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Environmental Aggression and Corrosion of Reinforcements. A Real Case.

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ABSTRACT : *In the current economic climate, where cuts in investment in public works make construction site stoppages commonplace, the maintenance and conservation of those structural elements which are kept outside must be a priority for construction companies. Passive reinforcements constitute one of the elements most affected by the passing of time and exposure to weather conditions, and may risk losing their mechanical and physical characteristics. In this article the authors analyse the state of the physical and mechanical properties of the passive reinforcements AEH-500 on a construction site, which have been exposed to the weather conditions for four years. The construction site analysed is a motorway, located 2 km from the coastline.The results prove that the average sectional loss is below 4.5% and that the adhesion values satisfy the limitations of EHE-08. Moreover, as laid out under this same rule, carrying out structural checks on piles and abutments where losses have been detected is essential in order to confirm their structural safety.*

Keywords: *reinforcement corrosion, loss of section in reinforcements, adhesion, outdoors works, marine environment*

I. INTRODUCTION

Activity in the construction sector has been reduced to a minimum due to the continuing problems on the financial markets and the uncertainty of the economies in both Europe and Spain. These problems inevitably condition the short- and medium-term recovery of the construction sector.According to the most recent statistics published by the Ministry of Public Works, during December 2011, 6,224 major building permits were granted, 50.10% less than in December 2010 (1)In this climate of economic instability,site stoppages have become commonplace. In this situation the structural elements already in place on site remain outdoors for as long as the work is stopped, meaning that the maintenance, conservation and performance of these elements must be taken into consideration. In a marine environment, chloride is present both in the seawater and in the atmosphere. This chloride penetrates the pores and fissures in concrete, and when sufficient quantities reach the reinforcements it produces localised breakages in the protective coat of the steel [2].This phenomenon is known as corrosion [3].
Corrosion usually occurs when there is a reaction between the acidic substances in the atmosphere (carbon dioxide, sulphur dioxide, etc.) and the alkaline elements in the cement, which causes such a significant reduction in the pH levels (from about 13 to almost 7) that the protective coat on the steel dissolves [4]causing a general corrosion of the reinforcement. The consequences of this corrosion can be seen on three levels: a) on the steel, with a reduction in mechanical capacity brought about by a decrease in section; b) on the concrete, as the products corroding the steel are bulkier than the original elements, creating tension which can crack the material,c) on the steel-concrete adhesion, precisely because of the expanding nature of the corrosion products [3].This research was carried out on a site which was stopped in 2010, and where work was resumed after two years in September 2012. The objective is the analysis of the results collected during the experimental phase of tests carried out on the protruding rebars and the structural evaluation of the different piles and abutments, taking into account loss of resistance or adhesion caused by a decrease in section.

Photo 1: Corroded reinforcements.

II. MATERIALS AND METHODS

A detailed study of the conservation of structural reinforcementson the construction site was carried out. The site is located in the south of Granada province, Spain, 2 kilometres from the coast in a coastal Mediterranean climate, making it subject to the aggressiveness of a marine environment.

The affected structural elements are mainly:

- In the viaducts, the protruding rebars of the piling with a diameter of 2000 mm, given that the pile caps had not been executed, and the pile startingswhich foundation footings had not been stripped.
- In the overpasses, the lintel and shaft reinforcements.

Between 28th and 31st August 2012, a series of corrugated bars were extracted from the following locations:

- Viaduct III
- Viaduct II
- Viaduct I
- Overpass Intersection I
- Overpass Intersection III
- Underpass Wings

The location and tracking scheme in each structure is laid out in APPENDIX 1 – TESTS CARRIED OUT ON EACH STRUCTURAL ELEMENT.

Each case deals with:

- Steel quality type 500-SD.
- The diameter measurements on thin [10], medium [12, 16, 20] and largebars.

