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STABILZED RAMMED EARTH- A REVIEW

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Abstract
Rammed earth construction has gained prominence as a sustainable building technique due to its eco-friendly nature and aesthetic appeal. However, ensuring the long-term durability of rammed earth structures remains a critical challenge. This paper investigates the efficacy of incorporating stabilizers, including cement, bagasse ash, and glass fibers, to address these concerns and enhance the performance of rammed earth structures. Drawing upon extensive research and experimentation, the paper examines the impact of stabilizers on material composition, structural integrity, and long-term durability. Through comparative analysis and empirical studies, the effectiveness of various stabilizers in improving compressive strength and resistance to weathering is evaluated. The role of cement as a traditional stabilizer is scrutinized, alongside emerging alternatives such as bagasse ash, a byproduct of sugarcane processing, and innovative additives like glass fibers. Furthermore, the paper investigates the influence of stabilizer incorporation on construction practices and life cycle considerations. Key factors such as cost-effectiveness, sustainability, and compatibility with traditional rammed earth methods are analyzed to provide comprehensive guidance for practitioners and researchers. The findings highlight promising avenues for enhancing the durability and compressive strength of rammed earth structures through stabilizer utilization. Practical recommendations are offered for implementing these strategies in real-world construction projects, emphasizing the potential for innovation and sustainability in contemporary architectural practice.

Keywords:

- Stabilized Rammed Earth
- Un-Stabilized Rammed Earth

Introduction

Rammed earth is an ancient construction technique that involves compressing a mixture of earth, gravel, sand, and sometimes clay between forms or molds to create solid walls. It's one of the oldest building methods known to humanity, dating back thousands of years. This sustainable building technique relies on locally sourced materials, making it environmentally friendly and cost-effective. Rammed earth structures offer excellent thermal mass, providing natural insulation and reducing the need for heating and cooling systems. Today, rammed earth is experiencing a resurgence in popularity due to its sustainable nature and aesthetic appeal, with modern advancements allowing for greater structural integrity and versatility in design. Additives like cement stabilize the mix, enhancing strength and weather resistance. Lime improves flexibility and reduces cracking, while asphalt increases water resistance. These additives broaden rammed earth's applications, making it more versatile and durable for modern construction needs.

Building with raw earth aligns with both self-help and productivism ideologies, allowing modest families and communities to achieve comfortable, healthy, and affordable housing. It contributes significantly to social well-being by meeting the housing needs of various socioeconomic classes. Additionally, it embodies ecological architecture ideals such as minimizing industrial input, balancing global and local considerations, and promoting sobriety in construction methods. Notably, raw earth serves as a commendable alternative to cement, mitigating the environmental impact associated with cement production, which contributes significantly to global carbon emissions.

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A building material's resistance to deterioration over time is measured by how durable it is. The linkages between the clay platelets that sustain unstabilized rammed earth walls are vulnerable to moisture infiltration. The mechanical strength of unstabilized rammed earth is lost as a result of water evaporating and penetrating, surface erosion brought on by wind, rain, or snow, and damage from recurrent freeze-thaw cycles. Suction has a significant role in the material-scale strength development of unstabilized rammed earth. Strength and internal cohesiveness of soil particles both rise with soil drying and suction. Because of the relative humidity absorbed, an outside rammed earth wall in a moderate area is predicted to have a moisture content of 3–10%.

Historical Background

The evidence for the origin of rammed earth structures is inadequate, but as per some of resources state that China was first country for construction of rammed earth construction [1]. But some sources stated two countries i.e. Mediterranean Gulf and China [2]. According to some of archaeological evidence the use of rammed earth walls and some houses dates back to 500-2000 BC in Qinghai and Tsaidam (lies between Tibet and Central Asia) and also points to 800 BC in Northern America [3]. Rammed Earth structures in Europe region were favoured for their superior fire resistance compared to traditional timber-based construction. However, the utilization of soil-cement composites reportedly experienced a decrease in popularity during 19th century [4]. A rich wealth of research exists on ancient rammed earth structures, offering valuable insights for reconstructing past architectural landscapes or elements. Gonzalez employed two-parts testing regime to evaluate the properties of ancient rammed earth walls located in Granada and Graciani [5]. Western Australia has spread the global adoption of cement-stabilized rammed earth (CSRE) construction since the 1970. This technique has become well-recognized method of construction in the region of North America [6].

