1 PATHOLOGY - 1.4 Diagnostic Techniques

"QUALIFICATION" METHOD FOR THE REINFORCED CONCRETE STRUCTURE

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ABSTRACT

The study aims to show a recovery intervention of reinforced concrete buildings, that present signs of decay and deterioration. In the reinforced concrete structures, the most important properties can be obtained using the "destructive" tests (that require a local removal of material) and "non-destructive" tests such as the sclerometer test, the ultrasonic test and the combined method called "SonReb"can be used. The combined results from different "non-destructive" tests are very interesting instruments to assess the concrete strength. This methodological approach can help to reduce the possible errors when using the sclerometer and ultrasonic tests separately; in this way, the combined method called "SonReb" (SONic + REBound) was developed. Using a combined method it is possible to balance some of the errors made when the two methodologies used separately. The above defined methodology has been tested on a building which is located in Matera (Italy): the "Annunziata" Brickwork; it was built in 1953 and it started the production in 1955. The kiln was built using a reinforced concrete structure and brickwork for the external envelope; the roof was realized using wooden structures. The diagnostic tests have shown a suficiently high ultrasonic speed and homogeneous surface values for all the pillars of the lower and middle level, but bad conditions for the upper level. These data were compared with the method "SonReb" to improve the qualitative interpretation of results.
This approach is useful for classifying the pathological events of a building and to implement the solutions to improve the durability of a recovery intervention.

Keywords: reinforced concrete structure, diagnostic tests, methodological approach

I. INTRODUCTION

The conservation intervention on a building is generally more appropriate if information on its construction, evolution to date, materials, construction techniques and structure is available. To undertake a suitable intervention, three questions have to be answered: whether, where and how to restore. The fourth question could be added, in which the economic aspect dominates: when to restore. To be able to respond adequately to these questions, it is necessary to proceed by developing specifications step by step, starting from a detailed knowledge of the entire building, the level and causes of degradation, and by finishing with the "operational" description of the proposed interventions. In other words, a more "flexible" approach is required, capable of interpreting the unique character of buildings in an area. The above premises form the foundation of a "global" methodological approach whose objective is to define performance requirements which will enable the selection of adequate intervention actions. Therefore, the first phase of this approach could consist of identification of the technical and technological options that meet the performance required from the building and the whole context of traditional architecture that will enable the transformation while preserving the character of built heritage. The second phase could define the criteria and methods for an appropriate intervention by assessing the compatibility of identified options and a building. Realising an intervention by applying the methods developed through this "global" approach enables determining a "well-balanced" attribution of the historical, functional, economic, technical and other values which can sometimes have conflicting aims.

II. THE METHODOLOGICAL APPROCH

The investigative techniques for concrete are also classified in two defined macro-categories ("destructive" and "non-destructive"). They are regulated[1] by the European standards UNI 6131:2002, UNI 6134:1972, UNI EN 12504-1 2002. The second investigative typology, the nondestructive tests, can be further subdivided in: really "non-destructive" investigations and "partially destructive" investigations. The latter include: (a) the penetration test with a Windsor gun (ASTM C 83) which enables the identification of compressive resistance of concrete by measuring the depth of penetration of the special metal pins projected with a Windsor gun into concrete, (b) the extraction test (pull-out) (UNI 10157:1992-ASTM C 900-06) which enables the assessment of compressive resistance of concrete by measuring the force used by a hydraulic jack for extracting a special plug inserted into concrete. The really non-destructive investigations include, among others: (a) endoscopy that enables a direct observation of form and appearance of an investigated object, (b) thermography that assists in recognising potential structural anomalies by using the capacity of materials to transfer heat; (c) magnetometry which enables localising metal bars in reinforced concrete; (d) measurement of the electric potential of concrete which enables defining the level of corrosion of metal reinforcements in concrete; (e) ultrasound investigation that allows qualitative assessment of the concrete resistance by using the capacity of the concrete components to transfer ultrasound waves; (f) sclerometric tests that assess the concrete resistance by reading the bounce results, and finally, (g) so called "SonReb" (SONic + REBound) that enables assessing the concrete resistance by combining the speed of ultrasound waves and the index of surface bounce through a synergic use of the two previous investigations.

