Bangkok Second-Stage Expressway System Segmental Structures

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In December 1988, the Expressway and Rapid Transit Authority of Thailand entered into an agreement with the Bangkok Expressway Consortium, Ltd., to build and operate the Bangkok Second-Stage Expressway for a period of 30 years. The project includes 66 km (41 mi) of elevated structures to be built in two phases. The precast segmental structures consist of over 2,000 spans with an average length of 42 m (138 ft). A gigantic precasting yard was designed to produce a total of 20,500 superstructure segments. New construction engineering procedures had to be developed to accommodate production of as many as 1,000 superstructure segments per month.

With less than half of the road density of similarly sized developed cities, Bangkok is notorious for its heavily congested roadways (*1*). To help alleviate this situation, in December 1988, the Expressway and Rapid Transit Authority of Thailand entered into an agreement with the Bangkok Expressway Consortium, Ltd. (BECL), to build and operate the Second-Stage Expressway. The contract was a build-operate transfer contract. BECL would provide the financing of the project in exchange for tax breaks and a 30-year operation concession. At the end of 30 years, the ownership of the expressway would revert to the Rapid Transit Authority of Thailand (*1*). This toll facility would be the world's second largest public utilities concession project. The firm Kumagai Gumi Co., Ltd., Project Manager for BECL, chose Freeman Fox Intercom to design the elevated expressway. J. Muller International (JMI) was hired to provide detailed engineering for production of the segmental bridge structure.

The Second Expressway System (SES) is a network of elevated express lanes through the Bangkok metropolis and suburban areas. The project includes a north–south route (Bangklo-Chaeng Watthana) and an east route (Phyathai–Srinakarin).

The project is built in two stages: (*a*) initial SES with a total length of 47 km (29 mi) completed in February 1993 and (*b*) incremental SES with a length of 19 km (12 mi), currently under construction and expected to be completed in 1995. The total cost of construction will exceed 1.2 billion U.S. dollars.

The initial SES includes the Chaeng Watthana Road to Middle Ring Road segment on the north–south route and the Phayathai to Rama IX Road segment on the east route. The initial SES is composed of 1,131 spans.

The incremental SES includes a north–south segment extending from Phayathai to the southern portion of the First-Stage Expressway. This section of the SES is composed of over 700 spans.

Description of Segmental Structures

The original concept for the Second-Stage Expressway utilized a U-beam section. Under the urging of JMI, the project manager, Kumagai Gumi decided to convert a large portion of the project, 770,000 m^2, to a precast segmental box girder. The decision to convert to segmental was based on speed of construction in this dense urban environment. The precast segmental superstructures are built from the top with almost no concrete cast in situ to minimize traffic interruptions. In addition, precasting allows for good quality control, and the concrete box girder provides pleasing aesthetics.

The segmental structures for the Bangkok SES consist of over 2,000 spans with an average length of 42.25 m (140 ft). Span length varied from a minimum of 24.9 m (82 ft) to a maximum 48.75 m (160 ft). To accommodate box girder width variations, two different sections were used for the project: (*a*) Section D2 for width up to 12.2 m (40 ft) and (*b*) Section D3 for width up to 15.6 m (51 ft). Both sections are 2.4 m (7 ft 10 in.) deep. In some areas two box girders are connected by a cast-in-place closure joint between the wing tips. The top slab of the box girder is transversely post-tensioned. The spans are simply supported to take into account potential differential settlements; however, the box girders are linked through continuity of the top slabs to provide good rideability. An in-situ slab was placed between adjoining spans' segments. The "link slab" restricted differential movement between the two adjacent spans. Expansion joints are placed approximately every four spans. The spans are divided into concrete segments with an average length of 3.40 m (11 ft 2 in.). Diaphragm segments are used at each end of the spans to receive post-tensioning tendon anchorages and distribute bearing reactions. The post-tensioning tendons are placed inside the box girders but outside of the concrete. They are typically draped and deviated at three locations within the span. The deviator segments are reinforced with ribs along the webs and a bottom slab beam. To simplify the post-tensioning layout, "diabolos" were used to each tendon deviation. The diabolo is a pipe with bell-shaped extremities, which is cast into the segment. After casting, the diabolo is removed, leaving a bell-shaped void, which will accommodate the longitudinal post-tensioning. The radii of the bells are computed to accommodate all variations of tendon angles caused by span length and geometry. This design allows simplicity and standardization of the tendon geometry and accelerates the casting process, thereby reducing possible offset caused by pipe fabrication or placement errors. The superstructure is erected by the "span-by-span" method with dry joints. After erection, the top slab segment joints are sealed with an epoxy compound, and an asphalt overlay 30 m (1 in.) thick is placed on the deck.

