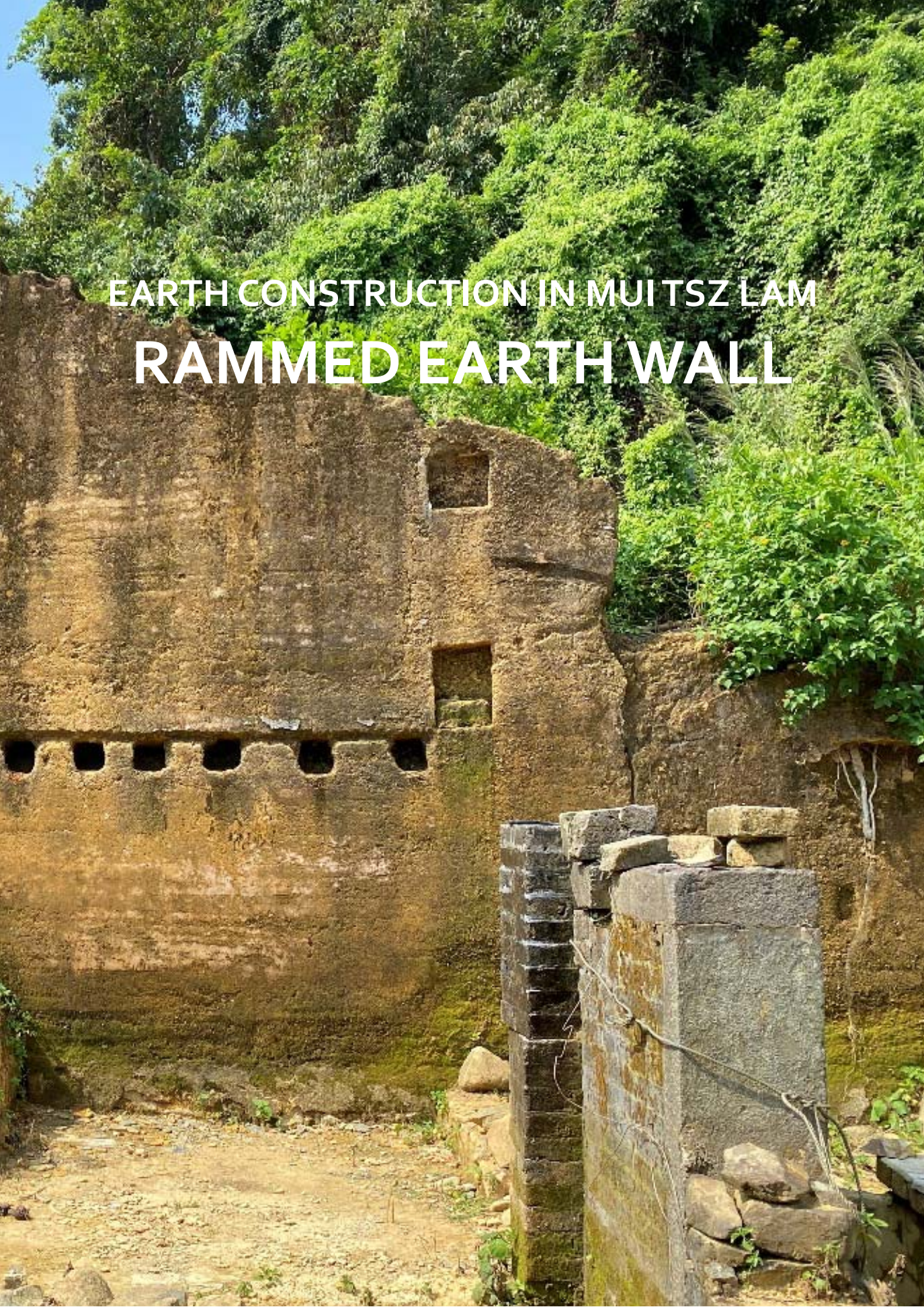


EARTH CONSTRUCTION IN MUI TSZ LAM

RAMMED EARTH WALL

Contents

1. Introduction

Earth construction process in Mui Tsz Lam village

1.1 Earth construction

Earth structure is a structure made largely from soil, it has been used widely since prehistoric times. Soil can be combined with other materials to produce different strength and appearance. Rammed earth, cob, adobe bricks, CEB and fired clay bricks are common earth construction materials.

Existing condition of Mui Tsz Lam village

Rammed earth wall of the Old House

1.2 Mui Tsz Lam village

Mui Tsz Lam, as one of the seven villages in the Hung Chun Yeuk Alliance, it has 360 years of history, includes different kind of dwelling units and building methods. Rammed earth wall is one of the most unique features found in Mui Tsz Lam, for example in Old House, most of the exterior wall and interior wall are built with rammed earth, alongside bricks. There are many combinations of ingredients in rammed earth wall such as sticky rice, lime, grain, clay, brown sugar, and straw etc.

2. Site Analysis

Rammed Earth 夯土

Poured Earth 生土澆築

Earth Motar 泥漿砌石

Earth Adobe 土坯磚

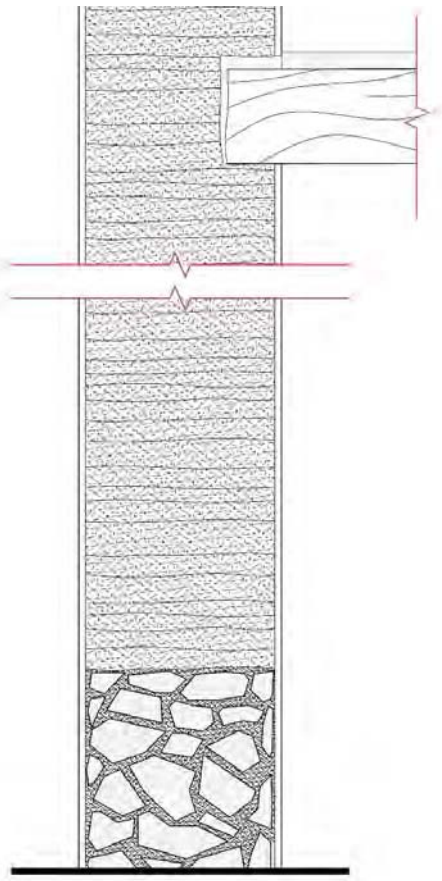
2.1 Earth construction in Mui Tsz Lam

Earth construction traces are found everywhere in Mui Tsz Lam including rammed earth, adobe bricks, poured earth, earth plaster and earth mortar etc.

