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# THE SOLBRITO VIADUCT: INSPECTION, ANALYSIS AND REHAB

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## ABSTRACT

Rehabilitation and improvement of road and existing bridges have become nowadays a matter of major concern for road Authorities: time, pollution and structural strain are one of the main causes in the aging of the structures.

In this paper is briefly described the visual inspection carried out, in the last ten years, by SATAP and SINECO to the bridges placed along the A21 Torino-Piacenza highway, as well a bridge management plan that brought about our case study: Solbrito Viaduct strengthening design.

The Solbrito viaduct is a late 60's concrete built bridge located between the cities of Torino and Asti along the A21 highway. The bridge structural scheme consists of thirteen concrete spans 15.5 m length constituted by three concrete beams, for each traffic direction, for a total length of 201 m. The existing bridge deck is 10.5 m wide and is subdivided by two lanes of 3.75 m each and an emergency lane of 2.5 m wide.

Several important issues were examined before the design plan as well the traffic management problems during the repair works, increment of the lane numbers, load capacity, geotechnical and seismic matters. After considering some design alternatives it was selected the enlargement of the deck by way of connecting a new lateral structure to the existing one and therefore increasing the number of lanes. It was also conducted a concrete rehab of the current slab, beams and piers.

The first part of the paper describes the base studies and inspection work made in order to acquire a sufficient level of knowledge to establish a correct structural rehabilitation design of the viaduct.

The second part explains the strengthening design performed oriented to solve some problems as: the almost complete road joint elimination and the new method for connecting the old and the new structure. Finally it is described the details collected during the managing of the work, that best illustrate the solution proposed.

## INTRODUCTION

The Satap S.p.A. is the Concessionary that built in the 60<sup>th</sup> the highway A21 from Torino to Piacenza and now manages the road.

The motorway path goes along a flat geographic area and ends up in a hilly area near Torino. The main characteristic are:

- total length 168 Km
- 37 main bridges;
- 260 secondary structures (overpass and underpass).

Nowadays the A21 highway is one of the most important of the north west of Italy connecting Torino to the A7 Milano - Genova and A1 Milano - Roma turnpike.

A great increase of heavy trucks passages in the last ten year has been recorded, and this situation has produced a lot of traffic congestion and an incremented live load on the road bridges.

Then the progressive aging of the structures (in the most of the cases the bridges are between thirty and forty years old) and the deterioration of material together with the environmental pollution attacks, produce a reduction of the structural safety. So it is easy to understand the importance of getting a more and more reliable and accurate control system of bridges. In this case study the main tasks were to verify the efficiency level of the structure and also to understand the feasibility of the bridge assessment.

Sineco from the nineties is performing the inspection of the structures every year, producing as a result the bridge management system (BMS) as a support to the Concessionary maintenance asset.

From the described situation, the following topics were highlighted by Satap&Sineco for guaranteeing a long time high service level of the highway:

- the need of a robust bridge survey method;
- the assessment of the design under new service loads due to the increase of the mobile loads limits;
- the need of improvement of the transversal section of the bridge, in the way to increase the lanes;
- to increase the knowledge about strengthening the structural elements and materials;
- the need to reduce the timing of "out of service" during the inspection and repair works.

The paper describes the Satap A21 Bridge Management System and the structural assessment of the SOLBRITO bridge, the first that needed some urgent action .

In this situation to achieve a correct structural assessment of the bridge a preliminary study was performed by Sineco S.p.A., oriented to collect all the historical design data archived and the information about structural elements (material, reinforced bars, construction methodology, etc) also by non destructive test performed.

After the preliminary study to evaluate the efficiency of the bridge Sineco in accord with the Road - holder it was decided to perform the rehabilitation design oriented to the widening of the road section. In the next part of the paper the structural solution together with the works performed step by step on the bridge in the way to better analyse the less impact produced on the traffic flow are presented.

## THE BRIDGE INSPECTION

The first inspection started in 1993 and was based on the study of all the bridges and viaducts in order to produce a general analysis of the state of the road. A visual inspection of all the structural elements was performed year by year. The deck, the superstructure and the substructure were taken into account. Each element was verified (using a by bridge ) by a set of inspections based on a system that allows the control of each component of the structure and all the visible damage were gathered and registered on the PC based program.

