Bang Na Expressway, Bangkok, Thailand — World's Longest Bridge and Largest Precasting Operation

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The new $1 billion Bang Na Expressway in Bangkok, Thailand, is not only the longest bridge in the world, but also represents the largest precasting operation ever carried out. The all-precast, prestressed concrete superstructure has a total length of 55 km (34 miles). This gigantic project provides an important link in the transportation system around Bangkok and is expected to play a major role in the commercial development of Southeast Thailand. The design solution was to use precast segmental, span-by-span construction. The box girders were match-cast and post-tensioned in place with dry joints and external longitudinal tendons. This article presents the design-build contract, describes the design features of the bridge, discusses the construction techniques used in the project, and gives the details of the precasting operation.

As of January 2000, the new $1 billion, 55 km (34 miles) long Bang Na Expressway (BNE) in Bangkok, Thailand, has earned the right for entry into the Guinness Book of Records as the longest bridge in the world (see Fig. 1). This project is also the largest precasting job ever undertaken. In breaking the record, the BNE project surpasses in length and size the bridge crossing Lake Pontchartrain, Louisiana, in the United States (see footnote).

The elevated expressway built on top of an at-grade highway for its entire length, stretches from the eastern edge of Bangkok to the city of Chon Buri. Conceived by the Expressway and Rapid Transit Authority of Thailand (ETA), BNE will form a major element of an extended and interconnected system of expressways in the greater Bangkok area. With the BNE

Editor's Note: Completed in 1956, Lake Pontchartrain Causeway, near New Orleans, Louisiana, is 38 km (23.8 miles) long. An all-precast prestressed concrete structure, it was constructed in 12 months, a major accomplishment at the time. The precast components were fabricated on site using the long line prestressing method. The superstructure consists of 17 m (56 ft) precast concrete sections composed of five parallel girders supporting a deck slab, all cast monolithically. The girders were supported on pile caps resting on hollow cylinder piles. Today, after 44 years in service, the Lake Pontchartrain Causeway is still operating satisfactorily.

Fig. 1. Overview of the BNE project in Bangkok, Thailand, completed in January 2000.

project, ETA intends to facilitate the industrial development of Southeast Bangkok and to connect the planned Second International Airport as well as to connect the deep-water harbor with the city. Another reason for the expressway is to alleviate traffic congestion in and around Bangkok.

The purpose of this article is to present the design-build contract, describe the design features of the bridge, discuss the construction techniques used in the project, and give the details of the precasting operation.

DESIGN-BUILD CONTRACT

In June 1995, a contract was signed between ETA and Joint Venture BBCD under the sponsorship of Bilfinger + Berger with Ch. Karnchang PLC as the important local partner. The contract covered 55 km (34 miles) of elevated expressway together with an additional 40 km (25 miles) of ramps and intersections for a total deck area of 1,900,000 m^2 (20,400,000 sq ft). The agreement stipulated the project would be completed within 3$^1/_2$ years.

The BNE contract was broken down into eight phases with each phase having a specific completion date. The reason for this requirement is that the expressway is a toll facility and, therefore, there was a financial incentive in meeting the schedule so that each completed section could be opened to traffic and start collecting toll fees. The entire project was stipulated to be completed by January 2000.

Because of the extremely short construction period, the design phase had to be completed quickly. This included soil investigations and foundation design, bridge alignment and geometry, structural design of the columns and superstructure, preparation of shop drawings, lighting, traffic control, and toll facilities. Also, a very large precasting yard had to be established.

In essence, this was a lump-sum design-build contract for the turnkey completion of the project. Thus, the start of construction had to overlap the ongoing design. In addition, Joint Venture BBCD, under the contract, had to finance the project until completion. The total cost of planning, designing, constructing and financing the project was approximately $1 billion.

DESIGN FEATURES OF PROJECT

The BNE was constructed throughout its entire length on top of the center and outside medians of the existing at-grade Highway 34 (see Fig. 2), where by contract the traffic must flow without interruption at a speed of 80 km/h (50 miles per hour). The Department of Highways is currently upgrading Highway 34 and the two projects had to be carried out simultaneously over the same route. JV

Fig. 2. Construction of the BNE project above congested Highway 34.

BBCD facilitated the coordination between the two projects.

During the planning and bidding phases of the project, JV BBCD compared an I-beam cast-in-place deck slab alternate with a precast segmental solution. It became apparent that segmental construction provided a more efficient, faster and more economical solution than the first alternate. Production, handling and hauling of segments, speed of construction, and pricing of units were all superior to any other method.

At the same time, the box girder solution provides for an aesthetically pleasing structure. Also, the attractive shape of the main line is highly influenced by the slender design of the box girder (see Fig. 3), which has a maximum span of 44.4 m (146 ft). The specific solution, then, was to use precast segmental span-by-span construction to build the elevated bridge. The box girders were match cast and when in place had dry joints. The longitudinal post-tensioning tendons were external to the box section. Adding to the aesthetics are H-shaped columns which support the superstructure.

Fig. 3. Main line span of 44.40 m (146 ft).

