Power Up

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Courtesy of Bechtel Power Corp.

Modular framing options are providing power plants with opportunities to become more structurally efficient.

WHILE THERE HAS BEEN A PUSH to develop more efficient electrical power, there has also been a trend toward more efficient framing systems for the facilities that provide it.

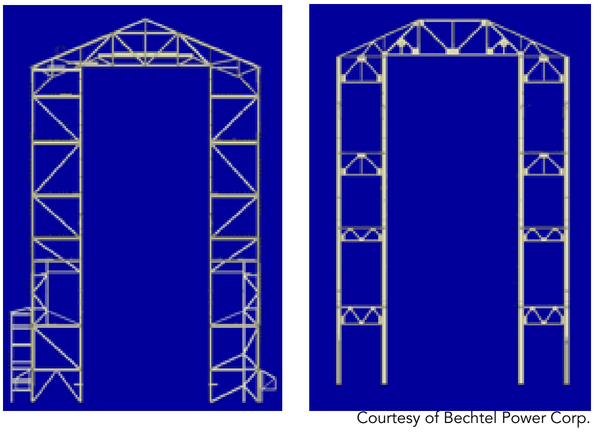
Over the past several years there has been increased use of modular structural steel framing layouts in the design and construction of solid-fuel power plants (those that burn fossil fuels to produce electricity). These newer framing layouts include modular floor and stair assemblies, boiler support trusses and simplified moment super-frames.

The primary benefits of these new framing approaches, in our experience, have been significant and include:

- Reducing ironworker/steel erection job hours by one-third, with corresponding critical path steel erection reductions of one month for 400-MW units and two months for 800-MW units
- Increased efficiency through a transfer of field work performed at up to 300 ft above grade in ambient conditions to a weather-protected fabrication shop and/or ground assembly area
- Mitigation of labor-intensive bolt installation (understood to be up to two-thirds of steel erection job hours) via heavily coped seated connections
- Preclusion of most interferences with large vendor-supplied ductwork and coal pipe, including supports, through a simplified structure
- Reduced material loading, unloading and erection through an order-of-magnitude reduction in the number of pieces—especially through the inclusion of miscellaneous steel in modules
- Increased safety and worker access through expedited completion of floor platforms for ironworkers and all subsequent trades, thereby mitigating temporary scaffolding

In short, the modular approach isn't about reducing tonnage, nor does it necessarily add tonnage, in our experience; it is about schedule savings and the subsequent economic savings. While the specific application of the modular and optimized framing layouts described here are for solid-fuel power plant construction, select approaches are also being applied in part to new nuclear construction and can have application to other industrial structures or perhaps even select commercial structures.

◀ Roof truss to which roof panels will be added.



➤ Comparison of a conventional braced frame versus a simplified super-frame.

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Economic Considerations

There are three key economic factors that affect the design of modular framing layouts for power plants:

1. The significant contribution of miscellaneous steel and bolting in the overall steel erection
2. The extent of modularization to concurrently optimize shipping weight and volume criteria
3. Consideration of indirect costs and capital costs of multi-billion-dollar jobs, often reflected in part by bonus/penalty clauses

Let's address the first issue by looking at a typical grating floor bay. A typical bay of a boiler building grating floor (up to 30 ft by 40 ft) is conventionally framed with steel beams at 6 ft to 7 ft on center, numerous infill members to cut down on each primary beam's unbraced length, an incremental column line girder, approximately 20 grating segments and several handrail segments. Cumulatively, approximately 50 pieces must be installed. Due to the heavy loads associated with industrial buildings, each bay may contain up to 100 large-diameter, high-strength bolts.

By comparison, we determined that the same bay could be framed with three floor panels, one incremental girder and 28 bolts when using a modular framing system (both shop-fabricated and ground-assembled configurations of structural and miscellaneous steel) and all seated connections. Similar optimization opportunities were found in modularizing checker plate floors and composite floors. The modular steel is comprised of what would otherwise be a combination of both structural and miscellaneous steel. Order of magnitude (i.e., significantly rounded) installation rates for the three groupings of steel are:

- Structural steel – 15 hrs per ton
- Miscellaneous steel – 50 hrs per ton
- Modular steel – 10 hrs per ton

Thus, for a grating floor panel consisting of one-half miscellaneous steel, the modular installation rate (i.e., 10 hrs per ton) is one-third the average "stick-built" rate (approximately 32 hrs per ton). As a result, one of the primary focus points of power plant modularization is to incorporate as much field labor-intensive miscellaneous steel as possible. Through our project experience, the remaining miscellaneous steel installation rate on modular plants (i.e., miscellaneous steel which can't be modularized) is reduced by half. This secondary benefit is due directly to the access provided by the modular steel, as well as the reduced need for temporary scaffolding and handrails.

