UDC 551.588.3:631.43
DOI: 10.15587/2706-5448.2024.298972

Menari Farouk,
Sabah Moussaoui,
Mourad Belgasmia,
Khelifa Abbeche

ENVIRONMENT EFFECT ON MECHANICAL PARAMETERS OF SOIL-MIXING

Soil improvement is originally an economical solution to make soil buildable, particularly compared to deep foundation methods using piles. The object of this research is the understanding of the behavior of soil-mixing material, in particular, what concerns the effect of environmental parameters, whether: temperature, water table level, chemical attacks, the phenomenon of aging etc. on the mechanical and physical characteristics (resistance to simple compression, resistance to simple bending, modulus of elasticity, porosity, density, etc.), of a soil-mixing column, in the short term and long term. The big problem is how to carry out experiments in the laboratory, which will be representative of the different phenomena that take place on a real scale (on site). To do this, our approach consists of studying different soil-mixing mixtures composed of «artificial» soils (clay and sand) and a CEM III/C cement, and with a variable W/C ratio. After making the test pieces, with the different dosages of cements and a ratio between clay and fixed sand, they were kept under normal temperature conditions, in order to reach a maturation age (180 days), to be able to begin the series of experiments. Once the specimens were subjected to the aging test, let's begin to crush them with simple compression and simple bending. The parametric study highlights a percentage of clay beyond of which the resistance decreases and the rigidity of the material can pose a problem for certain structural uses. The different results obtained show that for a low cement dosage, the humidification-drying cycle influences both the resistance to simple compression and to bending simple, as well as the number of cycles affects the resistance values in a significant way. On the other hand, for a greater or lesser dosage of cement, the resistance values are not affected. Based on the results obtained, it is possible to conclude that the choice of cement dosage depending on the nature of the soil influences the soil-mixing column and plays an important role on the lifespan of the column; therefore, it is necessary to give primary importance to the choice of cement dosage depending on the nature of the soil treated.

Keywords: *soil-mixing, formulation, mechanical properties, durability, damage, aging cycle, compressive resistance, bending resistance.*

Received date: 20.12.2023
Accepted date: 23.02.2024
Published date: 26.02.2024

How to cite
Farouk, M., Moussaoui, S., Belgasmia, M., Abbeche, K. (2024). Environment effect on mechanical parameters of soil-mixing. Technology Audit and Production Reserves, 2 (1 (76)), 6–11. doi: https://doi.org/10.15587/2706-5448.2024.298972

1. Introduction

The Soil-Mixing method has many advantages (respect for the environment, easy and quick execution as well as low cost) which have greatly contributed to extending its field of applications (soil improvement, containment of pollution and creation of elements structures). These new applications required a better understanding of the method and the material. The characteristics of the Soil-Mixing material (in particular homogeneity and continuity) are increasingly studied as the field of application expands. Likewise, methods for predicting material strength are being developed [1] cite four factors which influence the growth in the strength of the material: the characteristics of the binder, the nature and condition of the soil encountered, mixing and curing conditions. In [2, 3] is stating that it is commonly accepted that the resistance of soil treated with cement increases over time, in the same way as concrete.

Many studies have been carried out to propose formulas regarding the prediction of material strength. In [4, 5] proposed general relationships linking the gain in resistance to the nature of the soil to be treated, as well as resistance ranges achievable for these same soils after 28 days of curing. Furthermore, formulas have been proposed to predict material strength from one or more factors stated by [1]. For concrete, laws relating to the development of strength and depending solely on the cement to water ratio of the mixture studied have been established. These laws have been tested on Soil-Mixing, but other formulas have been proposed, taking into account cement, water and/or the fines content of the treated soil. However, there is still no widely applicable formula for estimating the strength of the material and integrating all the factors that should be taken into account, because until now, no international standard exists for the preparation of soil samples processed in the laboratory [6]. Additionally, some formulas can only be applied to a particular site, while others can only be applied to certain soils [7]. Additionally, some formulas can only be applied to a particular site, while others can only be applied to certain soils. In [8, 9] cite the impact of the type of soil, the dosage of cement and the water content on the mechanical properties of soils treated with cement: the characteristics of the binder, the nature and condition of the soil encountered, mixing and curing conditions. In [10] studied the influence of environmental parameters on the physical and mechanical characteristics of an artificial floor (concrete floor), where it cited the influence of temperature and chemical attacks on the mechanical characteristics of the floor artificial.