The main structure is a 27 m (89 ft) wide box girder spanning on average 42 m (138 ft) between single-column bents. The bents have a unique H-shape which was conceived to facilitate construction and to enhance overall aesthetics.

The expressway has two 13 m (43 ft) wide roadways with three traffic lanes each, supported by the box girder. This exceptionally wide box girder is comprised of a single cell (i.e., only two webs) with diagonal struts to support the long span of the top slab between the webs. Each precast segment weighs approximately 85 tonnes (94 tons).

The expressway has 36 ramps, all elevated, including 10 ramps, which lead into major interchanges. The 26 typical ramps are located symmetrically about the centerline of the expressway in pairs and lead from the elevated bridge to the frontage road of the existing highway below. Widening of the main line structure to accommodate acceleration/deceleration lanes is accomplished by using multiple box girders connected at the wing tips and supported on precast segmental portal frames spanning the roadway below.

Note that there is a clearance above the existing highway of approximately 14 m (46 ft). This space allows the construction of elevated U-turn ramps over the existing highway but below the new viaduct.

Two elevated toll plaza structures are included in the project, one at each end. These 80 m (262 ft) wide structures support up to 12 toll booths at the exits in addition to toll surveillance facilities. This unusually large increase in structure width is accommodated by a similar approach as the widening for the ramps. Up to six box girders are connected at the wing tips and supported on precast segmental portal frames.

An essential ingredient for the success of the BNE project was the establishment of an efficient precasting yard, which became the largest plant ever assembled in the world. A total of 40,000 segments, of varying proportions, were fabricated. The quantity and rate of production for box girders was one of the highest ever achieved. Approximately 60 percent of the overall concrete requirements for the project were used in the yard for the segments which were cast in carefully planned and always repetitive sequences in order to increase the speed of fabrication and quality of product. More details on the precasting operation will be given later on in this article.

The technology of precast segmental construction, and particularly span-by-span construction, was pioneered by Jean Muller and the firm he heads, Jean Muller International. Segmental construction with external post-tensioning and dry joints has been implemented especially by Bilfinger + Berger, Germany, on many bridge projects in Southeast Asia, Africa and Australia. The principles used on the BNE project have been achieved before but never on such a gigantic scale. For more information on segmental construction and on this project, see Refs. 1 to 7.

CONSTRUCTION TECHNIQUES

This section describes the various structural elements and techniques used in constructing the substructure and superstructure of the elevated bridge.

Foundation of Main Line

The city of Bangkok is situated in the delta of the Menam Chao Phraya River. The underlying soil can be simply classified as a three-layer model, namely, soft clay, stiff clay, and sand. It was, therefore, necessary to transfer all loads to the sand layer.

For the BNE project, 800 mm (31.5 in.) diameter precast spun piles, with a wall thickness of 120 mm (4.72 in.), were used. The piles are in general 30 m (98 ft) long. They are composed of two sections which are welded together to ensure the transfer of tension and compression forces (see Fig. 4).

Typically, 16 piles are necessary to transfer the loads from the main line columns into the sand layer. In order to produce the spun piles, a special plant had to be built with sufficient capacity to manufacture the 900,000 m (2,953,000 ft) of piles required for the project.

The difficulties in driving the piles were due to the very soft consistency of the upper clay layer [12 to 20 m (39 to 66 ft) in thickness] which does not provide any horizontal support for the piles. The heaving pressure of the cohesive soil during pile driving can cause a displacement of more than 1 m (3.3 ft). Thus, the speed of construc-

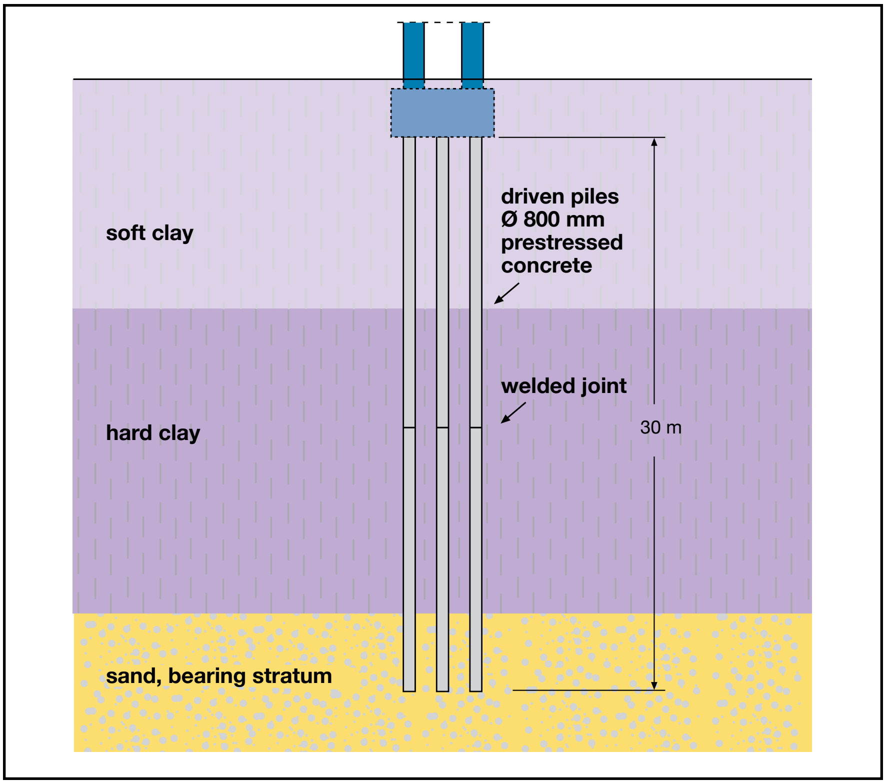

Fig. 4. Pile foundation.

