

Geotechnical Study and Determination of the Chemical and Mechanical Characterization of Clay Taken from the Gaoui Pottery Area Stabilised by Gum Arabic

Abdallah Ban-Nah Mahamat^{1,*}, Ali Abakar², Mahamat Barka³, Abraham Tetang Fokone⁴,
Abdallah Dadi Mahamat¹, Salif Gaye⁵

¹Mechanical Engineering Department, National Higher Institute of Sciences and Techniques of Abéché, Abéché, Chad

²Building and Public Works Laboratory, National School of Public Works, N'Djamena, Chad

³Faculty of Exact Sciences, University of N'Djamena, N'Djamena, Chad

⁴Department of Sciences and Technology, National School of Agro-Industrial Sciences University of Ngaoundéré, Ngaoundéré, Cameroon

⁵Materials, Energy, Electricity and Economy Laboratory, Institute of Technology, University Iba Der THIAM of Thies, Thies, Senegal

Email address:

addibannah@yahoo.fr (Abdallah Ban-Nah Mahamat), koudouri2019@gmail.com (Ali Abakar),
Mahamat.barka@gmail.com (Mahamat Barka), abramtetang@yahoo.fr (Abraham Tetang Fokone),
abdallah.dadi@univ-thies.sn (Abdallah Dadi Mahamat), sgaye@univ-thies.sn (Salif Gaye)

*Corresponding author

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Abstract: Clay has always been used by our ancestors for the manufacture of rudimentary pottery. Nowadays, the use of this material is experiencing a resurgence in the field of construction because of its availability, its abundance and its shaping requiring little energy. Clay materials are abundant, and the current trend is to build with sustainable, environmentally friendly and less energy-consuming materials by combining them with additives for stability. The geotechnical study includes particle size analysis, Atterberg limits, methylene blue tests and normal Proctor tests. The simple compressive strength of compressed clay bricks stabilized with acacia seyal gum arabic was determined. The experimental results show that the soil studied is too fine, with 97.732% passing through the 80 μm sieve, with 65.3% clay, 32% silt and only 2.7% sand, optimum moisture content of 18.6% and dry density of 1.66 determined by Normal Proctor test. The physico-chemical analysis shows that silica (SiO_2) is dominant, followed by iron oxide (Fe_2O_3) with respective percentages of 67.94 and 12.75. Finally, the addition of gum arabic improved the mechanical strength of this plastic type clay. It went from 3.14 MPa for 100% clay to 4.25 MPa for 8% gum arabic an increase of 35%.

Keywords: Clay, Gum Arabic, Geotechnical Study, Physico-Chemical Characteristics, Mechanical Characteristics

1. Introduction

The energy costs associated with the construction and especially the operation of buildings are among the highest of all sectors of human activity. One of the possibilities is the use of compressed raw earth, a local material whose shaping requires little energy, it can be fully recyclable [1]. The earth material can provide an effective response to the problems that constructions encounter in terms of societal, economic

and ecological issues. The development of sustainable building practices is therefore essential, not only to comply with the current objectives of reducing greenhouse gas emissions, but also to limit energy consumption at the scale world [2].

The cost of conventional materials, known as modern materials, plus the cost of transporting them, puts a strain on the budget, not to mention the waste and costs associated with building, not to mention the waste and pollution they

generate. These economic constraints, combined with a concern to protect the environment, are leading us to consider the use of raw earth as a building material [3]. Soil is the first building material used by man, widely available and energy-efficient. In fact, around 30% of the world's population today lives in earth structures, and in developing countries this figure rises to 50%, mainly in rural areas [4]. Certain natural materials, which are still poorly understood, can reduce the energy costs of buildings through better insulation, thereby helping to protect the environment [5].

The choice of local materials such as clay and gum arabic is not accidental, as the country has an abundance of them. These materials are mixed in a given proportion. The main objective is to experiment with new local building materials that are economical, ecological and comfortable, with limited durability but recyclable.

2. Material and Methods

This section describes the materials used and the methods for assessing chemical elements and mechanical strength. It is essential to identify the soil before determining the latter, hence the identification study.

