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NON-DESTRUCTIVE ASSESSMENT OF CONCRETE DURABILITY OF THE NATIONAL MUSEUM OF WESTERN ART IN JAPAN

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Abstract

The National Museum of Western Art (NMWA), designed by Le Corbusier and constructed in 1959, is an important cultural landmark of Japan. A working group (Chairman: Prof. Hiroyuki Suzuki, Aoyamagakuin Univ.) established under the Architectural Institute of Japan, assessed the condition of the structural concrete of this building, with the aim of devising a maintenance strategy in order to register the building as a national heritage site. This paper reports on the phenomenon responsible for the degradation and deterioration of the structural concrete members in the NMWA building, such as the steel corrosion risks due to carbonation. Non-destructive test (NDT) methods were employed for measuring the air permeability of the concrete cover and the cover thickness in order to assess the steel bar corrosion risk due to carbonation.

1. INTRODUCTION

The National Museum of Western Art (NMWA), designed by Le Corbusier and constructed in 1959, is an important cultural landmark of Japan. A working group established under the Architectural Institute of Japan, assessed the condition of the structural concrete of this building with the aim of devising a maintenance strategy in order to register the building as a national heritage site. Authors reported on the phenomenon responsible for the degradation and deterioration of the structural concrete members in the NMWA building, such as the excessive deflection of slab, presence of cracks, and corrosion risks due to carbonation [1]. In this paper authors will report on non-destructive (NDT) assessment of the steel bar corrosion due to carbonation of the structure as a whole. NDT methods were employed to determine the air permeability of a concrete cover in order to assess the steel corrosion risk due to carbonation. It was found that this historical reinforced concrete structure would face to the significant degradation. Reasonable repair methods that will also maintain the authenticity of this structure will be required in the near future. It is believed that many historical reinforced concrete buildings worldwide might suffer from similar types of degradation. This paper will provide a perspective to assess the condition of buildings, whose authenticity should be maintained.

2. THE NATIONAL MUSEUM OF WESTERN ART

The NMWA (Photograph 1 and Figure 1) was constructed in 1959 with a concrete design strength of 18 MPa. Further details of the building and specifications of the concrete mixture are listed in Table 1 and 2, respectively. Round bars with a yield strength of 235 MPa were used for reinforcement [2].

Photograph 1: Appearance of the NMWA

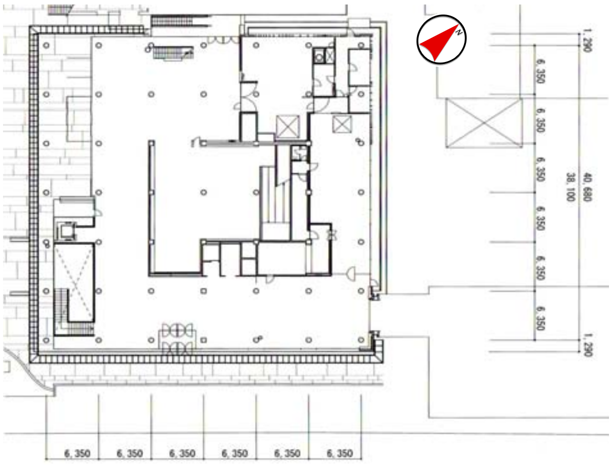


Figure 1: Plan of 1st floor

Table 1: Details about NMWA

Location	Ueno Tokyo
Completion	29 May 1959
Designer	Le Corbusier
Assistant designer	Junzo SAKAKURA, Kunio MAEKAWA, and Takamasa YOSHIZAKA
Structural design	YOKOYAMA structural design office
Contractor	SHIMIZU Corporation
Ground area	1,587 m^2
Total floor area	4,353 m^2
Height	11.46 m
Type of structure	Reinforced concrete 3 stories

Table 2: Concrete composition

Materials		Unit content
Water	-	204 kg/m^3
Cement	Ordinary Portland cement	340 kg/m^3
Sand	Sagami/Koito River	921 kg/m^3
Gravel	Crushed stone (Futo) Max.20 mm	829 kg/m^3
Admixture	Air entraining agent	-

