Precast Prestressed Segmental Elevated Urban Motorway in Italy

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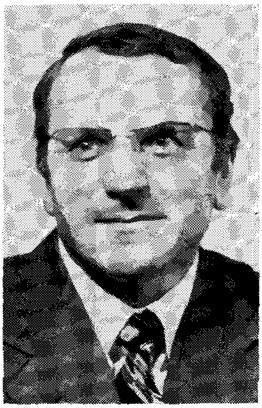

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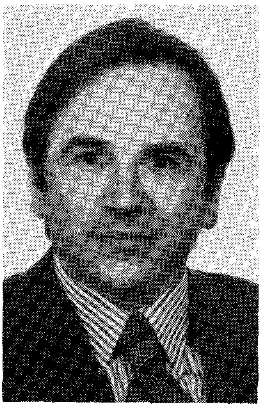

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The authors, who were responsible for the overall design of this important project, discuss the architectural, structural, fabrication, erection, and economic aspects of the job.

This imaginative precast prestressed segmental elevated motorway was built in the North of Italy, across the city of Bolzano.

A basic planning principle for the crossing of the city was to choose a location which avoids the creation of new physical barriers in the existing town. In Bolzano the most readily accessible "corridor" of this kind is the Isarco River, which has formed a natural division between the urban areas.

The elevated motorway, following

Describes the design and construction of an elevated urban motorway that was built in the city of Bolzano, Italy, using precast prestressed concrete segmental construction.
The viaduct consists of 74 spans giving an overall length of 2580 m (1.6 miles). The superstructure is made up of one post-tensioned concrete multi-cell box-section spine beam with cantilever side slabs.
The basic construction method of the superstructure is the span-by-span mode using precast segmental units erected on falsework and post-tensioned together.
Each of the 34.5-m (113.2 ft) spans is composed of nine segments 2.20 m (72.8 ft) wide by 1.6 m (5.2 ft) deep and weighing 110 tons.
The precast elements are connected by a thin layer of epoxy resin adhesive. In the wintertime, the surface to be bonded was electrically heated.
The average erection time cycle for the superstructure was one span per week. The viaduct was completed in April of 1974.

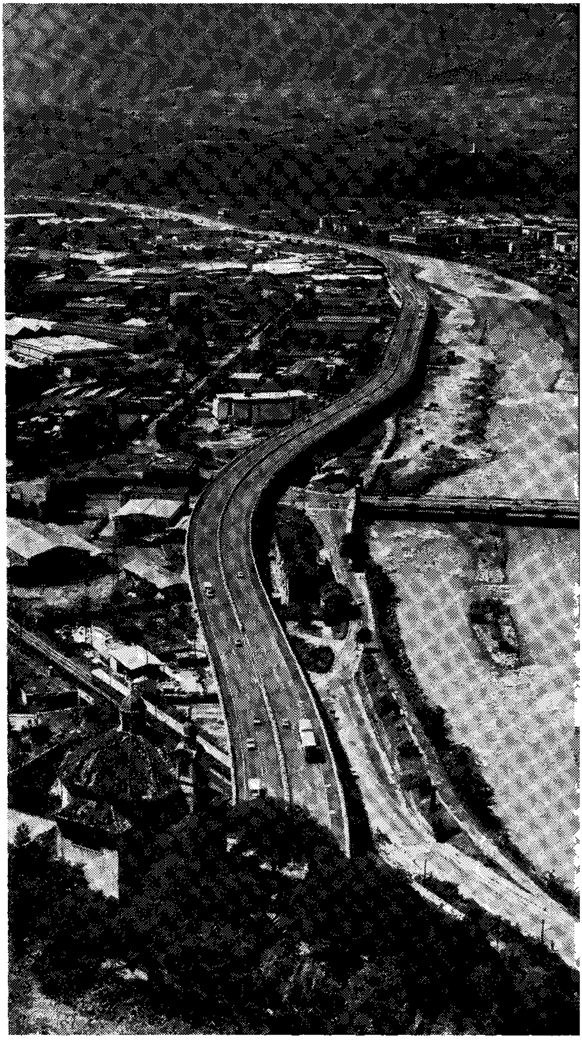

Fig. 1. Aerial view of elevated motorway.

this "corridor," causes a minimum amount of disruption to the existing urban and suburban traffic (see Fig. 1).

The structure is supported by centrally placed concrete piers which run along the left bank of the Isarco River (see Figs. 2 and 3).

The elevated motorway has a total length of 2580 m (1.6 miles), distributed over 74 spans of which 71 are 34.5 m (113 ft) each, and the three which leapfrog the two railway tracks are 39.7 m (130.3 ft), 51.00 m (167.3 ft) and 39.70 m (130.3 ft), respectively.

The highway's centerline in the horizontal plane is composed of six straight lines connected by seven transition curves with a minimum radius of curvature equal to 500 m (1640 ft); the longitudinal gradient

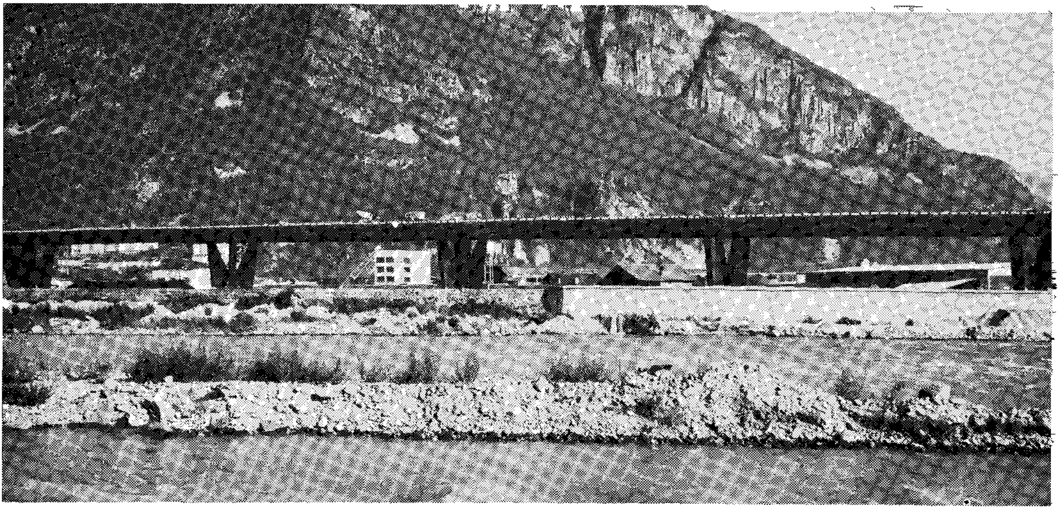

Fig. 2. View from Isarco River.

continuously varies between 0.7 and 3.7 percent.

The average height of the superstructure, measured from the vertical clearances above ground, varies between 5 and 9 m (16.4 and 29.5 ft).

The superstructure is 22.20 m (73 ft) wide with dual three-lane carriageways of 10 m (33 ft) separated by a median strip of 1.10 m (43.3 in.) and bounded on the outside by two 0.55 m (21.6 in.) edge beams. Fig. 4 shows the typical cross section of the viaduct.