External wall of the old house

2.1.1 Rammed Earth

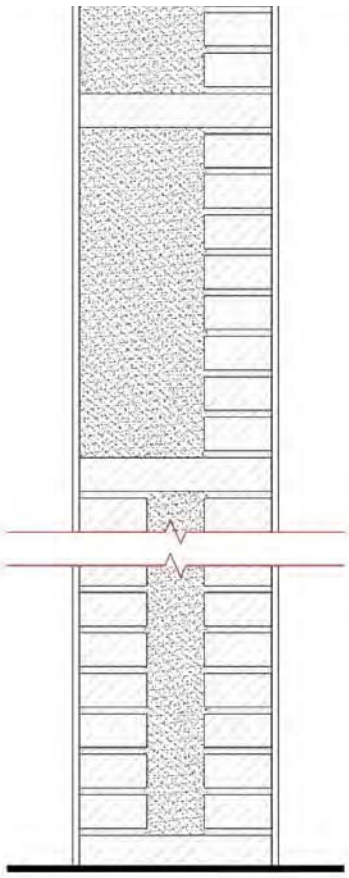
Rammed earth can be found in the walls of Old House. They were built on the compacted earth surface with 300mm high stone base and white plastering as finish. As high level, holes were present to hold beams supporting the loft floor plate.



Interior wall of the old house

2.1.2 Poured Earth

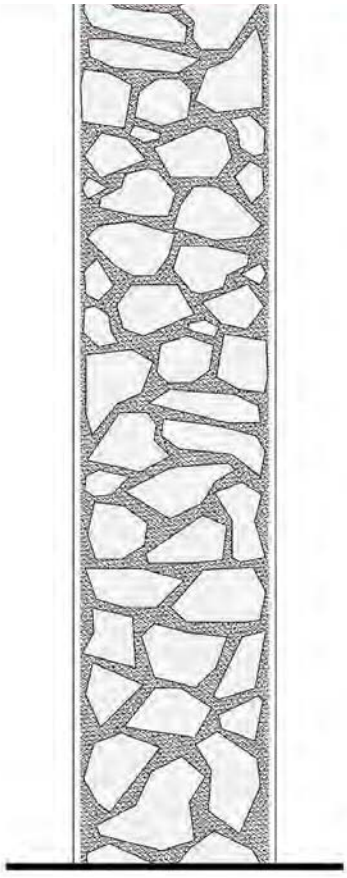
Poured earth makes use of earth as filling of walls. This method can be found in brick walls along the axis along Old House's courtyard. The wall was constructed with bricks forming the profile to desired thickness, and the void is filled with earth. The finish is either plastering or mortar to imitate granite texture. At certain level, the bricks were laid in perpendicular orientation to allow better incorporation between bricks and earth. The advantages of this method include saving bricks, allowing bricks to achieve different thickness, and maintaining good heat isolation.



External wall of the three-gate house

2.1.3 Earth Motar

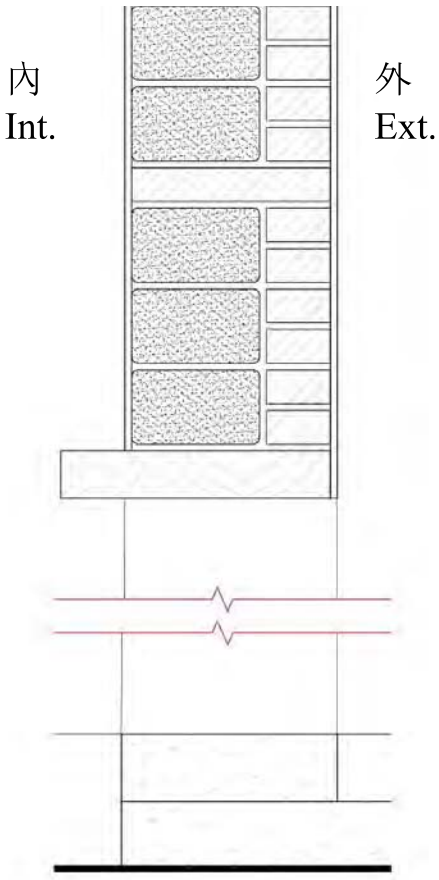
Earth mortar method makes use of stones as the aggregates of the wall, and earth as adhesive to hold them together. The finish is usually plastering. This method can be seen in the left gate and middle gate of the Three-Gate House.



External wall of the three-gate house

2.1.4 Earth Adobe / Mud Bricks

Earth abode brick can be found in the right gate of the Three-Gate House as well as the party wall of this house and the northern neighbor. They were normally laid on stones and bricks.


内
Int.
外
Ext.

Rammed earth + Granite + plaster

2.1.5 Combination Of Earth Materials

Typically in Mui Tsz Lam, different construction methods and materials are merged in one façade or one wall. For example, on the surface of rammed earth wall and mud bricks, plaster was applied on it; Blue bricks, rammed earth wall and cement screeding have different purpose in one wall. Blue bricks as structural support purposes, earth wall as main body and cement screeding as finish on the surface.

Earth mortar + Plaster

Earth Adobe + Plaster

Rammed earth + cement

Rammed earth + Granite + earth plaster + cement screeding

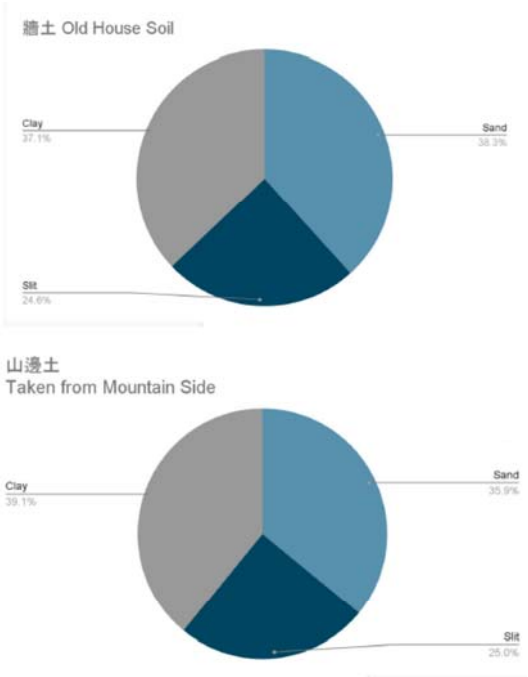
2.2 Soil characteristic in Mui Tsz Lam

To build a sustainable structure, a good soil source is crucial. The proportion of silt, clay, sand and gravels needs to be optimum to provide best strength.

Two sources of soil in Mui Tsz Lam were tested with their composition:

Old house soil has less clay content comparing to Mountainside soil, too much clay would lead to cracks in the wall due to its water absorbing properties; Organic matter was also found in mountain side soil which is not preferable in a wall.

The result has shown that ‘Old house soil’ is more suitable than ‘Mountain side soil’ since there is less clay content, and no organic matter.

