Construction of Long Key Bridge

Jean Muller
Chairman of the Board and
Technical Director
Figg and Muller Engineers, Inc.
Tallahassee, Florida

Describes the design concepts, alternate bidding options and erection techniques used in constructing the Long Key Bridge in the Florida Keys.

On September 25, the last box girder segment of Long Key Bridge was erected—culminating the successful completion of a structure that is among the longest box girder bridges in the world.

Long Key Bridge, however, is not important so much for its length but for the fact that for the first time in North America several new design concepts and construction techniques have been found to be feasible and economical.

The superstructure was erected in less than 12 months saving valuable construction time and money for all parties concerned. In the closing month of the project a record five spans of 118 ft (36 m) each, i.e., a total of 590 ft (180 m) of completed bridge deck, were erected. This rate of erection is indicative of the efficiency that can be gained using precast prestressed segmental construction and particularly span-by-span erection.

Long Key Bridge, located in the Keys off the southern tip of Florida (Fig. 1), will replace the existing Long Key Viaduct between Long Key and Conch Key.

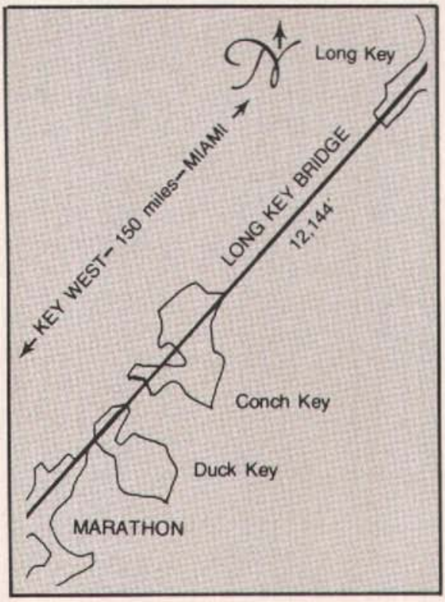


Fig. 1. Location of Long Key Bridge.

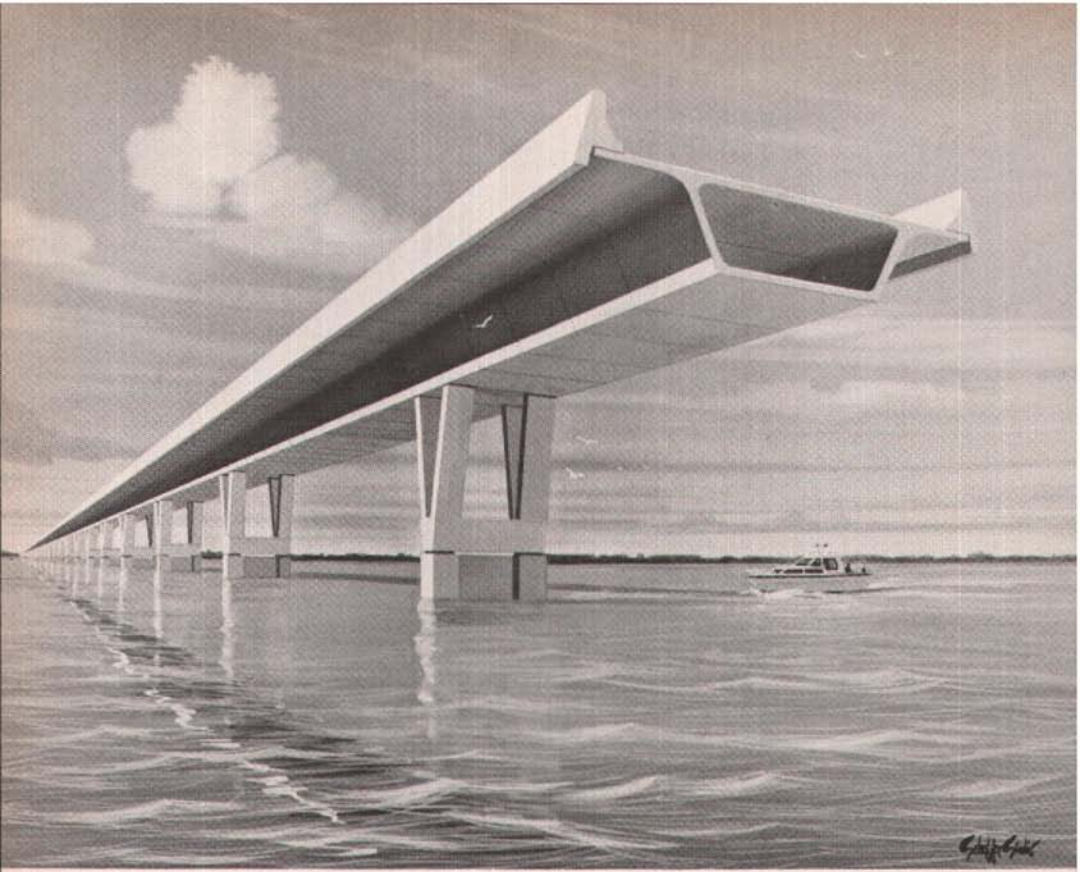


Fig. 2. Artist's rendering of Long Key Bridge.