A. Gum arabic

Gum Arabic is derived from trees that are well adapted to the African ecosystem. Gum has a wide range of properties and uses in Western countries, and is an essential component of many everyday products and foods. Sudan accounts for 80% of production. Europe remains the main importer, followed by the United States, Japan and India. The future of gum is promising, and could benefit from both significant developments in the agri-food industry in Western countries and changes in consumer habits [6].

Gum is the country's fourth most important export after oil, cotton and livestock, and is quite difficult to transport from the bush to the various ports in neighbouring countries. Gum from Chad takes 60 days to reach Europe, while its Sudanese and Nigerian competitors take just 20 days [7].

Gum from Acacia Senegal is the dried exudate obtained from the bled branches of the tree. It is solid, hard, known as kitir, orange-brown in colour and of the highest quality, a benchmark gum on the world market. The gum produced by Acacia seyal is the natural exudate from the branches and trunk. The gum is crumbly, known as talha. It is of poorer quality and therefore less expensive [8]. It is an acid polysaccharide in the form of potassium, magnesium and calcium salts. Commercially available, it comes in the form of pale yellow to brownish-yellow powder or crystals, is odourless, soluble in water and insoluble in alcohol [9].

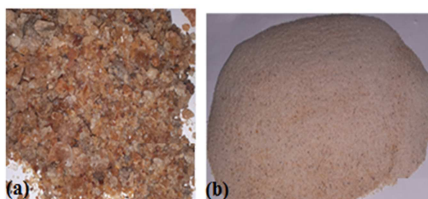


Figure 1. Photograph of gum arabic granules (a) and powder (b).

B. Clay

Clay is an earth-based product that has long been used in construction, especially in rural areas, and is found throughout the country. It is the oldest natural material used by man to build his home. It is available almost everywhere in the world, and working with it requires no particular effort or advanced knowledge [10]. Chad has enormous resources in clay formations that can be exploited and valued in their natural state, or improved by various additions of binders for various uses. The city of N'Djamena contains a large volume of clay materials, the recovery of which in the housing sector contributes to reducing the price of building materials [11].

Generally speaking, clay is formed mainly by the physical and mechanical disintegration, then chemical alteration, of certain minerals making up the rock. It is constantly changing over time on a geological scale, passing from one clay mineral to another and changing its initial properties as a function of the environment [12].

In our research, we chose clay from the Gaoui pottery site, known as the House of Clay. The latter was a village founded in the 19th century and located eighteen (18) kilometres north-east of N'Djamena, which supplies the capital and its surrounding areas with jars, pots, etc. The sample was taken from a depth of one meter.



Figure 2. Photograph of the Gaoui site clay sample (a) and aggregate (b).

C. Sample drying kinetics

Drying is an essential phase in the manufacturing process of building material samples, as it can be natural or forced. Depending on the type of drying, a certain amount of energy is inevitably required, and this has a major influence on the quality of the specimens obtained, so the role of the admixture is not negligible.

By monitoring the water content w of the product expressed as a function of time, it is possible to obtain the drying speed as a function of time or water content, and to establish classic drying curves [13].

D. Physico-chemical analysis

This chemical analysis of the sample was carried out by X-ray spectrometry in the laboratory, enabling us to classify the soil according to its various elements. The test was carried out at the laboratory of the Office of Expertise in Water, Energy, Environment and Agriculture (Burex-3eA) in Benin, and the raw results are shown in the following tables:

Table 1. Raw major chemical elements.

Total nitrogen (%)	0.298
Phosphorus (%)	0.187
Potassium (%)	0.143
Calcium (%)	2.834
Magnesium (%)	1.465
Sodium (%)	0.078
Iron (%)	4.465
Aluminium (%)	1.256
Manganese (%)	1.988

E. Geotechnical study

This includes the pycnometer test, granulometry analyses by sieving and sedimentometry, Atterberg limits, methylene blue and normal Proctor tests.

1. Specific mass of solid grains

The pycnometer test is carried out in accordance with standard NF P 94-054 and is used to determine the specific mass γ_s of solid grains. The soil sample is dried in an oven and then weighed; the volume of the particles is deduced by weighing using a water pycnometer by substituting water of known density for the solid particles. It is given by the following relationship:

$$\gamma_s = \frac{m_2 - m_1}{(m_2 + m_4) - (m_1 + m_3)} \quad (1)$$

2. Particle size analysis

The test is carried out respectively by granulometry by sieving for grains larger than 80 μm in diameter in accordance with standard NF P 94-056 and by sedimentometric granulometry for finer grains smaller than 80 μm in diameter in accordance with standard NF P 94-057. The first consists of separating the agglomerated grains from a mass of 471.9 g of the material by stirring under water, fractionating the soil once it has dried using a series of sieves and successively weighing the accumulated rejection on each sieve. The second test completes the first and enables the fractions of particles that cannot be sieved to be quantified.