2.1 Sample

A total of 60 thin, medium and large-diameter corrugated bars were used, from different manufacturers. Identification and brands of the bars were:

- ACECOR: 17 units. Diametres: 32, 25, 16 and 12 mm.
- ACEROS BALBOA: 7 units. Diametres: 25 and 20 mm.
- CELSAMAX 500 SD: 11 units. Diametres: 20 and 16 mm.
- DUCTICELSA: 3 units. Diametres: 32 mm.
- EURA: 2 units. Diametres: 32 and 25 mm.
- NERVACERO: 2 units. Diametres: 32 and 20 mm.
- NERVADUCTIL: 6 units. Diametres: 32 and 20 mm.

48 of the 60 bars were identified, in other words, 20% of the samples taken were unidentifiable.

2.2 Number of tests

The number of tests was set out by batch. Batch means the same structure, the same element within the structure (pile cap, foundation footing, abutment, wing), the same bar diameter and the same date of execution (see Table 1).

The number of tests on bars of each type was:

- For the tests used to determine mass, 1% of the bars in a batch were tested, with a minimum of two tests per batch, and always on the oldest elements.
- For the traction tests, two tests were carried out per batch.
- The adhesion tests were carried out on two bars for each diameter, and always on the oldest bars, or those bars first used on site, with the aim of assuring maximum corrosion. This test was carried out on eight bars.

						Nº. of Tests		
Structure	Element	Nº. Elements	Nº. Bars	Diametre	Total Bars	Geometry	Traction	Adhesion
Overpass IntersectionIII	Piles	5	52	25	260	3	2	
	Abutments	2	38	12	76	2	2	
Underpass	Wings	4	0	0	0			
Overpass IntersectionI	Abutments	4	77	12	308	3	2	
Viaduct III	Foundation footing P-3	2	200	16, 20	400	2+2	1+1	2+2
	Foundation footing P-2	2	200	16, 25	400	2+2	1+1	
	Pilings E-2	5	75	25	375	4	2	
	Pilings P-1	7	45	20	315	3	2	
	Pilings E-1	5	70	25	350	4	2	
Viaduct II	Foundation footing P-2 Left.	1	200	20, 25	200	1+1	1+1	2+2
	Foundation footing P-2 Right	1	200	16, 20	200	1+1	1+1	
	Pilings E-2	5	75	25	375	4	2	
	Pilings P-1	7	45	20	315	3	2	
	Pilings E-1	5	70	25	350	4	2	
Viaduct I	Foundation footing P-2	2	200	16	400	4	2	
	Foundation footing P-4	2	200	16, 20 y 25	400	1+1+2	2	
	Pilings E-2	5	70	25	350	4	2	
	Pilings P-1	7	45	20	315	3	2	
	Pilings P-3	7	45	20	315	3	2	
	Pilings E-1	5	70	25	350	4	2	
				Total	6054	64	38	8

Table 1. Number of Tests

2.3 Types of test

The tests carried out to determine the characteristics of the adhesion of the steel are those laid out in Article 32.2 of EHE-08., with an additional mechanical characterization.

- Geometric tests on the corrugation and on the determination of mass and the area of the transverse cross section to determine the realdiameter.
- Mechanical tests, traction tests to determine the stress-strain curves of the bars.
- Adhesion tests using Pull-out. For this test a specimen of the concrete with the features to be used on site and the planned coatings must be taken.
  To enable tests to be carried out on the samples taken they were cleaned as follows:
- On bars with significant incrustations: an electrical steel wire brush was used to eliminate the largest adhesions, followed by careful removal of further adhesions using a manual steel wire brush.
- On bars with few incrustations: Manual steel wire brush.

III. RESULTS

Following the geometric tests outlined above the following table has been drawn up to show the loss of resistant area in each structure.

Structure	Average loss (%)	Maximum loss (%)
Viaduct I	2.47	4.40
ViaductII	2.57	4.32
ViaductIII	3.20	4.39
Overpass IntersectionI	3.23	3.80
Overpass IntersectionIII	3.08	3.98

Table 2. Section loss

As seen in the table above, for all structures, the maximum loss of resistant area is similar and always below 4.5%, whilst average loss falls between 2.5 and 3.2 %.

