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Concrete Analysis for Petrographic Examination in Old Concrete Structures and their Corresponding Photomicrographs

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Research Article

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ABSTRACT

The old concrete in water structures such as old dams, bridges, piers and other concrete structures exposed to water and freeze thaw were constructed without using the current technologies. To understand their characteristics, we conducted many concrete testing. One of these testing was the petrographic testing of concrete and its corresponding photomicrographs ASTM C856. The examination was carried out by a specialized company that provided 14 core samples: 45, 60 and 100 mm in diameter, from piers 3, 6, 8 and 9 and from the abutment.

The samples were subjected to a detailed visual examination completed by thin section examinations of the concrete and aggregate. A Leitz Laborlux II Pol polarizing microscope was used. Also, two samples were prepared to determine the parameters of the air void system under the microscope, in accordance with ASTM C-457.

This article discusses the alkali-aggregate reactions in the abutment samples and the percentage and hardness of the cement paste in the mix that will determine the parameters of the air void system, in accordance to ASTM C-457 as well as the petrographic examination results (ASTM C856) and corresponding photomicrographs.

INTRODUCTION

The renovation of old concrete structures [1-6] in water took place such as dams and bridges that were constructed in places having harsh environmental conditions such as the Latchford dam on The Montréal River. The purpose of the investigation was to determine the condition of the concrete piers and abutments as well as the depth to the bedrock formation. Four boreholes were to be drilled; three in the piers and one in the South Abutment. Our goal is to drill 70 mm holes for the top 2 meters and then reducing the size to 50 mm for the reminder of the borehole **(Figures 1 and 2).**

A laboratory testing program was used. It consisted of three compression tests and three petrographic analyses to evaluate alkali-silica reactivity [7] from each of the boreholes and to evaluate if the materials used match the concrete design.

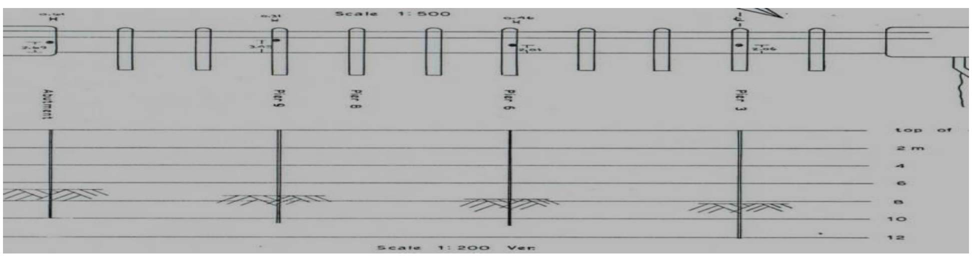

Figure 1. Plan View of the Dam and Places of Boreholes.

Figure 2. Illustrating the Dam site and its harsh Environmental Conditions.

The initial inspection of the dam, hampered by extreme low temperatures and ice accumulation, revealed the dam to be in a particularly poor condition due to badly deteriorated concrete. At that time, Alkali reactive aggregate in the concrete was identified as the probable cause of the extensive cracking observed in the exposed surfaces. As a result of that, a comprehensive drilling program was initiated to further evaluate the concrete and to obtain representative samples to determine its compressive strength. This testing further confirmed the poor quality of the concrete as well as the presence of reactive aggregate.

LABORATORY TESTING

The petrographic examination was used according to ASTM C856 [2]. The table below shows the description of specimen that was taken from the site for laboratory testing **(Table 1).**

Table 1. The Description of Specimen.

