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CEE 3410
Individual Case Study 1
11/8/2023

Earth Rammed Columns, Hollister Hall

By Jakobi Davis

7. Rammed Earth Columns: Using results from the labs done this fall for the existing rammed earth soil columns in front of Hollister Hall, what would you recommend for a soil specification for the columns if they were to be built again. Specify the preferred soil and the proposed relative density. You will be provided with the grain size analysis, plasticity, and sand equivalent test results for the three column materials.

To: David Orr, PE

From: Jakobi Davis, RE

Re: Earth Rammed Columns in front of Hollister Hall

Date: November 8, 2023

Dear Professor Orr,

I trust this message finds you well. I am writing to share the findings from my recent research on the degradation of the earth rammed columns in front of Hollister Hall and to propose tailored solutions for their restoration and conservation.

The columns, bearing witness to years of exposure to the elements, exhibit signs of deterioration, primarily manifested through uneven foundational settlement and a biased erosion pattern. Through a comprehensive set of laboratory tests, including grain size analysis, we gained insights into the physical and mechanical properties of the column materials. The analysis revealed significant variations and indicates the need for specific soil specifications for reconstruction.

Our proposed solutions for soil column degradation include:

- Replace deteriorating soil with well-graded gravels and sands, supplemented by CL type clay as a cohesive binder.

- Employ advanced compaction techniques during reconstruction to achieve higher relative density, ensuring improved load-bearing capacity.
- Apply a protective coating on reconstructed columns to shield them from direct exposure, reducing the risk of erosion.
- Implement regular inspections, especially during winter, to detect and address signs of settlement or degradation promptly. I would appreciate an opportunity to discuss these findings further and explore potential collaboration on implementing these solutions.

Thank you for your time and consideration.

Best Regards,

Jakobi Davis

Description of Problem

The enduring appeal of rammed earth construction lies not only in its historical significance but also in its ecological sustainability and architectural charm. Rammed earth structures, such as the columns currently standing in front of Hollister Hall, possess an intrinsic connection to the environment, reflecting an architectural tradition that melds seamlessly with nature. However, this harmonious relationship between architecture and the natural world can be precarious, as these earth-based structures are susceptible to degradation over time.

The columns in front of Hollister Hall, bearing witness to years of exposure to the elements and the passage of time, have experienced signs of deterioration, which, if left unaddressed, will continue to compromise their structural integrity. There is evidence of uneven foundational settlement. This has led to a bias erosion pattern on the left side of the column. This result is likely due to the soil composition of the columns as well as the construction techniques used to create them.

Review of Laboratory Test Results

In our pursuit of recommending a suitable soil specification for the reconstruction of the rammed earth columns in front of Hollister Hall, a comprehensive set of laboratory tests was conducted on soil samples obtained from the locations of the three soil types found in the earth rammed columns. These tests, which include a sieve analysis as well as plasticity and proctor, shed light on the physical and mechanical properties of each soil sample. Below are the specific results for each of the soil samples:

Sample No.	Arkport	For:	Geo Tech class
Location Sampl CEE 3410 Cor	CEE 3410 Lab	Depth Sample Taken:	bucket
Sample by:	Max	Date Sampled:	6-May-22
Date Tested:	17-May-22	Test by:	dpo

Course Fraction (+3/4" fraction)		Washed Data	
Total Sample Wt.	2812.8 g	Sample wt. (pre-wash)	1390.4 g
Total Wt. Retained on 3/4"	2337.0 g	Sample wt. (post-wash)	1044.6 g
Total Wt. Passing 3/4"	475.8 g	Washed wt (passing #200)	345.8 g
% Passing 3/4"	83.1%	% passing #200 sieve (washed)	24.9%
A		B	

Sieve Size	Wt. Retained (grams)	% retained	% retained (Combined)	% Passing	% Passing (Combined)
3/4"	0.0	0.0%	16.9%	100.0%	83.1%
1/2"	9.8	1.9%	1.2%	98.1%	81.9%
#4	26.8	5.2%	3.3%	92.9%	78.6%
#10	31.0	6.1%	3.8%	86.8%	74.8%
#20	31.6	6.2%	3.9%	80.6%	71.0%
#40	26.4	5.2%	3.2%	75.5%	67.8%
#60	50.0	9.8%	6.1%	65.7%	61.7%
#100	119.4	23.3%	14.6%	42.4%	47.1%
#200	160.6	31.4%	19.6%	11.1%	27.6%
Pan	56.6	11.1%	6.9%	0.0%	0.0%
Sieved Wt. (grams)	512.2	Washed	20.7%		
C		D/E			
Combined Wt. (grams)	820.6	Washed wt (combined)	169.6		
E = (C + D)/A		D = C*B/(1-B)			

General Summary

Gravel	Retained on #10	29.0%
Sand	Pass #10, Ret #200	43.4%
Silt & Clay	Passing #200	27.6%
Total		100.0%