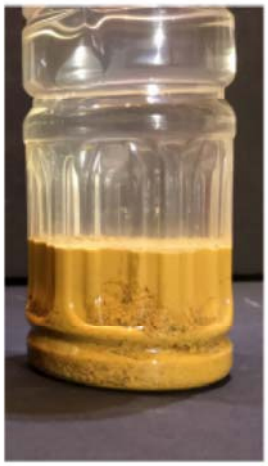


Soil composition percentage diagram

Sample A: Hill soil

1

2



3

Observation: (proportion in height)

Clay: 52.50%
Silt : 47.50%

Clay: 55.00%
Silt : 45.00%

Clay : 45.06%
Silt : 11.36%
Sands : 43.58%

Sample B: Old house soil

4

5

6

Clay: 15.69%
Silt : 63.64%
Sands : 20.67%

Clay: 35.79%
Silt : 64.21%

Clay: 38.56%
Silt : 61.44%

Rammed earth wall of the old house

2.3 Rammed earth wall in Mui Tsz Lam

Rammed earth walls are most commonly found in Mui Tsz Lam Village. Old house has the most signature earth wall. Still standing after at least 200 years, the traces of floor decking, beams, windows are still visible.

Our aim of project is to find out how it can withstand without adding chemicals or cement, analyses it, and recreate them. Combining old methods with new technology, we experiment to see the possibility of re-building in Mui Tsz Lam village.

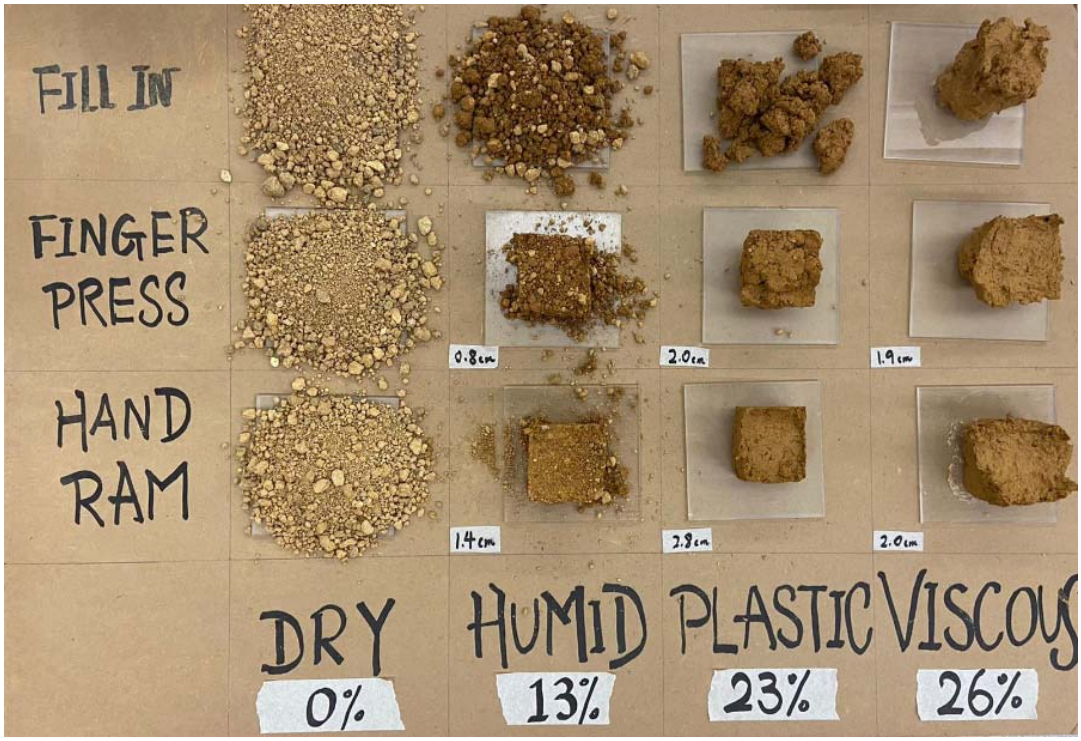
In some houses in Mui Tsz Lam, we found different organic ingredients added apart from soil, e.g. sticky rice, grain, lime, brown sugar, straw (chopped into 5cm long).

Not all walls are as strong and as lucky as the Old House, many interior rammed earth wall e.g. at Mural House had been destroyed over the years. In our research, we would like to find out the pros and cons of traditional method, can optimize it to re-create rammed earth wall without additional chemicals, hopefully can retain the traditional characteristic but at the same time increase the strength and appearance.

Grains found in earth wall

Grains found in earth wall

3. Experiments and Studies



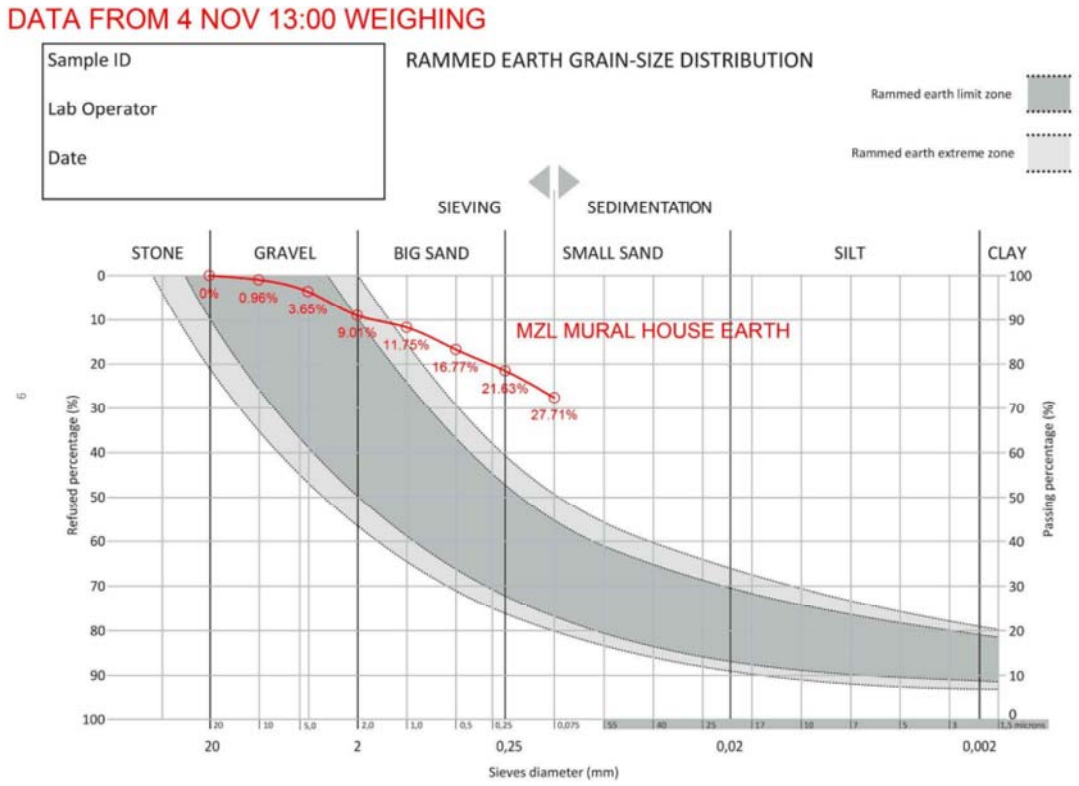
Carazas test by students

3.1 Mui Tsz Lam earth composition

3.1.1 Carazas test

Carazas test was done to see the form and appearance of soil with different water content and pressing method. The aim of this exercise is to observe the diversity of materials that can be obtained by changing the hydric state of earth (dry, humid, plastic, viscous or liquid) and the mechanical action applied on it (to fill, to press or to compact layer by layer). Participants can grasp by handling and observe the impact of some key processing parameters for various soils and fibers: consistancy, water absorption, compactibility, gesture, etc.

