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Permeability and condition of concrete in the Argentine Antarctic'Carlini' Base

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ABSTRACT

A condition assessment of several concrete buildings located in the Argentine Antarctic 'Carlini' Base was conducted. It consisted in a visual inspection of the main structural elements, detection of pathologies, *in situ* measurement of the coefficient of air-permeability kT and of the carbonation depth. This paper describes the scope of the investigation and the main results obtained. The main pathologies detected were: construction defects, shallow cover depths, freeze-thaw damages and chloride-induced steel corrosion. The kT values were in the "High" to "Very high" range for 3 out of the 4 buildings investigated and "Moderate" to "Low" for the other building. Based on the information collected, a prognosis of the durability of the buildings is attempted as well as recommendations for future constructions in the extreme Antarctic climate.

Keywords: Antarctic, pathologies, air-permeability, durability

1 INTRODUCTION

1.1 The 'Carlini' Base

The 'Carlini' Base is a permanent scientific Antarctic Base of the Argentine Republic, located on the Potter Peninsula of the 25 de Mayo Island (62°14′18″S 58°40′00″W). It was originally established in 1953 and later named after the late Argentine scientist Dr. Alejandro Carlini. It is located in a region of great biodiversity, which justifies its intensive involvement in glacier, atmospheric, oceanographic and marine research activities (Argentine and International). It houses the first cinema (52 seats) ever built in the Antarctic and *Ataque,* possibly the southernmost disco dancing in the world, providing entertainment to the staff (up to 80 people).

The Base houses a laboratory to study the green-house effect, within the frame of the Global Atmospheric Watch, which is located in Cabildo buildings. This laboratory was installed in cooperation with the Italian *Programma Nazionale di Ricerche in Antartide*.

In 2001, a seismological station was installed, in cooperation with Italian *Istituto Nazionale di Oceanografia e Geofísica Sperimentale*.

Finally, the Base houses the Dallmann Laboratory and Acquarium, installed in 1994 and 2001 in cooperation with the German Alfred Wegener Institute for marine research. Since 2004 it is equipped with facilities for diving activities.

1.2 Climate

The 'Carlini'Base is subjected to a rigorous, albeit slightly milder, typical Antarctic climate. Figs. 1 and 2 summarize the monthly average climatic conditions in the Base. Winds with velocities exceeding 150 km/h, predominantly from NE, hit the Base, dropping the thermal comfort to -50°C. Precipitation is in the form of snow in winter with some drizzles in summer time.

(3) Researcher at INTI at the time of the investigation

Fig. 1 – Mean Monthly Air Temperatures

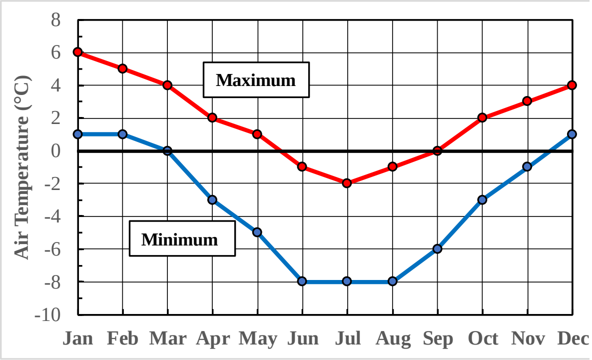


Fig. 2 – Mean Monthly Precipitation

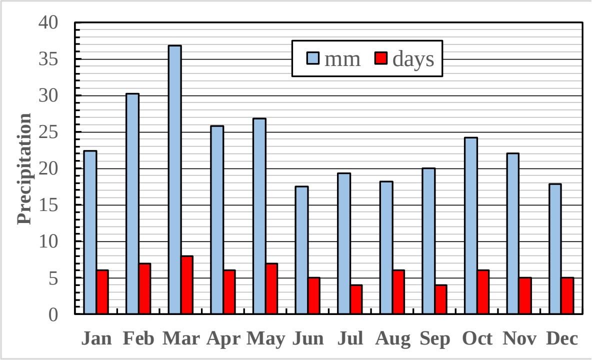


Fig. 3 presents a view of 'Carlini' Base showing its changing yearly climatic conditions.