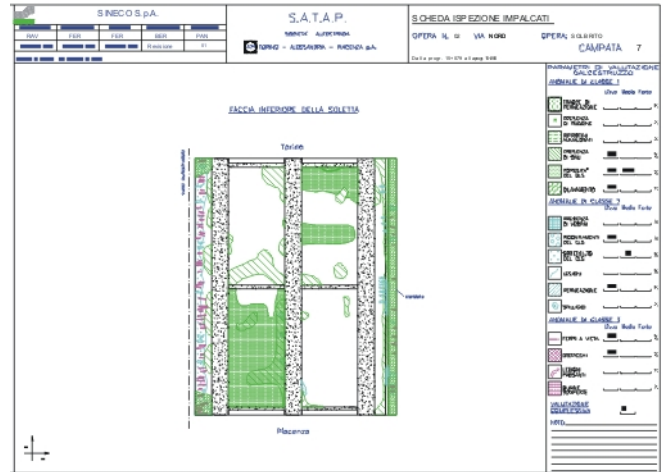


Fig. 1 Solbrito visual inspection of the deck and "damage data sheet" recorded by the inspector

The S.I.O.S. program, realised by Sineco, in agree with the Italian Code and Standards, works on a CAD system – computer aided design - that uses graphical input gathered during inspection (Fig. 1) and with the aim of an algorithm produces numerical data in order to build a database for damage assessment, comparison. As time passes this method also gives an idea of the damage evolution. The technique tries to reduce the subjective interpretation of the inspector, by taking a close established classification of the damage and with the use of an algorithm produces numerical result. It is called the “rating value pointing”, for instance the level of global damage of single elements of the structures. Along with this information for purpose of further evaluation the systems takes into account the analysis of the concrete material, like the determination of the presence of carbonation and chloride.

The data that are available to the design engineer and the technicians involved in an analysis of the structures after an inspection are: the historical data, the detailed damage data (the leakage of the deck due to deficiency of waterproofing of the slab, the spalling of the concrete bar cover and the corrosion of the reinforcing steel bars), its location for each structural element, the damage evolution forecast and at the end the damage index. This last parameter summarizes the state of each structure to give an idea of the whole road under analysis, using this index a classification of each structure from the worst to the better condition.

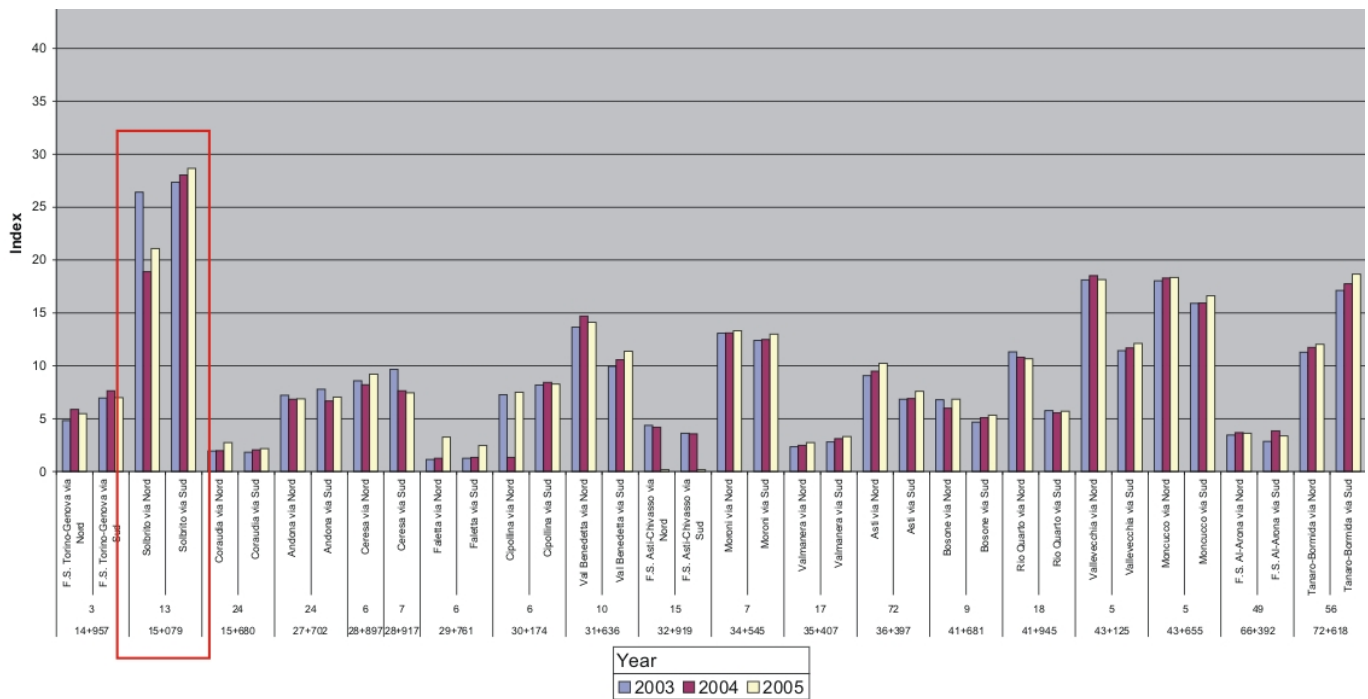


Fig. 2 Satap damage index trend

From the graphic above (Fig. 2) can be observed that the SOLBRITO viaduct was the first that needed a repair solution as more detailed in the BMS program defined. By this examination Sineco in according with the road owner started the design phase.



