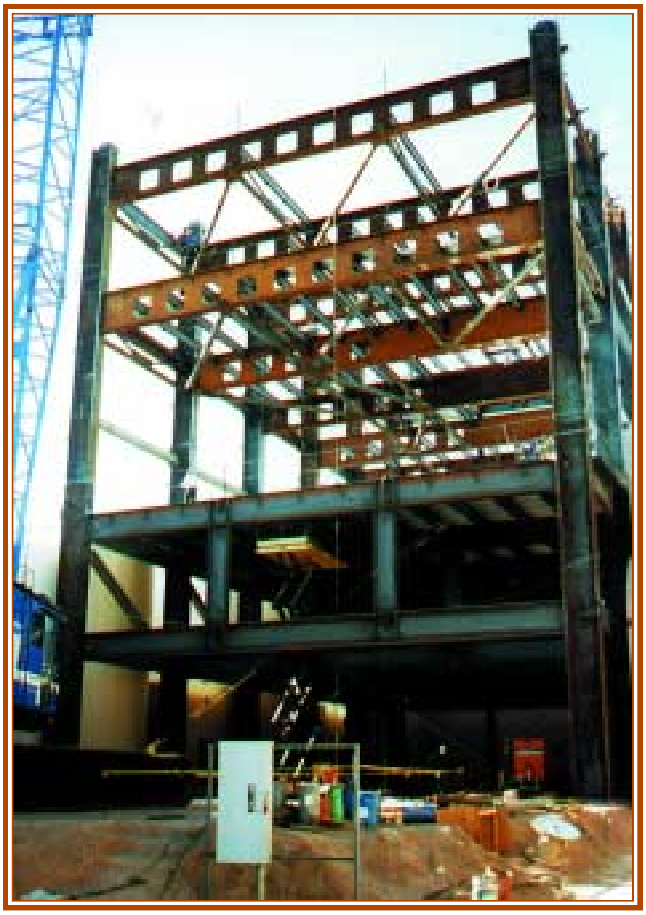
The keystone to the fast track process was the owner's early development of a thorough and flexible set of expectations in terms of strength and serviceability criteria for the structural system, foundations and cladding. These criteria were written contextual to the structural and other design disciplines to create a harmonious continuity between the disciplines without sacrificing flexibility or creating undesirable restraints for the ongoing process design. In addition to the usual serviceability topics of service life, deflection and drift, the owner added constructability/tolerances and flexibility.

An example of constructability criteria was that the design provide a means of tolerance reconciliation to account for the varying tolerances between the different materials and trades at the foundation structure interface, specifically the base and anchorage details. The early design team's mission included the task of creating a design and construction synergy to provide windows of opportunity in which risk to schedule and cost avoidance were to be evaluated and implemented.

For flexibility, the ability to easily modify the structure without compromising structural integrity was a strong consideration. For example, flexibility was accommodated by use of horizontal trusses in the structural strata in lieu of using the floor slab as a diaphragm. The need to be able to cut or core up to a 4' sq. or round penetration anywhere in the slab between the framing members was an owner requirement from the beginning.

PROJECT DESCRIPTION

The structure is approximately 200' tall and has seven primary elevated process levels. The floor elevations are set by the



Five-ft.-deep welded plate, rather than wide flange members, were used for the girders. Among the economic advantages was the ability to cut a regular pattern of 30" sq. openings through the webs of the girders for mechanical and other penetrations.

The use of steel grade beams had numerous constructability advantages, including eliminating the problem of connecting disparate materials.

process requirements with the floor-to-floor dimensions varying from 14' to 34'. The building footprint is 62'-wide in the north-to-south direction and 145' long in the east-to-west direction. It is bounded on the north and west sides by existing buildings and along the south side by an operating tank farm. The superstructure consists of clear span steel frames running in the north-south direction with braced frames in the east-west direction.

