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A Comparative Studies of CSEB by Using RHA and Lime as a Partial Replacement of Cement

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Abstract

In the growing concerns about sustainable building materials and environmental issues, Compressed Stabilized Earth Brick (CSEB) emerges as a notable solution. CSEB is recognized for its energy efficiency, cost-effectiveness, and eco-friendliness, making significant contribution to sustainable development. Unlike traditional concrete blocks and fired bricks, CSEB production requires less energy, as it involves compressing a mixture of local earth and stabilizers like cement or lime without high-temperature firing. This process reduces carbon emissions and conserves energy resources. Economically, CSEB uses locally sourced materials like RHA/Lime, cutting transportation costs and supporting local economies. Additionally, the simpler production process reduces labour costs. Environmentally, CSEB minimizes waste and the environmental impact of raw material extraction. Overall, CSEB's properties compare favourably with concrete blocks and fired bricks, offering a robust, sustainable alternative for modern construction. This research investigates the properties and internal mechanisms of soil blocks made with two different materials, specifically rice husk ash (RHA) and lime. Experiments were conducted with the main variables being RHA content at 0.2, 0.4, and 0.6 wt.% and lime content at 0.2, 0.4, and 0.6 wt.%. Tests included Atterberg's Limit Test, Plasticity Index Test, Soil Type Classification, Water Absorption Test, and Compressive Strength Test. Further investigation with soil blocks of different ratios and compositions concluded that among all the samples, CSEB with lime (20%) as a replacement for Ordinary Portland Cement (OPC) exhibited better water absorption capacity compared to RHA. Additionally, CSEB with lime (20%) as a replacement for OPC demonstrated the highest compressive strength compared to RHA.

Keywords: *compressive strength, lime, proportion, replacement, stability, sustainability*

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Introduction

Providing adequate housing is vital for ensuring socio-economic stability and promoting national development. For many individuals, housing represents the most significant investment of their lives. However, in developing countries, a majority of families lack access to sufficient housing and related amenities. Design, construction details, and the lifespan of the building influence the quality of housing. Utilizing affordable and locally available materials can significantly contribute to the sustainability of housing in the future. In Nepal, earth materials could be a viable option for low-rise structures. Technologies that can be easily implemented with available resources are essential, and one such technology is CSEB. CSEBs use stabilizers to ensure adequate compressive strength and durability, making them suitable construction blocks (Patil, Gawande & Khadilkar, 2015). This research focuses on using Rice Husk Ash (RHA) and lime as partial replacements for cement in the production of CSEBs. In Nepal, agricultural waste is often disposed of in ways that cause pollution. By incorporating RHA into CSEBs, this waste can be utilized beneficially, thereby reducing pollution. This research aims to develop alternative wall-making materials using locally available resources, aiming to produce durable and cost-effective building blocks. While CSEBs can perform adequately with good production control, further enhancements in material performance are necessary to improve their suitability for widespread use in construction.

This study has two main objectives first is to ascertain the characteristics of soils intended for the production of compressed stabilized earth blocks and second is to experimentally investigate impact of incorporating RHA and lime (as partial substitutes for cement in specific proportions) on the compressive strength and block water absorption test.

Scope of the Study

This research investigates the compressive strength and water absorption characteristics of soil blocks stabilized with cement and those stabilized with a combination of cement, rice husk ash (RHA), and lime. The study aims to determine the effectiveness of these materials in enhancing the structural integrity and durability of the soil blocks. Due to time and budget constraints, the research is limited to soil samples collected from a specific location, Kalika Chowk in Gaindakot. Including RHA and lime is intended to explore alternative stabilization methods that could offer improved performance and sustainability. By focusing on a single location, the study aims to provide detailed insights into the behaviour of these materials in the specific soil conditions of Kalika Chowk, potentially contributing valuable information for broader applications in sustainable construction practice.

Literature Review

Compressed Stabilized Earth Blocks are gradually recognized for their environmental and economic benefits. The concept used for compacting earth materials to improve the quality and performance of moulded earth blocks has substantially improved the housing material selection. Cement is a popular Stabilizer used in the manufacturing of CSEBs. Lime and RHA are used as stabilizers and replaced with cement in certain portions to increase block stability.

