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A Comparative Analysis Between the Egyptian Code, Auroville Code and Brazilian Standards for Compressed Stabilized Earth Blocks/Bricks

Nermine Abdel Gelil Mohamed*, Nourhan Abdelhamid Abbas

Department of Architectural Engineering, October University for Modern Sciences and Arts (MSA University), 6th of October City, Egypt

Abstract

The awareness of constructing with compressed stabilized earth bricks (CSEB) as an appropriate technology in Egypt is increasing. The Department of Architectural Engineering at MSA University took the initiative of sending a group of students and staff members to Auroville Earth Institute in India to attend an intensive training on the production of CSEB; the University however has preferred to import a hydraulic motorized press machine from Brazil instead of the Indian manual one. In this context, this paper aims at analytically comparing and highlighting similarities and differences between The Egyptian Code for Building with Stabilized Earth, Production and Use of Compressed Stabilized Earth Blocks – Code of Practice of Auroville Earth Institute in India and The Brazilian specifications for Ecological Bricks. The comparison covers the following points: 1) Soil selection, 2) Cement stabilization, 3) Compressive strengths and water absorption requirements, 4) Production, 5) Stacking and curing, 6) Types of foundations, and 7) Allowed building heights. It was found out that Brazil requires fewer precautions for producing CSEB. Also it accepts more sand content in selecting the suitable soil and recommends sieving the sandy soil on a 4.75 mm mesh instead of 10 mm (Egypt and India), which is widely available in the Egyptian market. Moreover, calculating and measuring the ingredients following the Brazilian Standards is easier and more user-friendly, but not as accurate as the other two codes though. The required compressive strengths in Egypt and India are similar but are double the figures required in Brazil; and the percentage of water absorption is much higher in Brazil, reaching double the first two codes. This means that the bricks approved for construction withstands less load and humidity. Although the remarkably shorter curing period in Brazil would make the produced bricks weak and not durable, together with the fewer stacking stages make the Brazilian production more tempting to follow. One should take into account though that the reasons behind this short curing could be the higher cement content in the mixture, the less strict physical requirements and the use of hydraulic press machines, widely available in Brazil. Finally, Brazil (3 floors) stands in the middle ground between Egypt (2 floors) and India (4 floors) in terms of the allowed building heights; this is in case of building loadbearing walls with CSEB.

Keywords

Compressed Stabilized Earth Blocks, Egyptian Code, Indian Auroville Code, Brazilian Standards, ABNT, Cement Stabilization, Compressive Strength, Water Absorption

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1. Introduction

The awareness of constructing with compressed stabilized earth bricks (CSEB) as an appropriate technology in Egypt is increasing to the extent that an Egyptian code for it has been issued by The National Housing and Building Research Center (hereafter HBRC). The future potentialities of the material and building technique in reducing the use

* Corresponding author
E-mail address: ngelil@msa.eun.eg (N. A. G. Mohamed)

of fired bricks and concrete in Egypt are very strong. The Department of Architectural Engineering took the initiative of sending a team of students and staff members to Auroville Earth Institute in India (hereafter AVEI) to attend an intensive training on the production of CSEB using sandy soil which is available in huge quantities all over Egypt. Later, the University has imported a hydraulic motorized press machine from Brazil instead of the Indian manual one on which the team was trained. In this context, this paper aims at analytically comparing between "The Egyptian Code for Building with Stabilized Earth – Part One: Building with Compressed Earth Units (2016 Edition) [1] (hereafter the Egyptian Code), "Production and Use of Compressed Stabilized Earth Blocks – Code of Practice - Auroville Earth Institute – 2010" [2] (hereafter Auroville Code) and The Brazilian Association of Technical Standards [3] to [16] (hereafter ABNT or Brazilian standards). There is no compiled code in Brazil for building with CSEB; instead there are a group of Standards revised in 2012 [3] to [16] (for English resources on the ABNT see [18]). The comparison covers the following points: 1) Soil selection, 2) Cement stabilization, 3) Compressive strengths and water absorption requirements, 4) Production, 5) Stacking and curing, 6) Types of foundations, and 7) Allowed building heights.

2. Soil Selection

2.1. Soil Grain Distribution

Soils are composed of solid components, water and air. A soil contains gravel, sand, and, silt & clay which act as binders. The grain size classification adopted by a large number of laboratories is based on the ASTM-AFNOR Standards [2].

The Egyptian Code for Building with Stabilized Earth classifies the soil according to grain size, as shown in Table 1, into coarse, medium and fine gravel; coarse, medium and fine sand; coarse, medium and fine silt; and clay [1].

