International Journal of Research and Review
Vol. 11; Issue: 1; January 2024
Website: www.ijrrjournal.com
E-ISSN: 2349-9788; P-ISSN: 2454-2237

Research Paper

Effects of Loading and Compaction Conditions on Permanent Strains of Unbound Lateritic Soils from Senegal and Burkina Faso

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DOI: https://doi.org/10.52403/ijrr.20240114

ABSTRACT

Permanent strains of granular materials result from the repetitive passage of heavy trucks on the pavement. Pavement design relies mainly on permanent strains to predict rut depths. In order to contribute to the improvement of technical documents used for the design and modelling of pavements in tropical African countries, the researchers have focused on the determination of the permanent deformation parameters of laterites (axial (εp,1) and radial (εp,3) permanent strains). The Repeated Triaxial cyclic Loading (RTL) apparatus was used according to the European standard (EN 13286-7: 2004, Multistage method). Four sites of gravelly lateritic soils chosen, two from Burkina Faso (Badnogo2 and Dédougou) and two from Senegal (Sindia and Lam-Lam) were tested in this research. They are compacted to 95% and more of the optimum with a variation in water content of ±2% of the optimum. The permanents deformations are influenced by the water content, the compaction rate and the stress level. The axial permanent deformation ε1,p (max) decreases by 83.4% when the water content decreases from 12.10% to 7.59%. Moreover with a compactness rate that varies from 95.58% to 100.06%, respectively from a water content that varies from 10.04% to 9.36%, we observe a decrease in deformation ε_(1,p) from 224.340*10-4 to 148.150*10-4 from the 50,000 cycles, which shows the effect of the compactness rate and the stress level on the lateritic gravels materials soils. however, for a good control of permanent deformations on flexible pavements using gravel materials, it is necessary to compact at water contents lower than the optimum added to average compaction rates.

Keywords: permanent strains (ε_p), lateritic soils, Repeated Triaxial cyclic Loading (RTL), Sindia, Badnogo2, Dedougou, Lam-lam.

INTRODUCTION

Laterites soils and many other soils of intertropical regions are located in areas where it is very hot and where rainfall is abundant, either all year round or during a wet season (Legros, 2013 in [1]). Routhier (1963) in [2] calls laterite a mixture of iron (Fe2O3) and aluminum (Al2O3) hydroxides (Dibara, 1978 in [2]. Unbound materials, in particular lateritic gravel, are the most widely used as base layers for the construction of road infrastructures in tropical Africa. Some authors claim that they are a detrital and sedimentary product, a residual product of rock alteration or even of volcanic origin. Each hypothesis is partly justified by the morphology and the site of the laterites [3]. The most observed degradations are either fatigue or rutting. Rutting is the main cause of deterioration of flexible pavements. It is mainly due to the accumulation of plastic strains in the layers made up of untreated gravel [4]. These permanent or plastic strains are left on the roadways following the repetitive passages of heavy goods vehicles. According to White et al. [5] and Meunier [6] this pathology of the flexible pavement is also caused by three different mechanisms including structural or large radius rutting which affects several layers of the structure, especially the lower layers of unbound materials. Permanent strains are one of the rheological parameters of road materials, determined from cyclic triaxial testing with repeated loading (RTL). European standard [7] (Nf EN-13286-7, 2004) (Multistage method [8]) is the one used for the determination of the permanent strains. This test procedure can be used to determine the permanent strains of the material for a particular stress level or to determine model parameters for predicting permanent strains which can be used for the prediction and design of pavements.

The context of our research is to seek to understand the long-term mechanical behavior of lateritic soils from tropical Africa (including two from Burkina Faso and two from Senegal located as show in the figures 1 and 2), in order to predict the permanent strains causing ruts. This theme has been treated since 1960 by many author ([9], [10], [8], [11] and [12]) and since 1993 in Africa precisely in Senegal ([13] and [14]). The Methodology adopted and the results obtained will be presented later, followed by a discussion of the results obtained.

MATERIALS & METHODS

Characterization of lateritic gravel materials of the study

Lateral gravelly materials come from the alteration of source rocks (granite, quartz, etc.) in tropical regions. Four sites of lateritic gravelly materials soils chosen, including two from Burkina Faso (Badnogo2 and Dédougou) and two from Senegal (Sindia and Lam-Lam) were the subject of this research. Figures 1 and 2 shows their location according to the territories of Senegal and Burkina Faso.

These materials have a maximum diameter of 20 mm, a percentage of fine (□□<80µm) less than 20%. The plasticity index (PI) is between 7.2% and 13%, the value of the dry density of solids is greater than 2.69 and the I_{CBR} index at 95% after 4 days of immersion is included between 30.5 and 65. The tests were carried out according to the French standard (particle size analysis NF P 18-101, Atterberg limit NF P 94-051, water content NF P 94-050, actual density (density) NF P 94-054, Proctor NF P 94-093 and California Bearing Ratio after 4 days of immersion (CBR) NF P 94-078). The results are given in Table 1.

Table. 1 Result of the bearing tests (CBR) of the laterites studied

Designation of borrow sites	Percentage of fine ϕ < 80µm	Plasticity Index (PI)	density dries solids _	Content in optimal water	CBR index after 4 days of immersion	Classification of materials		
	(%)	(%)	γs	(w%)	95%	AASHTO	USCS	Rodrigues *et al*. [15])
Sindia	17.86	9.2	2.76	9.66	54.8	A2-6	GC-CL	SLSL1
Lam - Lam	18.19	10.1	2.69	11.8	30.5	A2-6	GC-CL	SLSA
Dedougou	10.21	7.2	2.82	8.05	65	A2-4	GM-GC	SLGB1
Badnoogo 2	16.63	13	2.76	9.7	58	A2-6	GC-CL	SLSA

