Service d'Expertise en Matériaux inc.

Evaluation of Water Permeability in a Roller Compacted Concrete (RCC) and a Conventional Concrete

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Final report

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Service d'Expertise en Matériaux inc.

Mandate

By the end of the 90s, high performance roller compacted concrete (RCC) had emerged as a valuable product for pavement under severe conditions. In order to enhance mechanical properties, new roller compacted concrete mix designs methods were developed to reduce porosity which usually improve the water transport properties. The literature contains a good number of articles on the mechanical properties of these concretes, but no articles have been produced to date to address the water permeability of RCC for paving construction.

For environmental considerations, RCC pavings (used for composting, handling and storage of liquid manure) must meet government specifications for the physical properties of the materials used: water permeability, mechanical properties, etc.

Service d'Expertise en Matériaux (SEM) inc. was mandated to evaluate the water permeability of two concrete mixes, an RCC and a conventional mix. The main objective was to compare water permeability coefficients. Both mixes were produced under laboratory conditions. Water permeability is evaluated by measuring the quantity of water passed through the concrete sample. Pressure is applied to increase the water movement through the concrete sample. Knowing sample length, applied pressure and volume of water passed through the sample, water permeability for the concrete sample is easily calculated. Moreover, a specialized test has been developed at our laboratories. Using this test reference, we can evaluate the very low water permeability coefficients encountered in high performance concrete. The test is described later in this document.

Concrete mix compositions

Roller compacted concrete (RCC)

This concrete has 300 kg/m^3 Type GUb-8SF cement content (Type 10SF cement). A computer model was used to design the optimum combination of all mix constituents based on each constituent's characteristics (specific gravity, absorption and packing density). Table 1 presents the RCC mix composition, which is similar to that commonly used in this type of construction (high performance RCC for pavings).

TABLE 1 — RCC mix composition

Constituent	Quantity
Cement [1]	300 kg/m^3
Water	104 L/m^3
Sand (ssd) [2]	849 kg/m^3
Coarse aggregate 5-14 mm (ssd) [3]	1222 kg/m^3
Water reducer (Catexol 1000N)[4]	600 ml/m^3

[1] *Cement manufactured by St-Lawrence Cement – Type GUb-8SF (Type 10 SF)*
[2] *Sand – Sablière Ladufo inc., St-Joachim*
[3] *Coarse aggregates 5 -14 mm – Carrière Graymont, St-Marc-des-Carrières*
[4] *Manufactured by Axim Italcementi Group*

Conventional concrete

The conventional concrete was designed to meet CSA specifications for concrete with a class of exposure F-1. Concretes in this category are exposed to freeze/thaw cycles in a saturated condition but not to chlorides. This class of exposure was deemed most appropriate for a concrete slab intended for composting.

Other specifications for this class of exposure (F-1) are:

- Maximum water/cement ratio of 0.5
- Minimum compressive strength of 30 MPa at 28 days.

The conventional concrete mix composition is presented in Table 2. Water/cement ratio is 0.43.

TABLE 2 — Conventional concrete mix

Constituent	Quantity
Cement [1]	360 kg/m^3
Water	155 L/m^3
Sand[2] (ssd)	815 kg/m^3
Coarse aggregates 5-14 mm[3] (ssd)	1010 kg/m^3
Air entraining admixture (Darex EH)[4]	47 ml/m^3
Water reducer (WRDA-20)[4]	576 ml/m^3
Superplastiziser (ADVA 140)[4]	418 ml/m^3

[1] *Cement manufactured by Lafarge – Type GU (Type 10)*
[2] *Sand – Sablière Ladufo inc., St-Joachim*
[3] *Coarse aggregate 5 -14 mm – Carrière Graymont, St-Marc-des-Carrières*
[4] *Manufactured by Grace Construction Products*

Fresh concrete properties

The fresh properties of both concretes were determined using appropriate tests for their type. RCC density was determined using modified Proctor tests, and Vebe Time was measured at 10 and 30 minutes after initial contact of water and cement. Density of the conventional concrete was determined according to standard CSA A23.2-6C (*Density, yield and cementing materials factor of plastic concrete*), air content according to standard CSA A23.2-4C (*Air content of plastic concrete by the pressure method*), and slump according to standard CSA A23.2-5C (*Slump and slump flow of concrete*). All results are presented in Table 3.