**Figure 3.** Photograph of the series of sieves and two test specimens.

Depending on the diameter of the sieves, the soils can be classified according to the table below:

Table 2 Soil classification.

Sieve diameters (mm)	Type of soil
< 0,002	Clay
0,002 – 0,02	Silt
0,02 – 0,2	Fine sand
0,2 – 2	Coarse sand

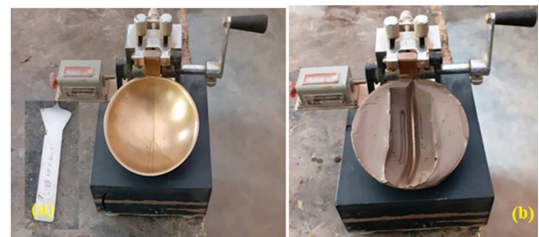
3. Atterberg limits

The Atterberg limit test is used to characterize the consistency of fine soils in accordance with standard NF P 94-051. The liquid limit (W_L) is the water content of the material which conventionally corresponds to a closure over 1 cm of the lips of the groove after 25 shocks. It is calculated from the mean line adjusted on the couples of the experimental values and the plastic limit (W_P), is to form a dumpling from the dough prepared well before, roll the dumpling on a smooth plate by hand or possibly using a plate so as to obtain a roll which is gradually thinned until it reaches 3 mm in diameter. The liquid limit and the plasticity and consistency indices are calculated as follows:

$$W_L = W_N \times \left(\frac{N}{25}\right)^{0,121} \quad (2)$$

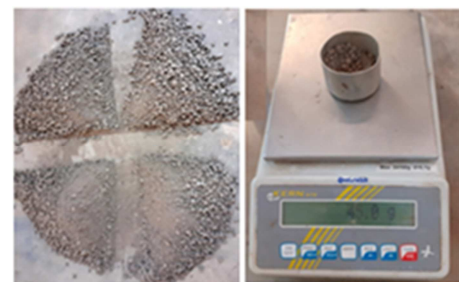
$$I_P = W_L - W_P \quad (3)$$

$$I_C = \frac{W_P - W}{I_P} \quad (4)$$

**Figure 4.** Casagrande dish.

4. Methylene blue test

The test consists of measuring the quantity of methylene blue adsorbed by the material suspended in water in accordance with standard NF P 94-068. This quantity is related by direct proportionality to the 0/5 mm fraction of the soil. The 0/5 mm fraction is quartered and homogenised in such a way as to prepare three test samples of approximately equal mass and of the order of 45 g. The range indicated is 30 to 60 g in our case of clayey soils.

**Figure 5.** Photograph of quartering and weighed mass.

5. Normal Proctor test

The principle of the Proctor test consists of moistening a soil with several water contents and compacting it using a conventional process and energy. For each of the water content values considered, the dry density of the soil is determined and the curve of the variations of this density is established as a function of the water content. The Proctor compaction characteristics of a material are determined using the so-called normal Proctor test in accordance with standard NF P 94-093.

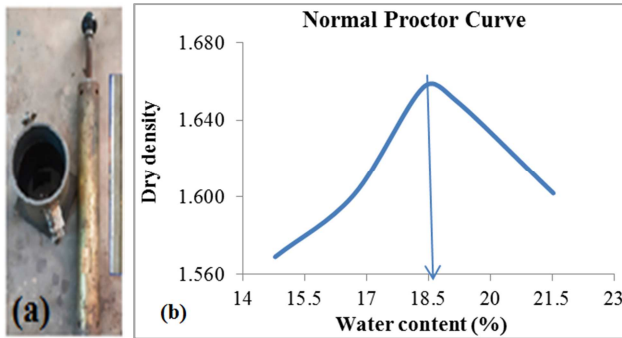


Figure 6. Photograph of the mould and the Normal Proctor curve.

