

NEW MATERIALS FOR STRUCTURES: PROJECT OF A CONCRETE CABLE-STAYED BRIDGE DRAWN UP WITH RECYCLED CONCRETE

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ABSTRACT

At times, the extension, renovation and/or conservation of certain structures of low initial patrimonial value, is in conflict with their planned functions and the new features required of them. In these cases, questions must be asked about the possibility of them being re-used in a much wider sense, such as using the original materials again, reconverting and transforming the structure, a metamorphosis into a new structure with its patrimonial components, while *conserving* and *maintaining* the genesis of its former functions: supporting load capabilities which allow optimum transit of vehicles and people.

Keywords: Recycled aggregate, recycled concrete, pilot project, bridges.

1. INTRODUCTION

The CV-371 (VV-6117) road provides access from Manises and from Paterna to the V-30, and it is the road link between the two municipalities. The road is 1.8 km long in total, although the section we are dealing with, between the end of the Manises urban area and the beginning of the Paterna urban area, is 0.75 km long.

The width of the road is 5.5m in the section from Manises to the V-30, and an average of 7m in the section from the V-30 to Paterna. Both these widths and the road layout are inadequate for the current demand of traffic, especially in the section between Manises and the V-30, which includes the bridge over the river Turia, with a limited width of 5.3m, which causes problems for buses and trucks travelling over the structure. As well as all this, it must be added that the physical proximity between the towns of Manises and Paterna is not reflected in terms of sociological, commercial and cultural contact, due to the lack of suitable road links.

For all these reasons, it has been deemed necessary to improve the conditions of the CV-371 road in the section between the two towns, with the aim of resolving these problems and improving the security, accessibility, capacity and functions of the main road from Manises to Paterna.

2. ANALYSIS OF THE PROPOSED SOLUTIONS

The bridge by which the CV-371 road crosses the Turia riverbed is a concrete structure of a total length of 145.8m, divided into nine isostatic structures of spans varying between 10.6 and 22.8m, with eight piers of between 2 and 3.6m thick (Figure 1).



Figure 1. Photograph of the present bridge



Figure 2. Extensions to the “pi” section and pre-stressed beams.

The bridge was already renovated and extended in the late '80s (the project for "Extension and completion work of the bridge from Manises to Paterna" was drawn up by the company "Sondeos, Estructuras y Geotecnia, S.A.", in March 1988). As a result of this restructuring, in the first 5 structures (from Paterna), the deck is made up of 70cm deep pre-fabricated, pre-stressed concrete beams and a reinforced concrete slab that is 20cm thick and 7.4m wide. In the remaining 4 structures, the original pi-beams were maintained, and the slab was extended to 7.4m (originally, the deck was 6.2m wide). To withstand this extension, the piers and supports were enlarged (Figure 2).

In despite of these improvements, the bridge has a limited useful width of 5.3m, which causes problems for buses and trucks travelling over the structure. On the other hand, the current structure is massive and has a limited drainage system (it can scarcely drain 1,000m³/s). Furthermore, adapting the road to the width planned for the future boulevard (useful width of 16.5m) involves a considerable increase in the permanent and variable loads for the old structure, directly calling its capacity for supporting weight into question.

A first proposal for solving this new structural problem, not the hydraulic one, involves separating the pavements and bicycle lane from the road, building footbridge lanes at both sides of the current bridge. In this way, the full deck of the existing structure is left for motor vehicle traffic. So that this solution does not worsen the situation regarding flows of water in the Turia riverbed, no support element should be situated in the riverbed, so that the main system of the new elements should be built on top of the current deck, with arches or cable-stayed bridge, thus resulting in a clear confrontation of types and eras. This solution does not provide any improvement in the original hydraulics (although does not worsen the drainage capacity of the current bridge either), and presents a high cost, since the new span to be covered by the footbridges is 145.8m.

A second alternative, which is along the lines of the first, is to separate the pavements and bicycle lane from the road just in the first three structures on the Manises side, the part at which the river is at its minimum. The span of this section, about 60m, is covered by a Z-shaped box beam, with a curved floor. In the rest of the bridge, the bicycle lane and the pavements are built onto the deck of the current bridge (although they are independent from it), and they have a support approximately every 25m, coinciding with every second pier of the current bridge. In comparison with the previous solution, this proposal has the advantage of costing less, since the maximum span to cover is about 60m. In addition, it does not cause such a strong aesthetic contrast between the old structure and its extension.