Table 1. Soil grain distribution according to the Egyptian Code. Source: HBRC (2016).

Gravel			Sand			Silt			Clay
Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine	
≥ 200	200 - 20	20 - 2	0.6 - 2	0.2 – 0.6	0.06 – 0.2	0.02 – 0.06	0.006 – 0.02	0.002 – 0.006	< 0.002

Auroville code classifies the soil according to the grain size in the same manner (based on the ISO 14688) but without detailed classification of each component, as shown in Table 2.

Table 2. Soil grain distribution according to Auroville Code. Source: AVEI (2010).

Pebbles	Gravel	Sand	Silt	Clay
200 to 2	20 to 2	2 - 0.06	0.06 - 0.002	≤ 0.002

The Brazilian Standards classify the soil grains according to ABNT [15], as shown in Table 3. While a 2 mm grain is considered the border line between gravel and sand in the Egyptian and Indian Codes, it is considered the border line between coarse and medium sand according to the Brazilian Standards. In addition, sand grain starts with a size of 4.75 mm in the Brazilian Standards while this is gravel according to Egypt and India.

Table 3. Soil grain distribution according to the Brazilian Standards. Source: ABNT (2012) NBR 16096.

Gravel		Sand			Silt	Clay
Coarse	Fine	Coarse	Medium	Fine		
75 - 19	19 - 4.75	4.75 - 2	2 - 0.425	0.425 - 0.075	0.075 - 0.002	≤ 0.002

2.2. Suitable Soil for Cement Stabilization

Not every soil is suitable for CSEB production. In general, topsoil and organic soils must not be used. Sandy soils are more suitable for cement stabilization while clayey soils are more suitable for lime stabilization. This is because Portland cement works as a binder between gravel and sand grains which creates an inert matrix restricts thus movement. It works less efficiently with silt and clay. Lime will also bind the grains of gravel, sand and silt, however, it is a weaker binder compared to cement. Lime is more suitable for soil with high clay content as it has a pozzolanic reaction with clay that creates chemical bonds between clay and sand [1-3] to [16]. As mentioned earlier, this paper is concerned with cement stabilization of sandy soil.

The suitable soil for CSEB production depends on the percentages of its components. The Egyptian and Indian codes are almost identical in their recommendations except for the gravel and sand ranges. Tables 4 & 5 show the suitable ranges and recommended percentages of gravel, sand, silt and clay for cement stabilization in both codes.

Table 4. Suitable soil contents, Egyptian Code. Source: HBRC (2016).

Range/Recommended	Gravel	Sand	Silt	Clay
Range	Gravel+Sand 40%-50%		Silt+Clay ≥ 25% ≥15%	≥10%
Recommended	15%	50%	15%	20%

Table 5. Suitable soil contents, Auroville Code. Source: AVEI (2010).

Range/Recommended	Gravel	Sand	Silt	Clay
Range	Gravel+Sand 45%-50%		Silt+Clay ≥ 25% ≥15%	≥10%
Recommended	15%	50%	15%	20%

The Brazilian Association of Technical Standards through its NBR 10832 and 10833 Standards establishes criteria for the selection of soils for use in the manufacture of soil-cement bricks (Table 6). It recommends the use of soils with 70% sand and 30%. However, up to 50% clay-silt content is acceptable and higher that 70% sand is also acceptable provided that the fine particles (silt + clay) are enough for bonding and bricks handling. If the soil is too sandy, handling trials are very important to determine the suitability of soil. One should not forget though that sand in the Brazilian Standards starts with particles as big as 4.75 mm, which are considered gravel in the other two codes.

Table 6. Suitable soil contents, Brazilian Standards. Source: ABNT (2012) NBR 10832 & 10833.

	Gravel	Sand	Silt	Clay
Range	-	50%-90%	Silt+Clay 10%-50%	
Recommended		70%	Silt+Clay 30%	

A comparison between the Egyptian, Auroville and Brazilian requirements of the suitability of soil for cement stabilization is shown in Table 7.

Table 7. A comparison between the Egyptian, Auroville and Brazilian requirements of the suitability of soil contents for cement stabilization.

