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Rehabilitation and Repair of Structures Using Composite Systems

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Summary

This paper presents a general and conceptual overview of the increasing importance of the rehabilitation and repair of existing structures that has been necessitated by growing demands and requirements of use. It calls attention to the positive features that both the direct application and derivations of composite construction can contribute to these types of activities. Finally, several unique cases of bridge modifications, such as the enlargement of platforms and the removal or translation of piers to increase low clearances, are introduced in order to help clarify the previous statements.

1. General overview

The incredible wealth that contemporary societies have in existing and utilized infrastructures and buildings, inherited from both historic and recent activity, is being subjected to degradation and aging with the passage of time, as well as to the loss of efficiency and safety against the growing demands of all types of activities: loadings, repetitive cycles, dynamic effects, etc., higher, in almost all cases, than the values considered during the design and construction of the work. This can be attested by the successive changes in codes and rules, even in the most recent periods.

The transformation of construction has been a systematic fact throughout history and there are many well-known cases in which a work was demolished in order to reuse its materials in the construction of a new, but conceptually different structure. At times this process was extreme, as can be seen in religious examples; but there are also cases in which the change was made for show or functionality or simply for urban renewal, prompted by the desires of a new invader, monarch or owner.

Today, this re-use of materials is non-existent. Our present construction materials, once dismantled, are of practically no value. Even to the point that a significant cost of transport to and storage at a rubbish dump must be taken into careful consideration in any demolition. And this comes before the negative ecological effect of this dumping is even considered, a problem which is gradually increasing and, will eventually make it necessary to find appropriate treatment methods for reducing its negative influence on the society.

For these and other reasons which will be introduced throughout this presentation, the best way to get the most out of this inheritance is to reuse the structural systems -not the materials- and to confer upon them new possibilities of resistance and improved durability and functionality that will adjust them to today's conditions and actively incorporate them in the process, thus avoiding the problems associated with demolition.

Rehabilitation conditions can be very wide and assorted, and therefore, although in general the total cost of the modification of a work tends to be cheaper, in many cases it can be equal to or even higher than the cost of the demolition and replacement of an older structure.

A number of factors such as the historic or artistic value of a building or bridge, its beauty or unique characteristics of its site; the reduction of nuisances that the preservation of the work would mean for the local residents and users (demolition; transport; noise; etc.); or even deeper, possibly ethical factors, which are of increasing importance due to the growing awareness of the intrinsic value of all the possible actions, can be determinants in the decision to choose an integral rehabilitation over the replacement of the work.

Furthermore, in the field of refurbishment or upgrading, higher costs, due to the greater construction periods and labor that this solution produces, can be a positive component for its selection in societies with high levels of unemployment, as it requires more manpower while reducing the basic energy costs of new materials.

In another sense, recently, new qualities and possibilities of a number of materials, techniques, equipment and processes of all types, which allow for a substantial improvement in the control, treatment and processing of methods used to facilitate and favor rehabilitation have appeared or been notably improved upon, independent of the similar advancements that new constructions techniques also provide.

This entire range:
- New and/or better materials to inject, replace or incorporate into existing structures.
- Improved knowledge of the true conditions of a work through precise control and detection equipment.
- Great precision and control of auxiliary systems, including monitoring that allows for the development of reliable processes in complex cases.
- Powerful equipment for all types of operations and processes:

significantly increases the potential of rehabilitation as a viable means of improving rather than replacing existing structures.

All of this, together with the previously mentioned, increasing social sensitivity to these methods, can lead to the conclusion that present conditions favor the development of this type of construction and that it is likely to become an important source of activity in many countries; especially when there is an historic component, that is, an important legacy to preserve in buildings and bridges.

From another side, apart from refurbishment or upgrading activities, other unexpected situations such as: earthquakes, impacts, and internal construction defects, can require the repairing or strengthening of structures or members. These activities must be done independent of economic criteria and, in general, in short terms and with guaranteed results.

The following presentation of the different topics or aspects that are a part of the modification of structures clarifies, in very broad terms, the importance of correct activity in this problematic field. For the most part, only an index with brief comments about the different possibilities which can be integrated in the modification of structures, will be shown. However, in the cases in which composite steel and concrete systems are used, some general ideas of the more common processes will be developed and then completed with a more detailed presentation of some unique solutions.

2. General lines of action

In general terms, the different fields that can reasonably be treated within the range of this presentation are:

2.1 Types of processes

The most generally used processes can be defined as the:
- Strengthening of structures and members to increase their: resistant capacity; fatigue resistance; stiffness against static or dynamic loadings; durability; etc.
- Repairing of structures damaged or affected by: impacts; overloading; intrinsic defects; etc.
- Rehabilitation, upgrading and adaptation of historic or even contemporary structures to better prepare them for today's demands such as: increased loading; repetitive forces; aggressive environment; etc.
- Enlargement of bridge platforms to increase their combined functionality and resistant capacity.
- Modification of a structure's supports to increase the clearance and functionality of its lower zones: translation or elimination of bridge piers or building columns; reduction of abutment areas; etc.

