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Condition assessment of a damaged reinforced concrete building according to Fib Model Code 2010

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ABSTRACT: The Model Code 2010 treats the problem of structural conservation by defining the activities aimed at maintaining a structure to a state which satisfies the defined performance requirements. The approach recommended in the Model Code 2010 has been applied to a damaged reinforced concrete building, built in the fifties and now owned by the public administration, devoid of a Condition Control Plan in place. Following the Model Code suggested procedure, a diagnostic campaign, including several non destructive investigations such as visual inspection, magnetic bearing of reinforcement, sonic tests, rebound hammer test, has been carried out on a significant and safe sample of structural elements. Strategies adopted for building conservation and assessment are illustrated and discussed, along with outcomes of the diagnostic campaign.

1 INTRODUCTION

In Model Code 2010 (2012),Volume 2, Bulletin 66, Chapter 9, the conservation activities are defined to mean all activities aimed at maintaining or returning a structure to a state which satisfies the defined performance requirements. For existing structures, without a Condition Control Plan in place, it is necessary to define conservation strategy and action activities, which shall be confirmed or revised on the basis of result evaluations obtained *in itinere*. It is necessary to minimize costs of conservation and renovation, which are influenced by many factors including constructive details, environmental conditions and performance requirements. Engineering evaluation and interpretation of the data obtained is central for converting data into useful context related information. The choice of conservation strategies to be used depends principally on consequences of potential failure, feasibility of evaluating the condition of the structure, feasibility of remedial interventions and cost of conservation activities. The available conservation strategies and respective tactics are classified on the basis of their proactive versus reactive characteristics. The conservation planning shall be prepared in accordance with the selected conservation classification for the structure or its component parts, as appropriate. Condition survey is understood to mean activities performed to gather information regarding the form and nature of the structure, current or potential deterioration mechanisms and change in performance of the structure or service conditions which are needed for evaluating the conformity with the design for actions, materials and properties. Tools and techniques for inspection, testing and monitoring could involve a wide range of procedures. Typically they are likely to include a combination of visual observations, material sampling and non-destructive testing methods. The deterioration mechanism, present deterioration level and deterioration rate of materials and structural performance shall be determined using appropriate models on the basis of the information obtained from inspection, testing and monitoring activities, from the design and construction records, from information upon previous interventions and the environmental conditions. In this paper, the approach recommended in the Model Code 2010 has been applied to an existing damaged reinforced concrete building.

2 THE BUILDING

The case study presented in this paper concerns a damaged reinforced concrete building which dates back to the 1950s and is today owned by the public administration of Cagliari (Italy). The structure is made up of reinforced concrete elements (pillars, beams, slabs) connected into a frame. The building has a T form in plant, and seven levels; it is 24 m high and a 2,200 m^2 surface area and consists of four building bodies (A, B, C e D) connected by three vertical joints (Figure 1). Currently several offices, a nursery school, a laundry, a kitchen, a library, an archive, are hosted in the building, but the room utilization is often varied. The original structural design is not available, the mechanical characteristics of materials are not known either, and no Condition Control Plan is in place.

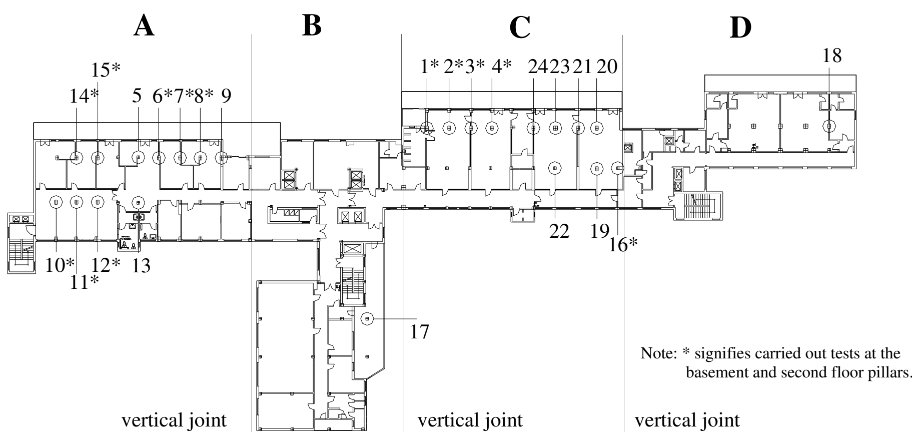

Figure 1. Horizontal plane section of a generic level, with vertical joints and tested pillars reported.