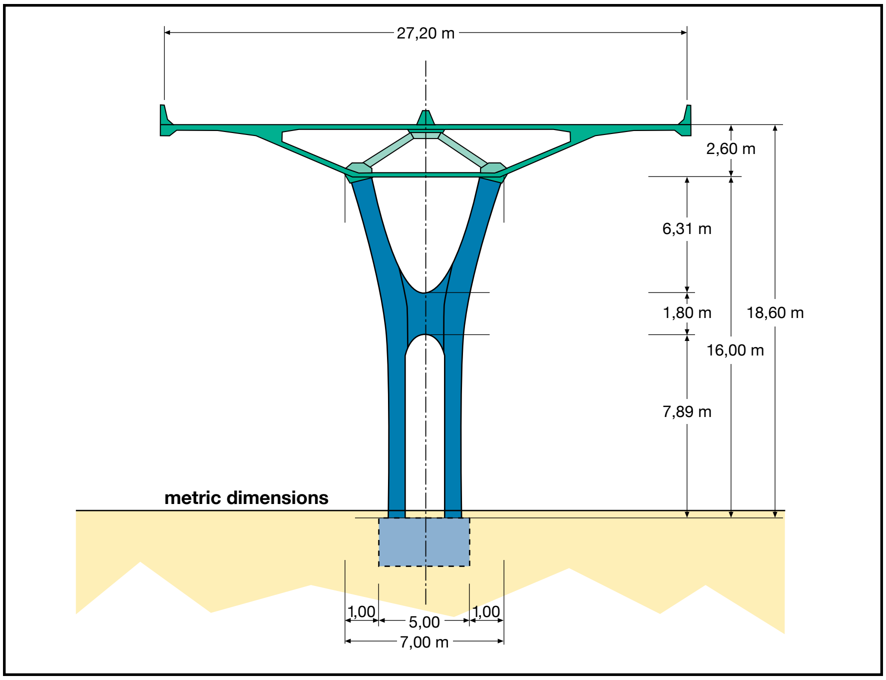

Fig. 5. Mainline column with superstructure.

tion was often impeded by soil profiles comprising five to seven intermittent layers of clay and sand.

The loads transmitted by the columns are transferred to the piles through a pile cap of 2.5 m (8.2 ft) thickness. The top of these pile caps is always below the flow line of the drainage in the center and outer medians of Highway 34.

Main Columns

The main line columns are H-shaped and display a slender light appearance. The H widens from its base at the pile cap to the top so that the outside corners are gracefully curved (see Fig. 5). The architectural design also serves a structural function.

The columns are located in the open drainage area of the center median of Highway 34 and reduce the section of this free flow channel by a minimum amount. In the erection of the superstructure, an underslung girder is used which moves through the upper arms of the column. Since there is no cross-beam, the launching is simplified.

The superstructure is placed on inclined elastomeric bearings in order to avoid moments from load transfer between the box girder and columns under symmetrical loads. This requires very tight construction tolerances because the planes of the bearings must be exactly parallel to the precast segments.

The average height of the main columns is 16 m (52.5 ft). The columns are cast in three parts, i.e., legs, struts, and arms. First, a kicker is cast to adjust for the differences in height between the varying top levels of the pile caps and the variable height of the superstructure. This allows the use of standardized formwork to fabricate the columns. Because the tangent at the foot of the column is vertical, the joint is easily handled.

The sequence of fabrication is to first erect the inner dome of the column formwork and then to place the prefabricated reinforcing bar cages for the legs. After the outside forms have been erected, the legs can be cast. The casting of the strut and upper arms follows the same procedure.