Both alternatives for extending the bridge present different drawbacks, although almost all of these are linked to the characteristics of the existing structure. Another very significant problem is that the piers of the current bridge may be undermined, an inherent risk, because the numerous supports in the riverbed obstruct water flow, and because of the type of foundation. This risk is not eliminated or solved by any of the possible extension solutions, and in some cases it might even be worsened.

Finally, from an aesthetic point of view, the existing structure does not have any value: it is irregular and heterogeneous in its shapes and proportions; it is massive, and is in quite a deteriorated state. Therefore, if the current bridge remains, this aesthetically detracts from any new solution for extension.

3. PROPOSED SOLUTION

For these reasons, the proposal is for a pillared bridge over the river Turia, with two asymmetric structures, with a 55m span on the Paterna side and a 90m span on the Manises side.

In the proposal being presented, the planned deck divides the space in two very different and differentiated areas: above the deck, the cable-stayed system dominates, creating a clear ascending force which ultimately focuses on the powerful beams with variable edges, while underneath the bridge, all the massive shapes of the substructures and the "belly" of the deck can be seen, with its concrete and corten steel coffering. The supports and strong bases of the pillar have wide covered horizontal listels, as well as the impost chamfer, in metal-coated ceramic, a direct tribute to the great ceramics tradition of Manises and Paterna. This space underneath the bridge will acquire even more interest if future environmental and recreational performances are held in the Turia riverbed.

In any case, aesthetic points are not the fundamental arguments of the proposed solution, although it is sensitive to these concerns. The main values of the proposal lie in its hydraulic and functional advantages, along with reasonable costs, since the complexity of building can be considered moderate (especially if the renovation costs of the current structure are taken into account, and the cost of an extension which would require either all the existing foundations to be reinforced, or footbridges of a 145m span to be built).

The improved drainage capacity is the result of reducing hydraulic interferences (since there is only one support in the riverbed) and raising the gradient of the road. The existing road is raised by 2.5m, joining the current level of the road before arriving at the crossroads with the V-30, at the same level as the second roundabout planned for the Paterna-Manises boulevard.

One of the main characteristics of this project is that the old structure is put to use as recycled material, in roads, pavements, ornamental elements, and in the new bridge as structural material. Although all the aforementioned parameters, which justify the solution adopted, in themselves make the new bridge a singular structure, the use

of the old bridge as recycled material in the new one makes this project a singular emblematic milestone in the use of deconstructed old structures. The concepts of sustainable construction, patrimonial conservation and environment factors are particularly important in the project being presented.



Figure 3. Virtual images of the new bridge

4. DEMOLITION AND RECYCLING OF THE CURRENT STRUCTURE

As was mentioned previously, due to the bad state of preservation and the unfavourable hydraulic conditions of the current bridge, we have decided to place a new bridge in the same location, therefore making it necessary to pull down the current one. Within this option, there are two possibilities to be considered: dumping the waste, or recycling it as part of the work of the project. This last option presents a number of advantages. On the one hand, it reduces the impact on the environment and landscape by avoiding the dumping of about 1,600m³ of good-quality material such as the waste concrete. On the other hand, the ecological impact is reduced by making use of raw materials, which with suitable treatment could be recycled.

Although the recycling of demolition waste is not very frequent in Spain, and there are few projects which can provide information, in other European countries its use is more common, in some cases reaching high percentages of recycling. Also, in Spain numerous studies have been carried out by different institutions about its use in various areas of construction, such as land, road or concrete projects. In this aspect we must consider the work being developed by CEDEX in order to standardise the use of construction and demolition waste (CDW) in different areas, which has focused its work on creating a “Guide to the use of recycled dry goods in roads” and a “Standard proposal for the use of recycled aggregates in structural cement”, which includes all recycled dry goods from concrete rubble.