F. Mechanical characterization test

One of the main factors which, throughout history, has led man to change the way in which houses are built, and to replace old materials with more resistant ones, is the problem of buildings collapsing.

Compressive strength and flexural strength are the most important mechanical properties when choosing a building material [14].

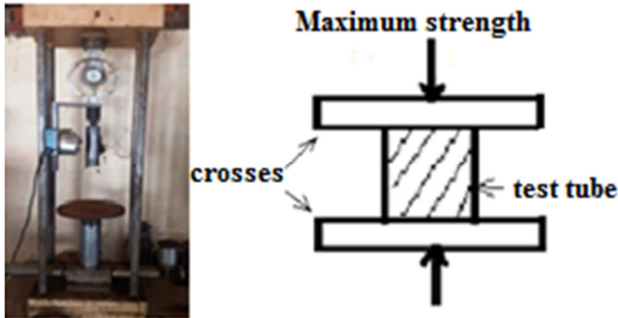


Figure 7. Photograph and diagram of the press.

1. Manufacture of test specimens

The sample was taken from the Gaoui pottery site to a depth of one meter. The sieves were 5 mm for the clay and 2 mm for the gum arabic. Grinding was carried out with a 10 kg tamper, and the two were mixed in the dry state by substitution with well-defined proportions, after which the mixing water was added with contents determined beforehand by the Proctor Normal test. The compaction energy is fixed for all our specimens. It is given by the following relationship:

$$E = \frac{N \times H \times m \times g}{V} \quad (5)$$

2. Simple compressive strength

As soon as the test specimen is placed on the test tray, the volent is manually operated in a clockwise direction. The lower piston moves up with the test piece until it makes contact with the upper piston. At this point, the 30 kN force transducer and the displacement comparator begin to record the force exerted by the frame on the specimen until it breaks and the deformation of the specimen, respectively.

The simple compressive strength of cylindrical specimens of section S is given by the following relationship:

$$\sigma_c = R_c = \frac{F_r}{S} \quad (6)$$

3. Results and Discussion

Drying kinetics is the monitoring of the water content of the samples (masses) expressed as a function of time and has enabled us to obtain the shapes of the curves below.

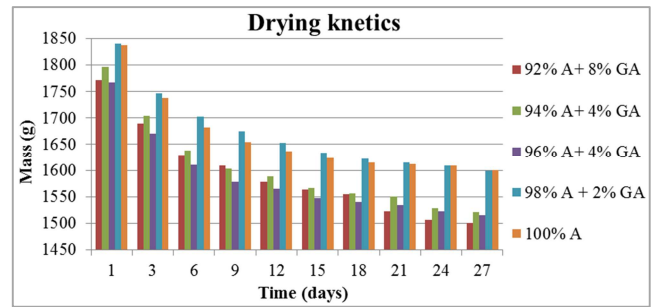


Figure 8. Drying curves for samples.

These curves show that the weight of the specimens decreases as the percentage of gum arabic increases, and two other important observations were made about drying:

1. The cracks observed are slightly wider during rapid drying than those observed during slow drying;
2. Similarly, the presence of gum arabic reduced the pores and prevented cracking during slow drying, which is also due to the salinity present in the gum arabic and therefore in the study material.

With regard to the physico-chemical analysis, after interpreting the raw results and the calculation carried out on the elements, we obtain the following table:

Table 3. Chemical composition of the sample.

Oxides	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	MnO	MgO	CaO
% of elements	67.94	12.75	4.74	2.56	2.44	3.96
Oxides	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	PF	Total
% of elements	0.21	0.34	1.56	0.85	5.63	97.36

This analysis shows that silica (SiO₂) and iron (Fe₂O₃) are the predominant constituents, followed by alumina (Al₂O₃). The sum of the SiO₂, Al₂O₃ and Fe₂O₃ content in accordance with the ASTM C618 standard is at least 70% [15]. In our case, this is 85.43%. In addition, the Alumina/Silica ratio provides information about the material's permeability to moisture [16]. The calculated ratio is equal to 6.97% and a

moisture content of 8.11%.

Pycnometer test allowed us to determine the specific mass γ_s of solid grains by carrying out three tests and applying equation 1:

Table 4. Experimental values of γ_s .

