Foundation Assessment
Municipal Pump Facility

40 Old Farms Road (Senior Way)
Willington CT

prepared for
Town of Willington CT

Tulis photo

by **Ralph H. Tulis, P.E.**
d/b/a Structures Consulting rht_pe@charter.net
Visual examination: 6 January 2020
Core sample extraction: 6 January 2020
Report date: 3 August 2020

STATE OF CONNECTICUT
RALPH H. TULIS
No. 15303
LICENSED
PROFESSIONAL ENGINEER

Project 19-163
Approximate year constructed: 2004±

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Core Sample Extraction.
Given this overall size of this structure only one core sample was extracted from the northeast wall. This wall envelops the ends of the three (3) water tanks and is a full-height wall (i.e. it extends from the footing to the roof). The core was extracted from the interior surface and due to the limitations of the drill bit used it was not possible to extract a full-thickness core.

As is sometimes common with commercial concrete construction, the walls, both inside and outside, were coated with a cementitious material, often called parging. This typically is done to fill the small air pockets (bug holes) and cover the recesses left from the form ties. It also helps to somewhat conceal the lines left in the surface by the formwork panels. This, unfortunately, does not permit a visual examination of the actual as-cast concrete surface and tends to fill any early-age shrinkage cracks. Surface color variations are also concealed by this finishing process.

The core sample was extracted on 6 January 2020. It was package and shipped via FedEx Ground to Sedexlab Materials Testing and Consultancy in Longueuil Quebec Canada on 8 January 2020 for petrographic examination. Sedexlab's report was received on 6 February 2020. Discussion of Sedexlab's findings follows.

Core Exam Discussion.
Sedexlab's report is attached to this report. Their findings are as follows.

From page 2, the coarse aggregate composition and quantities were found to be:

COARSE AGGREGATE		
Composition (avg %)	W/pyrrhotite (avg %)	W/higher potential reactivity (avg %)
Granitic gneiss (82), quartzite (7) and granite (11)	50	15

The important number is the 15% of the aggregate particles having reactivity potential. When compared to many other foundations, this amount of potentially reactive aggregate has been found to cause little or no distress in the concrete.

Sedexlab's conclusions on page 3 of their report are important in the following respects:

"No evidence of significant distress or cracking was observed within the concrete core sample. General concrete condition was characterized as good." Internal cracking is typically one of the initial observed results of the expansive effects of the byproducts of the chemical breakdown of pyrrhotite. In order for this to occur, water and oxygen must be present in sufficient quantity.

"Based on mineralogical, structural and textural aspects of some of the particles, we estimate that 15% of total coarse aggregate particles bear higher potential reactivity (11 of 74 particles). Low to moderate amounts of pyrrhotite oxidation and replacement iron oxides were observed in 24% of pyrrhotite-bearing coarse aggregate particles (9 of 37 particles), with no associated cracking distress." Realistically, the initial mix water used in concrete will instigate some breakdown of pyrrhotite. However, that water is also in demand by the cement for its hardening process. A vast majority of that water will be consumed in the hardening process, which progresses at a much faster rate than of pyrrhotite's breakdown. If no additional water is available, the pyrrhotite breakdown becomes starved of the water it needs to continue. Thus, to find some byproducts should be of no surprise.

"Based on the foregoing, we are of the opinion that the sampled concrete may be moderately susceptible to progressive pyrrhotite oxidation in the coarse aggregate if sufficient moisture is present within the concrete. Special care may be required to reduce as much as possible ground level humidity at the building's perimeter." [emphasis added] This is a consistent theme for all concrete structures that are found to contain some level of pyrrhotite-bearing aggregate.

Not truly considered in Sedexlab's observations is the one aspect of this structure that does NOT have something in common with most residential foundations—this structure foundation is reinforced concrete. The comparison of a properly steel reinforced concrete structure to that of a residential foundation containing little or no steel reinforcing when attempting to guestimate its life expectancy is not a fair comparison. This foundation has steel reinforcing bars running both horizontally and vertically just inside of both the interior and exterior faces. This offers resistance to shrinkage cracks (minimizing water ingress) and to the expansive forces should they exist now or in the future.