Code	Range/Recommended	Gravel	Sand	Silt	Clay
Egypt	Range	40%-50%		≥ 25% ≥15%	≥10%
	Recommended	15%	50%	15%	20%
India	Range	Gravel+Sand 45%-50%		Silt+Clay ≥ 25% ≥15%	≥10%
	Recommended	15%	50%	15%	20%
Brazil	Range	-	50% -90%	Silt+Clay 10%-50%	
	Recommended	-	70%	Silt+Clay 30%	

In addition to the aforementioned requirements, the three codes mention other characteristics of a good soil for cement stabilization. While the Egyptian and Auroville codes specify recommendations for plasticity, liquid limit, Sulphate content, chloride content and organic materials, the Brazilian Standards mentioned neither the Sulphate nor the chloride contents (see Tables 8 & 9). Except for the plasticity, the Brazilian limits are higher than those of Egypt and India. This means that the requirements are less strict. A comparison is provided in Table 10.

Table 8. Suitable soil characteristics, Egyptian & Auroville codes. Source: AVEI (2010) & HBRC (2016).

Plasticity	Liquid limit	Sulphate content So4	Chloride content	Organic Materials
10% - 20%	20% - 30%	< 2%	< 1%	< 1%

Table 9. Suitable soil characteristics, Brazilian Standards. Source: ABNT (2012) NBR 10832 & 10833.

Plasticity	Liquid limit	Organic Materials
< 18%	< 45%	< 2%

Table 10. A comparison between the Egyptian, Auroville and Brazilian requirements of the suitability of soil characteristics for CSEB production.

Codes		Plasticity	Liquid limit	Sulphate content	Chloride content	Organic Materials
Egypt	India	10% - 20%	20% - 30%	< 2%	< 1%	< 1%
Brazil		< 18%	< 45%	-	-	< 2%

3. Cement Stabilization

As stated earlier, Portland cement works to bind grains of sand, so it is suitable for stabilizing sandy soils. When mixed with water, the calcium silicates in the cement undergo a chemical reaction. They crystallize and establish a matrix with the grains of sand and gravel in the soil, which limit movement, especially of clay [2]. The Egyptian and Auroville codes agree that an average of 5% cement by weight is recommended. Deciding the percentage depends on the tests performed on the soil but in general, 3% is the lowest percentage that can be used and from 8% to 10% is considered the economic maximum. A percentage higher than this is neither economic nor environmentally-friendly. If the soil is too sandy, 6% by weight of cement may be preferable, especially for handling fresh blocks as this will increase the cohesion. If the soil is not too sandy and has good clay content, 4% of cement could give good results too.

Regarding the cement content, the Brazilian Portland Cement Association [17] recommends the addition of 7%–14% of cement content by weight, depending on the soil type. It is worthy to say that the range is very wide and the limit is very high. It surpasses the cement content ratio in the concrete (which is about 13% by weight) and while it will never reach the strength of the concrete, it is extremely costly (see Table 11, for further details see [20, 21]).

Auroville code provides a detailed method for calculating the percentage of cement taking into consideration the density of soil. However, the Egyptian code didn't mention how to do so. Whereas In Brazil, most manuals use a simple method for deciding the cement's quantity: using only buckets. 8 – 12 buckets of soil are used for each bucket of cement.

Table 11. Percentage of cement as stabilizer in the mixture of CSEB. Source: AVEI (2010), HBRC (2016) & ABCP (1986).

Code	Range	Average
Egypt-India	3%-10%	5%
Brazil	7%-14%	-

4. Compressive Strengths and Water Absorption Requirements

Compressive strength is the most important factor influencing the suitability of CSEB for loadbearing walls constructions. Dry compressive strength is the resistance of a dry brick/block to breaking under compression. Wet compressive strength is the resistance of an oven dried sample (90°C for 24 hours) after being soaked in water for 24 hours (for further details on the tests performed to determine compressive strengths see [19]). Water absorption, which measure how much an oven dried brick/block (105°C for 24 hours) will absorb water after being soaked in water for 24 hours [2]. The Egyptian code classifies the CSEB according to the water absorption into Class A, B and C and its requirements are illustrated in Table 12. Dry and wet compressive strengths are also mentioned as required numbers for each class.

Table 12. Physical Requirements of CSEB according to the Egyptian Code. Source: HBRC (2016).

Characteristics	Class A	Class B	Class C
Water Absorption by weight%	8-10	10-12	12-15
Dry compressive strength Newton / mm^2	5-7	4-6	3-5
Wet compressive strength Newton / mm^2	3-4	2-3	1.5-2
Dry shear strength Newton / mm^2	0.5-1	0.4-0.8	0.3-0.6
Dry bending strength Newton / mm^2	0.4-0.6	0.3-0.5	0.2-0.3

Auroville code classifies the CSEB into Class A, B and C according to their wet compressive strengths. The physical requirements and characteristics in Table 13 are indicative to give an idea of the characteristics to be expected and are measured after 4 weeks of curing and 2 weeks for drying.

