New repair system for slab front with stainless steel

1. INTRODUCTION

When we face the repair of a concrete element affected by corrosion of its reinforcements, it is important to know the degree of affection, in terms of the area to be repaired and in terms of the intensity of the repair.

In the reality of a structure of reinforced concrete affected, we find that the damage is practically never homogeneous, but varies in scope and intensity within a single element of concrete, and among some elements and others of similar characteristics. [Figures 1, 2, 3]

For this reason, the uncertainty of the scope of action and the intensity of each repair have to be assumed in a project prescribing an intervention protocol on how to act, when on site we find a situation or another.

The parameters of this "protocol" are related to the degree of oxidation, the loss of resistant section of the steel, the existing concrete cover, the contamination of chlorides in the concrete, etc..., so finally the scope of the condition and the intensity in each element are decided on site, and as the Facultative Management cannot have an uninterrupted presence, a large part of them is at the mercy of the interpretation criterion of the operator.

The field of intervention in concrete structures affected by corrosion of reinforcements is relatively young, and it is in these last 10 or 15 years, when we began to have sufficiently extensive data on the durability of the traditional repair systems of break up, clean up, protect and rebuild, which have been used with greater or lesser accuracy.

Before the studies of the different associations of concrete repairers, which warn of a high percentage of failure in this type of works, we understand that it is time to consider whether the traditional repair system provides sufficient guarantees of durability required by today's society in high-risk exposures.

In this article, an alternative repair system to the traditional one is analysed with the use of duplex stainless steel rebars, from the point of view of the execution risks and the economic cost.

2. ANALYSIS AND APPROACH

In recent years, the steel industry, specifically stainless steel, has evolved considerably, especially taking into account that it is relatively young in construction with only about one hundred years of life.

The properties of stainless steels against corrosion represent an obvious advantage for use in the repair of concrete, but the higher cost of the material has always been an unbeatable limitation in this type of work, and in most of the cases not even option to the property.

Even at the risk of summarizing too much, this high cost has always been marked by the fluctuation of the nickel price as a fundamental component of the existing austenitic stainless steel types.

In this sense, the development of Duplex stainless steel types (low nickel content) makes available to technicians a material economically worthy to be considered in the field of concrete repair.

To proceed to the analysis and comparison of both repair solutions, the traditional and with the use of stainless steel rebar, it is necessary to go briefly through the aspects of repair actions of a reinforced concrete element affected by corrosion, so that we can minimally quantify or at least limit, the deviation that one implies with respect to another.

In the traditional repair system, we find the following execution processes:

a) Break up concrete until the discovery of the affected reinforcement.

b) Removal of oxidation residues.

c) Reconstruction of the initial situation.

Breakdown of costs
REPAIR OF SLAB FRONT (case study)

m Repair type of concrete slab front with 30 cm edge, without increased capacity

Ud.	Concepto	rend	Precio	Importe
h	1st Official labour	0,32	19,33	6,19
h	Specialized labourer	0,30	17,14	5,14
h	Breaker pneumatic hammer	0,18	2,59	0,47
h	Electric radial	0,16	1,20	0,19
ud	Sanding disk	1,05	2,45	2,57
kg	Anti-corrosion protection	0,38	6,84	2,60
l	Concrete mortar joint bridge	0,12	18,45	2,21
kg	Amount ref. galvanized steel rebar	0,00	1,20	0,00
kg	Amount ref. duplex stainless steel rebar 2304	0,00	3,20	0,00
kg	Repair mortar according to UNE 1504	27,34	1,05	28,71
%	Complementary direct costs	2,00	48,08	0,96
%	Indirect costs	3,00	48,08	1,44
%	General expenses	13,00	50,48	6,56
%	Industrial profit	6,00	50,48	3,03
		TOTAL		60,07

(*) Due to the volatility in the costs of the different elements that are part of the alloys of stainless steels, the price used for the calculation in this table of decomposed rates, corresponds to a reference price of deliveries in November 2018, so it must be updated at all times for the supply on the necessary delivery date for each Project

Tabla 1: *Decomposed price table of repair of slab front type with traditional method [own documentation]*

Figure 1: *Fissures on the lower face of the slab front*

Figure 2: *Fissures on the lower face of the slab front*

Figure 3: *Detail of concrete spalling*

If we study these phases in detail, we can analyse the aspects or concepts subject to economic quantification.