Dry sieving and wet sieving test by students



Data Sheet

(Documented on 04/11/2021)

3.1.2 Size distribution curve

Dry sieving and wet sieving test were done to distinguish the grain size of Mui Tsz Lam soil accurately. According to the grain size distribution graph, Mui Tsz Lam's earth does not lie perfectly in the curve, which need additional gravel and stone to balance.

3.2 Adobe bricks

In addition to testing the feasibility of rammed earth wall, adobe bricks were also tested. These bricks are widely used in Lai Chi Wo to build and renovate houses.

With the help of Lai Chi Wo's experienced craftsman, old wall soil was first demolished and roughly sieved, then it was soaked in water for a week before making the bricks. After a week, soil can be mixed with soaked straw (soak for around 1 week) and sand.

GOAL 目標

To find the smoothest mud brick slipped off the molding
制訂最佳的泥磚配方

SIZE 尺寸

150mm(W)*380mm(L)*250mm(H)

INGREDIENTS 材料

Saturated Soil soaked for 7 days 已浸七日的土
Straw grass soaked for 1 month 已浸 1 個月的禾桿草
Dry fine sand 乾細砂

PROCEDURES 過程

1. According to Woody's experience, prepare adequate amount of saturated soil, soaked straw and dry sand.
2. Mix them in a bucket by machinery. Use feet to mix and compress the soil till the soaked straw could not be seen.
3. Add water whenever it is too dry and add sand whenever it is too muddy.
4. Pour the mixture into the mould and compress it .
5. Flatten and shave off excess mixture. Remove mould

1. 根據師父的經驗，預備適當的已浸過的土，禾桿草和乾細砂。
2. 用機器攪拌桶子內的泥漿。
3. 用腳將其攪拌均勻。
4. 當混合物過乾時加水；當混合物過黏時加砂。
5. 達到適合的稠度後，把混合物倒進模具裡並用工具壓實泥磚。
6. 把泥磚的平面掃平和撥走多餘的混合物。
7. 一人用雙手拿起模具的對角，脫模。

ADVANTAGES 優點

1. Easy to control 容易控制泥團的稠度

ISADVANTAGES 缺點

1. Difficult to quantify when craftsman only judge the mixture by experience and feeling
2. Most trials that demold smoothly cracks due to high water content

1. 因為師父只以經驗和感覺添加材料，故此難以量化材料的比例。
2. 水份多能令泥磚順滑脫模，過多水份卻導致泥磚在風乾的過程中裂開。

REMARKS 備註

1. Soak the straw grass in termite medicine beforehand to prevent eat away of grass by insects to affect brick structure
2. Make sure the mud brick surface is smoothened without protrusion, or else it may affect stacking of brick wall

1. 禾稈草要提前用白蟻藥浸泡過，以防含草量較高的泥磚被蟻蟲侵蝕
2. 泥磚表面寧願凹陷也不要凸起，以免影響上層磚塊的堆疊

Adobe brick traditional practice

Demolition

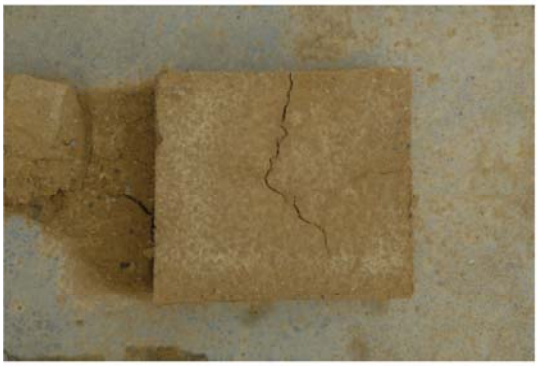
Preparation

Mixing

Making

10/7/2021: Fresh out of molds 剛脫模時的狀態

17/7/2021: After 7-days drying 七天風乾後的狀態



Trial 10

Trial 11

Adobe bricks' quality are difficult to controlled, due to its high water content: Problems like cracking and deformation occurred during trials.

Cracking due to:
- Clay absorbs and release water vigorously during the process, drawing out water excessively will pull soil particles apart and form cracks if there isn't sufficient fiber to hold the bricks together internally.

Deformation/ Collapsing/ Difficulty in getting out of mold due to:
- Adding too much water
- High humidity affects drying process

	Saturated soil	粗砂	幼砂	山泥(黏土)	老屋牆泥	+乾禾桿5g	+濕禾桿5g
Amount	3/5 桶	2.5 瓢	5 瓢	2 瓢	2 瓢		
Amount (cm3)	15543	6375	12750	5100	5100		
Ratio	3	1.25	2.5	1	1		
Simplified Ratio	12	5	10	4	4		

After trials and errors, it was found that mud bricks are less suitable for large scale wall construction in Mui Tsz Lam due to the following reasons:

- Labor intensive: Each mud brick needs human power to mix and press with foot. Removing the mold also require strength. More workers might be needed to hire to build an entire wall.

- Time consuming: Mud bricks are made one by one, at least 50 are needed to build a small wall. Mud bricks also need more time to dry before assembling to a wall.

- Inadequate space: Mud bricks need sheltered and well-ventilated space to dry. Mui Tsz Lam village does not have enough sheltered space at the moment, which make it difficult to implement.

- Soil properties not right: As seen from the trials, most of the bricks have cracks, meaning the clay content in the soil mixture is too high. Adjustments have to be made to create better brick.

