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Sustainable hempcrete wall solution and its benefits in reducing load impact on structural foundation: A case study of the Pace Building in Ho Chi Minh City

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ABSTRACT

The paper explores the benefits of reducing wall loads in construction by using lightweight hempcrete walls. The analysis focuses on the Pace Institute building located in District 1, Ho Chi Minh City. The evaluation criteria are based on load on piles transferred by both vertical and lateral (wind) loads. Load combinations are considered according to both Vietnamese (TCVN) and American standards. Two wall types- hempcrete and traditional fired clay brick are analyzed and compared to assess the advantages of using lightweight hempcrete walls. Structural analysis results indicate a significant reduction in column base loads when hempcrete walls are used in place of conventional brick walls. This reduction leads to more economical foundation design, saving both construction materials and costs. Furthermore, the use of hempcrete walls offers substantial environmental benefits, as this material is considered "carbon- negative", contributing positively to sustainable construction practices.

1. INTRODUCTION

Brick walls are widely used in construction projects in Viet Nam. Among them, fired clay bricks (red bricks) still account for the largest proportion in low-rise buildings (under 9 stories), as this is a traditional type of brick that is easy to produce and construct. Figure 1 shows a typical low-rise building ("tube house") in which all the walls are made of fired bricks.

In addition to the durability advantages of fired clay brick walls, this type of wall has several disadvantages, notably its environmental impact. The primary material for brick production is soil, and its extraction can affect agricultural land. Furthermore, the firing and manufacturing processes emit a significant amount of greenhouse gases, contributing to environmental pollution. Besides the environmental harm, traditional fired bricks are relatively heavy, typically having a density of 1600 to 1800 kg/m³. This results in a high self-weight of the wall, requiring larger beams and supporting structures to ensure strength and control deflection. The load transferred from the walls to the foundation also increases, which in turn necessitates larger, deeper, or more numerous foundation elements, thereby raising construction costs due to additional material and labor requirements.

Hempcrete is a natural-based material made from the woody core of the hemp plant (hemp hurds, also known as hemp shiv), lime, and water. The components of hempcrete are shown in Figure 2, along with its main products: blocks and cast-in-place walls.

Figure 1. The low-rise building is constructed with a reinforced concrete structure and fired clay brick walls in Ho Chi Minh City

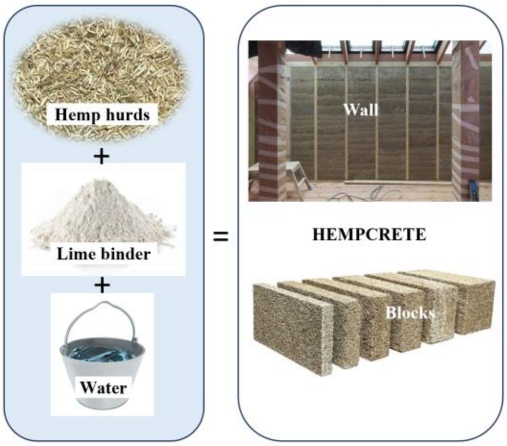

Figure 2. The composition of hempcrete and its application in bricks and walls

Hempcrete is a lightweight material with a significantly lower density than conventional construction materials such as cement, concrete, bricks, and stone. While traditional cement concrete typically has a density of around 2400 kg/m³, the density of lime-based hempcrete is only about one-tenth to one-fifth of that, ranging from 250 to 600 kg/m³ depending on the binder type, mix ratio, and porosity. Density is a key factor influencing many properties of hempcrete (Arnaud, 2006; Arnaud & Gourlay, 2012; Stevulova et al., 2012). Lower density generally leads to better thermal and acoustic insulation, while compressive strength tends to decrease with lower density. Hempcrete offers excellent sound and thermal insulation, with a low thermal conductivity, typically in the range of 0.05- 0.15 W/(mK) (Collet & Pretot, 2014; Ansari et al., 2025).