3 BUILDING CONSERVATION STRATEGY

While choosing conservation strategies and tactics the important social functions of the building (nursery school, canteen, public offices, libraries, archives) has been taken into account.
The adopted conservation strategy is of the reactive type and it is based on interventions aimed at arresting currently active processes which are causing damage. The general process assumed for conservation management, accordingly to Model Code 2010, is shown in Figure 2.

4 CONDITION SURVEY

The adopted condition survey process, with particular attention to circumstances where judgments need to be made, is illustrated in Figure 3.
The initial inspection highlighted a general deterioration, mainly in the lowest floor. Documentation of inspections beforehand carried out on the buildings - load tests on slabs and carbonation depth measures - pointed out the elastic behaviour of slabs and a concrete carbonation depth of about 70 mm. Given these outcomes, the condition assessment procedure has been focused on the pillars. No emergency measures were needed.

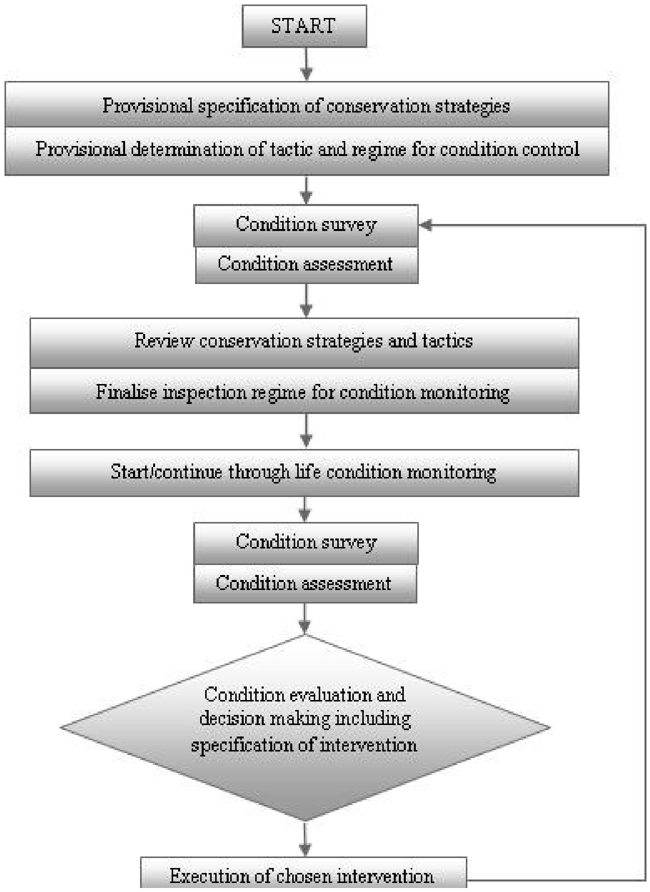

Figure 2. Through-life conservation process for conservation management.

The structure consists of four building bodies connected by three vertical joints (Figure 1). The building has 1,307 pillars distributed as follows: 194 in the first five levels (basement, ground floor, first, second, third floor), 179 on the sixth level (fourth floor) and 168 on the seventh level (fifth floor). The very high number of pillars has led to the selection of a significant, safe and representative sample of them, respecting, when possible, the facilities of the building.
According to these principles pillars of the basement and the second floor have been selected. The basement has been chosen because its pillars were the most loaded and in the worst condition – soil contact, poorly aired, very aggressive environment in kitchens and laundry – and the second floor because the rooms were not in use due to a restoration, and therefore possible surveys would be easier to be performed. 34 pillars have been tested, 18 in the basement and 16 on the second floor. The selected sample was meaningful and representative, according to the Italian Standard (2008) of concrete quality control.
A visual inspection of the pillars suggested the opportunity of performing detailed investigations. Aiming at not interfering with the state of the asset, a Non Destructive Testing (NDT) campaign has been run.

