BEHAVIOR OF HYPERESTATIC BEAMS CORRODED AND REAPIRED WITH MORTAR

A. Muñoz-Noval.
Comision Estatal de Caminos, Queretaro, Mexico.
amunozn@queretaro.gob.mx

C. Andrade-Perdrix.
Eduardo Torroja Construction Science Institute, Madrid, Spain.
andrade@ietcc.csic.es

D. Izquierdo-López.
SANDO, Madrid, Spain.
atorres@imt.mx

ABSTRACT

One of the main causes of the concrete structures premature deterioration is the reinforce corrosion. This process supposes the anodic regions metal dissolution, the reinforce cross section loss will be the immediate effect of the corrosion. This work reaches a better knowledge on the corrosion influence on hyperstatic reinforced concrete structures damaged by corrosion.

Seven hyperstatic reinforced concrete beams (3000 mm long, 15x20 mm cross section, 25 mm cover) were made with 25 MPa concrete compressive strength, 3% of NaCl were added to the mix in order to induce corrosion in the bottom of mid span and top of middle support. A galvanostatic corrosion system was employed to accelerate the corrosion process. During all the tests, the beams were instrumented with strain gauges and load cells to evaluate the strains and load bearing capacity by the beams during the tests. After the steel cross sections loss (estimated with faradays law), the beams damaged zones were repaired with mortar only to carry out ultimate load test.

Study results demonstrated that the beams reparation was successful; despite just repair the beams with mortar without steel addition, showing a repaired cross sections stiffness increase and bearing the same efforts that bore the control beam.

1. INTRODUCTION

Reinforce corrosion is one of the principal damage over the reinforced concrete structures designed. This damage, reduce the safety and functionality of these structures.

Corrosion is a complex electrochemical phenomenon in its nature, evolution and characteristics which depend of many factors. Determining the initiation and corrosion rate of the process, the heterogeneity of attack morphology on the reinforce surface, are additional complications for understanding the real state and the future behavior of structures damaged by reinforcement corrosion.

In this situation, many authors have focused their research on issues related to the influence of corrosion on the structural behavior in recent years.

There are three types of corrosion (Figure 1) that can occur in reinforced concrete structures:

1.- Carbonation corrosion occurs when high enough concentrations of carbon dioxide reach and saturate the concrete cover and corrosion initiate in the area where the pH is reduced.

2.- Chloride corrosion is generated when high enough concentrations of chloride ion reach and saturate the concrete cover and begins the reinforce depassivation, causing pitting of the steel.

3.- Stress corrosion in reinforcement under stress.

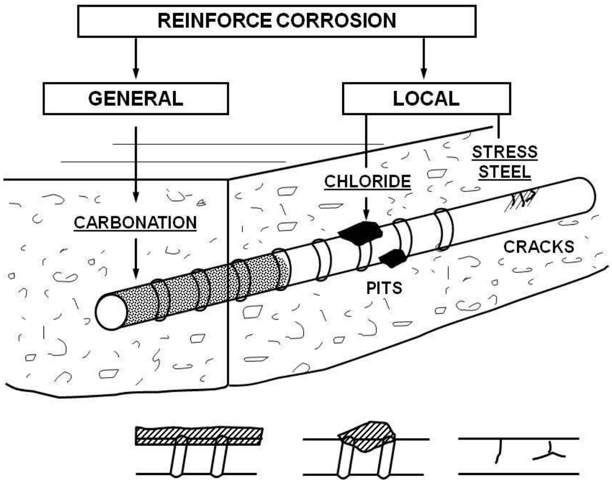


Figure 1 - Different concrete structures corrosion types.

When the steel embedded in concrete corrode, dissolve the passive layer of steel and corrosion products are formed whose volume occupied by the oxide (or hydroxide) is greater than that occupied the original steel, creating pressure against the concrete cover of the steel, cracking and spalling of the cover. These cracks and / or detachment of the concrete cover, besides being unsightly, can reduce the bond of steel and, potentially, the behavior of structural elements.

In reinforced concrete the basic model of service life related to corrosion of reinforcement due to Tuutti, 1982 (Figure 1.2).

It clearly distinguishes two periods. The first is the time it takes to get aggressive to the reinforce, this time known as the initiation period of corrosion.

Once achieved and reinforce depassivation by aggressive, reinforce corrosion is active. This time period is called propagation. The structure service life will end when you reach a unacceptable degree of corrosion in the reinforcement.

The main effects of reinforcement corrosion in concrete are: the loss of section of the reinforcement, the loss of mechanical properties of steel reinforcement, cracking of concrete cover of reinforcement, loss of bond between the steel reinforcement and concrete cover and loss of bearing capacity of the structure.

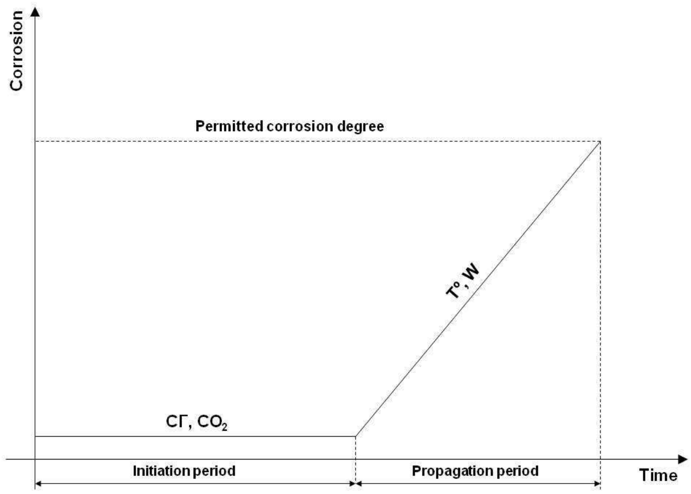


Figure 2 - Service life diagram, Tuutti, 1982.

The specific objective of this work is to obtain information about the nonlinear behavior of structures damaged by corrosion hyperstatic in their most vulnerable areas (the mid span and the central support area) and repaired with mortar, by laboratory tests and finite element modeling.

