A.I.P.C.R.
NATIONAL TECHNICAL COMMITTEE C.4.4
“ROAD BRIDGES AND ASSOCIATED STRUCTURES”

EXTENDING THE SERVICE LIFE OF BRIDGES: GUIDELINES FOR THE DESIGN, CONSTRUCTION AND MAINTENANCE STAGES

ABSTRACT

The National Technical Committee has produced a book entitled "Increasing the service life of bridges: guidelines for the design, construction and maintenance stages", which, with the prospect of extending service life, sets out guidelines for a bridge’s entire life cycle.

The book is divided into 5 sections:

1. Introduction: that after illustrating the premises of the work, addresses the essential matter of providing the reference regulatory framework.

2. General lines of analysis: which includes a brief description of the bridge assets in the territory, the analysis of their most common defects, their causes and the methodologies used to identify them.

3. Choice and description of the types of measure: after a rapid overview of the main measures used, some examples of work carried out are given. A detailed study on the methods at present in use for raising decks has also been included together with some brief documentation on the devices used (supporting equipment, joints, etc.).

4. Material characteristics: the innovative materials used in the section in the execution of the measures are described, especially when the technology to be applied is not covered by existing standards.

5. Recommendations for new constructions: this section is mainly intended for designers, and contains certain expedients to improve and extend the service life of structures as also economising on future running costs.

1. PREMISES

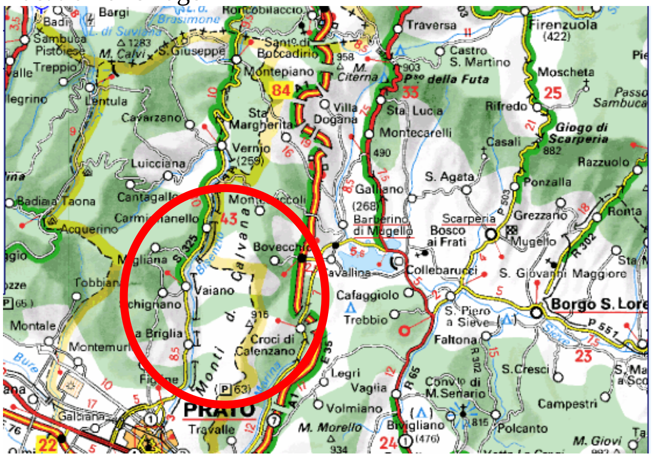
The technical study introduces guidelines for the various phases of the design, construction and maintenance of road bridges. However, attention is concentrated on operational aspects in order to increase the service life of these engineering structures.
This objective is pursued with reference to two possible areas of action: the first concerns engineering works in service, where a series of examples of ordinary, extraordinary and emergency maintenance work is given; the second refers to new work, which offers various types of advice based on working experience.

2. REFERENCE STANDARDS

National and community regulations were collected on public works referring to the construction of road bridges and associated structures.

POGGETTONE AND PECORA VECCHIA VIADUCT

Location of bridge



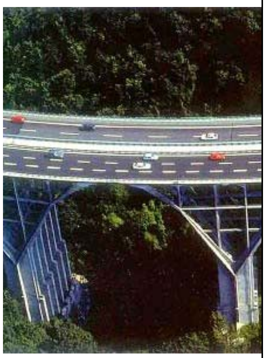
TITLE OF WORK: Viadotto Poggettone e Pecora Vecchia

DESIGNER: Engineers A. Carè and G. Giannelli

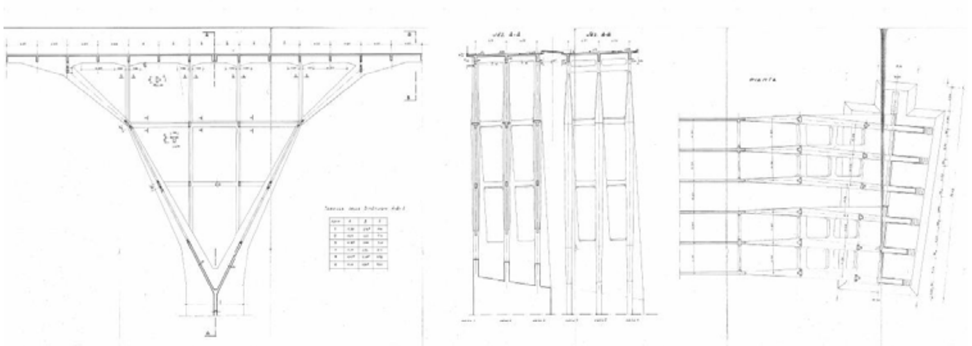
PLACE: Km 244 on the A/1 Milan Naples motorway

