EFFECT OF SEA WATER ON THE PROPERTIES OF COMPRESSED EARTH BRICKS IN MADAGASCAR

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ABSTRACT

During construction, water plays an important role in modifying the water content to facilitate the compaction process. Given the scarcity of water and even the drought that is currently raging in southern Madagascar, the possibility of using seawater, which is abundant in coastal areas, is an opportunity to be taken into account in the construction industry in order to preserve potable water for consumption. This experimental study was carried out to determine the effect of the intrusion of seawater in soil compaction operations, in view of its application in the fabrication of compressed earth bricks (CEB) in the coastal regions of Madagascar. Seawater for the study was taken from the eastern coast, and soil samples were taken from the southern coastal areas of the country. The mechanical behavior of CEB, including compression and water absorption, were tested. The results obtained were compared with those found with tap water which is considered as the reference water. The use of seawater did not have any detrimental effect during the compression tests; on the contrary, its presence resulted in a significant improvement in the resistance of CEB, especially in the stabilized state. Likewise, these bricks do not absorb more than 15% of water or seawater. It was concluded that seawater could be a good stabilizing agent, especially when construction works are close to the sea.

Keyword : *Absorption coefficient , Cement, Compressive strength, Sand, Sea water and tensile strengh*

1. INTRODUCTION

Earth, which is a natural raw material, does not require major energy expenditure when it is used in construction. It is always accompanied with water to provide the necessary humidity for the laboratory and to allow it to be mixed with other materials. However, water is sometimes difficult to find in some countries. During the COVID-19 pandemic, which caused a health crisis in the world, water problem was mainly observed in Africa: in the fight against this pandemic, some people had difficulties finding water just to wash their hands. In Madagascar, according to current statistics, more than 50% of people are deprived of basic access to water. It is the southern region of the country that mainly faces water supply problems. Thus, the difficulty of access to water only increases construction costs in certain regions of Madagascar while the country, which is bordered by the Indian Ocean, is surrounded by seawater. In the world, many studies and achievements have been made regarding the use of seawater in road soil compaction works, but little data is available on the effects of salt water on the mechanical parameters of soils. A particular attention is therefore turned to the use of seawater to replace running water in the construction of compressed earth bricks (CEB) in the southern regions. In other words, the main objective of this study was to promote seawater by studying the possibility of its use as composition water for compressed earth bricks in the southern coastal zone of Madagascar.

1.1 Methodology

The observation of the effects of the use of seawater in the manufacture of compressed earth bricks (CEB) was undertaken to determine the mechanical properties of these CEB, namely compressive strength, tensile strength, and absorption. Indeed, the first quality of a building material is to resist the effects, first of all, of their own weight, and then of the loads that they support without deforming. Moreover, compressive strength and tensile strength are of interest to researchers (Öztürk H. and Ayvaz Y., 2002) because of their importance for construction.

The experimental study consisted of studying the effect of water salinity on the properties of compressed earth bricks in Madagascar, in terms of compaction of soil materials, in order to determine its influence on resistance measurements: resistance compression, traction, and water absorption. The methodology included collecting soil and seawater samples at the desired locations. Tap water from the soil mechanics laboratory was used as the reference water.

Then, the experimental research part of the assessment of the different technical properties of compressed earth bricks was carried out using both tap water and seawater. Finally, the results found were compared to analyze the changes that seawater has brought to the properties of compressed earth bricks, not only in the natural state but also in the stabilized state. Using a machete, they were collected in plastic bags and sent to the laboratory for testing to determine their identifying characteristics :

- Initial water content (NF P 94-050)
- Specific density (NF P 94-054)
- Grain size analysis by sieving (NF P 94-041)
- Grain size analysis by sedimentometry (NF P 94–057)
- Atterberg limit (NF P 94-051)
- Sand equivalent (NF P 18-598)
- Methylene blue value (NF P94-068)

The fabrication of compressed earth bricks is described by standardization XP P 13-901. The bricks were molded in a cylindrical shape at a standard dimension of slenderness 2 and the process was carried out identically and consecutively for the sample treated with tap water and the one mixed with seawater in all the test pieces. In order for the seawater salts to react with the soil, a reaction time of at least 7 days, which is essential for drying, was given to the test pieces before they were crushed. It should be noted that the samples of compressed earth bricks manufactured were kept for 7 days in a cold room characterized by its hydrothermal properties, that is to say by regulated temperature and humidity, and the rest of the drying time is to expose the test pieces to the open air and even to the sun.