The structures are designed according to the AASHTO standard specifications of 1983 (*3*) and the Guide Specifications of Design and Construction of Segmental Bridges of 1989 (*3*). The highway loading was based on AASHTO HS20-44 loads increased by 30 percent with an overload provision of 27.8-ton (61.3-kips) trucks, centered at 11.15 m (36 ft 7 in.) and occupying a single lane.

Precasting

The production goal of the precasting yard for the initial SES was ambitious: all 14,400 segments were to be completed within a 2-year period.

PRECASTING YARD DESIGN

General

The project manager had the precasting yard built and equipped under a separate contract. After completion of this task the project manager selected the casting yard "operator," a joint venture of Bilfinger & Berger and CH. Karnchang, for manufacturing segments. The segments are then delivered to three erection contractors.

As previously stated, the production goal for the precasting yard was ambitious: a total of 20,500 superstructure segments had to be produced, of which 14,400 segments were for the initial SES and 6,000 segments were for the incremental SES.

Production of the 14,400 segments began in January 1991 and was completed in November 1992. The average monthly production was 630 segments, including the learning curve. The maximum monthly production reached a high of 1,013 segments.

The "short cell" casting method was chosen over the long bench method because of the necessity to build spans with variable curvatures in plan and elevation. In addition, a limited amount of space was available for the casting yard (200,000 m^2). It was necessary to install a total of 50 casting cells (34 for typical segments, 16 for pier segments), making the casting yard the largest of its kind in the world (see Figures 1 through 3). Because of poor soil quality, the casting yard is totally covered with a concrete slab, supported on piles in high load areas.

To ease the management of the casting operations, the yard was divided into four distinct production zones. However, reinforcing bars were produced at a single location, and concrete was produced at two concrete plants. Because of the high cost of imported equipment, the yard had to be designed to minimize the equipment requirements.

The following were other objectives of the casting yard design:

1. To maintain a continuous production flow (e.g., rebar → rebar cage → casting machine → segment → temporary storage → storage → erection);