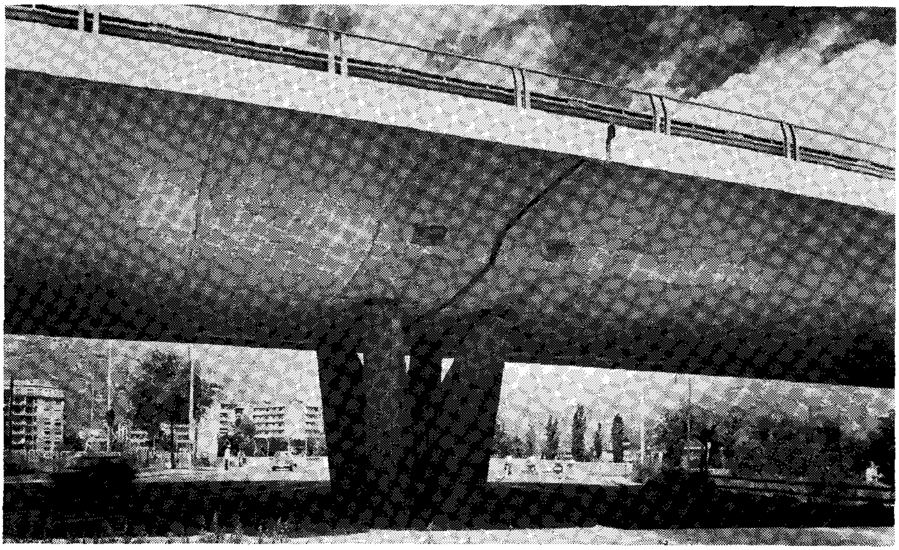

Fig. 3. Superstructure is sustained by central line of piers placed at 34.5-m (113 ft) intervals.

Optimization Studies of Superstructure

Architectural design

In order to affect the cross-sectional design of the superstructure, three types of decks were taken into consideration, all in prestressed reinforced concrete, namely, longitudinal T beams, solid slab, and multi-cell box girder.

From an architectural viewpoint, the last two cross sections look the best because the construction depths of the deck can be much thinner than the T beams. Undoubtedly also the depth of the superstructure, and therefore the level of the carriageway as well, of an elevated urban motorway must be reduced to the minimum so as to take up as little as possible of the space and light in the surroundings in which it is situated.

On the other hand, the continuous underside line of the "close" section creates a more graceful effect with respect to the breaking-up of the plane by the main T beams and the transverse diaphragm.

From a structural viewpoint, the solid slab or box-section superstructure is much more rational when it is supported by only one line of individual central columns. In fact, it can absorb bending and torsional stresses on the orthogonal plane better.

Economic evaluation

Despite the "close" cross section's architectural and structural superiority over the precast T beam, one usually opposes adopting a more difficult and expensive construction method. However, the great technological progress made in these last few years in both precast and cast-in-place construction has overcome these difficulties.

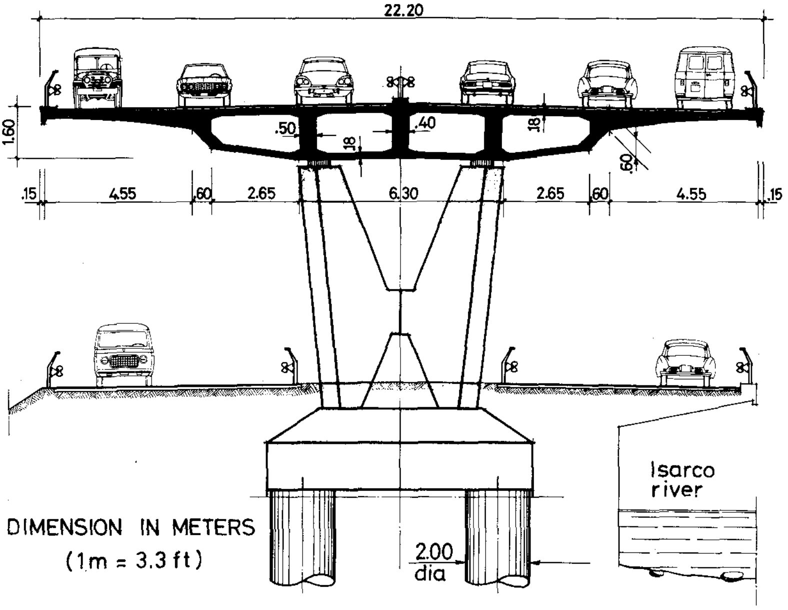

Fig. 4. Typical cross section of elevated motorway.

Table 1. Comparison between the costs of a typical span, 34.5 m (113 ft) long and 22.2 m (73 ft) wide, valued on the basis of the 1969 price list from the Tendering Society.

Material	Solid slab		Box girder	
	Quantity	Cost in $	Quantity	Cost in $
Concrete	563 m³	13,673	389 m³	9,447
Ordinary steel	26,806 kg	4,979	35,614 kg	6,613
Prestressing steel	24,914 kg	19,574	19,675 kg	15,459
Formwork	896 m²	1,856	1,859 m²	3,849
Falsework	766 m²	5,471	766 m²	5,471
Total		45,553		40,839

The box girders can be constructed at a rate and cost which is competitive with those for precast T beams due to the use of precast prestressed segmental construction.

The solid slab decks are nowadays cast-in-place rapidly and economically with the help of form-carrying trucks which are self-launching, span by span, and need no ground supports.

In order to select the best cross section, a careful economic evaluation was made of the superstructure.

The evaluation studies were carried out on a continuous prestressed concrete beam of 70 equal spans, 34.5 m (113 ft) long and 22.20 m (72.8 ft) wide, designed in two different ways:

1. **A cast-in-place solid slab.** Along the centerline the depth varies from 0.85 m (33.5 in.) at the center of the spans to 1.80 m (70.9 in) on the supports. Transversely the depth diminishes from the maximum at the center of the road to 0.20 m (7.9 in) at the free edges.
2. **A multi-cell box girder precast in segments.** Along the centerline the depth is uniform and equal to 1.60 m (63 in.). Transversely the depth diminishes from the maximum at the center of the road to 0.20 m (7.9 in.) at the free edges.

Table 1 shows an economic comparison between the two types of superstructure. The cost estimate was made on the basis of the price list (dated 1969) from the Tendering Society.

This list only provides prices for the following categories of work, namely, concrete, steel, formwork, falsework, without taking into account the varying costs of different construction methods.

Therefore, this comparison is not very meaningful as it does not emphasize enough the different manufacturing costs of the two types of structure.

Table 2. Comparison between the costs of a typical span valued on the basis of actual construction and material costs. For convenience, the total dollar value for the solid slab has been assumed to be a unit cost.

Item	Solid slab	Box girder
Materials		
Concrete	0.175	0.121
Reinforcing steel	0.081	0.108
Prestressing steel	0.366	0.289
Equipment	0.142	0.085
Labor	0.236	0.308
Total	1.000	0.911

A more realistic cost estimate was subsequently made, based on cost data collected during the construction of similar superstructure types.

This evaluation, shown in Table 2, explains the difference in cost for the two design alternatives. The solid slab structure requires a much greater amount of concrete and prestressing steel, while for the box section one requires more labor since it is more difficult to execute.