2. STATE OF THE ART

The mass concrete has very good compressive strength but low tensile strength. If placing reinforcing bars, the resulting material (reinforced concrete) is able to resist the efforts of the buildings. Therefore, the structural concrete is based on combining the concrete compressive strength and steel tensile strength work.

The behavior of the repair mortar is very similar to normal concrete only increase their tensile and compressive strengths and modulus of elasticity. Such materials are used for patching repairs (REHABCON, REPCOR) whose objective is the restoration of physical, chemical and mechanical to acceptable conditions to the durability of the repair. In those cases where the reinforcement corrosion is severe (loss of cross section) where due to an increased load force a strengthening of the structure, the patch would not be enough and should be strengthened with reinforced concrete structure.

When the stresses in the concrete exceed the value of the tensile strength then cracking occurs. Due to its discrete nature, between two consecutive cracks of a reinforced concrete tension members, there is a concrete part that contributes to the resistance of the part due to the bond stresses to steel. This collaboration between the cracks of concrete pulled causes a tension stiffening effect.

The first publication found by McLeish, 1987, which summarized and highlight the different effects of reinforcement corrosion in reinforced concrete elements, such as loss of reinforcement area, loss of ductility of the reinforcement, cracking of concrete cover, loss of concrete cover on the compressed area of the element, tensile reinforcement cover delamination, buckling of reinforcement subject to compression, reducing the bond between the concrete and steel, among others. The findings of this study were to corrosion and its consequences affect significantly the behavior of structures.

Okada et al. 1988, presents a study on the influence of longitudinal cracks due to reinforcement corrosion on reinforced concrete elements. Their conclusions were that the service capacity and ultimate load of the repaired beams was higher than that of beams without corrosion. The beams cracked have no significant reduction in carrying capacity with respect to the beams without corrosion.

Cairns, 1993a, b, c, d performed experimental studies and presented a numerical model for concrete beams without reinforcement concrete cover. With these studies, highlighted the factors that influence the behavior of concrete beams with unbonded reinforcement.

Cairns et al. concluded that the neutral axis depth decreases in the section of maximum moment and, therefore, increases the maximum shortening of the concrete. On the other hand, in sections outside the zone of maximum moment, the depth of the neutral axis increases. They may become enlarged in the supposedly compressed beam, if the length of the exposed frame is wide enough.

Rodriguez et al. 1996 made a complex study on the influence of the corrosion behavior of concrete, making tests with reinforced beams and columns corroded and in service and ultiamte load conditions. Studied different corrosion degrees, cross sections and the interaction between corrosion and load.

The results of Rodriguez et al. allowed developing some models to assess the effects of corrosion of reinforcing steel in reinforced concrete. With these computational models can predict a conservative value of the ultimate bending moment corroded (and ultimate shear) by using conventional models of reinforced concrete, as specified in Eurocode 2, and considering the reduced sections of steel and concrete. These models have been used in the calculation of structures that has damage caused by corrosion of reinforcing bars and were able to calibrate (with real data and laboratory tests) to lead to the development of guides or manuals, assessment, rehabilitation, repair and maintenance of existing structures (CONTECVET, REHABCON, REPCOR, etc.)..

Mangat et al. 1999a, b studied the behavior of reinforced concrete beams with and without stirrups, damaged by corrosion of reinforcing steel (Mangat et al. 1999a) and beams damaged by corrosion and repaired (Mangat et al. 1999b).

From the results we can see that the rate of corrosion is also a parameter to study due to the beams that have the same steel cross section loss due to corrosion present higher reduction of ultimate moment capacity for beams for which a rate was applied 4 mA/cm2 corrosion compared with the moment reduction of the beams to which they were given a corrosion rate of 1 mA/cm2.

In his second work, Mangat et al. 1999b studied the behavior of three materials used to repair damaged concrete beams due to corrosion of reinforcement (beams without stirrups). Analyzing the results and comparing the results obtained in other studies on repaired beams is concluded that the behavior of the repaired structures depends on the material used in the repair.

Izquierdo et al 2002 studied the service performance of reinforced concrete structures repaired by patching. They made 11 reinforced concrete beams. The central part of the beams was designed without stirrups to prevent corrosion-induced longitudinal reinforcement could affect the stirrups and the concrete in the area. They were given an accelerated corrosion system so that un10 lost ~ 15% section. The repair of the beams was made with a commercial pre-mixed repair mortar

Izquierdo et al. modeled the beams with finite elements (2D and 3D) and nonlinear analysis. The results of modeling of the beams are similar to those obtained in the tests and could predict the increased stiffness of the beams repaired with respect to the beam without damage, and ultimate load, location, inclination and opening cracks measured in the tests. However, they had trouble getting the convergence of the model under a plastic regime.

Ballim et al. 2003 made tests on concrete beams damaged by corrosion of reinforcing stel in tension with two load levels. The study results show that the beams of series 2 showed deterioration from corrosion 15% more than the beams of Series 1, possibly due to increased cracking generated by the load level. On the third day of application of load and speed up the process of corrosion found, as Rodriguez et al. 1996, with losses of around 0.6% of the area of reinforcement corrosion, the deflection of the beams was 27% higher.

Similarly, Ballim et al. measure of crack width in beams during the test and found in some concrete cover areas of the tension zone of the beams of series 2, the effect of spalling, contrary to Okada et al. 1988 and other authors, argue in their work, the longitudinal cracks have little effect in reducing the behavior of concrete elements corroded and cracked. The Ballim et al. argument is very reasonable, most measures of cracking performed in previous works are performed when the applied load has been removed and the crack widths are not generated and given that the actual maximum measured crack width are less, we can deduce that these crack widths do not affect the behavior of corroded elements.

