



Evaluating The Effect Of Underground Water Tables On The Stability And Durability Of Concrete Foundation

¹Lakhwinder Singh, ²Er. Raj Bala, ³Er. Hardeep Singh

¹ M. TECH Scholar, ²³ Assistant Professor

¹²³Department of Civil Engineering, JCDCMOE, Sirsa, India

Abstract

The concrete foundation of a building is the part that shoulders the load of the structure and also transfers the weight to the ground, which provides stability, strength, and durability over time. It is a key stage in construction, especially if the soil and groundwater conditions are not the same at all times. The study aims to review the influences of the water table on the strength and durability of the concrete foundation by focusing on water compositions causing the concrete to perform differently. The water samples from the underground of three different locations in Nawabshah, Pakistan, were used for casting the specimens and compared with the reference mix prepared in the laboratory using portable water. All the mechanical properties like compressive, tensile, and flexural strength along with the durability indicators such as density, ultrasonic pulse velocity, and permeability were compared at various curing ages of 7, 14, 28, and 90 days. Results indicated that the quality of water has an immense influence on the behavior of concrete: samples taken from Location 2 strongly matched control performance, whereas those from Location 4 regularly performed below par. Significantly, groundwater sources that were mineral-bearing enhanced strength but occasionally decreased initial strength. Such results emphasize the need to test groundwater properties during foundation design, especially in the case of ground with varying water tables, so that construction would be safe and long-lasting.

Keywords: Concrete Foundation, Water tables, Cement, Stability

1. Introduction

Concrete foundations are the critical structural members that bear and stabilize buildings by distributing loads to the ground. Concrete, consisting of Portland cement, aggregates, water, and admixtures, is the most commonly used construction material worldwide because of its strength, longevity, and flexibility [1]. It finds widespread application in foundations and other load-carrying members such as beams and columns. Renowned for its durability against environmental and chemical attacks—frost, rain, and pollution, for instance—concrete provides superior compressive, tensile, and flexural strength, which makes it very appropriate for foundation systems that are subjected to extreme conditions [2].

Concrete foundations contribute to a structure's fundamental stability as a whole. Being the major load-carrying component, a concrete foundation transmits the building's load uniformly to the supporting rock or soil and thus avoids differential settlement and structural imbalance [3]. The stability of such a foundation is essential to the long-term performance, durability, and safety of any kind of construction. A solid concrete foundation guarantees that all structural elements—walls, columns, beams—stay aligned and functional for years to come. It also grants resistance against natural loads such as earthquakes, soil loss, and underground water table level changes, which otherwise destabilize the structure [4]. Particularly in adverse conditions, a soundly engineered concrete foundation is crucial for lowering damage, maintaining cost savings, and prolonging the lifespan of the building. Essentially, foundation stability is the key to safe and sustainable construction [5].

Underground water tables, i.e., the top surface of groundwater, contribute substantially to determining the stability and durability of concrete foundations. These water levels fluctuate owing to changing seasons, rain, or construction activities nearby, and the changing levels cause a number of construction challenges [6]. Rising water tables is one cause that can generate hydrostatic forces to the foundations; thus leakage, shear strength of soil compromised, and still more dangerous condition of settlement or structural movement occur. Conversely, sudden low levels could depress the soil, causing voids in the earth below the foundation. These hazards are more so for concrete foundations in case of being continually wet for many years, especially in the case of chemically brutal environments, where the cumulative result would be the corrosion of the reinforcements, sulfate attack, and the disintegration of concrete chilling out with the gradual passage of time. It, therefore, becomes very vital to take full control of the wetting and drying of the soil in the foundation design to achieve both better safety and serviceability with less effort or money involved in maintenance or failure repairs that otherwise may be required [7, 8].

Groundwater may impose serious threats to the stability and longevity of concrete foundations. Most typical problems include water seepage, weakening concrete and corroding reinforcement, and chemical assaults by sulfates and chlorides that lead to cracking and strength reduction. Steady high groundwater levels can provide hydrostatic pressure, resulting in foundation heaving or wall settlement, whereas alternating levels can create soil expansion, shrinkage, or erosion—resulting in uneven settlement. These aspects emphasize the importance of comprehensive groundwater investigation and protective design practices for guaranteeing long-term foundation performance [9].