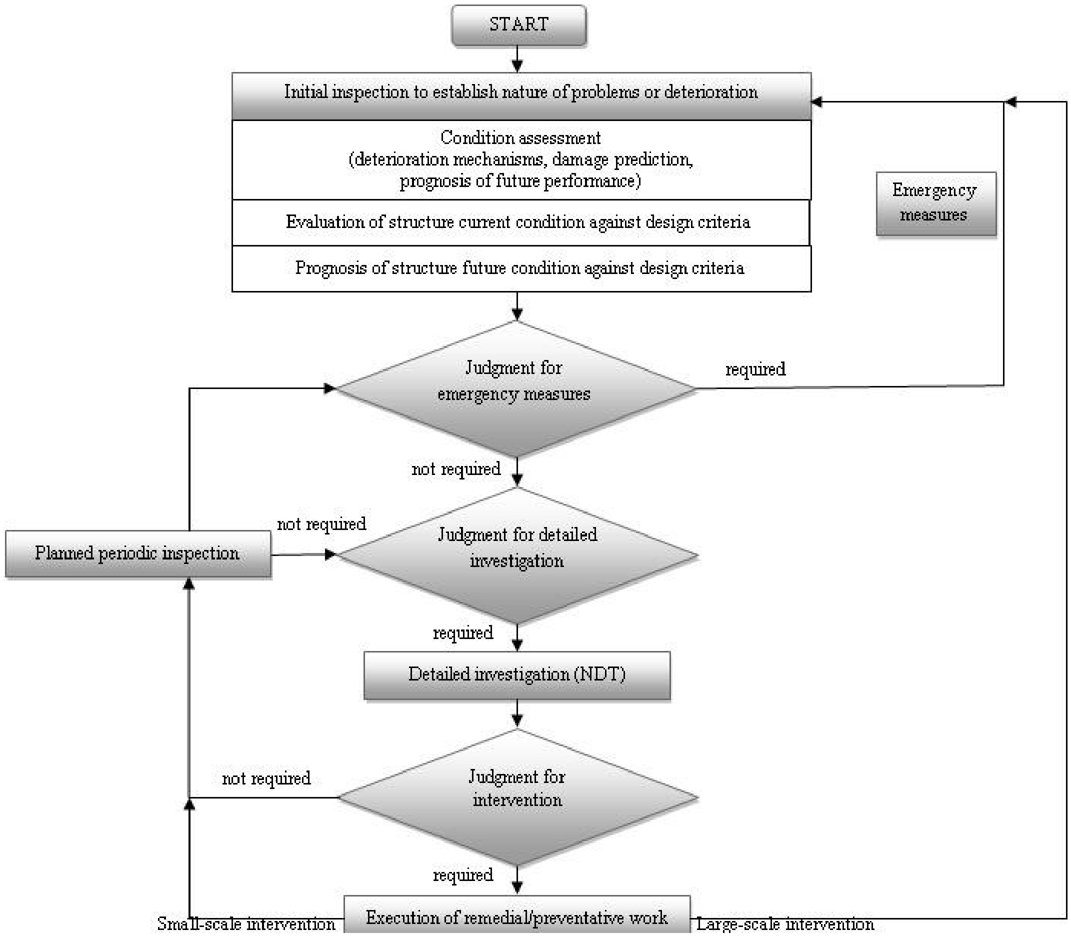

Figure 3. Flow chart of the condition survey process.

Beside visual inspection and dimensional control, the diagnostic campaign on pillars included electromagnetic rebar location, Papworth (2005), sonic tests, Berke (2000) and rebound hammer test Kolaiti (1993). It was not possible to carry out all investigations on each pillar because of the presence of obstacles: for example the electromagnetic rebar location cannot be performed if the pillar has metallic edge buffers; the rebound hammer test cannot be carried out if the pillar is covered by plaster or tiles; the sonic test cannot be performed whenever the instrumental set cannot be arranged on parallel sides of the pillar.