Fig. 3 Panoramic views of bridge



Fig. 4 Lateral view of bridge

### SOLBRITO VIADUCTS STRUCTURAL DESCRIPTION

The bridge is located in the Piemonte region at an altitude of about 220 m above the sea level in correspondence of the Monferrato hill starting from Asti to Torino in a high variable climate region.

As mentioned above the Solbrito viaduct is a late 60's concrete built bridge designed by the 1960 Italian Standards Codes. The structural layout consists of thirteen concrete spans 15.5 m length constituted by three concrete beams simple supported, for each traffic direction, for a total length of 201 m. The existing bridge deck is 10.5 m wide and it is subdivided by two lanes of 3.75 m each and an emergency lane of 2.5 m wide; the foundations are constituted with drilled piles connected by a beam on top and three pillars, connected to the extreme for supporting the girders on top.

### Inspection end test

The analysis of annual inspections, as explained before, permitted to indicate and characterize all the deteriorations of the concrete material (carbonation, chlorides penetration, mapping of degradation). The bridge presented phenomena of water leakage coming from the upper road, in particular next to the joint, diffused break up of concrete bar cover and steel bars revealed corrosion in advanced progress. In particular the steel corrosion was visible on the lower surface of the decks and on the pillars and, in minor measure, on the beams (see Fig. 5 and 6).



Fig. 5 Concrete bar cover damage



Fig. 6 Existing bearings degradation

The piers presented general surface degradation of concrete with spalling of re-bar cover. The bearing supports were deteriorated and therefore badly functional. In particular it was possible to observe the corrosion for most of the steel plate bearings and leakage of lead layer for some of them.

An extensive core sampling campaign were programmed in order to reveal the carbonation depth and the concrete resistance.

The measure of the depth of carbonation ( $>25$  mm) in the concrete reveals that the elements more involved in the phenomenon were the decks and piers, and it was reasonable to conclude that the steel bars are in a visible state of corrosion.

The resistance value of the concrete and the tension of yielding of steel bar was considered in base of the historical data found in as-built designs.

### **STRENGTHENING DESIGN AND REHABILITATION WORKS**

The extensive surveying activities presented above allowed us to obtain a sufficient level of knowledge to perform a numerical analysis oriented to evaluate efficiency of the bridge, defining the limit of live load and the structural elements damaged. Several alternatives technical and economic were proposed as:

- a. Restoration of concrete surface to ensure the structural safety to the design load;
- b. Rehab of the structure to loads of current Italian Standard for bridge design and the increase of lanes wide using the same section without emergency lane, together with the renewal of the cinematic behaviour of the bridge, reducing the road joints;
- c. Rehab of the structure to loads of current Italian Codes for bridge design, increase of lanes with new lateral structural elements, together the renewal of the cinematic behaviour of the bridge reducing the road joints and the installation of new safety barrier;
- d. Complete demolition of the viaduct and the reconstruction of new one.

As described before the structural elements of this bridge had deep degradation problems in particular to pillars and bottom slab. Also from the preliminary structural analysis it was understood that the existing

structures were not able to support a widening of the lane using the same road section without a vast and difficult strengthening; the curbs also needed a heavy strengthening for supporting new guard rail.

