Variations of physical and mechanical properties of concrete with the height

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Abstract:

Introduction/purpose: Concrete, mortar, and cement pastes are materials that have become central in various fields of construction, structures, and civil engineering. About 7 billion cubic meters of concrete are implemented. Concrete is generally considered a homogeneous material, but that is not always the case given its rheological behavior, which can be due to heterogeneous phenomena of segregation and bleeding.

Methods: The study tested a concrete column's physical and mechanical characteristics and deformation in elevation. The tests included measuring absolute and apparent density, porosity, capillary absorption, permeability, speed of propagation, compressive strength, and static and dynamic modulus of elasticity. For this purpose, the standards of non-destructive testing (sclerometer, ultrasound, etc.) were used to take the average of a series of points located at different levels of the element to be tested.

Results: The results indicate that changes in the column's height affect its physical and mechanical properties, either increasing or decreasing them (such as porosity, absorbency, permeability, compressive strength, and the static and dynamic modulus of elasticity). These changes are influenced by various factors, including the inherent properties of the concrete implementation (such as vibration and curing) and the climate conditions during construction.

Conclusion: The findings of this study emphasize the importance of a nuanced approach to testing and evaluating variations in concrete properties by taking into account the multifaceted impact of changes in column height.

Key words: concrete, porosity, compressive strength, modulus of elasticity, permeability, elevation.

Introduction

Concrete is a composite material, made up of cement, aggregates (gravel and sand), water and possibly additions. Due to its heterogeneity, concrete turns out to be a particularly complex and evolving material: it undergoes profound physicochemical transformations not only when it is subjected to a rise in temperature, but even from the moments following its preparation (especially the hydration reaction and the setting phenomenon). It is therefore essential to fully understand all the parameters that play a role in concrete, in order to be able to understand its behavior.

Ever since its inception, concrete has been the primary material used in building structures across various fields of civil engineering. It has been essential in constructing everything from industrial buildings like factories and warehouses to hydraulic projects such as dams and dikes. It is also integral in vital infrastructures like bridges, tunnels, and urban amenities like aqueducts. Concrete's favor is due to its economy, ease of use, strength against compression, durability, insulation properties for sound and heat, and its ability to enhance architecture with different shapes, textures, and colors (Mani et al, 2021).

However, as construction materials become more diverse, comparing their qualities and performance against the multiple criteria for construction or renovation has become increasingly difficult. Meeting the structural, economic, and environmental requirements has become complex due to a wide range of available composite products (El Mabchour et al, 2020).

The durability of structures is significantly influenced by their environment. It is crucial to enhance the strength of concrete when exposed to external factors such as harsh weather, aggressive soils, and chemically reactive atmospheres.This factor has become increasingly significant, posing a challenge to concrete structures. Among various indicators, permeability stands out as the key factor influencing the long-term effectiveness of reinforced concrete structures (Shi et al, 2012; Teng et al, 2014). The microstructural characteristics, encompassing aspects like the size, distribution, and interconnection of micro-cracks and pores, play a critical role in determining concrete's permeability (Zhang & Li, 2011).

Nowadays, cementitious materials such as concrete, mortars or cement pastes are materials that have become essential in various fields of construction, engineering structures and civil engineering. Concrete artificial stones are composed mainly of cement and aggregates.

The behavior of concrete depends on the properties of each constituent in its composition. Its properties are determined by methods frequently used in laboratories.

Concrete is generally considered to be a homogeneous material, but this is not always the case given its rheological behavior which can make it heterogeneous due to segregation and bleeding phenomena. Indeed, in a concrete column such as a post, the density can change from one level to another. By this principle, we tried in our study to evaluate the physical and mechanical characteristics of a concrete column in elevation. K.C. Nehar & D. Benamara (2021) investigated and predicted the mechanical performance of high-strength concrete formulated with recycled aggregates.

The examination of the progression of concrete's physical and mechanical properties with regards to height has been the subject of numerous scholarly articles. Zhang et al (2021) conducted a study on the impact of the proportion of reinforced concrete layer height to total height on the mechanical properties of functionally graded concrete (FGC) that incorporated fly ash and polypropylene fiber. Their findings revealed that FGC specimens created with an h/H ratio of 0.50 displayed superior flexural strength, flexural toughness, and compressive strength. Zhang et al (2022) explored the mechanical behavior of concrete under tension at varying levels of water saturation and temperatures. They observed that tension strength and elasticity modulus declined when saturation fell within the range of 35% to 65%, but subsequently increased for higher saturations. Kallel et al (2018) investigated the development of the temperature field, thermal conductivity, specific heat capacity, compressive strength, tensile strength, and elastic modulus in shaft lining concrete as it aged and the thickness of the lining increased. They discovered that compressive strength, tensile strength, and elastic modulus experienced significant growth as the concrete aged.

Aggregates make up the largest portion of concrete, accounting for 60-80% of its volume. It is crucial that these aggregates be appropriately graded to ensure the entire concrete mass acts as a solid, uniform, compact mixture, with smaller particles filling the gaps between larger ones. However, concrete, as a structural material, is not completely solid.

Apart from air porosity, it develops micro-cracks even before being subjected to load. These factors significantly influence the properties of concrete. M. Słowik (2021) shared findings from their numerical simulations, offering a deeper understanding of how the composition affects the fracture characteristics of concrete.

The standard procedure for determining the primary concrete attribute – compressive strength – is well established (Institute for Standardization of Serbia, 2019).