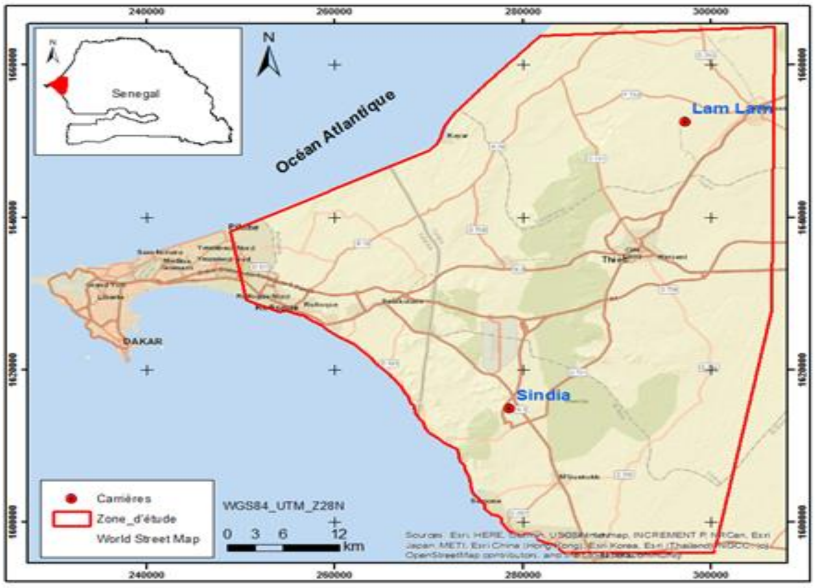


Figure 1 Location of borrowing sites in Senegal (Sindia and Lam-Lam) [16]

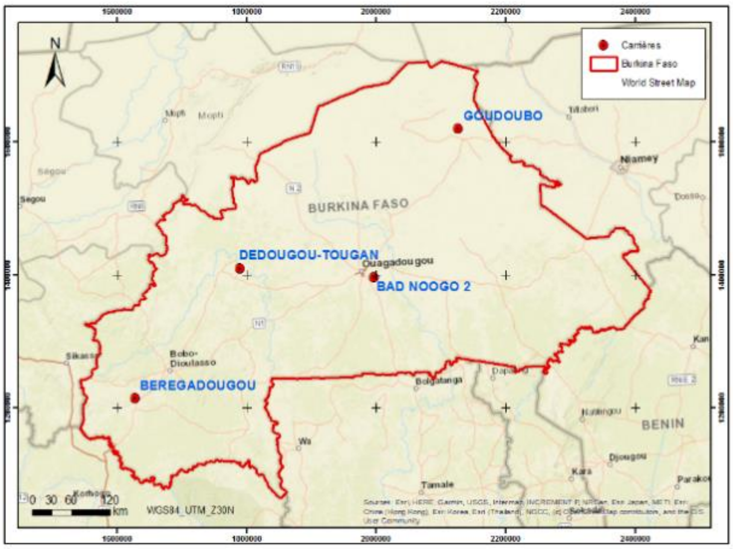


Figure 2 Location of borrowing sites in Burkina Faso (Dedougou and Badnogo) [16].

Triaxial test (RTL) with multistage method

The Triaxial Cyclic Repeated Loading (RTL) apparatus of the SCHENCK brand from the former IFSTTAR in Nantes was used for the advanced testing of materials, with the application of the European standard [7] (method by step of [8]. Five stress levels (3.216 kN to 10.75 kN) with a stress path of constant q/p = 2 was the adopted protocol (Table 2). The frequency of 2 Hz was applied for the determination of the permanent axial strains (ε_{p1}) and radial (ε_{p3}).

Table 2 The different stress levels used for the permanent strains by stage.

stress level (landing) (Lvl)	Constraint means p (kPa)		Confinement stress σ_3 (kPa)		Constraint deviatoric q (kPa)		Stress path $\Delta q / \Delta p = 2$		Max force (kN) 1kPa = 0.0201kN
	Minimum	Max	Minimum	Δ p	Minimum	Max	Δ p	Δ q	
Lvl 1	23.3	98.3	20	45	10	160	75	150	3,216
Lvl 2	23.3	135.8	20	57.5	10	235	112.5	225	4.7235
Lvl 3	23.3	173.3	20	70	10	310	150	300	6,231
Lvl 4	23.3	248.3	20	95	10	460	225	450	9,246
Lvl 5	23.3	285.8	20	107.5	10	535	262.5	525	10.7535

The materials were compacted by the Vibrocompression method (VCEC) with standard NF EN13286-52, at a rate varying between 95% and 100% and a variation in water content of ±2% of the optimum. These studied materials were labeled as follows :

- material followed by the RTL test number (LA02); which also corresponds to the site name followed by the compaction water content and the compactness rate (SIN/12.10/95.75);
- for example, LA02 = SIN/12.10/95.75: laterite 2nd RTL test from the Sindia quarry compacted to 12.10% water content and a compactness rate of 95.75%.

The triaxial cell of the device is designed to receive specimens 160 mm in diameter and 320 mm in height. A device for measuring axial strains made up of two Hall effect displacement sensors, 10 mm in stroke, are placed at 180° around the specimen; another device for measuring radial strains made up of a ring fitted with a Hall effect sensor placed half the height of the test piece matching the circumference of the test piece and an inductive displacement sensor LVDT “Linear Variable Differential Transformers” measuring the axial strains and placed outside the cell. The cell is equipped with a force sensor with a measuring range of 20 kN, a pressure sensor of 0.5 MPa attached to the outlet of the air/water interface tank, and a second sensor identical at the level of the lower base of the cell, to ensure that the cyclic variations of the pressure are homogeneous throughout the cell. The triaxial apparatus used has a hydraulic loading system for the application of the axial force and a servo -pneumatic loading system for the confining pressure. The advantage of the pneumatic system lies in its simplicity and low cost compared to a hydraulic system. These two loading systems make it possible to cyclically vary the axial force and the pressure in the cell, which makes it possible to carry out loadings along different stress paths. The fabrication and assembly process of the specimen on the RTL before the test is detailed in figure 3.

(a) Sampling

(b) Manual mixing

(c) Making the test piece

d) Compression by vibrocompression

(e) Demolding-preparation of the test specimen for the TCR test

(f) Membrane installation

(g) Installation of sensors

(h) Start of the testi TCR

Figure 3 Test specimen manufacturing procedure before LRT test [17]

The test consists in carrying out on the same specimen loadings in increments of increasing intensity during a test, the ratio q/p is unchanged. This condition is essential because it makes it possible to be sure of the erasing of the memory of the first loadings.

Thus, the permanent strains measured at the end of each level are independent of the stress of the previous levels. The specimens were stressed with a number of loading cycles for the five bearings of between 20,000 and 160,000 loading cycles. When the loadings of sequence 1 are finished (or interrupted because the limit of 0.5% strains has been reached), continue the test by carrying out sequence no 2, then sequence no 3. For each stress stage of each sequence, read and record the stress and strains values as indicated in the appendix to the aforementioned standard.