The aim of this research is to exhaustive parametric study which focused on the resistance of the Soil-Mixing material, and relationships linking resistance to Soil-Mixing parameters.

2. Materials and Methods

2.1. Origin and properties of studied materials

2.1.1. Soil material (clay). The soil used in our study is taken from Algeria, whose geological nature is characterized by an alternation between: silty clay, marly clay and gravelly clay [11]. Laboratory tests gave in Table 1.

Table 1

Characteristics of laboratory tests

Features		Values
Dry density, t/m^3		2.00
Water content, %		14.60
Saturation degree, %		100
Wet density, t/m^3		2.28
Granulometry	5 mm	88
	2 mm	79
	0.08 mm	66
Sedimentometry	20 µm	46
	2 µm	28
Atterberg limits	*Wl*, %	36.79
	Ip	19.34

2.1.2. Sand material. The sand used in our study is taken from local region [8], Table 2.

Table 2

Characteristics of the sand used

Features	Values
Dry density, t/m^3	2.66
Water absorption coefficient, %	0.53
Fines content, %	0.20
Equivalent sand	61
Blue value	1

2.1.3. Cement. The cement used in our work is CEM II/A-L 42.5 N, Portland limestone cement (CPC), from the factory: Groupe Industriel des Ciments d'Algérie, Société des Ciments de Ain KEBIRA (Table 3) [8].

Table 3

The characteristics of cement

Features	Values
Setting time	>60 minutes
Compression resistance at 2 days	>10 N/mm^2
Compression resistance at 28 days	>42.5 N/mm^2
Sulfate content SO_3	<3.5 %
Chloride content	<0.10 %
Clinker content	80–94 %
Addition of limestone	6–20 %
Secondary constituent	0–5 %

2.2. Experimental approaches. The objectives of this article are first presented in order to specify which parameters were studied to meet the need for prediction and reliability of soil-mixing performance. Different reasons and hypotheses led us to the choice of materials and formulations. In the absence of standards and recommendations dedicated to soil-mixing, the working method is therefore based on studies already carried out [6]. The different protocols adopted are also inspired by concrete and mortar standards. In this work research, let's also detail the different means of mechanical characterization implemented. The accelerated aging tests implemented are also presented, specifying in particular at what intervals the characterization tests are planned (number of cycles, time).

2.2.1. Supply of materials. The first step in our work is to procure a quantity of materials necessary to carry out the various tests. Subsequently, the choice of laboratory was made where it is possible to carry out the experimental part, the laboratory is: the chosen laboratory is Public Works Laboratory East (LTPEst) situated in Bejaia Algeria, which provides the different means necessary to complete the experimental part. To source materials, let's proceed as follows.

2.2.1.1. Clay material

– *Choice of intervention site*: In the absence of material at laboratory level, first of all, we did prospect work to be able to choose the sample collection site (a site whose soil type is of low physical characteristics and mechanical, like clays). The chosen site is located in the commune and Daïra of Amizour, Wilaya of Bejaia, where a program of 150 housing units is implemented.

– *Sampling:* The samples are taken after earthworks to a depth of more than 4.00 m (because the site in question was used for agriculture), the samples taken were preserved in polyene bags (Fig. 1).

Fig. 1. Sample taken

– *Cleaning*: The samples will be thoroughly cleaned of any substances strange to the nature of the soil.

ISSN 2664-9969

– *Baking*: Once the samples are taken to the laboratory, they will be placed in the oven at a constant temperature of 150 °C for 24 hours (Fig. 2).

Fig. 2. Oven

– *Grinding*: After 24 hours in the oven the samples will be crushed to obtain the maximum number of fine particles.
– *Sieving*: Once the samples are crushed, let's move on to sieving, where it is possible to pass the material through sieves of different diameters and take just the quantity passing through the 0.2 mm sieve (Fig. 3).

Fig. 3. Sample after sieving

– *Conservation*: The quantity obtained by sieving will be stored in polyene bags, in a place with constant temperature and humidity.