3. EXPERIMENTAL

The variables on which the experiment was performed as follows:

- The desired section loss of steel bars (10 and 20%)
- Areas of corrosion (lower bars of the central part of the span and top bars of the upper area of the central support)
- The behavior of the structure (with stirrups isolated and uninsulated)

The constants used in the trials were:

- The amount of current supplied to corrode the steel was constant for all specimens (200 μ A/cm2).
- The load imposed on the beams to measure their behavior and stiffness (100 kg.).
- The corrosion length (600 mm)

7 concrete beams specimens were fabricated with 3000 mm long, 150 x 200 mm cross section, with a reinforced area of the mid span of two bars of 12 mm in diameter at the top and three on the bottom, and in the central support of two bars of 12 mm and 16 mm at the top and three bars of 12 mm at the bottom with 25 mm cover (Figure 3.3). The stirrups were 8 mm in diameter and were placed each 100 mm.

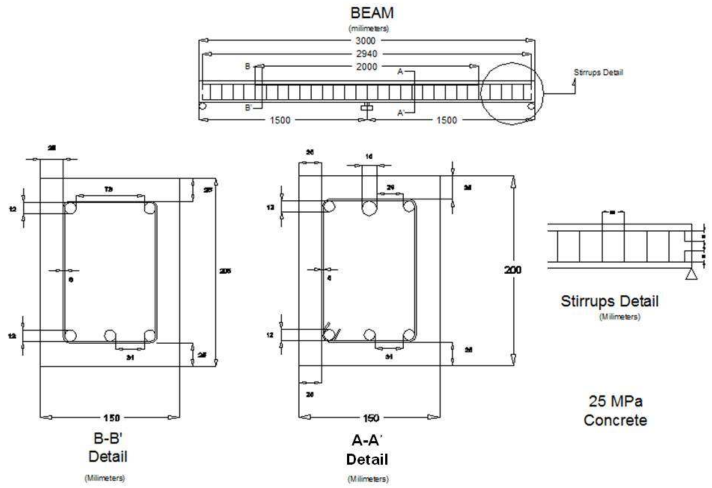


Figure 3 - Beams specifications.

Reinforcing steel used was B 500 S type with 500 MPa yield strength and 550 MPa ultimate strength.

The concrete used in the beams fabrication was A HA-25/P/20 concrete without additive with II A-P 42.5R cement type. The concrete mix dosage per cubic meter is shown in Table 1:

Table 1 - Concrete mix dosage.

Cement:	327	Kg.
Sand:	958	Kg.
Gravel:	1000	Kg.
Water:	160	Lt.
w/c:	0.49	

A cementitious cased steel reinforcement primer and bonding bridge and cement-based one component low permeability repair micro concrete containing silica fume and polymer materials were used to patch repair the beams.

Before producing the beams are separated a number of concrete where chlorides were added to accelerate the corrosion process.

Once manufactured the beams were kept in covered, subject to ambient temperature and humidity. The acceleration of corrosion occurred in 6 of the 7 beams (one beam was control) as the area where added chlorides and the loss of steel diameter was required in the experiment.

At the same time that begins and throughout the process of accelerating corrosion, permanent loads are placed at the center of each span of the beams. These loads will be used to observe the behavior of the structure by measuring devices of the deformation (strain gauge) and the reaction in the central support (load cell) explained below.

For strain measuring in the beams were used strain gauges placed at the top and bottom faces the center of each span (at / 4 supports) and the central support area (l / 2).

To measure the reaction in the central support was placed at a distance of l / 2 a load cell.

The device used to apply the corrosion current, strain gauges used to measure the deformation and load cells used to measure the reaction is connected to a data acquisition unit to take measurements every hour throughout the test accelerated corrosion (and subsequently load testing of the beams every 6 seconds throughout the test) of device, gauges and load cells.

Throughout the accelerated corrosion and ultimate load test was performed cracks widths in all elements.

Once the corrosion process finish, retired on cracked concrete cover using a chisel and hammer to avoid damaging the area of concrete and reinforcing steel, cleaning the corrosion product of reinforcing steel and take measurements of the residual diameters steel bars.

After performing the measurements of the residual diameters of reinforcing bars and longitudinal with a digital caliper, we proceeded to clean the surface of concrete and apply a coating layer 610 Sika MonoTop to allow better bond between the concrete substrate and repair mortar. While still fresh in the applied coating proceeded to empty the repair mortar mix Sika MonoTop 612 to complete the repair process.

Once past 28 days and setting repair mortar was conducted to ultimate load test. The load test was the same for all specimens and was performed in a universal machine with two loaded pistons with a capacity of 20 tons (200 kN) each and the rate of load application was 1000 kg / min.

To measure the applied load, load cells placed between the pistons and metal profiles that I helped to spread the load. Among the profiles and support beams were placed at 1 / 6 the length of the beam. In the center of each span were placed deflection digital meters. At the center of the beam was placed a load cell to measure the reaction in the "support" central and placed strain gauges to measure the deformation is placed in the same way as discussed in the accelerated corrosion test.

