Modernisation and widening interventions of bridge structures on the Adriatic highway in Italy

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Summary

After the realization of the "Variante di Valico", a new alignment aimed to double the A1 Milan-Naples highway in the Appenninic zone, the most important work currently under construction in Italy consists of the modernization of the Adriatic highway (A14 Bologna-Bari-Taranto), aimed to enlarge the highway carriageway by inserting the third traffic lane. Focusing the attention on the bridge structures only, the paper shows the most representative interventions realized to widen the existing bridges and viaducts, as well as to adequate the safety level to the most stringent requirements imposed by the actual Italian code.

Keywords: Bridge, Rehabilitation, Seismic Retrofitting, FRP materials.

1. Introduction

The oldest Italian highways were built in the Sixties and nowadays are inadequate to meet the actual functional and safety standards anymore. In order to answer to the continuously increasing demands due to higher volume of traffic flow, and to comply with the recent more stringent regulations, Autostrade per l'Italia, the main National transportation agency, and SPEA Ingegneria Europea, its design company, have been involved in designing upgrading and widening interventions of the most part of the national highway network.

After the realization of the "Variante di Valico", a new alignment aimed to double the A1 Milan-Naples highway in the Appenninic zone [1], the most important work currently under construction in Italy consists of the modernization of the Adriatic highway (A14 Bologna-Bari-Taranto), aimed to enlarge the highway carriageway by inserting the third traffic lane. The bridge structures belonging to this highway alignment were built in the 70's, and nowadays many of them result to be inadequate to comply with the actual functional and safety standards. This is also due to the recent upgrading of the national seismic code which states as mandatory the check of the seismic performance of all the existing structures to be considered strategic and to be widened to upgrade the number of traffic lanes. In fact, due to the more stringent safety requirements and the increased seismic forces to be accounted for, many existing structures usually show serious deficiencies including inadequate ductility caused by poor attention dedicated to construction details such as inefficient anchorages for both longitudinal and transversal reinforcements, inadequate amount of stirrups in order to improve the confinement of the structural members in correspondence of critical nodes, improper staggered position of longitudinal reinforcement in order to avoid weak sections, among others. In order to adequate the structural response to the new required safety level, proper strengthening interventions are then often needed.

This paper describes some of the most representative widening and rehabilitation interventions of bridge structures on the Italian Adriatic highway.

2. Basic design criteria for bridge upgrading interventions

2.1 Widening criteria

The modernisation of the Adriatic highway consists of an enlargement of the highway carriageway so to host three traffic lanes and the emergency lane. Since the previous configuration provided two traffic lanes only, the enlargement width is usually equal to about 6.50 m. In correspondence of bridges and viaducts, the widening intervention consists of an enlargement of both superstructure and bents in continuity with the existing parts. The proportions of the new structural elements are chosen to comply with the geometric characteristics and mechanical properties of the old ones so to reproduce a similar flexural stiffness and to assure an as uniform as possible structural behaviour [2].

Generally the existing bridge deck is composed by a grillage of prestressed concrete girders and its widening requires the use of additional beams, which can be made of steel or concrete depending on economical and technological reasons. In any case, a new concrete slab is always realized to link the beams, as well as a connection between the old and new deck portions. The design choice to connect the two parts by means of the concrete slab only, instead of additional transversal beams, is due to the will to avoid any interference problems between the anchorages of the connecting diaphragms and the reinforcement of the existing beams. As consequence, in order to ensure adequate slab flexibility in transversal direction, the distance between the last existing beam and the first new one should be generally greater than about 1.50 m. This slab area, due to its fundamental role in activating the cooperation between the old and new decks, always requires a special attention. As better described in the following chapter, different design solutions can be provided: in the most cases, after the hydro-demolition of the existing slab cantilever, preserving the existing reinforcement layers, and the removal of the superficial concrete surface of a part of the existing slab, a new system of steel reinforcement is provided by overlapping it on the existing one, and by using doweled bars anchored in drilled holes realized in the existing slab, sealed with epoxy resin. As an alternative, in case of tight time schedule, it is also possible to cut the whole existing slab cantilever and to entrust two upper and lower layers of doweled bars the task of connecting the old and the new decks.