Materials and methods

Materials and preparation of specimens

Concrete specimens were produced using the G. DREUX method for a desired strength of 25 MPa and a slump of 7 cm. The Portland cement used in this study was CEM II/A 32,5 provided by Zahana Cement Plant (Mascara, Algeria) with a 28-day compressive strength of 33 MPa. Blaine fineness of cement is 3100 cm^2/g and its specific gravity is 3.1.

The granular skeleton was composed of fine aggregates (sand 0/4), which generally contain quartz, and coarse aggregates (3/8 gravel), mainly composed of silica and quartz.

Table 1 shows the compositions of the concretes used, for water to cement ratio (W/C) equal to 0.58. Once the concrete was mixed, it was poured into a polyvinyl chloride (PVC) cylinder with a diameter of 40 mm and a height of 750 mm. Compaction is carried out using a vibrating table for 15 seconds.

Table 1 – Formulation of ordinary concrete (Kg/m3)

Component	Sand 0/4	Gravel 3/8	Cement	Water
Quantity (kg)	616	1143	350	202

The PVC tubes containing the samples were covered with plastic film to avoid any water exchange with the external environment and stored in the laboratory environment for 28 days.

Each PVC tube allows us to make up to 7 test pieces (Ø = 40; H = 75 mm) by sawing in a concrete saw as shown in the diagram in Figure 1.

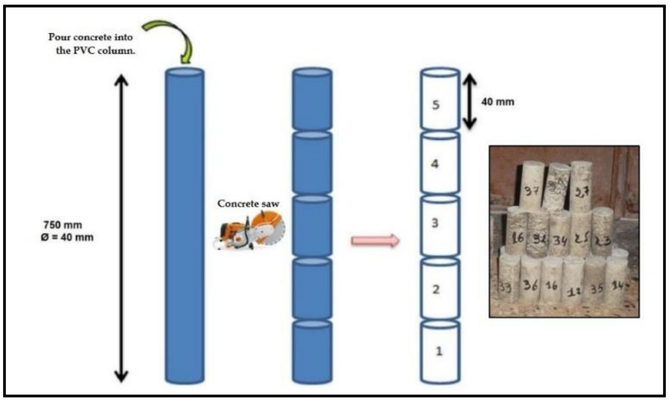

Figure 1 – Sawing of a concrete column

Test procedure

Apparent density (once called volume weight) is defined as the mass "M" per unit volume of the material "V", including pores and water (apparent volume). Therefore, it is measured in kilograms per cubic meter (g/cm3 or kg/m3). This can be represented by the equation:

$$\rho_{app} = \frac{M}{V} \quad (1)$$

The absolute density and the porosity accessible to water was determined in accordance with the recommendations of the AFREM group (RILEM TC 49-TFR, 1984) which predicts the saturation of samples in the single-phase mode (under vacuum). The tests were carried out on cylindrical samples 40 mm in diameter and 80 mm. The samples were then placed under a vacuum bell for 24 hours. Afterwards, they were immersed in water, and then kept under vacuum for 48 hours. It is worth indicating that the sample volume was determined by weighing it in air and then in water using a hydrostatic weighing device. Figure 2 illustrates the experimental setup.

Then, in order to obtain the dry mass, the samples were dried at 105 °C until a constant mass was reached. The absolute density and the porosity accessible to water could then be calculated using the following formulae (2) and (3):

$$\rho_{ads} = \frac{M_{air}}{M_{air} - M_{water}} \rho_{water} \quad (2)$$

$$\frac{M_{air}-M_{dry}}{M_{air}-M_{water}} \times 100 \quad (3)$$

Where Mair is the mass of the sample saturated in air, Mwater is the mass of the sample saturated in water, Mdry is the mass of the sample at the end of drying, and ρwater in the water density at 20 °C.

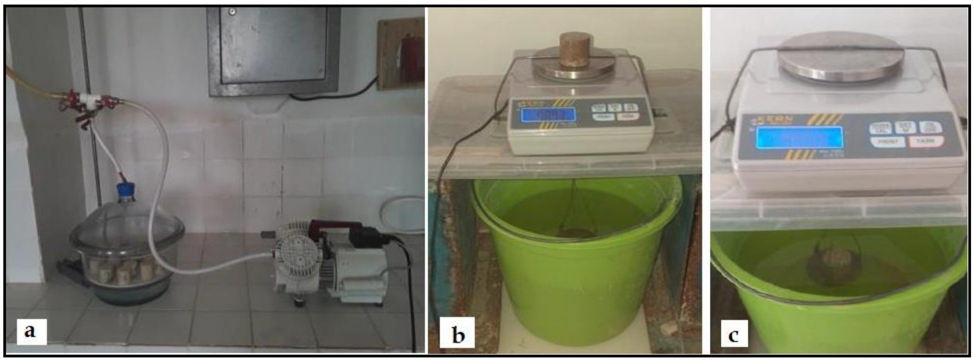

Figure 2 – Porosity tests: (a) vacuum saturation (b) weighed in air (c) hydrostatic weighing

The capillary water absorption test was performed according to ASTM C1585 (ASTM, 2020). Its principle consisted of placing one end of the sample on a support so that the liquid level was constant 1 to 3 mm higher than the bottom of the sample and then measuring the weight gain values of the sample at well-defined time intervals.

In this experiment, before a concrete sample is exposed to water, the sample must be dried in an oven at 105°C to a constant weight. The side faces were waterproofed by molten paraffin wax beforehand (Attolou et al,1989), which forced water to adopt a uniaxial path and prevent the evaporation of water from these faces. Figure 3 illustrates the experimental setup.

