Modular Stay-In-Place Formwork

By James L. Ryan, P.E., Neha Gidwani, P.E. and Luis M. Moreschi, Ph.D., P.E.

This article investigates the use of large ground assembly of stay-in-place (SIP) formwork, re-usable formwork support framing and reinforcing steel in 5-foot to 15-foot thick reinforced concrete power plant structures, in part to compress a project's critical path via parallel construction at grade.

The heavy industrial formwork and shoring required for constructing up to 6-foot thick reinforced concrete, aircraft-protection-shield (APS) roof slabs and up to 15-foot thick turbine generator (TG) decks in large (up to 1600 Megawatt (MW)) power plants are some examples of complex construction found in the industry. Both examples are labor-intensive and schedule consuming. In addition, shoring of the thick APS roof slabs and domes to multiple slabs or the containment structure below, and shoring the thick TG decks to a base mat up to 100 feet below, results in a delay of mechanical and electrical construction until the shoring is removed.

In addition to the labor-intensive shoring and formwork installation/removal, these structures are heavily reinforced, with multiple layers of large diameter reinforcing steel in each direction at both the top and bottom of the slabs and decks. Multiple layers of side bars are also required at the vertical faces of TG decks along with closely spaced reinforcing steel ties between the top, bottom and side layers. For TG decks, other associated tasks include the installation of work platforms, embedded plates and anchor bolts.

From a financial perspective, power plant projects with the aforementioned structural components have enormous indirect costs and capital costs on the order of $100 million per month in the latter stages of the construction schedule. Thus, substantial commercial benefit may be achieved by focusing on schedule compression. One method of achieving this schedule compression is through the use of standardized, modular stay-in-place (SIP) formwork and re-usable formwork support systems in lieu of conventional formwork and shoring. Such approaches increase craft productivity with work at grade, and amortize the formwork support system over multiple repetitive uses on a site or at multiple sites. Notably, the ever increasing crane capacities (now on the order of 1000 tons at over a 300-foot reach) facilitate such construction methods.

In this article, schematic designs are discussed for three specific applications:

- TG decks in standardized nuclear, fossil, or combined cycle plants
- Flat airplane-crash-resistant roofs for nuclear power plants and defense facilities

Figure 1: Conventional cast-in-place turbine generator deck (1,600 MW).

- Airplane-crash-resistant domes above containment structures

The schematic designs involve ground-assembled super-modules (up to 100 x 100 feet and 800 tons) comprising SIP formwork (or partial SIP formwork for TG decks), reinforcing steel, embedded plates, anchor bolts, work platforms, and a re-usable formwork support structure. Such ground assembly is performed in parallel with conventionally constructed adjacent areas, resulting in months of schedule savings. In the case of nuclear power plant APS structures, the schedule savings is typically for critical path construction activities. For TG decks, the modular approach may either facilitate critical path construction or, in the case of nuclear power plants, allow available craft to be shifted to the critical path Nuclear Island (i.e., containment and adjacent structures) construction.

The designs are merely incremental improvements, using standard structural steel trusses, shapes, plates, and formwork in specific configurations. In addition, the designs extrapolate from Bechtel Power Corporation's power plant floor modularization schemes used for pulverized coal projects for over 10 years. Specifically, shop-fabricated SIP formwork modules (up to 12 feet wide by up to 60 feet long) are used as permanent formwork components for the ground assembled "super-modules".

Turbine Generator Deck Modules

Figure 1 illustrates a 1,600 MW reinforced concrete turbine generator (TG) deck constructed with conventional cast-in-place techniques and discrete deck support columns. In addition to requiring an enormous amount of formwork and shoring, the conventional approach delays the erection of the adjacent turbine building bay. Although not visible, such TG decks are typically spring-supported, requiring 10-foot by 10-foot embedded plates on the deck underside at each deck support leg.

continued on next page

*James L. Ryan, P.E. is a Senior Engineering Specialist (Steel Structures and Modularization) at Bechtel Power Corporation. James can be reached at **jryan@bechtel.com**.*

Neha Gidwani, P.E. is a Senior Engineer at Bechtel Power Corporation.

Luis M. Moreschi, Ph.D., P.E. is a Civil/Structural Supervisor at Bechtel Power Corporation.