YEAR OF CONSTRUCTION: 1960

STATIC SCHEME: Arched bridge with ordinary reinforced concrete beams



View from above

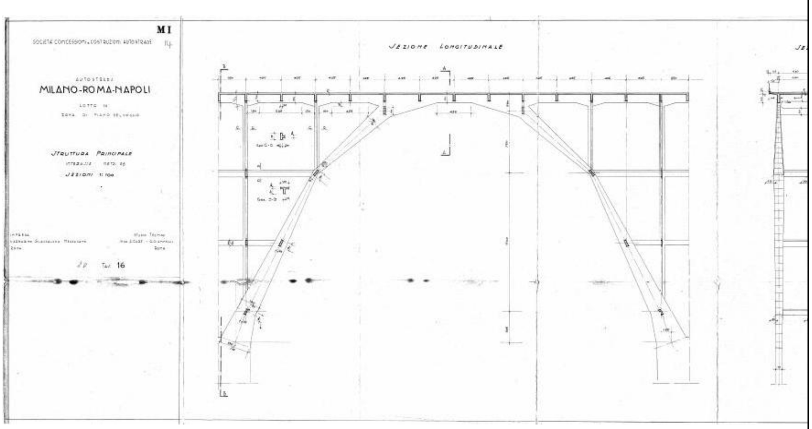


Detail of project

Side view

View from above

Maintenance work on bridge



Detail of project

Detail of pier

Figure 1 – Type profile

The collection also includes the regulations for the rehabilitation of bridges or parts of bridges, so as to increase their service life cycle.

For purposes of consultation, the list of standards is broken down by subject: general standards; steel; fire protection; structural controls; supports joints and barriers; concrete durability; seismic, geotechnical, water-proofing and other standards,

3. LINES OF GENERAL ANALYSIS

3.1. Bridge assets in the territory

Italian bridge assets comprise a wide and varied range of structures. This variety concerns not only materials but also structural types, whose great diversity regards both the various structural parts and the elements that make them up.

Deterioration determined by physical actions: Rain-weathering	
 **Absence of down-pipes and water drips**	 **Rain-weathering and corrosion of gerber saddles**
 **Rain-weathering and corrosion of edge beams**	 **Rain-weathering and corrosion of pulvino**

Figure 2.

This diversity is largely a function of the period in which the bridges were built. However, we have deliberately omitted the so-called historical bridges whose peculiarities merit separate discussion. The most significant sample of the most recent types was taken from the bridge assets managed by ANAS and motorway concessionaires. The assets in question cover a period of up to one century.

We begin with the less recent works where arched structures prevail.

The construction of the Autostrada del Sole initiated a period that gave full rein to the imagination of the designers. Thus a highly varied range of structures along with the use of many different materials (ordinary reinforced concrete, pre-stressed reinforced concrete, and steel and concrete) is found, often in the same work.

However, this phase was followed by a second period in which designs were orientated towards much more uniform solutions. The most common example is the scheme involving simply resting pre-stressed reinforced-concrete beams.

Deterioration due to accidental events	
	
Explosion	**Collisions involving tall vehicles**

Figure 3.

This large range of engineering structures in Italy has meant that various static schemes are also to be found: the gerber beam; the continuous scheme or that referring only to slabs; the supported or continuous caisson; the frame or semi-frame; the cable-stayed and the suspended bridge.

The work is arranged into technical sheets, ordered by type and chronology, that describe all aspects of the engineering works complete with photographs and designs (see figure 1).

3.2. The causes of deterioration

It is essential to identify the causes of deterioration if correct rehabilitation measures are to be designed. In addition to eliminating the damage found, they will also eliminate the situations that generate the defect at the point where it occurs and prevent such situations from reappearing in other, hitherto unaffected, parts of the structure.

Table of causes of bridge deterioration			
reasons intrinsic to the work	aging		shrinkage creep Relaxation
	design errors		errors in calculation or approach traffic underestimates underestimating other design inputs insufficient material specifications underestimating executive difficulties
	executive errors	materials not complying with specifications	unsuitable aggregates grading curve not respected
		material deployed incorrectly	incomplete curing erroneous water/cement ratio lack of or insufficient vibration
		erroneous assembly	errors in arrangement of supports inadequate reinforcement covering
external actions	environmental	physical/ mechanical	frost and thaw rainwater weathering/erosion fatigue abrasions overloading
		chemicals	sulphates carbonation salts chlorides sulphides alkali aggregates acids pure water stray currents
		biological	fouling
	accidental	natural	floods earthquakes landslips eruptions land subsidence
		anthropic	collisions fires explosions

Table 1: Causes of bridge deterioration

The causes determining bridge deterioration involve various factors. On this question, the book makes a first distinction between defects referring to the structure itself, and specific to each bridge, and defects due to external factors.