	Rammed earth 夯土	Mud bricks 泥磚
Difficulty in making 製作難度	Lower, easier to control with lower water content and with help of machinery 難度較低；因其含水量較容易控制，而且大部分過程有機器輔助	Higher, difficult to obtain perfect recipe due to higher water content with fluctuating soil humidity 難度較高；因其高含水量較難控制，當天泥土濕度對製作影響頗大
Duration of pre-construction preparation 備料時間	2 days for soil mixture to settle 需時兩天燜土	More than one week for the bricks to dry 需要超過一周
Labour 勞動力	Less labour-intensive (machinery-dominant) 少許勞動力	More labour-intensive for handmade mud bricks (individual molding) (if continuous construction) 勞動密集
Construction area 場地需要	Only the site area 只在建築工地	Large vacant land required to dry bricks Temporary roofing required in case of bad weather 需要大片空地風乾磚頭和臨時屋頂避免惡劣天氣帶來的破壞

3.3 Rammed earth trials

After comparing mud bricks with rammed earth, we found that rammed earth is a more suitable technique than mud bricks to be applied in Mui Tsz Lam earth construction due to the following reasons:

Water Content Test of Rammed Earth - Trial 2 13/7 夯土的水分測試

To find the ideal water content with the best strength and adhesives 配合黏合劑,尋找最牢固的理想含水量度

Water added	8%	10%	12%	14%	16%
Volume (m x m x m)	100 x 100 x 100	100 x 100 x 100	100 x 100 x 100	100 x 100 x 100	100 x 100 x 100
Initial Weight (g)	1934	1856	1966	1940	1874
Weight 4 Days after (g)	1495 (-439)	1664 (-191)	1594 (-372)	1699 (-241)	1597 (-277)
Density lost (kg/m3)	13.96%	14.12%	13.58%	14.12%	14.78%
Observation	Light colour Depleted more severely	Light colour Depleted more severely	Light colour	Light colour	Light colour Hardened No clear depletion

Preparing sample cylinder for compression test
(The left sample was made with 1:1 soil-stone proportion while the right one has 1:2 soil-stone proportion.)

Compression test in HKUST

In order to build a wall in Mui Tsz Lam, strength is one of the biggest concerns, especially with only all natural ingredients (soil, sand, gravel) without any additional chemical (cement).

Hence, two sample rammed earth blocks were made with different soil proportion and was sent to the Civil and Environmental Engineering Lab in the Hong Kong University of Science and Technology for a compression test.

3.4 Adjustment in proportion

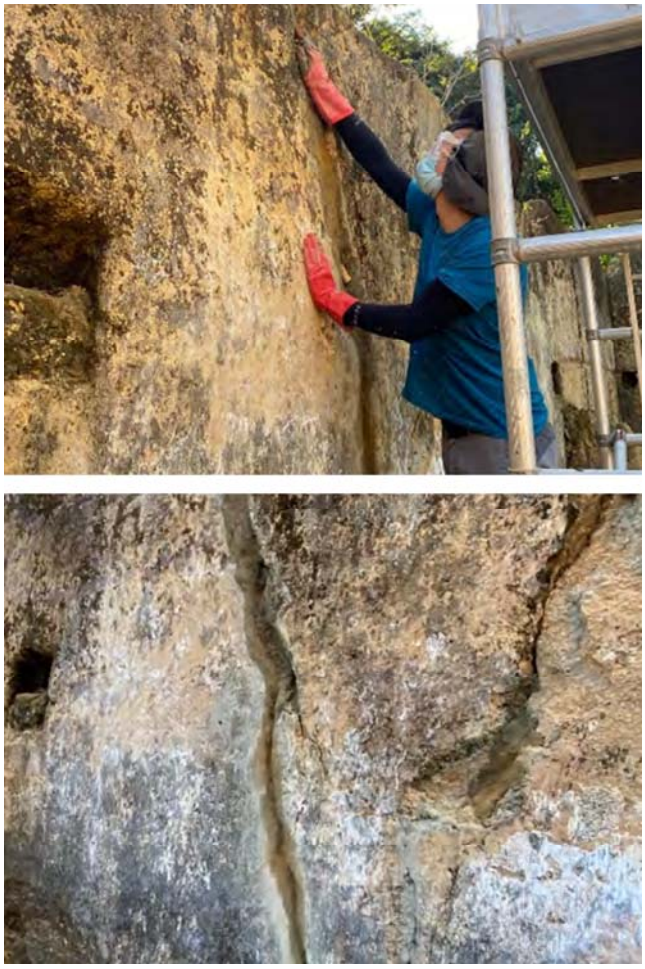
Since building the rammed earth wall requires mixture of soil and stone; Soil can be found extensively in Mui Tsz Lam with recycled old wall soil, while stone finding is a greater problem in Mui Tsz Lam. From the experiments and the grain size distribution curve, it is found that stone/gravel with 5cm or smaller are the optimal size. In Mui Tsz Lam, big stones can be found, however smaller size are very rare and sometimes hard to distinguish between small stone or scattered concrete block.

Hence, the project team bought a stone crushing machine and crushed the big rocks in Mui Tsz Lam to 5cm or smaller gravels, hoping to build the rammed earth wall. This requires a lot of labour to search for stones and transport them, as well as extremely time consuming.
Even though the proportion of soil: stone 1:2 has slightly better performance, we adopted the 1:1 proportion because of the lack of local stones and labour.

The test result for the compression test is:

	Soil: Stone – 1: 2	Soil: Stone – 1: 1
Final failure strength	1.193 mPa	1.097 mPa

4. Conservation and Reinforcement



Filling up the crack with cement, sand, soil and nails

4.1 Crack handling

Even though the exterior wall of Old House is comparatively stronger and stood for 200 years, there are a few main cracks go through the rammed earth wall, which might cause accidents in the future. The project team want to conserve the old walls and keep the history, at the same time make good the wall for further construction or development.

With the help of professionals from HKIC (Hong Kong Institute of Construction), one of the crack was filled with cement, sand, MTL soil and nails. It was also a trial to test the appearance and see whether it match with the original wall colour. This trial experiment the combination of old and new, which will be seen many places in Mui Tsz Lam during the project.

4.2 Reinforcement

Apart from filling the cracks, old walls with risk of falling needed reinforcement to stand longer. Professionals from HKIC has used wires to tie one of the walls of Old House, they anchored the wires to the ground and temporarily hold the wall safely. This was also an experiment to see whether this method works on the old walls since they deteriorate and weather at a fast pace.

-Tying and wrapping the wire around the wall through holes

-Welding the wire and nail to the ground

5. Construction of Rammed Earth Wall

Redo of stone wall base in March 2022

5.1 Stone wall base

To build a stable and strong earth wall, a well-built and water-resistant base is crucial. The project team first reached out to some experienced workers, they helped remove soil debris at the two side of rammed earth wall, and also attempted to build a stone wall base.

However, the result was not as pleasant as expected, thus other craftsmen were hired to redo the stone wall base. It turned out flat, balanced and more appealing.

The stone wall base is consisted of local big stone, cement, sand, and soil. Building the stone base requires specific skills of stone picking and arranging technique, skilled labour is essential to build a functional and aesthetic stone base.

Construction of stone wall base in September 2021

5.2 Preparation

Rammed earth wall construction requires preparation ahead and labour-intensive. The below steps are recurring after the start of construction, which can keep the progress on-going without insufficient soil mixture.