Rammed-earth construction techniques, originating in the Iron Age Mediterranean and the Neolithic Middle Yellow River Valley, spread globally over time. These methods were pivotal in building monumental structures like tombs and the Great Wall in ancient China. Understanding the labour costs involved in such projects is crucial for comprehending the organization of labour for public works. However, existing accounts provide inconsistent estimations for rammed-earth compaction labor. To address this gap, the researchers developed a method for contextually relevant and reliable labour estimations for archaeological rammed-earth structures. The build rammed-earth structures as the techniques are still occasionally employed for the construction of greenhouses, yard walls, and animal pens in the area (figure 1.1). They conducted experiments to quantify influential factors for rammed-earth quality and calibrated their results to match the archaeological record. Their calibrated estimations for rammed-earth walls at Taosi and Erlitou urban sites suggest relatively light labour demands, indicating that monumental architectures in early.Fig 1.1 Rammed-earth walls of a recently abandoned greenhouse constructed in the late 1980s in the edangtou village next to the Erlitou site.

China focused more on facilitating social changes than demonstrating power. This methodology can be applied to estimate labour costs for earthen structures and enable comparative studies across time and space concerning the relationship between massive earthen construction and social-political transformation [7]. Earthen construction dates back to 11,000 years, rammed earth, introduced in Tunisia in 814 BC, gained prominence in France's Rhône-Alpes Region due to its rich soil composition. Lyon, uniquely, boasts a significant concentration of rammed earth buildings, attributed partly to rural exodus in the 19th century. These structures, prevalent in both urban and rural settings, reflect a historical fusion of rural building traditions with urban expansion. However, the advent of concrete in the late 19th century led to the decline of rammed earth construction. Today, these structures, dating before 1900, serve as a testament to past craftsmanship amid contemporary environmental and economic concerns, warranting renewed recognition and preservation efforts [8].

Comprehensive exploration of the historical significance of rammed earth construction, particularly focuses on its journey to the High Hills of the Santee region. Rammed earth, a traditional building technique dating back thousands of years, experienced periods of resurgence and decline throughout history. It traces the modern rediscovery in the late 18th and early 19th centuries, fueled by dissemination of pisé construction ideas from Europe to the United States. Originating from traditional African and West Indian methods, rammed earth found its way to America through slave trade and immigration. In the High Hills of the Santee, exemplified by Dr. William Wallace Anderson's pisé structures, rammed earth stands as a testament to the region's architectural heritage. It delves into the historical context of rammed earth in this area, highlighting its cultural and practical significance. By examining the history, construction methods, and preservation challenges of rammed earth architecture in the region, this sheds light on its enduring importance as a sustainable and resilient building material with deep roots in local tradition [9]. Rammed earth architecture, emphases its historical importance and potential for conservation and sustainable development. It provides a thorough examination of traditional rammed earth construction practices in México, aimed at enhancing understanding of its technological principles and promoting its application in heritage restoration and new architectural projects. It highlights rammed earth's potential as a sustainable alternative to conventional construction techniques, aligning with contemporary environmental concerns.

By delving into the characterization of traditional rammed earth construction in México an example shown in figure 1.2 and 1.3, it aims to foster appreciation for this age-old building technique and encourage its preservation and revitalization efforts. Through a comprehensive exploration of its historical significance and sustainable attributes, it advocates for the promotion of rammed earth architecture as a viable solution for both heritage conservation and contemporary architectural innovation in México and beyond.

Fig 1.2 Traditional house in Calpan, México.

Fig 1.3 Rammed Earth walls

Literature Review

Soil Properties

Soil is a geogenic, unconsolidated assemblage of mineral particles, predominantly derived from the physical and chemical breakdown of the underlying bedrock, termed the parent material. The specific soil textural class, which refers to the particle size distribution, is largely influenced by the mineralogical composition of the parent rock from which it originated through weathering processes like erosion [10].

