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Seismic Evaluation of Compressed Earth Blocks Using Acoustic Waves: Case of Chichaoua Taroudant

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Abstract
Compressed earth blocks (CEB), also referred to as BTC, are a widely used traditional construction material known for their durability and energy efficiency. However, on September 8, Morocco experienced a devastating earthquake that claimed nearly 3,000 lives, severely impacting provinces such as Al-Haouz, Chichaoua, and Taroudant. In response to this event, educational activities were suspended in approximately 40 municipalities.As part of an effort to better understand the seismic behavior of local materials, raw soil samples were collected from the village of Amskrdad, situated within the affected Chichaoua-Taroudant region. These samples were then used to produce an unstabilized compressed earth brick. To analyze the mechanical response of the material, waves were induced along the x and y axes, allowing for the measurement of pulse velocity and time of flight. The obtained data enabled the calculation of the signal-to-noise ratio (SNR) for each signal.Test results revealed an elasticity modulus of 2819.92 MPa, while Poisson's ratio, determined using a Pundit PL200 Proceq device through a completely non-destructive testing method, was found to be 0.27. These findings contribute to a deeper understanding of the mechanical properties of compressed earth blocks in seismic conditions, offering valuable insights into the structural reliability of traditional construction methods in earthquake-prone regions.

Keywords: Compressed Earth Blocks (CEB), Acoustic Waves, Seismic Evaluation, Earthquake-Resistant Materials, Structural Reliability, Non-Destructive Testing (NDT), Poisson's Ratio, Elastic Modulus, Pulse Velocity, Traditional Construction Materials

Introduction
Compressed earth blocks (CEB) are a traditional construction material valued for their durability, energy efficiency, and minimal environmental footprint [1]. In Morocco, they are widely used, particularly in housing, due to their ability to provide structures well adapted to the local climate while maintaining a low environmental impact [2, 3].

However, the 6.8-magnitude earthquake that struck on September 8, 2023, revealed the structural weaknesses of these constructions in seismically active regions. This disaster, which resulted in nearly 3,000 casualties and widespread destruction in the provinces of Al-Haouz and Chichaoua-Taroudant, raised concerns about the resilience of CEB-based buildings commonly found in these areas [4]. To gain a deeper understanding of the mechanical behavior of this material under seismic stress, raw soil samples were collected from the village of Amskrdad, located within the affected Chichaoua-Taroudant province. These samples serve as the basis for evaluating the seismic performance of CEB in local construction.

This study involves the fabrication of unstabilized CEB using these soil samples, followed by ultrasonic testing to assess their mechanical properties. The primary objective is to determine whether these materials, in their conventional form, possess sufficient strength to withstand seismic forces. If shortcomings are identified, potential improvements and adaptations will be explored to enhance their seismic resistance. Ultimately, the study aims to provide scientifically based recommendations for rebuilding efforts in the affected areas while considering the unique characteristics of local materials.

Experimental Details

P The study followed a series of essential steps to analyze the mechanical properties of compressed earth blocks (CEB) obtained from the region affected by the September 8, 2023, earthquake. Soil samples were gathered from the village of Amskrdad, situated in the Chichaoua-Taroudant province, one of the most severely impacted areas. These samples were collected from locations traditionally used by local residents as a source of earth for construction. After collection, the raw soil was left to air-dry to eliminate residual moisture before being processed into CEB (Fig. 1).

Figure 1: Satellite Image of the Soil Sample Collection Site in the Village of Amskrdad, Chichaoua Tar-oudant, Morocco.

The collected soil samples were compacted into compressed earth blocks (CEB) without the addition of stabilizers. The compaction process was carried out using a hydraulic press capable of applying a force of 300 kN, producing standard-sized bricks measuring 17 × 12 × 8 cm. To ensure uniform and complete drying, the CEB were then placed in an oven at 105°C for 72 hours [5].

Subsequently, the CEB underwent non-destructive testing using the Pundit PL-200, a high-precision ultrasonic device [6]. This instrument measures pulse velocity and time of flight (TOF) along both longitudinal and transverse directions (x and y). Ultrasonic waves were generated for each sample, and the recorded signals were analyzed to determine the signal-to-noise ratio (SNR) for each measurement.