As laid out in Article 32 of the EHE 08 “Steel for passive reinforcements”, the equivalent section will not fall below 95.5% of the nominal section, if the equivalent section is:

$$S_e = \frac{W}{7.85 * L}$$

where:

S_e = equivalent section (cm^2), to three significant figures.
W = Weight of the specimen (grams).
7,85 = specific mass of steel (kg/dm^3) or (g/cm^3)
L = length of specimen (cm), given that $L \geq 50$ cm.

According to the results in Table 2, loss of area never exceeds 4.5%, therefore section loss caused by corrosion of reinforcements is admissible.

However, weight loss does exceed the minimum 1%, so, according to Title 7 “Execution” Article 69 “Construction, reinforcing and assembly processes for passive reinforcements” and Title 8 “Control” Article 88 “Control of passive reinforcements” of the EHE-08, a numeric justification which proves compliance of the sections of piles and abutments, under calculations of Project force, and with section losses found during the tests, is necessary.

Given that loss obtained through corrosion is similar in all structures, a constant loss is considered at 4.5%. Coefficients of safety for each element and structure have been compared with the reinforced section where no loss is incurred. This brought to light the fact that in all cases, the coefficient of determination was above a unit, so no additional reinforcement is required.

Using the results from the adhesion tests the following table has been drawn up:

Results of adhesion tests and minimum prescriptions from EHE-08 (art. 32.2):

Bar	τbm, test	τbm, EHE-08	τbu, test(MPa)	τbu, EHE-08

	(MPa)	(MPa)		(MPa)
Φ25	8.91	4.84	14.92	7.99
Φ20	9.28	5.44	15.41	8.94
Φ16	10.73	5.92	16.33	9.70

Table 3. Adhesion results

Furthermore, the geometry of the corrugated bars tested meets the values indicated in their corresponding Certificates of Approval of Adhesion.

Thus, relating to the level of aptitude of both the adherent and mechanical properties (shown through the traction test) of the corrugated steel bars laid out in article 32.2 of the EHE-08:

- 100% of bars tested conform to the minimum mechanical characteristics prescribed by table EHE 32.2.a.
- 100% of bars tested and identified by brand name conform to geometric characteristics (mass per linear metre, transverse cross section, roundness and characterization of corrugations) when the experimental results obtained are compared to the values stipulated by the reference standards and in the Certificates of Approval of Adhesion for each brand.
- For bars tested but not identified, 100% conform to the parameters of mass per linear metre, transverse cross section and roundness, compared to the values stated in the reference standards.
- 100% of the bars tested using the BEAM-TEST meet the reference values stated in article 32.2 of the EHE-08.

Regarding security tests against breakage in the starting sections, bearing in mind losses of section of passive reinforcements caused by corrosion, and considering the loss of bars used in the laboratory tests, in all cases the coefficient of determination was always superior to a unit, so no additional reinforcement was required.

IV. CONCLUSIONS

In this case study the maritime Mediterranean climate did not significantly affect the protruding rebars. The tests brought to light the following:
The average resistant section losses to corrosion are around 3%, the maximum losses are below 4.5%.
As for adhesion, the results of the tests show "τbm" and "τbu" values far above those prescribed by Article 32.2 of the EHE-08, and furthermore the geometry of the corrosion falls within the values stated in the corresponding adhesion homologation certificates. As stated in EHE-08 Articel 32 "Steel for passive reinforcements", the equivalent section must not fall below 95.5% of the nominal section. However Articles 69 and 88 of the EHE-08 advise against the use of passive reinforcements which have suffered a weight loss due to corrosion of over 1%. Structural tests are therefore essential on piles and abutments where losses have been detected to confirm structural safety. These safety tests have been satisfactory in every case.