Soil is mainly classified based upon particle size distribution i.e. Ciancio utilizes the soil particle size distribution for representation for gradation curve. For initial screening of potential earthen materials for rammed earth applications. Ciancio research employed ten distinct soil types among five undergoing stabilization, via cementitious or lime-based additives. This method leads to establish well defined material selection criteria based on critical performance parameters including compressive strength, volumetric shrinkage and erosion resistance [11].

Distribution of soil particles, sourcing of required and suitable materials for rammed earth structures is difficult. So, the acceptable range as per CSRE for clay and silt content to use during rammed earth construction, which falls under 10% to 80%, and for cement-stabilized rammed earth demands a strict acceptable range limited to 5% to 40% [12}. For optimal performance CSRE recommend ideal composition range for clay and silt content about 25% to 40% [13].

The plasticity index (PI), indicates a moderate plasticity range for the soil. Soils with a higherPI tend to exhibit more cohesive and workable properties. The Atterberg limits, including the liquidlimit and plastic limit, provide insights into the workability and consistency of the soil. The values obtained from the test soils help in understanding how the soil will behave during construction processes such as ramming[21]. According to The Australian Earth Building Handbook, when usinglime as stabilizer the ideal soil should have a plasticity index from 20% to 30% and liquid limit between 25 and 50, so lime would be particularly appropriate for stabilization of expansive soils[3] Atterberg limits are consistent at depth greater then 10m, with an average liquid limit (WL) of 47, plastic limit (WP) of 27, and plasticity index (IP) of 20 [22].

Dry density, the dry density of rammed earth materials depends mainly upon soil type, moisture content during compaction and compaction energy or effort. Instead of using the moisture level suggested in other studies, that compressing soil to its ideal density causes earthen materials to stick to the frame. To avoid the sticking, they recommended to use lower moisture content than given in literature [13, 14,15]. For the ancient and modern rammed earth structures, the density range is provided between 1770 to 1990 kg/m3 and 1700 to 2200 kg/m^3[11].

Moisture effects, the role of water in the degradation and adhesion properties of rammed earth structures. However, differentiating between water absorption and adsorption within the material remains the challenge, which hindering a complete understanding of the decay process. Water leakage leads to mould formation, which acts as a significant destructive factor [16]. Incorporation of materials like cement, lime, silica, and acrylic coatings has been shown to be effective in mitigating water ingress. This efficacy attributed to enhance interfacial bonding between particles, resulting in a denser and permeable matrix [17]. The influence of fine particle size distribution on the water absorption behaviour and pressurized capillary flow, as well as the moisture absorption capacity of rammed earth specimens [18]. a comprehensive investigation into the mechanical behaviour of rammed earth walls. Their study focused on the material properties which include compressive strength, elastic modulus, and poisson's ratio. Where they observed a significant influence of moisture content in the poisson's ratio. Dry samples exhibited a value of 0.2, whereas wet samples displayed a considerably higher value i.e. 0.37 [19].

A comprehensive analysis of the diverse characteristics of clay materials. Their work emphasized the potential of a clay as a cost effective and readily available material with well-defined properties, making it a promising candidate for various applications [20].

Stabilised rammed earth

Investigation on the suitability of rammed earth construction technique in Northern Portugal. Their focus was on structural integrity of walls built using un-stabilized sedimentary soils found in the region. Where these un-stabilized walls exhibited generally a low strength which implies that rammed earth construction in this specific context, without soil stabilization techniques, might not be sufficient to ensure the desired structural performance [23].

Research on rammed earth construction [24] reveals that stabilised walls exhibit a mean erosion depth of 2 mm, while un-stabilized walls erode at a faster rate of 6.4 mm. Wind-driven rain is identified as a significant accelerator of erosion, emphasizing the need for protective measures to mitigate weathering effects on these culturally significant structures. The study [25] finds that wind-driven rain significantly accelerates erosion in rammed earth structures, necessitating protective measures.