The devices used for the precasting, lifting and transporting of the segments and the very simple falsework for its support during assembling, cost somewhat less than the complex and heavy self-launching form-carrying truck needed for the cast-in-place of the slab.

The advantage of the box section over the solid slab design is increased even more if one also takes into account the cost of the piers and, above all, the cost of the foundation piles, since the solid slab weighs about 500 tons more per span.

Construction aspects

In the case of an elevated urban motorway, there are other reasons, not exclusively economic, which favor the use of the precast box girder.

The cast-in-place operation of the solid slab can dramatically disturb the townspeople because of the loud noise, large amounts of dust and loss of mold oil and curing steam.

Precast segmental construction overcomes all these disadvantages since it can be carried out without loud noise or environmental pollution.

From the viewpoint of construction time, there is no difference between the two types of superstructure as in both cases one can construct one span per week. However, one must point out that the box girder can be erected at this speed only if the segments are bonded together with a quick-hardening epoxy resin adhesive.

In fact, if the precast segments are connected by a cast-in-place joint of unreinforced concrete or mortar, one has to wait too long for the setting and hardening before applying the prestressing.

The depthless epoxy resin joints require perfectly matching surfaces at the end of the adjacent segments. This is easily achieved simply by casting each segment against the end face of the preceding one and later erecting the segments in the same order as they were cast.

However, it is not easy to precast the segments with such dimensional precision as to ensure proper lines and levels of the superstructure according to the theoretical horizontal and vertical alignment of the road surface.

This difficulty is especially considerable in this project where the road is very wide and has irregular "S" shape curvature on the plane and rises and sags in elevation.

When the viaduct was designed (1970) the technology available was not sufficiently advanced to allow the use of resin joints in the construction of very long and irregularly shaped continuous beams without some risk.

To avoid these difficulties, the preliminary static scheme of a continuous beam was modified. The final design uses simply supported girders, resting on the piers and separated by the expansion joints. In this way, at the expansion joint one can compensate for all alignment errors accumulated along the whole single span during the assembling of the precast segments.

The decision taken to use simple beams proved to be right. In fact, only after a long enough running period did the contractor succeed in precasting and assembling the segments with the tolerances required to ensure proper vertical and horizontal alignment of a continuous beam. Only today, after the experience gained in perfecting the equipment and the manufacturing methods, can the contractor safely use resin joints even for continuous beams 500 m (1640 ft) long.

Description of Structure

Fig. 5 shows the detailed elevation and plan dimensions of a typical span. The superstructure of the viaduct is sustained by a single line of central piers placed at 34.5-m (113.2 ft) intervals along the road's center line (see Fig. 6).

The piers are each supported by a pile cap connected to four bored reinforced concrete piles of 2.00 m (6.6 ft) diameter.

Each pier is made up of four columns in prestressed reinforced concrete vertically sloping and connected to each other at a third of their height so as to achieve a frame at the base which could withstand the horizontal forces.

The external dimensions of the pile varies from 4.90 x 3.85 m (16.1 x 12.6 ft) at the base to 6.30 x 4.80 m (20.7 x 15.7 ft) at the top.

The columns are prestressed vertically with Dywidag-type bars of 32 mm (1.26 in.) diameter, anchored at the bottom in the foundation pile cap; also, the horizontal connection is prestressed with the same type of bars.

The superstructure consists of prestressed concrete four-cell box-section spine beams with cantilever side slabs (see Fig. 4).

The main spine beam is seated on the sliding bearing, placed in the normal direction of the road axis, with center-to-center distances of 5.00 m (16.4 ft) on the supporting columns.

The depth of the girder, uniform in the longitudinal direction varies trans-

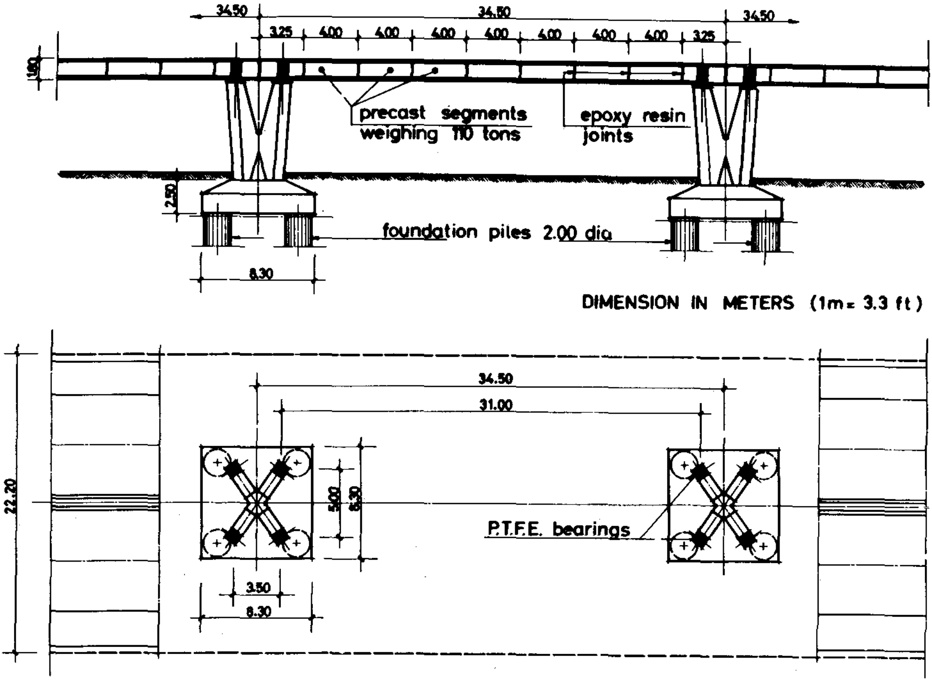

Fig. 5. Elevation and plan of typical span.

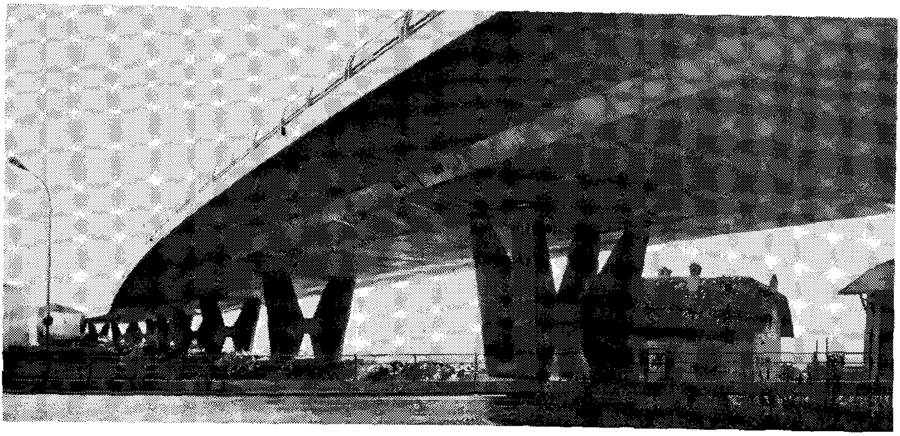

Fig. 6. Pier is made up of four columns in prestressed reinforced concrete.

versely from the 1.60 m (63 in.), at the center line, to 0.20 m (7.9 in.) at the edge, adapting itself to the transverse moment.