Data processing methodologies

After running the RTL test, a series of data processing follows to output the results. It starts from on the computer connected to the device by the TEMA-CONCEPT software, then with programming on the Scilab software. This program makes it possible to reduce the cycles according to what is recommended by the standard used (NF EN 13286-7). The axial strains, the confining pressure and the compression force are recorded at different numbers of predetermined cycles. This reduction in the values of the targeted cycles is as follows for the permanent strains (20,000 to 50,000 cycles per stage or level of loading following a single stress path q/p =2)
N = [0 – 10 – 60 – 110 – 210 – 510 – 710 – 860 - 1,010 - 1,510 - 2,010 - 2,510 - 3,010 - 4,010 - 5,010 - 7,010 - 10,010 - 15,010 - 20,010 - 25,010 - 30,010 - 35,010 - 35,010 - 35,010].
For each cycle at a frequency of 2Hz, 500 pieces of information are given and according to the standard the average of the last 10 results out of the 500 are taken into account for further processing, but the last 5 have been adopted. A program on Excel Visual Basic (VBA) was used for this processing. In addition, the Excel software contributed to the development of curves and graphs of the results.
To assess resistance to rutting, a value of the characteristic permanent strains ε_1^c given by the standard [7] is calculated, defined by the equation [Eq1]:

$$\varepsilon_1^c = \varepsilon_1^p(20{,}000) - \varepsilon_1^p(100) \qquad \text{[Eq1]}$$

With

$\varepsilon_1^p(20{,}000)$= axial permanent strains measured at the end of conditioning (after 20,000 cycles);

$\varepsilon_1^p(100)$= axial permanent strains measured after the first 100 cycles.

In addition to the classification defined above, the Shakedown theory of [18] makes it possible to delimit the domains A, B and C in order to evaluate the long-term plastic behavior of unbound granular materials. It is based on the difference ($\Delta\varepsilon_{1,p}$) of the values determined by the accumulation of the permanent strains obtained after 3,000 and 5,000 cycles of axial loadings ($\varepsilon_{1p,5000}$ and $\varepsilon_{1p,3000}$). These areas are detailed in Table 3 and Figure 4.

- accommodation corresponding to domain A (domain where the strains stabilize);
- Progressive accumulation of plastic strains corresponding to domain B (rupture with a very large number of cycles);
- Rochet corresponding to domain C (rupture after a small number of cycles).

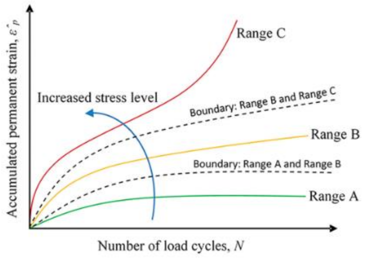


Figure 4 Typical PD behaviour of UGMs in different SDR classes, depending on the stress level [19].

Table 3 - Delimitation of domains A, B and C of the Shakedown theory [18]

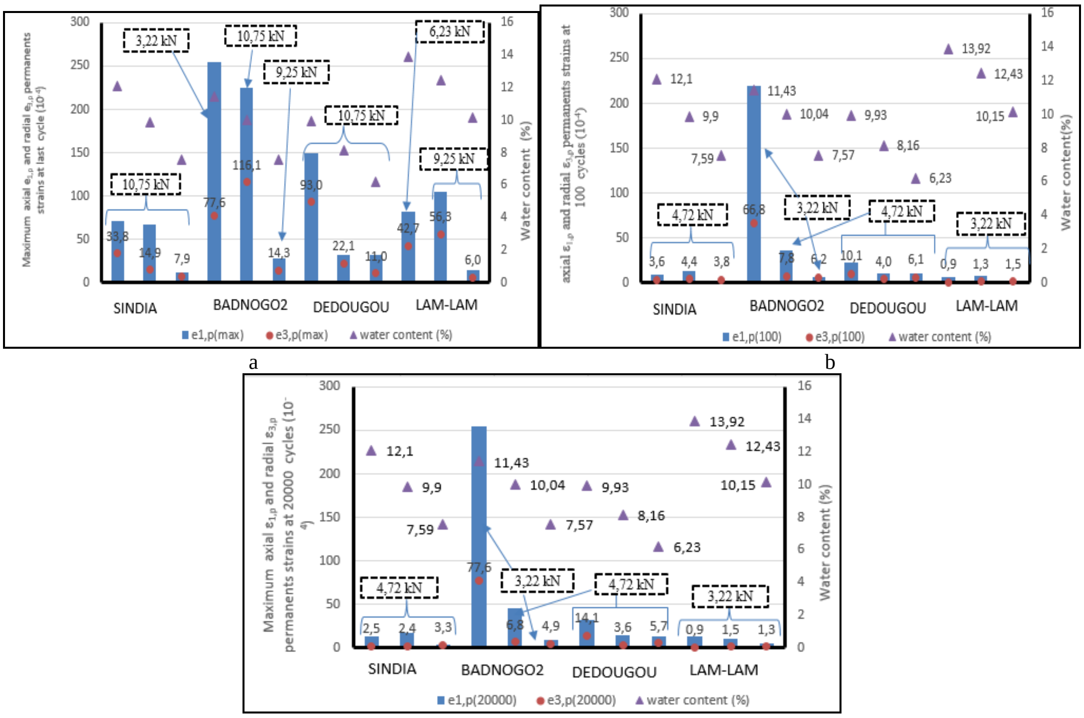
Areas	Value of plastic strains	Long-term trend
A	$\varepsilon^1_{p,5000} - \varepsilon^1_{p,3000} \prec 0.045*10^{-3}$	Stabilizes
B	$0.045*10^{-3} \prec \varepsilon^1_{p,5000} - \varepsilon^1_{p,3000} \prec 0.4*10^{-3}$	Increase in $\varepsilon_{1,p}$ up to breaking point
C	$\varepsilon^1_{p,5000} - \varepsilon^1_{p,3000} \succ 0.4*10^{-3}$	the break

RESULTS AND INTERPRETATION

Figures 5 (a, b and c) and tables (4 and 5) summarize the results of the axial ($\varepsilon_{1,p}$) and radial ($\varepsilon_{3,p}$) strains as a function of the loading level at (100th, 20,000th, and maximum of cycle) and the influence of water on these results of the lateritic materials used in the study. It is found that:

- the values of $\varepsilon_{1,p}$(max) are 4.2 to 7.81 times those of $\varepsilon_{1,p}$(100) for the Sindia material, 1.2 to 6.3 times those of $\varepsilon_{1,p}$(100) for the Badnogo2 site, 2.9 to 6.4 times those of $\varepsilon_{1,p}$(100) for the Dedougou material and 1.6 to 13.7 times those of $\varepsilon_{1,p}$(100) for the Lam-lam site. This proves that the materials from the Lam-lam site deform more than the materials from the other sites. This justifies the fact that it is necessary to carry out tests at high loading levels (number of cycles) to verify the long-term behavior in order to predict the degradation;
- for the Sindia material, the values of the axial and radial permanent deformations vary according to the water contents for the same level of loading. The permanent deformations $\varepsilon_{1,p}$ (20,000) at conditioning are 17.690*10^{-4} for the specimen compacted at the Proctor optimum (9.90%), and drop to 4.160*10^{-4} for a water content of (7.59%). This informs us that the water content influences the $\varepsilon_{1,p}$ and $\varepsilon_{3,p}$ causes of the degradation of the road infrastructures. When the water content increases the deformations $\varepsilon_{1,p}$ and $\varepsilon_{3,p}$ also increase. Moreover, it is also noticed that when the loads increase the permanent deformations $\varepsilon_{1,p}$ and $\varepsilon_{3,p}$ also increase. Also figures 3 (a, b and c) show that the deformation $\varepsilon_{1,p}$ (max) decreases by 83.4% when water content varies from 12.10% to 7.59%;
- For the material at the Badnoogo2 site, the Bad/11.43/95.48 specimen shows a high deformation $\varepsilon_{1,p}$ and $\varepsilon_{3,p}$ at the 100th and 20,000th cycles of the order of 254.65*10^{-4} and 77.59*10^{-4} respectively. Then with a decrease in water content from 10.04% to 7.57% we observe a decrease of 81.12% in the strain $\varepsilon_{1,p}$. Moreover, with a compactness rate that varies from 95.58% to 100.06%, respectively from a water content that varies from 10.04% to 9.36%, we observe a decrease in deformation $\varepsilon_{1,p}$ from 224.340*10^{-4} to 148.150*10^{-4} from the 50,000 cycles, which shows the effect of the compactness rate and the stress level on the lateritic gravels materials soils (Figure 8);
- For the material at the Dédougou site, the deformations $\varepsilon_{1,p}$ and $\varepsilon_{3,p}$ at the 20,000th cycle vary respectively from (32.41*10^{-4} - 13.45*10^{-4}) and (14.11*10^{-4} - 3.62*10^{-4}). The ratio $\varepsilon_{1,p}$ (20,000) / $\varepsilon_{1,p}$ (100) varies from 1.22 to 1.38 and the ratio of $\varepsilon_{1,p}$ (40,000) / $\varepsilon_{1,p}$ (20,000) we have 1.9 to 1.46. Moreover, for the same compactness with a water content that drops from 9.93% to 8.13%, the permanent deformations (max);
- For the material of Lam-lam site, figure 3c and table 5 show that the permanent deformation $\varepsilon_{1,p}$ at the 20000th cycle decreases by 59.58% when the water content decreases from 13.92% to

10.15%. Also for a decrease in strain $\varepsilon_{1,p}$ (20,000) of 13.45%, the water content decreases from 13.92% to 12.43%. Furthermore, Figure 5a shows that with an increase in the number of cycles and loading level combined with the decrease in water content, the strains increase.



a b

c

Figure 5 Effect of loading level and water content on the axial ($\varepsilon_{1,p}$) and radial ($\varepsilon_{3,p}$) permanents strains of the different quarry sites: a) maximum axial ($\varepsilon_{1,pmax}$), b) at the 100th cycle and c) at the 20,000th cycle

Table 5 also provides information on the classification of the level of rheological behavior of our materials from the standard [7] (Nf EN-13286-7, 2004), based on the characteristic permanent strains (ε_1^c). The class obtained is C1 ($\varepsilon_1^c < 2.5.10^{-3}$) for all materials except the LA05 specimen which is classified C2 ($\varepsilon_1^c > 2.5.10^{-3}$).

Table 6 presents the ratio between the permanent strains at 3,000 cycles and 5,000 cycles axilally $\varepsilon_{1,p}$(3,000) et $\varepsilon_{1,p}$(5,000)) and radially ($\varepsilon_{3,p}$(3,000) and $\varepsilon_{3,p}$(5,000)). This will allow to classify the materials on the basis of their resistance to permanent strains according to the standard (Nf EN-13286-7, 2004). Three types of behavior are distinguished, as shown in Figure 2 and Table 3 (Shakedown theory [18]). The domains selected for these materials studied are A ($\varepsilon_{1p(5000)}$-$\varepsilon_{1,p(3000)}$ < $0.45.10^{-4}$) and B ($\varepsilon_{1,p(5000)}$-$\varepsilon_{1,p(3000}$< 4.10^{-4}).

Figures 6, 7, 8 and 9 show the influence of the number of cycles, the variation of water content and the rate of compaction on the axial ($\varepsilon_{1,p}$) and radial ($\varepsilon_{3,p}$) permanent strains of the Sindia, Badnoogo2, Dedougou and Lam-lam sites. For Figure 4 we have chosen to assign a negative sign (-) to $\varepsilon_{3,p}$ because the strains is in extensional format (increase in volume). The following observations are taken from :

- Figure 7 (Dedougou site) shows that when the optimal water content increase 1.77% and combined with an increase of 150kPa of deviatoric stress (q), the material becomes more plastic and deforms at an exponential rate, it's visible from 40,000 cycles;

- Figure 8 shows than after 30,000 cycles, the effect of the water content combined with an increase of the stress level is felt, which tells us that materials at a level of loading can have a very plastic behavior.

The authors, Haynes and Yoder [20]; Barksdale [9]; Fall [13]; Hornych [10]; Thom and Brown [21]; Ba [14]; Jing [22] and Rahman *and al*. [19] all observed the exponential increase in permanent strains when the water content exceeds that of the optimum during their research. The explanation they gave for this is due to the decrease in matrix suction, the development of pore overpressures, and certainly the lubricating effect of water that lead to a decrease in the permanent strains resistance of the materials.

In figure 10, we notice that the strains increase proportionally with the average stress. Moreover, the number of bearings is highlighted.