Step 1 - Dry and granulate soil

- Dry under the sun
- Granulate the soil with the granulator
- Pack with plastic bag/ dry and sheltered space at the end of the day

Step 2 - Crush stone

- Find fist-size stone
- Crush into 0 - 2mm diameter size
- Store crushed stones in covered dry place (Box or canvas)

Step 3 - Mix soil and stone

- Mix well with mixer
- Add water slowly and evenly (Water content approx. 8-10% (~11L water)
- Pinch test with hand

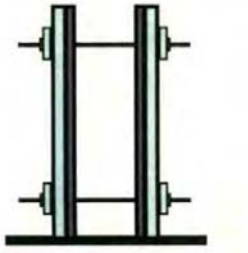
Step 4 – Let soil mixture rest

- Place in canvas/bucket/trolley
- Cover well with canvas for 1-2 days

5.3 Construction procedures

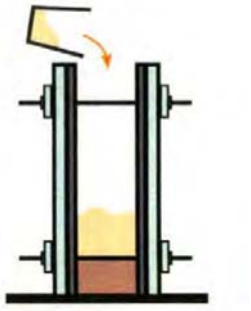
Step 1 - Set up formwork

- With aluminum formwork
- Leveling
- Apply lubricant oil on the inner surface of the formwork



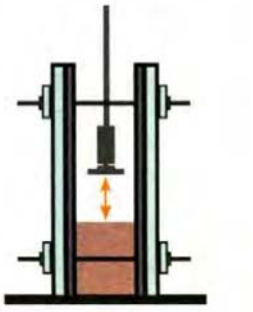
Step 2 - Add water and/or cement

- In the soil mixture, add water if too dry
- Add small amount of Portland cement and mix well, to increase the strength of wall



Step 3 - Ramming process

- Use feet of timber pole to press down soil first
- Use electric hammer to press down soil mixture
- Add max. 200mH soil mixture and ram to 100mH



Step 4 - Let dry

- Can remove formwork directly after ramming
- Let dry under sheltered space for at least 1-2 weeks
- If not yet completed, cover well with canvas to prevent drying out or rainwater going in.

Construction of rammed earth wall in 2022

First trial (2021.11.13 – 2022.1.8)

The project team had started the first trial of rammed earth wall in November 2021, with the help of HKIC and public volunteers, all without experience working with rammed earth wall. Combining the skills and data from previous experiments, the sample wall of 1800lx300wx600h was finished in January 2021.

From the previous experiment and trials, with only soil, stone and water, the best and most feasible proportion is: soil: stone - 1:1 (in weight), and water 8-10%. In the mixing machine, not more than 3/4 should be filled, thus the following table shows the mixture data for this trial for one mix.

Each mix could produce a 1.8m x 300w x 100h wall. Hence for Trial 1, the project team used 6 of the above mixtures to build the wall section.

Shortcoming:
- Water content too high
- Strength not enough (can be easily break with hammer)
- Soluble in water
- Stone sizes too large.

Unit	Soil	Stone	Water
Weight per bucket	13.4kg	16.9kg	11kg/L
Bucket (11L)	5	4	~1
Weight per mix	67kg	67.6kg	10-12L

Limitation

Although many experiments and trials were made in the lab and CUHK, the site conditions affected the preparation and construction a lot, which largely reduced the accuracy of the soil mixture.

Since there is no cement or lime added to the mixture, clay is the only bonding agent to stick sand and stone together, and its strength and performance will be affected by the water content. The proportion between clay and sand+stone should also be taken more precisely since the ratio of clay determine the success rate of the wall. Too much clay would result in cracking while the mixture may not bind well if too little amount of clay was added.

Limitation	Problem	Details
Weather fluctuation	Imprecise water content	The weather condition largely affects the drying of soil and the water content in the mixture, this made it hard to get precise water without professional machines. The range of the hand pinch test is very large and cannot be used to determine whether the mixture is good to ram.
Insufficient small stone	Grain size too large	Due to the insufficient small stones and high transportation fee, a stone crushing machine was bought to Mui Tsz Lam to crush the larger stones to under 2mm in size. However, the machine could not crush perfect 2mm sizes, which made some larger than 2mm, while the proportion from 0-2mm was also unpredictable. Without knowing the grain size precisely in the mixture, the grain size curve would not be the same as done in the lab which further led to the failure of the wall.
Lack of workers	Slow progress and unprofessional skills	Mui Tsz Lam as a remote area, it was hard to hire experienced workers at a reasonable rate. Hence, the project team experimented with public volunteers and was assisted by HKIC. However, most of them did not have experience in building rammed earth walls, leading to overall slow and inefficient progress.

Second trial (2022.3.9 – now)

After reviewing the previous trial, it is concluded that soil mixture with only all natural ingredients (soil, stone, water) are not feasible in Mui Tsz Lam village. Taking the suggestion from experienced craftsmen, lime and small amount of cement were decided to add to the soil mixture, which would raise the overall strength of the wall.

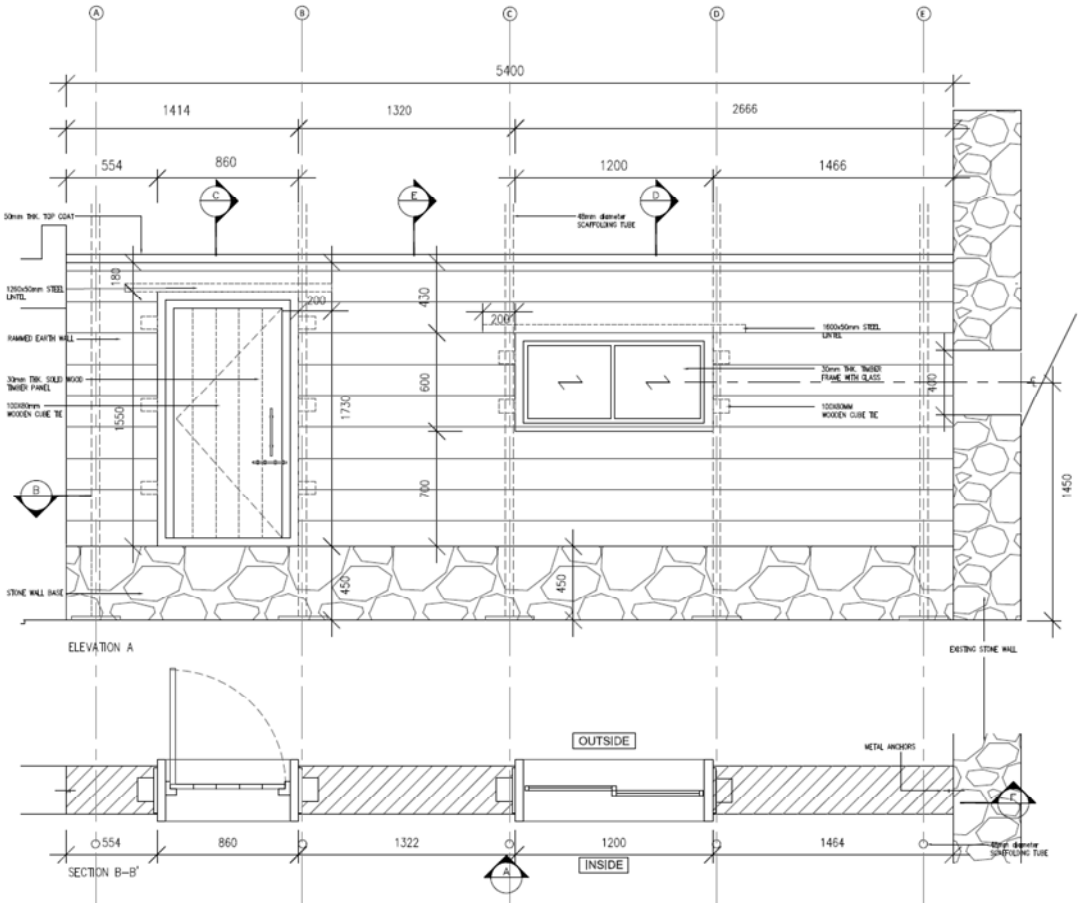
The result of Trial 2 turned out much more appealing. Not even completely dried yet, the wall is already strong enough to withstand punching and hammering.