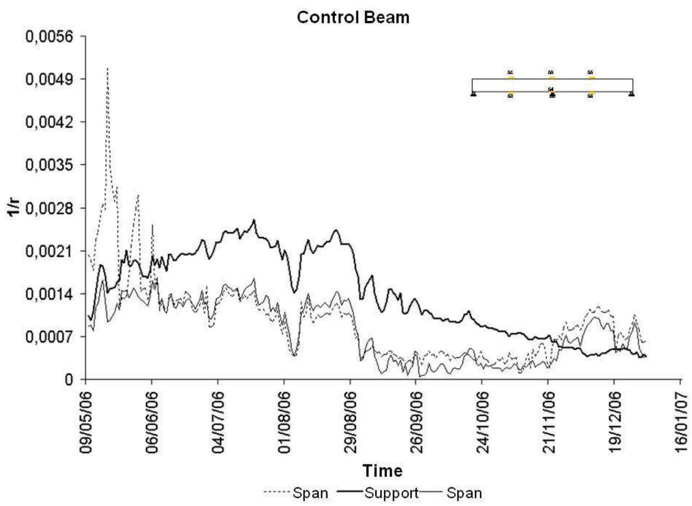
4. RESULTS AND DISCUSSION

4.1 Accelerated corrosion process

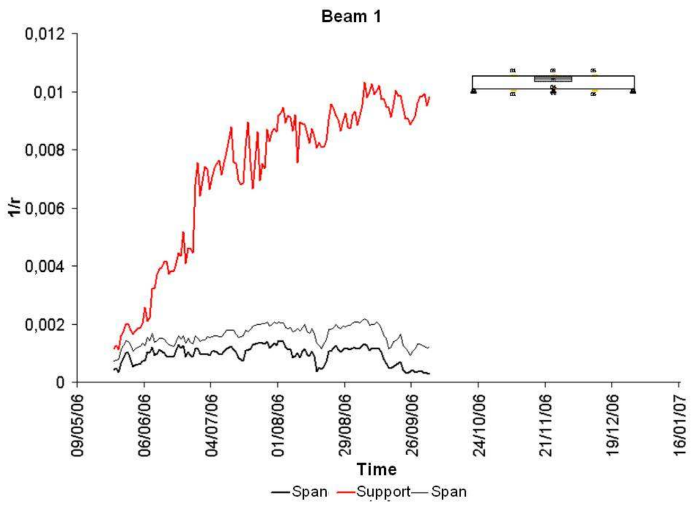
In the present study, an analysis of the beams tested is made in the development of which have been taken into account the equilibrium equations and compatibility, taking into accounts the behavior of materials defined by their constitutive equations.

In the general approach of the work we have considered the following hypotheses:

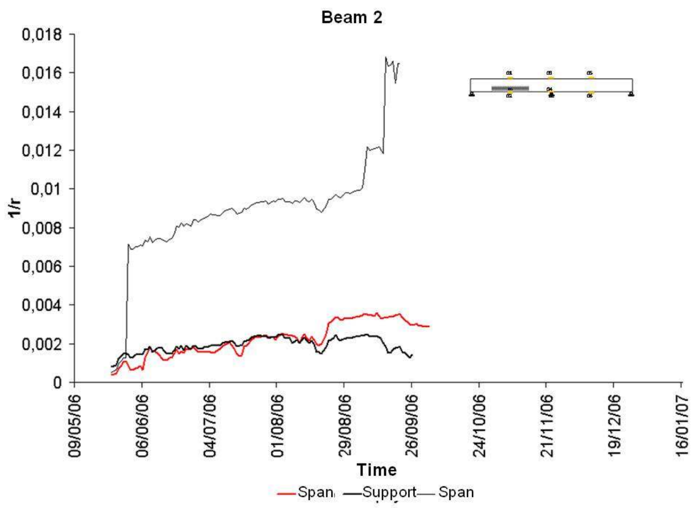
- It assumes the beam embedded in the central support to reach the yielding of the area. Usually occurs earlier in the support than in the span, due to the highest moment in this applied in this section, except in cases where corrosion attacks take place in the mid span.
- It is recognized that there is reinforce in the sections analyzed, with enough anchorage length and covering the displacements of bending the law.
- When you reach the plasticization on the central support, it supports the formation of a kneecap, and can cause depletion of the beam by the lack of rotation capacity in the central support or depletion in the section of the span. These effects may occur sooner or later, if the depletion zone has a section loss due to corrosion and is repaired.



a) Control beam.



b) Beam 1



c) Beam 2

Figure 4 - Central support and mid span sections curvature.

According to the above, the sections near the supports tend to be plasticized before the sections of the mid span. If we add in any section deterioration due to corrosion, the stress redistribution along the beam and corroded sections plasticize will occur earlier. If corrode central support section, this section plasticize before and begins to support the mid span efforts of the support section cannot bear to plasticizing and the beam is broken. Otherwise, when corrosion occurs on the section of mid span, the support section and the section of plasticized mid span cannot bear all the efforts that the support section and fails to support the beam breaks. The placement of strain gauges and permanent loads for accelerated corrosion tests provide direct information to confirm this and, in turn, this is confirmed by the diagrams moment - curvature obtained with the test data. Reactions measured in the beams 2, 4 and 6 load cells tended to increase as the trial proceeded, while the reactions of the beams 1, 3 and 5 were stabilized after a while, remaining unchanged. The reactions of beams 1, 3 and 5 are slightly lower than that of the control beam, while the reactions of the beams 2, 4 and 6 are slightly higher. This confirms the hypothesis of redistribution efforts, as seen in the measurements of the gauges.

Upon completion of the accelerated corrosion test measured the cracks along the entire beam and the cracks generated by corrosion of reinforcement in the defined area. The longitudinal cracks generated in the beams 1 to 4 due to the acceleration of corrosion thickness were expected while the widths of longitudinal cracks in beams 5 and 6 were lower than expected. The lengths of the cracks are almost equal to the corrosion of the beams 1 to 4 lost 10% of the reinforce section, while the lengths of cracks in beams 5 and 6 are up to a meter due to 20 % loss of section. Because of this, the crack widths generated in the beams with a 20% section loss was minor.

4.2 Ultimate test load.

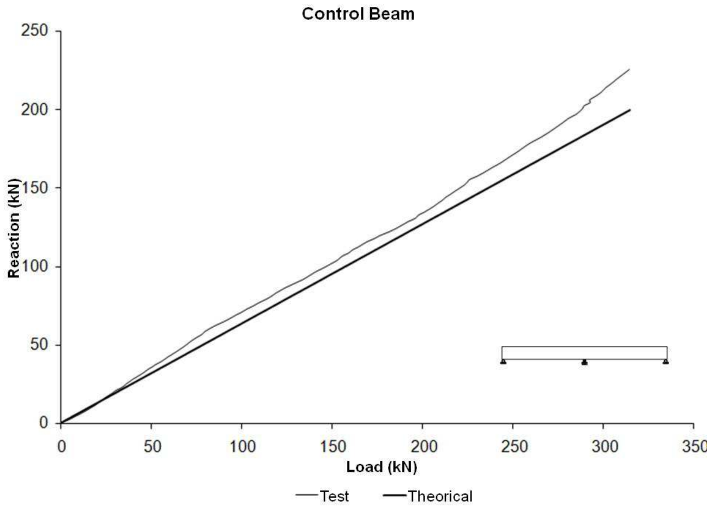
During the ultimate load test was observed that the gauge G3, placed in the support section, and gauges G2 and G6, placed in the bottom of each span of the beams is that measured greater deformation depending on the corrosion-damaged area because they were placed in the tensile zone. G4 and G5 gauges measured in some cases the deformation of the compressed area of the support section and mid span in some beams respectively.