The superstructure is prestressed in the longitudinal and transverse directions with tendons of the BBRV type, respectively placed in the inner webs and in the top flanges; the lower flange is made with ordinary reinforced concrete in order to resist transverse bending and torsion.

Both the top and bottom flanges are 0.18 m (7.1 in.) deep, while the cantilever side slabs vary in depth from 0.20 m (7.9 in.) at the free extremities, to 0.60 m (23.6 in.) in the fixed sections.

Construction Method

The superstructure was completely precast. Every beam, 34.50 m (113.2 ft) long and 22.20 m (72.8 ft) wide, was subdivided into nine segments, each one weighing about 110 tons (see Fig. 5).

The seven intermediate segments are 4.00 m (13.1 ft) long; the two terminal ones are only 3.25 m (10.7 ft) long so that they will always weigh 110 tons, even when including the weight of the diaphragm on the bearings.

The precast elements were connected by a thin layer of adhesive, based on epoxy resin, no thicker than 0.8 mm (0.033 in.).

Precasting method

Each segment was cast against the end face of the preceding one. The form was fixed into position and after each casting the segment was removed to the position of "counter-form" for the next segment (see Fig. 7).

Before moving the segment, the top transverse tendons were tensioned to take only the dead load in order to prevent the deflection of the cantilevered ends of the "counter-form."

The lower and front parts of the steel form were adjustable so as to be able to shape the segment according to the three-dimensional layout of the road surface.

The concrete was cured by saturated steam. The reinforcement cage, including ducts for tendons, was preassembled and taken into the form (see Fig. 8).

Erection methods

The segments were taken from the casting yard riding on rails. They were then lifted onto the top of the superstructure and transported into their final position

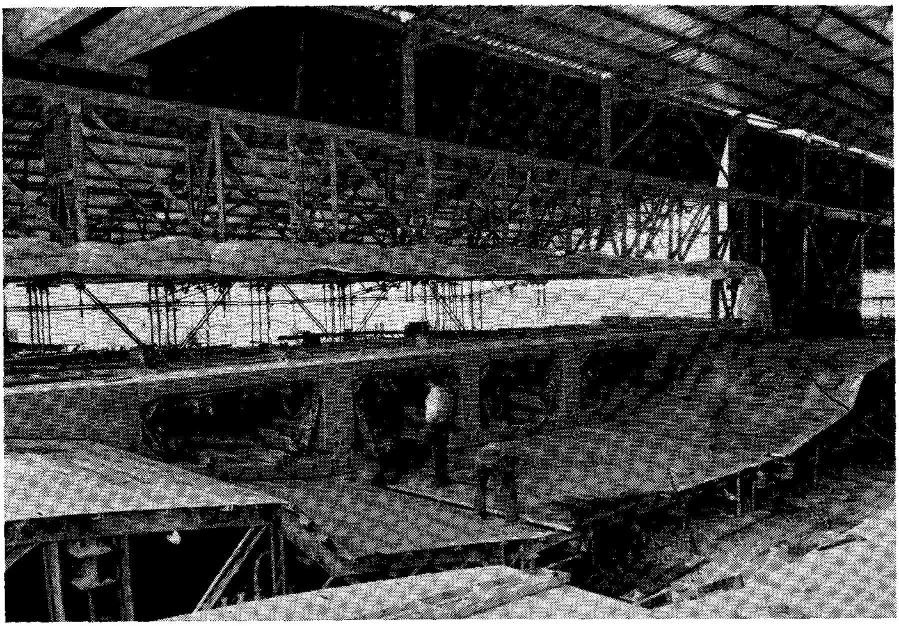

Fig. 7. The precast segment being removed from form and positioned as *"counter form" for next segment.*

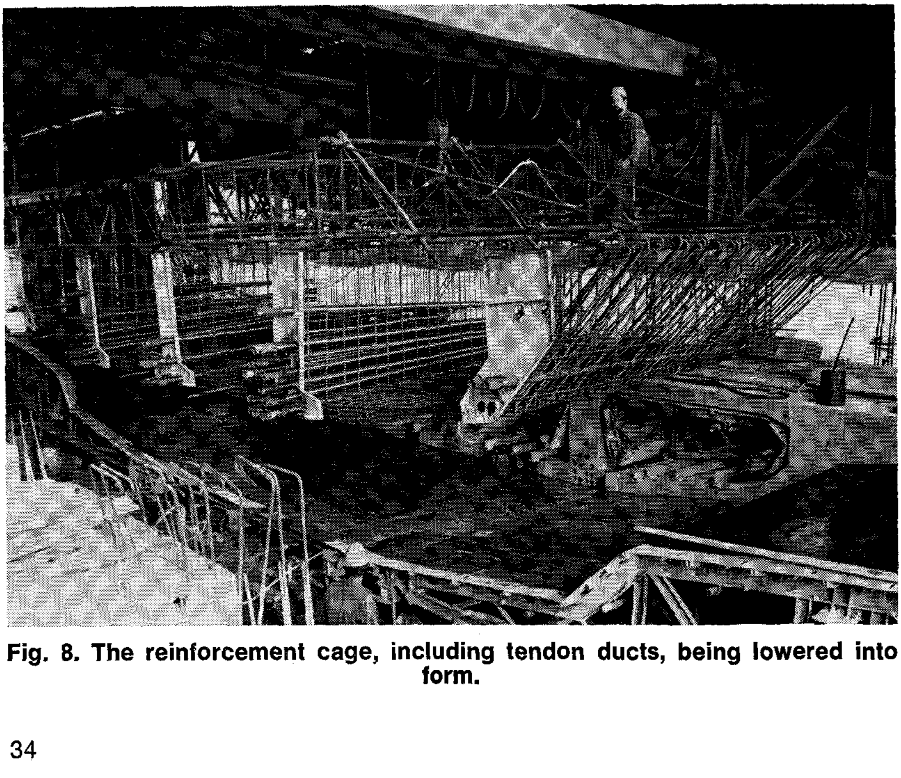

Fig. 8. The reinforcement cage, including tendon ducts, being lowered into form.

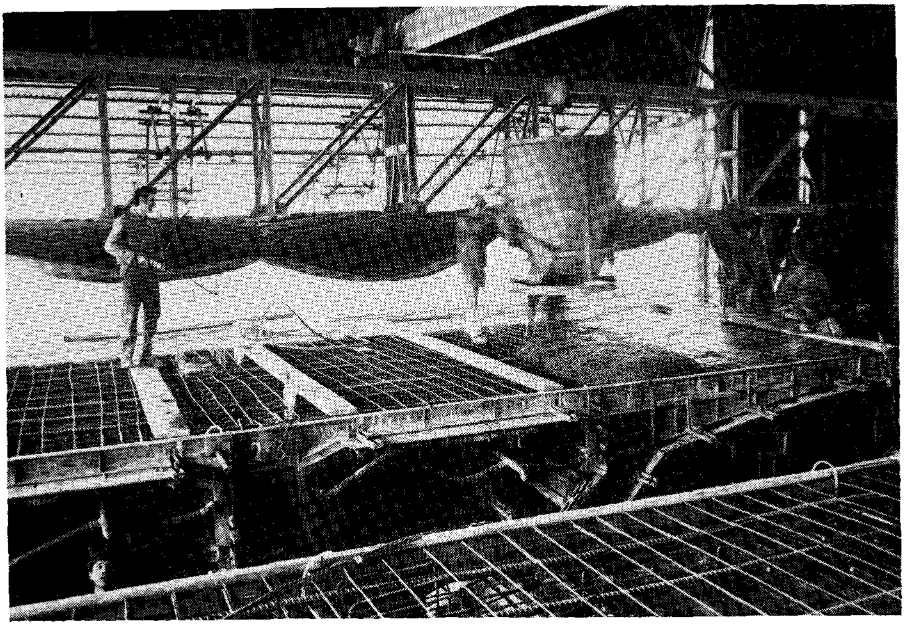

Fig. 9. Casting of segments.

