

# External Prestressing for Bridge Rehabilitation in Italy

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The Italian motorway network was built about 20 to 30 years ago; it has a large number of prestressed concrete viaducts often located in mountain regions where deicing salts are used. Most of these bridges must now be rehabilitated. The main reasons for the rehabilitation, besides the use of salts, are (a) the increased live loads, (b) the insufficient knowledge of seismic problems at the time that the bridges were built, (c) underestimation at the time of building of the effects of time on the concrete, and in some cases, (d) the poor quality of the construction. External prestressing has been found to be a powerful tool for repair work; therefore, it is used extensively in Italy. Three stages in the evolution of this technique can be focused: (a) the additional cables are embedded in new concrete and are added and attached to the old concrete, (b) the cables remain external to the original section with few points of contact with the deck; the wires or the strands are encased in high-density polyethylene pipes that are grouted with cement mortar (no petroleum wax or grease has been used in Italy until now), and (c) the cables are composed of single sheeted and greased strands located inside a high-density polyethylene pipe that is not grouted. Each strand acts as a unit and can be easily replaced. Three examples, one for each of the techniques, are provided.

**M**ost of the Italian motorway network, which is more than 8000 km long, was built about 25 years ago. A large number of prestressed concrete (p.c.) viaducts and tunnels were needed to cross the Apennines Mountains running along the

whole length of the peninsula: the 440-km A3 Motorway linking Naples to Sicily has 264 p.c. main viaducts whose total length is about 56 km, that is, 13 percent of the length of the entire motorway. •

A number of these viaducts now need to be rehabilitated, with the main causes of deterioration being (a) the aging of the concrete and subsequent corrosion of p.c. cables and rebars, which occurs frequently where deicing salts are used; (b) the lack of seismic strength because of insufficient design knowledge at the time that the bridges were built; (c) the underestimation at the time of building of the effects of time on the concrete; and (d) deficiencies in the construction.

The two public agencies managing all of the main roads in Italy, Autostrade for toll motorways and ANAS for all of the remaining roads, are now carrying out an extensive program of inspection and rehabilitation of these bridges.

## BRIDGE ASSESSMENT

### Inspection

A program of instrumentation tests and controls was planned for each bridge, as a rule, on the basis of qualified visual inspections. These tests concerned (a) the geometry, (b) the foundations, (c) the materials, and (d) the overall behavior of the bridge. Neglecting here the wide range of problems that often arise in the foun-

dations because of ground instability, the relevant tests of the p.c. decks can be summarized as follows.

### **Materials**

Boring of 100-mm-diameter cores with stress release, ultrasonic pulse velocity measures in conjunction with the surface hardness, and Windsor penetration tests were commonly used to assess the concrete. The efficiency of the grouting as well as the possible corrosion of the prestressing cables were systematically inspected with an endoscope (fiber optics), which proved to be a powerful tool (Figure 1). The 3-mm-diameter holes, which were needed to thread the instrument head to the cable, were easily drilled at single points.

### **Overall Behavior of Bridge**

The most complete information about the soundness of the bridges was obtained by appropriate static load tests, although these tests required the interruption of traffic. To reduce the number of these tests, alternative dynamic tests were carried out extensively. In this case



FIGURE 1 Control with an endoscope of a prestressing cable embedded into a beam. Photographic images of cables can also be obtained by this technique.

the traffic was not stopped and the transit of heavy trucks was used as the external stimulus. The free vibrations of the structure after the transit of the truck were recorded and analyzed.

Numerical nonlinear analyses were carried out to check the behaviors of the bridges in the case of strong earthquakes. The requested ductility was compared with the available ductility; the available ductility was derived theoretically by using the original drawings together with the results of the materials tests.

### **Level of Repair**

A wide range of situations were identified. For the most common type of p.c. viaducts, that is, those composed of a number of simply supported T- or V-shaped beams, some typical situations can be described, as follows.

#### **Low-Level Damage**

Bearing devices and the deck joints need to be changed. Some parts of the concrete surface must be restored. This was the situation for most of the viaducts examined.

#### **Need for Seismic Retrofitting**

A number of viaducts built in the south of Italy between 1965 and 1975 do not comply with today's Italian seismic code. This may be due to an initial insufficiency of the structure or to a revised and more severe classification of the site with respect to seismic action.