With reference to the bents, the basic design criterion is to provide an enlargement which is as similar as possible to the existing part. In fact, the widening portion has not to weight down on the structural behaviour of the existing part, but, if possible, it has to be designed to compensate any possible deficiency of the existing structure. To this aim, pier elevations formed by multiple column frames are thus widened by providing new columns characterised by almost the same ultimate flexural resistance of the existing ones, as well as wall piers are usually widened by maintaining the same dimensions and steel reinforcement amount of the existing parts. Analogous concepts have to address the dimensioning of the foundations, which usually have to reproduce the typology adopted in the original design, except than in case of any structural deficiencies.

2.2 Seismic retrofitting strategies

Any widening intervention usually leads to a modification of the working state of the existing structures. In order to correctly calibrate both the characteristics of new elements and the strengthening/retrofitting interventions, a preliminary assessment study has to be carried out in order to investigate any structural deficiencies of the old parts due to less stringent requirements imposed at the original time of design and construction of the bridge under examination. In case of assessment under seismic condition, a non-linear pushover analysis has been generally carried out.

The most significant deficiencies generally emerged in existing bridge structures can be resumed as follows: the bearing system often is inadequate to comply with large seismic displacements, and no mechanical connections are present between deck and bents; pier elevation sometimes shows low ductility reserves due to poor detailing of steel reinforcement; many bridges are irregular in terms of geometry and/or structural behaviour, and it can cause premature collapse of non-ductile elements (mainly foundation systems), and/or not full exploitation of post-elastic capabilities of plastic hinges in seismic conditions. In order to supply to these deficiencies, specific retrofitting strategies have been set up. In particular, to avoid the falling down of the superstructure during the seismic events, the realization of a system of seismic restrainers has been provided. The restrainers are usually formed by concrete blocks anchored with doweled bars to upper surface of the bents and positioned in order to allow the free movement of the deck under thermal actions. As an alternative, for the longitudinal direction, the restraints can be realized by means of steel devices anchored at the intrados of each beam. In addition, in all cases existing bearing system and expansion joints have been replaced so to improve displacement capability.

In general, to design seismic retrofitting interventions, two alternative approaches can be adopted. The first approach acts on the seismic demand by reducing the induced forces by means of base isolation or seismic protective systems [3]. The second approach, instead, influences the structural capacity by intervening on specific structural members [4]. In this latter case, a typical retrofit strategy consists of increasing the strength and/or the stiffness, or upgrading the mechanical properties of the structure. Another efficient, even if counterintuitive, retrofit strategy consists of a rational weakening of selected structural members. In fact, by using this strategy, the seismic demand can be reduced and the inelastic mechanism can be changed according to capacity design principles in order to avoid non-ductile failure modes [5].

In the following, representative cases of retrofitted bridge structures by using the above mentioned retrofitting techniques, acting at both the seismic demand and capacity level, are presented.

3. Widening and seismic retrofitting interventions

A selection of the most representative upgrading interventions of existing bridges is now presented, according with the previously described criteria. In all cases, the widening intervention consisted of an enlargement of both superstructure and bents in continuity with the existing parts. With reference to the structural behaviour under seismic conditions, the three selected bridges have revealed different deficiencies which have required different retrofitting strategies. In the first case, an inadequate level of deformation ductility in plastic hinge regions of the piers has needed the use of fiber reinforced polymer materials; in the second case, the deficiency of the foundation in resisting bending moment due to an over-dimensioning of the pier cross-section has been solved by a rational weakening of the pier base; in the last case, the unsuitability of the abutments in contrasting seismic horizontal forces has been solved by providing a system of passive anchors.

3.1 Morignano Viaduct

The Morignano Viaduct is composed by a long sequence of simply supported prestressed concrete decks, 32 m long, sustained by framed bents having height ranging from 8.30 to 21.50 m. The deck is formed by four prestressed concrete beams and by a concrete slab, 0.25 m thick and about 10 m wide. The bents consist of framed structures formed by four rectangular columns linked by a cap pier and, in case of high piers, by an intermediate transversal beam. The foundation system is composed by a plinth on large diameter piles.