Figure 3 shows hempcrete brick blocks cast by the CESD research team (of which the author is a member) on March 17, 2025, at the laboratory of Ho Chi Minh City University of Transport (Campus 3, District 12, Ho Chi Minh City). The mix proportion selected by the team was Lime: Hemp hurds = 1: 3 by volume. The hemp hurds were sourced from Sapa, Lao Cai, and the hydrated lime of $Ca(OH)_2$. The bricks were cast using wooden molds with dimensions of 80×80×180 mm.

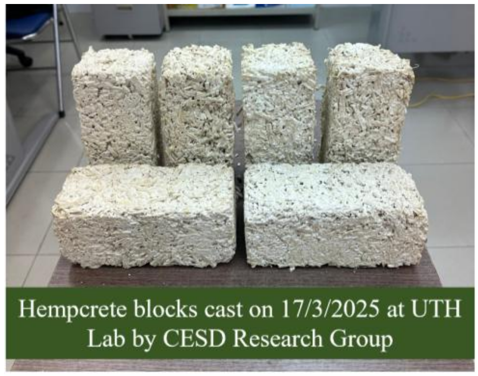

Figure 3. The hempcrete brick samples were cast by the CESD research team on March 17, 2025, at the Lab of the University of Transport in Ho Chi Minh City (District 12, Ho Chi Minh City)

Hempcrete is easy to produce and construct, and unlike concrete or fired brick walls, it requires no curing, as lime sets through carbonation with air. The application of hempcrete as a lightweight wall material for housing projects has not yet been implemented in Viet Nam. Meanwhile, the raw material for hempcrete-hemp hurds, is readily available but remains underutilized. The H'Mông ethnic people in the northern mountainous provinces of Viet Nam, such as Lao Cai and Ha Giang, grow hemp primarily for extracting fibers to weave traditional clothing and brocade textiles.

In this study, the research team aims to leverage the outstanding feature of hempcrete- its lightweight nature- to optimize foundation systems by replacing traditional brick walls with hempcrete walls. Due to the significantly lower weight of hempcrete walls, this substitution offers economic benefits, environmental protection, and energy savings in buildings. Comparative analyses will be conducted in accordance with current Vietnamese standards, the American standard ACI 318-19 (The American Concrete Institute, 2019), and the structural analysis software ETABS v22.5.1 (Computers & Structures, Inc., 2024).

2. MATERIALS AND ANALYSIS MODEL

2.1. Introduction to the building

The Pace Institute of Management building was constructed in District 1, Ho Chi Minh City, in 2024. The building consists of 2 basement levels and 8 above-ground floors. Its primary function is to serve as a venue for training and research, including classrooms, administrative offices, and other functional rooms. The typical floor height is 3.6 meters. The building is made entirely of cast-in-place reinforced concrete, with the exterior and partition walls primarily built of brick, along with a smaller proportion of glass walls. The typical floor plan of the building is shown in Figure 4. There are two types of walls used: 100 mm thick walls (W100) and 200 mm thick walls (W200).