The drastic reduction in bolts comes from heavily coped and seated connections. Keep in mind that seated connections use only two bolts, even with reactions of many hundreds of kips. Erection of structural steel in industrial buildings reflects the following job hour distribution:

- Piece installation – 30%
- "Stuffing" bolts – 30%
- Bolt tightening – 30%
- Bolt inspection – 10%

Thus, approximately two-thirds of the hours (starting at lay-down retrieval) are associated with bolt installation. With modular framing, eight bolts for each of three panels and four bolts for a column line member yields a total of 28 bolts, or a reduction of approximately 70% in the non-diaphragm floor bolts, along with a 50% reduction in the number of field connections requiring ironworker access.

Shipping is the second major economic consideration. Delivery costs for structural and miscellaneous steel are a function of both weight and volume. Realizing this, floor modules incorporate as many structural steel members and as much miscellaneous steel in modules to concurrently optimize the weight and volume criteria. Activities at the site other than erection (e.g., unloading, storage and transporting panels to under the erection crane) are minimized as well.

To represent the order of magnitude contribution of schedule cost (via indirect/capital costs or bonus/penalty value), a lower bound value of $100,000 per day is used for a single 10,000-ton unit. If a modular steel design results in a reduction of one month in the schedule, the calculated schedule cost savings would be $3 million. As a percentage

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Courtesy of Bechtel Power Corp.

A simplified super-frame during boiler erection.

of the total installed cost of structural and miscellaneous steel, it would be in the range of 10%. Thus, a significant and additional cost incentive (i.e., beyond conventional fabrication and erection costs) exists for introducing modularization.

Finally, economic benefit is realized from the reduction in scaffolding and temporary handrail installation and removal. With several thousand commodity supports per unit, the benefit of early platform installation can be significant. Note that adequate temporary and permanent floor openings should be provided for commodity entry and rigging when such an approach is selected.

Floors and Stairs

Grating floor panels. Shop-fabricated grating floor panels consist of two parallel beams with perpendicular channels supporting the grating.

The channels and beam top flanges together form a horizontal Vierendeel truss, which serves as a structural diaphragm for lateral-torsional restraint of parallel beam compression flanges, as well as lateral support for small-bore piping loads. The channels can be adjusted to facilitate framing around pipe and other commodity penetrations. In addition, the channels allow for a grating overlap (typically 4 in.) between any two adjacent panels, thereby mitigating potential tripping hazards. Finally, the channel attachment via direct welding to the top flange avoids the shear tabs required with conventional framing.

The panels, which span from column line girder to column line girder, are installed more quickly and safely by using bearing connections. These bearing connections consist of coped wide-flange shapes with ends reinforced by horizontal angles on either side of the web.

Heavily coped ends allow the structure to be arranged with very tight floor-to-floor heights without affecting code headroom requirements. With lightly loaded panels, end bearing connections using extended angles preclude the beams from requiring any beam line fabrication other than being cut to length.

An alternate design with the grating spanning over the two primary steel beams may be used. In this case, infill beams are provided between the primary beams. However, the maximum width of these panels is nominally 8 ft wide due to the grating span. This results in a 50% increase in panels relative to the previous approach. In addition, local reinforcement around large openings is not easily achieved, unlike the condition with the channels. If this option is selected, special attention must be paid to grating stability at all openings, especially those done in the field.

Composite and checkered plate floor panels. Modular composite floor panels may be shipped with all subcomponents (beams, infill cross-members, headed studs, composite deck, closure angles, closure strips, etc.) and shop installed. Each panel is set with bearing connections and a minimum of four high-strength bolts to lock the location in place.

Composite panels may be used for the turbine building operating deck, tripper floor, feeder floor and other composite slabs. The heavy coping at the primary beam ends allows for minimal loss of headroom versus conventional framing. As an alternative (and a requirement for heavy composite primary panel beams), the decking may be rotated 90°, with the addition of infill members as required.

A similar approach is used for the non-pressure-relief wall panels of the tripper gallery above coal silos. During the postulated coal dust explosion, these walls are subject to deflagration back-pressures, typically on the order of 150 psf.

Silo bay tripper floors are typically located at elevations between 150 ft and 200 ft above grade. For these floor panels, all concrete work (rebar and embedment installation, concrete placement, etc.) may be performed at grade.

Historically, checkered plate burner decks use stiffened grating panels up to 6 ft by 8 ft, reinforced with two discrete angles or WT stiffeners). At each edge, a support beam or girder is provided. A typical bay thereby has an inefficient load path. As an alternative, large checkered plate burner panels (up to 12 ft by 60 ft) are shop-fabricated to mitigate both the cited structural inefficiency and quantity of field welding required.

For this modular checkered plate floor framing, panel fabrication is performed upside down on the shop floor, with all fillet welds in the downward position. WT sections are used for stiffeners to form equivalent braced wide-flange shapes. Two parallel channel framing members facilitate attachment to the WTs.