The structure (Fig. 2), 12,144 ft (3701 m) long, consists of 101 spans each 118 ft (36 m) in length plus two spans of approximately 117 ft (35.6 m). The 38 ft 6½ in. (11.8 m) wide superstructure is built from box girder segments that are 7 ft (2.1 m) deep and 18 ft (5.4 m) long. On each side of the box there is an 8-ft (2.4 m) slab cantilever. The pier segments are 9 ft (2.7 m) long.

Altogether, 722 segments, weighing about 65 tons (59 metric tons) each, make up the structure.

Expansion joints are present every eight spans [944 ft (288 m) on center]. The precast V-piers bear on the drill shaft pile caps. All drill shafts are 42 in. (1067 mm) in diameter and there are two per pile cap.

The original Long Key Viaduct, completed in 1907, was and still remains a great engineering accomplishment. It is located approximately halfway between Key West and Miami. Originally built by H. M. Flagler as a railroad bridge to take passengers to Key West where they caught a boat to Cuba, it has withstood the rigors of hurricanes and constant salt water atmosphere plus sea wave action for over 70 years.

For the past 44 years the bridge has carried a highway 22 ft (6.7 m) wide which was built on top of the roadbed for the railroad tracks. Because of its extreme deterioration in recent years, the Florida Department of Transportation and the Federal Highway Administration decided to replace the structure with a new one.

The challenge of developing an economical precast segmental bridge for the Florida Keys required the development of several new design and construction techniques.

Florida wanted to stay within budget on this project. Therefore, Florida Department of Transportation Bridge Engineer, Tom Alberdi, and Florida FHWA Division Bridge Engineer, Jerry Potter, wisely decided in 1976 that they could probably save construction money through alternate designs for Long Key Bridge. (If this worked they planned to have alternates on several other larger bridges in the Keys bridge project.)

The replacement of the 37 bridges that link the southern coast of the Florida Peninsula to Key West was a large Federal Bridge Replacement program that was funded before the National Bridge Replacement program was established.

Alternate Bidding Options

Long Key Bridge was bid using the concept of alternate designs. Four complete sets of contract plans were prepared for the alternate construction schemes shown in Table 1. Plans for the AASHTO precast, pretensioned I-girders were prepared by the Florida Department of Transportation while plans for the three basic precast segmental schemes were prepared by the State's consultant Figg and Muller Engineers, Inc.

In the preliminary design stage three methods of segmental construction were considered for this project: balanced cantilever, span-by-span, and progressive placing. The progressive placing method was discarded because it was felt (at the time) to be too new for acceptance in American practice. (Note that this technique was later introduced on the Linn Cove Bridge in North Carolina.) The basic difference in the two span-by-span alternates for the Long Key Bridge is in the pier configuration, namely, V-piers or vertical piers.

Aside from the construction alternates and pier types, the contractor was of-

Table 1. Alternate bidding system for Long Key Bridge.

Superstructure		Substructure	
		Precast Piles	Drilled Shafts
Precast Girders—AASHTO		A	B
Segmental	Span-by-Span V-Piers	C	D*
	Span-by-Span Vertical Piers	E	F
	Cantilever Vertical Piers	G	H
	First Option Slab Reinforcement	Reinforced Concrete Epoxy Coated Pretensioning	
	Second Option Barrier Curbs	Cast-in-Place (Conventional) Precast (Never Integral)	

*The low bidder (Michael Construction Company) bid on Alternate D (Precast Segmental) with precast V-piers and drilled shaft foundations; top slab transversely prestressed in the upright position; segments 118 ft (36 m) long and barrier curbs cast-in-place (slip formed).

Table 2. Bid tabulation.

Bid Rank	Alternate* Chosen	Relative Bid
1	D	1.0000
2	F	1.0225
3	F	1.0539
4	F	1.0963
5	B	1.1731
6	F	1.1844
7	F	1.2557
8	H	1.3063

*For key to symbols see Table 1.

fered the option on all segmental alternates of transversely reinforcing the top slab with either epoxy coated conventional reinforcing steel or by transversely pretensioning with ½-in. (12.7 mm) diameter strand. Further, he had the option on all segmental alternates of either precasting or casting in place the traffic barriers.

The contractor also had the option to cast the segments right side up or upside down. Casting the segments upside down was intended to facilitate transversely pretensioning the top slab. However, since no waterproof membrane or wearing surface was specified, the top slab surface of the deck was required to have a grooved or tined surface for skid resistance. This would require that if the segment were cast upside down, the form would be required to produce the desired texture. Specifications were left open in order that strand or bar prestressing tendons could be bid. All conventional steel reinforcement was required to be epoxy coated in all alternates.

Bids on the project were received on June 28, 1978. The eight basic alternatives for this project produced bids from eight contractors as indicated in Table 2. It should be noted that there were six bids for the span-by-span method, one for the balanced cantilever method, and one for the precast pretensioned AASHTO I-girders.