Fig. 3 – Changing climatic conditions at 'Carlini' Base

The characteristics of the waters (marine and fluvial) at the Base are described in Table 1.

Table 1 – Characteristics of the waters affecting the buildings of 'Carlini' Base

Source	Temperature (°C)	Salinity (g/dm³)	Conductivity (mS/cm)	pH	Turbidity
Marine (Caleta Potter)	2.3	32.1	51.5	8.05	1.6 NTU
Fluvial (Chorrillo)	3.7	< 0.1	0.115	8.59	0.45 NTU

1.3 Buildings Construction and Exposure

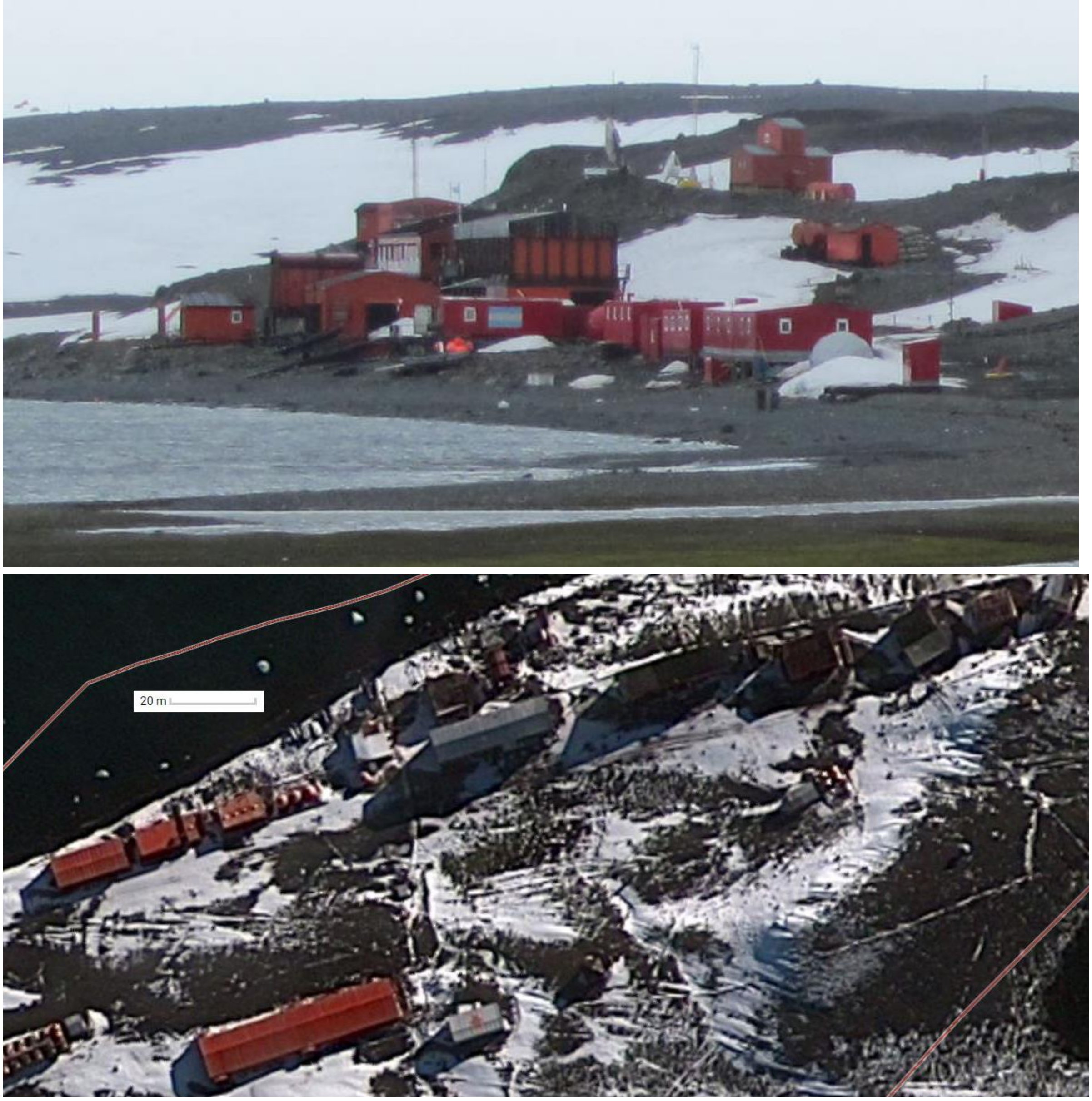
The Base includes some 30 buildings, gradually built, containing residential, sanitary and laboratory facilities, plus meteorological, IT and communications stations.