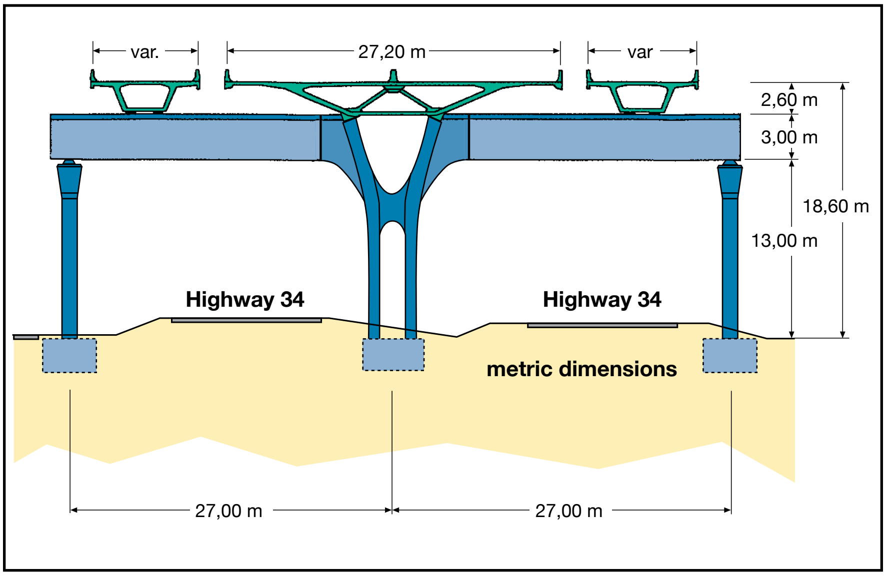

Fig. 6. Configuration of portals.

Fig. 7. Erection sequence for portal segments.

Portal Beams

In areas where the main line is widened, i.e., at the toll plazas and the merging areas of the ramps, it is necessary to place the superstructure on portal beams because the same cross-section of Highway 34 must be maintained. A total of 180 portals were erected.

The portal beams are rigidly fixed at the main line portal column and at each end connected to the outside columns by a hinge. The maximum span is typically 27 m (89 ft) long. The beams are formed by match-cast box girders with vertical webs, which are externally post-tensioned.

The portal columns have the same form as the H-columns but have, in addition, corbels with the same cross-section as the portal beams. A cast-in-place joint is necessary to provide for the adjustment between these corbels and the first match-cast segment. The rigid connection and the resulting tensile forces in this area are not only precompressed by the external tendons in the beam but also by internal tendons in the upper part of the column (see Fig. 6).

The portal beams span three traffic lanes in each direction and it was not permitted to interrupt the traffic for construction operations. The conventional method of using beams cast-in-place on lower formwork was in addition too slow considering the tight time constraints. To fulfill both demands, it was decided to use precast components that could be erected with an overhead truss.

This portal truss has two components, namely, a launching girder with a length of approximately two main line spans and an erection girder, two portal spans long. Both components are connected by a turntable, which is placed on one column.

The complete truss is first launched one span between the arms of the H-column, and then vertically and horizontally supported on three columns. Then, the turntable is fixed on the portal frame. Finally, the erection girder is turned by 90 degrees and is then supported at the ends by the outside portal columns.

The portal segments are delivered to the center median where they are picked up by a winch and taken to their final location. Erection is, therefore, completely separated from traffic flow. Fig. 7 shows the erection procedure for portal segments.

D2/D3 Segments

D2 and D3 segments for two- or three-lane decks are used for the ramps, interchanges, and toll plazas. These types of segments have been previously used successfully on other expressway projects by Bilfinger + Berger in Bangkok. Both are box girders with a deck having a maximum variable width of 15.60 m (51.2 ft) (see Fig. 8).

Note that these segments are erected with an overhead truss girder, which is launched from column to column. First, the segments are hung from the truss and properly aligned. They are then post-tensioned longitudinally by external tendons in the box, and finally placed on the bearings.

D6 Segments

The D6 segments are the main part of the structure. They span in the transverse direction with a width of 27.20 m (89 ft) over six lanes of traffic. For typical segments, their height and length are 2.60 and 2.55 m (8.53 and 8.37 ft), respectively; for pier segments, their width is 1.775 m (5.82 ft). The weights of typical girder and pier segments are 85 and 100 tonnes (94 and 110 tons), respectively. The unusually slender cross-section has inclined webs and two struts in the middle of the segment (see Fig. 9). The inclination of the webs accentuates the curvature of the outside of the columns and carries this line to the horizontal plane of the deck.

The spans are longitudinally prestressed by 22 tendons. Twenty of these tendons are placed externally in the box and two are placed internally in the edge beam. The transverse post-tensioning is accomplished not only by

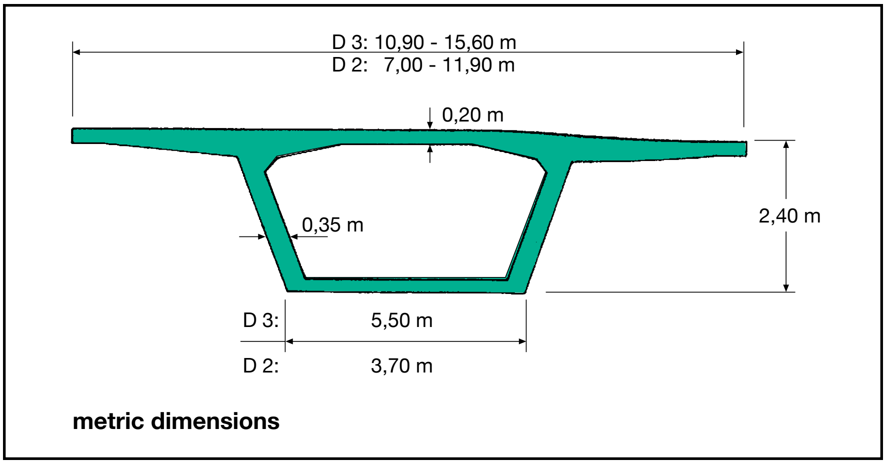

Fig. 8. Configuration of D2/D3 segments.