The low bid in precast segmental was $2.6 million less than the AASHTO I-girder bid. Low bid was for the span-by-span alternate with precast V-piers and drilled shaft foundations. The contractor elected to precast the segments near the project site and cast the segments right side up utilizing transverse prestressing in the top slab. He opted to slip form the cast-in-place barriers after segment erection. Further, he elected to move the scaffolding trusswork from span to span by using a barge mounted crane as opposed to having the falsework trusses mounted on barges.

Table 3 presents a cost analysis of the low bid as compared with the AASHTO pretensioned I-girder alternative. The low bid of $26.63 per sq ft compares very favorably with the cost of other bridges across North America with similar span ranges.

Table 3. Cost comparison between span-by-span bid and AASHTO I-girder bid.

Item	Span-by-Span Segmental	Precast AASHTO I-girder
Total Cost*	$26.63 per sq ft	$30.95 per sq ft
Superstructure Cost	$21.43 per sq ft	$23.59 per sq ft
Substructure Cost	$ 5.20 per sq ft	$ 7.36 per sq ft
Segments Erected	$19.16 per sq ft	
Total Bid	$15,307,375.91	$17,956,538.75
Total Area	468,301 sq ft	470,277 sq ft

*The mobilization bid items were proportioned to the structural items in all cases. The Florida Department of Transportation estimate was $14,550,000.

Note: 1 sq ft = 0.093 m².

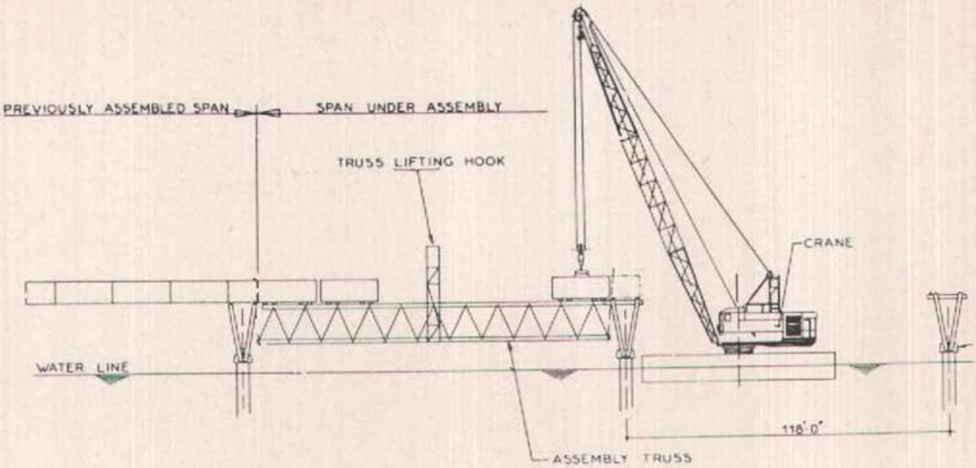


Fig. 3a. Erection scheme shown in contract documents. The span-by-span erection concept utilizes a temporary assembly truss in conjunction with a barge mounted crane.

Design Considerations and Erection Sequence

We realized that contractors in the southeast United States had not bid on segmental bridges. This had a strong influence in the following major considerations for the design of Long Key Bridge in concrete segments:

- Keep the erection scheme simple.
- Be as repetitive as possible.
- Labor is expensive in the Florida Keys.
- All reinforcing steel is epoxy coated.
- Bridge is built over water.

It is important to mention that the contractor, Michael Construction Company constructed the bridge using all of the methods we developed and considered as most economical. The new concrete segmental bridge is almost totally precast.

The span-by-span erection method was the most important new idea for constructing Long Key Bridge. The simplicity of this erection scheme allowed the contractors to bid with only a minimum investment in erection equipment and induced fast construction time. Also, it only required a single application of post-tensioning and helped eliminate an epoxy application in the match cast joints.

This construction method utilizes an adjustable temporary erection truss below the segments. It allows placement and alignment of segments for the entire span prior to final stressing of post-tensioning tendons. Fig. 3a shows the erection scheme in the contract documents. Fig. 3b is an artist's impression of the overall segment erection operation.

The typical erection sequence includes:

1. Installing the erection truss between piers (Fig. 4).

2. Placing and positioning all segments on the erection truss—then adjusting segments for vertical and longitudinal alignment (Fig. 5). Pulling two tendons at 100 kips (445 kN) each to close the joints between the segments.