The investigation focused on four buildings, known as Main House (MH), Cabildo Building (CB), Argentine Laboratory (AL) and Dallmann Laboratory (DL). The age at the time of the survey was approximately was 30 years for the MH and CB, while the DL was 20 years and the AL 5 years.

As shown in Fig. 4, the buildings are displayed along a predominant E-W axis, with the main façade facing N (sun). Most buildings are located at short distance (typically 5 to 10 m) from the seaside, with the prevailing winds blowing from the sea.

As a consequence of the buildings' location, a considerable amount of chlorides is deposited on the surface of exposed concrete elements, especially those facing N. Given the climatic conditions (Figs. 1 and 2), the other obvious environmental action affecting the concrete structures is freezing and thawing cycles.

Fig. 4 (top and bottom) – General arrangement of buildings in 'Carlini' Base



The CB, easily identifiable in Fig. 4 (top), is the one with a 'tower' and located on a hill; it is 10 meters from the seaside, somewhat farther away than the other three buildings investigated which are located along the front row, very close to the sea (3-5 meters).

Predominantly, constructions in the Base consist of reinforced concrete framed buildings, resting on isolated foundations, not deeply seated under the ground level. The superstructure is composed of timber or laminated steel structures with timber panels or timber-corrugated steel mixed panels, combined with thermal insulating materials, such as expanded polystyrene or polyurethane foam. The construction was carried out by military personnel devoted to the maintenance of the Base, without knowledge and experience in construction techniques.

The concrete was prepared on site, with the limitations associated to the local prevailing conditions, namely: unqualified manpower, inadequate constituents and equipment for site concreting, lack of technical specifications or documentation and cold weather.

The aggregates, both coarse and fine, were quarried locally, although some evidence of the use of expanded clay lightweight aggregates was observed (CB). According to verbal declaration of the Base personnel, mixing water was taken from melting snow, sometimes helped by ice heating.

The situation of DL building is entirely different as the superstructure was built and assembled in Argentina's mainland, disassembled and transported by ship to the Base, where it was reassembled in 1994. So, the infrastructure may have had a better construction planning.

The superstructure of both DL and CB was built elevated from the ground, thus allowing the circulation of wind underneath and reducing the accumulation of snow and ice on the walls. Where this was not the case, frequent accumulation of snow leads to flooding and damage of the enclosures.

1.4 Scope of the Investigation

In 2013, the Argentine Antarctic Administration asked the National Institute of Industrial Technology (INTI) to conduct a comprehensive survey of the conditions of the buildings in 'Carlini' Base, reporting the identified pathologies and recommending remedial measures.

The survey included the following aspects: structures' conditions, electrical installations, drinking water supply, liquid and solid waste management and fire protection facilities. The survey was conducted *in situ* by a multidisciplinary team of specialized professional and technical personnel.

In this paper, just the results of the survey focused on the condition of the concrete structures are presented and discussed, with special emphasis on the site measurement of the coefficient of air-permeability kT.

2 IDENTIFIED PATHOLOGIES

2.1 Concreting Deficiencies

The poor concreting techniques applied are revealed by:

- Exposed coarse aggregate particles consisting of smooth rounded gravel, with maximum size above 30 mm, incompatible with the geometry of the structural elements, with the distance between steel bars and with the cover thickness
- Insufficient or null cover thickness over steel bars
- Segregation, due to incorrect aggregate grading and/or mix design
- Inadequate compaction
- Insufficient or inexistent curing
- Concrete without air-entrainment

2.2 Physical Action

- Temperatures below zero for most of the year, freeze-thaw cycles, leading to scaling and cracks
- Wetting and drying cycles, due to the accumulation and melting of snow and ice, leading to high saturation degrees of concrete, aggravating the effect of freezing temperatures

