INSPECTION AND DIAGNOSIS TESTS FOR STRUCTURAL SAFETY EVALUATION – A CASE STUDY

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ABSTRACT

Diagnosis and assessment of existing structures is a developing area due to the appearance of a high number of building defects, structural and non-structural deterioration and precocious loss of quality, and, consequently, lower expected durability. With the aim of verifying the viability of rehabilitation or the need to demolish an existing fifteen year old parking building, several inspections and diagnostic non-destructive and destructive testing, visual inspection, were carried out to evaluate the structural safety conditions.

1. INTRODUCTION

The investigation was requested to assess the degree of deterioration of the parking lot of a commercial area at ground level (foundations) and on first floor (beams and slabs). The referred parking lot is a mixed structure (steel-concrete) constituted by encased metallic beams, pre-cast concrete elements and reinforced concrete "in situ". The parking building was built in the 90`s, presenting to the date visible signs of deterioration and excessive deflection of transverse supporting beams that evidenced structural stability problems. To stop the transversal beams deformation, the steel channels were applied as a correction measure immediately after the conclusion of the structure construction. To fullfill this aim, several destructive and non-destructive evaluation tests were performed at the ground and first level for several constructive elements. All testing results were gathered in a final report with the contribution of expert entities in the different areas which were involved, to guide the owner decision in the eventual demolition or rehabilitation of the structure. It should be noted that the contractor diagnosis test campaign of the structure defined precisely the type of tests, number and location.

2. DIAGNOSIS AND INSPECTION

The building was constructed in the 90's and provides parking at ground floor and at a single suspended level. The investigation of the existing structure intends to provide information regarding: geometry, strength, global degradation conditions and structural details.

In Table 1 the destructive tests (DT) and non-destructive tests (NDT) that have been carried within this study.

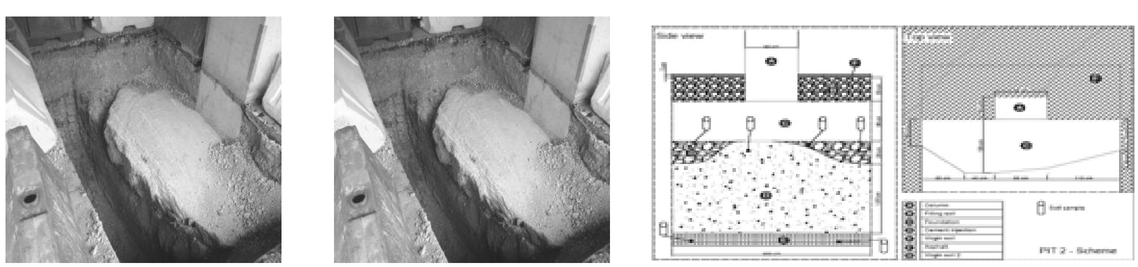
Table 1 – Tests performed

	Tests	Objectives
Destructive testing (DT)	Trial pits	Visual examination and sampling
	Encased beams and slabs	Breaking away concrete finishes on suspended slabs to evaluate arrangement of reinforcement, corrosion, etc
	Water proof	Evaluate the state of damp proof membrane and water-tightness
	Pull-Off Test	Complement the evaluation the completeness of the bond between concrete ribs and strengthening steel channels
	Bond material sampling	Chemical epoxy identification
	Compressive strength	Evaluate the compressive strength of concrete
	Petrographic analysis of Concrete	Description and commentary on the components of the concrete
	Carbonation	Assessment of the concrete carbonation depth
	Groundwater, soil structure and sulphate attack tests	Visual examination. Soil and groundwater sampling
	Chloride Ion Determination	Analysis for chloride ion content in concrete samples
Non-Destructive testing (NDT)	Visual inspection	Visual examination of cracking, crushing, dampness, etc
	Ultrasonic test (Pundit)	Evaluate the completeness of the bond between concrete ribs and strengthening steel channels
	Cover survey	Evaluate the density of steel in pre-cast and concrete elements and covering thickness
	Steel section reduction	Evaluation of material thickness of steel channels
	Movement joints and planters	Register important movements and water tightness of joints

