MATERIAL ANALYSIS – EARTHEN CONSTRUCTION TECHNIQUES

ABSTRACT

Understanding material characterization is extremely important for implementing proper interventions; however there is a step between material diagnosis and treatment: suitability of the material—in this case the soil—to be used for the original construction of a particular site. The question,"Was this soil good for the construction of this site?," is a very important one in order to further understand material diagnosis and, particularly, causes of deterioration.

Even though the existence of historic sites can prove that soils are suitable to last for centuries, it is important to understand that the soil chosen for a particular technique was not made by chance. Most probably, ancient civilizations tried several techniques before perfecting the ones we know now. Furthermore, the occurrence of natural disasters also likely helped ancient peoples to modify and adapt the techniques to better withstand such disasters over time.

Soil suitability based on properties such as permeability, plasticity, compatibility, bulk density, among others, have been defined by engineers working mostly for road construction and design. These tables are far from appropriate for the analysis and understanding of historic soils and the correlation of them with ancient construction techniques. Recent studies, however, particularly for new construction, have provided useful information on the type of soil suitable for specific earthen construction techniques (Houben and Guillaud 1984).

Soils can be processed into twelve different states of hydration varying from solid to liquid: rocky concretion, friable concretion, solid concretion, friable aggregation, dry soil moist soil, solid paste, semi-solid paste, semi-soft paste, soft paste, mud, and slurry. In each specific state of hydration the soil can be workable as a monolithic, unit base or mixed structure. These three main construction classification systems are subdivided in twelve different construction techniques: dugout, earth-sheltered space, fill-in, cut-blocks, compressed earth, direct shaping, stacked earth, molded earth, extruded earth, poured earth, straw clay, and daubed earth. These construction techniques, as mentioned before, have likely evolved through time and are still in use in many countries around the world. Among those techniques, four are very common: adobe, rammed earth, cob, and wattle and daub.

The suitability of a soil for a particular application and its associated construction technique is determined by the combination of its: i) texture, mostly linked to particle size distribution; ii) hydration state, driven by the amount and the type of reaction to water at the molecular level; and, iii) its stabilization, which determines its resistance to erosion, compression, flexural stress, and other chemical and mechanical properties.

OBJECTIVES

As a result of this session, the participant should be able to:

- Classify and characterize soils by texture (organic, gravely, sandy, silty, and claley soils)
- Identify concrete, dry, humid, plastic, soft, and liquid hydration states of soils and how those are found in nature
- Build wet, plastic, humid, and compressed earthen molds using different types of soils and determine the water content of each
- Identify, describe and understand the main earthen construction techniques
- Build scale models using the most common earthen construction techniques
- Understand the relationship between the different states of hydration of the soil, the material characterization, and the type of construction for which it can be used

CONTENT

Field exercise:

The field exercise will introduce the subject of earthen construction techniques by demonstrating the relationships between the type of soil, water content, workability of the material, and molding type. The field exercise will be dived into three phases and one introductory session. During the introductory session the instructor will encourage student participation and emphasize the relationship of this session with the previous one (3.2 Material Analysis – In Situ and Laboratory Material Characterization).

1. Phase 1- Different soil states for different molding techniques:

    1. The instructor will then talk about the 12 hydrous states of soils and the suitability of each of them for different molding type[1]. The instructor should show samples of different type of soils encountered in nature through physical examples or images.

Rocky concretion:	Monolithic agglomerations of coarse material; compact and heavy earth difficult to cut.
Friable concretion:	Agglomerations of crumbly or decomposed material, including peat and sod, easy to cut.
Solid concretion:	Perfectly dry soil in large, solid lumps.
Friable aggregation:	Absolutely dry soil in powder form.
Dry soil:	Soil characterized by a naturally low humidity (4 to 10%); it is dry rather than moist to the touch.
Moist soil:	Soil unmistakably moist to the touch (8 to 18%), but cannot be shaped because of its lack of plasticity.
Soil paste:	An earthen ball (15 to 30%) which flattens only slightly when dropped from a height of one meter.
Semi-solid paste:	Slight finger pressure is sufficient to form an earthen ball (15 to 30%) which flattens slightly but doesn't disintegrate when dropped from a height of one meter.
Semi-soft paste:	Very homogenous material, easy to shape an earthen ball which is neither markedly sticky nor soiling (15 to 30 %) that flattens markedly without disintegrating when dropped from a height of one meter.
Soft paste:	Very adhesive and soiling (20 to 35 %), extremely difficult, if not impossible, to form balls.
Mud:	Saturated with water and forms a viscous, more or less liquid mass.
Slurry:	Suspension of clayey earth in water and constitutes a highly liquid, fluid binder.