Malkanthi, Balthazaar and Perera, (2019) investigated that 5%, 10%, and 15% lime was replaced with clay and silt to stabilize Compressed Stabilized Earth Blocks. The clay and silt replaced by 10% lime gave the optimum block strength (Ojerinde et al., 2020). conducted this study to achieve the provision of a possible low-cost sustainable building material for wall construction in Nigeria based on the poverty level. He used the laterite soil and RHA of 0%, 10%, 20%, 30%, 40%, and 50% as a partial replacement for OPC. He cured the block sample in 14, 21 & 28 days. The results showed that Solid CEB with RHA at 20% replacement of

OPC has the best combination with mechanical & hygrothermal properties. Patil, Gawande and Khadilkar (2015) used the black cotton soil and 10% lime. They cured the block sample in 7 days. Hence, they concluded that the block sample gave maximum dry density and block density. For 10% lime content, 0.5% and 1% increased the compressive strength by 60.54%, 95.92%, and 115.30%, respectively.

Research Methodology

The investigation is carried out on CSEB containing soil, sand, and cement where RHA and Lime replace cement content at a certain percentage by weight and to know whether the partial replacement of typical cement stabilization in combination with RHA and Lime brings about enhanced properties. Preparation of CSEB involves the following method:

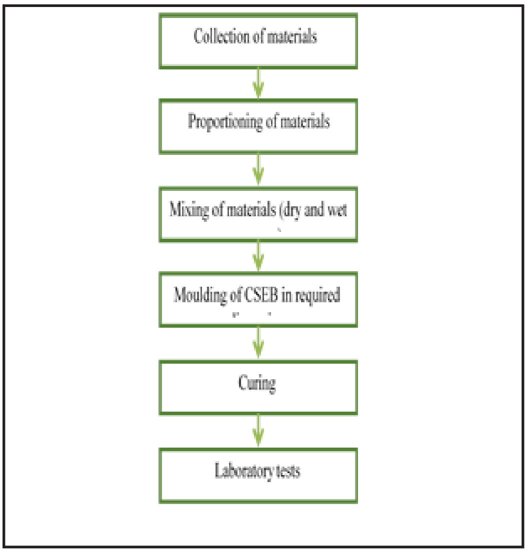

Figure 1: *Step by Step Procedure*

Material Used

The main material required to produce compressed earth blocks is Red soil. It is the predominant soil in Nepal and was extracted from the base of Maulakalika. For the production of CSEBs, mixtures of clay soil, silt, and sand are commonly used. Sandy soil would be added to the mixture to reduce the ratio of clay content, and Lime, Rice HuskAsh(RHA) and Ordinary Portland Cement(OPC) would be combined in different proportions to stabilize the soil. The soil used should be native to the locality, ensuring it is well-suited to the specific environmental conditions. It is crucial that the soil contains no organic matter, as this can affect the stability and durability of the blocks. The size of the soil particles should be less than 2.75 mm to ensure proper compaction and strength. Fine soil particles may consist of silt or clay, which are necessary for achieving the desired consistency. Additionally, the soil should bond well when wet and shaped, ensuring it maintains its form and integrity during the construction process. Similarly, the materials used in this research include Ordinary Portland Cement (OPC) of 43 grade, which is commonly used for building construction in Nepal. Rice Husk Ash (RHA) was sourced from a rice milling factory in Thumsi, Gaindakot, and used for soil stabilization. Lime, an inorganic material primarily composed of calcium oxides and hydroxides, was purchased from an agro-vet shop in Bharatpur, Chitwan. Sand, composed of finely divided rock and mineral particles, was collected from the beach of the Narayani River, air-dried for several days, and sieved through a 2.75 mm sieve. Potable water from a water tank at the production site was used for mixing the materials.

To ensure the suitability of the raw materials for creating Compressed Stabilized Earth Bricks (CSEBs), various tests were conducted to evaluate their particle distribution and plasticity index. Soil must have specific characteristics to be considered appropriate for engineering purposes. One of the tests performed was Atterberg's Limits, which measure the physical properties of clays based on their water content. The Liquid Limit, determined using the Casagrande Apparatus, indicates the water content at which soil begins to behave as a liquid. The Plastic Limit is the moisture content at which fine-grained soil can no longer be remolded without cracking. These tests help in understanding the consistency phases of clay soil and its suitability for CSEB production.