The collected data were used to compute two key mechanical properties: the elastic modulus and Poisson's ratio, utilizing the PL-LINK software [7].

Since these measurements were performed without causing damage to the material, they provide valuable insight into the strength and mechanical behavior of the CEB under seismic conditions. The results are then analyzed to assess whether these blocks require modifications or improvements to meet construction standards in earthquake-prone areas (Fig. 2).

Figure 2: Pundit PL-200 Proceq instrument and Compressed Earth Block (BTC).

Results and Discussion

Measurements of gain and voltage combinations were conducted in both the x and y directions, ensuring proper transducer positioning to facilitate wave transmission [8]. The PL-Link software was employed to record time of flight (TOF) and pulse velocity, with the data exported in Excel format for further analysis [9]. The presence of higher frequencies during testing suggested greater ultrasonic wave absorption by the material, whereas lower frequencies indicated deeper wave penetration [10]. As illustrated in Figure 3, increasing the voltage and gain of the ultrasonic transmitter in CEB led to a rise in signal power, thereby accelerating wave propagation speed and decreasing TOF. The relationship between voltage, gain, TOF, and SNR confirms that at higher voltages (300–400 V), the SNR significantly improved, ensuring better wave transmission with less noise. Notably, at 300 V, the SNR exceeded 50 dB, demonstrating the accuracy of TOF measurements. Furthermore, as gain increased, TOF exhibited a slight decrease due to enhanced signal power, which facilitated faster wave propagation within the material.

A comparison of x and y directions revealed anisotropic behavior in wave propagation, with the x-direction displaying higher TOF and lower velocities than the y-direction. This suggests slight material inhomogeneities that could affect wave transmission. Figure 4 demonstrates that increasing voltage or gain resulted in higher TOF, while velocity and SNR also increased.