Table 13. Physical Requirements of CSEB according to Auroville Code. Source: AVEI (2010).

Characteristics	Class A	Class B	Class C
Dry compressive strength	5 to 7 Mpa	4 to 5 Mpa	3 to 4 Mpa
Wet compressive strength	3 to 4 Mpa	2 to 3 Mpa	1.5 to 2 Mpa
Dry bending (flexural) strength	0.5 to 1 Mpa	0.4 to 0.8 Mpa	0.3 to 0.6 Mpa
Dry shear strength	0.4 to 0.6 Mpa	0.3 to 0.5 Mpa	0.2 to 0.3 Mpa
Water absorption by weight	8 to 10%	10 to 12%	12 to 15%

The Brazilian Standards [16] set the limits in a very simple form as shown in Table 14. Dry compressive strength and water absorption are the only two physical requirements that are important. They require lower compressive strengths compared to Egypt and India: 2 Mpa (20kg/cm^2) and higher water absorption 20%, even higher than class C which has a water absorption proportion of up to 15%. It is important to mention however that, during the test, the area of the tested face is calculated differently. In the Egyptian and Auroville codes the compression force of the testing machine is calculated on the net area of the brick while in Brazil, the 2 Mpa (20kg/cm^2) represents the compressive strength of the hollow brick regardless of the two holes. If calculated on the net area, it would have been 24.5kg/cm^2.

Table 14. Physical Requirements of CSEB according to the Brazilian Standards. Source: ABNT (2012) NBR 10836.

Limit Values	
Compressive Strength in Mpa	≥ 2
Water Absorption	≤ 20%

5. Production

The production starts by sieving the soil, then preparing the mixture ingredients, dry and mixing, pouring the mixture in the press machine, and finally pressing the CSEB.

5.1. Sieving Sandy Soil

Almost all types of soils have to be sieved. According to the Egyptian and Indian codes, sieving a soil is necessary to remove gravel larger than 10 mm and most of the lumps. For sandy soils, sieving with a mesh of 10 to 12 mm is sufficient to loosen and aerate the soil. It is important to control the angle of the sieve because a very flat sieve will allow more coarse particles to pass through and a very vertical sieve will remove more coarse particles and the soil will be thinner. As mentioned earlier in the suitability of soil, a maximum of 15% of gravel or lumps shall be allowed through the sieve. If they are too many lumps or gravel, the sieve shall be laid more vertically. On the other hand, if more gravel is needed, the sieve shall be laid flatter [1, 2].

The Brazilian standard, on the other hand, requires sieving the soil with a mesh of 4 to 6 mm with the optimum size 5 mm; 4 to 6 mm is also an acceptable range. This is because, according to ABNT NBR 12023, 12024 & 16096 (2012) Standards, particles more than 4.75 are not allowed to pass (see 2.2 Suitable Soil for Cement Stabilization) [8, 9, 15]. Moreover, the sieve shall be laid with an angle of 45°.

5.2. Mixture Preparation

5.2.1. Measuring

Egyptian and Auroville codes agree that the volume of every container shall be known and all containers used for soil shall be filled to the top and levelled with a straight edge. The container should never be filled partially nor should it be overfilled. As for the cement, the 50 kg bag should be divided, once opened, into 3 or 4 buckets according to the needed mixture quantity (Figure 1). As a general guideline, 1/4 bag cement will need 4 buckets of 10 liters and 1/3 bag cement will need 3 buckets of 15 liters.

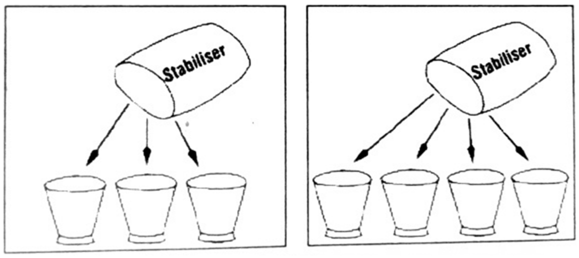

Figure 1. Dividing the 50 kg bag of cement into 3 or 4 buckets. Source: AVEI (2010).

In Brazil, the ingredients are measured differently. They are expressed by parts. For instance: 8-12 parts of soil to 1 part of cement (Figure 2). A part is usually one bucket with any volume [5-7].