In terms of deflections, it was observed that generated in the mid spans of beams Control, 1, 3 and 5 are very similar because the corrosion damage was generated in the central support area, while the deflections beams 2, 4 and 6 are different because the generation of corrosion damage in one of the mid span and deflection was greater.

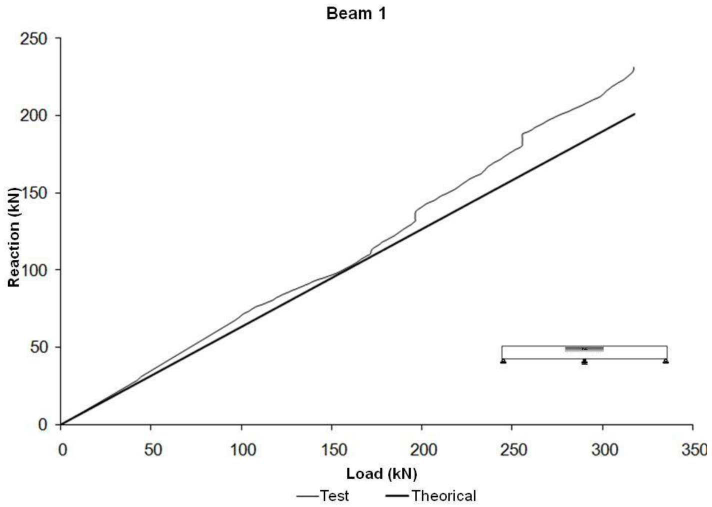
Reactions measured by load cells placed on the beams were kept constant and there were some pending changes that indicate the plasticizing of the sections and the behavior of the beams. In the case of the Control beam the reaction remains linear while for beams 1, 3 and 5 the slope of the line has a slight increase once the yielding of the section damaged by corrosion and beams 2, 4 and 6, the slope of the line has a slight decrease once the plasticizing of the area damaged by corrosion.

Once you completed the process of accelerated corrosion and taken measures losses section of the reinforcement, it was observed that the efficiency of corrosion was approximately 77%. This may be because the test lasted more than three months to the beams and it is possible that the device employee was unable to keep current losses estimated. Another important factor to consider in the tests was that these took place during the summer where the temperatures were very high and low humidity, so it is not kept moist at all times and lost contact, the applied current decreased considerably.

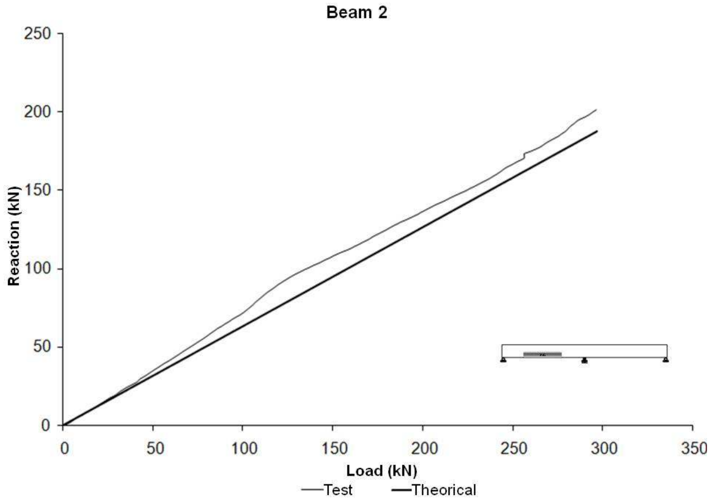
Losses section of reinforcement beams 1 to 4 (10% loss of section approx.) were uniform in bars, while losses on some stirrups of beams 1 and 2 were localized. The beams 5 and 6 losses (20% loss of section approx.) were more localized, coming to have losses of up to 60% section. However, in general, the results of corrosion section loss were lower than estimated and gravimetric losses were higher than those estimated there were at most of the stirrups and some points of the main bars.