The location of the study areas where the soil samples were taken is shown in the figure 1.

Fig -1: Location of study areas

1.2 Materials used

- Water :

There were two types of water used in the composition of natural and stabilized soil mixtures for brick making: tap water and seawater. The tap water from the LNTPB laboratory was considered as the reference water in order to compare the results obtained with those of seawater.

The seawater was taken in Tamatave, in the eastern part of Madagascar, placed in closed containers and stored in the laboratory at room temperature. It was mixed successively with the clay bricks of the soil samples before being compressed with a LNTPB hydraulic press. The two types of water were tested in the chemical laboratory of LNTPB to provide possible data for the comparison, the results of which are given in the table 1. Note that the ionic concentrations are expressed in mg/kg.

Table -1: Chemical analysis of the types of water studied

Type of water	pH	Ca^{++}	Na^{+}	Mg^{++}	SO_4^{--}	SO_3^{-}	Cl^{-}	Dissolved salts
Tap water	6.8	2.95	-	-	1.52	0.18	-	4.65
Sea water	6-7	417.26	4566.98	1312.25	2 914.53	-	20 620.53	30 741.55

The table 1 shows that tap water, delivered at a temperature of around 22 ° C depending on the time of year, contained little sulfate while sea water contained cations in large quantities which can undergo a cationic exchange with the ions of the double layer of the clay mineral and thus cause various changes. The dissolved mineral (salt content) of seawater taken in the eastern part of Madagascar considered in this study was of 30,741.55 mg /L, or approximately 31 g/L. Its pH was between 6 to 7, which means that it has an acidic character as a result of discharges linked to human activity, since it was taken in a confined port area.

- Soils :

To study the effect of salinity on the mechanical parameters of CEB, this study used two soil samples from southern coastal areas of Madagascar. The samples were taken, as shown in the figure 1, in Toliara (South West) and Manakara (South East). The Toliara sample consisted mainly of sandy loam soil, while that of Manakara was lateritic soil. Using a machete, they were collected in plastic bags and sent to the laboratory for testing to determine their identifying characteristics.

- Cement :

Lafarge CEM II / AL 42.5 cement was used for the stabilization of the bricks of the Toliara sand-silt sample because the cement acts mainly on the sand and also because it is the cement that withstands the most in construction works at sea. The properties of the cement were determined according to the standard and the results obtained are given in the table 2.

Table -2: Properties of cement

Properties	Values		
	2 days	7 days	28 days
Compressive strength (MPa)	26.2	38.5	47.7
Tensile strength (MPa)	4.1	5.2	6.1
Initial setting time (h)	3.8		
Final setting time (h)	4.9		
Specific density (T/m^3)	2.98		
Apparent density (T/m^3)	0.96		
Specific surface area blaine (cm^2/g)	3804		
% of mixing water	27.4		

- Sand:

When we have samples of soils with enough clay material or when we want to have more resistant earth blocks, the granulometric correction, apart from the addition of a hydraulic binder, is also one of the methods of stabilizing the soil. Stabilization by increasing the sand concentration concerned the lateritic soil sample from Manakara. The choice of sand was based on the fact that this soil sample contains enough clay material.

In order to study the influence of seawater use on stabilization, two sand contents were adopted: 5% and 10% of the soil weight, and these quantities were respectively for fine sand of Fort Dauphin and coarse sand from Toliara. Their characteristics were collected in the results of geotechnical characteristics of soil samples according to the Table 4.

In order to facilitate reading, the following coding system was adopted for the soil samples considered in the study which are:
- the type of soil from Toliara consisting mainly of sandy loam soil is codified by SL-T, which corresponds to the first letter of the names of their elementary constituents and that of the place of origin
- the type of lateritic soils from Manakara is designated by LAT-M.