A change in the static scheme was the solution often adopted for decks originally joined on each pier. The deck slab has been made continuous over 8 to 10 piers, that is, over a length of 300 to 400 m, so that all of the horizontal forces are transmitted to a new abutment to be built behind the original one (Figure 2).

Special energy-dissipating devices have been placed at the new abutment to reduce the seismic forces (Figure 3).

#### **Need for Serious Repair Work**

Serious repair work was necessary when the controls and the analysis showed a lack of strength with respect to the ultimate or serviceability limit states.

Appropriate solutions to these problems were offered in many cases by adding external prestressing tendons (1-3), as in the examples illustrated later.

#### **Removal of Existing Decks**

In some extreme cases replacement of the old decks with new ones offered the most economical solution.



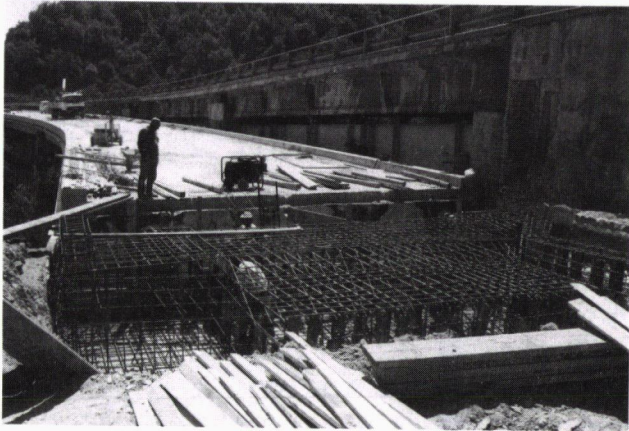


FIGURE 2 New abutment built to withstand longitudinal horizontal forces; in front, deck with continuous slab.

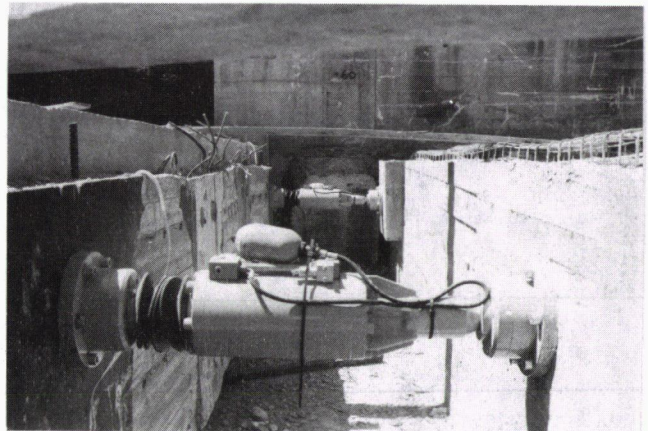


FIGURE 3 Energy-dissipating devices for strong earthquakes: (left) modified old deck; (right) new abutment.

## EXTERNAL PRESTRESSING

### General Features

Three stages in the development of the external prestressing technique for bridge retrofitting in Italy can be recognized.

#### *Embedded Cables*

In the very first application the new cables were embedded in new reinforced concrete that was added to the old concrete. The tendons were external to the original section, but they acted as traditional p.c. cables with respect to the final section.

#### *External Grouted Cables*

The use of external grouted cables is the most common application in Italy. The new cables are external to the concrete section that is not modified. They are placed inside a duct, generally made of high-density polyethylene (HDPE), and are grouted with ordinary cement mortar. To date no petroleum wax has been used in Italy.

#### *External Nongrouted Cables*

In the last application the new cables were composed of single sheeted and greased strands. In some cases the wires or the strands are zinc coated. These units are placed in HDPE ducts without grouting except to the lengths of the anchorages and the crossings of the deviation blocks.

These cables are similar to the stays of the cable-stayed bridges of the last generation.

### Deviation Blocks

The deviation blocks have usually been cast in situ with ready-mixed concrete with a minimum compressive strength of 45 MPa. The blocks are joined to the original section by steel dowels (20 to 24 mm in diameter) embedded with resin in 30- to 40-mm-diameter holes drilled in the old concrete (Figure 4).