V. ACKNOWLEDGEMENTS

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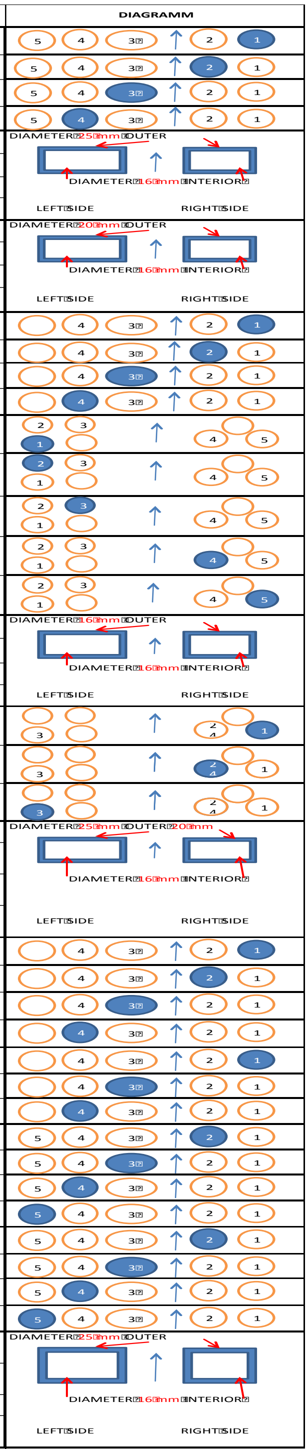
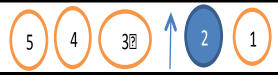
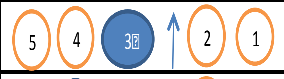
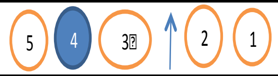
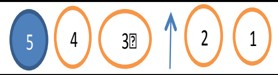
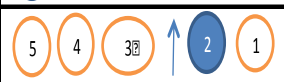
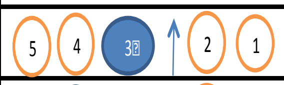
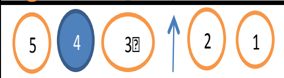
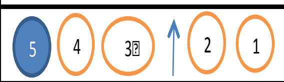
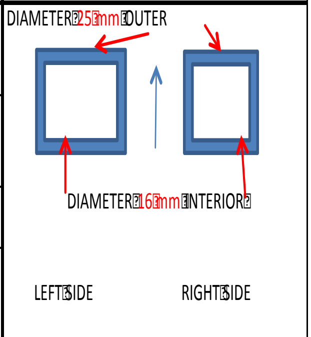
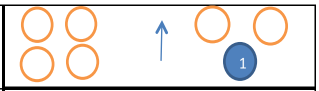
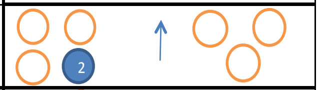
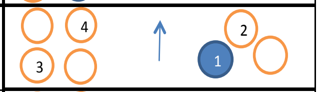
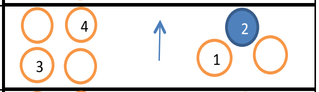
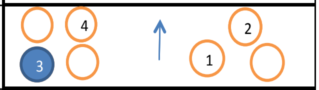
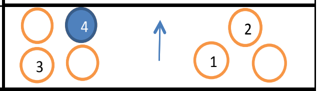
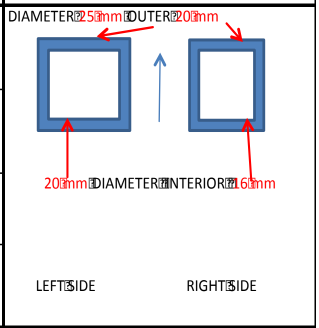
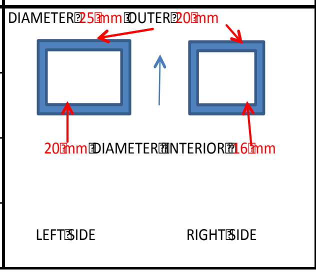
APPENDIX 1 – TESTS CARRIED OUT ON EACH STRUCTURAL ELEMENT.