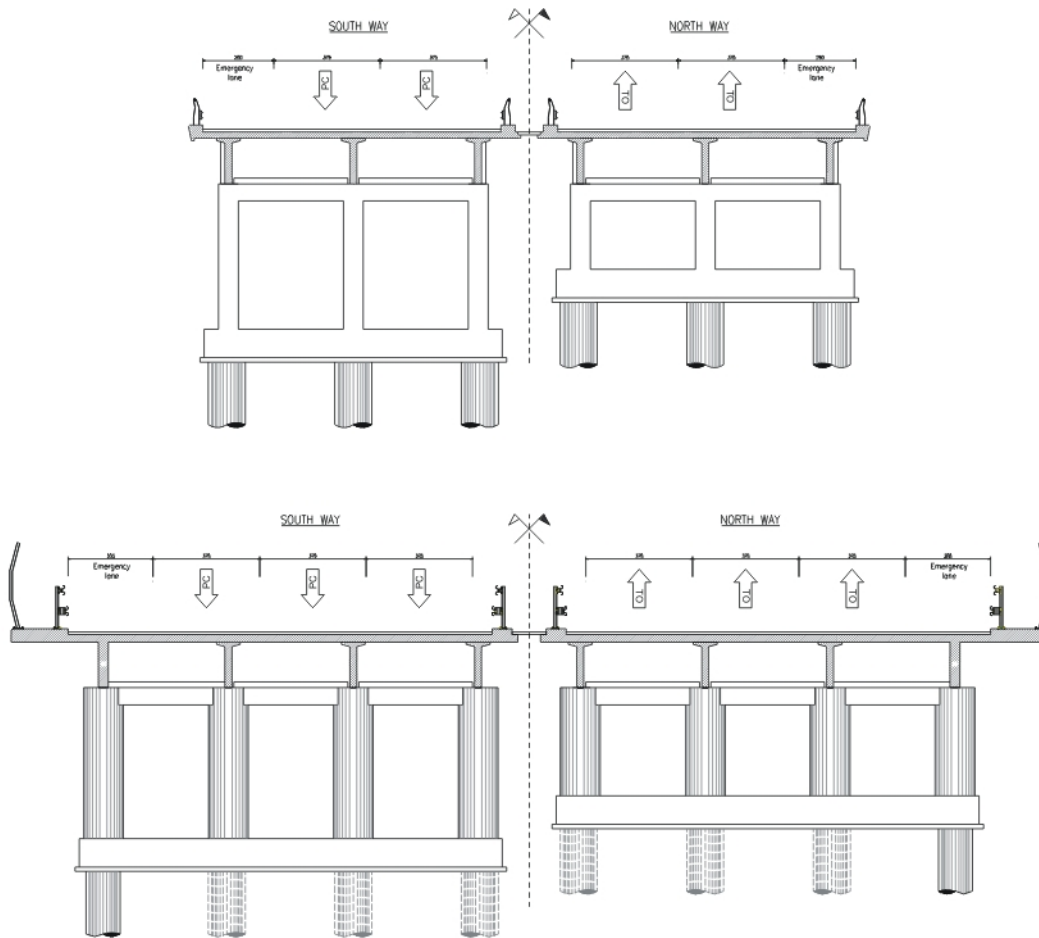


Fig. 7 Old and design bridge section

The Road Owner decided for the solution described at the point c), widening the road section, for the following reasons:

- traffic disturbance had to be reduced and the deck was prepared to the third lane for future needed;
- The rehab proposed had a simple approach more economic than a replacement with a complete new structure (the most radical assumption of complete remaking of the bridge would require an increase in costs of approximately 20% and, especially, a high indirect cost on normal road traffic);
- The bureaucratic authorization iter was easier in regard to the environmental impact assessment procedure, the bridge location is very critical due to environmental configuration near the rail way.

The rehabilitation project was oriented to strengthening the structural elements following the loads requirements, taking into account the input received by the Road Controller to produce the minimum disturb to traffic and widening the deck with a preparation for the third lane.

The design is elaborated, in detail in the subsequent paragraphs. Recovering the existing structures with the adaptation to the loads of existing Italian Codes, the enlargement of the road section from 10,50 m of road section up to 14,95 with the possible addition of a new lane in each direction, using new structural elements in support adding new lateral structure, beams and new piers, using the existing structural geometry already in use. It was also performed a seismic analysis using site earthquake, the lowest of the Country.

The main aspects of the strengthening design and rehabilitation works are:

- Reinforce of the existing and construction of new structures in support;
- repair the concrete by selective hydro-demolition and casting new material increase section (pillars and slabs);
- replacement of existing bearings with new PTFE bearings and introduction of cinematic connection for the reduction of the road joints;
- increase road safety by installation of new guard rail;
- placing a new water drainage system (new waterproof, new road drainage system).

In the next part of the paper are presented the structural design solutions along with the construction site executions.

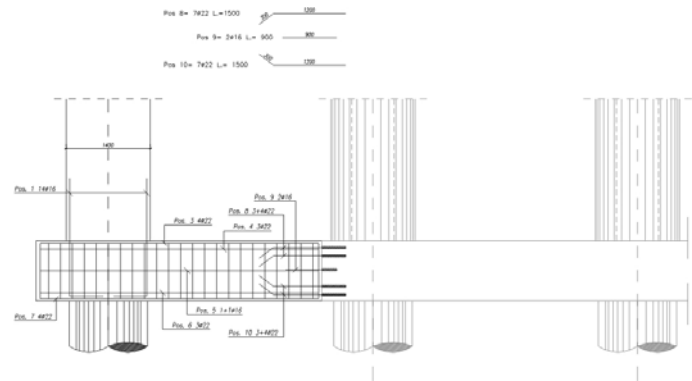
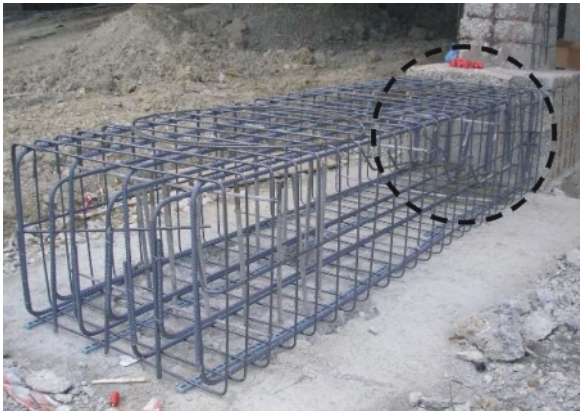