2.1 Destructive and semi-destructive tests (DT) for structural elements evaluation

2.1.1 Trial pits

Two pits were carried out to inspect the foundations and soil stratum. Excavation was performed through an area of approximately 2×3 m^2. In a first phase, the excavation of both pits was done until 1.6 m depth, from the top of the foundation. In a second stage, one of the pits was excavated until 3.6m depth. In both pits no water was found and the soil stratum was dry. Before extracting the cores on the top surface of the foundation (Figure 1) and from the buried part of the column, a reinforcement cover survey was done. However, the cover meter did not detect the presence of reinforcement on the top surface of the foundations in either pits.



(a) Pit opening (b) Core extraction (c) Foundation geometry and soil stratum - scheme

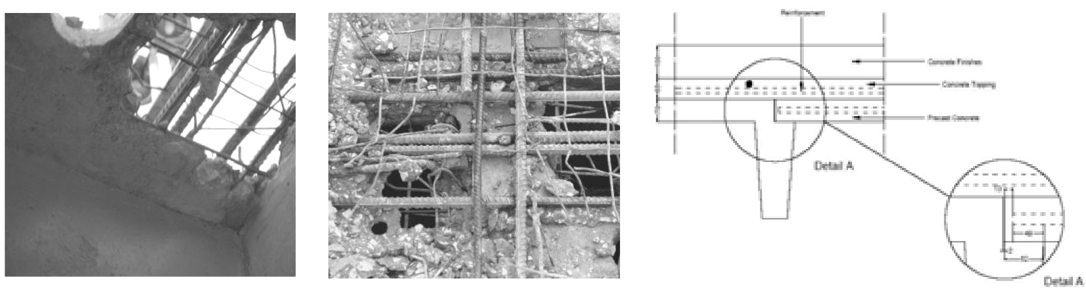
Figure 1: Trial pits

Four soil samples were taken per pit underneath the lower surface of the concrete foundations, as specified by the contractor. Two samples have been collected at the mid span of the foundation and the other two were collected at the borders. Additionally two more samples in PIT_2 were collected at an approximately 3.6 m depth. The locations of the samples taken are represented in Figure 1.

The nature of the soil stratum was described in a specific report (sulphate attack and chemical composition), supported by the analysis of the soil specimens taken out. At first sight, the soil stratum seems compact and does not reveal any kind of contamination or significant changes that could produce a noteworthy decrease on the load capacity bearing of the structure. Concrete foundation does not have regular dimension and is not in accordance with the design drawings.

2.1.2 Encased transversal beams and suspended slabs

The concrete pavement covering was removed on an area of $1.0m^2$, on the suspended slabs in four locations. Cores into the top of the reinforced concrete pre-cast unit below the reinforced concrete topping were taken off and the test results for compressive strength, petrographic analysis, ion-chloride carbonation of the concrete removed in each location, present a range of results that did not suggest any serious problem. No signs of damage, cracking or corrosion were found in the "in situ" topping concrete and pre-cast slab unit or in the supporting pre-cast concrete rib. The thickness of the in situ structural concrete topping is 65 mm (see Figure 2) and is constant in all the other four locations. However, the concrete finishes vary in the four locations ranging from 100 mm to 140 mm. An existent gap between the pre-cast slab units has been observed, which is empty and has a constant thickness of 2 mm (see Figure 2c).