CSEB Mix Ratios: All of the blocks required for a single mix ratio were created in a single mix to ensure that each individual block within a batch received the same mix. Three different ratios with four different compositions of Lime and RHA were used to produce 63 solid CSEBs to determine the best mixture ratio. The ratios of OPC, sand, and soil used as control mixes for solid CSEBs are 1:1:9, 1:2:8, and 1:3:7, respectively. The goal of the experimental CSEB was to investigate the possibility of using RHA or lime in place of OPC. For this reason, the ratios of sand to red soil were the same as those in the control mix. For every block shape, RHA/Lime substituted 0%, 20%, 40%, and 60% for the OPC component (Kuma et al., 2020).

Production of Solid CSEBs: For each CSEBs mix, the amounts of Red soil, Sand, Ordinary Portland Cement, Lime and RHA were measured using a weighting machine and well mixed with a shovel to obtain homogenous mixtures. Additionally, 15% of the entire weight is made up of water, which is needed to create homogeneous mixes. Then, the associated mixtures were individually put into a (225 × 110 × 85) mm mould and placed within the mortar interlocking press to produce solid CSEBs.

"The figure provides a detailed illustration of the process involved in making compressed stabilized earth blocks, highlighting various stages and techniques used in their production (see Plate 1 & 2).

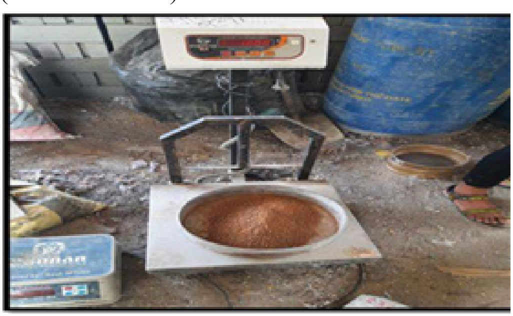

Plate 1: *Weighing of materials as per set ratios*

Curing: The blocks were laid on the floor and kept in a controlled environment during curing and watered with a spray container at least twice a day to guarantee sufficient hydration reactions. The sets of blocks were left to cure for 28 days.

Plate 2: *Dry mixing of materials*

Plate 3: *Filling the mould with wet mixture*

Plate 4: *Compressed Stabilized Earth Brick*

Water absorption capacity refers to the ability of material to absorb water when fully immersed in it for duration of 24 hours. Water absorption rate is expressed as a percentage of the weight of the dry unit. The water absorption rate of the block samples was determined in accordance with British standard (BS, EN 772-21:2011).

Procedure

For the test, three solid block samples with a regulated mix ratio, cured for 28 days, were selected. These samples were oven-dried at 105±5°C until they reached a consistent mass across successive measurements.

Table 1: Composition of Mix for CSEBs – Solid

Shape	Sample	Red Soil Proportion	Sand proportion	Stabilizer proportion		Curing time (days)
				OPC	RHA /Lime	
				1	0	
			1	0.8	0.2	
	S1	9		0.6	0.4	28
				0.4	0.6	
				1	0	
				0.8	0.2	
	S2	8	2	0.6	0.4	28
Solid				0.4	0.6	
				1	0	
				0.8	0.2	
	S3	7	3	0.6	0.4	28
				0.4	0.6	

Water Absorption Capacity of Compressed Earth Block Principle

After cooling to room temperature, each block was weighed using a digital balance and the measurements were recorded. The blocks were then submerged in water for 24 hours. After removal from the water, the surface of each block was dried with a

damp cloth. The damp bricks were individually weighed using a digital balance. The water absorption ratio was calculated using Equation 1, and the mean water absorption ratio was determined using Equation 2.

$$\text{Water absorption rate (WS)} = \frac{Ms-Md}{Md} * 100 \text{ .... Eq(1)}$$

Where Ms is mass of wet sample and Md mass

$$\text{Mean of water absorption} = \frac{WS1+WS2+WS3+\cdots+WSn}{Number\ \ of\ Sample} \text{ ...... Eq(2)}$$

Plate 5: *Mean of water absorption is Oven drying of block for 24 hrs*

Compressive Strength of Compressed Earth Block

Compressive strength refers to the capacity of

Plate 6*: Soaking blocks for 24 hours*

CSEB to withstand loads before failure. It is one of the major mechanical property of construction material. The failure of the block can lead to cracks and weakness which can cause the immersion of water or moisture into the block which reduces the interior comfort level.