Among the first can be enumerated defects due to the natural aging of the materials. Then there are defects due to design errors, as also defects due to poor construction.

Among the second set of factors, those due to external factors, the defects related to the environment in which the work is situated, are listed, as also the defects due to accidental causes.

Descriptive images of the defects are provided of the defects, broken down by underlining cause.

Therefore, a "List of bridge defects" is proposed for use in assessing the state of repair of the engineering works. The defects are divided into homogeneous groups, indicating, first, those typical of specific structural parts, then those typical of a specific material and, in conclusion, those with peculiar origins or characteristics.

Table 1, summaries the foregoing description.

4. Methods and systems for inspecting and surveying the state of repair

The systems at present used for investigating the condition of bridges and surveying their defects are mainly based upon visual inspection, as laid down in the reference regulations.

The instructions contained in the relevant regulations are:

- supervision should take the form of "visits" conducted at "fixed intervals" on the works in question. These are:
  - a quarterly inspection to be performed by technical personnel;
  - an annual inspection to be performed by engineers (only for the most important structures);
  - extraordinary inspections conducted by engineers, in the event that there emerge signals of abnormal or uncertain situations concerning the structures;
- the preparation of a report based on quarterly, annual and extraordinary inspections. These reports can also, where necessary, suggest measures to be taken, a summary judgement and the need for specialist controls, in addition to reporting the findings of such surveys.

The methods to be followed for the performance of visual inspection are also summarily illustrated. Visual inspection is then completed by including the data collected in a data bank so as to organise the indications on the basis of predetermined conditions and conduct research and calculations on the data collected.

Once the inspections are performed, the works can be divided into:- works for which repair measures must definitively be carried out, those in a good state of repair and those for which the visual inspections to define the situation were insufficient and require supplementary instrumental checks.
Such instrumental checks are listed in a number of tables (local, global and monitoring tests) and ordered according to materials, objectives and tests.

5. CHOICE AND DESCRIPTION OF TYPES OF MEASURE

After discussing the decision-making process, the main technical measures are illustrated. These can be broken down into the three main groups listed below.
In addition, these measures are also divided into "passive" and "active" with an explicit reference to techniques used for the application of the reinforcement. Active measures require greater commitment on the part of the designer but often mean a greater guarantee of successful results.