The water absorption per unit area of cement-based materials tended to be linearly proportional to the square root of time. This law is also known as the square root law:

$$\frac{d_m}{A} = S\sqrt{t} \quad (4)$$

where dm is the quantity of water absorbed in grams at time t, t is the elapsed time in seconds, A is the bottom surface of the sample in cm^2, and S is the capillary water absorption coefficient.

The amount of water absorbed per unit area after one hour was used as a quantity that represents the volume of the largest capillaries present in the skin area (Hall,1989).

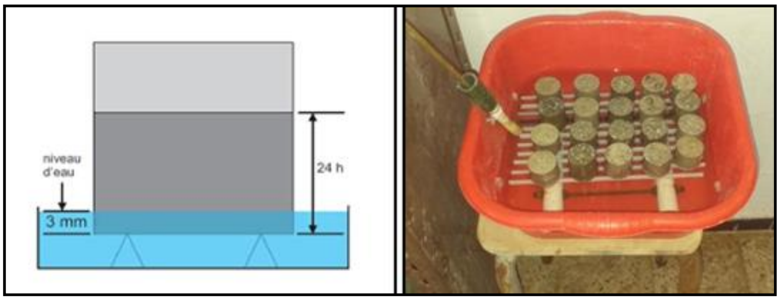

Figure 3 – Capillary water absorption tests

The Ultrasonic Pulse Velocity of concrete cylinders by direct transmission was evaluated using the standard test method (ASTM, 2016). The equipment used was the portable ultrasonic non-destructive digital indicating tester (PUNDIT), shown in Figure 4. In this method, an ultrasonic pulse is generated by a pulse generator and transmitted to the surface of concrete through the transmitter transducer. The time taken by the pulse to travel through the concrete, t (μs), is measured by the receiver transducer on the opposite side. To ensure good contact, a thin couplant (solid Vaseline) was used on the interface between transducers and concrete.

The Ultrasonic Pulse Velocity can be determined with equation (5):

$$V = \frac{L}{t} \tag{5}$$

where V is the ultrasonic pulse velocity (m/s), L is the path length in concrete (mm), and t is the transit time (μs).

The dynamic modulus is linked to the density of the concrete, its Poison's ratio, and pulse velocity according to the following relationship:

$$E_d = \frac{(1+\nu)\cdot(1-2\nu)}{(1-\nu)} \rho \cdot V^2 \tag{6}$$

where V is the ultrasonic pulse velocity (m/s), ρ is the density of concerete in (Kg/m^3), and υ poison's ratio of concrete.

This velocity is then used to calculate the compressive strength of the concrete using the following formula:

$$f_{cj} = 0.08177 \cdot e^{(0.00147 \cdot V)} \quad (7)$$

Figure 4 – Ultrasonic Pulse Velocity tests

The test for compressive strength of cylindrical specimens was performed according to ASTM C39 (ASTM, 2010) using a 1500 kN compression test machine (ELE International). The loading rate was set to 0.2 MPa/s.

Moreover, the instantaneous elastic modulus can be calculated as a function of its compressive strength based on the following empirical model:

$$E_c = 11000\sqrt[3]{f_{cj}} \quad (8)$$

where f_{cj} is compressive strength (MPa).

The dynamic elastic modulus is generally 20%, 30%, and 40% higher than the static elastic modulus for high, medium, and low-strength concrete, respectively (Mehta & Monteiro, 2014). There are several empirical equations that relate Ed and Ec. Lydon and Balendran (1986) proposed the following empirical relationship between Ed and Ec:

$$E_c = 0.83E_d \quad (9)$$

Figure 5 – Compressive strength test tests

Table 2 and Figure 6 present the variation of the apparent and absolute density of the concrete column according to the cutting heights. Each value shown in this graph corresponds to the average of the results obtained on three test specimens. It can be seen that the density, whether apparent or absolute, decreases as the level of the test piece increases. Certainly, this drop in concrete density is attributed to the presence of greater porosity in the specimen. These results are explained by the fact that certain grains, especially denser ones, descend downwards while fine grains remain at the top (due to gravity).

Table 2 – Variation of the apparent and absolute density of the different levels of the concrete column

Level of the specimen in relation to the height (cm)	ρ_{abs} [g/cm^3]	ρ_{app} [g/cm^3]
4	2.259	1.737
12	2.258	1.725
20	2.249	1.705
28	2.233	1.70
36	2.207	1.70
44	2.213	1.7
52	2.205	1.66

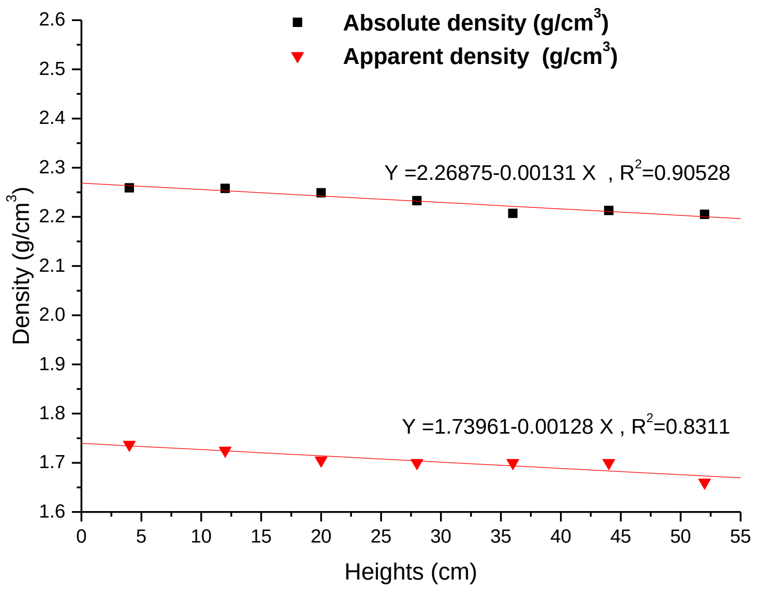

Figure 6 – Variation of the absolute and apparent density of the different levels of the concrete column

Table 3 and Figure 7 illustrate the variation in porosity as a function of the cutting height of the concrete column.