4.1 Visual inspection

Visual inspection highlighted the pillars different degradation levels, summed up as follows: Condition A: good condition and no cracks, Condition B: longitudinal cracks in the plaster of pillars edges, Condition C: inadequate reinforcement covering which caused bars corrosion and diameter reduction. The degradation levels classification is summarized in Table 1. Cracks depending on excessive loading have not been singled out; in this case, cracks would have been arranged in a hourglass shape disposition, stirrups would have tended to open, longitudinal bars would have buckled and concrete would have been locally expelled, ACI 36. 1R-94 (1994). The rooms in the basement showed a very high humidity level, particularly on the lower parts of pillars, walls and partitions up to 1 m. Many pillars were close to spaces hosting pipes; the inspection carried out on some of them showed the pipes degradation, probably damaged by leaks. Pillars plaster tended to detach and showed longitudinal cracks running along the pillars edges. The inspection, carried out by removing the reinforcement cover, showed closed stirrups and oxidized longitudinal bars. Some pillars were tiled up to 1.80 m.

Table 1. Pillars degrade levels resulting from inspection

Pillar label and location	Visual inspection	Pillar label and location	Visual inspection	Pillar label and location	Visual inspection
1 basement	Condition C	13 basement	Condition B u	8 second floor	Condition A*
2 basement	Condition C	14 basement	Condition B u	10 second	Condition A*
3 basement	Condition C	15 basement	Condition B u	11 second	Condition A*
4 basement	Condition C	16 basement	Condition B	12 second	Condition A*
5 basement	Condition C u	17 basement	Condition B	14 second	Condition A*
6 basement	Condition C u	18 basement	Condition B u	15 second	Condition A*
7 basement	Condition C	1 second floor	Condition A	16 second	Condition A* u
8 basement	Condition A*	2 second floor	Condition e A	19 second	Condition A
9 basement	Condition A*	3 second floor	Condition A	20 second	Condition A
10 basement	Condition B u	4 second floor	Condition A	21 second	Condition A
11 basement	Condition B u	6 second floor	Condition A*	22 second	Condition A
12 basement	Condition B u	7 second floor	Condition A*	23 second	Condition A
				24 second	Condition A

Notes: * signifies recent restyling; u signifies presence of humidity

4.2 Electromagnetic rebar location

The electromagnetic rebar location showed the number and the diameter of longitudinal bars, confirmed by some low-invasive samples, as well as the distance between stirrups and the reinforcement covering thickness. Results showed that longitudinal bars were not perfectly vertical, therefore covering thickness was not constant either (Figure 4). This might be due to both the pressure exerted by the casting of the fluid concrete and by the concrete vibration. These outcomes were very useful to evaluate the covering thickness and to define the kind of restoration required on bars and pillars.

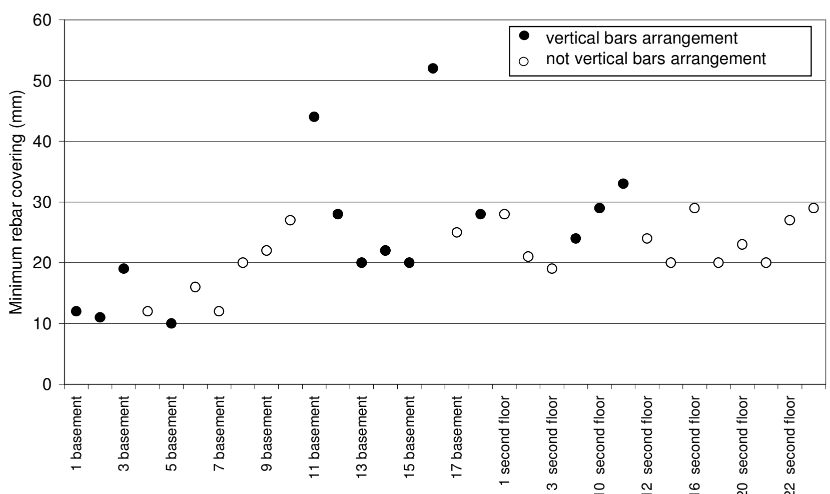

Figure 4. Minimum rebar covering for each pillar.

4.3 Sonic tests

Sonic tests performed on the basement pillars showed uniform results; the average velocity value was about 3,000 m/s, thus matching with the concretes fairly good elastic-mechanic characteristics, Popovics (2003). Some pillars showed lower velocity in restricted regions of the investigated surfaces; in these areas the hammer produced a dull noise and the waveform was very jagged, due to the vibration of the hit material. This occurrence indicated the external covering detachment, due to the lack of adhesion between plaster and concrete and between bars and covering. Tiled pillars showed higher velocity, as if the covering had protected the material against environmental attack. Pillars located on the second floor showed a very uniform behavior, the average velocity being about 3,000 m/s and the lowest value about 2,000 m/s. Figure 5 shows average, maximum and minimum sonic velocity of pillars.