In order to enlarge the highway carriageway of about 6 m, the deck has been widened by a steel-concrete composite structure formed by three new steel beams and a concrete slab, 0.25 m thick, linked to the existing one. To support the new deck, all the bents have been widened by realizing three new columns, identical to the existing ones, linked to those by means of the cap beam and the plinth (Figure 1). In order to assure the continuity between new and old parts, a system of doweled bars has been used. In particular, the connection at the slab level has been designed with great attention. As shown in Figure 2.a, the existing slab cantilever has been cut and the superficial layer of the existing slab has been removed for about 0.70 m. Two systems of steel bars, anchored in the existing slab in drilled holes sealed with epoxy resin, have been provided at both bottom and top levels (Figures 2.b-c). The final casting has been made by using a special concrete able to reduce shrinkage phenomena.

To verify the seismic suitability of the widened bridge, a pushover analysis has been carried out. The main results have consisted in the incompatibility of the displacement capability of the existing bearings with the demand of large seismic displacements, and the inadequacy of the smallest piers in terms of ductility and confinement during longitudinal seismic events. As consequence, a complex retrofitting intervention leading to uniform distribution of seismic forces has been designed to improve the whole seismic performance [6]. First of all, existing bearings have been replaced by elastomeric pads and new expansion joints have been provided. To prevent deck jumping, longitudinal and transversal seismic restrainers have been also introduced by means of reinforced concrete elements doweled to the existing cap beams (Figure 3.a).

Fig. 1: Widening intervention of Morignano Viaduct

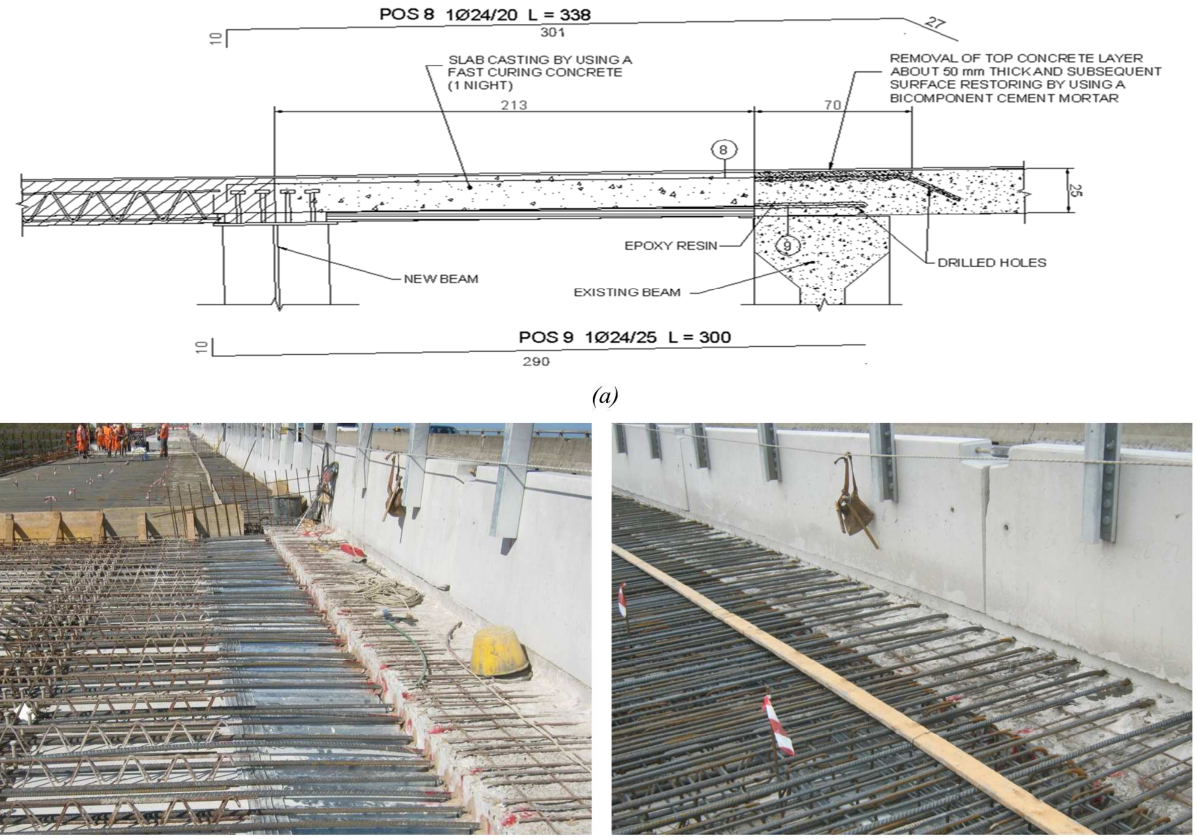
As usual in case of irregular bridges, the collapse under longitudinal seismic events has been revealed caused by the premature exhaustion of the ductility reserves of the smallest piers. The retrofitting solution has consisted of the enhancement of the ductility of the weak members by FRP wrapping (Figure 3.b). Since the columns have rectangular cross-section of dimensions 0.70 m x 2.30 m, and the confinement effectiveness of the externally bonded FRP jackets depends, among other parameters, on the shape of cross-sections and radius of the corners, a modification of the cross-sectional shape has been needed. In fact, to reduce any detrimental effect of the sharp corners on the tensile strength of the FRP, the corners have been rounded and an elliptical-shaped external cover surrounding the old rectangular cross-section has been realized by using cement grout. Finally a multilayer Carbon FRP jacket made by unidirectional fiber epoxy-impregnated sheets has been wrapped around the elliptical-shaped region (Figure 3.c).

