Investigating the Suitability of In-Situ Soils Of Peshawar For Un-Stabilized Rammed Earth Construction

a Amina Durrani, b Mohammad Adil, c Mohammad Wasim
a: National Institute of Urban Infrastructure Planning, University of Engineering and Technology, Peshawar, adurrani78@gmail.com
b: Department of Civil Engineering, University of Engineering and Technology, Peshawar, adil@uetpeshawar.edu.pk
c: Department of Civil Engineering, University of Engineering and Technology, Peshawar

Abstract- Rammed earth building is a sustainable solution globally. Particularly when built utilizing local soils it reduces the carbon footprint. The time-tested examples of traditional rammed earth constructions and the achievements/accomplishments of contemporary rammed earth constructions is appealing. Though remarkable buildings are being constructed by a handful of experts yet the data supported knowledge base and expertise is scarce locally. Other than careful design detailing and controlled construction, material suitability plays a vital role in its success. For sustainable earth building construction with the optimum use of material resource, soil suitability must be determined. In this research, five random soil samples from all around Peshawar were selected and their suitability for un-stabilized rammed earth application was investigated according to NZS 4298:1998. All the specimens failed the compression and wet-dry appraisal tests. All the specimens passed the Geelong Drip Test. S1, S2 and S4 passed the spray erosion test and S5 passed the linear shrinkage test. No soil specimen passed all the tests suggested by the standard for rammed earth construction. Hence silty-clayey soils of Peshawar with approx. 985 kN-m/m^3 compactive effort at optimum moisture content (OMC) was found to be not suitable for rammed earth application according to NZS 4298:1998.

Keywords- Earth building, Earth construction, Soil suitability, Un-stabilized rammed earth

1 INTRODUCTION

Rammed earth (RE) construction is one of the earthen building techniques that is gaining popularity globally. In this technique thick monolithic walls are directly produced by ramming moist soil (around OMC) in a bottomless formwork with the help of tampers or vibrators until a ringing sound is heard. Such structures do not require the use of mortar or plasters. In this method the void ratio is reduced and the density of the soil increases. This technique is also known as pisé de terre or simple pisé in France [1]– [3]. There are many multi-storied examples of this technique found in both hot and cold climates [2]– [5]. The Hakka Tulou in Fujian Province are one of the popular and ancient forms of such examples [6]. Now-a-days stabilized rammed earth (SRE) structures with fine finish are gaining popularity [4], [7].

For sustainable practices, earthen construction requires to be carried out with locally available materials. This drastically reduces the environmental impact of constructions [8]. To achieve better quality constructions, material selection, that is soil selection, with appropriate properties is an essential step [9]. Globally, in different regions there are soils that are suitable for a certain type of earthen construction and such constructions with good maintenance have lasted for centuries. Generally, clay rich loess soil is found to be suitable for traditional rammed earth structures [5].

Traditional rammed earth construction has also taken place in the alluvial plains in China [6]. However, for a specific technique one might not be able find ideal soils that can satisfy code requirements and stabilization may be required [10]. Also, to avoid unnecessary use of stabilizers and optimize associated costs, soil evaluation and selection is essential [1].

Currently, earthen building construction in Pakistan is mostly carried out by those who cannot afford conventional industrial building materials. The construction type is mostly adobe, cob or wattle and daub, which is carried out in available soils without material evaluation [11]. Rammed earth is not a common practice in Pakistan. However, the world's tallest stabilized rammed earth building, the headquarters of Telenor, has been recently constructed in Pakistan by foreign consultants SIREWALL [12].

Approaches for evaluation of soils for earth building construction vary from qualitative field tests, to quantitative soil and product laboratory tests. The approach in which products produced from soils are tested for strength, durability and shrinkage is followed in the New Zealand Standards and USA building codes.

[13], [14]. The New Zealand standards are considered comprehensive and have been referenced in developing standards and guidelines by others such as ASTM E2392/E2392M − 10 Standard Guide for Design of Earthen Wall Building Systems as well [13][15].