Description of Specimen (location and size)	Description of Specimen Concrete and Aggregate
Origin: Pier 3, at depth, from: 0.875 to 1.08 m, diameter: 100 mm, thin section no. 1	Concrete without entrained air, average quality, with 40-2.5 mm coarse aggregate, coarse aggregate: Crushed stone generally well-coated but poorly graded, the dominant fraction is comprised between 30 and 15 mm.
Origin: Pier 3, at depth from: 5.35 to 5.41 m, diameter: 60 mm, thin section no.2.	Concrete without entrained air, average quality, with 40-2.5 mm coarse aggregate. Coarse aggregate: crushed stone, generally well- coated but poorly graded. The dominant fraction is comprised between 30 and 15 mm
Origin: Pier 3, at depth: 1.36 to 1.46 m, diameter: 60 mm, thin section no.3	Concrete without entrained air, average quality, with 40-2.5 mm coarse aggregate. Coarse aggregate: crushed stone, generally well- coated but poorly graded. The dominant fraction is comprised between 30 and 15 mm
Origin: Pier 6- 4.34 to 4.45 m, diameter: 60 mm, thin section no.4	Concrete without entrained air, average quality, with 40-2.5 mm coarse aggregate. Coarse aggregate: crushed stone, generally well- coated but poorly graded. The dominant fraction is comprised between 60 and 20 mm
Origin: Pier 6- 6.36 to 6.48 m, diameter: 60 mm, thin section no.5	Concrete without entrained air, average quality, with 30-2.5 mm coarse aggregate. Coarse aggregate: crushed stone, generally well- coated but poorly graded.
Origin: Pier 9- 1.20 to 1.46 m, diameter: 100 mm, thin section no.6	Concrete without entrained air, average quality, with 30-2.5 mm coarse aggregate. Coarse aggregate: crushed stone, generally well- coated but poorly graded
Origin: Pier 9- 3.24 to 3.37 m, diameter: 100 mm, thin section no.7	Concrete without entrained air, average quality, with 30-2.5 mm coarse aggregate. Coarse aggregate: crushed stone, generally well- coated but poorly graded. Concrete without entrained air, average quality, with 50-2.5 mm coarse aggregate.
Origin: Abutment - 0.40 to 0.62 m, diameter: 100 mm, thin section no.8	Coarse aggregate: natural stone, generally well- coated but poorly graded. The dominant fraction is comprised between 50 and 20 mm.
Origin: Abutment - 3.45 to 3.65 m, diameter: 100 mm, thin section no.9	Concrete without entrained air, average quality, with 50-2.5 mm coarse aggregate. Coarse aggregate: natural stone, generally well- coated but poorly graded. The dominant fraction is comprised between 50 and 20 mm
Origin: Abutment pier - 5.30 to 5.60 m, diameter: 100 mm, thin section no.10	Concrete without entrained air, average quality, with 80-2.5 mm coarse aggregate. Coarse aggregate: natural stone, generally well- coated but poorly graded. The dominant fraction is comprised between 80 and 30 mm
Origin: Pier8 - 0 to 0.30 m, diameter: 100 mm, thin section no.11	Concrete without entrained air, average quality, with 50-2.5 mm coarse aggregate. Two fine fissures were observed near the surface. Coarse aggregate: crushed stone, generally well-coated but poorly graded. The dominant fraction is comprised between 50 and 15 mm
Origin: Pier8 – 1.15 to 1.46 m, diameter: 100 mm, thin section no.12	Concrete without entrained air, average quality, with 60-2.5 mm coarse aggregate. Two fine fissures perpendicular to the axis of coring were observed. Coarse aggregate: more or less-coated crushed stone. We choose s typical section from our report showing the testing and the findings

RESULTS OF THE LABORATOR Y TESTING OF S AMPLES

A typical laboratory testing [8] was achieved for sample from Pier 3, at depth from: 5.35 to 5.41m, diameter: 60 mm, thin section no.2, illustrate the flowing:

Description: Concrete without entrained air, average quality, with 40-2.5 mm coarse aggregate.

Coarse aggregate: crushed stone, generally well- coated but poorly graded. The dominant fraction is comprised between 30 and 15 mm. The main faces are:

- Greenish metasiltstone, with or without small sandstone 1aminates. It is composed of a high percentage of microcrystalline quartz grains often under 0.015 mm in diameter, with subrounded and sub angular quartz particles and a fraction of clay-sized mineral particles, often altered by chlorite. This face represents approximately 50% of the coarse aggregate.

- Reddish metasiltstone composed of microcrystalline quartz, subangular quartz, a fraction of clay-seized mineral particles (muscovite, calcite, clayey minerals). This fraction is altered by chlorite. This face represents approximately 45% of the coarse aggregate.

- Greenish quartzitic sand stone. This faces represents approximately 5% of the coarse aggregate.

These faces show obvious signs of alkali-aggregate reactions associated with the microcrystalline quartz. Several fissures were observed in the aggregates and have spread to the cement paste. These fissures are sometimes filled with silica gel. A peripheral reaction was sometimes observed on these faces **(Figures 3-6).**

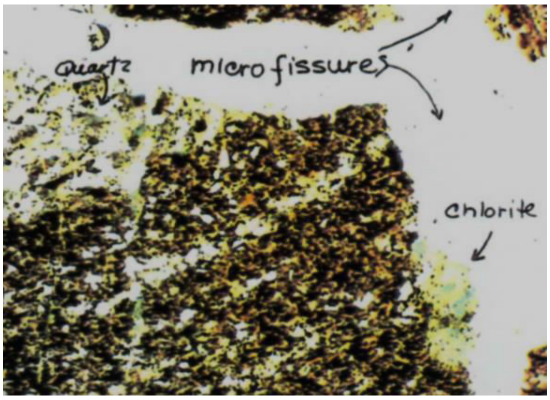

Figure 3. Illustrating the sample chemical content.