Table 3 – Values of the porosity accessible to water at the different levels of the concrete column

Level of the specimen in relation to the height (cm)	ε [%]
4	15.11
12	15.5
20	16.7
28	16.9
36	17.4
44	17.5
52	17.7

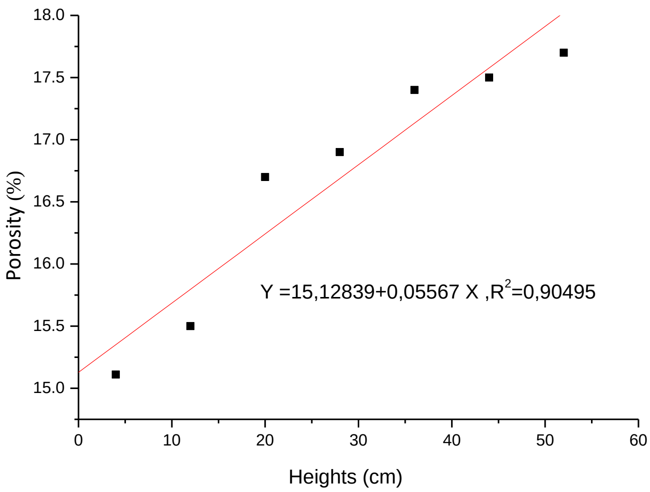

Figure 7– Variation in the porosity accessible to water at the different levels of the concrete column

It can be seen from the curve of evolution of the porosity accessible to water as a function of the cutting height of the concrete column shown in Figure 7 that the porosity evolves in an inverse manner to the density (the porosity increases according to the cutting height). This is explained by the decrease in density which inversely influences the volumes of pores.

The results obtained from the variation (dm/A) according to the square root of time and the different levels of the cut concrete column are shown in Table 4 .

Table 4 – Variation of dm / A according to the time of the different levels of the concrete column

P.H	30 sec	1mn	5mn	15mn	30 mn	1 h	2 h	4 h	7 h	24 h	72h
4	0.0238	0.074	0.1058	0.14	0.158	0.1776	0.1856	0.22	0.2673	0.387	0.517
12	0.0344	0.087	0.1083	0.151	0.171	0.1946	0.1933	0.2546	0.2673	0.4346	0.599
20	0.0344	0.093	0.1163	0.153	0.181	0.215	0.1963	0.2586	0.303	0.4426	0.605
28	0.0344	0.103	0.124	0.164	0.1883	0.23	0.206	0.2586	0.308	0.4773	0.651
36	0.0391	0.104	0.1298	0.164	0.1986	0.231	0.212	0.276	0.321	0.4773	0.666
44	0.045	0.105	0.159	0.193	0.22	0.235	0.2246	0.2953	0.348	0.52	0.689
52	0.0635	0.156	0.1856	0.243	0.2523	0.282	0.2913	0.338	0.3873	0.518	0.689

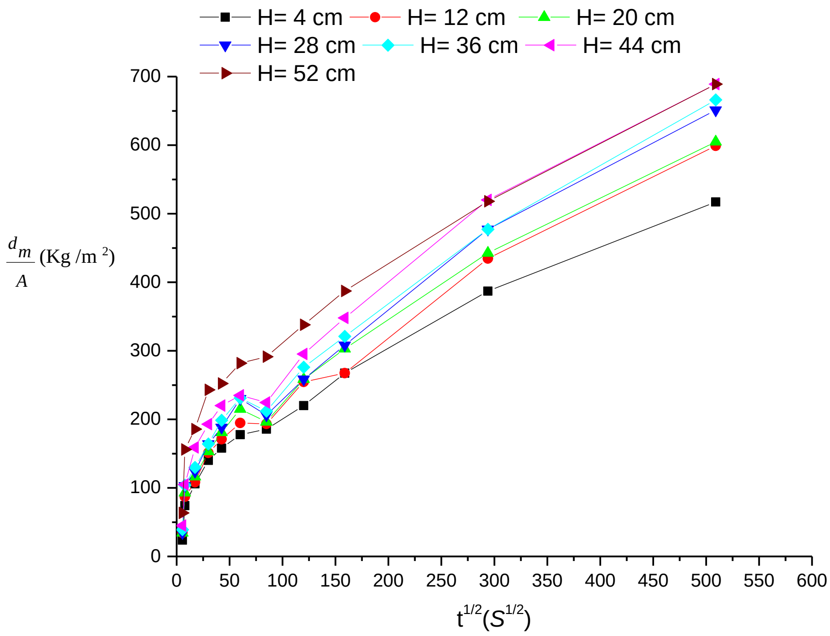

Figure 8 – Absorption kinetics S for the different levels of the concrete column

Table 5 – Measuring values of the absorptivity S of the different levels of the concrete column for t = 1 hour