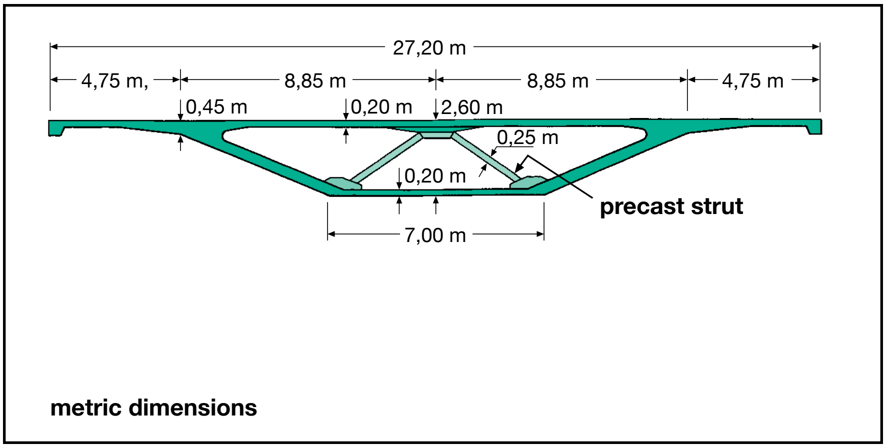

Fig. 9. Configuration of D6 segments.

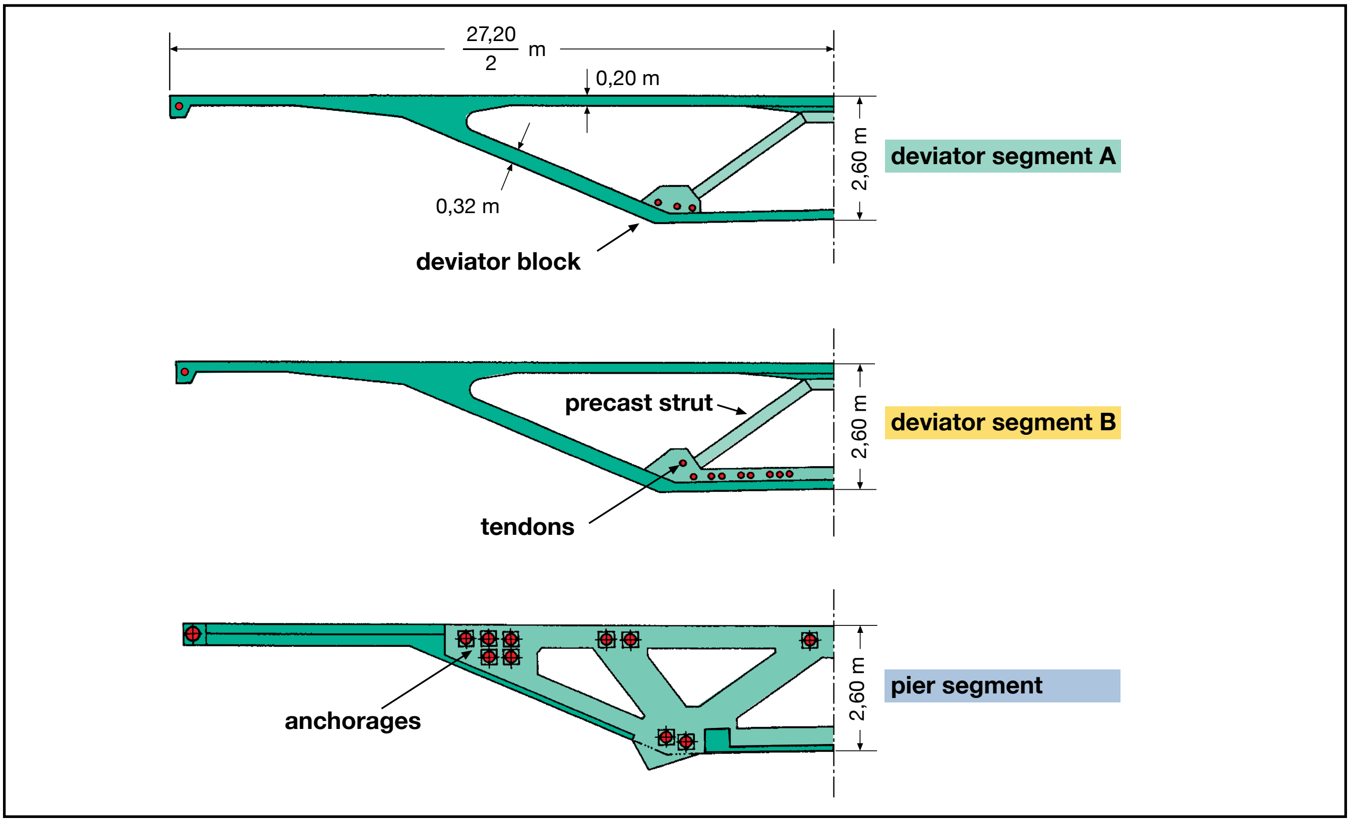

Fig. 10. Longitudinal post-tensioning.

the tendons in the top slab, but also by placing them in the webs and bottom slab (see Figs. 10 and 11).