I am in agreement with Sedexlab's General Recommendations found on page 5 of their report. However, most of those recommendations are currently in place. Not known is the nature of the exterior water-resistant coating that would have been applied to the below-grade concrete surfaces. Given the type of structure under consideration, it would be unlikely that it was omitted or was of poor quality. The single-slope roof on this structure does NOT have a gutter to intercept rainwater from the roof surface and its addition would be a prudent and minimal cost preventative measure. The downspout associated with the gutter should be equipped with an extension to convey the water as far from the foundation as practicable.

The retaining wall aligning with the southeast side of this structure currently exhibits poor adhesion of the parging to the underlying concrete wall. This degradation will continue as it experiences continued freeze-thaw cycles. Further, this water is exposed to moisture on both faces—the exposed face from rainwater, the earth-facing side from ground water that may penetrate the water-resisting coating. This wall is (or can be) independent of the building's foundation. Should it exhibit continued deterioration over future years, and if its replacement becomes necessary, it should not have an impact on the functionality of this facility.

Photo 1

Photo 2

Photo 3

Photo 4

Photo 5

Photo 6

Photo 7

Photo 8

Photo 9

Photo 10

Photo 11

Photo 12

Photo 13

Photo 14

Photo 15

Photo 16

Photo 17


Core sample was
extracted here.
See photo 19.
Facing northwest wall.

Photo 18

Photo 19

Photo 20

Photo 21


Photo 22

Sedexlab
MATERIALS TESTING AND CONSULTANCY

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Concrete Core Analysis Report

Client :	Structures Consulting 47 Village Hill Road, PO Box 280 Willington, Connecticut 06279	**Project :**	Pump House Senior Way, Willington, CT
		Owner (s) :	Town of Willington
Attn :	Ralph H. Tulis, P.E. Rht_pe@charter.net (860) 684-6404	**Year built**	
		Main building :	2004 (according to Client)
		Addition/Detached garage :	-
Date cores received :	January 16, 2020	**Client project n° :**	19-163
Date reported :	January 27, 2020	**Sedexlab project n° :**	AB-1009-004 **Report n°:** 1

Structures Consulting retained the services of *Sedexlab inc.* to carry out an analysis on one (1) concrete core sample identified as extracted below grade from the interior back foundation wall of the Pump House building located on Senior Way in Willington, Connecticut. Core 1-BW-MB-INT (PH-1) was received on January 16, 2020 from *Ralph H. Tulis, P.E.* of *Structures Consulting*.

The Concrete Core Analysis assesses the quality and condition of the concrete with a focus on the coarse aggregate as well as on the identification and quantification of the mineral pyrrhotite in the coarse aggregate. This report describes and summarizes the results and findings of our testing and examinations our conclusions as well as general recommendations. See the attached Concrete Core Description, Petrographic Examinations on Polished Sections, Density, Absorption and Voids in Concrete data sheet and total sulfur in concrete laboratory report (*Polytechnique Montreal*). Also attached are the Owner Questionnaire, Calculation Methodology as well as a Background and Regulatory Overview section. Sedexlab was not provided site photographs.

CORE DESCRIPTIONS*

Core ID	Dimensions	Coarse Aggregate Type	Concrete Condition	Moisture Barrier	
				Exterior	Interior
1-BW-MB-INT (Sedex PO-40033)	3 3/4''Ø X 11.221''	Crushed stone	good	Unknown (fractured)	None (cementitious coating)
-	-	-	-	-	-

*See attached Concrete Core Description (ASTM C856)

PETROGRAPHIC ANALYSIS

PYRRHOTITE	ESTIMATED PYRRHOTITE CONTENT IN COARSE AGGREGATE	
	In weight (w%)	(vol. %)
Present	**0.74**	0.47

COARSE AGGREGATE		
Composition (avg %)	W/pyrrhotite (avg %)	W/higher potential reactivity (avg %)
Granitic gneiss (82), quartzite (7) and granite (11)	50	15

Method: Petrographic examinations using stereomicroscopy and reflected light microscopy in accordance with the relevant guidelines outlined in ASTM C856 *Standard Practice for Petrographic Examination of Hardened Concrete;* See attached Petrographic Examinations on Polished Sections (ASTM C856). Calculation methods are based on iron sulfide surface ratios estimated during microscopic examinations on polished sections, results obtained from sulfur analysis and physical analysis of concrete, as well as parametric values obtained from local and federal level concrete and cement industry specifications (See attached Calculation Methodology).