3. Making connection between V-pier and pier segment, then casting in place the closure joint.

4. Stressing tendons after curing of closure joint.

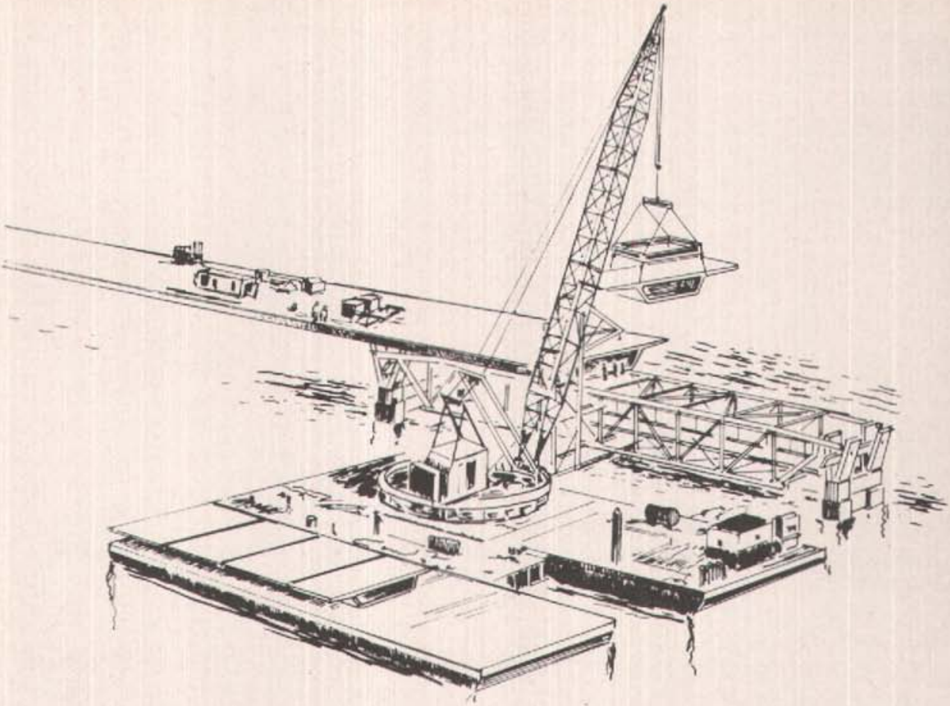


Fig. 3b. Artist's sketch showing overview of erection operations.

Fig. 4. Erection truss in place. It takes approximately 2 hours to move the truss.

5. Lowering the erection truss and moving to the next span (Fig. 6).

The span-by-span method developed for Long Key Bridge has a steel truss between the precast V-piers. Each segment on the truss is supported by three sliding bearings (one under one web and two under the other web) which allow the segment to be moved longitudinally and transversely towards the previously aligned segments.

The three bearing points provide stability along with adequate bearing capacity for supporting 65-ton (59 metric ton) segments. Each 118-ft (36 m) span has a closure joint approximately 6 in. (152 mm) in length adjacent to the pier segment. The closure joint is cast in place and must reach a specified

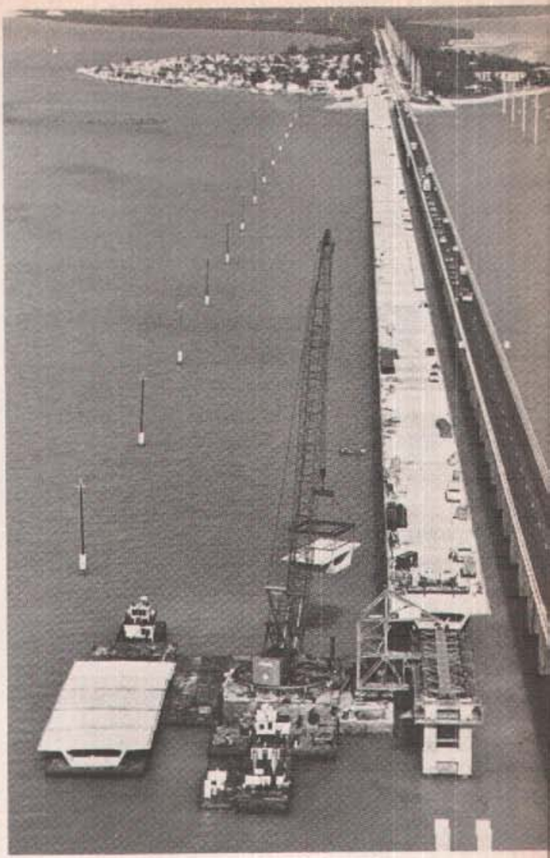


Fig. 5. Barge crane lifting segments from barge and placing them on erection truss. The original Long Key Viaduct can be seen on the right.

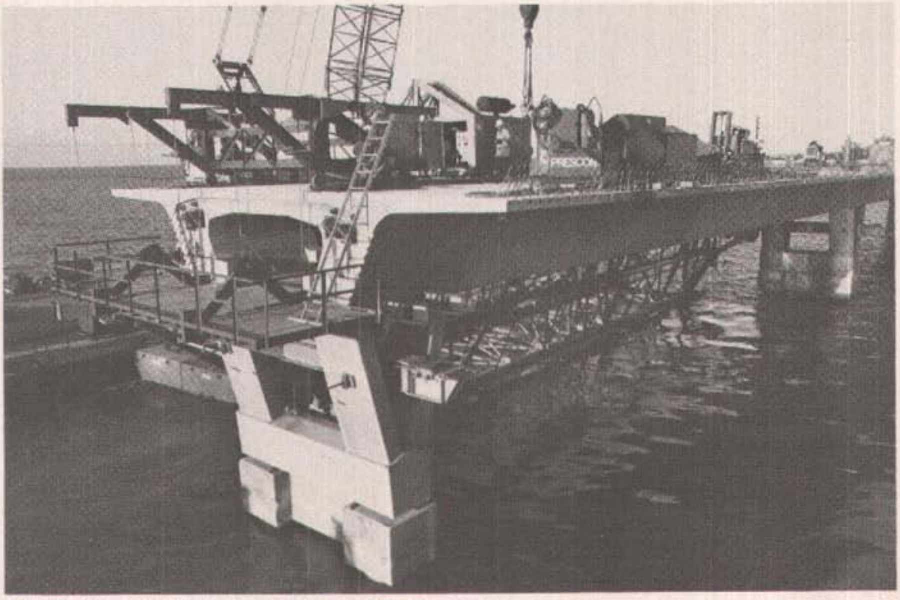


Fig. 6. Erection truss being moved to start another span.