a) Control beam

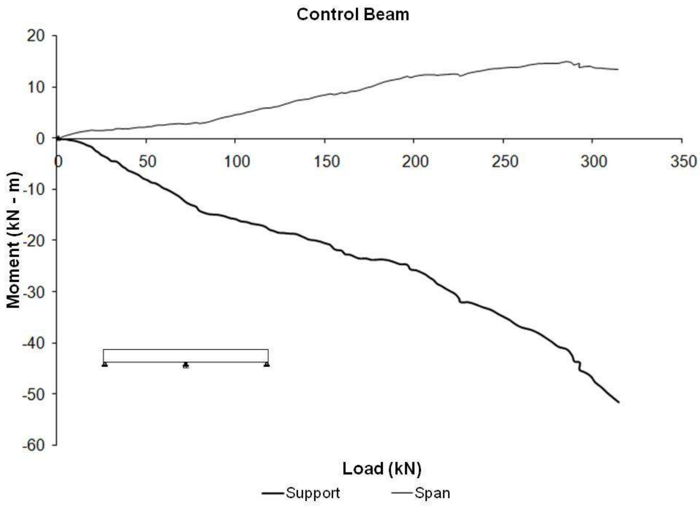


b) Beam 1

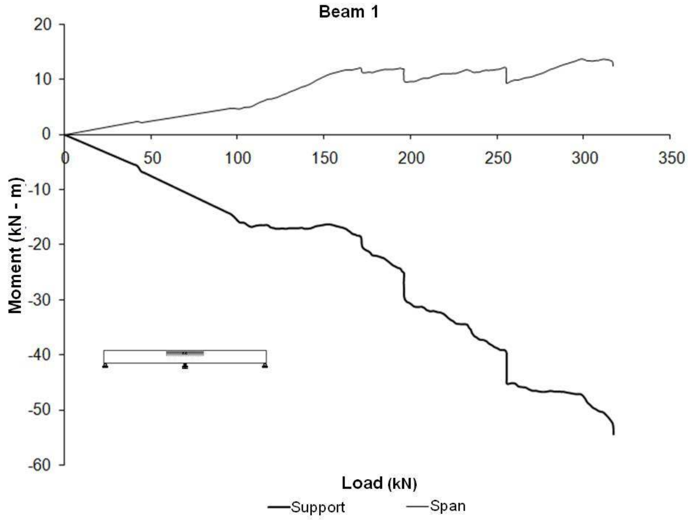


c) Beam 2

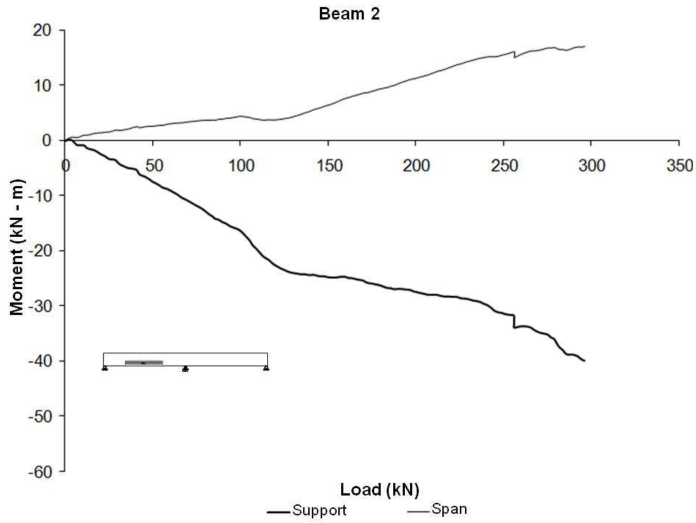
Figure 5 - Ultimate load test theoretical and experimental reaction comparison.



a) Control beam



b) Beam 1



c) Beam 2

Figure 6 - Support and mid span sections moments calculated.

With the data obtained by the load cell placed as central support of each beam during the ultimate load tests and equations 1 and 2 were obtained the bending moment of each section.

$$M_A = 0.375P - 0.75R \quad (1)$$

$$M_V = 0.3125P - 0.375R \quad (2)$$

As an example, Figure 6 shows the bending moments calculated with data obtained from load cells and the records of the load applied to the control beam, the beam V1 (central support corrosion damaged) and the beam V2 (mid-span corrosion damaged).

We can clearly observe the behavior of the sections during the test of the Control beam. It is noted that in reaching a load of 100 kN (approximately) the support section plasticized and the mid span section takes the effort that the support section cannot hold, up to a level load (200 kN, approximately) which mid span section plasticizing and both sections begin to load up to failure. This effect can be seen in all tests. In the beams in which the damaged section was the support section (beams 1, 3 and 5), the diagrams are very similar to those of the control beam, only the ultimate load and moments supported by the sections are slightly lower above all in the mid span. The beams were the damaged area was the mid span (beams 2, 4 and 6) shows the same effect as in the previous cases, only the section that supports a higher moment, once both sections plasticized is the damaged section.

Another factor that can be seen in the test is that depending on the corroded area the moment-load curves of the sections get away or close. In the case of beams 1, 3 and 5 curves separate while for beams 2, 4 and 6 the curves are close because the corroded section are the central support in the first case and the mid span for the second case.

The the plasticize load for the support sections of the beams is aroun 100 kN. In the case of the Control beam is slightly less.

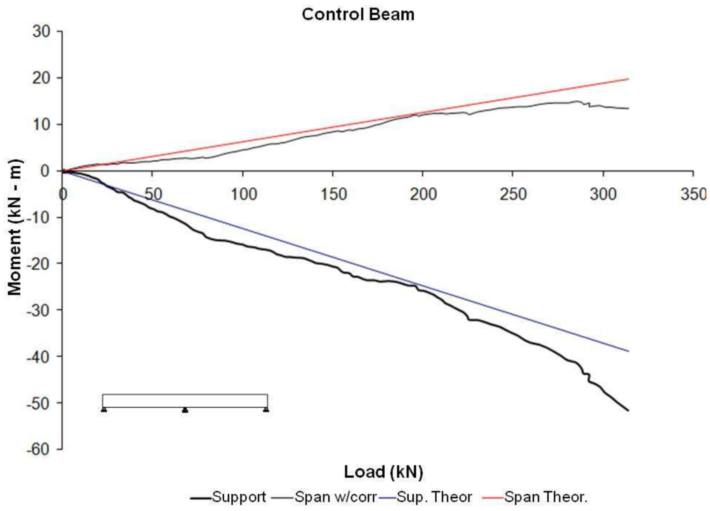
Comparing the results obtained in tests with the theoretical results of the moments of the sections note that the diagrams of the test beams are very similar to the diagrams of the sections calculated.

You can see also that the central support sections of the beams damaged by corrosion, slightly exceed the calculation of the theoretical section and likewise shows how to plasticize these sections, the diagrams are away. For tests of the beams with mid span damaged by corrosion shows the same behavior, only the section that shows the moment increase after plasticized is the mid span.