3. OUTLINE OF RESEARCHES

3.1 On-site air permeability test

According to the results of the preliminary investigations [1], [2], a detailed investigation on the deflection of the slab and the carbonation progress of concrete was carried out. The National Museum of Western Art (NMWA) is an important cultural landmark of Japan. In order to maintain the authenticity of the building, non/minor destructive test methods (NDT/MDT) were performed. A combination of a small core sampling test and a non-destructive on-site air permeability test [3] was performed to determine the carbonation progress of the concrete structures and also to minimize the impact on the concrete appearance. The method described here is known as the ‘Torrent Permeability Tester’ and was developed in Switzerland. In this test, the pressures in the outer and inner chambers are always maintained at the same value. Thus, the outer chamber acts as a 'guard-ring', providing a controlled, unidirectional flow of air into the inner chamber (see Figure 2). The latest report by RILEM TC NEC [4], mentioned two advantages of this system: (1) The spurious air entering through preferential paths (e.g. micro cracks or extremely porous outer skin) is absorbed by the outer chamber, and thus, it does not affect the measurements, and (2) This method is entirely non-destructive without unsightly spot on the concrete surface.

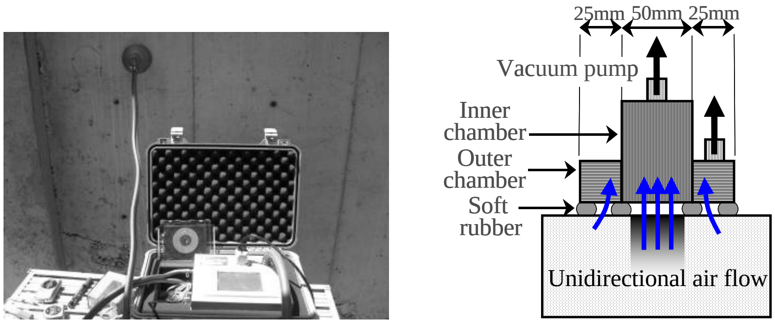


Figure: 2 Schematic description of Torrent permeability tester

3.2 Small core sampling

Small core specimens with a diameter of 20 mm were drilled in the structure in order to determine the relationship between the air permeability coefficient (kT) and the carbonation progress of concrete. The carbonation progress was measured, as shown in Photographs 2 and 3. After the core drilling, grout for the repair was injected into the hole and the sliced surface of the core was installed back into the structural member (see Figure 3). This process enables the impact of the core drilling to be invisible as shown in photograph 4.

Photograph 2 : Core drilling

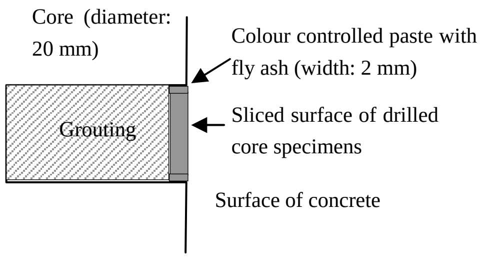
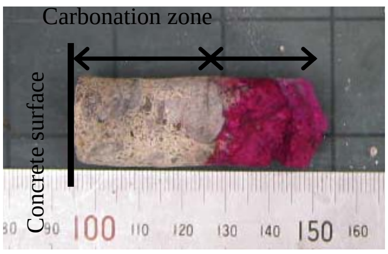
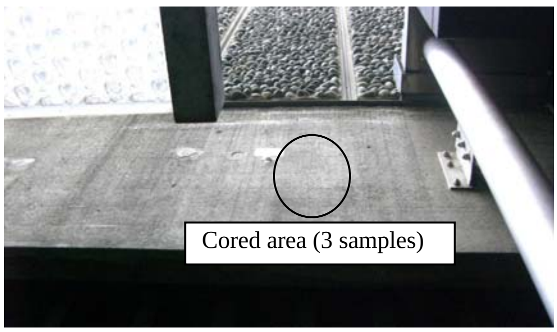