Fig. 8 Connection between new and existing vertical structures

### New structures

The new support structures are made of the same structural typology of the existing ones. The new stack of circular cross-section of equal size expected for the section increasing of the existing pillars, based on a plinth supported by a singular  $\varnothing 1200$  foundation pile; the new pillars are joined to the existing portal through the extension of the relative beams.

Regarding the abutments, new concrete walls in the external side (with piles and foundation) completed the new structures of the enlarged viaduct.

The structural bond between new and old structures (foundation and elevation transversal beams) was guaranteed by laying steel connectors into old concrete glued by special mortar products. No additional shear joints were designed because the vertical load was downloaded directly to the ground by the new pillars in elevation.



Fig. 9 New piers

### Widening and deck rehabilitation

After constructing the new piers new pre-cast beam was put on and the new slab. The new deck stretch, to about 8 m wide, extended up to the current external beam (after demolition of the external curb) to establish, through appropriate cross steel bars, a new connection to the old structures strong enough to ensure a good continuity.

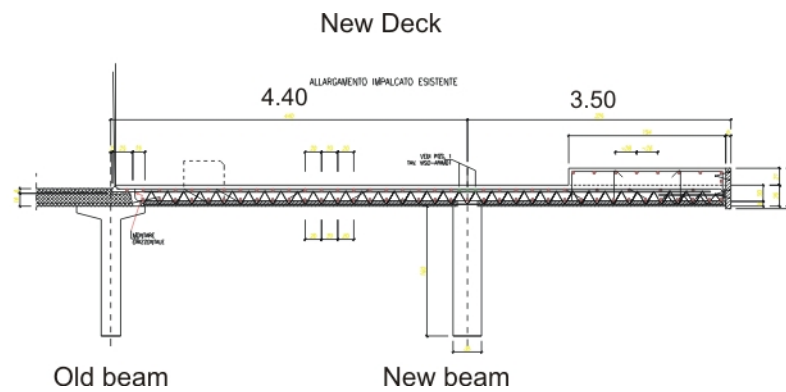


Fig.10 Widening of the slab

In order to consider the different "ages" of the structural elements that form the viaduct enlarged were held structural analysis and calculations in several phases using different values of bending Young modulus ( $E$ ), parameter characteristic of reinforced concrete structures to consider the influence of concrete rheological behaviour.



Fig. 11 Preparing works for the new slab

In fact the new bridge deck is built, for each span, adding a new concrete beam joined to the old structures between a new slab (thickness of 26 cm) and new transversal girders fixed joined with existing ones (by introducing some steel connections); this choice is also linked to the different ages of the structures and to the opportunity to distribute evenly road loads between the two structures.

The restoration of the existing part of the Solbrito viaduct has concerned: removal of the existing paving, hydro-demolition of diffused selective upper surface of the deck, reconstruction with laying down new reinforced bars and finally cast of concrete with elevated resistance.

For the demolition of the concrete on the top slab it was requested the use of selective hydro-demolition machine, that guaranteed a minor impact on the structure, a good productivity and also a good preparation of the surface for the cast of new concrete.



Fig. 12 Steel bars casting and connectors

The slab was strengthened in both longitudinal and transversal side with steel bars and with a uniform (60×60cm) distribution of steel connectors like “Nelson bolts” (Fig. 12) to provide a shear contribution between new and existing slab concrete; the thickness of new slab was increased from 12 cm on top up to a 26 cm.

The concrete mix design was defined to obtain a reduction of drying shrinkage, creep and thermal stress and to quickly develop over time resistance characteristics..

#### Reinforcing of existing piers

The concrete piers deterioration required a radical operation of restoration, after thorough selective hydro-demolition of all parts (thickness of 5-6 cm), between widening the former rectangular cross-section to a new circular Ø1400 wide, with adequate additional steel bars (for seismic reinforcing and deck uplifting) properly linked to the existing foundation and inserted in a new concrete casting.