In order to develop local knowledge and expertise, the soil samples from Peshawar, that are used in other techniques as well, are studied for rammed earth application by following the tests specified for rammed earth in the New Zealand Code NZS 4298:1998.

2 MATERIALS AND TESTING

2.1 Materials

To investigate the potential of un-stabilized rammed earth building construction, using in-situ available soils for Peshawar, soil samples were collected from five random locations. Soils from same places are also being used for other earthen building techniques. Table 1 shows the detail of the sources and the USCS classification of the soil. These sample were collected after removing the topsoil, from depths 3 feet and below.

Table 1- Location, coordinates and USCS classification of soil samples

Sample	Location	ISRIC Coordinates (Longitude,Latitude)	USCS Class
S1	Fields Palosai Maqdarzai	71.49, 34.04	CL (Lean Clay)
S2	Bilal Abad Gulshan Rehman Colony Kohat Road	71.57, 33.98	Cl (Lean Clay)
S3	Start of Zone 3 Regi Model town, near to Nasir Bagh Road	71.43, 34.03	CL-ML with gravel
S4	Shaheen Housing Society, Warsak Road Peshawar	71.47, 34.09	ML (Silt)
S5	Mattay Asshab Baba	71.48, 34.14	ML (Silt)

2.2 Experimental Work

NZS 4298:1998 requires testing the strength, durability and shrinkage for soil evaluation for rammed earth technique. The on-site moisture handful drop test was used to set the moisture content of the soil specimens. The compressive strength was tested using the UTM machine. The impact of a droplet and rain was investigated in the durability tests. The wet dry appraisal test, tested the behavior of the specimens after exposing them to six under water cycles. The shrinkage was observed using linear shrinkage box method. The investigations carried out and the procedures followed in this study have been listed in Table 2.

Table 2- Tests carried out on collected soil samples

Property	Procedure in Appendix Clause of NZS 4298:1998 [16]
Compression Test	A5
Wet-Dry Appraisal Test	C

Durability Test	D and E
Shrinkage	F
On-Site moisture handful drop test	G

2.3 Specimen Preparation

For the uniaxial unconfined compressive strength tests, three rammed earth samples were produced from each soil. The rammed earth samples were compacted into cylindrical molds with a height (400 mm) to diameter (200 mm) ratio of 2 as shown in figure 1a. The applied compactive effort comprised ramming with a 4.5 kg and 4 in diameter rammer, with a fall of 1.5 feet. The samples were compacted in three layers and each layer received 26 blows.

a. b. c.

Figure 1: Rammed earth test specimens, a. for compression test, b. for durability and wet dry appraisal test, and c. compression test being carried out in universal testing machine (UTM)

For the durability and wet dry appraisal tests, rectangular prismatic samples with 300 ×125 ×125 mm dimensions were produced as shown in figure 1b. To achieve the same compactive effort for these dimensions, the same rammer was used but the soil was compacted in 5 layers with each layer receiving 50 blows.

The compactive effort was calculated using equation (i) below:

$$Compactive\ Effort = \left(\frac{\left(\frac{Blows}{layer}\right) \times No.\ of\ Layers \times Weight\ of\ hammer \times Height\ of\ Fall}{Volume} \right) \quad (i)$$

For consistency, all the samples were produced at the same compactive effort and OMC as given in Table 3.

Table 3 – Compactive effort applied in rammed earth samples vs standard proctor and modified proctor

	Cylinder	Blocks	Standard Proctor*	Modified Proctor*
Blows	26	50	25	25
No. of layers	3	5	3	5
Weight of rammer (kg)	4.5	4.5	2.5	4.5
Height of Fall (mm)	305	450	450	450
Volume (m^3)	0.0016	0.0049	0.0009	0.0009
Compactive Effort ($kN.m/m^3$ approx).	985	989	600	2700

*For maximum particle size less than 3/8in or 19mm

The rammed earth samples have been cured in accordance with section 2.1.11.1of the NZS 4298:1998 for 28 days in average daily temperature of 13^o

3 RESULTS AND DISCUSSION

The strength and durability tests have been performed for rammed earth in accordance with *NZS 4298:1998 Materials and Workmanship for Earth Buildings.*

