Building prestressed concrete bridge using advancing shoring system

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1　Introduction

The Suez Canal, which divides Egypt into its African continent part and Sinai Peninsula, is a 162-kilometer-long sea route linking the Mediterranean Sea and the Red Sea and is one of the most important marine transportation routes in the world. At present, there is no road bridge leading to Sinai Peninsula, whose development has lagged behind because of the repeated Middle East Wars, and the only routes to the peninsula are the road tunnel located at the southern end of the canal, and the ferry lines. It is under these circumstances that the Suez Canal Bridge is being constructed with the full financial cooperation of Japan. Since the Suez Canal is to accommodate large ships such as oil drilling rigs, the main bridge was designed as a steel-concrete composite cable-stayed bridge having a vertical clearance over water of 70 m and a central span length of 404 m. As the approach bridges for the main bridge, prestressed concrete (PC) viaducts are built on both banks of the canal

The PC viaduct work reported here involves the construction of a total of eight (four each for east- and west-bound traffic) 7-span continuous PC rigid-frame bridges (total length: 2,240 m) in road sections with pier heights of 42.6 to 64.3 m on the right and left banks of the canal. This paper reports on the advancing shoring system(ASS) and on the plans and results achieved thus far of the PC viaduct construction by the ASS method of construction.

2　Outline of the work

The structure of the PC viaduct is summarized below. **Figure 1** is an elevation of the bridge, **Figure 2** shows a typical cross section, and **Table 1** shows the numbers of principal superstructure members.

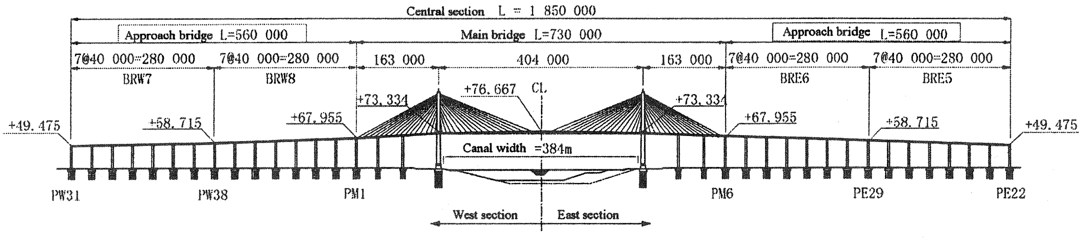

Figure 1　Bridge elevation

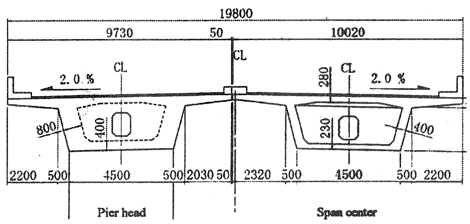

Figure 2　Typical cross section

Table 1　Quantities of major materials

Item	Specifications	Unit	Quantity
Concrete	σ=35N/mm^2	m3	15,922
Reinforcing steel	36/52※	tf	2,806
Prestressing steel	12S15.2	tf	496

※Egyptian standard : yield stress 36N/mm^2

Type of structure: 7-span continuous prestressed concrete rigid-frame bridge (single-cell box girder construction)
Total bridge length: 280 m×4 bridges ×2 (for east- and west-bound traffic)
Span length: 40 m, Total width East-bound bridge: 9.73 m West-bound bridge: 10.02 m
Longitudinal slope: 3.3%, Cross slope: 2.0%

3 Construction plan

3.1 Overview of advancing shoring system

The ASS used for the viaduct construction is a support type system manufactured by RoRo Gerustbau, a German company. The ASS supports a structure under construction with load-carrying girders located under the structure. In view of the construction period and other requirements, the type of ASS that permits concurrent construction of east- and west-bound lanes was used for the viaduct construction.

A side view and a cross section of the ASS are shown in **Figure 3**.

The ASS is composed mainly of a center girder (box structure), two side girders (truss structure), brackets that support these girders at both ends, and lifting beams used for traveling. The total weight of the ASS is about 850 tons. The brackets are inserted into blockouts located about 6 m underneath the pier tops, and the ASS is secured by interconnecting the inside and outside brackets with eight each prestressing steel bars and tensioning them.