SULFUR ANALYSIS

Sample	Total Sulfur in concrete (w%)	Average Sulfur in concrete (w%)	Estimated Sulfur in coarse aggregate (w%)
1-BW-MB-INT (Sedex PO-40033)	0.31	-	**0.30**
-	-	-	

Method: Concrete sulfur analysis using LECO infrared combustion sulfur analysis was carried out on a portion of each core in the as-received condition in accordance with the relevant guidelines outlined in standard NQ 2560-500/2003; See attached *Polytechnique Montreal report*. See attached Calculation Methodology for Sulfur Content in Coarse Aggregate.

PHYSICAL ANALYSIS

Sample	Density (kg/m³)	Absorption			Voids (%)
		After immersion (%)	After immersion and boiling (%)	Difference (%)	
1-BW-MB-INT (Sedex PO-39552)	2244 (140 lb/ft³)	5.23	5.69	0.46	12.78

Method: Determination of density, absorption and voids carried out on portions of one concrete core in accordance with the relevant guidelines outlined in ASTM C642 *Standard Test Method for Density, Absorption, and Voids in Hardened Concrete;* see attached density, absorption and voids in hardened concrete data sheet

Conclusions

- No evidence of significant distress or cracking was observed within the concrete core sample. General concrete condition was characterized as *good.*

- Visual examination of the as-received core sample revealed the absence of a moisture barrier on the core's interior formed surface (interior side of the wall). The formed surface was covered by a cementitious coating. The opposite extremity of the core sample (exterior side of the wall) revealed a fractured surface suggesting the core was extracted short of reaching the other side of the wall; therefore the presence or absence of a moisture barrier is unknown.

- The coarse aggregate is composed of graded crushed stone particles of igneous and metamorphic nature with a maximum size of 3/4 inch. Coarse aggregates are generally well distributed within the concrete mix. The fine aggregate is natural granitic sand mainly composed of sub-rounded quartz particles.

- Stereomicroscopic examinations revealed that 82% of total coarse aggregate particles are composed of granitic gneiss, 11% are granite and 7% are quartzite.

- Microscopic examinations on polished sections confirmed the presence of pyrrhotite in 50% of total coarse aggregate particles (37 of 74 particles). Based on mineralogical, structural and textural aspects of some of the particles, we estimate that 15% of total coarse aggregate particles bear higher potential reactivity (11 of 74 particles). Low to moderate amounts of pyrrhotite oxidation and replacement iron oxides were observed in 24% of pyrrhotite-bearing coarse aggregate particles (9 of 37 particles), with no associated cracking distress.

- **The estimated pyrrhotite content is 0.74% by mass of coarse aggregate.** This value is in the lower spectrum of values we have measured to date in Connecticut and Massachusetts (see graph on page 4)

- The estimated sulfur content is 0.30% by mass of coarse aggregate. This value exceeds the European standard NF EN 12620 (article 6.3.2), in force since 2003, which states that when pyrrhotite is present, total sulfur content in coarse aggregate must not exceed 0.1%.

- Absorption and voids (porosity) measurements are considered to be in accordance with values accepted for normal resistance concrete used in residential foundations.

- The following information was provided in the attached Owner Questionnaire: 1) No indications of damage commonly associated with pyrrhotite-bearing coarse aggregate. 2) No known waterproofing material on the surface of the exterior foundation walls. 3) No known perimeter drains around the building's foundation. 4) No guttering systems present.