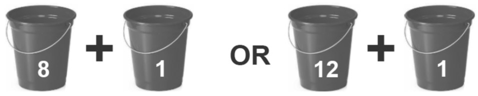

Figure 2. Cement soil ratio according to the Brazilian Standards. Source: ABNT (2012) NBR 10833 & ABCP (1986).

5.2.2. Mixing

The Egyptian and Auroville codes explain in detail the mixing process from dry mixing, wet mixing, and checking the moisture content. The Brazilian Standards [5, 6, 7] also explain the same steps, not in the same detailed manner however.

i. Dry mixing

The soil is first spread on a flat surface then the stabilizer is poured onto the soil and spread. Mixing is performed using shovels. The pile is then displaced gradually to an adjacent location; this step can be repeated twice to ensure that the mixture became homogeneous and has a uniform color (Figure 3).

Figure 3. Mixing process of CSEB ingredients. Source: AVEI (2010).

The Brazilian Standards didn't state the displacement of the pile, just mixing the pile in the same location till reaching uniformity (Figure 4).

Figure 4. Cement soil mixing according to the Brazilian Standards. Source: ABNT (2012) NBR 10833, NBR 11798 & ABCP (1986).

ii. Wet mixing

The three codes agree that because not every soil has same moisture content, it is not possible to measure the water quantity needed for the mixture; i.e. a quantity could be suitable for one mixture but not suitable for another mixture of same volume due to differences in moisture contents. It is therefore necessary to pour water onto the dry mixture gradually and uniformly by gently sprinkling it all over the pile.

Egyptian and Auroville codes recommend that the pile should be mixed by moving its location in the same manner as the dry mixing. Lumps of soil are crushed by pressing them on the pile with the palm of the hand. The mixture will be homogenous when it reaches a uniform color. The Brazilian code differs in this part. In addition to not mentioning the displacement of the pile, it recommends sieving the wet mixture using a wide mesh to make sure that all lumps are crushed. This is faster than pressing by hands. Making a test is indispensable to check whether the mixture reached the OMC (optimum moisture content). This is explained in the following part.

5.2.3. Checking the Moisture Content

Once the humid mixture is homogenous, a handful quantity is compressed and shaped into a ball by hand. The ball is then dropped from a height of 1 m onto a hard surface. If the ball breaks into 3-4 pieces, then the moisture content is fine. If the ball bursts apart in many pieces or into powder, then the mixture still needs water. If the ball does not break, in this case it became too wet (Figure 5).

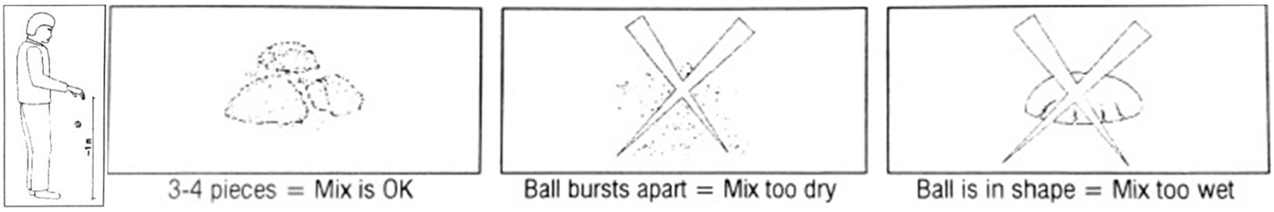

Figure 5. Checking the moisture content in Egypt and India. Source: AVEI (2010).

The test is performed differently in Brazil. Once the humid mixture is homogenous, a handful quantity is compressed into the hand. One should press it firmly by hand to compress it to a maximum. The shaped piece, which is not a ball, is cut it into two parts by the two hands. If it bursts apart in many pieces or into powder, more water should be added; if it is cut into two pieces, then the water content is fine (Figure 6).

Figure 6. Checking the moisture content in Brazil. Source: ABNT (2012) NBR 10833 & NBR 11798.

5.3. Pressing

Press machines are classified into manual and motorized. Although manually operated presses are widely used, motorized presses recently have been more and more used because of their higher productivity and easier operation. In all kinds of machines, the mixture is poured into a container that leads into a mold for being pressed. The capacity of the container, shapes and sizes of molds, the pressing method, etc., vary according to the machine type. In general, checking the consistency of the produced CSEB heights and their compaction degree is very important. Checking the height is performed using a caliper while for the compaction a penetrometer is used. A variation of ± 1mm is allowable.