(a) Pre-cast unit inspection (b) Reinforcement steel bars (c) Structural detailing

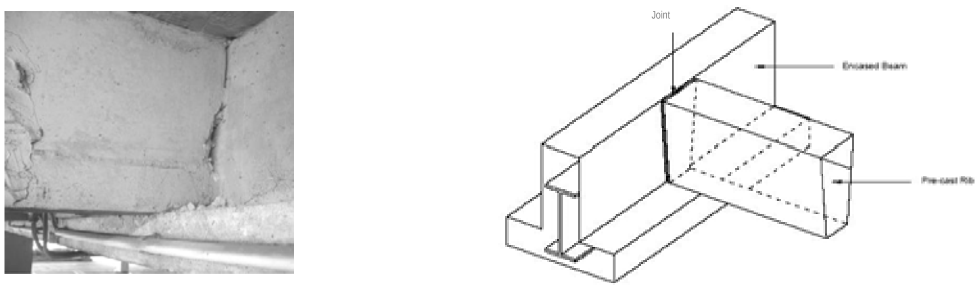
Figure 2: Semi-destructive tests on slabs

Based on the "in situ" inspection the geometric characteristics of the encased beams could also be defined as represented in Figure 3. No relevant damages or cracking were found in the supporting concrete flange or in the in situ topping and pre-cast unit. On the other hand some signs of corrosion were found in the wrapping mesh at the bottom of the beams. No signs of damage or corrosion were found in the reinforcements or in the flange of the steel beam. As represented in Figure 3 the cover at the bottom of the steel beam (supporting concrete flange) is sometimes inexistent. The observations "in situ" of the construction details are not in accordance with the available design drawings and schemes.

(a) Encased beam (b) Reinforcement bars (c) Structural detailing

Figure 3: Destructive testing on encased beams

After removing the concrete in some elements, an existent gap between the encased beams and the pre-cast ribs was found (see Figure 4). At first sight this gap (thickness ranging between 7 and 12 mm) seems to be filled. However, only the borders are "covered" by some mortar and sometimes the interior has some cement paste that was drained when the topping concrete was cast "in situ". A more effective connection should be guaranteed in order to obtain a monolithic behaviour.

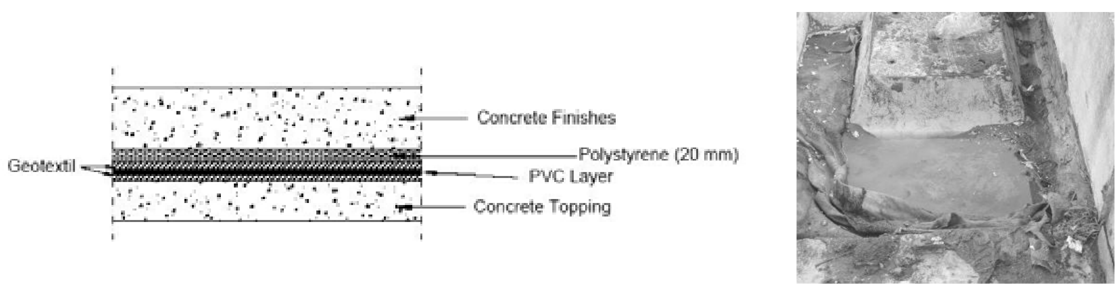


(a) Joint (b) Structural detail

Figure 4: Joint between encased beam and transverse pre-cast ribs

2.1.3 Coverings and waterproofing details

On the edge between the concrete finishes and the concrete topping, a waterproofing PVC layers was found. The scheme in Figure 5 shows the details. The presence of large quantities of water was also observed, which exist due to the geometric irregularities of the slabs which allow the accumulation of water in some points and also due to the physical separation between the concrete finishes and the concrete topping. In some locations the PVC layer was damaged allowing the presence of water in the structural concrete topping.