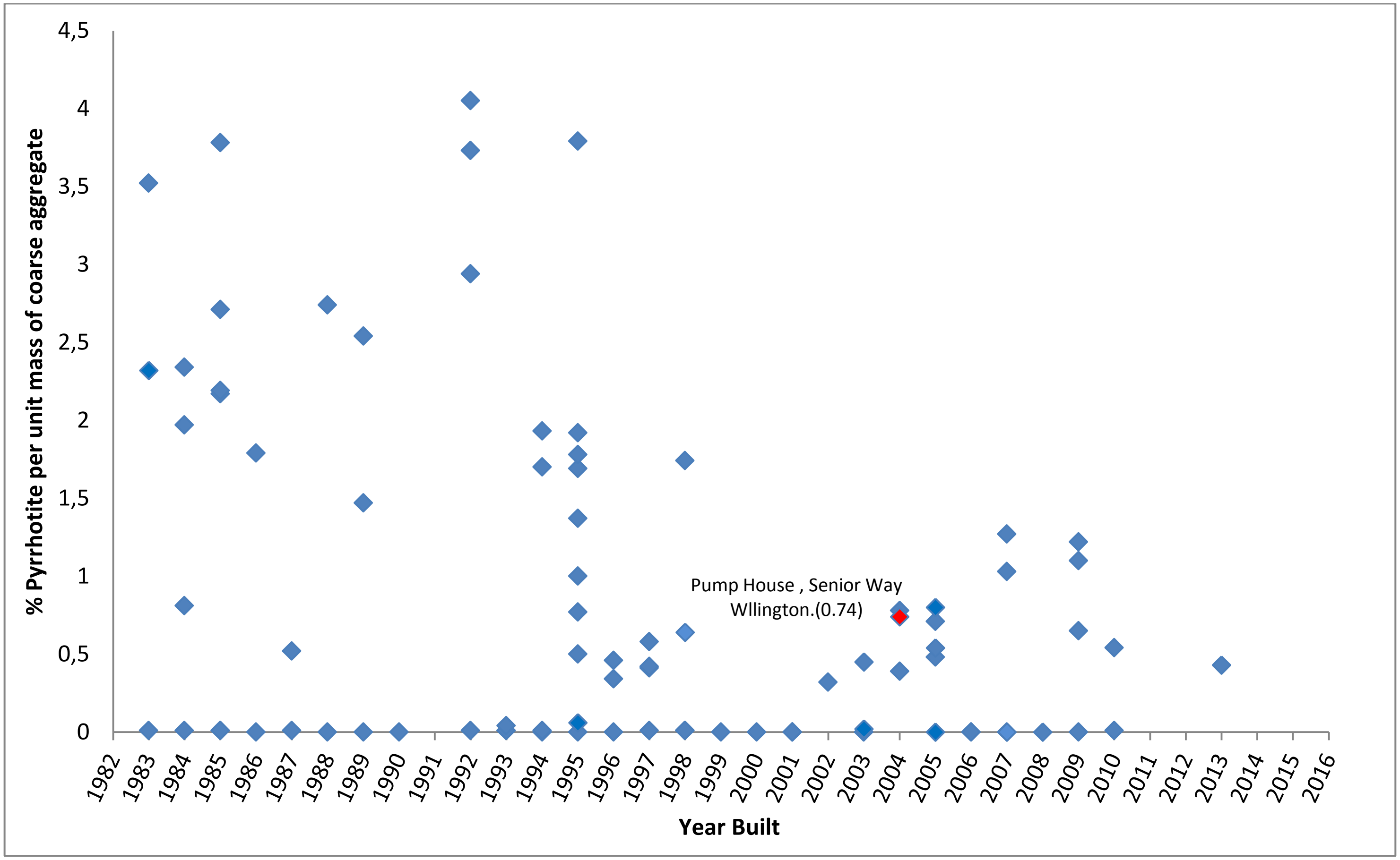
Based on the foregoing, we are of the opinion that the sampled concrete may be moderately susceptible to progressive pyrrhotite oxidation in the coarse aggregate if sufficient moisture is present within the concrete. Special care may be required to reduce as much as possible ground level humidity at the building's perimeter.

As of this report's date, no existing standard defining rules and references for testing pyrrhotite in concrete samples has been recognized by any U.S. state or Federal laws and no precise value has been issued as to the maximum authorized pyrrhotite content in coarse aggregate for use in concrete. Although correlations often exist between high pyrrhotite content levels in coarse aggregate and concrete deterioration, more research and case history data are needed to reveal with more accuracy the minimum level at which significant pyrrhotite induced concrete deterioration will occur. Results provided in this report cannot predict the amount of future concrete deterioration.