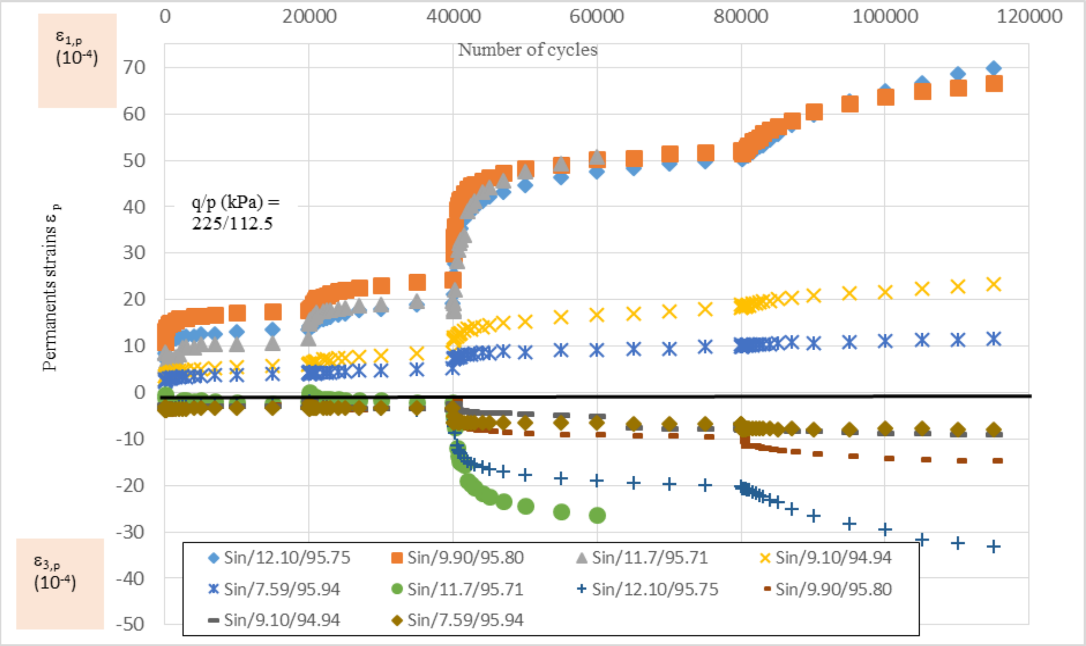


Figure 6 Effect of the number of cycles and the water content on the axial ($\varepsilon_{1,p}$) and radial ($\varepsilon_{3,p}$) permanents strains ($\varepsilon_{1,p}$) of Sindia materials.

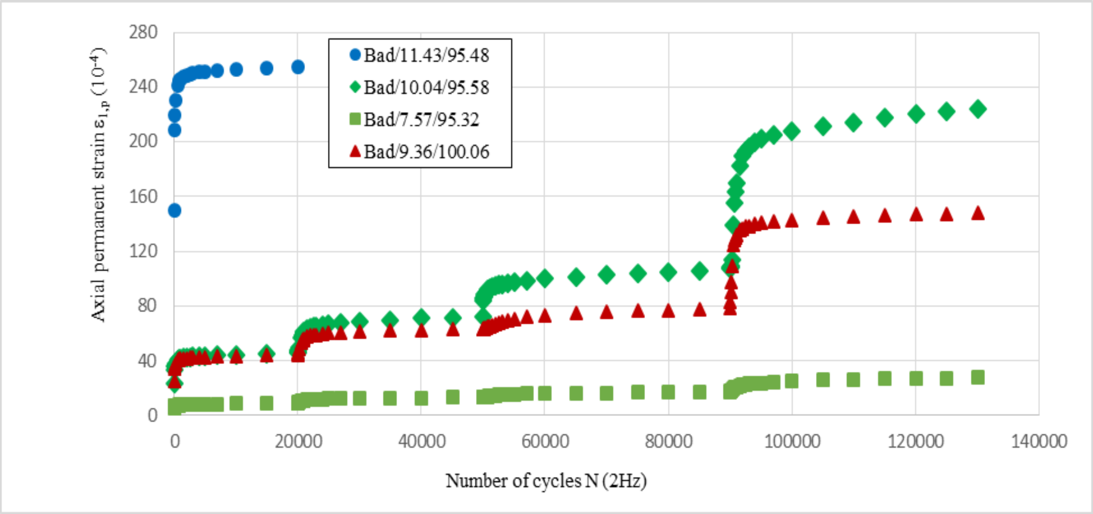


Figure 7 influence du nombre de cycle, de la densité et de la teneur en eau sur les strainss permanentes axiales (ε1,p) du site Badnogo2

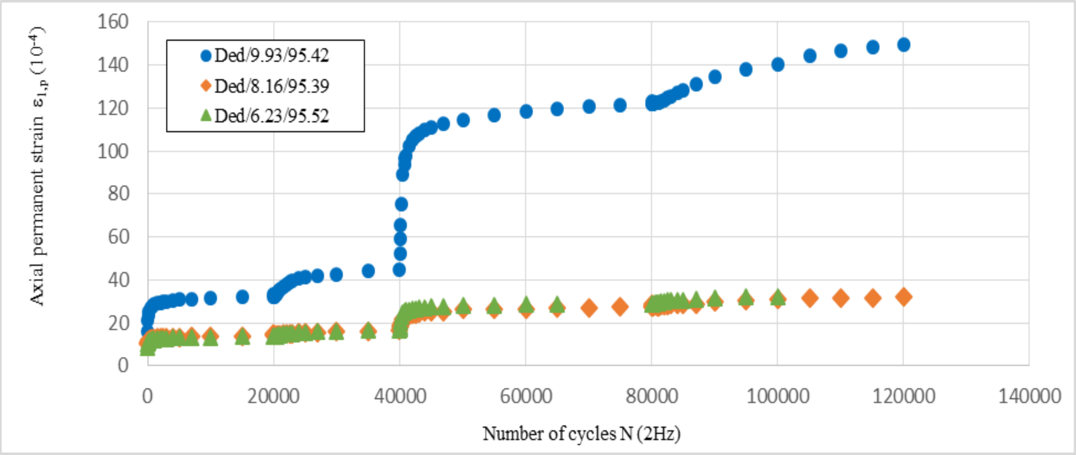


Figure 8 Effect of the number of cycles and the water content on the axial permanent strains ($\varepsilon_{1,p}$) of Dedougou materials.