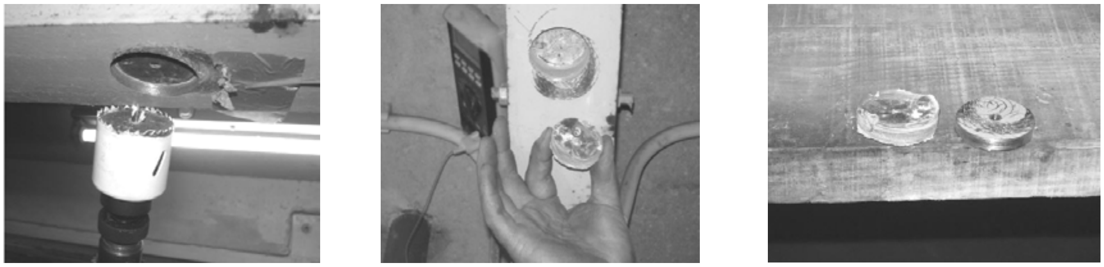


(a) Waterproofing – general scheme (b) Inspection

Figure 5: Waterproofing

2.1.4 Pull-Off tests

In situ pull-off tests were carried out in ten locations to determine bonding strength. The locations were chosen to representative of bond conditions. The proposed locations for the tests were calibrated using the ultrasonic tests. Taking into account the pull-off and the ultrasonic test results it can be concluded that, in general, epoxy bonding of the steel channels to the pre-cast concrete ribs is defective (see Figure 6).



(a) 50mm diameter core (b) Extracted samples

Figure 6: Pull-Off Tests

2.1.5 Bond characteristics

Samples of the material used to bond and of the steel channels were extracted to carry out the following tests (see Figure 7): FTIR analysis samples, TGA analysis, X-ray spectroscopy and Shear strength. However, from the extraction operation it was concluded that the epoxy adhesive was not bonded to the pre-cast concrete elements. Therefore these tests were not carried out, because they would not lead to relevant conclusions.

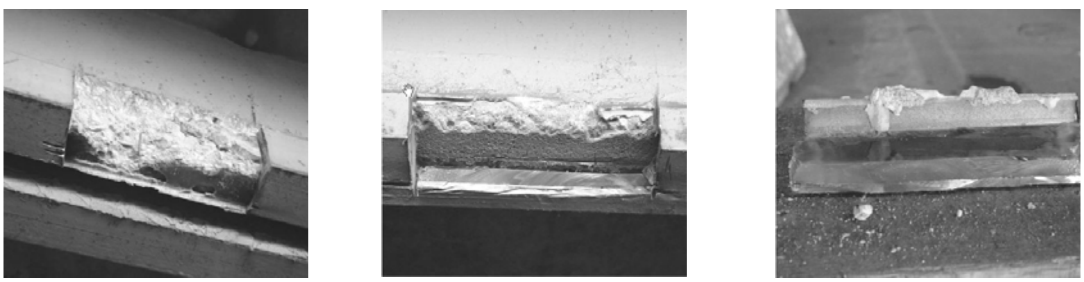


Figure 7: Bond sampling

2.1.6 Carbonation tests

The carbonation depth assessment in concrete elements was carried out on specimens drilled out of the structure from the points indicated by the contractor. The fresh fractured concrete samples was treated with an alcoholic solution of phenolphthalein indicator in accordance with the procedure established in the Portuguese Standard LNEC E391 [1]. The column samples present a carbonation depth of about 20mm but still very distant from the reinforcement (see Figure 8). The samples drilled from covered concrete elements have no carbonation signs. In relation to corrosion problems, it also seems insufficient to want to assess the corrosive state of the concrete without any measurement of its resistivity or of the elechtrochemical potentials of the armour or even a measurement of corrosion speeds.

The structure in question functions as a parking building, making it all the most logical to assess, for example, the carbonation fronts not on the external face of the pillars but on the more internal pillars and flagstones, at least for a question of less ventilation and consequent higher concentration of carbon dioxide in those inner areas.

2.1.7 Chloride Ion Determination

No chloride could be found in any of the samples tested independently of the depth of the concrete cover [2], [3]. The absence of chloride was confirmed by titration results and also by the use of a calibrated chloride sensitive electrode. The chloride contents found were all considered meaningless (inferior to 0,5% of the critical value), which should also be expected since the structure is about 12 Km away from the sea.