Knowledge of the effects of groundwater on concrete foundations is critical for engineers, contractors, and city planners, as it directly affects design, material choice, and construction technique. By dealing with groundwater issues early on, the professionals are able to apply successful waterproofing, drainage, and reinforcement techniques for the foundation [10, 11]. This early prevention aids in having safer, stronger structures, saves costly maintenance over the long run, and helps ensure sustainable city development through long-lasting building practice.

Here are the objectives of the research study are:

- Analyze the chemical and physical characteristics of underground water samples collected from different regions in Nawabshah, Pakistan.
- Determine the mechanical properties of concrete (compressive, tensile, and flexural strength) when mixed and cured using water from various underground sources.
- Evaluate the durability performance of concrete, including density and ultrasonic pulse velocity, under the influence of different underground water compositions.

- Conduct permeability tests to assess the potential long-term effects of water penetration on concrete integrity.
- Compare results with control samples prepared with potable water to identify deviations and their implications on structural performance.

2. Literature Review

Guo et al. (2024) [12] introduced an optimized waterproofing and anti-cracking scheme for underground engineering by high-performance self-compacting concrete. Implemented in a project for a basement wall, the scheme integrated external defense with internal paste methods. Outcome indicated good performance, ensuring humidity between 36–44% and conductivity between 32.9–52.3 $\mu\text{S}/\text{cm}$, validating the system's effectiveness in curbing water entry.

Li et al. (2024) [13] applied finite element simulation to investigate how different factors influence stress and deformation of plain concrete pile foundations. Findings indicated that both adjacent and remote piles dissipate excavation effects. Higher vacuum preloading pressure and time increased internal forces and displacements, whereas deeper embedding of retaining pile wall reduced significantly the effects of excavation.

Li et al. (2023) [14] applied DuCOM-COM3D simulation to study underground culvert works, obtaining better accuracy for porosity, temperature, humidity, and important mechanical behaviors such as long-term deflection and crack width. Although the model improved prediction accuracy, differences still existed between simulated and measured deflection values, leading to a limit analysis for the investigation of the reasons for the observed large deformations.

You et al. (2021) [15] tested the long-term performance of underground concrete in marine environments with seven mix designs exposed to groundwater. The findings indicated that a reduced water-cement ratio (0.34) and increased cement content (480 kg/m^3) greatly enhanced resistance to chloride and sulfate corrosion. High-efficiency additive mixes exhibited optimum sulfate resistance, validating their suitability for improving concrete performance in extreme coastal environments.

Ben-Owope et al. (2021) [16] proposed an exploration has been made about the influence of ascending groundwater levels on the integrity of concrete foundations and the delay of the construction. The pH measured at the analysis of thirty groundwater samples was found to fluctuate between 4.8 and 10.6; seven samples showed excessive iron content. The contents of sulfate and chloride stood at levels from 10 to 230 mg/L and from 10 to 180 mg/L , respectively. The results of the research on the water level showed a seasonal fluctuation which was caused by the rain, and which can provoke the threats of the construction stabilization and the concrete corrosion.

Al-Obaidi et al. (2020) [17] planned an undertaking and it was a Durability Assessment-based Design that uses Ultra-High-Durability Concrete (UHDC) which is part of the ReSHEALience initiative. Used in a geothermal water collection basin, the optimized UHDC enabled the use of a much thinner wall section for the structure which at the same time allows for a very much longer service life. That was the first time when the concept of durability was switched from the material to the structure of reinforced concrete with the best performance over time in comparison with the traditional type.

Fathi Salmi et al. (2019) [18] researched the destruction of the segmental concrete lining in the Zagros water transfer tunnel and stated that sulfate attack was the leading one. The hydrogeological conditions were equated to the four risk factors recommended by the UK Thaumacite Expert Group, indicating high susceptibility. It was observed from the current situation that the excavation in H_2S -bearing and water-saturated ground was the generation of aggressive environment ordering the demolition of concrete.