Figure 3 : Schematic description of repair of drilled hole



Photograph 3 : Carbonation of specimens



Photograph 4 : Impact of core drilling after repair (shown in Fig.3)

3.3 Radar test

The concrete cover depth and the steel bar arrangement were measured with a radar device shown in Photograph 5. This method utilizes the reflection of the radar from the device onto a steel bar installed in a concrete member. The receiver measures the round trip time, from which the position of the steel bar can be detected based on the relationship between the velocity and time of radar in concrete.

Photograph 5 : Radar device

4. RESULTS AND DISCUSSION

4.1 Carbonation progress

The carbonation depth was measured by conducting small core sampling tests at several places in the NMWA. Figure 4 shows the carbonation progress of concrete; carbonation gradually progresses with time and varies from 5 to 35 mm at the age of 50 years (2010). On the exterior wall, carbonation reaches up to 40 mm, and half of the steel bars face the risk of corrosion (the corrosion rate being 50%) 55 years later, based on the assumption that the cover thickness of the exterior wall is 40 mm.

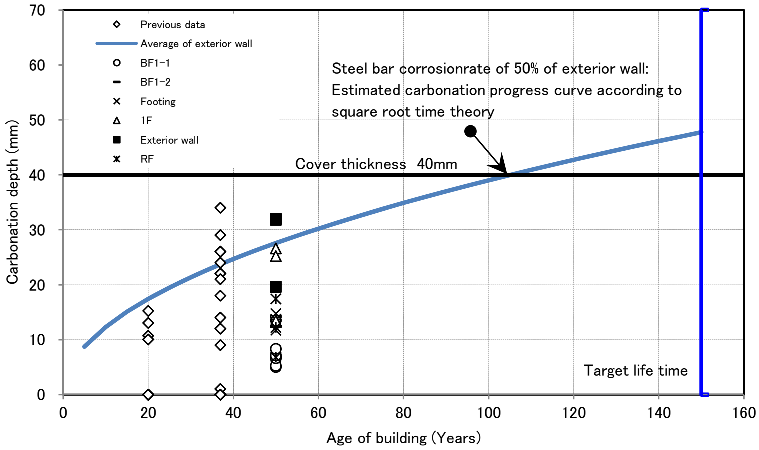


Figure 4: Carbonation progress of concrete by small core sampling test

Figure 5 shows the relationship between the carbonation velocity based on the square root theory and the air permeability coefficient (kT) of concrete. It can be seen that a good agreement can be obtained between them and the air permeability tester can be considered to be a suitable tool for estimating the carbonation progress of concrete in a non-destructive manner. Based on this finding, the steel bar corrosion risk of the north-side of the building (see Fig.6) was evaluated. Figures 7 and 8 show the distributions of carbonation depth, estimated through the air permeability test, and the cover thickness of the steel bar, measured through the radar test. Assuming that the steel bar would corrode if the carbonation depth exceeds the cover thickness, the corrosion rate of the steel bars in the north-side exterior wall can be evaluated as shown in Fig.9. According to a criterion of Architectural Institute of Japan (AIJ), the building will face to the end of its life time when the corrosion rate is over 20% [5]. In this case, the situation will come 25 years later. This result roughly meets to the evaluation obtained by core sampling test shown in Fig.4. Furthermore, evaluations of steel bar corrosion of structure as a whole (see. Fig.10) were performed according to AIJ guideline shown in Table 3. It can be seen that bottoms of slabs would face to significant deterioration as shown in Fig.11. This result well meets to the visual inspection of the bottom of slab. Hence, on- site air-permeability test will have a good perspective for the non-destructive condition assessment of NMWA.

