

Inspection and diagnosis of corrosion in reinforced concrete buildings of the cultural heritage

Introduction

Since the beginning of the 20th century, in Italy as in many other countries, reinforced concrete became one of the most popular construction materials and it was used for buildings, monuments, infrastructures and industrial structures. This work describes a study on several structures, that although of recent formation, have now been included in the cultural heritage, because of their architectural or social relevance (Figure 1, Table 1). As a consequence of the typical urban or rural exposure conditions of these buildings, they often suffer damage due to carbonation-induced corrosion of reinforcement, often associated with the presence of low values of concrete cover thickness (Figure 2).

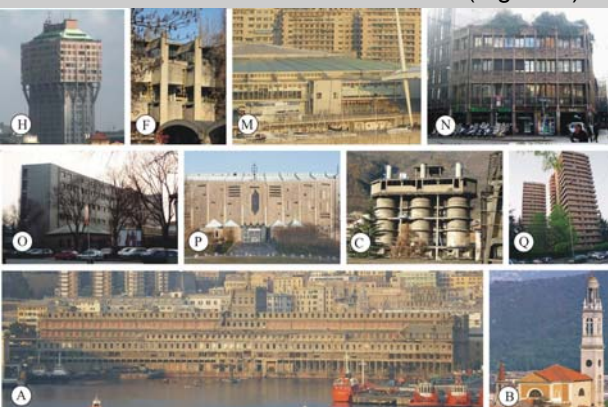


Figure 1 - Some examples of the inspected structures (labels refer to the designation of the buildings according to Table 1).

Evaluation of RC structures of the cultural heritage

Proper inspection and a correct diagnosis of the causes of corrosion as well as the evaluation of the development of corrosion in the future are essential in order to select the most appropriate repair technique. Table 2 shows the main results of the inspection on the reinforced concrete structures, made by means of both analyses on concrete and non-destructive techniques.



Figure 2 - Effects of corrosion (labels refer to the designation of the building according to Table 1).

Table 1 - Main features of the buildings subjected to corrosion assessment.

Building	Type	End of construction	Age ⁽¹⁾	Environment (Location)	Coating
A	Industrial building	1901/1945/1960	104/60/45	Urban-Marine (Genoa)	Render
B	Bell Tower	1926	78	Como lake (Valmadrera)	-
C	Industrial building	1942	63	Alps (Sellero)	-
D	School	1950	55	Urban (Milan)	Render
E	College	1951	52	Urban (Milan)	Tiles
F	College/School	1957	46	Urban (Milan)	-
G	Covered market	1957	48	Padana Plain (Crema)	Render
H	Residential/Office	1958	51	Urban (Milan)	Render/-
I	Office	1959	44	Urban-Marine (Bari)	Render
L	University building	1960	42	Urban (Milan)	Tiles
M	Sport building	1960	45	Urban-Marine (Genoa)	-
N	Residential/Office	1965	38	Urban (Milan)	-
O	University building	1965	38	Urban (Milan)	Tiles
P	Church	1967	42	Urban (Milan)	-
Q	Residential	1976	27	Urban (Milan)	Render

⁽¹⁾ Number of years from the construction until the time of inspection.

Table 2 - Summary of the main findings of the inspection of the buildings, regarding: Schmidt hammer tests, concrete cover thickness, carbonation depth under inside and outside exposure, total chloride content at steel depth by mass of cement.

Building	A/01	B	C	A/45	D	E	F	G	H(s)	H(d)	A/60	I	L	M	N	O	P	Q
Age (years)	104	78	63	60	55	52	46	48	51	51	45	44	42	45	38	38	42	27
Schmidt hammer	#	100	290	10	30	-	350	50	-	-	30	200	60	170	91	421	81	-
strength (MPa)	M	48	60	51	69	-	69	51	-	-	66	48	66	62	69	69	60	-
ave		36	33.2	38.2	50.7	-	56.6	33.9	-	-	57.6	33	46.6	43.6	43.9	54	52.8	-
Cover thickness (mm)	#	128	149	-	105	10	319	53	317	100	10	157	14	145	72	33	205	38
M		0	<5	-	21	30	7	0	19 ⁽¹⁾	5	28	2	22	<5	0	7	0	11
ave		59	44	-	47	48	48	53	80 ⁽¹⁾	57	40	54	35	57	45	54	56	59
Carbonation inside (mm)	#	2	-	-	2	6	4	-	-	-	-	18	-	2	2	-	-	12
M		54	-	-	55	20	18	24	-	-	-	-	-	16	25	-	-	9
ave		82	-	-	175	70	80	55	-	-	-	86	-	20	34	-	-	35
K		7.1	-	-	118	47.5	42.8	44.0	-	-	-	50.5	-	19.0	30.5	-	-	21.7
ave		7	-	-	15.2	6.4	5.9	6.5	-	-	-	7.6	-	2.8	4.9	-	-	4.2
Carbonation outside (mm)	#	25	14	-	-	20	16	8	53	22	2	3	2	7	7	4	11	9
M		0	7	-	-	0	0	5	0 ⁽¹⁾	0	0	0	0	7	6	5	0	3
ave		95	100	-	-	78	58	77	56 ⁽¹⁾	>60	6	20	15	33	49	19	32	35
K		31.3	57.5	-	-	23.6	28	43.5	24 ⁽¹⁾	>21	4.5	12.7	10	25.6	38.8	14.8	12.5	16.1
ave		3.5	7.2	-	-	3.3	4.1	6.3	-	>2.9	0.7	1.9	1.5	3.8	6.3	2.4	1.9	3.1
Chlorides (%mass)	M	-	-	0.2	-	<0.1	<0.1	-	<0.1	<0.1	0.15	0.4	-	0.4	0.12	<0.1	<0.1	-

(# = number of measurements; m = minimum value; M = maximum value; ave = average value; K = carbonation coefficient, in mm/year^{0.5}, estimated from the average depth of carbonation). ⁽¹⁾ Including the thickness of the coating made of a layer of plaster (thickness in mm: m = 5, M = 27, $\sigma = 13$) plus a layer of cementitious mortar (thickness in mm: m = 5, M = 50, $\sigma = 17$). H(s) and H(d): respectively structural and decorative elements.

Restoration of RC structures damaged by corrosion

Due to strict requirements related to the preservation of the original materials and texture, the repair of structures that belong to the cultural heritage cannot rely on the conventional repair technique. Therefore, the conservation of these reinforced concrete buildings requires the development of restoration techniques with the aim to ensure lasting protection of the structures and the materials themselves.

The paper summarizes some of the studies carried out by the laboratory of Durability and Cementitious Materials of the Department Chimica, Materiali e Ingegneria Chimica, "G. Natta" of Politecnico di Milano. Specific techniques for the restoration of reinforced concrete structures belonging to the Cultural Heritage were also developed and tested by the lab. Details can be found on the web-site: www.chem.polimi.it/mcd.