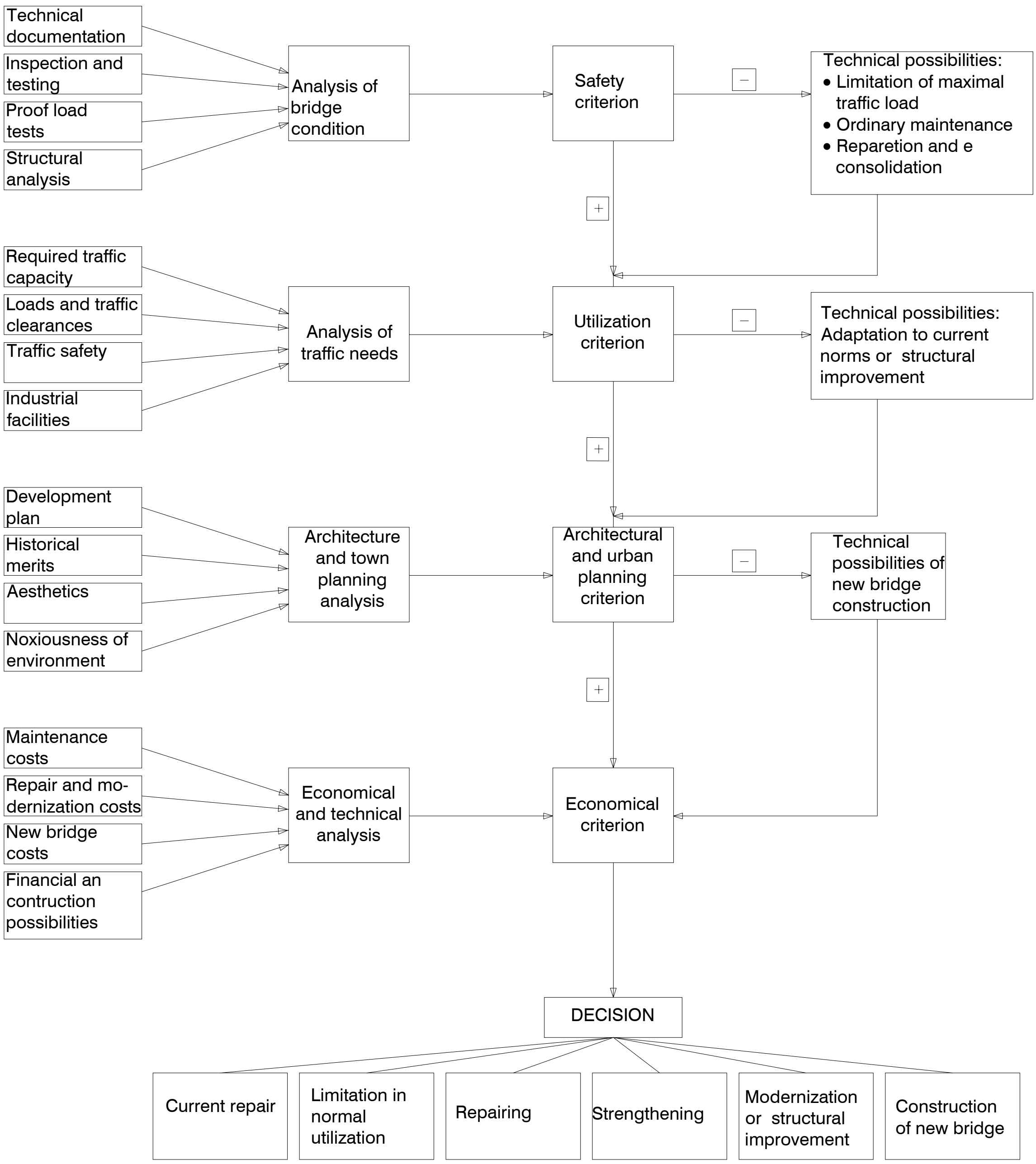


Table 2: Decision/making process

5.1 Three types of technical measure

5.1.1 *Methods to reduce the level of external stress upon a structure*

- Reinforcement by lightening the structures or by partial reconstruction (diminution of permanent loadings).
- Limiting loadings by road signals or by introducing physical barriers (limitation of live loads).
- Inclusion of new structural elements resulting in a new allocation of live loads.
- Upgrading by introducing new supports or constraining systems (reduction of friction and parasitic forces).

All the foregoing methods can be classified as "passive" methods.

5.1.2. *Methods to increase the hyperstaticity of the structure or apply new external forces*

- Reinforcement by introducing external pretensioning bars or cables.
- Reinforcement by applying distortions to the support constraints.
- Reinforcement by use of new constraints.
- Reinforcement by construction of structural continuity.
- Improvement by including elasto-plastic-devices for seismic protection.

All the foregoing methods are classified under "active" methods.

5.1.3. *Methods to increase the resistance of elements*

- Reinforcing and increasing ultimate strength by adding beton-plaquè.
- Reinforcing and increasing ductility by the use of CFRP.
- Reinforcement by correcting deformations, increasing the resistant section and inserting stiffening plates.
- Reinforcement by cladding existing structures.
- Reinforcement and upgrading by the partial reconstruction of structural elements.
- Reinforcement by construction of new sub-foundations.
- Upgrading by enlargement of existing foundations.
- Upgrading or replacement of structural devices (bearing supports, joints, barriers, water-drainage and water-proofing systems).

The foregoing methods mainly fall within the category of "passive" measures. Not infrequently these methods are coupled with external pre-stressing systems thus reclassifying them under the second classification.

The multiplicity of all the measures possible means that a single document attempting to illustrate them comprehensively would be so extensive as to be practically useless. Therefore, we have tried to limit the overview to a sufficiently high number of typical examples, in the form of data sheets, so as to propose methods and identify their technical value.

5.2. *Italian standards schemas*

The examples of the work proposed, in the form of data sheets, are grouped on the basis of the schemas included in the recent Italian standards, which distinguish between: “Measures aimed at increasing the safety of the construction", namely consolidation or repair measures, and "Measures required by new requirements and/or conversions of a construction" corresponding to upgrading and improvement.

5.2.1 *Consolidation measures*

The consolidation measure is a series of measures and operations that make an existing structure safer.

5.2.3. *Repair measures*

A repair measure is a series of operations that restores the pre-existing safety level of a damaged or deteriorated structure.