Fig.13 Piers rehab

High workability concrete packaged with Self Compacting Concrete (SCC) was used for reinforcing casting for the small thick available between the additional bars and the thicknesses to fill.

On the top of the piers were introduced boxes under the beam for holding hydraulic jackets during the deck lifting, for bearings replacement, (more details are available in the next paragraphs).

Selective hydro-demolition was used for the restoration of the transversal beam on the top and bottom of the piers, sandblasting for all inconsistent parts and cleanliness of the steel bars, tixotropic mortars (high flow behaviour and compensated shrinkage) and final acrylic painting as shown in fig. 13.

### Improvement of the cinematic behaviour

A detailed analysis of the connection was performed so to guarantee a level of efficiency and durability for the future and to improve the cinematic behaviour of the viaduct.

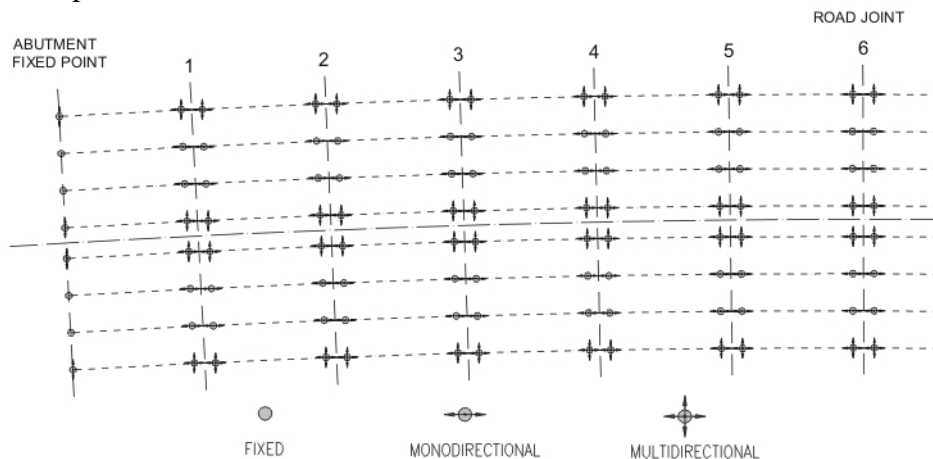


Fig. 14 New bearing location

In order to reduce road joints from 14 up to 1 the design defined a continuous deck of about 6 and 7 spans, the existing expansion joints were completely eliminated, with the exception of the joint in correspondence of the pillar n° 6 (this joint permits a total movement of 12 cm); between the adjacent slabs of each span it was built, during the works, on the slab a link in concrete with appropriate insertion of bars (this metallic reinforcement of connection is made up of stainless steel bars distributed lengthwise riding the passage between the spans for a total length of 2,0 m) that allows load transfer and horizontal displacements between spans; the beams maintained its original structural configuration in a simply supported style.

The solution designed had taken in account the seismic load provided for the site calculated by 3d modelling by finite element program.

The introduction of cinematic behaviour needed to transfer horizontal dynamic load, due to vehicles along the adjacent spans, through bearings appliances of fixed type on the abutments and to permit the thermal concrete expansion of beams all the other bearings must be mobile type to allow the deformation of the deck on the road joint in the middle of the viaduct. A structural analysis was performed for studying the possible changing in the fixed abutments, that in any case did not need particular intervention using the widening proposed of foundation and wall (passive anchorages in the ground were provided).

The design has foreseen to replace the existing beams bearings, dating back to the period of construction, with modern ones in steel-PTFE in order to ensure the perfect absorption of thermal expansions and movements induced implementing the cinematic connection; three types of bearings were used: abutment fixed bearings, unidirectional and multidirectional bearings on the pylons.

The replacement of old bearings took place after the controlled lifting operation, equipped with automatic control unit, that allowed the contemporary lifting of the beams constituting, through the use of boxes on enlarged piers, the subsequent removal of existing bearings and the positioning of the new ones.

To execute the lifting in the abutments provisional structures were used, a steel structure system hooked up on the frontal wall below the girder support .



Fig 15 Unit for lifting with hydraulic jackets and new bearings

### WORKS MANAGING AND TRAFFIC SUGGESTION

The main project, in agreement with the requirements of highway traffic management prescribed, planned to make the work so that in general were maintained two lanes of traffic, with a reduced lane width, for each direction.

The work established, phase 1, the deck enlargement and the adaptation of the existing structures in the north direction, preparing two lanes for the direction to Piacenza and a traffic lane for the direction to Torino in south and a traffic lane north; for the phase 2 it was completed the rehabilitation of the internal part of the viaduct in north with one lane for the direction to Piacenza and one lane in south adding two lanes for the direction to Piacenza.