2.2 Materials

In lines of resistance, durability and construction, aspects of great importance in the selection of solutions and alternatives, a wide range of possible materials can be relied upon, which includes, but is not limited to:
- High strength concretes and mortars.
- Fluid mortars, without shrinkage or expansion.
- Mortars and other chemical products with high qualities of inalterability, strength, adherence, and fluidity for injection or substitution of cracked or damaged areas.
- High strength structural steels which are easily weldable but don't require special precautions because of their low carbon equivalent.
- Weathering steel with its high quality color and texture.
- Stainless structural steels with a wide variety of textures: glossy, matte, colored.
- Stainless steel re-bars for regions with very restricted covering thicknesses.
- Prestressing bars with a wide variety of qualities and diameters.
- External prestressing steels in single, self-protected strands.
- Advanced, high strength, composite materials: wires, cables, and sheets with unlimited durability and great lightness that balance their elevated price in risky cases, especially in areas which are highly susceptible to corrosion.
- Elastic bearing systems and shock transmission units (STU) for selected damping effects

2.3 Connection methods

Also with large number and variety of conditions which include, but are not limited to:
- Glues and adhesive resins for very strongly bonded connections between: concrete and steel; concrete and composite sheets; steel and composite materials; etc.
- Standard and specialized welds with low heat procedures.
- Very reliable chemical or mechanical bolts.
- Welded or mechanical stud and bolt shear connectors for standard carbon or stainless steels.
- High strength bolts (HST).

General procedures

Regarding the different types of structures and conditions to be considered for each solution, there are many different procedures which can be used, such as:
- Precambering by different methods: mechanical; thermal (pre-heating of the steel strengthening elements to be welded); prestressing (external and internal); etc.
- Preloading by support settlement.
- Load transfer between members by jacks.
- Lifting and transversal sliding for widening and pairing.
- Launching systems by pulling or pushing.

3. Steel and concrete composite systems

The basic goal of composite structures, is to achieve the maximum collaboration between steel and concrete and to exploit the best qualities of both in order to obtain a global system which is superior to the simple addition or juxtaposition of the materials.

The development of composite construction, the types and units for connection and the ways to reach this objective are extremely similar to the basic concepts used for the strengthening, repairing or rehabilitating of existing structures: full-employment of materials from the existing structure, or at least those which are still suitable for use, combined with the minimum quantities of additional materials, in order to achieve the fixed requirements of the final restored structure.

The behavior and all of the resources: formal, geometrical, resistant, links, joints, etc., of composite construction and project rehabilitation and repair clearly coincide and, solutions similar to new, contemporary composite structures, can be obtained directly for the repair and rehabilitation of existing works allowing for changes in the dimensions and arrangement of the materials, but with a nearly identical approach.

In fact, there are many, very well known, typical cases of the direct employment of composite systems for repair and rehabilitation, and to complete this presentation, first, several of these more systematic cases, will be briefly reviewed. Then, some more unique and special cases which open up the field and might stimulate in others ideas for the possible uses of new and favorable shapes in composite systems will follow.

3.1 Strengthening of concrete members by attaching thin steel sheets with resins, not only to their bottom faces but to the upper ones

It is helpful to complete these types of joints with mechanical or chemical bolts at the ends of the sheets to avoid local and progressive peeling due to: slight impacts, vibrations, curvature, end defects, etc.

Typical carbon steel sheets can be replaced by stainless steel ones to increase the durability; or by composites strips of organic materials: carbon fiber; etc. The latter are very easy to use because of their light weight and adaptability, but can cost more per kN of introduced tension.

3.2 Placement of flanges, bars or prestressing tendons in the bottom of the steel members of the structure, with the possibility of eventually combining these with the placement of new or the improvement of existing upper concrete slabs, in order to increase the global capacity.

In general, the joining and anchoring of these elements is relatively simple and the only real difficulty lies in the capacity of the existing shear connections between the tension and compression reinforcement, which can be problematic, or even a reason to discard certain types of solutions.

3.3 Total or partial wrapping of concrete columns or piers in order to create a composite member with greater axial resistance and, more importantly, with a higher shear capacity to improve the performance of these members in seismic areas or in areas were they are susceptible to impacts.

Shear connections by studs or, preferentially, by bonded resins combined with hoop stresses due to the welding or pre-heating shrinkage of the partial elements which wrap the concrete shaft, can be use to obtain the final element or member.