5.2.4. *Upgrading measures*

An upgrading measure is designed to upgrade the safety of a structure when it is necessary:

- to enlarge and/or raise a structure;
- to make significant variations to a structure to accommodate higher loadings;
- to comply with new legal requirements.

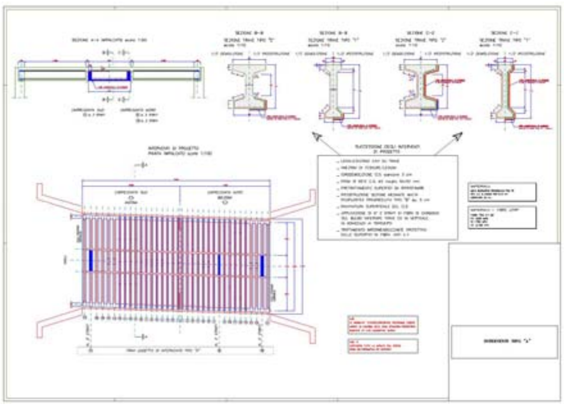
5.2.6. Improvement measures

An improvement measure is a series of operations on single parts of a structure required to confer a higher level of safety to the entire structure.

Selice Data Sheet

Damaged beams and rapid intervention measures

Repairs with CFRP and numerical simulation of the Moment – Curvature diagram



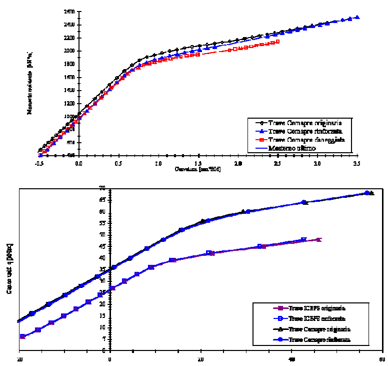


Table: Quantity and position of the reinforcements		
Beam	Description	Dimension reinforcement
Comapre	Bending moment: under the beam reinforcement Shear: transversal reinforcement.	2 bottom bands 1.3x3.5m 2 transversal bands 0.3x1.2m
ICEFS	Bending moment: under the beam reinforcement Shear: transversal reinforcement.	2 bottom bands 0.8x3.5cm 2 transversal bands 0.3x1m

Application method

- removal of the degraded or disconnected concrete, without damaging the reinforcement steel bars;
- cleaning by sanding of the zone to be strengthened, steel bars included, to eliminate the corroded film and to clean the whole steel bars to Svenk A3 grade (white metal);
- restoring degraded abutment stone zone with Emaco (compensated withdrawal mortar proved both in the air that in the water)
- complete limitation of the traffic on the carriageway immediately above to the zone to be strengthened;
- possible inside injection of the cracks of big entity;
- application of the primer;
- at the condition of tack-free, application of the longitudinal reinforcement and then of transversal reinforcement;
- reopening to the traffic not before 24 hours from the end of the operations of reinforcement;
- later around 48 hours, painting anti UV, e/o plaster or cement trimming of final protection.