Fig. 7. Casting yard. Typical scene every morning when reinforcing steel is being placed in the new box girder segments. The precast elements were produced by the short line method in four casting machines.

Fig. 8. Casting yard. Typical scene every afternoon (approximately 3:30 p.m.). The last of four box girder segments is being cast against its match cast mate.

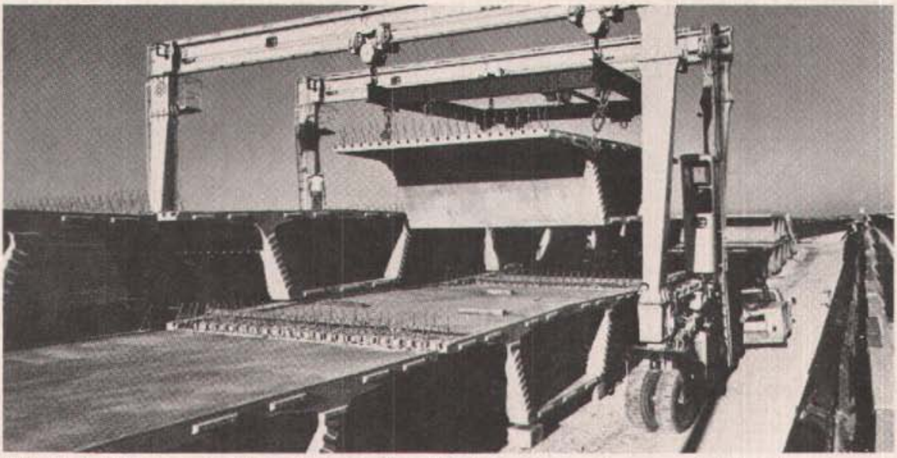


Fig. 9. Typical segment (weighing about 65 tons) being transported to storage yard. In the later stages of the project, segments were produced at the average rate of about 17 elements per week.

strength of 2500 psi (17 MPa) prior to stressing the post-tensioned tendons.

Seven segments that make a span are normally placed in 4 to 6 hours. In the latter stages of the project the contractor reached a maximum speed of completing five spans in one week. This equals 590 ft (180 m) of completed bridge in one week. The average erection rate was 2½ spans per week.

Many other new ideas reduced the construction cost and shortened the construction time of Long Key Bridge.

- External tendons inside the box but outside the concrete.
- No epoxy in the match cast joints.
- Transverse pretensioning of the top slab.
- Riding on the as-cast surface.

Two additional design features were introduced for the first time in the United States.

- Precast V-piers and concrete hinges for expansion joints at the V-piers every eight spans.
- Mutiple shear keys in the webs of the box girder.

Economy in span length was achieved by analyzing several different span lengths so that we could equate foundation cost to superstructure cost. The most economical concrete segmental span was between 105 and 120 ft (37 and 42 m). The 118-ft (36 m) span was chosen because it matched twice the 59-ft (18 m) span of the predominant arch spacing on the original bridge. This affords the maximum navigational ability for boats, since the new bridge is only 16 ft (4.9 m) from the historic Long Key Bridge that will remain intact for recreational purposes.

Both 9 and 18 ft (2.7 and 5.5 m) lengths were offered to the contractor for the segments. The 9-ft (2.7 m) long segments could be transported by truck and the 18-ft (5.5 m) segments could be transported by barge. With three typical segment casting machines and one pier segment casting machine, Michael Construction Company averaged 17 box girder segments per week.

Fig. 7 shows a typical scene every morning when reinforcing steel is being placed in the new box girder segments. Every afternoon either 3 or 4 segments were being cast (Figs. 8 and 9).

A tine finish was applied by hand to the top of the segment. This is the final wearing surface and the quality of the