Preparation of the samples for Test

The surfaces of the Compressed Stabilized Earth Bricks (CSEBs) were wiped and cleaned to ensure they were free from any debris or contaminants. Any unevenness on the surfaces was removed, and smooth, parallel faces were achieved through grinding. Subsequently, the CSEB samples were immersed in water at room temperature for 24 hours to simulate exposure to moisture. After this immersion period, the bricks were wiped with a cloth to drain out any surplus moisture, ensuring that they were in an optimal condition for testing or further use. This process helped prepare the CSEBs for evaluation while maintaining consistency and integrity in their surface characteristics.

Procedure for determination of compressive strength of CEBs

The test comprised three solid block samples cured for 28 days, employing a controlled mix ratio. To estimate the gross surface area of the samples, the length and width of each block were multiplied. Before conducting the test, the machine surface was wiped clean to remove any loose grits. The blocks were then aligned with the center platen to ensure uniform load distribution over the surface area. Perpendicular force was gradually applied to the Compressed Stabilized Earth Bricks (CSEBs) until failure or cracking occurred, and the force at which each block failed was recorded. The compressive strength of the CSEBs was calculated using Equation (4), and the mean compressive strength was determined using Equation (5). These steps ensured a systematic evaluation of the structural integrity and load-bearing capacity of the CSEBs (Adam & Agib, 2001) (see Plate 8). Some of the equations used uder this process are as below:

Cross section area of Solid Block (A) = $length \times breadth$.............. Eq(3)

Compressive strength (C) = $\frac{P}{A}$ ....Eq(4)

Where P = force at the point of failure

Mean compressive strength of Block = $\frac{C1+C2+C3+\cdots+Cn}{Number\ of\ compressive\ strengt\ h}$ ...Eq(5)

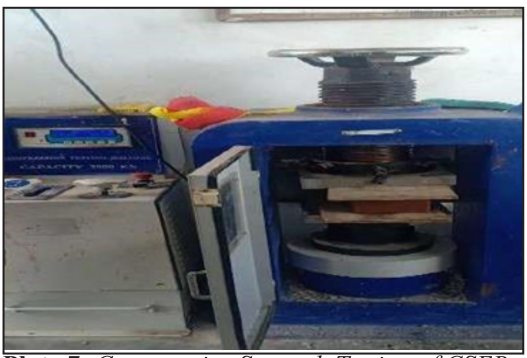

Plate 7: *Compressive Strength Testing of CSEBs*

Results and Discussion

Atterberg's Limit Test

Plastic Limit: Moisture Content where the material changes from a plastic to a semi-solid state. The average moisture content for the plastic limit test of the soil sample taken was obtained as 47.5 %.

Liquid Limit Test: The water content where the material changes from plastic to liquid state called liquid limit. The moisture content corresponding to 25 no. of blows obtained was 56.9% from the log graph plotted of the soil sample taken.

Plasticity Index Determination

It is the difference between the liquid limit and the plastic limit.

Here, PI = LL-PL = 56.9 % - 47.5% = 9.4 %

Hence, the plasticity index obtained is 9.4. Soil description based on plasticity index is given below:

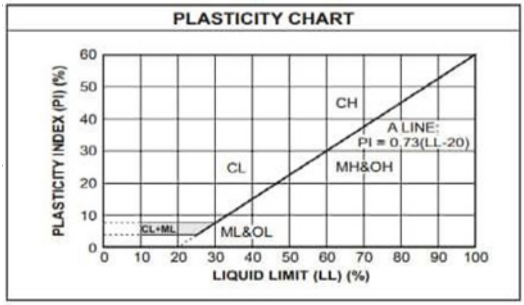

Figure 1: *Plasticity Chart for Classification of Soil Type*

According to Indian Standard Soil Classification System (ISSCS), the soil is Silty Clay as the equation of line A = 0.73(WL-20) = 0.73(56.9-20) = 26.937.