Jahandari et al. (2018) [19] examined the influence of saturation percentages on the unconfined compressive strength (q_u) of lime concrete. The research established the best clay and water percentages (23% and 24.04%, respectively) for lime concrete containing 7% lime. Findings indicated that higher saturation dramatically decreased strength; specimens in 100% saturation failed totally, whereas those in 20% saturation had a 42% loss in strength.

3. Problem Formulation

The challenge of assessing the influence of groundwater tables on the stability and durability of concrete foundations knows the manner in which changing groundwater levels affect both the behavior of the soil and concrete performance. Depleting or increasing ground water tables can not only reduce the soil bearing capacity but also have the negative consequences of expansion or shrinkage while differential settlement will be the case. Furthermore, water can mostly speed up the erosion of concrete by enabling moisture ingress, reinforcing steel corrosion, and such reactions as sulfate attack. The interaction between the water table and the concrete features (for instance, the porosity-penetrability combination) is a long-term durability determinant. The process of such a comprehensive evaluation should therefore encompass very definite conditions of the site e.g. soil type, climate, and water chemistry, facilities for immediate and long-term structural risk assessment.

4. Material and Methods

Figure 3 illustrates block chart methodology, which is used to assess the impact of underground water tables on the stability and durability of foundations made of concrete. The analysis starts with obtaining groundwater samples at three different places in Nawabshah, Pakistan—where each represents the varying characteristics of underground waters. These groundwater samples are first put through laboratory testing to examine their chemical nature and suitability for mixtures used for concrete production. Concrete is cast with the tested water and its fresh properties like workability and setting behavior assessed. Next, moulds are made ready for cube and cylinder specimens, which are then cured under controlled conditions to mimic real-world environmental exposure.

