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Performance of 90-year-old concrete in a historical structure

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HIGHLIGHTS

- Aged concrete in a historical structure were investigated.
- Mechanical properties of aged concrete were measured with core samples.
- The results are compared with the test results by non-destructive methods.
- Overall performance of aged concrete was evaluated.

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ABSTRACT

Surface and subsurface defects, such as the scaling of a concrete surface, corrosion of the reinforcement, carbonation of concrete, cracks in concrete, etc., are often observed in historical structures. In order to assess the performance of the aged concrete in a historical structure, a combination of impact echo and ultrasonic surface wave techniques as well as ground penetrating radar (GPR) are believed to be the most effective approaches to determine not only the overall quality of the concrete in the structural components, but also the extent of any internal deterioration that may be present in the structure. In this study, the field evaluation of the old concrete in a historical reinforced concrete structure (a stadium) has been conducted using destructive and nondestructive methods. The extent of the damage and unseen patterns of concrete deterioration were determined successfully based on the results obtained using GPR and a seismic property analyzer. In addition, the material properties of the old concrete were compared to laboratory test results.

1. Introduction

The historical reinforced concrete structure that is the focus of this study is the World War Memorial Stadium in Greensboro, North Carolina that was constructed in the mid 1920s. Cast-in-place reinforced concrete seating slabs, raker beams, and columns make up the primary structural system. Forty-foot tall towers at the entrance are covered with an exposed aggregate cementitious coating. An open roof structure supported on steel columns covers about two-thirds of the area planned for rehabilitation. Although properly embedded steel in concrete with a sufficient concrete cover can resist corrosion, chlorides from de-icing salts or addition at the time of mixing can provide an environment that sustains corrosion. The stadium appears to have experienced this type of deterioration.

The structural condition of the stadium has been evaluated over a number of years. Sutton-Kennerly & Associates, Inc. prepared evaluation reports in 2003 and 2008. The first report was mainly a description of the damage that was visually apparent and the latter one was based on a limited investigation into the quality of the concrete in the structure [1]. According to the 2008 inspection report [1], field tests were conducted at four randomly selected locations to determine the total acid soluble chloride content of the seating slab. The testing included samples obtained from both the top and underside of the slab because of the variable quality and thickness and relatively thin nature of the slab. Typically, concentrations of chloride between about 0.03–0.06 percent by mass of total concrete (0.0007–0.0014 g/cm^3 of concrete) are sufficient to initiate corrosion, although the percentage can actually be much higher than that in certain conditions. Although specific statements with regard to profiles of particular locations cannot be made about this study's historic structure due to the limited nature of the earlier testing and the different locations of the reinforcing steel throughout the slab, the 2008 report results (See Table 1)

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Table 1
Measured total acid soluble chloride content [1].

Test location	Slab depth (mm)	Depth of powder sample (mm)	Total acid soluble chloride content	
			Percent by mass of concrete	g/cm^3
1_top	63[a]	6.35–12.7	0.0600	0.0014
1_bottom		37.9–47.63	0.0030	0.0001
2_top	63[b]	9.5–25.4	0.0040	0.0001
2_bottom		6.35–22.2	0.0280	0.0006
3_top	10[b]	6.35–25.4	0.0120	0.0003
3_bottom		19.1–34.9	0.1400	0.0032
4_top	Not	19.1–25.4	0.0190	0.0004
4_bottom	measured	19.1–31.8	0.0450	0.0010

[a] Measured.
[b] Assumed from nearby measurements.

indicate that the levels of chloride content could potentially have contributed to the initiation of corrosion throughout the depth of the slab.

As presented in the earlier assessment [1], the overall condition of the aged concrete in the historical structure presented ‘very poor’ conditions, including cracking, scaling, rebar corrosion, carbonation, spalling of concrete, etc. However, the assessments were local and thereby restricted a thorough assessment of the overall performance of the aged concrete and determination of the degradation of the aged concrete.

In the earlier report [1], in order to determine the compressive strength of the aged concrete, three four-inch nominal diameter cores were extracted horizontally from three randomly selected representative raker beams. The test results Shows that the average compressive strength of these cores was approximately 14 MPa with an average unit weight of 2230 kg/m^3. In addition, petrographic analysis was conducted to assess the overall quality of the concrete and the depth of carbonation in two randomly selected slab locations. Carbonation was detected in the top 12.7 mm and in the bottom 41.3 mm of the core samples. This finding indicates that carbonation occurred in the concrete around the reinforcing steel and that it provided a corrosive environment.

Based on the literature, nondestructive methods are believed to be the most effective approach to determine not only the overall quality of the aged concrete in the structural components to be investigated in this study, but also the extent of any internal deterioration that may be present in a historical structure [2–10].

Celaya et al. [11] used impact echo and ultrasonic surface wave techniques to assess the integrity of concrete slabs using time and frequency domain analysis. They found that the frequencies and relative amplitudes of the peaks in the impact echo spectra can

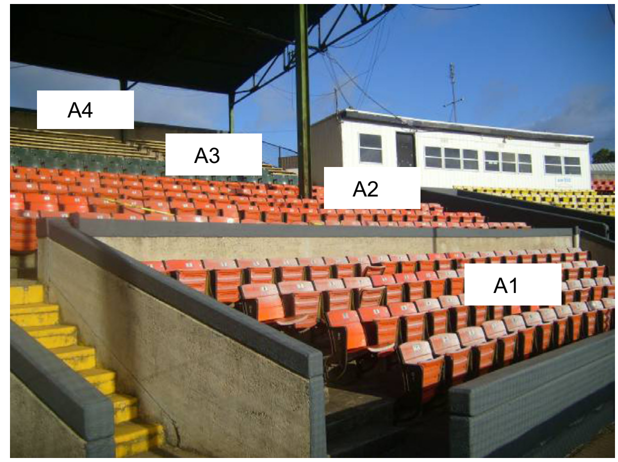

Fig. 2. Seating slab.

be used to assess the condition of a concrete slab in terms of debonding and spalling.

Taffe et al. [9] assessed a 45-year old prestressed concrete bridge using combined magnetization and a tractor appliance. Based on visual inspections, fractured prestressed steel, pitting corrosion, and delamination in the bridge deck were observed, and typical damage patterns, especially for the delamination in the bridge deck, also were seen. The results, based on ultrasonic-echo and radar nondestructive test methods, indicated the need for reconstruction and location of injection faults were warranted. Rickard [10] developed a technique for detecting subsurface defects in a bridge deck joint for a bridge built in 1959. He conducted destructive and nondestructive tests to determine the quality of the aged concrete in the vicinity of an armor deck joint and compared the results to laboratory test results using core samples.

In this study, two nondestructive methods, a ground penetrating radar (GPR) device and a portable seismic property analyzer (PSPA) in combination with impact echo and ultrasonic surface wave technology, were employed to determine the properties of the aged concrete in the overall area of a seating slab in the stadium. The nondestructive test results were compared to laboratory test results obtained from core samples.

2. Experimental program

The work for this assessment focused on two areas of the stadium. The first is a façade tower and the second is a section of the seating slab. First, visual inspections were conducted for these two areas, and the two nondestructive test devices (GPR and PSPA) were used to scan the overall area. The GPR unit used in this study is the StructureScan™ Mini (SSM) shown in Fig. 1(a). It is a compact, lightweight, handheld

(a) GPR test equipment (SSM) (b) PSPA test equipment

Fig. 1. Nondestructive test equipment.