    2. The instructor will then take a soil sample and describe each of the types defined in the previous sessions: organic, gravely, sandy, silty and clayley.

Figure 3.3.1 (left) and 3.3.2 (right)
Different soils being explained (left) and water added to soil samples(right) in different proportions to demonstrate the different hydrous states.
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[1] Houben, H. and Guillaud H. (1989). Earth Construction. A comprehensive Guide. Intermediate Technology Publication 1994:London. Pp 110-111

3. The instructor will add 8%, 12%, and 18% of water by volume to each of the soils samples. Using the 15 modified mixtures, the instructor should discuss each and choose 4 examples for wet, plastic, humid, and compressed molding, without revealing to the students the proportion of water added.
4. The instructor will prepare the 4 molds in front of the students and discuss i) the workability at the mixing stage; ii) molding; iii) unmolding; iv) the shape of the molded soil when fresh; and, v) the ease of transporting the mold.
5. As the molds take time to dry, the instructor should bring previously prepared dry molds for further discussion.
6. The students will then discuss the qualities of each of the sample mixtures used for molding.

2. Phase 2 - Students classification of the molding techniques:

1. Students will be divided into 5 groups and the instructor will assign a type of soil (organic, gravely, sandy, silty, and clayey) to each of the working groups.
2. Each group will add 8%, 12%, and 18% of water by volume to each soil type.
3. Each group will then use each modified mixture for 4 molding techniques, producing a total of 12 molds per group.
4. For each of the 12 molds produced, the students will take notes on i) the workability at the mixing stage; ii) molding; iii) unmolding; iv) the shape of the molded soil when fresh; and, v) the ease of transporting the mold.
5. Each mixture will then be characterized and classified according to the following chart:

Group	Type of soil – by texture	% water by volume	Wet	Plastic	Humid	Compressed
A	Organic	8%				
		12%				
		18%				
B	Gravely	8%				
		12%				
		18%				
C	Sandy	8%				
		12%				
		18%				
D	Silty	8%				
		12%				
		18%				
E	Clayey	8%				
		12%				
		18%				

6. If possible, prepare the table in a big open area and let students physically place their molds on the chart. Let the samples dry or bring pre-prepared samples to match each of the 60 molds produced by all the groups.

Figure 3.3.3 (left) and 3.3.4 (right)
Students preparing the molds (left) and molds placed on the chart (right)
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3. Phase 3 - Molding description and characterization:

   1. Students will record the shape and cracking patterns of each of the dry samples.
   2. Using some of the dry samples, the instructors and students will perform the following tests: i) flexural strength; ii) capillary rise; and, iii) resistance to erosion[2].


Figure 3.3.5 (left) and 3.3.6 (right)
Students performing flexural strength in-situ test (left)
and discussions about the performance of the different molds (right)
PAT course, 1999 © J. Paul Getty Trust

   3. Students will note the test results and, based on the tests and their experience with the material, discuss which mixtures are more suitable for each molding techniques.
   4. Lastly, the class will place a sign over the mold on the chart that best performed during testing and molding, defining the ideal correlations between molding techniques, type of soil and water content.

Classroom lecture:

1. The instructor will discuss the main earthen construction techniques and their relationships with different types of soils and states of hydration[3]. The instructor should provide samples of buildings for each of the techniques and explain the equipment needed to construct them.