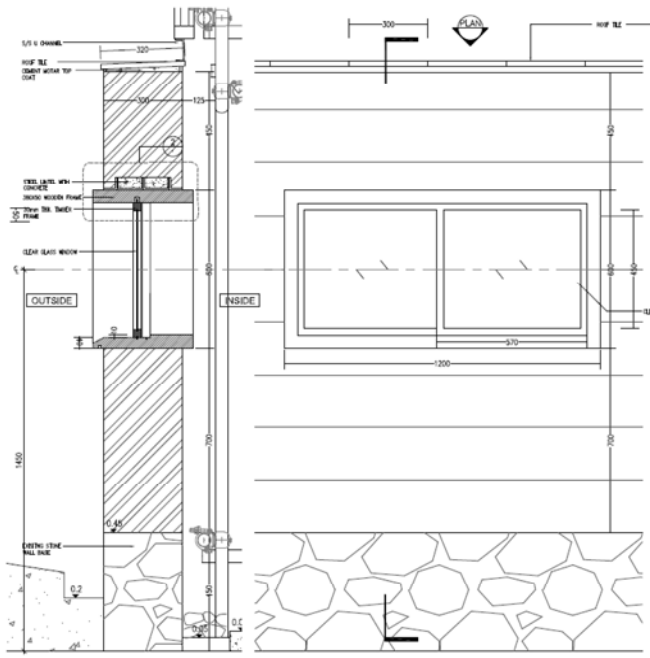
One concern was some of the surface turned out not smooth and sticked some soil to the formwork. It was then fixed by applying the soil mixture to the surface like a mortar, and smooth it out. Experienced craftsmen were able to handle it well.

	Lime	**Cement**	**Stone**	**Existing soil**
Amount added	~1.5kg	4kg	45%	50% (with some stone inside already)
Mixing	Mix with soil mixture in mixing machine	Add just before ramming process, mix with hand	Crushed with machine before mixing with soil	

5.4 Design drawings and openings

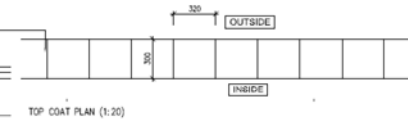
For experimenting rammed earth wall in Mui Tsz Lam, Mural House was chosen to be the site for building the wall. The design includes two opening, with different materials and opening methods. The location of openings is according to the grid lines of the scaffolding, and also the center line from the existing wall opening at the back.



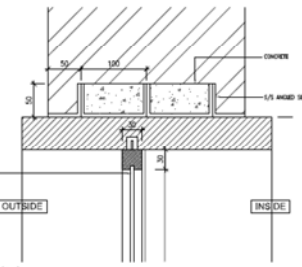


SECTION D–D'

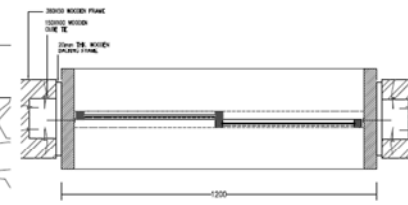
INTERNAL ELEVATION



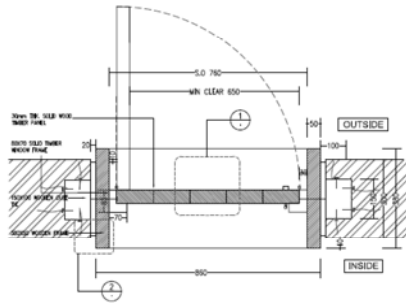
TOP COAT PLAN (1:20)



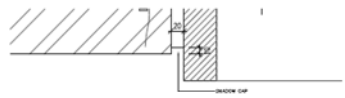
DETAIL 2 (1:4)



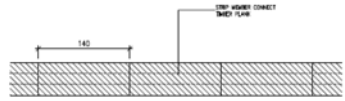
PLAN



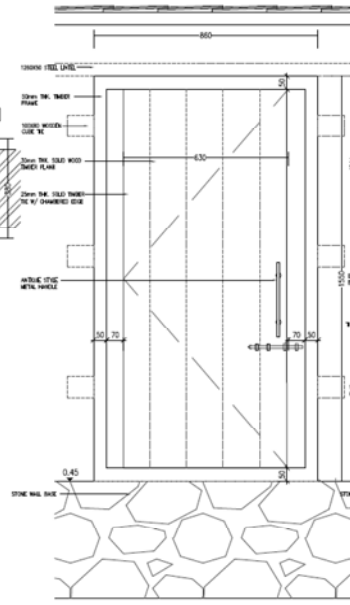
PLAN



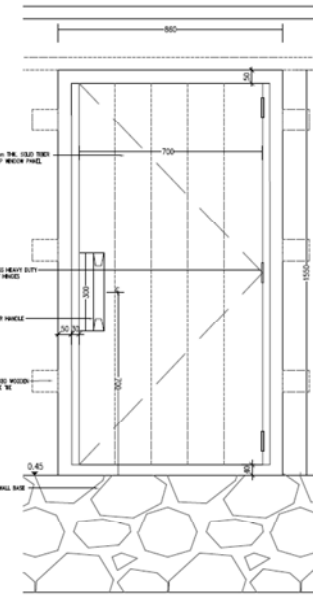
DETAIL 2 (1:4)