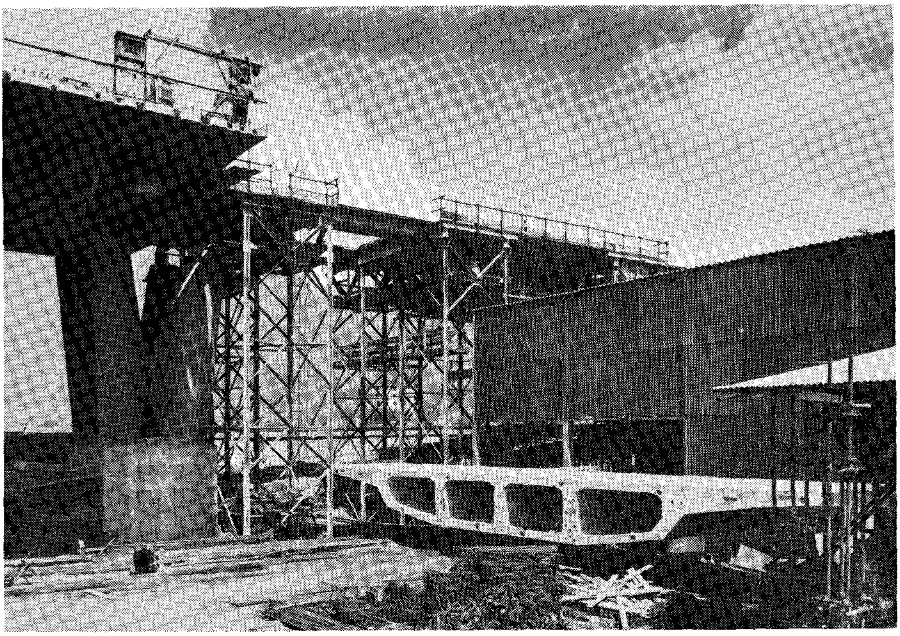

Fig. 10. Segment taken from casting yard.

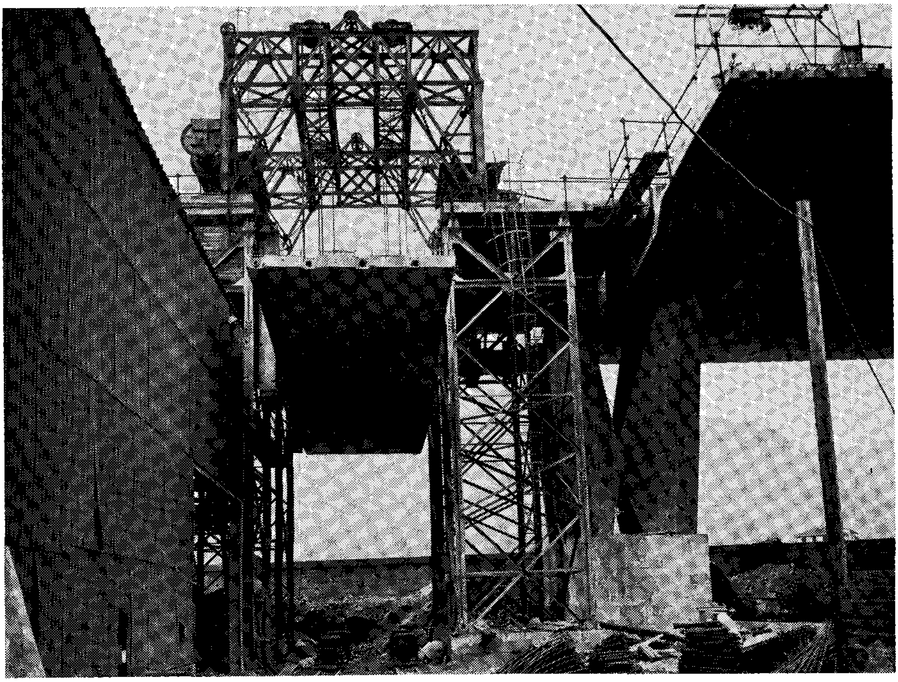

Fig. 11. Segment being raised on top of superstructure by a gantry crane.

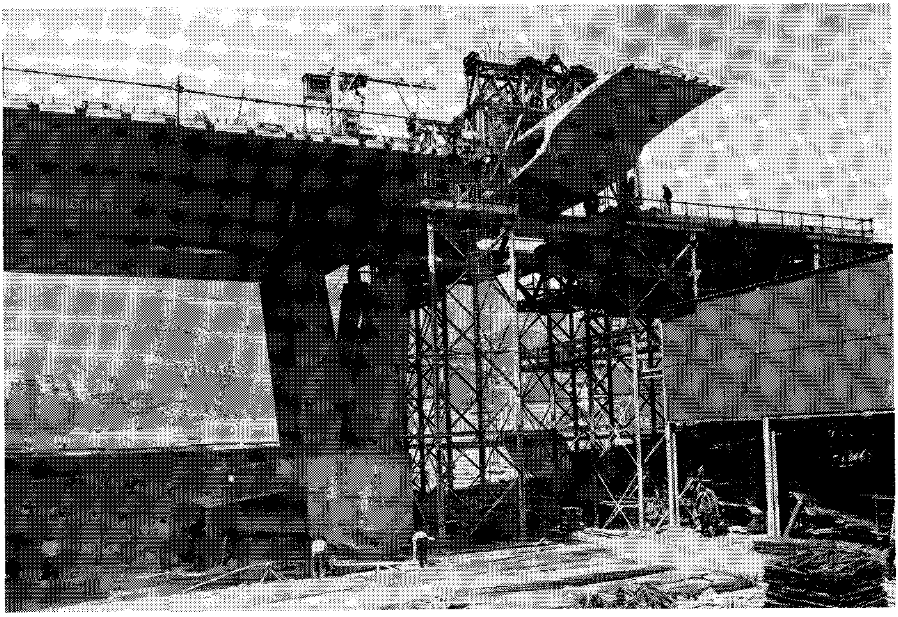

Fig. 12. Segment at level of superstructure.