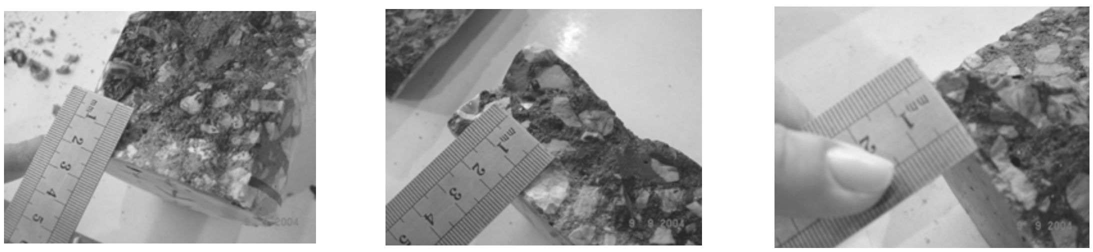


Figure 8: Carbonation results - Concrete from columns

2.1.8 Compressive strength and petrographic examination of concrete

Core specimens have been drilled through the structure with 100 mm of diameter [4], [5]. The results indicate that concrete strength is in accordance with the values specified in the project. The concrete slabs are in glass fibres reinforced concrete. The petrographic analysis using Polarized Light Microscopy, X-Ray Diffraction (Petrographic microscope) and X-Ray Diffraction (Post Difractograms on non-oriented preparations) of ten concrete specimens indicated that it was not observed rock fragments and their were no signs of evident tectonic actions of the Quartz [6].

2.2 Non-destructive evaluation (NDT) for structural elements evaluation

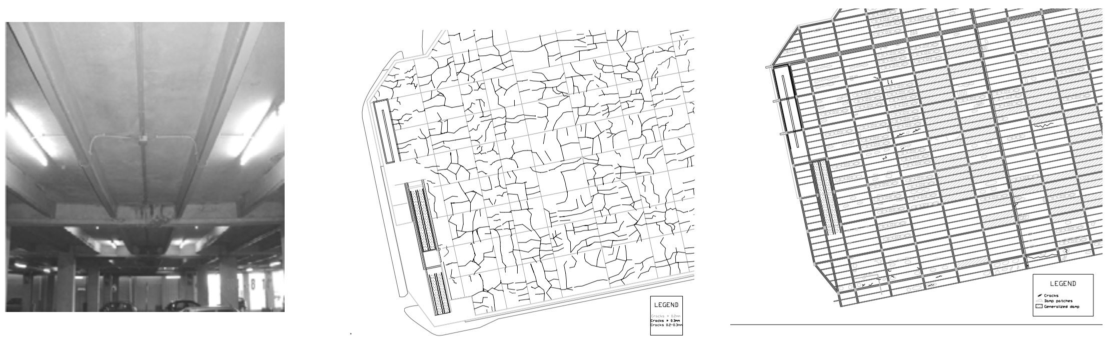
Careful conservation or rehabilitation of existing constructions implies extensive knowledge about the constituent material from the mechanical and physical point of view. A wide variety of tests can be performed for a specific purpose. These methods present several advantages such as their practical utilization. Presently these methods are used alone or at the same time with other NDT methods or techniques. In order to assess the corrosive state of the structure, the following tests were carried out: measurement of the carbonation front (24 points), measurement of chloride content (11 points), measurement of recovering thickness (4 zones) and visual inspection.

2.2.1 Visual inspection

This is the most simple and oldest NDT. The visual evaluation consists of examining directly, and at a relatively short distance, the elements along their length, checking and registering all the signs of alterations, global position, structural function, dimensions, accessibility, cleanliness of the element surfaces, luminosity conditions, existence of graphical and topographical elements and if they are in accordance with the actual structural conditions, type of repair or reinforcement, localization of the problems related with the loading conditions; cracking evaluation (see Figure 9), etc. However, the estimation of the serviceability properties of new and/or rehabilitated constructions, by visual grading is not entirely reliable with respect to a series of factors influencing the mechanical properties and, further, with respect to the influence of the human factor in the grading proper. Based on visual inspection to the structure, no iron oxide stains were found, nor drippings or any other kind of bleaching worth noticing.