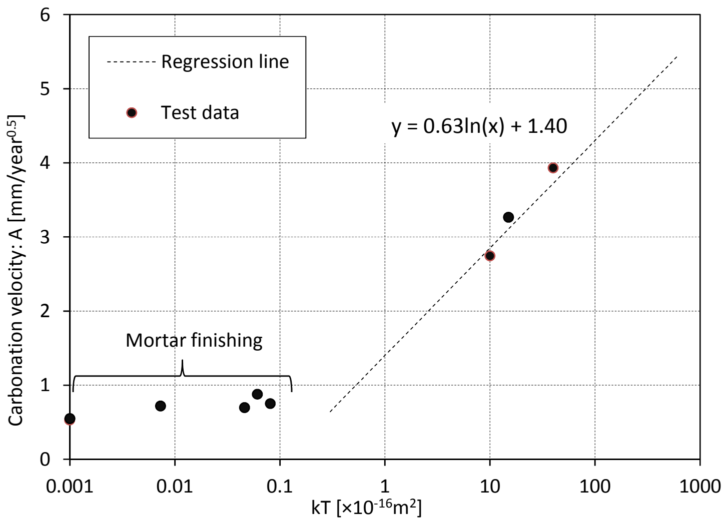
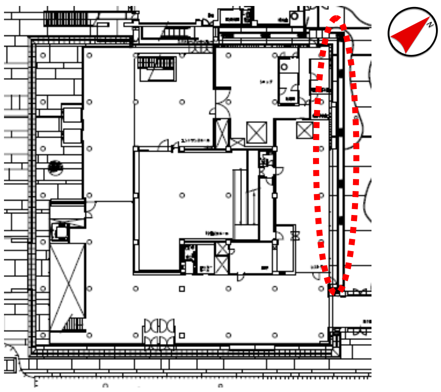