4. Unique systems

4.1 Widening of bridge platforms

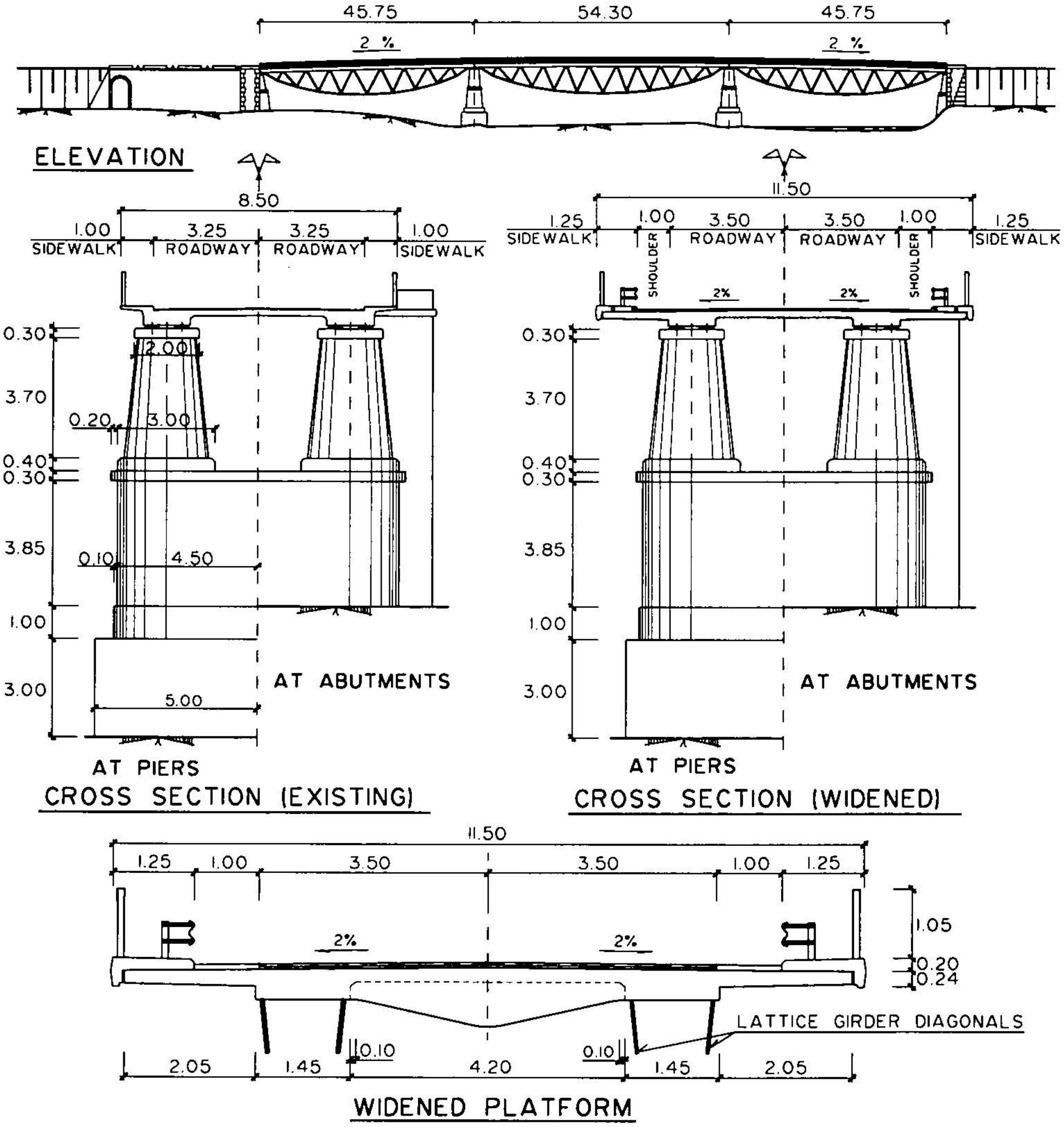
Bridge over Tordera River (Barcelona). 1940. Project by Eduardo Torroja. First composite bridge in Spain.
3 isostatic spans of 46-54-46 m. Twin, steel funicular truss girders with concrete deck.
Original platform width: 8.50 m. Final weight: 11.50 m. Δ_b = 35%

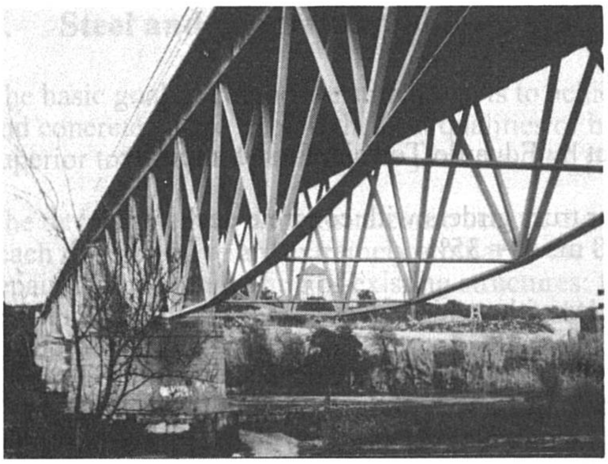
Procedure

- Strengthening of the bottom chord of the truss girder with welded plates.
- Removal by cutting of the existing cantilevers.
- Placement of precast, composite slabs, fastened to the existing concrete deck slab with HSTs.
- Placement of reinforcement, concreting over the precast slabs, and thickening of the central part of the deck.
- Finishing.

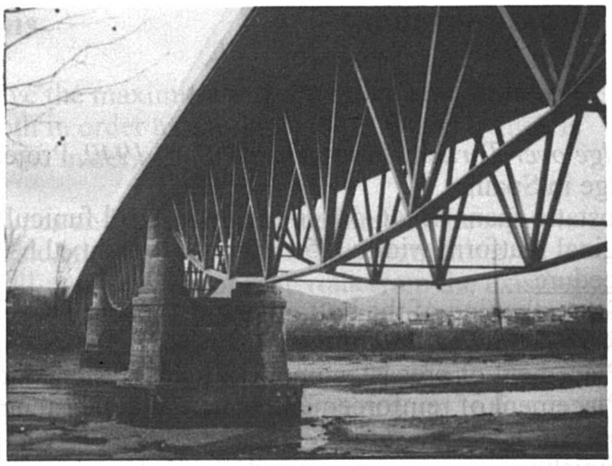
Final structural behavior

Complete, composite collaboration of the older system and the concrete newly incorporated into it.