Sample No.	Mardin	For:	Geo Tech class
Location Sampl CEE 3410 Cor	CEE 3410 Lab	Depth Sample Taken:	bucket
Sample by:	Max	Date Sampled:	6-May-22
Date Tested:	17-May-22	Test by:	dpo

Course Fraction (+3/4" fraction)		Washed Data	
Total Sample Wt.	2646.8 g	Sample wt. (pre-wash)	1050.2 g
Total Wt. Retained on 3/4"	2389.8 g	Sample wt. (post-wash)	1025.3 g
Total Wt. Passing 3/4"	257.0 g	Washed wt (passing #200)	24.9 g
% Passing 3/4"	90.3%	% passing #200 sieve (washed)	2.4%
A		B	

Sieve Size	Wt. Retained (grams)	% retained	% retained (Combined)	% Passing	% Passing (Combined)
3/4"	0.0	0.0%	9.7%	100.0%	90.3%
1/2"	0.0	0.0%	0.0%	100.0%	90.3%
#4	54.8	20.5%	18.1%	79.5%	72.2%
#10	101.6	38.0%	33.5%	41.5%	38.7%
#20	46.8	17.5%	15.4%	24.0%	23.3%
#40	29.0	10.8%	9.6%	13.2%	13.7%
#60	15.6	5.8%	5.1%	7.3%	8.6%
#100	9.0	3.4%	3.0%	4.0%	5.6%
#140	5.0	1.9%	1.6%	2.1%	4.0%
#200	5.6	2.1%	1.8%	0.0%	2.1%
Pan	0.0	0.0%	0.0%	0.0%	0.0%
Sieved Wt. (grams)	267.4	Washed	2.1%		
C		D/E			
Combined Wt. (grams)	303.3	Washed wt (combined)	6.5		
E = (C + D)/A		D = C*B/(1-B)			

General Summary

Gravel	Retained on #10	76.7%
Sand	Pass #10, Ret #200	21.2%
Silt & Clay	Passing #200	2.1%
Total		100.0%

Figure 1. Sieve Analysis of Arkport Location

Figure 2. Sieve Analysis of Mardin Location

Sample No.	Honeoye	For:	Geo Tech class
Location Sampl CEE 3410 Cor	CEE 3410 Lab	Depth Sample Taken:	bucket
Sample by:	Max	Date Sampled:	6-May-22
Date Tested:	5-Sep-23	Test by:	dpo

Course Fraction (+3/4" fraction)		Washed Data	
Total Sample Wt.	2688.8 g	Sample wt. (pre-wash)	1019.8 g
Total Wt. Retained on 3/4"	2387.0 g	Sample wt. (post-wash)	656.0 g
Total Wt. Passing 3/4"	301.8 g	Washed wt (passing #200)	363.8 g
% Passing 3/4"	88.8%	% passing #200 sieve (washed)	35.7%
A		B	

Sieve Size	Wt. Retained (grams)	% retained	% retained (Combined)	% Passing	% Passing (Combined)
3/4"	0.0	0.0%	11.2%	100.0%	88.8%
1/2"	42.2	10.5%	6.0%	89.5%	82.8%
#4	96.0	23.9%	13.7%	65.5%	69.1%
#10	60.8	15.2%	8.7%	50.4%	60.4%
#20	43.4	10.8%	6.2%	39.6%	54.3%
#40	33.4	8.3%	4.8%	31.2%	49.5%
#60	31.2	7.8%	4.4%	23.4%	45.1%
#100	38.0	9.5%	5.4%	14.0%	39.6%
#200	43.4	10.8%	6.2%	3.1%	33.5%
Pan	12.6	3.1%	1.8%	0.0%	0.0%
Sieved Wt. (grams)	401.0	Washed	31.7%		
C		D/E			
Combined Wt. (grams)	702.2	Washed wt (combined)	222.4		
E = (C + D)/A		D = C*B/(1-B)			

General Summary

Gravel	Retained on #10	45.7%
Sand	Pass #10, Ret #200	20.8%
Silt & Clay	Passing #200	33.5%
Total		100.0%

Figure 3. Sieve Analysis of Honeoye Location

Plasticity and Proctor (Density and OMC Data)

Sample No.	A	For:	Geo Tech class
Location Taken:	Arkport	CEE 3410 Lab	Depth Sample Taken: n.a.
Sample by:	Max R.	Date Sampled:	3-Sep-23
Date Tested:	Sep-23	Test by:	CEE 3410
Atterberg Limits	Standard Proctor Test		
Liquid Limit	17	Optimum Moisture	12 %
Plastic Limit	n.a.	Max. Dry Density	2070 kN/m ³
Plastic Index	NP		

Sample No.	B	For:	Geo Tech class
Location Taken:	Honeoye	CEE 3410 Lab	Depth Sample Taken: n.a.
Sample by:	Max R.	Date Sampled:	3-Sep-23
Date Tested:	Sep-23	Test by:	CEE 3410
Atterberg Limits	Standard Proctor Test		
Liquid Limit	30	Optimum Moisture	6 %
Plastic Limit	25	Max. Dry Density	2000 kN/m ³
Plastic Index	5		