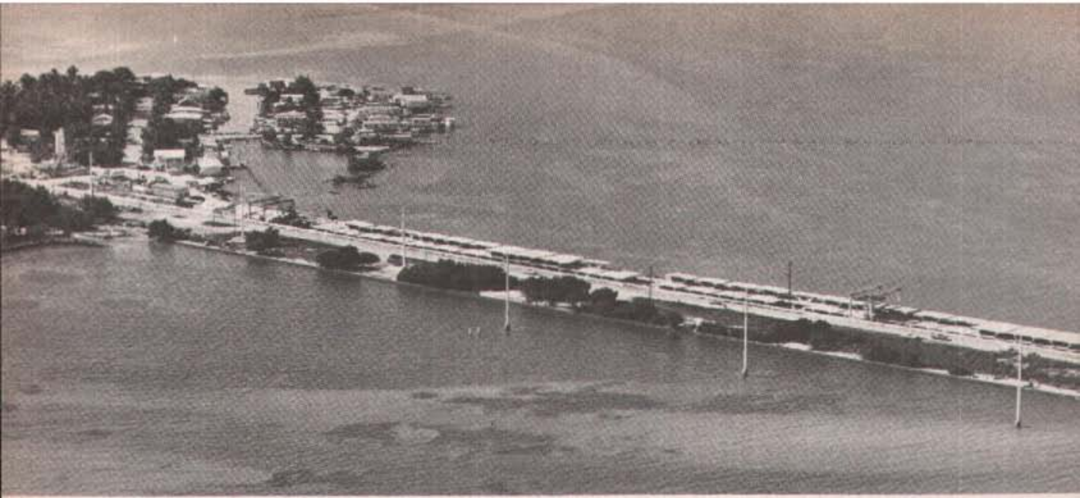


Fig. 10. Aerial view of casting yard with approximately 90 segments in storage.

joint between segments is so good that the as-cast segments do not need a wearing surface.

Since the contractor elected to accept our alternative to transversely pretension the top slab [½ in. (13 mm) diameter strands at 10 in. (254 mm) on center], the segments were steam cured overnight and 4000 psi (27.2 MPa) concrete strength was easily obtained the next morning. Then the pretensioned strands were released. The segments that are two days old were then taken to the storage yard (Figs. 9 and 10).

The process repeats itself and ultimately the 722 segments were cast in the yard on the rights-of-way at the Key West end of the new Long Key Bridge.

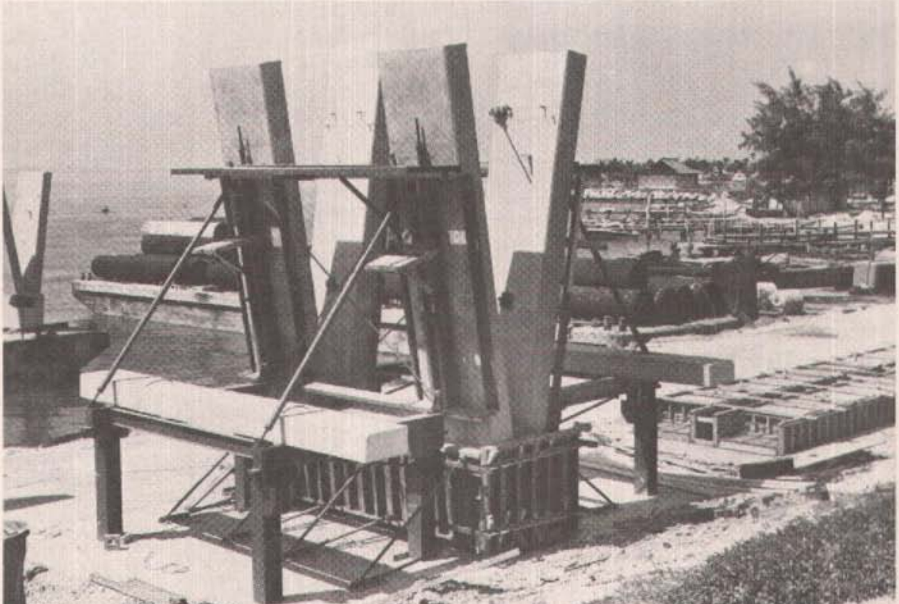


Fig. 11. Precast V-pier in form at casting site.

Fig. 10 shows some of the segments in storage at the bridge site.

At the opposite end of the bridge (Miami end), the contractor fabricated the V-piers. He precast the "arms" of the piers horizontally. Then he placed these precast "arms" in a form that accurately aligned the "arms" (Fig. 11). The base of the V-pier was cast while the vertical members were held in place. These totally precast piers were made in record time and with very good accuracy. (The average was one V-pier per day.) There are eight dowels that connect the box girder pier segment and the V-piers. Two dowels are placed in each arm of the V-pier.

Construction of the foundations started in November 1978, while all the precast operations were being established at both ends of the bridge. The 42 in. (1067 mm) diameter drilled shafts were constructed in about 70 percent of the time predicted by the contractor. Caps for the drilled shafts were cast in place with a precast strut between them.

The next step in construction was placing the V-piers on the pile cap (see Figs. 13 and 14).

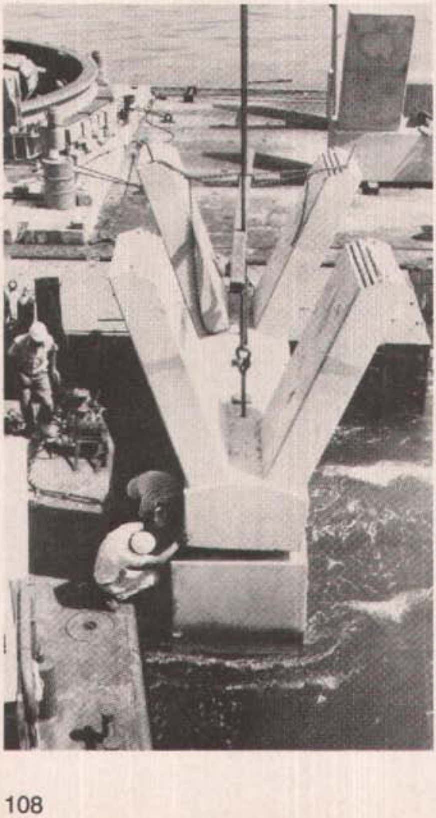
Neoprene bearing pads of varying thickness [9/16 to 5 in. (14 to 107 mm)] depending on their location between expansion joints, are between the base of the V-pier and the pile cap.