5. PILOT SCHEME IN SPAIN: PROJECT APPLICATION FOR THE BRIDGE OVER THE RIVER TURIA

In this case, the recycling of the concrete structure means that the aggregates obtained will be relatively homogenous. It has been decided that the entire structure will be recycled, using some of the materials for the new structure and the rest for work on the road joining the bridge to Paterna.

The phases of the study have included firstly a *description of the structure's materials*. This description has allowed us, among other factors, to establish the parts of the structure that will be re-used in the concrete of the new bridge.

An analysis has also been carried out of the *type of processing* required for the rubble produced, in order to obtain aggregates of a suitable quality. Finally, a plan has been drawn up for *keeping track of recycled aggregates*, both for the dry goods produced and the concrete to be made from it.

5.1. Description of the Structure's Materials

The starting point for describing the structure's materials has been to collect available information about the old project. The materials that make up each of the parts of the bridge are the following:

Table 1: Planned resistance of the different parts of the current bridge

PART	RESISTANCE	VOLUME
<i>REINFORCED AND EXTENDED SECTION</i>		
Piers	Unknown	300 m ³
PI-Beams of II	Unknown	240 m ³
Extension of the slab	H -25	90 m ³
Slab	Unknown	130 m ³
<i>SUBSTITUTED SECTION</i>		
Pre-stressed beams	H-42.5	50 m ³
Slab and lintels	H-25	100 m ³
Band around piers	H-20	-
Piers	Not known	300 m ³

To gain more knowledge about the materials available, a series of tests has been undertaken consisting of a visual inspection of the materials, which allows us to establish sample areas and different tests; and a combination of non-destructive tests, sclerometer and ultra-sound speed, as well as the extraction of test samples. These tests provide information about the resistance of the concrete in the structure, as well as other additional information, like pathologies it may have.

According to the criteria established by Model Code CEB-FIP (the International Federation for Structural Concrete) for the evaluation of concrete quality in relation to longitudinal ultrasound speed, the concrete of the different parts is of varying quality (Table 2), with good or excellent quality for the beam concrete, excellent quality for the slab concrete, average for the lintel, and poor for the PI-beams of II.

Table 2: Results of the ultrasound speed and sclerometer tests.

PART	Speed (m/s)	Quality	Sclerometer
BEAMS	4033-4719	Good or excellent	45-58
PIER 1	2586,7	Poor	49
PIER 2	3588,2	Average	49
PIER 3	2992,0	Poor	43
PIER 4	2371,6	Poor	32
PIER 5	1575,5	Very poor	37
SLAB	4592,4	Excellent	60
LINTEL PIER 3	3075,0	Average	48
PI-BEAM	2730,2	Poor	43

5.2. Demolition and Waste Processing

The demolition must be selective, separating materials other than concrete, such as railings, etc. Also, the materials that are to be recycled in the new concrete will be stored separately from the rest of the materials, which will be used to extend the road.

As regards processing to obtain the recycled aggregates, it is more suitable to use select them from a mobile recycling plant, situated as near the site as possible in order to avoid transport to a fixed recycling plant.

This mobile plant must include an impact crusher, as this is the type of crusher that produces the best quality aggregates, as well as a system for removing metal materials, mostly from the framework, and an initial sifting process to remove earth accumulated on the piles. It will not be necessary to employ additional systems for removing impurities, as it is a very homogenous material.

With this processing it is possible to obtain recycled aggregates from the concrete rubble that can be used for the work on the new bridge in Manises, both for the bridge itself and the extension of the road that joins the bridge with Paterna.

5.3. Conditions of Use

The conditions of use for the recycled aggregates and concrete have been established according to the studies carried out in CEDEX's Central Laboratory of Structures and Materials, which, as was mentioned above, has proposed the regulations for using recycled aggregate in structural concrete. The general criteria established are

as follows:

- Recycled aggregate produced in this way will be used as a substitute for part of the coarse natural aggregate, in a proportion of no more than 20%. Mixed aggregate used in this way must comply with the specifications established by the EHE for natural aggregates⁷
- Quality of the original concrete f_{cm} must be higher than 25 N/mm²;
- Maximum resistance of recycled concrete $f_{cm} < 50$ N/mm²;
- Specific studies in environments other than I and IIb.