Stair tower modules. Shop-assembled stair towers (up to 12 ft wide by 28 ft high by 60 ft long) provide early and safe access for all trades. In addition, they simplify steel erection as each single stair tower module contains several hundred individual components (columns, beams, vertical bracing, horizontal bracing, handrail panels, stringers, hangers, framing and grating for landings, firewall support steel, stair treads, girts and other elements). With either rail or water access from the fabrication shop, a cost-benefit evaluation of full shop assembly should be considered.

For job sites with only truck access, the cost of shipping such large components is seldom justified. Further, the results of a traffic and logistics study may preclude full shop assembly due to overhead lines, traffic signals, etc. In such cases, partially shop-fabricated stair towers (with subsequent full ground assembly) provide a cost-effective solution.

Each shop-fabricated frame includes landings, girts, columns, firewall support steel, handrails and vertical bracing. The two frames are mated with each other to mitigate the shipped volume, thereby lowering shipping costs. At the site, the two segments are separated for installation of intermediate stringers and framing. During this ground assembly, lighting and fire protection piping are also installed. Entire elevator machine rooms may be shop and ground assembled to lift as one unit on top of the stair tower and adjacent elevator area.

Boiler/Roof Support Systems

Historically, the support of boilers (of up to 15,000 tons in weight) has been provided by means of long-span plate girders. The plate girders are located up to 7 ft above the boiler penthouse roof to allow an individual to pass below. An independently framed, "stick-built" roof is provided above the plate girder, with the high point of the two bays immediately outboard of the boiler the same nominal elevation as the roof above the boiler.

In lieu of conventional plate girders, trusses with up to 110-ft spans can be used. Each boiler support truss is able to be set nominally 5 ft lower than a corresponding plate girder, as craft can pass within the depth of the truss. A modified Warren truss configuration is selected for the span supporting the boiler cavity, such that the roof height at their ends can be greatly reduced from the plate girder configuration. The truss depth is set at one-quarter of the boiler cavity clear span regardless of the clear span, both in order to efficiently satisfy the stringent deflection requirement of *L*/1,000 and to allow for a standard design.

American Galvanizers Association

While power plants have long been built with traditional steel frames (above), there has been a recent increase in modular framing design for these facilities.

ASTM A913, Grade 65 steel is used to reduce the truss weight. This also allows for smaller construction cranes as the boiler support typically determines the required crane capacity. Framing between the trusses is "layered" so that seated connections can be used in most instances. This results in a drastic reduction in the number of bolts relative to conventional construction with shear tabs. Specifically, the layered connections use only two bolts regardless of the beam end reaction versus historical connections of numerous large-diameter, high-strength bolts associated with a boiler weighing up to 15,000 tons.

Access around the boiler is critical for trade productivity. Thus, shop-fabricated walkway modules (with ground assembly of handrails) are used below the truss level. In the interest of cost, spans are reduced via the center of a boiler support truss. These modules are configured to function as girts spanning the clear boiler cavity width.

Simplified Super-Frame

The conventional structural system for a boiler building up to 300 ft high is a braced frame. As an alternative in low-seismic regions, a "simplified super-frame" consisting of large moment frame bents at each column line is used.

Braced frames are often "butchered" at the location of the secondary air ducts, leading to design inefficiency. Because of duct location and geometry, vertical bracing in some layouts actually requires a diagonal member to be located through a primary air duct (in these cases, a sheet steel tear-drop wraps the member along with insulation; it is not a preferred situation but occasionally results from the boiler geometry and primary diaphragm levels). In addition, the braced frame typically requires horizontal diaphragms at 25 ft on center to stabilize the wide-flange columns. These closely spaced diaphragms and vertical bracing limit space for commodities and commodity supports, leading to numerous interferences and obstructions for operations personnel.

In the simplified super-frame pictured on the previous page, large (40-in. by 40-in.) box-shaped super-columns of high-strength steel facilitate unbraced lengths of at least 60 ft, reducing the required number of levels of horizontal diaphragms by a factor of between 2 and 3. The columns are fabricated from up to approximately 2-in. plate or use large HSS members. Horizontal trusses are typically shop fabricated when up to 12 ft deep or ground assembled when more than 12 ft deep. The trusses are formed, in large part, through the expanded use of existing members—i.e., they are created by simply lacing together two column line floor beams.

The simplified super-frame has no diagonal bracing immediately above the base mat. This facilitates a much more efficient installation of large ductwork sections, as they may be trucked underneath their final position and then rigged into their permanent position. In a braced frame, such ductwork must be set on additional temporary steel as the building is erected, then subsequently rigged into the final position. This is merely one of the additional non-structural benefits of the design.

While these modular design/build methods have been shown to be successful for solid-fuel power plants, select components have also been used in combined-cycle power plants. Further, these methods can be directly extrapolated to other industrial structures—e.g., those in the oil, gas and chemical markets. And variations on these methods could potentially be applied to other large-scale projects as well. MSC