Level of the specimen in relation to the height (cm)	S(Kg/m^2.S$^{0.5}$)
4	2.960
12	3.243
20	3.583
28	3.833
36	3.850
44	3.917
52	4.700

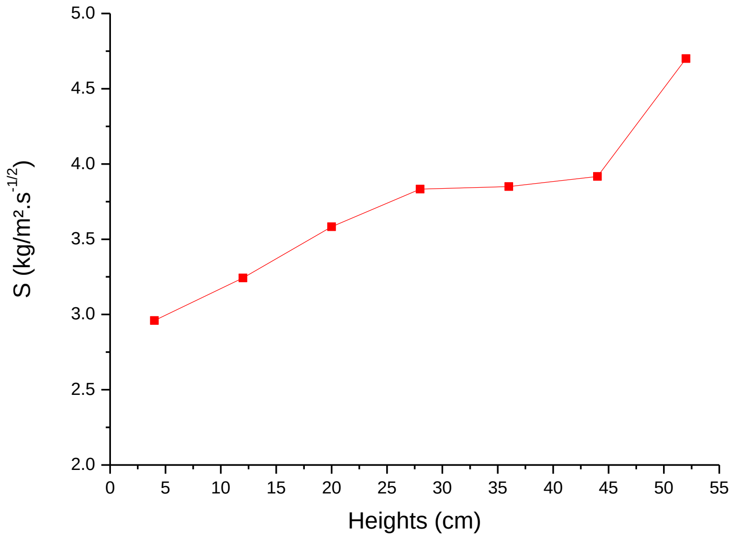

Figure 9 – Variation of absorptivity (S) as a function of the cutting heights of the concrete column for t = 1 hour

Figure 8 shows the absorption kinetics (the variations in the amount of water absorbed per unit area as a function of the square root of time) for different samples taken at different levels of the concrete column. According to Balayssac et al (1993), the water absorption curves make it possible to classify materials in accordance with the average size of the largest capillaries.

The curves in Figure 8, located between 0 and 1 hour, are curvilinear and they reflect the filling of the largest pores. And in the second part of the curves, more linear in appearance, they represent the filling of the finest capillaries. Table 5 and Figure 9 show the change in absorptivity according to the cutting height of the concrete column measured at time = 1 hour. It can be seen that the more the height of the cutting level increases, the more the absorption coefficient increases.

The results of determining the permeability and radius of the capillary pores of the different levels of the concrete column are shown in Table 6 and Figures 10 and 11.

Table 6 – Values of permeability and radius of capillary pores of different levels of the concrete column

Level of the specimen in relation to the height (cm)	V (cm ^{3})	e [%]	r x 10^{-6} (m)	K x 10^{-14} (m^2)
4	0.0022	15,11	1.3760	3.58
12	0.0024	15,5	1.4372	4.00
20	0.0027	16,7	1.5244	4.85
28	0.0029	16,9	1.5798	5.27
36	0.0029	17,4	1.5798	5.43
44	0.0030	17,5	1.6069	5.65
52	0.0035	17,1	1.7356	6.44

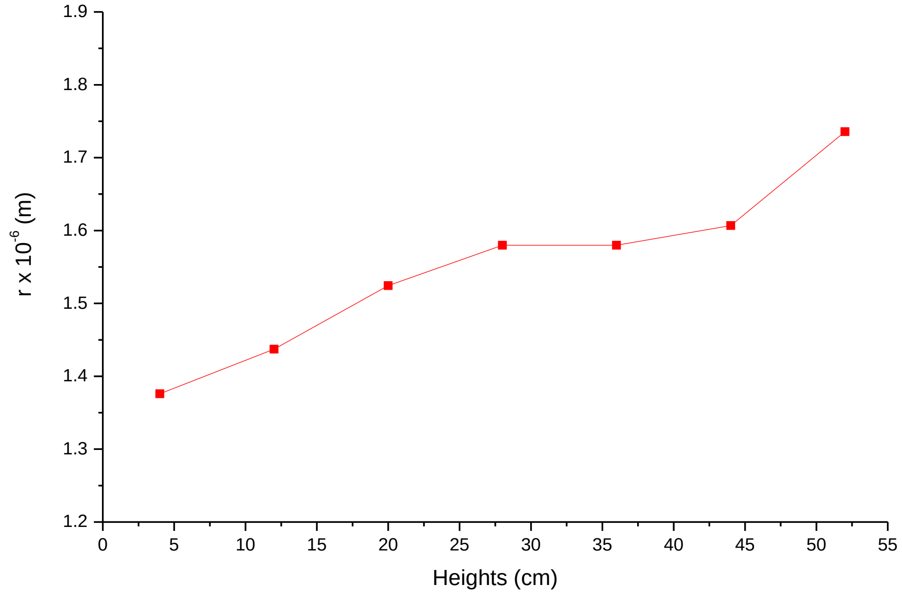

Figure 10 – Variation of the radius of the capillary pores in relation to the different levels of the concrete column