3.2 Foglia Bridge

The Foglia Bridge is composed by a sequence of three simply supported prestressed concrete decks, 32 m long, supported by concrete wall piers, having three-cellular box cross-section. The foundation is formed by a footing sustained by a system of micropiles.

In order to enlarge the highway carriageway of about 6 m, the original design has provided a solution equal to that above described for Morignano viaduct. Nevertheless, during the construction phases, the building firm has proposed to substitute the three steel beams with the two V-shaped prestressed concrete girders shown in Figure 4.a. In addition, the type of connection at the slab level has been modified: instead of cutting the existing slab, it has been decided to hydro-demolish it preserving existing steel reinforcement. In this way, after removing the top concrete surface 50 mm thick, the new top reinforcement layer has been overlapped to the existing bars, and the concrete surface has been successively restored by using a bi-component cement mortar. The bottom reinforcement layer, instead, has been anchored in the existing slab by drilling holes sealed with epoxy resins, as already shown for the Morignano viaduct (Figure 4.b).

The results of the structural seismic analysis performed in the final widened configuration have highlighted that the existing pier elevations had been over-designed and the old foundations were not able to sustain the resistant bending moment of the cross-section at the wall base. In conclusion, the capacity design criteria aimed to favour the flexural collapse of the wall and to avoid the early collapse of the footing, were not satisfied [7]. Among different design solutions, the chosen retrofitting strategy has been focussed on strengthening the footing as well as reducing the bending capacity of the pier wall, and has consisted in a programmed reduction of the ultimate bending moment of the pier base. In this case, the widening intervention has also played a fundamental role in improving the bending capacity of the foundation system (Figure 5). More in detail, the reduction of the bending capacity of the pier wall has been obtained by means of a local weakening of the base cross-section, realized by cutting a small selected part of the internal steel reinforcement of the elevations, obviously made in the respect of the U.L.S. and S.L.S verifications. To this aim, circular openings, with diameter of 1.20 m, have been made in the wall of each box of the existing pier. In this way, it has been made feasible to enter the internal part of each box in order to demolish the concrete cover at the bottom part of the pier along the whole internal perimeter of the cross-section, as well as to cut a selected number of reinforcing steel bars. After the intervention, the concrete cover has been completely restored, and the effectiveness of the reinforcing bars in correspondence of the circular openings has been also restored, by closing all the provisional openings (Figure 6).