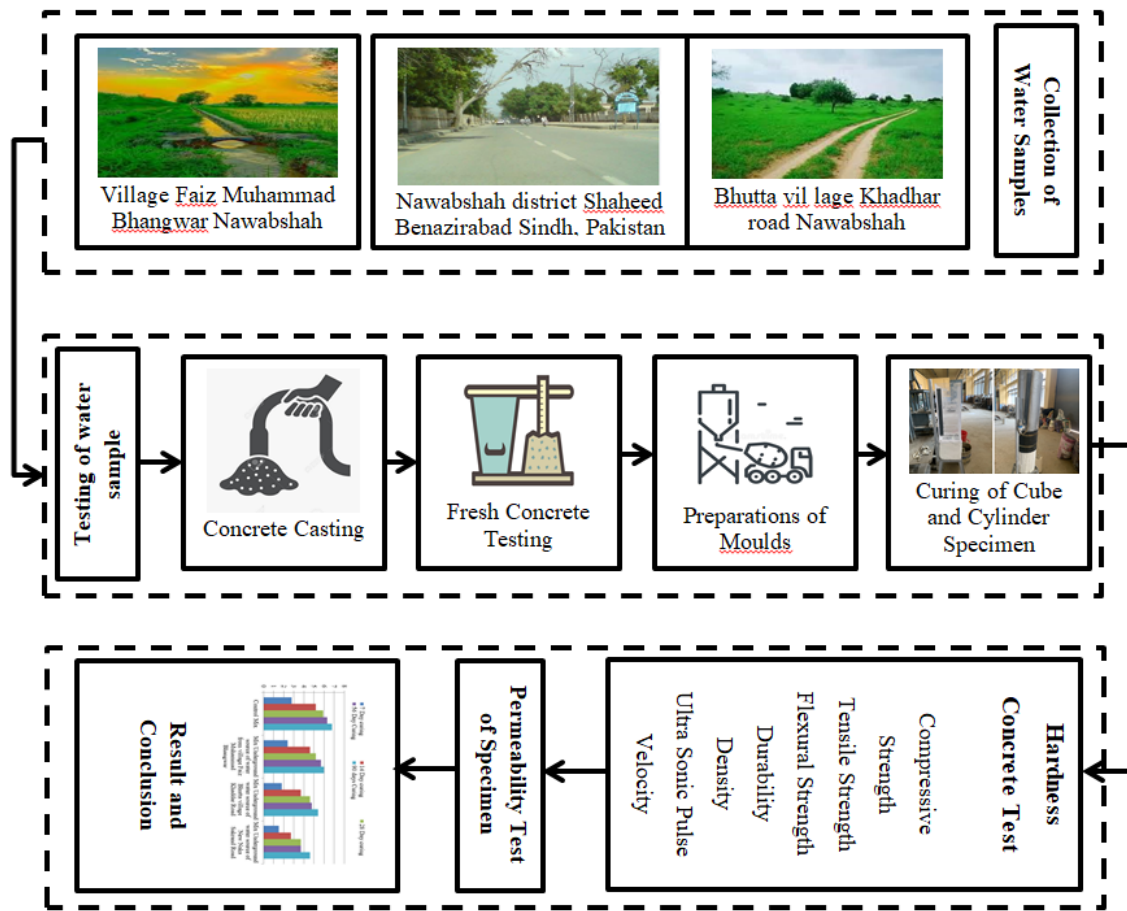


Figure 1: Block chart of suggested work

Once the hardening process is over, the solid concrete samples are tested in numerous ways to identify their physical and service life characteristics. The tests consist of a compressive strength test, a tensile strength test, a flexural strength test, an ultrasonic pulse velocity test, and a density test. Furthermore, durability tests such as water absorption, environmental durability, and permeability are conducted as well to find out the impacts of different water samples taken on the internal structure of the concrete. The whole set of results is gone through at different stages of the experiment to enable the scientists to draw conclusions, especially versus the composition of the groundwater in relation to the underground structure and stability of the concrete foundation over a period of time. The findings are essential for construction practices when having to consider either change or high-water table conditions when performing the construction practice.

4.1 Basic Material Used

- **Cement**

Maple Leaf Cement Company supplied 53 different grades of ordinary Portland cement (OPC) utilized in this research. When building in Pakistan, this cement is preferred over all others [20].

- **Fine Aggregates**

The Chenab River provided fine aggregates or sand, which are abundant and commonly used in the Multan area.

• Coarse Aggregates

Crushed circular granite quarried nearby as the project's aggregate. Sixty percent of the aggregate for the project was 20 mm in size and had a specific gravity of 2.7. In order to test the permeability and durability of various concrete mixes, we made sure to use variable water-cement ratios.

4.1 Mixing Water

Three separate locations in the Nawabshah district of Shaheed Benazirabad, Sindh, Pakistan, were surveyed for water sources: Faiz Muhammad Bhangwar village, Bhutta village on the Khadhar road, and the New Naka-Sakrand route. Here are the results of the water tests that were conducted: bicarbonates, conductivity, hardness, total dissolved solids (T.D.S.), total suspended solids (T.S.S.), dissolved oxygen, pH, biochemical oxygen demand, and chemical oxygen demand (As shown in Table 1).

Table 1: Chemical properties of water samples

Parameters	Maximum Allowable Limit	Village Faiz Muhammad Bhangwar Nawabshah	Bhutta village Khadhar road Nawabshah	Nawabshah district Shaheed Benazirabad Sindh, Pakistan
pH (N/A)	6.8–8.5 WHO	7.4	7.3	6.5
T.D.S (mg/L)	1000 WHO	899	1010	1007
T.S.S (mg/L)	150 EPA	52	75	155
Turbidity (NTU)	10 WHO	0.97	8.7	112
Bicarbonates (mg/L)	1000 WHO	330	200	600
Conductivity (micro-S/cm)	1000	1450	1630	1632
Hardness (mg/L)	100 WHO	360	270	280
D.O (Dissolved Oxygen) (mg/L)	4–7 EPA	6.3	6.1	4.7
C.O.D (Chemical Oxygen Demand) (mg/L)	150 EPA	18	55	257
B.O.D (Biochemical Oxygen Demand) (mg/L)	80 EPA	12	37	179

4.2 Casting of Concrete

In order to get concrete to the right shape and structural form, it is necessary to use molds or form work that has been created beforehand. After being cleaned, the formwork is treated with a release agent to ensure it does not stick. After the cement, aggregates, water, and admixtures are mixed in the concrete mix, it is poured, compacted to eliminate any air pockets, and then leveled. The next step is curing under regulated conditions so the construction can grow its strength and last for a long time.