If for example we analysed the steps to follow for the repair of a slab front, we would find something similar to this:

- Break up the concrete material that is affected by deterioration, cracking and/or disintegrating it, until reaching the affected reinforcement.

- Once the reinforcement bar is localized, we must provide full access to it in its entire outline for evaluation, and if necessary sanitation.

- In case the reinforcement has not lost its resistant capacity beyond what is allowable, the traditional repair systems consist of eliminating the oxidation to the degree of cleaning Sa ½ (according to ISO 8005-4) [5]. It should be noted that this degree of cleaning is only achieved by abrasive blasting.

- Despite the previous cleaning requirement, the usual practice is to sand down with sanding disc or steel tips disk. This cleaning must be complete around the perimeter of the bar, so it is necessary that sufficient concrete has been removed to be able to handle with guarantee the inside face of the bar.

- Once the bar is cleaned, during the same working day, protection should be carried out with an adequate anticorrosion paint according to the existing exposure and the required durability. At this point it is very important to respect the manufacturer's recommendations regarding the mixture, layers, yields, waiting time between layers, etc...

- If the protection of the bar does not have the capacity of connecting bridge between the steel and the repair mortar to be placed, we must use a joint bridge between steel and mortar.

- The same situation we find for the connecting bridge between the existing concrete and the repair mortar, with the singularity that this must be specific for the concrete element that is being repaired, making clear the consideration of structural element or not.

- Once all those processes have been overcome, the reconstruction of volume is done with repair mortar according to UNE 1504, respecting the recommendations of the manufacturer regarding the dosage and application modes.

From this moment, once sufficient resistance is reached, we can proceed to the removal of possible security elements, such as shoring, bracing, etc...

As we can see, throughout this process of traditional repair of a concrete element, we find numerous jobs that intervene in the repair which are difficult to control.

Breakdown of costs

REPAIR OF SLAB FRONT (with duplex stainless steel rebar)

m Repair type of concrete slab front of 30 cm edge, without increased capacity, with replacement of rebars by other of stainless steel Duplex 2304 (ACX915)

Ud.	Concepto	rend	Precio	Importe
h	1st Official labour	0,28	19,33	5,41
h	Specialized labourer	0,26	17,14	4,46
h	Breaker pneumatic hammer	0,16	2,59	0,41
h	Electric radial	0,05	1,20	0,06
ud	Sanding disk	0,20	2,45	0,49
kg	Anti-corrosion protection	0,10	6,84	0,68
l	Concrete mortar joint bridge	0,12	18,45	2,21
kg	Amount ref. galvanized steel rebar	0,00	1,20	0,00
kg	Amount ref. duplex stainless steel rebar 2304	3,80	3,20	12,16
kg	Repair mortar according to UNE 1504	23,85	1,05	25,04
%	Complementary direct costs	2,00	50,93	1,02
%	Indirect costs	3,00	50,93	1,53
%	General expenses	13,00	53,48	6,95
%	Industrial profit	6,00	53,48	3,21
		TOTAL		63,64

Due to the volatility in the costs of the different elements that are part of the alloys of stainless steels, the price used for the calculation in this table of decomposed rates, corresponds to a reference price of deliveries in November 2018, so it must be updated at all times for the supply on the necessary delivery date for each Project.

Tabla 2: *Decomposed price table of repair of slab front type with replacement by stainless steel bars [own documentation]*

Despite the difficulty of monitoring on site, the set of these jobs can be quantified economically through the system of decomposed concepts that is, to list all the materials involved, labour, machinery, tools and other aspects necessary for its correct execution.

Once all these concepts have been quantified, we apply the following costs:

- Complementary direct costs

- Indirect costs

- General expenses

- Industrial profit

- VAT

These concepts are not specific to repair works, so we will not go into their detailed explanation, considering they are concepts assimilated by any Facultative Management.