[1]RILEM Draft Recommendation, 43-CND. Combined non-destructive testing of concrete. Draft recommendation for in situ concrete strength determination by combined non-destructive methods. Materials and Structures n. 26, 1993, pp.37-52.

III. THE “SONREB” METHOD FOR QUALIFYING THE CONCRETE

The SonReb method, as mentioned in the previous paragraph, allows a qualitative determination of the concrete resistance4 through the cross-examination of the values of the speed of ultrasound waves and the values of sclerometric rebounce. This investigation method is standardised by RILEM Recommendations[2] 43 CND - EN 13791:2007, the EC regulation 1-2010 UNI EN 12504-2:2001, ASTM C597, UNI EN 12504-4:2005, the Test Report CUR 69, the standards UNI 7997, UNI 9524 and UNI 83308. The SonReb Method (Sonic+Rebound) uses the combined results provided by the above described tests that incorporate a useful instrument for assessing the resistance of concrete[3], enabling the elimination of errors, at least partly, that appear when the two investigation methods are separately applied. This method, in fact, allows reducing the errors made when the sclerometric and ultrasound tests are undertaken separately[4]. SonReb method, therefore, allows a quick and an economic way to obtain reliable qualitative results on the resistance of in situ concrete[5]. The application of Sonreb method requires the evaluation of values of ultrasonic speed “V” and “S” rebound index, from which it is possible to get the “Rc” concrete resistance using expressions as:

a) Rc1 = 9,27 * 10-11 * S1,4 * V2.6 RILEM[6] [1]

b) Rc2 = 8,06 * 10-8 * S1,246 * V1,85 J.GASPARIK[7] [2]

c) Rc3 = 1,2 * 10-9 * S1,058 * V2,446 DILEO,PASCALE[8] [3]

where “Rc” is the cubic compressive resistance in [N/mm2], “S” is the rebound index and “V” is the ultrasonic speed in [m/s]. The evaluation of concrete resistance can also carry out using diagrams (using “V” and “S” as Cartesian coordinates) containing isoresistance curves. Those curves are obtained by the expressions above.

IV. THE CASE OF STUDY: THE “ANNUNZIATA” BRICKWORK IN MATERA

Plate 1 - Brickwork “Annunziata”

The case study is the Brickwork “Arcangelo Annunziata” (Plate. 1) in Matera (Italy). The building was built in the years '50 and for 25 years has represented the most important industrial factory in Matera. The interest in the re-discovery of the cultural and architectonic values of “Industrial Archaeology” has developed simultaneously with that of the reuse of these architectonic complexes. Brickworks are a constant presence in the

[2] RILEM (The International Union of Testing and Research Laboratories for Materials and Structures) is an organisation which enables exchanges through an international network of testing engineers, researchers, academics, educators and practitioners.

[3] Giochetti R., Lacquaniti L., *Controlli non distruttivi su impalcati da ponte in calcestruzzo armato,* Nota Tecnica 04, Universita degli Studi di Ancona, Facoltà di Ingegneria, Istituto di Scienza e Tecnica delle Costruzioni, 1980.

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[7] J. Gasparik, 1992. Prove non distruttive nell’ edilizia, quaderno didattico AIPnD, Brescia .

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landscape. The Brickwork "Annunziata" is an important "monument" of Industrial Heritage in Matera. It - in which there was a "Hoffmann" [9] kiln for bricks, now destroyed – was realized in various building, built using different shape, materials and technologies.