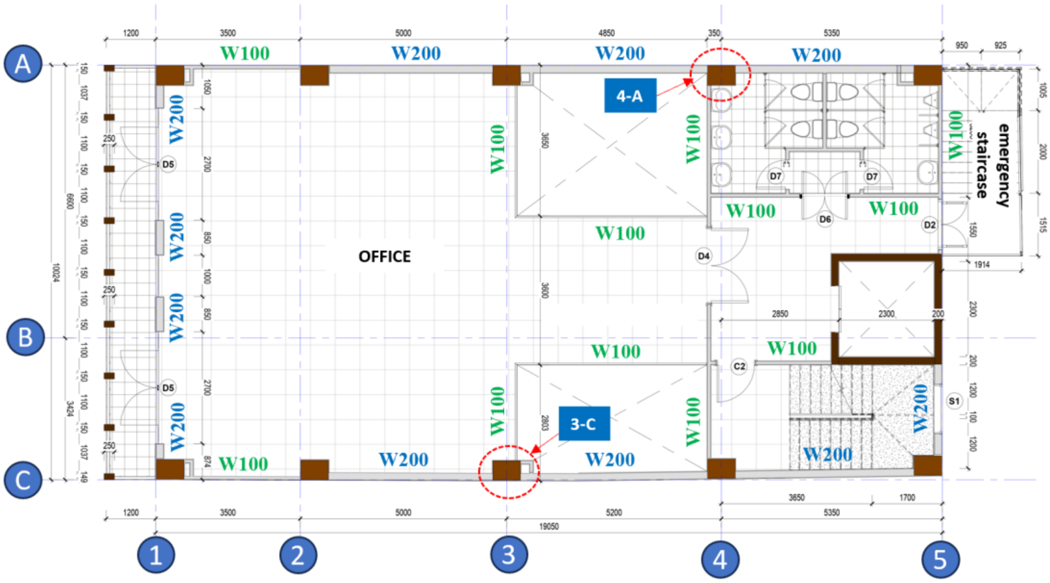

Figure 4. Typical floor plan of the Pace Building (floors 3 to 6)

2.2. Load and analysis model

The loads acting on the building include vertical loads and lateral loads caused by wind. The loads are determined in accordance with TCVN 2737: 2023 (Ministry of Construction, 2023). Vertical loads include both permanent loads and temporary loads (live loads on floors, roofs, and stairs). Two models corresponding to the two types of wall materials will be examined and analyzed:

– **Model WH**: Hempcrete walls with 30 kgf/m^2 for 100 mm thickness and 60 kgf/m^2 for 200 mm thickness.

– **Model WB**: Fired brick walls. The wall load is calculated as 180 kgf/m² for 100-mm-thick walls and 330 kgf/m² for 200-mm-thick walls.

The wall loads are calculated and directly applied to the beams in kN/m. The standard wind pressure W_k at the equivalent height z_e is determined in accordance with TCVN 2737: 2023, as specifically illustrated in Figure 5. Wind is analyzed for four different cases corresponding to four directions on the floor plan. The reliability factor for wind load is taken as 2.1.

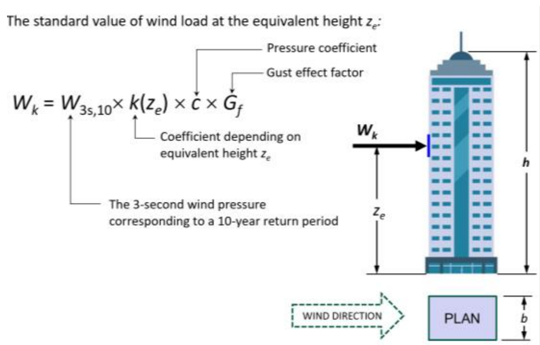

Figure 5. Definition of parameters for calculating wind load on structures according to TCVN 2737: 2023

The concrete material used for the building has a compressive strength grade of B25, according to TCVN 5574: 2018 (Ministry of Construction, 2018). The modulus of elasticity of the concrete is $E_b = 3.0\times10^4$ MPa, and the Poisson's ratio is 0.2. The unit weight of concrete is taken as 25 kN/m³ (used for calculating the self-weight of the load-bearing structure).

The floor slabs are 150 mm thick. The column cross-section is 600 × 700 mm. Longitudinal beams (along the length of the building) have cross-sections of 200 × (450–500) mm. Transverse beams have varying cross-sections of (700-1000) × (450-500) mm and are designed as shallow beams. Elevator shaft walls are made of concrete, 200 mm thick.

The structural analysis model is developed using ETABS v22.5.1, employing a 3D space-frame model in which the frame–slab system and elevator core serve as the primary load-bearing elements. The 3D structural analysis model is shown in Figure 6.

Figure 6. Structural analysis model of the building created by ETABS v22.5.1

The model is assigned wall loads for two cases: hempcrete walls (WH) and fired brick walls (WB). The wall load patterns are illustrated in the model shown in Figure 7. The structural analysis is performed using a linear static case, assuming rigid diaphragm behavior of the floor slabs within their planes. Wind loads are applied at the geometric center of each floor slab, corresponding to each direction and for all floor levels of the building.