Figure 5: Relationship between carbonation and air permeability



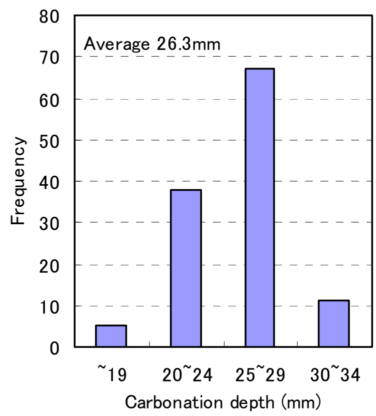


Figure 7: Distribution of carbonation depth

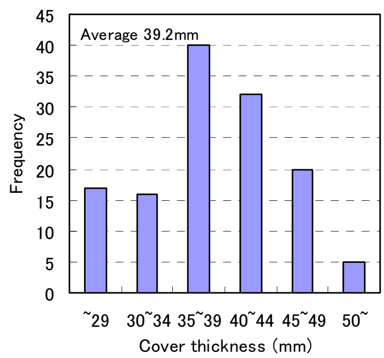


Figure 6: North-side of NMWA

Figure 8: Distribution of cover thickness

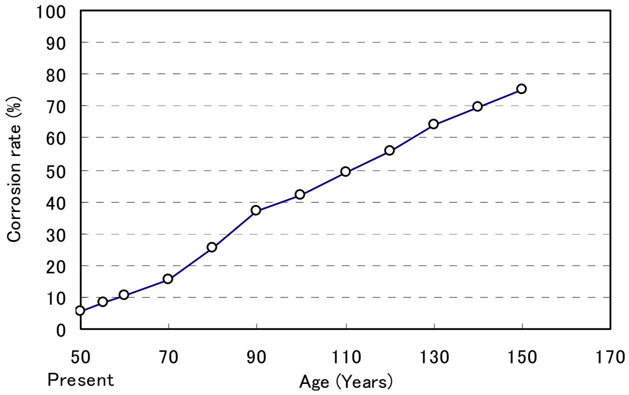


Figure 9: Progress of steel bar corrosion rate in north-side exterior wall

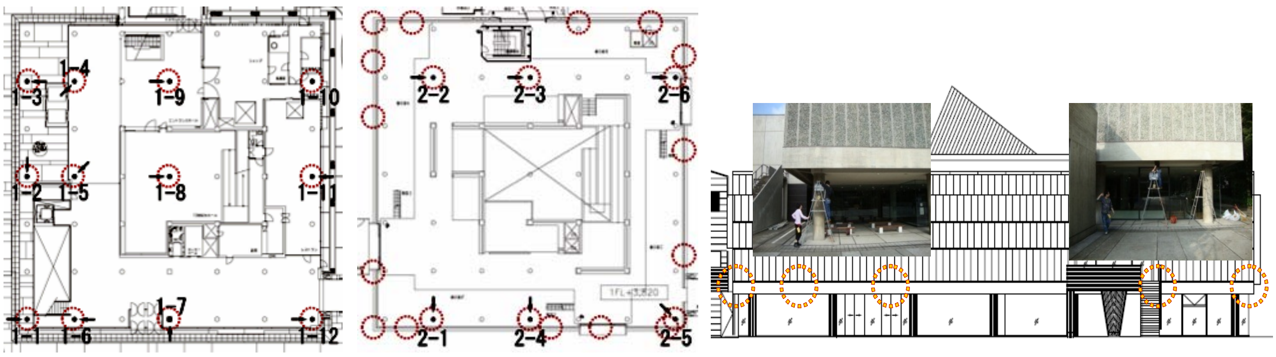
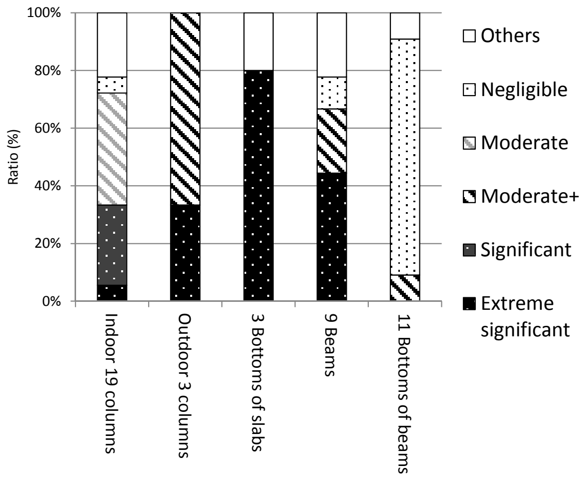
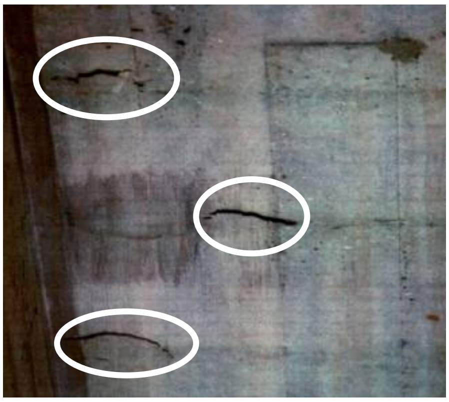


Figure 10: Tested points in NMWA

Table 3: Criterion of steel bar due to carbonation proposed by AIJ [6]

Corrsion risk	Ratio of carbonation depth to cover thickness (Cmm)	
	Outdoor	Indoor
Negligible	less than 0.5C	less than 0.7C
Moderate	from 0.5C to 1.0C	from 0.7C to 1.0C+20mm
Significant	Over 1.0C	Over 1.0C+20mm





Visual inspection of bottom of slab

Figure 11: Rate of steel bar corrosion in NMWA

5. CONCLUSION

The National Museum of Western Art is an important cultural landmark of Japan, and it is over 50 years old. The concrete carbonation depths of this building were investigated using non/minor destructive methods (NDT/MDT). It was found that concrete carbonation caused the significant risk of corrosion of steel bars. A non-destructive method, on-site air permeability test, and radar test were useful for assessing the risk of steel bar corrosion. The development of a suitable repair method will be required in the near future to maintain the authenticity of the building.

ACKNOWLEDGEMENTS

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