DATE COLLECTED	Nº GLB	Ø	STRUCTURAL ELEMENT	SIDE	LENGTH (m)	GEOMETRIC CHARACTERISTICS	MECHANICAL CHARACTERISTICS	PULL-OUT	DIAGRAMM
28/08/12	5170	32	PONTES II PILING 1 ABUTMENT 2	RIGTH	1,25	×			
28/08/12	5171	32	PONTES II PILING 2 ABUTMENT 2	RIGTH	1,20	×	×		
28/08/12	5172	32	PONTES II PILING 3 ABUTMENT 2	LEFT	1,25	×			
28/08/12	5173	32	PONTES II PILING 4 ABUTMENT 2	LEFT	1,20	×	×		
28/08/12	5174	16	PONTES II PILE 3	RIGTH	1,20	×			
28/08/12	5175	25	PONTES II PILE 3	RIGTH	1,20	×	×		
28/08/12	5176	16	PONTES II PILE 3	LEFT	1,20	×	×		
28/08/12	5177	25	PONTES II PILE 3	LEFT	1,20	×			
28/08/12	5178	20	PONTES II PILE 2	RIGTH	1,20	×	×		
28/08/12	5179	16	PONTES II PILE 2	RIGTH	1,20	×			
28/08/12	5180	20	PONTES II PILE 2	LEFT	1,20	×			
28/08/12	5181	16	PONTES II PILE 2	LEFT	1,20	×	×		
29/08/12	5182	32	VIADUCTO PROVINCIAS ABUTMENT 1	RIGTH	0,95	×	×		
29/08/12	5183	32	VIADUCTO PROVINCIAS ABUTMENT 1	RIGTH	0,80	×			
29/08/12	5184	32	VIADUCTO PROVINCIAS ABUTMENT 1	LEFT	1,05	×	×		
29/08/12	5185	32	VIADUCTO PROVINCIAS ABUTMENT 1	LEFT	0,96	×			
29/08/1012	5186	20	VIADUCTO PROVINCIAS PILE 1	LEFT	0,80	×			
29/08/1012	5187	20	VIADUCTO PROVINCIAS PILE 1	LEFT	0,75		×		
29/08/1012	5188	20	VIADUCTO PROVINCIAS PILE 1	LEFT	0,63	×			
29/08/1012	5189	20	VIADUCTO PROVINCIAS PILE 1	RIGTH	0,82	×			
29/08/1012	5190	20	VIADUCTO PROVINCIAS PILE 1	RIGTH	0,62		×		
29/08/1012	5191	16	VIADUCTO PROVINCIAS PILE 2	LEFT	1,15	×	×		
29/08/1012	5192	16	VIADUCTO PROVINCIAS PILE 2	LEFT	1,15	×			
29/08/1012	5193	16	VIADUCTO PROVINCIAS PILE 2	RIGTH	1,15	×	×		
29/08/1012	5194	16	VIADUCTO PROVINCIAS PILA 2	RIGTH	1,15	×			
29/08/1012	5195	20	VIADUCTO PROVINCIAS PILE 3	RIGTH	0,65	×	×		
29/08/1012	5196	20	VIADUCTO PROVINCIAS PILE 3	RIGTH	0,60	×			
29/08/1012	5197	20	VIADUCTO PROVINCIAS PILE 3	LEFT	0,62	×	×		
29/08/1012	5198	25	VIADUCTO PROVINCIAS PILE 4	LEFT (OUTER DIAMETER)	1,20	×			
29/08/1012	5199	16	VIADUCTO PROVINCIAS PILE 4	LEFT (INTERIOR DIAMETER)	0,83	×	×		
29/08/1012	5200	20	VIADUCTO PROVINCIAS PILE 4	RIGTH (OUTER DIAMETER)	1,20	×	×		
29/08/1012	5201	16	VIADUCTO PROVINCIAS PILE 4	RIGTH (INTERIOR DIAMETER)	0,93	×			
29/08/1012	5202	32	VIADUCTO PROVINCIAS ABUTMENT 2	RIGTH	1,20	×			
29/08/1012	5203	32	VIADUCTO PROVINCIAS ABUTMENT 2	RIGTH	1,26	×	×		
29/08/1012	5204	32	VIADUCTO PROVINCIAS ABUTMENT 2	LEFT	1,30	×			
29/08/1012	5205	32	VIADUCTO PROVINCIAS ABUTMENT 2	LEFT	1,20	×	×		
30/08/1012	5206	32	VIADUCTO PONTES I ABUTMENT 1	RIGTH	0,84	×	×		
30/08/1012	5207	32	VIADUCTO PONTES I ABUTMENT 1	LEFT	0,90	×			
30/08/1012	5208	32	VIADUCTO PONTES I ABUTMENT 1	LEFT	0,80	×	×		
30/08/1012	5209	32	VIADUCTO PONTES I ABUTMENT 2	RIGTH	1,20	×	×		
30/08/1012	5210	32	VIADUCTO PONTES I ABUTMENT 2	LEFT	1,20	×	×		
30/08/1012	5211	32	VIADUCTO PONTES I ABUTMENT 2	LEFT	1,20	×			
30/08/1012	5212	32	VIADUCTO PONTES I ABUTMENT 2	LEFT	1,20	×			
30/08/1012	5213	32	VIADUCTO PONTES II ABUTMENT 1	RIGTH	1,20	×	×		
30/08/1012	5214	32	VIADUCTO PONTES II ABUTMENT 1	LEFT	1,20	×			
30/08/1012	5215	32	VIADUCTO PONTES II ABUTMENT 1	LEFT	1,20	×	×		
30/08/1012	5216	32	VIADUCTO PONTES II ABUTMENT 1	LEFT	1,20	×			
30/08/1012	5217	25	VIADUCTO PONTES II PILE 3	RIGTH (OUTER DIAMETER)	1,50			×	
30/08/1012	5218	16	VIADUCTO PONTES II PILE 3	RIGTH (INTERIOR DIAMETER)	1,20			×	
30/08/1012	5219	25	VIADUCTO PONTES II PILE 3	LEFT (OUTER DIAMETER)	1,50			×	
30/08/1012	5220	16	VIADUCTO PONTES II PILE 3	LEFT (INTERIOR DIAMETER)	1,30			×	
31/08/1012	5221	10	ENLACE MOTRIL ABUTMENT 1 OVERPASS	LEFT	1,36	×			
31/08/1012	5222	12	ENLACE MOTRIL ABUTMENT 1 OVERPASS	RIGTH	0,90		×		
31/08/1012	5223	10	ENLACE MOTRIL ABUTMENT 2 OVERPASS	RIGTH	1,36	×	×		
31/08/1012	5224	12	ENLACE MOTRIL ABUTMENT 2 OVERPASS	LEFT	0,90	×			
31/08/1012	5225	10	VIADUCTO N-340 ABUTMENT 1	LEFT	1,20	×			
31/08/1012	5226	12	VIADUCTO N-340 ABUTMENT 1	RIGTH	1,20		×		
31/08/1012	5227	25	VIADUCTO N-340 PILES	BY ABUTMENT 1	1,90	×			
31/08/1012	5228	25	VIADUCTO N-340 PILES	PILE	1,50	×			
31/08/1012	5229	25	VIADUCTO N-340 PILES	PILE	1,60		×		
31/08/1012	5230	25	VIADUCTO N-340 PILES	PILE	1,40		×		
31/08/1012	5231	20	VIADUCTO N-340 PILES	BY ABUTMENT 2	1,40	×			
31/08/1012	5232	12	VIADUCTO N-340 ABUTMENT 2	LEFT	1,22	×			
31/08/1012	5233	10	VIADUCTO N-340 ABUTMENT 2	RIGTH	1,20		×		