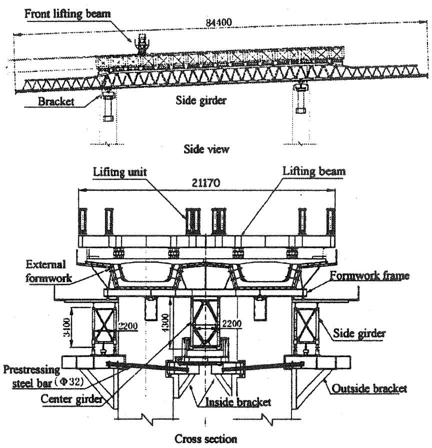

Figure 3 Structure of ASS

The formwork frames installed on the girders, along with the external concrete forms, can be moved past the piers when the ASS is moved.

1) Heavy lifting

While the brackets are suspended, the girders assembled on the ground are heavy-lifted with lifting units installed on the lifting beams. **Figure 4** shows the lifting units. Each unit has two built-in jacks. Eight units are installed on the front lifting beam, and four units on the rear lifting beam.

Used as hangers to connect the girders to the lifting units are steel strips measuring 5.25 m long, 25 cm wide and 25 mm thick. These strips have 80-millimeter-diameter holes for locking pins at 37.5-centimeter intervals.

After a pin is inserted into a hole above the shoulder beam that is to move in synchronicity with the jacks, the upper part of the lifting mechanism is jacked up by one stroke, and then a new pin is inserted into a lower hole so that the loads are carried by the fixed beams. The girders are lifted by repeating this procedure (**Figure 5**).

After the brackets suspended from the girders are raised to the level of the blockouts in the bridge piers, the hydraulic jacks installed on the brackets are activated to partially insert the brackets into the blockouts, and the prestressing steel bars are tensioned secure the brackets to the piers.

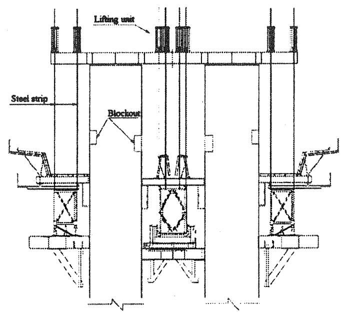

Figure 4 Lifting unit

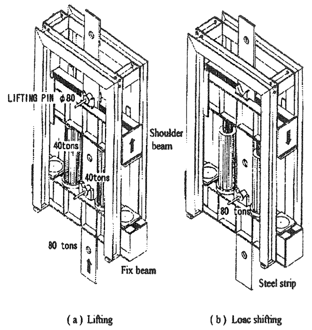

Figure 5 Lifting unit detail

2) Moving ASS

Figure 6 shows the procedure for moving the ASS.

Step 1:

After work for one span has been completed, the main jacks installed on each bracket are lowered to remove the external concrete form. The concrete form is also slid along so that the formwork moves past the bridge piers when the ASS is moved.

Step 2:

To move the brackets, horizontal jacks installed on the rear-side brackets are used to move the ASS until its front end reaches the next pier. The lifting beams installed on the concrete bridge surface are winched up to the lifting level.

Step 3:

Steel strips are attached to the center girder and side girders, and while these girders are supported by the lifting beams, the brackets are moved to the next pier using the winch installed at the front end of each girder.

Step 4:

After the brackets are secured to the piers, the steel strips are detached so that the ASS is supported by the brackets, and, using the horizontal jacks installed on the brackets, the ASS is moved to the next concrete placement location. While the ASS is jacked forward, the prestressing bar nuts installed beneath each girder as a guiding device are moved into the anchor zone.