Drip tests show peak erosion at 45 degrees for Y120 and Y240, and at 30 degrees for Y380. Rainfall simulation indicates peak erosion at 15–30 degrees. Historical evidence suggests that properly protected rammed earth can have an indefinite lifespan, offering a sustainable alternative to traditional construction materials [26]. Additionally, a life cycle analysis comparing stabilised rammed earth (SRE) construction with conventional materials indicates a 30% reduction in carbon emissions and a lifespan of 50 years with minimal maintenance for SRE [27] .

Innovations in mortar technology also contribute to sustainable construction practices. Sustainable composite mortars demonstrate an impressive compressive strength of 50 MPa and reduced spalling behaviour compared to conventional mortars, enhancing structural integrity while minimizing environmental impact [28]. Moreover, compressed earth blocks (CEBs) incorporating quack grass straw exhibit satisfactory compressive strength ranging from 2.0 to 3.5 MPa and enhanced thermal insulation properties, showcasing their potential as durable and eco-friendly building materials [29]. Furthermore, the addition of lime to rammed earth walls significantly improves durability by reducing erosion rates by 85% and increasing compressive strength by 20%, as revealed by accelerated aging tests [30].These findings underscore the efficacy of lime in enhancing both the durability and structural integrity of rammed earth constructions, providing valuable insights for sustainable construction practices.

Cement Stabilised Rammed Earth

Cement-stabilised rammed earth (CSRE) stands out for its remarkable thermal insulation properties and structural strength, offering a sustainable solution for modern construction [31]. studies underscore its durability, showing that even after five years of exposure, CSRE maintains a low moisture content of around 6% and achieves impressive compressive strength levels of up to 5 MPa [32]. Cement-stabilised rammed earth (CSRE) stands out for its remarkable thermal insulation properties and structural strength, offering a sustainable solution for modern construction [31]. Studies underscore its durability, showing that even after five years of exposure, CSRE maintains a low moisture content of around 6% and achieves impressive compressive strength levels of up to 5 MPa [33]. The addition of stabilising agents like cement and lime further enhances CSRE's mechanical properties and longevity, with cement increasing compressive strength by as much as 30% in laboratory experiments [34]. Long-term field studies provide valuable insights into CSRE's performance in real-world conditions. Over five years of observation, CSRE structures in Western Australia maintain their structural integrity, with compressive strength averaging 4.5 MPa and minimal moisture ingress [35]. Additionally, the composition of the soil used in CSRE construction plays a crucial role in determining its strength, with soils rich in clay minerals exhibiting higher compressive strength levels, exceeding 6 MPa in some cases [36]. However, CSRE's performance is not solely determined by its composition; environmental factors also play a significant role. Temperature fluctuations and moisture ingress can lead to degradation over time, highlighting the importance of careful design and maintenance to ensure the long-term stability of CSRE structures [37].However, CSRE's performance is not solely determined by its composition; environmental factors also play a significant role. Temperature fluctuations and moisture ingress can lead to degradation over time, highlighting the importance of careful design and maintenance to ensure the long-term stability of CSRE structures. Cement, nowadays commonly used to enhance the structural strength [38].

An extensive investigation was conducted on rammed earth walls utilizing three distinct lateritic soil types in Srilanka [39]. CSRE Properties such as compressive strength and stress strain behaviour mainly get effected by moisture content and cement contents [40]. With further investigation by Reddy and Kumar, related to the elastic properties and strength properties of CSRE [41].

Mechanical Properties of Rammed Earth

Stabilizers like cement, lime, and polymers play a pivotal role in enhancing the properties of rammed earth structures, including compressive strength, durability, and thermal conductivity [42]. Research indicates that these stabilizers significantly improve compressive strength, ranging from 1.5 MPa to 20 MPa, depending on type and dosage, while also enhancing durability by reducing susceptibility to weathering and erosion.

Un-stabilized rammed earth exhibits notable elastic stiffness degradation over time, especially when subjected to moisture and temperature fluctuations [43].This underscores the importance of employing appropriate stabilization techniques to enhance its long-term mechanical behaviour, emphasizing the necessity of considering durability and performance in structural design and maintenance. Varying lime content significantly influences the compressive strength and durability of rammed earth structures, with higher lime content leading to enhancements in both properties [44].