The building is designed to support the operating weight of the process equipment and an additional combined process collateral load and live load of 200 psf on each level. The local building code required conformance with the 1988 Uniform Building Code, which had a local modification to the Model Building Code increasing the seismic requirements and setting a seismic acceleration level. In addition to the seismic and wind loadings, the structure's lateral load resisting system was required to resist an "over pressure" horizontal force of 50,000 lbs. at the fifth level of the building. The owner required an additional preliminary design/analysis in conformance with the 1991 NEHRP to show adequacy for possible future Model Code modifications.

Structural System

The typical size bay selected is 20' wide in the east-west direction and 57' long in the north-south direction. Typically, the rigid frame girders span the width of the structure (57' column-center-to-column-center). Supporting the first elevated process level at 31'-6", the primary member is a Vierendeel truss spanning between the exterior columns. Thus, the only apparent interior columns in the building are the Vierendeel vertical members below this level. This provided a maximization of interior floor space for the process designs under consideration. The clear span built-up plate girders at each process level are welded built-up shapes with a maximum depth of 60". The perimeter columns are a combination of welded sections and W36 members varying from 650 lbs. per ft. at the base to 235 lbs. per ft. at the top tier. In the east to west direction, lateral loads are resisted by diagonal bracing frames of the tube steel in the vertical perimeter plane.

At each elevated floor level, the floor framing consists of steel composite filler/floor beams with a 5½"-thick reinforced concrete slab on a 1½" steel form deck. The concrete deck may act as a diaphragm, but a system of bottom flange bracing horizontal trusses was provided to transfer lateral loads to the vertical bracing system. The floor and horizontal truss systems are interconnected by steel "drag" frames to provide a positive load path to the perimeter diagonal bracing system. The horizontal braces were initially selected to provide bracing for the case where design and life cycle modifications compromise the effectiveness of the concrete deck diaphragm. The use of a horizontal bracing system also allowed the structural steel to be erected as a self-supporting steel frame per the AISC *Code of Standard Practice*. The ability to modify any floor without losing overall structural integrity and the ability to erect a self-supporting steel frames were both owner requirements.

As stated, the north-to-south clear span girders are each 5' deep. The economy of using welded plate girders was proven early in the project with collaboration between the designer and the fabricator. A regular pattern of 30" sq. openings cut through the webs of the girders was also proven to be cost effective. The typical floor beams are spaced at 4'-9" on center and the openings in the girder webs are centered in the space between the interior floor beams. This configuration allowed process piping, electrical conduits and other undefined collateral items to pass through the girders and subsequently reduced the overall clear height required in each level by up to 2'. This resulted in a total building height reduction of about 14'. The design of the reticulated plate girders omitted placing an opening in the region of the spandrel-to-first-interior-floor-beams. This was done to provide a solid web section at the regions of combined maximum negative moment and maximum shear. The moment gradient significantly reduces the stresses on the section of the reticulated plate girder between the exterior spandrel and the first interior floor beam such that the holes can be placed in the remaining web of the span. The result is an interior girder design with uniform flange and web thickness and no need for reinforcement around the penetrations. This reduction in stiffness is attributable to the added shear deformation in the member. Each of the 57'-long plate girders was fabricated and shipped in one piece and then field connected to the columns.

The reconfiguration of the moment connections between the plate girders and the perimeter columns was extensively studied in the preliminary design phase. The relative costs and tolerances for misalignment for both bolted and welded configurations was reviewed. Ultimately, field welded moment connections were selected as best meeting the criteria. Therefore, the Vierendeel trusses and the girders were connected to the perimeter columns with welded moment resisting connections throughout. The clear span rigid frame configuration has the advantage of bearing all of the building dead load on the same columns that are subject to uplift forces from the overturning effects of seismic and wind loading. The building dead loads are adequate to counteract all of the overturning forces so that no net uplift is transmitted to the foundation system under lateral load cases. The interior and all other framing was bolted except where practical constructability issues indicated field welding was appropriate to resolve tolerance issues (for example, at one end of each diagonal brace).