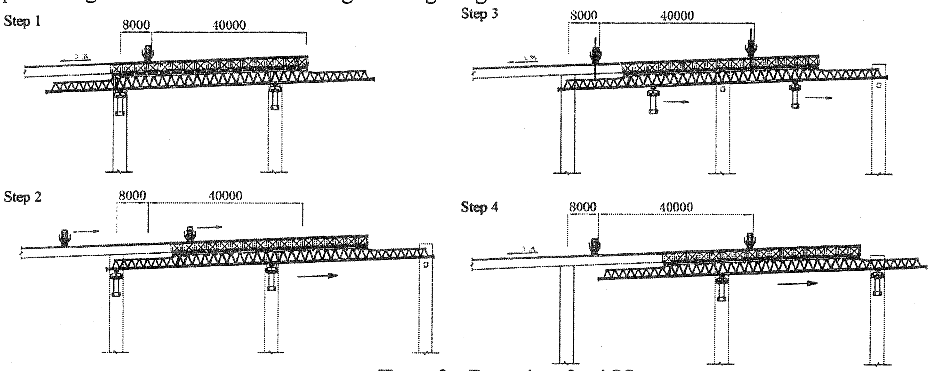

Figure 6　Procedure for ASS

3) Moving external forms into place

After the ASS is moved, the external concrete forms installed on the center girder and the side girders are slid along to the predetermined positions by using open/close jacks installed on the formwork frames and are locked in place with locking pins. **Figure 7** illustrates the structure of the external concrete form.

The height of each girder is adjusted with the main jacks installed on the brackets. The concrete form for the bottom slab is cambered with manual jacks installed on the formwork frames.

The amount of camber of the side girders and the center girder varies depending on flexural stiffness. The amount of camber, therefore, at both ends of the slab form on each formwork frame is calculated, and these points are taken as survey points.

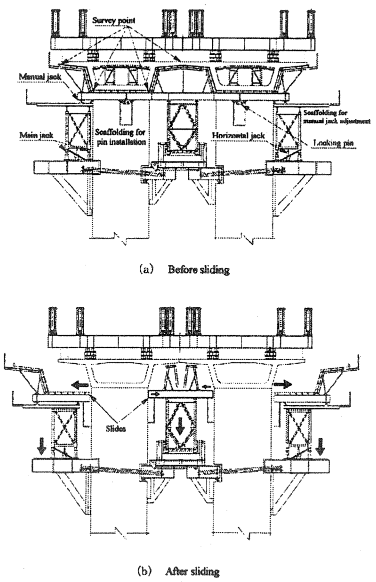

Figure 7　External formwork

3.2　Concrete work

1) Concrete mix design

The design strength and slump of concrete are 35 N/mm2 and 19±3 cm, respectively. Concrete is placed in two layers: bottom slab/web level and floor slab level. The mix proportions for concrete are shown.

Table 2　Concrete mix

Mix name	S/A	W/C	Water kg	Cement kg	Fine aggregate kg	Coarse aggregate kg	Admixture,kg	Type of cement
C−35	0.38	0.41	164	400	687.4	1121.4	5	Ordinary Portland cement

3.3 Prestressed concrete work

For prestressing steel strands, low-relaxation steel imported from South Africa that satisfies ASTM grade 270 (breaking load: 260.7 kN) is used.

Eight continuous cables (12S15.2) are laid in each web and are connected by coupler at construction joints. **Figure 8** shows a side view and a cross-sectional view of prestressing tendons.

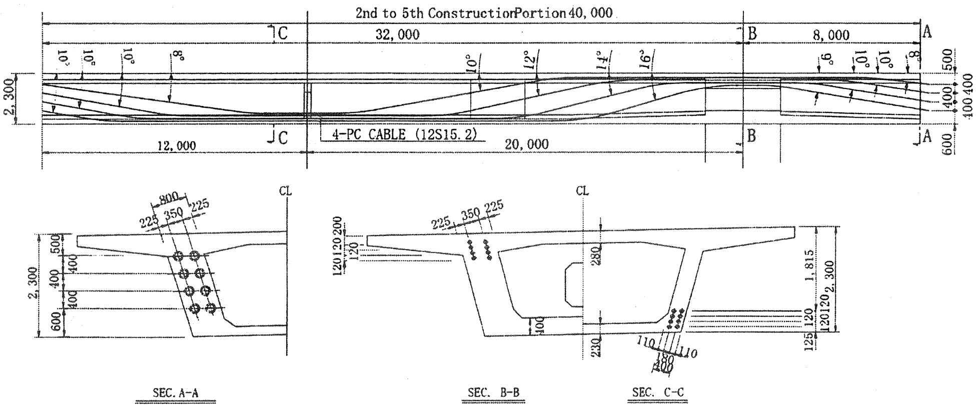

Figure 8　Arrangement of prestressing tendons

Tension requirements are calculated using the friction coefficient given in DYWIDAG's specification. Tension control is based on measurements of elongation and tension. The grout to be used is of nonbleeding type. Grout quality tests to be conducted are consistency, expansion and strength tests. These tests are conducted in accordance with DYWIDAG's specifications based on the DIN standards. **Table 3** shows grout mix proportions and specified values for quality testing.