2.2.2 Ultrasonic tests

Coupled with a thorough visual examination, this test can add significantly to the quality of an inspector's evaluation. The ultrasonic method is used in homogeneous, non-porous materials to evaluate the elastic properties [7]. 31 pre-cast ribs were tested. The values of the velocity of propagation range between 956.7 and 2531.7 m/s. The results were not very consistent, in part due to the difficulties in carrying out the tests: great moisture content and temperature variations, problems in calibrating the measurements with confidence (difficulties in finding a well bonded channel) and high wave attenuation due to the energy consumption by the reflection of the waves as a result of the significant existent gaps. The ultrasonic transmission shows low sensibility to areas where debond has occurred. A clear difference in terms of velocity of propagation in locations where debond occurred versus locations where the epoxy was (apparently) glued to the steel channels was not observed.



(a) Slab (inferior view) (b) Cracking maps (c) Damp patches

Figure 9: Visual grading results

(a) Ultrasonic equipment (b) Testing apparatus (c) Testing scheme

Figure 10: Ultrasonic tests

2.2.3 Reinforcement cover survey and section loss of steel members

Concrete cover thickness, diameter and location of reinforcement bars were evaluated as shown in Figure 11. Results indicate that concrete cover and reinforcement bars arrangement are thoroughly in accordance with the project drawings. The recovering thicknesses vary between 3,5 cm to 4 cm, which is quite acceptable for this kind of structure. The rust was totally removed with a metal brush from three steel channel sections. Corrosion is uniform in the most external steel channels. Thickness loss is worrying (only on the external ones), loss of more than 50% real thickness (see Figure 11c). From the samples extracted with reinforcement (two) and the zones with exposed for examination (five), it has been observed that the steel has no apparent section loss and is possibly in the passive state.

(a) Visible corrosion (b) Visible corrosion (c) Thickness loss

Figure 11: Cover meter survey and corrosion of steel members

3. ACKNOWLEDGEMENTS

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4. CONCLUSIONS

This work is relevant for the diversity and specificity of the tests which reveal the concern of the owning company with the structure's state of deterioration. Any action must be preceded by a planned tests campaign. The concern with test complementarity reveals the intention of giving more precision and reliability to the shown parameters.

Among the tests performed according to the level of decisions to make, less onerous tests could have been selected, simpler and whose results would probably present the same reliability. On the other hand, we consider the number previously set for some tests redundant. In what the localization of the tests is concerned, we believe, according to our experience, that the choices haven't been the best considering the results to be obtained. In spite of either the localization and the number or kind of tests being previously set, as the work unfolded some readjustments had to be made according to the results being obtained.

In order to avoid mistakes and omissions at the level of conception prone to cause structural anomalies and high repairing costs, a careful revision of the stability project should have been made. Moreover this would also have been a priority tool at this stage of inspection and diagnosis. From what has been observed and analysed, the conclusion can be drawn that the transversal beams present a problem of fatigue as a consequence of their underestimation and the incorrect reinforcement measures. The issue of the structure maintenance has been overlooked and contributes to the state of degradation.

5. REFERENCES

[1] Portuguese Standard LNEC E391 - carbonation
[2] Portuguese standard LNEC E 332 clhoride ion
[3] Portuguese standard LNEC E 231-1981 clhoride ion
[4] Portuguese Standard LNEC E226 - Concrete Compressive Strength Test
[5] ASTM C42/C 42M – 99 – Concrete Compressive Strength Test
[6] ASTM C856-83 – Petrographic examination
[7] ASTM C 597 ultra sons - PUNDIT