TABLE 3 — Fresh concrete properties

Properties	RCC	Conventional concrete
Consistency (Vebe Time) *(seconds)*		
at 10 minutes	60	n/a
at 30 minutes	90	n/a
Density *(kg/m^3)*	2 476	2 327
Air content *(%)*	--	7.0
Slump *(mm)*	--	20

Mechanical properties of both concretes were evaluated. Flexural and compressive strength testing was performed according to standard CSA A23.2-8C (*Flexural strength of concrete using a simple beam with third-point loading*) and CSA A23.2-9C (*Compressive strength of cylindrical specimens*), respectively. Results are presented in Table 4.

Concrete absorption and porosity were determined according to ASTM C642 (*Standard Test Method for Density, Absorption, and Voids in Hardened Concrete*). Results are presented in Table 5.

TABLE 4 — Mechanical properties

	RCC	Conventional concrete
Compressive strength *(MPa)*		
at 3 days	44.9	30.4
at 7 days	57.0	34.9
at 28 days	66.0	44.8
Flexural strength *(MPa)*		
at 3 days	5.6	5.0
at 7 days	7.0	4.9
at 28 days	8.3	5.5

TABLE 5 — Absorption and porosity in hardened concrete

	RCC	Conventional concrete
Absorption *(%)*	2.4	5.1
Porosity (%)	6.0	11.2

For a conventional concrete mix (water/cement ratio of 0.45 and Type GU cement), porosity is usually around 12%. Porosities of the two concrete mixes (RCC and conventional concrete) studied indicate that both concretes are of good quality.

Water permeability

Water permeability tests were performed on the concrete after 28 days of curing. Curing was done in a chamber at 23°C and 100 % relative humidity. The test sample was 150 mm in diameter and 50 mm in length.

The permeability cell used for this test is illustrated in Figures 1 and 2. Permeability testing was performed at an average pressure of 110 psi. Water pressure was maintained with a standard water pump. Testing ran for a 40-day period. Wood[1] provides a more detailed description of the test method in his article. As per the technical documentation, sodium chloride was used as a tracer, a requirement for testing high performance concrete. The tracer had a sodium chloride concentration of 500 mmol/l.

[1] Wood et al., *Improved Testing for Chloride Ingress Resistance of Concretes and Relation of Results to Calculate Behaviour*, 3rd International Conference on Deterioration and Repair of Reinforced Concrete in The Arabian Gulf, 1989, pp. 427-441.