Then, in the case of soil stabilization, the coding system for soil samples is retained but stabilization is marked by adding the first letter of the constituent used in the mixture and an index number which represents the rate in percentage of dry weight contained in the mixture.

Table -3: Designation of codifications

Codification	Designation
SL-T-$C_{1,5}$ and SL-T-C_2	Sandy loam soil of Toliara stabilized respectively by adding 1.5% and 2% of cement
LAT-M-SF_5 and LAT-M-ST_{10}	Manakara lateritic soils stabilized respectively by the granular addition of 5% of Fort Dauphin sand and 10% of Toliara sand

2. RESULTS

The basic properties of the 4 soil samples taken as well as the 2 sands added to the mixtures considered, from various laboratory tests, are summarized in Table 4 and the particle size distribution is illustrated in Figure 2.

Table -4: Properties of soil samples

Properties	SL-T	LAT-M	S-T	S-F
Specific density (g/cm^3)	2.73	3.02	2.79	2.74
Initial water content (%)	4.8	12.2	0.8	0
Methylene blue value VBS (g/100g)	1.6	0.6	0.3	-
Sand equivalent (%)	61	-	77	91
Granulometric analysis results				
Percent fines (< 80 µm)	37	59	5	3
% of gravel	8	12	4	-
% of sand	61	60	88	97
% of silt	-	20	-	-
% of clay	-	8	-	-
Atterberg Limits				
Liquid limit (%)	31	33	-	-
Plastic limit (%)	19	20	-	-
Plasticity index (%)	12	13	-	-
Classification of samples				
GTR classification	A1	A2	B2	B1

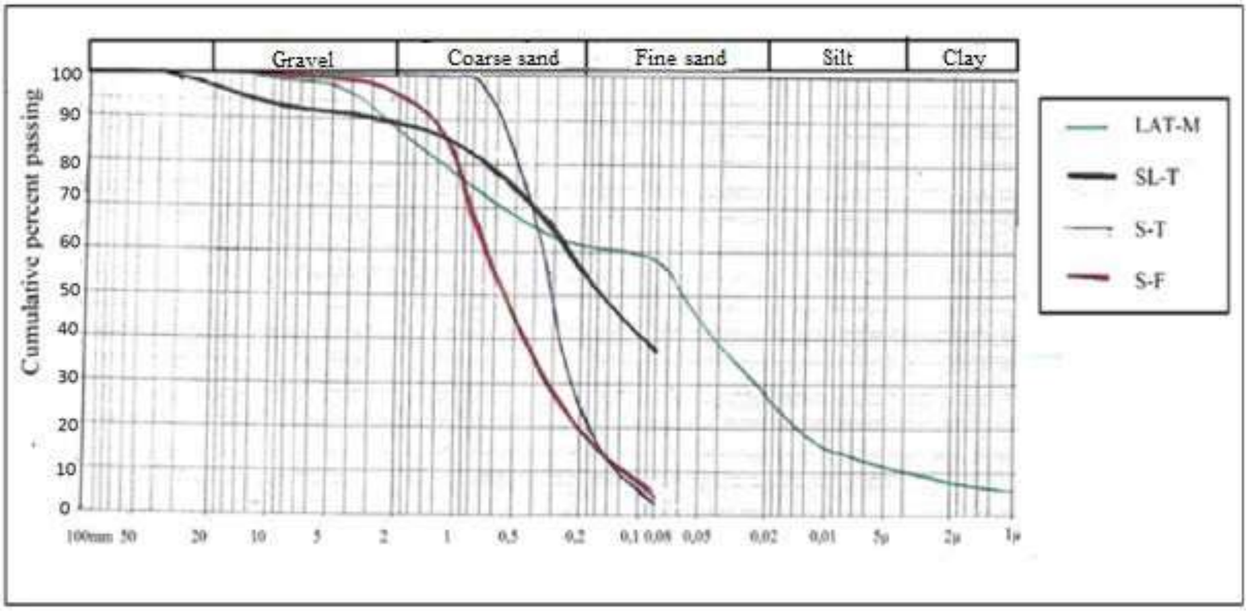

Fig -2: Grain Size Distribution

2.1 Effect of seawater on CEB compression tests

Compression tests are the most common test used to determine the characteristic properties of soil. were carried out on the two soil types compacted to optimum water content and there after molded to a cylindrical shape of dimensions approximately 8 cm diameter and 16 cm height. The results obtained, by using sea water are shown in Table 5, 6 and 7.