The main building was built in a concrete structure; it is 74 metres in length, has a sequence of 15 spans and three floors. The external envelope was a brickworks with a series of windows regularly organized. The bearing structure is formed by reinforced concrete beams and pillars that divides the interior space into five naves: the central one (Plate. 2) appears with a double-height pillars, covered with firebricks (in fact there was a kiln, as witnessed by the ruins still present). The side naves, close for the central one, develop a height twice the perimeter naves; the perimeter naves have a "margherita"[10] floor at an height of 3,40 m from the ground floor. The horizontal structure on the second floor is at an height of 7, 20 m from the ground floor; the reinforced-concrete slab has holes to drop the hot air coming from the kiln to the third floor. Here, there are the pillars that support the roof trusses. The chimney, that through the building from the kiln on ground floor up to the roof, is collapsed. Now the Brickwork is abandoned and in an evident state of deterioration caused largely by the presence of meteoric water. In fact, one of the most important causes of degradation is the meteoric water (that generates the crystallization of salts, which catalyzes in many chemical degradation processes (carbonation, sulphation, salts) and makes possible the growth of biological organisms). The reinforced concrete structure, among the consequences of the roof collapse, shows a high level of surface carbonation of pillars and beams; it is evident the separation of iron coverage due to the oxidation of the bars in the concrete. The signs of degradation have different causes due to chemical, physical or mechanical components; except for biological and man-made "aggressions", the signs are related to the conglomerate porosity: as much it's greater the concrete porosity as it's greater the probability that take place anomalies.

Plate 2 - The central nave

V. THE ANALISYS AND RESULTS

To carry out the analysis, it is numbered each pillars and beams in the main building of Brickwork. After the ultrasonic and sclerometric tests, the obtained results were included in a spreadsheet to calculate the average value of rebound index and average speed. These two values have been inserted in another spreadsheet to develop the SonReb method, according to the most representative methods (see above [1], [2] and [3]), obtaining three distinct values that are used to calculate the average "Rc". This processing has been carried out for the whole the mail building of the "Annunziata" Brickwork. The tables below show – as an example - a synthesis of the results (Table.1).

The obtained values would be considered as qualitative indications: in fact the used correlations, taken from literature and relating to a specific concrete reference, cannot be

[9] A.Carena, *L'industria dei laterizi: tecnologie ed impianti*, Lattes, Torino 1922.

[10] The "margherita" floor is the typical floor thrown entirely in situ; it is realized using a concrete casting, pots and steel, without use of prefabricated joists. It is the main floor used in the past.

extended directly to different concretes, especially when, as in this case, the concrete has a considerable age.

Riferimento:	S1	S2	S3	S4	S5	S6	S7	S8	S9	S_{Media}/Iv
TRAVE 1-2	42	43	44	41	43	42	43	44	41	43
TRAVE 1-7	40	41	40	39	42	41	41	38	39	40
TRAVE 2-3	39	40	42	43	41	42	40	40	38	41
TRAVE 3-4	41	40	43	38	39	40	40	39	40	40
TRAVE 4-5	41	40	43	43	44	40	40	41	42	42

Velocità US -->	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V media
Riferimento:	m/s	m/s	m/s	m/s	m/s	m/s	m/s	m/s	m/s	m/s	m/s
TRAVE 1-2	3930	3901	3924	3895	3890	3930	3884	3901	3868	3874	3900
TRAVE 1-7	2521	2552	2531	2521	2555	2539	2555	2527	2539	2555	2540
TRAVE 2-3	3649	3658	3648	3609	3608	3658	3608	3647	3648	3658	3639
TRAVE 3-4	3532	3544	3537	3542	3549	3551	3567	3544	3523	3549	3544
TRAVE 4-5	3812	3823	3807	3794	3808	3777	3801	3814	3823	3806	3807

S	V	Rc,1	Rc,2	Rc,3	Rc,medio
N/mmq	m/s	N/mmq	N/mmq	N/mmq	N/mmq
43	3900	38	38	39	38
40	2540	12	16	13	13
41	3639	30	31	31	31
40	3544	27	29	29	28
42	3807	35	35	35	35

$Rc_{r1} = 9{,}27 \times 10^{-11} \times S^{1{,}4} \times V^{2.6}$ RILEM
$Rc_{r2} = 8{,}06 \times 10^{-8} \times S^{1{,}246} \times V^{1{,}85}$ J.GASPARIK
$Rc_{r3} = 1{,}2 \times 10^{-9} \times S^{1{,}058} \times V^{2{,}446}$ DILEO,PASCALE

$Rc \geq 15$ N/mmq

S= 28÷32

V= 3200 ÷ 3600 m/s

Riferimento:	S1	S2	S3	S4	S5	S6	S7	S8	S9	S_{Media}/Iv
PILASTRO 1	40	40	38	39	38	37	40	38	41	39
PILASTRO 2	40	40	41	42	43	40	39	38	39	40
PILASTRO 3	38	38	39	41	38	37	42	38	42	39
PILASTRO 4	40	40	40	38	38	40	42	40	40	40
PILASTRO 5	32	36	36	36	40	40	40	40	40	38