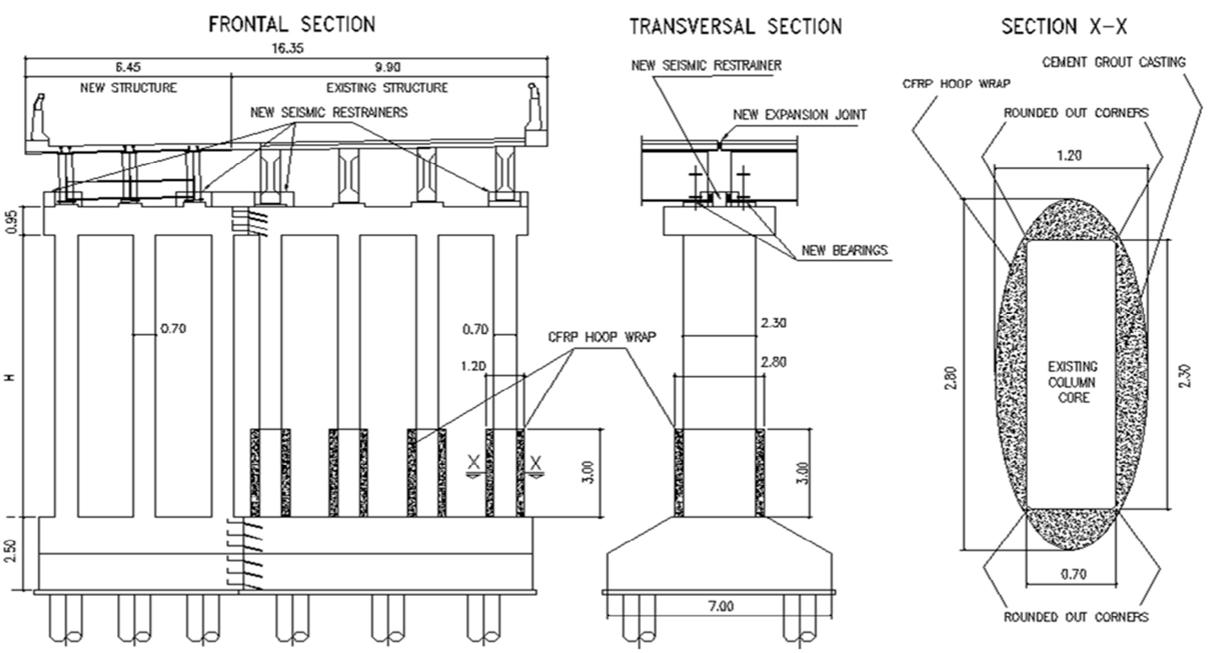


(a)

(b)

(c)

Fig. 2: Slab connection between new and existing decks. (a) Detail of slab connection. (b) Positioning of bottom steel reinforcement layer. (c) Positioning of top steel reinforcement layer.

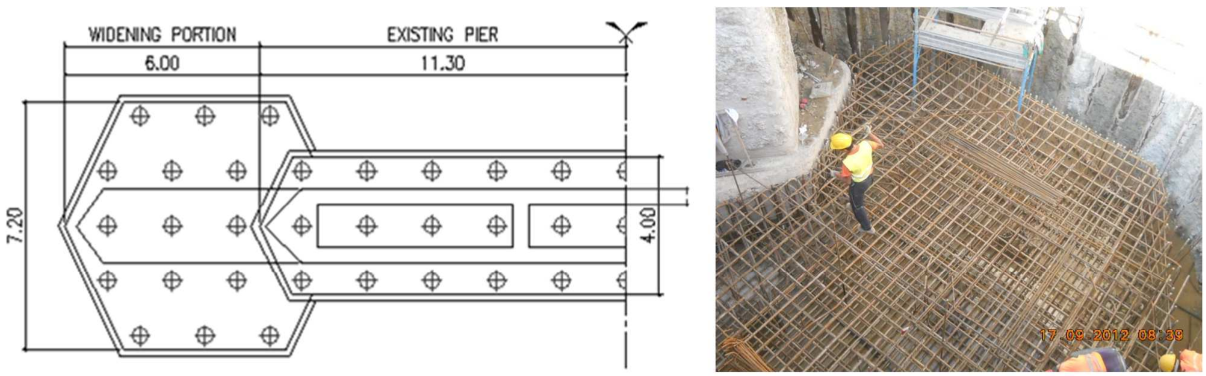


(a) (b) (c)

Fig. 3: Seismic retrofitting intervention of Morignano Viaduct: (a) Replacement of existing bearings and expansion joints; (b) CFRP wrapping of the bottom part of the existing columns; (c) Modification of the cross-section shape to improve wrapping effectiveness.

(a) (b)

Fig. 4: Widening intervention of Foglia Bridge. (a) Prestressed concrete V-shaped girders. (b) Steel reinforcement of new deck slab.



(a) (b)

Fig. 5: Widening and retrofitting interventions of foundation. (a) Plan view of new and existing foundations. (b) Positioning of steel reinforcement of the widening portion of the plynth.