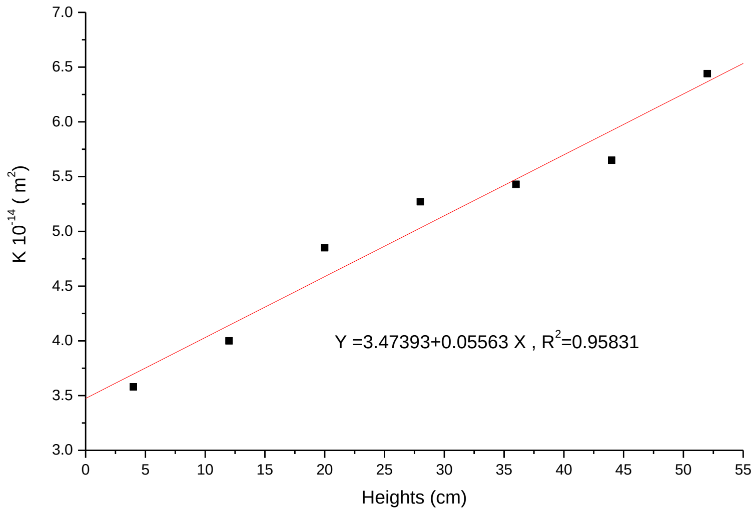

Figure 11 – Variation of the water permeability of the different levels of the concrete column

Calculating the radius of the capillary by the Washburn equation allows the water permeability of concrete to be determined as a function of height. It is observed that the more the level increases, the more the permeability increases. This property depends mainly on the capillary porosity as well as the size and interconnection of the capillary pores. In general, permeability increases with increasing porosity (Ollivier & Torrenti, 2008). The results already observed on the evolution of porosity justified this behavior.

The results of the propagation speed V, the compressive strength RC and the dynamic modulus of elasticity Ed of the different levels of the concrete column are shown in Table 7 and Figures 12 , 13 and 14.

Table 7 – Values of the propagation speed V, the compressive strength R_C and the dynamic modulus of elasticity E_d of the different levels of the concrete column

Level of the specimen in relation to the height (cm)	$t.10^{-6}$ (sec)	V (m/sec)	R_C	E_d (GPa)
4	20.2	3960.39	27.6	31.89
12	20.53	3896.73	25.13	30.86
20	20.6	3883.49	24.65	30.73
28	20.83	3840.61	23.14	29.64
36	20.83	3840.61	23.14	29.30
44	20.93	3822.26	22.53	29.10
52	21.33	3750.58	20.27	27.92

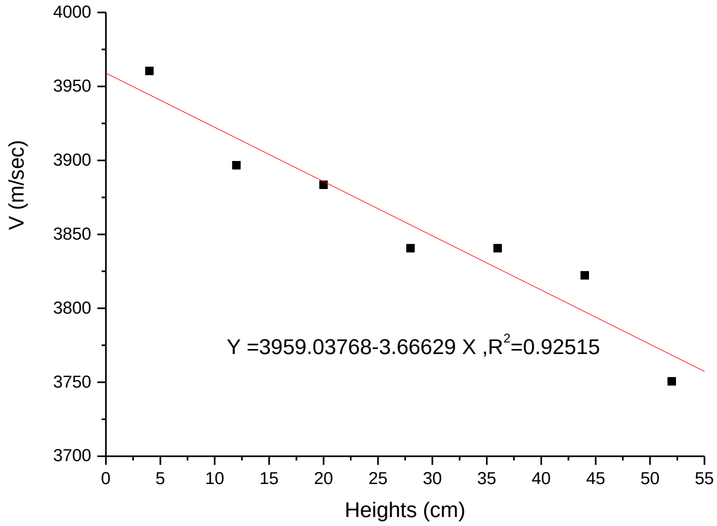

Figure 12 – Variation of the propagation speed of the different levels of the concrete column

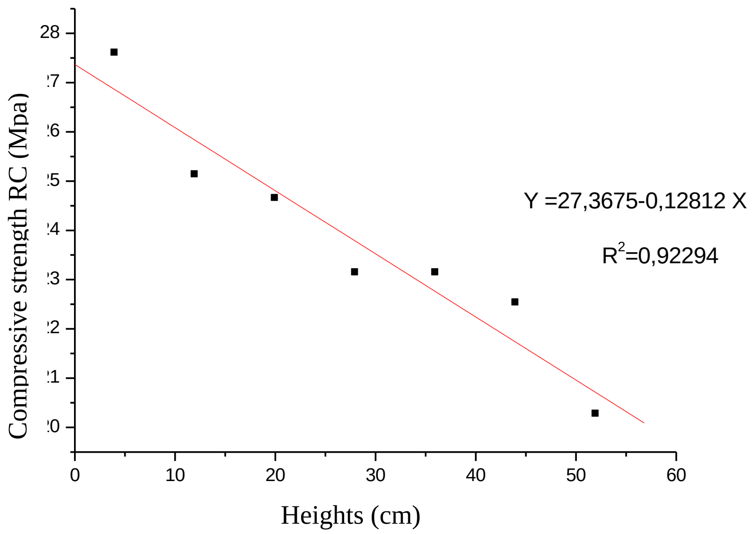

Figure 13 – Variation of the compressive strength RC of the different levels of the concrete column