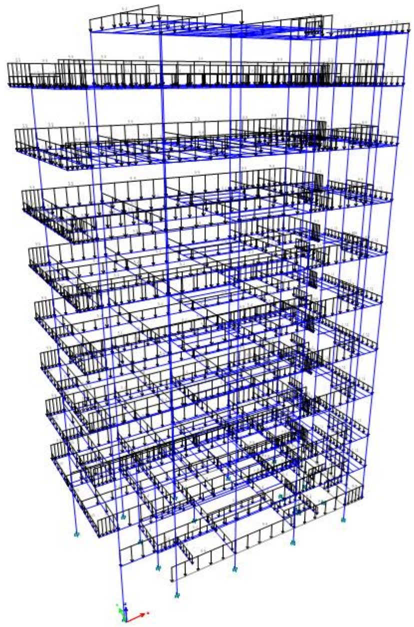

Figure 7. Wall load model on the structure using ETABS

The load combinations according to TCVN 2737: 2023 and ACI 318-19 are detailed in Table 1 and Table 2, respectively. In these tables, the load cases include: SW: self-weight of the structural elements; SD: weight of floor layers (finishes and additional dead loads); WB: load from fired brick walls; WH: load from hempcrete walls; LL: live load on floors/stairs/roof; WL: climatic load (wind load). The first column lists the load combinations. The values in Table 1 represent load and combination factors, while those in Table 2 are load factors according to ACI 318-19 (The American Concrete Institute, 2019).

Table 1. Load combinations according to TCVN 2737: 2023

Load / Com.	SW	SD	WB	WH	LL	WL
VB1	1.1	1.3	1.3	-	1.3	-
VB2	1.1	1.3	1.3	-	-	2.1
VB3	1.1	1.3	1.3	-	1.17	2.1
VB4	1.1	1.3	1.3	-	1.3	1.89
VH1	1.1	1.3	-	1.3	1.3	-
VH2	1.1	1.3	-	1.3	-	2.1
VH3	1.1	1.3	-	1.3	1.17	2.1
VH4	1.1	1.3	-	1.3	1.3	1.89

VEB = ENVELOPE (VB1, VB2, VB3, VB4)

VEH = ENVELOPE (VH1, VH2, VH3, VH4)

Table 2. Load combinations according to ACI 318- 19

Com. \ Load	SW	SD	WB	WH	LL	WL
AB1	1.4	1.4	1.4	-	-	-
AB2	1.2	1.2	1.2	-	1.6	-
AB3	0.9	0.9	0.9	-	1.0	-
AB4	1.2	1.2	1.2	-	1.0	1.0
AH1	1.4	1.4	-	1.4	-	-
AH2	1.2	1.2	-	1.2	1.6	-
AH3	0.9	0.9	-	0.9	1.0	-
AH4	1.2	1.2	-	1.2	1.0	1.0

AEB = ENVELOPE (AB1, AB2, AB3, AB4)

AEH = ENVELOPE (AH1, AH2, AH3, AH4)

3. RESULTS AND EVALUATION

Two columns located within the foundation system were selected for investigation and analysis, as well as for optimizing the foundation structure to highlight the benefits of using hempcrete walls. The two columns are located at grid lines 3-C and 4-A (Figure 4).

The structural analysis results for the axial force at the base of columns 3-C and 4-A were chosen from the load combinations and are presented in Tables 3 and 4, corresponding to the load combinations according to TCVN and ACI 318-19. The difference in axial force between the two models, WB (fired brick wall) and WH (hempcrete wall), is also shown in these tables. Here, Δ1 represents the percentage difference corresponding to the combination of all vertical loads applied to the structure, while ΔE represents the percentage difference corresponding to the combination that includes lateral loads (wind), which results in the largest axial force.

It is observed that hempcrete walls reduce the load by 20% to 26% compared to fired clay brick walls. When no wind load is applied, the difference can be higher, up to 26% for column 4-A. It is also important to note that the density of partition walls in the surveyed building is low, as the investor wanted to create a spacious area without room divisions from grid line 1 to grid line 4 (Figure 4). As a result, the wall mass is not large compared with that of typical low-rise buildings (tube houses).