By erecting segments with the span-by-span method the post-tensioning was designed as a single process with the tendons made of 19, 21 or 26 ½-in. (13 mm) diameter strand groups. These tendons are post-tensioned to develop continuity over the pier by overlapping the tendons of the previous span in the pier segment (Fig. 15). The post-tensioning was done by Prescon Corporation.

Polyethylene ducts are used to encase the tendons and grout is applied under pressure to protect the tendons in

Fig. 12. Precast struts join the tops of two piles by being cast integrally with a cast-in-place cap. V-piers bear on top of caps.

Fig. 13. First precast V-pier being placed on pile caps.



this duct (Fig. 16). Steel pipe sleeves are in the pier segments and the deviation saddles for the tendons.

The external tendons enabled optimization of the concrete cross section. Other benefits include:

- Simplification of all post-tensioning operations.
- Maximum corrosion protection due to tendons in polyethylene ducts; the grout inspection is easier and leaks can be seen during the grouting process.
- Simplified segment casting. There is no concern about conduit alignment.
- Increased speed of construction and reduced construction staff; one stressing operation per span is only necessary.

The elimination of the epoxy from the

Fig. 14. Closeup of precast V-pier being placed on pile caps.

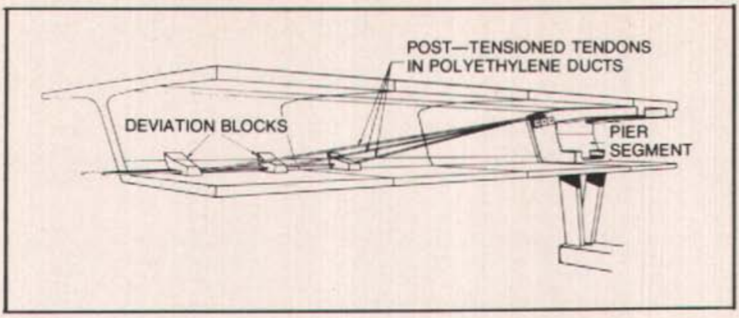


Fig. 15. Layout of external tendons as shown in contract documents. This arrangement, while protecting the tendons from corrosion, simplified the post-tensioning operations and provided other benefits in the erection process.

match-cast joints could be achieved because of the following factors:

- Multiple shear keys in the webs of the box girder develop the entire web in shear (Figs. 17 and 18).
- A sealant was not needed in the joint because the post-tensioned tendons are protected by the polyethylene ducts. Note that the tendons are continuous outside the concrete.

The top slab is sealed against water penetration by use of a polyethylene hose placed in a groove that extends the entire width of the roadway. After the hose is placed, grout is applied under pressure.

Upon completion of a span, the 30 in. (762 mm) diameter water line is placed inside the box section (Fig. 19). Other utilities will also be placed in the box girder.

When opened to motorists, Long Key Bridge will provide two 12-ft (3.7 m) driving lanes plus a 6-ft (1.8 m) pulloff lane on each side. In addition, a 30-in (762 mm) waterline containing the only supply of fresh water for Keys residents, will be carried inside the void of the box girder.

All the design and construction innovations that were used on Long Key Bridge proved to be successful.

Fig. 16. For corrosion protection the external tendons were encased in polyethylene ducts.

Fig. 17. Precast segments in storage yard waiting to be transported to erection site. Multiple shear keys and post-tensioning ducts can be seen. One purpose of the multiple shear keys is to obtain a more uniform transfer of shear stresses across match cast joints. Note that the joints between segments were dry (i.e., without epoxy).