Conclusions expressed in this report are based on the assumption that the received concrete core sample is representative of the totality of the building's concrete foundation walls. However, we are of the opinion that this amount of concrete material may be statistically insufficient and that more samples should be extracted and submitted for analysis to achieve better representativeness of the risk level associated with pyrrhotite-bearing coarse aggregate in concrete. It must therefore be borne in mind that a second expert assessment carried out by another firm on new cores could yield some variations in results obtained.

The following graph shows the results obtained from all concrete foundations tested by Sedexlab to date in Connecticut and Massachusetts (February 4th 2020). Pyrrhotite content results are plotted versus the year of construction of the foundations. Pyrrhotite content of 0.74% obtained from the sample extracted from the foundation located at Pump House, Senior Way in Willington, CT (red diamond) falls in the lower spectrum of measured values.

Pyrrhotite Content (w%) versus Year Built in Connecticut and Massachusetts (February 4th, 2020)



GENERAL RECOMMENDATIONS

Ongoing Monitoring of Concrete Foundations

Generally speaking for concrete foundation walls and floors, hairline cracks and cracks less than 1 mm (approx. 0.039’’) wide are fairly common and usually do not warrant any corrective action.

Cracks that are larger than 1 mm should be sealed with cement paint, caulk or mortar to prevent water from getting in and will help in monitoring. Be aware that flexible caulks should not be used to fill cracks you want to monitor, flexible caulk stretches and will not show continued movement.

Reducing Ground Level Humidity

Surface drainage should be the first line of defense in every residential moisture protection system. Groundwater can be controlled to a great extent by reducing the rate at which rainwater and surface runoff enter the soil adjacent to a building.

Roofs typically concentrate collected rain water at a building’s perimeter where it can cause groundwater problems. Water that is drained quickly away from a building at the ground surface cannot enter the soil and contribute to below-grade moisture problems.

Ground-level humidity can be reduced by improving surface drainage

- Repositioning gutter spouts to divert water away from the foundations.
- Modifying the slope of the ground around the foundations.
- Sealing the asphalt covering at foundation joints.
- Planting beds located next to the building walls should always be well drained to avoid concentrating moisture along the foundation line.

Perimeter Drain

- The most common method of keeping groundwater away from basement structures is to provide a perimeter drain or footing drain (French drain) in the form of perforated, porous, or open-jointed pipe at the level of the footings. Perimeter drains artificially lower the water table below the elevation of the floor. Crushed stone or gravel should always be placed above and below perimeter drains to facilitate water flow.

- When possible, the existing French drain should be assessed in order to verify proper functioning. This drain can gradually block after a long period of time.

Waterproofing Membranes (Moisture Barriers)

Waterproofing is the treatment of a surface or structure to prevent the passage of liquid water under hydrostatic pressure. When combined with effective subsurface drainage, a waterproofing membrane can provide good performance. In wet climates, or on sites with high water tables, fluctuating water tables, or poor drainage, a waterproofing membrane should be used in addition to subsurface perimeter drains.

All concrete samples used to prepare this report will be discarded 3 months following its submission unless otherwise requested in writing.

We would like to thank you for the opportunity to serve you. Please call if you have any questions regarding this report.

Sincerely,

Sedexlab Inc.

Approved by:

Patrick Usereau, Geologist/Petrographer
Principal

Sedexlab
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Concrete Core Description (ASTM C856)

Project address :	Pump House, Senior Way, Willington, Connecticut	**Client :**	Structures Consulting
Date received :	January 16, 2020	**Sedexlab project no :**	AB-1009-004
Sampled by :	Structures Consulting	**Core ID :**	1-BW-MB-INT
Date examined:	January 16, 2020	**Sedexlab ID :**	PO-40033

MATERIALS ENCOUNTERED

Cementitious coating:	1	mm
Interior moisture barrier :	-	mm
Original concrete::	284	mm
Exterior moisture barrier:	-	mm
Total length:	(11.221'') 285	mm

ORIGINAL CONCRETE - AIR

Air voids ☒ Yes ☐ No

Air entrained ☐ Yes ☐ No (not tested)

COARSE AGGREGATE

Nominal Max Size: 3/4 in. or 19 mm

Type : Crushed stone

Angularity: Sub-angular

Petrographic type : Metamorphic and igneous

Composition:

Granitic gneiss	☒ yes	☐ no
Granite	☒ yes	☐ no
Quartzite	☒ yes	☐ no
Siltstone	☐ yes	☒ no
Diabase	☐ yes	☒ no

Visible iron sulfides: Clusters

Magnetism : Weak to moderate

Oxidation/alteration: Trace

MOISTURE BARRIER ☐ext. ☐ int. ☐ both ☒ none

Type:	n/a
Adherence to concrete :	n/a
Condition :	n/a

CONCRETE QUALITY

General condition :	Good
Spalling :	none
Delaminating :	none
Cracking:	none
Aggregate/paste bond:	Good

STEEL REINFORCEMENT

Diameter:	none
Corrosion:	n/a
Orientation:	n/a
Steel/paste contact:	n/a

FINE AGGEGATE

Type: Natural sand < 5mm

Angularity : Sub-rounded to sub-angular

Nature : Siliceous (mostly quartz particles with some metamorphic/igneous particles and feldspar, mica, amphibole and garnet particles)

COMMENTS :

Examined by: Maxime Rousseau, Geologist/Petrographer

Verified by: Patrick Usereau, Geologist/Petrographer :

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MATERIALS TESTING AND CONSULTANCY

Petrographic Examination on Polished Sections (ASTM C856)

Client :	Structures Consulting	**Project address :**	Pump House, Senior Way, Willington, Connecticut
Project number :	AB-1009-004	**Date received :**	January 16, 2020
Core number :	PO-40033	**Date examined :**	February 2, 2020

Total number of coarse aggregates : 74 (two sections combined)
Coarse aggregate composition (avg%) : Granitic gneiss (82), quartzite (7) and granite (11)
% pyrrhotite-bearing aggregates : 50% (37 of 74 particles)
% higher potential reactivity aggregates: 15% (11 of 74 particles)
Iron Sulfide composition : Pyrrhotite (99%) Pyrite (0%), Chalcopyrite (1%)
Sulfide oxidation : Low to moderate amounts of pyrrhotite oxidation and replacement iron oxides were observed in 24% of pyrrhotite-bearing coarse aggregates (9 of 37 particles), with no associated significant cracking distress.

Examined by: Maxime Rousseau, Geologist/Petrographer

Verified by: François Hamel, Geologist/Petrographer

POLYTECHNIQUE MONTRÉAL
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Département des génies civil, géologique et des mines (CGM)

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To Pascal Fortin
email: p.fortin@sedexlab.com

Request : 0631 (1/4)

Sample #	labo #	**Total Sulfur expressed as S %m***
AB1009-004 PO-40033	LGC200076	0,31

*%m = 1g/100g
Réf.: **BNQ** 2560-500/2003, 6.2.1, A.2, A.3.2
S by LECO CS744

Analytical Geochemistry Laboratory
Jérôme Leroy, Chemical Laboratory Analyst
Phone: (514) 340-4711 #2199
jerome.leroy@polymtl.ca

January 21st, 2020

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Density, Absorption, and Voids in Hardened Concrete - (ASTM C642)

Sedexlab Project number:	AB1009-004	Date received	01-22-2020
Sedexlab Core ID:	PO-40033	**Start date:**	01-22-2020
Project:	Pump House, Senior Way, Willington, Connecticut	**End date:**	01-29-2020

Oven Dry Mass

Result 1 (g)	Result 2 (**A**) (g)	Diff. (< 0.5%) (%)
784,4	783,3	0,14

Saturated Mass After Immersion

Result 1 (g)	Result 2 (**B**) (g)	Diff. (< 0.5%) (%)
824,3	824,3	0,00

Saturated mass after boiling **C** (g):	827,9
Loss of mass in water (g.):	349
Immersed apparent mass **D** (g):	478,9
Density (kg/m^3):	**2244**

Absorption

After immersion (%):	5,23
After immersion and boiling (%):	5,69
Difference (%):	**0,46**

Bulk Density (mg/m3)

Dry g^1	After immersion	After boiling	Apparent density g^2
2,244	2,362	2,372	2,573

Volume of Permeable Voids (%): **12,78**

Measuring devices used
Scale no. : BJ 8100D
Oven no.: 1091-0041

Appoved by: Pascal Fortin, geologist

Date: 01-29-2020

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OWNER QUESTIONNAIRE – Foundations Testing