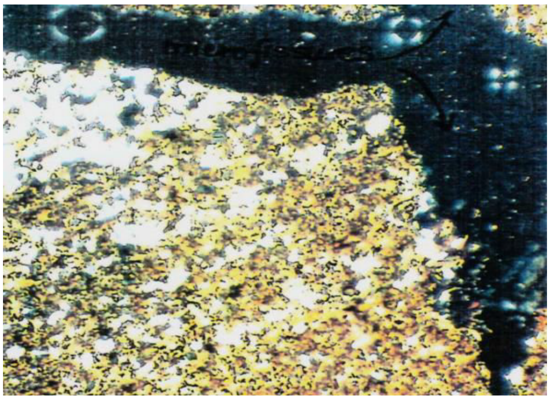

Figure 4. Illustrating the sample chemical content.

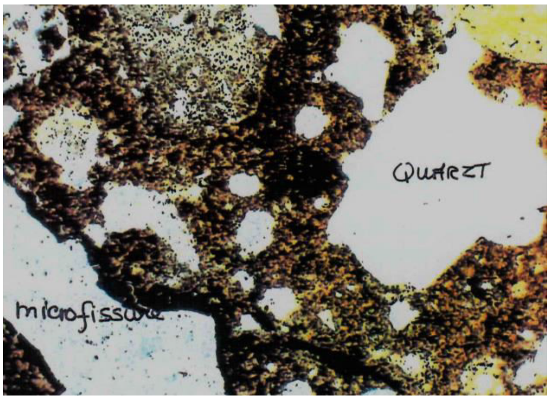

Figure 5. Illustrating the sample chemical content.

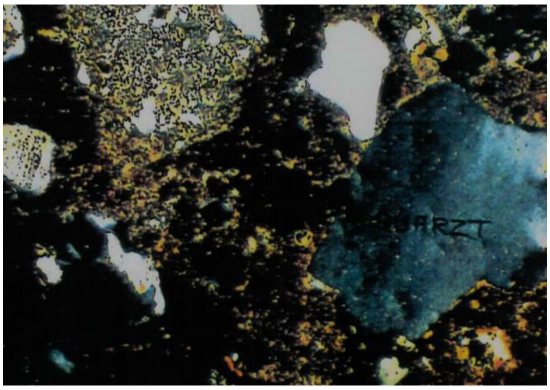

Figure 6. Illustrating the sample chemical content.

Fine aggregate: composed of manufactured sand, including: Metasiltstone, Quartz, Granitic gneiss and Feldspar Cement paste: the beige-colored paste contains entrained air. The percentage of paste is normal. It is of average hardness and has a low porosity. The percentage of air is estimated to be between 3 and 3.5 %. Whitish deposits were observed in the larger air voids of sometimes around the metasiltstone. The concrete's consolidation is adequate. The density of the micro fissures is average: (from 0.1 to 0.3 micro fissures / cm).

The **Figures 3-6** below are taken from Pier 3, thin section no.2, at depth: 5.35 to 5.41 m. and their results of its materials formation is **(Figures 3 and 4)**:

Reddish Metasiltstone composed of subangular Quartz, microcrystalline Quartz (with range), a fraction of clay-sized mineral particles (muscovite, calcite, clayey minerals [9]). This fraction is altered by chlorite (green range). The aggregate has micro fissures **(Figure 3).**

Reddish metasiltstone. Some view as the previous photo (polarized light, 40X) **(Figure 4).**

Cement paste and fine aggregate. Fine aggregate is composed of quartz, metasiltstone and granitic gneiss. The cement paste has a micro fissures (natural light, 40X) **(Figure 5).**

Cement paste and fine aggregate. Some view as the previous photo (polarized light, 40X **(Figures 5 and 6).**

Two different types of concrete were observed. Piers 3, 6, 8 and 9 are made from a concrete with a coarse aggregate mainly composed of crushed met siltstone, while the abutment's concrete is mainly composed of natural gravel of granitic origin. Concrete samples from piers 3, 6, 8 and 9 show a severe alkali- aggregate reaction. In the pier 8 samples, the reaction appears to be uniform, extending from the outside face of the concrete towards the inside. The petrographic examination shows that the concrete is without entrained air, and is composed of 80-100 mm crushed stone. The aggregate is often poorly graded and the dominant fraction is between 40 and 15 mm. The coarse aggregate's two main factors are:

- ❖ Reddish Meta siltstone: 5 to 90% in the various samples examined.
- ❖ The main minerals are quartz, feldspar, chlorite and clayey minerals.