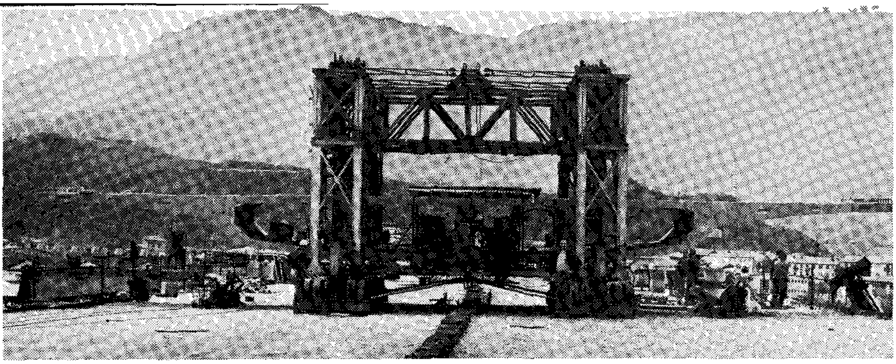

Fig. 13. Mobile gantry crane travelling along deck.

by a special mobile gantry crane on tires, travelling along the deck of the partially completed viaduct (see Figs. 10 through 14).

A pair of steel girders, as long as the span to be erected, were mounted on temporary steel supports.

The tops of these girders were set at the same height as the bottom of the box girder elements. The mobile crane set the segments on the top of the steel girders leaving gaps between the segments (see Figs. 15, 16, and 17).

The epoxy adhesive was applied to the adjoining surfaces (see Fig. 19) and then the segment was pressed against the preceding one by jacks and clamped together with a bolted connection.

After positioning the last span segment, the prestressing cables were threaded through the ducts left in the precast elements and post-tensioned.

The steel girders were then removed and taken forward to the next span (see Figs. 20 and 21). Fig. 22 illustrates schematically the erection method.

Construction sequence

To minimize construction time, maximum advantage must be taken of the equipment. Also, efforts must be made to reduce labor costs. Therefore, the precasting and erection sequence was planned so that two spans could be constructed simultaneously.

The precasting yard was setup at about the center of the viaduct area. In this way construction could proceed simultaneously from the center towards the northern and southern abutments, even while having only one mobile crane and only one team of specialists to transport and assemble the segments.

While northwards they could thread and prestress the cables and also move the falsework forward to the following span; southwards they could proceed with positioning and bonding the precast segments, and vice versa.

Two independent lines were planned in the precasting yard, one supplying the segments for the northern part of the viaduct and the other for the southern ones. Thus, it was possible to rationalize the use of labor and machin-

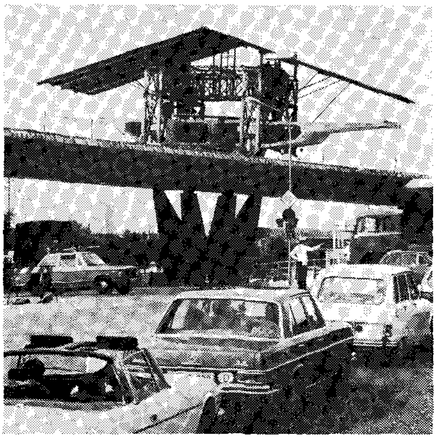

Fig. 14. View of precast segment carried by mobile crane, from city streets.

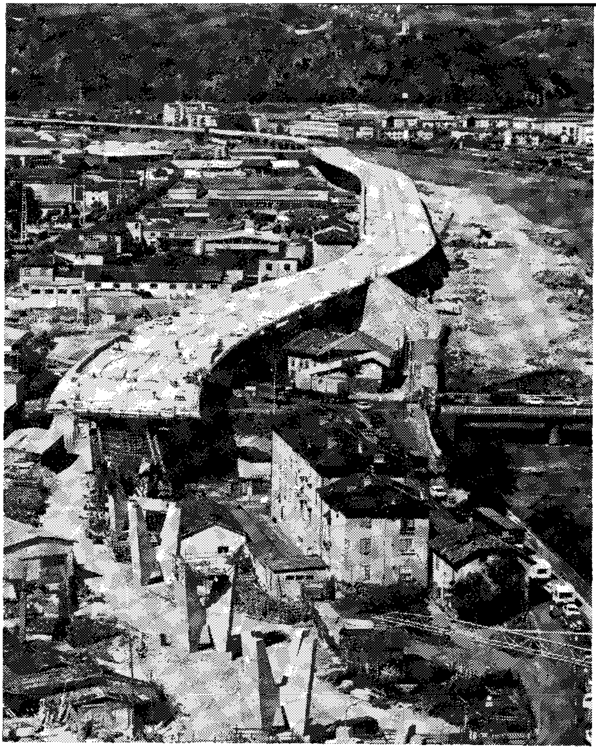

Fig. 15. Aerial view of elevated motorway during construction.

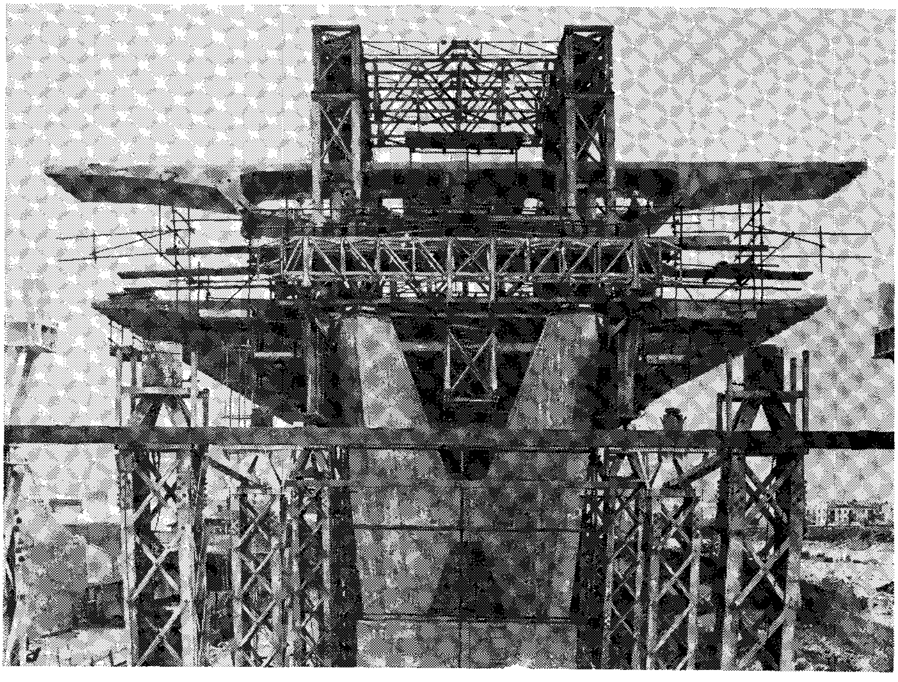

Fig. 16. Gantry crane, resting on false steel segment in front end on previously placed one on back, in readiness for positioning last segment.