3.3 Pesaro Station Underpass

The last retrofitting intervention deals with the underpass next to Pesaro Rail Station. The as-built bridge is composed by a single simply supported prestressed concrete deck, supported by two massive concrete walls having no steel reinforcement. Since the abutments had been designed for vertical loads only, a strengthening intervention has been needed to assure an adequate safety level against horizontal seismic forces [8]. To this aim, a system of passive anchors has been realized by using micropiles inclined of 15 degrees with respect to the horizontal line, and disposed at two different levels. Since the passive anchors have been designed to activate only under seismic condition, the rehabilitation intervention does not modify the static behaviour of the structure, but provides an increase of load-carrying capacity with respect to horizontal actions only. Together with the realization of the anchor system, a reinforced concrete cover has been added in front of the abutment wall, and connected with the abutment itself by a system of dowels (Figure 7).

4. Conclusions

One of the most important work currently under construction in Italy consists of the modernization of the Adriatic highway. The paper has illustrated the basic design criteria adopted for widening and upgrading interventions of existing bridge structures on this alignment and has shown a representative selection of interventions realized to widen bridges as well as to adequate their safety level to the most stringent requirements imposed by the actual Italian code. In conclusion, widening intervention has been proposed as a part of strengthening strategy of the existing structure, and three retrofitting examples have been shown.

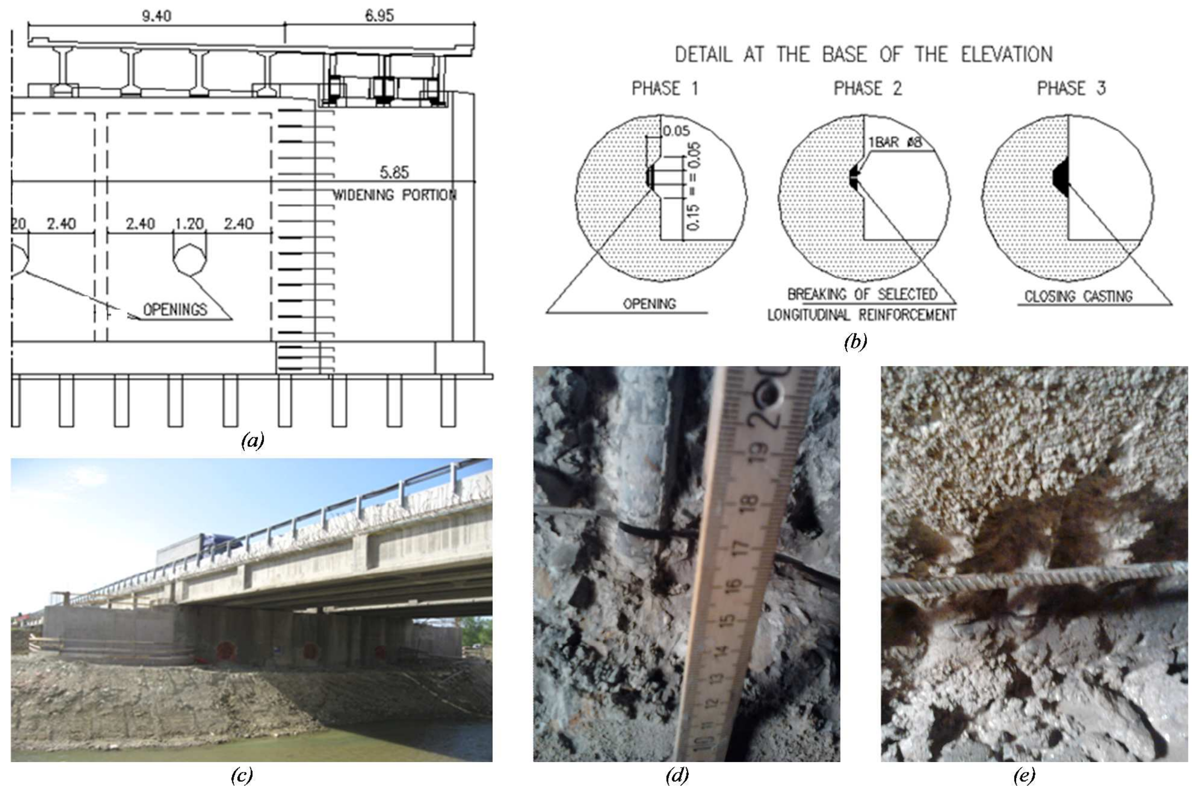


Fig. 6: Widening and retrofitting interventions of the piers. (a) Original design solution for bridge widening. (b) Selective weakening intervention at the base of the pier elevation. (c) Widening solution for piers. (d)-(e) Cutting of a selected number of existing steel bars.