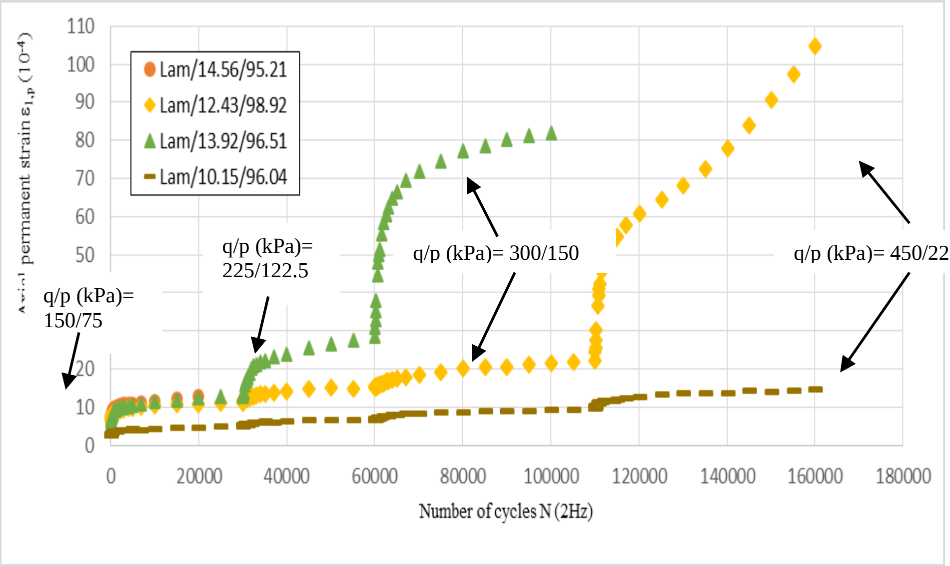
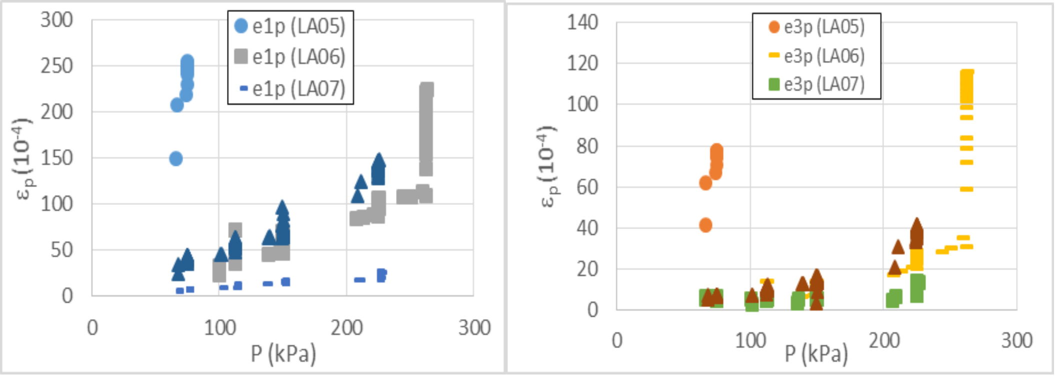


Figure 9 Effect of the number of cycles and the water content on the axial permanent strains ($\varepsilon_{1,p}$) of Lam-lam materials.



a b

Figure 10 Relationship between the permanent strains with the mean stress (P): a) axial ($\varepsilon_{1,p}$) and b) radial ($\varepsilon_{3,p}$) of the Badnoogo2 site

Tableau 4 Results of the axial ($\varepsilon_{1,p}$) radial ($\varepsilon_{3,p}$) permanents strains according to the loading level (100 cycles and end of cycle) of the materials

Designation	labeling	$\varepsilon_{1,p}$(100)	$\varepsilon_{1,p}$(max)	$\varepsilon_{1,p}$(max)/$\varepsilon_{1,p}$(100)	$\varepsilon_{3,p}$(100)	$\varepsilon_{3,p}$(max)	$\varepsilon_{3,p}$(max)/$\varepsilon_{3,p}$(100)	Number landings	Number of cumulative cycles

SINDIA Wop%= 9.66	LA01	Sin/11.7/95.71	8,480	50,695	5,978	1,080	26,330	24,380		
	LA02	Sin/12.10/95.75	9,100	71,135	7,817	3,645	33,790	9,270	3	60000
	LA03	Sin/9.90/95.80	13,330	67,340	5,052	4,405	14,865	3,375	4	120000
	LA04	Sin/9.10/94.94	3,490	23,582	6,757	3,190	9,055	2,839	4	120000
	LA14	Sin/7.59/95.94	2,820	11,810	4,188	3,840	7,895	2,056	4	120000
									4	120000
BADNOGO Wop% =9.7	LA05	Bad/11.43/95.48	219,580	254,650	1,160	66,800	77,590	1,162		
	LA06	Bad/10.04/95.58	35,650	224,340	6,293	7,840	116,085	14,807	1	20000
	LA07	Bad/7.57/95.32	6,670	27,530	4,127	6,245	14,300	2,290	4	130000
	LA17	Bad/9.36/100.06	36,385	148,150	4,072	7,110	41,605	5,852	4	130000
									4	130000
DEDOUGOU Wop% = 8.05	LA08	Ded/9.93/95.42	23,410	149,380	6,381	10,110	93,025	9,201		
	LA09	Ded/8.16/95.39	11,320	32,200	2,845	4,000	22,060	5,515	4	120000
	LA10	Ded/6.23/95.52	10,990	32,180	2,928	6,140	10,980	1,788	4	120000
									4	120000
LAM-LAM Wop%= 11.8	LA11	Lam/14.56/95.21	7,835	12,720	1,623	1,540	2,460	1,597		
	LA15	Lam/13.92/96.51	6,930	81,990	11,831	0,865	42,675	49,335	1	30000
	LA12	Lam/12.43/98.92	7,640	104,550	13,685	1,295	56,290	43,467	4	110000
	LA16	Lam/10.15/96.04	3,110	14,720	4,733	1,515	5,975	3,944	3	160000

Tableau 5 Comparisons of axial permanents strains ($\varepsilon_{1,p}$) of cycles (100 - 20,000 and 40,000) of loading , and classification of materials