Through this quantification process we can get to detail what the step-by-step repair consists of, and by sum of the parts, the unit price of the complete item, at least from a comparative point of view: [Table 1]

The total repair price of slab front by traditional method is € 60.07/m.

It should be noted that the risk of errors in the execution of this solution is high, being the most common the following:

- Insufficient break up of concrete that surrounds the bar, hampering the correct cleaning of oxidation of the bar, and in some cases leaving contaminated with chlorides

Figure 4: *Slab front affected boy oxidation*

Figure 5: *State of the reinforcements after coating removal*

concrete in the proximity of the repaired bar.

- Not enough cleaning and the application of the anticorrosive protection on traces of oxidation.

- Inadequate planning of the jobs, leaving too long time between the cleaning and protection.

Following this approach, we can evaluate what would be the cost instead of repairing with the traditional solution described, assuming the discussed risks of execution, we proceed to the replacement of the damaged bar affected by corrosion, with stainless steel duplex repair type of slab front according to the following breakdown [Table 2]:

The total repair price of slab front by replacement with stainless steel rebar is € 63.64/m.

Comparing both values, the use of stainless steel in repair supposes an increased cost of 5.94% with respect to the traditional repair.

While these prices may be individually debatable, as they depend on the uniqueness of the work, its geographical location, stability of the market, etc..., it is not so much the deviation in % when we compare one same type of repair with or without stainless steel rebars, so that we understand that the proposed increases are quite adequate to reality.

Despite this, it should be noted that these data have been contrasted in tests done on site and in the workshop, finding a correlation with an approximate error of ±8% of the mentioned increase, so that in the worst case we could find some increases that oscillate until 6.41% (5.94% x 1.08).

3. CASE STUDY

From professional practice, we have had the opportunity to apply the concrete repair process in a building, by replacement with stainless steel rebars.

The building object of the repair is located on the beachfront and it is about 35 years old. Concrete elements exposed to marine environment presented high chloride ion content, with values around 2% in content of cement.

The existence of numerous damages as cracks and concrete spalling have made necessary the complete intervention in slabs fronts.

Started-up the execution of the work, we proceeded to the removal of the concrete cover located on the front of the floor to visualize and study the real state of the concrete.

Given the original conditions of execution of the building, in addition to the exposure to the marine environment, it is added as a generalized additional factor, the lack of concrete cover in most areas with visible damage, being barely 1 cm.

Because of this fact, we found many areas with unacceptable section loss in the reinforcement bar, which required a repair approach by replacing the necessary affected bars in the most affected areas. [Figures 4, 5, 6]

In the cases in which we found reinforcement with very little concrete cover that had to be partially replaced, and in elements where we could not modify the volumetry to achieve more cover, we found that the most appropriate solution was the use of stainless steel rebars due to the following advantages:

- We can reduce section of the bar to reach the same resistance that we would have with carbon steel bar. [Figure 7]

Figura 6: *Oxidation remains in concrete*

- We can reduce cover of concrete since we do not need its contribution as corrosion protection of the stainless steel rebar.

- We eliminate practically all the inherent risks in the execution processes, precisely in the most difficult parts to be repaired. [Figures 8]

In collaboration with the construction company, with a strong track record in repairing concrete structures affected by corrosion of reinforcement, we have been able to verify that the economic hypotheses raised from a theoretical point of view, are very close to the reality of the work, since although the stainless steel material is initially more expensive, the reduction of processes on site, the non-obligation of waiting times of the products of anticorrosion protection, the reduction of concrete cover that is necessary to break up and then rebuild, and the simplification of the jobs as a whole, notably affect in the labour yields, reducing the deviation to more than reasonable figures, necessary for the durability that is achieved.

Figure 7: *Placing of stainless steel reinforcement*

Figure 8: *Retaking and regeneration of volume after placement of stainless steel rebar*

MATERIAL:
Stainless steel rebar
Manufactured and supplied by Roldan, S.A.

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