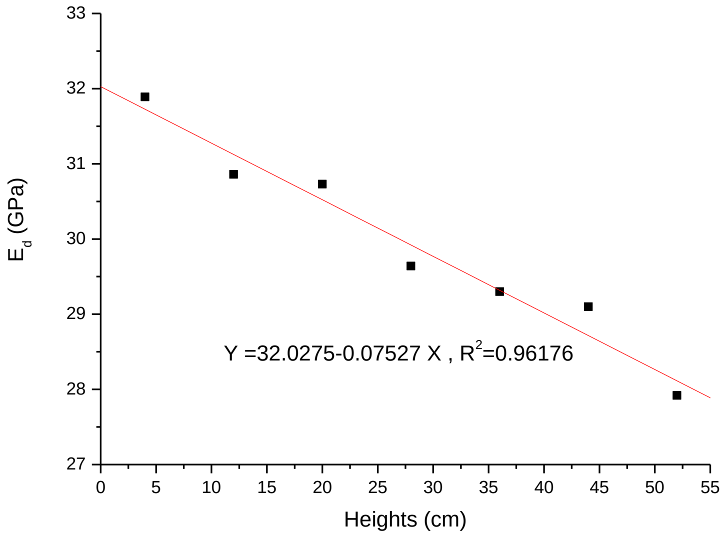

Figure 14 – Variation of the dynamic modulus of elasticity Ed of the different levels of the concrete column

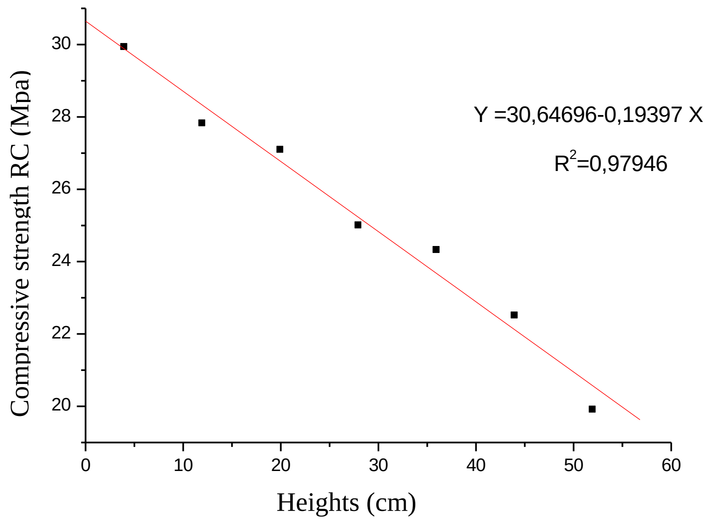

Figure 15 – Variation of the compressive strength of the different levels of the concrete column

Figure 12 shows a decrease in the propagation speed of the sonic wave as a function of the increase in the cutting height of the concrete column, and this is mainly due to the increase in porosity in the concrete confirmed by several authors. The wave propagation speed decreases when the porosity increases (Lafhaj et al, 2006).

The results of the RC specimen crush test are shown in Table 7 and Figure 15.

The values of the static modulus of elasticity Ec and dynamic Ed of the different levels of the concrete column are presented in Table 8 and Figure 16.

Table 8 – Values of the compressive strength RC, the static modulus of elasticity Ec and dynamic Ed of the different levels of the concrete column

Level of the specimen in relation to the height (cm)	R_{C28} (MPa)	E_c (GPa)	E_d (GPa)
6	29.92	34.15	41.14
18	27.81	33.32	40.14
30	27.08	33.03	39.80
42	24.99	32.16	38.75
54	24.31	31.86	38.39
66	22.5	31.05	37.41
78	19.9	29.08	35.04

It can be seen from Figures 15 and 16 that the compressive strength and the elastic moduli decrease with the cutting height of the concrete column and this is due to the increase in porosity and the decrease in density.

These variations in compressive strength and modulus of elasticity can reach 20 to 35%, which is in good agreement with the results in the literature (Giaccio & Giovambattista,1986). It is good, the PT which is at the origin of this phenomenon according to some researchers (Galan, 1981; Lafhaj et al, 2006).

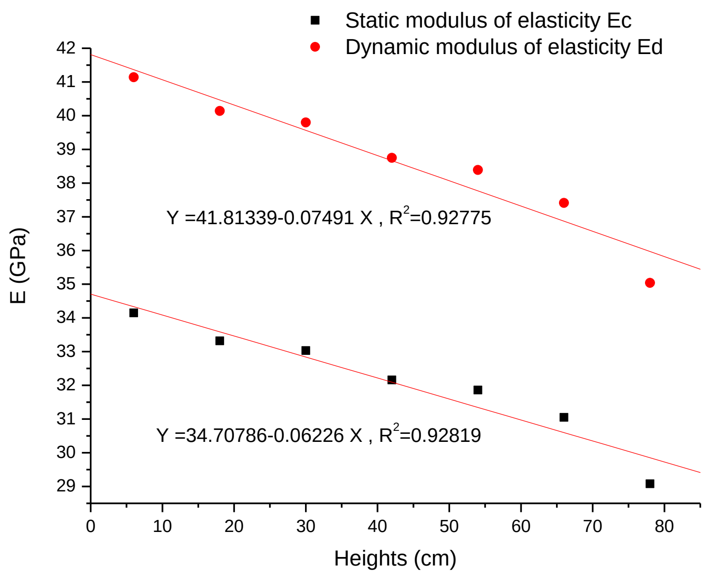

Figure 16 – Variation of the dynamic modulus of elasticity Ed and the static modulus of elasticity Ec of the different levels of the concrete column

Conclusion

The experimental study on the variation of the physical and mechanical characteristics of concrete in a vertical column was carried out using numerous tests.

The different results drawn on the effect of height are summarized as follows:

- A decrease of apparent and absolute density and the speed of sound, and
- An augmentation of porosity, absorbency, permeability, compressive strength and the static and dynamic modulus of elasticity.