Both the reddish Meta siltstone and Chloritized Meta siltstone show evidence of alkali- aggregate reactions. The cement paste has medium to high-density micro fissures. Many of aggregates are fissured and micro fissures have spread to the cement paste. The micro fissures and some voids near the aggregates are sometimes filled or coated with silica gel [8,10]. This reaction undoubtedly caused the fine fissures running parallel to the surface in the samples from piers 6 and 8. In general, in all pier samples, the cement paste has a medium hardness and the aggregates are generally well coated, except in certain locations where voids have formed under the aggregates. The determination of the air void system's parameters, carried out in accordance with ASTM C-457 [3], yielded the following results for the pier 9 sample collected at a depth of 3.24 to 3.37 m. Air content: 4.1%, Spacing factor (L): 325 um.

The values do not meet current durability criteria for concrete exposed to freeze- thaw cycles. However, research has shown that the critical spacing factor value, beyond which concrete is destroyed by the freeze -thaw cycle, is in the order of 350 to 600 um. This concrete therefore has a certain level of durability under freeze-thaw cycles. Due to the relative abundance of aggregates [11] which are considered as reactive in the presence of the cement's alkalis and their reactive fraction, the reaction is expected to continue for several decades. The abutment's concrete is composed of 80-100 mm natural gravel. The poorly graded coarse aggregate is mainly composed of the following:

❖ Granite: 45 to 60%, Metagraywacke: 5 to 35%. Rich in quartz and feldspar in Chloritized clayey Matrix, Greenish Meta Siltstone: 5 to 15%. Rich in Quartz and Feldspar in a Chloritized and epitomized Clayey Matrix and basic Intrusion Rocks

The alkali-aggregate reactions in the abutment samples are lower than in the prier samples due to the lower percentage of reddish and greenish Meta siltstone.

The percentage and hardness of the cement paste in the mix are low. The determination of the air void system's parameters, in accordance with ASTM C-457 [3], yielded the following results for the abutment sample collected at a depth of 3.45 to 3.65 m: Air content: 9.0%, Spacing factor (L): 209 μm, Paste content: 19.6 %. However, these results are only indicative since the quality of the paste in the concrete sample was very poor, and the sample section could only be polished after the application of an epoxy resin.

Normally, the conductivity of rock is increased with its crystallinity i.e. the conductivity depends on direction of flow of heat relative to crystal orientation. Trachyte and basalt are of low conductivity, limestone and dolomite are of medium conductivity and quartz shows the highest conductivity.

In summary, the abutments concrete is mainly characterized by the high porosity and law hardness of the cement paste. **ACI 207.1R** [12] provides some typical conductivity values of concrete. These are represented in the below **Figure 7.**

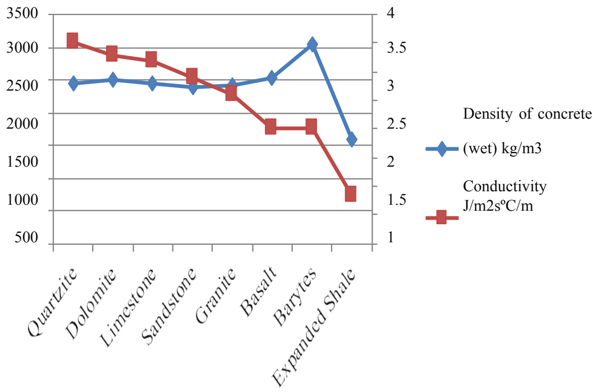

Figure 7. Graph shows the temperature resistance of Existing Materials used in Concrete Mix Design 6-Conclusions and Recommendations.

· Before starting any concrete repairs, destructive and nondestructive concrete testing and analysis are required in order to put the correct design for its structural and technological repairs [3,5,6].

- The qualified and experienced engineers are required to lead such concrete analysis for nondestructive petrographic examination in old concrete structures and their corresponding photomicrographs
- The Petrographic examination of old concrete structures and their corresponding photomicrographs is the best testing method to discover the biological and chemical conditions of concrete [10].
- Concrete petrography was used to investigate the constituents, the quality and the conditions of the concrete
- We had the information regarding the constituents of concrete: aggregate constituents, type, contaminants, mineral additives, cement type and matrix characteristic. The determination of the air void system's parameters, in accordance with ASTM C-457 [3], yielded the following results for the abutment

Sample collected at a depth of 3.45 to 3.65 m: Air content: 9.0%, Spacing factor (L): 209 μm, Paste content: 19.6 % [1,3,12].

- The quality of the paste in the concrete sample was very poor.
- The percentage and hardness of the cement paste in the mix are low.
- The alkali-aggregate reactions in the abutment samples are lower than in the prier samples due to the lower percentage of reddish and greenish Meta siltstone [13].
- The abutments concrete is mainly characterized by the high porosity and law hardness of the cement paste.
- FTIR analysis was used to identify contaminants and verify the composition of binders, epoxies, coatings, and other organic materials.

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