Table 3. Column base internal forces according to TCVN 2737: 2023

Col.	Column base forces F_z (kN)				Difference (%)	
	Model WB		Model WH			
	VB1	VEB	VH1	VEH	Δ_1	Δ_E
3-C	4955.5	5364.2	3863.4	4272.2	22%	20%
4-A	4264.9	4654.0	3247.5	3636.5	24%	22%

Table 4. Column base internal forces according to ACI 318- 19

Col.	Column base forces F_z (kN)				Difference (%)	
	Model WB		Model WH			
	AB1	AEB	AH1	AEH	Δ_1	Δ_E
3-C	4535.5	5265.1	3359.4	4257.0	26%	19%
4-A	4176.8	4477.6	3081.1	3538.5	26%	21%

Horizontal displacements and dynamic periods

The control results also include the peak horizontal displacement at the top floor, story drift, and the natural vibration period. The displacement accounts for lateral loading (wind effects) in accordance with TCVN 2737: 2023. In the dynamic analysis, 35% of the live load (using reduction factor $\eta = 0.35$) was included in the mass source, along with 100% of the permanent load.

The analysis results show that peak displacement at top floor of the building and story drift were reduced by approximately 3% when using lightweight hempcrete walls compared to traditional fired clay brick walls. Moreover, the natural vibration period decreased by nearly 9% due to a significant reduction in the wall mass participating in the vibration equation. This demonstrates that using hempcrete walls not only reduces foundation material requirements but also effectively decreases the structure's deformation and dynamic response parameters.

Optimization of foundation solution

The foundation is designed in accordance with current standards, including TCVN 10304:2014, "Pile Foundations – Design Standards" (Ministry of Construction, 2014). The foundation must ensure both strength (Ultimate Limit State) and deformation (settlement, stability) in accordance with the Serviceability Limit State.

The Pace building uses D600 drilled shafts with a depth of 44 meters, which have been designed and constructed. The design bearing capacity of each pile is 2400 kN (approximately 240 tons), and they were load-tested during construction (static compression and ultrasonic tests). For the two surveyed columns 3-C and 4-A, the design consultant has arranged three piles for each pile cap, as shown in Figure 8a. The number of piles as indicated is sufficient to bear the load for the case of fired brick walls. The maximum axial force in this case at column 3-C is up to 5364.2 kN. With the internal forces at the base of the column in the WB model as shown in Tables 3 and 4, the largest force transmitted to the pile head is 2023.5 kN for 3- C and 1644.8 kN for 4- A (according to TCVN 2737: 2023). For the load combination per ACI 318-19, the force applied to the pile head is lower than that per TCVN.

The loads acting on the pile head are calculated using formula (4) from TCVN 10304: 2014 (Ministry of Construction, 2014), which accounts for both bending moments in two directions and shear forces at the column base.

In the case of replacing fired brick walls with hempcrete walls (WH model), the axial force at the column base decreases significantly due to the lightweight nature of the hempcrete wall (Tables 3 and 4). With these results, reducing the number of piles per pile cap from 3 to 2 still ensures that the applied load on the pile head is smaller than the design bearing capacity ($P_{max} < P_{tk}$ = 2400 kN). Table 5 provides detailed results for calculating and checking the pile-head load condition for a 2-pile foundation. The results show that choosing 2 piles for the hempcrete wall case is fully satisfied and optimized for this scenario.

Table 5. Verification of the load applied to the pile head for the two-pile footing

Col.	Pile location	Pile axial force (kN) TCVN 2737: 2023		Verification
		VH1	VEH	$P_i \leq P_{tk}$=2400 kN
3-C	P1	2054.1	2142.2	OK
	P2	2005.1	2325.7	OK
4-A	P1	1869.0	1858.2	OK
	P2	1574.2	1974.0	OK

The optimized foundation option with only two piles for the WH model is shown in Figure 8b.