3.1 Uniaxial Unconfined compressive strength:

The uniaxial unconfined compressive strengths for rammed earth samples in accordance with appendix A of NZS 4298:1998 are presented in Table 4. According to the passing criteria, the lowest strength in compression should be greater than 1.14 N/mm^2 (165 psi) for a height to width ratio of 2. The moisture content for all the samples was set according to appendix G of NZS 4298:1998. Figure 1c shows the typical splitting crack in compression test under progress. The properties of investigated soils samples in Table 4 were found to be unsuitable for rammed earth construction. For rammed earth application, the compressive strength could be upgraded, by improving the gradation of the soil mix, increasing the compactive effort or reducing the rammer diameter and by chemical stabilization.

Table 4- Compressive Strength of rammed earth samples

Sample	Unconfined Compressive Strength	Result according to passing criteria
S1	2 samples had 92.8-93.50 psi 1 sample had 120 psi Average 102.33 psi	Fail
S2	65.1±10 psi	Fail
S3	70.1±12.5 psi	Fail
S4	59.7±6.1 psi	Fail
S5	25.4±5 psi	Fail

3.2 Durability Test using Geelong Drip Test:

The Geelong Drip test has been performed in accordance with the appendix E of NZS 4298:1998 rammed earth samples of size 300×125×125 mm. If the pit depth is equal or greater than 15 mm and the moisture penetration is 120 mm or greater or the erodibility index is greater than or equal to 5, the sample is considered to have failed the durability test. The moisture content for all the samples was set according to appendix G of NZS 4298:1998. The details of durability tests result, for rammed earth samples, have been provided in Table 6 below.

Table 5- Durability of rammed earth samples using Geelong Drip Test

Sample	Pitting Depth (mm)	Erodibility Index	Depth of moisture penetration (mm)	Result according to passing criteria
S1	5	3	10 Pass	Pass
S2	3.5	2	7.5 Pass	Pass
S3	5	3	20 Pass	Pass
S4	1.5	2	10 Pass	Pass
S5	0	2	24 Pass	Pass

3.3 Durability Test using Spray Erosion Test:

The test has been performed in accordance with the appendix D of NZS 4298:1998 rammed earth samples of size 300 × 125 × 125 mm. If the pit depth is equal or greater than 120 mm and the moisture penetration is 120 mm or greater and the erodibility index is greater or equal to 5, the soil sample is considered to have failed the durability test. The moisture content for all the samples was set according to appendix G of NZS 4298:1998. A post-test condition of a sample is shown in figure 2a. The details of spray erosion test results, for all types of samples, have been provided in Table 6.

Figure 2a: Post-test condition of specimens, a. after spray erosion test, and b. linear shrinkage box test

Table 6- Durability of rammed earth samples using Spray Erosion Test

Sample	Pitting Depth	Erodibility Index	Depth of moisture penetration (mm)	Result according to passing criteria
S1	45	2	Pass	Pass
S2	102	4	Pass	Pass
S3	≥120/hr	5	Fail	Fail
S4	45	2	Pass	Pass
S5	≥120/hr	5	Fail	Fail

3.4 Comparison between Geelong Drip and Bulletin 5 Spray Erosion Test Results:

All un-stabilized rammed earth samples passed the Geelong drip test which is a less aggressive test based on simulating the impact of a droplet. The S3 and S5 (Regi Model Town and Asshab Baba Mattay) samples failed the spray erosion test which is a more aggressive test based on simulating the impact of rainfall. The S2 (Kohat Road) sample also performed poorly in the spray erosion test. However, the S1 and S4 (Palosai Maqdarzai and Shaheen Housing Society) samples performed well in the spray erosion test. Hence, it is possible to pass one durability test and fail the other.