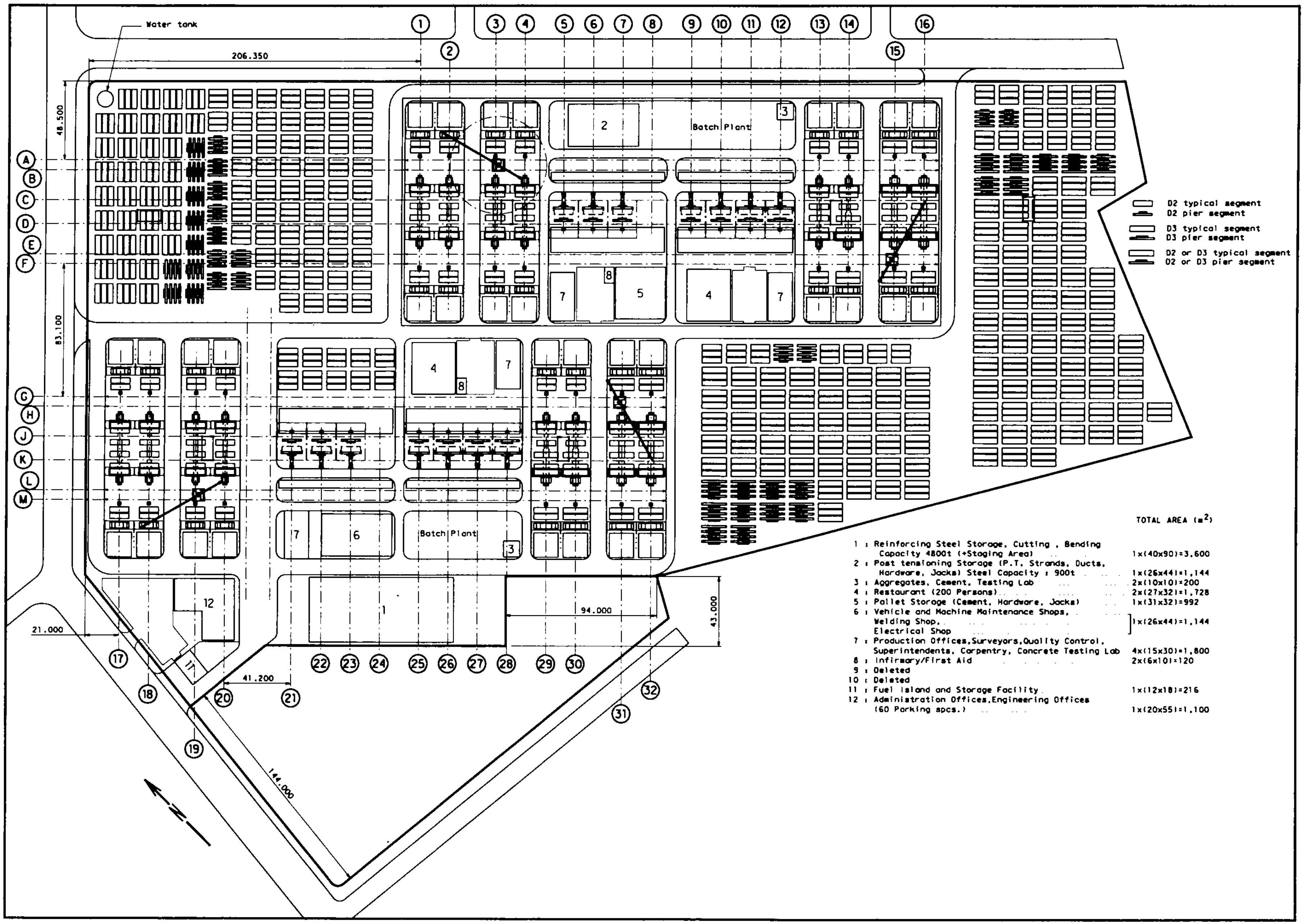

FIGURE 1 Layout of the Bang Pa-In casting yard.

FIGURE 2 Aerial view of casting yard.

2. Because of the layout of the production areas, to allow this flow to occur within a limited amount of space with minimum conflicts;

3. To separate the production areas from segment handling areas for safety reasons, and to reduce interruptions in the production process; and

4. To allow for the different levels of experience in segmental production by management and supervisors. The laborers had no experience in segmental production, and little or no experience in general construction.

Equipment

The casting machines were designed to accommodate the varying geometry characteristics of the superstructure: minimum radius 83 m (272 ft) and variable segment lengths and widths. Production requirements are one typical segment per machine per day and three diaphragm segments per machine per week. To accelerate operations, hydraulic systems were used to operate the collapsible core forms and adjust the soffits. Tight tolerances were given for fabrication of the casting machines—in particular for the form bulkheads—to ensure consistency of the concrete segment dimensions. Finally, the design of the casting machines had to take into account the high number of uses (approximately 450 uses per machine). Four tower cranes were placed on rails to service the four different production areas. They are used mainly to rotate form soffits and handle rebar cages, which were produced in jigs close to the forms.

Six travel lifts are used to carry the segments from the production area to storage. They are also used to load trucks transporting the segments to the erection site. The casting machines are equipped with three soffits, the wet cast, match cast, and a temporary storage. With this layout of the segment loading, storage operations are removed from the critical path and travel lift usage is optimized. For additional simplicity, the casting machines were aligned such that the segments produced were stored within the path of the shuttle lift.

The concrete is produced in two mixing plants at 80 m^3/hr (105 CY/hr) and delivered to the casting machines with concrete trucks. Adjustable conveyor belts are used to place the concrete in the forms. Conveyor belts were selected over concrete pumps because of their lower cost and simplicity of operation. In addition, limited amounts of concrete were wasted with this system. Special measures were taken to ensure that the segment production would not be affected by the rainy season; in particular, all working areas, including rebar cage assembly and casting machines, were protected with rolling sheds.

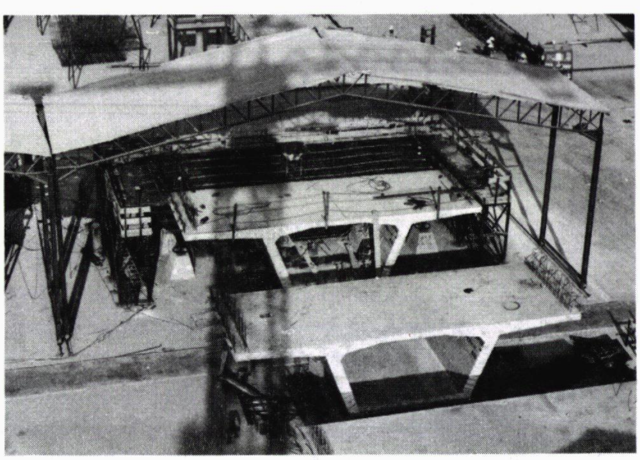

FIGURE 3 Typical D2 casting machine.

Supervision—Personnel

A crew was assigned to each casting machine to work on forms and assembly of rebar cages. Concrete crews rotate between forms to handle concrete pours. Each of the four production areas was organized with an independent engineering and supervision staff that included the following:

- Production superintendent,
- Quality control engineers, and
- Survey crews.

In addition, independent crews are used for handling of the segments and finishing work on the segments. Work is performed 20 hr/day with staggered shifts allowing for optimum use of the equipment.