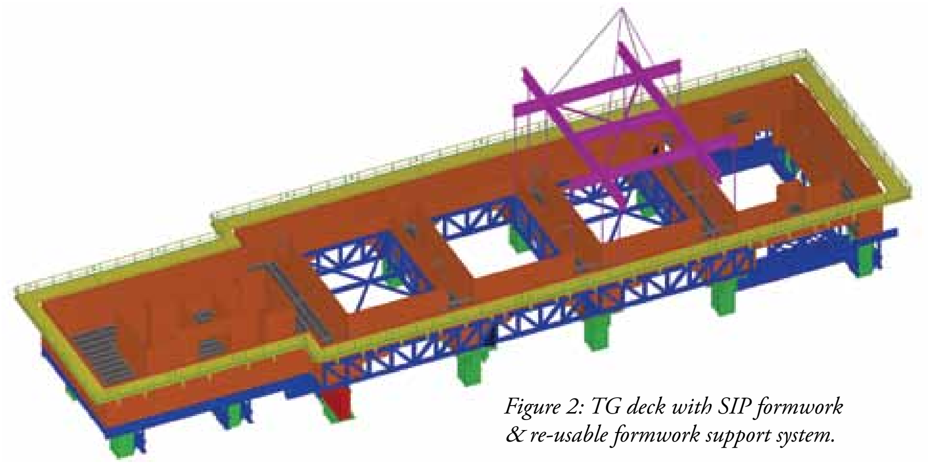

Figure 2: TG deck with SIP formwork & re-usable formwork support system.

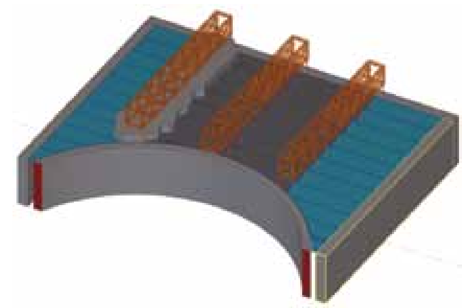

Figure 4: Isometric view of box truss-supported module (100-foot x 100-foot).

In lieu of conventional TG deck construction, a modular approach of large scale ground assemblies 60-foot by 60-foot, and 15 feet deep is used. These assemblies include SIP formwork, a re-usable formwork support system, access/work platforms, and the majority of reinforcing steel. With work at grade instead of 100 feet in the air, the modules are safer to construct, yet at a significantly higher craft productivity (i.e., on the order of 40 percent per a reference subcontractor). *Figure 2* provides an isometric view of the TG Deck with SIP formwork and re-usable formwork support system.

The shop-fabricated SIP formwork assemblies are up to 12 feet wide by 20 feet long. Shop welded WT-shapes stiffen ASTM A572, Grade 50 plate, ½-inch thick. The WT stiffeners are oriented parallel to the direction of the heavy reinforcing steel, such that any local void would have no impact on the gross section. These stiffened plate assemblies also function as embedded plates for commodity supports and deck support springs, mitigating direct field hours associated with discrete embeds. The stiffened plate assemblies, in turn, are supported by beams at truss work-points.

The maximum truss depth of the re-usable formwork support system is nominally 10 feet (dimensioned to the top and bottom chord centerlines) to facilitate shipment to the initial site and from site-to-site. This size typically precludes the need for a police escort. Stringent deflection criteria of L/1000 are used for all trusses. Templates above the trusses and top of deck are used for embeds to achieve/satisfy the TG deck supplier specified tolerance. The truss weights are reasonable, with a maximum member size of W14 x 68 for the deck shown in *Figures 2* and *3*.

Access for jacking, spring adjustment/setting, and shimming is only required parallel to or perpendicular to the TG axis. Therefore, there is no interference with the outboard truss support brackets. Inboard truss brackets are removable to avoid any interference with mechanical equipment (i.e., condenser) installation. For clarity, *Figure 3* provides an isometric view of the underside of the formwork support system.

Due to the size of the modules, which encompass many TG deck beams, a large amount of reinforcing steel (including a large number of splices) may be installed at grade before lifting. Up to three layers of reinforcing is typical for top and bottom layers of the TG deck beams, with up to two layers on each side. Closely spaced ties are required both horizontally and vertically. Thus, significant savings in field job-hours is achieved when mitigating work at 100 feet above grade.

Using standard historical rates, modularizing large TG decks up to 1,600 MW is estimated to save on the order of $1M for a single application relative to conventional TG deck construction. Cost savings are nominally $5M when such a design approach is replicated at three sites, primarily due to the amortization of the formwork support structure. In addition to cost benefits, construction safety is increased with work mostly being performed at grade. For nuclear power plants, increased overall project schedule certainty may be realized by shifting available craft labor to the Nuclear Island construction from the Turbine Island.