The H-column, the underslung truss, and the D6 segments of the superstructure were designed by Jean Muller International as an integrated approach to the construction of the elevated mainline structure. The cross-beam of the H-column forms the support for the launching girder and the arms provide the horizontal support. The cross-section of the girder is V-shaped and it is equipped with a swivel crane for lifting and placing the segments.

The segments are placed on chassis (frame supports), which are equipped with hydraulic jacks for adjusting and leveling the span.

The length of the girder is slightly longer than the maximum of two spans. It comprises a load carrying plate girder in the front and a truss to support the launching in the rear. The swivel crane can be placed either at the nose of the plate girder or on the last erected span. It is, therefore, possible to deliver the segment to a station below the swivel crane at grade as well as to the already erected deck (see Fig. 12).

The upper flanges of the launching girder form the planes on which the chassis move. The swivel crane places each segment on one of these chassis, which is then pulled by a winch to the place of erection. The chassis are equipped with hydraulic jacks, which allow for three-dimensional adjustments, i.e., vertical, horizontal, and rotational movements. After adjusting

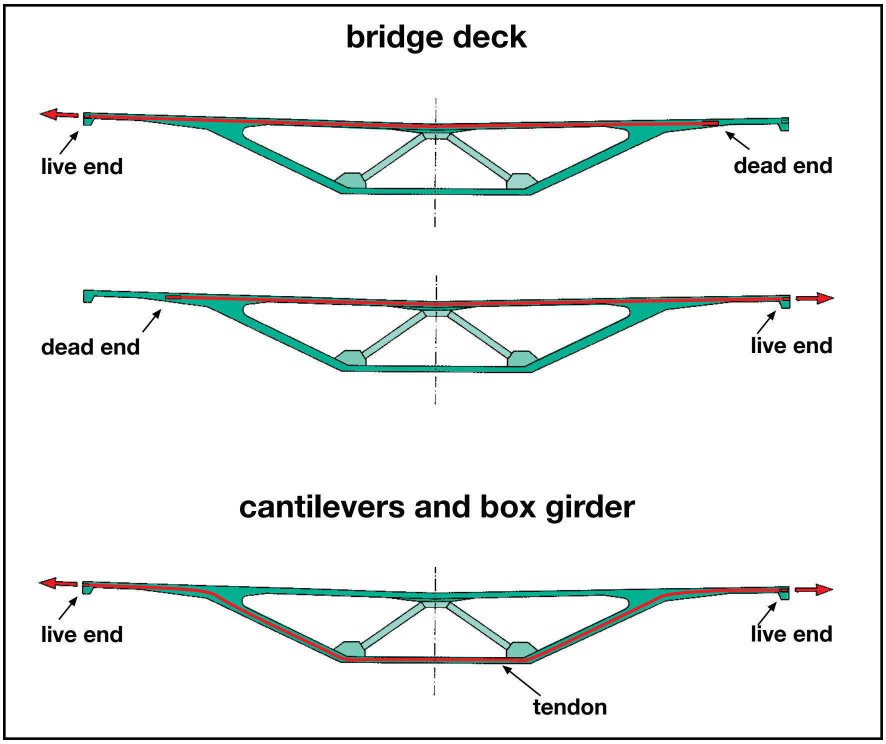

Fig. 11. Transverse post-tensioning.

Fig. 12. Underslung erection girder.

all the segments of a span, the external tendons are placed in the box and stressed. Then, the girder is lowered to transfer the load to the bearings.

The girder is supported by three sliding chairs and two temporary chairs that are required for launching. It is launched by the front chassis that is motorized. This chassis needed for launching is fixed to the erected superstructure and pushes the girder forward using a gear. For longer spans, the center of gravity during launching is in front of the last support. A reaction force is transferred through the truss and into the erected deck.

Comparison of D2/D3 with D6 Segments

The contract terms of the project allowed the bidders considerable freedom in bidding for the design. Bilfinger + Berger elected to use D2/D3 segments for the ramps with a width varying from 6.0 to 10.75 m (20 to 35 ft).

For the 55 km (34 miles) mainline, they selected the D6 segments. Almost 80 percent of the total deck area of 1,900,000 m^2 (20,400,000 sq ft) is formed by D6 segments. A comparison

Table 1. Comparison of material quantities in superstructure segments.

Quantities per square meter of bridge deck	Segment 2xD3	Segment D6
Concrete, m^3	0.51	0.49
Reinforcing bars, kg	70.6	59.2
Post-tensioning tendons, kg	24.4	24.0

Conversion factors: 1 m^2 = 10.76 sq ft; 1 m^3 = 35.3 cu ft; 1 kg = 2.2 lbs.