The parts of the old bridge that are to be used in the new one are selected on the basis of these criteria. According to the information in Table 1, with the data that is known at present, the parts that could be used in the concrete, having a resistance that is higher than 25 N/mm² would be the beams, slab and lintels in the substituted section. In the reinforced section, the concrete from the extension of the slab could be used, although it has been disregarded due to the complexity of separating it during demolition.

In Table 3, the types of concrete that are required for the different parts of the new bridge have been included, as well as the volume of concrete and the approximate volume of aggregate that would be needed to substitute 20% of the coarse natural aggregate for recycled aggregate. If we initially disregard the concretes in environment IIa, the selection will be focused on the shaded parts of Table 3. Due to the experimental nature of the project, it has been decided that the best quality parts are to be chosen for recycling, that is, the pre-stressed beams (with an approximate volume of 50 m³), using the recycled aggregate produced from them for the slab of one of the structures, which will be about 90 m long.

The rest of the material, both that from the substituted section of the bridge and the reinforced section, will be used in the section of the road leading up to the bridge, which will be approximately 750 m long. This will mean that all the waste from the demolition of the bridge is recycled.

Table 3: Types and volume of concrete of the different parts of the planned bridge

PARTS	RESISTANCE	VOLUME	
		Concrete	Recycled aggregate
Leveling concrete	HM-15/P/20/II a	240 m ³	8.7 m ³
Foundation concrete	HA-25/B/20/II a	2,400 m ³	240 m ³
Concrete screens	HA-25/F/20/II a	2,640 m ³	264 m ³
Concrete for supports	HA-30/B/20/II b	240 m ³	24 m ³
Concrete for braces	HA-35/B/12/II b	580 m ³	58 m ³
Concrete for impost	HA-30/B/12/II b	43 m ³	4 m ³
Concrete for slab	HA-35/B/12/II b	Structure 1-400 m ³	40 m ³
		Structure 2-900 m ³	90 m ³

These tables include each of the parts, their resistance and the corresponding volume of concrete. In the case of the concrete for the new bridge, the volume of recycled aggregate required has also been included, accepting an average measurement and with 20% of the coarse natural aggregate substituted for recycled aggregate.

As regards the parts to be recycled in the manufacture of concrete, only the parts of the substituted section have been included.

If we initially disregard the concretes in environment II a and the original concretes with a resistance of less than 25 Nmm², highlighted in orange, the selection will be focused on these parts, highlighted in blue. Due to the experimental nature of the project, it has been decided that the best quality parts are to be chosen for recycling, that is, the pre-stressed beams, using the recycled aggregate produced from them for the slab of one of the sections, which will be about 80 m long.

5.4. Testing the Recycled Materials

A detailed test will be carried out of the recycled materials, both the aggregates and the concrete.

The following properties are going to be studied: the physical and chemical properties established by the EHE for natural aggregates and also specific properties that are characteristic of these aggregates, such as the content of adhered mortar, the content of recycled sand or the content of total chlorides. The aggregates produced must comply with the specifications established on the basis of studies carried out in Cedex's Central Laboratory of Structures and Materials, which appear in the paper presented at this congress "Evaluation of the properties of recycled aggregate".

As regards the test on recycled concrete, dosage studies will be carried out in the laboratory and the properties will be tested for both fresh and hardened concrete.

6. CONCLUSIONS

A comparative study has been carried out in order to justify the advisability of substituting the bridge over which the CV-371 (VV-6117) road crosses the river Turia between Paterna and Manises, for another structure with a greater drainage capacity.

In view of the above, renovating the existing beam structure does not improve the bridge's drainage conditions and it is a costly and complicated process. As was shown in the introduction of this article, reusing the concrete in the construction of the new bridge will conserve the heritage of the existing structure. The use of its constituent materials in the new structure safeguards the real value of the old bridge.

Due to the innovative nature of using recycled aggregates in concrete, especially in the type of structure that is planned, the recycling will be carried out by substituting a maximum of 20% of the coarse natural aggregate for coarse recycled aggregate in the HA-35 concrete used for the slab of the new bridge.

This project is a milestone in the area of recycling waste from building and demolition, both in our country and on an international level, because of the type of bridge that is planned. This will undoubtedly contribute to a greater knowledge of these materials and promote their use.

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