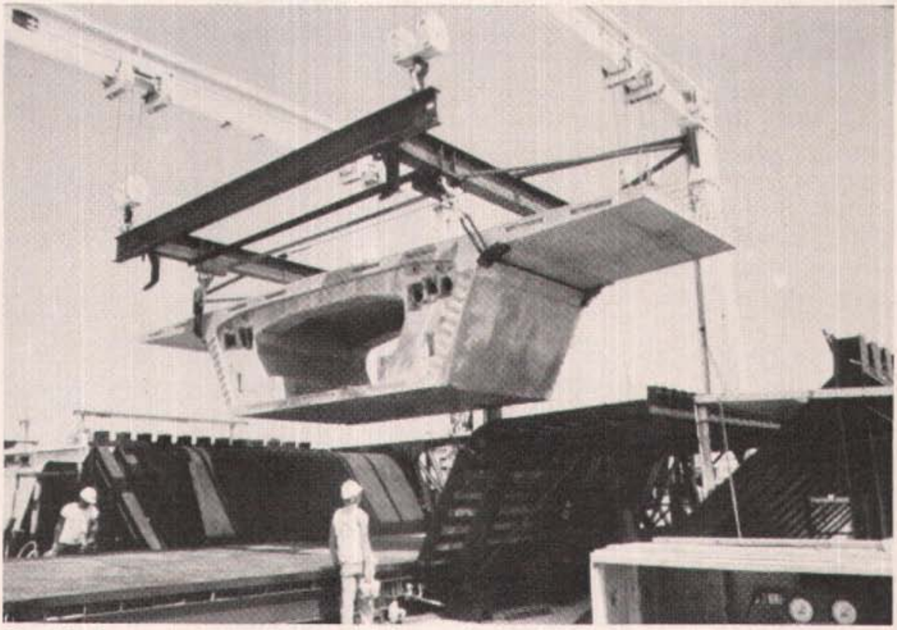


Fig. 18. Precast segment being lifted onto the erection truss.

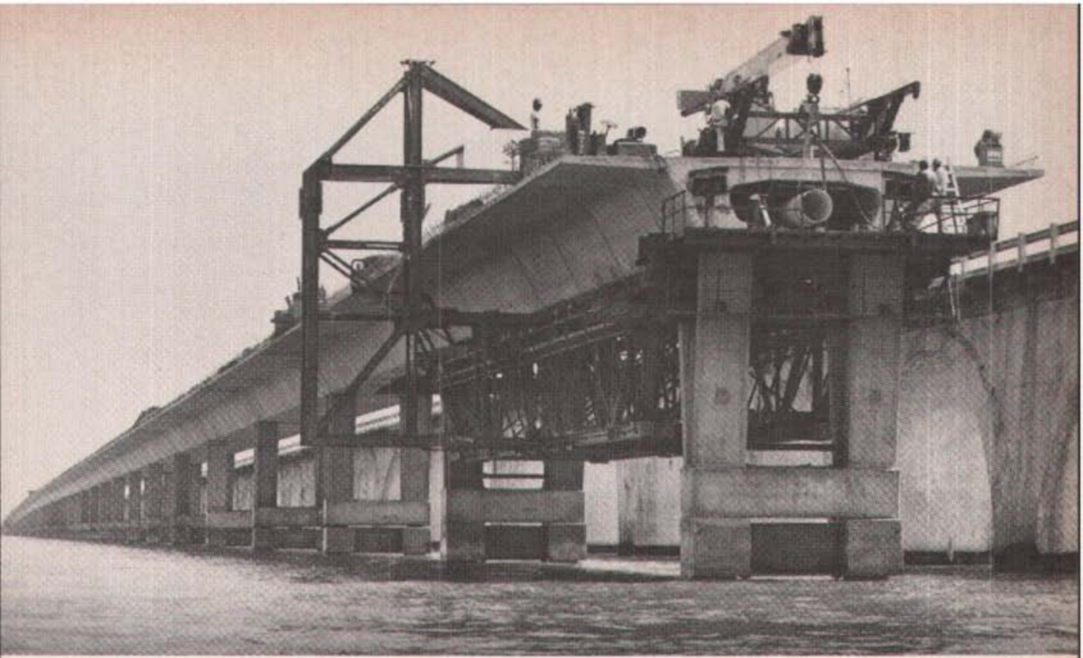


Fig. 19. 118-ft (36 m) span is complete and erection truss is still in place. Note that a 30-in. (762 mm) diameter water line is being placed in the middle of box girder.

Concluding Remarks

In summary, we believe that the alternate bidding system used by the Florida Department of Transportation proved to be economically successful. Our complete design of the segmental bridge, along with several options for the contractors showed that money can be saved in bridge construction with an economical concrete segmental design.

We believe that maximum economy was achieved for the segmental design because:

- Design and construction innovations were incorporated into the contract plans that simplified concrete segmental construction methods.
- New ideas were offered in combination with available construction alternatives, thus allowing the contractor to obtain the most efficient use of his labor and materials.

When Long Key Bridge saved the Florida Department of Transportation $2.6 million, the Federal Department of Transportation decided to have an alternate segmental design on Seven Mile Bridge. Here we used 135-ft (41.2 m) spans and precast, match cast, hollow box piers that were post-tensioned vertically. These box piers are being constructed at the high level portion of the bridge.

The low bid by Miesner Marine Contractors of Tampa, Florida, equaled $45 million which is $7 million under the FDOT estimate. (All six bids were for our segmental design.) Also, Channel No. 5 Bridge in the Keys was bid using the same design approach as Seven Mile and Michael Construction Company was low bidder at $12 million which was $3 million less than the low AASHTO girder bid. There is one other bridge to be bid with segmental alternate in the Keys.

Long Key Bridge and the other bridges in the Florida Keys are relatively short spans for concrete segmental construction. We knew the economics that can be achieved with long span segmental bridges. Now it is apparent that imaginative use of known design and construction techniques can make the concrete segmental bridge competitive in a wide range of span lengths.

* * *