2.3 Chemical and Electrochemical Action

- Despite high kT value carbonation depths measured were very low due to low CO_2 concentration, low temperatures and high saturation degree
- Marine environment, exposed surfaces in cyclic contact with salts (sulphates and chlorides) in humid conditions, in the form of spray and splash
- Leaching of hydration products due to wetting and drying cycles, leading to efflorescence when in contact with atmospheric CO_2
- Steel corrosion induced by marine chlorides

3 ON SITE MEASUREMENT OF THE AIR-PERMEABILITY

In order to check the effect of the poor concreting techniques applied and of the tough Antarctic environment, the coefficient of air-permeability *kT* was measured on site. The so-called 'Torrent' method [1,2] was chosen, following the prescriptions of Swiss Standard SIA 262/1:2013 [3] for site applications. The test method, briefly described in the Annex, provides a suitable durability indicator of concrete, especially of its outer layers, very sensitive to detect bad concreting practices, especially lack of curing [4]. It was found that kT correlates well with other durability tests, such as 'Rapid Chloride Permeability' (ASTM C1202), Water Penetration under Pressure (EN 12390-8),Water Sorptivity (SIA 262/1) and Carbonation Rate [5], Chloride Migration (NTBuild 492) [6] and even Freeze-Thaw-Salts scaling test [7]. The 3rd generation instrument *PermeaTORR*, manufactured in Argentina by Materials Advanced Services (www.m-a-s.com.ar), owned by INTI, was used in the Antarctic.

3.1Sampling and Testing Conditions

Between 4 and 8 points were chosen on the exposed concrete surfaces of the four buildings, where kT was to be measured, avoiding areas with visible honeycombing or exposed rebars. The tests were performed under natural outdoors conditions (no heating); only when necessary the cell and instrument were shaded from direct sunlight.

Figs. 5 to 8 show the typical conditions under which the measurements were made.

Fig. 5 – Test on uncoated vertical surface

Fig. 6 – Aspect of uncoated surface under test

Fig. 7 – Test on vertical coated surface

Fig. 8 – Test on underside of concrete beam

As prescribed by Swiss Standard SIA 262/1 [3], prior to initiating the tests, the instrument was conditioned and twice calibrated, verifying that the calibration pressure rise was ≤ 5.0 mbar and that the absolute difference in pressure rise between the successive calibrations did not exceed 0.5 mbar.

The same standard also prescribes the following conditions of the concrete surface for conducting the test:

- Temperature ≥ 10°C
- Moisture (measured with an electric impedance instrument) ≤ 5.5%

Regarding moisture, at the time of the measurements, INTI did not have the required measuring instrument, so it was decided to avoid (or disregard) tests on surfaces that were wet at touch.

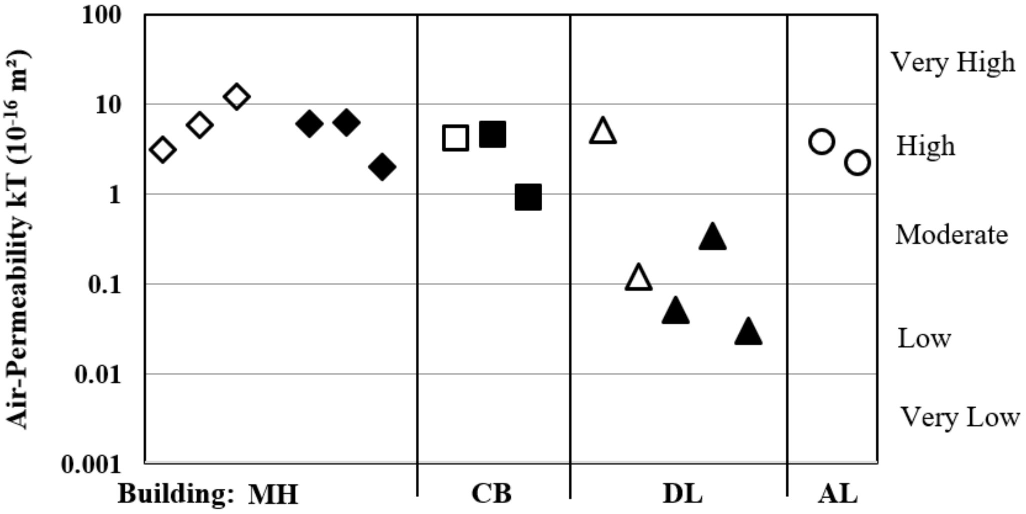
The air temperature was measured and recorded, ranging between 2°C and 9°C, which is below the limit established by SIA 262/1:2013 [3]. However, it has been shown that with the *PermeaTORR* and the last generation *PermeaTORR AC* instruments, it is possible to measure correctly the air-permeability kT down to temperatures near 5°C [8]. Most likely Swiss Standard SIA 262/1 [3] will modify the temperature limit to ≥ 5°C in its 2018 revision. Therefore, it was decided not to disregard any result, irrespective of the measured air temperature.