6. Stacking and Curing

6.1. Initial Stacking and Curing

The requirements in Egypt and India are as follows (Figure 7). Immediately after pressing, the construction units should be manually transferred to an area with hard ground near the press machine taking care of the edges during transportation and ensuring that they are not exposed to any shocks that could lead to cracks or fractures. They are placed in long piles on top of each other with 7-8 units high and tight gaps (5 cm). Each batch is then covered with plastic sheet to prevent water evaporation for two days. On the third day, the units are uncovered and transported using a flat wheelbarrow to another place with hard ground or on pallets for final stacking and curing.

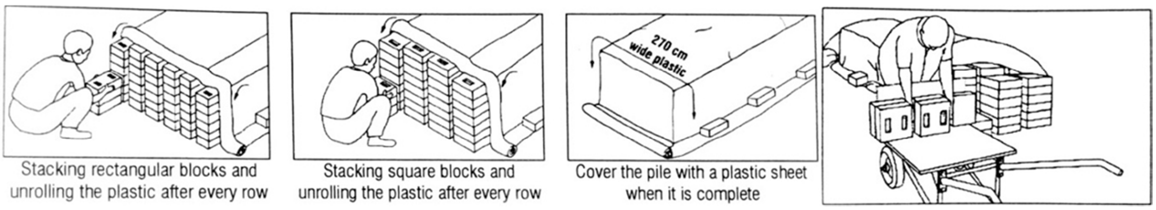

Figure 7. Stacking and moving CSEB according to the Egyptian and Indian codes. Source: AVEI (2010).

In Brazil the initial stacking and curing are quite different (Figure 8). Immediately after production, the bricks are stacked since the beginning on wooden pallets with a maximum height of one meter. Firstly, the freshly produced bricks are stacked up to half meter high simultaneously on several pallets; then the second half meter is stacked. The bricks are placed on their sides. Other method for initial stacking is to place the bricks in a staggered manner, also on the sides, so as to reduce the force on each brick. In this case each pallet is completed separately. The bricks should be then sprayed by water continuously for the first 3 hours with a light mist so as not to alter the texture of the bricks and ensure a slower and safer curing. They should be continuously sprayed for at least 3 days while covering them with plastic sheets.

Figure 8. Stacking and moving CSEB in Brazil. Source: ABNT (2012) NBR 10833, NBR 11798 & NBR 16096.

6.2. Final Stacking and Curing

According to the Egyptian and Auroville codes, the final stacking for curing starts on the third day after uncovering the units and transporting them to another place with hard ground or on pallets. The units are led on their sides above each other with a height of about 140 cm (according to the unit size). The units must be then covered with wet jute cloth and sprayed by water several times daily till the ending the final curing period, which is 28 days from the production day (Figure 9).

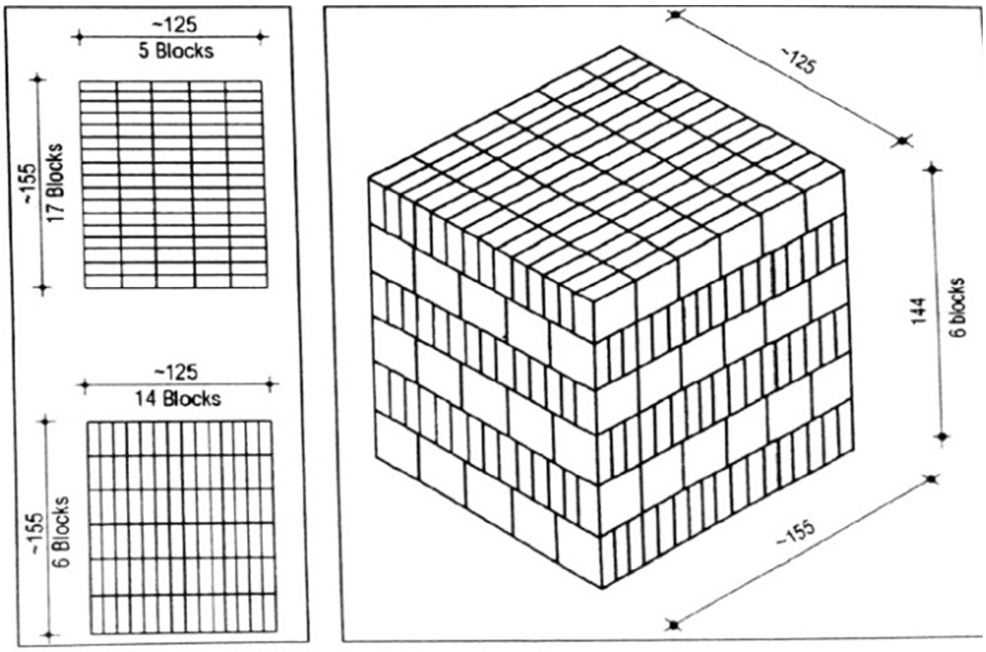

Figure 9. Final stacking, Egyptian and Auroville codes. Source: AVEI (2010).