Figure 2: Casting of concrete

4.3 Mix Design and Sample Preparation

Table 2 shows the concrete mix ratio utilized in the experiments, which is 1:2:4 with a water-to-cement ratio of 0.5. Cube specimens measuring 4x4x4 inches were utilized, while cylindrical specimens measuring 4x8 inches were cast for tensile strength. The concrete was cast using potable water and subterranean water sourced from three locations in the district of Shaheed Benazirabad in the Pakistani province of Shaheed Nawabshah: the hamlet of Faiz Muhammad Bhangwar, the village of Bhutta on the Khadhar road in Nawabshah, and the New Naka Sakrand road in Nawabshah. After 7, 14, 28, 56, and 90 days in potable water and subterranean water, respectively, the concrete samples were ready for testing.

Table 2: Concrete Mix Proportion

Samples	Brick Kiln Ash %	Brick Kiln Ash (kg/m ³)	Cement (kg/m ³)	F.A (kg/m ³)	C.A (kg/m ³)	Water (kg)	Cubes (4"×4")	Cylinder (4"×8")
Location 1	0	0	7.87	15.74	31.48	3.93	9	9
Location 2	10	0.79	7.08	15.74	31.48	3.93	9	9
Location 3	10	0.79	7.08	15.74	31.48	3.93	9	9
Location 4	10	0.79	7.08	15.74	31.48	3.93	9	9
Grand Total	2.36	2.36	29.11	62.96	125.95	15.73	36	36

5. Result and Analysis

5.1 Compressive Strength

The graph shows compressive strength of concrete mixes over 7 to 90 days by Location 1, Location 2, Location 3 and Location 4. With an increase in curing time, strength of all mixes increased. The highest strength was in the control mix, which crossed 50 at 90 days. Mix 3 on Location 2 worked next to Location 1 followed by Location 3. The Location 4 mix exhibited the lowest strength, which revealed that underground water quality plays an important role in concrete performance.

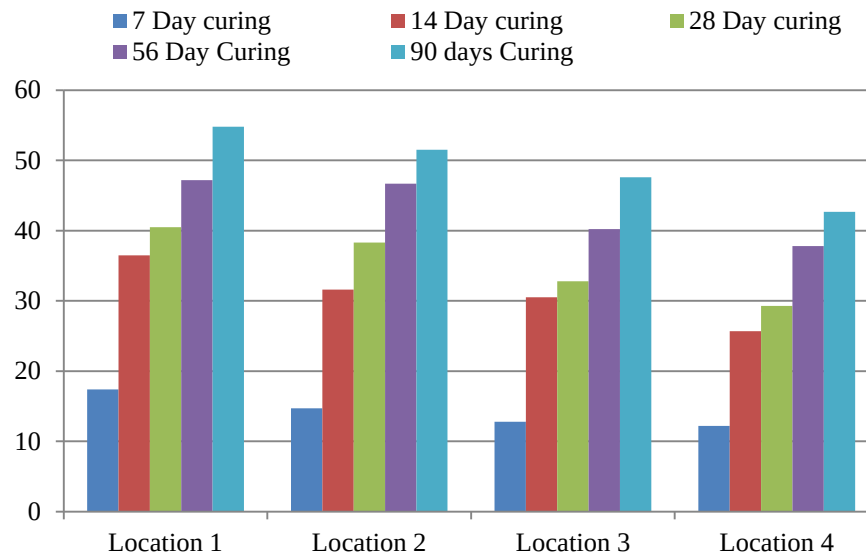


Figure 3: Compressive strength

5.2 Tensile Strength

The tensile strengths of the mixes of concrete from 7 days to 90 days curing times are reflected by the data. The highest was the strength of Location 1, rising from 2.8 on day 7 to 6.8 on day 90. The second-highest was that of the water from Location 2, going up to 6.0 on day 90. Lower values were produced by Location 3 and Location 4 mixes, reaching levels of 5.4 and 4.6 respectively. All blends exhibited gains in strength with age, and quality of water source impacted overall performance.