   Dugout: Dwelling dug directly out of a layer of the earth's crust

   Earth sheltered space: A structure built of a material other than earth is encased and covered with soil

   Fill-in: Ungraded soil used to fill hollow materials used as a framework

   Cut-blocks: Blocks of earth are cut directly from the ground

   Compressed earth: Blocks or massive walls are formed by compressing soil in formwork molds

   Direct shaping: Thin walls built by direct manual shaping of plastic soil

   Stacked earth: Thick walls built by pilling balls of earth on top one another

   Molded earth: Pasty soil is molded by hand or molded in various shapes

   Extruded earth: A soil paste extruded by a powerful machine used to make building elements

   Poured earth: Liquid soil poured into formwork or molds Straw clay: Slurry consisting of clayey soil binds shreds of straw fiber to produce a fibrous material

   Daubed earth: Clayey soil mixed with fibers is applied in a thin layer to infill a support

2. At the end of the session, the instructor will provide pictures of the construction techniques, giving particular focus to those most commonly used in the region where the class is taught. The students will then discuss among themselves and place the pictures over the molds that they think are most suitable for the selected examples.

[2] For further information on how to perform the tests see: Houben, H. and Guillaud H. (1989). Earth Construction. A comprehensive Guide. Intermediate Technology Publication 1994:London. pp 135-137

[3] For further information on construction techniques see: Houben, H. and Guillaud H. (1989). Earth Construction. A comprehensive Guide. Intermediate Technology Publication 1994:London. pp 163-192

3. Each group will present to the class the conclusions of their observations and discussion will follow.

Second field exercise:

The second field exercise will be an opportunity for the students to obtain practical experience with the different construction techniques. It would be preferable to choose four techniques commonly used in the region where the class is taught. It would be also preferable to work with properly trained masons, able to demonstrate best practice to the students. For each construction technique, the students should build either complete scale models or sections. Lastly, the instructor should discuss the connections between the first field exercise and the actual activity of building a scale model.



Figure 3.3.7 (left), 3.3.8 (center) and 3.3.9 (right)
PAT instructor demonstrating adobe construction (left), students practicing rammed earth construction (center) and PAT instructor and mason working on a "quincha" model (right)
PAT course, 1999 © J. Paul Getty Trust

Selected images

Arg-é Bam Citadel, Iran 2003, Photographer: Jonathan Bell, ©J.Paul Getty Trust

Located in Bam, a city in the Kerman province of southeastern Iran, the Arg-é Bam Citadel was at one point the largest adobe building in the world. The image shows a local mason working on new adobes for its reconstruction before the 2003 earthquake that destroyed the Citadel.

Urubamba Valley in Cusco, Peru 2003, Photographer: Claudia Cancino, ©J.Paul Getty Trust

The people living in the Urubamba Valley in Cusco still use adobe as a primary construction technique. The strong red color of the soil mixture indicates a particular type of clay (probably smectite) and/or other minerals as part of the chemical composition. The image shows a local builder producing a series of adobes that will later be dried and used for building houses. In this region, the construction process is a comunal activity where a group of citizens work together to produce adobes that will be used later to build houses for the community.

Casona San Marcos in Lima, Peru 2003, Photographer: Claudia Cancino, ©J.Paul Getty Trust

The Casona San Marcos in Lima, Peru was originally built in 1605 as part of a Jesuist convent. A1746 earthquake destroyed most of the original construction and, a few years later, the convent was rebuilt using adobe for the first floor and quincha for the second floor. Mixing both construction techniques gave stabilization to the structure, creatingthick adobe walls at the bottom and flexible shear resistant wooden and mud pannels at the top. The image shows a 1767 construction detail of the quincha pannels from the second floor of one of the complex patios during restoration. Founded in 1769, first as the Convictorio de San Carlos,today the Casona de San Marcos is the Cultural Center of Universidad Nacional Mayor de San Marcos, becoming part of the University in 1861.

Road to Aït Benhaddoud, Morocco 2007, Photographer: Claudia Cancino, ©J.Paul Getty Trust

The Sub-Saharan region of Morocco possesses outstanding earthen architecture built with a mixture of rammed earth and mud brick construction. The image shows the type of frame typically used in the region to construct rammed-earthen walls.

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🕮 = Essential reading material

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