Test	1 st test	2 nd test	3 rd test
m ₁	15.8	15.8	15.8
m ₂	25.0	27.5	25.8
m ₃	47.0	48.6	47.4
m ₄	41.5	41.6	41.4

Test	1 st test	2 nd test	3 rd test
γ_s	2.49	2.49	2.50
γ_{smoy}	2.49		

Experimental data from two analyses have enabled us to plot the particle size distribution curve. This curve needs to be described and classified.

The curve describes that a percentage of 97.732 pass through the 80 μm sieve. Classification according to the different sieve diameters shows that the soil is made up of 65.3% clay, 32% silt and only 2.7% sand.

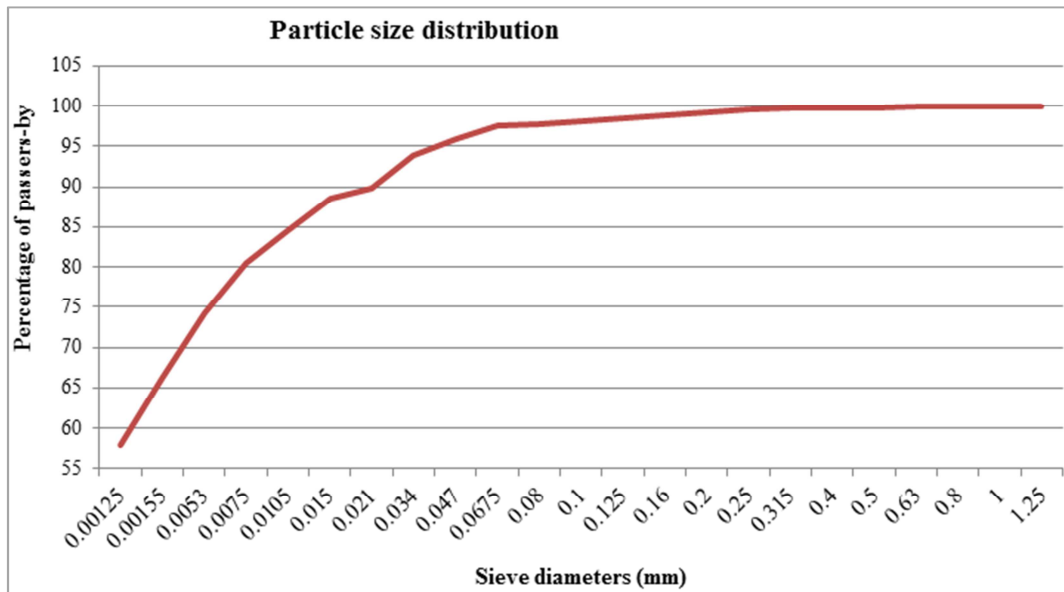


Figure 9. Clay particle size distribution curve.

The results obtained for the Atterberg limits, in particular the liquidity limit WL and the plasticity limit WP are 64.8% and 28.8% respectively, and the values for the plasticity

index IP and consistency index Ic are also determined: 36% and 0.283. All these values confirm that this soil is of the plastic type.

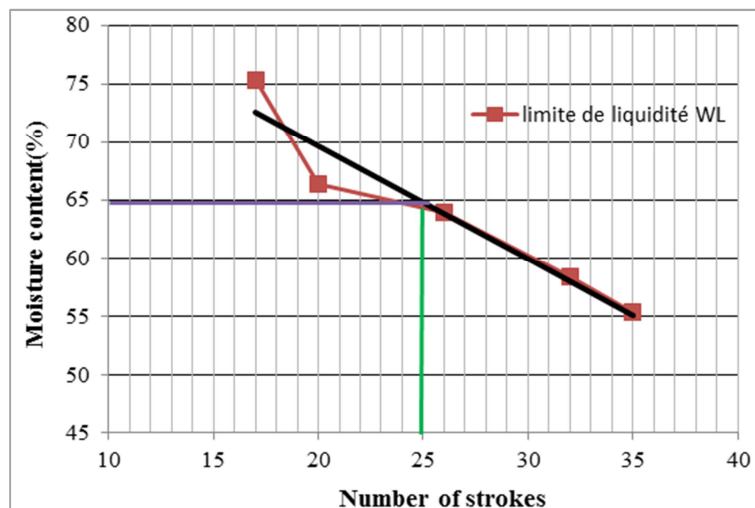


Figure 10. Determination of liquid limit.