Water Absorption

Table 2: *Average Water Absorption Values of Different Samples*

Sample Name	Average Water Absorption (%)
S1 (0%) (C:S:S=1:1:9)	28.36
S2 (0%) (C:S:S=1:2:8)	21.41
S3 (0%) (C:S:S=1:3:7)	15.9
S1R (20%)	29.16
S1R (40%)	26.8
S1R (60%)	29.72
S2R (20%)	13.9
S2R (40%)	18.13
S2R (60%)	29.7
S3R (20%)	12.76
S3R (40%)	24.13
S3R (60%)	24.36

Table 3: *Average Water Absorption Values of Different Samples with Lime*

Sample Name	Average Water Absorption (%)
S1 (0%)(C:S:S=1:1:9)	28.36
S2 (0%) (C:S:S=1:2:8)	21.41
S3 (0%) (C:S:S=1:3:7)	15.9
S1L (20%)	11.243
S1L (40%)	12.47
S1L (60%)	13.04
S2L (20%)	9.94
S2L (40%)	14.65
S2L (60%)	16.1
S3L (20%)	14
S3L (40%)	13.85
S3L (60%)	12.36

Note: *C:S:S= Proportion of Cement, Sand and Soil*

CSEB of sample 3 (C: S: S=1:3:7) with 20% RHA as partial replacement of OPC [S3R (20%)] has minimum water absorption value of 12.76% among all the samples taken with RHA as a replacement of OPC. Similarly, CSEB of sample 2 (C: S: S=1:2:8) with 20% Lime as partial replacement of OPC [S2L (20%)] has minimum water absorption value of 9.94% among all the samples taken with LIME as a replacement of OPC. Hence, we conclude that CSEB of sample 2 (C: S: S=1:2:8) with 20% Lime [(S2L (20%)] as a partial replacement of OPC have better water absorption capacity than as a partial replacement with RHA.

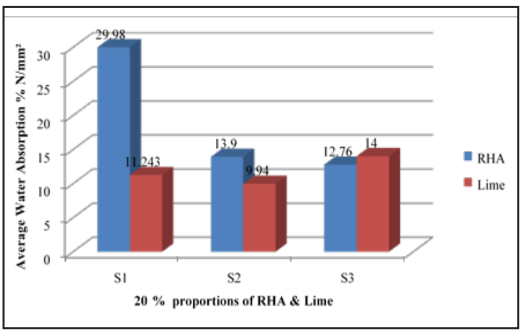

Figure 2 : *Graph representing average water absorption against 20% proportions of RHA and Lime*

Compressive Strength

Table 4: *Average Compressive Strength of Various Samples taken with RHA*

Sample Name	Average Compressive Strength (fc), N/mm2
RHA/LIME	
S1 (0%) (C:S:S=1:1:9)	0.61
S2 (0%) (C:S:S=1:2:8)	1.24
S3 (0%) (C:S:S=1:3:7)	4.04
S1R (20%)	0.62
S1R (40%)	0.47
S1R (60%)	0.12
S2R (20%)	0.85
S2R (40%)	0.23
S2R (60%)	0.12
S3R (20%)	3.76
S3R (40%)	2.2
S3R (60%)	1.13

Table 5: *Average Compressive Strength of Various Samples taken with Lime*

Sample Name	Average Compressive Strength (fc), N/mm2
S1 (0%) (C:S:S=1:1:9)	0.61
S2 (0%) (C:S:S=1:2:8)	1.24
S3 (0%) (C:S:S=1:3:7)	4.04
S1L (20%)	3.06
S1L (40%)	0.84
S1L (60%)	0.92
S2L (20%)	3.88
S2L (40%)	3.12
S2L (60%)	0.86
S3L (20%)	2.1
S3L (40%)	2.33
S3L (60%)	0.28

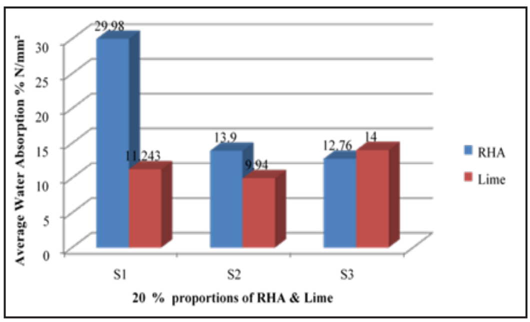

Figure 3: *Graph Representing average compressive strength (N/mm²) against different % proportions of Lime*