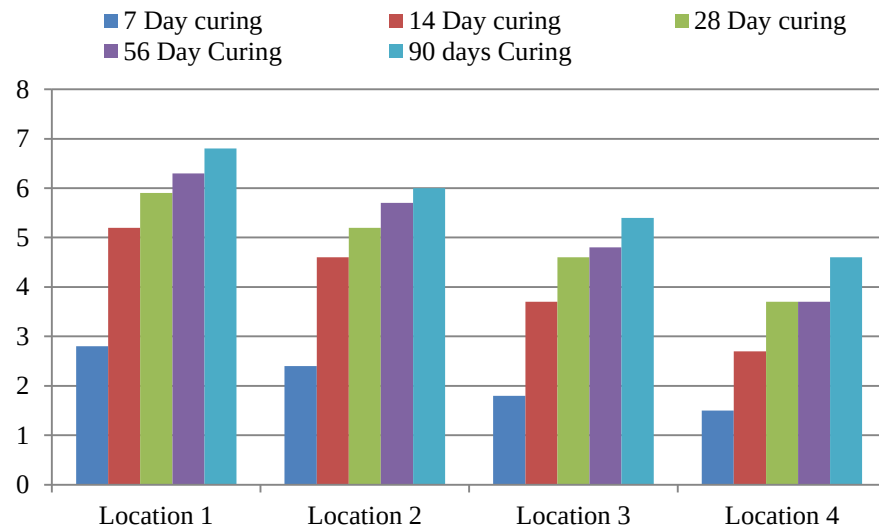


Figure 4: Tensile Strength

5.3 Flexural Strength

The graph shows flexural strength of concrete mixes over 7 to 90 days using Location 1 and underground water from three Location sources. Strength increased with curing time for all mixes. Location 1 reached the highest value of about 3.8 in 90 days, followed closely by Location 2. Mixes from Location 3 and Location 4 showed lower values, with the latter being the weakest. This highlights the impact of underground water quality on concrete's bending resistance.

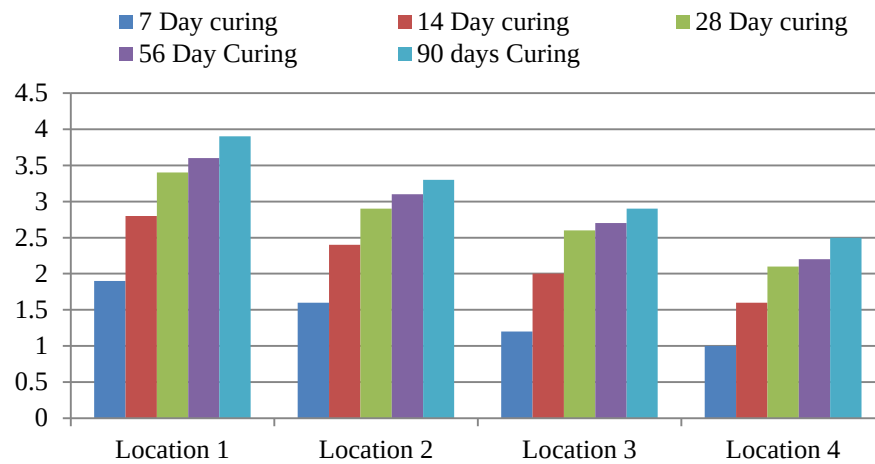


Figure 5: Flexural Strength

5.4 Durability

The data presents the durability test results of concrete mixes over curing periods from 7 to 90 days. Location 1 showed the lowest durability values, increasing from 15.1 at 7 days to 30.8 at 90 days. The mix using water from location 2 reached 36.7 in 90 days. Higher durability was observed in mixes from Location 3 and Location 4, which peaked at 47.3 and 50.7 respectively. All mixes demonstrated increasing durability with longer curing times, with underground water sources showing enhanced performance.