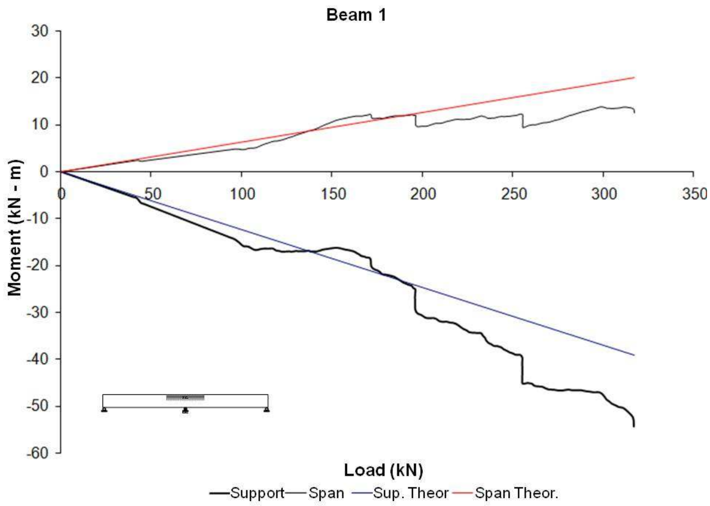
As for the service moment of damaged beams in the central support we can see a slightly larger moment than estimated, mainly due to the effect of repair performed. Otherwise, mid span sections of the beams damaged in the area of central support is slightly lower than expected due to the effects of repair mentioned above.

Once the stage of service is seen as repaired sections of the beams begin to support more moment to reach the yielding and then breaking the beams. At this stage the graphics of the ultimate load tests of the beams nearly coincide with the calculation of the elastic sections.

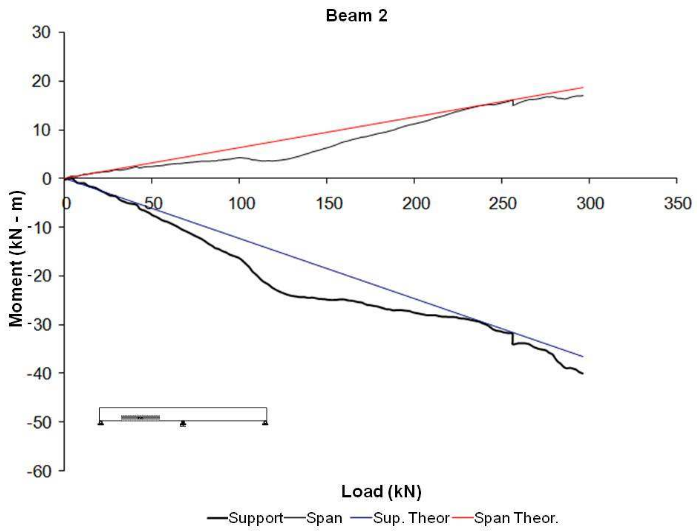
Comparing the results of tests of damaged beams from the control beam graph, we can see that the damaged beams graphics tests are very similar to those of the control beam at the service, once overcome this stage is a higher moment in the damaged sections of the beams with respect to the same section of the Control beam and upon breaking the curves again very similar.



a) Control beam

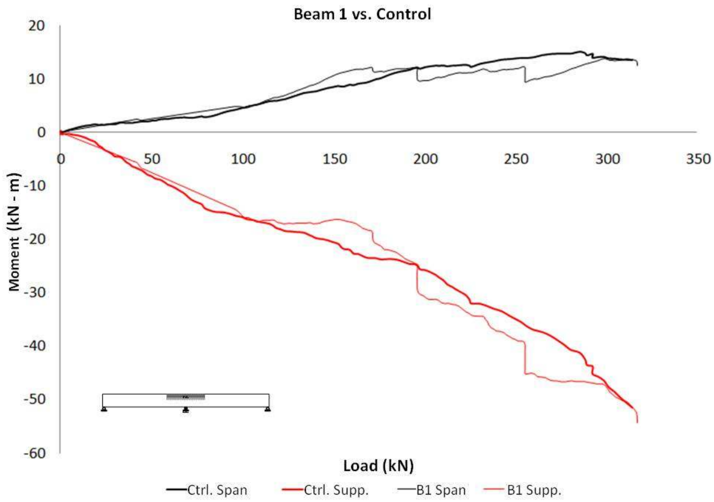


b) Beam 1

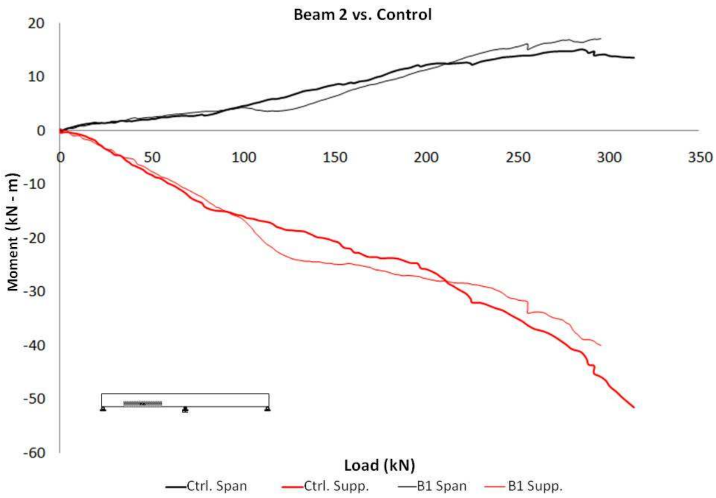


c) Beam 2

Figure 7 - Theoretical and experimental moments comparison of ultimate load test.



a) Beam 1 vs. Control beam



b) Beam 2 vs. Control beam

Figure 8 - Control beam and corroded beams moments resulting from ultimate load test comparison.

The purpose of structure repair is to restore its original properties. For this work the patch repairs of the beams was chosen and observe their behavior, especially the efforts redistribution along the beams during the ultimate load tests.

The patch repair of the beams change their behavior to ductile due to the reinforced cross section loss was not enough to change the beams behavior and increase their fragility. This confirms what has been said about the behavior of the damaged sections of the beams compared with the control beam.

In the figure above you can see the sections stiffness change of the beams, especially the sections that were repaired. This confirms that the repair mortar was adequate and, in general, be able to restore the stiffness lost due to corrosion damage to that of the same section without damaging of the control beam. In some cases sections repaired restore and increase the stiffness with respect to the control beam.