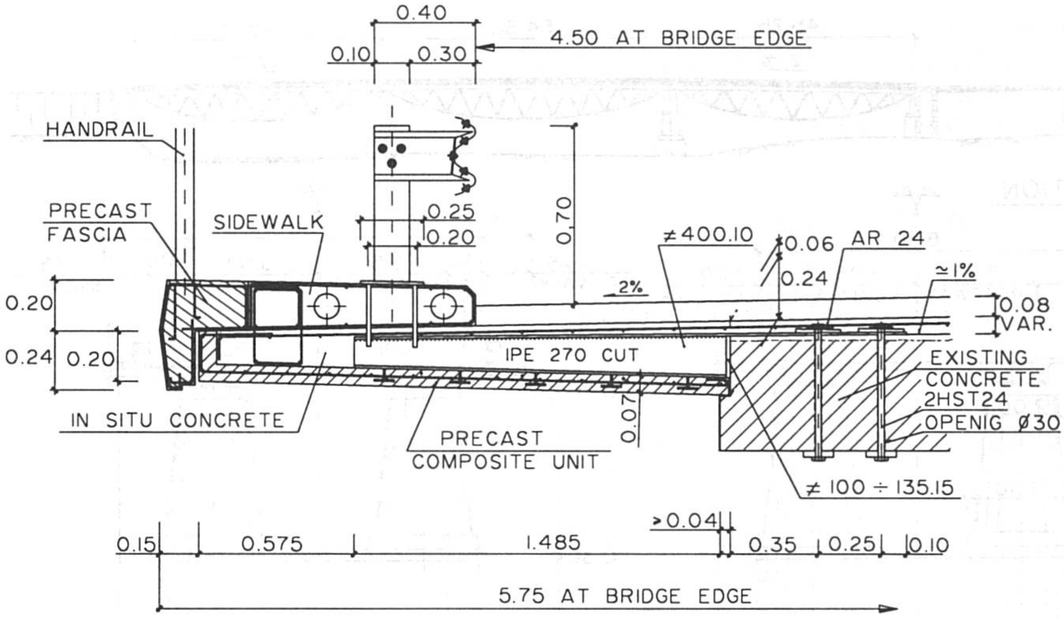




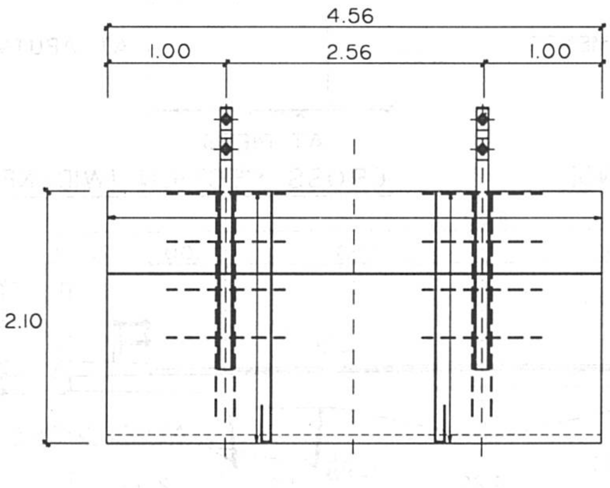
Existing structure



Widened structure



CANTILEVER WIDENING DETAIL



PRECAST COMPOSITE UNIT (PLAN)

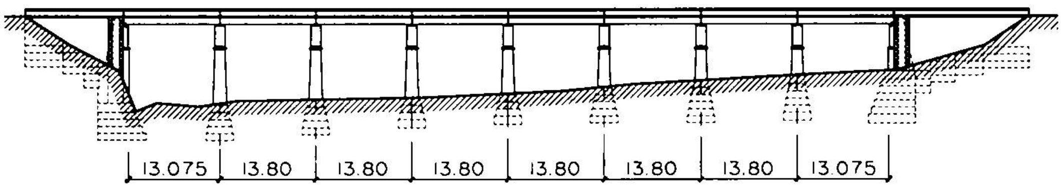
Bridge over Asma River (Tarragona). 1910. Eight single spans of 13.80 m. Reinforced π shape concrete deck platform.
Original platform width: 6.20 m. Final width: 10.50 m. Δ_b = 69.4%

Procedure

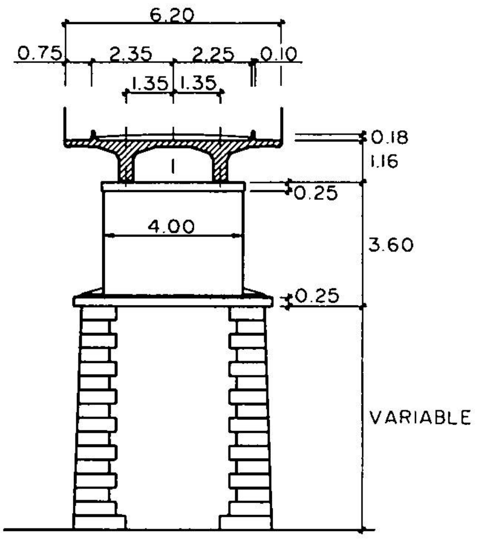
- Removal by cutting of existing cantilevers.
- Placement of weathering steel box girders that are attached with fasteners to the concrete Π member.
- Placement of precast composite slabs anchored to the steel girders.
- Placement of reinforcement, concreting over the precast slabs and thickening of the central part of the deck.
- Finishing.

Final structural behavior

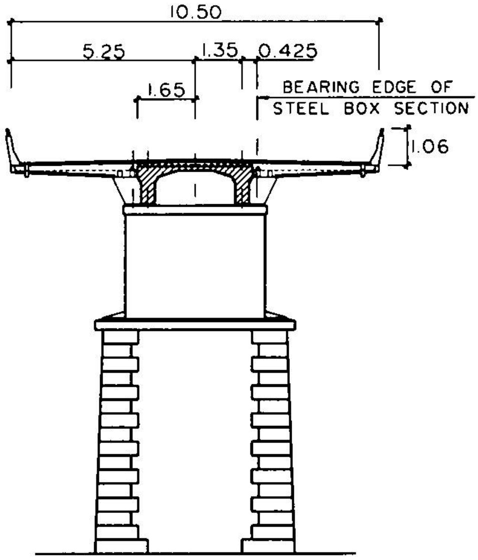
Completely composite structure with collaboration between the new concrete slab; the older π shaped slab, the reinforced concrete beam; and the steel box girders.