2.2.1.2. Sand material. Concerning the sand, necessary quantity for making the test tubes is found at laboratory level.

2.2.1.3. Cement. The cement used is that of Ainkbirasetif, present in the laboratory in sufficient quantity.

2.2.2. Preparation of mixtures (test tubes). In our research work, let's carry out three types of formulation depending on the percentage of soil and cement:

1) Formulation F1: 25 % soil, 75 % sand and 200 kg/m^3 cement.

2) Formulation F2: 25 % soil, 75 % sand and 250 kg/m^3 cement.

3) Formulation F3: 25 % soil, 75 % sand and 300 kg/m^3 cement.

Determination of the quantity of clay, sand, cement and water used for each formulation: The work consists of carrying out several experiments with different contents of water, cement, sand and clay, in order to have a spreading between 30 and 32 cm, Table 4.

Table 4

The dosage for each element

Element	Cement, kg/m^3	Clay, kg/m^3	Sand, kg/m^3	Water, kg/m^3
25 % soil, 75 % sand	200	243	743	557
	250	231	707	558
	300	220	672	559

Mixing: The mixtures are made in the laboratory under «ideal» conditions so that mixing does not influence the results and is reproducible. The soil, sand and cement are first mixed manually dry (approximately 5 minutes) [9], so as to obtain a visually homogeneous mixture. Mechanical mixing with water is then carried out using a mixer, leaving for at least 10 minutes.

Preparation of specimens: In the literature, cylindrical specimens of 50 mm in diameter and 100 mm in height are widely used for mechanical characterization tests of soil-mixing material. In our case, there aren't cylindrical molds for making the test pieces, let's use cubic molds, with the following dimensions: 4×4×12 cm^3. The mold filling procedure greatly influences the physical and mechanical properties of soil-mixing mixtures. For all mixtures, filling of the molds is completed no later than 45 minutes following mixing with the cement. This makes it possible to limit the influence of the rest time before installation, on material characteristics.

In order to optimize sample quality, mold filling must also take into account the workability of the mixture (Fig. 4). During this important stage of making the test pieces, the objective is to extract as much occluded air as possible, whatever the method used. The molds are filled in a single layer. The soil-mixing is tightened by the tapping method (15 strokes) for formulations containing clay consistency.

Fig. 4. Mold for making test specimens

Test pieces storage: The storage of test pieces is in a climatic chamber at a temperature of 20 °C, in a basin filled with water for 180 days (Fig. 5).

Fig. 5. Storage of test specimens

2.2.3. Accelerated aging tests. The objective is accelerated aging tests to better understand the durability potential of the material. Accelerated aging tests include: humidification-drying cycles or chemical attacks. In our study, humidification-drying tests were carried out. Accelerated aging tests are launched after 180 days of endogenous curing in order to compensate for the particularly slow hydration reactions of blast furnace slag and avoid their interaction with the influence of accelerated aging tests on damage to the material.

Accelerated humidification-drying aging cycle: After 180 days of storage, let's begin the humidification-drying cycle according to the following protocol: 24 hours in an oven at 53 °C and 48 hours of immersion in water at 20 °C vs. for the following cycles: 3, 6, 12 and 24 (Fig. 6).

a *b*

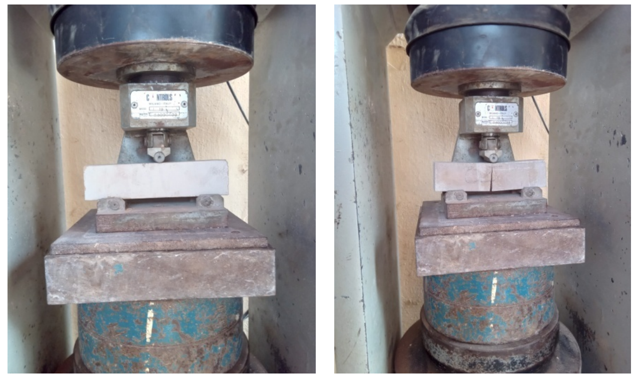
Fig. 6. Accelerated humidification-drying aging cycle: *a* – specimens; *b* – oven

2.2.4. Simple compression tests. *Crushing tests on the specimens:* At the end of each cycle, let's move on to crushing the specimens using simple compression tests with a hydraulic press (Fig. 7).

a *b*

Fig. 7. Crushing tests on the specimens: *a* – crushing press; *b* – specimens after crushing

2.2.5. Bending tests. At the end of each cycle, let's move on to crushing the specimens using simple bending tests with a hydraulic press (Fig. 8).



a *b*

Fig. 8. Placement of the specimen: *a* – before crushing; *b* – after crushing

In our case, the effect of the number of cycles on the compressive relative resistance was studied, as well as the effect of the cement dosage on the relative resistance to simple compression.