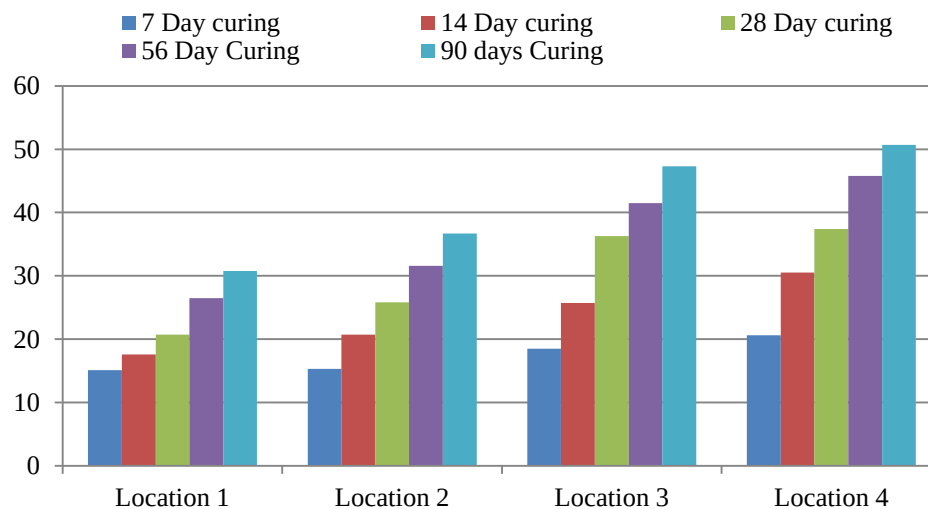


Figure 6: Durability Test

5.5 Density of Concrete

The information in figure 7 indicates the density of concrete of various mixes at curing times ranging from 7 to 90 days. Location 1 was the densest, rising from 2444 at 7 days to 2576 at 90 days. The mix with water from Location 2 came in second, rising to 2515 at 90 days. Mixes from Location 3 and Location 4 exhibited lower densities, culminating in 2462 and 2447, respectively. All samples exhibited a continuous increase in density with increasing curing time, reflecting enhanced compaction and material cohesion.

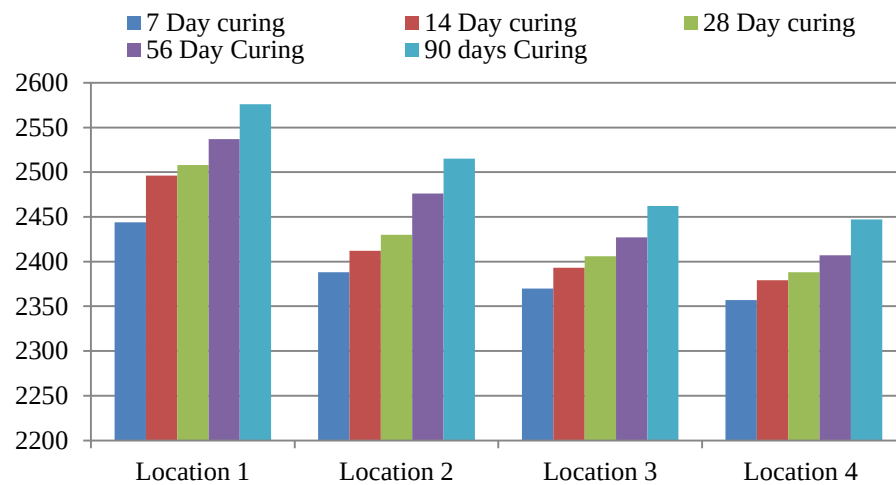


Figure 7: Density of Concrete

5.6 Ultra Sonic Pulse Velocity

Figure 8 shows the Ultrasonic Pulse Velocity (UPV) of concrete mixes at curing ages between 7 and 90 days. Location 1 achieved the highest UPV of approximately 5300 m/s at a curing age of 90 days, followed by the mix with water from Location 2 at approximately 5100 m/s. Mixes from Location 3 and Location 4 had lower readings, up to about 4900 m/s and 4700 m/s respectively. All of the mixes had a steadily improving UPV with increased curing times, reflecting better internal concrete quality with time.