All of the primary framing was specified as ASTM A572 Gr. 50 steel. In addition, the latest AISC requirements for Group Four and Five shapes were incorporated where appropriate. The structural steel was designed using the LRFD Specification. The use of LRFD was mandated by the owner based on the owner's experience of realized economy.

Foundation System

The building foundation system consists of a rectangular system of concrete encased structural steel beams or plate girders on 6'-diameter drilled piers socketed into the bedrock. Due to the proximity of the existing structures and the space requirements for construction equipment, the drilled piers had to be offset inward from the building columns at approximately 53' on center. The piers were terminated approximately 8' below the first finish floor level at grade. The building column loads are delivered to the drilled piers through the below grade structural steel grade beams. Each north-to-south frame line has a continuous plate girder grade beam spanning over the drilled piers and cantilevering out to support the building columns. The projected steel grade beams and columns are attached with moment connections to provide a fixed base column. The grade beam/transfer girders served the dual function of transferring the gravity loads to the drilled piers and contributing to the lateral load resisting system. The steel girders also provided the benefit of a steel-to-steel connection with respect to tolerances and constructability.

There are many advantages to using steel grade beams in place of the more conventional reinforced concrete. The first was to minimize a series of tolerance and constructability issues at the connection between the column and its support. Although later encased in reinforced concrete, the construction of the foundation grade beam system using steel members cut several weeks from the construction schedule. The conventional method of attaching fixed base columns is to use anchor bolts. Similarly, the conventional solution for attaching the steel grade beams to the drilled piers would have been to use cast-in-place anchor bolts. However, the accurate placement of anchor bolts and base plates for large columns is a difficult problem, especially below grade. The layout is often in a physically difficult location with safety and access concerns. Errors can occur in the initial placement of the bolts and even under good conditions the field personnel often have trouble in controlling the location of the bolts during pouring.

The obvious solution for the column base was to make the top flange of the steel grade beams the base for the perimeter columns. The design required that the flanges of the columns be bolted to connection plates shop welded to the flanges of the steel grade beams. The grade beams then act as cantilevered transfer girders because the columns are not directly centered over the drilled shafts. The transfer girders are attached to the drilled piers by surrounding the transfer girders with welded concrete stud anchors, reinforcing dowels and ties that project out from the top of the drilled piers and the steel framing to be resolved at these locations.

The construction of 6'-diameter drilled shafts is subject to many variables that limit the ability of the contractor to hold tight tolerances. On this project, the specifications were written with attention to tolerance and constructability. The center of each drilled pier was required to be constructed to within 6" of the theoretical center of the drilled pier (plus or minus 3"). The alignment of the steel grade beams needed to be maintained even if the shafts were poured 3" out of alignment. Therefore, the pier design included the effect of the girder being placed on the pier at the limit of the allowable construction tolerance. The early design team recognized that the use of a structural steel transfer/grade beam system provided a versatile mechanism to connect drilled pier construction with its inherently large tolerances to a structural steel superstructure, which requires closer tolerances. The steel-to-steel moment connection allowed continuity between the column and the steel grade beam, resulting in a reduction of total column weight by about 100 tons. As a result, a design was produced without the use of anchor bolts for this tall steel frame.

Construction Management

The owner's representative provided the coordination with the process vendors and designers and provided for continuity of the coordination of the structural design between the preliminary and final designs. The preliminary structural steel package and the "for construction" foundation package were designed by Computerized Structural Design, Milwaukee. The preliminary steel design was completed in eight weeks. Geotechnical Engineer of Record and the Quality Control Inspection for the foundation and the foundation steel was provided by Dames & Moore of Phoenix. Bids for the steel contract were limited to AISC Certified Fabricators, and the winning bid was submitted by LeJeune Steel Co. The final design for the building, excluding foundations, was completed by SSOE of Toledo, OH, and the foundation contract went to McCarthy Construction of St. Louis with Case International as the drilled pier subcontractor.

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