(IF SPACE IS INADEQUATE TO ANSWER, PLEASE ATTACH ADDITIONAL PAGES)

Address Tested	**Building(s) Tested**	**Year Built**
Pump house Senior Way Willington CT USA	☒ Main ☐ Detached Garage ☐ Addition	2004? ____ ____

Damage to the Foundations ☐ Yes ☒ No ☐ Unexposed | **Location of Damages** ☐ Walls ☐ Floor ☐ Both

FOUNDATION WALLS	CONCRETE FLOOR
Cracking pattern (please provide photos) ☐ Map-like ☐ Horizontal ☐ Vertical ☐ Diagonal	**Cracking pattern** (please provide photos) ☐ Cross-shaped ☐ Straight
Crack widths ☐ < penny ☐ Penny to 3/8″ ☐ > 3/8″	**Crack widths** ☐ < penny ☐ Penny to 3/8″ ☐ > 3/8″
Efflorescence (White powder) ☒ None ☐ Traces ☐ Abundance	**Efflorescence** (White powder) ☐ None ☐ Traces ☐ Abundance
Rust-like discoloration ☒ None ☐ Traces ☐ Abundance (please provide photos)	**Perceptible heave** ☐ Yes (please provide photos) ☐ No
CHECK LOCATION OF DAMAGES: ☐ Front wall (☐ Interior ☐ Exterior) ☐ Left wall (☐ Interior ☐ Exterior) ☐ Back wall (☐ Interior ☐ Exterior) ☐ Right wall (☐ Interior ☐ Exterior)	**DESCRIBE LOCATION OF DAMAGES:**

When did you start noticing damages? And how fast are damages progressing?

There are no indications of damage. This is a preemptive investigation of a municipal facility. This building houses pump equipment & tanks for a small-scale municipal water system.

Do you have any of the following in your house?

- ☐ Waterproofing on exterior surface of foundations
- ☐ Waterproofing on interior surface of foundations
- ☐ Finished Basement
- ☐ Gutters
- ☐ Gutters with extensions
- ☐ Perimeter drains (French/Footing/Curtain) ☒ Unknown

The undersigned confirms that information furnished in this questionnaire is correct to the best of his/her knowledge.

Owner name: Town of Willington CT USA Signature: N/A - Represented by below

Email: ____

Owner representative Signature: [signature] Date: 12 Jan 2020 Relation to owner: Ralph H. Tulis, P.E. Examining Engineer for facility owner

CALCULATION METHODOLOGY

INTERPRETATION OF TOTAL SULFUR IN CONCRETE ANALYSIS

Results obtained from concrete sulfur analysis using LECO infrared combustion can be interpreted by the sum of the following contributions:

- Sulfur bound to sulfides in coarse aggregate
- Sulfur bound to sulfides in fine aggregate
- Sulfur bound to calcium sulfate or gypsum in cement
- Sulfur bound to sulfates produced by the oxidation of sulfides in coarse aggregate
- Sulfur bound to sulfates produced by the oxidation of sulfides in fine aggregate

It is assumed that the aggregates initially contain negligible amounts of sulfates and that all other concrete constituents such as water and admixtures also contribute negligible amounts of sulfur.

CONTRIBUTION FROM FINE AGGREGATE (C_{FA})

$$C_{FA} = \frac{\text{Fine Aggregate Sulfur} * \text{Fine Aggregate Content in Concrete (kg/m}^3\text{)}}{\text{Concrete Density (kg/m}^3\text{)}}$$

CONTRIBUTION FROM CEMENT (C_C)

$$C_C = \frac{0.4005 * \text{SO3 Content in Cement} * \text{Cement Content in Concrete (kg/m}^3\text{)}}{\text{Concrete Density (kg/m}^3\text{)}}$$

Note: One (1) molecule of SO3 contains 40.05 w% of sulfur.

CONTRIBUTION FROM COARSE AGGREGATE (C_{CA})

$$C_{CA} = \%\text{Total Sulfur} - C_{FA} - C_C$$

Where %Total Sulfur = Results obtained from LECO infrared combustion sulfur analysis of concrete.