Some tests carried out in box girder bridges (Figure 5) showed that a pullout force of 100 kN can be easily reached with a 20-mm-diameter dowel and an anchorage length of 16 to 18 cm, provided that the old concrete can offer a strength of about 35 MPa. Maximum working loads of 20 kN (axial) and 40 kN (shear) per dowel were generally accepted at the stressing of the cables.

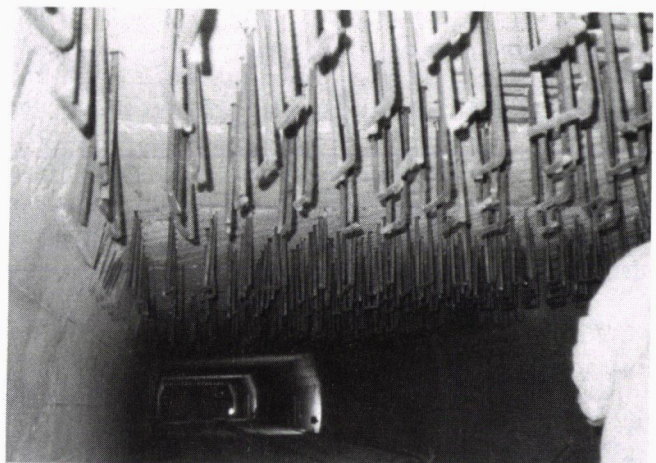


FIGURE 4 Dowels ready to connect new anchor blocks to existing p.c. box deck.



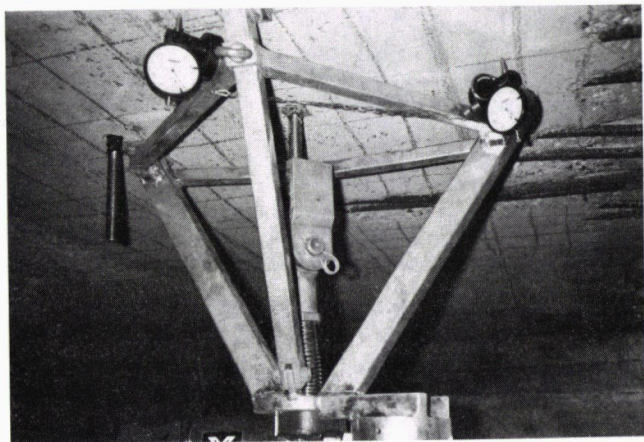


FIGURE 5 Device for a pullout test on a 20-mm-diameter, 170-mm anchored connector. The test was stopped at a force of 100 kN.

### Anchor Blocks

Both concrete blocks or steel frames placed at the beam ends have been adopted. When no room was available behind the end of the deck, interior anchor blocks similar to the deviation blocks, but with more dowels, were adopted. Steel frames, although more expensive in Italy, were found to be the best solution when time savings was fundamental.

## THREE EXAMPLES

### A3 Motorway Viaducts

Seven 25-year-old viaducts of a mountain section of the A3 Motorway had serious problems because of deficiencies in the construction and the effects of deicing salts. All of the viaducts have simply supported decks (32 in total) spanning over 32 m (Figure 6). Every carriageway had four double T-beams, that is, 256 in total, most of which were seriously damaged because of the lack of grouting in the prestressing cables.

When the results of dynamic and static tests found prestress losses greater than 60 percent with respect to the theoretical prestress loss, the removal of the old deck and the construction of a new one were found to be the best solution (4).

When the prestress losses were supposed to be between 60 and 10 percent, appropriate new cables were added to the beams. In this case the new cables were embedded in concrete cast around the lower flange of the beam. Rebars sealed in holes drilled in the existing beams guaranteed the connection between the old and the new concrete. The anchorages of these cables were

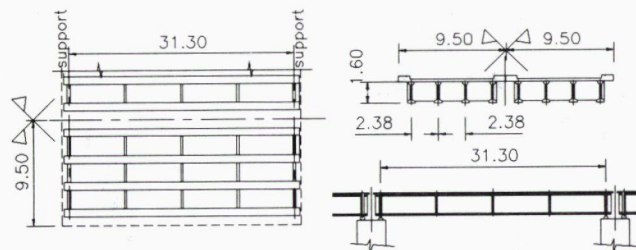


FIGURE 6 Typical simply supported p.c. deck built 20 to 30 years ago.

made with concrete blocks or steel frames according to each situation (Figure 7).