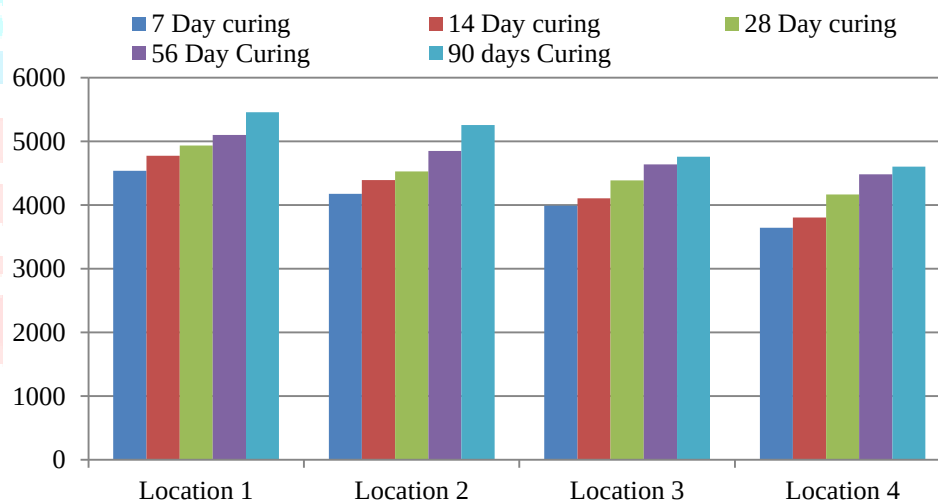


Figure 8: Ultra Sonic Pulse Velocity

5.7 Permeability Test

Figures 9 also show how the porosity and permeability of the concrete relate to one another. According to the results, there was a direct association between the porosity and the permeability of the concrete. In particular, the permeability of the concrete was shown to rise in direct proportion to its porosity. One possible explanation for this observation is that, as porosity increases, there are more and more open spaces inside the concrete structure. So, water can enter the material more easily due to the increased surface area of the amplified empty space.

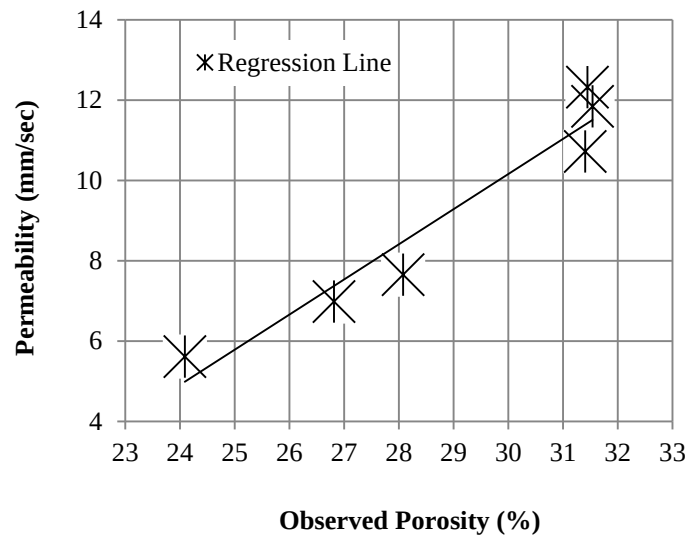


Figure 9: Plot of permeability vs. porosity for cubes

6. Conclusion

To conclude, the assessment of the repercussions of underground water levels on the durability and sustainability of concrete foundations is a major part of ensuring the long-term endurance of structures. The presence of high or changing water tables can deeply affect concrete through increased dampness, resulting in several problems of a negative nature. To illustrate, rusting because of continued access to water can lead to sulfate attack, alkali-silica reaction, and carbonation, decreasing the resilience and strength of the concrete over time. Besides, different water levels might exert an unbalance of pressure on foundation systems, which in turn might cause an unequal, downward movement and a fissure in any part of the foundation wall, thus losing its stability. If the water table proves to be high, then we will need some designing innovations like installation of watertight membranes, climate-friendly, efficient drainage systems, and the use of materials with long endurance for water as the best defense. Also, engineers should keep a closer look at the local hydrogeological situation by taking into account the groundwater level variations and the soil properties on the ground. The final point is that looking forward is the solution to both controlling and preparing for underground water's impact and thus the durability and the life of concrete foundations can be assured to be very long, and the building will be kept very safe and still in use in the long run.

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