Sedexlab MATERIALS TESTING AND CONSULTANCY

CALCULATION METHODOLOGY

SULFUR CONTENT IN COARSE AGGREGATE (%S_{CA})

$$\%S_{CA}\ (w\ \%) = C_{CA} * \frac{\text{Concrete Density } (kg/m^3)}{\text{Coarse Aggregate Content in Concrete } (kg/m^3)}$$

PYRRHOTITE CONTENT IN COARSE AGGREGATE:

Calculation for pyrrhotite content in coarse aggregate is made using the following values:

- Density of coarse aggregates : 2.75 g/cm³
- Pyrrhotite (Po): Density = 4.62 g/cm³ ; % Sulfur = 39.60 w%
- Pyrite (Py): Density = 5.02 g/cm³ ; % Sulfur = 53.45 w%
- Chalcopyrite (Cp): Density = 4.20 g/cm³ ; % Sulfur = 34.94 w%
- Pentlandite (Pe) : Density = 4.80 g/cm³ ; % Sulfur = 33.23 w%

From the following average surface ratios in coarse aggregate particles: Po/Py/Cp/Pe (ex. 90/5/3/2 where Po+Py+Cp+Pe=100), Py/Po (ex.:5/90), Cp/Po (ex.:3/90) and Pe/Po (ex.:2/90), as determined in reflected light microscopy examinations where surface ratios are equivalent to volume ratios according to the rules of stereology, the average pyrrhotite content in coarse aggregate can be calculated, both in percentage by mass (w %) and by volume (vol %).

Per unit mass of coarse aggregate

Po (w %) = $\%S_{CA}$ / {0.3960 + [0.5345*(Py/Po surf.ratio)*(5.02/4.62)] + [0.3494*(Cp/Po surf.ratio)*(4.20/4.62)] + [0.3323*(Pe/Po surf.ratio)*(4.80/4.62)]}

Per unit volume of coarse aggregate

Po (vol %) = Po (w %)*2.75/4.62

Background and regulatory overview

Pyrrhotite, a naturally occurring iron sulfide found in rock aggregate, is the suspected cause of the failing concrete foundations problem in Connecticut and Massachusetts. These foundations are experiencing a slow crack development, resulting in the eventual loss of concrete strength. The problems, sometimes developing within the first 10 years, often begin to appear after 15 to 20 years or more. According to the Geological Society of America, rock aggregate in these failing concrete foundations was largely mined from a single quarry in Willington (CT), within a stratified metamorphic unit mapped as Ordovician Brimfield Schist.

Pyrrhotite particles in coarse aggregates are unstable in oxidizing conditions. When exposed to water and oxygen, pyrrhotite oxidizes to form acidic-, iron-, and sulfate-rich by-products. One of these products is sulfuric acid, which results in an acid attack on the cement paste, weakening the paste, and generating sulfates as a by-product. These sulfates react with portlandite and hydrated aluminate phases in the paste, resulting in an expansion in the form of secondary minerals of greater volume. With more expansion and cracking occurring, more moisture is allowed in the concrete, exposing more pyrrhotite, and consequently increasing the rate of distress.

Although the undesirable nature of pyrrhotite for the manufacture of concrete is recognized and although contents as low as 0.3% pyrrhotite by mass of coarse aggregate has reportedly caused significant concrete distress (e.g., in Trois-Rivières, Canada), as of this report's date, no precise value has been issued in any U.S. State or Federal laws, as to the maximum authorized content in coarse aggregates for use in concrete.

The European standard NF EN 12620 (article 6.3.2), in force since 2003, mentions that when pyrrhotite is present, the total sulfur content in coarse aggregate must not exceed 0.1%. In Canada, CSA A23.1-09 (R2014) states that aggregate susceptible to cause excessive expansion of the concrete due to the presence of sulfides (pyrite, pyrrhotite, marcasite) should not be used in concrete. In addition, this standard recommends not using aggregates containing pyrrhotite in new concrete if these aggregates bear sulfur content higher than 0.1%.

The US Army Corps of Engineers recent recommendations state that aggregate for use in new concrete should be assumed pyrrhotite-bearing and should be accepted only if its sulfur content is below 0.1%.