Reinforcement operations on intermediate beams and rehabilitation detailing

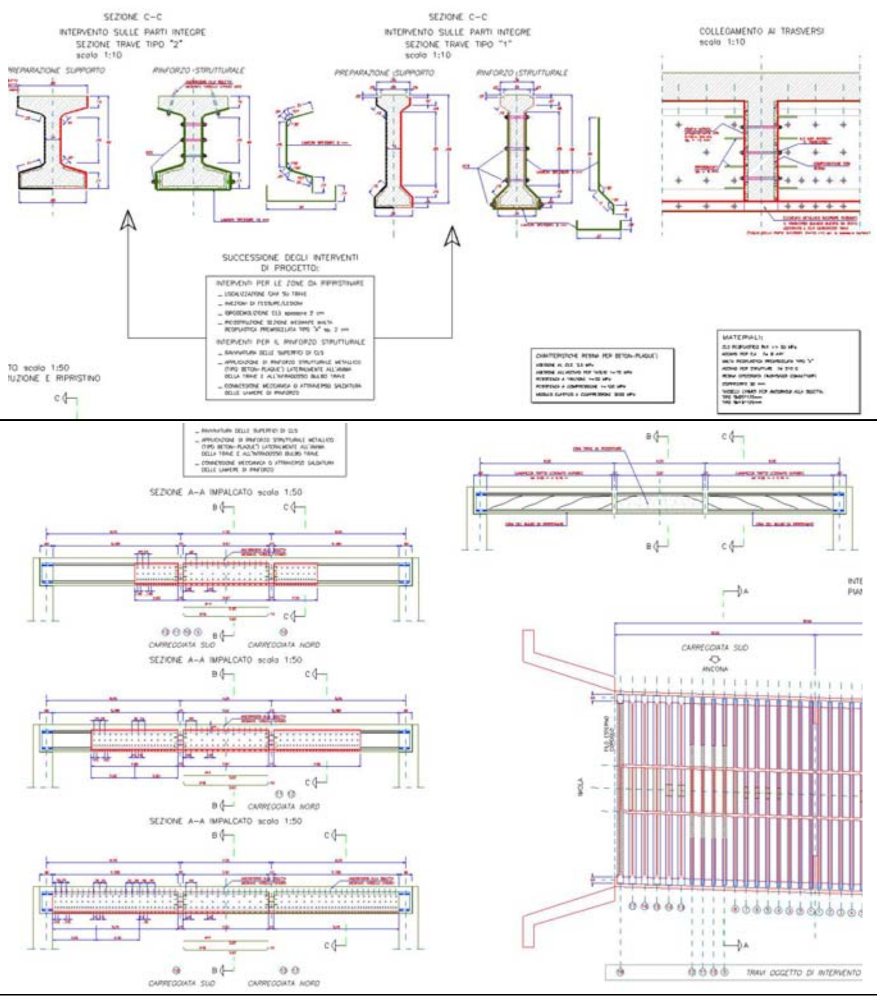


Table: Mechanical properties of the materials involved in the proposal, (negative values point out compression)

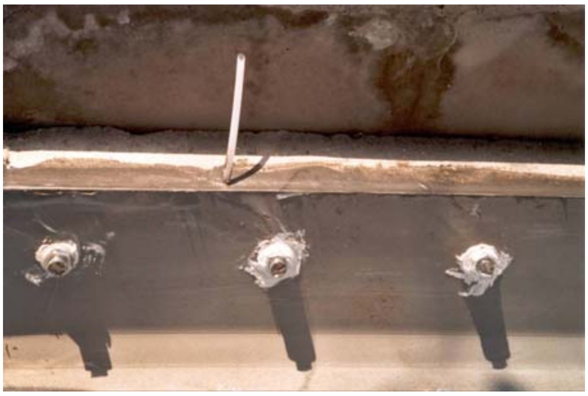
Material	Elastic Module E [GPa]	Characteristic strenght f_k [MPa]	SLU strenght f_{du} [MPa]	Strain tension [MPa]
Existent slab concrete	20	-35	-17	= =
Precasted beam concrete	20	-55	-27	= =
Comapre ropes	190	1900 breaking stress	1350	1000
ICEFS ropes	190	1500 breaking stress	1200	900
CFRP type MbraceC1-30	230	3400	2200	= =

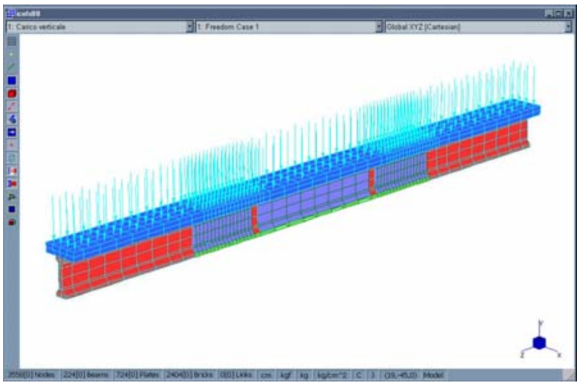
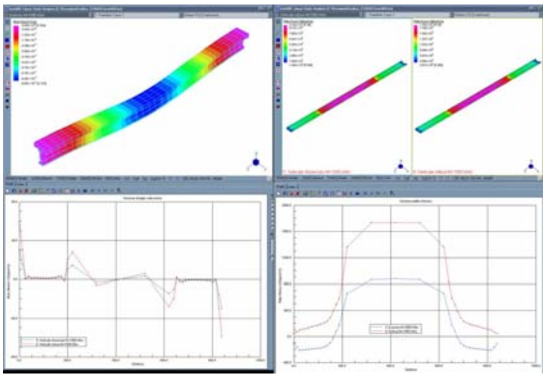
Table: Bending moment due to weight Mpp, at service load Ms and ultimate load Mu

Beam type	Mpp [kN*m]	Ms [kN*m]	Mu [kN*m]
Comapre	775	1450	2175
ICEFS	335	1000	1500