3. Results and Discussion

3.1. Effect of number of cycles on the relative resistance to simple compression. Monitoring the evolution of the relative resistance in simple compression (fc) as a function of the number of Humidification/Drying cycles is presented in Fig. 9, for different formulations cited above.

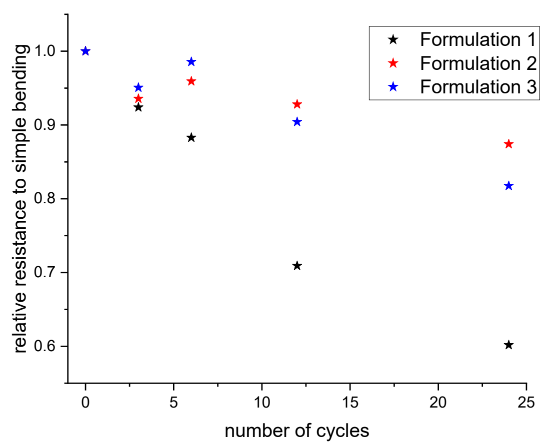


Fig. 9. Compressive relative resistance evolution function of number of Humidification/Drying cycles

The obtained results are normalized in relation to the initial values determined in the endogenous state after 180 days of treatment. The compressive strength of different formulations F1, F2 and F3 decreases depending on the number of cycles. It is possible to observe a practically identical reduction for the three formulations between 0 and 3 humidification-drying cycles. It is also possible to see that from the third cycle the shape of the curve changes from one formulation to another: for formulation F1 the relative resistance to simple compression continues to decrease depending on the number of cycles. On the other hand, for formulations F2 and F3, let's notice a slight increase in the resistance relative to simple compression until the sixth cycles after a sudden decrease, thereafter the rate continues to decrease. This sudden decrease between 0 and 3 cycles is however caused by an experimental artifact. The compressive strength of earth-mixing decreases by 18 to 40 % between 3 and 24 cycles, regardless of the cement dosage.

3.2. Effect of the cement dosage on the relative resistance to simple compression. The evolution of compression relative resistance (*fc*) as a function of cement dosage and Humidification/Drying cycles number, for all the formulations is presented in Fig. 10.

The obtained results are normalized in relation to the initial values, which are determined in the endogenous state after 180 days of treatment. The simple compressive strength increases as a function of cement dosage (Formulation), which is logical as the Water-Cement ratio has a significant influence on the simple compressive strength. It is also possible to see that for a low dosage of 200 kg/m^3 the resistance is very low, however the dosage of 300 kg/m^3 gives a greater resistance, which is around 30 %.

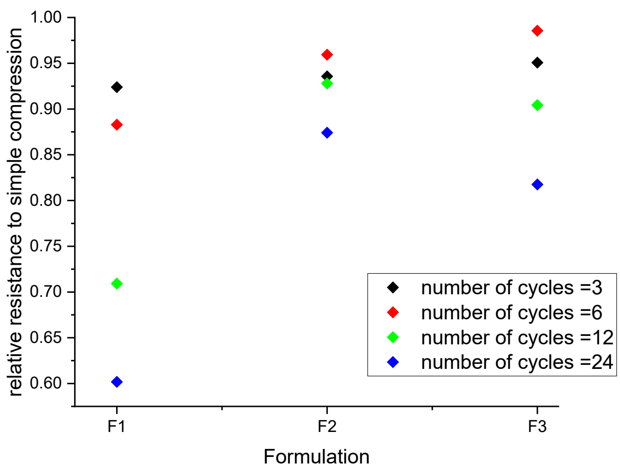


Fig. 10. Compressive relative resistance evolution function of cement dosage

3.3. Effect of number of cycles on the relative resistance to simple Bending. Monitoring the evolution of the relative resistance in simple compression (*fc*) as a function of the number of Humidification/Drying cycles is presented in Fig. 11, for all the formulations.