30/08/1012	5209	32	VIADUCTO PONTES ABUTMENT 2	RIGTH	1,20	X	X		
30/08/1012	5210	32	VIADUCTO PONTES ABUTMENT 2	LEFT	1,20	X	X		
30/08/1012	5211	32	VIADUCTO PONTES ABUTMENT 2	LEFT	1,20	X			
30/08/1012	5212	32	VIADUCTO PONTES ABUTMENT 2	LEFT	1,20	X			
30/08/1012	5213	32	VIADUCTO PONTES I ABUTMENT 1	RIGTH	1,20	X	X		
30/08/1012	5214	32	VIADUCTO PONTES I ABUTMENT 1	LEFT	1,20	X			
30/08/1012	5215	32	VIADUCTO PONTES I ABUTMENT 1	LEFT	1,20	X	X		
30/08/1012	5216	32	VIADUCTO PONTES I ABUTMENT 1	LEFT	1,20	X			
30/08/1012	5217	25	VIADUCTO PONTES I PILE 3	RIGTH (OUTER DIAMETER)	1,50			X	
30/08/1012	5218	16	VIADUCTO PONTES I PILE 3	RIGTH (INTERIOR DIAMETER)	1,20			X	
30/08/1012	5219	25	VIADUCTO PONTES I PILE 3	LEFT (OUTER DIAMETER)	1,50			X	
30/08/1012	5220	16	VIADUCTO PONTES I PILE 3	LEFT (INTERIOR DIAMETER)	1,30			X	
31/08/1012	5221	10	ENLACE MOTRIL ABUTMENT 1 OVERPASS	LEFT	1,36	X			
31/08/1012	5222	12	ENLACE MOTRIL ABUTMENT 1 OVERPASS	RIGTH	0,90		X		
31/08/1012	5223	10	ENLACE MOTRIL ABUTMENT 2 OVERPASS	RIGTH	1,36	X	X		
31/08/1012	5224	12	ENLACE MOTRIL ABUTMENT 2 OVERPASS	LEFT	0,90	X			
31/08/1012	5225	10	VIADUCTO N-340 ABUTMENT 1	LEFT	1,20	X			
31/08/1012	5226	12	VIADUCTO N-340 ABUTMENT 1	RIGTH	1,20		X		
31/08/1012	5227	25	VIADUCTO N-340 PILES	BY ABUTMENT 1	1,90	X			
31/08/1012	5228	25	VIADUCTO N-340 PILES	PILE	1,50	X			
31/08/1012	5229	25	VIADUCTO N-340 PILES	PILE	1,60		X		
31/08/1012	5230	25	VIADUCTO N-340 PILES	PILE	1,40		X		
31/08/1012	5231	20	VIADUCTO N-340 PILES	BY ABUTMENT 2	1,40	X			
31/08/1012	5232	12	VIADUCTO N-340 ABUTMENT 2	LEFT	1,22	X			
31/08/1012	5233	10	VIADUCTO N-340 ABUTMENT 2	RIGTH	1,20		X		