This study provides valuable insights into optimizing lime-stabilized rammed earth mixtures for sustainable construction, emphasizing the importance of lime dosage in achieving desired mechanical properties. Furthermore, the assessment of compressive strength in cement-stabilized rammed earth walls using a combined ultrasonic-rebound method proves accurate and reliable, offering a non-destructive and efficient alternative for quality control in construction projects [45].

Experimental testing also evaluates the influence of reinforcement on enhancing strength, ductility, and stability, demonstrating significant improvements in both compressive strength and shear resistance [46].Compression tests on cylindrical samples reveal rammed earth's non-linear stress-strain characteristics, with a peak compressive strength of approximately 3.8 MPa, providing valuable insights for its structural application and design, particularly in sustainable construction practices [47]. Milani and Labaki investigated the influence of rice husk ash (RHA) on the physical, mechanical, and thermal behaviour of cement stabilized rammed earth (CSRE) [48].

Table 1.1: Material properties obtained from Literature

Reference	Density (kg/m3)	Compressive Strength (MPa)
M. Hall et al. (2014) [49]	2020-2300	0.75-1.46
P. Walker et al. (2004) [50]	1850	3.88
T. Bui et al. (2014) [51]	1800	1.00
Fontana et al. (2104) [52]	2190	3.73
A. Romanazzi et al. (2019) [53]	2080	1.5

Fiber Reinforced Rammed Earth

Fibre reinforcement improves mechanical properties and durability of rammed earth structures. The study reviews existing literature and conducts experimental tests to evaluate the impact of different types and dosages of fibres on properties such as compressive strength, tensile strength, and crack resistance. Results indicate that the incorporation of fibres enhances both the strength and ductility of rammed earth, with a reported increase in compressive strength by up to 25%. The findings suggest promising avenues for the development and application of fibre-reinforced rammed earth in sustainable construction practices [54]. Effectiveness of natural fibre enhances the mechanical strength of rammed earth walls. Impact of natural fibre (jute or sisal) reinforcement on the structural performance of rammed earth walls under various loading conditions, significantly improves the tensile strength and ductility of rammed earth walls. For instance, walls retrofitted with jute fibres show a 25% increase in tensile strength compared to unreinforced walls. This study highlights the potential of natural fibre retrofitting as a sustainable and effective method for enhancing the mechanical properties of rammed earth structures [55]. Environmental impact of using stabilized rammed earth reinforced with natural fibres in Australian construction is being studied here. It employs (comprehensive life cycle assessment) LCA methodologies to assess various environmental indicators such as carbon footprint and energy consumption. Results indicate that the use of stabilized rammed earth with natural fibres reduces the embodied carbon footprint by approximately 25% compared to conventional construction materials. This research underscores the environmental benefits of utilizing sustainable building materials in Australian construction practices [56].

Summary

This review paper examines the performance of Rammed Earth elements by evaluating the basic properties, mechanical properties and durability of Rammed Earth elements by adding the stabilizers. Adding cement to the soil cement significantly improves the material's compressive strength compared to that of reconstituted soil. It indicates that the soil-cement mixture might improve the performance of rammed-earth buildings since it displayed enhanced mechanical properties.

Rammed earth components can demonstrate excellent compressive strength, durability, and aesthetic appeal when properly produced. However, the practical success of rammed earth construction is influenced by climate conditions and material availability. It is most effective in regions with high humidity and moderate temperatures. In colder climates, additional insulation may be necessary, while in areas with heavy rainfall, protection from rain is essential.

To make sure that there is enough moisture during construction, the standard proctor test to be used to determine the ideal moisture content and maximum dry density. Determining Atterberg's limit is necessary to guarantee that the soil contains enough clay for rammed earth building. Compressive behaviour of the rammed earth is important to determine the usage of rammed earth n construction. Rammed earth needs protection from driving rain and long-term exposure to moisture and hence its durability is determined using wire brush method and water absorption by alternate dry and wet cycle.

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