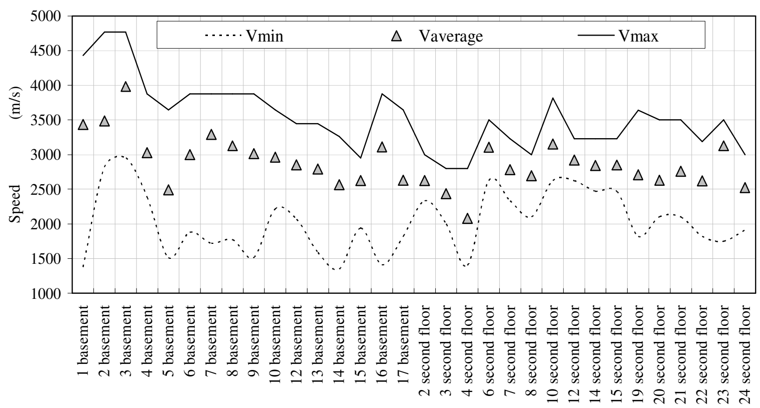

Figure 5. Average maximum and minimum sonic velocity.

4.4 Rebound hammer test

Average concrete strength value estimated by the rebound test hammer was high, but the results were considerably scattered and the range between maximum and minimum strength values was about 76%. This occurrence depends on the poor quality of the external concrete and on the detachment between bars and covering, which strongly affect the test. Figure 6 shows average, maximum and minimum strength for each pillar. Rebound hammer data is highly affected by the condition of the external concrete, while sonic data depends on the inner material condition. Thus, the two tests comparative evaluation strongly reinforced that the pillars core was in fairly good condition, and the damage was mainly reserved to the concrete covering.

5 CONDITION ASSESSMENT AND EVALUATION

After considering outcomes of the survey on the whole, the absence of damage due to excessive load was confirmed. Results suggested that damage was primarily due to the physical-chemical degradation process. When the relative humidity ranges between 50% and 80%, concrete being porous and permeable the corrosion speed is particularly high and thus it is essential to recreate bars passivity, even of those ones not highly damaged yet. On the basis of the tested sample (3.5% of buildings pillars) it could be affirmed that the 50% of pillars were not damaged and did not need any kind of restoration, 20% needed to recreate the passivity of bars in order to stop corrosion, and 30% needed a more intensive action because of the relevant corrosion and the concrete damage. Figure 7 summarizes the pillars conditions resulting from the tests.

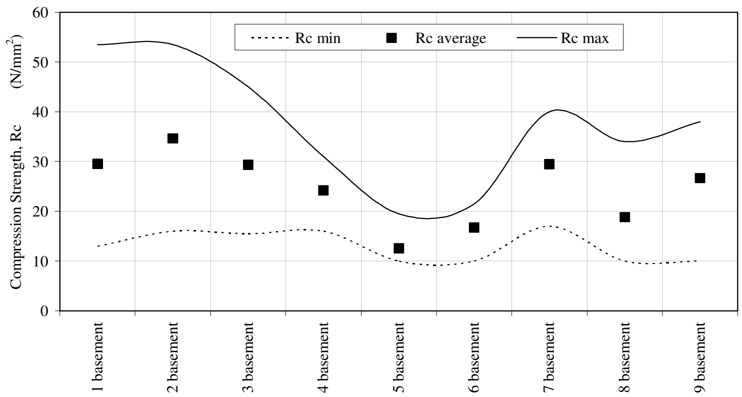

Figure 6. Compression strength estimated by the rebound hammer test.