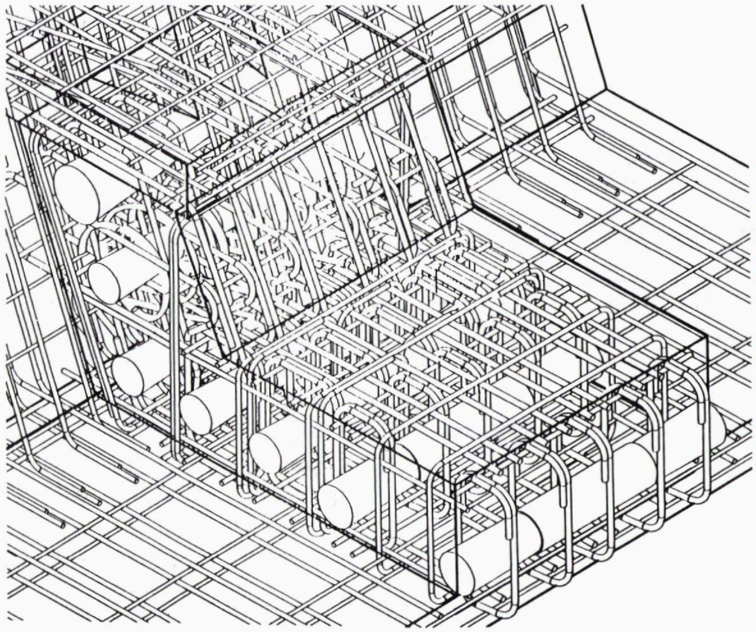

FIGURE 4 Reinforcement detail of typical deviation segment; note voids for diabolos.

Geometry Control

The short cell casting method was somewhat sophisticated. It relied on an accurate placement of the match cast segment in the casting machine for proper geometry control. It was necessary to check with great accuracy the relative positions of matching segments after each pour. The information obtained from these measurements was then used to compute the adjustment of the next match cast segment in the casting machine. This method had never been used before in a casting yard of this size.

FIGURE 5 Underslung truss; note portal frame on existing structure.

It was necessary to develop an iterative computer program to ensure that proper geometry control would be achieved for all casting machines. The three-dimensional computer program Precast-SC computed casting curves, provided setup values for the match cast segments before each pour, and "as-cast" coordinates for all control points after the segments are cast. These final coordinates are used to adjust segment positions during erection. The program works from theoretical three-dimensional coordinates of three control points at each segment joint and takes into account actual survey readings after each segment pour.

Superstructure Shop Drawings

Detailed drawings were required for all the superstructure segments to facilitate production. A span layout drawing was produced for each span. It provided the following information:

- Dimensions of all segments of the span,
- Three-dimensional coordinates of the control points at each segment joint,
- Orientation of segment joints at the extremities of the span,
- Coordinates of span supports to verify consistency with pier locations, and
- Location of embedded items such as access holes, drain holes or gullies, sleeves and blockouts necessary for the erection equipment.

FIGURE 6 Six overhead trusses converging at construction of interchange.

Drawings showing post-tensioning and reinforcing details for all segments were also developed along with bending diagrams, dimensions, and quantities for all reinforcing bars. As mentioned earlier, the post-tensioning layouts were simplified by deviating all the tendons at only three locations. Further simplification was achieved through the use of diabolos at each tendon deviation.

Three-dimensional computer-assisted design models were developed for all typical rebar cages (Figure 4). These models were useful for detecting potential conflicts between rebar and other embedded items. JMI produced approximately 10,000 shop drawings in a period of 1.5 years.

Erection Systems

The segments were assembled by the span-by-span method with ten erection trusses: four pairs of underslung triangle trusses and six overhead trusses. In unobstructed areas with ground access, the contractor used self-launching twin triangular trusses, equipped with a launching nose and tail, which supported the segment under the wing. The segments were delivered from the top, traveling over the previously erected spans, and placed on the truss with a specifically designed steel portal frame. Once the longitudinal post-tensioning was stressed, the trusses were lowered until the span rested on the bearing pads of the columns. Then the self-launching truss was advanced to the next span. In full production, the contractor was able to erect one span per truss per day (Figure 5).

In areas over waterways or existing roadways (including a three-level interchange with 83-m (272-ft) radii and 10 percent cross slope), the spans were erected with a self-launching overhead truss, which required no access to the ground level. The truss was supported entirely on the pier cap. The segments were delivered over the previously completed structure and suspended from the overhead truss until post-tensioning was completed. Once the post-tensioning is complete, the truss would advance to the next successive span. In full production, the contractor was able to erect one span per truss every 2 days (Figure 6). The first span of the initial SES project was erected in May 1991. The last span was completed in March 1993.

Conclusion

The precast segmental method of construction was successfully applied to this gigantic project built in a dense urban environment. Two of the casting yard production areas were opened in February 1991 and two more were opened in May 1991. In August 1991, the production reached 750 segments, which was the goal assigned for this project. The maximum monthly production actually reached over 1,000 segments.

The erection of the 1,131 spans of the initial SES was accomplished with a total of 10 trusses. It started at the end of June 1991 and was completed in March 1993.

ACKNOWLEDGMENT

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