Table 3　Grout mix proportions(1 batch = 36L)

Water/cement W／C	Water W(kgf)	Cement C (kgf)	Admixture Conbex220M (kgf)
40	20	50	0.227

Test name	Standard value	Remarks
Consistency	30 sec	Cylinder test
Expansion	2～6 %	
Strength	Min 30 N/mm²	

3.4 Equipment and facilities

It was decided to use a tower crane (rated capacity: 2.2tf × 55m) to erect main reinforcing steel and lift other heavy materials and equipment. The crane is installed on rails laid on the bridge. As bridge construction progresses, the crane is towed by winch to the next span (**Figure 9**).

4 Results

4.1 Advancing shoring system

1) Assembling

The ASS was erected between the first-span piers under the guidance of RoRo's German engineer.

Assembling all ASS members (excluding brackets) on the ground, using 150 tf and 50 tf crawler cranes, took about two months.

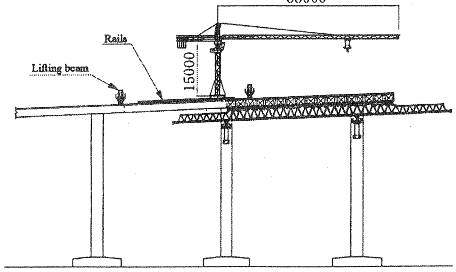

Figure 9　Setup of tower crane

2) Heavy lifting

After the lifting beams were placed on the bridge piers, the preassembled ASS and the lifting beams were connected together with steel strips, and the ASS was heavy-lifted to the level (about 33 m) of blockouts in the piers. Lifting of the ASS up to the predetermined level took about 15 hours (**Photo. 1**).

3) Moving

At first the ASS was moved under the supervision of the German engineer. Later, the ASS operations were carried out by directly employed foremen under the supervision of JV personnel. At early stages of construction, the process from the removal of external concrete forms to the relocation and setup of the ASS took about five days. As the number of bridge spans erected increased and the workers became more skilled, the time required for completing the same process decreased to about three days.

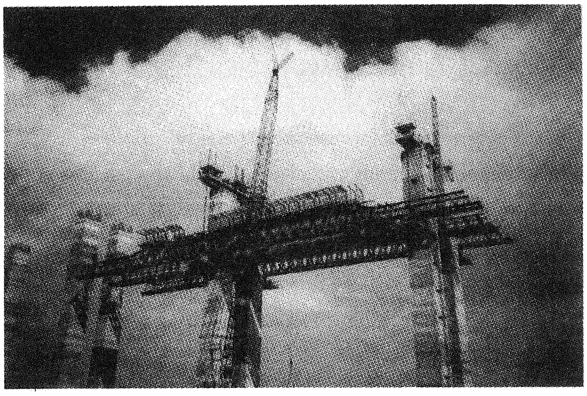

Photo. 1 Heavy lifting

4.2 Concrete work

Since daytime temperatures were high even in winter, piping was always wrapped in curing sheets and water was sprayed to reduce rises in concrete temperature, and effort was made to keep the piping unblocked. In summer months in which air temperatures rise above 35℃, concrete placement was carried out at night.

In placing the first layer of concrete, the procedure illustrated in **Figure 10(a)** was followed in order to prevent excessive deformation of the concrete form for the cantilever structure which was adopted for a reason associated with construction joints. For concrete placement in the girder cross sections, the procedure shown in **Figure 10(b)** was followed. Occurrence of openings between the previously placed concrete and the formwork was prevented by raising the formwork during concrete placement and pushing the newly placed concrete to the previously placed concrete.

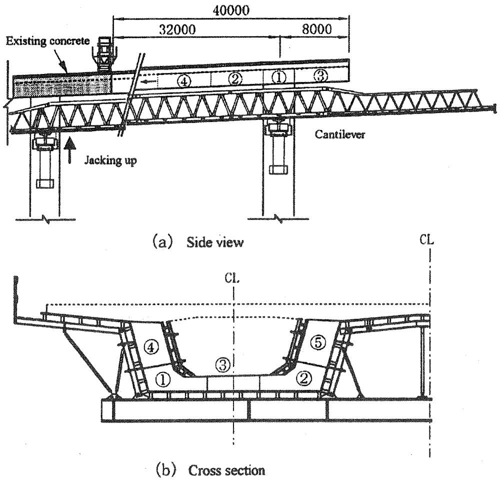

Figure 10 Concrete placement procedure for first layer

To ensure continuity of new concrete to previously placed concrete over the webs, a chemical retarder was applied after concrete was poured and the concrete was green-cut with a high-pressure water jet system. After the second layer was placed, the bridge deck surface was troweled and broomed and then wet-cured for one week.