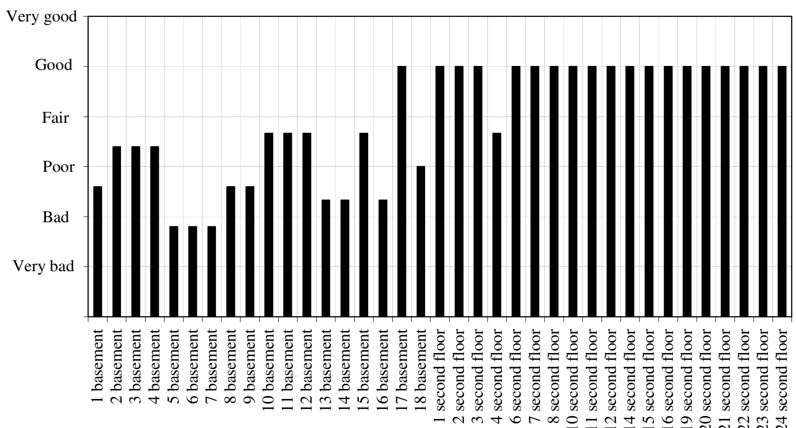

Figure 7. Pillars condition resulting from NDT.

6 DECISION-MAKING ON INTERVENTION

The intervention option has been selected with consideration of the reasons for undertaking the intervention, the conditions under which the execution will have to be carried out and the conservation strategy required after the intervention is made, so that the purpose of the intervention can be achieved in the most reliable way. Ease of conservation after intervention has also been taken into account. Accordingly to Model Code options (Figure 8), the selected option was the number 2, which envisages to restore the performance and to lessen the deterioration rate.

In order to reduce the humidity level, a large-scale intervention is needed. Pipes should be checked, laundry steam channelized, air circulation increased and solutions for soil capillarity effects avoiding adopted. Walls, partitions and pillars should be dehumidified by creating a chemical barrier with hydro-repulsive abilities but assuring perspiration: in this way pores are modified and lose the tendency of absorbing soil water. A macro porous and anti-moisture plaster is also necessary, at least up to 1.5 m from the floor. The diagnostic campaign highlighted that pillars restoration should be targeted depending on a pillar's individual damage. This would allow a correct restoration plan to be programmed and a realistic restoration cost to be estimated. The main goal is the reinforcements restoration, that should be achieved by removing any damaged concrete covering and by cleaning bars carefully through brushing and sand blasting. All operations should be done manually, not producing excessive vibrations and not damaging healthy concrete either. Next, bars should be treated with an appropriate product in order to restore their passive layer. After this, the concrete pillar transversal section should be restored by adopting different tactics depending on bars diameter reduction.

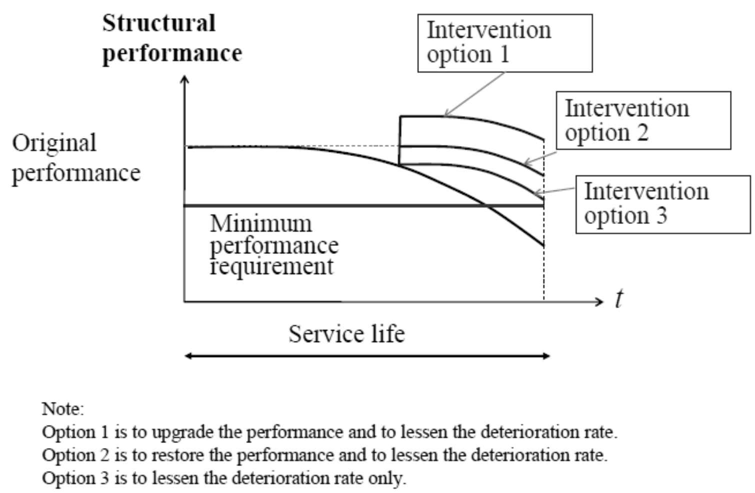

Figure 8. Schematic for intervention option selection in Model Code 2010.

7 CONCLUSIONS

The paper illustrates the implementation of conservation strategies and tactics as recommended by Model Code 2010. The presented case study concerns a damaged reinforced concrete building without a Condition Control Plan in place. According to Model Code 2010, a reactive conservation strategy has been adopted, based on remedial measures and interventions aimed at arresting currently active processes which are causing deterioration or damage. The condition survey has been run via several NDT, in order to get the most reliable data with limited costs and limited interference with the building functionality. Outcomes of the diagnostic campaign pointed out the kind and the level of degradation, thus allowing condition assessment, evaluation and decision making on intervention.

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