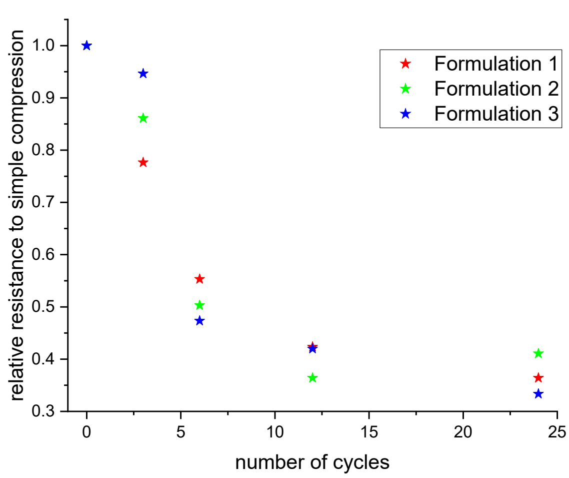


Fig. 11. Bending relative resistance evolution function of number of Humidification/Drying cycles

The obtained results show, that bending resistance decreases as a function of the number of cycles for all the formulations, this reduction is between 60 to 65 % whatever the cement dosage.

3.4. Cement dosage effect on simple bending relative resistance. The relative resistance in bending (*fc*) evolution as a function of cement dosage and the number of Humidification/Drying cycles, for all the formulations is presented in Fig. 12.

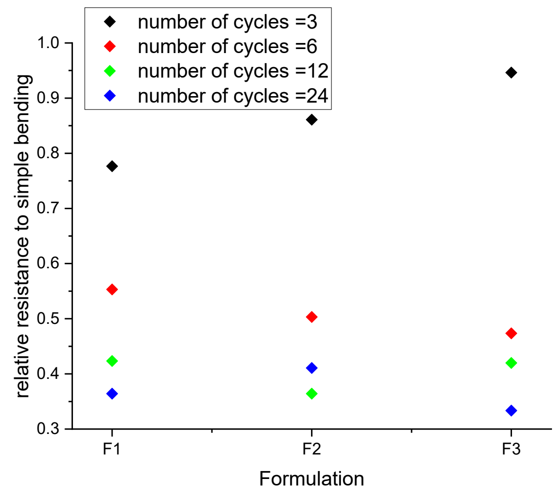


Fig. 12. Bending relative resistance evolution function of cement dosage

This graph shows the increase in the resistance to simple bending as a function of the cement dosage (Formulation), something which is expected because the W/C ratio has a significant influence on the resistance to simple bending. It is also possible to see that for a low dosage of 200 kg/m^3 the resistance is very low, however the dosage of 300 kg/m^3 gives a greater resistance of around 18 %.

3.5. Discussion. The various results and conclusions obtained from this research show the importance of carrying out an in-depth geotechnical study for the dimensioning of soil-mixing columns. The influence of environmental phenomena on the lifespan of the soil-mixing column is shown for soils whose physical and mechanical characteristics are low (clay, silt, etc.) with a low cement dosage. Our work was located in a single region in the commune of Amizour, Wilaya of Bejaïa, the extension of the research to other regions whether in the Wilaya of Bejaïa or national territory may be possible, of course by expanding the experimentation of other mechanical and physical parameters of the soil-mixing column, the influence of other phenomena (temperature, chemical attacks, long-term humidification-drying cycle, etc.) is examined.

The results presented in this experimental research work have raised the influence of the cement dosage and the number of humidification-drying cycles on the lifespan of the soil-mixing column, a well-determined adequate dosage can increase performance and durability of the soil-mixing column. The different areas of research that deserve to be explored in greater depth in order to improve the understanding of the behavior of Soil-Mixing are:

– study the effect of a different granular distribution (for example continuous, or coarser, etc.) on the performance of Soil-Mixing;

– the nature of the aggregates (silico-limestone or limestone), the clay (illite or even montmorillonite in varying proportions), or even the binder (CEMIII with less slag for example, other binders than Portland);
– finally, given the significant spreading of these Soil-Mixing, the addition of super-plasticizer could help reduce the water content and limit damage while better preserving the mechanical properties.

The extension of the study area can also be the subject of other research to better see the influence of the area on the lifespan of the soil-mixing column.