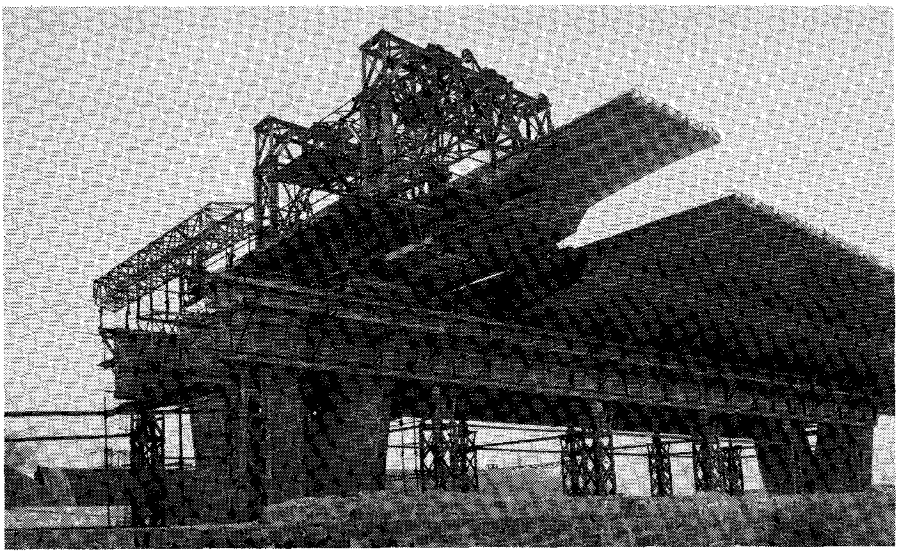

Fig. 17. Segment being lowered on top of falsework.

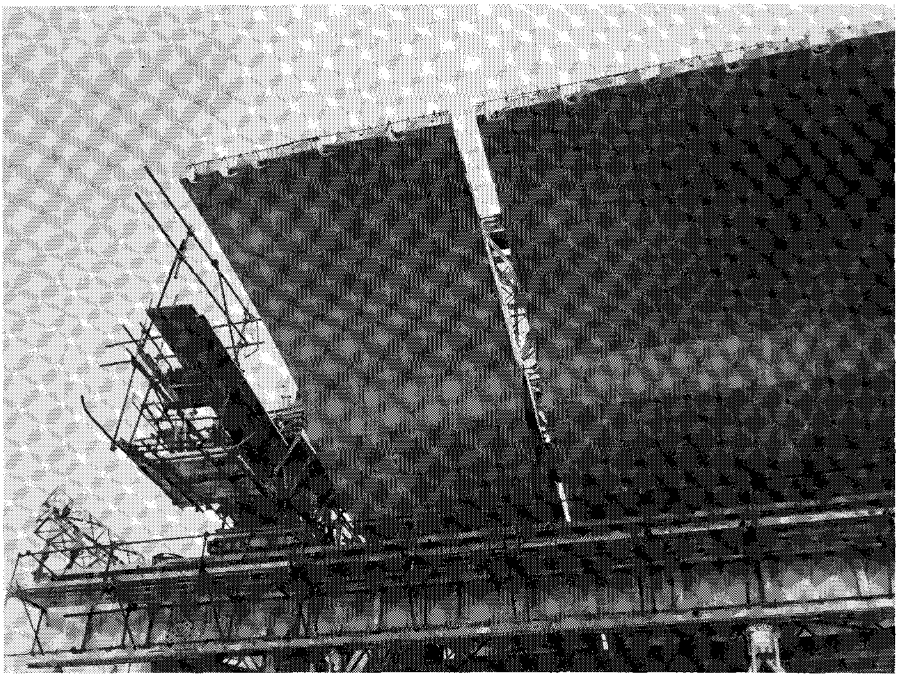

Fig. 18. Segment being set on top of temporary steel girders.

Fig. 19. Manual application of epoxy adhesive on precast concrete segment.

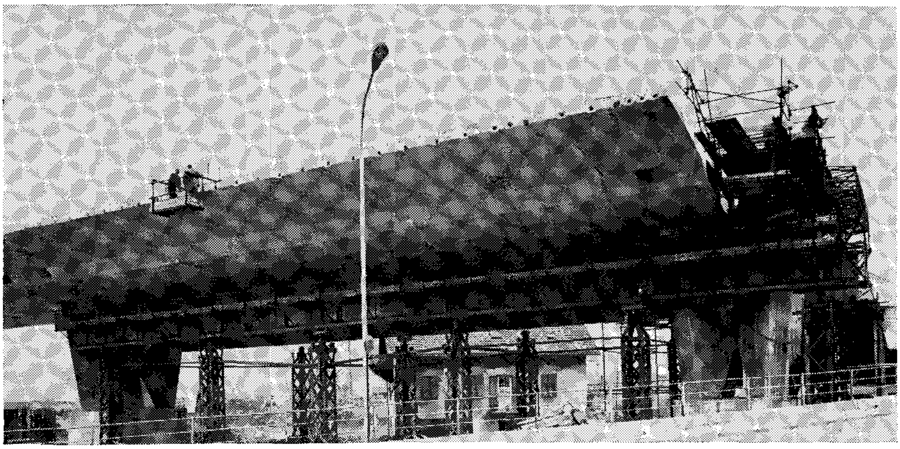

Fig. 20. Tendons being threaded through ducts left in precast elements so falsework can be reused.

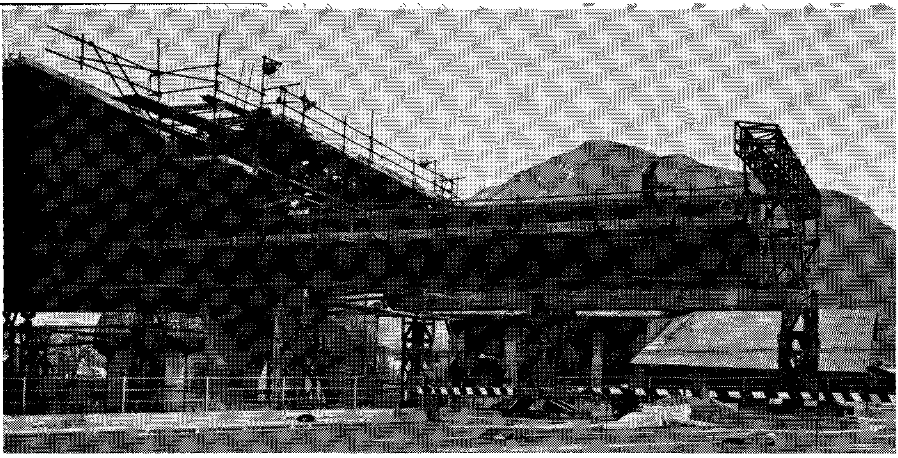

Fig. 21. Temporary steel girders taken forward to next span to be erected.

ery. While the workmen were proceeding with the casting of a segment for the north span, a segment for the south span was being cured or moved from the formwork, and vice versa.

Only two formworks, 22 m(72 ft) wide and 4 m (13.1 ft) long, were needed to construct the whole of the viaduct.

The average construction time cycle was one span per week.

Epoxy resin joints

The adhesive used is a product with an epoxidic base and divided into two components, epoxy resin partially loaded with filler and hardener.

When assembling segments the most critical operation is the joining. It must be carried out by specialists, according to the specification defined by qualified technicians who have experience in segmental construction. It is necessary to have a continuous control of the adhesive's properties, of the condition of the surfaces to be joined, and of the climatic conditions.