### Stupino and Ruiz Viaducts

The Stupino and Ruiz viaducts were built by the cantilever method. Spanning over 120 m and with piers with heights of up to 150 m, they can be considered among the most important of the A3 Motorway.

According to the solutions adopted at the time, no rigid connection was made at the end of the opposite cantilevers: a short dropped span (9 m) was built at the midspan of the Ruiz Viaduct, whereas a simple hinge connected the two facing cantilevers of the Stupino Viaduct at midspan (Figure 8). The large creep, developed over the 20 years of the bridge's life, caused unacceptable deflections at midspan (5).

The prestressing cables added inside the box girder, at the bottom of the upper slab, allowed a reduction in the deflections and the addition of a lightweight aggregate wearing course to make the road profile acceptable. This is a classic example of external prestressing with grouted cables. The prestressing forces were trans-

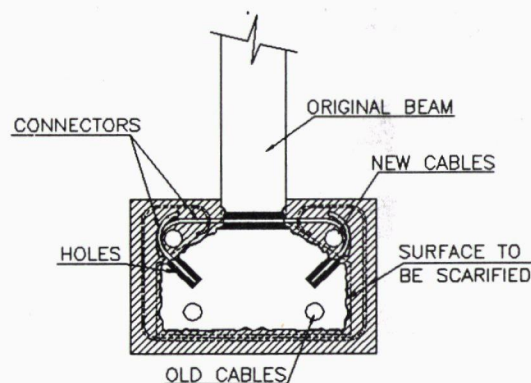


FIGURE 7 In early applications new cables were incorporated into concrete pour added to original section.



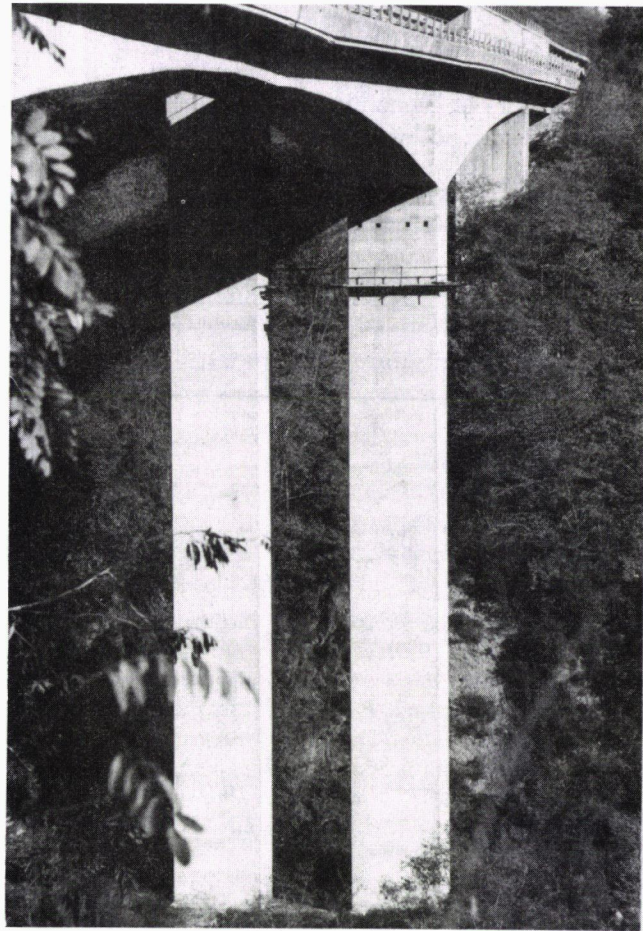


FIGURE 8 Ruiz Viaduct before repair. A large deflection at midspan is visible to the naked eye.