Another problem found was that some of the concrete surfaces were covered by a coating, asphaltic in the case of MH and DL buildings and latex in the case of CB, with tests made on areas with and without coating.

3.2 Test Results

A summary of the results of the coefficient of air-permeability kT, obtained on the four buildings is presented in Fig. 9 (each point represents the geometric mean of data obtained on the same element). The black symbols refer to tests made on coated surfaces, whilst the white ones on uncoated surfaces. The qualitative scale, shown at the right-hand side of the chart, indicates the 'Permeability Classes', updated and extended from those originally proposed in [9].

Fig. 9 – Results of coefficient of air-permeability obtained on four buildings of 'Carlini' Base



The first conclusion that can be drawn from the results in Fig. 9 is that the coatings of the concrete surfaces seem to have little or no effect on the measured value of kT.

The other important conclusion is that buildings MH, CB, AL present air-permeabilities within the 'High Permeability' range, whilst DL building results fall within the 'Moderate/Low Permeability' ranges (i.e. one to two orders of magnitude lower kT values).

The significantly better concrete quality displayed by the DL building, revealed by its lower permeability, can be attributed to better mix design and concrete practices, possibly attributed to a previous planning of the building's construction.

Based on the Exp-Ref model [10], the service life of a reinforced concrete structure subjected to chloride-induced corrosion is inversely proportional to $\sqrt[3]{kT}$. Hence, for the same cover thickness, the service life of the DL concrete structure can be expected to last $\sqrt[3]{10}$ -$\sqrt[3]{100}$(~ 2 to 4.5) times more than that of the other buildings.

The above mentioned Exp-Ref model requires, for assessing the service life of the buildings, field data on the cover thickness, as shown by the case of the Hong Kong-Zhuhai-Macao link [11], that are lacking from the survey. In any case, it should be borne in mind that, under cold weather conditions, the corrosion initiation time extends (lower rate of chloride diffusion [12]) as well as the corrosion propagation time (higher electrical resistivity [13]). To complicate matters further, possible frost damage may shorten the service life. Therefore, with the available information, it is not possible to make a reasonably accurate prediction of the service life of the inspected concrete structures, but just a relative assessment between DL with respect to the other buildings.

4 CONCLUSIONS

A comprehensive survey of the condition of buildings and installations of the Argentine Antarctic 'Carlini' Base was conducted *in situ*, including an assessment of the concrete infrastructure.

The latter revealed several deficiencies in the way the concrete elements were built, caused by: lack of specifications, untrained personnel, aggravated by the peculiar local conditions (lack of equipment, informal raw materials sources, concreting at low temperatures).

The resulting concrete quality was rather poor, as revealed by site measurements of the coefficient of air-permeability kT, showing high values in three out of the four buildings investigated. On the contrary, Dallmann Laboratory building, which was subjected to a more careful planning (and possibly construction as well) showed low kT permeability results. It is estimated that, other conditions constant, the expected service life of this building is about 4.5 times longer than for the rest.

The following recommendations can be formulated for future constructions in the Antarctic:

- Define an expected service life, to be used in the design
- Structural design, specifications and construction should involve well-trained personnel
- Concrete mixes should comply with the requirements and include air-entrainment
- Equipment should be adequate for cold weather concreting conditions
- Fixing of steel must leave sufficient room between bars and ensure a generous cover thickness
- The feasibility of using precast construction elements, manufactured in mainland and shipped and assembled on site, should be seriously considered

The measurement of the coefficient of air-permeability kT proved suitable, even under non-standard, rigorous conditions, to differentiate good from poor concrete quality in terms of durability performance. In future similar surveys, it is strongly recommended to combine the kT tests with surface moisture and cover thickness measurements.