Table 2. Quantities of components/materials in total structure.

Components/Materials	Quantity
Deck area, m^2	1,900,000
D6 deck area, m^2	1,400,000
D2/D3 deck area, m^2	500,000
D6 segments, pieces	21,320
D2/D3 segments, pieces	18,250
Mainline piers, pieces	1,255
Piles, pieces	28,882
Concrete, m^3	1,800,000
Reinforcing bars, tonnes	167,000
Post-tensioning tendons, tonnes	52,240

Conversion factors: 1 m^2 = 10.76 sq ft; 1 m^3 = 35.3 cu ft; 1 tonne = 1.10 tons.

of the main material quantities of D3 and D6 segments is shown in Table 1.

Evaluated by local prices in Bangkok, the quantity differences alone reflect a savings of 7 percent in the superstructure. Of course, these savings are not only limited to the superstructure, but extend to the substructures as well.

Construction Speed and Overall Material Quantities

The biggest advantage of segmental construction with external post-tensioning and dry joints is the speed with which the superstructure can be erected. In bridge construction, the critical path (after a given starting period) always shifts to the superstructure. Any increase in the rate of erection directly accelerates the construction period.

For the BNE project, six overhead trusses (D2/D3) and five underslung girders (D6) were used. When all the girders are in operation, 2500 m (8200 ft) of ramps and 2100 m (6890 ft) of mainline deck were erected per month. In square meters of deck area, the erection speed for D6 girders was twice as high as for the D2/D3 trusses. At the same time, all the logistics, i.e., production, handling, hauling, and other operations are simplified. The total quantities of components/materials of the project are listed in Table 2.

THE BANG BO PRECASTING YARD

In order to construct the BNE project, a giant precasting yard had to be set up to fabricate the thousands of segments required for the bridge. The Bang Bo precasting plant was constructed at Kilometer 29, about 4.5 km (2.8 miles) north of the expressway. Comprising an area of about 650,000 m^2 (7,000,000 sq ft), the plant was logistically planned down to the minutest detail.

The marshy terrain in the delta of the Menam Chao Phraya River, together with access roads, had to be completely developed in order to efficiently produce and transport the heavy precast concrete components. The entire production area was founded on driven reinforced concrete piles and overlaid with a cast-in-place concrete slab.

The amount invested in constructing the complete plant, without counting the cost of land, equipment, and transportation facilities was about $26 million. The Bang Bo precasting yard (see Fig. 13) is the largest plant in the world and boasts the highest installed production capacity of precast components ever achieved.

Construction of the plant began in the summer of 1995. Within 9 months after starting the yard fill, production of the segments commenced. A total of 40,000 bridge segments and 30,000 other precast reinforced concrete elements such as road barriers and I-beams for the ramps were produced. The facility also contained workers' camps, canteens, offices and laboratories, carpentry, mechanical and welding workshops, a central store, a reinforcing bar cutting and bending shop, plus an area for the production and assembly of post-tensioning ducts.

Approximately 1800 superstructure segments (D2/D3, D6, and portals) were produced per month in a quality controlled environment. The storage area for segments and other precast sections (see Fig. 14) was about 260,000 m^2 (2,800,000 sq ft), corresponding to a production period of 7 weeks.

Fig. 13. Layout of precasting yard.

Production of Precast Segments

For concrete production, there were two batching and mixing plants at opposite ends of the manufacturing area. The total concrete volume for the precast components was about 1,100,000 m^3 (38,830,000 cu ft), involving enormous logistical tasks.

Vertical shaft mixers were equipped with high-mixing devices to reduce mixing time and to increase the output of fresh concrete. The volume of each mixer was 3 m^3 (106 cu ft) and could produce concrete at a rate of 100 m^3/h (3530 cu ft per hour). Twenty-five truck mixers transported the concrete to the molds, where it was placed by conveyor belts. Both form vibrators and internal vibrators were used to consolidate the fresh concrete.

The heavily reinforced sections required extremely workable concrete with an initial slump of 200 mm (8 in.). The fresh concrete was highly cohesive to prevent segregation and was proportioned to reduce


Fig. 14. Storage area for D6 and D2/D3 segments.


Fig. 15. D6 segment production line.

bleeding water to zero. The specified compressive strength for the segments was 55 MPa (8000 psi).

In general, it is not practical to limit the placing temperature of fresh concrete, since a temperature suitable to one specific job might not be appropriate for another situation. For durability reasons, it is more beneficial to know the influence of temperature on fresh concrete and on the properties of hardened concrete, and to take appropriate measures to cool the concrete. In producing high quality precast concrete, it has been found that a maximum placing temperature of 33 to 35˚C (91 to 95˚F) is satisfactory.

The unformed surfaces of the concrete were covered with a plastic sheet to prevent evaporation of the mixing water. The plastic sheet is placed in such a way that a 3 cm (1 in.) thick layer of air is confined. This reduces heat dissipation due to cement hydration and minimizes thermal cracking.