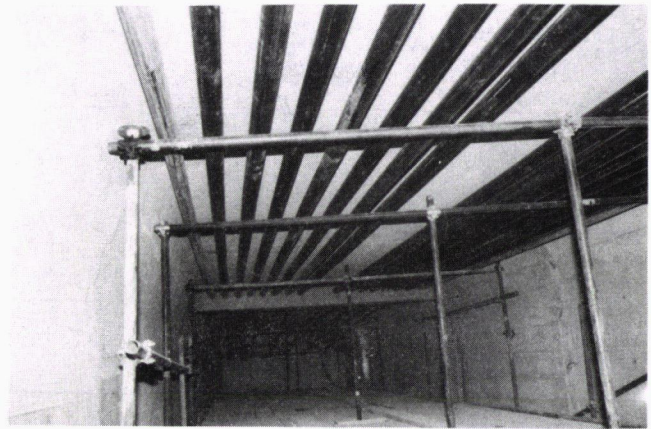


FIGURE 10 External cables added inside Stupino Viaduct. HDPE sheets were grouted with cement-mortar.

ferred to the existing section with concrete anchor blocks and shear connectors (Figures 9 and 10).

#### E45 Viaducts

Rehabilitation work was done on five viaducts with a total of 142 simply supported decks composed of two V-shaped beams for each carriageway (Figure 11). The decks had just been finished when some shear cracks appeared in a number of beams. The beams were initially prestressed with pretensioned strands, and the cracks were probably due to the insufficient strength of

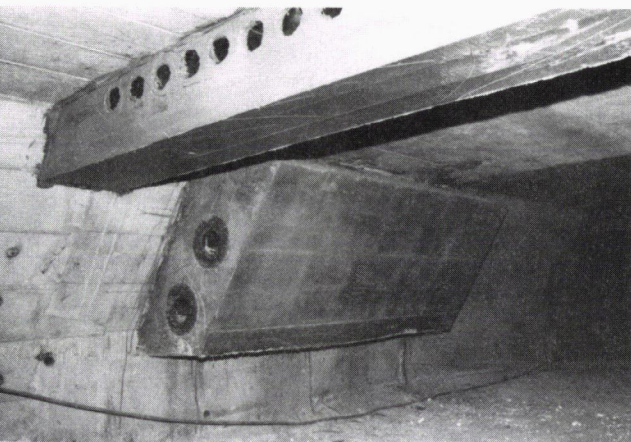


FIGURE 9 Deviation block (upper slab) and anchor block (web) ready to receive cables.



FIGURE 11 Deviation block added inside box girder. The external prestressing cables are composed of single sheeted strands. They will not be grouted.



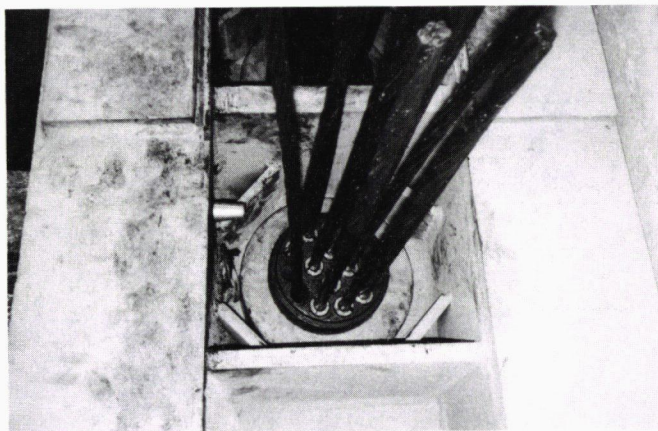


FIGURE 12 Steel frame placed at end of each beam to anchor new cables.

the concrete at the time of release of the prestress. Slippage of the strands near the beam ends occurred, and the sections in this zone behaved as nonprestressed ones.

In this case external cables formed with single sheathed and greased strands were used. The strands were encased in an HDPE tube without any injection, and the anchorages have been designed in such a way that a single unit can also be replaced. A steel frame that transfers the force to the p.c. beam at its ends was chosen because of the narrow distance between two adjacent beams (Figure 12).

## CONCLUSION

In the coming years in Italy, as well as in all of Europe, large amounts of economic resources will be necessary to rehabilitate road bridges mainly built 20 to 30 years ago with p.c. This budget is expected to be greater than the one for the construction of new bridges in the future.

The situation will require (a) reliable assessment criteria and (b) economical and efficient repairs.

The external prestressing offers in many cases an adequate answer, and it is expected to be used more and more frequently in future applications.

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