Here, S1 (0%) has more compressive strength than S1R (20%), S1R (40%), S1R (60%)

whereas S1L (20%), S1L (40%), S1L (60%) have more compressive strength than S1 (0%). Similarly, S2 (0%) has more compressive strength than S2R (20%), S2R (40%), S2R (60%) & S2L (60%) whereas S2L (20%), S2L (40%) have more compressive strength than S2 (0%). Also, Blocks with RHA & Lime replacement with different compositions of same ratio S3 have less compressive strength than S3L (0%). Hence, we conclude that CSEB with Lime (S2L (20%)) as a partial replacement of OPC has maximum compressive strength i.e. 3.88 N/mm2 than with RHA.

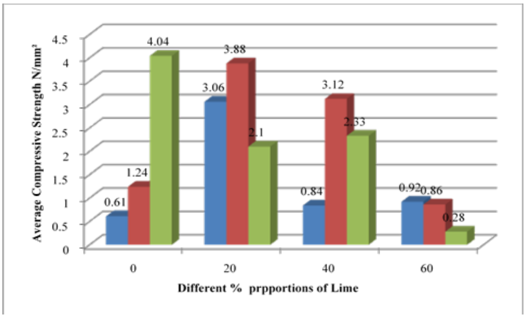

Figure 4: *Graph Representing Average Compressive Strength Against Different Proportions of RHA & Lime*

Discussion

The study delves into several critical aspects of Compressed Stabilized Earth Blocks (CSEBs), drawing insights from comprehensive testing and analysis. Firstly, the Atterberg's limit tests classify the soil sample as medium plastic Silty Clay, with a plasticity index (PI) of 9.4, according to the Indian Standard Soil Classification System (ISSCS). This characterization provides essential groundwork for understanding the soil's behavior and suitability for construction applications.

Secondly, water absorption tests underscore the influence of additives like Rice Husk Ash (RHA) and Lime on CSEB performance. Results indicate that CSEBs incorporating Lime (S2L (20%)) as a partial replacement for Ordinary Portland Cement (OPC) exhibit superior water resistance, with a notable absorption rate of 9.94%. In contrast, blocks with RHA replacements showed higher absorption rates, suggesting Lime's potential to enhance CSEB durability against moisture ingress (Al-Kiki et al.,.2011).

Lastly, the compressive strength analysis reveals significant disparities based on additive types and proportions. CSEBs with Lime (S2L (20%)) demonstrated the highest average compressive strength (3.88 N/mm²) among all samples tested, which height Lime's efficacy as a partial OPC replacement in improving structural integrity, compared to RHA, which yielded lower strengths in the evaluations (Duel et al., 2023).

The above findings highlight Lime's dual benefits in enhancing both water resistance and compressive strength of CSEBs, offering valuable insights for optimizing CSEB formulations towards sustainable and resilient construction practices. Further research could explore additional variables and long-term performance to validate and expand upon these initial findings (Rahman et al.. 2016).

Conclusion

This study aimed at exploring the properties and internal mechanism of soil blocks with two different stabilizers in a single type of soil. In the studies solid CEB with RHA at 20% replacement of OPC has the best combination with mechanical & hygro thermal properties (ojerinde, 2020) and from Malkanthi et al.(2020) investigation that among 5% ,10%, 15% lime addition, 10% lime addition showed the optimum block strength.

From our research, the results showed that CSEB with Lime at a 20% replacement of OPC in a 1:2:8 ratio had better compressive strength and water absorption capacity (after 28 days of curing) than OPC replacement with various proportions of RHA. Also, it was found that replacing OPCs excessively by lime and RHA was ineffective. Overall, soil blocks that were made these stabilizers in place of OPCs shown improved characteristics, making them suitable primarily for temporary construction.

Practitioners are advised to not use maximum ratio of OPC replacement with stabilizers because of their low properties and characteristics and less water content while mixing when the red soil's ratio is reduced.

Researchers are encouraged to explore various soil types for optimal soil's selection guidelines, investigate alternative agricultural wastes and stabilizers for sustainable construction and conduct extended studies on additional features like durability, tensile strength, thermal properties etc. for its long-term usage in environmentally friendly and building practices.

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