Table -5: Comparison of the compressive strength between SL-T mixed with tap water and then mixed with seawater treated with or without stabilizers

Soil type	**SL-T**		**SL-T-$C_{1,5}$**		**SL-T-C_2**	
Drying time	9 days		15 days		17 days	
Compaction stress (KN)	30		60		60	
Constituent water	**Tap water**	**Sea water**	**Tap water**	**Sea water**	**Tap water**	**Sea water**
Density (g/cm^3)	1.98	1.98	1.97	1.93	2.01	2.03
Charge (N)	9 10^3	9 10^3	12 10^3	14 10^3	25 10^3	32 10^3
Compressive strength(MPa)	1.8	1.8	2.4	2.8	5.0	6.4

Table -6: Comparison of the compressive strength between LAT-M mixed with tap water and then mixed with seawater treated with or without stabilizers

Soil type	**LAT-M**		**LAT-M-S_5**		**LAT-M-S_{10}**	
Drying time	9 days		9 days		9 days	
Compaction stress (KN)	30		60		60	
Constituent water	**Tap water**	**Sea water**	**Tap water**	**Sea water**	**Tap water**	**Sea water**
Density (g/cm^3)	1.92	2.02	2.06	2.20	2.15	2.21
Charge (N)	$12\ 10^3$	$14\ 10^3$	$17\ 10^3$	$27\ 10^3$	$25\ 10^3$	$28\ 10^3$
Compressive strength(MPa)	2.4	2.8	3.4	5.4	5.0	5.6

Table -7: Comparison of the tensile strength of soils mixed with tap water and then mixed with seawater treated with stabilizers

Soil type	**SL-T-C_2**		**LAT-M-SF_5**		**LAT-M-ST_{10}**	
Drying time	9 days		18 days		13 days	9 days
Compaction stress (KN)	60		60		60	
Constituent water	**Tap water**	**Sea water**	**Tap water**	**Sea water**	**Tap water**	**Sea water**
Density (g/cm^3)	2.0	2.10	2.05	2.11	2.12	2.21
Charge (N)	$3\ 10^3$	$5\ 10^3$	$5\ 10^3$	$10\ 10^3$	$6\ 10^3$	$8\ 10^3$
Tensile strength(MPa)	0.15	0.24	0.25	0.50	0.31	0.41

2.2 Effect of seawater on BTC absorption tests:

Note that the BTC water absorption test was intended to determine the amount of water absorbed by capillary action. The purpose of this absorption test was to compare the penetration of running water with that of sea water for a test piece compacted with sea water, while referring to the reference sample which is compacted with tap water. The test specimens were stored in the same way as those used to measure simple compressive strengths. However, after placing them in the cold room by adjusting the humidity and keeping the temperature constant for 7 days, they were dried in the open air, and were even exposed to the sun. Then they were dried in an oven until a constant mass was obtained before being immersed in a container with a water level of about a quarter of the test tube.

The results of the capillary absorption tests of the specimens with the best strengths are shown on the following figures:

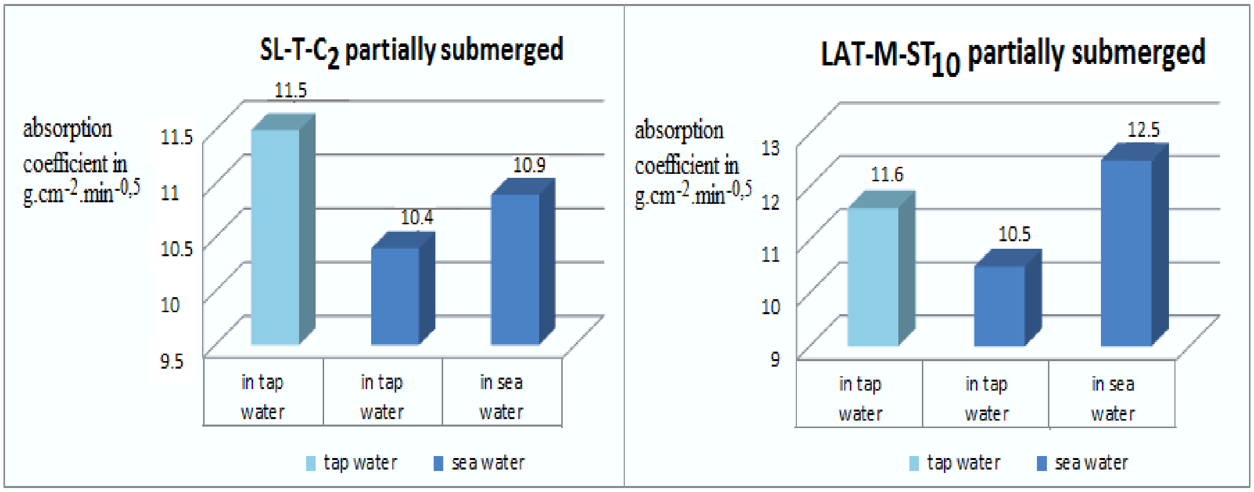

Fig. -3 : Comparison of the absorption coefficient of test pieces compacted with tap water and seawater and then partially immersed in tap water and seawater

3. DISCUSSION

The purpose of geotechnical studies (table 4) is to characterize the nature of the soil materials and thus adapt the construction project accordingly. Indeed, from the point of view of granularity, the maximum dimension of the largest elements contained in the two types of soil was less than 50 mm while the proportion of the fine elements of the fine particles, which corresponded to the sieve of 80 µm, was all greater at 35%. According to the guide for a classification of road materials [GTR], the two samples studied are classified in the category of fine soils A. However, the sand equivalent of the SL-T sample confirms the significant percentage of sand in its constitution. In terms of clayey, soils belong to the medium clay class 12 < Ip < 25.

3.1 Effect of seawater on CEB compression tests

It is found from the tables 6 and 7 that using the 30 KN compaction stress, the presence of salts in seawater for the composition of the soil mixture does not show a significant difference in the values of the simple compressive strengths of SL-T and LAT-M. In the case where the compaction stress is multiplied by two, and there is also the stabilization of the bricks whether by adding cement or sand according to their respective proportion, the results quickly brought to the material the resistance that characterizes it. However, this time, the value of the resistance of the cylindrical bricks obtained with the use of seawater, whether in compression or in traction, still exceeded the one that was found with the tap water.

It can be noted that in addition to the amount of sand incorporated into the soil LAT-M, the mechanical strength was influenced by the use of seawater in their composition. The sea water resulted an increase in mechanical resistance compared to the use of tap water (table 6). For the case of LAT-M-SF_5, it took twice the splitting tensile strength obtained from using tap water to break with sea water (table 7). In addition, it could be observed that the density values of the test pieces compacted with seawater clearly exceeded those compacted with running water.
Indeed, according to the general appearance of the test pieces produced, the presence of pores was more remarkable on the test piece produced with running water, even if the overall condition of the parts was acceptable. Thus, it can be said that the incorporation of seawater into the bricks contributes to reducing the porosity of the material and therefore to increasing its compressive strength.