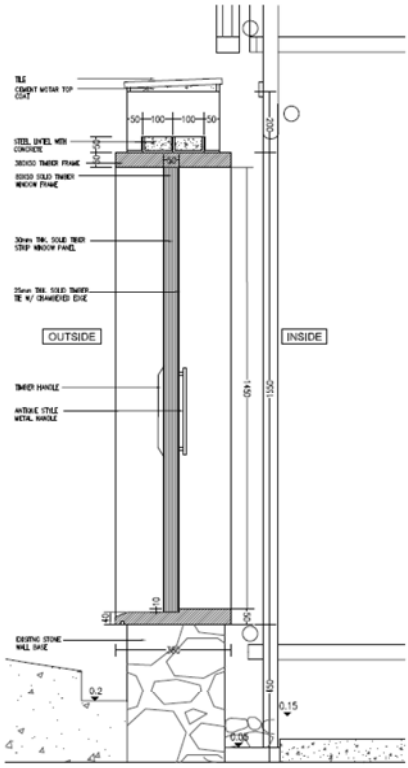
DETAIL 1 (1:4)



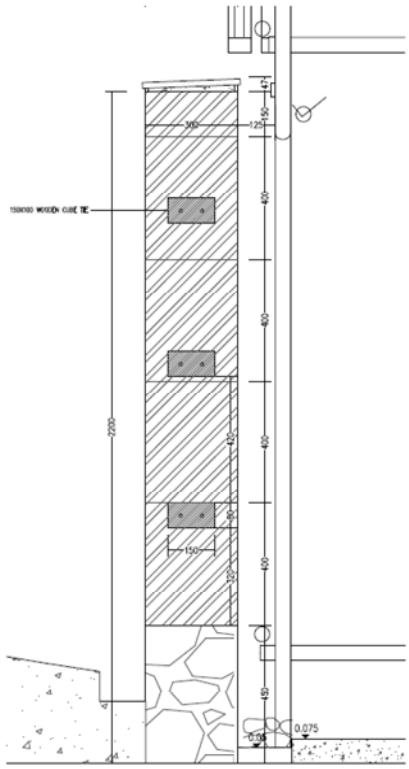
INTERNAL ELEVATION



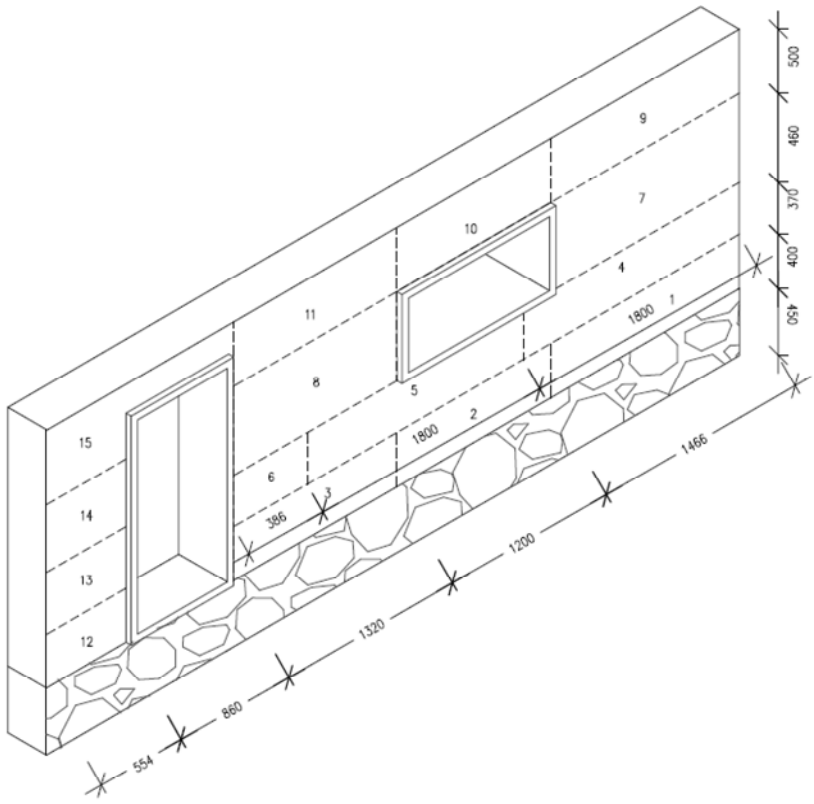
EXTERNAL ELEVATION



SECTION C–C'



SECTION E–E'



5 buckets of soil and 4 buckets of stones (each 11L)

Each layer (200mm height):
200h x 1800 x 300 = 135kg soil+ 14kg water (9 x 7L = 63000cm3
= 0.063m3)
= 150kg of soil-water mixture each time

Total amount of soil needed
Volume: 2.24m3
= 4800kg of soil mixture (2400kg stones + 2400kg soil)

Ram for 36 layers x 135kg soil mixture

6. Way forward in Mui Tsz Lam

6.1 Limitation

The logistics difficulty of the construction material was more than expected due to the remote locality of Mui Tsz Lam and the long and meandering narrow logistics path from Lai Chi Wo Pier to Mui Tsz Lam. The increased logistics cost incurred led to the higher construction cost.

Besides, the condition of the existing soil or stones found in MTL are not capable for making rammed earth soil, such as lack of viscosity. Therefore, a series of tactics had been adopted to improve the content of existing soil. For example, a certain amount of cement sand was mixed into the rammed earth soil to increase viscosity. Besides, the existing stones or gravels found in MTL are too big. This needs more processing time for crushing them into small pieces with a size suitable for rammed earth soil. To save time, certain amount of the gravels manufactured from factories is mixed into the rammed earth soil to speed up the progress of rammed earth wall construction.

6.2 Benefits and participation

Many stakeholders participated in the rammed earth wall construction and experiments, including: CUHK students, public volunteers, HKIC teacher and students, Mui Tsz Lam local villagers, experienced craftsmen and workers etc.

This rammed earth wall is just a first step of experimenting building earth wall in Mui Tsz Lam. With the experiences gain and the knowledge obtained, we hope to allow villagers and public to build more rammed earth walls together in Mui Tsz Lam village.

Participants	Benefits
CUHK students	- Have hands-on experience in earth architecture - Learn village history and culture - Communicate with villagers to know their needs
Public volunteers	- New experience and insight of rural village - To experience earth construction
HKIC teacher and students	- Provide and learn technical knowledge about earth construction and reinforcement - To build rammed earth wall and problem-solving experience out of school

Mui Tsz Lam local villagers	- Have new features in Mui Tsz Lam village - Provide trial and example for them to follow
Experienced craftsmen and workers	- Provide jobs for workers - Learn and cooperate with the project team and villagers
General Public	- Tour for the public to learn about the rural village and earth construction - Provide education to conserve and project Mui Tsz Lam village