Figure 9 shows schematically the effect achieved by the patch repair made to the beams taking into account that only repaired the concrete cover and did not recover the reinforced cross section loss due to corrosion to strengthen the beams.

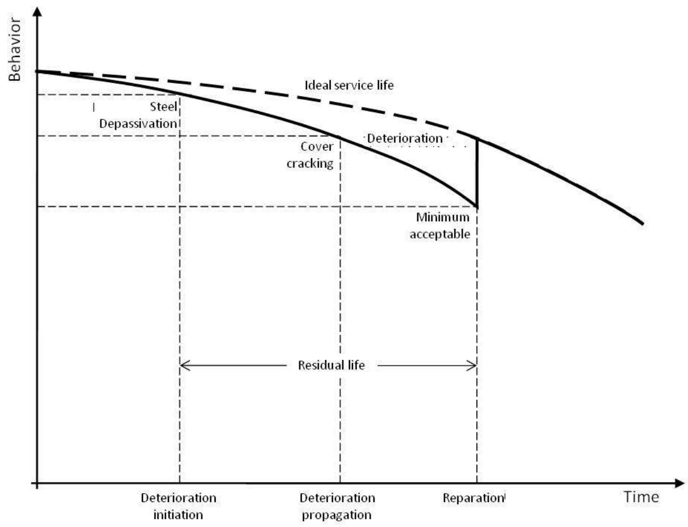


Figure 9 - Repair effect over the beams.

5. CONCLUSSIONS

The most relevant conclusions drawn from the results of tests of the beams are:

1.- There are not found in the literature a study about hyperstatic structures and less damaged by corrosion. This work is the first to study the behavior of hyperstatic reinforce concrete elements damaged by reinforce corrosion, with loads applied during the corrosion process, repaired and loaded until failure.

2.- In most cases, the data obtained in accelerated corrosion tests and ultimate load tests have confirmed the efforts redistribution hypothesis startup raised in this paper.

3.- Although that the static load applied during the corrosion process of the sections of the beams was small it has been possible to detect changes in the curvature of different sections of the beams and measuring the reactions of the load cells placed as support in the central part of the beams.

4.- The beams behavior during loading tests was very similar to that estimated with the equations of elastic sections.

5.- With respect to the control beam most of the beams damaged by corrosion and repaired showed an increase in stiffness in the service stage and the ultimate load tension stiffening effect with respect to the control beam due to patch repair of damaged sections by corrosion with mortar due to higher properties of repair material than those of the original concrete beams.

REFERENCES

1. Tuutti, K. 1982. Corrosion of steel in concrete.
2. REHABCON, 2004. EC DG ENTR-C-2, Innovation and SME Program, IPS-2000-0063.
3. REPCOR. I+D en Estrategias para la Reparación de Estructuras de Hormigón, Proyecto PROFIT FIT – 380000-2004-21.
4. McLeish, A. 1987. Structural assessment. manual for lyfe cycle aspects of concrete in buildings and structures. Taywood Engineering Limited: B4.1-B4.22.

5. Okada, K., Kobayashi, K., & Miyagawa, T. 1988. Influence of longitudinal cracking due to reinforcement corrosion on characteristics of reinforced concrete members. ACI Structural Journal, 85(2): 134-140.
6. Cairns, J. 1993. Changes in reinforced concrete beams behavior induced by reinforcement corrosion. Proceedings of 4th International Conference on Structural Failure, Durability and Retrofitting: 447-454.
7. Cairns, J. 1993. Consequences of bond loss for behavior of reinforced concrete beams. Proceedings of 5th International Conference on Structural Faults and Repairs, 3: 149-154.
8. Cairns, J., & Watson, D. 1993. Structural behavior of concrete repairs: Behavior of beams with exposed aggregates. Proceedings of 5th International Conference on Deterioration and Repairs of Reinforced Concrete in the Arabian Gulf.
9. Cairns, J., & Zhao, Z. 1993. Structural behavior of concrete beams with exposed reinforcement. Proceedings of the Institution of Civil Engineers, Structures and Buildings, 99(2): 141-154.
10. Rodriguez, J., Ortega, L. M., & Casal, J. July 1996. Load bearing capacity of concrete columns with corroded reinforcement. Proc., 4th Int. Symp. on Corrosion of Reinforcement in Concrete Construction.
11. Rodríguez, J., Ortega, L. M., Casal, J., & Diez, J. M. 1996. Comportamiento estructural de vigas de hormigón con armaduras corroídas. Hormigón y Acero, 837 - 8 - 23: 113-131.
12. Rodríguez, J., Ortega, L. M., Casal, J., & Díez, J. M. June 1996. Corrosion of reinforcement and service life of concrete structures. 7th Int. Conference on Durability of Building Materials and Components, 7(1): 117-126.
13. Eurocode 2: Design of concrete structures - part 1: General rules and rules for buildings. Brussels: prEN 1992-1-1. CEN. European Committee for Standardization. April 2003.
14. CONTECVET. Manual EC Innovation Program IN30902I
15. Mangat, P. S., & Elgarf, M. S. 1999. Flexural strength of concrete beams with corroding reinforcement. ACI Structural Journal, 96(1).
16. Mangat, P. S., & Elgarf, M. S. April 1999. Strength and serviceability of repaired reinforced concrete beams undergoing reinforcement corrosion. Magazine of Concrete Research, 51(2): 97-112.
17. Izquierdo et al 2002Izquierdo, D., Río, O., Andrade, C., & Alonso, C. Noviembre, 2002. Comportamiento en servicio de estructuras de hormigón armado reparadas por parcheo superficial: Modelización numérica. Comunicaciones II Congreso de la Asociación Científico-Técnica del Hormigón Estructural, 2: 755.
18. Ballim, Y., & Reid, J. C. 2003. Reinforcement corrosion and the deflection of RC beams—an experimental critique of current test methods. Cement and Concrete Composites, 25(6): 625-632.
19. Asociación Española de Normalización. 1994. Barras corrugadas de acero soldable para armaduras de hormigón armado. Madrid, España: AENOR.