All segments of the superstructure are produced by match-casting using the short-bed method. To expedite match-casting operations, a high-early strength concrete mix was required. After 10 hours, a 20 MPa (2900 psi) concrete strength was required before post-tensioning of a deck slab could get started. At this time, 50 percent of the prestress force was applied in order to allow stripping and shifting of the segment to the match-casting position.

Superstructure components were produced in stationary molds, where the previous segment serves as the bulkhead for the following segment to be cast. In general, these molds are fixed. However, to impart curvature on a particular segment, variable molds are also needed. In addition, there is also a difference between the molds for a typical superstructure segment and those for a pier segment.

For the production of D6 segments, 38 molds were typical whereas only 10 molds were needed for a pier segment. Molds for D2/D3 segments have a typical segment to pier ratio of 19 to 7, i.e., a total of 26 molds.

Typical segments were cast, stripped, moved to a match-casting position, and surveyed within one day. For the pier segments, the formwork and reinforcing bar cages were more complicated and, therefore, the casting cycle took 2 days. To achieve this high rate of production, special precasting knowledge and technical skill are required.

To illustrate this operation, two D6 production lines are shown in Fig. 15. In the transverse direction, they are arranged in the following pattern:

1. Reinforcing bar cage fabrication
2. Survey towers
3. Tower cranes on rails
4. Molds
5. Match-cast position
6. Intermediate storage with travel lift

In the longitudinal direction, 12 molds form one line, at the ends of which there are two storage areas.

First, the struts and transverse tendons were transported from the prefabrication area to the reinforcing bar jigs. The fixing of the reinforcing bars together with the struts, transverse tendons, and forms for the deviators with diabolos (through which the longitudinal tendons will later be pulled) required a full day's work. The molds and the match-cast segment were surveyed and the reinforcing bar cages were lifted by the tower cranes into the molds.

Span layout drawings define the geometry of each span. Before the concrete is placed for casting a new segment, the *x, y,* and *z* coordinates of the joints were checked for accuracy in accordance with the layout drawings. Special software was developed to monitor the geometric survey and to check the after-cast inspection survey.

Each mold has three soffit forms. After post-tensioning, the segment was shifted on rails to the match-cast position. After casting, the following segment is transported, again on rails, to the intermediate storage area, situated between two adjacent production lines. If necessary, finishing patchwork on the segments can be carried out. From here, travel lifts picked the segments up and brought them to the storage areas at both ends of the production line. When the concrete reached its required strength, the segments were fully stressed in the transverse direction.

Special attention was given to the time-dependent deformations of the wide spanning D6 segments (see Fig. 16). Such deformations can be caused by transverse post-tensioning especially since the cantilever arms of the pier and typical segments have different stiffnesses. Care must be taken to avoid different deflections (concrete mix, curing, layout, sequence, and timing of the post-tensioning).

Unlike the segments of the superstructure, the portal segments were

Fig. 16. D6 segment ready for transportation.

produced using the long bed method. This is because their dimensions are smaller, the spans are shorter, the geometry is simple, and the number of pieces is relatively limited. Here, the soffit form was laid out for a full span. The outside and inner formwork traveled to the next position after hardening of the last cast segment. To achieve a high degree of accuracy between segments, match-casting was also used in this operation. At the end of the casting operation, all segments of one portal span were aligned in a row.

Figs. 17, 18 and 19 show progressive views of the project under construction.

CONCLUDING REMARKS

Precast segmental, span-by-span construction using dry joints is particularly advantageous in serial production when a limited number of structural elements are reproduced many times. The rate of construction is much faster than any other comparable construction method. In addition, a very high quality product is ensured.

The planning of an industrialized serial production project must encompass all steps of the process, namely, planning of the production output, delivery of materials, production itself, storage, transportation, and erection of the segments. The required means of production form a fixed ratio. The production is equivalent to increasing all parts of the operation at the same rate. Therefore, the complete planning process and its adaptation to a changing environment requires special attention.

The above factors fit very well within the context of Thai society and culture, as well as the country's geographical configuration. This makes the BNE project, undoubtedly, one of the most interesting and challenging bridges of modern times. It is expected that the successful completion of the BNE project will not only improve the transportation system in the Bangkok area, but will also foster commercial growth in Southeast Thailand.

ACKNOWLEDGMENT

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Fig. 17. Positioning of Segment D6 on mainline column.

Fig. 18. Overview of progress in erection of bridge superstructure.

CREDITS

Owner: Expressway and Rapid Transit Authority, Bangkok, Thailand

Owner's Engineer: Louis Berger Group, East Orange, New Jersey

Engineering Consultants:

- Asian Engineering Consultants, Bangkok, Thailand (Alignment, Foundations)
- Jean Muller International, San Diego, California (Columns, Superstructure)

Contractor: Joint Venture, Bilfinger + Berger Bauaktiengesellschaft, Wiesbaden, Germany (Sponsor) and Ch. Kamchang Public Company, Limited, Bangkok, Thailand

Fig. 19. The new Bang Na Expressway was completed in January 2000. This picture was taken in December 1999. Figs. 17, 18 and 19 are published through the courtesy of Jean Muller International.

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