Sample No.	C	For:	Geo Tech class
Location Taken:	Mardin	CEE 3410 Lab	Depth Sample Taken: n.a.
Sample by:	Max R.	Date Sampled:	3-Sep-23
Date Tested:	Sep-23	Test by:	CEE 3410
Atterberg Limits	Standard Proctor Test		
Liquid Limit	28	Optimum Moisture	14 %
Plastic Limit	22	Max. Dry Density	1920 kN/m ³
Plastic Index	6		

Figure 4. Plasticity and Proctor for all locations

It is evident that we are working with a wide range of soil types based on the General Summary provided by my team in the sieve analysis. To get a concrete idea of what specific soil types are present, I used AASHTO methods of soil classification. (1) AASHTO classifies the Arkport soil as A-3; A fine sand, the Mardin soil as A-2-4; clayey gravel sand, and the Honeoye soil as A-2-4; clayey gravel sand with relatively high fines content.

In addition the relative density of each of these soils will tell us key information about the strength, permeability, and stability of the three samples. The relative density of each sample is calculated below:

$$\text{Relative Density (RD)} = (\text{Bulk Density}) / (\text{Maximum Dry Density}) * 100$$

Arkport Sample:

$$\text{Relative Density (RD)} = (1390 \text{ kn/m}^3) / (2070 \text{ kn/m}^3) * 100 = 67\%$$

Mardin Sample:

$$\text{Relative Density (RD)} = (1050 \text{ kn/m}^3) / (1920 \text{ kn/m}^3) * 100 = 55\%$$

Honeoye Sample:

$$\text{Relative Density (RD)} = (1019 \text{ kn/m}^3) / (2000 \text{ kn/m}^3) * 100 = 51\%$$

The data analysis of the relative densities of the three soil locations reveals significant variations in soil compaction. The Arkport sample exhibits the highest relative density at 67%, indicating effective compaction, while the Mardin sample demonstrates a lower relative density of 55%, suggesting less compaction. The Honeoye sample falls even lower at 51%, emphasizing the need for more thorough compaction efforts to achieve a final earth rammed column that is less prone to erosion.

Literature Review

Due to the long history of earth rammed structures, there is a long list of specifications to help fight their degradation and offer some suggestions for repairs. I was able to input a simple search of “soil specifications for earth rammed columns” and received a multitude of resources. Rammed Earth Works suggests a soil composition of 70% sand with 30% clay to act as the cohesive substance. (2) UpCodes provided a great breakdown of the history, learnings, and current specification of earth rammed structures. (3) Researchgate does an adequate job of discussing various methods of repair and reconstruction of earth rammed systems to ensure longevity. (4)

The main issues discussed throughout the literature are natural degradation and inadequate compaction during initial compaction. This inadequate compaction leads to differential settlement as the materials continue to settle in the column over time.

Conclusion

The earth rammed columns adorning the exterior of Hollister Hall are currently undergoing natural degradation, attributed to prolonged exposure to the elements. As the winter season

approaches, addressing the uneven settlement within the columns becomes paramount to prevent potential cracking caused by freeze-thaw cycles. Analysis of the soil composition reveals a crucial balance, with sands and gravels comprising 70%, providing essential structural support against vertical stresses, while the clay component at around 30% acts as the cohesive element binding the layers together.

To fortify the columns against further degradation, achieving higher relative density emerges as a key strategy. Enhanced compaction of each layer, especially during reconstruction, is vital to mitigate erosion caused by prolonged exposure to weather conditions. Ideal soils for this purpose fall within the AASHTO classification of Group A-1-a, characterized by well-graded gravels and sands, ensuring optimal compaction and stability.

Best Type of Clay for Binder:

The most suitable clay for acting as the binding agent in earth rammed columns is classified as CL (Low Plasticity Clay) according to the Unified Soil Classification System. (5) This type of clay exhibits low plasticity, providing the necessary cohesion without being overly susceptible to volumetric changes during wetting and drying cycles. Specifically, a clay with a plasticity index within the range of 10-20% is recommended, striking a balance between sufficient binding capacity and durability.

Solutions for Soil Column Degradation:

Reconstruction with Ideal Soils: Replace the deteriorating soil in the columns with well-graded gravels and sands (A-1-a classification) for optimal compaction, supplemented by CL type clay as a cohesive binder.

Compaction Enhancement: Employ advanced compaction techniques during reconstruction to achieve higher relative density, ensuring improved load-bearing capacity and resilience against environmental factors.

Protective Coating: Apply a protective coating on the reconstructed columns to shield them from direct exposure to harsh weather elements, reducing the risk of erosion and prolonging the lifespan of the rammed earth structure.

Seasonal Monitoring: Implement regular inspections and monitoring, especially during winter, to detect and address any signs of settlement or degradation promptly.

By incorporating these solutions, including the specification for the best type of clay, the Hollister Hall rammed earth columns can be rejuvenated with a comprehensive approach,

ensuring their longevity and preserving the architectural and historical significance they contribute to the campus landscape.

References

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