As we know, an adhesive has the advantage that, at an environment temperature of 18 to 20 C, it reaches, even after only 6 to 8 hours, a higher strength than that of concrete after 28 days. At lower temperatures, the speed of hardening rapidly diminishes.

Where the viaduct was erected, in the winter period the average environ-

Amount of Materials Used

(Examples for the surface units of the superstructure)

Superstructure			
Concrete	0.51	m^3/m^2	($1.67\ ft^3/ft^2$)
Reinforcement	47.1	kg/m^2	($9.65\ lb/ft^2$)
Prestressing steel	29.7	kg/m^2	($6.09\ lb/ft^2$)
Epoxy resin	0.8	kg/m^2	($0.2\ lb/ft^2$)
Piers			
Concrete	0.051	m^3/m^2	($0.17\ ft^3/ft^2$)
Reinforcement	10.4	kg/m^2	($2.08\ lb/ft^2$)
Prestressing steel	2.55	kg/m^2	($0.52\ lb/ft^2$)
Foundations			
Concrete	0.27	m^3/m^2	($0.89\ ft^3/ft^2$)
Reinforcement	10.4	kg/m^2	($2.13\ lb/ft^2$)
Piers	0.095	kg/m^2	($0.30\ lb/ft^2$)

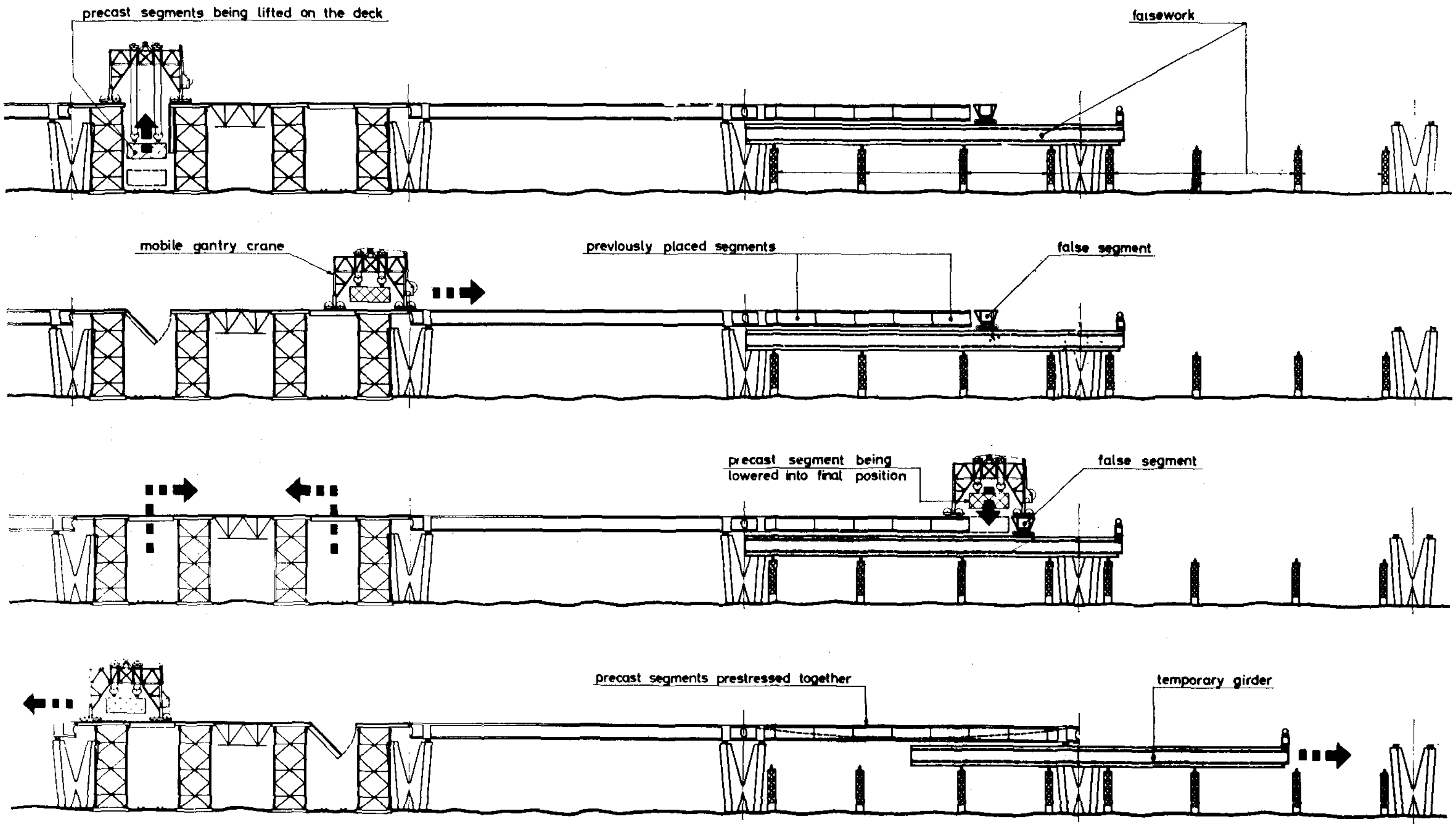

Fig. 22. Construction sequence.

Fig. 23. Elevated motorway completed.

ment temperature was near 0 C and the minimum was −15 C. In order to proceed with the construction even during winter, provisions were made, before and after application of the adhesive, to heat the surfaces to be bonded in such a way that the polymerization process could occur at an environment temperature of between 10 and 20 C.

An armored electric cable was buried in the precast segment at a depth of 2.5 cm (1 in.) from the surfaces to be bonded, to heat these same surfaces. This heating procedure was adopted after some negative experiments using traditional systems where heating is provided from the outside of the concrete. The epoxy adhesives were subjected to numerous preliminary tests to determine the hardening characteristics of the resin at various temperatures.

This meant that the best system for every weather condition could be selected and specifications defined for applying the adhesives. Selected tests were carried out on various epoxy mortar systems, each with a different "pot life:"

1. Compressive strength.
2. Tensile strength in bending.
3. Tensile strength on throttle section (Italian Specification).
4. Bonding strength.

These tests were carried out after 3, 6, 8, 12 and 24 hours and after 7 days at temperatures of +5, +10, +20, +30, and +40 C.

For every consignment of adhesive from the supplier, the tensile and bonding tests were carried out on a double series of specimens, one in a natural state and the other after artificial aging (20 cycles of −20 C to +60 C).

The tests were carried out at +20 C, +40 C, and at −20 C.

The reference strengths of the adhesives used, after 24 hours at 20 C, were:

Compressive strength	650 kg/cm^2
Flexural strength	375 kg/cm^2
Tensile strength	255 kg/cm^2
Bonding	90 kg/cm^2

As in any adhesive bonding, the preparation of the surface is very important and will quite often determine the success of the joint.

The surface to be bonded must be clean and sound. The formed concrete surface must be removed so as to increase the strength in direct tension to the true values of the concrete. Experience gained has shown that the best method of preparing a concrete surface for bonding is by using sandblasting.

Credits

The authors were responsible for the overall design of the elevated motorway.

Mondelli of Milan, Italy, was responsible for the entire construction of the viaduct.