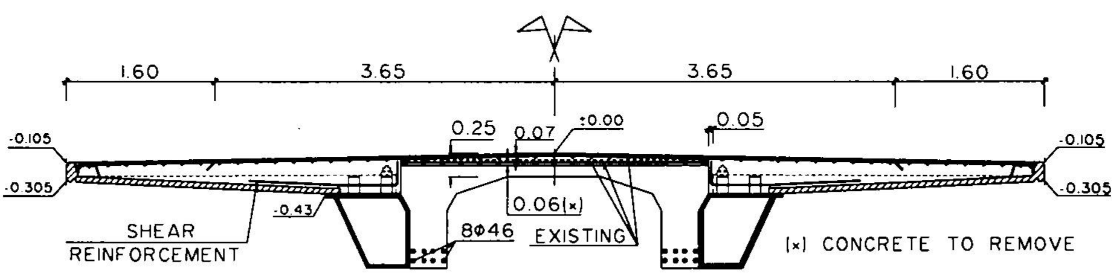
ELEVATION



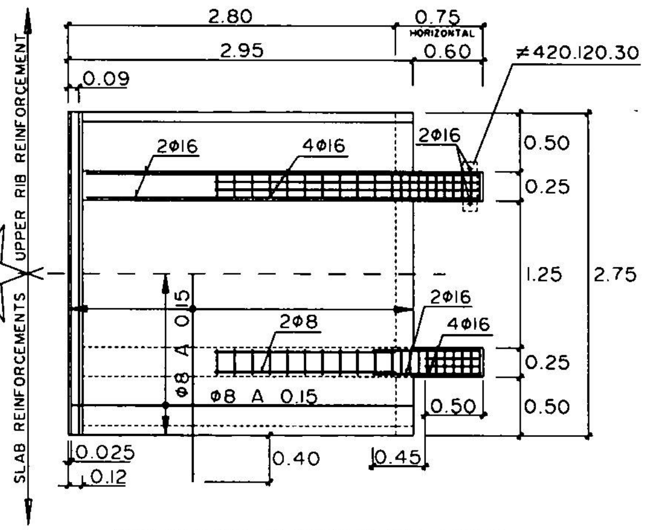
CROSS SECTION (EXISTING)



CROSS SECTION (WIDENED)



TRANSVERSE CROSS SECTION (REINFORCEMENT IN SITU CONCRETE)



PRECAST CONCRETE UNIT

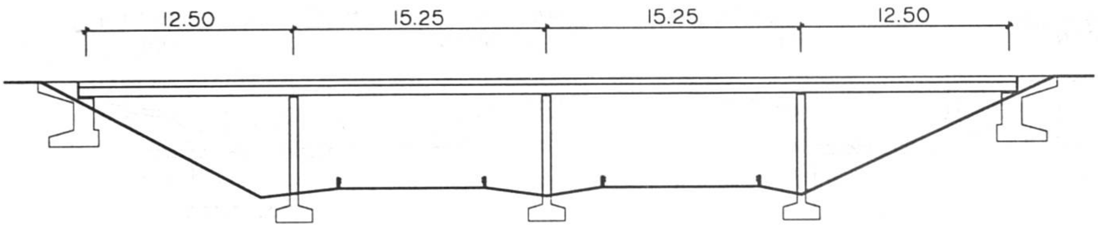
4.2 Amplification of spans of overpasses

14 Overpasses in the A7 Highway Barcelona-France. 1965. Prestressed concrete deck slab with cantilevers, lightened by circular openings.
Original spans: 12.50 - 15.25 - 15-25 - 12.50 m.
Final spans: 8.95 - 18.80 - 18.80 - 8.95 m. ΔL = 23.3%

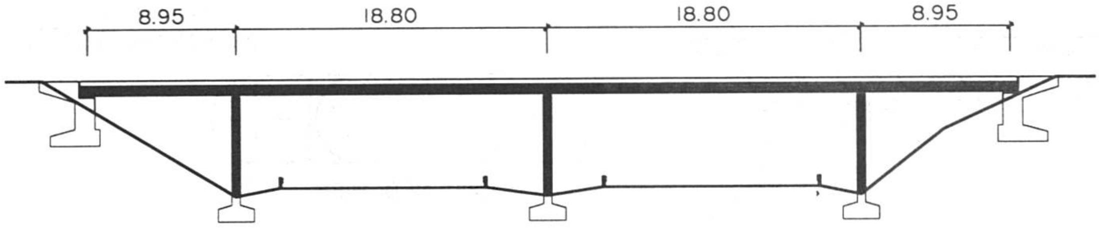
The solution is based on the incorporation of two weathering steel box girders placed parallel to the deck slab under its overhang. Like a stretcher, the system transfers the loads from the existing piers, to new ones.

Originally, several other solutions were analyzed, some with external prestressing, others which included modifications of the abutments, etc., but the cost, period, erection and, especially, the resulting aesthetics, determined the final solution chosen.
<u>Procedure</u>
- Amplification of unaffected piers by connecting hollow steel shafts to them.
- Erection of the new, composite piers, which appear identical to the previously widened, unaffected ones.
- Transverse drilling of the concrete deck slab over the piers to be eliminated, in order to introduce the tying prestressing bars.
- Placement of elastic, neoprene bearings over the new piers and in contact with the bottom of the concrete deck.
- Placement of the steel box girders, first with cranes and then by sliding them over teflon strips.
- Transfer of the loads from the piers to be removed onto the box using groups of hydraulic jacks. The initial position of the concrete deck slab remains unchanged. The precambered steel girders lose their curvature and their bottoms remain parallel and at the level of the deck slab soffit.
- Connection of the steel girders to the deck slab with prestressing bars.
- Removal of jacks.
- Load testing of the bridge.
- Demolition of old piers.