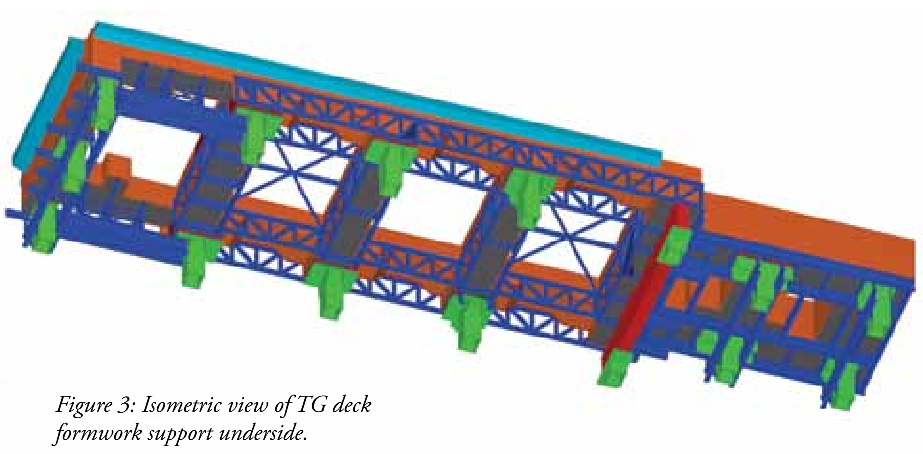

Figure 3: Isometric view of TG deck formwork support underside.

Ground Assembly of Flat APS Roofs

Flat APS roof slabs in standardized nuclear power plants and defense facilities require multiple layers of closely spaced reinforcing steel at the top and bottom, along with closely spaced ties. Construction also involves both installation and removal of formwork and shoring. Shoring may be of significant height with horizontal bridging (such as above spent fuel pools) or to multiple floors in other safety related structures. In addition, the shoring to multiple floors below interferes with the "open top" construction method, whereby large equipment and commodities are dropped from above prior to construction of the concrete slab immediately above.

To mitigate costs and the schedule duration, an alternate design/build methodology involves constructing large scale, ground pre-assembled roof super-modules up to 100 feet by 100 feet. As shown in *Figure 4*, these include modular SIP formwork panels (12 feet wide by 40 feet long), re-usable formwork support box trusses and reinforcing steel. The trusses are sized for truck delivery in two sections. The assemblies do not require removable formwork or shoring.

The SIP shop-fabricated formwork panels consist of ⅜-inch thick plate (conforming to ASTM A572, Grade 50), WT stiffeners, and two parallel beams at their longitudinal edges. Shop fabricated SIP formwork panels on the two sides of the 100-foot by 100-foot module can be installed after the large module is set in place. *Figure 5* provides a cross-section, illustrating how the SIP formwork panels are rod-supported from the trusses. Embedded couplers at the top of the concrete serve to permanently anchor the rods in the depth of the slab. In turn, these rods anchor the SIP formwork panels, including during a postulated aircraft impact. As such, the SIP formwork actually provides additional aircraft impact protection against scabbing of the roof slab.

To confirm the cost effectiveness, the evaluation included finite element analyses and preliminary design. The top and bottom chords of box trusses for the nominal 100-foot span are W14x233, with W14x145 diagonals and verticals.

For a single application of a formwork support system on a given 1600 MW plant, a nominal $1M premium is forecast. However, the approach is typically applied a minimum of two locations at any site, i.e., above the spent fuel pool and at least one other safety related building. When applied twice, the approach is cost-neutral. The approach has significant cost savings when applied to a second site. More importantly, as construction is typically on the critical path, the schedule compression of up to two months may yield enormous savings associated with the cost of capital and indirect costs. The cited critical path construction schedule compression results both from expedited APS construction and the ability to perform "open top" construction.