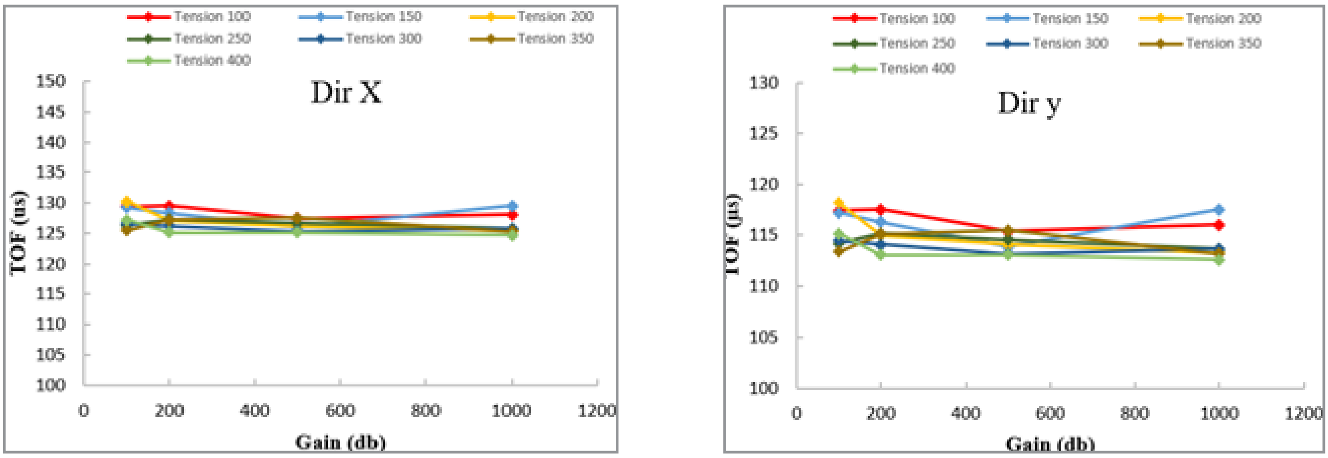

Figure 3: TOF as a Function of Gain and Voltage

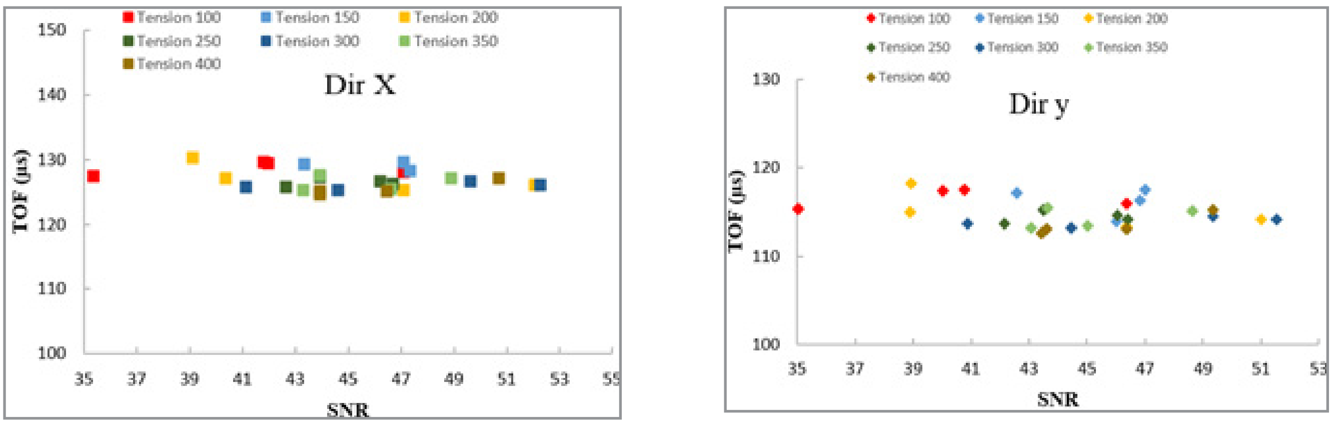

Figure 4: TOF as a Function of SNR for Transducer 54

A high SNR value corresponded to lower noise levels, improving signal clarity and ensuring more reliable data interpretation. Selecting an appropriate TOF was crucial for determining Young's modulus (E) and Poisson's ratio (υ), as accuracy depended on achieving a high SNR. According to Figure 5, the TOF values stabilizing at 126.65 µs for the x-direction and 114.78 µs for the y-direction were used in calculations [11].

From the velocities V(x) and V(y) (Table 1), Young's modulus (E = 2819.92 MPa) and Poisson's ratio (υ = 0.27) were determined based on the propagation velocities of P-waves (*VP*) and S-waves (*VS*), using the following relations [12]:

$$VP = \sqrt{\frac{E(1-\nu)}{\rho(1+\nu)(1-2\nu)}} \quad (1)$$

$$VS = \sqrt{\frac{E}{2\rho(1+\nu)}} \quad (2)$$

With:
- **VL:** The propagation velocity of the P-wave
- **VT:** The propagation velocity of the S-wave
- **E:** Young's Modulus (Pa)
- **σ:** Poisson's Ratio
- **ρ:** Density (kg/m^3)

From these equations, the values of Poisson's ratio and Young's modulus can be derived as follows:

$$\nu = \frac{VP^2 - 2VS^2}{2(VP^2 - VS^2)} \quad (3)$$

$$E = 2\rho VS^2(1+\nu) \quad (4)$$

Table 1: Calculation of Velocities V (0) and V (90).

	TOF (µs)	Distance [m]	velocities
V(0)	126,65	0,17	1342,20
V(90)	114,78	0,12	1045,40