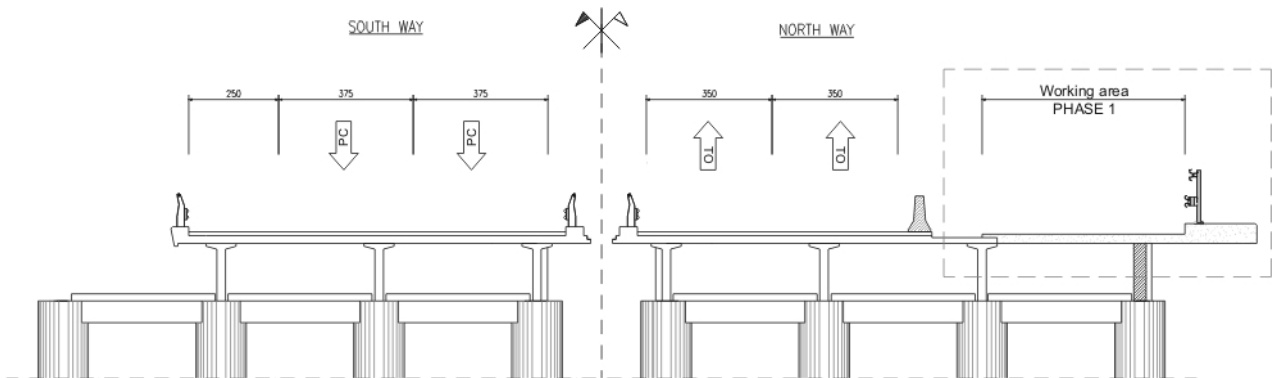


Fig. 16 Phase 1 – traffic diversion

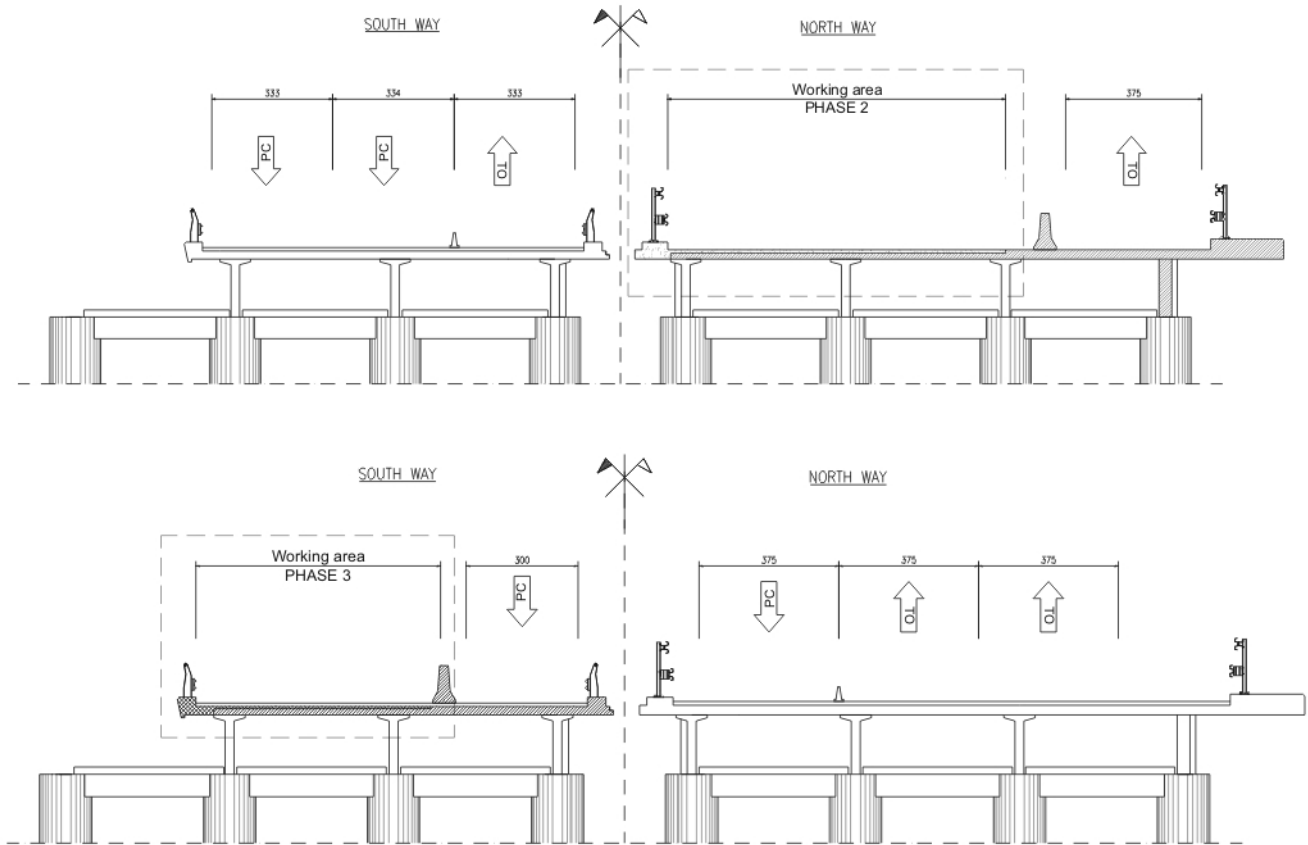


Fig. 17 Phase 2 and 3 – traffic diversion

Symmetrically the works of enlargement were concluded for the south part of viaduct with a larger lane. Unfortunately, for this viaduct, it was impossible put four lane in the north carriage widened due to a rail way passing close over the north abutment.

The quality of the materials used was another important aspect of planning and working; various types of concrete were studied and tested for the structure parts, due the differing needs of workability and to the time needed to reach required strength in the different construction phases.

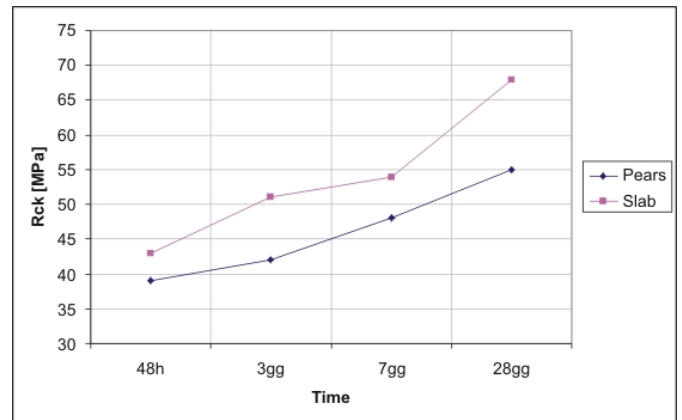


Fig 18 Diagram of concrete resistance

The special mix designs, analysed for the main structural parts comes from vibration induced by vehicles transit, the existing pears enlargement ( $R_{ck}$  40 MPa) and slabs casting ( $R_{ck}$  60 MPa).

The technical characteristics of two concrete materials used:

New slabs Concrete	
Mechanical Resistance	$R_{ck}$ 60 MPa
Cement type	CEM I 52.5 R [490 kg]
Water/Cement	0.6
Water	170 lt
Exposition class	XF4
Slump	S5
Max inert Diameter	20 mm
Expansive Additive	Compactcrete 39/T100

Enlarged Pears Concrete (SCC)	
Mechanical Resistance	$R_{ck}$ 35 MPa
Cement type	CEM II/A-LL 42.5 R [360 kg]
Limestone	Nicem 260 kg
Water/Cement	0.6
Water	165 lt
Exposition class	XF2
Slump	S6
Max inert Diameter	20 mm
Expansive Additive	Compactcrete 39/T100

For the rehab of existing piers it was used a high workability concrete (SCC), with small aggregates diameter and with quick mechanical strength development.

For the slab concrete, it was prescribed the traffic interlude on the viaduct's adjacent area of construction for at least 48 hours, thus limiting interference of induced vibrations, and it has chosen a high mechanical performance concrete with quick development of resistance.

The main general data are summarized below:

- Start working January 2006 end of works October 2007
- Total cost: €4.785.765,71
- 



Fig. 19 Panoramic views of Solbrito viaduct after rehab

## CONCLUSIONS

The paper presented a case study, involving visual inspection, non-destructive investigation technique turned to the final repair and widening of the bridge.

It is put in evidence the importance of making a detailed study to define a sufficient level of knowledge related to the importance of the bridge and to manage the effective economical resource available.

Moreover a carefully numerical analysis, reflecting the level of knowledge obtained by visual inspection and material analysis, could permit understanding the possible changing and damages produced during the life of the bridge structure.

The assessment described, in particular the deck widening, could be regarded to the simplicity of the structural solution and the construction procedure adopted (innovative material and construction technique) together with the quality of the information on which is based. Finally this solution could be an answer to maintenance and rehab bridges already in service; where the need it is not only the upgrade of the load capacity as new standard recommendation requires, but also widening a structure while increased vehicles passage with less disturb to the traffic flow. Also an economical evaluation has performed where a good ratio cost vs. benefit is achieved. A new bridge was built using the existing one under traffic: widening an strengthening were reached.

## ACKNOWLEDGMENT

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Fig. 20 Road view of new Solbrito viaduct

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