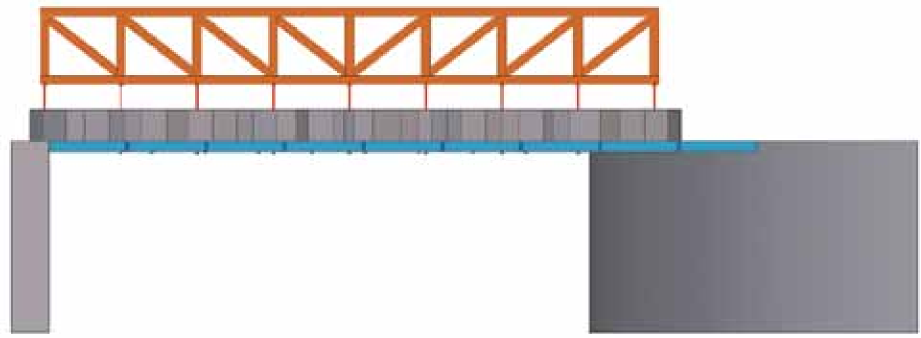

Figure 5: Cross-Section of box truss and rod hangers.

Ground Assembly of Reactor Building APS Domes

Construction of Reactor Building APS domes requires reinforcing steel placement and installation/removal of complex formwork/shoring systems in a confined space. To mitigate this issue, SIP formwork and a re-usable formwork support structure is evaluated. Design goals included:

- Maximizing the module size, yet assuring the lift is within available crane capacities,
- Mitigating the quantity of temporary shoring posts via detailed finite element analyses of the containment dome, and
- Mitigating the quantity of shop fabricated SIP formwork panels.

Figure 6 reflects the optimum framing selected from several configurations. The outside diameter of a ground-assembled module comprising reinforcing steel, SIP formwork, and support steel that could be lifted as one unit was defined by a 100-foot outside diameter of reinforcing steel, as well as support steel and SIP formwork extending to a maximum dimension of 60 feet from the dome apex. The temporary support posts consist of a single post at the apex, 8 posts at 30 feet from the apex, and 16 posts at nominally 60 feet from the apex. The outer ring is constructed using SIP formwork and conventional rebar construction for fit-up with the vertical rebar of the cylinder. The support steel consists of a mix of nominally 6 foot deep plate girders and W44 shapes. Shop-fabricated SIP formwork panels use materials similar to the flat APS roof slabs.

Static finite element analyses were performed using ANSYS software. Membrane and membrane plus bending stresses, as well as radial shear stresses in the concrete, were shown to be within code allowable limits.

Ground assembly of APS domes appears to be warranted if the construction is determined to be on the critical path or if improving schedule certainty is desired. A commercial comparison was not performed, as it involves non-standard fabrication costs and specialty formwork supplier pricing. Instead, the evaluation is intended to define one optimized approach for future consideration.

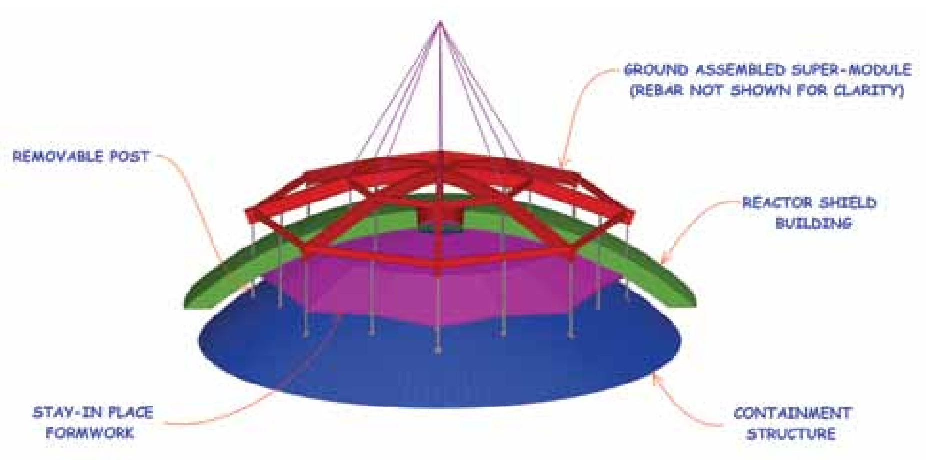

Figure 6: Isometric view of proposed SIP formwork system with RSB APS.

Conclusions

Significant cost, schedule and safety benefits may be achieved in standardized large power plants and defense facilities with the use of SIP formwork and re-usable formwork support structures. While not typically used in the past, industry developments since the previous generation of such large power plant units have made such approaches both viable and cost effective. These developments include increases in: crane capacities, material yield stresses, shop weld automation, and awareness of indirect costs and costs of capital in the early design stages of large projects.▪