Lateral beam reinforcement operations and FEM numerical simulation of the buckling and shear effects on the pressed reinforced concrete and steel bases





Static reinforcement of the beams through reconstruction of the section and following tackling in steel plates type Fe 510 of thickness 8-10 mm., welded in situ and connected to the slab through passing bolts.
The workmanships will be effected in the respect of the following prescriptions:

- Demolition of the portions of beam seriously damaged with hidrojet and/or scalpel.
- The demolition will be effected maintaining the existing steel bars
- Preparation of the surfaces of contact between different aged concrete.
- Put in work of additional steel bars and connection by steel hooks (type Feb44k).
- Reconstruction of the section with reoplastic fiber reinforced concreter Rck > 50 MPas.
- Preparation by sanding of the surfaces to be strengthened by smoothing the edges and by injection of micro-cracks.
- Superficial restoration by trimming of tixotropic mortar of the sections not reconstructed.
- Perforations of the steel plates and of the concrete beams to realize the bolt connections
- cleaning by sanding of the plates (either surfaces), to eliminate the corroded film and to clean to Svenk A3 grade (white metal);
- Positioning of the plates, preventively outdistanced opportunely by around 3 mm by the concrete surfaces;
- Execution of the weldings of connection of the plates realized in situ, (full penetration welding);
- Realization of puttyng to contain epoxidic resin and to seal the perimeter of plates, action to guarantee the perfect estate of the inside pressures of injection;
- Contextual positioning along the whole perimeter, to non superior footstep to cm 40 of the tubes injectors: (the tubes must have prepared in such way to guarantee the uniform diffusion of the resin and the total stoppage of all the voids)
- Injection, through specific unity of pumping with regulation of the pressure, of fluid epoxidic resin; At the end of injection, the unity of pumping must maintain once the inside pressure of the injection to guarantee the compensation of the losses of stoppage owed to the penetration of the concrete into cracked zones.
- Final painting cycles of the plates.

Test inspection

DESIGN MATERIALS:

REOPLASTIC CONCRETE RcK > 50 MPa
STEEL BARS FOR CONCRETE Fe B 44K
REOPLASTIC PREMIXED MORTAR TYPE "A" FOR THICKNESS TILL 2 cm
REOPLASTIC PREMIXED MORTAR TYPE "B" FOR THICKNESS TILL 5 cm
STEEL FOR STRUCTURE Fe 510 C
EPOXIDIC RESIN (TO FIX CONNECTORS)
ABUTMENT STONE 30 mm
CHIMICAL INSERTS TO CONNECT THE SLAB:
TYPE SM20*170mm
TYPE SM16*125mm

RESIN CHARACTERISTICS FOR BETON-PLAQUE':

CONCRETE ADHESION 3.5 MPa
STEEL SHARE ADHESION >=15 MPa
TRACTION STRENGHT >=50 MPa
COMPRESSION STRENGHT >=100 MPa
ELASTIC COMPRESSION MODULE 3000 MPa

FIBRES CFRP CHARACTERISTICS :

FIBRE TYPE C1-30
ftk 3500 MPa
fd 1750 MPa
S= 0.165 mm

6. LIFTING DECKS

An entire chapter is dedicated to raising decks in order to indicate possible solutions dealing with this frequent problem.
The heads of the deck are raised by applying force between the top of the pier and the deck's structure in order to separate them. This is the main technique used in maintenance work requiring work on the entire structure.
The operation subsumes very different characteristics and methodologies, according to the objectives sought and the type of deck involved. Consequently, the book not only lists the techniques to be followed but also provides a schema to approach the problem and offers a methodology to choose and design the most appropriate solution while simultaneously resolving the problems associated with it.

7. CHARACTERISTICS OF MATERIALS USED FOR THE MEASURES

Here the book sets out to provide assistance to the persons concerned with these questions by describing products recently introduced onto the market that offer greater design freedom and longer service life to structures.
The overview is intended to be a technical and operational aid. However, as concerns the details on materials, including theoretical questions, readers are referred to specialist publications.