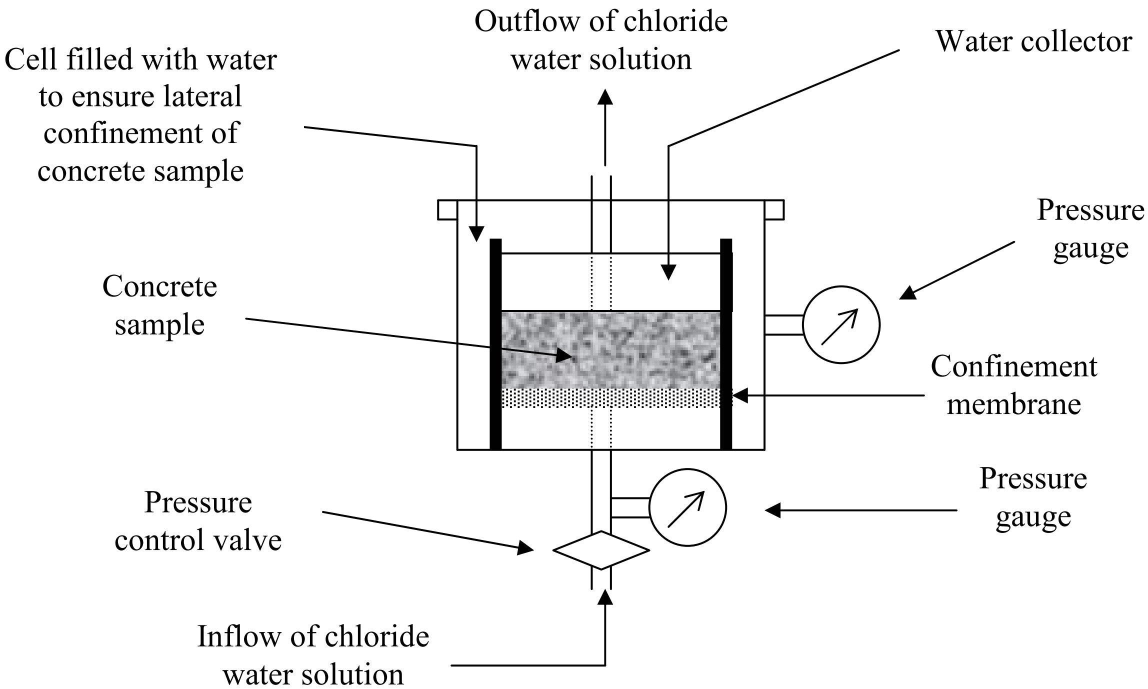

Figure 1 – Typical Water Permeability Test Set-up

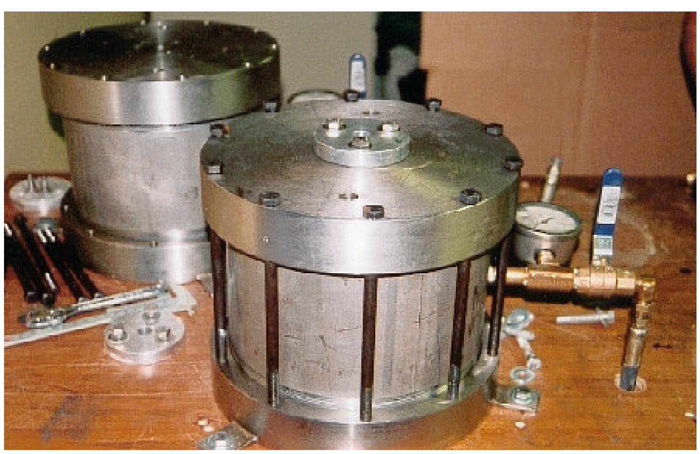

Figure 2 – Water permeability cells used to conduct permeability tests

At the end of the 40-day period, chloride profiles were determined for all concrete samples tested. Determination of **water permeability coefficients** using acid-soluble chloride content profiles was performed using a numerical analysis based on the following equations:

$$C(x,t) = C_0/2 \left[\mathrm{erfc} \{x / (2 (D_{app}\, t)^{1/2}) - ((V^2\, t) / (4\, D_{app}))^{1/2} \} + \exp (Vx / D_{app})\, \mathrm{erfc} \{x / (2 (D_{app}\, t)^{1/2}) + ((V^2\, t) / (4\, D_{app}))^{1/2} \right] \qquad (1)$$

$$V = K_w\, \Delta H / \Delta L \qquad (2)$$

$$\mathrm{erfc}(x) = 1 - \mathrm{erf}\,(x) \qquad (3)$$

$$\mathrm{erf}\,(x) = (2 / \pi^{1/2}) \int_0^x e^{-U^2}\, dU \qquad (4)$$

where D_{app} is the effective chloride-diffusion coefficient (m^2/s), t is the time (s), C_0 is the chloride concentration on the exposed chloride surface (g/100 g dry), x is the position along the sample, K_w is the water permeability coefficient (m/s), ΔH is the water head (correlated to the pressure applied to the concrete sample), and L is the sample thickness. This approach is valid for semi-finite media.

During testing, no water flow was measured for the tested samples. Chloride profiles were curve fitted using Equations 1 to 4. From Table 6, the results are subject to variability. The variability observed in water permeability coefficient is to be expected, according to Neville[2]. In this book, *Properties of Concrete*, he mentions that a variation of 4×10^{-12} m/s between 2 results is not significant. On this basis, we believe that the water permeability coefficients are similar for both concretes tested in our laboratories.

[2] Neville A.M., Properties of Concrete, Fourth Edition, Longman Group Limited, 844p.

TABLE 6 – Water permeability coefficient

Identification	Permeability coefficient, m/s	
	Test 1	*Test 2*
RCC	5.0×10^{-13}	0.1×10^{-13}
Conventional concrete	14.0×10^{-13}	9.0×10^{-13}

Conclusion

The tests conducted in this study show that RCC can have similar porosity and water permeability coefficients along with higher mechanical properties (compressive and flexural strengths) than those found in conventional concrete. The water permeability coefficients for the concrete mixes produced in this study are considered low (in the range of 1×10^{-13} m/s).

The properties presented in this report were obtained under well-controlled laboratory conditions. The properties are valid for the constituents used to prepare the concrete mixes. Nevertheless, these properties are liable to change with different constituents. This report is intended for the exclusive use of SEM's Client, and is provided on an "as is" basis with no warranties, implied or expressed, including, but not limited to, warranties of merchantability and fitness for a particular purpose, with respect to the services. SEM assumes no liability to any party for any loss, expense or damage occasioned by the use of the report. Only the Client is authorized to copy or distribute this report and then only in its entirety. The report's analysis, results and recommendations reflect the condition of the samples tested exclusively. The report's observations and test results are relevant only to the samples tested and are based on identical testing conditions. Furthermore, this report is intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who accept responsibility for the application of the material it contains.

We trust that this report meets your expectations. Please do not hesitate to contact us for any additional information.

Sincerely yours,

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