The Casagrande diagram containing the point with coordinates (Ip and WL) below also confirms the plastic state of the soil, as did the previous tests. The green point on the

Casagrande diagram with coordinates in percent 36 and 64.8.

The methylene blue test, like the others, reveals the state of our soil. For this test, we injected a precise volume of 240 ml

of methylene blue, and the VBS obtained was 6.32. This plastic clay. proves that the soil is plastic clay. This proves that the soil is

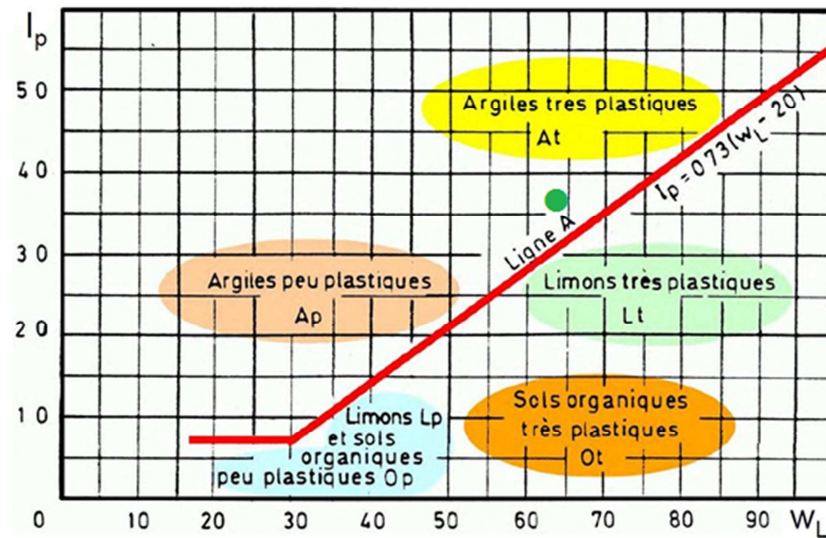


Figure 11. Casagrande diagram.

The normal Proctor curve gives us an optimum water content of 18.6% and a dry density of 1.66. The various parameters and their values are summarized in the table below:

Table 5. Summary of the various parameters.

Parameters	Values
W_L (%)	64.8
W_P (%)	28.84
I_p (%)	36.0
I_c	0.283
W (%)	18.6
VBS	6.235

Determining the other water contents for the mixture enabled us to make the different formulations of our samples and the simple compressive stresses obtained are shown in the figure below:

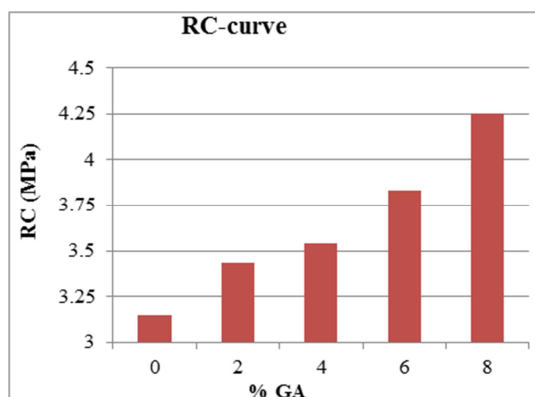


Figure 12. Mechanical stress as a function of admixture content.

Simple compressive stress increase with the percentage of admixture. With 8% gum arabic, it rises from 3.14 MPa to 4.25 MPa, an increase of 35%.

4. Conclusion

Raw earth is increasingly studied as a construction material because of its low environmental impact, its abundance and its processing, which does not require advanced knowledge but can erode. The addition of a stabiliser or binder such as gum arabic can visibly improve the mechanical parameter.

The geotechnical study of the soil enabled us to identify the state of the material, which is plastic, and the Proctor Normal test gave the optimum water content. The soil studied was too fine, and the physico-chemical analysis showed that silica dominated, followed by iron oxide.

Gum arabic played a role comparable to that of a mineral binder such as cement in the stabilisation of construction materials.

Future plans include a study to determine the thermo-physical characteristics of the soil and the addition of a few percent of sand to the formulations.

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