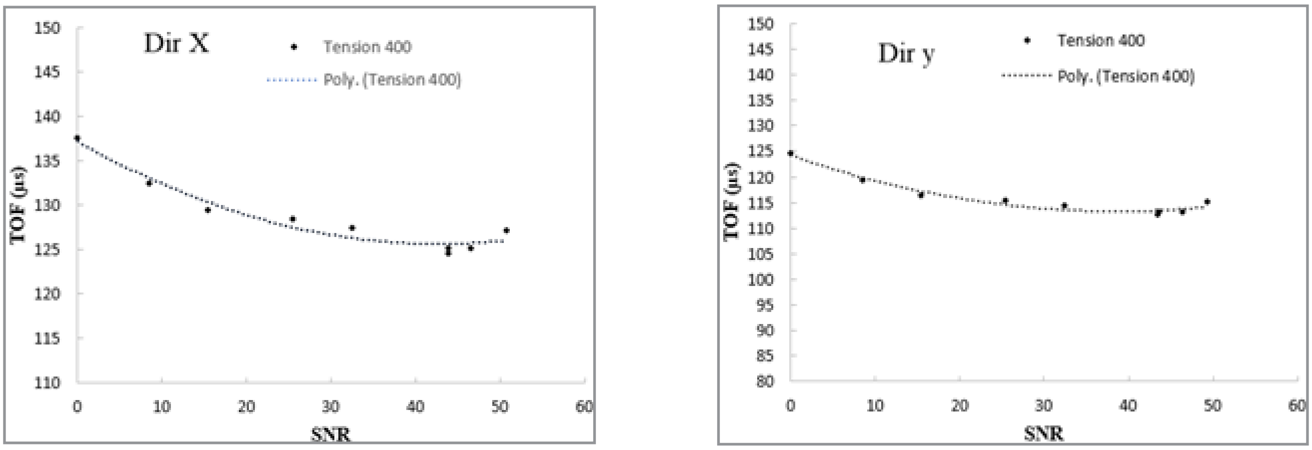

Figure 5: TOF as a Function of SNR for Transducer 54

These results indicate that CEB exhibit mechanical properties influenced by SNR and pulse velocity, suggesting a moderate level of stiffness and elasticity, which may not provide sufficient structural integrity in seismic-prone areas. An increase in voltage and gain resulted in higher wave propagation speed and reduced TOF, implying reduced attenuation and improved measurement accuracy. Higher SNR values recorded at increased gain settings confirmed enhanced wave transmission, reinforcing the reliability of derived mechanical parameters for seismic assessment.

The velocity differences between V(x) and V(y) emphasize material anisotropy, with the x-direction showing slightly higher propagation speeds than the y-direction, likely due to variations in raw earth composition. Although the measured Young's modulus falls within a moderate range, it remains lower than typical values for stabilized materials, indicating that unstabilized CEB may lack the necessary rigidity to withstand significant seismic stress. Additionally, the Poisson's ratio of 0.27 suggests moderate material compressibility, which could lead to substantial deformation under seismic forces if reinforcements are not introduced.

To improve the seismic resilience of CEBs, further investigations should explore stabilization methods, such as incorporating cement or natural fibers, along with optimizing compaction energy and water content to enhance mechanical performance. Additionally, seismic simulations replicating real-world conditions should be carried out to validate the findings obtained from ultrasonic testing. The results of this study underscore the importance of material enhancement to ensure safer construction practices in regions vulnerable to earthquakes.

Conclusions

This study assessed the mechanical properties of compressed earth blocks (CEB) using acoustic waves to analyze their behavior under seismic conditions. Ultrasonic tests conducted on unstabilized CEB, sourced from the earthquake-affected Chichaoua-Taroudant region, revealed Young's modulus and Poisson's ratio values indicative of moderate stiffness and elasticity. The analysis of wave propagation velocities highlighted the material's anisotropic behavior, suggesting variations in composition and density. The results demonstrated that increasing the voltage and gain of the ultrasonic transmitter improved wave propagation and reduced the time of flight (TOF), leading to higher measurement accuracy. However, the obtained elasticity modulus values remain lower than those of stabilized materials, indicating that unstabilized CEB may lack sufficient resistance to seismic stress. Furthermore, the Poisson's ratio of 0.27 suggests a moderate level of compressibility, which could result in significant deformation under seismic forces. To enhance the seismic resilience of CEB, further research should explore stabilization techniques, such as the incorporation of natural binders or cement, along with optimizing compaction and moisture content. More advanced seismic simulations should also be conducted to validate these findings and assess the effectiveness of the proposed improvements. In conclusion, while CEB is a durable and eco-friendly construction material, its performance in seismic zones requires adaptations to ensure safer and more resilient structures. This study contributes to a better understanding of the mechanical properties of CEB and provides scientific recommendations for safer construction practices in earthquake-prone regions.

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