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ANNEX. BRIEF DESCRIPTION OF ‘TORRENT’ AIR-PERMEABILITY TEST METHOD

The test consists in applying a vacuum cell, containing two concentric chambers, on the concrete surface. Initially, a vacuum is applied on both chambers by means of a vacuum pump; thanks to the presence of soft rings, the cell is pressed onto the concrete surface without external help (see Fig. A1).

Ø of inner cell = 50 mm
Ø of outer cell = 100 mm

Fig. A.1 - Aspect of the vacuum cell's concentric rings (l.) and cell applied on a vertical surface (r.)

After 60 s, with a vacuum typically around 30 – 50 mbar, the central test chamber is isolated from the pump. Thereafter, its pressure starts to rise due to the air in the concrete pores (originally at atmospheric pressure ~1000 mbar) flowing towards the evacuated cell. The more permeable the surface concrete layers affected by the test, the steeper the pressure rise in the central chamber.

The characteristic feature of this test method is the fact that, thanks to a pressure regulator, the external chamber (always connected to the vacuum pump) is evacuated at the exact rate needed to keep its pressure permanently balanced with that of the central chamber, thus acting as a ‘guard-ring’. Hence, a unidirectional flow (in the form of a cylinder of air) to the central chamber can be assumed (Fig. A2).

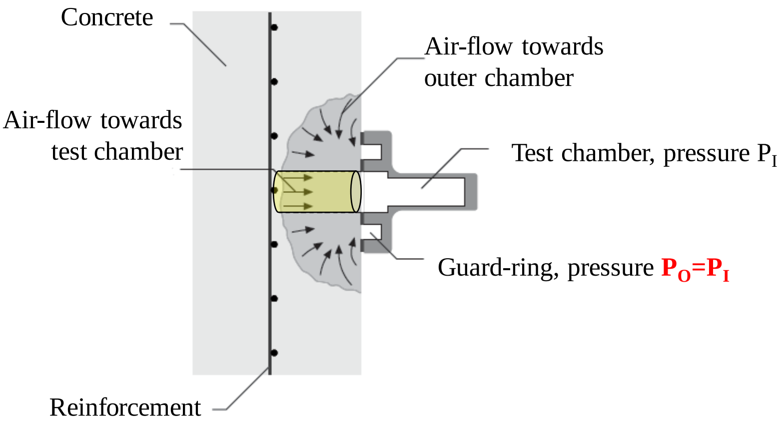

Fig. A.2 –Scheme of air-flow in the 'Torrent' method, assuming cylindrical flow of air into the central chamber

This controlled air flow allows the application of a model to derive Eq. (1), by which the coefficient of air-permeability can be calculated from the data collected during the test (www.m-a-s.com.ar).

$$\boxed{kT = \left(\frac{V_c}{A}\right)^2 \cdot \frac{\mu}{2 \cdot \varepsilon \cdot P_a} \cdot \left(\frac{\ln\left(\frac{P_a + \Delta P}{P_a - \Delta P}\right)}{\sqrt{t_f} - \sqrt{t_0}} \right)^2} \qquad (1)$$

where:

V_c = volume of the central chamber (m^3)
A = area of the central chamber (m^2)
μ = dynamic viscosity of air ($N.s/m^2$)
ε = open porosity of the concrete (-) which, by default is taken as 0.15
Pa = atmospheric pressure (N/m^2)
ΔP = increase of pressure in the inner chamber between time t_0 and t_f (N/m^2)
t_0 = once valve 2 was closed, time at which the increase in pressure is measured (60 s)
t_f = time at which the test is finished (s)

The final penetration of the vacuum front L (m), i.e. the depth of concrete affected by the test, can be calculated by Eq. (2).

$$\boxed{L = \sqrt{\frac{2 \cdot kT \cdot P_a \cdot t_f}{\varepsilon \cdot \mu}}} \qquad (2)$$