<u>Essential aspects</u>
Neither the traffic on the highway nor on the overpass was disturbed.
<u>Final structural behavior</u>
The concrete deck slab and the steel box girder work together to transfer the loads to the bearings. The elastic bearings at the new piers restrict the hogging bending moments of the concrete slab at these points to the maximum internal capacity of the affected cross sections.

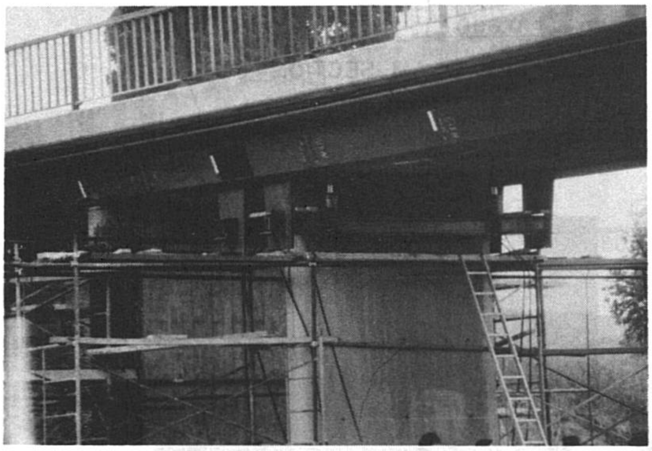


ORIGINAL ELEVATION

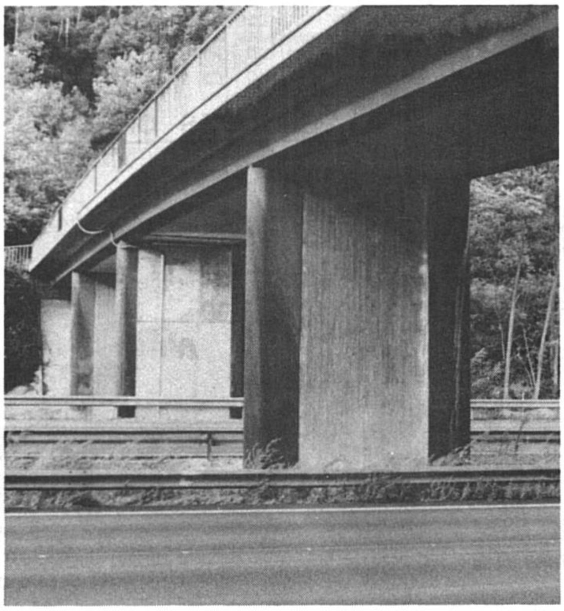


FINAL CLEARANCES

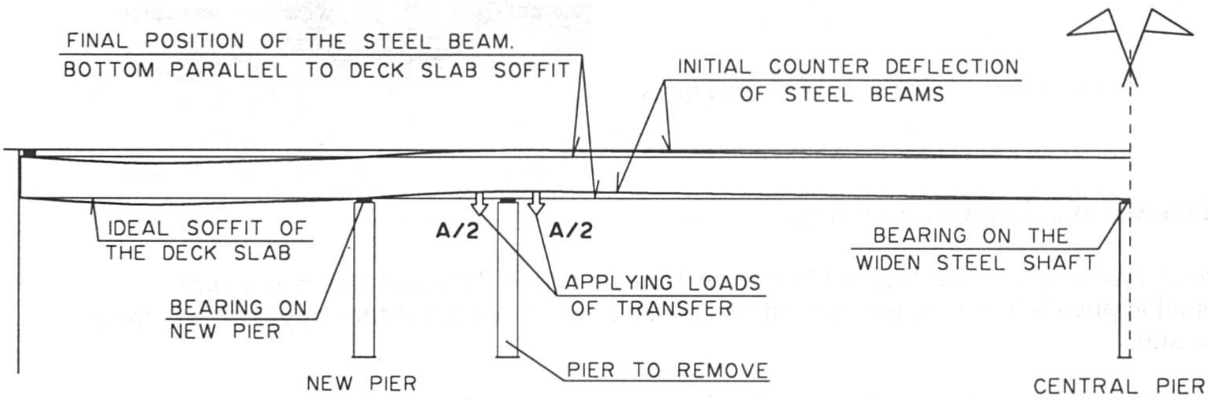
LAYOUT OF TYPICAL OVERPASSES



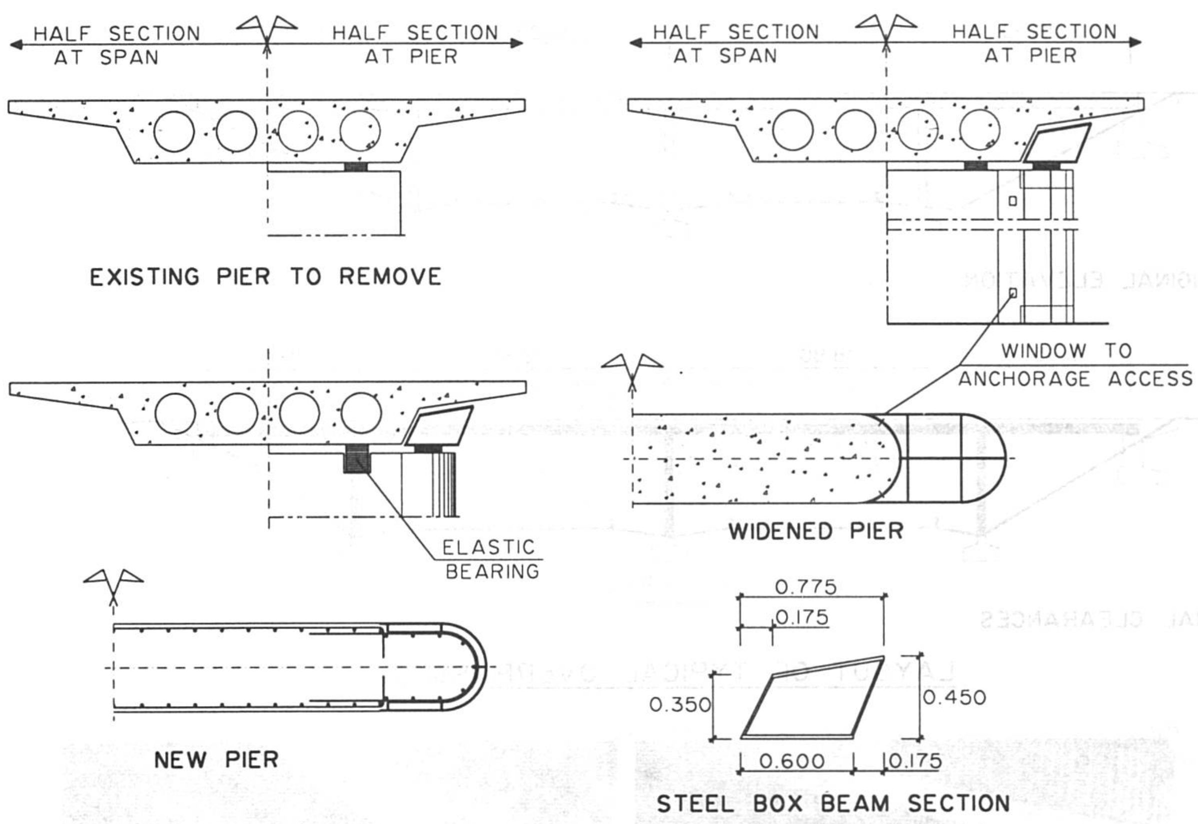
Transfer of loads



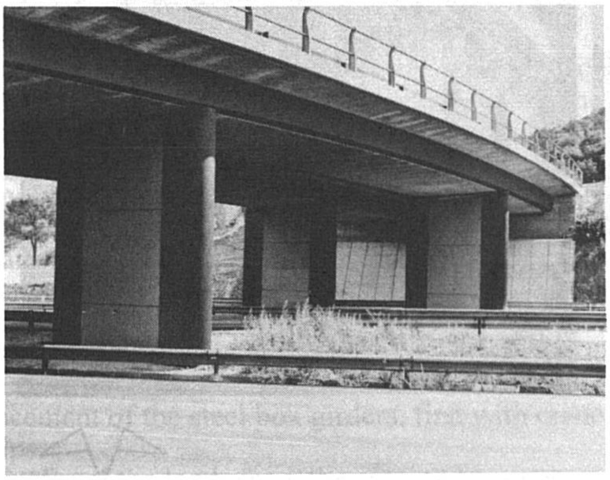