Designation		labeling	$\varepsilon_{1,p}$(20000)	ε_1^c	Classification (Nf EN-13286-7, 2004) (C)	$\varepsilon_{1,p}$ (40000)	$\varepsilon_{1,p}$ (20000) / $\varepsilon_{1,p}$ (100)	$\varepsilon_{1,p}$ (40000) / $\varepsilon_{1,p}$ (100)	$\varepsilon_{1,p}$ (40000) / $\varepsilon_{1,p}$ (20000)
			(10^{-4})	10^{-3}	ε_1^c	(10^{-4})			
SINDIA Wop%= 9.66	LA01	Sin/11.7/95.71	11,490	0,301	C1 because ε_1^c < 2,5.10-3	19,700	1,355	1,715	2,323
	LA02	Sin/12.10/95.75	13,650	0,455		19,280	1,500	1,412	2,119
	LA03	Sin/9.90/95.80	17,690	0,436		24,280	1,327	1,373	1,821
	LA04	Sin/9.10/94.94	6,057	0,257		8,730	1,736	1,441	2,501
	LA14	Sin/7.59/95.94	4,160	0,134		5,230	1,475	1,257	1,855
BADNOGO Wop% =9.7	LA05	Bad/11.43/95.48	254,650	3,507	C2	-	1,160	0,000	0,000
	LA06	Bad/10.04/95.58	45,970	1,032	C1 because ε_1^c < 2,5.10-3	70,840	1,289	1,541	1,987
	LA07	Bad/7.57/95.32	8,680	0,201		12,910	1,301	1,487	1,936
	LA17	Bad/9.36/100.06	44,395	0,801		62,515	1,220	1,408	1,718
DEDOUGOU Wop% = 8.05	LA08	Ded/9.93/95.42	32,410	0,900		44,730	1,384	1,380	1,911
	LA09	Ded/8.16/95.39	14,120	0,280		16,540	1,247	1,171	1,461
	LA10	Ded/6.23/95.52	13,450	0,246		16,630	1,224	1,236	1,513
LAM-LAM Wop%= 11.8	LA11	Lam/14.56/95.21	12,720	0,489		-	1,623	1,623	-
	LA15	Lam/13.92/96.51	12,790	0,586		28,490	1,846	2,228	4,111
	LA12	Lam/12.43/98.92	11,070	0,343		15,300	1,449	1,382	2,003
	LA16	Lam/10.15/96.04	5,170	0,206		7,110	1,662	1,375	2,286

NB: Test limited to 20,000 cycles (risk of shearing) represented by (-) in the tables

Table 6 Ratio between the permanents strains at 3000 cycles and 5000 cycles axilal ($\varepsilon_{1,p(3000)}$ and $\varepsilon_{1,p(5000)}$) and radial ($\varepsilon_{3,p(3000)}$ and $\varepsilon_{3,p(5000)}$)

Designation	labeling	q (kPa)	σ_3 (kPa)	$\varepsilon_{1,p(3000)}$ (10^{-4})	$\varepsilon_{1,p(5000)}$ (10^{-4})	$\Delta\varepsilon_{1,p} = \varepsilon_{1,p(5000)} - \varepsilon_{1,p(3000)}$ (10^{-4})	Shakedown's theory zone (Werkmeister,

								2003) **$\Delta\varepsilon_{1,p} = \varepsilon_{1,p(5000)} - \varepsilon_{1,p(3000)}$ (10^{-4})**
SINDIA Wop%= 9.66	LA01	Sin/11.7/95.71	150	37	9,99	10,33	0,34	A ($\Delta\varepsilon_{1,p}$ < 0,45.10^{-4})
	LA02	Sin/12.10/95.75	235	37	12,045	12,565	0,52	B ($\Delta\varepsilon_{1,p}$ < 4.10^{-4})
	LA03	Sin/9.90/95.80			16,135	16,455	0,32	A ($\Delta\varepsilon_{1,p}$ < 0,45.10^{-4})
	LA04	Sin/9.10/94.94			4,83	5,09	0,26	
	LA14	Sin/7.59/95.94			3,4	3,615	0,215	
BADNOGO Wop% =9.7	LA05	Bad/11.43/95.48	150	20	250,25	251,32	1,07	B ($\Delta\varepsilon_{1,p}$ < 4.10^{-4})
	LA06	Bad/10.04/95.58	230	37	42,83	43,2	0,37	A ($\Delta\varepsilon_{1,p}$ < 0,45.10^{-4})
	LA07	Bad/7.57/95.32	150	20	8,17	8,25	0,08	
	LA17	Bad/9.36/100.06			42,18	42,76	0,58	B ($\Delta\varepsilon_{1,p}$ < 4.10^{-4})
							0	
DEDOUGOU Wop% = 8.05	LA08	Ded/9.93/95.42	235	33	30,06	30,83	0,77	B ($\Delta\varepsilon_{1,p}$ < 4.10^{-4})
	LA09	Ded/8.16/95.39			13,21	13,35	0,14	A ($\Delta\varepsilon_{1,p}$ < 0,45.10^{-4})
	LA10	Ded/6.23/95.52			12,565	12,965	0,4	
	LA11	Lam/14.56/95.21	150	20	10,695	10,79	0,095	A ($\Delta\varepsilon_{1,p}$ < 0,45.10^{-4})
LAM-LAM Wop%= 11.8	LA15	Lam/13.92/96.51			10,28	10,61	0,33	
	LA12	Lam/12.43/98.92			9,465	9,865	0,4	
	LA16	Lam/10.15/96.04			4,1	4,32	0,22	

CONCLUSION

Rutting is one of the most frequent degradations on lateritic road infrastructures in tropical Africa and is the result of these lost strains over time. These lost strains are also called permanent strains obtained experimentally in the laboratory from the Repeated Triaxial cyclic Loading test. The lateritic gravel materials soils (Sindia, Badnogo2, Dédougou and Lam-lam) coming from Senegal and Burkina Faso were tested at three water contents ($w_{opm}\pm 2$). It was found that whatever the material studied, the influence of the water content and the stress level on the permanent strains was verified. When the water content exceeds that of the optimum, at a certain loading level the strains rise exponentially. For this reason, it is recommended to take a water content lower than the optimum one in tropical countries like Burkina Faso and Senegal. According to the standard (Nf EN-13286-7, 2004) the materials have a class of rheological behaviour level of C1 ($\varepsilon_1^c < 2.5.10^{-3}$) and C2 ($\varepsilon_1^c > 2.5.10^{-3}$) based on the characteristic permanent strains (ε_1^c). On the other hand, the domain of the Shakedown theory gives the classes A ($\varepsilon_{1p(5000)}-\varepsilon_{1,p(3000)} < 0.45.10^{-4}$) and B ($\varepsilon_{1,p(5000)}-\varepsilon_{1,p(3000} < 4.10^{-4}$).