4.3 Prestressed concrete work

1) Tensioning

Tensions were introduced using one pump (R77-134) and two jacks (HOZ 3000/250).

To prevent cracking in already hardened bottom slab and web concrete due to loads caused by the placement of the second layer (upper deck slab), a small amount of tension (435 kN/bar) was introduced into the prestressing steel bars placed at the lowest level in the web concrete. After the second layer was placed and the concrete reached the required strength was reached, full tension (2170 kN/bar) was introduced

2) Grouting

After the sheaths were washed by passing water and compressed air through them, grouting was carried out. The work was carried out at night because daytime air temperatures were high, particularly in summer. Water used for grouting was cooled in advance in a cooling device in the on-site plant and then transported to the grouting site. Grout temperatures were kept at or below 25℃ by keeping the water cold with ice during the grouting work.

4.4 Reinforcing steel work (prefabrication of reinforcing steel)

With the aim of rationalizing construction, the reinforcing steel for the web and bottom slab concrete of the fourth and subsequent bridges was prefabricated.

Except in areas where prefabrication is difficult, such as column heads and portions of concrete to be placed next to previously placed concrete, the reinforcing steel for a single span was divided into five blocks. Each block was assembled while the girder concrete was cured and the ASS was moved at a temporary yard. Each of these preassembled reinforcing steel blocks was then transported to the girder site in a trailer equipped with a specially designed holding stand, and the block was lifted, with the tower crane, into the specified position within the formwork (**Photo. 2**).

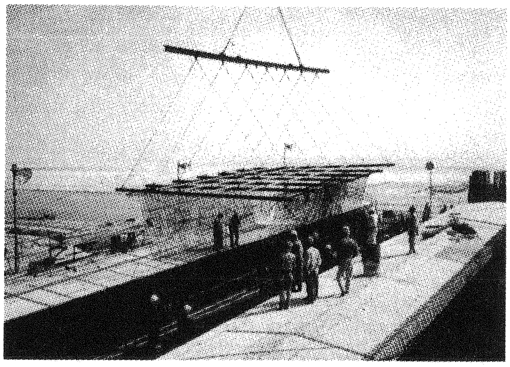

Photo. 2 Lifting in prefabricated reinforcing steel block

Compared with the conventional erection method, the prefabrication method described above shortened the construction period by one or two days per cycle.

5 Cycle time

The construction process is shown in **Table 4**.

The average cycle time for the first bridge was about 24 days, but it was shortened to about 18 day. The breakdown of the six days is as follows: two days by moving the ASS smoothly, two days by improving the procedures for assembling the deck slab formwork and reinforcing steel, and by one to two days by prefabricating reinforcing steel.

Table 4 Construction process (cycle)

Time (days)

	Work category	Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	ASS advancement	Removing external formwork and advancing ASS																		
		Installing formwork																		
1st layer (bottom slab & web)	Formwork	Assembling formwork																		
		Assembling internal formwork																		
		Removing internal formwork																		
	Reinforcement	Assembling reinforcement																		
	Prestressed concrete	Assembling sheaths																		
		Insereting prestressing steel strands																		
		Preliminary tensioning																		
	Concrete	Placing																		
		Curing, cleanup, etc.																		
2nd layer (deck slab)	Formwork	Assembling formwork for deck slab																		
	Reinforcement	Assembling reinforcement																		
	Prestressed concrete	Introducing full tension																		
		Grouting					(Previously built span)													
	Concrete	Placing																		
		Curing, cleanup, etc.																		

6 Conclusion

Use of an ASS was a new experience to Kajima, but the construction was executed successfully, although through some trials and errors, in cooperation with the Egyptian staff and workers. The bridge section thus constructed was successfully connected to the adjoining section while achieving the goal of "zero fatality accidents," one of the top priority goals of the Suez Canal Bridge Project.

The authors hope that this report on the ASS method of bridge construction provide useful information for other similar projects.