8. RECOMMENDATIONS FOR NEW CONSTRUCTIONS

In the past, the designer's viewpoint referred exclusively to the structural compliance with safety controls. However, the fact of continual growth in the operating costs of structures over their service life as also the growth in construction costs, have obliged all designers and other specialists to take account of various aspects for prolonging service life at the design stage.
From the end of the 1970s, the findings drawn from operating and investigation experience on structures were incorporated into the design process.
It is not by chance, therefore, that the Italian Regulations of 2/8/80 refer for the first time to designs and checks concerning non-structural accessory parts, such as joints, water-proofing, and stormwater drainage systems, that were found to be authentic "weak points" of bridges.
Consequently, design solutions should not be considered wholly in terms of structural terms or the intrinsic durability of constituent materials but also in terms of compliance with constraints and requirements that in the long time have a practical and economic impact.
The checks conducted over time on the operating condition of bridges reveal, in some situations, a number of critical aspects of the design solutions adopted.
The elements to be evaluated have thus been grouped into the following categories:

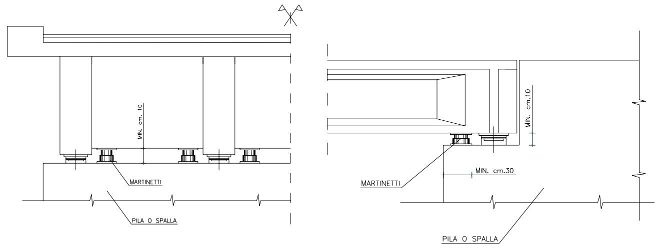
- the durability of the material;
- structural type;
- the size of the elements;
- accessory parts;
- construction details;
- reduction in accidental damage during operation.

In addition, expedients have been analysed that:

- facilitate surveillance activities;
- facilitate maintenance operations;
- guarantee the safety of both the user and staff.

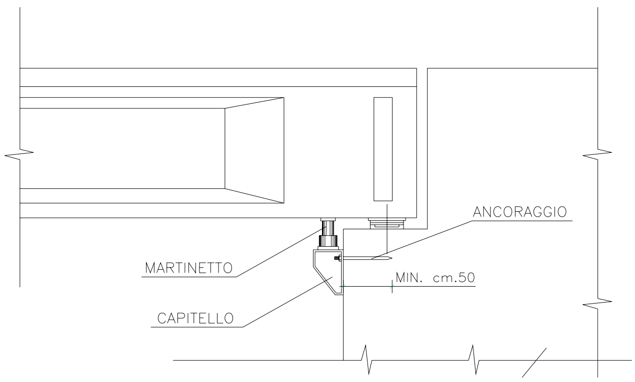
Naturally, this will help to reduce maintenance costs and, possibly, enable greater resources to be earmarked to maintenance.

Principal methods of bridge uplifting



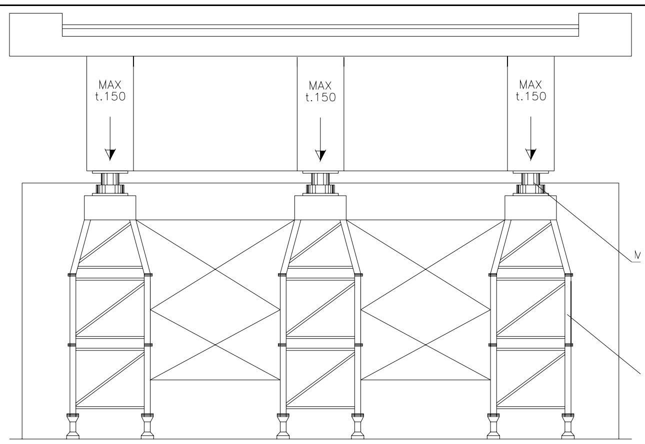
A) Uplifting by using jackets between abutment and beams

Hydraulic jackets



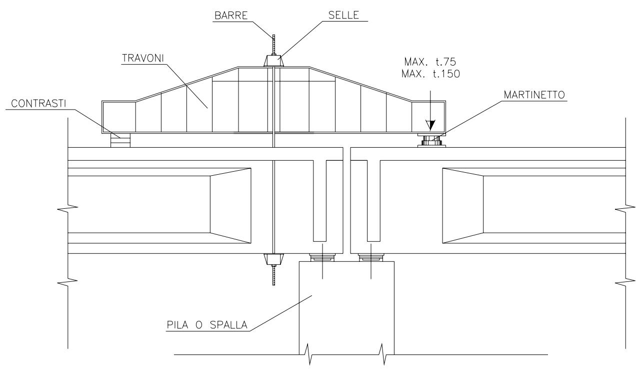
B) Uplifting from the lower part by using steel or concrete brackets to support jackets between abutment and beams

Hydraulic racket between steel bracket and concrete beam



C) Uplifting from the lower part by using lattice steel columns

Injured structures shored by lattice steel columns



D) Uplifting from the upper part by using steel beams

Lifting a concrete “gerber” span