3.5 Wet Dry Appraisal Test:

The test has been performed in accordance with the Appendix C of NZS 4298:1998 on rammed earth samples of size 300 × 125 × 125 mm. and the results have been provided in Table 7. The moisture content for all the samples was set according to appendix G of NZS 4298:1998. The samples were soaked for 2 minutes under 10 mm of water over three coins as spacer for 6 cycles and matched among the eight criteria in section C3.4 of NZS 4298:1998 as follows:

a. Crazing type Crack pattern
b. Star type Crack pattern
c. Local Swelling
d. Local pitting in at least 5 locations
e. Local or general fretting, that is loss of layers of soil either upon wetting or drying
f. Penetration of water, as indicated visually on the outer surface**s** of the brick, by more than 70% of the brick width
g. The loss of fragments of the brick larger than 50mm greatest dimension, except that part of the fragments which come from with 50mm from the edges of the brick shall not be included h. Efflorescence

Table 7- Wet dry appraisal test results of rammed earth samples

Sample	No. of Failed Criteria	Result according to passing criteria
S1	4	Fail
S2	4	Fail

S3	3	Fail
S4	2	Fail
S5	1	Fail

Criteria f and h was not satisfied for all RE samples. With respect to criterion g, there was no loss of fragments greater than 50 mm excluding the edges of the sample. However, the layers of the RE sample in case of the S2 (Kohat Road) sample separated. Star type and crazing type crack pattern, local swelling, local pitting and the loss of thin surficial layer locally or generally was observed in most of the samples. Although, all the samples failed till the completion of the sixth cycle, the samples made from Asshab Baba Mattay soil (S5) failed only one criterion from the above list.

3.6 Linear Shrinkage Test:

This test was carried out in accordance with Appendix F of NZS 4298. Smooth surface molds of 600 × 50 × 50 mm dimensions were lubricated with oil as shown in figure 2b. Moistened sieved soil passing the moisture content drop test prepared for the RE samples is placed and rammed in three layers and air dried for 28 days in the indoor environment at average daily temperature of 13ºC. The results of linear shrinkage box test for each sample is provided in Table 8 as under.

Table-8: Linear Shrinkage Test Results

Sample	**Measured Shrinkage at 28 Days in mm**	**Linear Shrinkage %**	**Result according to passing criteria**
S1	12	2	Fail
S2	8.5	1.42	Fail
S3	5.75	0.96	Fail
S4	4	0.67	Fail
S5	0	0	Pass

According to Table 2.1 of NZS 4298:1998, samples with linear shrinkage ≤0.05% are suitable for rammed earth construction. Hairline crack of less than or equal to 0.3 mm may be acceptable for the above-mentioned sample size in order to pass the criteria provided by the standard. Except for S5 (Asshab Baba Mattay soil) sample all other soil samples fail this criterion.

3.7 Summary of Results:

The summary of strength and durability tests for un-stabilized rammed earth applications is provided in table 9 below.

Table-9: Summary of Test Results

Sample Location	**Compression Test**	**Durability Tests**		**Wet Dry Appraisal Test**	**Linear Shrinkage Test**
		Geelong Drip	Spray Erosion Test		
S1	Fail	Pass	Pass	Fail	Fail
S2	Fail	Pass	Pass	Fail	Fail
S3	Fail	Pass	Fail	Fail	Fail
S4	Fail	Pass	Pass	Fail	Fail
S5	Fail	Pass	Fail	Fail	Pass

4 CONCLUSIONS AND FURTHER STUDIES

Pakistan lacks studies data and codes for rammed earth application. The aim of this study was to investigate the in-situ soils in their natural state for their potential of un-stabilized rammed earth. The conclusions drawn from this study are that in-situ soils from the selected locations in Peshawar are not suitable, in their current natural state, for rammed earth application. The soil sample in general passed one or two tests but not the overall tests required by NZS 4298:1998, prior for determining their suitability for rammed earth applications. This study provides baseline data for the silty-clayey in-situ soils in Peshawar for rammed earth application. The soils that failed the required criteria may be made suitable by either altering the gradation of the soil mix, increasing the compactive effort with respect to the tamper, reducing the rammer diameter, using green stabilizers or by varying moisture content. Further experimentation can be carried out in accordance with the recently superseded (20202) version of NZS 4298.

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