10/09/1012	5408	20	VIADUCTO PONTES PILE 1	RGHT	0,80	x	x		
10/09/1012	5409	20	VIADUCTO PROVINCIAS PILE 1	LEFT	0,80	x	x		
10/09/12	5410	20	VIADUCTO PONTES PILE 1	RGHT	1,20	x			
10/09/12	5411	25	VIADUCTO PONTES PILE 1	RGHT	1,20		x		
10/09/12	5412	20	VIADUCTO PONTES PILE 1	LEFT	1,20	x	x		
10/09/12	5413	25	VIADUCTO PONTES PILE 1	LEFT	1,20	x			
10/09/12	5414	20	VIADUCTO PONTES PILE 2	RGHT (OUTMETER)	1,50	x			
10/09/12	5415	16	VIADUCTO PONTES PILE 2	RIGHT (INTERIOR)	1,10	x	x		
10/09/12	5416	25	VIADUCTO PONTES PILE 2	LEFT (OUTER)	1,20	x			
10/09/12	5417	20	VIADUCTO PONTES PILE 2	LEFT (INTERIOR)	1,20	x	x		
10/09/12	5418	20	VIADUCTO PONTES PILE 2	LEFT (OUTER)	1,50			x	
10/09/12	5419	25	VIADUCTO PONTES PILE 2	LEFT (INTERIOR)	1,50			x	
10/09/12	5420	20	VIADUCTO PONTES PILE 2	RGHT (OUTMETER)	1,50			x	
10/09/12	5421	16	VIADUCTO PONTES PILE 2	RIGHT (INTERIOR)	1,15			x	