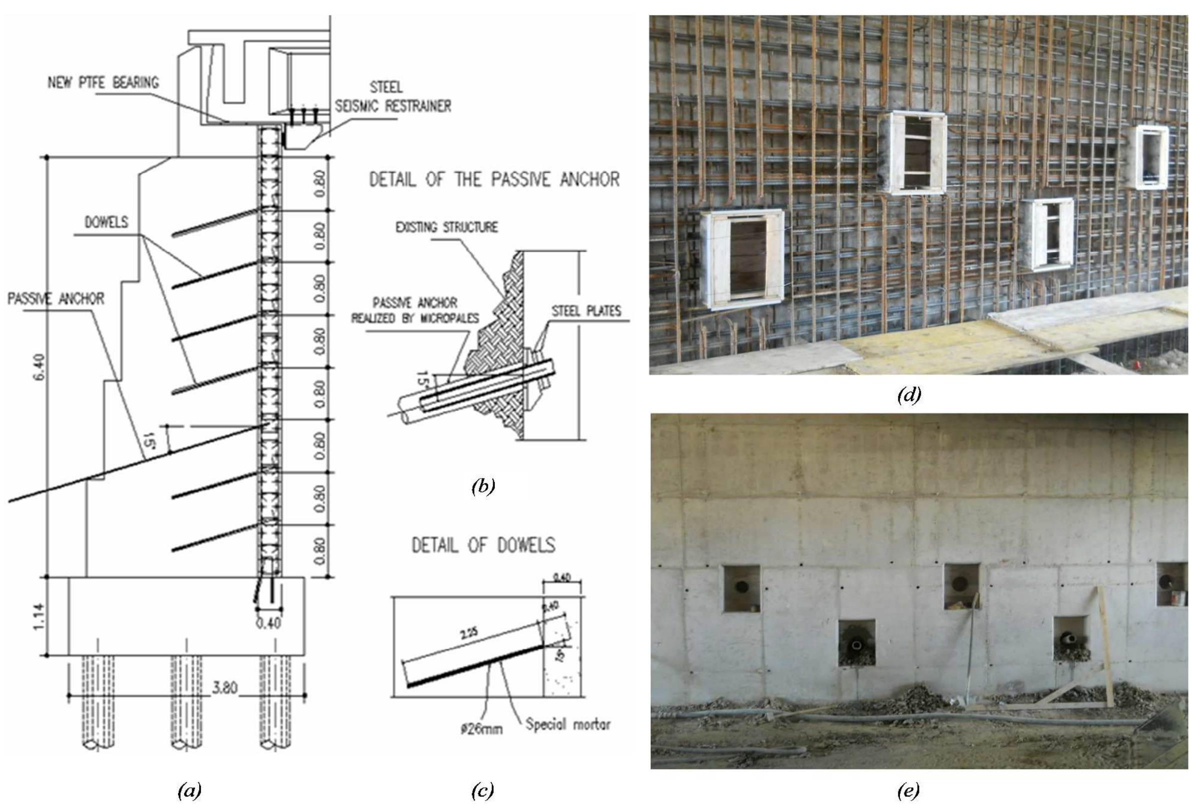


Fig. 7: Seismic retrofitting intervention. (a) Transversal section of existing abutment. (b) Detail of passive anchor. (c) Detail of dowels. (d) Positioning of steel reinforcement of the concrete cover. (e) Arrangement for passive anchors.

The first one has been aimed at improving the structural capacity by increasing plastic hinges ductility by means of CFRP wrapping. The second case has consisted of increasing the strength of inadequate structural members, such as foundations, by using a less intuitive method which consists of a rational weakening of selected steel bars at the bottom end of the piers, so to change the inelastic mechanism according to capacity design principles in order to avoid a non-ductile failure mode of the foundation. Finally, the last example has dealt with a bridge abutment, having no steel reinforcement, which has required a system of passive anchors to be able to sustain horizontal seismic forces.

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