Final structure



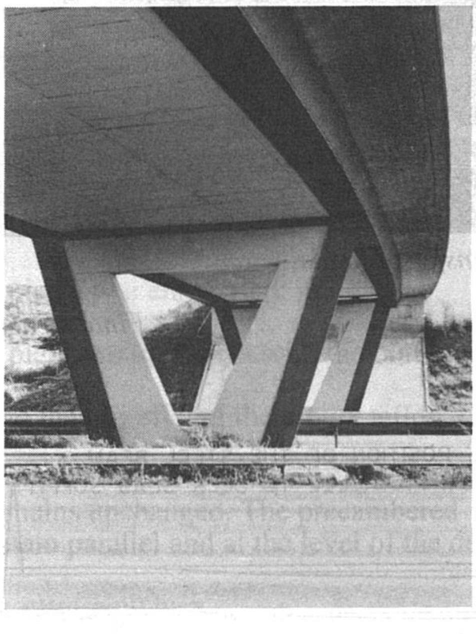
COUNTER DEFLECTIONS AND FINAL PLACEMENT OF THE STEEL BOX BEAMS AFTER THE TRANSFER OF LOADS



FEATURES OF CROSS SECTIONS



Two types of final widened structures



4.3 Removal of columns in buildings

Villanueva Auditorium at the Prado Museum in Madrid, below Paintings Velázquez Hall
Conceptual application of load transfer, similar to the process described for bridges above, for a sensitive site.

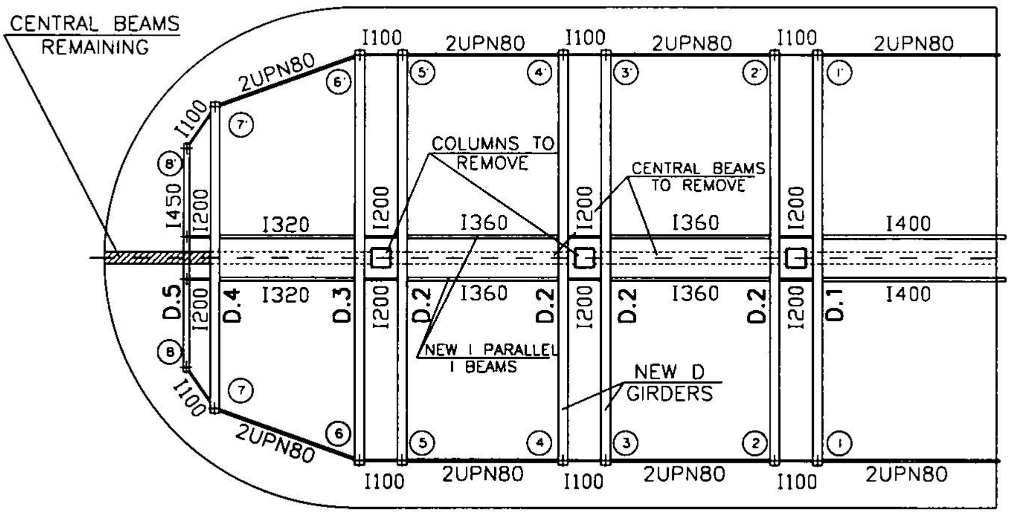
A system of parallel beams was placed under the existing longitudinal beam and adjacent to the columns to be removed, so that once they were eliminated the newly placed beams filled the gap that was left by the original.