Velocità US -->	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V media
Riferimento:	m/s	m/s	m/s	m/s	m/s	m/s	m/s	m/s	m/s	m/s	m/s
PILASTRO 1	2064	2122	2107	2133	2086	2156	2127	2156	2162	2141	2125
PILASTRO 2	3511	3499	3592	3542	3546	3539	3558	3574	3487	3477	3533
PILASTRO 3	3616	3484	3561	3594	3577	3593	3600	3587	3597	3593	3580
PILASTRO 4	3784	3802	3809	3820	3813	3824	3827	3895	3816	3816	3821
PILASTRO 5	3606	3619	3610	3610	3600	3616	3613	3610	3606	3613	3610

S	V	Rc,1	Rc,2	Rc,3	Rc,medio
N/mmq	m/s	N/mmq	N/mmq	N/mmq	N/mmq
39	2125	7	11	8	9
40	3533	27	29	29	28
39	3580	27	29	29	28
40	3821	33	34	34	34
38	3610	27	28	28	28

$Rc_{r1} = 9{,}27 \times 10^{-11} \times S^{1{,}4} \times V^{2.6}$ RILEM
$Rc_{r2} = 8{,}06 \times 10^{-8} \times S^{1{,}246} \times V^{1{,}85}$ J.GASPARIK
$Rc_{r3} = 1{,}2 \times 10^{-9} \times S^{1{,}058} \times V^{2{,}446}$ DILEO,PASCALE

$Rc \geq 15$ N/mmq

S= 28÷32

V= 3200 ÷ 3600 m/s

Table 1 – An example of results synthesis

In particular, as regards the pillars, the tests give good results, with resistance by 20 ÷ 40 N/mm2 (except for some cases where there are low results, even under 15 N/mm2 – lowest value imposed by Italian Norm). It is calculated the average of the rebound index (from 33 ÷ 43), all exceeding the rebound values that is from 28 ÷ 30 (as said in the norm), related to similar concretes; it is hypothesized that the sclerometric test has been conditioned by the large size of the aggregates and by the ratio cement-aggregate, visible where it lacks the iron cover and from carbonation. By ultrasonic test it is possible to calculate the speed inside the element (as said before); those values are higher than the acceptable values proposed in literature (3300-3500 m/s). While, for the beams the values differ for plans; in fact, the values obtained decrease while increasing the plan: the beams on the ground floor and first floor are relatively protected from the meteoric water (except for perimeter beams that are directly exposed to it); on the second floor, due to the collapse of the roof, the beams are always subject to atmospheric phenomena which have decreased the concrete resistance. The results of the second floor are not "acceptable" because the cracks in the structures are visible and create voids in the concrete, making it non-homogeneous and, therefore, unfit to be subjected to ultrasonic test. The SonReb method reproposes the above conducted evaluations through the comparison of the calculated values from each test performed; it provides a qualitative indication on the strength of concrete, regarding also its deterioration conditions. By reading the values obtained and those stated in the literature, it is possible to argue that the analyzed brickwork makes an acceptable structure concrete resistance that meets the limit values in literature. However, for more reliable results, the tests should be implemented, using a pacometric test (to detect the presence and position of the metal bars in the concrete elements) and verify the state of depth of carbonation.

VI. CONCLUSIONS

The study was carried out within the framework of the recovery of Industrial Heritage in an area, such as Basilicata (Southern part of Italy), that has not known a real stage of industrialization. The Recovery Project – that takes particular care in the methodological application of the diagnostic phase - cannot leave out of consideration the necessity of a careful and timely monitoring of building conditions. The carried out tests are the first and simplest analysis for a qualitative assessment; it is necessary to classify the structure regarding the following consolidation procedures. The recovery and conservation project, as well as an "indispensable" transformation of an old industrial factory, must be in that evaluations - of feasibility and suitability, both economic and practice - the basis for a "suitable choice" of recovery intervention, that permit to annul the "cancellation" of the "Archeo-industrial Heritage".

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