It should be noted that the use of seawater in the composition of SL-T enriched with 2% cement led to a significant increase in compressive strength compared with 1.5% cement, from 2.8 to 6.4 MPa, an increase of about 130%. The results from the published literature are also similar with those of the present work. Borgne (2010) [10] studied, in part of his research, the influence of the presence of NaCl salts on the compressive strength tests of the sand mixture with the addition of 6% cement. He found that there was an increase in compressive strength when the NaCl level considered in his study was high. The studies of Georges (2014) [8] also gave a high resistance when using salt water from the Atlantic Ocean in the respective mixtures of clay soil and clay sand ion of salt water in their respective mixtures (going respectively from 30kN/m^2 to 57 kN/m^2, and from 40 kN/m^2 to 63 kN/m^2) compared with tap water. The high resistance obtained with the use of salt water is due to the clay's sensitivity to salt water. Indeed, clayey soil has several layers of gibbsite and silica sheets with hydrogen bonds connecting these sheets, it is reported by Dunn, 1980 [3]. During axial compression, these sheets come closer to each other and the tendency of these sheets to resist compression is high. The increase in resistance could also be the result of a chemical reaction between the salt molecules and soil particles: sodium, potassium and magnesium chlorides in salt react with calcium oxides and hydroxides in soil to form calcium chloride, which hardens the soil and increases the dryness of the unit weight, it is reported by Lopez and al 2001 [6], Emil and William 1990 [5] and Emil 1962 [4].

In this case, a marked improvement in the compressive strength was observed. In other words, the presence of the dissolved salts of sea water in the material does not deteriorate the plastic properties of the paste. On the contrary it makes more cohesive and less porous this plastic properties and thus reinforces the mechanical properties of the bricks obtained. To obtain this better resistance, it can also be attributed the duration of maturity of the specimen before crushing. The resistance obtained over 17 days was relatively high with the use of seawater.

3.2 Effect of seawater on BTC absorption tests

According to the figure 3, the absorption coefficient by capillarity of soils stabilized by the addition of sand or cement showed a significant decrease during treatment with seawater (in the compaction and immersion of the bricks) except for the case of LAT-M.

There was a slight increase in the water absorption coefficient with the partial immersion in sea water, of the LAT-M specimen stabilized with 10% coarse sand and compacted with sea water.

The specimens stabilized with the cement, made from SL-T and compacted with seawater absorbed weakly both water and seawater. This observation can be attributed to the values of their simple compressive strengths which are the better resistance. It is found that the use of seawater has little influence on the absorption coefficient, just like the results obtained by Borgne [9]. The absorption rate can be further reduced if, whatever the water used, the cement, mixed with the material of constituting the test pieces, has time to complete setting and hardening to fill the inter-granular voids.

The water absorption coefficient by capillarity of all the test pieces being less than 20 g.cm^{-2}.min$^{-1/2}$, they are qualified as weak capillary blocks whatever the compaction water used in the composition mixture.

It can be said that the porosity accessible to water decreases with the increase in the sand content and also with the use of seawater. The results are consistent with those found by Hachichi and Fleureau [1], who showed the swelling of a clay immersed in solutions loaded with different salts. The authors showed that adding chloride salt reduces the swelling of a clay by half when sodium chloride was used. This is also what was found by Lamara, M. K. Gueddouda and B. Benabed [7] who studied the effect of salt on the swelling parameters of clays taking into account the different concentrations of the saline solution. They found a significant reduction in the swelling potential by increasing sand and also by high concentration of saline solution. Saline water, in particular sodium chloride, is considered as a setting accelerator when using cement and also as a reducer of swelling potential.

4. CONCLUSIONS

The aim of this study was to see the effects of seawater intrusion on the properties of bricks. Based on a systemic experimental study of the compaction characteristics, the following conclusions can be drawn.

The use of seawater, compared to tap water, had no effect on the compression tests of bricks in their natural state for a compaction stress of 30 KN. On the other hand, it increased the mechanical resistance of CEB in the stabilized state. The significant improvement in compressive strength was found to be significant with the addition of 10% sand for the lateritic soil of Manakara, and also the addition of cement at only 2% for the sandy loam soil of Toliara. The value increased respectively 2 and 3 times higher than that of soils in their natural state and treated with tap water. This is due both to an increase in dry unit weight and to chemical reactions with seawater or to some cementing action of the salts in the soil. It appears that this better result corresponds to the increase of the compaction stress (60 KN) and the drying time of the compressed earth bricks. The same for the result found with the absorption coefficient, the stabilized compressed earth bricks absorb weakly with the use of sea water.

Based on the published literature and the results of this study, it can be concluded that the results obtained present an economic advantage and encourage the use of seawater in construction projects of CEB.

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