All the results show that the variation of the height of the column modifies the physical and mechanical properties either by an increase or a decrease. For this, it is recommended by the standards of non-destructive testing (sclerometer, ultrasound, etc.) to take the average of a series of points located in different levels of the element to be tested.

These variations have consequences for several parameters such as the intrinsic properties of concrete, the implementation (vibration, curing, etc.) and the climatic conditions of the implementation.

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Variaciones de las propiedades físicas y mecánicas del hormigón con la altura

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CAMPO: materiales, ingeniería civil
TIPO DE ARTÍCULO: original de la investigación científica

Resumen:

Introducción/propósito: Las pastas de hormigón, mortero y cemento son materiales que se han vuelto centrales en diversos campos de la construcción, estructuras e ingeniería civil. Se utilizan aproximadamente 7 mil millones de metros cúbicos de hormigón. El hormigón generalmente se considera un material homogéneo, pero no siempre es así dado su comportamiento reológico, que puede deberse a fenómenos heterogéneos de segregación y exudación.

Métodos: El estudio probó las características físicas y mecánicas de una columna de concreto y la deformación en elevación. Las pruebas incluyeron la medición de densidad absoluta y aparente, porosidad, absorción capilar, permeabilidad, velocidad de propagación, resistencia a la compresión y módulo de elasticidad estático y dinámico. Para ello se utilizaron los estándares de ensayos no destructivos (esclerómetro, ultrasonidos, etc.) para tomar el promedio de una serie de puntos ubicados a diferentes niveles del elemento a ser probado.

Resultados: Los resultados indican que los cambios en la altura de la columna afectan sus propiedades físicas y mecánicas, ya sea incrementándolas o disminuyéndolas (como la porosidad, la absorbencia, la permeabilidad, la resistencia a la compresión y el módulo de elasticidad estático y dinámico). Estos cambios están influenciados por varios factores, incluidas las propiedades inherentes de la implementación del concreto *(como la vibración y el curado) y las condiciones climáticas durante la construcción.*

Conclusión: Los hallazgos de este estudio enfatizan la importancia de un enfoque matizado para probar y evaluar las variaciones en las propiedades del concreto teniendo en cuenta el impacto multifacético de los cambios en la altura de las columnas.

Palabras claves:. hormigón, porosidad, resistencia a la compresión, módulo de elasticidad, permeabilidad, elevación.

Изменения физико-механических свойств бетона с учетом высоты

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Резюме:

Введение/цель: Такие материалы, как бетон, строительные растворы и цементные пасты являются главными материалами в различных областях строительства, конструкциях и структурах. Ежегодно используется около семи миллиардов кубометров бетона. Бетон считается однородным материалом, но это не всегда так, учитывая его реологические свойства из-за возможных гетерогенных явлений сегрегации и протечки.

Методы: В ходе исследования были проверены физические и механические характеристики бетонной колонны и ее деформация по высоте. Испытания включали измерение абсолютной и удельной (кажущейся плотности), пористости, капиллярного поглощения, проницаемости, скорости распространения, прочности на сжатие, а также статического и динамического модуля упругости. Были использованы стандартные неразрушающие методы контроля (склерометр, ультразвук и т.д.) для определения среднего значения ряда точек, расположенных на разных уровнях испытуемого элемента.

Результаты: Результаты показывают, что изменения высоты колонны влияют на ее физические и механические свойства, увеличивая, либо уменьшая их (такие, как пористость, поглощение, проницаемость, прочность на сжатие, а также статический и динамический модуль упругости). На эти изменения влияют *различные факторы, включая присущие бетону свойства, такие как вибрирование и отверждение, а также природно-климатические условия во время строительства.*

Выводы: Результаты данного исследования подчеркивают важность тщательного подхода к испытаниям и оценке изменений свойств бетона с учетом многогранного воздействия изменений высоты колонны.

Ключевые слова: бетон, пористость, прочность на сжатие, модуль упругости, проницаемость, перепад высот.

Варијација физичких и механичких особина бетона по висини

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ОБЛАСТ: материјали, грађевинарство
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Материјали као што су бетон, малтер и цементне пасте постали су кључни у различитим областима конструкција, структура и грађевинарства. У свету се годишње користи око седам милијарди кубних метара бетона. Обично се сматра да је бетон хомогени метеријал, али, с обзиром на његова реолошка својства услед могућих хетерогених појава сегрегације и цурења, то није увек случај

Методе: Испитиване су физичке и механичке карактеристике бетонског стуба, као и његова деформација по висини. Испитивања су обухватила мерење апсолутне и привидне густине, порозности, капиларне апсорпције, пропустљивости, брзине пропагације, компресивне снаге, као и статичког и динамичког модула еластичности. Коришћене су стандардне методе испитивања без разарања (склерометар, ултразвук, итд.) на серији тачака лоцираних на различитим нивоима испитиваних епрувета.

Резултати: Показано је да промене у висини стуба утичу на физичка и механичка својства бетона, тако што их појачавају или смањују (као, на пример, на порозност, апсорптивност, пропустљивост, компресивну снагу и статички и динамички модул еластичности). Ове промене узорковане су различитим факторима, попут својстава бетона приликом његовог справљања *(нпр. вибрација и умрежавања) и климатских услова током конструкције.*

Закључак: Резултати овог рада наглашавају значај изнијансираног приступа испитивању и процени варијација својстава бетона тиме што узимају у обзир вишеструки утицај промена висине стуба.

Кључне речи: бетон, порозност, компресивна снага, модул еластичности, пермеабилност, елевација.

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