Procedure

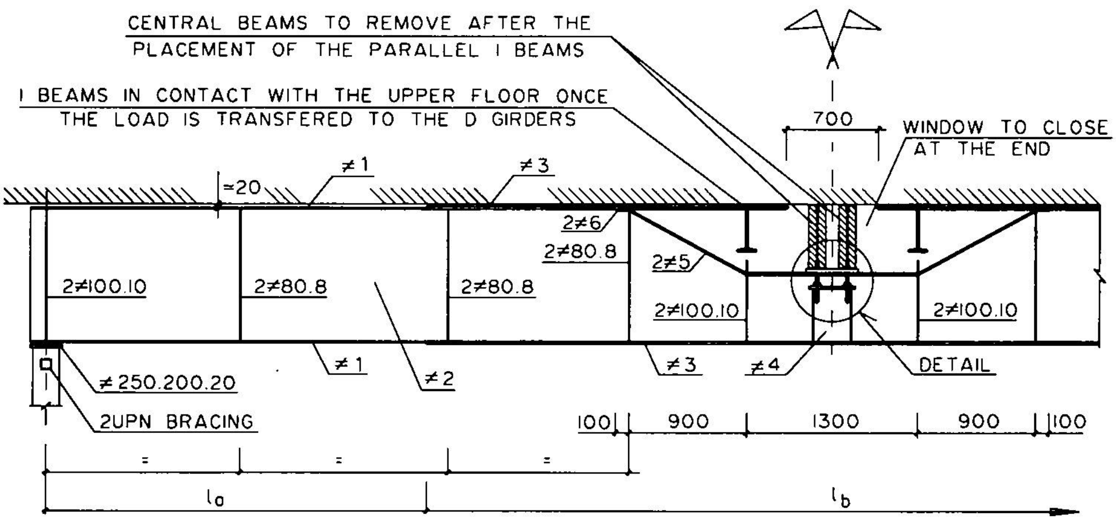
- Placement of pairs of new transverse girders.
- Placement of plates and bolts for transfer.
- Turning of bolts with gradual transfer of the column's loads to the new girders, which are free to deflect, without changing the position of the original structural system.
- Placement and welding of a pair of ancillary beams, parallel to the existing central one.
- Removal of the original central beam.
- Removal of the columns.
- Closing of the central holes in the transverse grids.
- Finishing.

Final structural behavior

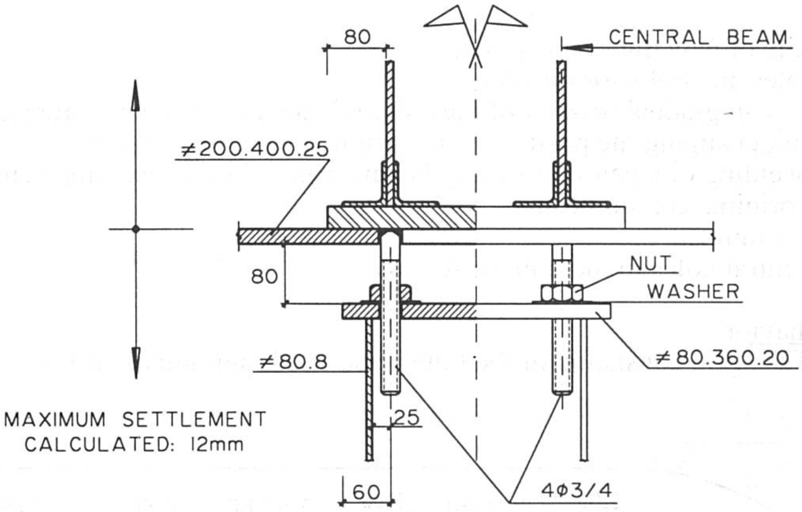
Combined work of the grid consisting of the transverse and longitudinal girders.



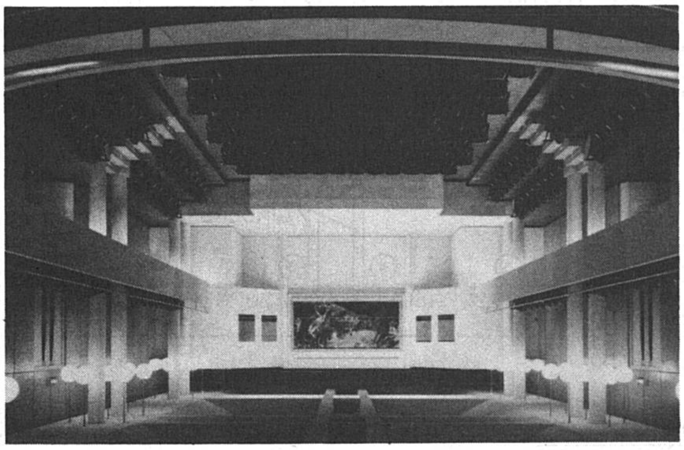
NEW SUPPORTING STRUCTURE OF VILLANUEVA AUDITORIUM



NEW GIRDER D



DETAIL: TRANSFER DEVICE BETWEEN CENTRAL BEAMS AND NEW TRANSVERSAL D GIRDERS



Final Auditorium