Declaration by Authors

Acknowledgement: My gratitude goes to the place of the staff of the “Laboratoire, Auscultation, Modélisation, Expérimentation, des Infrastructures de Transport” (LAMES) of the University Gustave Eiffel campus Nantes, former the institute IFSTTAR of Nantes, who accompanied me in the execution of the triaxial tests (LRT). My thanks to the staff of the “Laboratoire National du Bâtiment et Travaux Publics” (LNBTP) of Burkina Faso and also the staff of the “Laboratoire de Mécanique et Modélisation” (L2M) of the University of Thiès of Senegal. Without forgetting all those who participated in the shadow for the elaboration of this document, I thank them greatly.

Source of Funding: None

Conflict of Interest: The authors declare no conflict of interest.

REFERENCES

1. Issiakou, M.S., 2016. Caractérisation et valorisation des matériaux latéritiques utilisés en construction routière au niger (phdthesis). Université de bordeaux.
2. Millogo, Y., 2008. Etude géotechnique, chimique et minéralogique de matières premières argileuse et latéritique du burkina faso améliorées aux liants hydrauliques : application au génie civil (bâtiment et route). Université de ouagadougou.

3. Maignien, R., 1966. Compte rendu de recherche sur les laterites.
4. Habiballah, t.e.m., 2005. Modelisation des deformations permanentes des graves non traitées. Universite de limoges.
5. White et Hongbing., 2002. Contributions of pavement structural layers to rutting of hot mix asphalt pavements - national research council, transportation research board - national cooperative highway research program (report 468) - 65 pages.
6. Meunier, M., 2012. Prédiction de l'orniérage lié aux déformations permanentes des enrobés bitumineux (phd thesis). Ecole de technolgie supérieure.
7. NF EN-13286-7, 2004. Norme européenne pour l'essai triaxial sous charge cyclique pour mélange sans liants hydraulique.
8. Gidel, G., Hornych, P., Chauvin, J.-J., Breysse, D., Denis, A., 2001. Nouvelle approche pour l'étude des déformations permanentes des graves non traitées a l'appareil triaxial a chargements répétés. Bulletin de liaison des laboratoires des ponts et chaussées 233, 5–21.
9. Barksdale R.D. (1972). "laboratory evaluation of rutting in base course materials," in proceedings of the third international conference on structural design of asphalt pavement, London, pp. 161-174.
10. Hornych P., Hameury O., Paute J.L. (1998) influence de l'eau sur le comportement mécanique des graves non traitées et sols supports de chaussées, Simposio International Sobre Drenaje Interno de Firmes Y Explanadas, Granada, Espagne, Pp. 249-257.
11. Gidel, M.G., 2001. Comportement Et Valorisation Des Graves Non Traitées Calcaires Utilisées Pour Les Assises des Chaussées Souples. Université De Bordeaux I.
12. Chazallon, C., Koval, G., Hornych, P., Allou, F., Mouhoubi, S., 2009. Modelling of rutting of two flexible pavements with the shakedown theory and the finite element method. Computers and Geotechnics 36, 798–809. https://doi.org/10.1016/j.compgeo.2009.01.007
13. Fall, M., 1993. Identification Et Caracterisation Mecanique De Graveleux Lateritiques Du Senegal : Application Au Domaine Routier. Institut National Polytechnique De Lorraine Ecole Nationale Supérieure De Géologie De Nancy.
14. Ba, M., 2012. Comportement mécanique sous sollicitations cycliques de granulats quartzitiques de Bakel - Comparaison avec des matériaux de référence du Sénégal et d'Amérique (USA). Application au Dimensionnement Mécanistique-Empirique des chaussées souples. Université Cheikh Anta Diop de Dakar, Sénégal.
15. Rodrigues J.K.G., Reiffsteck P., Auriol J.C., Ndiaye M. (2010). Rationalisation de l'utilisation des sols latéritiques en corps de chaussée durable et de faible coût. XXVIIIémes Rencontres Universitaires de Génie Civil. Session Ouvrages – Bitume, page 1122
16. Ki, B.I.J., Ba, M., & Coulibaly M., 2022. Modelling of the Resilient Modulus (Mr) of Lateritic Soils in Tropical Africa (Burkina Faso and Senegal): Determination of Model Parameters K1, K2 and K3 (Thom and Brown (1987), Uzan (1985) and the NCHRP 1-28A (2004) (National Cooperative Highway Research Program) London Journal of Engineering Research Volume 22 | Issue 5 | Compilation 1.0 DOI: 10.17472/LJE
17. Ki, B.I.J., Ba, M., Gueye, R., Hornych, P., Sana, A., 2021. Effect of Water Content and Grains Size Distribution on the Characteristic Resilient Young's Modulus (Ec) Obtained Using Anisotropic Boyce Model on Gravelly Lateritic Soils from Tropical Africa (Burkina Faso and Senegal). Open Journal of Civil Engineering 11, 134–152. https://doi.org/10.4236/ojce.2021.111009
18. Werkmeister, S., A. R. Dawson, and F. Wellner (2001). "Permanent Strains Behavior of Granular Materials and the Shakedown Concept," In Transportation Research Record: Journal of the Transportation Research Board, No. 1757, TRB, National Research Council, Washington, D.C., pp. 75–81.
19. Mohammad Shafiqur Rahman, Sigurdur Erlingsson & Abubeker Ahmed (2022): Modelling the permanent deformation of unbound granular materials in pavements, Road Materials and Pavement Design, DOI: 10.1080/14680629.2022.2108883
20. Haynes, J. G., and Yoder, E. J. (1963). Effects of repeated loading on gravel and

crushed stone base course materials used in the AASHO Road Test. Hwy. Res. Rec. 39

21. Thom, N. H., and Brown, S. F. (1987). „„Effect of moisture on the structural performance of a crushed-limestone road base. Transp. Res. Rec. 1121, Transportation Research Board, Washington, D.C., 50–56
22. Jing, P., 2017. Etude de l'effet des fines et de la teneur en eau sur le comportement hydromécanique des matériaux granulaires (PhD Thesis). Strasbourg.

How to cite this article: KI Bibalo Ida Josiane, COULIBALY Mory, GUEYE Rokhaya, BA Makhaly, HORNYCH Pierre. Effects of loading and compaction conditions on permanent strains of unbound lateritic soils from Senegal and Burkina Faso. *International Journal of Research and Review*. 2024; 11(1): 127-139. DOI: *https://doi.org/10.52403/ijrr.20240114*

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