4. Conclusions

This research work shows that it is possible to accurately predict the evolution of the resistance in simple compression and simple bending, as a function of time, the number of humidification-drying cycles and the cement dosage, only from of *fc28*. An experimental campaign shows that the simple compressive strength of soil-mixing specimens decreases by 18 to 40 % between 3 and 24 cycles, whatever the cement dosage. And the resistance to simple bending decreases depending on the number of cycles for all the formulations, this reduction is between 60 to 65 % for the different formulations. Furthermore, it should be noted that: The presence of clay in Soil-Mixing promotes cracking of the material linked to Humidification/Drying cycles. This type of disorder results both from the incompatibility of the deformations between the sand grains and the binding phase, and from the prevented shrinkage of the clay under the effect of a drying gradient.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The research was performed without financial support.

Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

References

1. Babasaki, R., Terashi, M., Suzuki, T., Maekawa, A., Kawamura, M., Fukazawa, E. (1996). Japanese Geotechnical Society Technical Committee Reports: Factors influencing the strength of improved soil. *Proceedings of the 2nd International Conference on Ground Improvement Geosystems, 2,* 913–918.
2. Porbaha, A. (1998). State of the art in deep mixing technology: part I. Basic concepts and overview. *Proceedings of the Institution of Civil Engineers – Ground Improvement, 2 (2),* 81–92. doi: https://doi.org/10.1680/gi.1998.020204
3. Porbaha, A., Shibuya, S., Kishida, T. (2000). State of the art in deep mixing technology. Part III: geomaterial characterization. *Proceedings of the Institution of Civil Engineers – Ground Improvement, 4 (3),* 91–110. doi: https://doi.org/10.1680/grim.2000.4.3.91
4. Bruce, D. A., Bruce, M. E. C., DiMillio, A. F. (2017). Dry Mix Methods. *Dry Mix Methods for Deep Soil Stabilization,* 15–26. doi: https://doi.org/10.1201/9781315141466-2
5. Topolnicki, M. (2004). In situ soil mixing. (2004). *Ground Improvement.* Spon Press, 339–436. doi: https://doi.org/10.1201/9780203489611-15
6. Kitazume, M., Terashi, M. (2013). *The Deep Mixing Method.* CRC Press. doi: https://doi.org/10.1201/b13873
7. Le Kouby, A., Duc, M., Szymkiewicz, F., Shen, S. (2016). *Impact of soil type, cement content, water content on mechanical and porosity properties on cement treated materials.* IFSTTAR.
8. Semde, I. (2012). *Etude d'impact environnemental et social du projet de construction de laboratoire de biosecurite.* Available at: https://www.academia.edu/48188451/Etude_dimpact_environnemental_et_social_du_projet_de_construction_de_laboratoire_de_biosecurite
9. Guimond-Barrett, A. (2013). *Influence of mixing and curing conditions on the characteristics and durability of soils stabilised by deep mixing.* Université du Havre. Available at: https://hal.science/tel-02497429
10. Helson, O. (2017). *Comportement thermo-hydro-mécanique et durabilité des bétons de sol: influence des paramètres de formulation et conditions d'exposition.* Available at: https://theses.hal.science/tel-01566852/
11. Purohit, P., Höglund-Isaksson, L., Dulac, J., Shah, N., Wei, M., Rafaj, P., Schöpp, W. (2020). Electricity savings and greenhouse gas emission reductions from global phase-down of hydrofluorocarbons. *Atmospheric Chemistry and Physics, 20 (19),* 11305–11327. doi: https://doi.org/10.5194/acp-20-11305-2020

✉***Menari Farouk,*** *Postgraduate Student, Department of Civil Engineering, University de Batna, Batna, Algeria, ORCID: https://orcid.org/0009-0000-4758-307X, e-mail: menarifarouk@yahoo.fr*

Sabah Moussaoui, *Associate Professor, Department of Civil Engineering, Civil Engineering Research Laboratory, Sétif 1 University, Sétif, Algeria, ORCID: https://orcid.org/0000-0002-8641-089X*

Mourad Belgasmia, *Professor, Department of Civil Engineering, Civil Engineering Research Laboratory, Sétif 1 University, Sétif, Algeria, ORCID: https://orcid.org/0000-0003-1409-0281*

Khelifa Abbeche, *Professor, Department of Civil Engineering, University de Batna, Batna, Algeria, ORCID: https://orcid.org/0009-0006-2476-6408*

✉*Corresponding author*