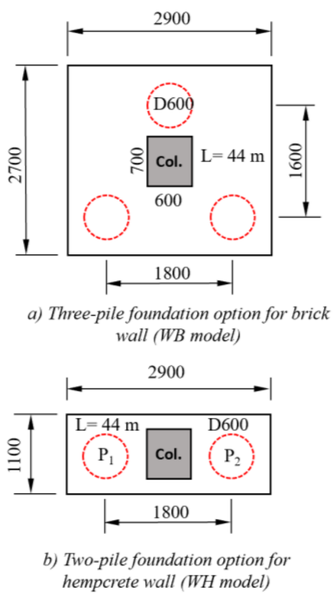

Figure 8. Foundation layout options for columns 3-C and 4-A in the two models wb and wh

Material saving and optimization

Optimization of the number of piles: The number of piles in the WH model is reduced by one-third compared to the model using fired brick walls. A 33% savings is significant from an economic perspective.

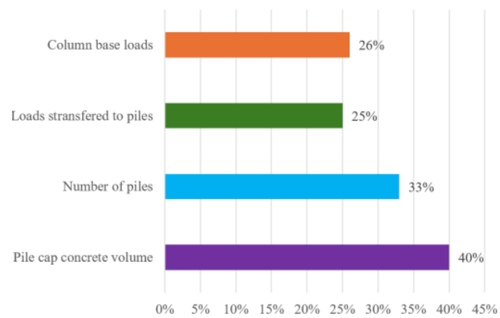

Figure 9. Reduction rates in load and material when using hempcrete walls compared to fired clay brick walls

Optimization of the pile cap volume: The original design and construction required 3 piles with a pile cap size of 2.7 m × 2.9 m, while the WH model only uses 2 piles, and the pile cap size is significantly reduced to 1.1 m × 2.9 m, as shown in Figure 8b. Assuming both designs have the same pile cap height, the WH model saves 40% of the pile cap concrete volume, and of course, the rebar in the two-pile cap is significantly reduced, by more than half, up to 55% (as shown in Table 6).

The results of the structural analysis and optimal design for the foundations of columns 3-C and 4-A are summarized in Figure 9.

In order to assess the effectiveness of material volume reduction when using the hempcrete wall solution, we have rearranged the foundation plan with 21 piles compared to 32 piles in the original design and optimized the pile cap dimensions. The material volume for the piles and pile caps has been significantly reduced for the entire foundation system, as shown in Table 6.

Table 6. Comparison and analysis of the percentage (%) difference – reduction for the Hempcrete wall option (WH model)

Items	Model WB	Model WH	Percentage of reduction
Pile cap concrete (m^3)	106.4	44.9	58%
Pile cap reinf. (kg)	8302.1	3758.5	55%
Number of piles	32	21	11
Total pile lengths (m)	1408.0	924.0	34%

4. CONCLUSION

Hempcrete is a green material, naturally sourced and environmentally sustainable, making it an ideal solution for use as walls in buildings. This paper introduces the application of this green concrete in construction and provides a detailed analysis, comparing it to traditional fired brick materials in terms of load effects on the foundation, thereby optimizing the foundation structure to save materials and reduce construction costs. Two models corresponding to the two types of walls have been analyzed, compared, and evaluated. The optimal foundation solution was selected based on the piles' bearing capacity for the Pace Building in District 1, Ho Chi Minh City. Several conclusions about the significant numbers when using hempcrete walls instead of fired clay brick walls are as follows:

– A 19% - 26% reduction in total load on the columns and foundation.

– An 18% - 25% reduction in the load applied to the pile caps.

– A reduction of up to 34% in the number of bored piles in the foundation.

– A reduction of up to 58% in the amount of concrete used for the pile cap.

– A 55% reduction in the amount of rebar in the pile cap.

Furthermore, hempcrete is a "carbon-negative" material, as the amount of CO_2 it absorbs through photosynthesis and carbonation exceeds the amount released into the environment. This contributes to environmental cleaning and sustainability in material development.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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