In Brazil, this step is faster by 21 days. There is no need to transport the bricks as they are already stacked on pallets since the production (Figure 10), unless there is a lack of space. In this case the pallets are transported using a forklift. After seven days of continuous spraying and covering, the bricks can be uncovered and transported. Stacking could be then stacked in cubes to be transported to the construction site with the bricks put on their lower face instead of their side. The construction may start after 7 days because the bricks already gained approximately 65% of its strength;

however it is recommended to use them after 28 days because in general, CSEB with cement stabilization reach around 96% of their compressive strength after this period. The reason for this shorter period of curing is the lower compressive strength required by the Brazilian Standards and the higher cement content.

Figure 10. Final stacking, Brazilian Standards. Source: ABNT (2012) NBR 13555.

7. Types of Foundations

According to the Egyptian code, concrete strip foundations should be used. Their types, explained briefly below, vary according to the design requirements.

a. Strip foundation of stabilized soil (containing Portland cement not less than 7% of the total weight of the mixture) topped by a reinforced concrete beam or strip foundation.

b. Strip foundation from plain concrete, topped by a reinforced concrete beam or strip foundation.

c. Strip foundation from reinforced concrete topped by a plain concrete beam.

Auroville code, however, recommends stabilized rammed earth strip foundations as an economic and greener substitute to plain and reinforced concrete strip foundations. This technique can be used on constructions up to 4 floors high. On top of the stabilized rammed earth foundation, 4 stepped courses of CSEB are laid followed by a U-shaped CSEB (beam) in which reinforced concrete is casted (Figure 11).

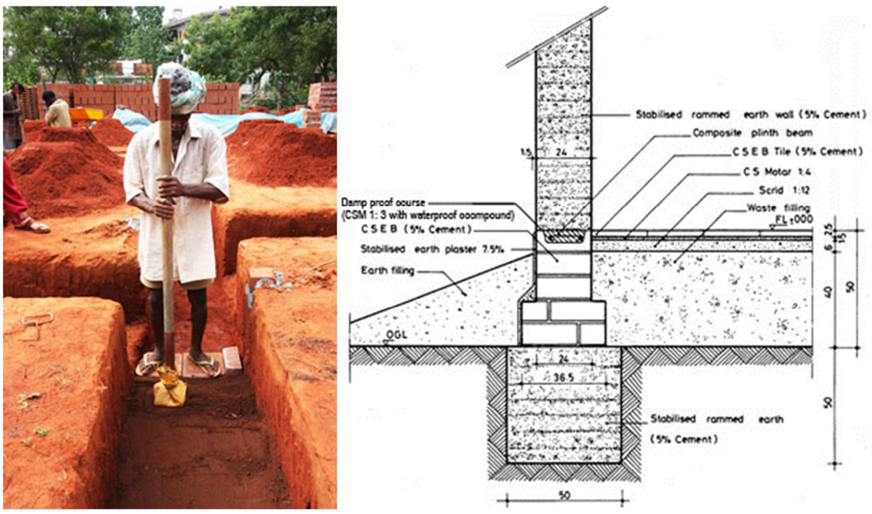

Figure 11. Stabilized rammed earth foundation, 4 stepped courses of CSEB and U-shaped CSEB (beam). Source: AVEI (2010) & www.earth-auroville.com.

In Brazil, ground reinforced concrete beams are very common for small-scale constructions with CSEB (Figure 12). In addition, the code stated other kinds of concrete foundations such as strip foundations and raft that could be used according to the building scale and structural calculations. Rammed earth foundations are not stated.

Figure 12. Ground reinforced concrete beams: right, cross section; left, after completion. Source: ecomaquinas.com.br.

8. Allowed Building Heights

The maximum building heights are 2 floors in Egypt, 4 floors in India and 3 floors in Brazil (see Table 15 & Figure 13). Although the required compressive strength in Brazil is lower than in Egypt, buildings higher by one floor are allowed. Moreover, it is remarkable that Auroville code permits up to 4 floors while using stabilized rammed earth foundation without reinforced concrete except for the RC used in the U-shaped CSEB fixed on top of it. This implies that the safety factor in Egypt is much higher.

Table 15. Maximum building heights when building with CSEB in Egypt, India and Brazil.

Code	Egypt	India	Brazil
Max. Building Height	2 floors	4 floors	3 floors

Figure 13. Example buildings showing maximum building heights. Left, India (Vikas community in Auroville); upper right, Brazil (apartment building in Natal RN Brazil); lower right, Egypt (experimental building at HBRC location).

9. Discussion

Producing stabilized compressed earth bricks manufactured in Egypt with sandy soil and stabilized with Portland cement using Auroville training experience with a Brazilian press machine imported by MSA University in Egypt was the main context that initiated the present comparative analysis between the Egyptian Code, Indian Code (Auroville) and Brazilian Standards. Soil selection, cement stabilization, physical requirements such as compressive strength and water absorption, production, stacking and curing, types of foundations, and allowed building heights were covered. Although The Egyptian Code is derived from the Indian Code, Egypt follows more detailed soil grain distributions and wider gravel and sand content range (40%-50%) for selecting a suitable soil. The Brazilian Standards, on the other hand, accept more sand content to select the suitable soil (up to 90%, recommended 70%). The mesh size recommended to sieve the sandy soil is completely different between the Egyptian and Auroville codes: 10 mm, and the Brazilian Standards: 4.75 mm. The latter is widely used in the construction sector in Egypt and known among workers as “Sand Mesh”. The determination of ingredients, while being not very accurate when following the Brazilian Standards, is easier and more user-friendly. As for physical requirements of CSEB, the Indian code classifies them into class A, B & C based on their wet compressive strengths whereas the Egyptian code classifies them based on their water absorption while keeping the same categories and needed numbers. The compressive strengths required by ABNT in Brazil are much lower, reaching half the other two codes, and water absorption is much higher, reaching double the other two codes. In Egypt and Auroville (India), stacking of freshly produced bricks/blocks is done on a straight hard floor and they are cured then for 28 days; in Brazil, on the other hand, they are stacked on wooden pallets and cured for 7 days only, which results in weaker bricks. This is due to the higher cement content and lower physical properties required by ABNT. While the three codes require strip foundations for this type of construction (loadbearing CSEB walls), they differ in their materials. The Egyptian code and Brazilian Standards state the use of combinations of plain concrete /reinforced concrete in the strip foundations, in addition to stabilized soil/reinforced concrete in the former (see 7. Types of Foundations). The Indian code recommends stabilized rammed earth foundation topped with CSEB courses and a U-shaped CSEB course filled with reinforced concrete. Regarding the allowed building heights, a higher factor of safety is followed in the Egyptian code which approves only 2 floors for loadbearing walls constructed with CSEB, versus 4 floors in Auroville. ABNT allows up to 3 floors. It is important to draw the attention to the fact that the required compressive strengths of blocks are not reflected in the allowed heights: the allowed height in India is double the allowed height in Egypt despite that the required compressive strengths of blocks are similar. In Brazil, while the compressive strengths of bricks are half the ones in the other two codes, a height of up to 3 floors is allowed.

10. Conclusion

This paper has analytically discussed and compared between three important codes and standards for building with stabilized compressed earth bricks manufactured with sandy soil and stabilized with Portland cement: the Egyptian Code developed by HBRC, the Indian Code (Auroville) developed by AVEI and the Brazilian Standards developed by ABNT. What has initiated this comparison was that the Department of Architectural Engineering at MSA University in Egypt took the initiative of sending a team of students and staff members to Auroville Earth Institute in India to attend an intensive training on the production of CSEB using sandy soil which is available in huge quantities all over Egypt. Later, the University has imported a hydraulic motorized press machine from Brazil instead of the Indian manual one on which the team was trained. The comparison covered soil selection, cement stabilization, physical requirements such as compressive strength and water absorption, production, stacking and curing, types of foundations, and allowed building heights. In general, ABNT requires fewer precautions for producing CSEB. Also it accepts more sand content in selecting the suitable soil and recommends sieving the soil on a 4.75 mm mesh, which is widely available in the Egyptian market. Calculating and measuring the ingredients is easier and more user-friendly. The required compressive strengths are much lower and water absorption is higher. Although the remarkably shorter curing period would make the produced bricks weak and not durable, together with the fewer stacking stages make the Brazilian production more tempting to follow. One should take into account though that the reasons behind this short curing could be the higher cement content in the mixture, the less strict physical requirements and the use of hydraulic press machines, widely available in Brazil. Finally, Brazil (3 floors) stands in the middle ground between Egypt (2 floors) and India (4 floors) in terms of the allowed building heights; this is in case of building loadbearing walls with CSEB.

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